THE ROCKET

The History and Development of Rocket & Missile Technology.

David Baker, Ph.D.

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READING PLAN

This book is designed for the general reader, while at the same time providing ease of access to specific periods of rocket development for students of historical events. It will be observed that the history section comprises eleven chapters dedicated to a discussion of development on a subject-classification basis. This means, for example, that a description of the launch vehicles used in the space programme since 1958 is contained within a specific chapter, while military developments in the same period are dealt with in the following chapter. In this way, the description of historical events is separated by function rather than time. In the period between 1945 and 1957, up to the launch of the first artificial satellite, space and military applications are inseparable. Before 1945 there was little or no separation by function, rocket vehicle applications being almost wholly experimental or military in nature.

While a full and comprehensive view of rocket development can only be had from a careful examination of both space *and* military applications, the student of military activities should read Chapters 1, 2, 3, 4, 5, 6, 7 and 10 before turning to Chapters 8, 9 and 11. Persons primarily interested in the application of rocket vehicles to space activities should read Chapters 1, 2, 6, 8, 9 and 11 and then turn to Chapters 3, 4, 5, 7 and 10. It is recommended, however, that these staggered reading plans should only be attempted after at least cursory examination of the full text of the history section.

Technical histories of specific missile and launch vehicle types are contained in the Compendium and will be found to follow an alphabetical order, first by country and then by type name or letter. A separate Compendium covers the progressive development of aircraft using rocket motors as the sole source of propulsion. If readers wish to examine the history of a specific rocket but are unaware of the country of origin, the Index at the back of this book will provide the page number where it can be found in the Compendium and the page(s) where it is discussed in the history section.

The emphasis on cross-references is felt to be the best way of providing full access to any comment, in either the history section or the Compendium, on specific projects. All space launch vehicles ever brought to operational status are discussed in the Compendium, together with strategic and tactical missiles of military application. Types grouped in air-to-ground, surface-to-air, air-to-air, anti-ship, anti-submarine and anti-tank roles are too numerous to permit detailed description in the Compendium and summary data will be found in the comprehensive tables at the back of the book.

Frontispiece
Although developed into the A-series satellite launcher, credited with launching all the Soviet manned space flights and many of the lunar and planetary space probes, the rocket began life as the first Russian ICBM, code named SS-6 Sapwood.

Front Endpaper
Historic calculations preserved at a museum in Kaluga performed by Konstantin Tsiolkovsky during his early work at the beginning of the century. This 'father of space flight' was to greatly influence Soviet developments in the exploration of space, long after his death.

Back Endpaper
Engineering drawings of the Saturn IB launch vehicle. Saturn was the first major launch vehicle developed for peaceful application. It did not, like its contemporaries, stem from existing military hardware. The drawings were prepared at the Marshall Space Flight Centre in 1964.

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Introduction

In this work an attempt has been made to trace the political and technological progress of the rocket from its introduction in ancient times to the present day. When dealing with the massive advance of rocket technology during the 20th century, it is simply not possible to extricate its progression from the political aspirations of its major progenitors. Rockets may be described as all vehicles which utilize reactive propulsion created by chemical reaction with the unique characteristic of being able to operate in either an atmosphere or a vacuum. A rocket carries its own energy sources and, in particular, its own oxidizing agents. In this respect it differs fundamentally from other forms of reactive propulsion, e.g. the jet engine, in that it has an autonomous source of energy and its engines are not reliant on an atmosphere to provide either cooling or in-flowing oxygen.

In all the more important aspects, rocketry has re-shaped the period since the end of World War II into an age of space travel and potential nuclear conflict on a global scale. No other single product of technology has equalled the rapid development of rocket propelled vehicles and the past fifty years has seen the emergence of a radical new form of transportation, capable of delivering satellites into orbit or warheads on strategic military targets. The history of missiles and space launch vehicles provides a unique insight into the changing political philosophies of major nations and at the same time reveals a new dimension on the important issues facing mankind today.

While military missile technology continues to move through successive generations of development and sophistication, the application of rocket motors to the space programmes of leading countries around the world ushers in a new era of innovation and inventiveness unlike any other form of transportation yet developed. In just twenty short years of space exploration, the rocket has carried satellites into orbit, men to the Moon and unmanned robots to the very edge of the solar system. But it is from the field of space applications that the greatest benefits are seen to accrue; earth resource satellites are inventorying the agrarian and mineral deposits of the land, ocean survey satellites monitor wave strength and sea currents, meteorological satellites chart the progress of weather patterns and communications satellites bring modern farming techniques to remote and isolated communities.

The increasingly productive use of a space-borne capability has driven the United States, and possibly the Soviet Union, toward reusability for the delivery systems that will carry payloads into orbit for the remainder of this century. In the form of a Space Shuttle, the recoverable transportation system promises to revolutionize space operations and bring orbital flight closer to the scheduled regularity of air transport. Because of the fundamental change inherent in the Shuttle system, it is appropriate to examine the historical genesis of rocket flight at this time and recap on the sequential and evolutionary steps leading toward the culmination of theoretical and practical development.

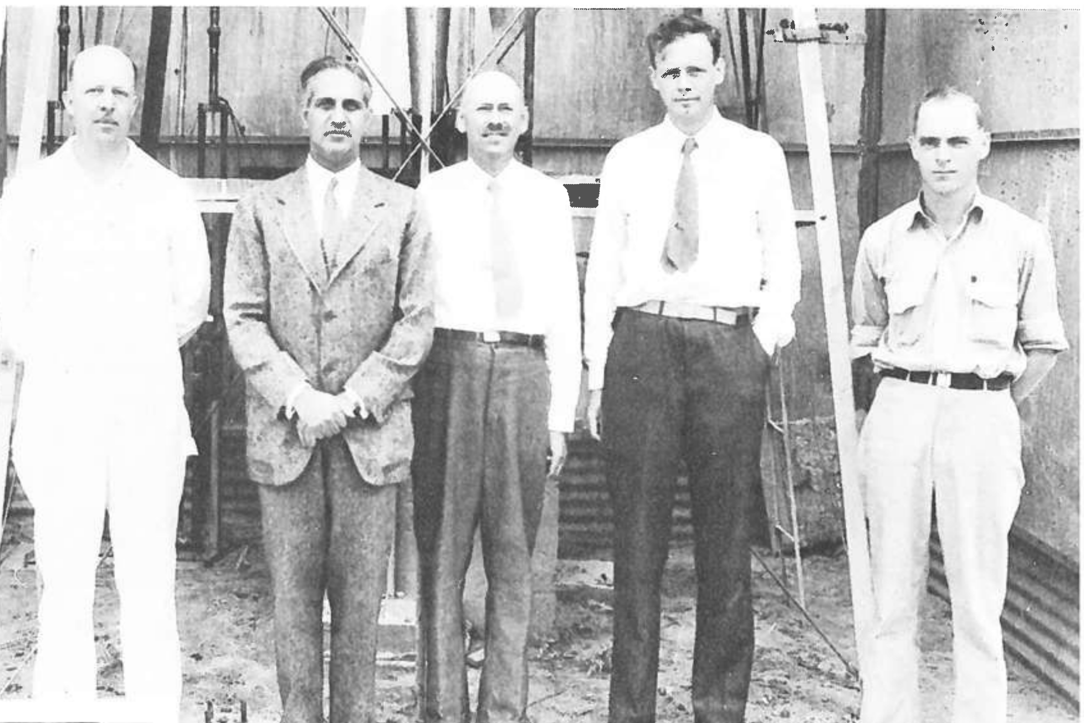
Two parallel paths of application have matured the rocket into an instrument tuned to every facet of war and a delivery system for space probes and satellites. The former continues to threaten the very existence of life on Earth, while the latter holds a promise for the future in timely synchronism with the pressing demands for new sources of energy. It is fortunate that we possess the capability of rising above our energy problems in both metaphorical and literal expression: sustained development of economically viable transportation systems offers opportunity for the assembly of large solar power satellites capable of converting sunlight into electricity and for giving dimension to the cultural aspirations of a space-borne community in large orbital colonies. Whichever path we choose – nuclear conflict or new frontiers for development in space – the rocket is synonymous with the expanding goals of a future society.

The history of rocketry spans two millennia and absorbs important stages in the evolving civilizations of Earth. I feel it is particularly important to secure major events in rocket applications to parallel developments in the political and social events of the day. For that reason the reader will detect a symmetry between the technical exploits of rocket pioneers and the moving dialogue between the internal and foreign affairs of respective countries. Political interplay, particularly in this century, has frequently provided a platform upon which technical developments are built and it is impossible to appreciate the full significance of relevant decisions about specific programmes, without setting them in contemporary events.

But if Man has had a protracted association with reactive chemistry, so too has nature. The South American Bombardier Beetle carries hydrogen peroxide and hydroquinone in two separate sections of a gland at the tip of its abdomen. When mixed with a catalyst they combust at a temperature of 100°C and the ejected gas is used to discourage potential predators. For millions of years, evolution has sought to refine the concept that ensures survival of the human species and in perfecting the rocket Man is at last capable of departing the solar system for new worlds around other stars. One day, when the Sun reaches the end of its stable life, conditions will demand an exodus from planet Earth. To be capable of surviving the death of the solar system represents a major step in human evolution, perhaps the most important step since *Neanderthal* hordes of Europe and Asia were replaced by *Homo sapiens sapiens* some 40,000 years ago.

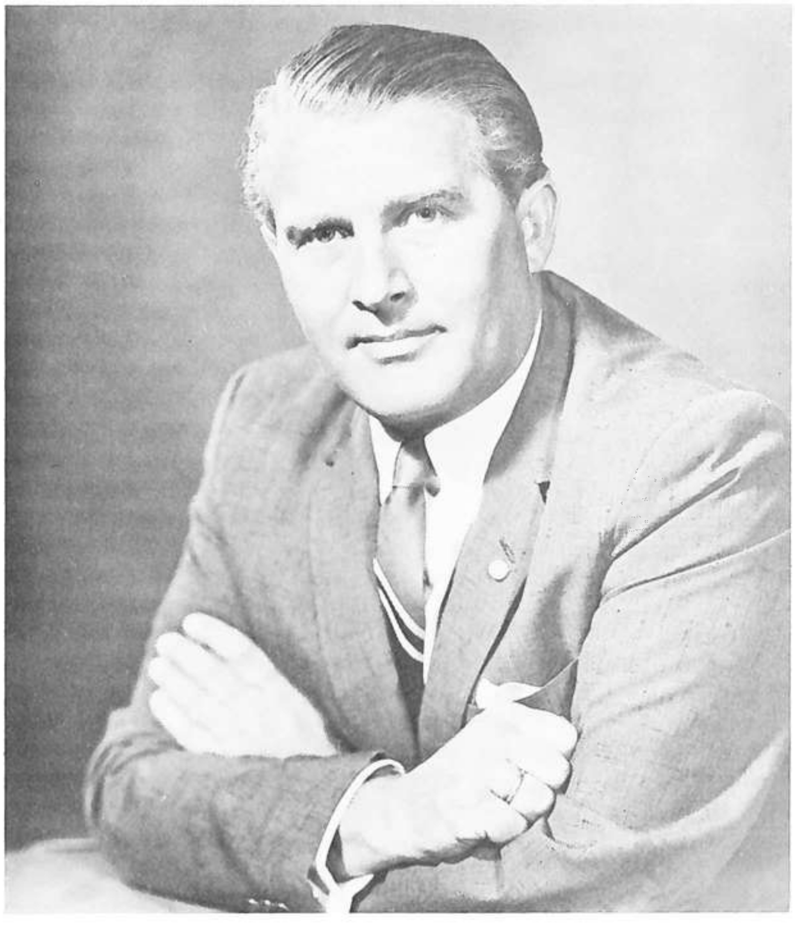
The development of rocket propulsion is inextricably linked to the deepest aspirations of the human spirit. It is not surprising that the transition from Earth-man to cosmic-man should have been pursued with such verve and determination by those whose responsibility it has been to ease the human race through this last great barrier. The history of rocket development is the story of man's unending quest for a cosmic identity and having trod the dusty surface of the Moon, he has begun a timeless journey that will never end.

Constantin Eduardovitch Tsiolkovsky (1857–1935), the father of Soviet rocketry, who foresaw the day when man would venture into space with liquid propellant rockets, seen here with his grandson.



Robert H. Goddard (1882–1945) *centre* is visited by Charles A. Lindbergh, the first man to fly the Atlantic solo (to Goddard's left). Goddard laid practical foundations for liquid propellant rocket motors and was the first person to launch, in March 1926, a rocket of this type.

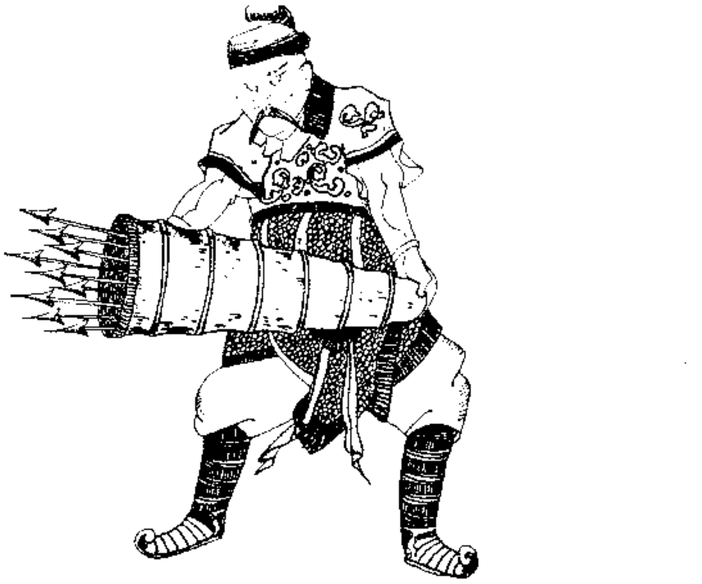
Sergei P. Korolev (1906–1966), who married rocket technology to the concept of manned space flight, seen here with Yuri Gagarin, the first man to orbit the earth.



Wernher von Braun (1912–1977), the German engineer who played a major role in the development of the A4 (popularly known as the V2) and, later, several of the early US military missiles and space rockets.

CHAPTER ONE.

Fire-Sticks & Gunpowder



A basket of fire arrows could be loosed upon the enemy by igniting the narrow end of the container. Chinese developments like this in the early centuries of the second millennium AD represented a unique adaptation of basic chemical law.

There is no sure way of knowing where to start our story. If we did it would fit the penchant for dates beloved by classical historians but the very beginning is just a bare strand in the fabric of history. Nevertheless, that trace thread has left an imprint just barely discernible yet sufficiently visible for a reasoned chronology banded by centuries rather than specific years. It would be useful to define the very concept of a rocket but that too is bound by traditional thoughts of a flaming, thundering fire-cracker streaking through the air and trailing a rigid, slender shaft. Before those traditions could be built preconceptions were rooted in the existing technology, the fabulous concoctions of primitive alchemists and the world's first unnamed scientists. Thus, in true subservience to the mythology of a fable, the scene for the genesis of rocketry is fairly placed on the far eastern segment of the sprawling Asiatic land mass.

Before the beginning of the first millennium BC, while Britain was emerging from a protracted phase of celestial deification where Sun and Moon provided stimulus for cult and culture, the Chou era prepared the way for Chinese experiments leading to the discovery of black powder. The Chou period dragged ponderously on to an inglorious end in the third century BC after a period of nearly nine hundred years during which regional dissent brought fragmented chaos and saw the establishment of local monarchies, lordships and kingdoms. In 221 BC this patchwork assembly of power was combined under the conquering prince Shih Huang Ti and so began the Chin Dynasty.

In less than two decades of rigid, authoritarian rule the oppressive dictates of the 'First Emperor' emphasized the military necessities of the new government. While intellectual expression was stifled and the freedom of individuals severely curtailed China had truly evolved to empire status and brought its people to a new level of organized control. By 207 BC Shih Huang Ti was dead, military commanders had wrestled a bloody fight for supremacy and a puppet prince, Kao-tsu, was established in power to begin the four hundred year Han Dynasty.

Somewhere in China, at an unspecified time, the Han Dynasty must be credited with the first use of black powder. It is an expression of the difficulty in precisely dedicating a date for the discovery of rockets that we must separate the practical use of flaming projectiles from the first application of exploding chemistries. In the noted literary works to emerge from the Han Dynasty there is shrouded mention of an exploding fire-cracker which confirms that it was the alchemists of this era that gave the world the formula for later developments leading to the rocket as an instrument of war and celebration.

In the Han *Classic of Strange Spiritual Manifestations* mention is made of a compound which, when packed tightly in a hollow bamboo cane, will explode with terrifying noise after a few moments in a fire. For several centuries the fire-cracker was used at celebratory functions, and probably military campaigns, but its unique properties were relegated to the awe and wonder it provoked in watchers and bystanders. There is little confirmation of a practical application for nearly one thousand years.

The technical revolution of the first years of Empire, begun under the aegis of the Chin Dynasty, may have stimulated the development of black powder as a usable mixture or it may have been in some obscure kingdom during the latter years of the Chou period that the first chemical formula for this unique powder was discovered. We will probably never know and all that can be said with confidence is that the Han Dynasty confirms the use of fire-crackers somewhere between 200 BC and 200 AD. It is interesting at this point to draw a distinction between discovery and invention. While the former is a chance encounter with the fundaments of nature the latter is a purposeful manipulation of physical processes. It is unlikely that the first meander through the chemistry of exotic materials was performed with any specific point in view; highly unlikely that Chinese alchemists sought a force potentially more combustible than fire. While the discovery of black powder was in all probability a chance encounter divorced from intent, its application to fire-crackers and fire-works relied wholly on invention.

Yet the stimulus for that invention seems to have suffered a decidedly protracted gestation for it is not until the end of the first millennium AD that records of the period detail the manufacture of black powder for its explosive properties. If uncertainty surrounds the date attributed to the first use of black powder the application to destructive inventions is less obscure. For nearly nine hundred years after the Han Dynasty, Chinese culture swung pendulously from one extreme to the other while foreign based incursions sent an almost constant flow of migratory hordes in to the emerging civilization: wars, regional struggle, dictatorships toppled by autocracies; replaced in turn by democracies. Century after century saw the turbulent birth pangs of a new China wrestle with the past, procrastinate in the face of advancement, resist the emerging call for centralized government. Finally, in the 10th century AD, baronial lords gave way to democratic commoner-judges and a new governmental structure emerged.

Although beset by tribal indifference and border scuffles (which were never satisfactorily resolved) the so-called Sung Dynasty emerged to spur trade with Japan, lands to the south and west, India, the middle east and even North Africa. In a climate of increased foreign trade internal wealth grew and urban cities developed at an unprecedented level. Community services included council overseers, marketing halls for domestic and imported produce, shops and fairs through which to trade and exchange the precious goods brought from far off places. In sprawling citadels, walled for protection and guarded by a regular militia, the great centres of Chinese wealth prospered and grew strong.

By the 12th century almost every technology of the modern world had been introduced, developed and implemented. Chemistry became a respectable science, medical research contributed whole libraries of information on every imaginable form of disease and, in a more practical attempt to combat smallpox, the first innoculations were performed. Within this panoply of advancement came the sophisticated instruments of war which would form the pillar of strategic assault for the next thousand years. Flame throwers, bomblets (released on to the heads of vulnerable foot soldiers from city walls), grenades and cannon were designed and built. In this time too the Chinese navy could outmatch anything then afloat elsewhere in the developing world, man-carrying observation kites formed an important part of tactical reconnaissance and all manner of armaments were brought to bear on opposing factions during the sporadic military encounters.

Within this age the rocket emerged as a fiery projectile spreading burning powder across wide areas propelled by mixtures of charcoal, sulphur and saltpeter. Batteries of rocket launcher tubes formed an important and prominent arm of land forces and by the 13th century Temujin, founder of the Yuan Dynasty, was engaged in territorial wars which established his status as Genghis Khan, conqueror of the Mongols. In practical terms the rocket was probably quite inefficient, its real value lying in the utter confusion wrought among opposing forces as several score of 'fire-arrows' streaked and crackled over the heads of ground troops to fall with abandon, creating much noise and not a little smoke among field personnel to the rear of front-line engagements. It was a powerful propaganda weapon, a token of aggressive intent – even today war gains vigour from terror strikes accompanied by noise and fire.

The first real progress in fire-arrow technology was documented in the *Complete Compendium of Military Classics*, a reliable treatise on weapons development and the means by which to achieve tactical and strategic advantage in combat. Written less than one hundred years after the start of the Sung period in 960 AD it provides clear evidence that the then Emperor Tseng Kung-Liang had a contingent of rocketeers equipped to manufacture, prepare and fire powder rockets in the field of combat as and when required. If war had not served as a direct stimulus to the discovered properties of black powder it certainly promoted the invention of the fire-tube.

Improvements were proposed during the 10th century and it seems that fire-crackers, fire-arrows, fire-tubes and other similarly named devices encompassed a range of pyrotechnic armaments from the very small mortar-like projectiles to the long tubed rockets of traditional design. The smallest was no more than 10 cm in length and packed with powder in such a way that when it was placed 5 cm from a fire the device rapidly reached combustible temperature, ignited and flew off at a rapid pace falling to earth several tens of metres away. In other cases conventional arrows, probably made from steel obtained by bartering silks and exquisite pottery abroad, carried a short tube strapped to the forward end immediately behind the barb. With the rear of the tube open, and the interior packed with powder, the arrow would be sent off at great speed toward the target. Fuse leads or the application of a fire brand at the open end of the tube caused combustion of the powder.

In the opening years of the 11th century rockets like these were effective over a distance of up to 300 metres. For a period of just about three hundred years from its introduction in the 10th century the fire-arrow was just that, little more than a thrust-assisted arrow catapulted in most instances from a crossbow device which could put fear into the enemy, create a loud noise and provoke panic among the recipients. During the 13th century rockets emerged to establish a more effective military role than the early fire-arrow and developments led to a rocket launcher carrying an explosive grenade. Transported across a distance of several hundred metres the grenade would explode, probably by way of heat penetrating the small wooden case holding the explosive, and spread fire across a distance of 10 metres.

In other applications, arrows tipped with poison were propelled by exploding powder packed in a cylindrical tube with the forward end of each tube containing up to twenty arrows which would separate in mid-flight and fall upon the unlucky souls below. Contingents of mobile rocket groups were formed and all manner of devious contraptions were tested during the Chinese wars of the late 12th and 13th centuries. In one instance Mongolian naval vessels bombarded Japanese soldiers with rockets and although the flaming weapons did considerable damage to morale and sent forces scurrying in retreat, the effective range was quite limited and only a small number could be used. Within a few years Japan and all of eastern Asia had acquired the science of manufacturing the important black powder and the practice of rocketry held increasing sway in the fortunes of territorial and colonial conflict.

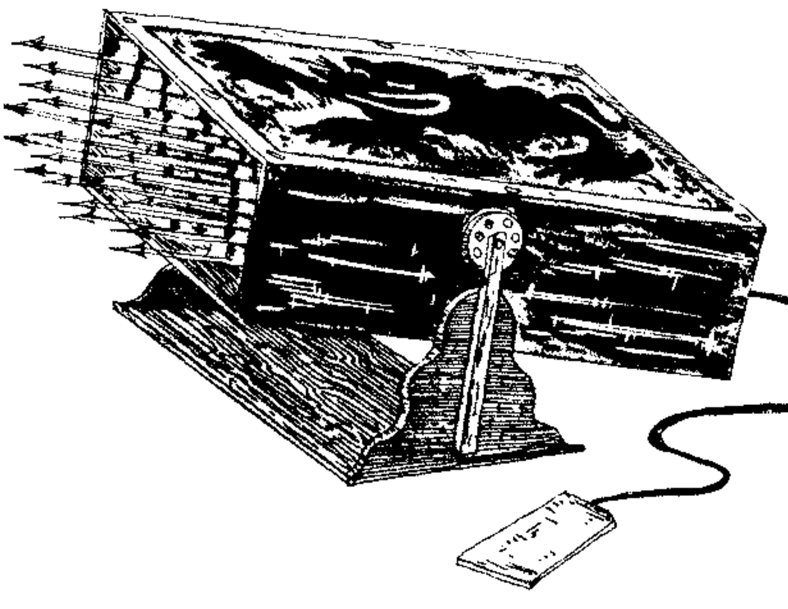
In the mid-13th century Chinese trade routes established during the early years of the Sung Dynasty carried word of black powder and fire-works throughout Asia and on in to Europe in a diffusion of technology which introduced a new concept to war and military campaigns. The Mongols spread rapidly through western Asia and by 1241 were knocking on the door of Europe. While the use of rockets in this territorial campaign is only surmised they did play an important part in the Middle East in 1248 when Arab armies came under attack from lances propelled by powder cases attached in similar fashion to the fire-arrows. Quick to utilize any efficient stimulus to conquest, the Arabs had obtained knowledge of powder preparations within a decade following this encounter and introduced innovations to counter efforts by French forces to drive them from the Nile in Egypt.

Elsewhere, the Englishman Roger Bacon wrote up coded formula for black powder which certainly improved upon the performance of Chinese chemistry and by 1248 he had mastered the theoretical principles of boosted projectiles as used in Asia during this period. It is very difficult to be certain as to the originality of this work and a possible information route can be traced which suggests that Bacon, along with other contemporary alchemists in western Europe, obtained knowledge of Chinese developments before commencing work on the combustible properties of black powder. Polish armies under the command of Henry the Pious were defeated at the town of Legnica on 15 April 1241, in the face of a Tartar onslaught that was only a part of the westerley rampage of this mongol group. Although there is only superficial evidence that rockets were used by the Tartars in this engagement it is reasonable to assume that from such scant indications as exist, their knowledge may have spread through this encounter.

Just seven years later Bacon was writing up black powder formulae and in Germany one Albertus Magnus documented a mixture of powder, using saltpeter, sulphur and 'coals of willow', necessary to prepare an explosive grenade device. A few years later Marc the Greek expended considerable energies reporting on the black powder preparations developed by alchemists and neo-scientists in countries as far apart as Egypt and China, adding commentaries on his own theoretical deliberations. West European knowledge of black powder, fire-crackers (grenades) and fire-arrows (rockets) was at any rate well established by 1270 and from this diffusion of Chinese technology came the basis for later developments and far-east application seems to have reached a maximum at this point in time.

From now on the continued development of rocketry and combustible projectiles would centre on European applica-

This Chinese contraption was designed to fire off a fusillade of fire-arrows from a boxed launcher placed on the ground. Note the fuse lead.



tions. Not that Europe was confined to theoretical contact with the rocket. As Arab influence extended throughout North Africa, trans-Mediterranean incursions along the coast of Spain brought encounters between Christian and Islamic factions. When Moorish attacks on Valencia began in 1288 the rocket was used with frightening results but the precedent for this type of warfare had been established thirty nine years earlier when the Arabs brought fire-arrows to the Iberian Peninsula for the first time.

For the next four hundred years little progress was made to adapt the basic principles of fire-works and fire-arrows to more efficient methods of assembly and launch. But perhaps this is not surprising; not until the late 17th century would the world of science digest the tangible laws of motion written down by Isaac Newton and move forward with development of the rocket. Hitherto, the ethereal concepts of matter left as a legacy from Greek philosophy inhibited a realistic view of the physical world and only when laws of motion and force were recognized could experimentation generate useful developments. Yet long before these laws were written down for all to see concepts were developed which, in theory at least, pointed the way forward to better designs.

In the early 15th century Jean Froissart wrote of the improved accuracy to be obtained if rockets could be launched from inside a tube, stabilizing the flight path and controlling the angle of ascent during the burning phase. In other applications, theoreticians proposed the construction of a rocket propelled battering ram which, if pointed at the appropriate castle wall and lit by intrepid siege troops, would surely compel those inside to call off their defence and give up the struggle. There is no record of such a contraption actually reaching the test stage and probably just as well; any such device would doubtless have been more destructively offensive to the assailants than the assailed!

Throughout the 15th century German and Italian theorists proposed bizarre applications of the rocket which paid little heed to the practicalities of design and invention. In one concept a rocket would be launched horizontally from a boat, rush along the surface of the water and drive a steel spike firmly into the hull of an attacking ship. In another, rockets would have been launched at a high angle, releasing a parachute device at the top of the trajectory which would then gently lower message canisters to friendly forces a kilometre or so distant. Despite these ambitious and often humorous ideas the rocket made little progress although its use was diversified to embrace signalling, ship to ship battles and piratical ventures of all kinds.

Throughout the period between the 13th and 17th centuries rocket devices were used mainly in land engagements and the French military engineers became more ingenious in their application. The Italians meanwhile concentrated on the explosive properties of black powder to set up impressive and entertaining displays to demonstrate their fascination with the new toy. For much of the 16th and 17th centuries they amused and delighted droves of foreign dignitaries with crackling fire-work displays elaborately and expensively staged to please affluent guests. This was not the last instance when rocket power played its part in structuring foreign relations.

Although the precise mechanical and physical laws pertaining to rockets and fire-works were still to be written down, the mid-17th century provides documentary evidence of intuitive knowledge of these basic principles. From the first application of black powder by the Chinese, the duration of the burn phase had been so brief that ranges were limited to a few thousand metres at most. In the 13th century Roger Bacon experimented with different chemical mixture ratios and this provided increased or decreased burn times according to the relative abundance of saltpeter, sulphur and charcoal. Despite this, however, the fire-arrow and rocket had a short lived flight time and thus had a limiting effect on its military usefulness. Then, in 1650, the Polish artillery specialist Kasimir Simienowicz published a review of guided rocket devices in which he mentioned a way of improving the range and accuracy of a projectile.

By placing a series of three or four powder filled tubes in tandem the rocket could be made to fly further. First, only the extreme rear tube would be lit to set the rocket in motion. After this section had burned through it would ignite a fuse which would light the next tube in line and the exhaust product of this combustion would blast the inert rear section away. This would reduce the weight of the projectile and increase the power/weight ratio thereby making the device more efficient as successive sections were jettisoned. This seems to be the first real attempt at 'staging' and although there is absolutely no evidence to indicate the construction of this design, it certainly marks a significant turning point in rocket theory.

Simienowicz also proposed fitting fins to a single-stage rocket to stabilize its flight and improve the accuracy; in other areas he spoke of clustering several rockets together in parallel to increase the weight carried at the front or extend the range according to the requirements of the operator. Within eighty years this treatise had been translated into French, German, English and Dutch and found its way into every corner of Europe, a veritable bible of summaries and conjecture on mechanical improvements to the rocket. Although it is just possible that Simienowicz took up ideas originally formulated by earlier Chinese proposals, there is little doubt that the substance of his work was original and for that reason alone this genius of creative thought marks the end of the old world, a world in which fantasy and mythology were never very far from reality.

A new age was dawning. In one glorious century Galileo provided astronomical science with its most valuable tool to date, the telescope, and Isaac Newton filled the theoretical void and wrote laws which form the basis of rocket flight on the Earth and in space, provide quantifiable values for measuring performance and establish a practical set of probabilities with which to design more complex methods of propulsion.

Newton was born in the rural hamlet of Woolsthorpe, not far from the town of Grantham, in Lincolnshire, on Christmas Day 1642. His mother, widowed two months before, married a second time and left Isaac in the care of his grandmother, returning to Woolsthorpe when she was widowed for the second time in 1656. The young fourteen year old Newton was brought home to begin a four year period of work on the family farm during which he proved to be a competent dreamer and student, but a poor labourer. His penchant for mathematics and physics so impressed his uncle that he was returned to scholarly servitude, and preparation for admission to Trinity College Cambridge, which he gained a year later. At the age of twenty two he obtained his B.A. and was back at Woolsthorpe for almost the entire two-year duration of the Great Plague which began in 1665. Much of his time was now spent in developing the binomial theorem and setting out ground rules for the development of differential calculus. In 1669 Newton took a chair in mathematics at Trinity College and the young Professor spent the next few years following in the footsteps of his predecessor by concentrating on problems related to optics. Later, when approaching his forty second birthday, Newton began setting out his theories on the qualities of gravitation, mass and force which would be published in 1687 as the *Mathematical Principles of Natural Philosophy*.

While much of this great work was used over the next two centuries to lay down the principles of modern astronomy, its three laws of motion defined working models for rocketry and, when married to the former, laid the theoretical foundation for space flight upon which countless theoreticians and prophets would base their predictions thereafter. The first law stated that every object, particle or constituent of a particle will remain in a state of rest or motion until some other force is made to change it. This says that a body moving through a vacuum will continue in the same direction and at the same speed until some other force is encountered to modify its velocity (direction and speed), a highly relevant characteristic of the physical universe directly applicable to rocketry and space travel.

In the second law Newton states that a force acting on a physical body or particle will cause it to accelerate in the same direction as the force and that the value of the acceleration will be proportional to the force and inversely proportional to the mass of the body. In other words, force equals mass times the acceleration (or $F = ma$). This will quantify

In this contemporary illustration of the mid-19th century, naval rocket brigades can be seen assaulting a rocky promontory during the Abyssinian expedition. Note the ground launchers employed to fire the missiles.

the amount of work (force, F) which a rocket must perform in order to move its weight (or mass, m) at a given acceleration (a). The first two laws had been applied by earlier scientists as a direct result of observation and practice, but the third law provided a framework against which to measure the orbits of planets, the path of the Moon about the Earth and the force exerted on a rocket when its combustible products are discharged from one end.

The third law states quite simply that every particle of matter on this Earth and throughout the Universe exerts a similar force in return to that which is received and that mutual interaction generates all known forces. In short, to every action there is an equal and opposite reaction and this fact alone sets a measure against the amount of work which can be performed by a given force. Quite basically it affirms that a discharge from one end of a rocket will, if of sufficient force, cause the assembly to move along in an opposite direction until, by incorporation of the first law, another force becomes dominant and changes the state within which the rocket exists.

Another Newtonian law, that of universal gravitation, is related to the problem of determining the magnitude of body attraction as a mass moves through space. It states that every particle attracts every other particle with a force that is directly proportional to the product of the masses of the two particles and inversely proportional to the square of the distance between their centres. This inverse square property means that if a rocket travels out from Earth to a point four times the distance from the Sun as the Earth is, it will feel a pull from the Sun only one-sixteenth as strong as the pull felt by the Earth.

The implications of these laws were fully appreciated by Newton's contemporaries, but their physical application to rockets and the like was still far off. Despite other accomplishments the *Mathematical Principles of Natural Philosophy* established Newton as a giant among his peers and today he is universally recognized as one of the greatest scientists that ever lived. After a term as member of Parliament Newton went on to become Master of the Mint. Following a short illness, he died at the age of eighty four on 20 March 1727. At last a precise dialogue had been established between practical experiments and natural law, providing an opportunity to exploit technology and apply quantifiable values to design and invention. Yet for a hundred years after publication of the three laws of motion, little interest was shown in the rocket and when Britain and Europe were forced to wake up and seize the new technology, it was because of a stimulus from abroad, a stimulus of the most bitter kind and one which was directly coupled to increasing imperial interest on the Indian subcontinent.

British interests in India were built up by the East India Company during the years that Newton lived and worked at Trinity College and he was doubtless unaware of the foreign discontent which would boil over in the next century and promote investment in rockets and rocketeers at home. In 1781 Haidar Ali of Mysore, a region of India covering a large part of the south-west coast and bisected by the Ghats Hills, rose in defiance of directives covering administration of the area and took his army on a march to occupy the town of Madras. Warren Hastings, then the Governor of Bengal, ordered naval forces to engage the rebel leader and in a series of bitter engagements put down the insurrection before French interests vied with the British and turned these two powerful European nations against each other in a military campaign staged in the Bay of Bengal. The outcome firmly established British rights in India and peace returned with a recognized trade-off for French territories in America.

However, Haidar Ali, quick to exploit the prestigious aura surrounding rocket equipment, built up a contingent equipped with metal tubed projectiles with very high internal density. Fastened to a 3 metre-long bamboo cane, each rocket weighed between 3 kg and 5 kg and was found to have an effective range of up to 1½ km, an outstanding performance for the time. Haidar Ali developed the device, his son Tipu Sahib took it into action. In a bloody engagement with the British on the island of Seringapatam in 1792, Tipu Sahib sent five thousand rocket troops into battle. In preparation for the first attack rocketeers surrounded the British camp and began an assault simultaneously from all sides with a hail of fiery projectiles bombarding cavalry and foot soldiers in a frenzy of activity, which took the British completely by surprise.

Accounts differ as to the effectiveness of this onslaught and vary from the austere commentaries prepared by battle-

Examples of different Congreve solid propellant projectiles. Note the looped bands for emplacing the wooden guide stick and the single orifice through which the exhausted gases would escape.

hardened troops to the essays and diaries of terrified young officers exhilarated by their baptism of fire but totally unprepared for the weapons they now encountered. Several rocket cases were collected and returned to Britain for analysis and one particular example was found to be bound up with strips of hide to a sword blade, in lieu of a stabilizing stick, but a rudimentary device which would, nevertheless, have worked surprisingly well. Other rockets were packed with black powder, now more commonly going under the name of gunpowder, so that upon falling to earth they continued to bounce and twirl on the ground adding chaos and confusion to surprise.

A second battle at Seringapatam in 1799, with rocketeers going into action against the British, spurred action among the military commanders of the time and the Royal Laboratory at Woolwich Arsenal in London was ordered to design and test rocket devices which could effectively be used against the French. Records of the Indian engagements endorsed the potential capability of the rocket when casualty lists included a high percentage of injury and death directly attributable to the projectiles. At Woolwich Arsenal, Colonel William Congreve was assigned the task of initiating a workable rocket which could become standard equipment for the artillery, for production in large numbers for test and operational use and carry the maximum achievable effectiveness to the enemy ranks.

In 1804 Congreve published *A Concise Account on the Origin and Progress of the Rocket System* in which he put expression to a fundamental asset of rocket engineering. Recognizing that the operation of a conventional artillery piece had the disadvantage of recoil, or a reaction equal and opposite to the action as detailed by Newton's third law of motion, he thought the rocket could find more appropriate application in activities which all but obviated the use of cannon. In this he must have fully appreciated the interchangeability of roles presented by the cannon and the rocket. Now that Newton's work was forming the basis of every mechanical invention, it could be said with qualification, that while the cannon was designed to absorb the recoil during the process of discharging a ball shaped mass, the rocket was most effective when it used the discharge of a gas to improve the efficiency of the recoil. In other words, so Congreve's theory went, apply the rocket to situations where the unavoidable recoil of a cannon all but prevented the effective use of artillery: seaborne assault, where the recoil severely upset the stability of the vessel to which it was attached. The rocket, imparting no recoil to the vessel at all, but rather carrying its own recoil along with it in flight, was the perfect answer for such a situation.

With this purpose in mind Congreve designed an iron rocket case 107 cm long and 10 cm in diameter with a conical forward section and a weight of 14.5 kg. Attached to a 4.6 metre-long wooden stick 3.8 cm in diameter, the device had a range of 1.8 km and cost the sum of £1 to produce. By November 1805 the Royal Navy had assembled a flotilla off the city of Boulogne with rocket carrying launches standing by to bombard the French. Unfortunately the attempt had to be called off when a storm blew up in the English Channel and carried several launches to a watery demise. The next attempt came on 8 October 1806 and this time eighteen launches fired more than two thousand rockets on to Boulogne. The 14.5 kg rocket had, by then, been improved to provide a range of 2.7 km and they were so effective that several buildings were set on fire with attendant chaos that completely routed attempts to return fire on the British.

A year later the British launched several thousand Congreve rockets against the city of Copenhagen, terrifying the Danish populace, burning down many homes and severely damaging manufacturing yards and warehouses. Throughout the next few years Congreve rockets formed a unique arm of British naval operations, taking effective measures against the town of Callao in 1809, against Cadiz in 1810 and against the German city of Leipzig in 1813. During this period several European countries followed Britain's example and set up rocket factories to manufacture small projectiles on a production basis.

Elsewhere, and with increasing emphasis on the rocket's military application, the Russians set up production in the late 18th century with designs adapted to land and naval use. By the early 19th century a considerable amount of experience had been gained in chemical composition of powder and the preparation of cases and appended artifacts (warheads, stabilizers, etc.). The Russian Army, technical branch, put considerable emphasis on the tactical advantage of surprise bombardment and Alexander D. Zasyadko (1779–1837) teamed with associates to head an engineering directorate concerned with the application of rocket technology to military needs. Advances in the existing technology were more the personal responsibility of Zasyadko and from early developments begun in 1814, came a series of test flights in 1817 which demonstrated a device with a range of 2.7 km. Production was set up in the town of Mogilev.

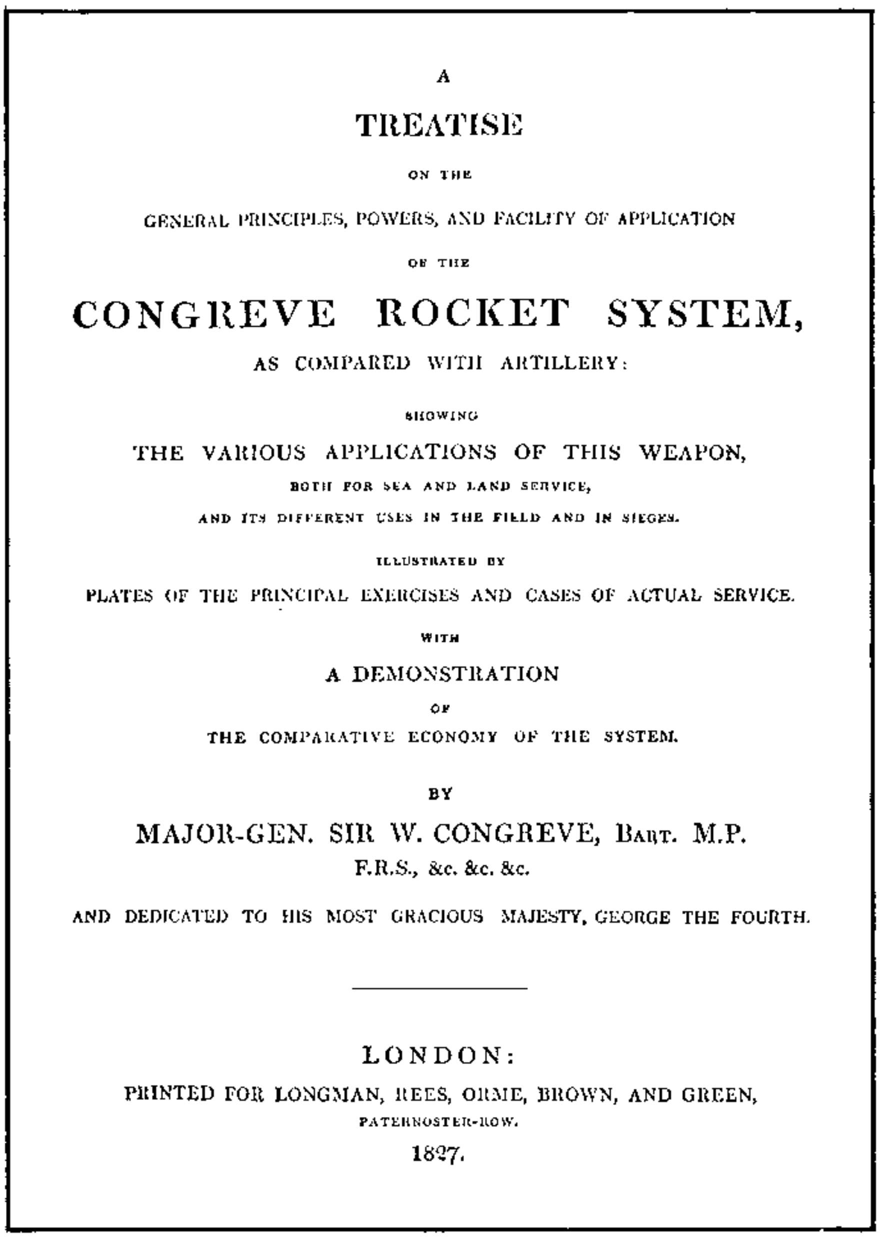
Meanwhile, the British had taken the rocket to war against the United States, fully resolved to put the work of Congreve firmly in the hands of infantry, artillery and in-shore forces at every possible opportunity. During the war which began in 1812 a British rocket bombardment on Fort McHenry was made from the Baltimore harbour during the night of 13–14 September, 1814, with creditable results. On 24 August, a decisive note was struck when a flurry of rockets drove the Americans to retreat, thus enabling the British to capture Fort Washington.

Congreve had gone to great lengths to adapt the rocket to close in-shore bombardment and several naval vessels had been converted for the purpose of carrying rockets and serv-

Alexander Dmitrievich Zasyadko (1779–1837). A contemporary of Congreve, this Russian theorist conducted practical research into the potential military use of solid propellant rockets.

A quaint contemporary illustration from the 19th century, showing the method of preparation and launch employed in a land-based solid propellant rocket system.

This title page from a treatise on the comparative merits of rockets and conventional artillery appeared a year before Congreve died.



A

TREATISE

ON THE

GENERAL PRINCIPLES, POWERS, AND FACILITY OF APPLICATION

OF THE

CONGREVE ROCKET SYSTEM,

AS COMPARED WITH ARTILLERY:

SHOWING

THE VARIOUS APPLICATIONS OF THIS WEAPON,

BOTH FOR SEA AND LAND SERVICE,

AND ITS DIFFERENT USES IN THE FIELD AND IN SIEGES.

ILLUSTRATED BY

PLATES OF THE PRINCIPAL EXERCISES AND CASES OF ACTUAL SERVICE.

WITH

A DEMONSTRATION

OF

THE COMPARATIVE ECONOMY OF THE SYSTEM.

BY

MAJOR-GEN. SIR W. CONGREVE, Bart. M.P.

F.R.S., &c. &c. &c.

AND DEDICATED TO HIS MOST GRACIOUS MAJESTY, GEORGE THE FOURTH.

LONDON:

PRINTED FOR LONGMAN, REES, ORME, BROWN, AND GREEN,

PATERNOSTER-ROW.

1827.

ing as a launch platform. One of these, the Erebus, was brought into the war with America and used during several engagements. It had a cluster of twenty metal box frames facing outboard through cutouts in the hull. Each rack carried a set of tubes with rockets and a lanyard for safely triggering the powder and launching the projectile from a respectable distance.

Congreve's rockets had been a great success. Not only had he provided the British forces with an effective and deadly weapon capable of flying a distance of 2.7 km, he had also demonstrated a semi-mobile launch concept, taking the weapon to the man in the field and giving the infantry a potential which had hitherto been realized only under the umbrella of artillery bombardment. No one had improved Congreve's rocket up to his death in 1828. During his lifetime he was well assured of a place in history, and indeed was knighted for his services to Great Britain.

Again, toward the mid-19th century thoughts turned to fundamental issues of rocket technology which, if utilized, could transform the weapon into a device of strategic importance. Throughout Europe and the United States experimenters debated the problem of stability, arguing that the long cumbersome stick could be replaced with a screw-head which would cause the rocket to spin like a rifle bullet and stay on a true course. Other propositions envisaged angled vanes situated in the rear of the rocket and made to project into the exhaust, so that the impinging gas would impart a rotational motion to the device and thereby achieve spin-stabilized flight, while some said that three fins on the outside of the rocket would do much to improve stability; that concept had been proposed by Kasimir Simienowicz two hundred years earlier.

In Russia Konstantin I. Konstantinov (1817–1871) was appointed Director of the St. Petersburg laboratories, an establishment set up in 1826, and under his lead tests were made of a rocket with an effective range of 5 km. A creditable record for 1860. Ingenuity was widespread in Russia as well as in Europe and K. A. Shilder, a rocket engineer at St. Petersburg, designed a submarine in 1834 which could theoretically fire rocket-propelled torpedoes under water or on the surface. The technology, on this occasion at least, was found to be more inaccessible than the idea. Yet, despite bizarre designs bearing little resemblance to realistic or practical application, much was achieved during the second half of the 19th century laying the foundation for the great strides to be achieved in the first half of the 20th century.

It was, above all else, a time in which theoreticians, philosophers and prophets would far outstretch existing technology and draw up proposals for outlandish schemes; shocking to pious Victorians, outrageous to classical scientists. Serious studies would be made of the use of rockets for leaving the Earth and flying to the Moon, engineering studies would visualize massive orbiting space stations and, in turn, lengthy expeditions to the planets would be proposed. And all of this before two great World Wars of the 20th century which would accelerate the needs of conflict and fabricate the means by which these dreams could be transformed into reality.

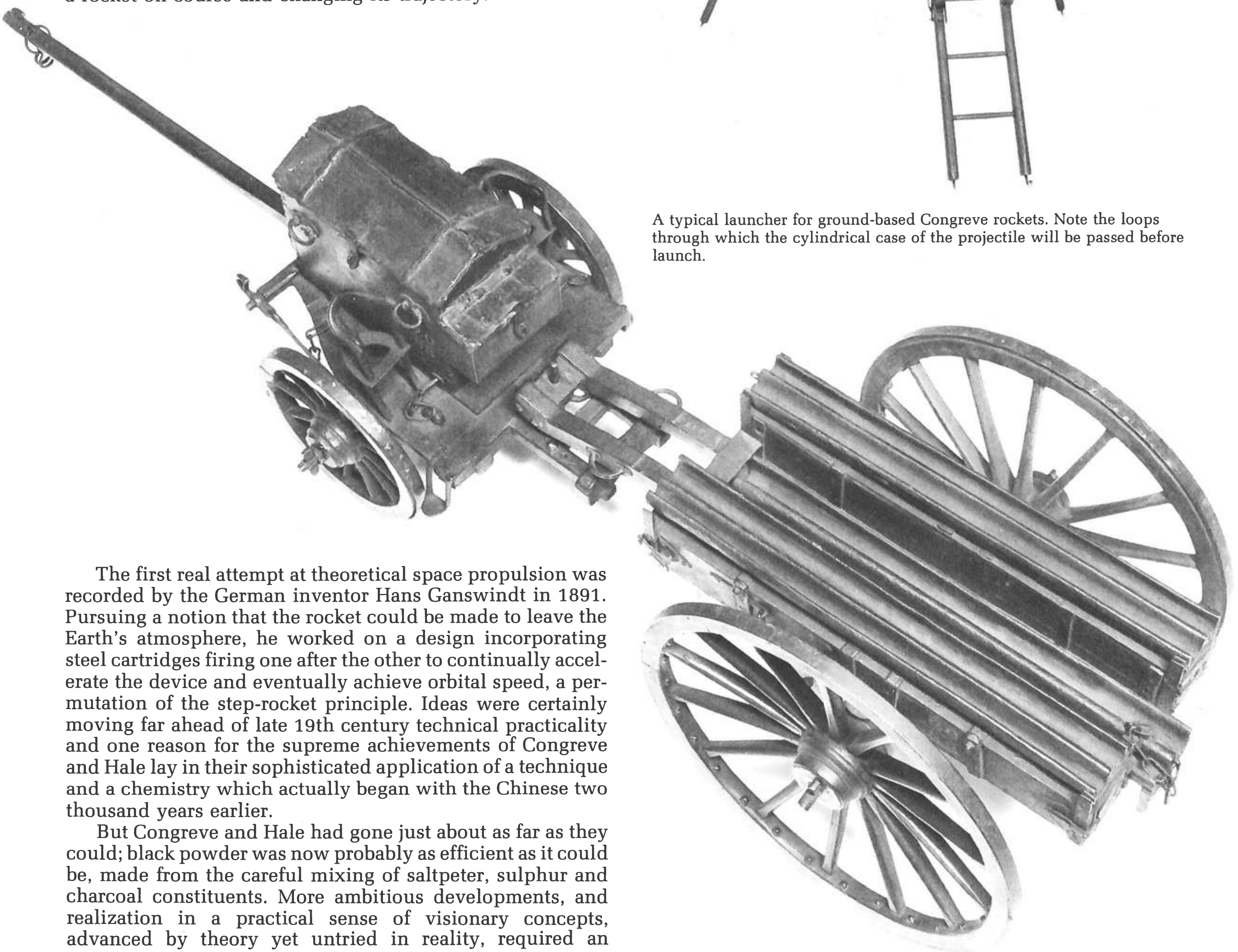
Men had been trying to fly, leave the Earth or reach the Moon for centuries and now it seemed there may be a way to get there. The laws of Isaac Newton, written two hundred years earlier, had defined the mathematics of the Universe. The dream of practical space flight, long in gestation, was achieving form.

At a more practical level, Congreve's rockets grew in sophistication until a range of projectiles were produced varying in weight from 12 kg to 25 kg with a variety of warheads, including grenade type incendiaries or clusters of small iron balls. An Englishman, William Hale, made a practical contribution by actually fitting angled fins to the rear of his rockets so that they could be spin-stabilized, removing the need for the cumbersome guide stick. At long last the design proposed by Simienowicz in 1650, debated in the early 19th century, was put to practical use. Used by the United States during the war with Mexico in 1846, the Hale rocket found competition with new developments in artillery devices and rifles and by 1861, when the Confederate States united to begin the American Civil War, rockets were losing favour. Only in unique situations, where heavy field cannon was compromised, did the Hale and Congreve projectiles linger on.

Yet despite this seeming hiatus a number of other ideas germinated and found application. The step rocket, two powder cases mounted in tandem, was first used in 1855 to fire a line between ship and shore and although the military use of rockets declined, the civilian benefits were applied with ever increasing effectiveness. Soon, rocket carrying rescue lines became a life-saver to stranded sailing ships, and signal flares were fired by rockets on land and at sea. With whale hunting expeditions gathering support from commercial enterprise, the need to speed up the hunt was spurred by the insatiable appetite of Victorian indulgence. Here, too, the rocket found application and was quickly developed to accelerate the wholesale slaughter of whales with an efficiency typical of the period.

While the further technical development of rockets became temporarily stymied, and diverse peripheral applications became commercially viable, the philosophers and dreamers kept up their perambulations through a variety of ideas which must have seemed at least partially tolerable to the late 19th century mind. In 1881 N. I. Kibalchich devised a rocket propelled aeroplane while awaiting execution in a Russian prison for the attempted assassination of Tsar Alexander II. Earlier, Kibalchich had been head of a research laboratory and worked intently on the possibility of controlling a rocket's flight by changing the direction of the exhausting gases. This concept, later to become known as vectored thrust, would emerge as the most satisfactory way of keeping a rocket on course and changing its trajectory.

A typical launcher for ground-based Congreve rockets. Note the loops through which the cylindrical case of the projectile will be passed before launch.

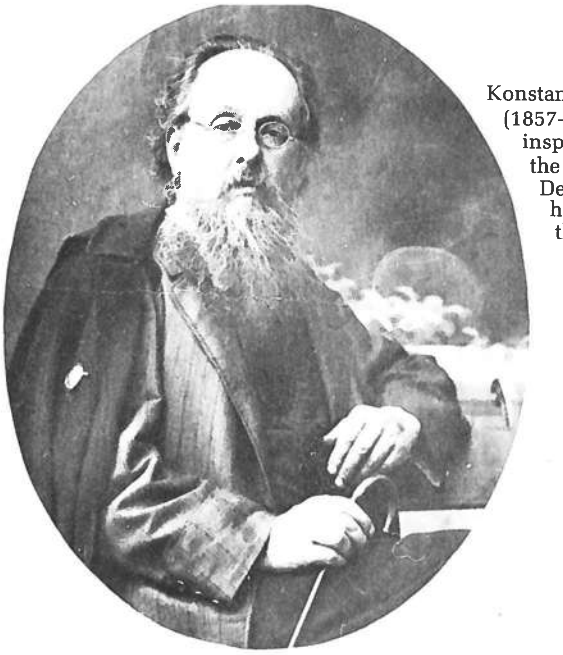


The first real attempt at theoretical space propulsion was recorded by the German inventor Hans Ganswindt in 1891. Pursuing a notion that the rocket could be made to leave the Earth's atmosphere, he worked on a design incorporating steel cartridges firing one after the other to continually accelerate the device and eventually achieve orbital speed, a permutation of the step-rocket principle. Ideas were certainly moving far ahead of late 19th century technical practicality and one reason for the supreme achievements of Congreve and Hale lay in their sophisticated application of a technique and a chemistry which actually began with the Chinese two thousand years earlier.

But Congreve and Hale had gone just about as far as they could; black powder was now probably as efficient as it could be, made from the careful mixing of saltpeter, sulphur and charcoal constituents. More ambitious developments, and realization in a practical sense of visionary concepts, advanced by theory yet untried in reality, required an increase in the productive yield of the chemicals necessary to propel the rocket. Nothing more powerful had yet been found, but soon ideas took root to change all that. The firework was at the peak of its development; discoveries in the early 1900's would give the World a tool for space flight and a weapon for global bombardment.

Carried by the artillery in carriages like this, Congreve rockets were an important addition to the inventory of 19th century fighting equipment before improvements to gun technology heralded their demise.

Vision and Reality



Konstantin Eduardovich Tsiolkovsky (1857–1935), who did so much to inspire Russian theorists during the early part of the 20th century. Decades ahead of his time, he will be remembered as the 'father of space travel.'

Despite the efforts of Congreve and Hale in the first half of the 19th century, the rocket as an instrument of war was slowly giving way to the sophisticated developments in conventional artillery. Major improvements to the gun ousted the rocketeer's improvisation of existing design and the rocket settled back as a useful adjunct to civilian life, plaything for public extravaganzas and, only occasionally, a supplement to heavy field cannon in tactical engagements. During the middle decades of the 19th century the United States produced several thousand examples of the Hale rocket, but the expeditious production lines conflicted with the requirements for effective use: a calculated trajectory, valid definition of wind patterns and strength across the line of flight, an experienced firing team and a carefully selected objective. None of these requirements were effectively met by soldiers recruited from pastoral, farm-land backgrounds and the weapon fell into disuse after the Mexican War of 1846–48. There is little evidence of its effective use in the Civil War of 1861–65 and for at least half a century technical developments awaited the discovery of new materials which would lift it from obscurity.

The latter half of the 19th century was to be a time of 'grand design' encompassing the full spectrum of science and technology. While the internal combustion engine was emerging and the steamship loomed promisingly on the horizon, thoughts turned to the theoretical application of basic concepts. This transformation in the thinking process drove theoreticians into the open and visionaries began to explore the physical laws which powered a host of new developments. Within this climate of exploratory evaluation, mathematicians and physicists looked closely at the reason for a rocket's motion.

Newton's three laws could define why the rocket worked, new thoughts would explore the 'how' of reactive flight and instead of concentrating on permutations of the old black-powder chemistry, the mathematics of reactive flight would push aside the restricting envelope of existing and well tried concepts. Surprisingly late in the day it was recognized that the kinetic use of energy to achieve a reaction was far more important than the measured reaction from a potential force. In other words, reaction could be induced by other means than the limited effectiveness of black powder. The panoply of historical events had woven the use of rockets around the basic Chinese invention, which itself had matured from a chemical discovery, but when war advanced beyond the capabilitites of the firework, it was to very old principles that technology turned for guidance in seeking the next path to innovation.

In the 1st century AD a Greek geometrician and inventor known by the simple title 'Hero of Alexander' developed several models demonstrating the use of steam to perform work and, thereby, bringing to reality the principles (written down five centuries later) of reactive thrust. In one famous example he formed a sphere and attached two short pipes bent 90° to opposite sides. With the sphere held in a frame so that it could rotate like a ball, water inside the sphere was heated to boiling point whereupon the resulting steam was forced by the build-up of internal pressure to escape through the two bent pipes. Because the exit sections of each pipe faced opposite directions, the sphere rotated under the influence of reactive thrust. It was an interesting toy but one which held the germ of a new technology, which after eight centuries of lying dormant, would move on and form the basis of liquid-propelled rockets.

There was, in fact, nothing overtly original about Hero's aeolopile, as it was called, although his was the more famous reaction device recorded by historians. In the 4th century BC one Archytas of Tarentum, a close friend of Plato, yet totally original in his philosophical expressions, applied the principle of reaction to an amusing little device which used steam to propel it around a central support from which it was hung. Fashioned in the shape of a bird, the hollow vessel was filled with water and heated so that when the resulting steam discharged through an opening in the tail it moved round the support to which it was attached. Archytas made several contributions to Pythagorean mathematics and would probably have achieved singular recognition were it not for the eclipsing magnitude of his more prominent contemporary, Plato. As it is, his steam propelled bird is the first device on record to use the principle of reaction, its application coming more than two thousand years before Newtonian law replaced Aristotelian philosophy.

It is interesting to note the use of basic rocket principles several centuries before the discovery of the explosive properties of sulphur, saltpeter and charcoal mixed together. Not for fourteen hundred years would reaction and black powder come together in the form of the rocket. Yet, in spite of the profound logic behind Newton's laws of motion, only the most perceptive of men held on to the implications behind his philosophy and centuries went by with the main body of science hanging on to the mythical and ethereal concepts of Aristotelian naivety. As late as the early 19th century, the basic Newtonian truths were still falling on deaf ears and the full expression of action and reaction had not been truly appreciated.

Following the bombardment of Copenhagen in 1807, the Royal Danish Academy of Science and Letters, intrigued by the fiery success of the Congreve rocket, issued a call for scientific study of the principles involved in rocketry, formulation of propellant and the mathematics necessary to define performance. Spurred by this call for serious deliberation, a mathematical master at the Woolwich Royal Academy, published a treatise in 1813 covering important parameters in the definition of a rocket's trajectory, and intelligently put together an extrapolation of Newton's laws of motion as they applied to reactive flight. This obscure theoretician, known to history simply as William Moore of the Royal Military Academy, foresaw the need to define aspects of thrust, propellant density, combustion pressure and flame temperature; not for nearly a century would these qualities be fully defined and only then in the comparatively obscure writings of a Russian school teacher. But William Moore had presented a treatise which, if only it had been more acceptably received by the general scientific community, could have put Europe in the vanguard of rocket development.

There was much in the 19th century world of discovery and invention to stimulate brave new ideas and while fiction writers in the civilized world pandered to the needs of an increasingly literate working population, engineers and mathematicians in Russia had put down the theoretical foundations for exploration of a new frontier – space. Although, to date, the most vigorous incentive to rocket development has matured through the necessities of weaponry and military missiles, the underlying stimulus among scientists and engineers alike has gathered momentum from the possibility of travel to other planets.

The Russians were consistently attached to the theoretical possibilities laid bare through rocket technology and as early as 1680, more than a hundred and twenty years before Congreve organized the first serious European development of rockets, a production line had opened in a suburb of Moscow to prepare and supply ground forces with powder-filled projectiles. By 1826 the St. Petersburg Laboratories were hard at work developing new variations of the black powder rocket and several theoreticians were openly discussing the possibility of using reactive thrust to achieve powered flight. For a while it seemed as though air travel would mature into reality through the generic development of rocketry and not by way of screw propulsion as eventually demonstrated by the Wright glider, modified to carry a petrol engine. Yet for all their drive and perseverance the Russian engineers knew only too well the limitations of the powder rocket and as if in reward for determination and verve, they were to receive into their halls of learning a prophet who would illuminate the necessity to seed the invention.

The Russia of the mid-19th century was in no fit state to spawn advancing technology. With an Imperial ruler, Nicholas I, at the head of a ruthless and domineering minority power controlling the lives of millions of serfs, the oppressive and intense political equation was dangerously inclined toward revolution. By 1848 the Tsar was threatening eastern Europe, cracking the whip of subjugation, and within five years had plunged Turkey, France and England into a pseudo-Holy war over Christian rights in Jerusalem. At home, Nicholas was hounded by peasants and serfs in every corner of his tottering domain and when he died in 1855, the people of Russia had set themselves on a collision course with revolution; four centuries of Romanoff Tsardom was nearing an end, although the coup de grace would not be administered for more than half a century.

It was during the reign of Alexander II, successor to the autocratic Nicholas, that Konstantin Eduardovich Tsiolkovsky was born on 17 September 1857, in the town of Izhevskoye, south west of Moscow. This man was to make greater theoretical contributions to the emerging concept of space flight than any other before, during or since his lifetime and, in becoming the father of Soviet rocketry, stimulate one of the greatest nations on Earth to reach for the stars.

As a boy, Tsiolkovsky did not enjoy good health and suffered from incessant ear trouble, but early on he showed a passionate interest in astronomy and the physical world around him. When he was sixteen, the family sent him to Moscow where he attended lectures on science and mathematics before returning home three years later. Pursuing his interest in science, he became a teacher of physics and mathematics at a school in the town of Borovsk, about 90 km south-west of Moscow, and continued his studies in all aspects of mechanical physics. Before long his humble home had become a veritable library of books and documents related to the problems of rocket development and soon he produced a generous collection of models. Although the youthful Konstantin had received little in the way of formal education, his genius shone through and he started writing technical articles on a variety of topics, all with the central theme of space flight and rocket propulsion.

The national arena in which he grew to maturity was dominated by the struggle to maintain a stable standard of living, albeit meagre, but Konstantin, with his visionary preoccupations, had little contact with the professed realities, struggles and day to day activities of those around him. Nevertheless, he pressed on and furthered his own research into the realms of theoretical physics.

They were hard days in Imperialist Russia. While Alexander II expressed a moderate line towards the peasants and serfs and set about restoring a peaceful foreign policy, the oppressions were too deep-seated to be swept away by anything but radical transformation; with Imperial autocracy rampant in a more subtle manner than hitherto, the Tsarist regime feathered its own nest at the expense of the vast majority of the population. Divorced from the machinations of illegal revolutionary groups, Tsiolkovsky pressed on and in the year Alexander III came to Tsardom, 1881, the teacher of physics made contact with the famous chemist Mendeleyev from whom he learned much. A year later Tsiolkovsky moved to Kaluga, 170 km from Moscow, and quietly taught at the local school, but still worked fervently on problems close to his heart.

On and on he read, familiarizing himself with the laws and philosophies of the then modern science and teaching himself, by endless study, the principles of rocketry as related to theoretical space travel. Tsiolkovsky had little money and could extract no interest from a leadership steeped in imperial aristocracy, but his incessant writings were recognized by the Society of Physics and Chemistry at St. Petersburg and he was admitted to their ranks.

By 1883 he was describing the principles of a throttleable rocket motor and, just two years later, wrote a book which prophesied the advent of earth orbiting satellites. After spending more years in defining the concept he finally prepared a paper, at the age of forty, entitled *Exploration of Outer Space with Reactive Devices*. Tsiolkovsky led a peaceful life with little thought for the mechanics of war and to him the great dream of space travel could be transformed into reality. Repeated calculations convinced him of this possibility and in 1903, at the age of forty six he described in detail how a rocket device could be made to transport men beyond the atmosphere using liquid oxygen and liquid hydrogen.

He believed that if the two liquids could be brought together in a chamber where they would be ignited, the resulting gases could be channelled through a narrow orifice at the rear where they would expand and be exhausted at high velocity, thereby initiating a reaction which would propel the device and anything it carried in the opposite direction. He was right in theory. Moreover, Tsiolkovsky went on, to reach a speed of 8 km/sec the device must carry propellant weighing four times the empty weight of the rocket and its cargo. The significance of achieving a velocity of 8 km/sec was that this is the speed necessary for orbital flight.

Recognizing the difficulty inherent in this requirement, Tsiolkovsky proposed the use of a staged rocket whereby successive sections could be jettisoned as they were expended of propellant. Alternatively, a cluster of small rocket motors could achieve the same objective. These are the exact principles upon which Russia built its rocket programme half a century later. Although the precise details of construction and operation were evaluated theoretically and without practical experiment, it is interesting to note that Tsiolkovsky conceived a device with twenty rocket motors, which could reach Earth orbit. When the Soviet space programme began in October 1957, with the launch of Sputnik I, the rocket which put the bleeping sphere into space had twenty main rocket motors; pure coincidence in reality, but nevertheless a poetic bow to history.

The most important elements of rocketry were being defined with a clarity equal to the precise articulation of

The spartan surroundings to Tsiolkovsky's study. Note the stereo viewer on the desk and the numerous documents assembled from correspondence with other theorists.

Newton's three laws of motion and in concentrating on the product rather than the artifact, Tsiolkovsky provided theoretical proof that space travel was not only possible, but practical. The conception of a liquid oxygen/liquid hydrogen rocket motor was made in the same year that Orville Wright flew into the history books as the first man to publicly demonstrate powered flight with a heavier-than-air machine. The great importance of Tsiolkovsky's work covers four basic principles of rocket flight, all of which stemmed from his desire to formulate a concept which would find application to space travel.

Again and again progress in rocket propulsion would receive stimulation from the visionary dream of leaving planet Earth and exploring other worlds and apart from the necessity of practical demonstration and development, the greatest spur to new technology is the will to achieve a distant objective.

The first principle recognized by Tsiolkovsky was that reactive thrust is the key by which to achieve motion or acceleration in a vacuum. Recognizing the limitations imposed by the technology of the day, he nevertheless adhered firmly to the principle that a motive force, totally independent of the environment, was the only means to travel in space. The aeroplane uses a propeller to draw the mass along and a lifting surface to control independent flight, but a rocket engine must carry reactive chemicals which could achieve combustion and, as a product of their active forces when expelled in a given direction, achieve reactive flight in the opposing direction. This is the principle of the jet engine except here the oxidant necessary for combustion with a fuel is drawn in from the surrounding atmosphere. Because space is a vacuum, both fuel and an oxidizer must be carried integrally, but the principle is the same and fundamental recognition of this requirement satisfied the physical problems associated with the theoretical aspirations of Tsiolkovsky.

Even as late as 1813 William Moore had thought the mechanics of reaction to be sufficiently profound as to explain with complex equations that reaction is a product of action and not, as so many still thought, the consequence of pushing against the surrounding air. Newton had explained this nearly one hundred and thirty years earlier; Tsiolkovsky applied it fully ninety years later.

The second important principle concerned the measure of thrust achieved by the exhausted gases. As a definition of the work achieved by a given product, it is necessary to use a precise value for the performance of the rocket and this is usually obtained by equating the force, or thrust, obtained from a consumption of 1 lb of the propellant (fuel plus oxidizer) in one second of time. If this is referenced to a gravity field, as experienced at the surface of the Earth, the specific impulse, or Isp, can be expressed in seconds and throughout the history of 20th century rocketry the Isp value will provide a readily accessible frame of comparison between motors of different design and quality.

Up to the late 19th century, when Tsiolkovsky was formulating most of his original ideas on how to bring chemistry and physics together in the form of a rocket for space flight, black powder was the only tried and tested chemical combination which had been used with propulsive success. In a formula comprising 75% saltpeter, 15% carbon and 10% sulphur it was possible to achieve an Isp of 45 to 70 sec depending upon the precise density and pressure of the resulting gases contained within the tube, or combustion chamber, which channelled the products through the exhaust orifice. With a flame temperature exceeding 1,000°c it is easy to see why early Chinese, Arab and Russian fire-work developments captured the imagination of military personnel, not to mention the respect of rocketeers firing the infernal contraptions.

In studying these qualities Tsiolkovsky recognized the limitation imposed by the low specific impulse of black powder and must have felt incessant frustration over the incredible speed needed to achieve orbital flight: 8 km/sec. He understood that the speed which can be reached by any rocket depends on the temperature of the combusted gases and the weight of the molecular constituents of the gas. Since the velocity of the expelled gases dictates the reactive velocity of the rocket vehicle, pursuit of one objective will automatically enhance the other. In order to achieve an ideal performance for his seemingly outlandish aspirations, Tsiolkovsky sought a high combustion temperature and a low molecular weight. Hence his choice of hydrogen, lightest of all the elements, for the fuel and oxygen as the oxidant.

Carried internally within the rocket structure, these light gases could be accelerated to higher exhaust velocities within the operating environment of a given temperature and pressure regime. Although used in the late 18th century for inflating balloons, hydrogen was not considered for extensive practical use during the years Tsiolkovsky worked away on theoretical rocketry and a measure of the forward thinking he applied to his philosophies can be appreciated from the enormous engineering problem of preserving hydrogen in a liquid state; it boils at −253°c. In fact, it was 1963, before the world's first liquid hydrogen/liquid oxygen rocket engine flew into space, thirty seven years after the first liquid-propelled rocket flight. Theoretical specific impulse values of nearly 400 sec could be achieved with a hydrogen/oxygen liquid propellant combination and this gave Tsiolkovsky the performance he required to satisfy his objectives.

But this was theory and the Russian school teacher did not pursue his calculations to practical conclusions. Yet the ideas had promise even if they were far in excess of the technology of the day and it should be remembered that by this time nitroglycerine was in the early stages of application as a very mediocre improvement on the combustible energy achieved with black powder. Meagre, that is, in consideration of the enormous developments necessary to actually demonstrate a liquid-propelled rocket.

Mention should perhaps be made here of the work of a Swedish engineer, Carl de Laval, who in 1889 designed a device which would be fitted to gas turbines to convert thermal energy into kinetic energy more efficiently. Known as the convergent-divergent nozzle, it conformed to the theoretical necessity of a rocket engine, by easing the expendable gases from the combustion chamber at low velocity and causing them to accelerate away from the nozzle at a high velocity. In practice the Laval nozzle provided a narrowing orifice, or escape route, for the gases burned in the combustion chamber, smoothing the flow and converting random molecular motion into efficient and directed energy. Once past the converging flanges of the exit nozzle, the divergent portion of the design provides for a continuing expansion and acceleration of the gas up to the point of theoretical maximum efficiency.

The precise shape of the bell-like divergent exit cone (or expansion chamber, skirt, exhaust cone as it is variously called) is tailored to the calculated velocity of the exhausting

Patents taken out by Tsiolkovsky during his lifetime are seen here preserved for all time at the Moscow Polytechnic Museum.

Tsiolkovsky's home town of Kaluga now proudly boasts a statue to the great pioneer, part of which supports a monolith shaped to represent a rocket.

gases. Ideally, the shape should be so configured that gases at the exit end will escape with a pressure equal to the ambient atmosphere and if the cone is incorrectly shaped conditions of under- or over-expansion will occur. In the case of under-expansion, the exhausting gases will depart the exit cone with a pressure greater than that of the ambient atmosphere, with the result that once past the end of the cone they will continue to expand at an acute angle away from the centre line of thrust and lose energy in spreading the exhaust cone pattern, rather than discharging it in a single vector. With a condition of over-expansion, the exhaust pressure at the end of the exit cone will be less than that of the ambient atmosphere and the gases will separate from the wall of the cone, break into turbulence and vortices and waste energy in the ensuing molecular chaos. Under ideal and perfectly balanced conditions the exhaust gases will follow the curvature of the cone and seem to continue the smooth, straight flow patterns set up by the divergent nozzle.

It is possible that Tsiolkovsky was unaware of the extreme importance attached to this end of the rocket and most of his early drawings and calculations seem largely to ignore the virtues of the Laval nozzle, if indeed he had heard of, or fallen upon, its physical properties at this time. He does mention the need to reduce the random molecular motion after combustion and to accelerate the gases once they have left the main chamber, but the precise dynamics of thermal to kinetic energy conversion may have seemed less important to him, than the problems associated with gross thrust, although in fact the two are inseparable. Nevertheless, the high specific impulse and greater efficiency of subtle combinations of chemical formulae mark the third important principle recognized by Tsiolkovsky.

The fourth, as evidenced by his advocation of staged propulsion, concerns thrust to weight ratios. Although protagonists of long range rocket flight had consistently pointed to the desirability of placing a series of stages, or separate rockets, in tandem, so that when the first had expended its propellant the second could separate and take over, the very nature of early black powder rockets made this only a marginally acceptable proposition. With the aim being to reduce excess weight as the propellant was consumed, the powder rocket would benefit but marginally from this idea. In many cases it was simpler to avoid the problem and carry the case along as the rocket cruised in flight. With a liquid propellant system, however, the problem was magnified and made the staging principle all the more attractive. Tsiolkovsky's theoretical work was devoted almost entirely to liquid propelled rockets and so he rightly saw this problem as a major barrier if his designs, as and when brought to reality, were ever to achieve orbital flight, let alone journeys to other worlds.

With a liquid propellant rocket, the motor itself had to be made to operate with the same precision and efficiency at the end of the combustion phase as at the beginning and with a complex system of plumbing and propellant tanks with which to store, control and deliver the fuel and the oxidizer, the system had a necessarily higher inert weight than the simple fire-tube carrying a core of compressed black powder. Tsiolkovsky was the first theoretician to derive the rocket equation which relates the velocity of the exhausting gases to the final velocity of the vehicle when it has consumed all of its propellant and this was the key to his emphasis on separate stages.

Using a single stage, the rocket would be required to achieve its desired velocity at the time the propellant was consumed, and the velocity of the rocket would depend upon the velocity of the exhausted gas, with consideration to the propellant mass ratio. The propellant mass ratio is merely the fraction of the rocket's weight given over to the fuel and the oxidizer, in a single stage design, the only elements to change mass during flight. If the structural assembly of a rocket weighs 10,000 kg and carries a 90,000 kg load of propellant it is said that the propellant mass ratio is 0.9 because propellant alone accounts for 90% of the total assembled weight. But, if the rocket consisted of a number of stages, the decrease in mass as the rocket progressed along its flight path would consist not only of the expended propellant, but also tanks, plumbing and engines discarded as successive stages were separated. Moreover, the final speed achieved by the rocket will be the summed values of the burnout velocity for each individual stage and since successive stages ignite at a velocity imparted by the preceding stage(s), the total impulse provided by the various stages can be added together.

Another way of clarifying the advantages of a staged concept can be had from consideration of the following. If a propellant mass fraction of 0.9 is provided for each individual stage of, say, a three-stage vehicle, the structural mass accelerated to the final velocity will be less than 1% of the total assembled weight at launch. In a single stage concept, where all the assembled mass is accelerated to the final velocity, the structural mass at burnout will be 10% of the initial launch weight. If the thrust to weight ratio of each stage in a multistage vehicle is approximately the same, say 1.4, the successive stages ignite with a flying start, based on the velocity of the preceding stage as outlined above.

Tsiolkovsky readily saw an advantage here in that as the rocket climbed through the atmosphere and out into space, specific impulse would increase due to the reducing atmospheric pressure with altitude and if a 100,000 kg rocket provides a first stage thrust of 140,000 kg (thrust/weight ratio of 1.4) during lift-off, this will increase as the rocket goes up.

The Russian theoretician had one single objective at the end of all his research: to express satisfactorily a set of equations, and describe the physical means, which would enable men to fly into space and from an orbital platform above the Earth, set out on journeys of exploration to the Moon and the planets. Many of the principles he recognized and wrote about could be directly related to the military application of rocketry, but Tsiolkovsky saw none of that as being important. His vision for a new age of space travel embraced sound engineering concepts and his contributions form a very real and practical basis for the tangible developments which were to come in the 20th century.

Passionate adherence to the promise of a new and expanding technology was inseparable from Tsiolkovsky's belief that Man would sooner or later have to face the spectacular and dramatic challenges of the space frontier if he was to evolve into a true child of the cosmos. His vision was all consuming and took in the full spectrum of human society leaving not one activity untouched by the progression into space; article after article written by the great rocket prophet explained how many earth-based activities would be better served with a ready access to manned orbital platforms. This, thought Tsiolkovsky, was to be the key to a new Utopian way of life. Unlimited energy from the sun would provide power for colonies of men and women living under ideal environmental conditions and working in orbital factories which would produce material for use on Earth more efficiently than they could be manufactured on the surface of the planet.

Tsiolkovsky foresaw the consuming demands of an increasingly industrialized society and knew, it seems, the danger of exploiting the limited resources of a finite world. There was perhaps no better place in which to come to terms with the inevitability of future needs than in the Russia of the early 20th century. We can never be sure how affected Tsiolkovsky was by the poverty and wretched misery he saw around him, but the advantages he outlines for an Earth orbiting production facility seems to assure us that he was only too well aware of the dangers of over exploitation.

Consistently, he tells of the possibilities for utilizing solar energy and explains that all space dwellers will have the same benign environment, warmth when they need it, abundant food from beds of plants vitalized from the ever present rays of the sun and a restful weightlessness which will not tire the bones or stress weary muscles. Perhaps in this Tsiolkovsky saw a domain where the forces of nature had imperial domination and all men could be equal under their influence. The enthusiasm which the Soviets have placed on the teachings of this philosopher seem to express a more profound significance than the mere exploitation of space, indeed, it seems to reveal the works of Tsiolkovsky as a microcosmic summary of the need to shed oppression and rise above the hierarchical tiers of a dominated society. If this is true, then it may explain why Tsiolkovsky was unable to get any official recognition, assistance or help from the government of Tsarist Russia. Perhaps the new promise of space was too close to revolutionary principles of equality for comfortable acceptance by a regime that held power on the premise that its rulers were blessed by a divine right to control the destiny of ordinary men and women.

Despite the fact that Tsiolkovsky was only able to devote time to his theories and philosophies when school work was over, he kept up a steady concentration of time and effort on many of the problems he saw as standing in the way of efficient travel between Earth and space. It was recognition of the extremely difficult task of lifting anything through the atmosphere that caused him to concentrate on principles of rocketry and reactive thrust. He was very concerned to solve the transport problem, but spent time increasingly on the tasks which could be accomplished in space.

In spite of the fame his name enjoys today, albeit posthumously, Tsiolkovsky was not well known in the early years and one of the reasons why his ideas were not given public credibility has been discussed already. The last of the Romanoff rulers came to power in 1894, nine years before the publication of Tsiolkovsky's major work *Exploration of Outer Space with Reactive Devices* which detailed the principles of rocket flight, staged rocket vehicles and the famous liquid oxygen/liquid hydrogen engine, all of which are outlined earlier.

Nicholas II was a somewhat weak and ineffectual leader who was not unmindful of the desperate plight attending the vast majority of his subjects yet he was unable to instigate a bloodless transformation. While history has looked with moderate kindness upon the charms and good intentions of Nicholas II, it is, nevertheless, difficult to find evidence of a real change of heart anywhere within the Russian leadership. Nicholas thought himself to be the Holy ruler of all the Russias, defender of the Tsarist regime and champion of a monarchistic throne with which he had God-given responsibilities to defend, preserve and strengthen for his descendants. The people on the other hand felt remote from a government, used by the wealthy minority for their own whims and tastes and abused by the entrenched solidarity of mediaeval philosophy.

During the period Tsiolkovsky was working at the school in Kaluga, (the last two decades of the 19th century) increasing unrest was expressed at the aura of detachment engendered by the Tsar and his family. Government was loose and uncoordinated and departments operated autonomously without the centralized control essential in the establishment of a modern industrialized society. Localized dissent followed hard on the heels of government policies, which directed church funds into national coffers, enforced a rabid anti-semitism and sought to widen the province of national law so that it could embrace communities hitherto remote from rigid Russian control.

Despite a dramatic increase in the industrial potential of the nation, civil unrest grew as the ruling classes of the day orchestrated production at the expense of basic human freedoms. Indecision and procrastination plunged Russia into a war with Japan in 1904, while the Tsar, assuming his role as God's representative on Earth, acted aloof from the day to day bickerings between people and government leaders. Local councils, or zemstva, were denied the means (or, indeed, the legal right) to make regional improvements for the community and the two factions went in opposing directions: wealthy aristocracy to increased preoccupation with Imperial philandering; industrial workers and the lower classes to frenzied dissatisfaction with the ruling minorities. One of the basic underlying reasons behind the blind disinterest in novel scientific initiative, ably represented by the writings of Tsiolkovsky, had its roots in the governmental mistrust for any propositions from the lower classes.

Finally, in 1914, Russia went to war with Germany and everywhere the problems were seen to increase. The army was under-equipped for the massive onslaught attempted on East Prussia, casualties were horrifyingly high and throughout 1915 and 1916 the fabric of government fell more and more into tatters. An attempt by a re-organized national coalition to implement internal reforms was aborted when Nicholas II abolished the plan and took over personal command. His ineptitude, magnified by the high level of participation he had himself assumed, was added to military defeat, a crumbling economy and wide suspicion of a high-level plot to switch sides and give up vast territorial lands for peace with Germany. Suddenly, without warning and certainly without any coordinated plan, the Romanoff dynasty was toppled, Nicholas was arrested and a power struggle began for leadership.

After the revolution a new awareness slowly dawned and the All-Russian Communist Party, established in March 1918, set the climate for a more acceptable rapport with many ideas and philosophies suppressed during the tortuous years of the Tsarist regime. It was within this climate that Tsiolkovsky's work was brought from obscurity and used as the foundation for Soviet interest in rocketry and space travel. Throughout the following sixty years the increasing importance placed on work leading to the development and further exploitation of reactive flight was a direct result of philosophies and concepts first mooted by Tsiolkovsky.

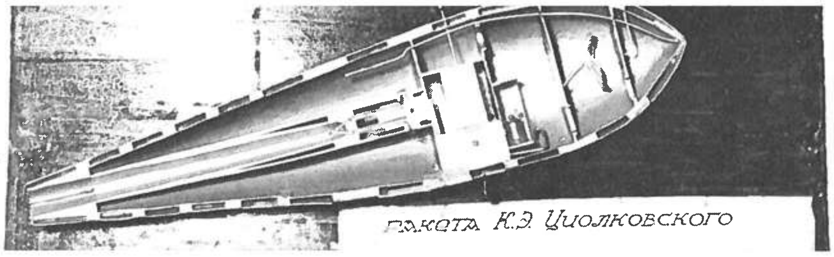
His ideas and writings detailed everything associated with space travel to the extent almost, but outlining a policy plan for a national space programme. The stress placed upon space stations, orbital bases and large urban space facilities has forged the Soviet long-term objective in space and although his vision transcended even today's accomplishments, the basic approach of using Earth orbiting manned stations is being fulfilled already by the currently expressed priorities of Soviet space scientists and engineers. In one prophetic discourse late in life Tsiolkovsky wrote:

> 'The idea of utilizing a major portion of the solar energy is most tempting. After all the inhabitants of the Earth use plants for food. Plants cannot exist without the light of the Sun. The productivity of man would increase two thousand million times, if he could master the entire energy of the Sun. There outside the Earth man will enjoy many advantages in addition to an abundance of sunlight. The atmosphere distorts, weakens and disperses the image of a celestial body seen through the telescope. In space there is no atmosphere, therefore the naked eye and even more so the telescope and photographs, will show us new wonders of space and enlarge our knowledge of astronomy.
>
> 'The virgin energy of the Sun there is not weakened or destroyed by the atmosphere. This factor will affect the growth of plants and the need for artificial decomposition and synthesis of matter under the impact of the sunrays. In its pure form solar energy will be used for the destruction of pernicious bacteria and germs; this will be done in growing plants, sanitation of the soil, water and man.'

Never far from the vision, but always aware of the realities, Tsiolkovsky outlined the way man would live on a space platform:

> 'Industries in the ether (space) will score unimaginable success. Therefore it will be easier to build even tremendous structures in no time. The asteroids will provide the necessary materials in abundance. A multitude of dwellings separated by firmly closing air-tight doors will be linked together into an endless maze of buildings. There will be boundless opportunity for variety, plenty of space and good possibilities for communication, even for the most particular personality.
>
> 'By separating the maze into chambers, relative safety is ensured. If one of the chambers begins to leak and gas begins to escape from it, it will be possible to find shelter in another. But people will have to leave their dwellings from time to time. For this purpose they will have special suits like those of a diver with a supply of oxygen and absorbers of human excretions. They will also be equipped with means of propulsion. We could mention the danger of the lethal ultra-violet rays of the Sun. But man will always be either in his dwelling (space station) or in his suit. In both cases he will be protected against harmful radiation by ordinary glass which filters the short light waves.'

Tsiolkovsky finally provides us with a view into the future when massive space colonies orbit the Earth and spacecraft take personnel from one facility to another in this excerpt from his writings:



This model of a man-carrying rocket testifies to the visionary studies of Tsiolkovsky and remains to this day a remarkable product of his agile mind.

> 'Imagine a trip in your own house (spacecraft). The temperature may be maintained at any selected level or changed at will. There is always plenty of light. Darkness may be created when necessary. One experiences an incomparable state of rest. The body feels no weight, no pressure or sagging. Inside the (spacecraft) movement is ease itself. There is a supply of books, pictures and all kinds of entertainment. The rooms are filled with indoor plants which make up a luxurious garden. Beautiful fruits, excellent meals. One only has to stretch his hand to satisfy his thirst and hunger. The flowers and fruits fill the space with pleasant odours. The air is always pure and well saturated with oxygen. There is no possibility of contagion.
>
> 'You fly along a definite route between (colonies) built in the ether. You take a look round and see an endless chain of all type of structures floating by. There are also crowds of beings dressed in space suits and people in mobile homes just like yours.
>
> 'What cares can you possibly have: you work, eat and look round out of the windows of your (spacecraft) as long as you like. And if you wish you may put on your impenetrable suit and get out into open space. But one cannot stay very long in a gas-tight suit because the reserve of oxygen is limited. However, in the (colony) the source is unlimited – plants lighted up by the virgin rays of the Sun. It is the plants that provide food and drink for the inhabitant.'

With hindsight it is possible to assess the major contributions from Tsiolkovsky's pen and from a knowledgeable posture a century after he first began to apply serious thought to the problems of rocketry and space travel, we can readily see that, in the third decade of the space age, many of his prophetic works are still a century ahead of present technology. This degree of foresight is rare and has helped to amplify the high level of perceptive genius which Tsiolkovsky brought to his studies.

The original publication of *Exploration of Outer Space with Reactive Devices* in 1903 was followed by supplements published in 1911, 1912 and 1914 with an enlarged and updated edition released in 1926. During the political readjustments following the October 1917 revolution, Tsiolkovsky was brought from obscurity and appointed in 1919 to the Socialist Academy, an organization which would eventually be replaced by the Soviet Academy of Sciences. From 1876 to 1921 Tsiolkovsky had worked away in his spare time with no additional help other than a grant for a meagre sum, issued by the Mathematics Department of the governing science body in 1899.

At the age of sixty three he was rewarded by the Soviet government with a state pension which enabled him to leave teaching and devote full time effort to developing his theories and philosophies associated with rocket propulsion. Tsiolkovsky contributed more than five hundred scientific writings, papers and books before his death, at the age of seventy eight, on 19 September 1935. Perhaps the most fitting epitaph for a lifetime's work can be found from his own writings: 'I hope that my studies will perhaps soon, but perhaps in the distant future, yield society mountains of grain and limitless power.' Here too there is recognition of a profound application of space operations: the advantageous earth resources survey for discovering new mineral deposits, observing the health of crops and the conversion of solar energy into electricity.

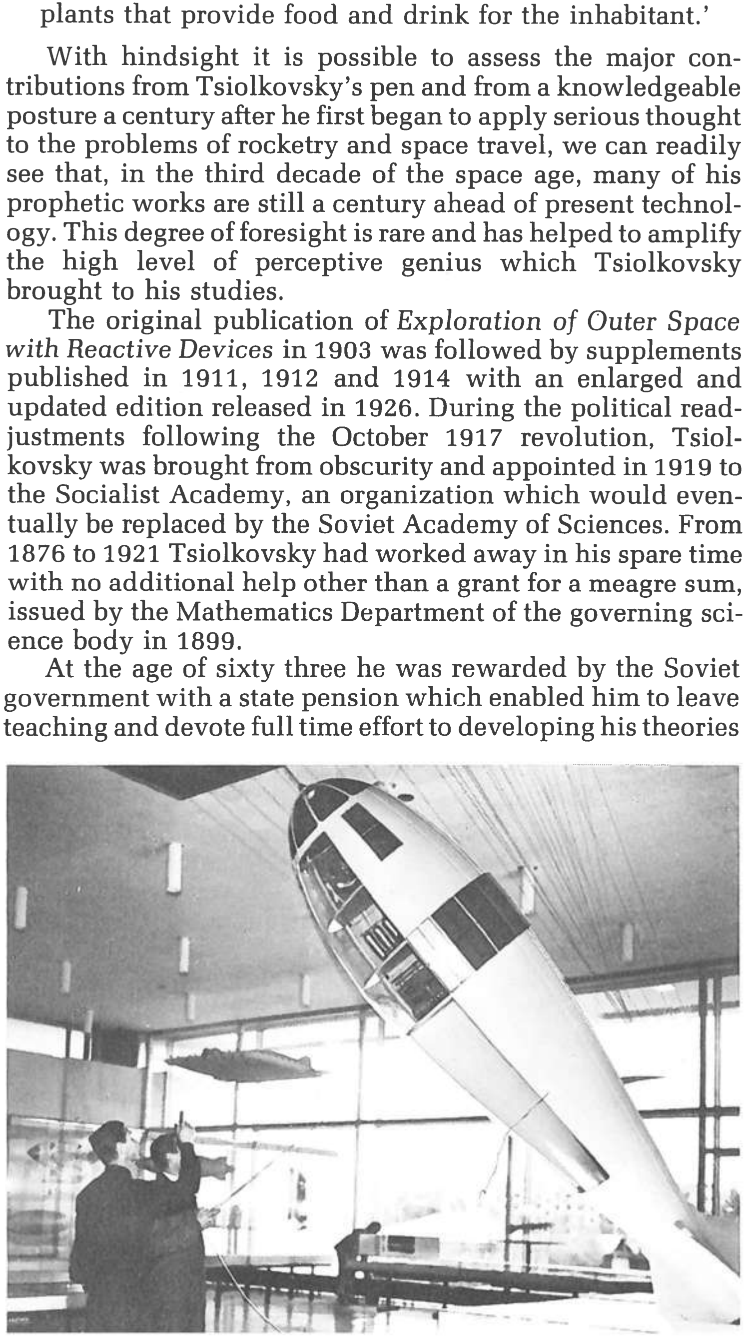
While Tsiolkovsky worked hard on the theoretical aspects of rocket propulsion and the practical problems of space flight, he never once tested, or indeed assembled, a working model of his designs. While he could adequately gather together a theoretical knowledge of the physical and chemical laws necessary to define a rocket, the practical experience he could have acquired to work with the materials then on hand never seemed to spur him on to actual demonstrations. Elsewhere, however, there was a consistent and sustained effort at refining the powder rocket which, although it was a solid propellant device and lacked the sophisticated promise of Tsiolkovsky's liquid propellant designs, nevertheless gave Russian experimentalists invaluable experience in building upon the work of the St. Petersberg Laboratories set up in 1826.

In 1850, a year after taking up a position as director of the establishment, K. I. Konstantinov (see chapter one) was put in charge of the St. Petersberg Rocket Manufacturing Plant and a decade later he was to be found briefing artillery troops on the techniques of powder rockets and their application to a combat situation. The work performed by Konstantinov centred almost wholly on the use of solid propellant rockets for military purposes and he wrote several papers and books during this period which advanced the theoretical application of the powder-filled projectile across a wide range of uses. Finally, four years before his death in 1871 at the age of fifty four, he was appointed head of the Nikolaev Rocket Manufacturing Plant.

During the closing decades of the Tsarist regime, a flurry of theoreticians and experimenters put forward ideas for propulsive techniques. N. A. Teleshev designed a reaction-propelled aeroplane called the Delta and took out a patent on the device in 1867. Earlier still, the engineer I. I. Tretesky proposed several concepts for a gas-propelled flying device and in 1866 Admiral N. M. Sokovnin wrote a book about a balloon, powered by reaction motors, which took air in from the surrounding atmosphere much like the conventional jet engine of the mid-20th century. Abundant evidence here for the claim in chapter one that for a while an independent observer viewing the developments in propulsion worldwide could have more confidently expected the first flying machine to use a reaction motor rather than the petrol driven engines that were married to airframes early in the 20th century.

As the world moved towards the dawn of a new century, the rocket, still basically a powder-filled fire-work, fell increasingly into disuse and when several advances were effected in the fields of artillery and gun performance, the limited advantage of the short range projectile was eclipsed by a host of new developments which seemed to spell redundancy for the black powder descendant of the Chinese firecracker. With the advent of heavier-than-air flying machines prior to World War I, the internal combustion engine found a new and promising application and there were few who could look with confidence to earlier proposals for reaction-propelled air-borne devices.

The monarchistic strategy of European kingships moved ponderously toward inevitable conflict and, while feeble attempts were made to weld the Imperial states of Russia, Germany and Great Britain into one governable union, politics strode along a collision course with fate. Proposals from the German Kaiser for unification of the three great trans-European nations, were the last decadent attempts to weld an ever-lasting peace, and territorial struggles burst into military conflict in 1914. The new technologies developed in the



This model of a Tsiolkovsky rocket design hangs in the State Museum of the History of Cosmonautics in Kaluga.

closing decades of the 19th and first decade of the 20th century were unleashed in a European war which would stagger on for four long years and leave nearly thirty million persons dead or wounded from sixteen countries around the world.

The Great War would reshape Europe and re-structure the entire spread of social and political activities, but if it was a spur to many new devices and inventions, spawning a wide range of its own devilish contraptions, the rocket was bypassed as a redundant if not antiquated method of short range bombardment. Rapid development of high explosives and the introduction of heavy field artillery for short range 'block-busting' purposes, gave the entrenched war a killing power far in excess of anything that could be carried to the enemy by a powder rocket strapped to a wooden guide stick. As if in final and subservient withdrawal, the rocket found moderate usefulness as a flare launcher and occasional signalling device, although the advent of radio and telephonic communication virtually negated the value of this latter role.

But just as Congreve had promoted the use of rockets for ship-to-shore bombardment, where the lack of recoil through the launch rack had decided advantage for a small boat, so the rocket was temporarily lifted from obscurity and fitted to the frail structure of small aeroplanes. Early in the Great War aviators quickly recognized the advantage of carrying a small hand-gun with which to frighten away the opposition and, when the scouting role of aeroplanes began to contribute more effectively to ground based activities, the daunting task of eliminating enemy aircraft from the sky was seen as a valuable contribution to assault or artillery barrage. With the enemies 'eyes' plucked from the sky his accurate artillery ranging and photo-reconnaissance role was obliterated.

So began a race to arm the aeroplane for air-to-air combat and soon the fighter aeroplane emerged for the specific purpose of shooting down the enemy scouts. A Frenchman, Roland Garros, recognized the advantage of diving headlong at the enemy aircraft and bringing a machine gun to bear when the target came within range; hitherto, guns were hand-held by the rear observer and brandished at the enemy aircraft as the pilot tried to manoeuvre round the target. Garros placed small blocks on the propeller blade with the idea that as the machine gun fired from a fixed mounting on the fuselage, through the propeller arc some of the bullets at least, would get through and hit the enemy aircraft, while those which would otherwise contact the propeller blades, could be deflected by the channelled blocks.

This concept, although moderately effective, was soon eclipsed by the interrupter gear, developed by the Dutch aircraft designer Anthony Fokker, then working for the Germans. This device prevented the machine gun from firing during the fraction of time that a propeller blade was directly in line with the hail of bullets. In the ensuing struggle for air supremacy, a variety of unique adaptations emerged and the rocket was, for a short time, given the task of improving the balance.

A French naval Lieutenant by the name of Y. P. G. Le Prieur proposed a concept which would circumvent the disturbing effects of vibration experienced by the comparatively frail airframe during bursts of machine gun fire. He thought that if rockets could be used for air-to-air combat the aeroplane would suffer less from vibration and provide the pilot of the aircraft with a more reliable weapon for attack. Machine guns frequently jammed and left the pilot in the alarmingly compromising position of having to concentrate on evasive tactics, while struggling with the externally mounted machine gun in desperate attempts to unjam the offending device. It very soon became obvious that the necessity for accuracy in hitting the small target area of an enemy aircraft would be compromised by the rockets then available, which were prone to wander off target in the slightest wind and thrash about the sky on unpredictable trajectories.

Nevertheless, there were larger targets available and Le Prieur rockets were carried on the interplane struts of scout biplanes outboard of the propeller arc. Fired electrically, they achieved moderate success against reconnaissance balloons and the massive Zeppelins – German airships used on long-range bombing duties early in the war. The most successful application of Le Prieur rockets was in their marriage to the Nieuport Scout, a small biplane normally equipped with a single machine gun on the top of the upper wing, firing above the propeller arc. Up to four or five rockets could be carried on the wing struts on either side of the aeroplane and the lack of recoil inherent in the operation made it a deadly and effective combination. Soon, French forces on the ground were using Le Prieur rockets as anti-aircraft missiles, albeit unguided, and front line troops would attempt to bring down German observation balloons with the projectiles. Although the use of rockets in the Great War was almost totally confined to this application, it nevertheless goes down in history as the first air-to-air missile although it would be thirty years or more before the concept reached maturity and threatened to supplant the machine gun as an effective air combat weapon.

Meanwhile, in a very different part of the world, far removed from the acrid atmosphere of European trench warfare, a young physics professor was developing theoretical principles which would lead to a demonstration of the first working liquid propellant rocket motor. The man was Robert H. Goddard and the world would come to hail him as the father of modern rocketry.

Goddard was born in the town of Worcester, Massachusetts USA, on 5 October 1882. Worcester is a medium-sized American town located 64 km west of Boston, close by the shores of Lake Quinsigamond and although its population today stands at one hundred and eighty thousand, in 1882 the inhabitants numbered a mere thirty five thousand. Its only other claim to fame is that the first envelope-making-machine was operated there, but this belies the cultural and educational importance it has locally. Worcester is typical of the area with rolling hills enclosing shallow valleys, blending harmoniously with liberal vegetation and open woods. The tranquil surroundings of this peaceful town form the backdrop against which the young man Robert Goddard grew to maturity.

Early in life Goddard developed a keen interest in science fiction and read avidly the works of Jules Verne and H. G. Wells, always stimulated by fictitious journeys to other worlds and the awesome prospect of space flight. As a youth Robert showed a flare for the sciences and his acquired penchant for scientific speculation, partnered well with clear abilities in physics and mathematics – essential aptitudes for the budding rocket designer of any era, let alone the pioneering days of a new technology. At school, in Worcester, he found stimulation from what he learned of the real world and early on found it satisfying to marry science fiction and science fact in a philosophy based on practical results from tangible demonstrations.

It was perhaps these early influences that shaped his future attitude the most. While undoubtedly recognizing the enormous potential of the rocket, he found the incremental challenges along the road to practical demonstration more attractive, than theoretical evaluation of the rocket's future role. If Tsiolkovsky was the father of rocket science, Goddard had to be the father of rocket engineering and although the two were to remain unaware of each other's work for decades, they represented the two main pillars of reactive flight: the theoretical philosopher and the practical demonstrator.

By the time Goddard was in his late teens he had been thoroughly briefed with all the facts to prove to himself that flight into space could only be achieved after the development of an efficient reactive device and he touched on the problems inherent in the search for such a practical means with an article, which was rejected for publication, titled *The Navigation of Space*. For many years Goddard was to shroud his enthusiastic support for the possibilities of space travel and concentrate, instead, on practical engineering problems related to the rocket as a method of reactive flight. Prolific interest in science fiction would dull the public senses and subject proponents of space flight to ridicule.

Following his initial tutorials at Worcester South High School, Goddard went on to the Worcester Polytechnic Institute and graduated in 1908 at the age of twenty five. At about this time he significantly increased his spare time studies in theoretical rocketry and came to the conclusion that liquid propellant rockets would have greater potential than further adaptations of the solid propellant types. Like Tsiolkovsky, Goddard concluded that liquid oxygen/liquid hydrogen motors held the greatest promise and that if he could organize

Robert H. Goddard (1882–1945), seen here on the campus of Clark University, Worcester, Massachusetts, during early rocket experiments in World War I.

the assembly of all the many and varied components necessary to actually build such an engine, the day could not be far off when flights into space would become a practical reality. Half a world away and totally unknown to Goddard, Tsiolkovsky was preparing the first supplement to his book proposing development of a liquid oxygen/liquid hydrogen engine.

Goddard received his Ph.D. in 1911 from the Worcester Clark University – an institution where he was to become professor of physics – and left for a year long period at Princeton University in 1912. Spurred on by progress in his design tasks, he began to prepare a set of papers showing the feasibility of liquid propulsion and by 1914 he had applied for, and been granted, patent licences for a host of devices related to rocket motors. These included combustion chamber design, a propellant feed and control system, rocket nozzles (expansion chambers) and a multistage rocket which would carry a second stage within the upper frame of the first stage.

Although America was playing a watching role on the darkening war clouds over Europe, the government under Woodrow Wilson, former president of Princeton and now President of the United States, maintained a congressional policy of isolation and while fervently adopting a policy of embracing the Caribbean and preserving Chinese trade outlets, the fear of being drawn into a bloody conflict in what was seen as an imperialistic struggle for territory, deepened the resolve to stay neutral. Gradually, and primarily because they felt the German territorial threat to be greater than that posed by the existing British Empire (which was judged not to be interested in US possessions), congress leaned toward support of Britain, France and the Low Countries and thoughts turned toward the preparation of military forces for participation in the European war.

Meanwhile, Goddard had experimented with solid propellant rockets near his home town with good success and he soon reached a point where, having satisfactorily shown that his device would work, further research was warranted in the form of experimental flights carrying simple instruments for measuring characteristics of the atmosphere. By early 1917 Goddard had received the sum of $5,000 from the Smithsonian Institution to continue his research. Lacking firm government support Goddard had, nevertheless, reached a point where he was about to give new meaning to the solid propellant rocket and though an engineer by nature and profession, he fully appreciated the tactical advantage of providing a useful end product to rocket tests.

Before Goddard could use the grant to further his work, the United States was at war with Germany and the physics professor was hustled off to California to conduct experimental work on military rockets. Here, again, his inventive ingenuity shone through and work progressed on ideas for a portable high-velocity rocket launcher which could be carried to a firing position by one man. The result was a design for a device which could fire a 3.5 kg explosive charge across a distance of 1.2 km. By November 1918 Goddard had built and demonstrated a variety of rocket propelled projectiles, the largest of which weighed 20 kg and would be fired from a 7.6 cm diameter tube, 1.7 m long.

Before these designs could be adopted, however, the Great War was over and interest in exotic areas of war munitions faltered and soon disappeared. The military research and development programmes instigated by the government had no place for sophisticated, theoretical concepts and during this period Goddard's proposals for liquid propellant rocket motors had no use and, therefore, no justification as a basis for official research and development. No one in the world had yet built a liquid propellant motor and theory suggested that the largest weight associated with its assembled components would have rendered it more suitable to scientific tasks than deployment for a military function.

It is perhaps interesting at this point to consider the claim of one Pedro A. Paulet, a Peruvian engineer who said in an article published as late as 1927, that he had performed tests with a liquid propellant motor in 1895. While researching for a book on rocket propulsion, a Russian engineer by the name of Alexander B. Scherschevsky, summarized this achievement and noted that Paulet had used nitrogen peroxide as the oxidizer and gasoline as the fuel, to achieve a thrust of 90 kg as a result of igniting the propellants with a spark plug. The tests had allegedly been carried out while Paulet was in Paris, a student at the University's Institute of Applied Chemistry. The article, published in a Lima newspaper, was more of a letter of intent notifying the world that the first man to successfully test a liquid propellant motor was now coming forward to receive acclaim.

For a while this was the case, but the total lack of additional evidence and the inability of Paulet to produce artifacts associated with his 'experiments', leaves the entire issue in grave doubt. In any event, the aeolopile device designed by Hero of Alexander could be thought of as a liquid propelled reaction motor, since it turned water into steam and rotated as the expanding gases were released under pressure. The single most important experiment that had to be performed as the Great War came to a close, was the demonstration of free flight by a liquid propelled motor and even if Paulet's claim is true, he did nothing more than assemble a crude test bed.

Shortly after the war was over, Goddard was back in Worcester at Clark University. In 1919 the Smithsonian Institution published a report he had written titled *A Method of Reaching Extreme Altitude*. This work would clarify the innermost desires of Goddard's mind and at the same time prompt a measure of introspection and withdrawal, which was to remain with him for much of his life. Based on his work completed up to America's entry to the European war, it carried definitive values for a rocket design required to perform a limited demonstration and then, almost cautiously, introduced a much more ambitious proposal.

Recognizing the problems associated with accurately measuring the altitude reached by successively higher rocket trajectories, Goddard felt it would be a good idea to set off a small explosion by means of 'flash powder' so that instruments on the ground could register the height reached by the projectiles. In a subtle piece of word manipulation, and no doubt with a certain amount of 'tongue in cheek', he went on to admit that this would of course be very difficult to accomplish; the angle of the rocket's ascent would be difficult to predict and glare from the Sun would compromise satisfactory observation of the flash. Ready with his solution, he then exposed a suggestion whereby a rocket should be made to fly to the Moon, while the latter was between the Earth and the Sun, so that it could impact the surface, set off the powder flash and provide a visible light source against the darkened background.

In one move he had shown that the only way to demonstrate the rocket's potential satisfactorily would be to send it to the Moon, and in so doing ably provide the world with proof of the important developments which could result from such experiments. Concluding the report, Goddard admitted that the plan had little scientific merit, but that the flight could lead to more important tests which would carry scientific instruments into space. This latter possibility was only hinted at and this was undoubtedly because few who were not directly associated with rocket development could see any real long term value in the device. Nevertheless, Goddard had provided an exciting idea for those who had the foresight to see it and the report serves as a reminder that he was ever concerned about the rocket's potential, although the rest of his life would be devoted to engineering developments of more short term interest.

Not long after the work appeared in print, newspaper reports emerged which highlighted the concluding sections dealing with the proposed Moon flight. Always ready to amplify and very often ridicule the extravagent mumblings of the eccentric minority, the popular press had a field-day with Goddard, labelling him the 'Moon Man' and developing a caricature out of what was later to be seen as a highly prophetic piece of scientific intelligence. Goddard had always been reluctant to advertise his beliefs, ideas or work and he was deeply upset by the apparent humour which had attended the popularization of his idea. This incident, among others, was to leave Goddard somewhat disillusioned by contact with the general public and for the rest of his life he would sustain a measure of introspection and remoteness which did much to consolidate apathy in the very real possibilities of advanced rocket research. Not for thirty years would serious government backing be given to liquid propelled reactive devices.

In 1920, a year after publication of the Smithsonian report, Goddard received a further $3,500 to press on with his experiments. In the same year he began work for the United States Navy in Maryland and concentrated on basic military weapons research, but all the while he studied the problems still separating theory from practice and came to the conclusion that a liquid propellant device just had to be built so that practical experimentation could explore the unknowns and prove the theoretical engineering designs he envisaged. By 1923 Goddard was back at Worcester, resolved to construct a liquid propellant rocket.

He had given much thought to questions of fuel delivery, stabilization in flight and guidance equipment and had probably gone as deep into these problems as anyone could without actually assembling and testing a flight-worthy product. By 1924 the physics professor, now intent on fabricating the hardware for a rocket motor, worked away to develop a satisfactory engine and produced an oxygen pump and motor which achieved moderate, but limited success. A year later he had everything ready for a simple bench run and was using a pressure feed system in which the liquids were forced into the combustion chamber without the aid of a pump.

On 6 December 1925, he successfully ran the motor for 24 sec during which time the rocket rose slightly in its cage before exhausting the propellant supply. More tests, a month later, had a similarly successful outcome and on 20 January 1926 the device rose as high as it could in the restrained test stand. Independent flight was the next step and for this Goddard took his apparatus from the physics laboratories at Clark University and set up the equipment on a farm at Auborn, just outside Worcester. Tests began early in March 1926 and Goddard was ready to demonstrate a free flight.

With four assistants to help him and his wife taking notes, Goddard placed the rocket in a 2 m tall A-frame ready for an attempt on 16 March. Lit by a blowtorch, the liquid oxygen and gasoline propellants ignited and the rocket slowly lifted into the air. The flight was over in just 2½ sec but during that brief historic interval of time the rocket had accelerated to a height of 12.5 m, with an average speed of 96 km/hr. It fell to earth just 56 m away from the test stand, landing in a cabbage patch. The world's first free flight of a liquid propelled rocket had been a success. A second flight, this time lasting all of 4.2 sec, followed on 3 April and Goddard, spurred on by his successes, went back to the drawing board and more calculations hoping to add refinements which would improve the performance of the basic design.

He soon realized, however, that a more ambitious design would be necessary; the first rocket had ably demonstrated the principle of liquid propulsion, but it had little room for growth. It was, in essence, a minimum sized device. Goddard decided that he would build a rocket twenty times larger than the first and toward this end he set about constructing a new test rig and launch stand. A new electrical ignition system was incorporated and new designs for injecting the propellant into the combustion chamber emerged.

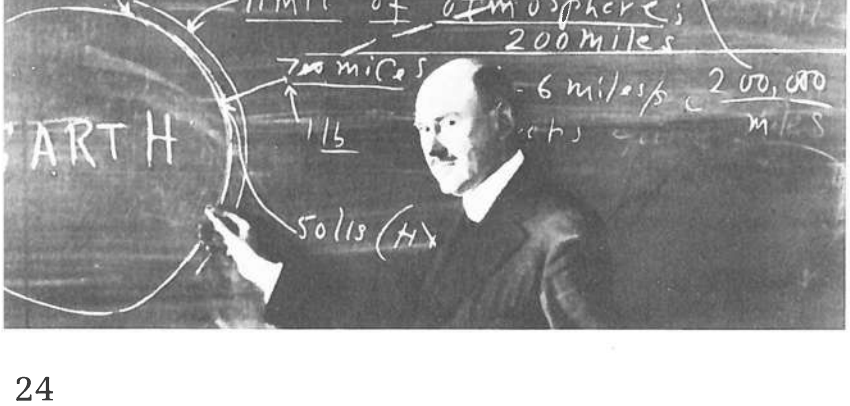
By January 1927 all was ready and several tests were carried out, but with little result. Anticipating that probably having gone too far too quickly, the new design would hinder the smooth progression of test flights, Goddard decided to scale down his ambitious enthusiasm and go for a design only four times larger than the first. This he did and in the layout, proceeded to emphasize the need for simplicity, with many of the parts being assembled in such a way that they could be easily removed in the event of trouble, thus causing the minimum of delay to flight test attempts. The new rocket took Goddard several months of painstaking work to assemble and it was mid-summer 1928, before field tests could begin, preparatory to a live launch attempt.

Once again the faithful few assistants helped Goddard through the test firings, while his wife kept the records – her invaluable penchant for note-taking was a boon for historians, quite the reverse of the situation attending the Wright Brothers during their early flying experiments. Several problems attended the trials and as the year dragged on continual adjustments had to be made before a successful flight was finally achieved on 26 December, which, if nothing else, testified to Goddard's enthusiasm! The device flew 62.3 m. The final flight from Worcester was made seven months later on 17 July 1929 when the rocket flew a range distance of only 52.1 m after a flight lasting 4 sec.

In three years and four months Goddard had demonstrated four flights with his liquid propellant rockets but, ever reluctant to openly broadcast his achievements, he failed to fire the enthusiasm of the surrounding populace who seemed more interested in the daily affairs of life, as America slid

This historic scene records the actual liquid propellant rocket that became the first of its kind to fly on 16 March 1926, at Auborn, Massachusetts. Robert Goddard, the 'father of the rocket', is seen shortly before it took off for a flight lasting 2½ sec. →

Goddard taught physics at Clark University and is here seen with a blackboard diagram in 1924 describing the basic requirements of orbital flight. The 'X' between Earth and Moon marks the point of equal gravitational attraction.



ominously toward economic depression. For the first six months of 1930 tests were conducted at Camp Devens, an artillery range some 40 km outside the town of Worcester, and Goddard pressed on with many and varied tests of components and systems which would, he hoped, lead to improved performance and better demonstrations.

During the years preceding the first successful free flight, in March 1926, a variety of unique applications had been contrived and partially evaluated. Goddard built one device which would use a parachute to gently lower it to the ground and in other applications he rigged restraining stands, which caught the rocket after a rise of a few metres, the function of the rocket having been fulfilled during the brief period of unrestrained ascent, when performance could be measured and results compared. A moderate level of scientific application had been married to the engineering tests when, during the fourth flight, in 1929, Goddard's rocket had carried atmospheric measuring instruments to a height of 27.4 m. The rocket tumbled to an inglorious end, while the instruments, separated at the peak altitude, floated down by parachute.

With many tests and free flights now behind him, Goddard began to plan a more ambitious series of experiments, but ever concerned with the public attraction his work was causing, he decided that he would have to move from the Massachusetts area and seek a more remote location where he could work away in peace – unmolested by the inquisitive locals. Nevertheless, his work had caused a stir in certain circles and one day in 1929, Charles A. Lindbergh, who two years earlier had risen to fame as the first man to make a solo crossing of the Atlantic, visited Goddard and was so impressed with his work that he persuaded the Guggenheim Fund to allocate the sum of $50,000 to finance further tests.

Lack of government interest, perhaps partially engendered by the inventor's own reluctance to advertise the research, denied Goddard the backing which could have carried his tests even further. It is rather doubtful if Goddard would have appreciated the imposed team work, however; he continually mistrusted the collective capabilities of classic laboratory situations and much preferred to carry on alone rather than campaign for additional public support. But even if government support had been requested, it is extremely doubtful that any would have been forthcoming during those bleak days of the early 1930's, when financial collapse, economic depression and high unemployment was rife. Yet there was still the money from the Guggenheim Fund and with this Goddard set off to find a more remote site for his work, finally ending up on a ranch outside Roswell in New Mexico, 140 km due west of the Texas border.

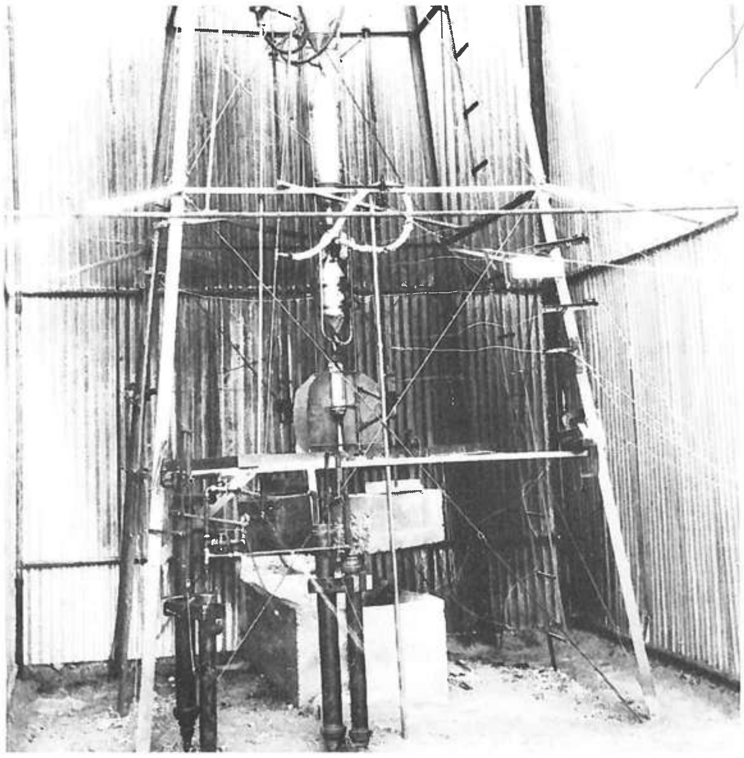
With his wife and the few assistants, Goddard arrived at Roswell in July 1930 and for the next two years the team conducted a series of tests, experimented with different design concepts and improved upon their already creditable successes. By December of their first year at Roswell, Goddard and his assistants had flown a rocket 3.35 m long, using propellants forced into the feed lines by a gas under high pressure, the precursor of several such designs which would form the mainstay of space vehicle propulsion thirty years later. The device was quite successful and rose to a height of approximately 610 m and a maximum speed of 800 km/hr. It is perhaps interesting to note here that the fastest aeroplane had not yet reached a speed of 650 km/hr.

On into 1931, the tests moved rapidly ahead, with Goddard concentrating on refining the methods of operation, rather than going for all out speed or altitude results. The value of this approach was manifested in the multitude of ingenious devices and appendages contributed by the work, among which was a means of terminating (or 'shutting down', a phrase which will often be used in future chapters) the main thrust chamber operation with a fuel control valve. This had a decided advantage over the earlier, less sophisticated means of operation which relied on the rocket shutting itself down when all the propellant had been consumed. In other areas, the team experimented with a free flight demonstration of a stabilizing device, which relied on vanes protruding into the exhaust flow, to control the line of flight, much like the control surface on an aeroplane can be used to stabilize the angle at which the vehicle flies. During this time rocket thrust of up to 132 kg was achieved, with exhaust gas velocities of 1,550 m/sec.

By mid-1932 the Guggenheim money had run out and there was no more to follow. The effects of the depression had embraced an increasingly wide circle of even privileged groups and towards the latter part of the year Goddard was back at Worcester, Massachusetts, in his old teaching job at Clark University. Nevertheless, the Smithsonian Institution forwarded a small grant which enabled the great rocket pioneer to continue his bench and laboratory tests in the physics department. Then, a year later, the Daniel and Florence Guggenheim Foundation found it possible to lend financial support once again and Goddard pressed ahead with a remarkably copious set of experiments and procedures which investigated properties of different metals, assembly techniques, propellant pumps, combustion chambers and methods of insulation.

There seemed no end to the advancing levels of competence and diversity from this work and if foresight had stimulated academic and government support at a more realistic level, the United States may very well have led the world in rocket development. As we shall see later, developments were now moving ahead elsewhere to keep America in the backwaters of reactive flight for several decades. But the nucleus of an emergent technology was in being and the cause, brilliantly followed by Goddard and his few associates, had found a torch bearer. Time and again the 20th century has demonstrated sparks of brilliant expertise ignored because of entrenched ideas and absence of foresight. There was no greater example of this than in the total lack of support attending the early rocket tests.

By 1935 Goddard had returned to Roswell and for the next six and a half years would press ahead with a series of



Goddard (second from right) and assistants prepare for a flight test which came on 27 October 1931, from Roswell, New Mexico. The new streamlined shape is in marked contrast to the earlier test vehicles and fins were added for stability. It flew to a height of 405 metres and a range of 283 metres.

This Goddard rocket, set up for a flight on 30 December 1930, was the first of a series launched from a site north-west of Roswell, New Mexico. It flew to a height of 600 metres and a speed of 800 km/hr. Note: the rocket itself is the triple tank structure arranged in tandem and held by the main support frame.

remarkable tests and free flight experiments, going far beyond anything he had attempted hitherto. Goddard's wife kept accurate and articulate records of all this work in a detailed compendium of success which only serves to punctuate the amazing lack of national understanding about the importance of this work. The first major series of tests lasted from late 1934 to the end of 1935 using liquid propellant rockets up to 4.65 m in length, with an empty weight of 38 kg and incorporating the gyroscopically controlled exhaust vanes for stability during combustion chamber operations, with fuel and oxidizer delivered on the press-fed concept. Use of exhaust vanes soon permitted not just stability, but actual control of the flight trajectory and on one flight Goddard's rocket achieved a range of nearly 4 km and, on another, an altitude of 2,300 m.

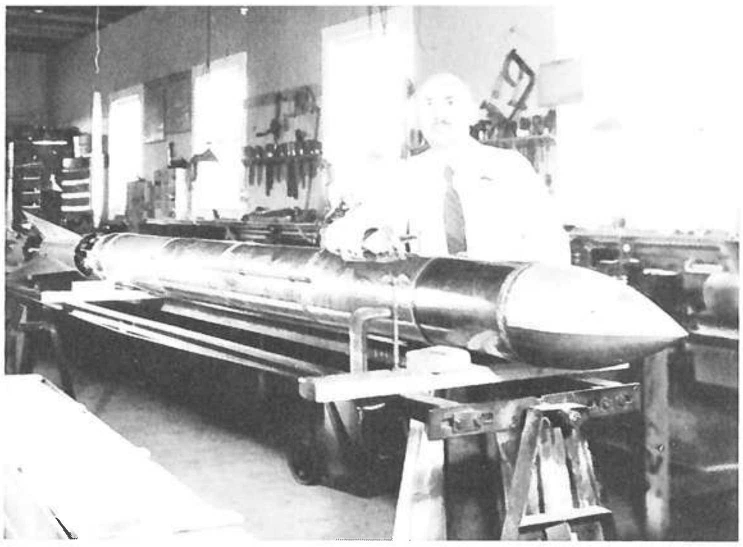
By the end of 1935 work had progressed to a series of test-stand firings of a new motor with a measured thrust of 225 kg and then, in 1936, to a thrust of 283 kg with an exhaust velocity of 1,323 m/sec. These 'K-series' tests led on to flight experiments with the new motor from mid-1936 to August 1938, divided into phases according to objectives and the level of sophistication employed. Called the 'L-series', they gathered experience with gyroscopic control techniques and a host of innovations to increase performance and reliability. Multi-chamber tests were made and parachutes ensured safe recovery of important components.

On one flight in 1937, an L-series rocket rose to a height of nearly 2,700 m and on others, Goddard fitted a device which was capable of steering the rocket by moving the exhaust end to control the direction in which it flew. Several flights went wrong and even more failed to achieve their desired objectives, but the experience gained, by repeated practical demonstration, spurred Goddard on to further experimentation. On one occasion the cement deflector beneath the exhaust plume shed pebbles of fire several metres from the test stand, starting small fires up to 15 metres away, and during another attempt, the ground was fused into a solid brick by the intense heat generated in the downward firing motor. In the final series of L tests, Goddard measured motor thrusts of between 103 kg and 216 kg with exhaust velocity up to 1,628 m/sec.

By late 1938 he recognized the importance of long propellant delivery times and concentrated on a series of static tests which would enable him to demonstrate satisfactorily a fuel pump delivery concept. Up to now the propellants in most of the tests had been pressure fed and a certain number had used nitrogen as a pressurizing gas. All attention now focused on design of an efficient turbo-pump which, by its very concept, would dramatically improve the operating potential of the liquid propellant rocket. Soon, with the results of several static tests and dry runs, it became apparent that gaseous oxygen would produce the best result in driving the turbine.

Early in 1939 Goddard tested a turbo-pump equipped rocket producing a thrust of more than 304 kg and this was followed by experiments with a gas generator capable of providing an oxygen flow rate of 0.22 kg/sec. From the end of 1939 to October 1941 Goddard tested several pumps and achieved the first pump-assisted rocket flight on 9 August 1940, followed by a second, nine months later. By mid-1941 rocket thrust had increased to 375 kg with a specific impulse of 128 sec and Goddard had successfully traversed a major hurdle in rocket development. Pump-fed propellant delivery was shown to be both feasible and efficient, effectively maximizing the performance of the rocket by maintaining a consistent supply of fuel and oxidizer throughout the important period of combustion chamber operation. Combustion chamber pressures had been raised to 24,600 grams per square centimetre and thrust levels had increased enormously in the several years of development prior to the pump-feed tests.

But if Goddard showed a consistent success rate throughout the entire series of research tests and experiment programmes, it was in a very different vein to the fortunes of many of his fellow Americans, during the troubled days in the 1930's and early years of the 1940's. Poverty and depression, brought about by the Wall Street fall of 1929, reverberated through the nation, as industry upon industry closed its gates and the marching feet of unemployed workers threatened to shake apart the very foundations of democracy. Roosevelt was elected to the White House in 1933 and while the nation gradually fought its way back to normality, the clouds of war once more gathered across the fields of Europe. With rampant fascism unleashed and roaring about the central states of Germany and Italy, the economic future of Europe was in question and once again the United States felt a backlash of depression, cooling its resurgent policies and halting aid schemes before they could get congressional approval.



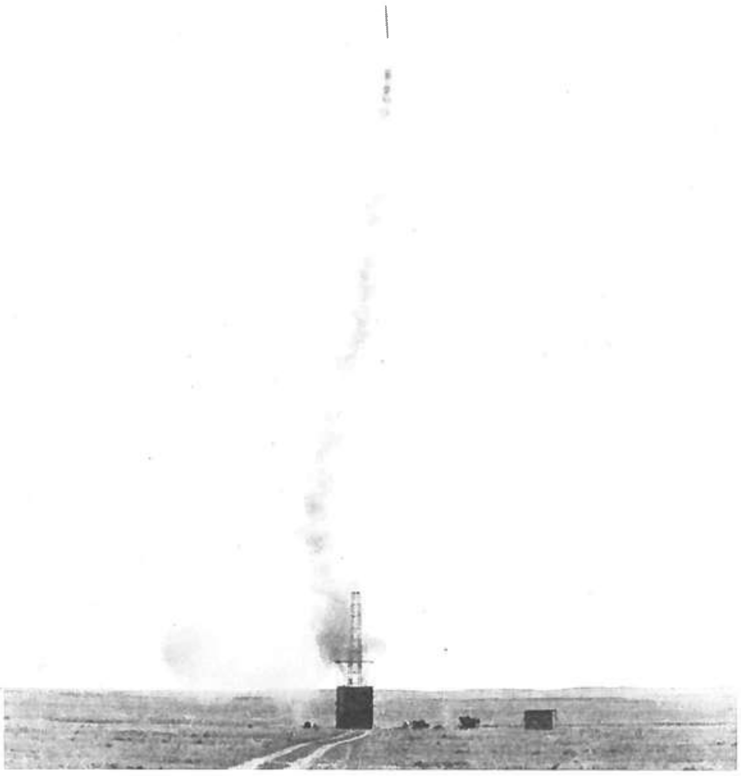
This view of Robert Goddard in his Roswell workshop records the preparation of flight tests for the K-series rocket launches that began in November 1935.

When war broke out in Poland in September 1939 Britain, France and the Low Countries were embroiled in another European conflict that would escalate into World War II and while Congress bargained ships and weapons for anchorage rights and airports, citizens rallied round Charles Lindbergh and his 'America First' campaign. Less than two years later a minor incident, by a German submarine, plunged the United States into its undeclared war with Germany and by December 1941 the Japanese government reciprocated, on behalf of the Nazis, by attacking Pearl Harbour, forcing congress to declare war on Japan next day. This, in turn, provoked Germany and Italy to declare war against the United States within the following seventy two hours.

During these troubled times of war and conflict abroad, Goddard went ahead with testing his turbo-pumps and performing free flight demonstrations. Far removed from the politics and policies of governments and nations, he was soon to be swept up in the giant techno-industrial machine of weapons research and development. His quiet, productive days at Roswell ended in July 1942 when the little group transferred to Annapolis in Maryland to work for the US Navy Bureau of Aeronautics.

For twelve years, apart from a two-year break beginning in 1932, Goddard and his wife had worked under difficult conditions, alone and unaided by government funds or plush workshops and developed the liquid propellant rocket engine to a high stage of success and sophistication. From 1940, several friends who remained in contact with Goddard and keenly followed the progress of his work, tried in vain to stir government interest in his experiments. Even the military mind, keenly honed to follow up any possible advantage arising from new technology, had a pathetically ignorant lack of foresight and refused to consider any practical use for further development. Quite simply, the attitude was that America, being a 'free' country, could live with the balding physics teacher playing with his hissing toys in the New Mexico sand, but could never grant financial support to such bizarre activities.

Goddard, by his own admission, was disgusted at the attitude and response to news of his work and throughout 1940 high ranking military officials denied him the opportunity of conducting government research in rocket propulsion, saying instead, that it had no practical application to weapons research and showed no value whatsoever. Faced with opinion that labelled his work a thorough waste of time, Goddard was, nevertheless, drawn into service when America went to war and at Annapolis he was to spend his time working on rocket packs for assisting heavy aircraft to get off the ground.



This L-series test was performed on 26 August 1937, with a rocket 5.6 metres long, 23 cm in diameter, weighing 73.5 kg. It was catapulted into the air and carried a movable tail piece for guidance, seven attitude changes being accomplished during the flight to a height of 610 metres.

Goddard conducted his rocket tests from a shed placed as far as possible from the launch stand, but the sandbags testify to the ever present danger of flying debris from an unexpected explosion. Note the small table attached to the side of the shed with electrical wires connected (off picture) to the rocket.

For three years he remained at this work, producing a throttleable rocket motor after much experimentation. He died at the age of sixty two on 10 August, 1945. The world had lost a great inventor and the most powerful nation on Earth had failed to recognize the brilliant genius of his work. Over the decades that followed, Goddard was to be seen as an important founder of the new technology and hailed as the 'father of rocketry'. Indeed he was, but the remarkable achievements recorded now as important milestones on the road to the Moon and the Inter Continental Ballistic Missile, were lost to an apathetic and preoccupied people who were to ignore the potential of reactive flight until another nation gave up its own rocketry and provided a rude awakening to its awesome potential.

But here and there, in isolated groups, visionaries in Germany, Great Britain and America saw the value of such research and rallied together to pound away at governmental indifference. In one country at least – Germany – great strides had been made which temporarily left the rest of the world far behind and in those other countries teams of part time advocates worked away at the theoretical possibilities of advanced rocketry and the coming age of space flight.

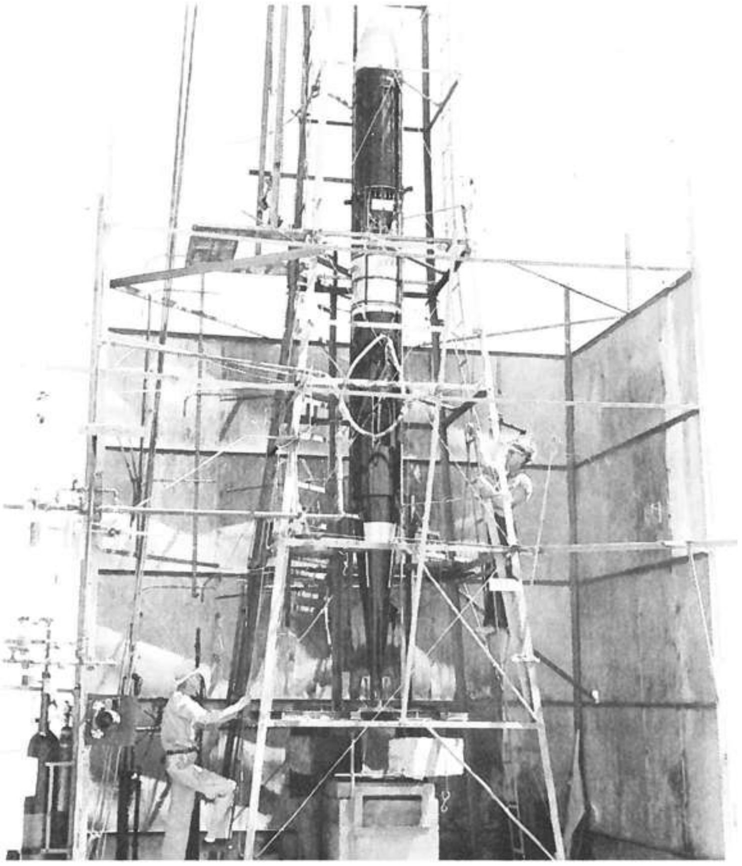
As early as 1927, enthusiasts in Germany, had formed themselves into the Verein für Raumschiffahrt (VfR), or the Society for Space Travel, spurred to open admission of their interest in this seemingly bizarre form of transportation by the publication of *The Rocket into Interplanetary Space* by Hermann Julius Oberth.

Oberth was born on 25 June 1894, in Hermannstadt, then a part of Transylvania, in the Austro–Hungarian empire. His father was a local medical doctor and the young Hermann was greatly influenced by the aura of scientific activity that surrounded the household. However, medical research was the stimulating concern of the family traditions and although the young Oberth favoured more mechanical devices, he bowed to his father's will and enrolled for medical studies at Munich University at the age of nineteen.

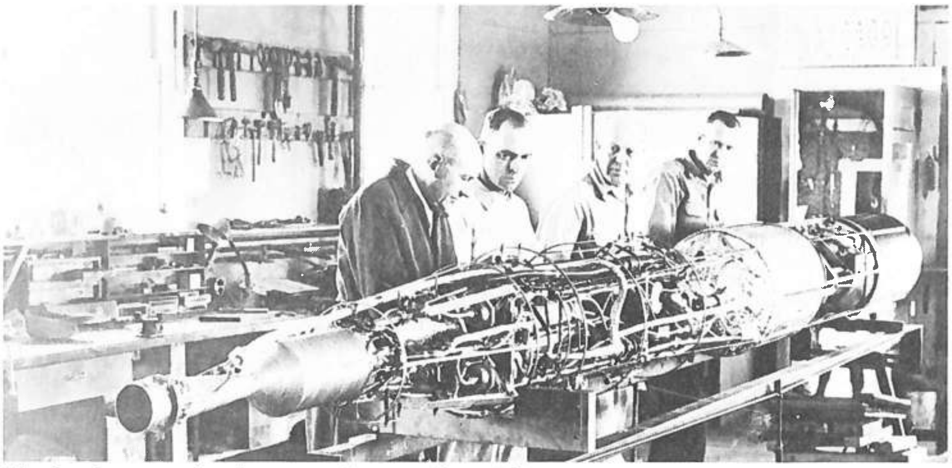
Despite the dedicated hours necessary to progress with his academic work, he found time to pursue matters closer to his heart and much stimulated by the writings of Jules Verne, set his mind to solving problems of interplanetary travel. It was a daunting task, but like Tsiolkovsky and, to a lesser extent, Robert Goddard, he was totally committed to the concept of space flight and this fuelled the fires of enthusiasm and drove him on through ideas totally unsuited to the objective, until he narrowed on the basic underlying principles. Little more than a year after starting medical studies, Oberth joined the Austro–Hungarian army and was wounded in battle, falling again on an imposed occupation when he was directed to the Medical Corps.

Here the physiological aspects of space flight caught his attention for a while, but soon he was devoting his spare time to the engineering problems again. Recognizing the need for an efficient and reliable mode of propulsion, he combined this concept with the military activities around him and went to his commanding officer with a proposal for a ballistic missile which could carry an effective warhead on long range flights, propelled by liquid propellant rocket engines. His superior must have been much impressed with the idea and the written proposal was sent to the German War Ministry for consideration as a project worthy of technical development. It was promptly returned as a totally unsound figment of fantasy; less than nine years later Robert Goddard fired the first liquid propellant rocket.

With the cessation of hostilities in 1918 Oberth, now twenty six years old, continued his studies at Heidelberg University and prepared a Ph.D. thesis consisting of a set of



By August 1940 Goddard was ready to test a rocket using pumps to deliver the propellant to the combustion chamber. Note the small fins at the base.



The development of turbo-pumps for propellant delivery was an important part of Goddard's work from 1939 to 1941. A pump-fed rocket is seen here in the Roswell assembly shop. By this time Goddard, single-handed, had probed areas of rocket technology that even eclipsed contemporary developments at the large Peenemunde facility operated by the Germans on the Baltic coast.

Hermann Julius Oberth, the Rumanian-born rocket pioneer who did so much to stimulate European interest in reactive flight.

theoretical proposals for accomplishing liquid propellant rocket flight. He came to similar conclusions as those reached by Tsiolkovsky and Goddard and discussed the value of high energy propellants, the basic principles of rocketry and a means by which to reach the environs of space. The University rejected the thesis in 1922 and Oberth wrote to Goddard at Clark University, Worcester, Massachusetts, for a copy of his Smithsonian report, *A Method of Reaching Extreme Altitude*, stating his belief that pioneers of theoretical space flight should work together as brothers in a common cause.

After many unsuccessful attempts at getting the text of the thesis published, he finally agreed to underwrite some of the expenses and *The Rocket into Interplanetary Space* appeared as a book in 1923. Two years later Oberth heard of the work of Konstantin Tsiolkovsky and the two theoreticians corresponded with each other in praise of their dream for a progressive rocket programme. A second edition of his book appeared in 1929 under the revised title *The Road to Space Travel* and this work won Oberth a 10,000 franc literary prize, which he put to good use in furthering his activities associated with liquid propulsion.

From the establishment of the Society for Space Travel in June 1927, came a veritable barrage of interest and enthusiasm, membership in the VfR grew to several hundred persons, accompanied by publication of several new books on the subject, and a year later space writer Max Valier, ever ready to advertise the new technology, put solid propellant rockets on the back of a modified automobile. In a series of runs, each one using modifications dictated by the lessons of the preceding test, Valier reached speeds of up to 200 km/hr and attracted considerable public interest in the process. With an eye for the spectacular, the VfR conducted tests with rocket propelled sleds and a rocket propelled glider, although success was somewhat limited by the simplicity of the equipment.

Hermann Oberth, an active participant in VfR activities, joined forces with the Ufa film company, who were at that time involved with production of the film *Frau im Mond*, a hypothetical story embracing a flight to the Moon and for several months, tried in vain, to develop a working model which could be used to simulate sections of the celluloid events.

At about this time the VfR energized a substantial shift in emphasis and while it had always appreciated the value of providing members with a regularly published journal, keeping the dispersed supporters in touch with events in Germany and around the world, the Society felt the need to concentrate on practical experiments and demonstrations. Because of the high costs associated with even a low level of research, it was necessary to dispense with the printing costs demanded by the journal and conserve funds for rocket construction and test. With Germany suffering from recession and a depressed economy, any move which would voluntarily cut off funds for the Society was both unwise and institutionally suicidal and although the VfR saw it as an expansion of their activities, it had in fact, just the opposite effect. Members were cut off from the events they had joined the Society to follow and many saw their contributions going in support of practical experiments in which only a few could participate.

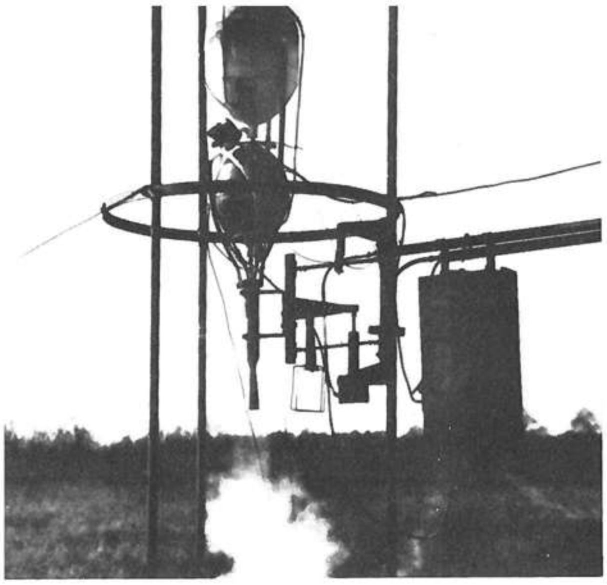
Nevertheless, the VfR moved in to a suburb of Berlin and an old ammunitions dump provided them with a 'proving ground' for rocket tests. Many young enthusiasts were associated with the experiments and among them were Wernher von Braun, Willy Ley and Hermann Oberth; names which would eventually gain immortality in the annals of rocket history. By the end of 1930 the VfR had prepared a small liquid propelled rocket, using oxygen and gasoline, whereby the combustion chamber protruded up into the liquid oxygen tank to facilitate cooling. Unfortunately it was destroyed in ground tests before flight trials could begin; within a few months its successor, Mirak 2, was demonstrating a thrust of 32 kg, but again the tiny motor blew up before it could be tried out with a launch attempt.

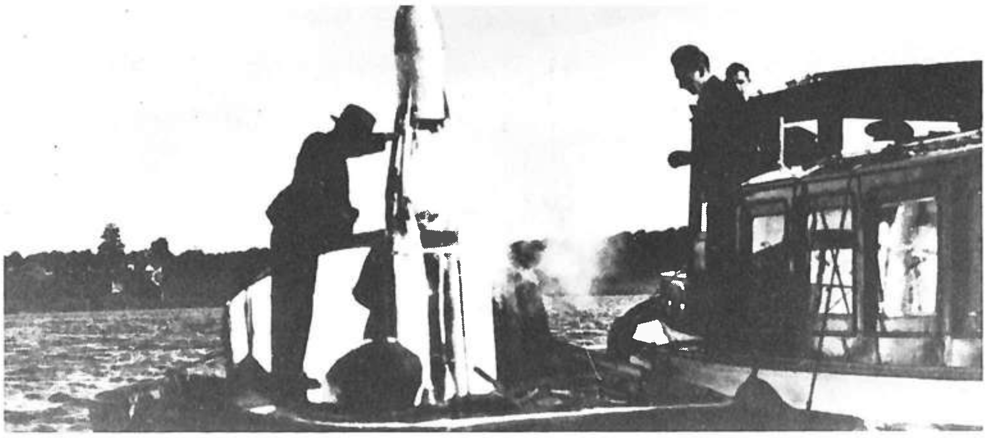
Shortly after these abortive efforts from the VfR proving ground – actually a pitifully dilapidated conglomeration of tumble-down buildings and weed strewn land – the concerted efforts of several lone experimenters paid off and an enthusiast by the name of Johannes Winkler sent a liquid oxygen/liquid methane rocket on a successful ascent from Dessau on 14 March 1931. It was the first liquid propellant rocket flight outside the United States and only the sixth in history.

By now the VfR had re-designed their rocket and named it, at Willy Ley's insistence, Repulsor I. The problem with the earlier 1930 design had been one of inadequate cooling and the copper combustion chamber of the Mirak rocket was replaced by an aluminium chamber cooled by a water jacket on the outside. Repulsor I was successfully launched on 14 May 1931, reaching a height of nearly 61 m before falling back to earth. By late that summer other versions of Repulsor had flown to a height of more than 1 km and early in 1932 the Society invited support from the German Army, who after a trial demonstration, were impressed to the extent of inviting von Braun to prepare his doctoral thesis at Kummersdorf, not far from Berlin. It was the beginning of a long association that would take von Braun on the road to the development of the world's first ballistic missile.

The flurry of practical commitments to developing working models of liquid propellant rockets had drained the VfR of vital funds needed to sustain their activities and hold the Society together. In the five years since its formation, more than half its time had been spent in practical tests performed by a nucleus of enthusiasts who lived close to Berlin and who had the time to devote to its activities the effort needed to achieve the moderate level of accomplishments. Membership had fallen dramatically and money was scarce. It was primarily because of this uneasy situation that the VfR turned to military support, so that it could continue with its activities.

Earlier in 1932, political elections in Germany, had brought the Nazi party to power with the unpredictable Adolph Hitler as head. Now, two ex-corporals wielded fascist power from the Baltic to the Mediterranean: Germany and





Boat launch of the Magdeburg Startgerat rocket, August or September 1933, Lake Schweilow, Nr. Potsdam, Germany.

The Johannes Winkler No. 2 liquid propellant rocket on test in 1932. Winkler had performed the first liquid propellant rocket flight outside America on 14 March 1931.

Italy under Hitler and Mussolini respectively. But the VfR had an international interest at variance with the policies of the Nazi party and pressure was brought to bear from suspicion that the notorious Gestapo would step in and create difficulties at a personal level. Moreover, the local police had been disturbed by the successful rocket flights so close to Berlin and the VfR were forced to vacate their test site at the end of 1933 when the Army took over and restored it to its original function.

Without the resources of the Army, there is little doubt that practical rocket developments would have ended in Germany at this time; the VfR had to disband and theoretical pursuit of rocketry and space travel would have been very difficult in the climate of political domination. As history would show, the Army was not backward in recognizing the rocket's potential application to military needs, but this was never the intention of the VfR, or the few experimentalists, who had struggled for several years at great personal cost, to prove that the liquid propelled rocket was a viable concept and here to stay.

Like their contemporaries elsewhere the young German enthusiasts had one eye on the day men could leave the enveloping blanket of Earth's atmosphere and fly to other worlds. In turning to the Army for support, they merely sought a means to an end and could not have foreseen the way their designs would form the basis for 'city busters' of the future. Yet, had it not been for the practical demonstrations performed by the Repulsor rockets, based on hard-won lessons from the little Mirak design, the authorities may never have understood the potential behind the theoretical promise. Although, as we shall see, the liquid propelled rocket was to enjoy a long career in the service of war, the activity which began with von Braun's arrival at Kummersdorf, would ultimately provide the western world with a technology base for advanced rocket development. And so, in abolishing the journal, losing members' contributions in the process and turning to practical tests, the VfR showed what rockets could do and in this way opened up a new chapter in technical developments of the 20th century. Their demise had been the price for making it possible.

The American Interplanetary Society tested their first rocket from a farm near Stockton, New Jersey, on 12 November 1932.

In America amateurs and enthusiasts had already achieved moderate success with a series of liquid propelled rocket tests, instigated by the success of the German Verein für Raumschiffahrt, in firing Europe's first liquid rockets. The American Interplanetary Society had been formed on 21 March 1930 in New York and began publication of its magazine three months later. The total lack of appreciation for the serious intentions of its members, echoed the ridicule attending any long suffering advocate of rocketry and/or space flight in the United States before World War II and this had already been partially responsible for driving Goddard into seclusion.

When Goddard was approached by founders of the AIS with requests to join the Society and inspire the enthusiasts, he turned them down and would later express unhappiness at the way (he thought) experiments abroad had caught public attention as a result of the practical use of his own invention and ideas. Goddard was not enamoured with public proclamation of rocket work and developed a certain hostility toward those who used his work as a basis for continued, albeit diversified, research. However, concerned about their prestige at home, the AIS changed their name to the American Rocket Society in 1934 but not before preliminary tests with a selection of prototype rockets.

Among their membership list were several engineers, chemists and newspaper people, not least of whom was founder member G. Edward Pendray, who upon visiting Europe in 1931, called upon the German Society for Space Travel a month after they had launched Europe's first liquid propellant rocket. Much impressed with the comparative urgency placed upon practical demonstration, Pendray returned to the United States and spurred the AIS into action. Based on the German Mirak design, the AIS developed a rocket of their own, with modifications which they felt would improve the chance of success and tested the device, called logically Rocket No. 1, at the end of 1932.

From a tiny combustion chamber just 15 cm long and 7.5 cm in diameter, fed with oxygen and gasoline propellants, the first live test run was accomplished on 12 November when the motor developed a thrust of 27 kg for a few seconds. Modifications were made and the design was re-named Rocket No. 2 for the first AIS launch attempt which came on 14 May 1933, two years to the day after the VfR fired off their own prototype rocket outside Berlin. The flight lasted 2 sec, the rocket rose 76 m into the air and fell into the sea 122 m from the Staten Island launch stand. By this time Goddard had

A liquid propellant motor under test at the American Rocket Society's testing ground at Crestwood, New York, in the summer of 1935. Dials on the panel mounted on a sawhorse registered pressure in each propellant tank, pressure in the motor, thrust, and time in seconds. Data on the tests were preserved for later study by photographing the dials with a motion picture camera.

The first test of a liquid propellant motor at the now famous Jet Propulsion Laboratory was performed on 31 October 1936 under the auspices of the California Institute of Technology (see page 73).

fired quite sophisticated models from Worcester, Massachusetts, and Roswell, New Mexico, but the AIS felt singular pride in having done all the groundwork unaided and with very little financial resource.

More tests followed with improved rockets in 1934 until the Society had test fired motors with high chamber pressures and specific impulse up to 430 sec. From 1935 the American Rocket Society, as it was now called, concentrated on exploring the technology necessary to improve efficiency. One of the first problems encountered by any enthusiastic rocket designer was the enormous heat generated in the combustion chamber and this had caused total re-design of the German Mirak into the Repulsor, in which cooling was effected by a water jacket. The American experimenters likewise, suffered setbacks from this heating problem and a notable achievement was made when James H. Wyld built a regenerative cooling chamber in 1938. In this approach the fuel was first circulated around the walls of the combustion chamber so that it could act as a heat sink and hopefully prevent the chamber walls from reaching destructive temperatures. The approach to thermal control was as novel as it was inventive and additional bonus accrued from the increased temperature of the fuel, which made it more efficient when introduced to the inside of the combustion chamber.

There is an interesting comparison which can be drawn between the German and American efforts under the organized auspices of respective societies and the productive work accomplished by Goddard at Worcester and Roswell. Although amateur contributions were commendable and achieved many successful results, the sheer wealth of engineering data acquired by Goddard, lifts his efforts far above those of any other group throughout the ten years following his first liquid propelled rocket flight in 1926. As we shall see, the German Army quickly developed ideas and capitalized on the tedious groundwork laid down by the VfR between 1929 and 1933, but the importance of Goddard's work is difficult to underestimate, especially in view of the lone role he performed for so many years.

Numerous individual efforts at various forms of rocketry were made in the period leading up to America's entry into World War II, too many to detail here, but one or two are noteworthy for their unique contribution. Robert C. Truax, working at the US Naval Academy at Annapolis, did much sound research on the problems of cooling and in 1938 he built a rocket motor just 35.5 cm long with refractory materials lining the nozzle. Several different materials were tested and nearly all the equipment was hand-built or adapted from whatever he could lay his hands on. At the United States Army Ordnance Department, Captain L. A, Skinner was instrumental in developing test projects centred around German solid propellant rockets which could, thought Skinner, lead to an operational air-to-air missile for shooting down hostile aircraft. Several tests were carried out with little promise of any operational advantage.

The decade of the 1930's had been a time of faltering progress, measured steps forward at an imprecise pace and uncertainty as to where rocket development was going. The often daunting stimulation of prospective flight into space, lit the fires in a score of hearts and minds across Europe and the United States, but the sheer magnitude of the problems separating theory from the reality of a manned journey to other worlds, was brought fully home when practical testing began. Few doubted that men would leave Earth behind and fly into space eventually, but few thought it would come in their lifetime. The enormous problems revealed by repeated failure to achieve satisfactory short duration rocket flights in the atmosphere, seemed to magnify the enormity of the task. For this reason few practical experimenters spent much time or energy in resolving the problems of interplanetary flight.

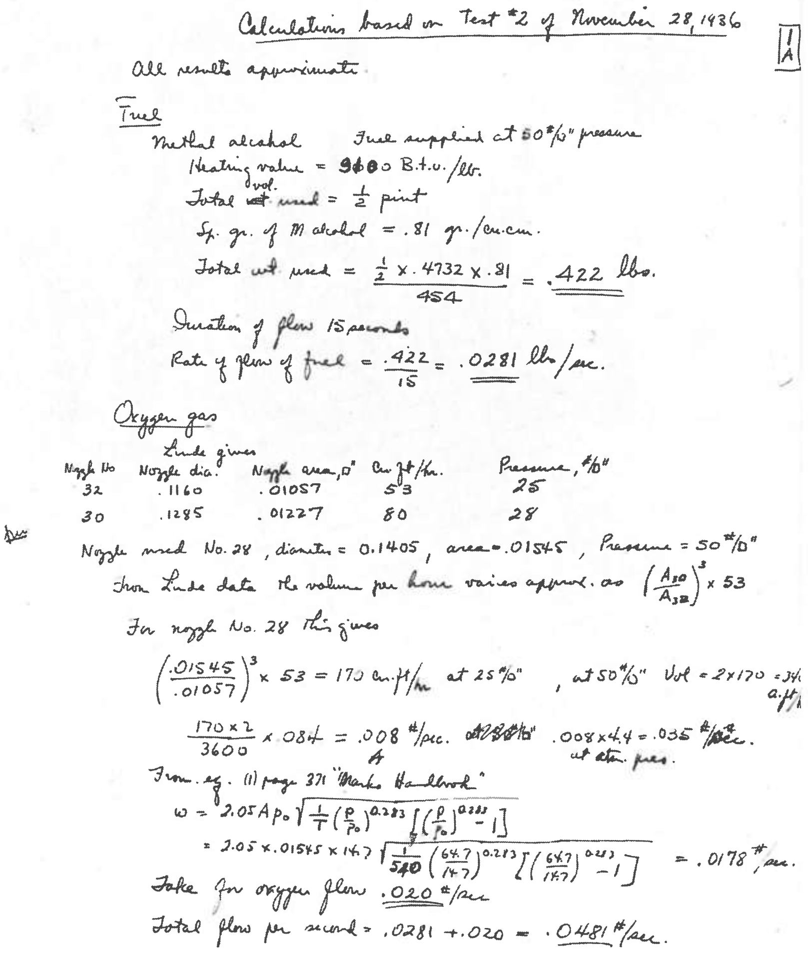
Tsiolkovsky, who contributed his most valuable work between 1903 and 1935, had concentrated on the basic theoretical problems of rocket propulsion, the best way to use space for human needs and the importance of rocket development for the future expansion of the human race. Goddard had demonstrated the practical feasibility of liquid propelled rockets and gone on to explore the many varied technical developments essential to the construction and efficient use of large rockets performing a useful task. Both had been stimulated by the prospect of space travel; Tsiolkovsky in a direct, philosophical manner and Goddard in an indirect but practical sense.

As the 1930's dragged on through depression, recession and fascist domination of central Europe, the cause seemed to have lost momentum and the ultimate goal appeared far off, probably farther than it had in the 1920's. Great progress had been made since the first liquid propellant rocket flights of 1926–33 and problems of cooling, stabilization and flight control, were no longer seen as insurmountable. But as the days of peace drifted slowly toward a six-year war which would embrace nearly every country on Earth, the goal was re-defined and brought into a new and promising focus by a dedicated group of enthusiasts in Great Britain.

Just as the German Society for Space Travel was winding up its activities outside Berlin, a handful of interested people gathered at the Liverpool home of Philip E. Cleator. It was October 1933 and plans were laid to hold an inaugural meeting of the British Interplanetary Society on the 13th of the month, in offices elsewhere in the city. At that time Britain had a poor record of support for rocketry and the prospect of space travel.

Since the inventive contributions made by Congreve and Hale early in the 19th century, only one practical British experimentalist could lay claim to fame: Major-General Edward Mourrier Boxer, born February 1822 and a graduate of the Royal Military Academy at Woolwich. Shortly after his appointment as Superintendent of the Royal Arsenal, he designed and tested modifications to the basic Congreve rocket, strengthening the solid propellant cases and more efficiently arranging the chemical ratios of sulphur and saltpeter. By 1857 Boxer had developed a life-saving rocket weighing 7.2 kg mounted on a fixed tripod supporting the 3 m long guide stick. With an effective range of nearly 350 m the life-saver lived up to its name and was used extensively up to 1948 as standard equipment for shore-to-ship rescue attempts.

Historic test reports detail the success with the first and second liquid propellant rocket motor tests at the site of the Jet Propulsion Laboratory.



Calculations based on Test #2 of November 28, 1936

1A

All results approximate.

Fuel

Methal alcohol   Fuel supplied at 50#/□" pressure

Heating value = 9600 B.t.u./lb.

Total ~~wt~~ vol. used = ½ pint

Sp. gr. of M alcohol = .81 gr./cu.cm.

Total wt used = $\frac{\frac{1}{2} \times .4732 \times .81}{454}$ = .422 lbs.

Duration of flow 15 seconds

Rate of flow of fuel = $\frac{.422}{15}$ = .0281 lbs/sec.

Oxygen gas

Linde gives

Nozzle No	Nozzle dia.	Nozzle area, □"	Cu ft/hr.	Pressure, #/□"
32	.1160	.01057	53	25
30	.1285	.01227	80	28

Nozzle used No. 28, diameter = 0.1405, area = .01545, Pressure = 50#/□"

From Linde data the volume per hour varies approx. as $\left(\frac{A_{30}}{A_{32}}\right)^3 \times 53$

For nozzle No. 28 this gives

$\left(\frac{.01545}{.01057}\right)^3 \times 53 = 170$ cu.ft/hr at 25#/□", at 50#/□" Vol = 2×170 = 34 cu.ft/

$\frac{170 \times 2}{3600} \times .084 = .008$ #/sec. ~~at 28#/□"~~ .008×4.4 = .035 #/sec. at atm. pres.

From eq. (1) page 371 "Marks Handbook"

$$w = 2.05 A p_0 \sqrt{\frac{1}{T}\left(\frac{p}{p_0}\right)^{0.283}\left[\left(\frac{p}{p_0}\right)^{0.283} - 1\right]}$$

$$= 2.05 \times .01545 \times 14.7 \sqrt{\frac{1}{540}\left(\frac{64.7}{14.7}\right)^{0.283}\left[\left(\frac{64.7}{14.7}\right)^{0.283} - 1\right]} = .0178 \text{ \#/sec.}$$

Take for oxygen flow .020 #/sec

Total flow per second = .0281 + .020 = .0481 #/sec.

But unsanctioned rocket trials were discouraged in Britain and in 1875 Parliament passed a law prohibiting tests by members of the general public. This restriction did much to stifle basic research, but when Boxer died in 1898 he left a tangible legacy much valued by imperilled sailors for decades after. So it was that when the British Interplanetary Society was born in 1933, thoughts concentrated on the theoretical problems of rocketry and the much discussed function of reactive motors in outer space. By January 1934 the BIS had published the first edition of its Journal, a quarterly review of technical and scientific developments embracing propulsion and the problems associated with space travel. But now the American Interplanetary Society was considering changing its name to the American Rocket Society, in the hope that it would be taken seriously by the general public, and the BIS faced an agonizing decision of whether it should follow along with a similar change of title.

Late in 1934, the quarterly Journal published views for and against a change and the editorial from P. M. Cleator, came down strongly in favour of retaining the Interplanetary segment of its name: 'The *raison d'être* of the Society – however remote it may seem at present – is to achieve the conquest of space, and thence interplanetary travel. There can be no question, therefore, but the term "interplanetary" is a fitting designation. Moreover, the word suggests, and embraces, rocket research. But is the contrary really true? I doubt it. While it is very probable that space will be conquered with the aid of the rocket motor – which, at present, admittedly provides the only feasible method of propulsion in a vacuum capable of immediate development – there is no guarantee that this will always be so. It must be remembered that man did not think of a propeller when he first attempted to fly.'

The name remained unchanged and in the light of more recent developments, the title now fully includes all the aims and objectives which the Society serves to advance. In 1935 the BIS considered a proposal from G. Edward Pendray, that the American Rocket Society should merge with the British group and although this could have brought advantages in the form of a monthly magazine, the necessary contribution was not thought to be practicable and the idea was deferred.

From time to time, particularly throughout the early years of its expanding success, the BIS was called upon to evaluate its future role. Several prominent leaders in the field of science and technology had joined the BIS by 1935 and the Society's roll call included Willy Ley, Professor A. M. Low, G. Pendray, Professor Nicholas Rynin from Russia and Esnault-Pelterie from France. The suggestion was made that it might be desirable to move into practical development of reaction motors, but lessons from the German Society for Space Travel indicated that support would fall and funds would quickly disappear if all the available finance went on rocket tests. The BIS had already built up a creditable reputation for itself and the quality of its Journal was to gain respect from all quarters of the globe as an authoritative reference work on the varied stages of rocket development around the world.

In several of the 'Journals' issued in 1936, news was given of attempts in Australia to send mail across a river on a precursor flight to regular operations, of the successful launch of 'two live birds and two hundred letters' across a short distance in India and of Willy Ley's endeavours to fly mail across a distance of nearly 5 km in the United States. In the same year a London branch was set up and in 1937 the BIS headquarters shifted from Liverpool, to the capital, where it remained.

Early in 1937 work began on a project which was far-seeing as it was audacious and firmly established the BIS as the world's foremost theoretical space society. This was the so-called BIS Spaceship, a concept designed to satisfy the objective of a round trip to the surface of the Moon, using technology then within reach. The design council included H. Bramhill, Arthur C. Clarke, Val Cleaver, M. Hanson, Arthur Janser, S. Klemantaski, H. E. Ross, R. A. Smith and J. Happian Edwards, the latter in charge of work. Much of the credit for the design must go to Ross, Smith and Edwards.

When the design appeared in the January 1939 issue of the BIS Journal, it represented the most plausible scheme for reaching the Moon then advanced, embodying basic developments which had already achieved moderate success, such as solid propellant rockets and separate stages. The entire assembly, it was proposed, would weigh 1,112 tonnes and consist of two thousand, four hundred and ninety solid propellant rockets in various stages. The structure would be 30 m tall with a constant diameter of 6 m. The clustered rockets would be mounted in cylindrical batches and fired from the outer periphery to the centre in succession. As each 'ring' of rockets was expended, the individual components would fall away due to the lack of acceleration; this approach was used in a more subtle form just twenty years later, when Russian engineers considered the latch mechanism for the world's first satellite launcher.

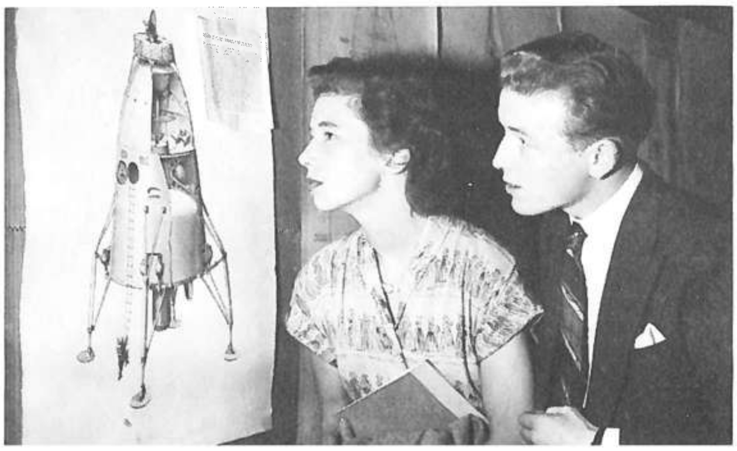
Many features of the proposal were quite prophetic in nature and compare well with the Apollo Moon landing concept thirty years on. A three-man crew was envisaged riding in a double-walled pressure cabin at the forward end and the outer casing to the crew compartment would be jettisoned after passing through the Earth's atmosphere. As the spaceship approached the Moon, stabilized by small liquid propellant thrusters, it would be turned around so that it could back down on to the surface, landing legs would be deployed and the vehicle would touch down on an illuminated area facing Earth.

When it was time to leave, the crew would fire off the upper section of their spaceship leaving the lower landing-leg section on the Moon. Retro-rockets would have been used to land and similar rockets mounted to the upper component of the ship would blast the crew back to Earth. With the crew positioned in contoured couches to support them against the high forces of deceleration, the spaceship would re-enter the atmosphere before lifting again and then plunging back into deeper layers, repeatedly descending and partially rising again, to reduce the temperature on the surface of the ship and slowly decelerate to a height and speed where the parachutes could be deployed. The decision to go for solid propellants in the main stages, centred on their availability and the basic simplicity of operation. Liquid propellant rocket motors were thought to be too unwieldy to provide good thrust/weight ratios provided by the solids and the elimination of unnecessary plumbing and tanks was a fundamental aspect of the design philosophy.

The BIS had done more than any other group to recognize and bring before the public an awareness of the coming age of rocketry and space travel. Although devoid of any practical experience with testing rocket motors, the British Interplanetary Society had gathered a distinguished group of specialists together and provided a stimulus to enthusiasts across the country. The BIS Spaceship served to re-define the goal and highlight the objective of one day leaving planet Earth and setting foot on the Moon as a preparatory step to more ambitious and rewarding ventures.

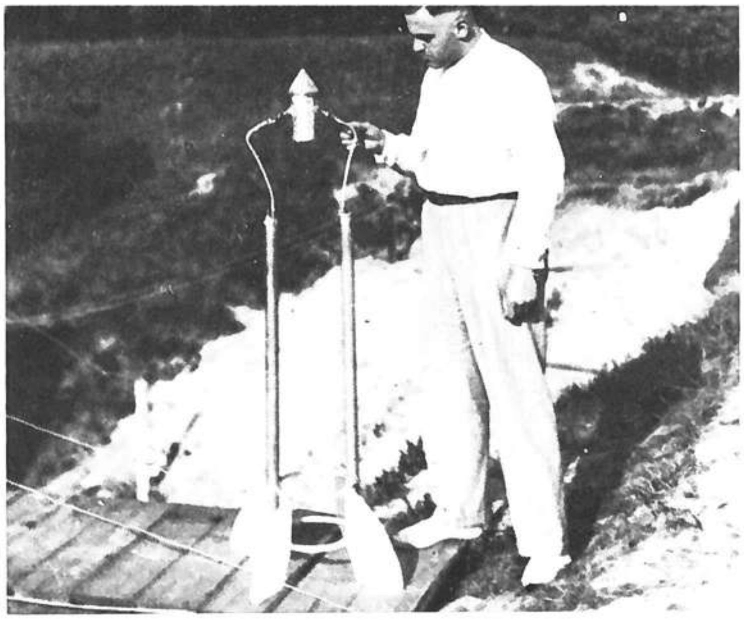
Tsiolkovsky had pioneered the concept of liquid propelled rockets and high energy propellants, setting goals which would influence Russian plans for the remainder of the century, and Robert Goddard had demonstrated the feasibility of liquid propulsion and patented a host of components and devices which would be picked up and adapted in succeeding decades. In Germany the VfR had laid the foundations for the next major step in the development of rockets and in Britain the BIS had pointed the way toward a new and exciting frontier. The world was poised on the brink of a war so total that it would change the entire course of history and two nations, that until now had been in the shadow, would soon play the leading roles: Germany and Russia.

In 1937 the British Interplanetary Society prepared a detailed study of a possible lunar landing spaceship. In 1947 intrigued visitors to a BIS exhibition view a derivative of the original concept.



CHAPTER THREE.

New Politics and a New Technology



Klaus Riedel inspects the German Society's Repulsor 2, two-stick rocket, in May, 1931.

It is very difficult to over-emphasize the intense effort applied to studies in rocket propulsion and practised by the VfR on the outskirts of Berlin between 1931 and 1933. Several specialized craftsmen and engineers were recruited from the ranks of the mass unemployed and, keen to exercise their talents in respective capacities, were central to the progress that was made during this time. The disused ammunitions dump in the Reinickendorf suburb of Berlin received the optimistic title 'Raketenflugplatz', or Rocket Flying Place, and rented for a very small annual sum, the facility provided good opportunity for moving progressively ahead with successive developments. It has been noted in the reports from the Secretary of the VfR, that propellant tank capacity in the various designs formulated by the group, increased from 1 litre to more than 500 litres and that rocket weights increased from 3 kg to 250 kg; in the first year of operations (up to May 1932) the VfR launched more than eighty rockets and performed over three hundred static tests and demonstrations.

But 1931 was the year of rapid development and several different designs emerged under a new generic title: Repulsor. Repulsor I had been developed from the earlier 'Mirak' series and went on to achieve recognition as the first official flight of a VfR rocket. Repulsor II was ready by 23 May, nine days after the successful achievement of its predecessor and the liquid oxygen/gasoline motor provided a height capability of 60 m and a range of 0.6 km. A unique feature of this design adopted an integral pressurization system in the oxygen tank. This highlighted one of the basic difficulties with rocket propulsion adopting liquids placed in separate tanks, which would have to be delivered to a single combustion chamber: how to ensure that the oxidizer and the fuel are brought to the chamber for ignition.

In America, Robert Goddard had considered, and would go on to experiment with, concepts which embraced so-called pressure-fed and pump-driven designs. In the former case the liquid (be it oxidizer or fuel) is expelled from the respective tank by a gas forced into the vessel under pressure, which causes the fluid to flow into plumbing between the tank and the combustion chamber. In a pump-driven approach the liquid is physically moved into the chamber by a mechanical delivery system. In the case of Repulsor II the liquid oxygen was delivered to the combustion chamber by using a portion of the fluid that had boiled to a gaseous state and in this way a pressure was exerted on the liquid which then was forced down the feed lines. By contrast, the fuel was expelled with gaseous nitrogen held in an adjacent tank for this purpose. In addition, a moderate level of sophistication was achieved with the use of a parachute for retrieving the casing at the end of the flight, activated by a pyrotechnic charge.

A month later Repulsor III was ready and this increased the altitude capability to nearly 650 m in a series of four flight trials. By August 1931 the Repulsor IV model was ready and with this the VfR achieved heights of up to 1.6 km. Later, in the early months of 1932, other models adopted liquid oxygen/liquid alcohol propellants and tested the concept of regenerative cooling, whereby the fluids are circulated around channels or tubes in the walls of the combustion chamber and exhaust nozzle to simultaneously cool the hot sections of the engine and pre-heat the liquids for better combustion. The problems of cooling the extremely hot chamber and nozzle sections would continually plague engine designers and technicians; the magnitude of these problems was almost insurmountable during the early years of rocket design and experimentation. Nevertheless, the incredible achievements of the VfR served as a momentous precursor to the events, then forming, which would lead these early pioneers to work toward development of the first ballistic missile, the V-2.

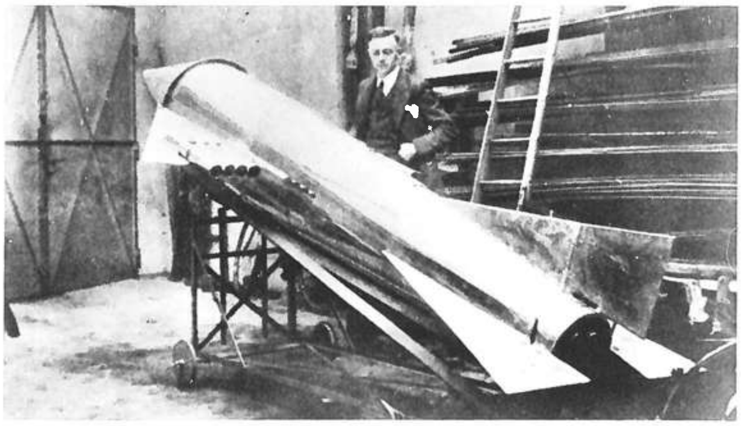
With meagre funds and very little outside help, they were spurred more by dedication and a single-minded drive toward the ultimate realization of space flight, than monetary or professional gain and this altruistic approach would bring dividends unrecognized at the time. But just as the VfR were active in practical tests and demonstrations, new thoughts sprang to the grander objectives of the work and ever mindful of the enormous resources which would be necessary to provide technology with a viable tool for flights beyond the atmosphere, the dedicated core of workers considered the possibility of engaging industrial support for their primitive activities. Few companies were interested in this bunch of 'amateurs', however, and the only active support received during the entire existence of the VfR was granted in 1930 when the Reich Institute for Chemistry and Technology successfully tested an early rocket motor and calibrated its performance.

Meanwhile, the Army had turned to thoughts of rocket propulsion with stimulation from a technical contribution in the 1926 Textbook of Ballistics by Karl Emil Becker. By 1929 Becker, then already at the rank of Colonel and charged with heading the Army Weapons Board, decided to move positively toward investigation of the rocket as a likely prospect for development and ordered Ritter von Horstig to examine technical literature and the activities of experimenters so that a comprehensive dossier could be assembled. The report soon confirmed the suspicions of its instigators, that rocket propulsion held great promise for military weapons development, and before the end of 1929 the Minister of National Defence, still tied to the Treaty of Versailles, promoted technical studies on the future role of rockets in battlefield situations.

Initially, work was to concentrate on solid propellant devices which could be fired, en masse, across a distance of 7 km as a sort of short-range artillery weapon. In the early months of 1930 Captain Walter R. Dornberger was assigned to Becker's Army Weapons Department and served on the Ballistic Council under von Horstig. But the intentions of the Army were frustrated by a necessity to uphold extreme secrecy about military interest in rocket propulsion and by the lack of any co-ordinated study on the strategic questions involved.

These were difficult days for Germany as political factions vied for control of the Reich and Adolph Hitler stamped his brownshirts into direct confrontation with the ageing President von Hindenburg. There was nothing in the Versailles

A soldier of the Reichswehr holding the one-stick Repulsor at Kummersdorf in August 1932.



Austrian Friedrich Schmiedl was the first man to use rockets in mail carrying experiments, an activity also pursued by the German experimenter Gerhard Zucker, seen here standing next to his design. Zucker came to England in 1934, exhibiting his rocket at the Apex Philatelic Exhibition in London, and afterwards attempted to launch rockets at Scarp, Scotland. In an attempt to fly a rocket from Lymington towards the Isle of Wight, the projectile went off course and landed at Pennington.

Treaty to prohibit the development of rockets, the very concept had seemed so ridiculously nebulous when the agreement had been drawn up. However military developments in the German state were under close scrutiny by other European nations and it was early days to flaunt the independence of original research, especially on weapons which eclipsed the existing machinery of other, ostensibly more powerful, countries. So it was that a measure of subterfuge was necessary and the German Army orchestrated a monitoring posture remote from public scrutiny.

Throughout 1931 the Army Weapons Department scoured the country for leads which might point a technical finger at some as yet undefined role for rocketry to which the military could lend full support, albeit under a shroud of anonymity. Two key factors were evolving which embraced VfR and the Army and yet which neither could recognize: the successful acclaim surrounding early Mirak and Repulsor tests at the Raketenflugplatz and the Army's own conviction that much would come from reactive devices. A flurry of popular articles and semi-scientific periodicals had lain a carpet of hope before armchair theorists across the country, but preoccupation with the far-off concept of space flight and trips to the Moon did little to hide the underlying promise so eagerly interpreted by a few military minds of the day. The very fact that VfR tests had been successfully advertised and the submission of a confident report to the Minister of National Defence, tied long-term weapons development firmly to the new device.

For a while the Army secretly funded VfR tests, but the enthusiastic researchers were bent on their own developments and only minimal support could be lent to what was still publicly retained as a non-productive venture. There was nothing for it but to set up a separate Army research facility where military tests could build up a diagnostic reference for possible future use.

Early in 1931 the Army were working on their own primitive rocket motor designs at an artillery proving ground at Kummersdorf-West, some 27 km south of Berlin. Progress was slow and although a motor producing a thrust of 27 kg had actually ~~been built~~ by the end of the year, it was too heavy to achieve flight and only served to emphasize the difficulties then facing rocket pioneers. Although the VfR had initially received only cursory attention from the Army Weapons Deparment, and only latterly gained reluctant support in the form of limited funds, the problems at Kummersdorf-West drove Becker to return to the Society's proving ground in search of ideas and advice. Convinced that the rocket would eventually prove its worth, he took Horstig and Dornberger to the Raketenflugplatz early in 1932 to invite the VfR to bring their rockets to Kummersdorf and demonstrate the devices.

Kummersdorf had originally supported test stands and sheds for research into solid propellant rockets, a result of the orders issued by the Minister of National Defence in 1929 acting on the report compiled by Karl Becker. However, when Becker, Horstig and Dornberger set up the facility it was equipped to provide research on liquid propellant rockets as well. The Becker report had enthusiastically supported the idea of developing long range rockets for artillery work and this idea was firmly established in the somewhat nebulous strategy surrounding its inception. Such ambitious objectives seemed to call for liquid propellant developments and Kummersdorf matured as a site capable of supporting both liquid and solid propellant research. Experience and know-how was, however, in less abundant supply and for this reason the nucleus of ardent supporters from the Army sought direction for their efforts. It came in the form of a young graduate from the Berlin Institute of Technology called Wernher von Braun.

As a young boy von Braun, born to a wealthy Wirsitz family on 23 March 1912, enjoyed the stimulating effect of astronomy and spent many happy hours at his boarding school studying the stars and discussing the possibility of travel to the planets. At the Berlin Institute of Technology von Braun got in touch with the Verein für Raumschiffahrt which had been formed on 5 July 1927, in a ground floor room of the Golden Sceptre drinking house in Breslaw. He soon became an energetic leading light in the VfR, although his tender years mitigated against a leading role; pre-war German traditions prevented such a possibility, but nonetheless his confident and articulate conversation could win over the most ardent anti-rocketeer. Von Braun was a natural, unpaid propaganda machine and would never fail to rally his colleagues on to greater effort and wider vision for the coming day when men would leave Earth behind and fly in (his) rockets toward the stars.

So it was that on that July day in 1932 when Becker, Horstig and Dornberger received a delegation from the VfR at Kummersdorf-West, von Braun was in the forefront and eagerly awaiting his role as commentator for the simple tests

Early German rocket enthusiasts, August 1930. Left to right: Rudolf Nebel; Dr. Franz Karl Ritter, physicist; Hans Bermeuller, an unemployed enthusiast; Kurt Heinisch, later in charge of a test stand at Peenemunde; unknown assistant; Prof. Hermann Oberth; unknown assistant; Klaus Riedel, holding one of the Mirak rockets; Wernher von Braun; unknown spectator.

that would be carried out before the Army Weapons Department. Unfortunately all was not well and the small Repulsor rocket, brought along for the show, failed to achieve successful flight, but the enthusiasm of the ragged group of experimentalists caught the attention of Dornberger who set his mind to encouraging this nucleus of dedicated workers.

But while the VfR enthusiasts were set on space travel, Dornberger's attention at Kummersdorf centred on the very practical aspect of rocketry. Much had to be learned before plans could mature for development of its much discussed military application: missiles and long range liquid propellant designs. Clearly Dornberger would need the support of key members of the VfR and toward this end he approached von Braun and offered him a job at Kummersdorf working in complete secrecy, but with access to all the funds and equipment he would need. The secretary of the VfR, Rudolf Nebel, had attempted to secure financial gain by privately offering his services to Dornberger and to this end he had persistently visited Becker but in the event left little impression. However, the Army was not won over by his mediocre achievements.

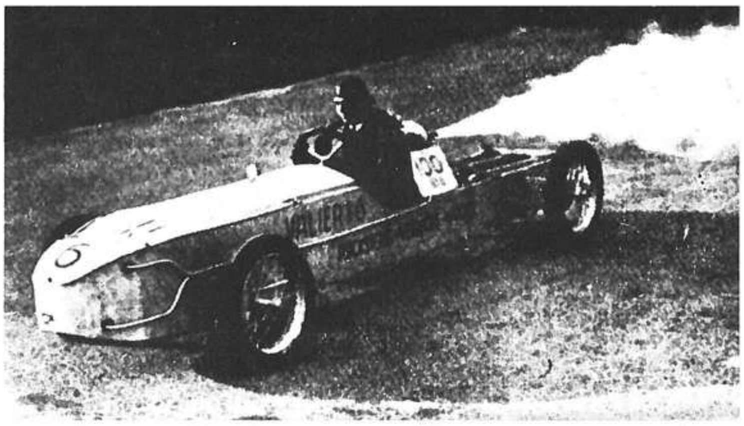
Von Braun joined the Army Weapons Department as a civilian research worker along with two important members of the VfR: Heinrich Grunow and Walter Riedel. The latter had played a prime role in developing the Mirak series of small test rockets and would become guide and mentor to von Braun whose energies required restraint from the fervent enthusiasm that drove him to continually speak of space travel and flights beyond Earth's atmosphere.

By October 1932 the three key figures in the early fortunes of Kummersdorf-West were busy working on Dornberger's first major research project. This would take the form of a liquid propellant rocket, fed with liquid oxygen and alcohol, with a design thrust of 295 kg, serving as test-bed for future systems with more powerful thrust. Officially designated the Kummersdorf-West Experimental Station, the facility nestled comfortably in a wooded area flanked by pine trees at the edge of the Brandenberg forest. Dornberger had set up a new concrete test stand consisting of three 3.7 m tall walls and a fourth side supporting metal doors. The roof could be rolled back to expose the internal platform and an adjacent building contained equipment for measuring the performance of the rocket engines under test.

Throughout the main test chamber the apparent confusion of pipes, wires, tanks, conduits and instruments belied the efficient simplicity that characterized the guidelines which controlled early experiments. It was this precise, yet uncluttered attention to critical detail, that enabled the group to emerge as the World's first large-scale rocket research establishment. Within weeks of von Braun, Grunow and Riedel arriving at Kummersdorf-West the first 295 kg thrust rocket motor was ready for testing and on 21 December 1932, the combustion chamber was ready for a hot run. With liquid oxygen stored in an ice packed vessel on one side of the test shed and a liquid alcohol vessel on the other, the scene was more reminiscent of a twentieth century alchemist's shop, than the physical research facility it purported to be. Nevertheless, Riedel positioned himself at the control valves that would release the propellants into the combustion chamber, while von Braun made ready with a small can of petrol at the end of a 3.7 m long pole.

At the right moment von Braun lit the primitive igniter and held it under the combustion chamber just as Riedel opened the valves to admit the propellants. With an ear-splitting roar the entire assembly seemed to erupt in one violent conflagration setting light to pipes, plumbing, wires and tanks. The explosion had all but blown von Braun off his feet and sent fragments of metal flying through the air to start a dozen or more fires all over the test shed. By mid-January 1933 all was again ready for a second combustion chamber test and this time the igniter did its work and lit the motor into action, followed seconds later by a searing stream of flame as the walls of the small rocket engine melted under the intense heat.

Back into the design phase, corrective measures were worked out, applied, tested, re-worked and tested again. Finally, the success rate began to increase and moderate progress was made toward achieving full stability at rated thrust. Numerous measurements were made, instrument dials swung in response to the repeated calibrations and soon the group was compiling the data that Becker, Horstig and Dornberger had sought on that spring day 1932 when they visited the VfR at Reinickendorf, the site of the famed Raketenflugplatz.


Max Valier is seen here during a successful run of his liquid propellant rocket powered car which, if nothing else, did much to popularize the new technology of reactive propulsion.

Throughout 1933 the basic principles governing the physics of rocket propulsion were tested in all manner of configurations and gradually the design details fell into place, theoretically at least. During this period the Army Weapons Department at Kummersdorf-West were keen to develop a deep understanding of the many and varied problems which could hamper development of a truly flight-worthy rocket. As yet key personnel had only a vague idea of how the basic rocket motor could be made to work with consistent reliability and were unsure of the precise concept around which any future missile would be structured. At the back of their minds was the very sure belief that if only the teething troubles could be ironed out, the product would carry itself forward on a momentum of success that, in the final analysis, would provide a usable tool for research and then application.

Military preoccupation with the promise of rocket technology was not the prime motive behind the sustained enthusiasm expressed by workers at Kummersdorf-West. All were mindful of the enormous benefits to science that would accrue from access to a reliable rocket system and Dornberger himself was concerned to probe the upper layers of the atmosphere and set the scene for the peaceful exploration of space. Elsewhere, forces were gaining power which would take hold of this new development and fashion it into a tool for war, but the political machinations of the extremist fascist order was far removed from the thoughts and actions of the little band of dedicated engineers working, seemingly alone, in the forest south of Berlin.

However, if Dornberger's team was unconcerned with events which would again threaten world peace, the outside community was not unaware of the efforts underway to produce a reliable rocket motor. As word spread on the successes at Kummersdorf-West, many would-be participants flocked in to offer their services and lay claim to a role in the new developing technology. Charlatans and fakers tried in vain, to convince key personnel of their own peculiar successes, but with the exception of one or two all proved unworthy of a part in the unfolding story.

In 1931 the Army Weapons Department had contracted the Heylandt Works to produce a small rocket motor for experimental purposes and in association with this activity, Dr. Wahmke went on to work with a fuel mixture of hydrogen peroxide and alcohol. His earlier work had been sufficiently valid to draw the attention of the Army to his promising ideas and this new concept of mixing the propellants before delivering them to the combustion chamber was sufficiently interesting for tests to be carried out. In March 1934, during this operation, the resultant ignition fed back to the tank holding the two liquids and caused an explosion which resulted in the death of Dr. Wahmke and two assistants. Another design engineer at Heylandt, one Arthur Rudolph, brought a copper rocket motor using liquid oxygen and alcohol to Kummersdorf. It worked so well that he was absorbed into the group and contributed valuable and original ideas.

By now von Braun had become something of a leading light in the research establishment at Kummersdorf-West and

The rocket car Opel RAK-2 being prepared for its run on the Avus Speedway, Berlin, 23 May 1928. Fritz von Opel is behind the car, next to the driver's seat. Friedrich Tsander, who teamed with Opel to provide the solid propellant rockets, is at the rear of the car in a peaked hat and dark suit.

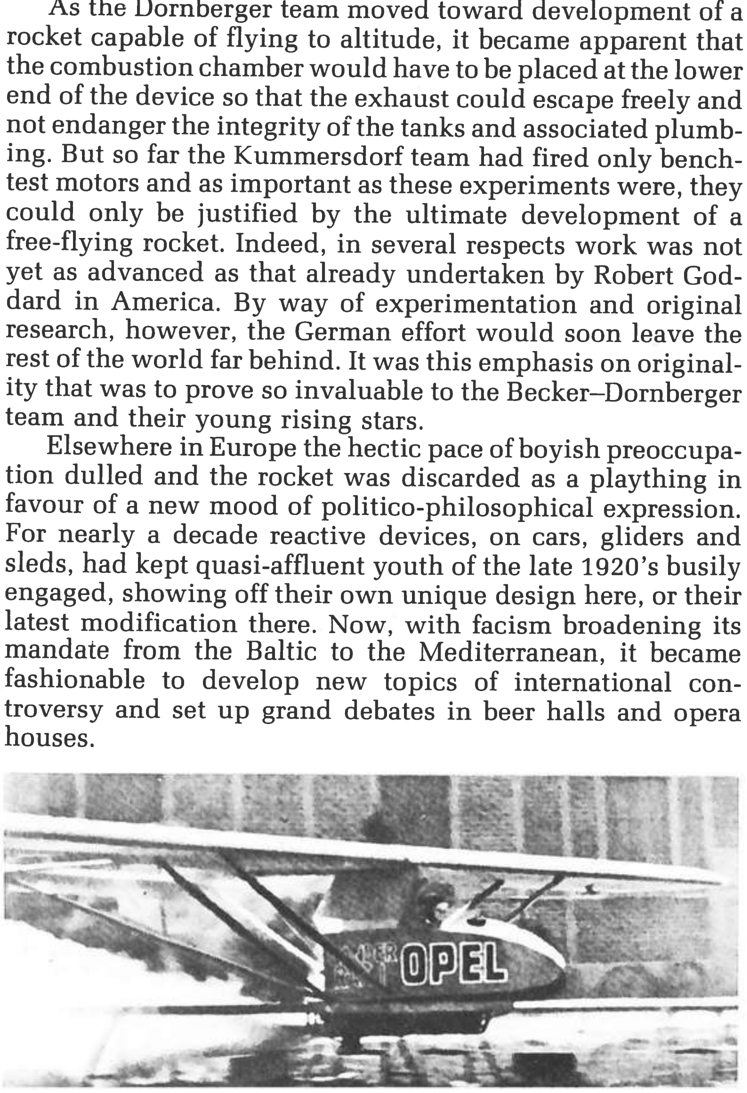
Karl Becker, now a General, encouraged him to study for his Ph.D. at the University of Berlin. Secrecy still surrounded the activities of the Army Weapons Department and the interest in military rocket developments, but von Braun received his doctorate in 1934 with a thesis bearing the evasive title, *About Combustion Tests*.

At the test stands, rocket motors had been run with exhaust velocities approaching 1,800 m/sec and major progress had been made with cooling the combustion chamber and calibrating thrust levels against propellant consumption and mixture ratios. All this basic knowledge was essential if the Army was to move ahead with development of a rocket that could be made to fly. As related in the previous chapter, the VfR had collapsed at the end of 1933 and now it was up to the military authorities to carry the lead role in any future patterns of development. Although the VfR had made several successful flight attempts with Repulsor type rockets, the design approach adopted in these early tests was at variance with the practicality of large scale rocket engines.

In the VfR design the combustion chamber was at the extreme forward end of the projectile and held in place on top of the two propellant tanks, mounted in tandem, by the delivery lines that carried the liquids from the oxygen and alcohol vessels. When the motor fired, a deflector plate situated above the forward tank prevented the hot exhaust from burning a hole in the top. This concept was limited, in that no amount of protection would prevent the tanks below from rupturing under the intense blast of a high thrust engine; only low thrust motors could be built this way.

As the Dornberger team moved toward development of a rocket capable of flying to altitude, it became apparent that the combustion chamber would have to be placed at the lower end of the device so that the exhaust could escape freely and not endanger the integrity of the tanks and associated plumbing. But so far the Kummersdorf team had fired only bench-test motors and as important as these experiments were, they could only be justified by the ultimate development of a free-flying rocket. Indeed, in several respects work was not yet as advanced as that already undertaken by Robert Goddard in America. By way of experimentation and original research, however, the German effort would soon leave the rest of the world far behind. It was this emphasis on originality that was to prove so invaluable to the Becker–Dornberger team and their young rising stars.

Elsewhere in Europe the hectic pace of boyish preoccupation dulled and the rocket was discarded as a plaything in favour of a new mood of politico-philosophical expression. For nearly a decade reactive devices, on cars, gliders and sleds, had kept quasi-affluent youth of the late 1920's busily engaged, showing off their own unique design here, or their latest modification there. Now, with facism broadening its mandate from the Baltic to the Mediterranean, it became fashionable to develop new topics of international controversy and set up grand debates in beer halls and opera houses.



The Hatry RAK-1 aeroplane was built by Opel using Tsander rockets. The first flight took place on 30 September 1929.

By the early 1930's many things started to change and the demise of a decade of preoccupation was punctuated on 17 May 1930 by the death of Max Valier, ardent supporter of the VfR and famous for his rocket-car runs since 1928. As the VfR was moving inevitably toward extinction through lack of funds and an increasingly hostile regime, others were showing originality of approach if not of concept. Most notable among the flurry of amateurs who flowed on to the scene was Reinhold Tiling. In 1931 he made several successful tests with solid propellant rockets from Osnabruck and then from the Frisian Islands. Accurate flight data was missing from these experiments, as it was from so many potentially valuable tests conducted with minimum funds and few active supporters, but it is likely that Tiling achieved heights of up to 9 km and speeds of 1,100 m/hr.

Meanwhile, in France, a lone voice had for two decades prophesied the forthcoming age of rocket travel and tried in vain to gather public and governmental support for active research. His name was Robert Esnault-Pelterie and while his sustained contributions to rocketry kept the effort in prominent view, he supplied very little of an original nature and this resulted in Esnault-Pelterie becoming a name associated with publicity rather than new concepts. His contribution was, nevertheless, a saving grace for France; without his enthusiastic and consistent work that country would have little mention in the annals of rocket history.

Esnault-Pelterie was a contemporary of Tsiolkovsky and Oberth and like those two great pioneers concentrated on the theoretical aspects of rocketry and space travel. By 1912 he had established recognition by delivering a lecture in St. Petersberg and this was followed by an address before the prestigious Society of Physics in his native country. Concentrating on the possibilities afforded by a reactive device that would become more effective as propellants were consumed, he displayed knowledgeable awareness of the elementary physics involved and in 1927 lectured the Astronomy Society of France on the possibility of probing the upper atmosphere and exploring space.

Along with a banker friend he set up a prize of 5,000 francs to be awarded annually for notable achievements in astronautics – a word coined by Esnault-Pelterie to cover activities in celestial propulsion and navigation. In 1930 he published the book *L'Astronautique* and followed it with a supplement four years later which together with the earlier edition covered all the known experiments, tests and philosophies concerning what was still at that time viewed as a somewhat suspicious concept. Yet his vision for the future of rocketry was clarified by a proposal, as early as 1928, for development of a strategic missile capability by which France could acquire a military potential of incalculable magnitude. Speaking to General Ferrie of just such a possibility he purported to foresee the day when mass rocket attacks would replace artillery bombardment and three years later Engineer-General J. Barre was appointed to monitor Pelterie's work and report on developments. For a while experiments were carried out at Versailles, but there was little official support for the tests and although several motors were built, the work led to nothing and France was left without a major programme to structure future activities.

In Germany the picture was very different. After more than a year of hard won lessons and frustrations, the Kummersdorf-West team under Walter Dornberger pressed ahead with plans to move from bench tests to design of a flying rocket-powered projectile. In 1933 the department began work on Aggregate 1, or A-1 as it would be more popularly known, so that basic design approaches could be tried and evaluated prior to the development of a large scale rocket.

The A-1 comprised a single liquid propellant motor capable of delivering a thrust of nearly 300 kg situated at the rear end of a fuel tank containing alcohol. The upper end of this tank supported a fibreglass liquid oxygen vessel with a container for nitrogen which would be used to pressurize the two propellants. At the top of the rocket the design team placed a gyroscope, which was provided to ensure stability by spinning before ignition and during the flight. This concept was in many ways paralleled by similar theories on the stability of a high speed artillery shell where a spinning motion imparted to the missile ensures a straight-line course to its target. The A-1 was required to spin rapidly at the forward section and retain the initial flight trajectory, while the aft section, with the propellant tanks and motor, would remain stable to prevent the liquids from being hurled to the outer walls of the tanks. The 38 kg forward section was also made to form the rotor of an electrical motor and in all the A-1 weighed 150 kg, was 1.4 m tall and had a diameter of about 30 cm. The 38.6 kg of liquid oxygen and alcohol would provide a burning time of just 16 seconds and the combustion chamber would be cooled by the contents of the fuel tank into which the motor itself was built.

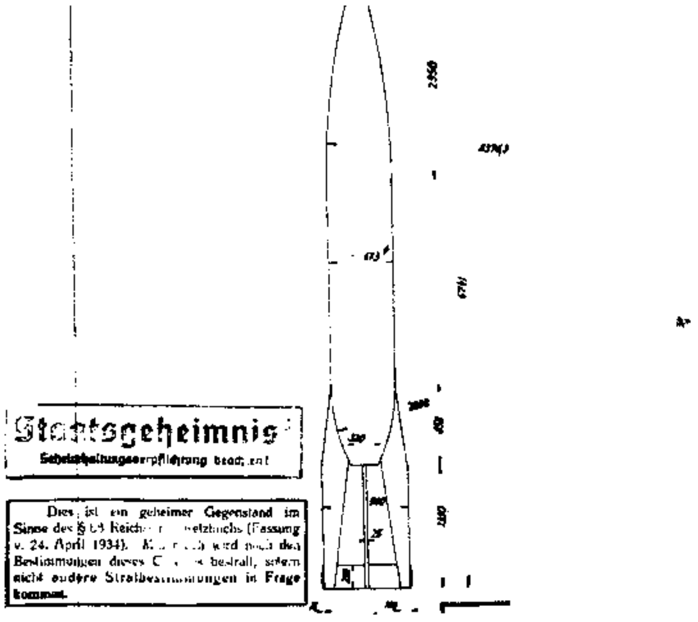
Early tests with the A-1 comprised a series of bench runs and moderate success was achieved. But even before work on the A-1 was completed thoughts turned toward the requirements surrounding larger rockets, missiles which would be necessary to retain interest in official circles and provide practical demonstrations of the awesome possibilities attending the military potential. In 1934, and as a result of lessons learned on the A-1, the second Kummersdorf flight project got under way. Called A-2 it was essentially the same as the A-1, but with the propellants carried in two separate tanks and the spinning gyroscope re-located to a position between the two vessels. However, the engine was still buried within the base of the fuel tank for cooling purposes.

Late in 1934 tests were completed and the rocket was ready for a flight attempt. For this the team journeyed several hundred kilometres from their research facility south of Berlin to a small island off the coast of north-west Germany called Borkum. Situated about 15 km out into the North Sea from the mouth of the river Ems, Borkum is the southernmost island in the East Frisian chain and afforded good and secluded opportunities for rocket flight. The first ascent came in December and heights of up to 2.2 km were achieved. This was a much needed fillip to the workers at Kummersdorf as they saw their hours of effort and frustration maturing toward reward and successful achievements.

At the development section work was advanced on the design and construction of rocket motors capable of delivering thrusts of 1,000 kg and 1,600 kg, by far the most powerful engines yet built. Although these were essentially test projects designed to explore problems of stable combustion, cooling and propellant delivery, the Kummersdorf team were already formulating basic principles around which they presumed any future development would mature. Several engineers preferred to move slowly from stage to stage in the evolutionary progression of ever larger rocket projectiles, but two at least, von Braun and Riedel, favoured a rapid test schedule which would quickly produce an effective long range military weapon suitable for mass bombardment and capable of carrying a substantial warhead. Ever the economist and administrator of the group, Dornberger knew that only when the authorities could be made to recognize the rocket's potential would it be possible for the team to command the financial resources essential for the development of useful weapons.

Partly because of this, it was decided to move ahead with the A-3, a totally different missile from the A-1 and A-2, in an attempt to demonstrate, on a small scale, all the position characteristics of a full size vehicle. The ultimate specification had yet to be written and the team was unsure about the final size of a vehicle which could be employed on effective military duties. Nevertheless, the A-3 would use the most powerful liquid propellant rocket engine then in development at Kummersdorf, the 1,600 kg thrust motor, and provide the team with a power plant capable of impressing officials and proving the concept. Only when the A-3 had successfully flown, could the engineers obtain the necessary and essential information for design of a long range weapon which would be sufficiently powerful to warrant development, yet simple enough to be put on a large scale production line and operated by non-technical personnel.

All this, however, would require large test facilities, a long distance firing range and an administrative complex far removed from the limited resources available at Kummersdorf. The work would have to be transferred to some other more suitable location and Dornberger's design team was anxious to set up shop elsewhere just as quickly as possible. Again, money was the problem and only when the facility had impressed the Army High Command would the necessary access be gained to treasury funds. So, while Dornberger worked away to draw high level military interest, von Braun and his engineers defined the requirements and specification for the new research facility which would, it was appreciated, have to be a totally self-contained establishment supporting design, test, flight, management and pre-production activities.



Developed at Kummersdorf, the A-3 was a radical departure from the design philosophy pursued on the A-1 and the A-2 and would lead directly to the A-4, more popularly known as the V-2.

Much of 1935 was spent defining the future posture of work on rocket flight. Kummersdorf-West had already grown as large as was possible bearing in mind its proximity to the major suburbs of Berlin and further flight testing which would be essential to the continued development of increasingly high thrust motors was severely restricted. There was, in addition, increasing international interest in the events associated with political change in Germany and the secret activities of Dornberger's team would be exposed if a more remote establishment was not quickly set up and put into operation.

Adolph Hitler had moved from a position of convenient co-operation with Field Marshal von Hindenberg to total control of the Reich. In the course of this transfer of power Hitler eyed with concern the dominant position of the German Army which retained allegiance to the principles of Hindenberg. It was the beginning of a suspicious relationship which would lead the military forces of the Third Reich to openly contest the wisdom of Hitler's consuming policy and all but instigate revolt at the increasing power given to fanatical groups such as the SS and the SD. Nevertheless, Hitler realized that he would need the support and confidence of the Army if he was ever to achieve satisfactory re-armament and gain the advantage over other European countries in the never ending search for Lebensraum – living space – for Germany's millions.

But the traditional power of the German military hierarchy threatened the balanced manipulation of conquest and occupation east and west of German borders; the struggle for total control of the armed forces, was to endure for a further decade. It is important to appreciate the separate channels of command that faced the research activities of Kummersdorf-West. It would have been feasible for Dornberger to approach the SS and the SD for separate control of funds and activities, aligning the chain of command with the political wing of authority instead of holding fast to the Army. But such a possibility was outside the power of a man who had little to do with politics and to Dornberger the Army was a bastion of moderation and purpose totally incompatible with the intolerant activities of Hitler and his bullies. Nevertheless, the SS would shortly employ unscrupulous tactics in an attempt to take over rocket research.

By the end of 1935 personnel at the rocket research station at Kummersdorf-West were intent on finding adequate facilities far removed from areas of habitation and outside the known areas of military weapons development. Several places seemed suitable, but for one reason or another all were deemed to be unsatisfactory upon close examination. One of the major hurdles to be overcome grew from the desired length of the firing range which would have to be an integral part of any new facility. Although the specification for an operational military missile was still far from clear, the projectile would have to have a range of at least 300 km and to test such a device the trajectory would have to lie across unpopulated areas. This drove Dornberger and his team to look for a coastal location and since Germany could not run the risk of its secret rocket programme being detected on the North Sea coast, it left only the Baltic area for consideration.

Then von Braun went to stay with relatives near the town of Anklam for the Christmas festivities in 1935. Anklam lay close to the Peene river which followed a straight course to the Baltic, flowing round a large island called Usedom and into an estuary beyond which lay another island, much smaller, called Greifswald Oie, about 10 km from the nearest land. Reporting back to Kummersdorf-West a few days later von Braun discussed the possible use of this area with Walter Dornberger who was then putting finishing touches to plans for a visit from the Army High Command. Dornberger went up to Usedom with von Braun and saw for himself how ideal the place would be for rocket research.

Kilometre after kilometre of sand dunes, reed beds, marsh land and conifer forest stretched across the sinuous threads of waterways and estuary. Wildlife was in abundance, deer roamed the wooded flatlands and birds flocked in profusion. It was utterly remote; totally unspoilt by human habitation. Above all, it was a great distance from the nearest town of any substance, far removed from the major industrial centres of Germany and provided good access to at least 400 km of potential firing range across the Baltic coast. Although a considerable quantity of material would have to be transported into the area, its remoteness from the Ruhr engineering facilities had an advantageous effect: the rocket research establishment would not need the large quantities of metal usually required for a major military project and its distance kept it in confident seclusion from the prying eyes of intelligence agents. Once the enormous task of building up the necessary buildings, test sheds, launching pads and tracking facilities had been accomplished, the area would achieve a level of autonomy until production line deliveries were ready to begin, probably from some other, equally remote and obscure location.

Now, at last, prospects seemed to be improving and the Kummersdorf-West team could lay plans for a development programme which would match the splendid facilities envisioned for construction on the north German coast. But money was still scarce and the existing facility south of Berlin had problems keeping the workers up to schedule on the meagre sums allocated by the Army. Nevertheless, it had been arranged that the Army would come to Kummersdorf in the following spring to inspect the work and to review plans for proposed expansion. Dornberger and his team knew that further progress depended on their being able to secure substantial funds both for the continued research activities and for the planned occupation of the Peenemunde estate. If they could not convince the High Command of the need to move, all further progress would be severely curtailed and the Kummersdorf facility would remain essentially a test-bench station incapable of launching large rockets. The first successful launch, in December 1934, had certainly provided proof of the team's effort and without the results of the A-2 flights it is extremely doubtful that further work could even have been anticipated.

In March 1936 Army Chief of Staff, General Freiherr Werner von Fritsch, arrived at Kummersdorf-West for an inspection of the test site and a report from Dornberger and his men. Lectures accompanied with charts and diagrams previewed a demonstration of the three rocket engines so far developed and with thrust outputs of 300 kg, 1,000 kg and 1,600 kg the ear-splitting cacophony thundered through the air in physical endorsement of the inherent power. Thoroughly impressed, Fritsch expressed his profound admiration for the level of effort so ably demonstrated and went into conference with Dornberger over the future possibilities. The results of this meeting were everything the team had hoped for. If the rocket could be turned into an efficient weapon he, Fritsch, would see to it that they got anything they needed to accomplish the task.

Several weeks later Dornberger managed to get the chief of the Development Branch of the Air Ministry, Lieutenant-Colonel von Richthofen, to call at Kummersdorf and see for himself how work was going. He did and was equally as impressed as Fritsch with the work. In particular he was interested in the proposal to assist heavy aircraft into the air by means of rocket-assist from solid propellant motors and went away convinced that Germany had hold on the future and access to a remarkable new means of propulsion – which it did. With increasing likelihood that the Kummersdorf team would be able to persuade the Army to finance their removal to Peenemunde and the construction of an integrated research station, it became apparent that basic specifications would have to be written for the work which would be conducted over the next decade or so.

Military considerations of the future rocket's performance objectives was more the province of Dornberger, a military man with a background in artillery, while professional engineers like von Braun and Riedel concentrated on the specification for test equipment, firing stands, launch pads, etc. Dornberger emphasized the need to provide a weapon which would eclipse the capabilities of the most powerful long range gun and used a value of 260 km for the necessary range and a mass of 1,000 kg for the explosive warhead. Toward this broad objective, von Braun and Riedel wrote the requirements for ground structures and assembly facilities. Von Braun's enthusiasm was such, that provided the means were available, the military end was not at this time, an overriding consideration.

Although the first long range missile was considered to need a motor capable of delivering a thrust of as much as 30 tonnes, in order to meet the Dornberger specification, the primary test stand was designed to accommodate rocket motors with a thrust of up to 100 tonnes. This would serve rocket design developments for many years to come, without necessitating the intermediate construction of additional stands. Now that the prospects of setting up a new research base were becoming reality the Kummersdorf team began immediate design of the long range rocket. The A-3 was already on the drawing board and so the project was officially designated A-4. Under the capable control of Walter Riedel the design team moved ahead.

Working to the specification which demanded a range of at least 260 km, with a warhead weighing 1 tonne, the A-4 emerged on paper as a rocket more than 13 m long, more than 1.6 m in diameter with a single rocket motor providing a thrust of over 25 tonnes. With more than 12 tonnes of propellant on board, the vehicle would produce its rated thrust for more than a minute and accelerate to a speed of 5,800 km/hr on the product of a stream of exhaust, leaving the nozzle at 2,130 m/sec. This was far more ambitious a concept than anything yet developed and would penetrate unknown areas of aerodynamics.

Because of the comparatively short burn duration, the maximum power of the rocket would have to be expended in gaining speed and this meant passing through Mach 1 – the speed of sound. No more daunting task could possibly be imagined by rocket engineers in the 1930's. Theory said that it could not be done, although earlier research at German test centres had confirmed the possibility of designing a projectile which would be capable of holding together through Mach 1. But the problems would be enormous and the shape of the missile would need as much care in the design as in the interior components. A profile had to be selected which would be as stable at Mach 3 as it was at launch and hold together during the punishing plunge down through the atmosphere and on to the target. Yet the rocket would achieve what no other device had: a flight to the very edge of space itself; in selecting the optimum trajectory for a 260 km flight it was seen to require an altitude of nearly 90 km.

Many other problems remained, not least of which concerned the accurate guidance required to keep the missile on course and control of the exact duration of burn. At the end of the powered phase the rocket would be moving at a speed of

5,800 km/hr and the slightest delay in cutting off the motor would result in an extension of the flight trajectory, bringing the warhead down on to a target far beyond that which was planned. Other considerations affected thoughts on the precise design configuration. Dornberger pointed out that the rocket, eventually put into production runs of several thousand units, would have to negotiate road and rail systems then in existence. Conventional methods of transportation would probably be employed to move the rockets from the assembly plants to the launch batteries and the size and weight would have to be tailored to these factors. So much remained to be done and so little was really known about the problems waiting just around the corner. Only brief glimpses of potential disaster showed up in the myriad calculations which turned the designer away from a course which could result in months of wasted work. So much had to be known in advance to prevent complex and expensive components entering production for a test that would be doomed to catastrophe.

So far the Kummersdorf team had only experimented with flight models of the A-2 and its 300 kg thrust rocket motor, but they were confidently planning motors of 25 tonnes thrust for a missile ten times larger. The basic philosophy of operation anticipated parallel development of the A-3 and the A-4 with lessons from the former fed into the design flow of the latter as it matured to flight status. As the work progressed it became increasingly apparent that the requirements of the A-4, the long range weapon destined for production, were far in excess of the equipment then available. The simulated speeds were much greater than that which could be achieved in any wind tunnel and several engineering problems emerged which challenged the ability of the design team to come up with a working concept.

In July 1936 the Kummersdorf-West group received a partial set-back when a certain Dr. Hermann produced wind tunnel test results from a facility at Aachen, demonstrating the problem with a fin configuration designed for use on an intermediate A-3 rocket. The A-3 project was put back several months by this news and while engineers wrestled with a variety of shapes and profiles, plans were firming up for the transfer to Peenemunde.

Soon after the enthusiastic visits from Army and Air Force officials in March 1936, Dornberger managed to arrange a conference at which General Kesselring, the Director of Production, was to review the planned move and give the final word. Accompanied with masses of charts and diagrams Becker, Dornberger, von Braun and the chief of the Air Ministry Development Branch (von Richthofen) put their case to Kesselring who examined the proposed layout on the islands of Usedom and Greifswald Oie as a part of the Peenemunde experimental research station. After much discussion it was agreed that the Kummersdorf-West team would design the facility, while the Army would construct and manage the project under joint Army/Air Force funding.

At last the hopes and dreams of the Kummersdorf pioneers were achieving fruition and it would only be a matter of time before the group had command of all the equipment they would need to set up a large scale research establishment and build the world's first long range production missile. With Army and Air Force approval now on hand events moved rapidly and Dornberger soon received the news that the necessary land had been purchased.

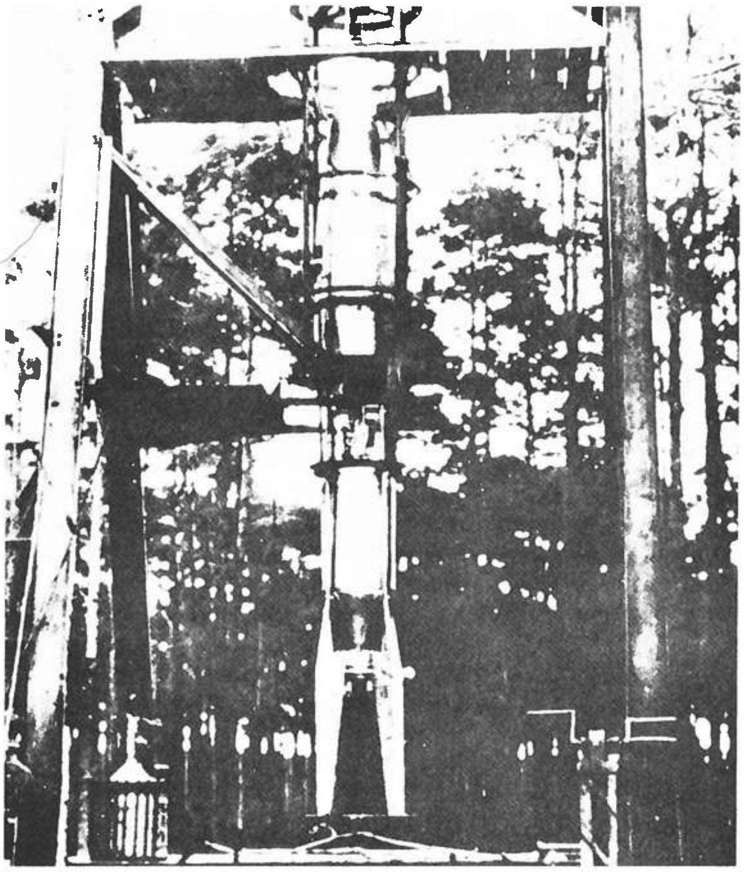
Much of 1936 was taken up with the administrative design planning for Peenemunde, while the engineering shops at Kummersdorf slowly progressed with the A-3 and its associated systems. Following the wind tunnel results on the A-3 fin design in July, activity concentrated on refining the concept, but the problem was magnified by the lack of adequate wind tunnel facilities close to Kummersdorf. Several times engineers came up with new configurations, but these had to be sent off to Dr. Hermann at his Aachen wind tunnel before tests could be carried out to evaluate the modifications.

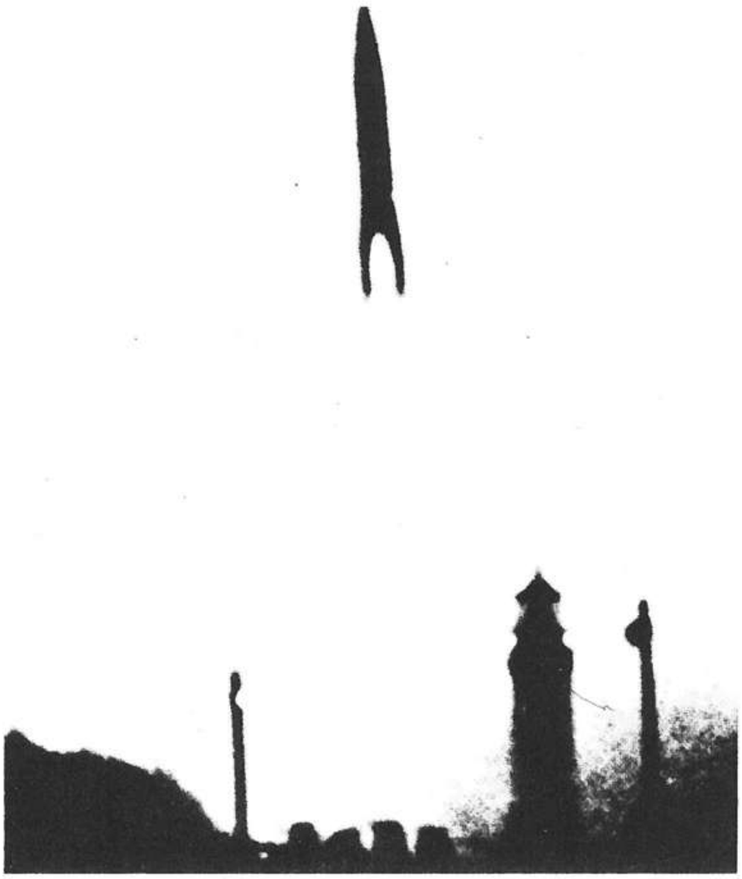
For a long time the engineers pressed Dornberger to request funds for a wind tunnel at Kummersdorf so that any design changes could be quickly tested on site. Not least among these was von Braun, who now launched full force to get permission for such a tunnel. Recognizing that the days at Kummersdorf were numbered, and explaining the futility of funding development of a new set of equipment for the existing facility, Dornberger pressed for approval to build a wind tunnel at Peenemunde so that it could be ready when the team moved in during 1937. General Becker, Dornberger's superior, cautiously approved the plan with the proviso that at least one other section of the Army Weapons Department Research and Development Branch also request a wind tunnel to justify the expense. Dornberger knew that without a wind tunnel at Peenemunde delays would be even worse than those experienced at Kummersdorf, so he toured several experimental facilities working in various categories of weapons development and finally got the head of the anti-aircraft defence department to back him. Becker approved, with the promise of appended funds to the already large bill for construction work at Peenemunde and Dornberger brought von Braun in on the project to set up a design specification for the new wind tunnel. It would be built on the island of Usedom and provide a test capability far in excess of anything yet available in Germany or elsewhere. When the wind tunnel became operational Dr. Hermann would take over as head of operations since he was already familiar with the work of the pioneer rocket group through their cooperative liaison in the previous months.

By September the design bureau at Kummersdorf had finally got successful results on the A-3 tail fin shape and went ahead to prepare the rocket for flight. Many months were taken up with design refinements, re-worked specifications and long hours of bench testing. The entire design approach to the A-3 was totally different from that employed for the A-1 and the A-2, which were in effect only flight-rated test models of a dated concept. With this new design the basic philosophy of engineering principles had been set, and the A-3 would pioneer the type of design criteria employed on the A-4, still very much on the drawing board and awaiting A-3 flight tests before further development could be accomplished.

The A-3 used a liquid oxygen/alcohol propellant combination pressurized with gaseous nitrogen. The fuel tank was mounted directly on top of the rocket motor, with the oxygen tank above and the nitrogen reservoir attached to the interior of the oxygen vessel. The entire assembly was encased within an aluminium skin structure supporting an instrument unit at the top, above the oxygen tank, and four fins at the rear, to provide aerodynamic stability. Instead of adopting the A-1/A-2 concept of a spinning forward section to maintain course, the A-3 had a built-in system of gyroscopes which would operate in conjunction with molybdenum vanes in the exhaust efflux. If the missile pitched in excess of the desired angle the gyroscopes would sense the motion and

An A-3 liquid propellant rocket stands ready on a test stand at Peenemunde in 1937, the first rocket to be launched from the Baltic coast research station.





In a period of one week beginning 4 December 1937, four A-3 rockets were flown with only partial success. Recognizing the need for an interim test vehicle before details on the A-4 (V-2) could be finalized, the Peenemunde team went back to the drawing board and came up with the A-5. In this view, an A-3 ascends under the reactive influence of its 1.6 tonne thrust motor.

order the vanes to change angle, so deflecting the exhaust stream and literally steering the rocket back on course.

At launch the A-3 would weigh 750 kg and supply the engine with 450 kg of propellant for a total burn time of 45 seconds. In the combustion chamber, nearly 1.8 m long, the gases would be accelerated to an exit velocity of 2,800 m/sec. Delivery of the propellant was ensured by the nitrogen pressure system and each tank would withstand a wall pressure of up to 20 kg/cm^2. Made of light alloy, they were a considerable improvement on the A-1/A-2 design. During the early portion of the flight the four fins would be stabilized by a plastic ring 25 cm wide to prevent flutter which could result in distortion of the clean aerodynamic profile or, at worst, total break up. Electrical power was to be provided by batteries in the forward equipment section, which also contained the autopilot, attached to the six gyroscopes.

At the maximum height of the rocket's trajectory a parachute would be deployed to lower the equipment back to the ground, but since the A-3 would be fired from Peenemunde, a watertight compartment was provided to prevent delicate instruments from being lost on impact with the water. Inside the compartment engineers placed a barograph for measuring atmospheric pressure and a small camera for recording the measurements during the critical portions of the flight. There was, at that time, no means of transmitting information to the ground and any lessons to be learned from the way these systems worked, would have to come by way of physical retrieval and post-flight examination of the record.

In all, the A-3 was 6.7 m tall with a diameter of 67 cm and produced a maximum thrust of nearly 1,600 kg, employing the same motor design as that shown off at the Kummersdorf works during the visit by Fritsch in March 1936. In all respects the A-3 pointed the way toward the final design configuration of the A-4 and firmly set the engineering approach for future patterns of development.

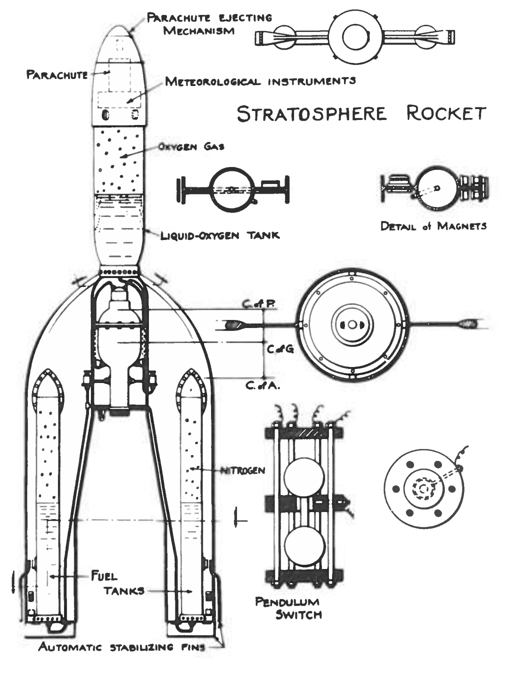
By spring 1937, teams of construction workers under the authority of the Army moved in to the deserted natural landscape around Peenemunde and gradually began to convert the pastoral scene into one of hectic activity. The island of Greifswald Oie was already selected as the site for the rocket test stands and launch pads, which would also be required to support observation facilities, triangulation stations, monitoring facilities and a host of electrical and telephonic connections. The wind-blasted island was hardly suitable for land access and most of the construction equipment came in by sea during that spring. Most of the design details on the entire complex had been worked out during the summer and autumn of 1936, but the inclement weather of a Baltic winter deferred a start on the work until calmer days arrived and the nights became shorter.

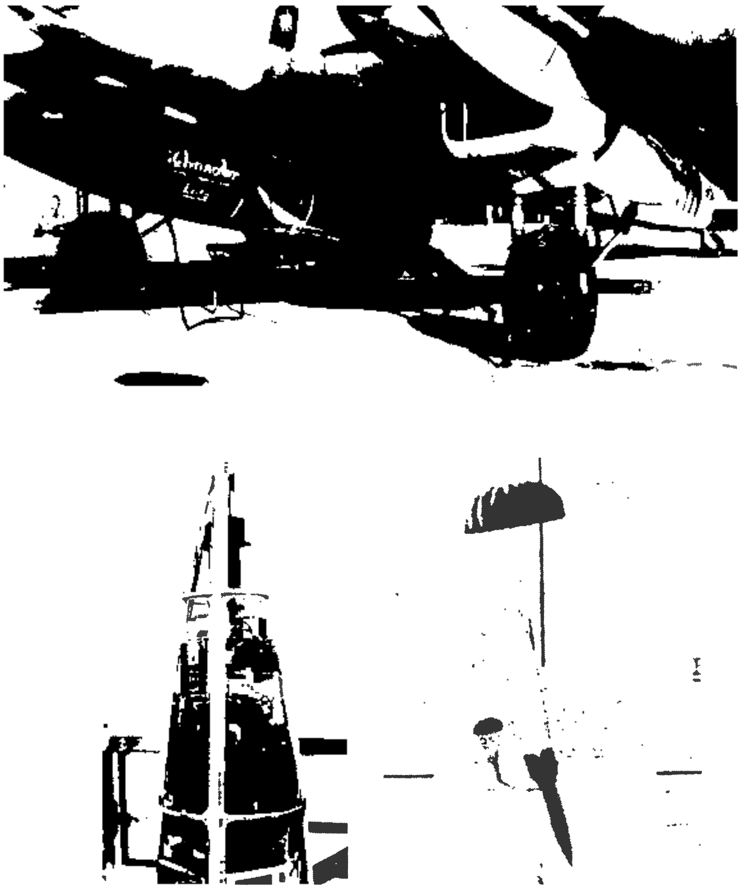
Greifswald Oie is about 1 km long and 280 m wide at its broadest point. Situated nearly 10 km out into the Baltic it has a weathered surface rising to a maximum height of 18 m above sea level. The southern part of the tiny, inconspicuous island was populated with a few hardy fishermen and their families operating from a sheltered harbour. The stone houses at this point were provisioned from the mainland, but had the satisfying services of a small inn which would henceforth serve to re-vitalize the depressed spirits of rocket engineers. To the north of the island the full fury of the Baltic cold had fashioned a rocky landscape eminently suited to the construction of rocket test pads.

On nearby Usedom work concentrated on building the living quarters for the personnel assigned to the facility, together with support buildings, drawing offices, research departments and the all-important wind tunnel. Not far away was the small town of Wolgast and to the east lay the Oder estuary. Passage between Usedom and Greifswald Oie was to be effected by ship into a small harbour, albeit considerably modified during the initial construction phase to accept cargo ships bringing heavy equipment. Most of the summer and autumn months were taken up with preparations for A-3 flights and while design engineers put the finishing touches to changes brought about by the extensive series of laboratory and bench tests, the administrative changeover was completed.

By November the first A-3 rockets were brought into Greifswald Oie by ship and the following month Peenemunde was ready for supporting test flights. The rocket was mounted on a small, circular pedestal at the base of the four fins, with each one resting on plates set into the firing table. In December 1937 the first A-3 was launched from Peenemunde, but problems quickly developed and the attempt ended in total failure. There was little to indicate the reasons for the unexpected catastrophe and the team pressed ahead with a second flight, but this too resulted in an uncontrollable gyration shortly after ignition and the A-3 plunged to an impact with the Baltic shore. Over the next few days weather prevented more tests and the team gathered together for discussions on the probable cause of the accidents. Several views were put forward and eventually it was decided to go ahead with another shot, but this time without the recovery mechanism. Although all record of the vehicle's performance would be destroyed on impact, it was felt likely that the parachute system had somehow deployed too early and caused the failures and it was more important to demonstrate

While secret design studies went on at Peenemunde, Alfred Africano of the American Rocket Society's Experimental Committee designed this stratospheric rocket and won the Rep-Hirsch Award in Astronautics for 1936. The award had been established some years earlier by Robert Esnault-Pelterie, the French aeroplane manufacturer and astronautics enthusiast, and his friend, the French banker André Hirsch. The design never progressed beyond the drawing board.





In the summer of 1938, Heinkel He-111 aircraft were employed as carrier-planes for drop-tests with scale models of the A-5. Test launches of other A-5 models took place in March 1939.

a reasonably successful ascent, than gather all the necessary data on the first good flight. Nevertheless, the third launch ended in another crash from a height of about 1 km and again engineers and design staff gathered for deliberations on the future course of test objectives.

It was recognized that the A-3 represented a considerable advance on the A-1 and A-2 rockets of 1933–34. In an attempt to move as quickly as possible to the definitive long-range weapon that justified continued Army funding, the engineers had put all the essential features of a ballistic missile into one rocket. But the design requirements were taken straight from theoretical analysis and many components would have to be tested in flight before the complete assembly could be made sufficiently reliable to warrant development and flight testing. The gyroscope control system, feeding the exhaust vanes with attitude instructions, contained many features completely new to the Peenemunde team and this, together with a complex recovery and measurement recording system, was too big a step to take before tests had proved the validity of each component.

Meanwhile, the long range ballistic missile project, the A-4, was in a state of limbo. Much important information was expected from the A-3 rockets which would lead to definitive design of the A-4 and since the A-3 was proving troublesome work could not progress at the anticipated rate. But design of the big 25-tonne thrust rocket motor that would power the A-4 continued under the expert guidance of a Dr. Walter Thiel who had joined the Kummersdorf team late in 1936. This was a very exciting probe into totally unknown areas and with serious laboratory work in progress on a rocket engine far larger than any other device yet conceived, Dr. Thiel and his team wrote new chapters in the theory of rocket propulsion. All the old problems of cooling and stability were there, but in greater magnitude.

Through 1937 and on into the following year, the work progressed to a point where most of the problems had been defined and slowly resolutions emerged which over the next few years would lead to a respectably reliable engine. The road would be a long one, but the technology was so new that even a minor step forward was greeted with excitement. This was fine, detailed work unsuited to the operational tests going on at Peenemunde and because of the suitability of the earlier location, Dr. Thiel stayed on at Kummersdorf-West and steadily progressed with work on the big engine. Many A-3 tests and checks had been performed at the small experimental facility south of Berlin and it would continue to provide basic research data and serve as a more accessible link with several other research institutes in Germany; the important wind tunnel work would have to be conducted at Army and Air Force facilities since the structure at Peenemunde was not expected to be ready for another two years.

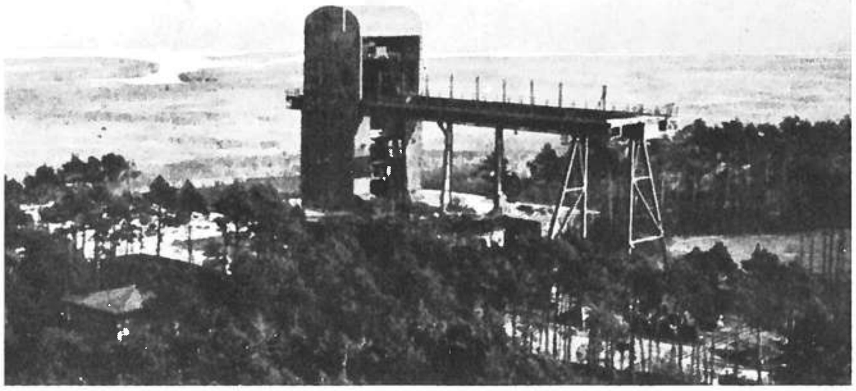
By early 1938 the work encountered an unexpected impasse generated by the failures with the A-3 rockets at Greifswald Oie the previous year. If design details could not be confirmed with a reliable series of launch tests, A-4 activity would stagnate. Because of this all-important need to come up with a reliable 'workhorse' for sustained flight testing, Dornberger and von Braun decided to re-design the A-3, simplify its systems and incorporate a much more powerful attitude control function. Because the A-4 was designated as the projected long range weapon which would eventually emerge for operational battle use, this new rocket was called the A-5, adhering to the numerical sequence for project categorization.

Externally the A-5 was very similar to the A-3 and it did use the same propellants, the same engine and had a shape almost identical to that of the earlier project. But the main body of the rocket was larger in diameter by 8 cm and it was built to carry a radio command system for ground control of engine cut-off and parachute deployment. In addition, and with recognition of the attitude problems associated with the A-3, engineers designed a new set of fins and sent them to wind tunnels at Friedrichshafen and Aachen for analysis. Dornberger, in control of the test sequences leading up to A-4 development, wrote up a series of flight objectives and scheduled A-5 production at the rate of 10 units a month. When the A-5 was ready, it was expected to perform all the in-flight research tasks essential to final design details on the big A-4. But knowledge was far from complete on the ideal shape and configuration of the control fins and stability would depend on the successful design of a profile which would ensure good flight dynamics all the way through the speed of sound and beyond. No other work had provided comparative data on the kind of problems which would be encountered when a rocket went through Mach 1 and consistent reliability would be an essential feature of future military developments in this field.

While wind tunnels and design offices worked away to put the finishing touches to the A-5, a series of air-launched drop tests began using small iron models, each one shaped to a different profile so that a comprehensive bank of data could be set up on which future designs would rest. Each iron model was about 1.5 m long and 20 cm in diameter, weighed 230 kg and achieved Mach 1 by being dropped from a Heinkel He-III flying at a height of 6,000 m. Observation of the model's response proved the validity of the tests and details quickly emerged which confirmed the hypotheses expressed by the research team. Combined with the wind tunnel data, providing information on performance below the speed of sound, the drop-tests did much to accelerate preparation of the A-5.

Guidance for the new rocket had been designed to ensure stability during the powered portion of the flight and while industrial contractors were putting the final touches to the equipment, the Peenemunde team launched four A-5 rockets from Greifswald Oie to check performance and quicken the pace of development. Devoid of the gyroscope and attitude control system, the rockets displayed good characteristics and reached a maximum height of 8 km, providing confidence in the capabilities of the vehicle and reflecting the steady progress that attended the many months of work and test. Now the team was anxious to take the data on fin shapes acquired from the iron model drop-tests and apply it to flight situations so that stability and control characteristics could be demonstrated with live rockets.

The large A-5 was not necessary for this purpose and so while the new gyroscopes were in the final throes of development, a series of flights began using smaller rockets procured from the Helmuth Walter Kommandogesellschafft at Kiel. The propellant for these rockets was hydrogen-peroxide which, when decomposed over a potassium permanganate catalyst, provided a thrust of 120 kg. The 1.5 m long projectiles had a diameter of 20 cm and weighed 47 kg of which 20 kg was taken up with propellant. The first flights came early in 1939 and many tests were made with a variety of



Metal and concrete rises from the Peenemunde estate, heralding the introduction of the massive research effort culminating in the A-4.

different shapes and fin configurations, all of which led to the final A-5 and A-4 designs.

By 1939 the political face of Germany was scarred with the warts of fanaticism in high places and although much of what went on in the back and forth of international relations was of no interest to the rocket team, events were fashioning a cauldron of violence that would spill beyond fragile frontiers and envelop the whole of Europe. In March 1935 Hitler began a policy of re-mobilization by introducing conscription, against the advice of the military (whom he distrusted) and set course for a confrontation with France a couple of months later, when he negotiated the Anglo–German naval agreement. In tearing up the Treaty of Versailles, which forbade Germany the right to re-arm, he entered into a series of testing moves against other European nations, but even when a Franco–Soviet pact provided cover for German military occupation of the Rhineland in March 1936, the world stood by and threw only paper protests.

In November 1936 Hitler negotiated a pact with Japan which effectively repudiated that nation's alliance with Russia and a year later brought Italy in to an axis triumvirate which spanned half the globe. In March 1938 German forces occupied Austria and in March 1939 swept Bohemia and Moravia under the Nazi boot. Intent on pushing east, and using the right to open a corridor through Poland to Prussia as an excuse, Germany polarized a diplomatic offensive and provoked anger from France and Great Britain. During the four-year period between 1935 and 1939 the friction between the Nazi party and the heads of Germany's armed forces reached crisis point. They saw all too clearly the awesome repercussions of an impending war and recognized the frantic efforts under way in England to stem the tide of fascist domination: in January 1938 the British foreign secretary, Anthony Eden, offered large territorial portions of Africa in an effort to bribe Hitler into moderation. That this failed was only another indication of the deep rift which separated Germany from her European neighbours.

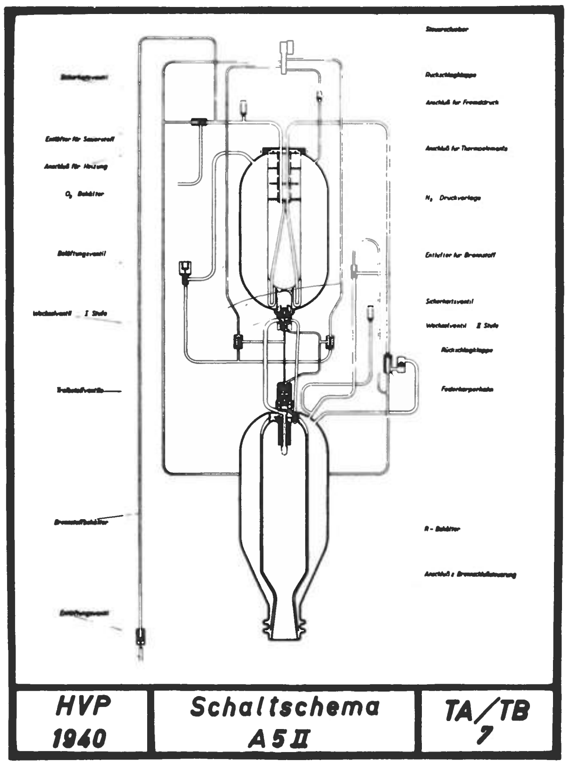
Ever at loggerheads with Army chiefs, the Nazi Chancellor drummed up a scurrilous accusation against von Fritsch, then Army Commander-in-Chief and had him hounded from office. Field Marshal Walther von Brauchitsch was put in Fritsch's place in February 1938, immediately followed by a full reorganization of the Wehrmacht which placed Hitler in control of the armed forces and gave Hermann Göring the rank of Luftwaffe General. From then on the armed forces were drawn under the paper-thin umbrella of the political leaders and exposed to inspection and intimidation from the loutish SS and SD.

Throughout 1938 von Brauchitsch fought hard to bring the facts of life home to the Reich Chancellor, but all to no avail. Hitler openly confessed his intention to settle the eastern question and then turn his fury on the west – France, the Low Countries and Scandinavia. Bitterly opposed to any such move which might involve military campaigns, the New Army chief pointed to desperate inadequacies which left him with the opinion that Germany was sure to lose any major conflict which could all too easily ensue from their marauding. Nevertheless, in spite of intolerable pressure, the Army gave its full backing to rapid re-armament, which had already brought Germany to a level of force strength at par with most other countries, in the hope that suicidal moves could be avoided until the country had a reasonable chance of surviving, if not winning, a major conflict.

It was against this background, that Adolph Hitler accompanied Generals Becker and von Brauchitsch to the rocket experimental station at Kummersdorf-West in March 1939. With von Braun chatting to the visiting dignitaries about their work on the A-3, proposed plans for the A-5 and the activities in the far north at Peenemunde, the group inspected replicas of the missiles then under test and saw the fury of a 300 kg thrust engine blasting forth from its static test rig. Moving from building to building, Hitler seemed totally preoccupied, while the military chiefs strode confidently around the enclosure gaining enthusiastic and justifiable pride from this demonstration of German engineering prowess. Dornberger was moved to comment later that he was appalled at Hitler's diffident attitude. But this was only typical whenever the Nazi architect found himself in the company of trained experts capable of energizing the resources of technicians and engineers. Just a month later, Göring stamped around Kummersdorf-West on a similar inspection and while leaping about with boyish enthusiasm, with a mass belying agility, he too failed to comprehend the enormous potential in rocket technology.

The attitudes exposed by the Kummersdorf visits, gave the research teams valuable insight to the inner convictions of a political hierarchy that had hitherto been remote from the small band of technocrats. Quite obviously the Nazi party would permit work to continue only as long as it seemed feasible to plan development of a long range ballistic missile. Hitler was totally incapable of realizing what rocket supremacy would mean to the progress of a nation bent on stretching its military muscles and while Dornberger, Becker, von Braun and the engineers were well aware of the new tool they were forging, the short application to offensive bombardment was to Hitler, the all consuming justification for continued effort. Now, with the Army under direct control from the party, everything would have to be justified, authorized and developed so as to appeal to these arch-sculptors of destiny.

By the late summer of 1939, work at Peenemunde had transformed the facility into a true launch station, with special instruments set up on the neighbouring island of Rugen and connected to Greifswald Oie by under-sea cables. Rugen consists of an irregularly shaped land mass stretching 40 km and cut with estuaries, bays and inlets. It is separated from the mainland territory of Rostock by a narrow strip of water joining the Baltic Sea on each side of Rugen. The nearest station for measuring the trajectory of rockets launched from the Oie lay across 10 km of water and was set up at the extreme eastern point on Rugen. On the rocket island itself, concrete stretched in all directions and numerous flat-roofed buildings stood here and there with test rigs, blast ducts and conduits liberally spaced around the firing area. More under-sea cable connected the island with points on Usedom specifically set up to work in conjunction with the Rugen



An engineering drawing showing the layout of the A-5.

station and a continuous traffic of boats plied between the isolated land masses, carrying engineers and technicians back and forth to places of work.

In October 1939 the first A-5 was ready on its test rig for a maiden flight across the Baltic waters. The four A-5 rockets launched in late 1938 had carried no guidance and were flown only to test basic modifications when the design had matured from A-3 technology. Now the fully equipped A-5 would be put through its paces in a series of three flights designed to prove the suitability of the rocket for an intensive series of tests aimed at qualifying aspects pertinent to the definitive A-4. When the first of these shot up from the Greifswald Oie weather conditions were good and there was little wind aloft. On and on the rocket swept, behaving perfectly and just as predicted by the launch team. Von Braun was at the controls of the radio transmitter which would command the final sequence in the rocket's flight and when the motor cut out at a height of about 1.5 km, 45 seconds after lift-off, all eyes were on the trajectory as the brightly painted shape gently arched over before falling back to the sea. At the high point of the trajectory von Braun pressed the button, which sent a radio signal to command release of the braking parachute, followed seconds later by another signal which released the main descent parachute. Slowly the hull of the rocket drifted down into the waters of the Baltic, close to the harbour, and splashdown was easily visible to all the anxious watchers witnessing the fruitful climax of several years' work. Before long the inert mass had been retrieved for a post-flight inspection.

The second flight on the following day (a repeat of the first) was a similar success and conducted a vertical ascent to maximum altitude without the complexity of any changes to the trajectory. But because the A-5 was intended to qualify all the principal features of the proposed A-4, it was designed to apply commanded guidance which would demonstrate stable flight during a curved flight trajectory. The gyroscopes would be instructed to tilt in the desired direction of flight and this would result in the auto-pilot instructing the graphite vanes protruding into the exhaust efflux to turn the rocket slowly over so that it continually sought to align the longitudinal axis of the rocket, with the primary axis of the gyroscopes. Basic flight control along a given path worked on exactly the same principle: if winds caused the rocket to tilt and veer from a truly vertical ascent, the vanes would similarly tilt to deflect the exhaust and bring the rocket back on course. By intentionally commanding the gyroscopes to move, the guidance system of the rocket would be operating in exactly the same way, but with the desired result that the missile would follow a curving flight path. This was the methodology applied to the proposed A-4 so that its vertical ascent could quickly be turned into a 50° tilt, with the result that the rocket would follow a ballistic path designed to achieve maximum possible range rather than altitude.

Because the A-5 was expected to test this concept, the third flight incorporated an active guidance system and again the rocket roared away from its test stand, followed seconds later by the programmed tilt. As the motor died away the rocket drifted on its long arching flight path and the parachute was deployed at a height of about 4 km. Once more the rocket was recovered and subjected to a post-flight scrutiny. Now the experimental research station had a proven tool for sustained tests with all the many and varied concepts which would have to be introduced on the embryonic A-4 – the big missile still very much in the definition stage, but destined to eventually go into production as the world's first long range ballistic rocket. The A-5 would be used throughout 1940 to ensure progress with the A-4.

A month before the first fully equipped A-5 had been launched in October 1939, Germany descended upon a road that would inevitably lead to the complete destruction of the Third Reich and sent its troops into Poland to occupy the Danzig corridor and take over the country. The brutish political machinations had paid off and the Nazi party had succeeded in mobilizing the armed forces for a conflict that would last 68 months. But just as the need to invest in advanced weapons research had kept the rocket research team going, thereby ensuring that if the Chancellor incited war the armed forces would be ready, so the final legacy of this total conflict would force a deep rift between two halves of the torn Germany and spur opposing factions into a long struggle for armed supremacy. With a signed agreement endorsing Anglo–French support for Poland only a week old, the British Prime Minister Neville Chamberlain sent Hitler an ultimatum that demanded an immediate withdrawal. Silence prevailed and on the 3 September, Britain and France declared war on Germany.

For several years the Commander-in-Chief of the Army, Field Marshal von Brauchitsch, had warned of the consequences arising from an aggressive foreign policy and even though Hitler had placed himself in control of the armed forces, the Army high command was in continual disagreement with the Nazi hierarchy. It was a disillusioned von Brauchitsch who went to war on that fateful September day. Nevertheless, review of existing weapons research projects was essential for balanced force posture in future months and the rocket activity at Kummersdorf-West and Peenemunde was an integral part of this work.

Accordingly, von Brauchitsch received General Becker and Walter Dornberger on 5 September at his military camp located at the town of Zossen, 25 km due south from Berlin. He heard again the reports of promising work which would lead to the long range missile capable of sending a 1 tonne high explosive warhead across a distance of 260 km, with the final descent above the speed of sound: the A-4. They discussed, too, the successful flight tests of early model A-5 rockets less than a year before and spoke of the new guidance system which would enable the A-5 to demonstrate the feasibility of a programmed trajectory, seeking distance rather than height.

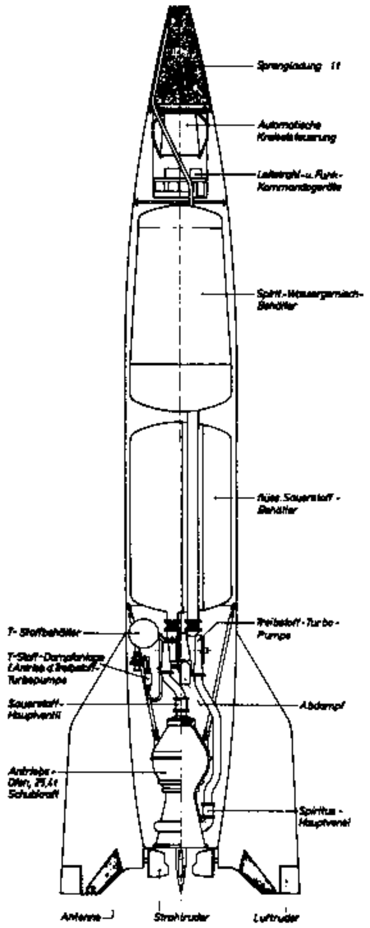
Von Brauchitsch was impressed with the news of work performed since his visit with Hitler to Kummersdorf-West the previous March and re-asserted his intention to thoroughly support research on rocketry. More money was needed to support Dr. Thiel with his pioneering work on the big 25-tonne thrust combustion chamber which would power the long range A-4 and press ahead with development. Dornberger was confident that the A-4 could be in production by 1943, perhaps earlier, but only an all-out commitment on the part of the Army would ensure success at the earliest possible date. At this meeting it was decided to give the research establishments the highest military priority, affording access to funds and equipment reserved for only the most important activities. While the Army still had its own Commander-in-Chief the logical progression of selected technical developments would mature to fruition.

But the Army was not as free to select and prune its own research work as it had been in earlier years and since the sacking of von Fritsch, the Nazi regime kept close rein on the many activities associated with military matters. Unimpressed by the technical sophistication of rocket power, Hitler failed to recognize the value of continued research, preferring instead the Wagnerian drama of high-speed ground armour and the all consuming destruction of an air-launched blitzkrieg. With territorial gains in the east, it was time to turn west and in April German forces invaded Norway before turning to the occupation of Denmark, whose King would compliment Hitler on the magnificence of his military campaigns! By May 1940 Panzer divisions had rolled through Holland, Belgium and France. A sword of unparalleled ferocity had slashed to the east and west of the German border sending French patriots and a pitifully small (and outrageously named) British Expeditionary Force reeling back against the turbulent waters of the English Channel.

Hitler was elated. Hadn't he been right all along? Hadn't the Wehrmacht been wrong in warning him of the tragic result of all-out war? It was early in the day to count the battles and predict war's end. Now, just when Kummersdorf-West was achieving tangible results from long hours of work on the big A-4 engine, and Peenemunde was well into flight trials with the experimental A-5, the research teams were to receive a major setback. Less than six months after Field Marshal von Brauchitsch had placed a high priority order on the Becker–Dornberger–von Braun work, Adolph Hitler made another incredible mistake and cancelled the directive. Germany he claimed would have no need of over-sophisticated dream toys.

CHAPTER FOUR.

Vergeltungswaffe Zwei – V-2



The world's first long range strategic weapon system propelled by a rocket motor, the A-4 ballistic missile, in its final design configuration

Despite the hesitant start of military operations in France and the Low Countries, Adolph Hitler was convinced that existing weapons would fashion a new order throughout Europe and fulfil his dreams of an expanding and totalitarian dictatorship. He would simply have no need for a complicated and lengthy development period demanded by exotic research efforts; the war would be over in a few months and technical ingenuity would be better directed to improving existing weapon systems. Hitler failed to see the slowly developing potential of rocketry and guided missile research and consistently favoured the brute-force strength of air and ground forces. At a time when expanded rocket development was essential for the future conduct of the war, he turned his back on the Peenemunde facility and concentrated instead on a protracted series of command struggles within the armed forces. Any rational overview of the new technology would have endorsed the enthusiastic predictions of the cadre of rocket engineers at Kummersdorf and Peenemunde. But without a fully developed ballistic missile on hand, the rocket engineers were unable to generate even a modest response from the Nazi hierarchy. They were totally incapable, it seemed, of visualizing anything beyond their own experience.

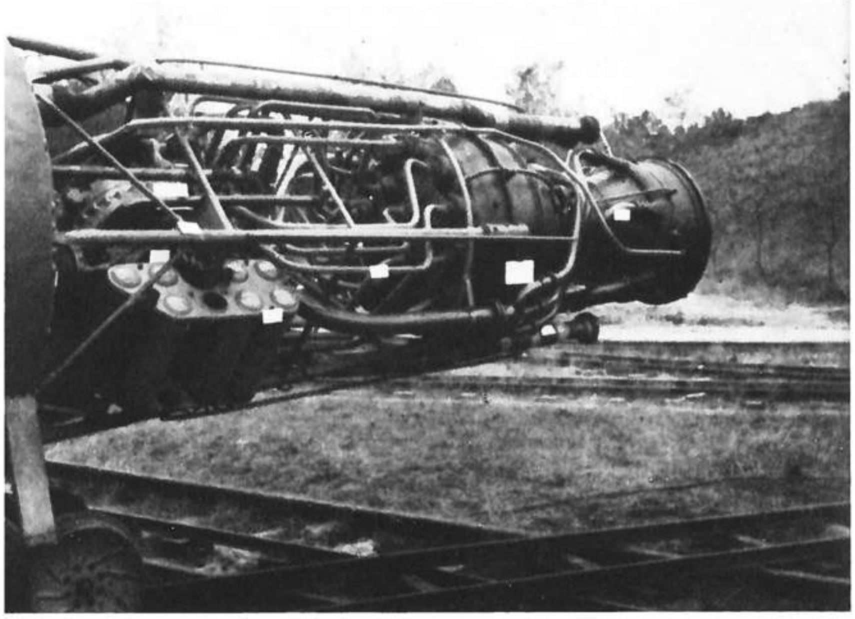
So, by the spring of 1940, the rocket-research team had progressed with A-5 flights, but could only talk theoretically of the big A-4 which was slowly maturing to a point where prototype models could be assembled and tested. Many problems lay unresolved, but careful examination of the records since 1933 revealed steady progress towards completion of the first true ballistic missile. None of this was acceptable to the political bullies in power who questioned the logic of diverting technical and material resources to an as yet unproved research project. But the Army was committed to the need for such a weapon and moved internal policy toward a clandestine support in tangible terms. When Hitler's directive of spring 1940 turned its back on rocket research, Field Marshal von Brauchitsch drew 4,000 technicians from the front line and sent them to Peenemunde as the Northern Experimental Command, a cover designation for continued research on the Baltic coast. But this was just the beginning of an interlocking series of move and counter-move, whereby the Army manipulated its own affairs to cover up the gross errors and misjudgements of the Nazi politicians.

Little love was lost between the military brains and the Nazi brawn. Rocket development had a staunch ally in von Brauchitsch, a man who was resolved to diplomatic contest against political machination. Yet for all its internal strength and prestige, the Army was under suspicion along with the industrialists and the reasoned stability of these two powerful groups contrasted with the ideological dreams of fascism to such an extent, that instead of absorbing the genius of German organization and administration, the Hitler gang continually sought ways to reduce the influence and stature of the realists.

The first real move to centralize military and industrial weapons development came in March 1940, with the appointment of Dr. Fritz Todt to the position of Munitions Minister. Dissatisfaction with weapons production figures (which had shown a marked decrease in the early months of 1940) prompted the Nazis to expand the role of the Ministry to one in which it had control of all three armed services' weapons departments. Instead of responding to service initiatives the armaments industry would now find a column of political bureaucrats governing contracts and research activities. Very few industrial representatives were involved in the administrative structure of the Ministry of Munitions and little technical know-how was present in this politically based organization. This was to have a profound effect on the activities of the rocket teams at Kummersdorf-West and Peenemunde and is an important link in the chain of incompetence that injected a high level of lethargy over most Army, Navy and Air Force research projects. For their part, the services had stressed the importance of grouping technicians and scientists into the existing weapons departments, but representations were largely ignored. There was a far more sinister motive behind the gradual involvement of political offices: basic Nazi philosophy distrusted the private industrialist and experience had shown that the military machine would need to be controlled by Party chiefs. Within a few years, domination would be total and before war's end even the echelons of Nazi power would fight for control of important industrial activities. Nevertheless, Todt was a Party man and promised major changes in the drive to improve industrial armament production.

This dichotomy between the lack of faith in private industrial interests on the one hand and the appointment of a leading industrialist to the position of Munitions Minister on the other, would endure for nearly two years until a Nazi diehard, Albert Speer, replaced Todt in this all powerful role. It is of interest to note that Todt was keen to display allegiance to Nazi principles and because the Party failed to recognize the value of basic rocket research, he too was unable to move outside the sphere of governmental lethargy towards the new technology. If there is one single reason why the Becker–Dornberger–von Braun work was held at a low level of priority during the early years of the war, it must surely be that productivity for a given financial sum was seemingly low compared with other military activities. But this is always the case with an embryonic technology and politicians are notoriously blind to potential applications which have yet to be shown worthy of practical development. On the other hand, military supplies in 1940 were not as satisfactory as propaganda would lead the German public to believe and the high cost of moving into a realm of even moderate success with rocketry needed real faith to justify.

Developed by Dr. Thiel, the large liquid propellant motor used by the A-4 developed more than 25 tonnes of thrust.



Yet, for all that, the cancellation of high priority work on rockets in early 1940 would endure for nearly three years and, in the final event, prevent the German High Command from mobilizing the A-4 in sufficiently large numbers to provide an effective counter to increasingly abundant British and American equipment. As we shall see, if full priority development had been given at the outset the Army may well have turned the tide of war in favour of the Axis powers.

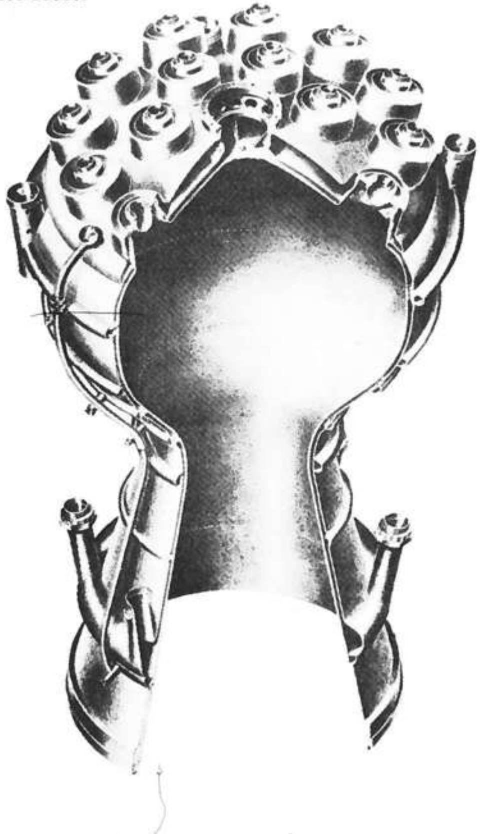
Shortly after Todt's appointment General Becker, head of the Army Weapons Department and a key figure in German rocket development since 1925, committed suicide as a release from his depressions brought about by the intolerant vacillations of the Hitler hierarchy. At sixty years of age Becker was tired of the continual in-fighting and its resulting frustrations. His greatest legacy had been to mobilize the leading lights of the VfR and to push von Braun into a key position at Kummersdorf-West; von Braun was to play a major role in rocket history for the next 30 years.

By now, with Germany embroiled in territorial conquests across Europe, the writing was on the wall and at the experimental station at Kummersdorf-West, Dr. Thiel worked long, hard hours to perfect the big 25 tonne thrust rocket motor which would be used with the A-4. At Peenemunde, the A-5 continued to provide valuable flight results leading to the technical development of a host of systems and components which would have to be incorporated in the definitive missile.

Throughout 1940 and 1941 the A-4 progressed, albeit as a low priority project, to the point where metal could be cut and the first missile assembled. For a time it looked as though the problems would be almost insurmountable, but most of the difficulties came with the rocket motor itself and a variety of designs were tested in the continual search for a reliable high-thrust engine which could provide consistent power. It was bad enough having to break through totally new technology barriers, but worse still was the need to design an engine which could be mass produced on an assembly line and readily assembled before fitting the unit to the rocket's aerodynamic shell. The basic shape of the A-4 was dictated by the need to achieve good stability all along the flight path, successfully move through the speed of sound and remain intact as it plunged down through the denser layers of the atmosphere to deliver its warhead to the target.

The struggle to develop the motor was amplified by the lack of existing experience in designing big rocket engines and Dr. Thiel progressed through a series of design configurations which resulted in the main combustion chamber moving through a variety of different shapes and sizes until the optimum was achieved. Initially, the combustion chamber was designed to be long and thin with propellants brought to the interior by way of concentric ducts. Very soon this was seen to be a bad approach and the final shape was more like that of a fat barrel with an injector plate at the top. The injector head comprised 18 roses with concentric orifices through which the fuel would be brought to mix with the oxidizer.

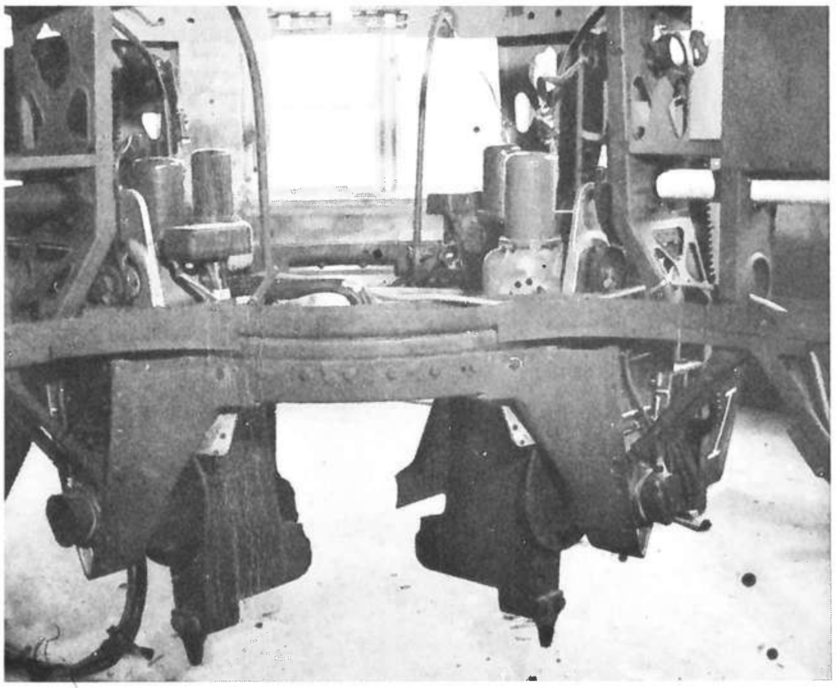
This cutaway view of the combustion chamber shows the location of the 18 injector roses.



The propellants were stored in two large propellant tanks occupying a major part of the missile's main cylindrical structure and placed in tandem above the combustion chamber. Oxygen, stored as a liquid to increase the density and reduce the required size of the tank, was contained immediately above the combustion chamber and brought to the chamber through a main valve assembly and 18 pipes connected to the 18 injector roses. The oxygen tank had a volume of 4.8 cubic metres and could contain some 5,533 kg of the liquid oxidizer. The fuel tank, containing a mixture of ethyl alcohol and water was situated directly above the oxygen tank. It had an internal volume of 5.18 cubic metres and was capable of accommodating up to 4,173 kg of fuel. Unlike the oxygen tank, the fuel container tapered at the forward end to permit the external skin of the missile to achieve the desired level of contouring demanded by the aerodynamic profile. Both tanks were fabricated from light alloy sheet and were capped at each end by flattened hemispherical plates. Fuel was brought from the tank through the centre of the oxygen vessel below, by way of a single pipe which prevented any external protuberance from disturbing the smooth, streamlined profile of the rocket. This then bifurcated into two pipes and then three at the bottom of the combustion chamber, so that the ethyl alcohol could be fed through the walls of the chamber for cooling purposes, before arriving at the top of the injector head, where it was passed to the inside of the chamber, via the 18 roses, for combustion.

The entire centre section of the A-4 was 6.2 m long and had a maximum diameter of 164.6 cm. The combustion chamber and the expansion nozzle (see Chapter Two) were manufactured as one single welded assembly and formed the aft section of the rocket. The propellants were brought from their respective tanks in to the single combustion chamber by two pumps driven by gases given off from a chemical reaction. Two chemicals were necessary: hydrogen peroxide stored in a 172 kg capacity tank and a 13.1 kg supply of sodium permanganate. When these two chemicals were brought together in a chamber the resulting steam was ducted to a turbine which spun at 4,000 r.p.m. and pumped the propellants into the combustion chamber at the rate of 125 litres per second. The exhaust gases from the turbopump were fed via a heat exchanger to a vent in the tail of the missile.

The rear end of the missile supported a thrust unit consisting of a cast alloy channel ring secured around the outside of the expansion skirt, the latter being the bell shaped structure



A-4 guidance was controlled in flight by four carbon rudders connected to servo-motors which in turn responded to signals from the guidance platform.

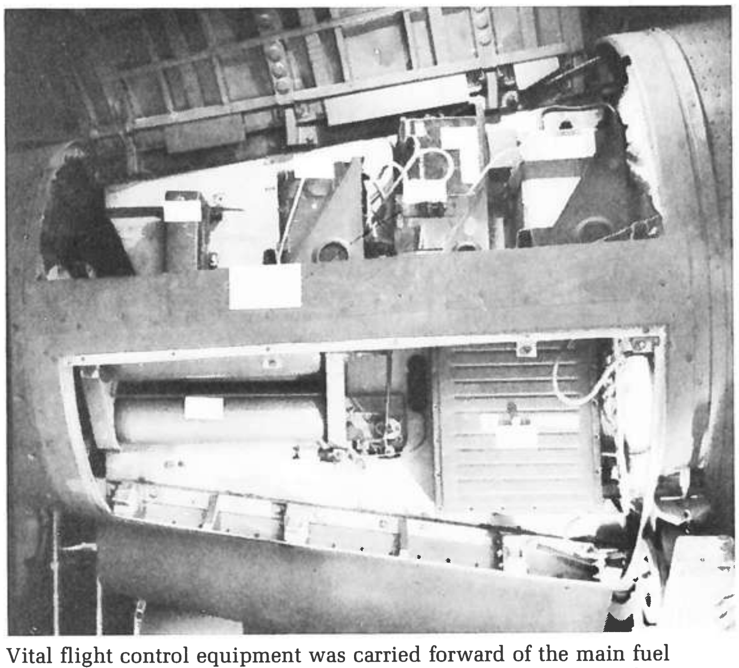
Each of the four rudders was attached to the base of a single fin and placed so that it would intrude into the exhaust flow.

through which the rocket's exhaust was released. The thrust unit was essentially a stiffener for supporting the four carbon rudders which were located so that they lay within the stream of hot gases from the combustion chamber. Control of the missile would be effected by setting the angle of the four rudders so that the exhaust would be deflected. Because of the extreme velocity of the gases, the missile would tend to turn away from the exhaust flow so enabling the rudders to steer the rocket much like the tiller on a boat. This was the guidance technique pioneered by the A-5, described in Chapter Three, and was used in conjunction with two gyroscopes carried in the forward section of the rocket.

The exterior of the A-4's tail section carried four large fins spanning 3.5 m. They were primarily designed to stabilize the rocket, but also carried four small vanes, one to each fin, located on the lower edge and which would operate in conjunction with the four exhaust rudders to control the flight path angle during the early stages of flight. Used somewhat like the flying controls of an aeroplane, they would only be effective in the comparatively dense layers of the atmosphere and flight control would come to rely more on the exhaust rudders as the A-4 climbed to higher altitude and atmospheric pressure was reduced. Two of the carbon rudders impinging into the exhaust plume controlled roll and yaw (sideways motion) and the other two checked pitch tendencies. The two corresponding fin vanes worked with the roll and yaw rudders, while the vanes in line with the pitch rudders, helped control roll. This complex system of servo-assisted control surfaces was a major step forward in rocket control systems and pioneered basic systems design which would influence missile development for several decades to come.

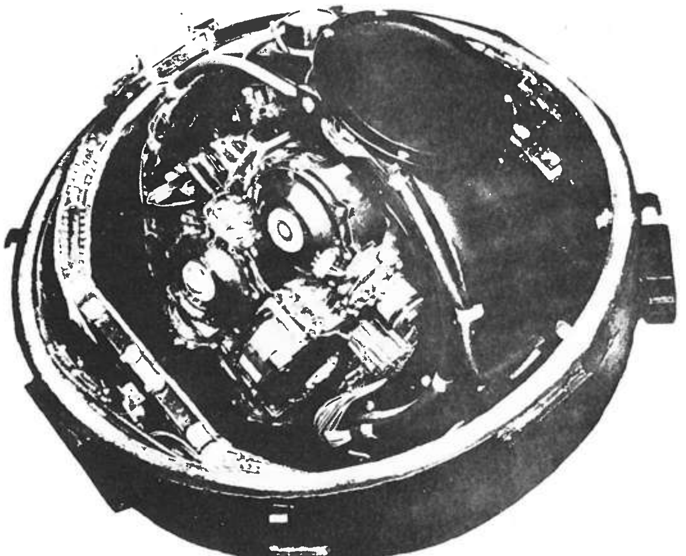
At the other end of the rocket, and directly above the long centre section containing the two large propellant tanks, engineers placed the forward compartment, a truncated cone about 1.4 m long divided into four equal sections by radial plywood sheets set 90° to each other along the length of the compartment. This was the brain of the rocket and each section contained vital flight control equipment, batteries, radio receivers, velocity measuring instruments and the two important gyroscopes. Two 16 volt batteries supplied electrical power for the missile and a single 50 volt nickel-iron battery provided power for signals from the gyroscopes to the servo mechanisms used for controlling the flight path via the four rudders and the four fin vanes. Emergency fuel cutoff equipment, ground power control sockets, alternators and three compressed air bottles were also housed in the forward compartment. This latter equipment was to be used to pressurize the fuel tank while the missile was still on the ground and other installations included a device for arming the fuses in the warhead two minutes after takeoff.

The radio equipment had an important function in that it was required to receive signals from the ground to command cutoff by shutting down the pumps delivering propellants to the combustion chamber. Another radio receiver would operate in conjunction with a beam from the ground, for keeping the missile on course, movement to left or right of the desired track being corrected by signals generated on board the rocket ordering the flight control system to use rudders and vanes to correct the dispersion. The two gyroscopes were complex devices, simplified in concept by considering one for roll and

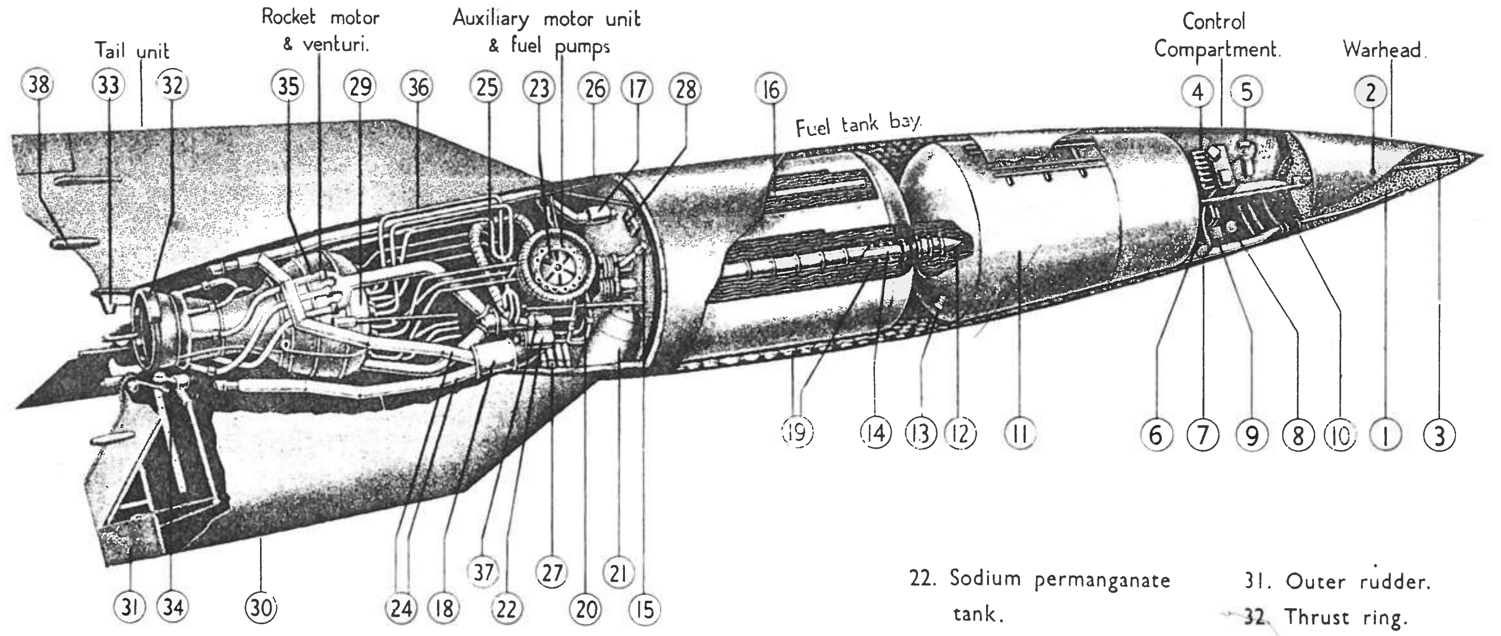


Vital flight control equipment was carried forward of the main fuel (alcohol) tank, the area divided into four sections by plywood sheets.

The A-4's guidance platform, and its successful operation in flight, was fundamental to satisfactory operation along a pre-determined trajectory.



GERMAN LONG-RANGE A-4 ROCKET.



1. Alcohol tank pressurising pipe.
2. Slinging point.
3. Central exploder tube.
4. Main distribution box & ground control plug
5. Alternator & regulator.
6. Time switch
7. Alcohol fuelling inlet.
8. Air pressure gauge & hand control cock.
9. Automatic pilot.
10. Control amplifier.
11. Alcohol tank.
12. Outlet valve.
13. Drainage valve.
14. Alcohol delivery pipe.
15. Oxygen fuelling inlet.
16. Stack pipe.
17. Oxygen tank vent valve.
18. Heat exchanger unit.
19. Glass wool.
20. Turbine.
21. Hydrogen peroxide tank.
22. Sodium permanganate tank.
23. Oxygen & alcohol pumps.
24. Turbine exhausts.
25. Oxygen main valve.
26. Braced steel frame.
27. Compressed air bottles.
28. Distribution box.
29. Combustion chamber.
30. Stabilising fin.
31. Outer rudder.
32. Thrust ring.
33. Carbon rudder.
34. Servo motor.
35. Alcohol feed pipes.
36. Oxygen feed pipes.
37. Auxiliary combustion chamber.
38. Aerial supports.

The mass of equipment necessary to achieve adequate performance was stored within the aerodynamic profile dictated by the requirement to minimize frontal area and provide a smooth and undisturbed passage through the air.

yaw and the other for pitch. These control functions, when translated into the flight path of the rocket, would be responsible for azimuth and elevation angle respectively: changes from the desired azimuth angle would result in the missile flying to left or right of track and changes in elevation angle would shorten or lengthen the trajectory; both vectors had to converge on the pre-planned lines to bring the rocket down on target.

The extreme nose of the A-4 comprised a 1.7 metre-long cone warhead with side casing made of mild steel plate and internally braced with struts. This would carry a 750 kg explosive charge for detonation at the target. A single pressure pipe was fitted to the extreme nose so that air could enter the duct and flow down through the forward compartment into the top of the fuel tank, keeping the ethyl alcohol mixture pressurized during the ascent for the first 40 seconds of flight. At that point the rocket would have reached an altitude where ram-air pressure was insufficient to keep the fuel tank pressurized, so the three compressed air bottles in the forward compartment would then take over and keep the fuel tank fed with a pressurizing gas.

In all, the A-4 stood a little over 14 m tall and weighed nearly 4 tonnes empty or nearly 13 tonnes with a full propellant load. As the design stood in early 1942, the missile appeared capable of sending its warhead across a distance of more than 300 km, rising to a height of about 85 km midway along its flight path before arching over to hit the target at a speed of 4,000 km/hr. But, although the basic design was sound, and a brilliant assemblage of new and as yet untried techniques and design solutions, teething troubles would accompany the missile through the first two years of flight trials. Hindsight reveals all too obviously the inherent errors in the early years of work, but the A-4 was a magnificent creation in its own right, forging new paths through an embryonic technology. Many of the design concepts relating to propellant delivery and basic engineering details borrowed much from the work of Robert Goddard and interesting comparisons can be made between the rockets built by the American pioneer and the products of the weapons research establishments at Kummersdorf-West and Peenemunde. Goddard had already – as early as 1934 – tested gyroscopically controlled exhaust vanes on small rockets and moved ahead with patents on turbopumps and control systems.

That the Germans were aware of this work is not in doubt and indeed at the end of World War II they would express surprise at the lack of US interest in the activities of the American physics professor. But the growing team of specialists and technicians at Peenemunde had moved a step beyond the Goddard accomplishments and developed a viable weapon system of then unparalleled size and potential. Goddard was interested primarily in the scientific use of the rocket, seeking ways to improve performance as a means to this end, and neither sought nor received very much military interest.

There is perhaps a geographical explanation here in that the continental United States was far removed from potential theatres of military conflict. If the rocket was to be used by US forces it would have had to be promoted on the grounds of long range back-up to existing heavy artillery and in the 1930's, the liquid propellant rocket was far from providing a capability of this magnitude. Any large rocket conceived in the United States would require a range of several thousand kilometres to provide a useful function in war; its complexity and sheer size would have prevented the concept of mobility from attracting much rational interest. Germany, on the other hand, was keen to examine the rocket's potential and early work, between 1931 and 1933, laid a sufficiently valid foundation for the Army to seize the new device with interest. The Kummersdorf activities, between 1933 and 1935, proved that sufficient potential existed for a more concentrated assault on basic engineering problems associated with rockets that could provide a useful military service. This led to the establishment of the Peenemunde site and a steady progression of tests leading toward the A-4 which, had it not been for political intervention, could have achieved test flight status by early 1941 following conception in 1936.

As soon as the Army weapons research department saw the rocket's potential, it was only a very short step to recognition of the strategic possibilities. Instead of the several thousands of kilometres that an American rocket would have to travel to reach a potentially hostile target, a range of only a few hundred kilometres would provide the German Army with a valuable supplement to its existing artillery. Centrally placed in a Europe covered by different political factions, Germany, unlike the United States, would have need to fight any future conflict along its existing borders. It was for this reason that the rocket was seen to move more efficiently toward maturation in Europe. Only the National Socialist Party failed to embrace the vision so ably demonstrated by Robert Goddard a full ten years before the first military ballistic missile was conceived in 1936.

For more than two years the Peenemunde team had been proceeding with little or no assurance that its efforts would be rewarded with full scale production. Since early 1940 work had gone on primarily under the aegis of Army confidence and by 1942 the first A-4 was assembled and ready for initial flight trials. During this period Dr. Todt had headed the Munitions Ministry and turned a bland attitude into indifference over the gradual progression from drawing board to construction. In February 1942 Todt was returning by air from a meeting with Hitler, when his aircraft crashed leaving the top position at the Ministry open. Grieving over the loss of his close associate, a man who had in fairness completely vindicated his appointment by dramatically improving weapons' production, Hitler appointed Albert Speer Minister of Munitions.

The following month Dornberger made concentrated efforts to get a higher priority for the Peenemunde work and formulated a plan whereby the A-4 would go into large scale production late in 1943. The memoranda visualized operations against England, beginning in December 1943, with missiles assembled in a large shed at Peenemunde and at facilities belonging to Hugo von Eckener's Zeppelin Works at Friedrichshafen. Dornberger had often talked with Speer about the possibilities of upgrading the level of work on rocket research while the latter was Inspector General of Works and felt that the time was right to move more forcibly toward reversing the negative attitude in the Nazi hierarchy. Working with Colonel Zanssen, chief of the Peenemunde Army Experimental Station, Dornberger and von Braun stressed the need for more attention to the A-4 and warned of the military consequences arising from administrative lethargy.

But it was to be a troubled summer for the A-4. Just at the time when everybody associated with the project needed a successful first flight, to add weight to their demands, the big rocket failed catastrophically on 13 June. A second attempt, on 16 August, was similarly unsuccessful. Dornberger was depressed by the rocket's reluctance to vindicate itself and briefed engineering teams on the need to get at least one A-4 off the launch pedestal and away on a successful flight. Only with good results at hand, could Peenemunde hope to influence the Ministry.

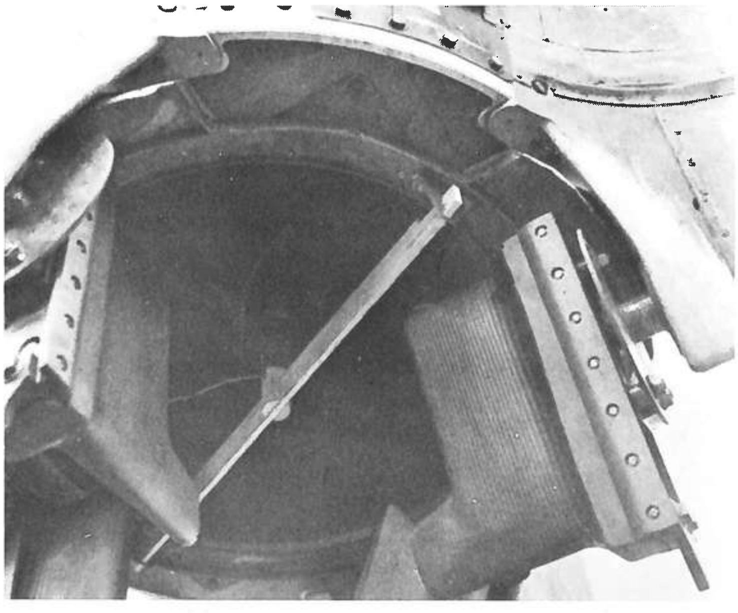
The third attempt came on 3 October. Most of the original Kummersdorf team was on hand for this important shot: von Braun, the A-4 technical chief, Dr. Steinhoff who headed the Instruments, Guidance and Measurements section and Dr. Thiel who had brought the big rocket motor from a vague idea to a working powerplant. Dornberger, who had prominent responsibility to his Army chiefs for organizing the project, stood on the roof of the Measurement House and watched the final excruciating seconds tick away, hearing the loudspeaker warn technicians of the imminent launch. On its platform, designated Test Stand VII, the A-4 stood with plumes of liquid oxygen boiling away from the pressure release vents, while ground connectors were adjusted and electrical lines disconnected. Directly beneath the rocket, now resting alone on the strengthened bearers at the base of the four fins, was the ignition assembly. This took the form of a long pole with an electrically activated four-chamber wheel at the extreme end. When the time came to ignite the rocket the fuel and oxygen valves would open and allow the liquids to fall by gravity from their respective tanks down into the injector head at the top of the combustion chamber. The four chambers in the igniter would then fire and spin like a catherine wheel to ignite the foaming propellants.

Inevitably, the assigned moment arrived and the base of the rocket was enveloped in a cloud of super-cold oxygen pouring through the injector, down through the combustion chamber and out through the expansion nozzle. At the critical moment, when the fuel started pouring through the lines, a lever was pulled in a remote, but safe, building and the igniter whirred around inside the combustion chamber. With propellants flowing down to the chamber by freefall, the motor ignited and a thundering roar split the air to the accompaniment of searing flame and smoke. Within a second the smoke had vanished and the pedestal deflected exhaust to right and left, sending tongues of flame scorching across the test stand. About 3 seconds later, with instruments giving a good account of conditions inside the rocket, a second lever was pulled to start the turbopump. Suddenly the cacophony of sound erupted into even greater ferocity as thrust went quickly from 10 tonnes to nearly 28 tonnes, driven to the higher level by the high speed of the propellant pumps and the greater quantity of alcohol and oxygen delivered to the combustion chamber. Spent gases blasted from beneath the rocket, at a speed of more than 2,000 metres per second, sending dust and loose particles flying from all directions. Now, just 5 seconds after ignition, the third lever was pulled and the rocket slowly lifted itself from the pedestal with a metallic roar that seemed to change pitch as sound waves bounced off the concrete beneath.

Every minute component whirred and ticked in accord with intent and the A-4 gathered speed, slowly at first and then with increasing rapidity as the rocket, lighter by 150 kg for each second of flight, roared away on its curving trajectory. Just 4 seconds after liftoff the big rocket began to tilt slowly in the desired direction and 20 seconds later it was through the speed of sound. On it sped becoming an ever smaller pencil of flame, its deep roar muted now by the echoing claps of thunder caused by reflected shock waves. Over and over it tilted until, one minute after launch, it was fully 50° from the vertical and at a height of nearly 30 km. Just 12 km away from the scorched launch pedestal a radio tracking station sent the important command to cut off the propellant flow and the A-4 became a silent projectile hurtling through the rarefied layers of the atmosphere, still climbing, on course for impact 201 km away.

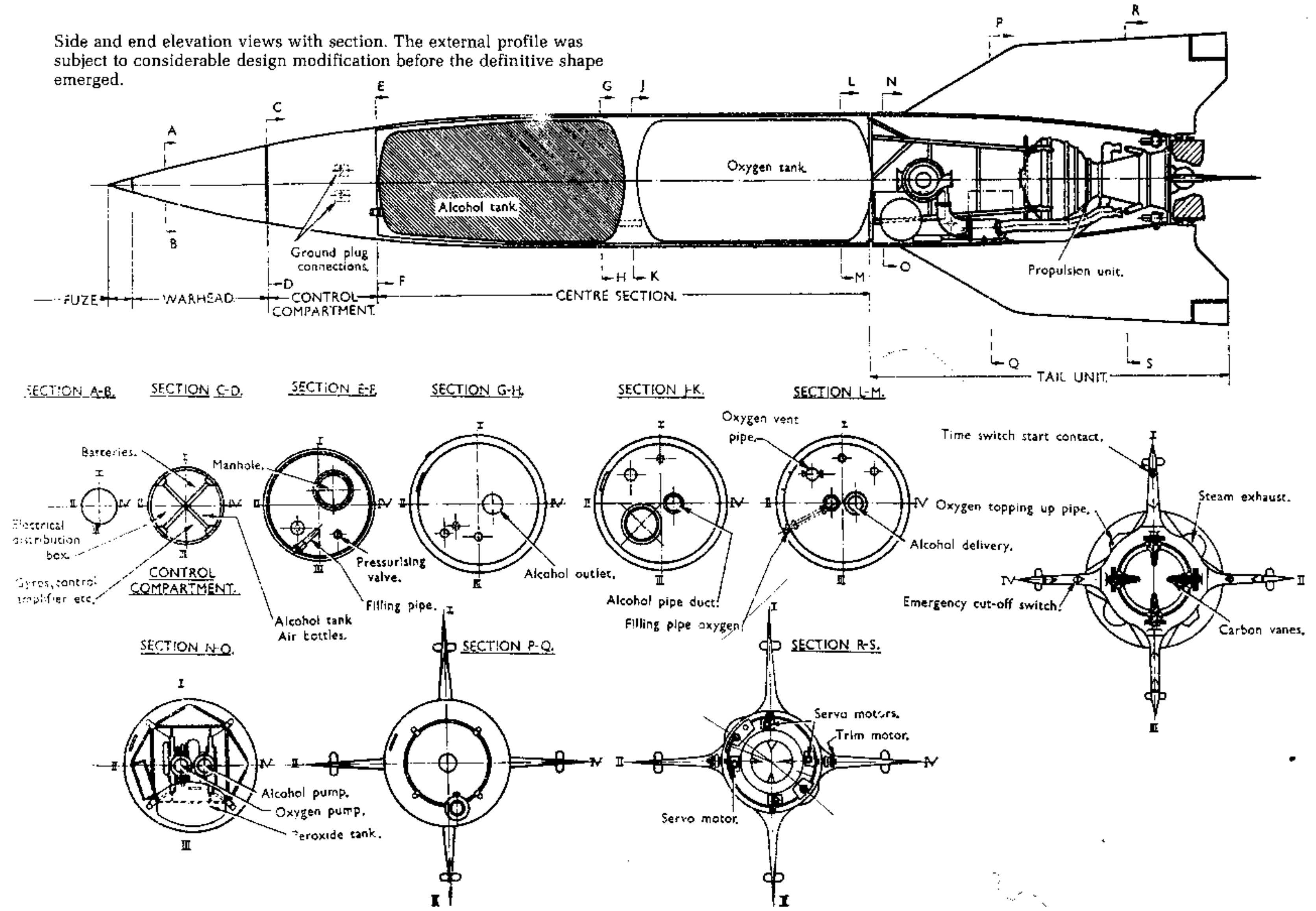
Minutes later it fell to ground with, as Walter Dornberger would later recount in his memoirs, the force of 50 express trains at speed. When technicians arrived at the impact site it was found that the rocket had veered from its course by only 4 km. It had worked. Years of work were suddenly rewarded with a success that for months had seemed all too elusive. Now, at last, there was good reason to express confident hope for plans which had spurred engineers and technicians on toward this day. Now, more than ever before, the Army Experimental Station at Peenemunde could point with pride where once they spoke with hushed uncertainty.

The objectives for this first successful flight, the third attempt in less than four months, were limited by the experimental nature of the test and the A-4 had cruised to an impact little more than half way along its potential range: 320 km. Uncertainty as to just how the missile would behave had reduced the performance requirement, but over the next few months minor improvements would be made and more



The igniter was supported by a wood stick and consisted of a four-chamber drum, designed to spin and fire the propellants.

Side and end elevation views with section. The external profile was subject to considerable design modification before the definitive shape emerged.



flights would demonstrate the full capability. By the end of 1942 there was a glimmer of hope for the Peenemunde team that it would, after all and in no uncertain measure because of the successful flight demonstration, be able to approach the High Command for more money, higher priority and approval of the ambitious production plans which would transform the A-4 from an experimental ballistic missile into a weapon for strategic war.

In December, Dornberger, von Braun and the nucleus of diehard engineers made plans to see Albert Speer and press for unrestricted development toward service introduction; the earlier Dornberger plan envisaged production from December 1943 and that target was now only one year away. A new launch complex on the Channel coast would have to be built and a special production committee would have to be set up to control suppliers and test launches away from Peenemunde. It was felt that the production committee, chaired by a leading figure from Peenemunde, would serve as liaison between the engineers on the one hand and the Ministry of Munitions on the other, thus giving the project direct ministerial, and hence political, support. This would smooth the echelons of command into a coherent body, with each element retaining the full authority of its expertise and yet speed through the many decisions which would have to be made between test flights and operational use.

During that Christmas Dornberger ordered Major Thom and Dr. Steinhoff to travel to Watten and survey the site which would have to be built for launching the A-4 against targets in England. There was still a lot of persuading to do, not least of which required authorization from Hitler, and pressure for a production committee chaired by a Peenemunde man (Stahlknecht was the preferred appointee) was strong now that good flight results were being obtained from the A-4. Dornberger and von Braun saw Speer on 8 January 1943, and discussed the future strategy for A-4 development. Speer carried the bad news that Hitler was still not convinced that the ballistic rocket held any value for Germany's war effort and was loathe to order priority service for a weapon system that took more than its fair share of vital supplies and equipment, not to mention technicians and engineers badly needed elsewhere. But the Ministry of Munitions had listened earlier to the call for a production committee and already appointed Herr Gerhard Degenkolb to head a new adminstrative group to oversee the introduction of the A-4 to a production line status.

Degenkolb cut little ice with the Peenemunde group on that January day when they met together for the first time in the palatial offices of the Ministry. Dornberger knew this man of old and recognized him as the special friend of one Hauptamsleiter Saur, Speer's deputy, but an ardent opponent of the rocket research activities and as such a dangerous man to have in so influential a position, when reported speech could stand trial as effectively as a judge and jury. For his part, Degenkolb was known to the entire industrial umbrella of Germany as the man who had reorganized the railways via the slashing axe of his 'Special Committee'. Locomotives were the stock in trade of this obnoxious character and he had little feel for fine tuned gyroscopes or sensitive measuring instruments. There would be many confrontations between Degenkolb and the Peenemunde men and these began on their very day of introduction when the former, no doubt wishing to impress the visiting engineers as much as the resident administrators, proposed the immediate establishment of a whole series of sub-committees to monitor and control all the many and varied activities felt necessary for getting the A-4 into production.

This was just what the Peenemunde men had hoped to avoid, and pre-empt by proposing earlier in 1942 the setting up of a technical production committee under the control of Stahlknecht. For several years the slow delivery of material and supplies had hampered the steady progress at Kummersdorf and Peenemunde and the engineers saw this more as a result of the cumbersome administrative weight, which bogged down the smooth transition from decision to implementation. Now, just as the Ministry were awake to the rocket's potential, another bureaucratic machine was being set up. With his single-minded approach, Degenkolb failed to appreciate the need for a flexible attitude toward the new technology and totally ignored the special demands of the project by using 'locomotive' engineering, which worked well enough for boilerplate and rivets, but had little application to this wholly new form of design and manufacture. Rocket production would not follow standard factory procedure if it was to be made as efficient as it could be and these lessons would not be learned until well after the war was over, and only then in another country. But the engineers could see it and fumed over the impending delays it would cause.

The following day, 9 January, Degenkolb arrived at Peenemunde to inspect the facility, observe progress on the A-4 and size up for himself the scale of the project and the requirements of the projected production schedule. This was a critical time for the A-4 and many rockets were being prepared with special equipment to measure and record a variety of phenomena which would lead toward a more effective and efficient missile in production and operational use. Degenkolb seemed unable to appreciate that the A-4 was still in a period of gestation and would emerge as a somewhat different vehicle, internally, than that which he was seeing at the present. Production requirements would demand special design considerations which could be ignored for the select few test rockets used to develop a reliable missile. This point was emphasized by Dr. von Braun, who would continue to stress the experimental nature of many of the tests then going on, pointing to more advanced designs which would have the full potential afforded by rocket technology.

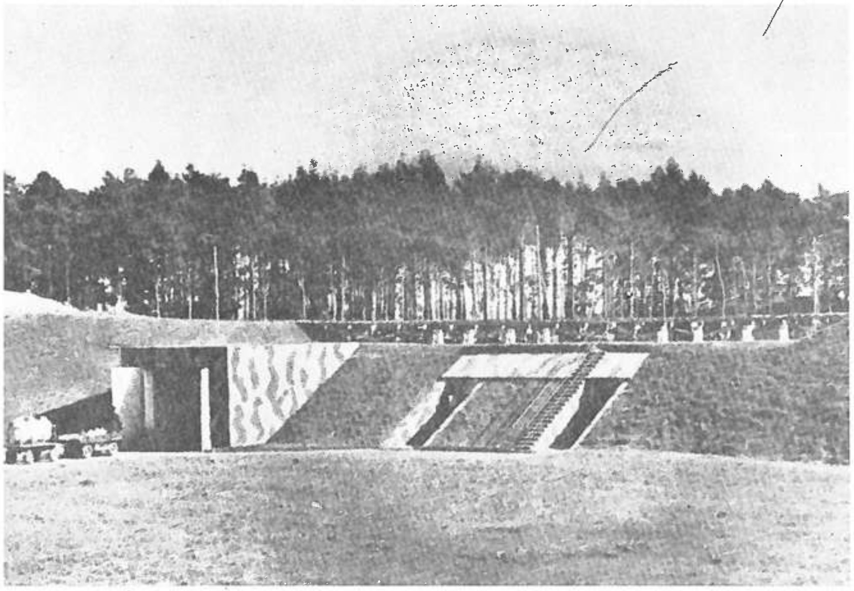
Although the A-4 was a proud masterpiece of engineering, it was seen as only the precursor to much more powerful rockets of the future, each one building on the lessons of its predecessor and all stemming from the basic A-4. Because of this it was stressed that the A-4 would still need considerable attention if it was to be presented as a reliable weapon capable of assembly on a production basis. In retrospect, and in the light of lessons that would be learned in future decades, this was an enormous undertaking which required the basic test-bed to be used in only moderately modified form as a full scale weapon. Peenemunde knew the pitfalls of rushing the A-4 into production; Degenkolb saw the rocket working and immediately convinced himself that it was ready for full scale production. This dichotomy of function would continue to confuse the plans for rapid service introduction.

While at Peenemunde, Dr. Thiel spoke to Degenkolb about the minor problems which still troubled the big rocket motor and Stahlknecht presented his own idea as to the precise level of unit output: for several months he had been working up the figures preparatory to heading the production committee, but now felt that the Ministry could benefit from his own experience, stating that the Peenemunde target was seen to be 300 A-4 rockets each month beginning in January 1944 rising to 600 per month by June of the same year. Back in Berlin, Degenkolb began to set up his unwieldy administration and became convinced that the Army, and primarily Dornberger, were not putting sufficient emphasis behind the project and its imminent introduction. This was indeed a strange reversal of the true situation where for nearly three years it had been Army perseverance that brought the rocket to fruition. Nevertheless, seeds of discontent were sown that would bring the Peenemunde team into question, but for the present Degenkolb was convinced that he alone could accelerate the seemingly reluctant technocrats into a production status. Accordingly, he sent Peenemunde his plan for a production start in October 1943 with 300 missiles per month rising to 900 a month by December!

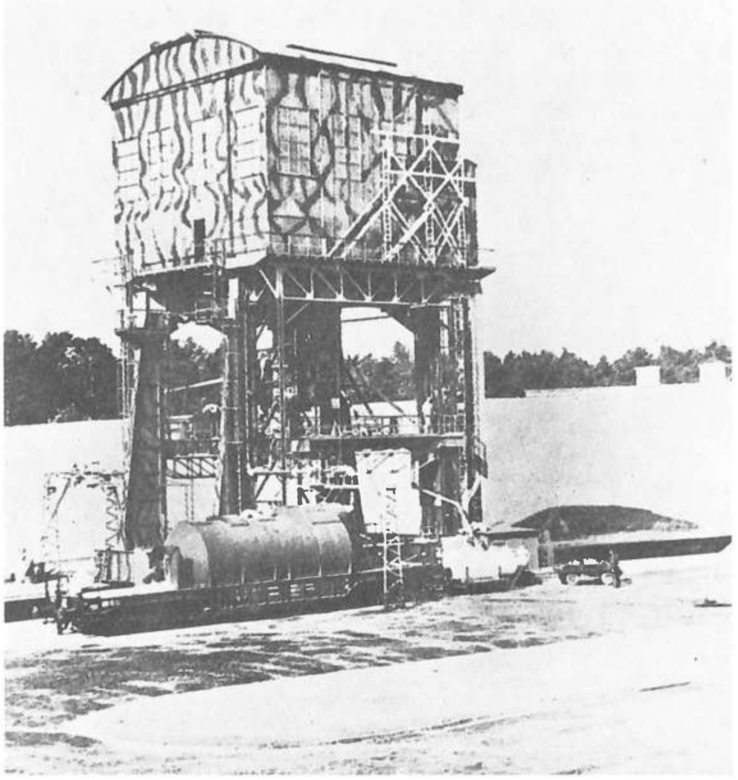
It was an impossible task, a product of Degenkolb's total inability to understand the problems that still remained before the rocket could be cleared for mass construction. On 4 February 1943, Dornberger was summoned to Berlin and a meeting with Professor Hettlage the department chief at the Ministry of Munitions in charge of finance and organization. Degenkolb was delegating the presentation of a unique proposal and Dornberger was introduced to Mackels, the representative of the Stettin defence sector and Kunge, an administrative deputy who would present the new line in control functions.

Hettlage carried Degenkolb's conclusion that Peenemunde was an inefficient station incapable of organizing the necessary command structure for full production; in effect an indictment of Army administration and a conclusion that would transfer control from military authorization to one headed by a private company to be set up for all future activities. Accusations flew thick and fast with Mackels revealing purported complaints from Peenemunde workers that they were not being employed as efficiently as they felt they could be. Dornberger was completely taken aback by this and protested vehemently against any such change, emphasizing once more that the rocket research so far accomplished had only served to endorse the belief that the A-4 was still in a very sensitive stage of development and would stand little interference from the proposed reorganization. The meeting broke up in heated controversy, with Dornberger inviting Hettlage to come to Peenemunde and see for himself how difficult it would be to continue work and at the same time transform the facility into a private organization.

Hettlage went to Peenemunde, reported back to Degenkolb and then Speer sent a director from the AEG, an electrical company, into the research station to report back on the technical aspects of A-4 work. Professor Petersen returned much impressed by the advanced electrical systems then under development and proffered the opinion that Peenemunde was as far advanced in electrical control systems for automated flight as any civilian factory anywhere in the country. For two days Petersen examined the level of progress, returned to Berlin and was shortly thereafter appointed chairman of a Long Range Bombardment



The evergreens at Peenemunde contrast sharply with the concrete 'bunkers' built in support of rocket research activities.



Service sheds and rail cars frame this launch preparation car used to move A-4 rockets to the test stand at Peenemunde.

Development Commission (LRBDC) set up within the Ministry of Munitions.

The following month, with Speer taking closer interest in the rocket work, Degenkolb decided on a compromise and fell back to a production plan that all but reinstated the original Stalknecht proposal. Production would start in December 1943 with 300 missiles disgorged from the assembly line at Peenemunde, a facility at the Rax Works at Wiener Neustadt and at the Zeppelin Works at Friedrichschafen.

Prospects were certainly looking good as spring came to the Baltic research station, although the ambitious drive to get the A-4 into production was confounded by consistently poor management by the Degenkolb office. The necessity for more staff fell on deaf ears and personnel were taken away on other activities that threatened to delay service introduction. Degenkolb had so far failed to obtain the necessary supplies that would be essential to the effort and threw the whole question of priority back into the limelight. Hitler would have to give the project higher authorization and Speer had gone as far as he could in pressing ahead with ancillary work preparatory to the beginning of launch operations against England. Dornberger had tried, in vain, to envelop the Degenkolb committee in his own organization and Speer decided to approach Hitler once again with a request for full support.

But it was only a paper request to the Fuhrer of the Third Reich and when the answer came back, several days later, it was to go henceforth into history as one of the more bizarre statements ever issued by a politician. Hitler had had a dream that the A-4 would never become the wonder weapon he secretly hoped it could become and that the missile would never reach England! He had, he said, had a vision revealing the truth about all the protracted effort going on at Peenemunde and could never give his approval to requests for higher priority, preferring instead to keep the project together just in case he had been misled by the nocturnal message. On such foundations were dreams of a thousand-year Reich founded.

Already, work was under way at the Watten site and the big concrete launch complex on the Channel coast would soon be ready. In the role of mediator, Speer smoothed tensions between Dornberger and Degenkolb and more than once had to re-define respective roles. Dornberger knew that he alone had access to a full and unexpurgated interpretation of the requirements and needs attending work at Peenemunde.

In the three years since the subjugation of western Europe, effectively complete by June 1940, the fortunes of war had declined and the early hope for a quick victory had become a long drawn out fight for territorial survival. In the spring of 1941, the German Army had been ordered into the Balkans in a political move to back up the flagging Italian campaign, postponing plans to move east and conquer Russia. Finally, on 22 June, some 136 divisions with nearly 4,000 tanks and 2,000 aircraft swept across the Russo–German frontier in 'Operation Barbarossa'.

For months Stalin had ignored intelligence reports that the German Army was massing for an attack, in the vain hope that a passive observation of the situation would prevent an induced assault. The fact that it came all the same had little effect on the total lack of preparedness and Soviet forces found themselves pressed back by the three Army groups under Rundstedt, Bock and Leeb along a massive front stretching from the Black Sea to the Baltic. By 10 July the river Dneiper had been crossed and a few days later German forces were within 300 km of Moscow. For the second time in the European war, Hitler faltered and like the abortive attempt to secure the British Isles in 1940, produced a situation which would eventually lead to excessive German losses and the end of World War II.

Instead of pressing on and capturing Moscow, which would undoubtedly have broken the will of the Russian people to fight on, Hitler split his forces and sent them to the north and south to secure Leningrad and Kiev respectively. This was a fateful move and although aware of the impending Russian winter, and mindful of the destructive lesson from the Napoleonic campaign in 1812, he gambled on a quick victory. The Moscow offensive got under way on 2 October 1941, but the Army was tired and exhausted from ten weeks of fighting, the forest areas around the capital were difficult to penetrate and German forces ran into stiff and deadly opposition from spirited locals.

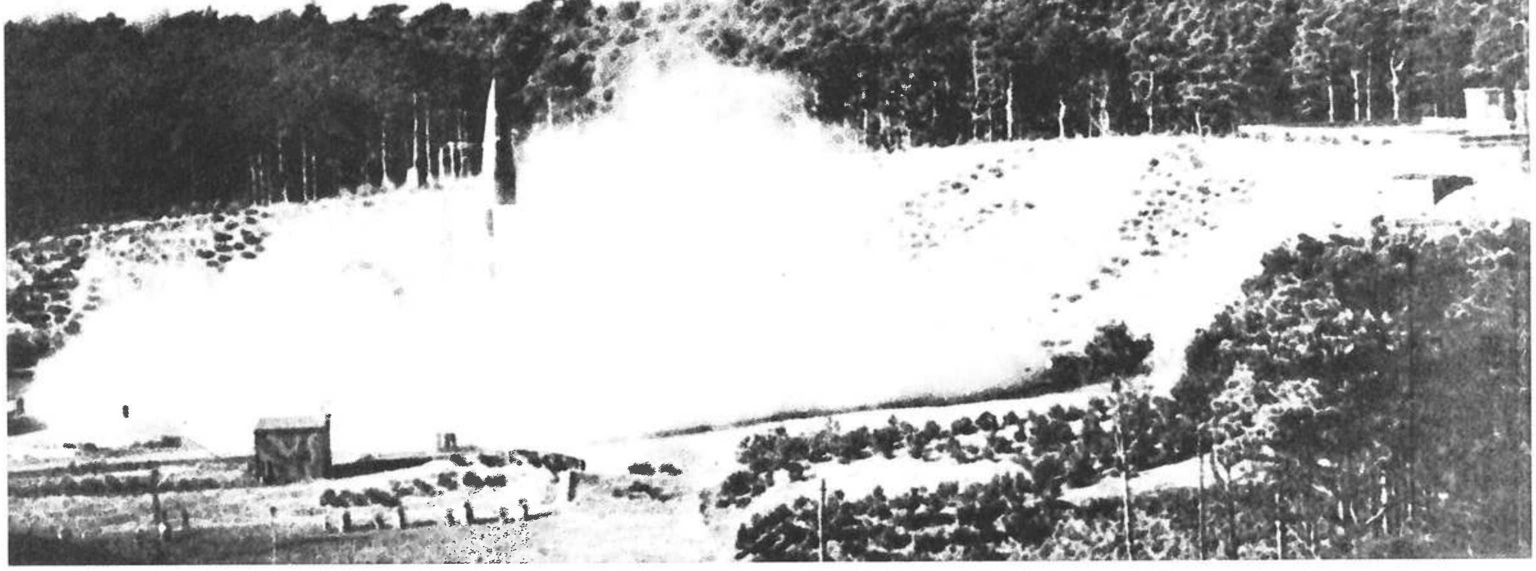
Just two months later a spearhead managed to reach the Moscow suburbs, but by then the winter had firmly set in and the die was cast. Further to the south, von Kleist's army had reached the mouth of the river Don only to be thrown back in a confusion of flagging command and military uncertainty. Hitler, taking an increasing part in orchestrating move and counter-move, forbade a withdrawal on any section of the front and on 6 December Field Marshal von Brauchitsch tendered his resignation. Just one day later Hitler took over as Army Commander in Chief and thus obtained absolute power over the fate and fortunes of the German people and its armed forces. On the same day Japanese naval air forces attacked the American base at Pearl Harbour and brought the United States into World War II.

On through 1942 the Russian campaign ebbed and flowed with the net result that the German forces were slowly, but effectively, pushed back from their original lines. By April, Soviet forces had recaptured more than 100 km of territory west of Moscow and by October General Paulus was engaged in a war of attrition at Stalingrad, the coup de grace coming a month later with the capture of 250,000 German troops. The year had seen a remarkable mobilization on the part of Russian industry and munitions with massive production facilities set up east of Moscow. The full force of Soviet resilience was now unleashed in a series of battles that would drive the Red Army on past Berlin and into Europe within two years. Resolved never to surrender, Hitler sent millions of troops to their death where another leader might have withdrawn, re-grouped and turned again to face the Urals.

On the North African coast, a year of only minor campaigns turned 1942 into Allied victory, as American and British troops established a valuable foothold from where they would drive north into Italy. By early 1943 the German forces were in retreat from the east, while at home the civilian population was coming under increasingly fierce air attack from American and British raids. Throughout that year a new style of war was to be waged with the Royal Air Force bombing targets by night and the US 8th Air Force by day. The tide had turned and few could now doubt that Germany was fighting a losing battle for survival.

It was only a matter of time before the German nation would be consumed by a fire of such conflagration that it would re-forge the future of the entire world. But in 1943 this was not apparent and many loyal Germans, in conflict with Nazi doctrine, felt that Hitler would lead them to an era of peace and prosperity. It had for them been worth the effort and if the Nazi Party had perpetrated civil and social obscenities, that was perhaps tolerable, compared to the situation between the Treaty of Versailles and the economic depression of the 1920's. However, the fact could not be avoided that air warfare was being brought to a new level of ferocity and increasing civilian involvement in what had been up to now merely a series of campaigns fought on foreign territory, and this shocked the people into a new state of awareness. Many now began to question the stability of the government and the validity of extremist foreign policies. It was within this climate of increasing discontent, that the Long Range Bombardment Development Commission met at Peenemunde to decide the fate of not one, but two potentially revolutionary weapon systems, each one of which could, if introduced early enough, play a significant role in the future course of the war.

The Army put up the A-4 and the Air Force, for several years now co-tenants of the experimental station, showed the flying bomb. Although this project is outside the scope of the history of rocketry it does have an interesting part to play in the continuing story of the struggles to get the A-4 out of an experimental stage and into full scale production. Called the Fieseler Fi 103, it adopted an idea put forward by Paul Schmidt, whereby a pulse-jet engine could be attached to an inherently stable airframe and launched from a nearly horizontal ramp. Propelled by a motor which took air in at the front and expelled combusted gases from an exhaust tube, the flying bomb would fly a low trajectory to its target, whereupon the engine would cut out and the device fall to ground



An early A-4 rocket ignites seconds before launch, sending smoke, dust and debris scattering.

in the vicinity of its objective. With a warhead in the nose the 'missile' would perform the function of an unmanned bomber and, if produced in sufficient numbers, partially replace the manned bomber fleet and reduce the high attrition rates experienced by flight crews.

It was an attractive idea and Walter Dornberger had given the project an enthusiastic hearing when the Air Force took the proposal over early in 1940. The engine worked by a series of louvres in the front, opening to admit air and then closing when pressure in the combustion chamber built up to a sufficiently high level for fuel to be injected. The resulting explosion, triggered by an igniter, sent a stream of hot gases from the burnt propellants out through the rear exhaust tube and gave the device a reactionary movement forward in much the same way that a rocket is propelled upward by the reaction from hot gases released in the opposing direction. Unlike the rocket, however, the pulse-jet engine required an intake of oxygen from the surrounding air and was, therefore, much closer to the principle of a pure jet engine, a concept already under development in Britain, Germany and the United States and which would herald the introduction of two jet fighters before the end of the European war. Moreover, the Fi 103 motor pulsed at the rate of more than 500 explosions a minute and because of this it could not provide the sustained acceleration of a rocket motor which burns continuously from the moment the propellant is ignited to the point where fuel and oxidizer is either depleted or intentionally cut off, as with the A-4.

Nevertheless, the flying bomb was seen as a remarkably cheap and effective means of placing a bomb on its target and with a range of nearly 300 km could compete with existing aircraft for many of the important objectives. Cost was certainly much higher than with a conventional bomber, but the flying bomb's reliability and sustained launch rate was thought by many to outweigh the disadvantages. These included the requirement for fixed launch sites, its vulnerability to air-attack at the comparatively slow cruising speed of 560 km per hour, susceptibility to interception at its operating height of 200–2,000 metres and the possibility of detection due to the high noise levels associated with its flight and the tracking capabilities of enemy radar.

During 1942 the Fi 103 was seen to be in direct competition with the A-4 and one of the problems associated with large scale production of the big rocket lay in the requirement for comparatively exotic propellants; the Fi 103 used only low grade fuel. At a time when Germany was beginning to feel the need for higher levels of chemical production, the allocation demanded by even a minimum force of rockets was seen as a major incursion of existing supplies. In addition, there was the old problem of component supply. It was one thing to order a limited number of specialized items of equipment and quite another to mobilize full industrial production of complex and intricate designs using scarce materials. Also, the A-4 would have to be launched from a fixed site which could easily fall prey to detection and subsequent bombing raids. But this was a problem common to the Fi 103 as well and the Air Force was working on a design which would give the flying bomb greater operational flexibility. The Army too was working on simplification of the A-4 launch requirements although, as we shall see, its true mobility would be restricted by lack of adequate recognition.

Competition between the two projects reached a climax in May 1943 when a host of dignitaries arrived at Peenemunde to see the two projects, talk to the military personnel involved and take a decision as to which weapon to support with full production. Among the visitors was Albert Speer, Field Marshal Milch, Admiral Doenitz, Colonel-General Fromm and a retinue of Army, Air Force and Ministry staff. The LRBDC had convened this meeting because of a direct order from Hitler to evaluate the projects and select a single design, thereby conserving existing war supplies.

For most of that day, 26 May, technicians and engineers showed off their respective wares and the Army launched two A-4 rockets on perfect flights over a range of 260 km. The two flying bombs launched by the Air Force both failed, but the decision had already been made, endorsed by the Bombardment Commission: both projects would have to move into full scale production. Not least among qualities favouring the A-4 was its subsequent development into a truly strategic weapon. Several ideas were aired which envisaged a rocket of intercontinental range and other, more advanced proposals, saw the day not far off when men could fly half way round the world in the nose of a ballistic rocket. Clearly, the A-4 would have to go ahead if only to preserve a technology which could lead to an 'ultimate' weapon and the Ministry of Munitions were aware, if not free to speak of, the impending development of an atom bomb. The two would form a decisive combination. For its part, the Fi 103 would be a valuable asset and increased Allied bombing raids over Germany re-kindled plans for a re-vitalized assault on England by air.

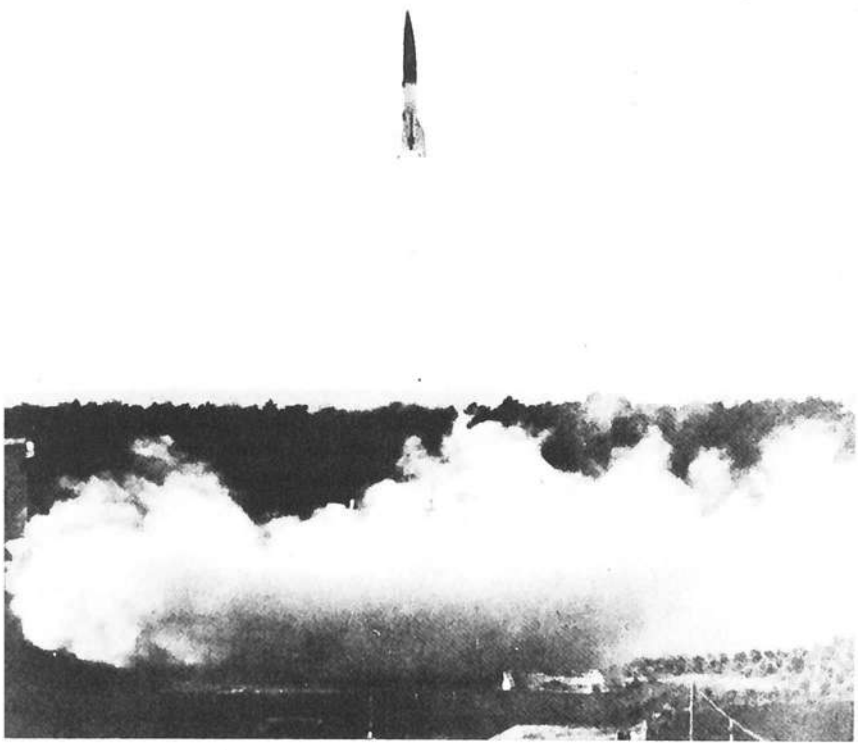
From the Peenemunde meeting on 26 May came clear evidence that the ranking officials of Nazi doctrine were looking with ever increasing interest at the activities of the rocket engineers. The fact that the entire project was in the hands of the Army was leading to a suspicious dialogue between civilian industrialists in high places at the Ministry of Munitions and their service counterparts in the armed forces. The summer of 1943 would see attempts to wrest control of the A-4 and other related work away from military oversight and place it firmly in the hands of Party officials.

The most prominent organization that now cast its gaze upon the work at Peenemunde was the respected SS (Schutzstaffel); respected through fear alone and not through any well earned admiration from the Army or the Air Force. The SS had been formed in 1928 from a group of teenage youths dedicated to the higher ideologies of extreme right wing socialism as practiced by the emerging Nazi Party. They saw themselves as the final line of communication between the mass of German people and the Fuhrer himself, vowing to follow him to the Chancellery or the grave. As it turned out they would achieve both objectives. By 1939 the SS had evolved to powerful levels of command and yet had little in common with geniune military interests, indeed the Army, Air Force and Navy were more in conflict with the SS than with their own competitive factions. By now the SS had been strengthened and arranged into four specific groups.

There were the Allegmeine SS whose function lay in embracing important political and administrative positions throughout industrial and civilian professions, the Reichssicherheitshauptampt and its seven departments embracing state, criminal and security police forces and the Waffen SS who comprised the elite of Germany's fighting youth in a military unit dedicated to Nazi policy. Finally, there was the Totenkopfverbande, or Death's Head unit, utilized for conducting sensitive activities and implementing the more vile policies of Nazification such as concentration camp duties and organization of the death chambers. Since 1929 Heinrich Himmler had been serving as the Reichsfuhrer SS and played an important part in preserving the dominant posture of Adolph Hitler even when the brownshirted SD, a political wing of the Nazi Party, revolted the following year. True to their leader and none other, the SS became all powerful and under Himmler were forged into a fearsome organization with almost absolute power subordinate to Hitler alone.

By 1936 the SS had seized control of the police forces and within two years the Army was placed under closer control by the sacking of von Fritsch (see Chapter Three) and the setting up of a more direct chain of command from Hitler in person. That move meant that the SS, under Himmler, could control military situations more effectively than hitherto, when the Army was in a stronger position to protest its use for purely political purposes. By 1943 the SS had built up a formidable fighting force of more than 20 active divisions and was thus seen as an important challenge to the Army's role.

It was against this background of increasing SS control that the Peenemunde team learned of the impending visit of Himmler to their research facilities. Arriving for the first time early in April 1943, just seven weeks before the Bombardment Commission would review the A-4 and the flying bomb, Himmler told Dornberger that Hitler was very interested in what was going on in the field of rocket development and that the SS could provide valuable services if the Army Experimental Station was willing to cooperate. Colonel-General Fromm was present at this discusson and proposed that the Peenemunde facility be protected by a prohibited zone under the command of SS General Mazuw, the Police Commissioner for Stettin. Dornberger was somewhat confused by the sudden interest of the SS and several days later learned that the SS were taking steps to discredit him so that Himmler would have the administrative excuse for relieving him of command and moving in his own men.



A successful development model of the A-4 ascends under the thrust of its 25 tonne thrust motor from Peenemunde.

Discussing the matter at length with Fromm, Dornberger was cautioned to be careful in his dealings with the SS and encouraged to bolster his own position by preparing a document detailing the progress that had been achieved under his direction. He was aware of SS interest in rocket propulsion and invited General Gartner, head of the SS Weapons Department Development Branch, to visit Peenemunde along with Captain Engel. Engel had originally worked at Kummersdorf-West and now headed an SS research complex outside Danzig. At Fromm's direct instigation Dornberger prepared his treatise entitled *The Achievement of the Army Weapons Department, 1930—1943* and had this published to provide solid evidence of the great strides taken at Kummersdorf and Peenemunde.

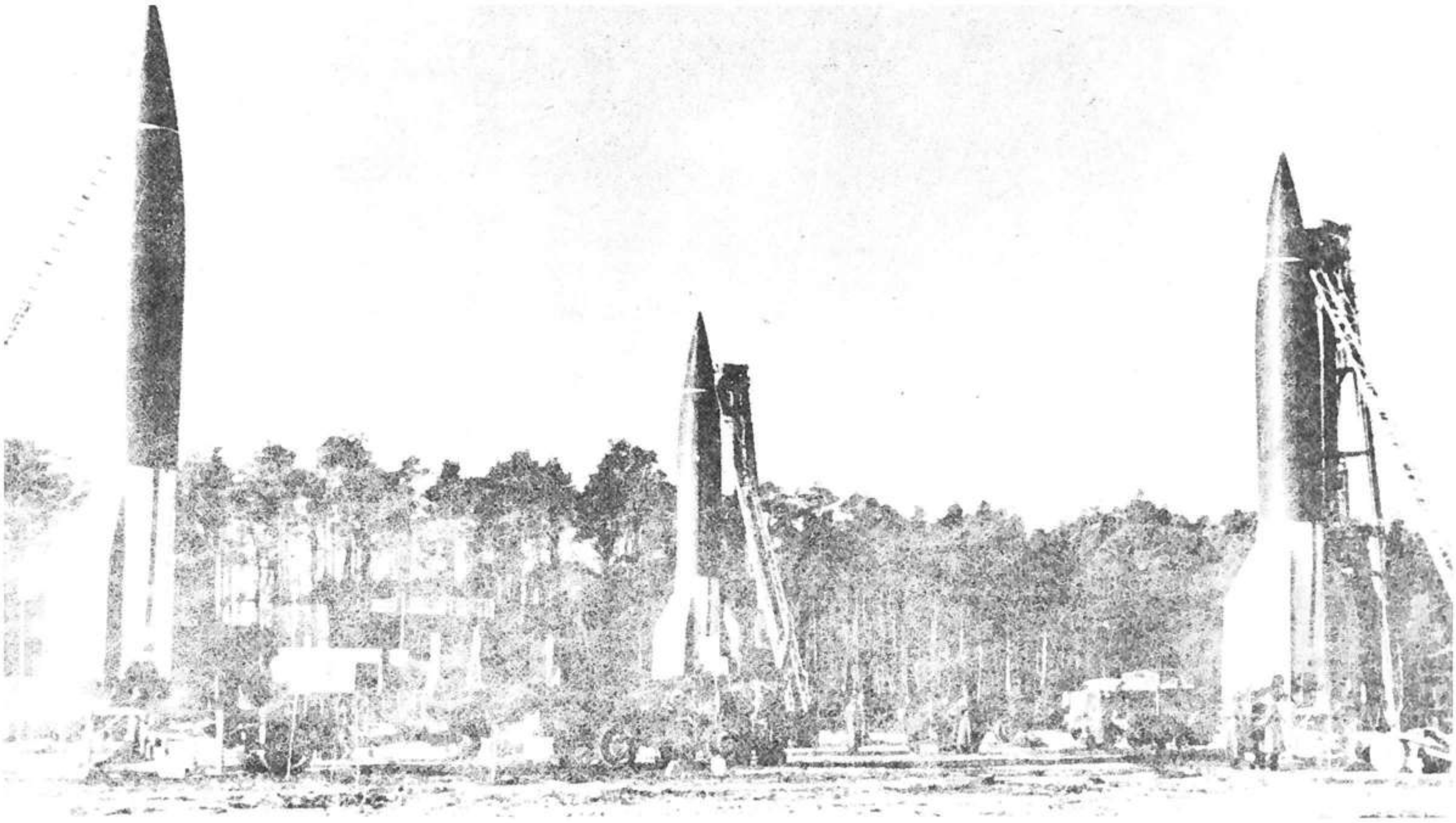
Dornberger's replacement would have caused major turmoil both at Peenemunde and at the Ministry and the SS turned their attention to Colonel Zanssen, head of the Baltic research station. On 26 April the Army Weapons Department telephoned instructions to Dornberger ordering him to relieve Zanssen of his command on the direct instructions of the Personnel Office in Berlin. On hearing this, Zanssen was as perplexed as Dornberger, who immediately contacted Fromm and told him of the situation. Moves were now being made by the SS to seize control of Peenemunde and there could be little doubt that without a confrontation, the rocket work would fall directly under Himmler's command. Fromm ordered Dornberger to take direct charge of an investigation and so spike further attempts to remove power from the Army. But the only information that he could obtain showed that a Colonel Schniewind at the Personnel Office had been ordered to pass along the instruction from Major-General Linnartz. From another source came clarification that endorsed the worst fears.

Officials at the Ministry of Munitions had received word that the Army would be disengaged from Peenemunde by first ordering Dornberger to get rid of Zanssen and then removing Dornberger himself. A few days later an official letter reached Peenemunde from Himmler, containing a text of the note delivered from the Reichsfuhrer SS to the Personnel Office accusing Zanssen of traitorous letters purported to have been written by the Peenemunde commandant. With insufficient power to reverse the decision, Dornberger sent Zanssen back to Berlin as requested and took over temporary control of Peenemunde himself, while preparing a report completely exonerating the Colonel. Shortly thereafter Dornberger went to Berlin and saw SS General Berger.

Gottlob Berger, a ruthless lieutenant of Himmler, was in charge of the Main Office. This department was dealing with the Zanssen affair and Dornberger challenged the SS to produce the incriminating evidence. Berger refused. Back with Fromm, Dornberger received full approval for his actions and returned to Peenemunde with the assurance that Himmler would receive curt notification that the accusations were false and that Colonel Zanssen would be returned to Peenemunde shortly.

For a while, at least, it seemed as though the SS had been rebuffed in their attempt to seize power and it did at least provide circumstantial proof that the A-4 and associated rocket work was now seen to be an enviable prize to the Nazi leaders. Success, it seemed, had its price and this was not in fact to be the end of SS intervention. On 29 June, less than three months after the first visit, Himmler came again to Peenemunde, this time accompanied by Mazuw and a Lieutenant Colonel Muller, for a two day visit.

Dornberger recalls in his memoirs that many evening hours were spent discussing the finer points of Nazi politics with leading personnel from the research station in efforts to gain insight on puzzling aspects of ideologies which seemed very remote to the growing band of technicians and engineers. There is much evidence to support the theory that at no time did Dornberger, von Braun, Thiel, Steinhoff, or any of the original staff at Peenemunde find even moderate association with the beliefs and principles expressed by Nazi or SS doctrine. For them, the demands of a powerful war machine provided the setting for continued rocket research and there was little concern for military progress or foreign



Launch preparation and service technicians tend the A-4s as they stand in readiness for ascent.

policies. On the second day of Himmler's visit, the SS General went across to the tiny island of Greifswald Oie and, later in the afternoon, watched the successful launch of another A-4 rocket. Dornberger recalls that Himmler would not discuss the recent accusations against Colonel Zanssen and that he, Dornberger, should be satisfied that Fromm had succeeded in reversing the decision. Unschooled in the vagaries of SS activity, Dornberger had come close to stirring a hornets nest and with a modicum of naivety placed himself perilously near the lion's den.

That Hitler was interested in the work at Peenemunde is borne out by the increased activity following the visit of the Bombardment Commission on 26 May. Just two days later Dornberger received his promotion to Major-General and within a week preparations were under way for leading personalities to fly to Rastenberg in East Prussia and report direct to Hitler on progress. Ever ready to seize an opportunity to increase support for their work, von Braun put together film of the more successful A-4 flights and arranged the sequence to show a running vindication of the years of effort and accomplishment. But it was a fine line between gaining the support of Hitler and expressing an impossibly out-landish capability. This was only typical of industrial presentations; Adolph Hitler was either indifferent or abundantly enthusiastic and many times throughout the war he would make impossible demands from limited capabilities. More than most, von Braun knew the limitations of the A-4 and would continually stress the need for more work and steady progress with a meaningful improvement as designs evolved from tests.

It was with these thoughts in mind that Dornberger, von Braun and Steinhoff packed up models, charts and film and flew in a Heinkel He III to the Wolf's Lair, the Hitler HQ, on 7 July 1943. It had been more than four years since Hitler had spoken personally to any of the rocket engineers and at the last visit, to Kummersdorf-West (see Chapter Three), the Fuhrer had been unmoved by what he had seen. But at that time only the A-5, a developmental precursor, was available and this time they would show him ample proof of their earlier predictions. During the meeting Hitler looked over models of the A-4 and its proposed launch complex at Watten with interest and was visibly moved by film of the rocket flights accompanied with the able commentary of von Braun, rapidly becoming a master at the art of selling rockets to diffident politicians!

Yet, despite the efforts of Dornberger and von Braun to present a realistic appraisal of their work, Hitler ran away with the concept of rocket bombardment and urged the group to develop a 10 tonne warhead for the A-4. That this was impossible seemed beyond the scope of Hitler's mind for he had little knowledge of the technicalities involved, seeing instead only the blistering effect of a total war waged with missiles. More than this, he demanded a production rate of 2,000 A-4's a month, an impossible task for the foreseeable future. Nevertheless, Hitler made a momentous apology to Dornberger for having doubted his claims and authorized full scale development at the highest levels of priority.

Doubts crept in as to the ability of the Peenemunde team to meet the excessive demands of the Nazis. Propaganda Minister Goebbels had already dubbed the flying bomb and the A-4 Vergeltungswaffe Eine and Zwei (Revenge Weapon 1 and 2) respectively and henceforth they would be known as the V-1 and the V-2. In the belief that they had developed the wonder weapons that would turn the tide of a stagnating war in the favour of German forces once again, the politicians failed to appreciate the balance between research and application. Failing to appreciate the limitations, Hitler was concerned to build more fixed concrete shelters for the A-4 on the Channel coast, but Dornberger pointed out that his team had developed a concept whereby the A-4 could be launched from a mobile stand, thereby evading the possibility of a destructive bombing raid.

The excessive production demands had come from Karl Saur, Speer's deputy, earlier in the month when he convened a meeting at the Ministry of Munitions and announced that a new production facility at Nordhausen would deliver 900 missiles a month. On top of the 900 delivered from the facilities at Peenemunde, Wiener Neustadt and Friedrichshafen this gave a figure of 1,800, conveniently rounded up to 2,000 on paper! Saur believed, or at least gave verbal expression to the idea, that this rate would begin in December against fierce opposition from industrial contractors who pointed out that chemicals and propellants could be delivered for less than half that number. In the end, industry chiefs had nodded approval for the production rate in an attempt to curry favour from the Ministry, privately holding out little hope of matching the excessive demand.

It was becoming a bizarre situation. From a position of obscurity the rocket research team had been propelled full tilt into outlandish demands for impossible tasks. Late in the day the Nazis realized the full potential of this revolutionary new weapon. Back at Peenemunde the team heard with dismay that Degenkolb had given the production figures his blessing and Dornberger was hard pressed to restrain his engineers and technicians who only wished to proceed along well planned lines and move towards achievable objectives. Already, in the weeks following the July meeting with Hitler, more than 1,000 personnel arrived at Peenemunde and work was well advanced on the Pre-Production building that would soon begin to disgorge fully assembled V-2 rockets. But events were marshalling forces of opposition that would add a new dimension to production efforts.

For nearly a year now British intelligence sources had frequently reported curious activity along the northern coast of Germany and word from Norway all but confirmed the establishment of a new weapons testing station somewhere south of the Baltic. Since October 1942, when the first A-4 rocket to successfully fly a ballistic trajectory rose high into the atmosphere, the Peenemunde teams had been expecting detection. It was inevitable and the revolutionary concept of the device gave it an unmistakably obvious profile. For a while the British were confused, but as more and more evidence came in from increased test activity the War Cabinet resolved to pin down the location of prime development, and toward this end, Duncan Sandys set up his own unique investigative analysis. By pooling all the reports he drew the right conclusions and before long the Royal Air Force was ranging up and down the Baltic coast searching for the possible launch sites. Photographic reconnaissance aircraft brought back endless views of suspicious buildings or suspect patterns on the ground until one day, in the summer of 1943, the rocket establishment at Peenemunde was finally put on the British maps of Germany.

It was not at first apparent what was going on at Peenemunde and the aerial photographs showed tantalizing smears and smudges trailing back along the ground from strange little 'T' shaped objects, or pencil like structures casting long shadows above concrete ramps and clustered buildings. Nevertheless, the site was undoubtedly related to the object of existing intelligence reports and the network of blockhouses and roads certainly confirmed the existence of a major research effort. For many months Dornberger had been wary of continued missile test activity at Peenemunde, leading to his request for increased anti-aircraft weapons at the Hitler conference on 7 and 8 July.

In England, no time was lost and the Royal Air Force set out after dusk on the evening of 17 August to bomb Peenemunde. From Bomber Command airfields in Lincolnshire, more than 300 aircraft assembled in the air and headed out over the North Sea leaving behind the sleepy coastal towns clustered between the Wash and the Humber. Their flight path took them across the northern reaches of Denmark and down past Rugen, north-west of Usedom and the Peenemunde facility. Well into the night hours, and with most of the more than 4,000 engineers and technicians already asleep, the heavy bombers unleashed their load and pounded the works with more than 1,000 tonnes of high explosive. By morning it was possible to count the cost.

The Pre-Production Works, a building more than 30 metres tall and several hundred metres long designed to provide an assembly line for the A-4, was hit with nine 450 kg bombs. The Development Works was all but totally destroyed and construction workers' quarters at Trassenheide were badly hit; more than 170 were killed in this area alone, among this number many foreign labourers still putting final touches to the assembly plant. In all, 735 people lost their lives during the night's raid including Dr. Thiel, who for nearly seven years nursed the A-4's big rocket engine through design and into operation. Of the total bomber force that set out, 47 were brought down by anti-aircraft fire and fighter interception.

During the following day word came in that Friedrichshafen and Wiener Neustadt assembly plants had also been bombed. The raid was a bitter blow to plans for expediting rapid production of the A-4 and was particularly unwelcome at a time when the Army Experimental Station was only just beginning to get the higher levels of priority they had sought for more than three years. Pressed into action by the visible evidence of detection, it was necessary to make a decision as to the future of Peenemunde. The research establishment would soon be back in operation as an experimental station, but continued launch activity would only serve to draw increasingly hostile response from the Allies.

It was a critical time for the A-4. Production plans were nearing completion and the Army was putting final touches to plans for its introduction. A conversion unit would have to be set up where troops could learn how to fire the A-4 and this

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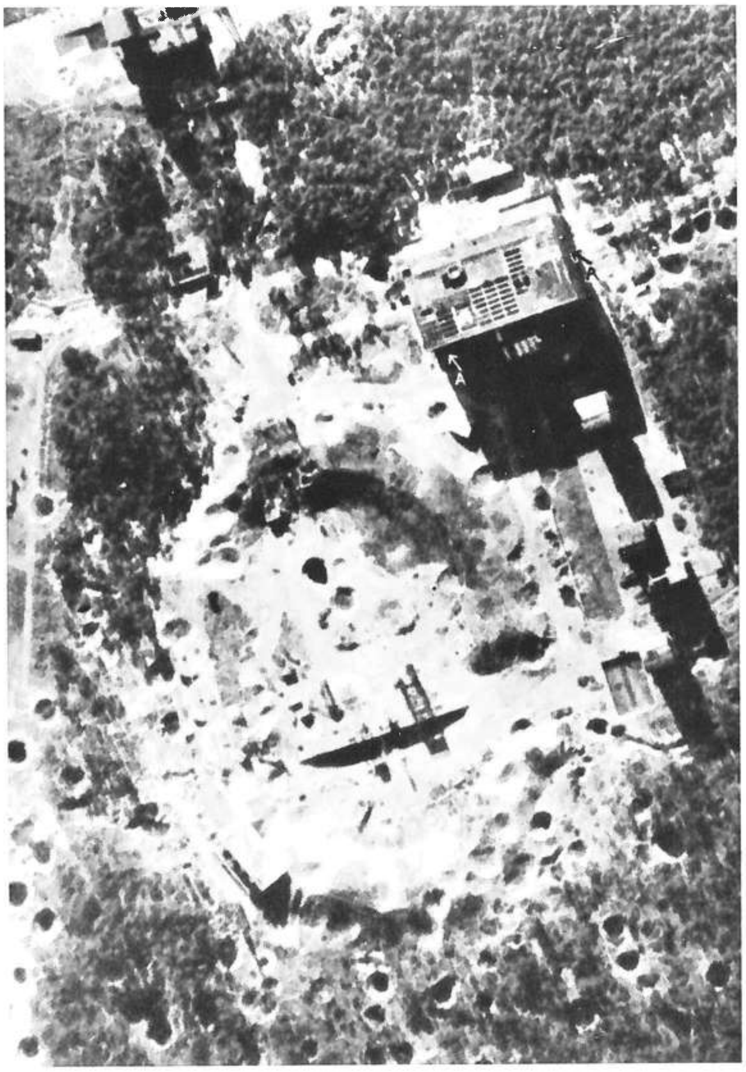


required a high launch rate. But teething troubles were still plaguing the big rocket and the nucleus of Peenemunde engineers associated with further development of the missile would have to continue their own test schedule, demanding sustained firing, over the next few months.

By September it had been decided to move the active flight tests over to the east away from Peenemunde and continue to use the existing research facility for design modifications, wind tunnel activity and component tests. This indoor activity would not draw the bombers, creating the impression that the British had succeeded in destroying the works, while active flight testing would get under way far from the prying eyes of photographic reconnaissance aircraft. The new firing site selected for this work was in dense wooded land more than 600 km away in Poland.

The precise area was due south of the junction of the rivers Wisla and San, almost due north of a direct line between Krakow and Przemsyl and not far from the town of Tarnobrzeg. Here, at the place known locally as Blizna, the firing teams set up a secluded complex of wooden buildings and makeshift test stands with hurriedly fabricated living quarters, sheds and storehouses. It was a far cry from the comfort of Peenemunde and the buildings were secured by a double line of barbed wire fencing running right round the site with only a single gateway leading off down a newly constructed roadway joined to an existing track. By the end of October 1943, Experimental Battery 444 had been set up at Blizna under the command of Major Weber.

Here, the first rocket troops would learn all they needed to know about the A-4, develop an operating plan and experiment with live firings before taking the rocket into action. A training school had already been set up under Colonel Stegmeier at Koslin on the Baltic coast, but now the service introduction of the A-4 would centre on the teaching school in Poland. Active service commanders would prepare for introducing the rocket and the first flight demonstration came on 5 November in freezing weather. The struggle to get the A-4 approved as a mobile weapon had been blocked by Hitler's preoccupation with the idea of hardened concrete launch pads, but this first flight from Blizna was made from a launch table set up on the frozen ground. Unfortunately, lack of experience and the necessity to quicken the pace of test launches, caused the table to tilt slightly as the hot gases from the A-4's engine thawed the earth below, resulting in the rocket rising at an acute angle to crash in the nearby woods. On hand was General Heinemann, charged with mobilizing field employment of the A-4, who on seeing the catastrophe became firmly convinced of the need to launch from a concrete platform, thus further compromising the conviction that the A-4 would lend itself to rapid launch from an unprepared site.

By the time the Allied raid on Peenemunde forced a change in the test schedule, work was well advanced on the hard stand at Watten from where it was hoped the A-4 would be launched against England. Only 10 days later the Royal Air Force bombed this area, while the concrete was still drying out, with the result that shock waves distorted the structure and rendered it totally unusable for the purpose it was designed to serve. Hitler had demanded a roof 7 metres thick to be built for protection of the Watten rockets. Dr. Xaver Dorsch, a leading civil engineer in charge of the Todt Organization responsible for this construction work, proposed a scheme for lifting the existing concrete hydraulically and then thickening it to the prescribed 7 metres. A second A-4 launch site at Wizernes would be prepared by roofing a small quarry with a bell-like structure and then burrowing in to the existing hole to provide feeder lines for equipment and supplies.

All this was contrary to the launch mode preferred by Dornberger and his men who still retained the notion that the A-4 would be used more efficiently from mobile sites such as forest clearings and the like. As it turned out the invasion of Europe and delays in getting the A-4 operational would render fixed sites totally unsuitable, as by then the German forces would be engaged in a running war. Nevertheless, for the time being Dorsch impressed Hitler with his impressive building schemes (always a way to delight the Fuhrer) and work continued for the next few months at least.

As 1943 drew to a close it became increasingly apparent that design plans drawn up at the Peenemunde facility for more advanced successors to the A-4 would have to wait until the end of the war. In July the largest Allied invasion of the war put 8 divisions on the island of Sicily after having driven Rommel from North Africa and by September, the toe of Italy was itself under the tramping feet of the British 8th Army backed up by American troops pouring across the Straits of Messina. To the east, Soviet forces had steadily pushed west and by November had taken Kiev and moved to within 450 km of the A-4 test battery at Blizna. The great battles of 1943 kept the Red Army struggling for territory and grand strategy gave way to personality as Hitler played an increasingly meddlesome role.

With pressure from all sides, only the Atlantic Wall was safe and bitter, hard fought campaigns from Russia to the Mediterranean heightened the need for mobilizing the A-4 as a ballistic weapon in the field. But as early as 1942 the Peenemunde team had designed more ambitious rockets which, they believed, would be more properly suited to the adopted role; key personnel were not happy with the way the A-4, essentially an experimental 'first generation' missile, was being seen as the ultimate device.

The A-6 was to have been an improved version of the A-4, but with propellants that could be stored for long periods of time, thereby improving the handling characteristics and enhancing the missile's flexibility. It was never built and served only as an experiment in advanced technology design. The A-7 was based on the old A-5, a precursor test-bed for A-4 technology, and several models were built and successfully dropped from aircraft to check aerodynamic qualities. Later models used the A-5 engine with a thrust of 1,600 kg and adopted wings placed either side of the cylindrical body to give it a range of up to 24 km from launch to impact. In the terminology of post-war missile development, this would have been seen as a medium range tactical battlefield weapon, but development was stymied by the lack of interest in so short a range capability.

The next design concept took the basic A-6, modified it internally, and placed the wings of the A-7 each side. Called the A-8, the missile was never built and suffered a similar fate to that of the A-7. The most advanced concept, at this time, envisaged a modified A-4 with two wings providing a surface area of nearly 14 square metres to generate lift after the missile fell back to the denser layers of the atmosphere. It was known as the A-9 and would travel 650 km in a 17 minute flight before eventually dropping, at low speed, on to the target. Ever mindful of the enormous potential unleashed by rocket technology, Dr. von Braun was enthusiastically confident of being able to use the rocket for peaceful purposes. War had never been his forte and the A-9 was seen as a continental transporter which, with flaps and an under-carriage, would glide to a conventional landing at less than 160 km/hr. There was little time for such exotic research in 1943, however, and the work on advanced projects became increasingly difficult as the A-4 moved toward quantity production. Much time had to be spent on ironing out the teething troubles with the existing missile.

Meanwhile, in September 1943, a flurry of rapid policy changes re-structured the Peenemunde team and shuffled the Nazi hierarchy toward increasing domination by the SS. Tired of the struggles involving Colonel Zanssen, the Army withdrew its opposition to his replacement and approved the appointment of Major-General Rossman to command of the research establishment. Dornberger's power was similarly reduced by setting up Weapon Test II, devoted wholly to the development of solid propellant rockets and placing Rossman in charge of Weapon Test X which embraced all existing liquid propellant work, the A-4 included. This change removed Dornberger from the Army Weapons Department and placed him firmly under the direct command of Fromm as his special representative for the rocket work, securing an increasingly administrative role. He was, however, firmly placed in command of operational training on the A-4 and as such, still had a say in test launches designed to remove petty problems with the missile.

On 6 September Dornberger was summoned to Berlin to meet Major-General Dr. Hans Kammler from the SS. Kammler had been appointed head of the construction programme for the A-4 production facilities from his position as chief of the SS Head Office Building Branch. The two were in conflict from the start, but more because of role than personality: Dornberger was an ex-artillery officer, Kammler was a fanatical SS man to the core. Nevertheless, Dornberger would find Kammler continually irritating and see in him the same explosive, uncompromising and pompous character that had done so much to change the Germany he once knew, into an arrogant and totalitarian empire. By this time Albert Speer, forever in search of increased power, had been promoted to Minister of Armaments and War Production and the increasing entourage he commanded saw in him the new right hand of Hitler in a post-war Nazi dictatorship. Many of Speer's new associates were SS men intent on following his successful climb to favour. As events would show, it was short-lived.

The technical progress of the A-4 during late 1943 and early 1944 resolved several outstanding problems, including sudden explosions on the ground before liftoff, break-up in the atmosphere near the end of its trajectory and teething troubles from the new flight control system. The rocket flights from Blizna in Poland were achieving the unsatisfactory rate of less than 20% success and for several weeks the leading figureheads at Peenemunde sought ways of improving the launch record. Clearly, the A-4 could not be permitted to go into production with such an abysmal chance of doing the job it was designed for.

At first von Braun, technical chief for the entire A-4 project, recalled the words of the late Dr. Thiel when he expressed grave doubt over the ability of comparatively inexperienced troops to take the missile from a production line and fire it successfully. Blizna was a convenient halfway-house between the research station and operational use, with most of the firing personnel coming straight from military duties elsewhere. Could it be that Thiel had been right and that the missile was just too sophisticated to place in the hands of untrained personnel? A contingent from Peenemunde soon put paid to that idea, when they too found it impossible to improve the success rate. Something had to be done quickly.

The increasing interest of the SS was a savage spur to rectification and with production plans moving to fruition, the Himmler men would not look kindly on inadequate performance. Perhaps the failures were generated by incompetent work on the production line rolling off the few test missiles each week? More Peenemunde men joined the assembly lines to monitor the work and provide assistance. Still to no avail. Only 10 to 20% of A-4's launched from Blizna satisfactorily reached their test targets. Concerted efforts in the workshops and on the drawing boards eliminated one possible source after another, until finally it was felt that the curved propellant pipes might be subjected to undue stress in the manufacturing stage and that the stresses induced at launch could lead to a rupture resulting in ignition of the fuel pouring through the split. This did help considerably and subtle changes in the order of work during assembly, extreme care in test firing the engines and additional bearers placed in the engine, brought the success rate up to one-third of all attempted flights.

Now at least most of the rockets were getting off the ground, but still many were breaking up before they reached their targets. Increasingly, the Peenemunde team felt that aerodynamic pressure was responsible, since accidents occurred after the engine had been shut down. In the final analysis there was nothing for it but to restore the launch schedule to Peenemunde where engineers would have access to all the complex monitoring equipment and the valuable wind tunnel. Blizna was, after all, only a basic launch complex with little equipment for studying engineering design problems. By now Major-General Rossman had taken over command at Peenemunde and he authorized test launches to start up again from the Baltic coast research facility. A-4 rockets would now be fired vertically from the Greifswald Oie and engineers experimented with various types of insulation, among which was glass wool, around the liquid oxygen tank. With a boiling point of −168°c, the oxygen could rapidly increase the internal pressure of the tank if heat got through from the exterior skin of the rocket as it plunged through the dense layers of the atmosphere toward its test objective. It would not take much to rupture the thin walls causing the forward section of the rocket to break up in flight, exactly the phenomena that had been observed on so many occasions.

This and other work resulted in improvements which, by the middle of 1944, led to a 70% success rate, still far from that desired, but well on the way towards an acceptable figure. Gradually the rocket became more and more reliable until, in early autumn, more than 8 rockets out of 10 reached their targets. Already, the original production plan had gone far beyond the service introduction date of December 1943 and not until the following September, would the A-4 achieve operational status. During the early months of 1944 another problem arose. Should the missile be fitted with a highly sensitive fuse in the warhead, or one which would only detonate on impact with the ground.

If the highly sensitive fuse was carried, the warhead would blow up if and when the main body of the rocket ruptured during the final stages of descent, as many were still doing. If the impact fuse was adopted, the missile would bury itself in the ground and reduce the explosive effect of its warhead. On the other hand, it was felt that even if the missile did break up in flight, the warhead would remain on essentially the same ballistic trajectory and still reach its target. This was felt to be the deciding factor so that even with only a 70% success rate almost 90% of warheads would reach their destination. The ground impact fuse was carried through to the production phase.

More and more vertical launch tests flew off from Greifswald Oie and on one occasion, a 67 second burn duration took an A-4 well into space at a recorded height of about 190 km. Peenemunde was now well established as the world's first space launch complex, although the significance of this was appreciated by only those closely associated with the technical details of the project. Nevertheless, von Braun was ecstatic at the prospect of the day when flights to the planets would become reality.

As related earlier, all the A-4 launches along the ballistic flight paths selected for missile qualification had required a radio command to cut off the main engine when the rocket reached the desired speed to achieve maximum range. This was seen to compromise its full operating potential for it would be unnecessarily complex to set up a radio guidance command station several kilometres from the launch site operated by field troops. Accordingly, for the past four years or so Professor Wolman had been working to perfect the Doppler tracking system, but now a new control system was to be introduced which would enable the missile to achieve autonomous operation from the moment it was launched. This was an integrating accelerometer, so called because it was sensitive to minor variations in speed and would compare velocities in all three axes, translate them into a figure representing the forward motion of the rocket and then, when the desired speed was reached, instruct the flight control system to shut down the engine.

It was a major step forward and one which would be taken up and developed to perfection after the war. With a pre-set value to work with, the A-4 could be programmed to reach specific targets at any desired range within certain limiting bands. Tests were now providing a working manual for operational field troops and with the accelerometers checked in flights from Blizna, the A-4 was seen to be capable of a maximum range of about 330 km. Minimum range was dictated by limitations in the time switches which required the engine to burn for at least 45 seconds and so achieve ram-air pressure for the fuel tank. This gave the missile a flight path of at least 80 km, but selection of the precise range was now at the prerogative of the firing team.

Suddenly, on the morning of 15 March 1944, General Buhle, Chief of the Armed Staff at Armed Forces High Command, Berchtesgaden, put in a telephone call to Dornberger at home in Schwedt, 65 km north-east of Berlin, ordering him to the Fuhrer's headquarters for a meeting with Field Marshal Keitel. Wilhelm Keitel was Chief of the Oberkommando Wehrmacht (Armed Forces High Command) and Buhle was serving as the Staff head, and, as such, Keitel's deputy. Upon arriving at Berchtesgaden, Dornberger was told the stunning news that von Braun and engineers Riedel and Grottrup

(Steinhoff's assistant) had been arrested and taken to Stettin where they were imprisoned by the SS, although the first word on their incarceration implied that the Gestapo had control of the case. This latter group was the Geheime Staatspolizei (Secret State Police) operating under the fourth Bureau of the Reichssicherheitshauptampt, essentially the security wing of the SS covering non-military crimes.

Keitel qualified the injunction by saying that the three men had been overheard in Zinnowitz expressing their displeasure at the military use of the A-4, the planned bombardment of England and the lack of interest in the true values of rocketry. They had, in short, extolled the virtues of space flight at the expense of support for the military objectives of the Third Reich. Dornberger was appalled and dismayed to learn that Reichsfuhrer Himmler had placed spies in the Peenemunde area immediately following his first visit in April 1943 and later, to hear that Himmler had sent for von Braun and asked for his help in cooperating with moves by the SS to seize control of the rocket research establishment. Von Braun had given Himmler short shrift, saying that he would report any such clandestine activity to his Army superiors at the first opportunity.

Keitel told Dornberger that Himmler had taken direct control of the case and the following morning he went, with his Chief of Staff Lieutenant-Colonel Thom, to the Berlin headquarters of the security bureau in Prinz Albrechtstrasse, hoping to see Kaltenbrunner at the Reich Main Security Office. He was ushered in to the office of SS General Muller who cautioned the Major-General that he should be careful of exuberant intervention and that he, Dornberger, was also under suspicion. The old accusations of lack of competence, insufficient progress and shoddy administration at Peenemunde were trucked out and Dornberger left resolved to take issue at a higher level.

Two weeks later, after asserting that the A-4 would never become the V-2 it was supposed to be without the able services of von Braun, the three men were released from Stettin into Dornberger's personal custody for a period of three months, until the work had reached a level where the rocket could be handed over for full production. By the end of June, a further stay of trial was granted and the case gradually dissolved as more pressing matters caught the attention of the SS. By then moves had already been made for the Schutzstaffel to virtually dominate the A-4 rocket programme and there seemed little point in pressing the matter.

Two months later, at the end of May 1943, Dornberger pressed Fromm for greater control over the project and then appealed to Keitel for more clearly defined authority to establish command firmly in the hands of the Army. Keitel had already received a letter from Himmler demanding more power for Kammler who was by now being groomed to take over A-4 operations. It was a stalemate and the Army feared for its future as far as the Peenemunde work was concerned. Accordingly, it snipped at least *some* SS glory in the bud by making the Development Works a private company under the directorship of an industrialist from the firm of Siemens.

Despite the May request to Fromm, Dornberger was kept in check while the SS man Kammler (now a Lieutenant-General), stamped around the halls of administration flouting the authority of anyone who stood in his way and openly complained of the lack of competence from everybody associated with the A-4 project. Even Degenkolb came under criticism. Following the 20 July bomb plot against Hitler, General Friedrich Fromm was removed from command and condemned to death for failing to reveal the attempt. On 4 August, Kammler was made Himmler's special commissioner and with the latter already in charge of Fromm's duties, the scene was set for a full SS takeover of important political and administrative positions. Just four days later Kammler was placed in complete charge of the A-4 project.

Dornberger's dissatisfaction with the new command structure was amply demonstrated by his resolution to resign from the project and let it take its own course. Dornberger's memoirs, and the testimony of Dr. von Braun, affirm his bitter discontent at having come so far only to be shouldered aside by a quasi-fanatical wing of the politically motivated power blocks. At the end of August Kammler held a conference with the Chief of Staff of Army Corps 15, the unit set up to begin operations with the A-4, and leant heavily on the Army for the right to take over personal command.

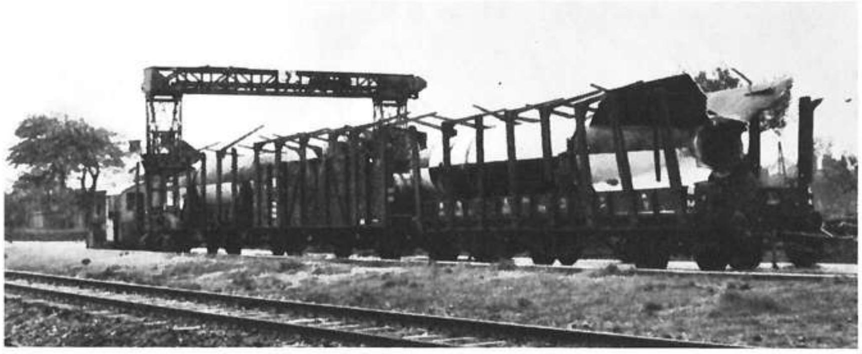
8 September 1944, and the first V-2 falls on England, re-kindling the horror of Göring's air bombardment earlier in the war.

By 4 September the first operational A-4 rockets began arriving at the field and just four days later, the first V-2 assault began with a bombardment of England from a site in the Netherlands. Two days earlier, on 6 September, two V-2 rockets failed in initial attempts to reach Paris. Events of the preceding months had changed the character of the war. On 6 June an Allied invasion force set down on the Normandy beaches and by July, German forces were fighting a losing battle for control of France and the Low Countries. Refusing to withdraw and re-group, Hitler lost time and men in stubborn mopping up operations which depleted his forces and opened lines of resistance to Allied spearheads. On 25 August German forces surrendered the city of Paris, liberated the previous day by a French led force under General Leclerc. It was because of these sweeping gains that the first V-2 objective was sited on the French capital.

During the month of September, 350 V-2 rockets were launched, followed by 500 in the following month. Strategic war had prevented the V-2 from taking full advantage and soon the field troops would be engaged in a mobile offensive, firing the rockets wherever and whenever they could. By November, production had reached more than 600 per month and with operational experience at last to hand, the rocket was shown to require remarkably little modification. The jump from theoretical planning, to actual operational use would normally bring a host of minor technical requirements unforeseen during the stages of preparation.

Historians have in the past, pointed out the deficiencies presented by V-2 operations, but considering that the basic design was laid down as early as 1936 and that the missile was essentially experimental in nature, going a significant step beyond the performance of the precursor A-5, the rocket performed remarkably well and more than vindicated the hopes of its mentors. In a period of eight years the engineers and technicians associated with development of the A-4 transformed an advanced idea into a meaningful weapon, heralding a new age of rocket power and taking a quantum leap in the state of the art. Debate will continue as to the rocket's impact on the war, but the most that can be said is that it demonstrated a capability and a system approach which created a precedent by which to measure succeeding developments. If the A-4 had become the operational V-2 much earlier, if other more advanced designs had received the same level of priority, albeit slow to start in the case of the A-4, the tide of Europe's devastating war may possibly have taken a different turn. Indeed, it is hard to see how the contrary could be true for, with several thousand missiles produced each month, year after year, the effect of sustained bombardment could have been decisive. But arguments such as these could embrace the German atom bomb, which never emerged, or the nuclear powered submarine which was similarly delayed. As events proved, the A-4 stayed too long on the shelf of half-measures and only in the last two years of the

V-2 rockets were delivered to field troops by train. Rail cars are seen here straddled by the Strabo crane that will lift them on to a Vidalwagen.



war would the rocket come to be universally recognized as a devastating weapon for which any counter measures were seemingly light years away.

Six weeks before the first operational V-2 was launched, at the end of July 1944, the Blizna site was evacuated to the advancing Red Army and ordered to the forests of Tuchel Heath. By the end of the year, Kammler had wrested total control of V-2 operations, a sad reflection on the years of Army development. Wielding a power-crazy threat over any member of the armed forces who opposed him, Kammler rapidly replaced unit commanders with his own SS men and effectively obtained absolute command under Hitler. From September 1944 V-2 operations were stepped up quickly, although production was soon outstripping the rate at which the field troops could fire the missiles. As more and more personnel were trained on the rocket, however, the increasing backlog of completed V-2's caught up with the steady levels of supply.

In the early weeks of operation a significant number of rockets had to be stored, temporarily, in ammunition dumps and other suitable facilities. But the emerging cadre of rocketeers were slow to appreciate the missile's delicate engineering and many rounds were left out in the open until ready for use. Failures increased alarmingly and studies at Peenemunde revealed the cause: bearings in the servoactuators, part of the active flight control system, were being distorted by the increasingly inclement winter weather. Henceforth the V-2 would be fired, if at all possible, within three days of manufacture and so avoid the decaying effect of storage. With Allied ground and air forces taking an increasing toll of the German munitions industry and with troops moving slowly across western Europe, the V-2 at last became the highly mobile artillery weapon it was expected to be and, with characteristic ingenuity, the German teams devised a flexible procedure for sending the missiles off to their respective targets.

From the assembly plant, V-2 rockets were moved rapidly by train to a receiving area and launch teams grouped into 1 Technical Troop to 3 Firing Troops. The Technical Troop was responsible for de-training the missile and holding it in readiness for handover to a Firing Troop, several hours later or three days at the most. When the rail wagons arrived, a Strabo crane would be set up to straddle the horizontal V-2 and a road transporter wheeled up alongside. The Strabo was a self-powered structure about 10 metres long which could be raised to provide two vertical support towers 6.3 metres tall with a horizontal crane between the top sections. With the Strabo in position over the rail line and the transporter, a V-2 would be winched up above the train, moved horizontally to a position above the transporter and gently lowered to support struts.

The transporter, called the Vidalwagen, was 14.1 metres long and 2.8 metres wide. With the missile attached, the assembly was about 3 metres tall. Still in the horizontal position the Vidalwagen would take the rocket to a field store where the Technical Troop attached the warhead by lifting the transit container up to the nose of the V-2 and securing it to the front of the missile. The Strabo crane was used throughout these operations and although it was not specifically designed for use with the V-2, its 10.2 tonne lifting capacity was more than sufficient for handling the 4 tonne rocket. The warhead would only be attached when a Firing Troop was ready to collect the missile and take it away for launch and for this the Strabo crane would be set up so that the Vidalwagen could be driven underneath, followed by a Meilerwagen positioned alongside the road transporter. The Meilerwagen was operated by the Firing Troop and would be used to carry the V-2 to its launch site.

Personnel from a Firing Troop collected V-2s from the Technical Troop and, using a Strabo crane, lifted the weapon from the Vidalwagen to a Meilerwagen.

It consisted of a wheeled base on which rested an erector to which the missile was attached. Transfer from the Vidalwagen to the Meilerwagen was performed in much the same way that the rocket had been lifted from the rail wagons to the road transporter. During this time the liquid oxygen road tanker collected a 6.6 tonne load of propellant from a cylindrical rail container brought up by train. Liquid oxygen would evaporate at the rate of 3% per day and it was important to synchronize delivery of the propellant with collection of the missile from the Technical Troop's field store. When the Meilerwagen arrived at the selected launch site it would be met by the liquid oxygen tanker, the fuel tanker (carrying the alcohol), a Firing Control Vehicle and the vehicle used for bringing up the firing table. The firing table was a 1.6 tonne square shaped pedestal supporting a circular support ring which could be turned by ratchet to provide the missile with its azimuth to the target. Underneath, a cone shaped blast deflector would prevent the exhaust plume bouncing off the ground and back up into the combustion chamber.

The Firing Troop would bring up the firing table and secure it to the ground by four legs screwed into the earth. The table would be accurately aligned and surveyed so that the guidance instruments in the rocket could be set for the desired trajectory. The Meilerwagen would then have to be winched back on to the side of the firing table after which two hydraulic jacks raised the erector, and its V-2, into a vertical position above the table. Held just 2.5 cm above the circular support ring, technicians then raised the upper section of the table on adjustable screw jacks so that the four fins at the base of the missile could be secured. The Meilerwagen backed away a short distance so that work platforms could be attached to the erector and afford access to a variety of positions along the length of the rocket.

British Army personnel give scale to a captured V-2, covered with a camouflage sheet.

Raised to the vertical position by Meilerwagen, a V-2 is positioned on its launch pedestal and surrounded by support vehicles bringing liquid oxygen, alcohol and generator equipment.

The Firing Control Vehicle from which final countdown and launch preparations were conducted before ignition of the V-2 propulsion system.

Satisfactorily set up on its launch table the V-2 was levelled by a collimator and further adjusted with the screw jacks. The fuel tanker was now brought up alongside the rocket and a long probe raised to the centre section of the missile so that the ethyl alcohol could be transferred to the propellant tank, an operation which took about 10 minutes to complete. Within an hour of launch the liquid oxygen road tanker was positioned against the V-2 and a large flexible pipe used to move the propellant into the rocket's oxygen tank. This took 8 minutes and was performed as close as possible to the appointed launch time so that evaporation would not significantly deplete the tanked quantity. Just as the liquid oxygen propellant was being placed in the tank, the sodium permanganate, used with hydrogen peroxide to produce the steam which would drive the turbine, was being heated prior to feeding it through to the rocket's reservoir. Hydrogen peroxide was, meanwhile, already being introduced to the steam heater aboard the V-2 and when liquid oxygen fuelling was completed the sodium permanganate was poured into its container through an opening in the side of the rocket.

After this, the igniter was placed up inside the combustion chamber and the work platforms were taken down so that the erector section of the Meilerwagen could be removed. The personnel would then take cover, most probably in makeshift trenches, and the Troop Commander would go to the Firing Control Vehicle to conduct the ignition of the engine and liftoff. An electrical cable ran from the firing control vehicle to the V-2 through which signals would be sent to start the igniter. The procedures for launch have been described earlier in this chapter and suffice it to say here that the propellant valves were opened so that the liquid oxygen and alcohol could fall by gravity through the injector head to the combustion chamber, where the igniter would start the engine for a low thrust level lasting several seconds. When the performance of the motor was observed to be satisfactory the main turbopumps brought propellant down at the higher delivery rate and increased thrust to about 28 tonnes, whereupon the rocket was released for flight.

On 1 November 1944, a Lieutenant-Colonel A. R. Greatbatch of British Intelligence conducted two interviews with a Dutch resistance worker who, on 25 October had passed through the German lines with reports of V-2 operations from mobile sites close to Eindhoven. The following is a condensed extract from the report on the patriot's story:

'Mr (C. Van) Fliet lived at Wessemaar, a small town north of the Hague. At about 6.30 p.m. on a day between 6 and 10 September – his memory on this point was not good, but he said it was the day after a violent storm – probably the Friday – he heard a terrific noise as though at least 30 Spitfires were flying low overhead. He looked up to see a pointed projectile, about 10 metres long, rising slowly and majestically above the tree tops. A cloud of black smoke billowed slowly after reaching a height of about 15 metres. The projectile gained speed rapidly with a flame emerging at the rear extending to about half its length.

'There was no smoke at this stage, but at 300–500 metres a white smoke appeared leaving a trail in the form of a spiral. This smoke disappeared at about 2,000 metres. The projectile was now accelerating quickly and its trajectory was flattening out somewhat. It finally disappeared travelling at a terrific speed. The initial angle of launching was about 80° and was not vertical. A second rocket was launched from a nearby site about 15–30 minutes later.

'Mr. Fliet visited the scene of the launching as soon as possible after the event. Both sites were in the middle of roadway passing through a wood. At each place there was a circular patch from which the tar had been melted or burned. The patch had a diameter of 9 metres and the road was about 10 metres across. In the centre of each burned patch was an unburned part in the form of a regular pattern which suggested that some form of stand had been used. The trees by the side of the road were very badly burned up to a height of 1 metre and less badly burned to their tops. There was also evidence of a violent low blast. The grass was flattened out and all the leaves had vanished from the trees. The thatched roof of a nearby small house had been lifted and blown off.

'No equipment had been left behind and there was no sign of any having been used except for the unburned portion of the road in the centre of the burned patch. Mr. Fliet learned that about two hours before the event, four trucks had driven up to the site from different directions. One of them was a long truck having sixteen wheels and with some lifting tackle stowed underneath. Another was a tank car. A radio car had been left about 500 metres away. The crew consisted of 16–20 soldiers who at the time of launching were completely clad from head to foot with asbestos helmets and overalls. The projectile was fired by a high tensioned cable brought out from a nearby electric supply point, a number of which had been built by the Germans in the neighbourhood.

'No one had been allowed within half a mile of the site, but several people had heard a pump being worked for about two hours. The tank truck had been filled from a rail wagon in the town. The tubes used for transferring the liquid were covered with ice and it was concluded that it was liquid air which was being transferred.

'The day after these launchings, which were thought to be the first, the inhabitants of Wessemaar left the neighbourhood for fear of allied air-raids, which were anticipated as a result of the event. Other launchings took place afterwards from Goasterland (Friesland), west of Meppel, south of the Hague, Loosdiumen, and the Hook of Holland. Launchings took place mostly from roadways bordered by trees. It was reported that on an average, one man of the crew died from severe burns for each launching that took place. In many of the events the noise appeared to stop prematurely and in these cases an explosion was heard soon afterwards.

'Some projectiles appeared to travel inland, on some occasions at night time a "blue ray" had been seen "striking" the projectile and this was attributed to counter-measures directed from allied warships to interfere with the flight of the projectile. Mr. Fliet was a captain air pilot in the last war and afterwards he became Fokker's test pilot. He is a trained engineer and appears to be capable of making accurate observations. Mr. Fliet also mentioned a rumour he had heard to the effect that some special spherical containers about 6 cms diameter were being made in steel to hold "miltfreur". He emphasized that this was only a rumour. "Miltfreur" I found out to be anthrax.'

Many V-2s were launched from hurriedly prepared clearings in forest or wooded country and as production stepped up through the winter of 1944/45, more personnel were added to the growing numbers forming Technical and Firing Troop contingents. Soon, however, the increasing output from assembly plants exceeded the number of V-2 missiles which could be supplied with the all important propellants necessary to fire the rockets. As more and more of the German war production went on supplies for the ground and air forces, there was a decreasing quantity available for the exotic developments from Peenemunde. Oxygen manufacturing plants were overrun by the advancing Allied forces and at the height of V-2 operations there was sufficient for about 35 launches per day. Of this total, about 20% were allocated to tests and training, with the balance available for operational flights.

To provide the nearly 5 tonnes of liquid oxygen carried by each V-2, the oxygen production plants had to generate a full 9 tonne load so that losses from evaporation during transfer from plant to rail tanker and thence to the road tanker would ensure a sufficient quantity when the missile was fuelled. Thus, an 80% excess had to be generated at source. The alcohol propellant too was soon in short supply and this contributed toward an effective ceiling on the numbers prepared for launch.

Meanwhile, in December 1944, Dornberger was summoned to the Development Department at the Ministry of Munitions and asked if he would like to head the Long Range Bombardment Development Commission, a position recently vacated by Petersen due to illness. After years of struggling against administrative reluctance to grant him the civil power he sought, Dornberger was at last invited to ministerial levels of control. By this time SS General Hans Kammler was in control of virtually all operational V-2 decisions and Dornberger knew that to associate his office with so radical a personality would court the confrontation he hoped to avoid. Accordingly, and after much discussion with leading colleagues from Peenemunde, Dornberger decided to propose a new working party which he could set up for monitoring the administration of production and test schedules.

The request to join the LRBDC had come from Speer by way of a Colonel Geist at the Development Department and on 12 January 1945, Geist carried Speer's approval and authorized the new committee. Dornberger hoped to apply the knowledge he had gained over the past 15 years of association with rocket development to problems little understood by the bureaucratic commissions set up earlier to monitor production and service introduction. Few of the pioneers from Peenemunde had liked the idea of handing control to Kammler, although their deep involvement with the technical and engineering problems had kept them at a comfortable distance from daily interventions; lessons learned from the Degenkolb fiasco had prepared them in advance for the impossible demands they were to receive from the SS.


Technicians prepare for the launch of a V-2, observing the missile through observation slits.

Shortly after the new working party got under way, Kammler increased his influence over the V-2 project and soon embraced Dornberger's team into his own administrative umbrella. A full and complete examination of the programme set up by the Nazi bosses revealed numerous deficiencies and exposed duplication and bad planning at many levels. Many subcontractors throughout Germany were working on V-2 components and one of the first moves was to group factories of supply, production and assembly in one selected area. This would reduce delivery times, increase the effective liaison between administrative and technical controls and improve the quality control. During February 1945 production centred on the Nordhausen area, south of the Harz mountains and Dornberger moved his staff from their previous headquarters at Schwedt on the Oder to Bad Sachsa.

A static test facility had already been set up in the Lehesten area following the 17 August 1943, raid on Peenemunde, with two stands built into the side of the cliff overhanging a quarry. Each firing chamber consisted of a building 3.7 metres long, 3 metres wide and 4.3 metres high fabricated with walls 50 cm thick. The two chambers were open at the rear, the front wall consisting of a steel grating with a large circular hole in the floor through which the exhaust would escape. Between the two chambers, 23 metres apart, a small observation hut provided the opportunity to monitor the performance of instruments set up in either or both.

Von Braun and his technicians vacated Peenemunde in February and moved south to join the main body of production workers at the town of Bleicherode, 1.7 km south-west of Nordhausen. Orders flowed in abundance as district commanders and SS generals wrestled with each other to exert diminishing authority over an increasingly chaotic situation; the order to move to Nordhausen had come from the Munitions Ministry, but the engineers had need to use a great deal of subterfuge to successfully gain passage through the districts bridging north and south Germany. By now the bombardment of London had ceased and Kammler's V-2 operations were directed against battle targets such as the town of Antwerp and the famous bridge at Remagen. During the intense bombardment of Antwerp between December 1944 and March 1945, 65% of all attempted V-2 launches reached their target with range errors of only 0.2–0.8 km, but 18% failed after launch and 17% succumbed to explosions on the launch platform.

By 27 March all V-2 operations had ceased and in the period since the missile's operational introduction early the previous September, more than 4,300 rockets had been launched against operational targets. Of this number about 1,500 were directed against England and about 2,100 against the docks at Antwerp. Londoners had grown used to the sudden surprise attack from a weapon that came out of the sky without warning and whose arrival on the target was signalled by the detonation of the warhead. Flying faster than the speed of sound, it could not be heard whistling down through the dense layers of the atmosphere and there was nothing that could be done to shoot it down or warn of its impending approach. The V2 would impact at over 3,000 miles per hour. The V-1 flying bomb, on the other hand, cruised at low altitude and at a speed accessible to patrolling fighters.

Before long the Royal Air Force had developed a procedure whereby Spitfire pilots would fly alongside the V-1 and manoeuvre the aircraft's wing under the wing of the flying bomb to literally flick it over and off course where, hopefully, it would rapidly go out of control and crash short of the target, usually a heavily populated area in the south of England. Of the 9,300 V-1s launched against England, 6,000 reached their targets. By the end of the war 2,700 lives had been lost in V-2 attacks and although the rocket was impossible to detect during its last few seconds to impact, at least one person, a Mr. S. Cunnington now living in Boston, Lincolnshire, watched V-2 rockets ascending from their mobile launch platforms. Working at Peterborough, a town famous

With a flame more than 15 metres in length, a V-2 rises from the launch pedestal and begins its flight.

for its brick works, he watched the vaporized trail of V-2 exhaust plumes as they came up over the horizon and broke into the characteristic zig-zag pattern in the turbulent regions of the upper atmosphere.

In the last few months of the war several minor modifications were made to the V-2 which resulted in moderate improvements to performance and operability. In the final weeks before Peenemunde was vacated, tests were successfully carried out on a V-2 using larger propellant tanks and the range was successfully increased to some 480 km. This particular version was never put into production or used operationally. The most effective operational 'stretch' increased range to about 360 km by careful manipulation of the trajectory to most effectively utilize the power of the rocket's engine.

Ever more closely controlled by Kammler's SS, the engineers and technicians from Peenemunde set up temporary work facilities in the Nordhausen-Bleicherode area and for little over a month remained at this location. But advancing Allied troops necessitated a further move, this time at the direct instigation of the SS who were becoming troubled at the possibility of being captured. Dornberger, von Braun, and a few trusted associates discussed the options which were available. It was becoming clear that if the SS were cornered they would have little hesitation in using engineers and Army staff as hostages with whom they thought to bargain with Allied commanders. Recognizing the repugnant reputation they had received, and as if in self-condemnation for nearly two decades of fanatical extremism, the SS were in no mood to quietly surrender their freedoms. Kammler directed Dornberger and von Braun to take the 450 top Peenemunde engineers to an old army camp at Oberammergau in the Bavarian Alps.

On 6 April the convoy set off for its new retreat just as Allied armour was pushing through to the town of Bleicherode. Upon arrival at Oberammergau, 425 km south of Nordhausen, the group were incarcerated in an open stretch of land, at barracks surrounded with barbed wire. Recognizing the vulnerable position they now occupied, open to both Allied attack and SS detention, von Braun and Steinhoff persuaded the SS to disperse the group among local villages and towns. Von Braun and Dornberger took up temporary quarters at the small town of Oberjoch and waited for the end which was by this time all too inevitable. In those last days of the European war there was time to reflect on the accomplishments of the past twelve years since Dornberger, under the direction of General Becker, came to work for the Army eventually leading to inception of the A-4 and the Peenemunde research facility.

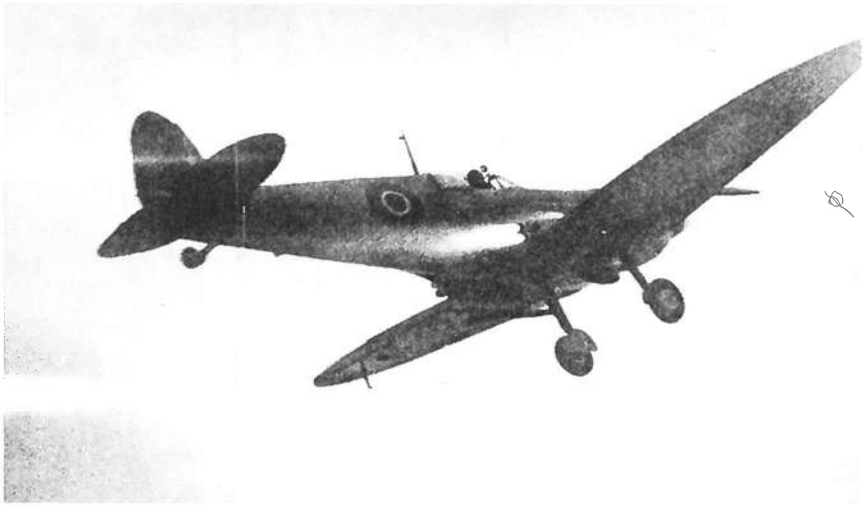
On 30 April, Adolph Hitler shot himself and provided the final spur for surrender to the Allied forces. The engineers were resolved to seek out approaching American combat units and surrender themselves before waiting for Soviet troops to break through and ship them to the Soviet Union. With an eye on the future, when peace again returned to the world, von Braun was instrumental in exercising a clinical judgement over the possibilities laid open by release from the turbulent and unpredictable machinations of the Nazi hierarchy. In the early years of German rocket research the dedicated team had been left alone to conduct experiments and tests leading toward the first ballistic missile, but the higher levels of authority that eventually became essential to full scale development brought with it a spectre of unparalleled ferocity that sought continually to obtain control that should more properly have been left to engineers and military prerogative.

Accordingly, and as a result of their resolve to seek further rocket work in the United States, von Braun sent his younger brother Magnus through the American lines one day early in May. Magnus von Braun encountered American infantry troops at the town of Reutte, 29 km south-west of Oberammergau, and told them that several hundred rocket technicians wished to surrender. Openly professing their interest in furthering the pioneer work on rocketry, von Braun was then interrogated before an American intelligence officer – sent through to the Oberammergau area where he found the group waiting. Shortly thereafter the engineers were moved to the town of Garmisch-Partenkirchen, 35 km to the east, where they were interviewed and interrogated further. Eventually, Dornberger was handed over to the British who kept him in prison for two years before permitting him to go to the United States in 1947.

But for the many who had worked for long years at the technical details of the new technology, the real work was just beginning. The romantic dreams of rocket pioneers embraced the full spectrum of imaginative thought and many expected to see space flight in their lifetime. But it would be another ten years before the legacy of the V-2 reached fruition in the form of a concerted effort to develop long range ballistic missiles. For a few years at least, the great adventure was over.

CHAPTER FIVE.

Parallel Developments



Launched from an aircraft carrier, the Supermarine Seafire receives a takeoff boost from two solid propellant rockets mounted each side of the fuselage on the upper surface of the wing.

During the last two years of the European war, British and American intelligence agents had struggled to keep abreast of German rocket development. Ever since the information had been obtained that a major effort was under way at Peenemunde on the Baltic coast, plans were being continually refined for seeking out possible launch sites embracing V-1 and V-2 weapons activity. On at least two occasions the Allies received V-2 equipment for analysis. A rocket had gone out of control and fell to earth in Sweden from where the British retrieved the wreckage and promptly set about its technical examination. Still more valuable, another V-2 had crashed alongside a stream in the remote regions of Poland. Patriots radioed the Allies who sent out an aircraft to recover the wreckage and return it to England.

Supreme Headquarters in London authorized a full evaluation of the missile's capabilities and from this and other bits and pieces the rocket was partially re-assembled into its original configuration. Early in 1944 the commanding officer of Eglin Field, Florida, USA, General Grandison Gardner, constructed mock V-1 launching ramps and subjected them to a variety of tests to seek out the most efficient way to bomb the actual sites then under construction in Europe. This information was passed on to the British who sent Royal Air Force bombers out to destroy the facilities before they could be used. Nevertheless, when the first V-1 weapons were launched on 12 June 1944, a new design of launch ramp had been perfected. When V-1 operations began to step up in the weeks following, however, the Allies were sufficiently knowledgeable about the weapon's potential to employ several defensive measures, including barrage balloons and fighter interception (see Chapter Four).

The V-2 had been a different story: there was no defence and, once launched, not even the possibility of detection or warning of impending detonation. Consequently, the possibility of reaching the vast production facilities in the Nordhausen area was considered a rich prize by the handful of technical and engineering personnel assigned to various branches of the intelligence network. But not so with the military forces in general; very few realized the potential knowledge which could be gleaned from discussions with the German rocket pioneers and British and American commanders were slow to react.

This is not altogether surprising. For nearly a year the bitter and hardfought struggle to push the Germans back to the Elbe had brought in its wake a veritable host of scientific and technical people, given honorary rank to enable them to gain access to the military secrets of the Third Reich. All over Germany a state of confusion and uncertainty surrounded attempts at obtaining key personnel known to have played important roles in advanced research. Many projects had been taken over by the SS and in the last days of their authority, rank and file scurried to and fro destroying documents, buying an escape route, or merely mingling with the civilian population. Many civilian engineers and industrialists sought to hide their association with important military projects and the speed of the advancing armed forces left intelligence experts far behind the front lines.

As a result, it was not until the end of May 1945, nearly a month after the end of hostilities, that quantities of the important V-2 equipment were safe in Allied hands. Before the end of the war British and American intelligence officers had drawn up a list of important people known to be associated with rocket development. The first positive move to find and interrogate these key personalities came when the head of the United States Ordinance Corps Rocket Branch, Colonel G. W. Trichel, sent a staff member, Major Robert Staver, to London for conference with the British intelligence network leading to the setting up of a short list. Soon, Trichel authorized the then Colonel Holgar N. Toftoy, at that time in Paris as chief of the Ordinance Technical Intelligence work there, to make his way to the Nordhausen area and retrieve equipment, components and documents for the assembly of V-2 rockets after shipment to the United States from Antwerp.

Toftoy was ordered to make all speed and stop for nothing to achieve his objective. The Russian forces were moving into the area known to be full of V-2 production facilities and no time could be lost if the invaluable hardware was to be seized before the Red Army got there. Meanwhile, von Braun and two trusted colleagues had hidden vast quantities of the important documents relating to German rocket development in a secret location outside the town of Dorten; with knowledge of their imminent removal to the Oberammergau district more than 400 km farther south, they had no wish to have the important papers and drawings destroyed by the SS and it was considered an impossible task to take them along on the final leg of their migration from Peenemunde.

Von Braun had every intention of surrendering to the American forces and no wish to lose all the valuable paper work. Now, under the specific control of Colonel Toftoy, Staver went to the Nordhausen-Bleicherode area and interviewed several key persons from the rocket programme before obtaining the location of the secret hoard and successfully retrieving more than 12 tonnes of documents on 21 May 1945. By this time Toftoy had sent Major J. P. Hamill to Nordhausen with authority to pluck all the equipment he could get out before the Russians arrived. Under the Allied agreement signed at Yalta, the Soviet forces would be permitted to occupy this region and Hamill was aware that he would have to move fast to ship the weighty equipment out before the American troops fell back to the previously agreed positions. The war with Germany was over; the precursor wind of a new 'cold war' between east and west was blowing with increasing ferocity.

The Nordhausen V-2 production facilities had been in the hands of the American forces since the second week in April and even cursory inspection revealed the intact condition of much of the valuable material. It was a truly staggering discovery. Five underground factories were located in the Niedersachswerfen region: two (Mittlewerk and Junkers Nordwerk) had obviously been in operation for some time; three more were in various stages of construction. Set beneath the Kohnstein Hill, the two fully equipped production facilities took the form of a double tunnel, one running along the side of the other for a distance of 1.68 km, 100 m apart.

Some 49 galleries connected the two tunnels with the northern 20 galleries constituting the Nordwerk section. In all, there was more than 80,000 square metres of floor space and the western tunnel in the Mittlewerk section was given over to an assembly line for V-2 rockets, while the eastern tunnel housed production facilities for the V-1 flying bomb and a 76 cm gauge railway system.

Under the direction of a Dr. Zawatzki, the Mittlewerk line received cast or forged turbopumps, combustion chambers, and the like for assembly into rocket projectiles. Machining was carried out here and the rockets were disgorged minus their warheads and fuse assemblies. Administration was carried out from offices in the Napola Building at Illfeld, nearly 13 km north of Niedersachswerfen. Work on anti-aircraft missiles was to have been carried out within a network of artificial caves at Woffleben, a little more than 3 km to the north of the main V-2 assembly tunnels. Work at Woffleben had begun in September 1944, but the facility had not reached full operation by the time the place was vacated. Additional tunnelling was also noted at Ellrich, 3 km to the west.

But the Bleicherode area had been the main centre for evacuation from Peenemunde and the firm of Heimat Artillerie Werke G.m.b.H., renamed Electromechanische Werke G.m.b.H. on 1 August 1944, had moved there from Karlshagen, Pomern, in February 1945. The firm had been capitalized by the state and employed many people from Peenemunde when they arrived in the middle of February. A new headquarters was being set up in the Ueberlandzentrale, at the town of Bleicherode, and villages, farms and salt mines for a radius of 35 km were sub-centres of the evacuation, housing several thousand engineers and their families – the last retreat for the brilliant team that had brought the A-4 rocket to reality as the V-2 ballistic missile.

When the US Army arrived, supplies were still en-route to the area with only 6 of a planned 30 ships having arrived at Barby and Schonebeck on the Elbe from the evacuation port of Lubeck, far to the north on the Baltic coast. One of the main reception centres for the equipment from Peenemunde was to have been the Kali Werke at Bleicherode. There, the main assembly and test facilities for V-2 rockets was already partially equipped but only a fraction of the planned inventory had arrived by the time US Army ground forces broke through. Kali used a 600 metre-deep mine, with a single steam operated cage, for access to the maze of underground tunnels. Despite the paucity of installations there had, nevertheless, been a considerable amount of looting and destruction by foreign construction workers, troops and civilians.

Two names on the work register were already historic: Dr. von Braun and Dr. Rees, the latter technical director for experimental production. In the general round-up that followed the US 9th Army evacuated 6 persons for questioning: Dr. Rees, Director Fleischer (commercial operations manager), Dr. Groetropp (a physicist engaged as senior technician on control problems), Herr Temesvary (ballistics and astronomy), Herr Gengelbach (electrical engineer working on the practical solution to A-4 control problems) and Herr Kagerer (electrical engineer working on A-4 control problems and flight controls for the Wasserfall anti-aircraft missile). Walter Riedel was located in Thuringia and brought back to Nordhausen for questioning. The main headquarters of the Electromechanische Werke G.m.b.H. at Bleicherode was found to have been ransacked and to contain only a damaged gyro stabilization auto-pilot control platform for the V-2. It was here that Rees and Fleischer were to have worked in administrative offices and test laboratories reminiscent of the Peenemunde facility.

An indication of the expanding production capability envisaged for the V-2 and the flying bomb was gained from careful examination of the Kali Werke mine, where it was intended that tunnels and galleries would be extended to connect with other production facilities 10 km away. Existing galleries were found to be up to 2.2 metres high and up to 6.1 metres wide. Farther afield more evidence was uncovered of the hasty withdrawal to Oberammergau. At Freidrichslora, where the offices of a Dr. Schmidt were set up to work on ground survey and range observation for long range rocket firings, intelligence officers found theodolites, phototheodolites and kinetheodolites hastily thrown into a pig sty on a farm outside the village. About 1.6 km away to the east of the farm there were two stores partially hidden in wooded land containing miscellaneous A-4 equipment. All of it had been looted with only sundry items left for the invading armies.

Under 'Special Mission V-2', Major Hamill organized local labour to assist with stripping the main Mittlewerk and Junkers Nordwerk production lines, left virtually intact. With no time to lose, Hamill rapidly brought out sufficient equipment to fill more than 300 rail wagons – sufficient for about 100 V-2 rockets which would be assembled later. The entrance to the Mittlewerk facility looked like the tunnel for a railway line and telephone poles lined the crowded roadway that led into the hillside. All around, dense wooded vegetation encroached to the very edge of the brick surround that marked access to the interior of the hill. By 22 May, the first train pulled away from Nordhausen and within nine days the entire stock had been sent north-west to Antwerp. On 1 June, the Russians were expected to occupy the Nordhausen area by agreement at the Yalta conference.

Of the 5,000 people assembled in the area during February, only 1,500 had left by the time the Red Army walked in; nearly 500 had been sent south to Oberammergau at the behest of SS General Hans Kammler and a further 1,000 left of their own accord. Nevertheless, with documents and equipment from the Nordhausen facility, Colonel Trichel sought to acquire 300 leading engineers and technicians in addition to design staff and test supervisors. Many of the leading figures could not be found and Toftoy was instructed to use every power at his disposal to get the relevant people, even resorting to paratroop operations behind the Soviet front if necessary.

The United States government was uncertain as to its view of the situation: if the military brought several hundred leading munitions experts from Germany it could well stir public outrage and create an adverse reaction; on the other hand, the secrets of the V-2 were too valuable to betray with compromise and if the US failed to exploit the newly acquired asset, the Russians would be only too quick to step in. Such thoughts were fashioned by the politics of civilian control; the administration of national security and public order were often to go in separate directions. Toftoy was keen to have as many leading engineers brought to the US as he could possibly arrange and, by July, was given final approval to secure 127 top people. The most prominent among this group was Wernher von Braun and they all readily accepted the offer of a one year contract to work in the United States and reveal the levels of rocket development as achieved in Germany up to that time. They would also supervise assembly of the equipment which would provide up to 100 V-2 rockets and then perform test flights to demonstrate handling characteristics and performance.

Before this, in May 1945, Major General Alexander M. Cameron, then chief of the Air Defence Division at Supreme Headquarters Allied Expeditionary Force, pursued a proposal that envisaged British troops enlisting the aid of German technicians to test launch a few V-2 rockets and thus obtain valuable technical data on the performance of the rocket. After consultations at the War Office in London, the proposal was approved and Cameron set about obtaining as much equipment as he could possibly lay his hands on. The American intelligence officers at Nordhausen allowed the British to interrogate the key German personnel being held there and before long Lieutenant Colonel Wolfgang Weber, former head of V-2 Tactical Group South, was organizing nearly 1,000 workers on what had become known as 'Project Backfire'. Recovery teams scoured Germany for V-2 rockets and components and brought them to a launch site at Altenwalde near Cuxhaven. Propellant was hard to come by, but eventually sufficient was obtained for a few test firings.

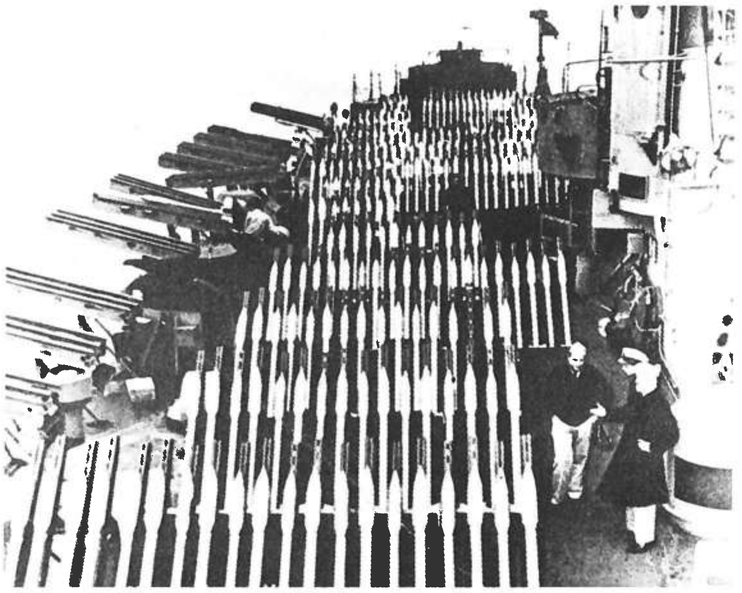
By August the Americans were keen to recover the services of several engineers 'loaned' to the British, thereby ensuring that the most valuable personnel would not be lost. A compromise was reached, a few were sent back and plans moved ahead to fire a V-2 on 1 October. Abortive attempts at ignition delayed the launch 24 hrs and on 2 October the first British-launched V-2 successfully flew 240 km out into the North Sea. A somewhat less successful, and final, flight was performed on 14 October, three years and eleven days after the first V-2 flight from Peenemunde.

The sudden emergence of British interest in the liquid propellant ballistic missile, was the very antithesis of policy in earlier years. No major efforts were applied to the concept of (then) long range rocket bombardment and the state of liquid propellant rocketry in general was contained solely within the experience of one Dr. Isaac Lubbock. In 1940, Lubbock determined that the most effective weapon for the emerging nature of the European war would centre on cross-Channel rocket bombardment, a concept that had spurred German efforts a decade earlier. Working with Professor F. A. Lindemann, scientific advisor to Winston Churchill, Lubbock sought potential design solutions by way of a solid propellant rocket. He argued that, as simplicity would be important in the operational deployment of a production missile, the complexities of liquid propellant designs ran counter to the necessary reliability, mobility and serviceability dictated by the requirements. The government was unimpressed and suggested that he turn his attention to the development of liquid propellant rockets which could be used to assist with the problem of getting aircraft into the air; heavily laden bombers would benefit, it was thought, by using some form of supplementary boost for assisted take-off (ATO).

From a position of almost total ignorance as to the emerging concepts in Germany and the United States, the latter concerning work performed by Robert Goddard, Lubbock moved ahead with tests in 1941. By 1942 he had demonstrated engines developing 800 kg thrust for durations of up to 30 seconds, but little use was made of the research. There was certainly no attention to the problems of developing a rocket which could be used for long range bombardment. In the end, Lubbock was frequently consulted by British Intelligence for his interpretation of German liquid propellant rocket developments and throughout the war had sole access to authority over international progress in the new technology. But if slow to appreciate the potential inherent in the liquid propellant motor, Britain did maintain a consistent, if somewhat lethargic, commitment to solid propellant designs.

As early as 1934, acting on information about the emerging rocket tests in Germany, the Director of Ballistic Research at Woolwich Arsenal, A. D. Crow, pushed for experiments leading toward powder rockets using cordite as the propellant. A year later Woolwich Arsenal began a theoretical study of such a device and by 1936 attention was focusing on the possible application of this solid propellant projectile to anti-aircraft defence. Test firings of a 5.1 cm diameter rocket began in 1936 in England and then moved to the more remote ranges on the island of Jamaica. In 1937 the design concept matured to a 7.6 cm diameter and by 1939 more than 2,000 test rounds had been fired. The performance was considered poor and this helped to delay further developments, although work continued in England to provide a satisfactory launch system. Crow vacated his office at Woolwich Arsenal in 1938 and set up the Projectile Development Establishment for Unrotated Projectiles with direct responsibility to the War Office.

Batteries of Landing Craft Tank (Rocket) projectiles were used for bombarding shore emplacements, softening up the defences prior to an assault.



Ground crew prepare a Seafire for takeoff and attach solid propellant rocket tubes to either side of the fuselage centre-section on the upper surface of the wing.

During the period 1938–39 interest increased, due partly to the worsening political situation in Europe, and plans were laid to introduce a 5.1 cm diameter rocket which would burn for less than 3 seconds and produce a thrust of nearly 8 kg. Primarily configured for defence against low-flying aircraft, this design was followed by a modified 7.6 cm diameter missile in 1940. From the end of that year, the UP-3 (Unrotated Projectile with a 3-inch (English unit) diameter) was being used for anti-aircraft defence of strategic objectives. The launch system adopted a twin-barrel device called the 'projector' and by the end of the year the system had been placed in quantity production and sent into operational use under the command of Major Duncan Sandys. Delaying plans to send the unit overseas, Sandys took his weapons to Aberporth in Wales and succeeded in broadening the potential scope of the missiles.

During the early months of 1941 many tests were carried out using radar detectors to warn of approaching bombers and before long Sandys had demonstrated a capability embracing the enemy aircraft flying at higher altitudes to that thought possible. Two versions were developed, each 7.6 cm in diameter, and the performance of the missiles enabled aircraft to be intercepted at a height of up to 6.4 km. With fins the UP-3 weighed 23 kg, without fins it was 122 cm long and weighed 50 kg. While development continued, the manufacturing facilities in England were bombed, temporarily reducing output, but by 1942 the projectors had been modified to carry 9 barrels. During that year field strength totalled more than 5,800 projectors (launchers) with a combined launch capability contributing to military campaigns in North Africa.

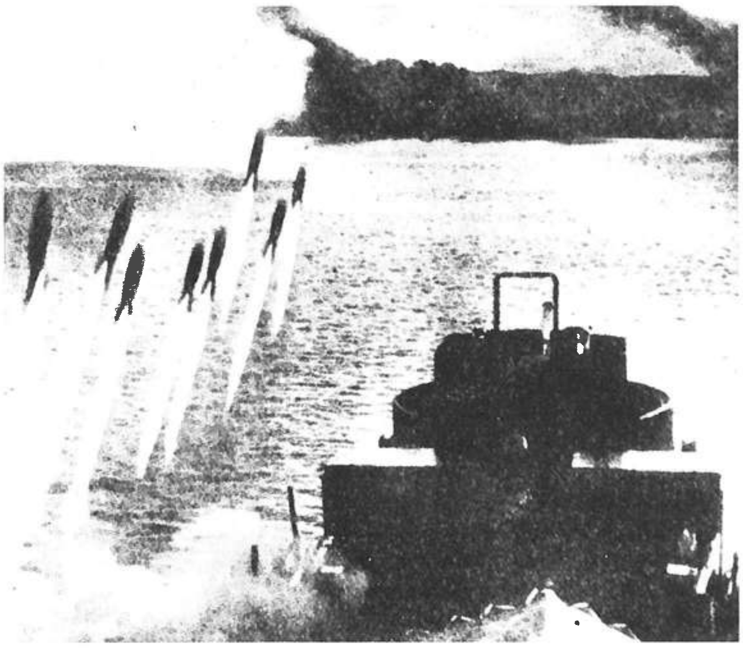
The UP-3 rockets had found valuable application as supplementary equipment to existing anti-aircraft defences and were particularly suited to warding off low-level attack from hostile aircraft. In a variation of the basic UP-3/projector combination, Project Snare was developed, whereby a 7.6 cm diameter rocket would fire to a height of 170 metres and then release a parachute to which was attached a trailing wire, 61 metres long, and a second parachute. Released just as an enemy aircraft was approaching, the wire would endanger the safety of the plane and this equipment was in use as early as June 1940, primarily carried by ships. The only solid propellant motor of comparatively high thrust developed during the 1939–45 war was called Stooge. With a thrust of 345 kg, the pointed missile was developed in 1944 and would be launched with the aid of four supplementary solid propellant boosters developing 2.5 tonnes of thrust for 1.6 seconds. The missile carried a radio guidance system in the nose and was effective at a range of up to nearly 13 km and with a maximum speed of over 800 km/hr, the Stooge was designed to counter high speed enemy aircraft.

During 1942 the British developed a 12.7 cm diameter rocket for use from a portable launch frame; later models utilized a special launcher attached to the back of a truck and in this mode the weapon could accommodate 6 missiles simultaneously. The main purpose of this device was to serve as a short range battlefield weapon, but it saw little action and was not considered to be worth further development by the Army. In 1943 the Royal Navy took up development of the missile and used it in action during campaigns in the Mediterranean. A special Landing Craft Tank (Rocket) vessel was equipped with the 12.7 cm rocket and, with a range of up to 2.7 km, it could fire off 800 missiles in little more than 30 seconds. With spectacular results, the Navy achieved several successes with the LCT(R) and in 1944 the Army again turned its attention to the concept.

The Projectile Development Establishment worked on a new launch system and eventually came up with a 'Land Mattress' that could be fitted to the back of a truck equipped to fire 30 rockets in salvo. Several of these combinations were used in Europe late in 1944 and early in 1945. But there is little doubt that the stress of war production exerted a crippling strain on resources and if there is one single cause for the lack of major rocket work in Britain between 1939 and 1945, it must be due to the necessary emphasis placed on existing and well-tried weapon systems. It is doubtful if German rocket developments during the European war would have reached the level they did had the designs not already been there before hostilities broke out. While the British explored many exotic avenues of weapons research, the pressing need to maintain supplies of basic munitions prevented a full and expanding application of the solid propellant rocket. It would be amiss to ignore the development of air-to-surface missiles, however, and it is in this area of research that results were the most satisfactory.

Although Britain failed to recognize the possible application of rockets to aerial warfare until 1941, progress after that was rapid and by mid-1942 tests had shown the feasibility of placing 5.1 cm diameter missiles under the wings of aircraft. The first tentative experiments had been carried out using a Hurricane fighter as early as 1941. The basic missile consisted of a cast iron pipe filled with solid propellant and carrying a warhead at the front and four fins at the rear. The warhead was changeable and could be either a 11.3 kg armour piercing charge, or a 27.2 kg high explosive. The 27.2 kg warhead soon became standard and the 163 cm missile had a range of 1.6 km and a maximum speed of 1,600 km/hr. Called the RP-3, the missile was attached to long launch rails on the undersurface of the wing by connector lugs and electrically ignited from the cockpit.

The RP-3 entered operational use on anti-shipping duties in 1942 from Royal Navy Swordfish and Royal Air Force Liberator aircraft. Toward the end of the year the Royal Air Force fitted the missiles to Typhoon aircraft and later to Hurricanes, the latter carrying four under each wing. Although the rockets brought a performance penalty to the carrier aircraft, they were particularly effective against large and slow moving targets and 603 Squadron introduced the rocket to Mediterranean operations in November 1943, when their Beaufighters carried 8 RP-3's apiece into action against targets in Crete. Following the invasion of Europe in June 1944, British aircraft made many successful rocket attacks on troop concentrations, trains, small boats and other inland targets.



A battery of ship-to-shore rockets is loosed against Mindoro in this dramatic photograph taken seconds after ignition.

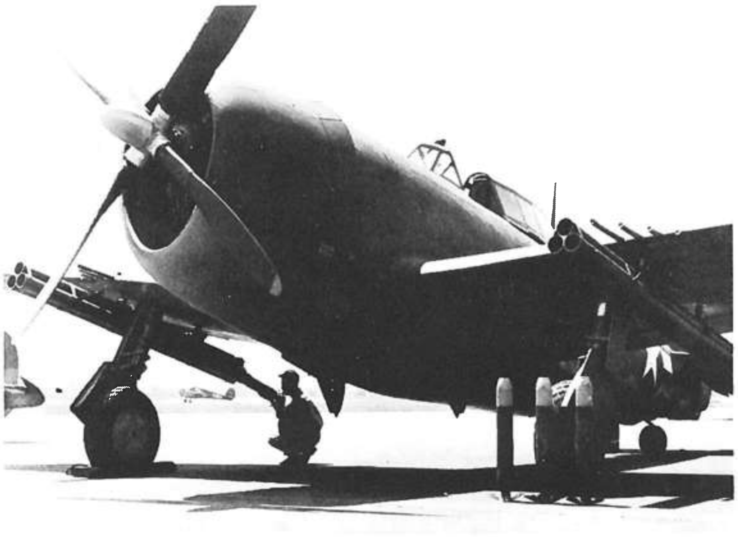
When V-1 flying bombs began their assault on London and the Home Counties, air-defence units were withdrawn from the capital and set up along the coastal area of the English Channel so the intruders could be brought down before reaching heavily populated areas inland. Batteries of Royal Navy rockets are seen here in action against the V-1.

In naval operations the rocket was found to be particularly effective, its penetration crippling many submarines on or just below the surface. Production difficulties early in 1945 prevented the missile from achieving even greater prominence, although its contribution to the evolving history of ballistic and guided rocket development was not confined to the British alone. Although the United States were late in joining the conflict in Europe the alarming attack on Pearl Harbour in December 1941 brought a new awareness of its existing technology and with American troops soon to be fighting in almost every theatre of the war, fresh appraisals brought hesitant action to a lethargic American rocket programme. Not until the British had successfully demonstrated the performance of RP-3 rockets in early 1942, were the Americans prepared to commit major resources to development of a comparable device.

At that time work had been under way for two years leading toward the first US solid propellant battle missile. In June 1940, President Roosevelt authorized the establishment of the National Defence Research Committee, or NDRC, with a division specially set up to monitor progress in various fields of technology pertaining to rockets. Under the direction of Vannevar Bush, the NDRC controlled an Armour & Ordinance Division with authority over test and development sections run by Clarence N. Hickman and Charles C. Lauritsen. The latter was to head work on rockets at the California Institute of Technology; Hickman was to work with Colonel Leslie Skinner in bringing to fruition the design concept which matured into the first US general purpose missile.

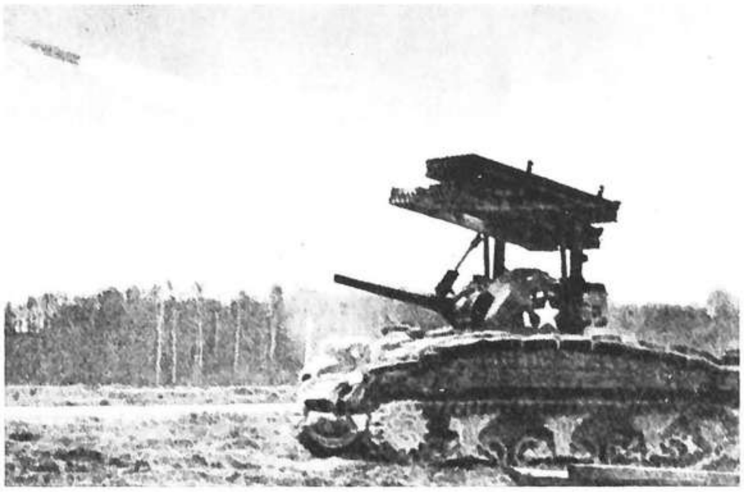
During 1941 ideas were bandied around on the apparent superiority of reaction weapons suited to a variety of launch modes and mission tasks. Nothing positive had yet emerged and several different concepts were drawn up so that the team could select one promising proposal. It was decided that the air-to-ground missile looked the most suited to current levels of technology, but Hickman, Skinner and a Captain Edward G. Uhl, late of the Aberdeen Proving Ground and now working with Skinner to refine design details, found reluctant Army Air Corps staff unconvinced of the project's suitability. It was only as a result of the successful British tests that the project was finally approved.

As conceived, the missile would adopt a 11.4 cm diameter solid propellant case and before the end of the war it would be adapted by land and air forces before further developments led to a 12.7 cm diameter version for use from naval vessels.



A Republic P-47D Thunderbolt sports six 11.4 cm diameter solid propellant air-to-ground rockets in two triple-tube launchers, one to each wing. Three projectiles can be seen standing in front of the port wing, minus fuse caps, while, under the starboard wing, a ground crewman feeds a missile into a launcher.

The 12.7 cm diameter High Velocity Aircraft Rocket (Holy Moses) was fitted to the P-47N Thunderbolt from mid-1944 with five missiles per wing. Note the short fins at the rear of each projectile.



A US Army Sherman tank fires off a 11.4 cm solid propellant rocket from a special turret mounting. Each Sherman modified for the rocket assault role could carry sixty projectiles.

The most popular air-launched model was 84 cm long and could carry a payload of up to 2.3 kg. With a launch weight of 17.3 kg it was launched from beneath the wing of a modified fighter aircraft and could achieve a speed of nearly 1,000 km/hr. The first operational use of the 11.4 cm diameter rocket came in late 1943, over Burma, and less than a year later a specially modified version weighing 46.7 kg was developed for use against 'hardened' targets. With a length of 1.8 metres it was expected to possess a range in excess of 6 km, but the device was never introduced into service use.

A basic launcher modification for the standard 11.4 cm rocket, grouped three tubes in a cluster under each wing of a P-47 Thunderbolt and this was brought into action in October 1944 against targets which were being used as fortified defence positions. The accuracy and pilot skills acquired during rocket attacks on ground facilities brought new operating procedures into being and with the standard equipment installed, ground troops were backed up by low level attack on enemy positions only 1 km in front of advancing ground forces. Meanwhile, work was under way on a 8.9 cm diameter rocket not unlike the British 7.6 cm diameter anti-aircraft rocket and by late 1943 the California Institute of Technology had produced an effective, 1.4 metre long, missile weighing 24.7 kg.

By 1944 the rocket had been developed in two versions: one adopted a special penetration warhead that could be used against sub-surface targets and the other carried standard warheads for use against surface ships. Designated the Forward Firing Aircraft Rocket (FFAR), the missile was precursor to a specially developed, 1.6 metre-long, design which was eventually used by the US Navy for shore attack. By mid-1944 the NDRC, working with the California Institute of Technology, produced a 12.7 cm diameter High Velocity Aircraft Rocket (HVAR). Dubbed 'Holy Moses', the rocket saw action in France late in the year and was then brought into wide use against ground and shore targets during operations in the Pacific theatre.

While all air-to-ground rockets discussed so far were launched from rails or tubes on the undersurface of an aircraft's wings, the largest missile in this category employed a delayed action launch technique whereby ignition was triggered by a lanyard connecting the rocket to its rack. Called 'Tiny Tim', it was a 29.8 cm diameter solid propellant device, 3.1 metre long and with a thrust of 13.6 tonnes. Because of the sheer magnitude of the missile's thrust, exhaust products would have destroyed the wing surface of the launch aircraft, so it was necessary to release the device, allow it to fall to a safe distance and then ignite the propellant. Although the rocket weighed only 582 kg its 68 kg warhead was said to be the equivalent of a 30 cm shell. From late 1944, Tiny Tim was used with increasing effectiveness against targets in the Pacific.

Some effort was made in the closing months of the war toward development of an air-to-air missile based on the standard 11.4 cm diameter rocket and it was hoped to place these on bombers for defence against high speed fighters. As it turned out, the war drew to a close before production could begin and the weapon was never used in any great numbers. However, the mainstay of solid propellant rocket applications continued to be the 11.4 cm diameter design and this was used in a variety of versions for ground and seaborne forces. Mounted on the back of a truck, or set up in tube launchers on naval vessels, the missile saw action with a wide range of warhead configurations and did much to supplement conventional artillery.

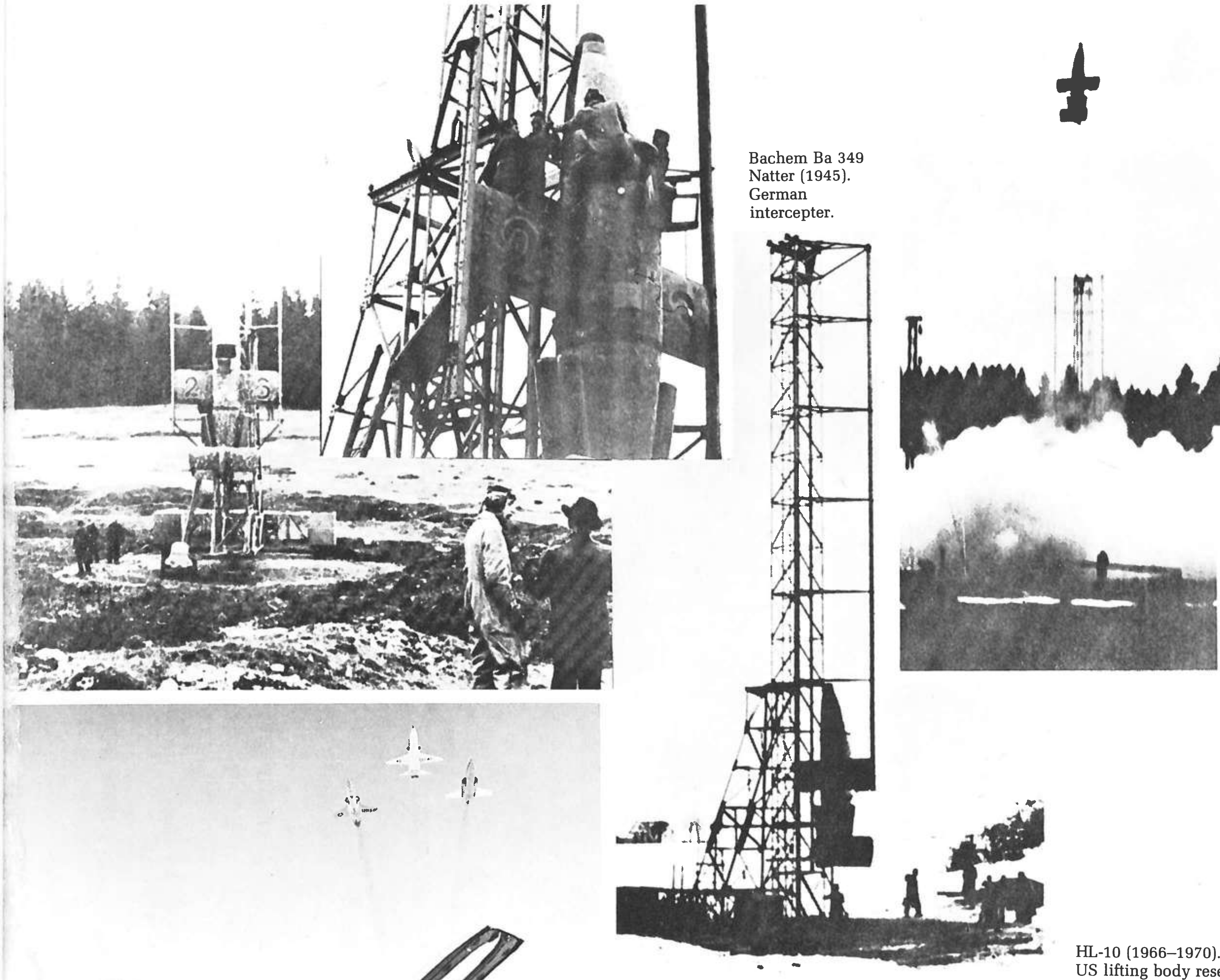
A special High Velocity Spin Stabilized (HVSR) Rocket was developed for use from off-shore boats and this design adopted a 12.7 cm diameter projectile to achieve a range of about 8 km. Specially adapted launch ships were brought into use, with a capability of firing 500 missiles a minute in sequential salvo. With a warhead charge of up to 1.3 kg, the larger rocket was used to supplement the 11.4 cm diameter missile of lesser range.

One of the most successful projects involving rocket propulsion was designed as an infantry weapon for use against mobile armour and fixed concrete emplacements. Called the Bazooka, it took the form of a cylindrical tube launcher 1.37 metres long and 7.6 cm in diameter. With a self-contained ignition system, the launcher housed a 55 cm long, 6 cm diameter, projectile with solid propellants and an explosive charge of 0.7 kg. The Bazooka, at 7.6 kg, was sufficiently light to render it a valuable addition to an infantryman's equipment; placed over the shoulder so that the eye could align sights on the target, the weapon was fired by a trigger mechanism connected to a small squib igniter. Bazooka development began with the requirement for a recoilless grenade launcher late in 1940 and within two years the rocket launcher was in full production. Capable of hitting targets at a range of 640 metres, the Bazooka was used in large numbers throughout European and Pacific theatres.

The Bazooka became standard equipment with US infantrymen d·
World War II, a highly effective weapon against hardened emplace·

(Continued on page 72.)

A pictorial survey of piloted, rocket powered aircraft



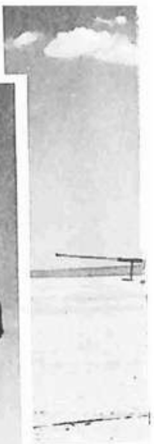
Bachem Ba 349
Natter (1945).
German
intercepter.

1970–1972).
g body
aircraft.

HL-10 (1966–1970).
US lifting body research aircraft.

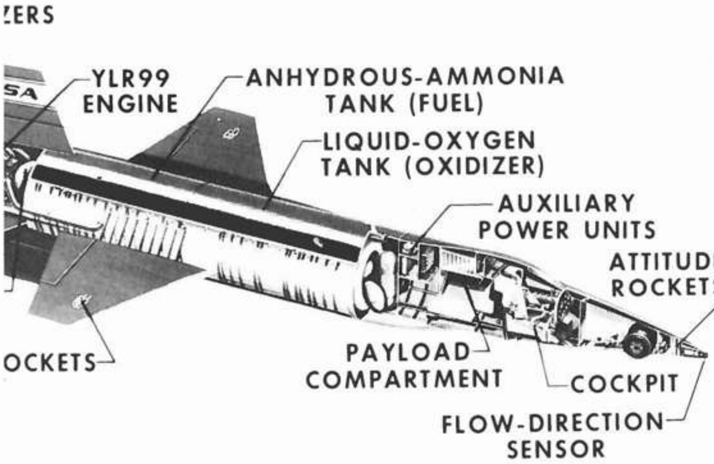
Me-163 Komet (1941-1945). German fighter.

X-1 (1946–1951). US research aircraft; first past Mach 1.

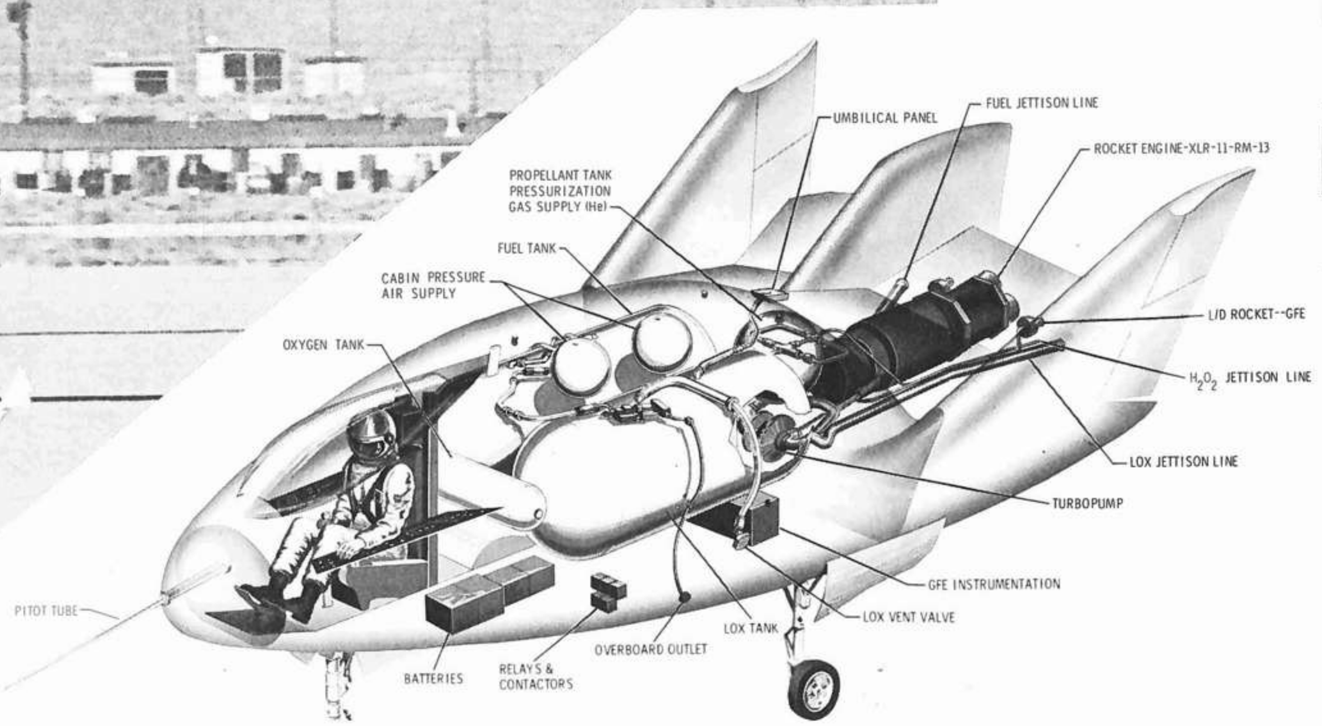


Me-263 V1 (1944). German fighter.
Formerly JU248V1.

X-15 (1959–1968). US research aircraft.



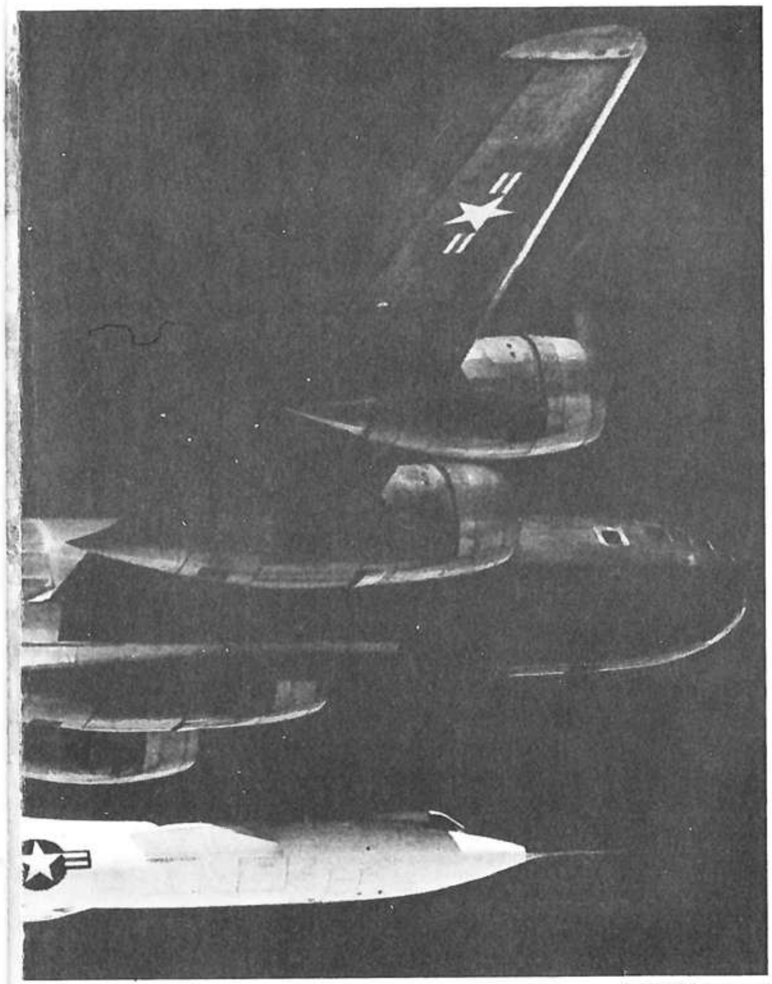
HL-10 landing.



X-24a (1969–1971).
US lifting body research aircra

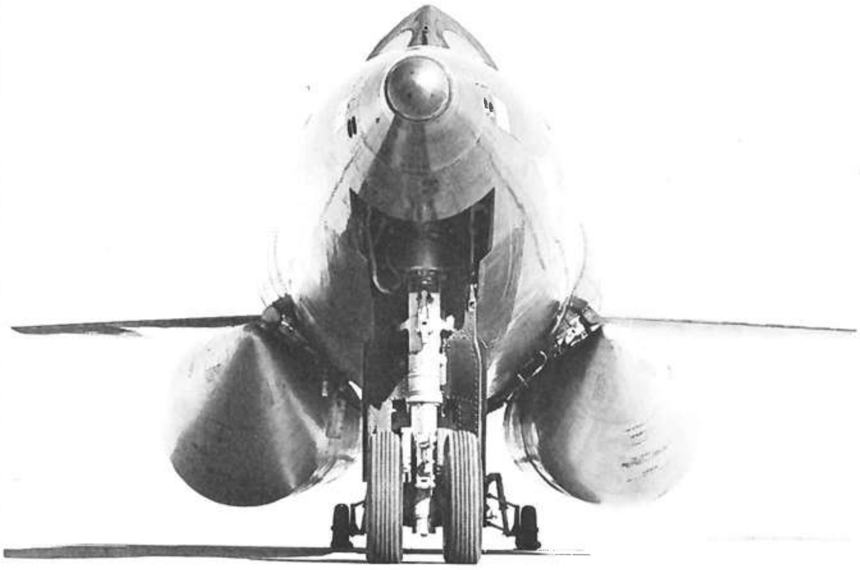
X-1E (1955–1958). US research aircraft.

X-2 (1952–1956). US research aircraft.

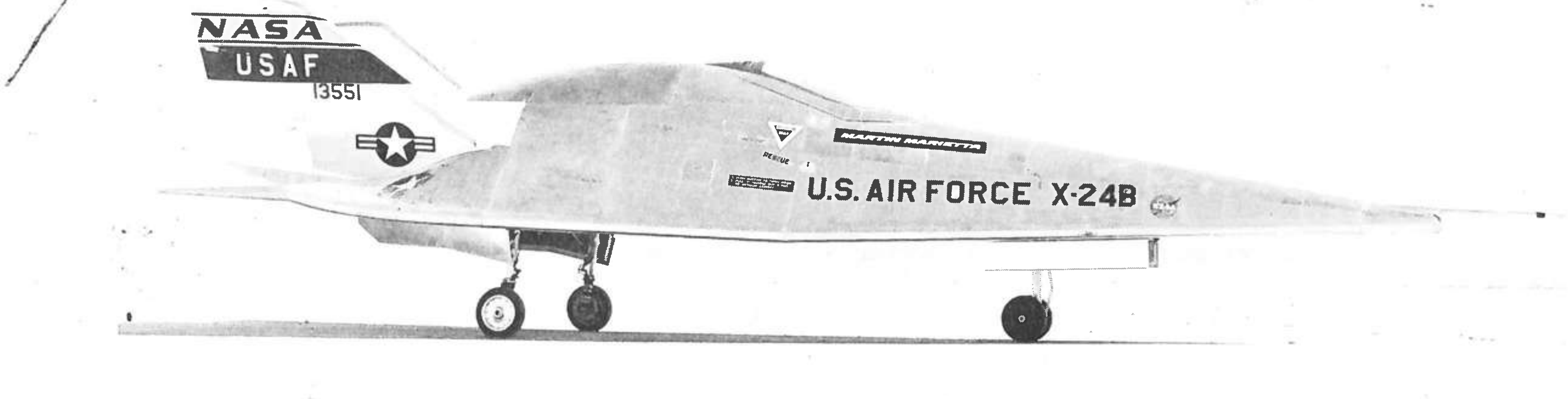


Skyrocket (1951–1956). US research aircraft.

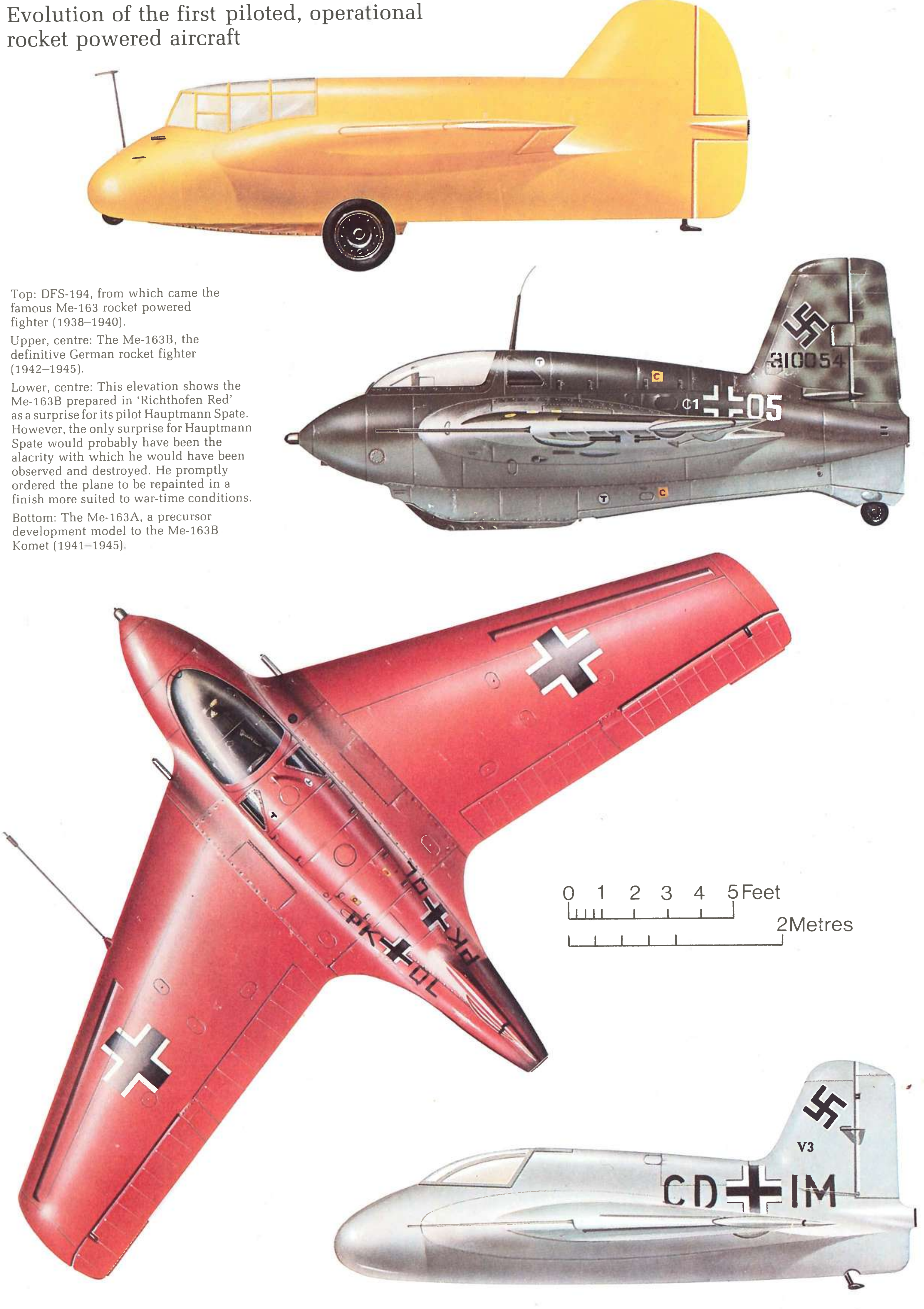
X-15-A2 (1964–1967). US research aircraft with drop tanks.



X-24B (1973–1975). US lifting body research aircraft.



Evolution of the first piloted, operational rocket powered aircraft



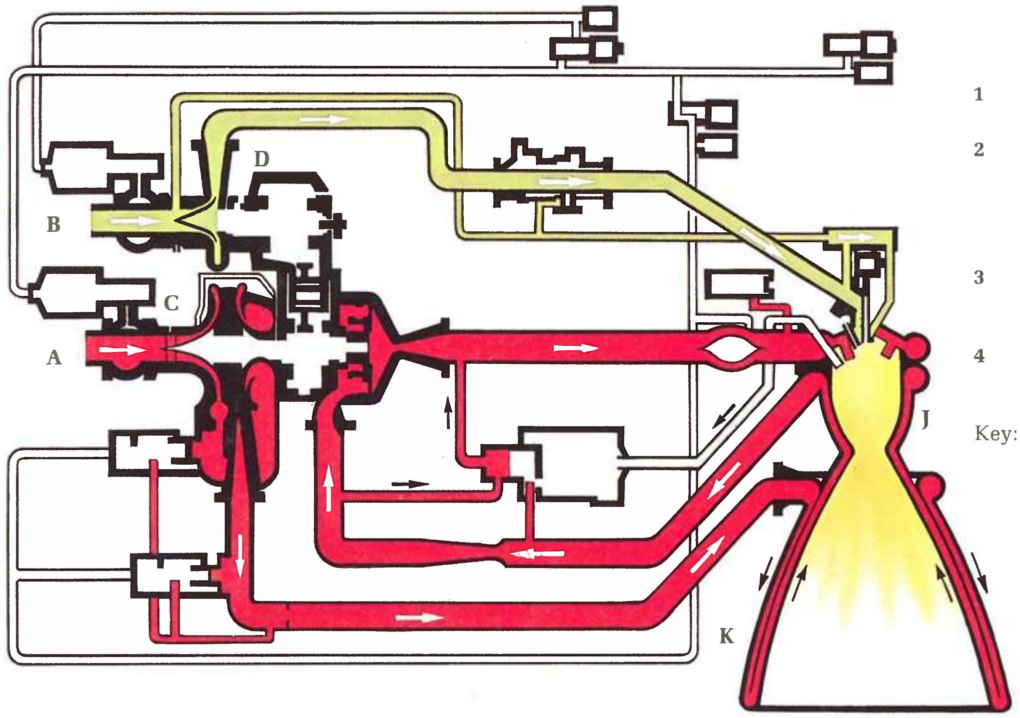
Top: DFS-194, from which came the famous Me-163 rocket powered fighter (1938–1940).

Upper, centre: The Me-163B, the definitive German rocket fighter (1942–1945).

Lower, centre: This elevation shows the Me-163B prepared in 'Richthofen Red' as a surprise for its pilot Hauptmann Spate. However, the only surprise for Hauptmann Spate would probably have been the alacrity with which he would have been observed and destroyed. He promptly ordered the plane to be repainted in a finish more suited to war-time conditions.

Bottom: The Me-163A, a precursor development model to the Me-163B Komet (1941–1945).

1



1 A typical rocket engine layout as adopted for numerous designs in the early 1960s.

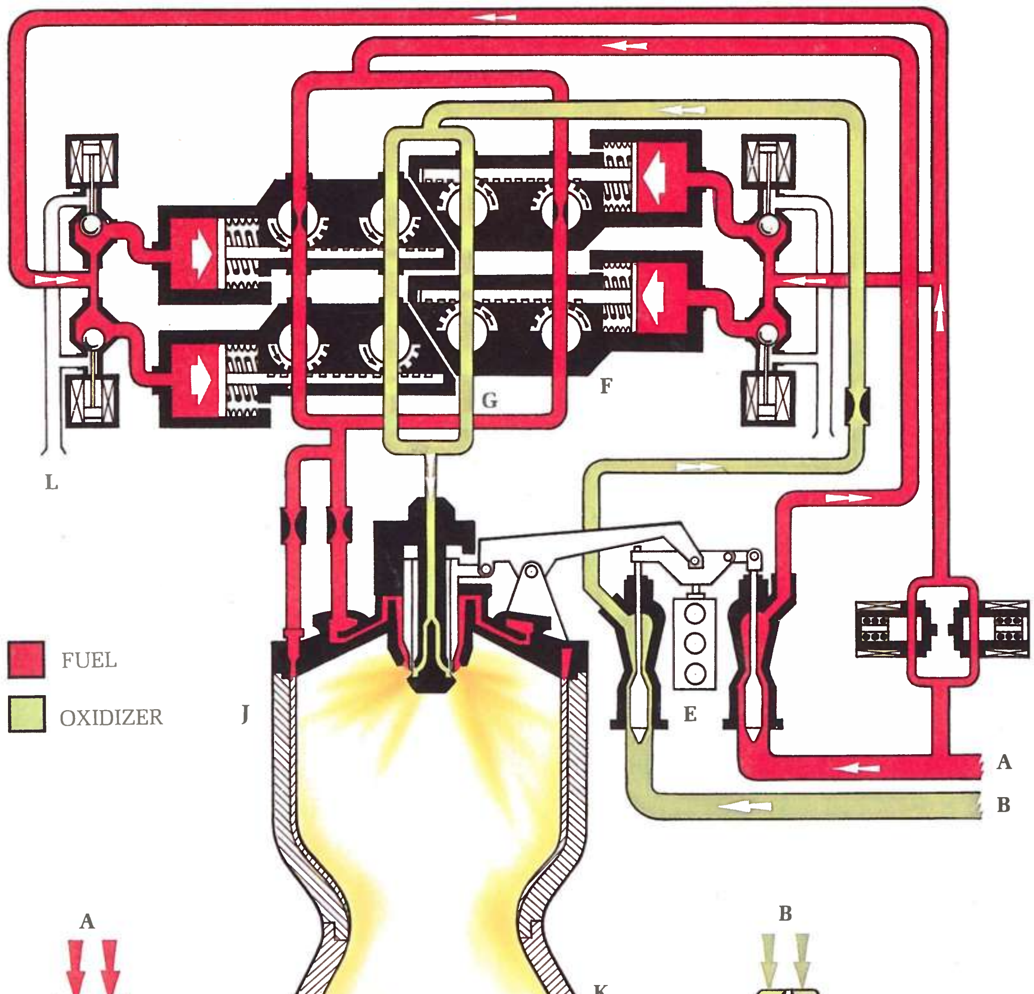
2 Designed for high reliability, with back-up systems not usually designed into a rocket engine, this shows the Lunar Module descent engine used to land astronauts on the Moon during Project Apollo.

3 The advanced nature of the Shuttle's propulsion system adopts very high chamber pressures and incorporates a pre-burner for fuel and oxidizer.

4 NERVA, the nuclear rocket engine which used reactor heat to replace conventional chemical combustion.

Key: (A) Fuel inlet. (B) Oxidizer inlet. (C) Fuel pump.
(D) Oxidizer pump. (E) Flow control valves.
(F) Fuel shutoff valve. (G) Oxidizer shutoff valve.
(H) Fuel preburner. (I) Oxidizer preburner.
(J) Combustion chamber. (K) Expansion nozzle.
(L) Vent.

2



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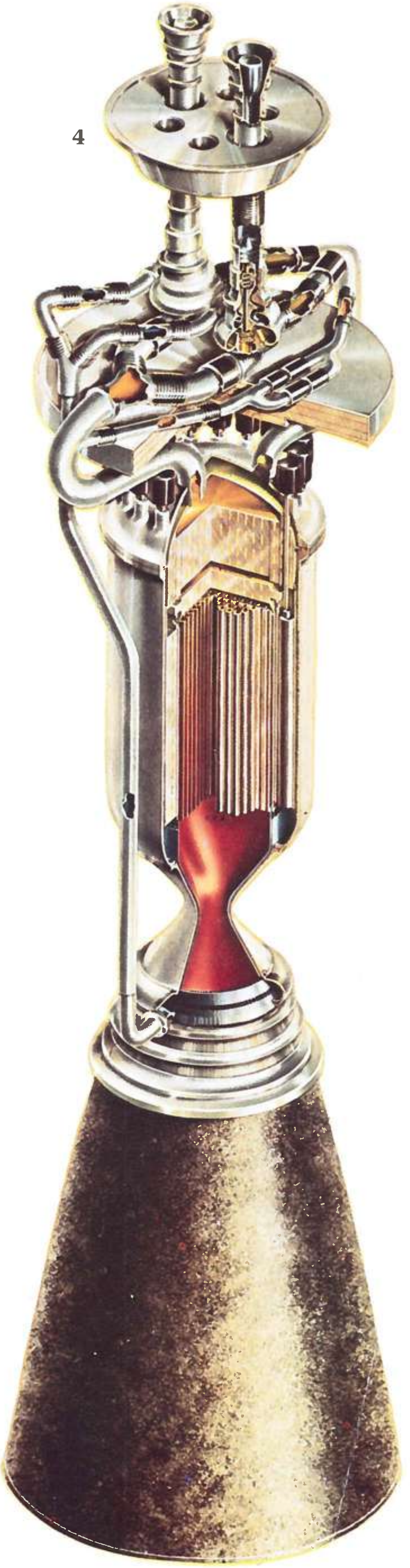

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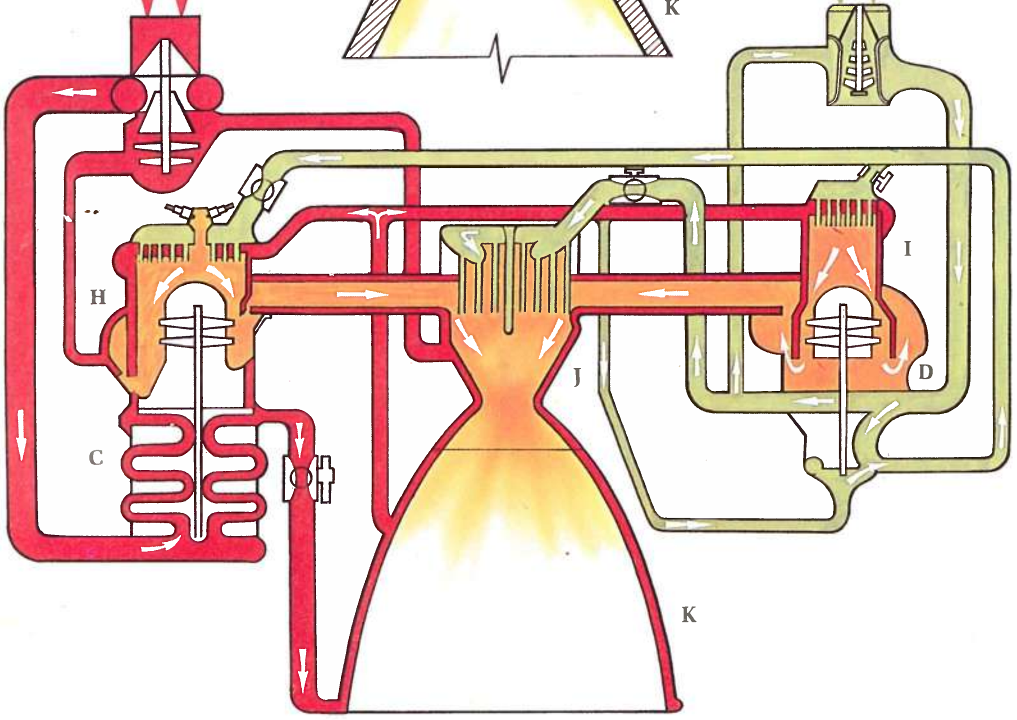


(Continued from page 66.)

Long before the attack on Pearl Harbour brought the United States into a war with Japan, a nucleus of engineers and technicians had set themselves up at the California Institute of Technology (Caltech). Calling themselves the GALCIT Rocket Research Group (GALCIT was an acronym for Guggenheim Aeronautical Laboratory at the California Institute of Technology), the team operated on funds organized by Weld Arnold and worked on both solid and liquid propellant rocket research under the directorship of Theodore von Karman; leading personalities during these early days of GALCIT included Frank J. Malina, Hsue-shen Tsien and Edward S. Parsons, all of whom would play important roles in the development of America's first major rocket programmes a decade later.

The main objectives of the team were the peaceful application of the rocket to sundry research tasks in the upper atmosphere and the gradual maturation of existing technology to a level where it could be applied to precursor space programmes, albeit on a very modest scale. A considerable amount of assistance came from existing records of tests performed by members of the American Rocket Society and members of that voluntary organization did much to spur the team on with theoretical and practical help at all levels of study and evaluation. A considerable portion of the GALCIT work embraced problems associated with liquid propulsion and, in the end, it was because of the attention to this less exploited concept, that America was able to develop its first research rocket toward the end of World War II.

One of the most important projects undertaken in these lean years was a variable pressure combustion chamber using methyl alcohol and gaseous oxygen propellants. But already events on the political front in Europe, instilled an awareness of impending hostilities and in December 1938 the Army Air Corps recognized the progress being made by the California team and requested that the National Academy of Science provide the stimulus to develop rocket boosters which could be used to assist take-off with heavy aircraft. By July 1939 Caltech had set up the Jet Propulsion Research Project under the directorship of von Karman and in 1940 the Army Air Corps wrested control of the work from civilian authorship. It is interesting to note that while most of the work embraced by these assignments was centred on rocket propulsion, the word 'jet' was applied in each and every case when an organization was set up to conduct theoretical and practical tests. The popular interpretation of the word 'rocket' had too flippant a connotation to engender the degree of respectability demanded by the work!

All the lessons that had been so carefully learned in the years since GALCIT was formed in 1936, were now applied to the design problems associated with jet-assisted-take-off (JATO), along with many new areas of technology, including research into slow burning solid propellant chemistry (always a difficult thing to achieve) and several efforts directed towards the continued work on the application of liquid propellants for this purpose. By mid-1941 a reasonable success record had been established with a motor designated GALCIT-27 which produced a thrust of 12.7 kg for up to 12 seconds. During August of that year tests were carried out using this rocket motor on an Ercoupe monoplane, a very light aircraft which showed that the GALCIT-27 could halve the time required to become airborne.

The JATO motors used in this test series adopted an amide propellant, that is to say a group of organic compounds resulting from atomic changes to ammonia. But, good as it was, GALCIT-27 was only the beginning of a series of developments leading to a larger series of JATO rockets which could be used by heavy aircraft. Meanwhile, a group from the American Rocket Society formed the world's first commercial business based solely on the requirement for JATO packs: Reaction Motors Incorporated of New Jersey. The company would remain in the forefront of rocket motor technology and still play a leading role in solid propellant research and production. Elsewhere, in California, the Aerojet Engineering Corporation set up shop on the strength of work carried out at Caltech and this firm too would produce many JATO packs during the war years before being absorbed into the General Tire and Rubber Company.

Work generated by the successful tests with GALCIT-27 led to the production of JATO motors capable of delivering thrusts of up to 450 kg and these were based on a solid propellant formed from potassium perchlorate and an asphalt compound. Other developments in 1941 and 1942 centred on liquid propellants and these used a mixture of nitric acid and aniline to produce a similar thrust.

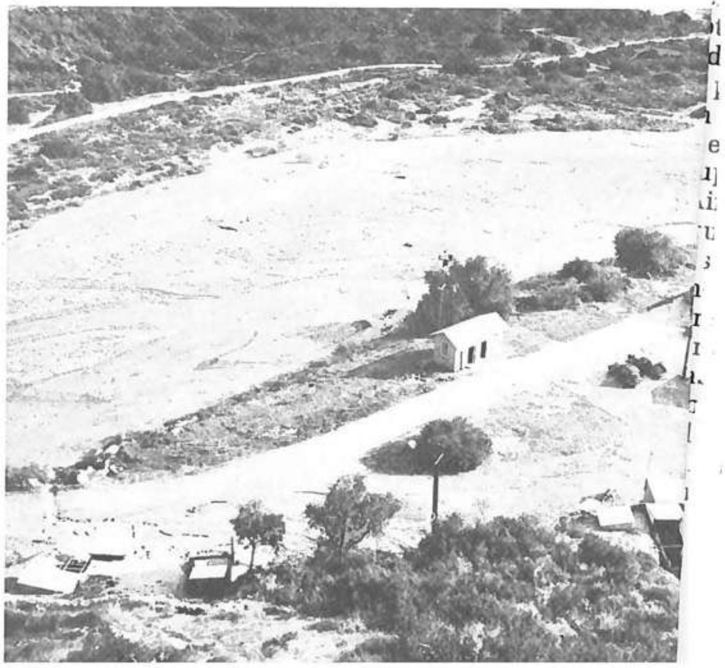
In August 1941, Robert Goddard was invited to go to Washington and attend a conference on the strength of a report from Navy Lieutenant Charles Fischer, who had been sent to New Mexico to see the great pioneer; for the past year Goddard had been serving as consultant to Vannevar Bush at the NDRC, the only government function he had so far been called upon to perform. A month after arriving in Washington, Goddard was offered the opportunity of applying his knowledge to the development of JATO rockets under a joi Navy–Air Force contract granting him $20,000 for twelve months work. Back in New Mexico he pressed ahead with tests and reported, in May 1942, that he would soon be ready to begin live demonstrations. The Navy responded by exercising a contractual option to move him to Annapolis, Maryland and in July Goddard packed up shop at Roswell to commence his new appointment.

Arriving at the Naval Engineering Experiment Station five days later, Goddard set to work on the development of liquid oxygen and petrol-propelled motors until, on 22 September, the Navy pressed him for a live test and had the engine installed in a PBY-2 seaplane called the Catalina. It was a large aircraft, with a length of 19.8 metres and a wingspan of 31.7 metres, grossing over 10 tonnes. On 23 September, six good takeoffs were performed, but against the advice of Goddard, a seventh run began and nearly ended in disaster when the combustion chamber on the JATO rocket blew apart under the stress of continued testing, sending the Catalina back into the water.

Critical of the hurried nature of the Navy tests, blaming haste and mishandling for the accident, Goddard was put to work on less demanding projects and spent the rest of his time at Annapolis on contract work for other laboratories. The Bureau of Aeronautics were not enamoured by the individualistic approach that Goddard took to his work and h was unable to gain further governmental support. In the end it was the GALCIT work that led to an evolving series of JATO packs, together with other liquid propellant motors developed at Annapolis under the auspices of Robert Truax.

While most of the work performed by the GALCIT Je Propulsion Research Project had contributed toward th steadily evolving development of booster rockets for assiste takeoff, a wealth of knowledge was steadily emerging on variety of propellant configurations and combinations whic would stand the group in good stead from 1943 on. Th practical problems of handling solid propellants and th eternal quest for stable, storable liquid propellants generate

As seen in 1941, the Jet Propulsion Laboratory site was little more than collection of shacks and wooden buildings. From here the GALCIT test were carried out which led to major advances in the technology of soli propulsion.



continued dialogue between Caltech and the emergent cor- orations such as Reaction Motors and Aerojet. Gradually, a ompetent library of successful tests was built up, leading oward the fulfilment of the original purpose of the GALCIT oundation: the application of rockets and their associated echnology to the scientific analysis of the upper atmosphere nd near space. The group were still a long way from justify- ng developments of a missile to perform such feats, but the echnology was leading toward the day when such a project ould become feasible.

There followed, from mid-1943, a series of events which in many respects, echoed the path taken by German rocket pioneers several years before. In July, GALCIT was asked to evaluate the British Intelligence reports associated with Ger- an rocket activities. Von Karman enlisted the aid of Dr. e-Shen Tsien and Frank Malina in drawing up a report, ch was completed by 2 August, indicating likely areas of chnology development based upon the meagre scraps of nformation. Very little was known about the German effort at his time, but the GALCIT report was sufficiently alarming to xcite the interest of Air Force Colonel, W. H. Joiner, who studied the findings and concluded that some effort should be applied to studying the potential application of American rocketry to military tasks.

It will be remembered that at this time the United States was in the process of building up an inventory of air-to-ground, and ship-to-shore missilry based on storable solid propellants; Joiner, the technical officer assigned to monitor theoretical work at Caltech, appreciated that the GALCIT and JATO work was now building toward the possible design of a ballistic missile, based, perhaps, on liquid propellants of high thrust yield and increased specific impulse. Consequently, von Karman took matters into his own hands and decided to give the prospect a nudge in the right direction by appending recommendation that the United States authorize develop- ent of a long range ballistic missile. Frank Malina recalled ater, that it was at this point that the investigative trio coined e title 'Jet Propulsion Laboratory', a name it was later to quire with pride.

The report and its appended recommendation was sent to ght Field and the office of the Commanding General at the Force Materiel Centre. It was taken up by Colonel G. W. ichel, then chief of the Rocket Development Branch at the dinance Department, after receiving a copy from the then tain R. B. Staver; both men would later play an instrumen- l role in retrieving documents and hardware associated th the German V-2 rocket, as related earlier in this chapter. ere followed, over the next few months, controversy as to o should be more properly associated with development of ng range weapon. The Army felt it was within their man- e; the Air Force argued that it was theirs. Nevertheless, mulated to concentrate on the technical problems leading a large military rocket, von Karman set about the prelimi- ary evaluation of matching extant technology to a potential esign concept.

Staver and Trichel were in a position to recognize the great rides that were then being made and wished to get authority a major rocket programme before war's end and a return to demic isolationism, which they felt the government may pt. All too aware of the fate awaiting advanced research d development projects in such a climate, they did all in ir power to push the proposal and contacted von Karman ain in January 1944 with a request for more precise details e desired approach. Frank Malina would later recount prise at the total lack of interest in such a project from ir Force.

uring the first month of the new year, Colonel Trichel sed the singular interest of the Ordinance Department nding the project, if Caltech would donate facilities and nnel to the effort. Also, the GALCIT team was asked to are financial estimates, a list of development tasks, a able of events associated with the development phase an indication as to the various precursor rockets which ld have to be built leading to a definitive ballistic long e missile.

on Karman, taken aback by the sudden burst of astic interest in their proposal, sought council with tech administration and secured authority to present the new proposal on the grounds that the necessary facilities would be provided as and when the project moved ahead. The re-submitted proposal was sent to Major General G. M. Barnes, at the Technical Division, Ordinance Department, in Washington on the last day of February, 1944. With almost unobtrusive simplicity, it seemed the United States' first long range ballistic missile was maturing into a funded project. Confirmation of this came in a reply from Major General Barnes, which accepted the proposal and endorsed the specification written up earlier.

The missile was to be capable of achieving a range of 240 km carrying a high explosive warhead weighing 450 kg. It was to be capable of high accuracy at the target and to fly along its trajectory at sufficient speed so as to render it impossible to intercept with conventional aircraft. In several respects the specification contained parallel features to those written up for the A-4 in 1936 from the Kummersdorf-West rocket research facility south of Berlin. A letter of confirmation arrived from the Ordinance Department in June 1944 and before long a contract authorization had stipulated that work should be performed from January 1945 to June 1946.

At about this time the Jet Propulsion Research Project at Caltech was re-designated ORDCIT, for Ordinance at California Institute of Technology, and the facility title was officially changed to JPL-GALCIT, for Jet Propulsion Laboratory-Guggenheim Aeronautical Laboratory at Caltech. In May 1944, von Karman, director of what was then to be called the Jet Propulsion Laboratory, fell ill and vacated his position to Frank Malina until his return in the following September. Administrative control of the very much expanded role of the original GALCIT group at Caltech, was to be lodged with a new Executive Board, chaired by Clark B. Millikan, with responsibility to executives at Caltech who, while preventing additional burdens falling on the shoulders of the Institute, preserved the authority and autonomy of the JPL team. From the Ordinance Department, Colonel L. A. Skinner would liaise with the ORDCIT project and oversee Army interests.

The Assistant Military Attaché to the Ordinance Department in England, Colonel F. F. Reed, paid a visit to Caltech and reviewed the scope of ORDCIT as then envisaged. As a reciprocal gesture, Malina flew to London in October to discuss British interests in rocketry. He soon found that they centred on the problems of applying solid propellant rockets to ground-to-air, anti-aircraft, duties and among the distinguished personalities he saw were Alwyn D. Crow, a leading figure in the development of British rockets, R. F. Fraser from the Imperial College of Science and Technology and Air Commodore Frank Whittle, a pioneer in jet propulsion for application to powered flight. For ten days in November, Malina visited V-1 flying bomb launch sites in France, recently captured from the Germans, and the concrete complex at Watten, originally designed to provide a hardened launch stand for V-2 rockets.

In establishing the requirements for the ORDCIT programme, von Karman, Malina and Tsien envisaged three sequential developments, each producing a rocket with different characteristics and called, in turn, Private A, Private F and Corporal. Later, a sounding rocket project would adopt the name Wac Corporal and, still later, the Army's first guided missile would be called Sergeant. The first three projects under the ORDCIT mandate explored three very different approaches to missile design.

The first adopted a composite solid propellant, the second used the same engine, but carried wings and the third adopted a liquid propellant combination. When the Private A emerged in late 1944, it was seen to form the first experimental platform for a series of sequential tests leading to development of the long range missile. Work on this latter design, the Corporal, would await preliminary results from the precursor vehicle.

Private A was a little more than 2.3 metres in length, 26 cm in diameter and carried four fins at the rear spanning 87 cm. Propulsion for the rocket came from the newly formed Aerojet Engineering Corporation and consisted of an asphalt based composite propellant motor, with a thrust of 450 kg and a specific impulse of 186 seconds (see Chapter Two). Much original research would be conducted on composite solids by the ORDCIT project leading to the first effective application of this concept in several prominent military missiles of later decades. The GALCIT 61-C motor, fitted to the Private rocket, was capable of steady burn for a period of 30 seconds and the projectile weighed 249 kg and proved capable of carrying a payload weighing 27 kg.

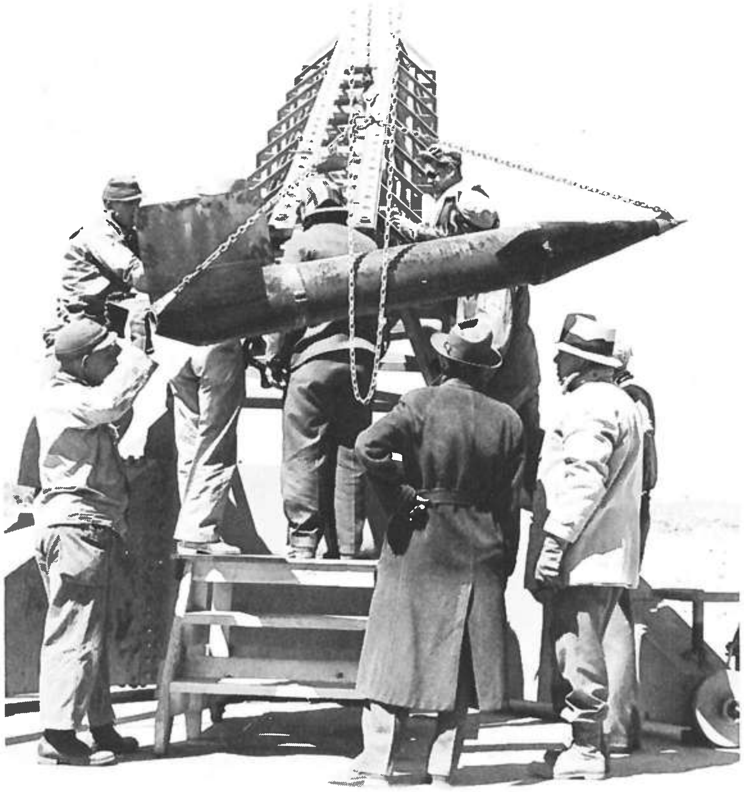
Composite propellants form a group whereby separate fuel and oxidizer is brought together and mixed into a single solid mass called the 'grain'. The fuel is usually prepared in the liquid state and in these early days of research on composite propellants, consisted of an asphalt-based product; the oxidizer was in the solid state, usually as a powder, and mixed well in with the fuel. Later developments would explore the resin family of fuels. When the grain was prepared it solidified and this formed the composite propellant. The alternative solid propellant is the double-base type and in this approach each of two primary constituents could, theoretically, burn of its own accord in a vacuum, containing a mixture which includes the properties of both fuel and oxidizer. However, the two constituents together provide better burn characteristics than either would demonstrate alone.

Supplementary thrust was granted to the Private A design in the form of four solid propellant boosters, developed by the Ordinance Department and providing a total thrust of nearly 10 tonnes for 0.2 seconds. Private A was launched from a quartet of guide rails inside a steel boom assembly 11 metres tall and the first flight was performed on 1 December 1944. In all, 24 Private A rockets were launched, with a demonstrated range of up to 18.3 km and a peak altitude of some 4.4 km. Maximum speed achieved was 1,400 km/hr. By mid-December the tests were over with good results in flights that originated in the Mojave Desert near the town of Barstow, California. Work had now reached a point where the second rocket, Private F, could be brought to the test stage and this resulted in a configuration very similar to the first design.

The principal difference resulted from the fitting of wings, two small canard surfaces toward the nose and a tail unit at the rear, incorporating horizontal stabilizers and a vertical tail. The main wings had a span of 1.5 metres and the forward aerodynamic surfaces spanned 92 cm. Theory predicted that the range of the basic Private A would be increased by as much as 50% with these added lifting surfaces and flight trials got under way on 1 April 1945. Within two weeks, the series of tests was over, having demonstrated little of the hoped for increase in performance. All the Private F rockets fired, exhibited loss of stability shortly after launch and the project was deemed a failure by the ORDCIT group. Nevertheless, it did contribute useful information on the problems associated with aerodynamic stability.

As an outgrowth of GALCIT research, ORDCIT produced the Private A experimental rocket, seen here streaking away from Leach Spring, California, in December 1944.

In a two-week period during April 1945, the ORDCIT team test fired Private F rockets as part of the continuing research effort that led to Corporal. Note the aerodynamic control surfaces: two forward and three at the rear.



Work continued apace on the Corporal long range missile, the basic objective of the ORDCIT programme at its instigation, and a more comprehensive portrayal of its place in the development of post-war missilry will be found in a subsequent chapter. Suffice it to say here that the project was still in theoretical stage by the time the United States accepted the surrender of Japanese forces, which effectively brought a close to hostilities in August 1945.

During the second week of December 1944, while Frank Malina was returning from his tour of V-1 and V-2 launch sites in France, the prospect of developing a reliable sounding rocket arose which was to lead to the Wac Corporal; a very different rocket to the Corporal that would be used in the 1950's as a battlefield weapon, but one which, nevertheless, would provide a valuable contribution to the growing need for more information on the structure of the upper atmosphere and the characteristics of near space.

Malina tried to sell this idea when he briefed Washington officials on the results of his tour, generating support from Colonel Trichel at the Ordinance Department. Like many of the early German rocket pioneers, Malina had high hopes that the rocket would play an increasingly successful role in the field of pure science, but recognized the difficulty in getting military funds for a project which had little application to the needs of the armed forces. Yet, there was much that a sounding rocket could provide that would be essential information for the following generation of ballistic and guided missiles and the drive to pursue a more benevolent, scientific, research activity could well find equivalence in the requirements of the services.

Although the more promising roles awaiting the development of advanced rocketry envisaged ground-to-ground projectiles, the trajectories of long range missiles could only be successfully mapped with full and unexpurgated access to details such as temperature, pressure, chemical composition and wind strength in the upper reaches of the atmosphere. Malina recalled later that he was only interested in achieving flights above the altitudes already reached by balloon carriers and that the ORDCIT team set no specific limit on the altitude that they felt the sounding rocket should be designed to attain. Malina decided that, at the current level of development, it would be better to aim for a liquid propelled rocket, due to the extreme heights that were envisaged; a solid propellant rocket, with its lower specific impulse, and hence efficiency, would be unnecessarily large to accomplish the same task that a liquid propellant motor would be required to perform.

In addition to the increasing need to obtain direct measurements in the upper atmosphere, the sounding rocket could be pursued on a basis of non-interference with the existing Corporal design activities so as to complement studies of guidance and launch techniques. Trichel found this proposal both stimulating and applicable to the long range objectives of the ORDCIT project and within a month of arriving back in the United States, Frank Malina, with Homer J. Stewart, had drawn up preliminary plans for the first true sounding rocket. Because the sounding rocket would be called upon to lift a package of delicate instruments through the dense regions of the atmosphere, it was necessary to limit the initial acceleration of the rocket and so prevent undue stress on the payload.

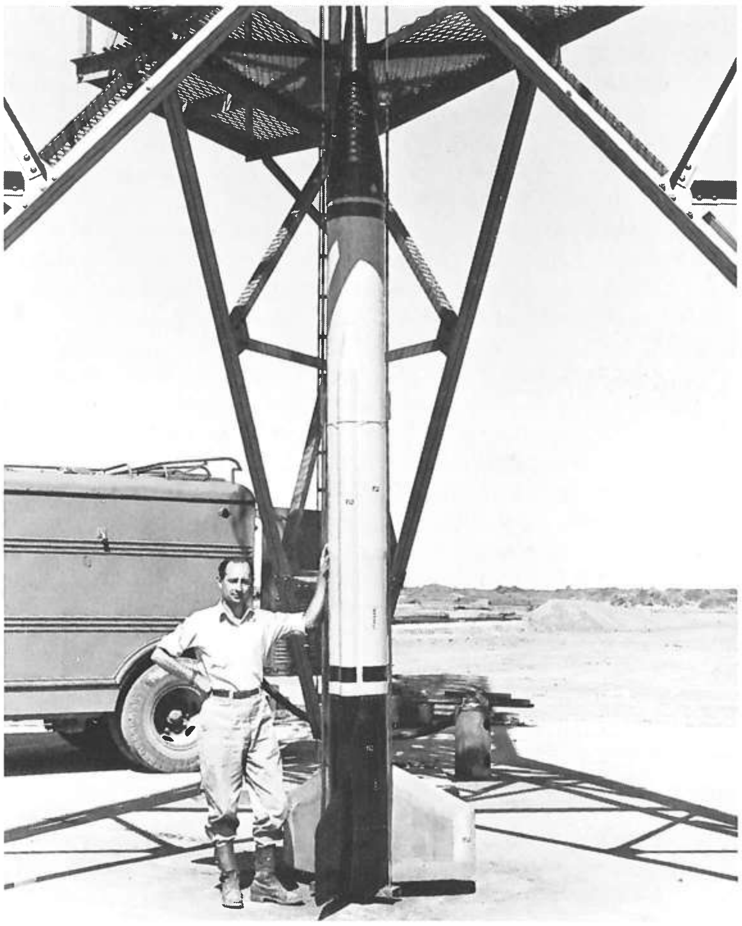
This requirement was satisfactorily met by the decision to use a liquid propellant motor of comparatively low thrust, but the second problem, that of accurately guiding the rocket through unstable air, would be overcome by using a booster stage below the main rocket to impart a high launch speed, still retaining the required limit on acceleration, during the main portion of the ascent. The basic performance requirement dictated a capability to send a 11 kg package to a height exceeding 30 km, the latter parameter being the effective altitude reached by balloons for meteorological duties. With almost uncommon haste, the Ordinance Department approved the project, and work began on the design details.

At last, the ambitions of the original GALCIT group were being met, almost nine years after their first tentative deliberations on the desired objectives. Three possible modes of propulsion had originally been considered for the sounding rocket project, now called Wac Corporal, which incorporated research efforts already in existence at the Jet Propulsion Laboratory (JPL hereafter). One envisaged application of the type of motor used by existing military rockets, a second embraced the GALCIT 61-C used with the Private A and Private F rockets and a third proposed a liquid propellant combination of nitric acid and aniline. It soon became clear that the latter was most suited to the new project and Aerojet Engineering were asked to supply an improved variant of their existing motor, delivering a thrust of 680 kg, for a duration of 45 seconds.

A truly vertical ascent would be ensured by the high velocity boost, provided by a solid propellant motor, with burnout of the latter before the assembly left a launch tower incorporating guide rails in a principle similar to that employed for the Private rockets. The booster for Wac Corporal was taken from an existing military air-to-ground missile called Tiny Tim (see earlier, in this Chapter) and in its application to the sounding rocket project was 2.4 metres long, 29.8 cm in diameter and carried three tail fins for stabilization. The booster weighed 344 kg and carried 67.5 kg of propellant to produce a thrust of nearly 22.7 tonnes for 0.6 seconds. The Wac Corporal was 4.9 metres long with a maximum diameter of 31 cm and weighed 301 kg with its 167 kg load of red fuming nitric acid and aniline-furfuryl propellants.

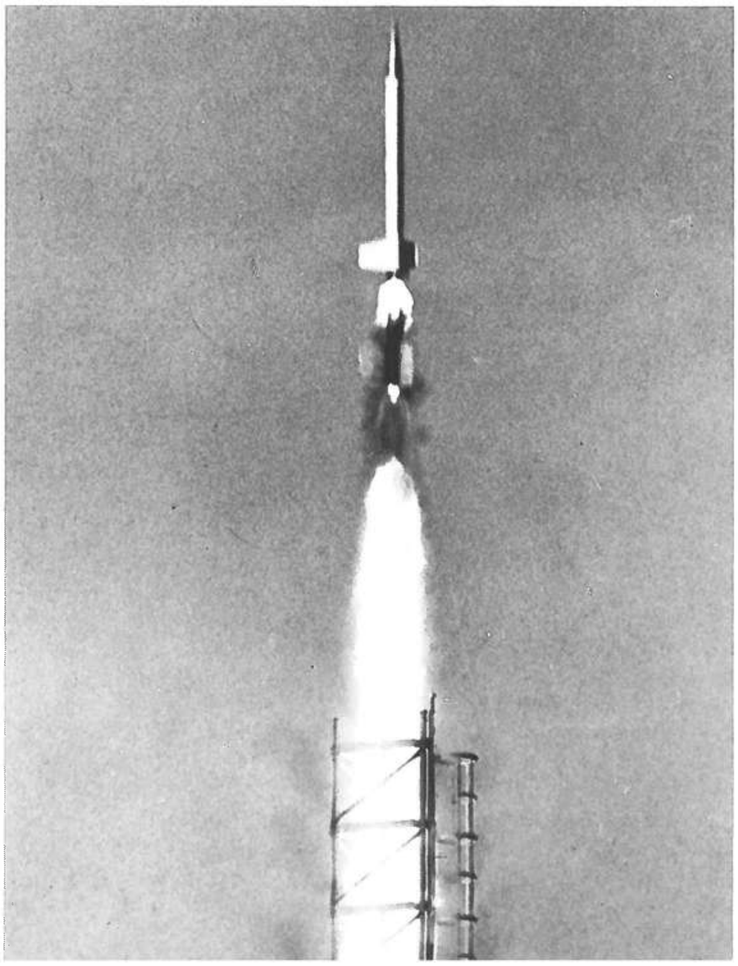
The rocket was expected to go into widespread use for scientific research in the upper layers of the atmosphere and was designed to carry a 3 metre diameter parachute which would be deployed at maximum altitude to lower the assembly back down to the ground at a descent rate of 21 metres per second; the payload would carry its own parachute for safe recovery of instruments after separation from the main body of the rocket. The combined Wac Corporal/Tiny Tim booster was launched from three rails, spaced 120° apart, and providing a vertical run of 25 metres. The rails were supported inside a steel tower 23 metres tall, which was itself situated on a structural tripod 7.6 metres high and 8 metres across the base. The entire launch stand was 31 metres tall and the rocket was placed at the bottom of the guide rail assembly some 6 metres above the ground, controlled from a station 142 metres away.

Starting early in 1945, work got under way on the new Ordinance Department's firing range at White Sands, New Mexico, and it was from here that the first Wac Corporal flights would be made. Before completion of the first definitive sounding rocket, however, the JPL team wanted to verify certain aspects of the rocket's design and constructed a 1/5th scale model called Baby Wac. Flying it in tests from Camp Irwin, California, beginning early in July, the design engineers were able to confirm the fundamental accuracy of their work on the larger product. The first active test with Wac



Dr. Frank Malina, the first Director of the Jet Propulsion Laboratory, gives scale to an early model of the Wac Corporal research rocket. The associated steelwork is the lower section of the vertical launch tower.

The liquid propellant Wac Corporal was boosted into the air by a Tiny Tim solid propellant motor. In this view the booster has reached the end of its burn phase and the upper stage is taking over. Note the three guide rails (one hidden from view) topping out the launch tower, the base of which can be seen in the preceding view.



Corporal hardware was accomplished on 26 September 1945, from the White Sands test rig, when the modified Tiny Tim booster was fired to check out launch operations and qualify the structural changes.

Next came tests with a dummy Wac Corporal boosted above the test rig by the Tiny Tim solid propellant rocket in two flights which successfully qualified the dual configuration. After this, two flights were accomplished with a partial propellant load where altitudes of 8.5 km were achieved with almost total perfection. Finally, on 11 October 1945, the first fully fuelled flight of the Wac Corporal was accomplished in clear weather, into a bright New Mexico sky. The culmination of less than one year's effort rested on the hard and bitter struggles fought in the preceding decade and when the rocket thundered away from its test rig, it opened a new era in atmospheric investigation. At a height of about 24 km, the liquid propellant motor ran out of its fuel and oxidizer and the projectile coasted on to an altitude of about 72 km before falling back to earth just 7½ minutes after launch. It was noted, after impact, that the rocket had veered from a truly vertical course by only 1 km.

Before the end of the year, five more Wac Corporal flights were accomplished and work was authorized to begin on a modified version, the Wac Corporal B, with a lighter propulsion system to improve the power-weight ratio. This, in turn led to the development of the Aerobee by Aerojet Engineering and so on into a new family of operational atmospheric sounding rockets. Coming at the end of a war, unlike the German V-2 which pre-dated the onset of hostilities, the American effort was quickly turned into a valuable tool for scientific research and the sounding rocket still retains a valuable niche in the inventory of space science hardware. The basic Wac Corporal would find still greater potential when called upon to take part in a programme adopting the V-2 as a boost stage, instead of the smaller Tiny Tim motor, but this will be dealt with in the next chapter.

Despite the successful application of GALCIT technology to the already creditable achievement of the Wac Corporal, personnel at JPL were thinking far ahead of the somewhat limited capabilities afforded by a purely ballistic sounding rocket. With the pressing need for war munitions over at least for a while, it seemed an opportune moment to consider the entire future of rocketry in context with the needs of the armed services and the preferred pursuits of pure science. Toward the end of 1945, JPL conducted a brief study on the possibility of launching an artificial earth satellite and concluded that it would require a rocket weighing 1.4 million kg to place a payload of 4½ kg into a path that would reach escape velocity, using the same propellants as those designated for the Wac Corporal. The rocket would consist of 5 stages and each would operate sequentially to achieve the speed of 40,000 km/hr. If more efficient propellant combinations could be used, theorized the team, the mass of the rocket would decrease accordingly, but even with the most ideal chemistries, the assembly would still be prohibitively large for the technology then in existence.

In a number of respects the American effort had compressed into a few years what it had taken the German pioneers more than a decade to achieve, successfully moving forward with an operational rocket system for sounding purposes and initiating the technology for a long range ballistic missile. While the German research had quickly matured into a forcing house for weapons development, the work at JPL since 1936 had encompassed a broad range of applications. The really outstanding accomplishment of the Peenemunde workers had been in taking an ostensibly research-orientated product, the A-4, and transforming it into a usable production-line vehicle, the V-2. Although designed to eventually lead rocketry into military operation, the A-4 was originally seen as precursor to a future production-line weapon and it had only been at the continued insistence of Nazi intervention that more advanced projects were left on the shelf.

So it was that by 1945 both Germany and America had progressed a good way along the road towards large scale development of major projects leading to a space-age capability. When American forces broke through to the Harz Mountains in April 1945, they seized hold of a large part of the German research effort. But fast approaching from the east was a contingent of Soviet troops, rapidly followed by a team of experts who, for twenty four years, had moved progressively toward a similar capability, if not in practice, at least in theory. The Russian rocket programme relied to a lesser degree on personalities and remote experimentalists struggling for governmental approval, than did its western counterpart.

Under the authoritarian rule of a communist leadership, there was little or no room for individual effort and what was deemed unnecessary by the government, remained to a large degree, unexploited. It is because of this that the early attention to problems associated with rocket flight were all the more creditable, coming as they did on the recommendation of ministerial dictates. Theoretical analysis of rocket flight, the development of staged launch vehicles and liquid propulsion, had been sustained through the early years of the 20th century by Konstantin Tsiolkovsky and other dedicated visionaries operating under the constricting influence of a Tsarist regime. With the revolution in 1917 came a decade of readjustment, internal unrest and a persistent attempt to restore stability.

As early as 1915, Y. I. Perelman, by then thirty three years of age, published a book entitled *Interplanetary Travel* and discussed the method by which science fiction writers transported their heroes on journeys beyond the atmosphere and concluded by convincing his reader that the rocket was the only conceivable method by which space flight could be brought to reality. In 1919 Y. V. Kondratyuk finalized the first stage of his evaluation of the basic principles of rocket propulsion and, a decade later, produced a monumental work examining the theories laid down by Tsiolkovsky, although at this time he was unfamiliar with the mathematical and scientific deliberations of his more famous contemporary. Elsewhere, F. A. Tsander worked on the design of a spaceship by which human beings could travel the corridors of interplanetary space and submitted his proposal to the Moscow Conference of Inventors in 1921 after fourteen years of study.

But the first real steps towards practical research began as a result of the experiments performed by N. I. Tikhomirov between 1894 and 1897. Born in 1860, Tikhomirov constructed several models of powder rockets and in 1912 prepared plans for a larger solid propellant rocket, which he duly presented to the then Minister of the Navy, Admiral Birilev. Throughout the next five years, Tikhomirov submitted continuously refined proposals to a host of scientific personalities and organizations, but it was not until 1919 that he was finally able to bring his theories to the attention of the authorities. In a letter dated 3 May 1919, he appealed to Lenin for approval to start work and for the authorization of governmental funds, submitting in addition, a bona fide certificate of invention, awarded three years earlier. The inclement political climate prevented immediate recognition of his request, but the much sought approval finally came two years later when the Revolutionary Military Council recognized the unique importance of his work and, at the behest of the Commander in Chief of the Armed Forces, S. S. Kamenev, authorized the setting up of a research laboratory to study rocket propulsion.

This is the earliest known date at which any governmental body officially recognized such work. Now, working with his assistant, V. A. Artemiev, Tikhomirov went to several sources of potential application in his quest for an efficient smokeless powder propellant. The laboratory began work officially on 1 March 1921, situated at 3 Tikhvinskaya Ulitsa in Moscow, but funds and the necessary supplies of equipment arrived irregularly and with little consistent support. Many projects were in the offing, but the laboratory had to contend with only moderately suitable conditions and work with a few machine tools obtained from various sources.

Artemiev had already had experience with powder rockets and a year after formation, the laboratory embraced the experimental work of O. G. Fillipov and S. A. Serikov, at that time operating from the State Scientific and Technical Institute. Between 1923 and 1925 the laboratory conducted successful tests on a powder rocket projectile at an artillery range in Leningrad and were soon doing work for several military establishments, with the object of demonstrating the advan-

Yuri Vasilyevich Kondratyuk (1897–1942) was a contemporary of Tsiolkovsky and published many analytical works, studying basic principles of rocketry and discussing possible methods of reactive flight.

Fridrikh Arturovich Tsander (1887–1933) spent much of the early part of the 20th century designing spaceships and studying rocket flight.

tages of solid propellant rockets. With increasing activity necessitating work at the Leningrad range, the laboratory moved to the city in 1925.

By now the idea of rocket flight and space travel was well publicized and there was a measure of determination and respect towards the possibility of actually achieving reactive flight, that was missing from the contemporary activities in Europe and America. In 1921, V. P. Vetchinkin began studies into the possibility of using rockets for travel into space and toured the country, up to 1925, lecturing on the subject. In the latter years he developed theoretical concepts of rocket-powered aircraft and went on to reveal his findings in articles published by leading magazines of the day. In April 1924, G. M. Kramarov headed an Interplanetary Travel section appended to the Military Research Society of the Air Force Academy and several months later this became the Society for the Study of Interplanetary Travel, with a membership approaching 200 and the patronage of leading figures such as Tsiolkovsky, Tsander and Vetchinkin.

Just one year later, a space study society was set up in Kiev by D. A. Grave and the group played an instrumental part in preparing an exhibition on 19 June 1925, with lectures and abundant publicity material. By now popularity in the subject was reaching unparalleled heights and all over the Soviet Union local communities set up their own space discussion groups, or organized themselves into satellites of the larger societies. In April 1927, the Association of Inventors staged an exhibition of space vehicle design, concentrating on the possible configuration of space ships, as well as space rockets, with publicity covering the works of Tsiolkovsky, Oberth, Goddard, Max Valier and Esnault-Pelterie. This was repeated in June of the same year and did much to increase government awareness of the potential inherent in rocket technology, as well as providing the public with a stimulating diversion from hardship and depression, still all too common after ten years of dictatorship.

The following year, full recognition of the important work underway in Leningrad came with the re-designation of Tikhomirov's laboratory into the GDL, or Gas Dynamics Laboratory, under responsibility to the Military Research Council. During the previous year great progress had been achieved with flight tests of powder rockets and already there was much concern to apply the principles of rocketry to the requirements of the armed forces; it was felt that troops operating short-range field rockets would achieve a decided advantage over enemy forces.

Beginning in 1928, N. A. Rynin published an encyclopedia, in three volumes, covering important aspects of rocketry and space flight, detailing the early work of many pioneers and evaluating the technical descriptions of theoretical projects, including those proposed by Tsiolkovsky. A considerable level of effort was being applied to the use of rockets for boosting aircraft into the air and the first tests in this application, date back to 1927. Although only ten people were working for the GDL in 1928 and 1929, their impact on Soviet rocket development is unquestioned. Operating from a variety of facilities in and around Leningrad, they adopted existing research laboratories to develop a range of powder projectiles which could conceivably find use in military activities. Moving from scattered buildings, to artillery ranges, the group sought whatever premises they could acquire, until the Deputy Commissioner for Army and Navy Affairs, M. N. Tukhachevsky, approved their use of rooms in the Peter and Paul Fortress.

Active flight testing was carried out at the Komendantsky airfield and use of machine shops in the Rzhevsky artillery range was obtained, together with facilities at the Navy Engineering School and the Artillery Technical School. Control of this patchwork technology was administered from 19 Ulitsa Khalturina, in Leningrad. Tikhomirov died in 1930 at the age of seventy and was succeeded as head of the GDL by B. S. Petropavlovsky. The former GDL chief is immortalized by a memorial in Moscow and by a crater on the far side of the Moon which bears his name. By 1931 research on several potentially promising projects was under way, including booster rockets, for assisting aircraft into the air, construction and test of solid propellant rocket projectiles and design and assembly of the first Soviet liquid propellant rocket motors.

It was in this latter area that the Soviet researchers were particularly successful and between 1929 and 1933 developed a creditable range of liquid propellant engines of varying types. The man who was chiefly responsible for some of the more outstanding achievements in Russian rocketry, began studies in the applications of reactive motion to space flight shortly after the revolution in 1917, and by 1923 was corresponding with Tsiolkovsky on the technical aspects of his work. Later in the decade Tsiolkovsky was to anticipate the remarkable achievements that would be credited to this man: Valentin Petrovitch Glushko; the great space pioneer would write that Glushko was one of the leading exponents of reactive flight and this statement was made long before the latter began to contribute meaningful practice to the work of the GDL.

The Admiralty building in Leningrad. The GDL design bureau for electrical and liquid propellant rocket engines was located on the second floor, right of the arch.

Early in 1929, Glushko put the finishing touches to a proposal that the government should set up a more concentrated appraisal of liquid propellant rocket motors and actually proposed construction of a unique reaction device, operating with a beam of electrons, the so-called electric rocket. In April of that year Tikhomirov and Professor M. V. Shuleikin were asked to study the Glushko proposal and by 15 May, the latter was installed as department head at the GDL to work on liquid propulsion.

As work progressed, over the next couple of years, the GDL increased its work force and divided itself into seven sectors. The work conducted on solid propellant rockets was headed by G. E. Langemak and this formed sector 1, while Glushko's new department became sector 2. Before long there was a requirement to set up a sub-group concentrating solely on the application of solid propellants to aeronautics, which principally embraced the most common emergent use among pioneer rocket workers the world over, namely the JATO concept outlined earlier, under the direction of V. I. Dudakov and known as sector 3. A fourth sector was responsible for studying the application of sectors 1 and 2 to the needs of short-range projectiles, but this was largely a theoretical group, emphasizing the essentially research-orientated nature of the GDL. Another organization would be set up to concentrate on the physical construction of rockets, as against the laboratory work on the propulsion systems alone.

Sector 5 had the responsibility of investigating the chemical nature of various potential powder (including solid propellant) compounds for rockets and this team was under the control of I. I. Kulagin. Sector 6 departed from the familiar bench-test role of the other sectors and conducted control of production under Ye. S. Petrov, while sector 7 looked after the daily administration and procurement of materials under the control of sector heads. Working with his small nucleus of enthusiasts, Glushko began to explore the possibilities afforded by many chemical combinations, among which were the oxidizers hydrogen peroxide, nitrogen tetroxide, nitric acid and tetranitromethane with fuels like beryllium.

He worked on the problems of contoured nozzles and studied control mechanisms, adopting a gimballed concept whereby the entire rocket motor could be swivelled to change the thrust line and thereby alter the trajectory of the rocket. This is one of three primary modes of control that were being evaluated. Adequate control of rockets in the lower, dense, regions of the atmosphere could be accomplished by fitting aerodynamic fins, incorporating rudders, designed to operate in conjunction with a selective guidance system which could sense the changing profile of the trajectory and command the rudders to move and thereby alter the flight path. The second system, necessary for rockets operating at higher altitudes and in space, could use vanes placed within the exhaust efflux of the main rocket motor to work in a similar manner to the external aerodynamic control surfaces. Both concepts were used in the German developments and achieved moderate success; the description of A-4 elements in Chapter Four contains information on this approach. The third concept, gimballed motors, offered the opportunity of a more refined control function, but many difficulties stood in the way of full scale adoption of this technique, not least of which was the problem associated with converting the fixed propellant tank assembly and delivery system, to the moving platform of the rocket engine itself.

Glushko also worked on the theoretical possibility of using hypergolic propellants, fuel and oxidizer which would ignite on contact and which would be brought together for the first time in the combustion chamber, obviating the need for an ignition system. Both gimballed control and hypergolic propellant systems would form an important stage in the development of rockets for military applications after World War II, but the theoretical possibilities were already being explored if not exploited.

By 1930, work was advanced on Opytnyi Reaktivnyi Motor number 1, or ORM-1, a liquid propellant rocket motor burning nitrogen tetroxide and toluene to deliver a thrust of 20 kg. ORM-2 followed a few months later and in 1931, 46 test firings were accomplished. The combustion chamber and its nozzle were made from steel and lined with copper with gold-plated propellant injectors to protect the minute orifices from chemical decomposition. Variable sized nozzles were tested and the combustion chamber was cooled by a water jacket. Mounted on a bench for firing tests, the propellants were brought to the motor by the application of compressed nitrogen.

A variation on the basic ORM-1/-2 design adopted a monopropellant combination and introduced electric ignition; ignition for the original design was effected by way of a cotton wad soaked in toluene and set alight by a short fuse, the whole placed inside the combustion chamber. The monopropellant variant, however, only produced a thrust of 6 kg. It should be stressed that the monopropellant, used with the modified ORM, is not in the same category as propulsion systems generally said to come under this designation. Monopropellant chemistry provides a discharge of propulsive energy as the result of a single fluid providing the characteristics of both fuel and oxidizer and is usually used with a catalyst which ensures chemical decomposition into working energy. The ORM monopropellant merely brought nitrogen tetroxide and toluene together before introduction to the combustion chamber, an interesting research experiment, but one which soon displayed the desirability of returning to a more conventional bipropellant concept.

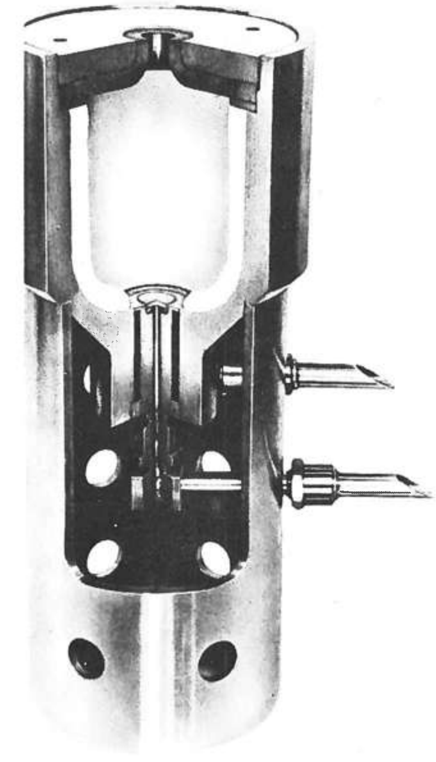
During the test runs of ORM-1 and -2, the GDL were developing more advanced motors which would be tested in 1932 and provide a more effective base from which further designs would emerge capable of flight trials. The more significant developments among the group, were the series ORM-4 to -12, which would reach levels of technology approaching that required to support outdoor ascents.

So far the Soviet experiments had been with quite small motors and none had yet reached a status where they could be flown as the powerplant of a rocket. The 1932 ORM designs experimented with different chemical combinations in the propellant and among the fuels used were petrol, benzene and toluene; oxidizers were mainly liquid oxygen, nitric acid and nitrogen tetroxide. Tests with different combinations of petrol and benzene were carried out and at various times during these combustion chamber developments, the group tried different forms of ignition. The liquid oxygen chamber runs were evaluated with an ignition system using TNT and pyroxylin grains, at other times electric spark igniters were used.

Up to ORM-8, the 1932 activities adopted cylindrical combustion chambers made from steel and ORM-9 used a lining of magnesium and glass on the interior face of its 9 cm

Valentin Petrovich Glushko has spent an entire lifetime promoting and advancing the state of rocket engine technology. He was mentioned by Tsiolkovsky and later headed a design bureau at the GDL-OKB.

The world's first experimental electrical rocket engine was designed by V. P. Glushko.



Developed in 1932 by the Gas Dynamics Laboratory, ORM-9 had a copper lined, 9 cm diameter, combustion chamber. Note the propellant feed ports at centre right and the channeled injector. Propellants were oxygen and gasoline.

Mikhail Klavdievich Tikhonravov (1900–1974) assisted Sergei Korolev in the preparation of the first Soviet Liquid propellant rocket in 1933.

diameter chamber. The convergent-divergent throat of the nozzle was 1.5 cm in diameter and the main section of the nozzle proper was coated with a layer of copper 8 mm in depth. ORM-11 was very similar to its predecessor, but had a different shape to the combustion chamber, assuming a more elongated profile, with a length of 9 cm and an internal diameter of 8 cm. Different types of injector were tested out with the ORM-4 to -22 series, including those designed to provide a spray pattern, others which imparted a swirling action to the propellants and still more which brought fuel and oxidizer down into the combustion chamber through slots rather than holes.

Chamber pressures achieved during these tests approached 52kg/cm², with burn times of up to 60 seconds. But by the end of 1932, other organizations had been set up with the especial purpose of studying the possibility of adopting GDL motor developments for installation in small liquid propellant rockets; GDL was, after all, a laboratory organization, with little application to flight tests.

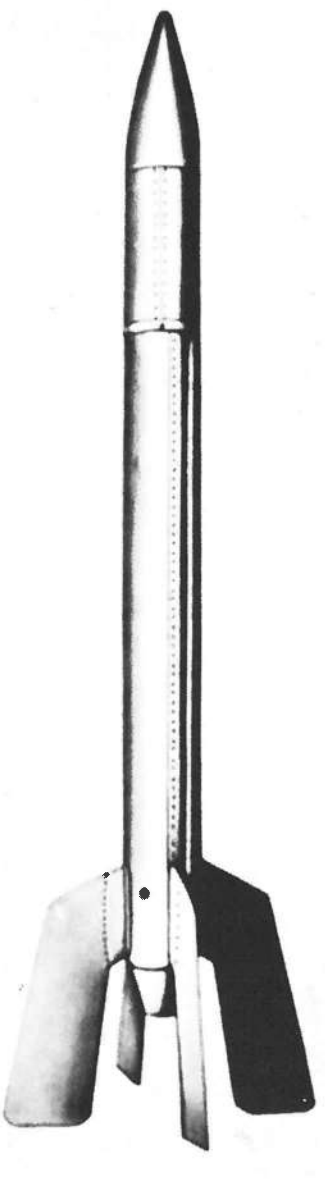
On 18 November 1931, F. A. Tsander officially began work as the head of the Moscow Gruppa Isutcheniya Reaktivnovo Dvisheniya, or the Moscow Group for the Study of Reactive Motion, Mos-GIRD for short. This came only five days after V. V. Raxumov formed the Leningrad GIRD, or Len-GIRD, with such distinguished personalities as Perelman and Rynin. The GIRD groups had as their aim the promotion of space flight, support for local societies and the development of active test programmes leading to the successful flight of a Soviet rocket. A year after formation, the Leningrad group had grown to around 400 members and set up courses on the physics of reactive flight, a study which embraced the jet as well as the rocket engine.

Gradually, more and more interest gathered on the work of the Mos-GIRD and the Len-GIRD, until several major cities formed their own regional Groups. Almost immediately after its formation the Mos-GIRD was involved with Tsander's reactive motor, designed to run on petrol and air, the latter ingested from the atmosphere. Designated OR-1, the motor had a thrust of 5 kg and led to the OR-2 of 1932 which used gasoline and liquid oxygen to produce a thrust of 50 kg. This was a big improvement on the former and comprised a cooling circuit which passed water through the walls of the nozzle. The combustion chamber was cooled by first passing the liquid oxygen through its wall and then introducing it into the injector, where it facilitated combustion with the fuel.

The main reason for developing Tsander's motor was to provide propulsion for the RP-1 glider and the first tests were carried out in March 1933, resulting in an explosion which destroyed the chamber.

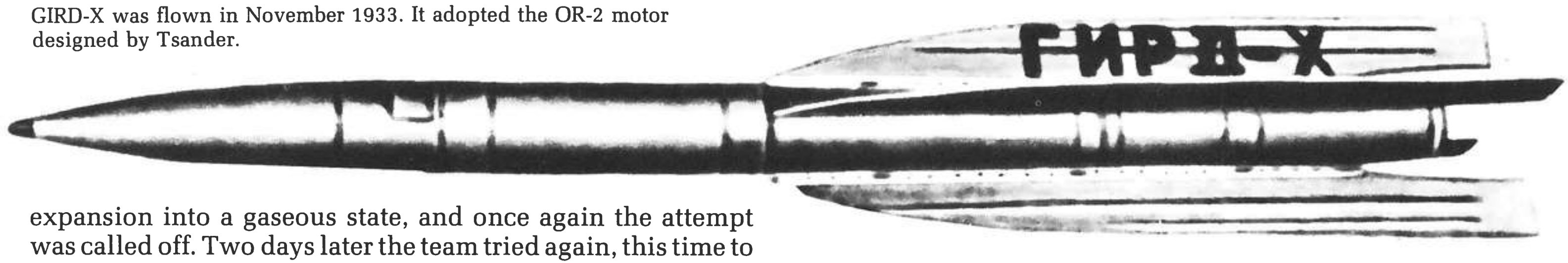
Further developments by the Mos-GIRD team, now under the leadership of Sergei P. Korolev, led to the first Soviet flight on 17 August 1933, from the Nakhabino test range, more than seven years after Robert Goddard flew the world's first liquid propellant rocket and only two years after German endeavours were brought to fruition. Under the simple designation of rocket 09, Mikhail Tikhonravov and Sergei Korolev brought the device up to a stage of development where flight trials could begin. The rocket was about 2.4 metres long, with a fuelled weight of 19 kg and carried a motor which would produce an average thrust of 30 kg from the combination of liquid oxygen and a charge of solidified gasoline placed in the combustion chamber. A small ramp was prepared and the first flight attempt was scheduled for 9 August.

Delays in its preparation caused a postponement until the 11th and confidence was sufficiently high for about 30 people to gather and await its ascent. Leaks developed in the liquid oxygen system, which was designed to allow the oxidizer to reach the combustion chamber under pressure from its



Rocket 09, designed by Tikhonravov, was flown on 17 August, 1933, as the first Soviet liquid propellant rocket to achieve free flight.

GIRD-X was flown in November 1933. It adopted the OR-2 motor designed by Tsander.



expansion into a gaseous state, and once again the attempt was called off. Two days later the team tried again, this time to the accompaniment of a smaller group of watchers, and again the rocket could not be prepared to the point where a flight was deemed to have a reasonable chance of success. Finally, on the 17th, the Mos-GIRD team went out to the test site for the fourth attempt and this time everything went well.

At about 7:00 p.m., local time, the rocket rose into the air for an 18 second flight, to a height of about 400 metres before the combustion chamber was destroyed and the device fell back to the ground. Nevertheless, it was the first major breakthrough and a solemn notice for history was written little more than an hour after the event: 'Launching took place at base No. 17 of the engineering proving-ground in Nakhabino . . . The first Soviet rocket operating on liquid propellant has been launched. The 17th of August is undoubtedly a portentous day in the life of the GIRD, and starting with this moment Soviet rockets must fly over the Union of Republics . . . Soviet rockets must conquer space!'

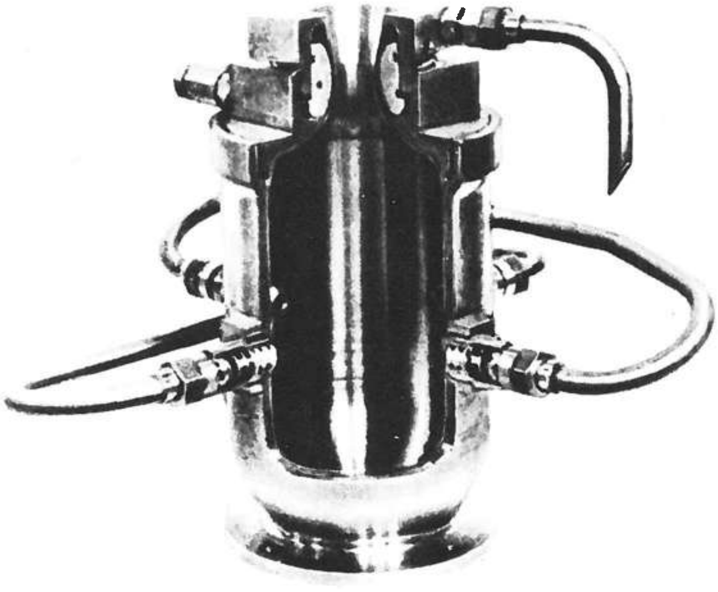
It had already become apparent that rocketry was here to stay and that something should be done to set up a national institute for the study of reactive devices, emphasis on this view coming from the military, as well as the civilian and private sectors, of the society. Pressure to set up such an organization began with a letter to Yefimov, the Red Army Deputy Chief of Armaments, from the Chief of the Artillery Department to the Scientific and Technical Committee in 1931. This was followed, in 1932, by a suggestion from the Moscow and Leningrad GIRDs that they should combine to form a technical research institute, although it was the Leningrad group, under V. V. Razumov, its chairman, Perelman and Rynin who drafted the letter of request to M. N. Tukhachevsky, the Chief of Armaments. Tukhachevsky was already in control of the Gas Dynamics Laboratory and had personally witnessed several static tests from the GDL at Leningrad.

On 16 May he responded by reporting to the chairman of the Defence Commission that a special institute should immediately be set up to develop reaction motors, with emphasis on liquid propellant rockets. This was followed by a further letter, this time from Yefimov, urging that the Secretary of the Central Committee of the Communist Party should recognize the extreme importance that the technical staff placed upon the continued development of rockets and that its use for military purposes should be protected by the proposed new institute. Yefimov went on to say that, 'Apart from work on armaments, the Reaction Propulsion Institute should be a guiding body responsible for the integration of reaction propulsion in the various branches of national economy where the reaction engine can find a diverse and fruitful application.'

The wheels had been set in motion for the amalgamation of the best talents from the two principal GIRD teams and the evolving GDL, with its nucleus of gifted inventors. On 21 September 1933, the Reaktirnyi Nauchno Issledovatel'kii Institut (RNII), or Reaction Propulsion Research Institute, was officially brought into being by order of M. N. Tukhachevsky, acting on the authority of the Revolutionary Military Council of the USSR. I. T. Kleimenov was to head the institute and Korolev was his deputy. The Council of Labour and Defence placed the RNII under the auspices of the People's Commissariat of Heavy Industry on 31 October, and the team got to work on several ambitious projects which would build on the rocket designs of the GIRD at Leningrad and the test-bench performance of the GDL.

Before the end of the year, another rocket design had performed preliminary tests and based on the original OR-2 conceived by the now late F. A. Tsander, it adopted the same engine as had earlier been applied to the abortive glider flight during the March fiasco. With thrust uprated to 70 kg, it used a combination of liquid oxygen and petrol, which provided a specific impulse of about 170 seconds for a burn duration of between 16 and 22 seconds. After ten months of development, the engine was tested in October 1933 and just a month later powered the GIRD-X rocket in a successful flight trial. Ascent came on 25 November, and the 2.2 metre rocket, weighing less than 30 kg, reached a height of nearly 80 metres from where it fell to the ground, its engine having burned through in the process of combusting the propellants.

The ORM-50 kerosene and nitric acid liquid propellant rocket motor used four swirl injectors, seen here as four plugs at 90° intervals around the sides of the combustion chamber. The exhaust chamber is at the top with channeled paths for nitric acid to cool the nozzle walls. Note the pipe leading from the top which removed the oxidizer. ORM-50 was the first ORM-series motor to fly, equipping Rocket 05.



Throughout 1933, the GDL pressed ahead with development of their ORM series and during the year continued the evolving class of liquid propellant test models, with ORM-23 to ORM-52. All were the inspirational brain-children of V. P. Glushko, rapidly achieving fame for his leading role in this class of rocket engine, and his small team of section 2 personnel. While many of these tested a variety of propellant and combustion chamber configurations, they can broadly be categorized into ORM-23 to -49, which had water-cooled chambers for long duration firing tests, ORM-50, using kerosene and nitric acid propellant to find application in Tikhonravov's anti-aircraft missiles, and ORM-52, which used the same propellants, but pioneered the concept of regenerative cooling, whereby the fuel is passed through the chamber walls before combustion.

Throughout the series, steady progress was achieved in combustion chamber pressures and in the operating performance as defined by specific impulse. ORM-50 was the first to find application as the powerplant of a rocket and was capable of re-use and multiple ignition, whereby the same engine is used many times. Bench tests in 1934 led to it being installed in rocket 05, produced by the GIRD team, but its first trial launch attempt from the Nakhabino range, left the rocket standing on the test rig when the fuel system failed to develop the correct flow rate. In all, ORM-50 performed 10 static tests accumulating 314 seconds of operating time. The chamber had a thrust of 150 kg, with an internal diameter of 12 cm and a 23 mm throat. Four swirl injectors brought propellant into the motor and intruding fins were cooled by the oxidizer.

The ORM-52 used a similar combination of propellants in a chamber of the same dimensions as the ORM-50, but it produced a thrust of 300 kg, had an internal combustion pressure of 26 kg/cm² and operated with a specific impulse of 210 seconds. With this motor, the injector was equipped with six swirl nozzles and the exit throat leading to the nozzle was slightly larger, with a diameter of 32 mm. ORM-52 was the first motor credited to the newly formed RNII, although the basic design and test work was undertaken by the GDL.

1933 was a very effective turning point in the development of Soviet liquid propellant engines and brought to fruition the several years' work leading to reliable motors which would find use in practical applications; ORM-52 was the basic powerplant of a new group of rockets being developed by the GDL and would be used in tests with rocket torpedoes and aircraft. In association with this design, the GDL developed special pumps which could be used to deliver the propellant more efficiently into the engine. By now, the RNII were gearing up for major inroads into Soviet rocket research and they gathered together several leading proponents to their ranks, most notably Konstantin Tsiolkovsky.

Tsiolkovsky was made an honorary member of the RNII and generated enthusiastic support through his many years of writing, during which time he had prophesied the time would come when rocketry would develop into a practical arm of science and technology. Once, when Sergei Korolev paid Tsiolkovsky a visit, the ageing space prophet was moved to comment, 'For me there is nothing dearer than this great undertaking. . . . I'm sorry I didn't make it in time.'

Under the increasing interest from Soviet leaders, the GDL moved towards a series of test rockets between 1931 and 1933, which led to completion of the first generation rockets in Soviet Russia. Called the RLA-1, -2, -3 and -100, they contributed valuable experience to the fast developing technology. RLA-1, -2 and -3 were designed as experiments in the fabrication of a rocket capable of reaching an altitude of 4 km and consisted of re-worked artillery shells, fashioned into projectiles, 1.8 metres long and 19.5 cm in diameter. They adopted a propulsion system capable of delivering a steady thrust of up to 300 kg from propellants consisting of nitric acid and kerosene. With the fuel tank located inside the oxidizer tank, the fluids were moved to the combustion chamber by the force of a nitrogen gas contained under pressure and introduced to the propellants for ignition.

Only the RLA-3 had any guidance equipment and this consisted of two gyroscopes which would drive mechanical linkages connected to control surfaces at the rear. The RLA-2 was built to carry a standard parachute inside a nose cone, fashioned from duralumin and with this installed for deployment at altitude, a cluster of instruments could be safely lowered to the ground. Only the RLA-2 was brought to the bench-test stage by the end of 1933.

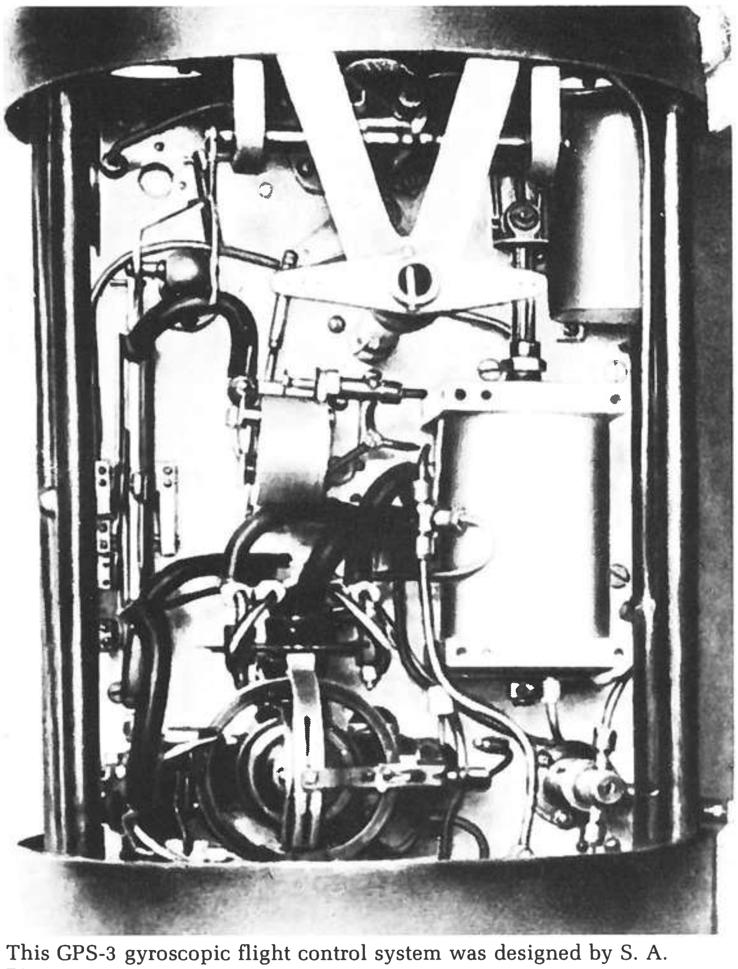
The RLA-100 was altogether different, designed to be capable of carrying a 20 kg package of instruments to a height of 100 km. With a liftoff weight of 400 kg, the rocket would rise under the influence of a rocket motor, delivering a thrust of 3,000 kg for 20 seconds and which would burn nitrogen tetroxide and petrol propellants. This rocket would carry a gimballed rocket chamber at the rear and like the RLA-2, provide recovery of the instruments by way of a parachute packed into the nose section. Design details included provision for a camera in the duralumin tail section for recording the visual performance of the engine. All four RLA rockets were expected to ascend from a fixed launch stand, unlike earlier rockets which used guide rails, and the RLA-100 was stabilized in flight by a gyroscope. Although the project models never achieved their claimed performance, they contributed a valuable lesson in systems design.

By 1934 the GIRD team adopted the ORM-50 motor, developed by the GDL, and after the initial failure recorded earlier, the same motor was used in analysis of further refinements. January saw the pressure of work commitments to the RNII move the GDL liquid propellant motor section to Moscow to continue its efforts under the tutelage of the competent Glushko. Between 1934 and 1938 many ORM designs emerged, each one exploring a new facet of rocketry. ORM-53 to ORM-70 used nitric acid oxidizers and most notable among this group, was ORM-64, developed in 1935–36, using kerosene as the fuel for a thrust of 150 kg and a specific impulse of 216 seconds. Design work on a new gas generator, GG-1, got under way in 1935 and within two years had reached final acceptance tests. With a potential of delivering up to 70 litres of gas per second, it ran on nitric acid, kerosene and a water solution at temperatures approaching 590°c. This led to GG-2 in 1937, producing 100 litres per second and an operating temperature of 600°c.

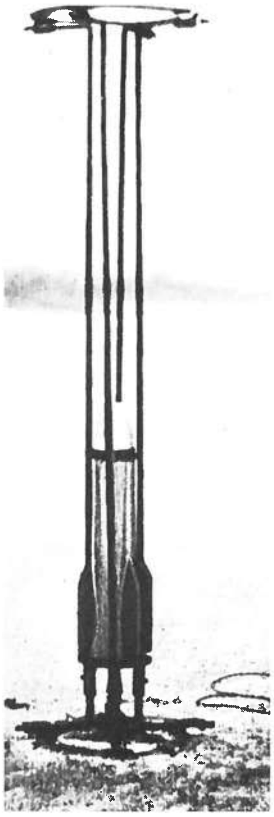
In this year also, the GDL produced the ORM-65 motor, with a variable thrust of from 50 kg to 175 kg, burning nitric acid and kerosene propellants. Its principal feature was the capacity to multiple use and the first model was said to have performed 50 firing runs, totalling more than 30 minutes operation, including some 21 tests with the RP-318 glider. The second engine was tested on the same aircraft and then performed 5 tests with the Project 212 flying bomb. Mounted under the tail section, the propulsion unit would power the winged aircraft in very much the same concept to that used by the German Air Force in the V-1. The assembly weighed 210 kg, had a span of 3 metres and could fly a distance of 50 km, carrying a warhead packed with 30 kg of explosives. The variable thrust ORM-65 was ideally suited to this project, and although the flying bomb was never introduced into service, Korolev was one of the key persons in its promotion and development.

Several engines in the ORM-53 to ORM-70 batch, mentioned earlier, were purely research experiments into higher levels of thrust burning the usual propellants, nitric acid and kerosene. Some of these motors were shown to be capable of generating up to 590 kg of thrust, but none were actually used in practical applications, except the notable ORM-65. The ORM series 67 to 70 used nitric acid as the oxidizer to kerosene fuel and produced a rated thrust of 300 kg. Two designs, ORM-101 and -102, retained the same chemical fuel, but adopted tetranitromethane as the oxidizer to develop a thrust of 79 kg and 100 kg respectively. These were developed through 1937 and testing continued into 1938.

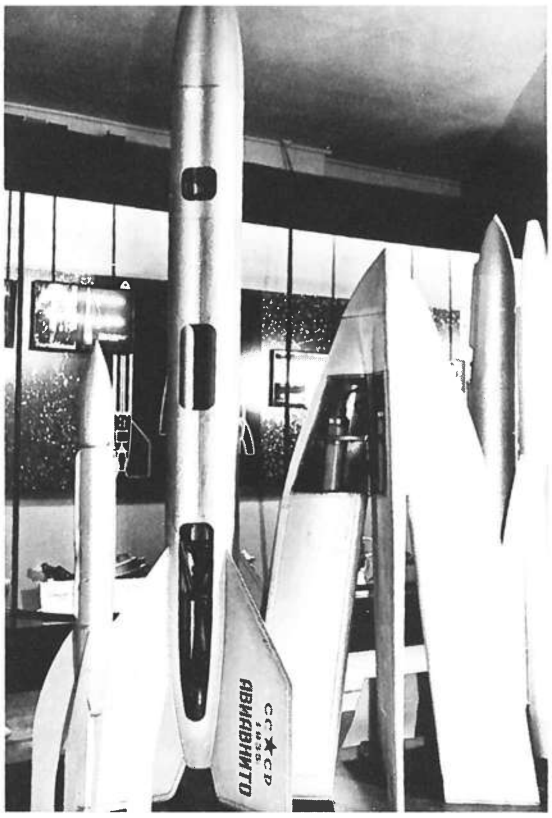
Although the history of Soviet rocketry moved with apparent smoothness through milestones and achievements of GDL, GIRD and RNII activity, the years between 1935 and 1938 were troublesome for the Russian people and at the very least disruptive, for science and technology. Changing political affiliations wreaked havoc at the administrative level and it is not without a certain appreciation of those times that the full repercussions of the so-called 'Stalin purges' can be fully understood.



This GPS-3 gyroscopic flight control system was designed by S. A. Pivovarov in 1937–38.



This design by I. A. Merkulov was the first Soviet two-stage rocket, using powder in the first and a ramjet engine in the second stage. It was built at the Jet Propulsion Section of the Stratospheric Committee of the Society for the Promotion of Defence and was launched from a range near Moscow on 15 May 1939.



This collection of historic hardware seen at the Moscow Economic Achievements Exhibition, recalls early design effort with Rockets 06, 07, 05 and 03, dating from 1933 to 1935.

Since 1917 the Soviet Union had moved through an almost continual state of change until, by 1928, Lenin was dead and Trotsky was sent into exile. Bitter conflict grew over agricultural policies, foreign relations, the composition of the Supreme Soviet, a rising discontent with merchant profits and an increasingly profitable banking system. After 1924, Joseph Stalin achieved prominence and eliminated opposition to his concept of control by setting first one against the other and then reversing the process. During this time, many of the old revolutionary diehards were either eliminated or forced to leave the country. By 1936 the desire to purge party dissidents reached a peak and stayed thus for at least two years, during which time an untold number were shot, imprisoned, murdered and pursued.

Within that brief historical period, at least 4 million persons lost their lives, among which was the notable Mikhail Tukhachevsky in June 1937, and at least a further 5 million were arrested and subjected to varying degrees of abuse, humiliation or torture. Yet the emerging theme in the mid and late 1930's was continued expansion, with emphasis on industrial production. The armed forces increased greatly in strength during this period and cursory examination of the figures for 1938, compared to those of just eight years earlier, reveals the product of massive reorganization and dramatically increased defence budgets; aircraft production went from 860 to 5,500, tank production from 740 to 2,300 and manpower level from 750,000 to more than 1.5 million.

Foreign policy during the latter half of the 1930's centred on a reluctant co-existence with Germany and almost open hostility to France, Great Britain and the United States. The reason for Russia's massive arms build-up can be found in the increasing suspicion over Germany's intentions and while negotiations for non-aggression pacts and diplomatic agreements continued at an open level, very few Soviet leaders were wooed to apathy by the show of concessionary overtures. By 1938 it was becoming all too apparent that Germany would soon marshal her forces against Russia and considerable attention was given to munitions production and the preparation of a satisfactory 'wall' between the two countries.

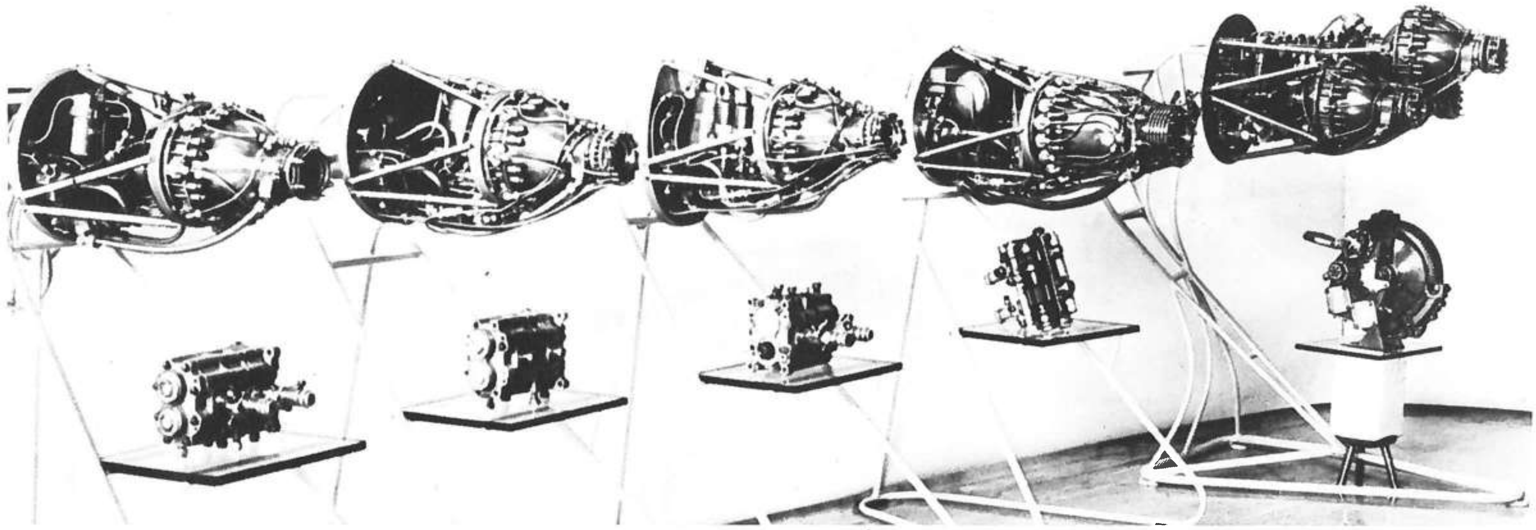
Work on rocket development had reached a point where there was an obvious potential for military requirements, but like Britain a few years later, emphasis was to be placed on the exploitation of small, solid propellant missiles, rather than on the possible fabrication of a long range liquid propellant rocket. Instead, liquid propulsion was gradually adopted for tasks such as assisting heavy aircraft into the air to the exclusion of more long-term objectives. Since 1935–36 the work conducted by the GDL and the RNII had been appreciably disrupted by the political purges and this contributed towards a delaying posture whereby Soviet liquid propellant research would remain stagnant for nearly a decade. Nevertheless, the adaptation of liquid propellant rocket engines to aeronautical requirements kept at least some work alive and this was manifest through motors developed for supplementary boost in the early 1940's.

In 1941, the GDL was given full status as an OKB, or Experimental Design Bureau, and increasing demand for aircraft-boost propulsion, brought Glushko and Korolev together to produce the RD series of rocket motors. The basic RD-1 was a pump-fed engine delivering a thrust of 300 kg and burning nitric acid and kerosene propellants. It was to find application as a boost unit for fighter aircraft, leading to three derivatives that put Russia in the forefront of this activity, pursued in several countries, but almost exclusively with solid propellant motors.

In the early hours of 22 June 1941, the German armed forces rolled east and savagely thrust deep into the heart of Mother Russia, setting a scene that would provoke the Soviet Union into mobilization such as the world has never seen before or since. Soon 136 German divisions were moving towards Moscow and before the month was out, 5 million Russians were in uniform and fighting for their very existence. Within six months the German forces occupied vast stretches of western Russia and this sealed the fate of any further progress that may otherwise have been achieved in developing a strategic rocket capability, with liquid propellant engines from the GDL-OKB. Every opportunity was taken to exploit rocketry, for the pressing needs of national defence and long-term objectives were relinquished in favour of more lucrative applications in the short term.

In the very month that Hitler moved on Russia, production began of a solid propellant ground-to-ground missile known as the BM-13, but more popularly remembered as the now famous Katyusha. With a length of 1.8 metres and a diameter of nearly 13 cm, the rocket weighed 42 kg including its 22 kg warhead and could hit targets at a distance of some 5 km. Soon, several variants were conceived on the drawing boards and before the end of the war, many adaptations of the basic Katyusha had earned a justified reputation as one of the most effective field applications of the solid propellant rocket that had up to that time been demonstrated by any country. Mounted on the back of a truck, the specially constructed multiple launcher could fire a salvo of up to 48 Katyusha, in rapid fire succession. The rocket was, in several respects, a parallel development to the standard UP-3 and RP-3 from Britain and the 11.4 cm diameter missile from the United

The Soviet Katyusha was usually used from a launcher mounted to a lorry. Here, Russian troops move up through Poland as German forces are pushed west.



This display of Soviet kerosene and nitric acid liquid propellant engines shows, from left to right, the RD-1, RD-1HZ, modified RD-1HZ, RD-2 and the triple-chamber RD-3. This series was developed between 1940 and 1946 and flew in several rocket boosted aircraft.

States, although the Katyusha was in the vanguard of a multiplicity of emerging off-springs that found application on aircraft and naval vessels.

By late 1941, Russian aircraft were firing air-to-ground missiles at German troop positions and the rapid introduction into service of many different models and variants laid open testimony to the enormous progress that had been achieved since 1928. First in the air, with missiles fired from aircraft to ground targets, discounting the makeshift rockets used in the First World War and discussed in Chapter Two, the Soviets had concentrated on this application in the late 1930's and one of the more notable designs was designated the RS-82 with a diameter of 82 mm, initially tested in 1937, and fitted to most Russian fighter aircraft in the 1941–45 war against fascist intrusion.

First used in 1939 in Mongolia, the RS-82 was initially disappointing, but the technology developed for this precursor model soon found more successful application as the RBS-82, which was to be fitted to heavy aircraft, including bombers, as a ground attack weapon. Beginning in 1938, tests with a 132 mm diameter rocket, the RS-132, led to gradual introduction to service use and a derivative, the ROFS-132, was particularly effective against hardened targets due to its armour-piercing capabilities. Larger still was the BETAB-150DS, of which there is little operational mention, although the projectile did achieve notable merit for its capacity to penetrate concrete emplacements.

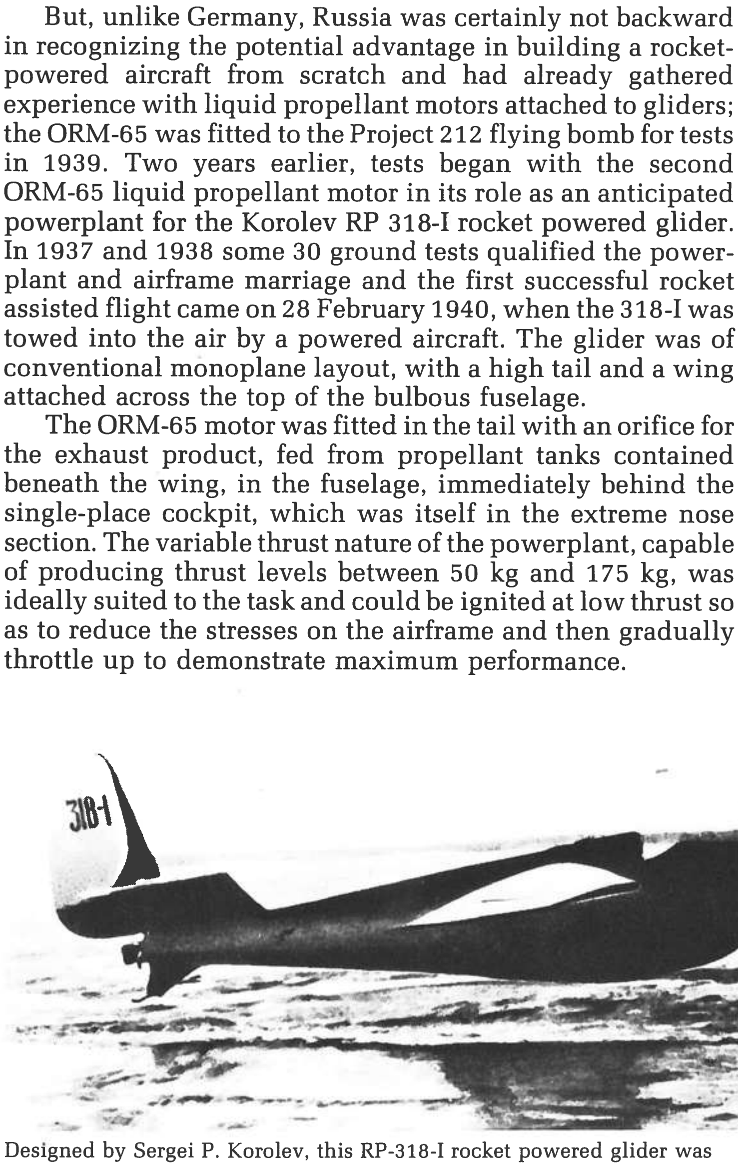
By 1943 most Soviet fighter aircraft were equipped with racks for either three or four RS-82 missiles under each wing and since the evolving pattern of Russo-Germanic conflict dictated an operational preference for ground based warfare, the solid propellant rockets were in their element; Soviet Air Regiments must have been the only air arm of any combatant nation during World War II to equip their fighters with more rocket armament than bombs. Almost at the extremes of technology, the Polikarpov I-153 biplane fighter was a leading exponent of rocket power, as it bore the brunt of fighting with its eight RS-82 missiles.

Meanwhile, and in spite of the almost monopolistic presence of solid propellant research, which had by now overtaken Soviet rocket work (due, understandably, to the urgent needs of the war machine), the GDL pressed on with liquid propulsion for aircraft boost. The GDL had disengaged its liquid propellant research from the RNII in 1939, before becoming involved with the GDL-OKB in 1941, but its more promising applications received constant support, albeit at a less productive level than that given to air-to-ground solid propellant missilry. By 1942 the RD-1 boost engine was providing successful bench-test results and in that year accumulated 70 minutes of operating time. The RD-2 was a dual chamber assembly, providing a thrust of 600 kg, while the RD-3 clustered three similar chambers to yield a total thrust of 900 kg.

Spark plug ignition was provided for the RD-1 and RD-3, while the twin-chamber variant adopted a carbynol fuel ignition system. The main feature of the RD series was that they could all be used many times over and provided long duration thrusting, competently demonstrated by the RD-1 which, in 1942, ran for 40 minutes before shutting down, its life extinguished by depleted propellants. Several flight trials were performed with the RD engines in aircraft such as the Petlyakov Pe-2R, the Lavochkin La-7R and the Yakovlev Yak-3. Although none of these aircraft used the RD engine as the primary powerplant, they did achieve success to the point where production was authorized in 1944. Pilots' reports indicated high satisfaction with the motors and although the engine performed well, the accelerations it induced were the limiting factor; aircraft designed for conventional power-propellants are ill-suited to the sudden stress imparted by rocket propulsion.

But, unlike Germany, Russia was certainly not backward in recognizing the potential advantage in building a rocket-powered aircraft from scratch and had already gathered experience with liquid propellant motors attached to gliders; the ORM-65 was fitted to the Project 212 flying bomb for tests in 1939. Two years earlier, tests began with the second ORM-65 liquid propellant motor in its role as an anticipated powerplant for the Korolev RP 318-I rocket powered glider. In 1937 and 1938 some 30 ground tests qualified the powerplant and airframe marriage and the first successful rocket assisted flight came on 28 February 1940, when the 318-I was towed into the air by a powered aircraft. The glider was of conventional monoplane layout, with a high tail and a wing attached across the top of the bulbous fuselage.

The ORM-65 motor was fitted in the tail with an orifice for the exhaust product, fed from propellant tanks contained beneath the wing, in the fuselage, immediately behind the single-place cockpit, which was itself in the extreme nose section. The variable thrust nature of the powerplant, capable of producing thrust levels between 50 kg and 175 kg, was ideally suited to the task and could be ignited at low thrust so as to reduce the stresses on the airframe and then gradually throttle up to demonstrate maximum performance.



Designed by Sergei P. Korolev, this RP-318-I rocket powered glider was powered by the ORM-65 liquid propellant rocket motor with a thrust of 50 kg to 175 kg. It first flew on 28 February 1940, with V. P. Fyodorov at the controls. It was towed in to the air before release for independent flight.

On that historic first flight, piloted by V. P. Fyodorov, the RP-318-I was released at a height of 2.6 km from the towing cable that was attached to the front. With a weight of 700 kg the glider shot up under the influence of its motor and was soon at a speed of 140 km/hr, having risen 300 metres in under two minutes. The flight was a success and began the long series of laboratory developments, leading to the first Soviet rocket powered aircraft of 1941.

Three designs were completed in an attempt to provide a short range interceptor which would be capable of outpacing existing (German) aircraft: the Tikhonravov 302, the Polikarpov Malyutka and the BI-1, designed by Berezniak and Isaev, but taking its designation from Bolkhovitinov (the project manager) and the word Istrebitel (Fighter). Equipped with a variable thrust rocket motor, based on the ORM-65, and developed by L. S. Dushkin, all three projects were brought to fruition by July 1941. The Soviet Defence Committee comprising Stalin, Kaganovich, Beria, Molotov and Malenkov, reviewed the three proposals and selected the BI-1 for flight trials, with the first of a planned five models.

On 10 September the BI-1 was towed into the air behind a Petlyakov Pe-2, with subsequent trials flown by pilots K. Gruzdev and G. Bakhchivandii, on alternating, un-powered flights. By the end of 1941 the project was evacuated further east due to the presence of German armed forces in the vicinity of Moscow and this delayed the first powered test until 1942. The BI-1 was a low-wing monoplane, with a span of 7.2 metres, a length of 7 metres and a height of 2.1 metres. The Dushkin rocket motor produced a thrust of between 160 kg and 500 kg and was fitted inside the rear fuselage, with propellant tanks between the motor and the single-place cockpit.

Two 20 mm ShVAK cannon were mounted in the nose, along with the communications equipment. The undercarriage was of conventional geometry, with skid supports under the wings and a tailwheel at the rear; the skids could be exchanged for wheels and the operational version of the BI-1 would have carried the latter. The first powered flight was performed successfully on 15 May 1942, at the hands of G. Bakhchivandii, not the first rocket powered aircraft to fly, but certainly the first for Russia. Disaster struck on the third flight, however, and the BI-1 was destroyed on impact with the ground.

Several features led to its abandonment as a viable interceptor, not least of which was its extremely short range and low endurance: the rocket aircraft would reach high altitude in record time, but the 15–20 minute flight time rendered it unlikely to accomplish the defence role for which it was designed. Germany had better luck with its own rocket fighter project, probably because the territorial range requirement was less severe than in the Soviet Union; the story of the Messerschmitt Me-163 is told elsewhere in this book, together with the development of the unique propulsion unit which was specially built for aircraft application.

Toward the close of the war with Germany, Russia spent increasing resources on obtaining details about the varying levels of development reached at Peenemunde. It was becoming obvious that they, the Russians, would soon have access to major secrets about the German rocket programme and that several key personalities would have to be interrogated to obtain the most effective explanation for test stands and research laboratories. A lot of the information about the German rocket programme came via the Byuro Novoi Tekhniki Ministerstva Aviatsionnoi Pomyshlennosti (BNT-MAP), an intelligence organization set up to monitor technical progress in aviation and to obtain secrets from abroad in the hope that Soviet scientists would glean valuable pieces of data from the reports.

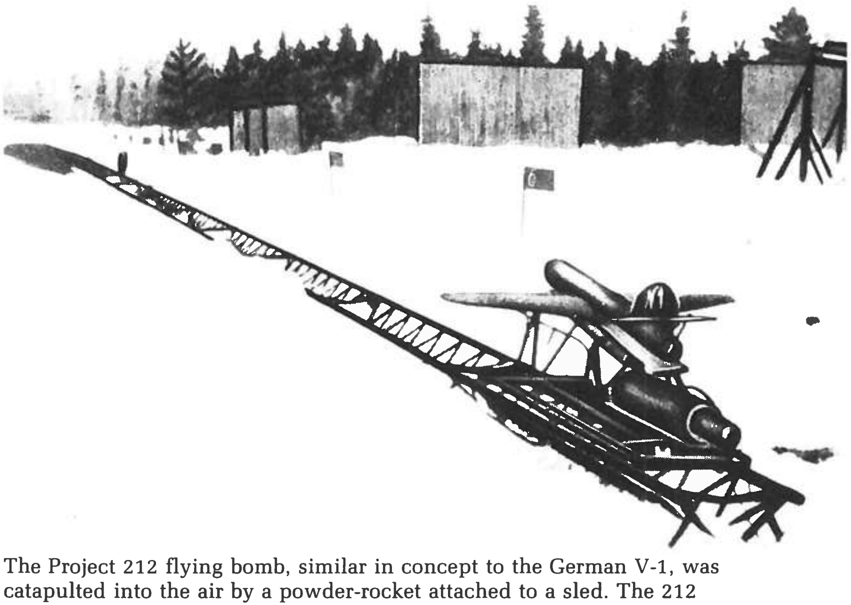
With this line of information continually disgorging the activities of the World's aeronautical and rocket industries, the Soviet military presence in Germany had double significance: not only were the teutonic forces of Nazism being crushed under the tramping boots of the Red Army, but existing facilities and research laboratories could be exploited, both for the information they would provide and for their adaptation to current military requirements. When the Soviet 19th Army broke through to the Baltic research station of Peenemunde in February 1945, they found very little which would be of use to intelligence officials or the host of engineers and scientists already en-route to numerous German sites of technical development. Von Braun and his team, together with families and every conceivable piece of potentially valuable material, had already left for the Harz Mountains.

Until then the exact dimensions of the German rocket programme had been known to only a very few military personnel, but with the increasing importance to seize hold of as much booty as possible, questions began to emerge as to the progress made by Soviet engineers and design staff. Historical analysis revealed the ready availability of a machine for fabricating a valuable rocket programme, but it was increasingly apparent that German progress had far outstripped that of the Soviet Union. Why? The answer was not a simple one and even today it is not easy to select any single criteria by which to measure the level of progress.

Small liquid propellant rocket motors had been built in abundance since the early 1930's, but for the duration of the war with Germany, all research had centred on the application of solid propellant technology to military requirements. Not until 1945 would Russia turn again to the promising technology of liquid propulsion. Lack of a coordinated production line was one cause of diminished performance, compared with the highly efficient assembly plants of the V-2 engineers. But the most obvious reason must be that there was insufficient time to develop a long range strategic weapon when war supplies were needed more urgently than anywhere else in the world at any time this century.

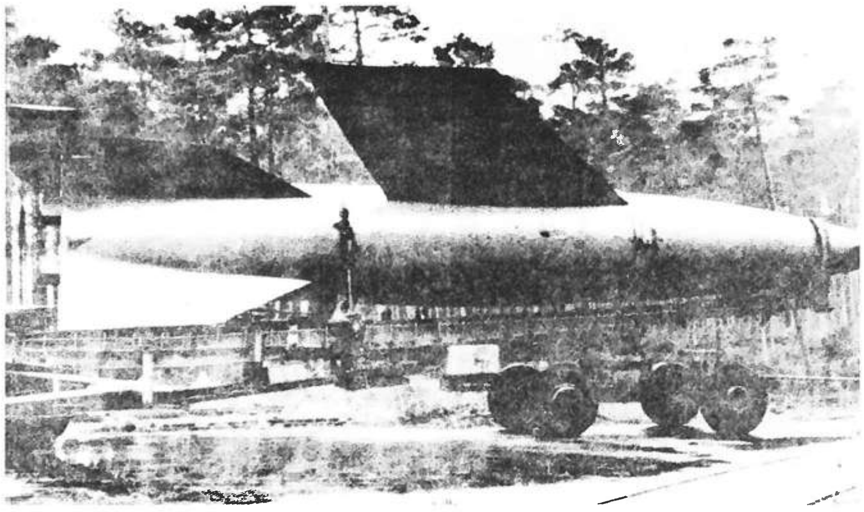
If a rocket of V-2 potential had been on the drawing boards before the conflict, it is possible that priority would have been given over to the new weapon; abundant evidence exists to belie the fallacy that Soviet style communism was incapable of marshalling the production programme required to put large numbers of such a device into service. In the three years up to Hitler's assault, in June 1941, Soviet industrial output rose by 13% per annum, while military production rose by an average 39% per annum; in the very month that war began, Russian industry was outstripping that of Germany by a full 50%. In the four years of conflict the Soviet war machine produced 37% more combat aircraft, 77% more tanks and self propelled guns and 84% more pieces of field artillery than did Germany in the same calendar period.

From a pitiful state of technical unpreparedness in 1917, through a civil war lasting four years, to the Stalin purges of 1936–38, the Russian military technocrats had little opportunity to exploit the more sophisticated products of an increasing know-how. Despite the early establishment of government bodies, in both research and administration, devoted to rocket research, the stimulus to forge ahead with a weapon on the scale of the V-2 had been left too late and when there was a requirement for such a missile, emphasis had to be placed on a technology which would bring a more immediate return. It is hardly surprising, therefore, that Russian rocket experts were intrigued by the imminent post-mortem on the seemingly successful German developments.



The Project 212 flying bomb, similar in concept to the German V-1, was catapulted into the air by a powder-rocket attached to a sled. The 212 carried the ORM-65 liquid propellant motor and first flown in 1939.

Ideas and Applications



The A-4b was never used operationally (only two were ever launched) and the missile was unable to prove its basic design objectives. It was, nevertheless, a true attempt to marry rocketry and aeronautics.

Always with an eye on the day when rocket technology could be unleashed from the pressing demands of the war, von Braun had led his team to theoretical designs which would expand on the already creditable V-2 accomplishments. Mention has already been made of the proposed A-9 rocket, which would, if developed, have used existing A-4 propulsion systems in a missile equipped with wings for generating a degree of lift and so increase the range. In a variant of this concept it was felt that a crew cabin could have been placed in the forward section, thereby transforming the military weapon into a trans-continental transporter. But still more advanced designs resulted from the ambitious aims of the von Braun team.

Suppose the A-9, externally similar to the A-4, could be the second stage of a two-step rocket, so that when the A-9 flew under the influence of its own rocket motor it was already travelling at high speed. This multi-stage approach has already been seen to date back to the work of Kasimir Simienowicz in 1650 and to have been adopted for ship-to-shore rescue in the mid-19th century. Re-discovered by the German Hans Ganswindt in 1891, the step-rocket came close to fruition, in its more elaborate form, with the von Braun design for a so-called A-9/A-10 configuration.

The A-10 would have been a totally new development, envisaged to have a length of 26 metres, a diameter of 4.1 metres and a launch weight of 101 tonnes. Equipped with a liquid propellant motor delivering a thrust of about 200 tonnes, and fed during the course of its 50 second burn duration by 62 tonnes of nitric acid and diesel oil, the A-10 would carry the A-9 to a height of nearly 60 km and to a speed of about 4,300 km/hr. At launch, the total assembly would have weighed nearly 113 tonnes and stand about 40 metres tall, with the two stages situated one above the other.

When the A-10 had consumed its propellants, the A-9 would separate, ignite its rocket motor and fly to a speed of more than 10,000 km/hr before beginning a long descent to its destination, 5,000 km from the launch pad, 35 minutes after liftoff. The A-10 meanwhile, would fall back into the dense layers of the atmosphere and be programmed to deploy braking flaps and a parachute system so that it could be recovered and used again. An earlier, alternative, method of boosting the A-9 before ignition of its own propulsion system, envisaged use of a catapult device to impart an initial speed of 1,300 km/hr so that the missile would achieve high lift characteristics from its two wings; a high initial speed would be essential, especially if launched from an inclined ramp, so that the wings could generate sufficient lift to prevent the missile prematurely falling back to the ground.

There was little enthusiasm for devoting further research time to such ambitious projects, outside the nucleus of Peenemunde visionaries at least, nonetheless, the von Braun team went still further with their propositions. In an attempt to cloak the true intent of their continued efforts, the A-9 work was designated A-4b, so as to preserve the continued development of this advanced concept without the need to justify a completely new project. Work on the A-9 had been dormant since early 1943, but towards the end of the war, interest picked up as the design staff were increasingly caught up with flight tests supporting introduction of the V-2 to service use. The first flight attempt with the winged A-4b came on 8 January 1945, but the rocket plunged back to the ground after reaching a height of only 30 metres. Another attempt was made on the 24th and this time the rocket reached a height of 80 km and achieved a speed of 4,350 km/hr. This was the one and only flight of the A-4b and represented the peak of German wartime rocket research.

Beyond the A-9/A-10 would come work on a very powerful rocket stage which could, theorized the von Braun team, be used to lift the two-stage upper configuration on a trajectory to place the A-9 in orbit; beyond that the next step would be fabrication of a still larger first stage delivering a thrust of 1,000 tonnes, which could carry the post-A-10 rocket to a height from where a third stage, the A-10 proper, would place 27 tonnes in earth orbit. Fitted with wings, the modified A-10 could be made to fly back down through the atmosphere where it would land, like a conventional aeroplane. There was a prophetic tone about this ultimate project, which predated the exact line of development nearly three decades later, but in 1945 the A-9, the A-10, the more powerful advanced stage and the 1,000 tonne thrust rocket were, just theoretical design exercises.

Nevertheless, while Peenemunde had been primarily concerned with development of the V-2, it played host to several other important rocket projects which resulted in tests of an underwater launch capability as early as mid-1942. This led to studies of the underwater launch in 1944 at Unterbuss, aimed at providing an anti-aircraft missile; tests were performed from a depth of about 5 metres and resulted in satisfactory flights of up to 6 km, but the project was too late to achieve production status for the resulting design. Just as the Peenemunde site was being evacuated, the team got authority to begin testing a water-launched V-2, but this was to have been launched from the surface and the hurried evacuation of the complex precluded further work. The trend towards consideration of sea-launched missiles was, again, a prophetic prelude to similar work, many years later, in the United States and the Soviet Union.

Unlike their counterparts in America, Russia and Britain, work on anti-aircraft rocket design was to receive little emphasis, at first, from the German design teams. However, when it became apparent that British and American air raids were taking an increasing toll of the production lines, so essential to continued orchestration of the war effort, several such designs emerged.

Work on one of the first of these began under a Professor Wagner in 1941, but very little interest could be roused and it was not until 1943 that the German Air Ministry authorized the production of the 'Schmetterling', manufactured by the Henschel company. The missile took the form of a winged, cylindrical body carrying a cruciform tail and a jettisonable booster unit at the rear. At launch, the 3.8 metre long rocket weighed 444 kg, but this was reduced to 258 kg when the booster was released, the projectile, left to itself, reaching a speed of 870 km/hr, with a maximum range of 15 km. The missile was designed to be fired by a ground control unit which had the opportunity of maintaining visual contact with both projectile and target, while it was controlled by radio command. The Schmetterling used a liquid propellant motor developed by the Bayerische Motorenwerke G.m.b.H. (BMW) under the designation 109–558, but production, as the Henschel Hs-117, was hampered by Allied bombing raids and of the 59 that were tested only 25 achieved moderate results.

In 1942 work got under way on the C-2 Wasserfall ground-to-air missile at the Peenemunde research facility. The project came under the partial authority of von Braun and his lack of enthusiasm for anything short of long range ballistic missile development, was reflected in the low priority given to the venture. When envisaged, the Wasserfall was seen as a weapon which could be deployed, en masse, along the exposed western flank of Germany so as to put up a veritable barrage of anti-aircraft projectiles which would prevent Allied planes from reaching their objectives. At one time it was proposed that 300 batteries would be equipped with the missile to shoot down enemy aircraft, but the protracted research and development phase prevented service introduction before the end of the war. Nevertheless, the missile was very advanced for its day and gained much from the enormous effort applied to aerodynamic wind tunnel tests, in support of development of the 'A' series ballistic rockets.

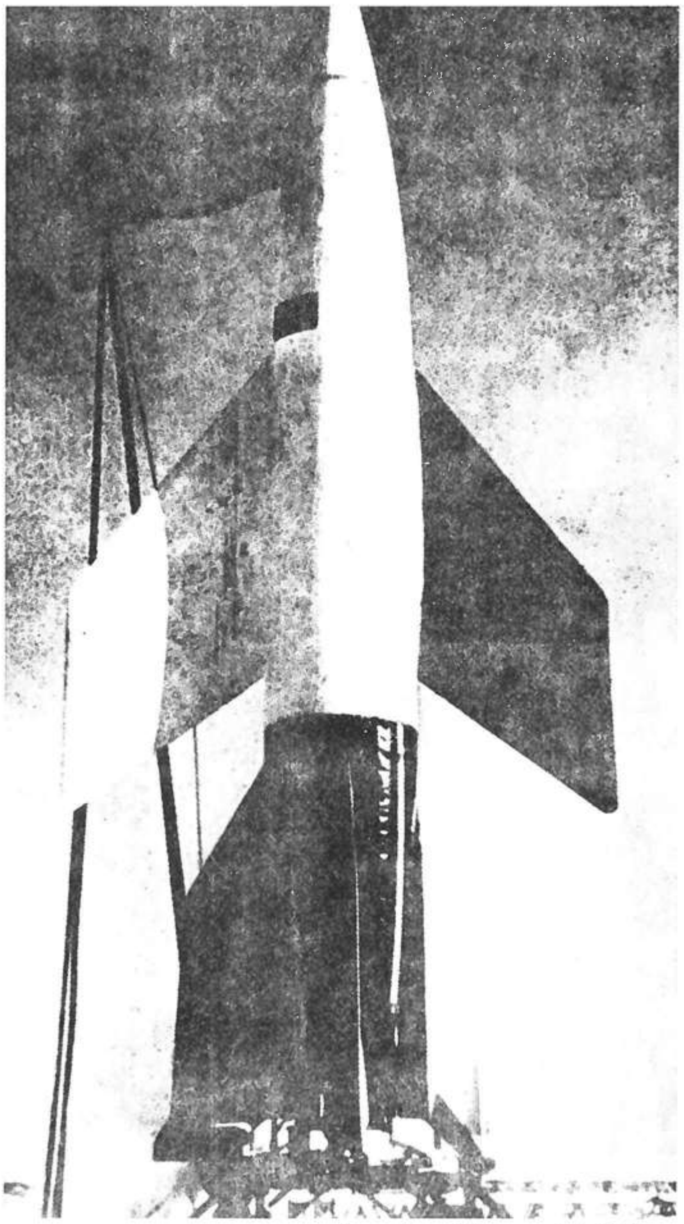
The justification for development of the Wasserfall pivoted on the cost effectiveness of using two such missiles, costing up to 10,000 German marks ($4,000) each, to shoot down one aircraft. Proponents said that this was preferred, economically, to the cost of 4,000 standard 'flak' projectiles, each costing 100 marks, to do the same job. By early 1943 the Air Force took over control of the project and under their auspices, the Wasserfall moved ahead.

In many respects the projectile was a scaled-down V-2, being 7.9 metres long with a cylindrical 91 cm diameter body, supporting four fins at the rear and four stub-wings mid-way along the shell. The four tail fins each supported a single rudder and four vanes intruded into the exhaust efflux like the V-2. The missile was designed to accommodate a radio guidance system and some consideration was given to fitting an infra-red homing device in the nose for terminal guidance. With a launch weight of nearly 3.5 tonnes, Wasserfall carried more than 1.8 tonnes of propellant and produced a thrust of 7.9 tonnes for 40 seconds. This was expected to give the projectile a maximum speed of 2,700 km/hr and a slant range capability of 29 km, with a potential altitude of 17 km at motor burn-out.

When the missile reached its target, the 235 kg warhead was to have been detonated by a radio command. With an infra-red homing device installed, the missile would switch to the heat-seeking role about 5 km from the target, responding to information supplied by the sensors, which could 'read' the thermal signature of the engines on the enemy aircraft, so that guidance commands would steer the missile to its objectives. A proximity fuse would detonate the warhead at a distance of 10 metres from the target to ensure at least partial damage to the aircraft in the event that the Wasserfall missed direct contact.

The first flight was performed on 28 February 1944, from Peenemunde. In all, 35 missiles were launched before the end of the war, but the project was far from reaching production status which was at that time envisaged for May 1946. Had the Wasserfall received top priority attention from the beginning, it would have been a formidable barrier to mass air raids on the industrial heartland of Germany, another example of the mismanaged nature of German research and development under the Nazi regime.

The inability to recognize important weapons development schemes when they were promoted by industrial companies as part of private investment, is seen best in the abysmal story of the Messerschmitt Enzian ground-to-air missile. Conceived by Dr. Wurster in 1942, the weapon consisted of a squat 3.7 metre long body containing a Hellmuth Walther liquid propellant rocket motor and supporting two fins, 180° apart, in the tail. The missile would be launched from an inclined ramp and receive supplementary thrust from four solid propellant boosters, which would be jettisoned on the ascent. With a launch weight of nearly 2 tonnes, the Enzian gained assistance from two swept-back wings and could achieve a speed of 965 km/hr and reach a target 14 km in height, or at a slant range of 28 km.


Essentially a basic A-4, the winged version of Germany's ballistic missile was dubbed A-4b by the Peenemunde design team and employed two swept wings for lift and, consequently, increased range.

The first prototype models were produced by Messerschmitt in 1943, with test flights beginning in the following year. However, the German Air Ministry were not enamoured with the independent development of an uncommissioned project and argued that the company should give total commitment to its existing obligations for aircraft production. In an effort to prove the soundness of the design, and to stress its relevence to arms requirements, Messerschmitt proposed a large range of different variants, with each one tailored to specific objectives. The Air Ministry were still unimpressed, however, and cancelled further work on the Enzian in January 1945. Still working away to perfect the missile, Messerschmitt ran into problems of component supply, as the Ministry blocked materials and deliveries dwindled. Work was finally abandoned in March of that year and the missile never achieved operational use, seeing only 25 test flights before the end of the war.

Another anti-aircraft missile to carry a Hellmuth Walther liquid propellant motor, was the Hecht, a 2.5 metre long device weighing 140 kg with two swept-back wings and a central fin. Launched from a ramp like the Enzian proposal, Hecht was to have been capable of reaching an altitude of 6 km at a speed of 1,050 km/hr and as such represented one of the few subsonic ground-to-air missiles built. The project was cancelled after one flight, however, in favour of the Feuerlilie rocket developed by the Luftfahrtforschungsanstalt Herman Göring E. V. using solid propulsion from the Rheinmetall-Borsig company.

Work on the first Feuerlilie, the F-25, led to a flight in April 1943 when the subsonic missile began a short test programme which would lead to its abandonment in favour of the F-55. As conceived, the first model was 2 metres long and weighed 120 kg, with a potential range of nearly 5 km. Flying control surfaces would have been operated in conjunction with gyroscopic guidance systems to steer the projectile to target encounter and detonation of the warhead. The F-55, its successor, was a very different missile, with a single liquid propellant rocket motor supplemented by the thrust of a solid propellant booster. Again, the F-55 sported wings and the first flight was performed from Leba in May 1944. With a length of 4.8 metres, the F-55 was capable of reaching a speed of 1,450 km/hr and had twice the range of its predecessor.

Another missile to make a first flight from Leba was the Rheintochter 1, produced in response to a requirement from the Luftwaffe for an anti-aircraft missile capable of reaching targets at a height of 12 km. Work on the Rheintochter 1 began at Rheinmettal-Borsig in 1942 and resulted in a ramp-launched projectile with a solid propellant propulsion system and a solid propellant booster at the rear, which would be jettisoned on the ascent. The entire assembly was 6.3 metres long, weighing 1.7 tonnes, capable of carrying a 135 kg warhead to a speed of 1,100 km/hr. Six wooden stabilizing fins were fitted to the rear of the main body of the missile with four smaller fins at the front end; a cluster of three more fins was attached to the booster at the rear.

In this configuration, the Rheintochter I was capable of hitting enemy aircraft up to a height of 6 km: much too low for the anticipated performance requirement stipulated by the Air Force. Nevertheless, out of 80 flight tests, 22 were conducted with a radio controlled guidance system and these proved a valuable series of research trials in preparation for the definitive version, the Rheintochter II.

By mid-1944 the Luftwaffe had changed its mind on the specification and demanded a substantial increase in performance, resulting in the Rheintochter III, which first flew early in 1945. This missile was shorter than the 'I' by nearly 1.3 metres and weighed 180 kg less than its predecessor. Nevertheless, it was capable of reaching a speed of over 1,200 km/hr and could reach an altitude of almost 15 km. Slant range was more favourable than the 'I', at 35 km compared to the mere 12 km of its predecessor, and this had been an important addition to the specification. The only other major external change was a reduction from six to four main fins, but internally the missile could accommodate either solid or liquid propulsion units; the booster was the same solid propellant motor as that employed by the first model. Control of the Rheintochter was by radio command from the ground, with a sound-sensitive proximity fuse for detonation of the warhead. Flights without guidance equipment installed were under way at the end of the war, but yet again, the missile was too late to enter service.

Another product from Rheinmettal-Borsig was the RSK-1000 21-cm rocket which would have been fired from small tubes, positioned around the perimeter of airfields so that when enemy bomber formations approached, the projectiles would be fired and release steel wires 1 km long. Supported by parachutes, the wire would cause aircraft to become entangled in the network of steel thread and thereby provide inexpensive anti-aircraft defence. It was never used operationally, although tests were carried out toward the end of the war.

At a more personal level, the Fliegerfaust enabled one man to fire off 9 20-mm cannon shells from a barrel launcher supported on the shoulder against aircraft up to 2 km away. Each cannon shell carried a small solid propellant charge to supplement the boost and ignition was by electric charge with rounds fired off in two salvos 0.1 seconds apart. Production began in January 1945, but could not reach sufficient quantities for the weapon to be introduced.

One of the more ambitious anti-aircraft projects, the Bachem Natter, was a vertically launched, piloted projectile and a full description is given (see page 261). A prolific abundance of air-to-ground missiles was developed during the war years, including the Blohm und Voss BV-143 primarily designed for use by long range maritime aircraft against targets at sea. With wings for lift and control surfaces for remote control, the missile was eventually cancelled in favour of a gliding bomb, which, incidentally, was similarly unsuccessful.

The most successful design in this category was undoubtedly the Henschel series of powered glide-bombs, beginning with the Hs-293 first tested in 1940 at Peenemunde facilities given over to the Luftwaffe. The missile was 3.8 metres long and gained its power from a Walther liquid propellant motor in the tail. The bomb was in service use by 1942 and could reach targets 16 km away at a speed of 750 km/hr. The next development, the Hs-294, carried two Walther motors and was designed to impact the water in horizontal attitude whereupon its short wings and the tail section carrying the motor would break away and allow the device to proceed, underwater, to its target like a conventional torpedo. The Hs-295 was not a great success, being designed as a radio-guided armour-piercing missile tested in 1943 and cancelled a year later. The Hs-296 combined aspects of the three earlier Hs rocket propelled projectiles, but never got out of the experimental stage.

Yet another abortive attempt at advancing the technology of air-to-ground warfare was the SD-1400, developed by the Deutsche Versuchsanstalt fur Luftfahrtzeug-und Fahrtzeugmotoren (German Research Centre for Aeronautical and Automated Propulsion). Also known as the Fritz X, or the Fritz X-1, it did achieve fame for sinking the battleship Roma although it saw little use generally.

The final category of missiles involving some form of aircraft use or confrontation is, of course, the air-to-air class and here the Germans achieved a measure of success. Unfortunately, the missiles were, again, late in the day and still in varying stages of development at war's end. The most famous is the R4M, so called because the letters signified a rocket projectile of 4 kg warhead mass, with a thin-walled shell. Designed by K. Heber and developed by the Deutsche Waffen-und Munitionsfabrik, the R4M was ideally suited to its most preferred mount, the Messerschmitt Me-262 turbojet interceptor, and was designed to be fired from a wooden launch rack beneath each wing.

Each rack held 12 missiles and the entire battery could be loosed in a 0.03 second burst. The R4M emerged as the result of an intensive study into the quantity of explosive which would be required to shoot down any aircraft then flying in the Allied air forces inventory and a considerable amount of work resulted in the conclusion that 400 grams would be necessary to do the job. Coupled with an inertial velocity of 550 metres/second the studies also concluded that an interceptor of the calibre of the Me-262 could not fail to achieve its objective, if the missiles could be fired off at 50 millisecond intervals.

This was satisfactorily met by the DWM design team and they received a contract order for 25,000 R4M missiles in April, 1945. Almost none of these reached operational status, but the potential kill rate of the R4M equipped Me-262 is revealed by the results of an active test during which 6 of the turbojet fighters were sent off hunting Allied bombers, each carrying 48 missiles. On the single test sortie, the Me-262s shot down 14 bombers before returning to their base of operation.

An interesting note on the Me-262 is that a series of tests were carried out using a Walther HWK-509 liquid propellant motor to boost the take-off capability and then to assist with gaining altitude. Nothing much came of this work due to problems with thrust control and fuel feed. Nevertheless, the R4M also found a potential application with the Heinkel He-162 single-seat turbojet fighter. With this aircraft it was proposed that batteries of 15 missiles should be fitted to the wings, two each side, and thereby present a firepower of nearly 57 projectiles a second. Nothing resulted from this due to the termination of hostilities.

In an attempt to provide a more satisfactory assurance of hitting the target, the Ruhrstahl A.G.X-4 was a wire-guided missile 2 metres long and weighing 60 kg. When launched, the X-4 would pull out up to 1.1 km of wire so that the pilot could manually guide the projectile to its objective at a speed of up to 885 km/hr. The warhead, packed with 20 kg of explosive, would be detonated by a proximity fuse and the missile was test fired in September 1944. The project was cancelled early in 1945 due to the retarded stage of development.

The third air-to-air missile which achieved a moderately advanced stage of development was the Henschel Hs-298, a radio guided two-stage solid propellant device, first tested in December 1944. With a length of 2 metres and a weight of 120 kg, it could reach a speed of 860 km/hr and target interception was assisted by the lift from wings spanning 1.2 metres. It too was late on the scene and it went the way of the R4M and the X-4.

Apart from the V-2 and the Rheinbote, both of which are described elsewhere, Germany developed other surface-to-surface missiles, although none were more famous than these. First into the field was the Nebelwerfer which appeared on the Eastern Front in 1941. As an artillery weapon the missile was a great success, being produced in a variety of sizes, among which were 15, 21, 28 and 32 cm diameter projectiles, all about 1.2 metres long with a weight of 109 kg and a range of 6.4 km. The Nebelwerfer was eventually matched with a special launcher, called the Wurfgerat, which could accommodate up to 6 projectiles.

Although originally conceived as an anti-aircraft device, the 7.3 cm Fohn missile system saw great success as a field artillery weapon and provided a formidable barrage from its 35-round launcher, capable of sending the solid propellant projectiles off at a speed of 1,400 km/hr. Looking more like a conventional artillery shell, each missile carried a 250 gram charge and was usually fired in salvos. It never did shoot down any enemy aircraft and its resulting application places it firmly in the category of a surface-to-surface weapon. Two developments were completed as infantry weapons, called the Panzerfaust and the Panzerschreck, the former firing a 6 cm diameter rocket and the latter using a 8.8 cm missile. Fired from the shoulder against tanks or self propelled guns, they weighed only 4 kg at most and led to a requirement for a more advanced weapon in this class.

Called the X-7, it could have been fired from either the shoulder or a small ground launcher. The missile was 76 cm long and would have been guided to its target by a wire connected to a control device which could easily be operated by one man. The X-7 adopted a two-stage solid propellant motor and utilized small wing surfaces for aerodynamic control of the trajectory or course changes necessary to hit a moving target. Although it was tested before the end of the war, it never saw operational service.

One project which did see operational service, however, was married to what must surely rank as one of the most audacious aeronautical endeavours of World War II: the Messerschmitt Me 321 and 323 power assisted gliders, popularly and appropriately, called the Gigant. Its origin dates back to October 1940 when Hitler officially postponed his planned invasion of the British Isles due to the inability of the Luftwaffe to destroy the Royal Air Force and so prevent air attack on invading paratroops. When this decision was made, Hitler hoped to deal with the Soviet Union in an 18-month-long campaign and then turn his attention back to the indomitable British. In the intervening period, while his troops were to be occupied with the eastern front, industry would develop a massive glider which could then be used to land the heavy supplies and munitions thought to be essential for the subjugation of the United Kingdom.

Accordingly, the Reichsluftfahrtministerium (Ministry of Aviation) issued a specification to Messerschmitt and Junkers for design studies leading to quantity production of such a glider in time for the invasion of Britain. The two contracts were not competitive: Messerschmitt was ordered to use welded tubular steel in the design; Junkers were instructed to build their Ju 322 project from wood. By February 1941, the first Messerschmitt 321 prototype was rolled out the Leipheim hangar to reveal itself as one of the largest aircraft ever conceived; its original designation, Me 263, having been changed two months before.

With an empty weight of 12.2 tonnes, the Me 321 could carry a load of some 27 tonnes in a structure 28.1 metres long and with a wing span of 55 metres. The aircraft carried its massive wing across the top of the fuselage and sported a conventional tail at the rear, 10 metres high. Defensive armament was provided in the form of two machine guns mounted in the sides of two enormous clam-shell doors, comprising the front of the fuselage. The basic concept envisaged the aircraft taking on its cargo through the nose by way of a special ramp and then being towed to its destination by three Messerschmitt Bf 110 twin-engined fighter-bombers. At the appropriate time, the towing aircraft would release the glider, from where it was expected to be flown down to a rough landing, controlled by a pilot high up in a cabin on top of the fuselage and immediately aft of the huge nose doors.

Nevertheless, even the performance capability of the Bf 110 left an uncomfortably narrow margin between the desired takeoff speed and the actual value, so it was decided to supplement the ascent with clusters of solid propellant rocket engines under each wing surface attached to the massive main spar on the Me 321. At first, 6 hydrogen peroxide rockets, delivering a thrust of 500 kg for a duration of 30 seconds, were fixed beneath each wing in two clusters of three. But even with this assistance, the configuration was a frighteningly cumbersome device.

After trundling down the runway for about 1.2 km, with the three Bf 110 aircraft spread out in front, each one pulling a tow wire, the two outer aircraft lifted into the air immediately after the Me 321 became airborne. Finally, at a speed of less than 90km/hr, the centre aircraft would take off and the entire group would climb to altitude at the uncomfortably low speed of 130 km/hr, eventually settling into a cruise speed of 190 km/hr all the way to their destination. As development continued with tests on the production versions, designated Me 321 A-1 and B-1, various combinations of rocket boost assemblies were tried out. The preferred configuation was soon determined to be either 6×500 kg thrust motors, 4×750 kg motors or 3×1,000 kg motors under each wing, providing the aircraft with total supplementary boost of 6 tonnes for 30 seconds.

But such were the dynamics of aircraft that if one cluster of solid propellant rockets failed to fire as planned, the entire assembly would be thrown into a sideways slewing manoeuvre due to the asymmetric line of thrust and this is exactly what happened during one tragic episode in the Gigant's development. Shortly after takeoff, and with the assembled group of four aircraft tied together, one cluster of motors failed to fire and the Me 321 slewed round to the right, causing the tethered group to crash to the ground with the loss of 129 lives. Nevertheless, the search for an adequately powerful towing aircraft continued and this resulted in another extraordinarily bizarre endeavour.

Two Heinkel He III twin-engined bombers were physically joined together, side by side, with a constant wing section in between supporting three engines, in addition to the single power plant on the outboard wings of the original two aircraft. This aircraft, called the He IIIZ-1 Zwilling, was capable of towing two Me 321 gliders, one behind the other, at a speed of 360 km/hr. By early 1942 the full production batch of 200 gliders had been delivered, but already the limited performance capability generated a request from the RLM for studies into a powered version with six 14-cylinder radial engines mounted in the wings.

This modified transport aircraft was designated Me 323 and the first flight was performed in March 1942. Unlike the Me 321, which had a jettisonable undercarriage dolly for takeoff and four skids under the fuselage for landing, the Me 323 carried two rows of 5 wheels along each side of the lower fuselage fixed within extended fairings. Supplementary boost was still provided by solid propellant rockets, with either four 500 kg, three 750 kg or two 1,000 kg thrust units under each wing outboard of the radial engines.

The general dimensions of the Me 323 were similar to its predecessor, but the aircraft weighed 29 tonnes empty and could carry only 16 tonnes fully laden. Production was halted in April 1944 and both designs saw limited service on the Russian front, never having achieved their planned objective of landing troops and equipment on English soil. But, with six radial engines and up to eight solid propellant rockets all firing at launch, the Me 323 must have been one of the most incongruous sights ever to grace the skies above the battlefields of World War II.

It must by now be apparent to the reader that German rocket research can be broadly categorized into three separate, and sequential, periods of development. It is a productive exercise to ponder the cause and effect of changing

German propaganda took various forms during World War II. This stamp was issued to signify the military application of rockets and to convey a sense of superiority in weapon development.

attitudes both inside and outside the detached professions that led to many of the achievements listed earlier. If it is possible to reach any conclusions at all about the shifting scenario in Germany between, say, 1930 and the end of the war in 1945, they will doubtless be found valuable in reaching a decision about the future course of science and technology as applied to rocket activities today.

Between about 1930 and 1935 the cadre of scientists and engineers, who developed the basic principles upon which later more practical developments would rest, were a group apart from the majority of Germans. A considerable aura of respect and admiration surrounded the academic fraternity and the justifiable pride expressed by any one or a group of participants in major research endeavours was recognized as fulfilment of the teutonic capacity for supreme challenge and accomplishment. We shall see, later, that this attitude would permeate the American rocket programme of post-war years and it is helpful to recognize its origin.

The accepted belief that scientists and engineers were an elitist faction working at the pinnacle of Germanic authorship, instilled a deep sense of pride, both within the research teams individually and, in broader scope, within the majority of the community at large. This kept alive the fundamental belief that Germany would seek a way round constraints imposed upon its people by the victorious powers after the First World War and while it is true to conclude that many devious plots were hatched to evade the restrictions, it is also necessary to accept the fact that German ingenuity would inevitably lead to a compromise situation: the compromise would always be demanded of the conquering nations to the benefit of Germany herself.

Nevertheless, coupled with a total fascination for fine engineering and all things mechanical, the tenacious hold on rocketry forged by men like Oberth and welded by practical men such as Dornberger and von Braun, would cement the intellectual pursuits of the nation solidly to a classic and fundamental respect for science and engineering. In essence, rocketry became the post First World War tool by which a few dedicated practitioners restored Germanic supremacy. This was the first period in a sequence of transitional changes which would, within two decades, move the nation far from its road of traditional philosophy and take it full circle back to the original stimuli.

Between about 1935 and 1943, the latter date more solidly recognized than the former, German research and development was greatly influenced by the dictates of the new political order and this brought in its wake a shifting-sand approach to proposals for new projects and revolutionary concepts. Gradually, throughout the duration of this eight-year period, there was an increasing call for better and more sophisticated weapons. Hitler's pathological obsession with the idea that Germany could only be strong through the enforced respect of peripheral nations, was a fallacy; events would bring about the total collapse of this philosophy and from the ashes of the Third Reich would come a strength and a power that were, in all probability, at the base roots of Hitler's expectations all along. But the latter would be achieved with a strong economy and little military prowess.

The effect that Hitler's regime had on the scale and direction of German research is best expressed by considering the Fuhrer's own attitude to technical and academic subjects; two facets of applied science that achieved greater unity in Germany than in any other country. While it would be true to say that he misunderstood and totally distrusted the scientist, it would be equally as wrong to interpret from that a totally negative response leading to stifled research opportunities. Indeed, under Nazi authority, the technical and scientific communities prospered and had greater opportunities for expanding the technico-industrial backbone of the nation than at any other time before. Yet the constraints and channels that research was forced to follow, was inspired by political objectives and frequently, deliberately structured so as to accomplish tasks and objectives which would have been denied to the regime had science been given free reign.

On the other hand, many beneficial avenues were left unexploited and the result of having inexperienced persons, with very wide ranges of mental and intellectual capabilities take over the administration of research programmes, is exemplified by the A-4 story. In this situation the Hitlerian attitude reverberated throughout the various levels of control, with each section head duplicating the negative approach of his superior. It might have been a very different story if Hitler had set up autonomous supervision of advanced research projects, with the authority to orchestrate the best talents in the most fruitful areas. It would have accelerated the course of German weapons development and harnessed the most talented assets of the nation into a more productive and coherent matrix.

Germany certainly had a head start in many areas that were to prove pertinent to rocket and missile development, but this was a product of the old school approach where academic, scientific and technical personnel had the respect which allowed a certain remote detachment from the machinations of extreme political philosophy. Instead of preserving this valuable, hard earned, elite, Hitler shackled the research effort to his own structured concept and made it work for the ultimate objectives of his own deliberations.

By 1943 the rot had already set in and the result of many years of directed effort tore apart the solid background of technology and science. It is true, as related above, that many projects were accomplished which would never have been brought to fruition were it not for the dominant authority of the Nazi regime, but many, many more were left unaccomplished because of the channelled direction applied to research. When the time came to re-build the decaying remnants of a coherent scientific policy it was too late. Nevertheless, programmes introduced in the last two years of the war did some good in making up for lost time and this set Germany back on the road to its original goals. Total restoration of old values would await a decade of peace, but by 1943 Hitler was too embroiled in his military tasks to hold reins on the technical community.

At last he sought their help, apologized on at least one occasion for his lack of foresight, and provided a stimulus for originality and invention once again. Most of the truly novel applications in rocket propulsion and missilry were allowed to emerge during the 1943–45 period; they had been around for many years before that, but only as theoretical concepts by the unstilled mind of the scientist and the engineer. Only when events began to generate concern about the future course of the war, did Hitler allow his judgement to be guided by experts. Before this he had recognized the need to exploit technology for the good of the nation, and more especially for the good of the Party aims, but found himself incapable of delegating authority to those who knew best.

The prolific abundance of remarkably advanced projects in 1944 and early 1945 is testimony to this misspent transition period between 1935 and 1943. There was, of course, contest between the two modes of rocket propulsion: liquid propellant or solid propellant, and the more complex nature of engines utilizing the former, provided an opportunity for speedier application of the latter. Indeed, many of the tasks called upon to be performed by rockets were more suited to the advantages of solid propulsion. Anti-aircraft rockets, air-to-ground missiles and anti-tank projectiles were required to be small, simple to operate and to have a high initial acceleration. Because of the comparative sophistication of liquid propellant engines over solid propellant motors, it was left to the well established avenues of research to exploit an application for the former.

This matured to perfection (as an example and not necessarily a concept) in the A-4, or V-2, and liquid propellant engines were not developed to the same standard for any other application. So, there was a markedly competitive element about the methods of propulsion and specific objectives dictated their preference for either mode. A similar bifurcation of application applied to the very nature of the device that was to be powered by rocket propulsion.

Up to now the rocket, as a propulsion system, has been considered as the motive (reactive) device by which a ballistic missile could achieve high velocity or by which a smaller device could gain high acceleration. It took just a few experiments to show that the engine of a liquid propellant motor was more properly situated at the bottom of the assembly, so that when the exhaust gases were released following combustion, they would move, unimpeded, away from the main structure above. It seems quite logical to conclude that this would be the only obvious way to build a rocket motor into a missile. Nevertheless, Robert Goddard in America and early German experiments performed by the VfR, initially adopted a system whereby the rocket motor was located above support structures which required some form of deflector plate which could protect the metals directly in line with the exhaust efflux.

However, it soon became apparent that the now classic shape of a ballistic rocket would require the engine to be at the bottom with the propellant tanks placed one above the other in a vertical stack that minimized the overall diameter of the device and facilitated the provision of a pointed nose section. This is the preferred configuration for a device that would be required to reduce frontal area and cut a path through the dense layers of the atmosphere. In other words, the popular school of thought relied wholly on the rocket engine to provide the impulse, the flight control mechanism (by way of rudders, or deflectors, placed in the path of the exhaust) and the velocity for the most efficient movement through the air. Based on well known principles of ballistics and the supersonic flight of artillery shells, the missile was made to the contours most admirably suited for rapid flight.

In space, the shape of the projected mass has little effect on the efficiency of the device, because there is no fluid, such as air in the atmosphere, to retard the forward motion; problems of drag are dissipated in the almost pure vacuum beyond Earth's veil. The A-4 was the only missile up to the end of World War II that had to be designed with consideration for flight outside the atmosphere, although minimal work in this direction was already under way in the United States in connection with the Wac Corporal sounding rocket. The same A-4 control vanes used to deflect the thrust line of the exhaust efflux in the atmosphere, would ensure adequate control outside the atmosphere, where aerodynamic control surfaces would be useless and there was little additional work on the problems associated with re-entry, except those required to provide a smooth return in stable attitude at the end of the ballistic trajectory.

But from quite early on in the century another school of thought had emerged, which challenged the apparent preoccupation with assembly of a missile along lines dictated by purely ballistic considerations. It has already become apparent that much of the stimulus for original research in Europe came from the prolific writings of Hermann Oberth; many of the now famous names in rocketry were stimulated to practical tests by this remarkably literate 'prophet' of space travel and flights to the Moon and the planets. Oberth, however, was an arch-proponent of the rocket engine married to a cylindrical projectile, designed to follow ballistic laws and this may have done much to divert attention from other, equally valid, concepts which are only reaching fruition today. Max Valier favoured the marriage of a reactive device to a winged aeroplane capable of generating lift.

After reading a copy of Oberth's book called *By Rocket to the Moon*, published in 1924, Valier conceived the idea of converting an existing aeroplane into a precursor rocket-powered transporter, by first fitting turbojet engines in the wings to test the device at high speed and then building a rocket-plane proper which would be launched from a tower into near-space. Returning to the atmosphere at will, the wing structure would generate lift and permit the vehicle to glide to a conventional landing. Valier corresponded with Oberth on this idea and by 1928 a third theorist was on the scene: Dr. Franz von Hoefft.

Von Hoefft proposed the concept whereby the rocket vehicle would be built as a flat-bodied lifting device, so that it could return to the atmosphere and land like a hydroplane. Soon, preliminary tests had been conducted at the Aerodynamic Institute in Vienna, confirming many of von Hoefft's ideas and, with very little consideration of the practical development of such a device, discussions were held with a young technician at the Institute called Eugene Sanger. Sanger was particularly interested in rocket flight and quickly developed a preference for matching the reactive motor to a lifting device which could be piloted like a conventional aeroplane.

With youthful exuberance, Sanger, born on 22 September 1905, pressed ahead with design theories for his lifting device, while also proceeding to explore the technology of high thrust liquid propellant motors; it was in this latter category that Sanger would perform the practical side of his work. Nevertheless, with a desire to pursue the notion that rocket flight could be better served by development of a lifting device, he tried to present a doctoral thesis propounding the mechanics of flight into the stratosphere by reaction motors married to an aeroplane. This was disallowed and he was forced to return to the classic engineering problems associated with conventional flight.

By 1932 Dr. Sanger had prepared the draft of a book called *Raketenflugtechnik*, Rocket Flight Technique, and sought a publisher to publicize his theories. After many refusals he finally negotiated a successful contract with the same Munich publisher that had marketed the words of Oberth and Valier. The dedication to publication of rocket propelled lifting devices can be appreciated from the fact that Sanger went into debt for three years to put the book before the public. Exploring the possible avenues of development, this book considered the specification for a rocket plane and theorized that it would be powered by a liquid propellant engine burning oxygen and petrol to achieve a speed of 10,000 km/hr and a maximum height of 70 km.

Publication in 1933 led to interest from several leading journals and Sanger exploited this attention by expanding further on his ideas. But the enormous problems associated with development of a suitable propulsion system kept him at work on more fundamental issues until, in 1936, he was called to Germany to set up the Research Institute for Rocket Flight Technique at Trauen. Along with his mathematician assistant Irene Bredt, later to become his wife, Sanger moved into the research facilities in order to conduct tests on the propulsion system and continue to refine the concept of a stratospheric aeroplane.

Early in 1938 Sanger prepared a study paper discussing the problems associated with high-speed, high-altitude flight and later in the same year began construction of a small scale model of a supersonic glide vehicle. Work at the Research Institute picked up during 1939, when most of the laboratories and test facilities had been completed. Between 1936 and 1942 Sanger progressed with his design for the revolutionary vehicle which led to the now famous 'antipodal bomber'. It had never been Sanger's intention to develop the supersonic glider for military purposes, but the onset of hostilities brought a pressing requirement for a less benevolent application and the work conducted at Trauen would never have been allowed to continue if he had been unable to couple the project to the requirements of the war effort.

Although the Sanger–Bredt antipodal bomber was never built, its design featured several revolutionary principles, both in concept and operation and it is worthy of further description, if only for the remarkable nature of its supposed application. The basic structure consisted of a flat, square-sided, fuselage nearly 28 metres long, 3.6 metres wide at its broadest point and 1.8 metres deep. The forward section would have carried a pressurized cabin with facilities for a single pilot and all the necessary controls and instruments to conduct the flight. The fuselage itself was sharply pointed at the extreme nose and would have carried a bluff tail through which would protrude the nozzle from the liquid propellant rocket motor.

The engine would provide a total thrust of 100 tonnes for a duration of exactly eight minutes, burning a combination of liquid oxygen and a mixture of gas-oil and water. The propellant tanks would have taken up the rear two-thirds of the fuselage, beginning at a point immediately forward of the main rocket motor, with the two cylindrical oxidizer tanks side by side and forward of the two similarly configured fuel tanks. A retractable undercarriage was to have been located under the fuselage, between the two oxidizer tanks. Two wings were designed into the antipodal bomber, with a total span of 15 metres and placed either side of the fuselage, just forward of the mid-point, set into the flat underbody, so as to present a continuous lifting surface with the underside of the fuselage. A horizontal tail would have been located at the rear of the fuselage, with two vertical fins placed on top of each extremity.

The proposed method of launch was quite unique. The 'bomber' itself would have rested on a single-piece sled in the horizontal position, with a booster fixed behind the aerospace plane. The booster was essentially just a large rocket motor, capable of delivering a thrust of 610 tonnes for a duration of 11 seconds. With the booster securely fixed to the sled, and the bomber mounted on the forward section of the sled in front of the booster, the entire assembly would accelerate along a track 2.9 km long. At the end of the 11 second run the booster/bomber combination would have reached a speed of about 1,840 km/hr at which time the bomber would become airborne, rising under its imparted momentum at an angle of 30° to a height of nearly 1.7 km.

At this point the liquid propellant rocket motor would be ignited and, from an initial weight of 100 tonnes, the 90 tonnes of propellant would be consumed to carry the vehicle to a height of 150 km and a speed of 22,100 km/hr. From here the bomber would then coast back down into the atmosphere where, at a height of 40 km, it would position itself for maximum lift and rise back into more rarefied regions like a stone skipping across the surface of a pond. Several such 'skips' would be performed to extend the range and minimize the heat load built up on the outer surface due to friction. Finally, with speed down below that which would have been required for generated lift to carry the vehicle further, the bomber would glide to a conventional landing on a prepared runway. It was confidently predicted that the maximum range of such a system would be 23,490 km.

Three important features of the design and operating plan would be taken up later and used in definitive projects. First, all the components would be reusable: the bomber itself would, of course, return for safe recovery of the vehicle and its pilot and the rocket boost unit would be decelerated after releasing the bomber at the end of its launch run. Second, the bomber would have utilized the lift qualities it possessed to extend the range by dipping in and out of the atmosphere several times; this concept was adopted for re-entry trajectories in the Apollo Moon landing programme of 1961–72, with the advantage that it ensured a degree of control on the descent for trimming out any inconsistencies in the flight through the atmosphere. Third, the skip technique would have reduced the thermal stress imposed by atmospheric friction, so that the exterior skin could radiate heat back into the rarefied layers, before dipping back down for a further reduction in speed. Reusability, a key aspect of the Sanger–Bredt antipodal bomber, would pursue rocket engineers into the 1960's, until America would finally devote a larger portion of its financial resources to the development of a reusable space transportation system: the Shuttle.

The main engineering problems which would probably have delayed the successful application of the Sanger–Bredt proposal, centred on the tremendous stresses that such a system would be called upon to survive, the successful fabrication and production of a 100 tonne thrust liquid propellant rocket motor and last, but probably most prominent, the enormous difficulty in arranging the chemical matrix of a compound which could have survived the searing heat of re-entry. This latter aspect would only be achieved in practice after several years of work on ballistic missile nose cones. A decided drawback with the project, was the impossibly small payload that it could, theoretically, carry. To achieve a range of 23,490 km, the antipodal bomber would have been able to lift a load of only 300 kg. This deficiency is a product of the project's inception in pre-war days, when the concept was more properly thought to have found application as a hypersonic aeroplane, leading towards a true aerospace transporter.

Much of the detail on the project had been worked out by 1938, when a 1/20th scale model was built, followed, in early June 1939, with tests on the friction problem as it related to the running sled launch technique. Very little was understood about the characteristics of metals and adjoining surfaces exposed to a relative velocity of more than 1,800 km/hr and Irene Bredt did much work on the problem before results indicated that there were no insurmountable barriers to the concept. In the first two years of the war, work on the project was slowed by shortage of materials and the necessary emphasis on more pertinent aspects of the munitions industry. Nevertheless, plans for construction of the 100 tonne thrust motor went ahead and Sanger developed a combustion chamber capable of supporting full thrust tests with an internal pressure of 103 kg/cm^2. This was a remarkable advance on the 30 tonne thrust rocket motor developed for the A-4, which had a combustion chamber pressure of less than 16 kg/cm^2. Cooling for the Sanger engine was to have been provided by a circulation of water through tubes wound round the combustion chamber and this too reached a high stage of development, as did a liquid oxygen pump capable of delivering propellant at the rate of 240 litres/minute.

By December 1941, Sanger had prepared a report on the project detailing the application of the antipodal bomber, but this was turned down by the German Research Institute for Aeronautics. Less than a year later, all work on the 100 tonne thrust rocket motor was cancelled and the Sanger–Bredt team were put to work on less exotic schemes at the Research Institute for Gliding Flights. Two years later, in September 1944, Sanger did manage to get permission for publication of a secret report on the aerospace bomber concept, but events moved towards the occupation of Germany by Allied forces and nothing further came of the work. During the initial work on transforming the transporter into a bomber, it had been proposed that the vehicle could be used to carry a bomb load to New York, but there is little doubt that the basic project would have required considerable modification to achieve this objective.

Yet the idea was sound and could have led to development of a totally novel approach, whereby the rocket motor would have been joined by aeronautical science, to create a vehicle capable of substantially advancing the state of the art. The three primary phases of science and technology in Germany between 1930 and 1945 discussed earlier, can be seen to perfection in the attitude toward Sanger's concept. During the early period his revolutionary ideas brought a degree of recognition leading to the establishment of a unique facility at Trauen from where he had hoped to conduct the precursor studies essential to continued, and practical, development. But by that time the war effort was claiming priority for projects which offered a comparatively short 'lead-time', the period required to bring a concept to fruition.

Later, in 1944, there is evidence that the relevant authorities were more interested and this too is in line with the earlier conclusion that restoration of pre-war attitudes were prevalent at that time. As we now know, it was left to Sanger to provide a potentially workable design for the concept, that dictated an alternative approach to the purely ballistic technology adopted for classic missiles. The two schools of thought had pursued an asymmetric course: winged rocket vehicles were never given the credence they deserved, while activity focused totally on the notion that rocket motors would find the most appropriate application as propulsion systems for pointed projectiles with minimum aerodynamic resistance. This philosophy would be retained for the next three decades. Yet, despite its shortcomings, German rocket research was considerably ahead of comparative levels of development elsewhere.

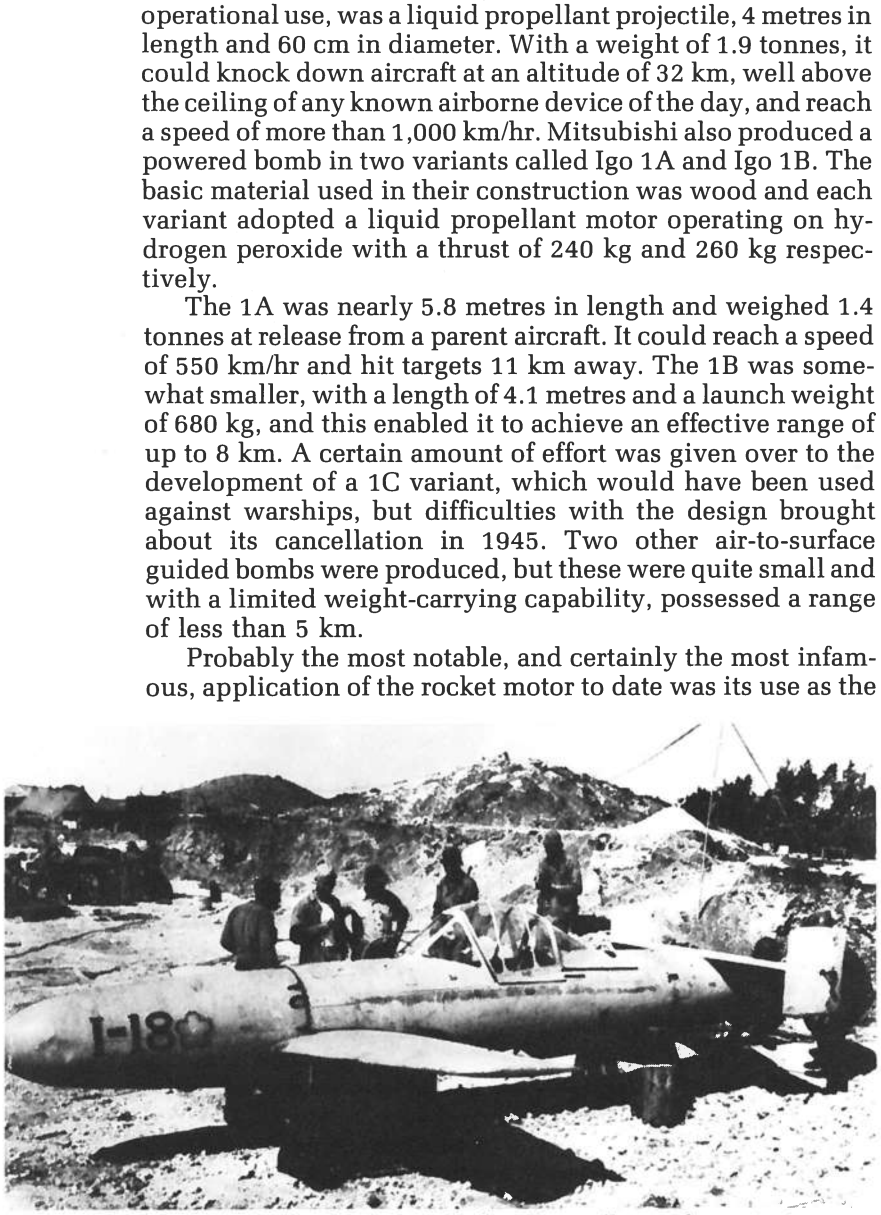
Some would argue that the tremendous strides of the Soviet rocket programme at least equalled that of the German effort, but if the criteria for achievement rests with the copious demonstration of test flights and a production status, then the Peenemunde work should be considered as the most productive. The story may very well have been different if Russia had maintained a degree of consistency in its liquid propellant motor designs, but the pressures of war brought a demand for military weapons to the exclusion of other, more exotic work; the Soviet Union had no ballistic missile programme in 1941 and that sealed the fate of any such proposition until peace returned in 1945.

By the end of April 1945, the German rocket programme was in ruins, the result of fourteen years work, since the country's first liquid propellant rocket flight, brought down in the consuming fires of Allied conquest. The European war was over. On the other side of the world, on numerous Pacific islands and in the dense jungles of south-east Asia, conflict would continue for several more months, its last violent battles inciting retribution of an horrendous nature: the dropping of a single atom bomb on each of the two now famous Japanese cities, Hiroshima and Nagasaki.

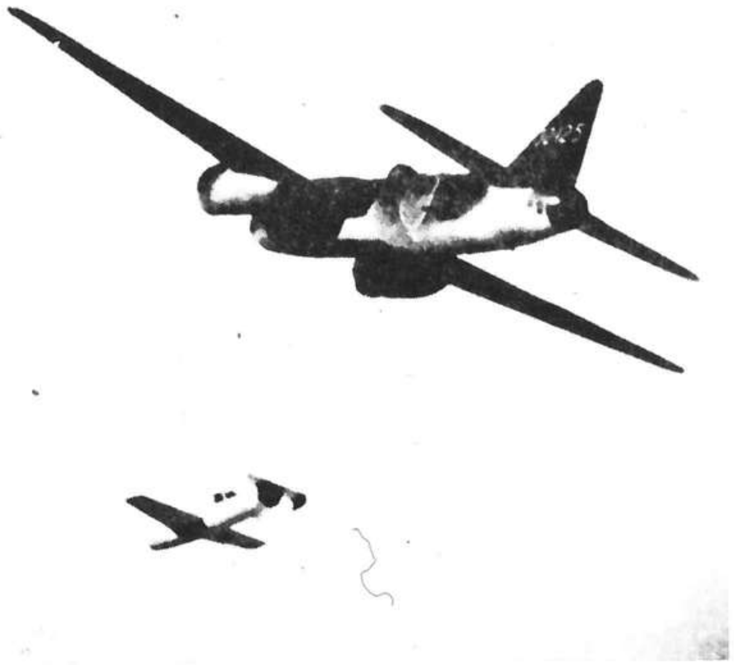
The Japanese rocket programme was slow to start and languid in its application of the principles of reactive flight. The only notable exception to an almost total lack of weapons application, was a series of ground-to-air missiles in the Funryu class. Under intense pressure from American air attacks, the Japanese Navy Technical Research Institute financed development of an anti-aircraft projectile built at Yokosuka using a solid propellant motor constructed by the firm of Mitsubishi, famous for its aircraft designs.

Funryu 2 was 2.4 metres long and 30 cm in diameter, with a weight of 370 kg. It could reach a speed of 845 km/hr and an altitude of nearly 5 km. Funryu 3 was conceived as a liquid propellant version of the former, but it failed to reach production status. Funryu 4, the only other missile of the series to see operational use, was a liquid propellant projectile, 4 metres in length and 60 cm in diameter. With a weight of 1.9 tonnes, it could knock down aircraft at an altitude of 32 km, well above the ceiling of any known airborne device of the day, and reach a speed of more than 1,000 km/hr. Mitsubishi also produced a powered bomb in two variants called Igo 1A and Igo 1B. The basic material used in their construction was wood and each variant adopted a liquid propellant motor operating on hydrogen peroxide with a thrust of 240 kg and 260 kg respectively.

The 1A was nearly 5.8 metres in length and weighed 1.4 tonnes at release from a parent aircraft. It could reach a speed of 550 km/hr and hit targets 11 km away. The 1B was somewhat smaller, with a length of 4.1 metres and a launch weight of 680 kg, and this enabled it to achieve an effective range of up to 8 km. A certain amount of effort was given over to the development of a 1C variant, which would have been used against warships, but difficulties with the design brought about its cancellation in 1945. Two other air-to-surface guided bombs were produced, but these were quite small and with a limited weight-carrying capability, possessed a range of less than 5 km.



Japan's Ohka dive-bomber used a liquid propellant rocket motor to accelerate the device in the last 30 sec before impact. American personnel are seen here examining a captured example.



The Ohka was released from a Mitsubishi G4M bomber within 80 km of the planned target. The pilot had no chance of escaping death, whether by impact with his target or prior interception.

Probably the most notable, and certainly the most infamous, application of the rocket motor to date was its use as the powerplant for the Yokosuka MXY-7 Ohka Model II Kamikaze suicide bomber. This bizarre project envisaged the marriage of a three-barrel liquid propellant motor, delivering a thrust of 800 kg to a very light airframe capable of carrying a single pilot and a heavy warhead in the nose. The concept was proposed in 1943, the device was developed in 1944 and resulted in operational use during 1945.

Built primarily of wood, the fuselage was a cigar-shaped cylinder of circular cross section, 6 metres in length, incorporating a rounded nose, in which was situated an explosive charge of 1.2 tonnes containing tri-nitroaminol. The two wings spanned 5 metres and the horizontal tail section supported two vertical fins at each extremity. A large bulbous cockpit canopy was positioned just aft of the mid-fuselage section and the contraption was 1.2 metres high. In the empty configuration, the Okha weighed a mere 440 kg, increasing to more than 2.1 tonnes loaded. The Ohka was designed to be carried beneath a Mitsubishi G4M bomber, modified as the 2e variant, and the rocket-propelled dive bomber would be carried thus to within 80 km of a designated target.

Released for free flight, the Ohka pilot would use aerodynamic control surfaces on the wings and in the tail to glide from a height of about 8 km and at an average speed of only 375 km/hr. Steering a course to the target, the liquid propellant engine would be ignited within 30 seconds of impact, and the 10 second burn of the motor would accelerate the flying bomb to a speed of 1,000 km/hr at impact. During the terminal phase of the dive, the pilot would be likely to lose consciousness and this resulted in many Ohka dive bombers falling to impact some distance away from the target. Nevertheless, the sure knowledge of certain death rendered the Ohka a particularly obnoxious instrument of war, although several hundred were produced and delivered for operational use.

Flights began in April 1945 during the bloody battles on the island of Okinawa and the first successful 'kill' was recorded on the 12th of that month, when a single Ohka sank the USS Abele, an American destroyer. Before long the American forces awarded the Ohka the nickname Baka, Japanese for 'Fool', but the sight of a winged Ohka streaking down in an almost vertical dive was rendered all the more startling, by the knowledge that grim determination to kill, was backed by a coldly planned suicide mission. Several Ohka models were delivered for training purposes and a few were fitted with a jet engine delivering 200 kg of thrust, although this latter variant was pitifully underpowered and comparatively easy to shoot down. Still other modifications incorporated a ground launch capability, somewhat after the fashion of the German V-1, and one design envisaged the Ohka being launched from submarines. None of these latter applications were developed due to the cessation of hostilities in August 1945.

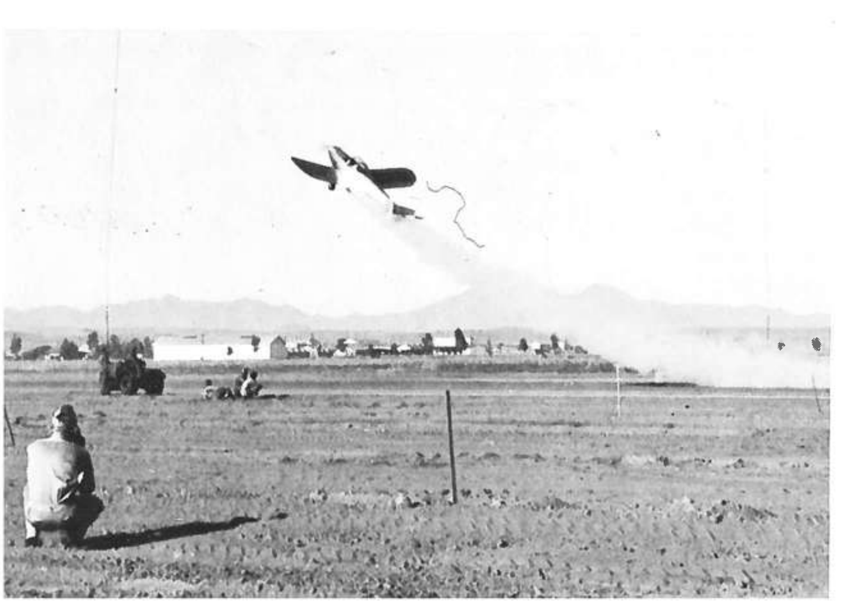
Nevertheless, Japanese interest in rocket powered airborne interceptors took a slightly less successful turn. It all began when Japan sent a contingent of high ranking officials to view the experimental tests under way in Germany on the Messerschmitt Me 163 rocket fighter. Before long the Japanese government purchased the manufacturing rights on this aircraft and Germany shipped out a production machine, along with all the details required for assembly. Unfortunately, the ship was sunk before it arrived at its destination and Japan was left with only an instruction manual to go by in designing its own version based broadly on the Me 163. Work started in July 1944 on the aircraft, designated J8M1 and called Shusei (Rigorous Sword), while a number of wooden gliders were constructed to provide potential pilots with experience in handling the delta-winged aircraft.

Manufacturing rights for the German engine, the HWK 109–509, had been obtained earlier in the year and the Yokosuka Naval Aeronautical Engineering Arsenal re-designed the production methods to Japanese techniques. The first powerplant, called the Toku Ro 2, was delivered to Mitsubishi in June 1945, followed a month later by the first flight attempt with the J8M1. Shortly after takeoff, the aircraft lost power and crashed, carrying with it the hopes for a Japanese rocket propelled interceptor. Four other J8M1 models had been completed but none were flown and work centred on a modified version with a re-designed fuel system designated J8M2 Shusei-Kai.

Before the end of the war, the Japanese Army Air Force relinquished development to the Army Aero-Technical Research Institute, where the project received the designation Ki 202. However, no prototype was ever built and nothing came of the protracted effort. Had the Shusei been developed to operational standards, it should have been capable of a 5½ minute flight, during which it would accelerate to an altitude of 10 km and dive through enemy bomber formations in the hope of shooting down hostile aircraft, with the aid of two 30 mm cannon, the latter situated in the wing roots either side of the single-place cockpit. The rocket interceptor would have weighed 3.9 tonnes fully loaded and its external appearance was virtually identical to the Messerschmitt Me 163.

Although Japan had a somewhat inglorious rocket programme during the war, other belligerent powers contributed even less to the advancing technology. The Italian rocket work had a fitful history of moderate success and common failure. During the 17th century Italian pyrotechnic displays were the pride of the Florentine aristocracy and much use was made of the firework and its powder propellant. By the 18th century this preoccupation, with fiery display and nocturnal extravaganza, subsided and the resurgence of interest, albeit on a modest level, awaited military research in the third decade of the 20th century.

In 1927, General G. A. Crocco conducted tests with solid propellant missiles in the hope of developing a useful weapon, but within two years the effort was relinquished in favour of work on a liquid propellant engine. In less than eighteen months this too led to a change of thought on the part of the Italian General Staff and work was cancelled. The only product to emerge was a small combustion chamber, set to run on nitrogen dioxide and petrol. In 1932 Crocco was back at work, this time for the Air Ministry, and in the following three years developed useful statistics on various chemical combinations which could effectively serve as propellants.



By 1935 amateur enthusiasts had organized the Piedmontese Rocket Society and begun work on a small family of solid propellant projectiles up to 1 metre in length. Again, as with so many of their contemporaries at this time, the Italian protagonists studied the possibility of sending a rocket to the Moon and much effort was expended in designing a lunar spaceship powered by engines using high energy propellants. With a not uncommon lack of foresight, the Italian government were aloof to the opportunities which would accrue from this research and there the work ended.

France, meanwhile, had pursued a more active interest in reactive flight. Shortly before the invasion of France in 1940, work was carried out on the possibility of using rockets for supplementary boost with heavy aircraft during takeoff and this led to studies by a private organization, Air Liquide, into the application of a 45 kg thrust motor for this purpose. The work came to nothing, but interest in the theoretical possibility of space flight had been demonstrated at the 1937 Paris exhibition where many exhibits had shown off the European ideas on reactive motion.

An intriguing postscript to the story of France's rocket programme reveals a masterpiece of clandestine activity. Shortly after the German occupation of France, and the resulting collaboration with the Vichy government, Colonel Joseph Dubouloz controlled a series of experimental rocket tests unbeknown to the Nazi administrators. Under the technical supervision of J. Barre, a man who had been associated with the work of Esnault Pelterie several years before, a small group of engineers developed a liquid propellant chamber operating on a mixture of petrol and liquid oxygen.

Late in 1941 the programme reached a level where static tests were needed to qualify the design and a moderate sequence of firing operations were carried out from a location near to the town of Lyon. The motor was regeneratively cooled and could be controlled by the rate of propellant delivered to the chamber. Nothing much came of the work, but it ranks as one of the most interesting interludes in rocket history, if only because of the rare adversity under which the programme was carried out. There is no evidence that the Germans ever knew about this work in the full 4½ years of their occupation.

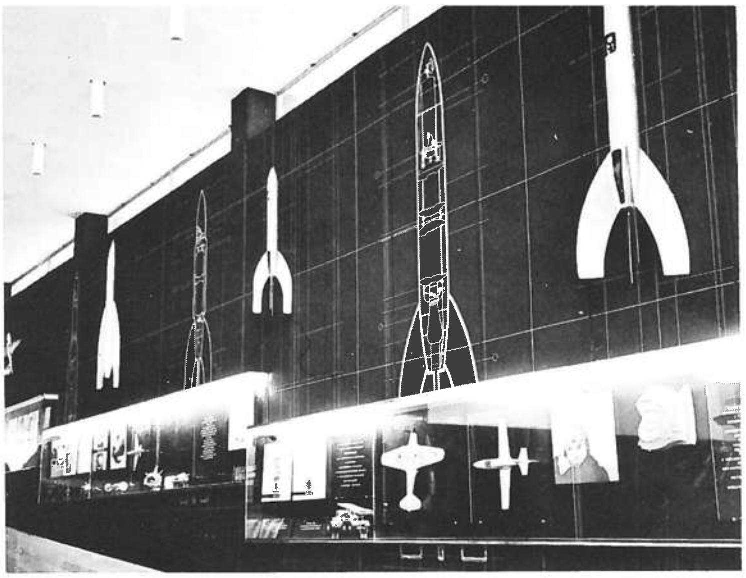
The ten years between 1935 and 1945 had seen a transformation in the study of rocket propulsion. In the early years of that period, the liquid propellant motor concept had been proved to work and to carry sufficient promise for several major development programmes to emerge in Germany and the Soviet Union. Solid propellant research continued apace, but by the time conflict broke out in Europe in 1939, it was becoming apparent that the short-term demands of a war which was expected to last only months, required rapid evolution from project inception to definitization in the hardware stage. Consequently, and with a lack of vision for the future, research moved quickly ahead on small, solid propellant missiles. In the United States, slow at first to conduct research into solid propellant chemistry, an unhappy apathy set in which was to be broken only at the direct instigation of the Caltech group and programmes like GALCIT and ORDCIT toward the closing months of the war.

Britain, its face firmly set against private endeavour with the 1875 Explosives Act, prohibiting unlicensed rocket flights, never really organized its technical competence into a homogenous and coordinated plan. By 1945 it was universally apparent that Germany had taken the initiative early enough to organize a promising research structure that led to the first tangible results in the form of the V-2, the von Braun designs for long range intercontinental rockets and tentative plans for orbital satellites. But the expensive facilities developed by the German Army were dismantled and the principal characters responsible for this remarkable series of developments were dispersed into the camps of the Allied invasion force. A new chill wind had blown through the affairs of the conquering warriors and an iron curtain of political segregation was dividing Europe from the Black Sea to the Baltic. When the next major developments were authorized, it was in response to growing concern, east and west, that a third World War was imminent.

An American Ercoupe monoplane is assisted into the air by a rocket motor attached to the underside of the fuselage. This test was performed in 1941.

CHAPTER SEVEN.

Deadly Payloads



This display of Soviet rocket achievements at the Tsiolkovsky museum at Kaluga, testifies to the early Russian commitment given to reactive flight.

By May 1945, the two most powerful nations on Earth had tramped across Europe to face each other in a confrontation of ideology and politics that would last until the present. Whereas world events had brought America and the Soviet Union to a greater level of military strength than any other two nations heretofore, the massive arms build-up would, within two decades, play a principal role in a game of move and counter-move which more than once would bring the world to the brink of a major holocaust. This transposition of functions – events bringing a need to arm and then arms themselves instigating conflict – would pivot on the strategic parity, or lack of it, and place economies on a war footing through an entire generation of military leadership

It had taken nearly twenty years, from the date of Goddard's first rocket flight at Auburn, Massachusetts, to the first successful ballistic missile bombardment of an enemy country, to assemble the tools for reactive flight and fashion a sword of destruction; twenty years on from the end of World War II missiles would stand ready to bombard any city on Earth. The development of the long range ballistic missile is the most dramatic demonstration yet of the theory that a multiple 'kill' capability can re-structure world events and breed a hostility all of its own. The roles of participants in this post-war World carve-up is central to the history of rocketry, for without the political need deemed to have been present, the story of the rocket may very well have taken a totally different turn. It is necessary, therefore, to inspect, albeit superficially, the primary cause of east-west tension which still spurs technology on to an ever more efficient machine for mass destruction.

Although the terrible destruction suffered by Russia at the hands of the German armed forces had brought partial respite in the ideological struggle of communism versus capitalism, bitter conflict was still lying in wait for more peaceful days and the Soviet Union lost little time in re-shaping its policies in readiness for the post-war World. A considerable amount of material support had come from the United States and Great Britain in the last three years of the war and political differences were allowed to dissipate under the common threat from Germany and her axis partners; quantity-wise, the supplies were brought to Russia in large amounts and with much loss of life, not to mention comfort, as arctic convoys struggled against the ravages of nature and German submarines, but the volume of traffic to the Soviet Union was small, compared with the total requirements of the Russian armed forces.

Nevertheless, by 1943, when it was becoming apparent that the tide of war was turning in favour of the allied efforts, Stalin structured a territorial philosophy, that he would enforce with certainty, when the German conflict was won. If, for a while, it seemed that communist and capitalist were linked in a cooperative crusade to rid the world of a land-hungry regime, hopes that this mutual toleration could be retained after the war were dashed by early 1945, when in the February, a conference between Stalin, Roosevelt and Churchill at Yalta, decided the fate of central European states. Soviet armour would reach a line west of the river Elbe in Germany and the western alliance of the United States and Great Britain would match it with territorial occupation of all lands to the west. One of the most significant errors of judgement introduced, which reached both east and west, concerned the apparent lack of one to interpret the strategic intentions of the other.

Russia, still in a profound state of shock over its enormous war toll, was unable to accept the capitalist countries as hospitable neighbours and formed the conclusion that a similar challenge to that posed by Hitler may, at some future date, overtake the Socialist Republics if they withdrew from a wide territorial buffer zone, loosely defined as 'eastern' Europe. For its part, the United States was concerned that if the Soviet Union held fast to land gained in war, expanding its own growth potential on the economic successes of her satellites, the time could come when other territorial gains would incite the outbreak of a major conflict in Europe. America was not overly concerned about the military might of the Soviet Union. The dropping of two atomic bombs on Hiroshima and Nagasaki in August 1945 provided ample demonstration of the new strategic tools forged in the United States. Nonetheless, this state of affairs induced a sense of paranoia, expressed most vividly in the witch-hunts for communists, both real and imagined, during the McCarthy campaign of 1950.

Throughout 1946 and 1947 the communist elements in Greece and Turkey were bolstered by aid from the Soviet Union, exacerbating the tension between east and west, and this opened the second stage of developments in Europe. Unable to sustain its aid to right-wing political factions, Britain withdrew from intervention. At this the US President, Harry S. Truman, called on Congress to openly assist in the preservation of free states, by authorizing the Truman Doctrine, which pumped massive financial and material assets into the countries concerned. Several months later, the Secretary of State, George C. Marshall, introduced a subtle policy of preserving a US buffer, by stimulating the flagging economy of western Europe and thereby reducing the possibility of communist incursions into democratic states. This was a sure way of providing a strength of economy and, as a result, preserving political power in parties which would implement policies favourable to the interests of the United States. By 1950, seventeen countries were embraced under the Marshall Plan and the Congress had authorized, in the intervening period, nearly 15 billion dollars-worth of financial bolstering.

Throughout 1948 Russia entered into several alliance agreements with Rumania, Hungary, Bulgaria and Finland and forced Czechoslovakia into the communist umbrella, while withdrawing all support from pro-right wing forces in control of Yugoslavia under Marshal Tito. These were parallel moves: the United States was strengthening its bulwark against further communist incursions and the Soviet Union was drawing tight the strings of economic and military subjugation of satellite countries; one done by persuasion, the other by eliminating alternatives.

The worsening relations between east and west moved a step closer to conflict when Britain and the United States opted to restore the autonomy of western Germany and stimulate its economic growth into a separate state once again. This was anathema to the Soviet Union, who consistently maintained the need to retain political and financial control of Germany: in the east by its own structured doctrines and in the west by the United States, Great Britain and France. Any move to restore Germany to a single-nation state would be bound to create further tension and the Soviet Union responded by cutting off all western access to east Germany by land and sea.

The importance of this is made all the more obvious by the quadra-partitioning of Berlin, well inside east Germany, into controlled areas by the four allied powers of World War II (Russia, the US, the UK and France). The blockade effectively cut the western sectors of Berlin off from the outside world by all routes except one: air. Throughout the last six months of 1948 a massive airlift kept supplies streaming in to the besieged city, by now a veritable tinder-box, until the Soviets gave way, almost a year after the curtain came down, and withdrew the blockade. By this time, however, a very physical wall had divided east and west Berlin and fortifications were set up along the east-west German border.

By April 1949 the increasing distrust of east for west and west for east finally burst out from behind the Atlantic wall of Europe and spilled over into the rest of the world: an agreement was signed by twelve western nations establishing the North Atlantic Treaty Organization (NATO), deepening the rift between western Europe and the Soviet Union about each others intentions. Throughout the five years of cold war in Europe, the United States maintained its policy of holding communist forces behind the German wall, preferring, in the event of war with the Soviet Union, to fight it out on the battlefields of Europe – the 'west's' buffer zone – rather than withdraw behind its own Atlantic moat and risk the consequences of direct confrontation. This is still American policy, but in the mid and late 1940's, the presence of American and British armed forces in western Europe was felt, by the Soviets, to be an undesirable thorn uncomfortably close to the homeland. It is not surprising, therefore, that Russia too was keen to set up a territorial buffer on its side of the east-west divide.

In the wake of a stengthened west Germany and the setting up of a combined maritime threat, potentially at least, in the form of the NATO organization, moves were made to cement responsibilities among the communist ruled east European states. Moscow was unsure that it could rely on the satellite countries for support in time of war and felt that its own mobile forces may come unstuck on the passage through these areas between the Soviet Union and western Germany. But Russia was going through a series of internal changes, which temporarily put aside the move to consolidate an agreeable pact with its neighbours: Stalin died in March 1953, a triumvirate of Kruschev, Malenkov and Beria came to power and then this too was dissolved in a bloodless transformation that put Kruschev and Bulganin firmly in control two years later.

Little time was lost in welding a military liaison between Russia and her border states. In March 1955, Marshal Ivan S. Konev, a veteran of the German war, was placed in control of the so-called Warsaw Pact countries, consisting of Russia, Albania, Bulgaria, Czechoslovakia, East Germany, Poland and Rumania. The Soviet Union had its buffer at last. But the Warsaw Treaty Organization provided more than that. It gave Russia direct control over the affairs of states overrun in 1944-45 and enabled the Soviet armed forces to embrace the military contributions accruing from the alliance. As Deputy Defence Minister of the USSR, Konev had more than 300 divisions at his command and could call upon the services of more than 6½ million men in arms. Coming as it did just five days after West Germany was admitted to NATO, left little doubt in the minds of western leaders that the WTO pact was designed to unify the collective assets of the seven members in the face of a consolidated west-European threat.

But almost immediately the Soviet Union moved towards proposals that envisaged a unified security agreement to protect the interests of all European states, saying that if ratification could be achieved, the Warsaw Pact would be dissolved. It seemed as though the Soviets had manoeuvred themselves into a new bargaining position, deliberately using the Pact as a diplomatic means by which to buy a potentially less hostile situation and so achieve political goals. Just four months after the Warsaw agreement, Moscow called for the abolition of both NATO and the WTO and drew the United States into the proposed 'collective security' umbrella. This had no productive end result and the situation stagnated into a posture of mutual tolerance. Within certain Soviet satellite states however, public opinion was hostile to the Warsaw Pact and this was one of the main reasons behind the Polish and Hungarian uprisings of 1956.

The success of the Polish communist leader, Wladyslaw Gomulka, in removing Soviet troops and quelling the rebellion inspired similar moves in Hungary, but here the Russians stood firm. The Hungarian Premier Imre Nagy succeeded in obtaining tacit agreement for the withdrawal of Russian troops and arms, but the inflammatory mood of the people led to open revolt, with bitter street fighting and bloody violence. Incensed by this open hostility, and seeing their carefully structured alliance breaking down to a point where Soviet interests would be back where they originated – in Moscow – the Russians reversed their moderate attitude and returned to full military occupation.

A year later, in June 1957, the Soviet Praesidium tried to oust Kruschev from power, but a hurried return from foreign visits restored his authority. Appealing to the Central Committee of the Communist Party, mostly composed of members already placed in position by the Premier, Kruschev ejected dissident elements and by March 1958, had seized control of both Party and Government. With Bulganin labelled an 'anti-party' troublemaker, the scene was set for complete and total monopoly of the armed forces and state policy; only Marshal Zhukov, a prime mover in the Kruschev takeover, tried to separate military and political interests, but he too was dismissed in favour of Marshal Malinovsky.

On the broad, international level, the wartime alliance of states opposing Axis rule led to the setting up of a United Nations, with the first draft Charter signed on 26 June 1945, effective from the following October. The Charter outlined the basic purpose and objectives of the UN and began with the affirmation that it was to strive 'to save succeeding generations from the scourge of war, which twice in our lifetime has brought untold sorrow to mankind. . .'. At the beginning the United Nations embraced fifty one states and would soon grow to include most of the world community.

The General Assembly of the UN was established so that each member state could send a single representative to vote on issues relevant to the Charter. Decisions would be taken on majority vote, or on a two-thirds majority basis for more important issues. It would serve to stabilize the politics and policies of participant countries, in so far as their actions infringed the established rights of either the international community or neighbouring states alone. The Security Council was set up to preserve international peace and initially, eleven states participated. The Economic and Social Council was concerned with the rights, freedoms and cultural issues brought before the UN with an initial membership of eighteen states. Finally, the Trusteeship Council is responsible to the General Assembly for administering the aims of the United Nations and an International Court of Justice monitors and directs legal aspects of events related to unilateral or multilateral action by member states. The entire organization is controlled by the Secretariat, headed by the Secretary-General appointed at the General Assembly level.

It is primarily against this backdrop of political and international events, that the technology of war matured in the decade or so after World War II, spurred to an increasing capability by the continued distrust that separates states into 'east' and 'west'. The ability of one major power to inflict intolerable devastation on the other comes as a result of improved delivery systems and the dramatic increase in explosive yield afforded by the rapid development of atomic and thermonuclear weapons. In 1939 words like 'strategic balance', 'arms parity' and 'mutually assured destruction' were non-existent, but the domination of rocket technology has forged a new terminology to match the present strategic posture.

Before World War II, defence took account of the arsenals developed by potentially hostile countries, but the post-war transition matured to a new system of accounting whereby the effective kill capability of opposing forces must be matched by an equally effective potential for annihilation. The rapid development of military missiles in the post-war world was slow to start, but once under way, made phenomenal strides. The lack of immediate interest in the potential usefulness of a long range rocket powered projectile was brought about by the unique possession of the atomic bomb by the United States. In several respects the success achieved by the German rocket development teams at Peenemunde was paralleled by the remarkable strides taken by scientists and engineers working on the first US atomic bombs: both projects achieved a level of maturation uncommon in high technology ventures, in that they moved quickly from research and development (R&D) to use-application and production status. Because of this the United States found itself in possession of a weapon which could be delivered quickly and accurately.

By the end of 1945, the US Army Air Force had a valuable delivery vehicle in the form of the B-29 Superfortress and within a few years large numbers of an improved version, the B-50, were rolling off the production lines. Capable of delivering a nuclear war load to any target within 2,400 km of a suitable airfield, the Superfortress series was supplemented from 1948 by massive fleets of B-36 bombers with provision for carrying atom bombs a distance of 6,500 km and returning to the home base after devastating the target. A year before the introduction of the B-36, the 1947 National Security Act set up the Department of the Air Force, under the control of the Department of Defence, and the United States Army Air Force became simply the United States Air Force, effective from 8 September. Long range objectives were under the authority of the Strategic Air Command and it was to this element of the US Air Force that missile development would be assigned.

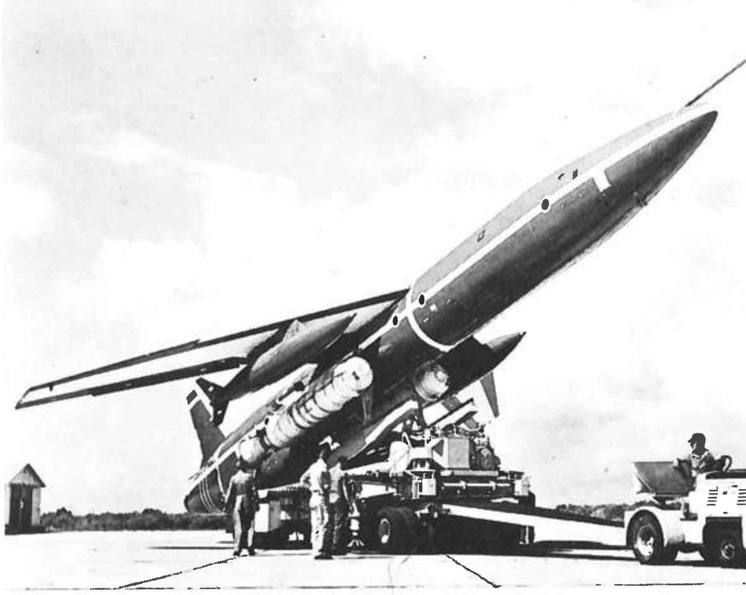
But reluctance on the part of the military planners to invest large sums of money on an Intercontinental Ballistic Missile (ICBM), pivoted on the massive tonnage which could be delivered across global distances by air. With bases in England and on the continent of western Europe, the potential targets in Soviet Russia were only a comparatively short flight away and for every group in service overseas, many more were waiting to back up an initial attack from the United States mainland.

Before the end of World War II the US Army Air Force had conceived a requirement for a short-range missile capable of hitting targets 1,000 km away from a launch site and the Glenn L. Martin Company were asked to develop the device – called Matador – two years later. But it was 1951, six years after the war's end, that production was finally authorized and not until 1955 was the missile put into operational service. Outdated before it first flew, Matador was powered by a 2.2 tonne thrust turbojet engine capable of propelling the missile at a speed in excess of Mach 1 (the speed of sound) with a small nuclear warhead in the nose. With wings spanning 8.8 metres and a tail unit at the end of its 12 metre-long body, the Matador looked more like a conventional aircraft, than the sleek projectiles by then coming into final design. Its speed and the altitude ceiling of 15,000 metres, gave it a performance spectrum uncomfortably close to that possessed by current jet powered interceptors and the missile was thus never a potentially effective weapon.

Less than a year after the Matador specification was written up, in January 1946, the Army Air Force planned a cruise missile of truly intercontinental range. Called Snark, the project envisaged the development of a turbojet powered missile capable of flying a distance of up to 11,000 km with a nuclear payload weighing 2.3 tonnes. At launch, Snark would be boosted by two solid propellant rocket motors, each delivering a thrust of 15 tonnes and the winged missile would cruise to its target in a similar fashion to the Matador. Efforts to marry jet engines to winged cruise missiles culminated in one of the most promising developments of the period called Navaho. Conceived as a winged projectile capable of speeds in excess of Mach 3, it would have weighed 136 tonnes and been boosted into the air by three liquid propellant rocket motors delivering a total thrust of 184 tonnes.

The first flight of this 29 metre-long missile came in November 1956, again too late to effectively compete with ICBM projects then under development, and the project was cancelled eight months later. Matador, Snark and Navaho, although never fully exploited, did contribute valuable research work to systems and components used in later missile programmes such as Atlas. But the effectiveness of the cruise missile as a medium or long range weapon was dramatically reduced by increasingly sophisticated air defence systems and, relying as they did on flight through the atmosphere, remained exposed throughout the period from launch to impact.

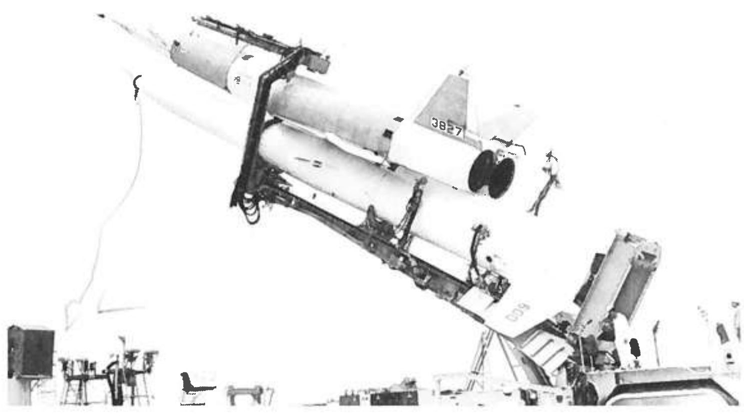
This pre-occupation with the winged missile stemmed from an over confident assumption that with a massive air-

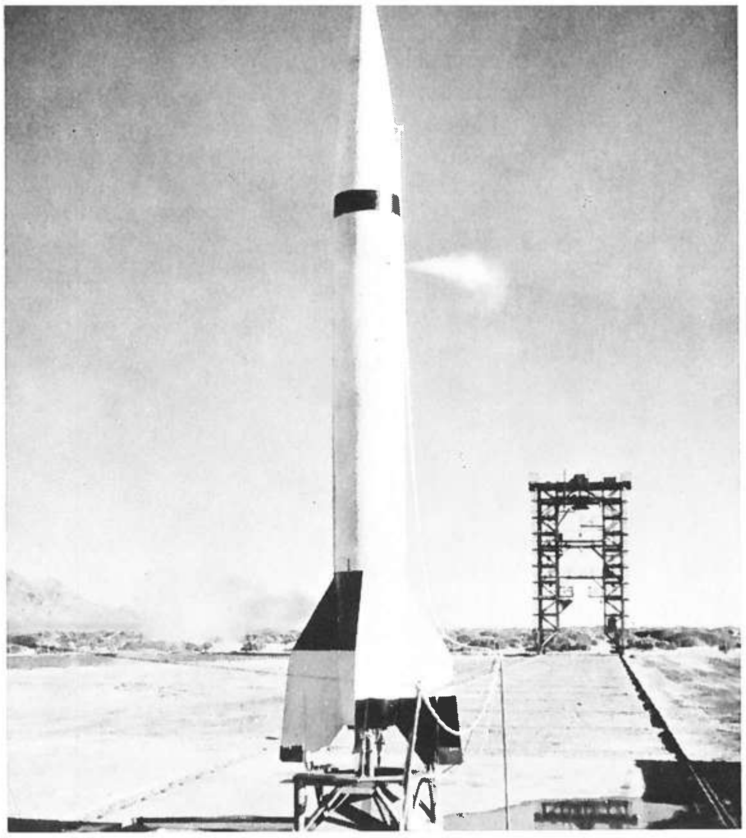


The turbojet powered Snark was propelled into the air by two solid propellant rocket motors, seen as white cylinders under the body of the missile, and could reach targets 11,000 km away with a 2.3 tonne warhead. Snark is here being towed from a test area to the main hangar at Cape Canaveral, Florida.

The Martin B-61 Matador, in service from 1955, is seen leaving its launcher at Holloman Air Force Base, New Mexico.

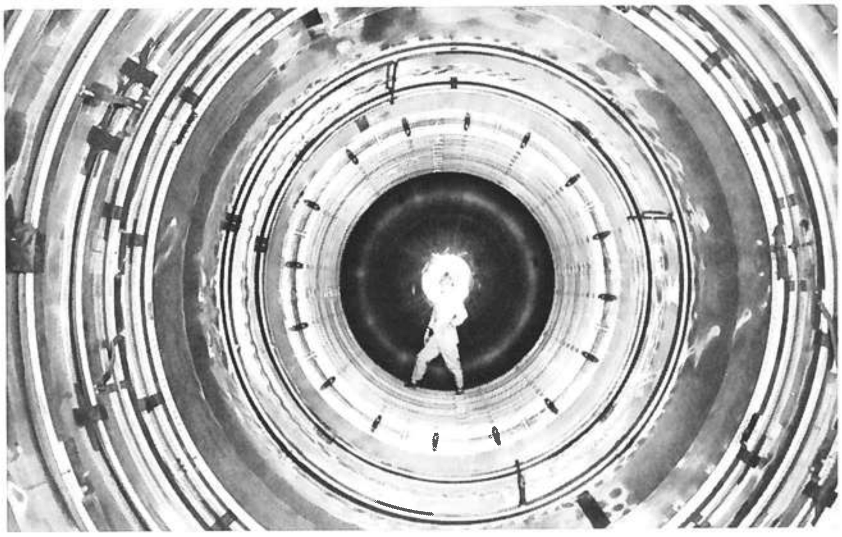
The SM-64 Navaho was powered by two jet engines and was carried into the air on the back of a large liquid propellant booster, itself supported on an elevated launch ramp. This view was taken in May 1957, at Pad 10, Cape Canaveral.





The earliest post-World War II effort in long range liquid propellant missile design was the brainchild of Karel J. Bossart, working at the then Consolidated Vultee Aircraft Corporation. Project MX-774 bore superficial resemblance to the V-2 (note the fin shape and the launch pedestal) but pioneered several revolutionary concepts.

The stainless steel monocoque construction of the ICBM that grew from Project MX-774, is seen to good effect in this view of the interior of the Atlas missile.



borne bomber fleet, there was little or no requirement for investing large sums of money in expensive ICBMs. The Air Force, reluctant to re-define its traditional areas of responsibility, failed to foresee the day when the effectiveness of the manned aircraft would be challenged, and partly replaced, by a long range bombardment role embracing guided missiles carrying the same payloads. Although it was accepted that the strategic missile would have a partial usefulness, in being able to move fast to its target along a trajectory that placed it, for the most part, well out of range of hostile interceptors, the difficulties seemed to outweigh the advantages. Not only would a long range ballistic missile of the ICBM class be very difficult to develop, forging new areas of technology, but the payload it would conceivably carry, the atom bomb, was far too large and cumbersome to be easily packaged in a warhead of suitable dimensions and weight. Nevertheless, the remarkable story of America's first true ICBM – the Atlas – had its roots in the months following the end of World War II.

At this time the Army Air Force was not at all convinced of the need to progress with studies on any form of long range rocket propelled device, especially in the light of recently acquired data on the comparatively inaccurate V-2, compared with the assured accuracy of pin-point bombing techniques developed by B-29 Superfortress crews (later to be raised to even higher standards by the B-50 and the B-36). But studies were authorized and Consolidated Vultee Aircraft began feasibility work on two distinct approaches to satisfying the requirements of Project MX-774. This specified conceptual analysis of potentially viable unmanned delivery systems capable of sending a warhead across a distance of 8,000 km.

In one approach to the problem, the company looked at a winged missile propelled by a turbojet engine which would cruise to its target below the speed of sound and in the other they examined the feasibility of designing a purely ballistic missile powered by a conventional liquid propellant rocket motor. By December 1946, the Army Air Force cancelled the winged concept in favour of the Snark missile proposed by Northrop and authorized Consolidated Vultee to continue with their theoretical examination of the rocket powered missile. Although the Army Air Force had its doubts about the feasibility of building a ballistic projectile with reliability and performance to rival the massive intercontinental bomber, it felt that the studies conducted during 1946 carried sufficient promise to continue further work.

Consequently, Convair, the re-structured Consolidated Vultee Aircraft Corporation, obtained permission to build 10 such missiles and perform a limited research programme with the hardware. Much of the design effort at Convair borrowed novel aspects of the German V-2 rocket and used this successful missile as the basis for a series of modifications which would do much to advance the technological innovations which characterized the first generation ICBM's. Engineering considerations were under the control of Karel J. Bossart, a Belgian designer who had been in the United States for twenty years, and the unique talents of this gifted man brought a revolution to missile design. While the V-2 had used a structural framework to provide the shell in which was mounted the liquid propellant tanks necessary for feeding the engine with oxygen and alcohol, Bossart developed the concept of a pure monocoque construction: the shell of the missile was itself the wall of the propellant tanks with a hemispherical dome separating the interior into two compartments, one for the fuel and one for the oxidizer.

This single-wall design had considerable advantage over the double-walled approach used for the V-2, in that it reduced the weight of the empty structure and enormously improved the power/weight ratio. Bossart designed the cylindrical wall to be fabricated from thin sheets of aluminium and structural rigidity would be ensured by pressurizing the interior with nitrogen until such time as the propellant was introduced; without internal pressurization the single thin-wall tank would collapse under its own weight. What Bossart had achieved by this novel approach, was to effectively improve the propellant mass ratio (see Chapter Two). The V-2 carried nearly 9 tonnes of propellant in a structure weighing almost 13 tonnes, the propellant mass ratio for this rocket then being said to be less than 0.7 because the liquid oxygen and alcohol together amount to less than 70% of the weight of the missile at launch.

Another way of expressing the gain from monocoque versus double-wall construction is to use the propellant: structure weight ratio. For the V-2 this came out to be 1:2.24 (that is, the weight of the propellant was 2.24 times the empty weight of the rocket). Bossart's work during 1946-47 on the MX-774 design would lead to the Atlas missile with a propellant:structure weight ratio of 1:21.25 and a propellant mass ratio of 0.95. However, in 1946 the promise of a dramatic improvement in both these values afforded by forming the tank walls into the shell of the rocket, did much to upgrade potential performance and, eventually, provide a capability that the Army Air Force would accept.

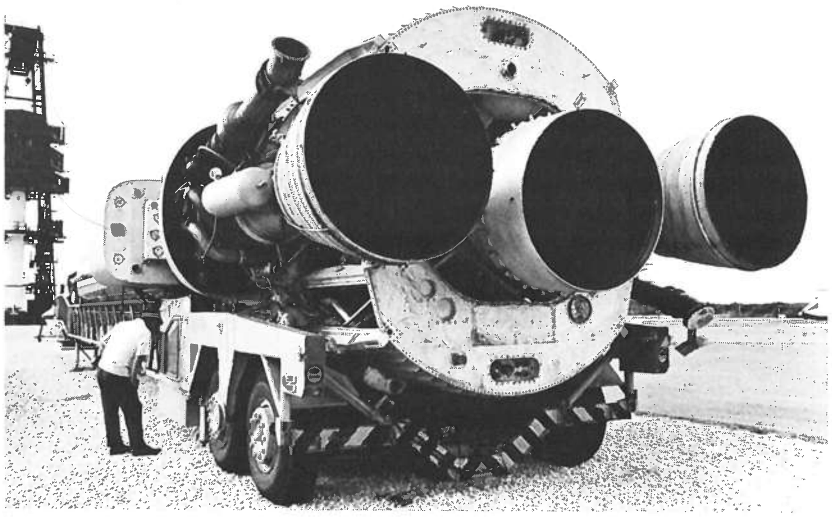
The other novel feature about the MX-774 missile was that it supported a nose cone that would separate from the main body of the projectile. In this way the warhead alone would be required to survive the punishing temperatures encountered on the long descent to the target, while the large mass of the rocket could be allowed to burn up through friction; the V-2 had been designed to survive all the way to the target. A bonus accrued from this new proposal in that there would be less drag on the warhead, devoid of the large assembly to which it was formerly attached, thus increasing the potential range of the missile.

Reaction Motors Incorporated, formed by a nucleus of enthusiasts from the American Rocket Society in 1941 (see Chapter Five), was asked to contribute the propulsion system for MX-774 and this took the form of four modified motors of the type used to power a rocket research aircraft called the Bell X-1. The X-1 was developed as a research aircraft to perform supersonic flight and it successfully broke the sound barrier for the first time in October 1947. Its full story is told in the Compendium (see page 261). MX-774 motors would each deliver a thrust of 907 kg for a total launch thrust of more than 3.6 tonnes. Although some work had been conducted in Germany on the concept of swivelled rocket nozzles, whereby the rocket's course is controlled by physically altering the line of thrust, it was Bossart's MX-774 design that first introduced the so-called 'gimballed' rocket nozzle to flight tests. Instead of using graphite or carbon vanes placed in the exhaust stream, the missile would be kept on a desired trajectory by a guidance system working in conjunction with the swivelling nozzles.

The external appearance of MX-774 was certainly very similar to the V-2, even down to the four fins that were placed at 90° intervals around the base of the missile, but the monocoque construction, the separating warhead and the gimballed rocket nozzles, gave it a more advanced performance than any other project of comparable dimensions at the time. The fins were largely superfluous and Bossart has been noted as remarking that they were only attached because no-one could quite believe that the gimballed nozzle control concept would actually work in reality! Nevertheless, the project was very advanced for its day and did much to stimulate research along the lines that would be essential to future ICBM technology. Work on the guidance system followed two lines of development: a simple autopilot using gyroscopes and, later, a phased comparison system whereby the signals from two separate tracking antennae would provide updates to the missile's guidance system while it was in flight.

Throughout the first half of 1947, Convair worked toward the fabrication of 10 test missiles and came to within a few months of the first launch when a report from the Department of Defence criticized the duality of concepts being funded by the newly formed US Air Force. MX-774 was cancelled. At this time production of the B-50 Superfortress was in full swing and the enormously expanded potential of the B-36 was looming on the horizon. There seemed little point in struggling on with expensive research which would, in all probability, lead to nothing in the final analysis. Despite the gloom over continued ICBM investment, Convair was allowed to continue with the preparation of three MX-774 test vehicles and the first static firing was performed on 20 November the same year.

With meagre funds, less than $2 million remained available, the team gathered together the necessary equipment for 3 test flights and by May 1948 the static firing trials had been completed. The first MX-774 missile was taken to the Army's proving ground at White Sands, New Mexico, for launch from a captured V-2 firing platform. After delays lasting more than two weeks, the missile was launched on 13 July, but after 60 seconds of a planned 75 second burn, the motors cut out and the rocket fell back to the ground. Two months later, on 27 September, the second missile reached a height of 47 km and began to fall back to earth when excessive pressure in the propellant tanks caused the rocket to explode. As with the first, albeit unsuccessful, attempt, the cameras carried for filming the rocket's ascent were recovered for analysis. The final flight under Project MX-774 repeated the failure of the No. 2 rocket when, on 2 December 1948, the missile blew up, due to vibrations in the liquid oxygen delivery system.



Although originally expected to require five rocket motors, when Atlas emerged it had three motors placed in line. The outer two are boosters jettisoned on the ascent.

The June 1947 report that effectively put an end to Air Force ICBM development for 3½ years helped dismember a team that would, in 1951, be called upon to take their work off the shelf and try again. The greatest contributions from the MX-774 work were in the totally new concepts for ICBM design that they pioneered and in an age when the efforts of an individual are lost in the halls of corporate management, the name of Karel Bossart must stand as one of the more significant signposts on the road of post-war rocket development.

Between 1947 and 1950, two events helped transform the thinking that had impaired the continued development of intercontinental missiles. The first of these came on 23 September 1949, when the then US President, Harry S. Truman, announced from the White House that there had been positive indications that the Soviet Union had detonated an atomic bomb on test during the previous few weeks. After more than four years, during which the United States had sole access to nuclear weapons, its chief opponent in the affairs of international relations had acquired the atomic bomb. To American political strategy this was a sobering event. If the Soviet developments led to production of a weapon of dimensions small enough to permit its carriage in the bomb bay of a conventional aircraft, the time would surely come when Russian objectives could be achieved by way of force threat to any state on Earth. The continued presence of large numbers of Soviet forces in eastern Europe had given cause for concern, especially in the wake of American withdrawals, but the prospect of facing a challenge of global dimensions was all the more daunting.

In the closing months of 1949 considerable debate surrounded the options then becoming available from theoretical work on atomic physics. The existing nuclear weapons used the fission reaction, whereby uranium or plutonium could be made to explode if it was put into quantities known as the critical mass. There is only one specific value of the critical mass and this limits the size of the potential device, more popularly called the Atom Bomb. Now, with the Russians having demonstrated the capability to assemble and detonate the critical mass necessary for fission reaction, the United States began to consider one of the most turbulent issues of modern history: whether to proceed immediately with the development of a much more powerful device, theoretically proven to be feasible, or whether to ignore the possibility of an escalating nuclear threat and limit the explosive yield.

While fission yield was limited because of the critical mass factor, nuclear physicists across the United States believed in the possibility of building an explosive device working on principles of atomic fusion. There was no potential limit on the force of the explosive yield which could be developed on the fusion principle and very soon the device was dubbed Hydrogen Bomb because it used isotopes of this element to create the fusion bomb.

In principle, the H-bomb would require a conventional fission device to trigger a quantitiy of tritium, which in turn would set off an explosive chain reaction with a substance called deuterium; tritium and deuterium are both isotopes of hydrogen, hence the name Hydrogen Bomb. The awesome potential of this device opened a new scale of comparative yield values: whereas the atomic bomb had been measured in thousands of equivalent tonnes of TNT, the hydrogen bomb would be exploded with a force of millions of equivalent tonnes of TNT. The first operational use of an atomic bomb against the city of Hiroshima had exploded with a force equal to 20,000 tonnes of TNT, expressed as a 20KT yield, and the

The Atlas missile was assembled from cylindrical skin sections here being seam-welded from flat sheets of alloy.

potential force of a hydrogen bomb would be several thousand times this value.

The decision to proceed with full development of the Hydrogen Bomb was announced by the then US President Truman on 31 January 1950. Although the United States had the largest fleet of bombers ever assembled in time of peace, with a capability of dropping nuclear explosives several thousand kilometres from the operational airfields, the threat of a similar strike capability from the Soviet Union tipped the scales in favour of H-Bomb tests. The arms race had begun.

On 25 June 1950, east-west tension reached an unsavoury level when the communist forces of North Korea invaded the democratic Republic of South Korea. Since the end of World War II the Russians had exercised considerable influence over the affairs of North Korea and faced American forces in the south. By mutual agreement, at the behest of the United Nations General Assembly, both sides agreed to withdraw, but in the light of open violation of the recognized democracy in South Korea, the UN voted to support the independent Republic and called upon leading states to go to the defence of the South (which ultimately involved conflict with Chinese 'volunteers' and later the threat of the first atomic conflagration since World War II). Meanwhile, work accelerated on preparation for testing the first Hydrogen Bomb and thoughts turned again to strategic delivery systems.

These two events, the explosion of a Soviet atom bomb and the invasion of South Korea, caused the US Air Force to re-consider its mandate and seek further definition of unmanned rockets and their potential application in ICBM roles. In January 1951 the Air Force Air Research and Development Command re-opened its contract with Convair and authorized a study, called Project MX-1593, into winged cruise missiles and ballistic projectiles. The effort was little more than a re-worked mandate to perform analyses originally ordered in 1946 under Project MX-774. However, warming to the advantages of flight outside the atmosphere, the Air Force required the winged cruise missile to be equipped with a rocket motor for flight through the rarefied upper layers. It was becoming increasingly apparent that turbojets would never provide the performance required to justify full scale development of an unmanned delivery system and would in fact render the missile vulnerable to interception from conventional aircraft or ground-to-air projectiles. For its part, Convair was more concerned with the second element of the MX-1593 contract: research into the possible design of a rocket powered ballistic missile.

During the period between the demise of MX-774 and the award of the new contract, Karel Bossart had struggled on with theoretical studies of an efficient long range missile and refined several areas that had seemed to compromise the earlier design. Working to a presumed specification that envisaged a missile with sufficient lift capability to send a nuclear (Atom Bomb) warhead across intercontinental distances, Bossart attacked the problem of separate rocket stages by developing a solution that was both novel and inventive. He recognized that if rockets were to be seen as a reliable delivery system the most efficient design mode would require at least two stages to propel the warhead toward its target; the high weight still associated with nuclear weapons dictated a rocket of considerable size and the use of multiple stages would be essential to achieve the necessary performance. But work on the MX-774 design had shown problems could easily develop with ignition of a large missile and the failure of an upper stage to ignite would bring disaster to the flight. It would be much better, thought Bossart, if booster engines could be placed at the base of the missile along with central sustainer motors so that all elements of the propulsion system would be ignited simultaneously on the launch pad.

Both propulsion elements would obtain their propellants from the same tanks, but the booster engines could be jettisoned during the ascent. The reasoning behind this philosophy was that it would be less of a problem to discard the boost motors than it would be to separate the first stage and then to ignite a second stage in flight within seconds of release. Coupled with the single thin-wall tank concept developed during work on MX-774, the missile would achieve a level of efficiency beyond anything then built, albeit not quite as efficient as a missile of thin-wall tank design adopting separate stages mounted in tandem, but certainly good enough to impress the Air Force. The only real disadvantage in this concept arose from the fact that the large propellant tanks making up the main body of the missile would be retained after booster jettison, thereby necessitating the projectile to have a higher mass at the end of powered flight than it would have with tandem stages where motors *and* tanks are released sequentially.

Consideration of the basic role of an ICBM highlighted a potentially insoluble problem related to the performance of the rocket motor. If the missile was to achieve a high level of accuracy at the target, falling to within a few hundred metres of the objective, the trajectory would have to be very carefully controlled and this meant a great deal of attention would have to be placed on the performance of the rocket motor. It would, for instance, be necessary to achieve a specific velocity at a certain altitude from where the missile would continue on its unpowered coast after the motor(s) had been shut down. Because the large mass which would be required to lift a meaningful payload across intercontinental distances would require a large propulsion system, it would be very difficult to shut down the motor at the precise velocity necessary to achieve a highly accurate trajectory: if the speed of the missile varied by as much as two or three metres per second above or below the value determined for a specific target, the warhead would fall several kilometres off target. Clearly, the concept of an ICBM could only succeed if it was seen to provide a level of target accuracy comparable to a free-fall bomb released from an aircraft.

So, on the one hand the high level of thrust demanded by the large ICBM would render it almost impossible to achieve a precise shut down to within fractions of a second and, on the other, the extremely long range of the missile would increase the necessity to precisely control the shut down velocity. Bossart chose a way out of this dilemma by fitting small vernier motors to the missile. In this concept the main, and very powerful, rocket motor would be cut off when the missile had reached a high fraction of the desired velocity so that the small verniers could take over and nudge the speed up to the required value. It would certainly be less trouble to control the thrust duration of a small engine, than to achieve the same controlled cut-off time with the large, high thrust motor used for launch and ascent.

When the MX-1593 contract went to Convair in January 1951, the company had been fortunate in having Bossart's theoretical work to hand in a series of informal studies that partially compensated for the lack of Air Force interest since 1947. The requirement, as written down under the project specification, envisaged a missile with a range of 8,850 km, capable of delivering an atomic bomb to a specific target. Throughout 1951 work progressed on the definitive aspects of the design and the missile matured as a projectile with single thin-wall tanks, gimballed engine nozzles replacing the need for fins, a warhead which would be separated shortly after engine shut-down, boosters at the base which used the same propellant as that carried for the sustainer and with vernier motors for fine-tuning the final velocity. All five principal features were the product of Karel Bossart: the first three during work on MX-774 and the last two as a result of studies carried out between 1947 and 1951. Before long the Project MX-1593 missile became known as Atlas.

By 1952, work on the Hydrogen Bomb had reached a point where test explosions could be planned and the first of these was scheduled for 1 November from a Pacific Island in the Marshall chain. Under the code name of Operation Mike engineers and scientists set up more than 60 tonnes of equipment in a massive structure that would introduce the world to the awesome capabilities of the thermonuclear device. Along a plywood covered tunnel stretching more than 3 km away from the site, were electrical cables and measuring instruments designed to record, fractional second by fractional second, all the important repercussions of the impending detonation. From an area 50 km away, observers set up view stands and blockhouses from where they would witness the dawn of a new and terrifying age. When the time came to prepare the device for detonation, commentators counted down the seconds, but when the explosion occurred it was beyond any sight ever witnessed by human eyes.

Working on the principles that controlled the enormous release of energy at the centre of the Sun, the fireball grew in size until it was 5 km across – a brighter light than ever seen on Earth before. More than two minutes after the explosion, the deep thunder spread its acoustic shock waves over the watching technicians and a voluminous cloud of grey-black smoke slowly climbed higher and higher into the sky, each rolling wave of the dark mass pursuing, as if in slow motion, the bright halo of light that bounced back from the surface of the sea into the air. The explosive yield of Operation Mike was equivalent to seven million tonnes of TNT, a force 350 times that of the Hiroshima bomb. America, once again, had moved ahead of the Soviet capability and regained a certain satisfaction over having the most powerful weapon on Earth. The effect of this was to once again send ripples of doubt through the Pentagon about the need to finance development of an ICBM fleet.

Already, the six-engined turbojet B-47 Stratojet bomber was rolling off the production lines at Wichita, with other facilities shortly to come into operation at Tulsa and Marietta and so feed the Air Force requirement enhanced because of the Korean War; it would be July 1953 before a truce was signed. Just 6½ months before the first H-Bomb test, the Boeing Company flew the first B-52 Stratofortress into the air as the world's largest and heaviest bomber ever built. Eventually, it would be capable of flying non-stop for a distance of more than 20,000 km without in-flight refuelling and provide stowage space for up to 32 tonnes of bombs and/or guided missiles.

It was not a good time to extol the virtues of unmanned ballistic missiles. With a global airborne capability and possession of a nuclear deterrent, with more efficient delivery systems rolling out from the Boeing factory and sole possession of the H-Bomb, American defence requirements seemed well matched by the existing inventory of hardware. Nevertheless, a growing awareness of increasingly successful Soviet weapons projects gathered a nucleus of far-sighted protagonists and while development of the Atlas continued apace, the struggle to get full unexpurgated approval for the ICBM was only just beginning.

In December 1952, Professor Clarke B. Millikan was asked to chair a committee for the Air Force Scientific Advisory Board which would look into long term planning objectives and study the Air Research and Development Command belief that it would take about ten years to deploy a meaningful ICBM fleet. Four months later Special Assistant to the Secretary of the Air Force, Trevor Gardner, recently appointed to the position, exhibited a pro-ICBM attitude by pushing for a review of the existing missile situation. In June 1953 the Director of Research and Development for the Air Force, General D. M. Yates, pressed the Secretary of Defence for a major assessment of Air Force missile programmes and the projected value of ICBMs.

On 12 August 1953, the short-lived monopoly of the H-Bomb came to an abrupt end, when the Soviet Union dropped a thermonuclear device of similar potential to that detonated by the United States less than nine months before. The lead had been dramatically cut short: it had taken the Russians more than four years to join the United States with possession of an Atomic Bomb and now they had matched the American performance with successful demonstration of a fusion device. Concern over the availability of a Soviet delivery system, which would be capable of transporting the nuclear weapon to targets in the west, was prompted by intelligence reports, that hinted at the imminent construction of a Russian long range missile.

(Premier Kruschev would recount in his memoirs that Russia already possessed long range rockets by 1956 and subsequent information has revealed the development of a Soviet ICBM long before that date. During his visit to London, in April 1956, he remarked to the wife of Prime Minister, Anthony Eden, that the Soviet missile force was capable of hitting targets far beyond the environs of the United Kingdom. Later, when addressing a party given by the First Lord of the Admiralty, Kruschev waxed philosphical on the traditional strength of the Royal Navy which was, he said, rendered obsolete by missiles that could devastate their targets. Before leaving from his visit to the British Government Kruschev professed to have assured the politicians that Russia had large numbers of 'rockets of various ranges'.)

There was good evidence too that the Soviet Air Force was building up its bomber fleet: the Tupolev Tu-16 twin-engined turbojet bomber had a range of 4,800 km and was first flown in 1952 and the Myasishchev Mya-4 carried four turbojet engines for a range of 11,000 km. Going under the NATO code names Badger and Bison respectively, these two intermediate range aircraft were soon to be joined by the Tupolev Tu-20 (Bear) with four turboprop engines and a range of nearly 13,000 km.

Just one month after the first Soviet H-Bomb test, in September 1953, the Air Force set up the Strategic Missiles Evaluation Committee with an assignment '. . . limited to that of studying long range intercontinental strategic missiles under development . . . and making suitable recommendations for improving this programme'. Note was taken of the inadequate intelligence about Soviet ICBM work and of the need to consider development of long range ballistic missiles in the light of Russian anti-aircraft capabilities. The SMEC was composed of ten leading figures in industry chaired by the eminent Dr. John von Neumann. Within weeks of its first meeting, von Neumann, who was also heading an Air Force investigative panel on nuclear weapons, brought news of an impending breakthrough in the size of atomic warheads. This threw additional light on the possibility of building a missile system which could satisfactorily transport a nuclear weapon across intercontinental range; hitherto, nuclear weapons had been unwieldy devices ill suited to the reduced dimensions of a missile warhead compared to the voluminous bomb bay of a winged aeroplane.

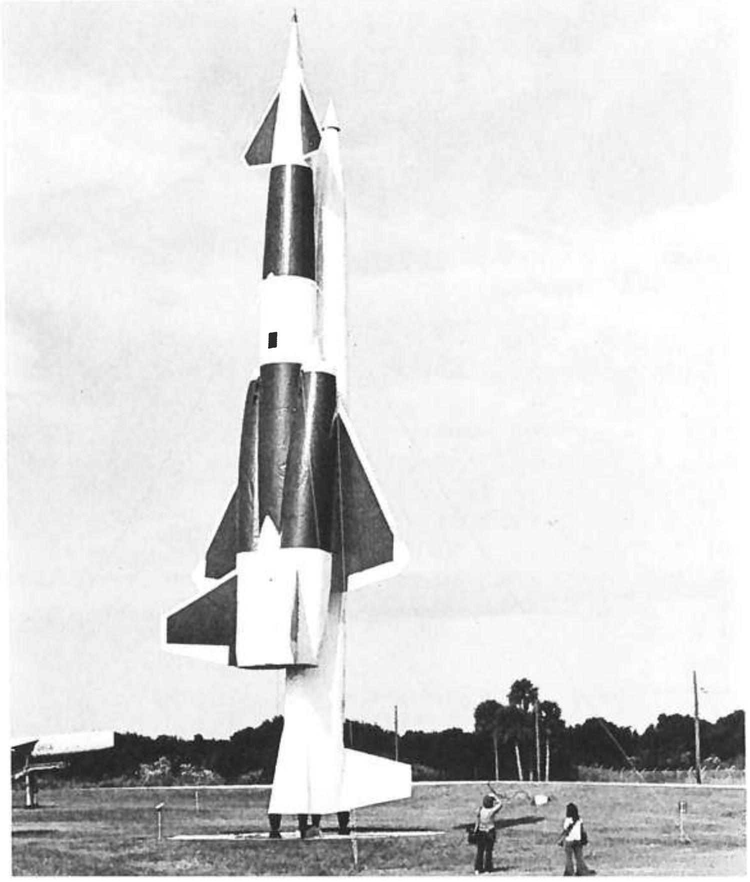
This breakthrough was all the more acceptable in the light of news that the Soviet H-Bomb had been dropped by an aircraft, unlike the American test which had been set up on the ground in a barn-size building. Progress had already been achieved in reducing the size of the American fission bomb, but the thermonuclear device was seen as the justification for building an ICBM fleet and von Neumann brought reassuring news on that count. When the Committee reported its findings in February 1954, it came down firmly on the side of an accelerated programme leading toward operational basing of the Atlas ICBM. In fact, '. . . the Committee (saw) no technical reason why by such a procedure, assuming proper direction and support, a period of six to eight years should not permit the attainment of the beginnings of an operational capability'.

The report went on to say that the Air Force's insistence on a target accuracy to within 460 metres was unrealistic and that the ICBM fleet should be developed with each missile having an accuracy at the target of 3.7 to 5.5 km. The value known as 'circular error probability', or c.e.p., was used with the product prescribing the radius of a circle within which 50% of the warheads would fall. The generous reduction in the desired c.e.p. value was said to result 'from the very recent progress toward larger yield warheads which could hardly have been predicted when these specifications were originally established.' Moreover, based on the Von Neumann news that nuclear technology was bringing down the size of the warhead, the report recommended a payload capability no greater than 680 kg. The combination of a reduced c.e.p. value and the availability of small warheads led the Committee to favour an all-inertial guidance system and to endorse the Bossart concept of a separable warhead which would minimize the problems of thermal protection and stability over the alternative approach which required the entire missile to fall to the target.

Just a month later, on 1 March 1954, the second thermonuclear device was detonated at Bikini Atoll in the Pacific. With an explosive yield equal to 14 million tonnes of TNT (14 megatonnes, or 14 MT) the Hydrogen Bomb was 700 times as powerful as the Hiroshima bomb, using a fission reaction to liberate the energy. Known as Operation Castle, the detonation generated more explosive yield than had been calculated and a further test was cancelled pending detailed evaluation of the results of the measurements gathered at Bikini.

Work on the Atlas ICBM was directly affected by the recommendations of the Von Neumann Committee. Convair had been developing a missile more than 27 metres long with a diameter of 3.65 metres and a cluster of five engines delivering a total thrust of 295 tonnes. Various test sections of the projected missile were built and a full size wooden mock-up was constructed for a systems layout check. Because of the impending availability of the smaller thermonuclear warheads, the Air Force re-wrote its specification for Atlas and during 1954 the missile was reduced to a length of 22.9 metres and a diameter of 3.05 metres. Three engines would be carried at the base adapted from the ageing Navaho cruise missile project. The evolution in propulsion systems leading to many of the more important missile programmes of the 1950's and 1960's would stem from this initial requirement to adapt Navaho liquid propellant motor design for use in Atlas.

It is important to establish the early development links in this chain and follow the chronological sequence leading, through Atlas, to present day rocket motors. The story really began when North American Aviation (now Rockwell International) were asked to develop the Navaho cruise missile in 1947. At that time the Navaho I was envisaged as a winged, ramjet powered, projectile which would be boosted to a speed in excess of Mach 1 by a liquid propellant rocket motor delivering a thrust of 34 tonnes. Much of the technology for the Navaho I booster came from examination of the propulsion system used in the German V-2 ballistic missile and it is within this project that the legacy of the pioneering efforts of Dr. Thiel are best exemplified (see Chapters Three and Four for a description of Dr. Thiel's work in developing the A-4 (V-2) engine).



The Navaho long range missile used a liquid propellant booster which emerged from studies of the German V-2. It carried a jet engined projectile on its back as seen here in this view of a display missile at the Kennedy Space Centre.

The same propellant combination that was used in the V-2 formed the basis of studies into the ideal chemistry for the new cruise missile booster and a switch was made to a liquid oxygen and alcohol/water mixture. Whereas the V-2 engine had required 18 injector roses to bring the propellants into the combustion chamber, Rocketdyne produced a single injector assembly, but retained the concept of a double-walled combustion chamber, so that fuel could be passed through and remove excess heat in the process. Several tests were made with this engine and it soon demonstrated superior performance to that of the V-2 motor. When a re-written specification for Navaho came along, the propulsion system required two uprated liquid propellant boost motors developed directly from the Navaho I type.

The most notable achievement in this phase of the technology programme was a dramatically improved turbopump, operating at a speed of 5,500 rpm, and the tubular-walled thrust chamber for regenerative cooling. Thrust was uprated to 54.4 tonnes and the motor operated with even greater efficiency than its predecessor. Many of the design details had been simplified, the engine was a lot lighter and became the basis for the final cruise missile booster development called Navaho III. Thrust chamber pressure in the first two developments had been about 21 kg/cm², but now the requirement demanded a still more efficient motor and Rocketdyne raised this to an unprecedented 35 kg/cm². Total thrust output went up to 61.24 tonnes, burning a mixture of kerosene and liquid oxygen and this change in propellant chemistry increased the specific impulse from 267 sec to 286 sec. This was the first time kerosene had been used in a large rocket motor intended for operational development and the shift inspired future engine designers to select the same mixture. When applied to the Navaho III, the booster would require three such rocket motors to be strapped together for simultaneous operation and the total thrust output, 184 tonnes, was greater than that envisaged for any other project.

When Convair sat down to draw up the detailed design changes resulting from the Von Neumann Committee report, in 1954, they looked to North American Aviation to provide the rocket motors for Atlas. It was from the advanced technology resulting from the booster work on Navaho III, that North American Aviation would develop the MA-2 propulsion system used by this, the first American ICBM. When the Strategic Missiles Evaluation Committee handed their report to Trevor Gardner, it was taken, along with a study performed by the Rand Corporation, to the Air Force Chief of Staff with the recommendation that the United States implement a ballistic missile programme with a high level of priority and at the maximum pace acceptable. During the latter half of 1954, the Air Force evaluated the proposals and put its weight behind their recommendations, seeking to implement a new organizational structure to manage the unparalleled complexity of major systems development. The Von Neumann report pointed out that a full scale ICBM programme would bring new problems of management and control in its wake and because of this, it was felt unwise to leave the project in the hands of one company.

Technical direction on the programme would have to come from an independent source and the Space Technology Laboratories of the Ramo–Woolridge Corporation was eventually set up to do the job. Dr. Simon Ramo and Dr. Dean Woolridge had been two of the participants on the Von Neumann Committee and worked with the SMEC in providing detailed technical advisory services. It was not an enviable task and many saw the ICBM project as being one of the most advanced and complex research and development programmes ever conceived. For its part, the Air Force put Atlas development firmly in the lap of the Air Research and Development Command (ARDC) and its vice commander, Major General James McCormack. Brigadier General Bernard A. Schriever was named as programme director. Within six weeks of his appointment in June 1954, Schriever had established the ARDC Western Development Division.

Proceeding with the re-worked specification resulting from the Von Neumann reports, Convair, for nearly two years now a division of the General Dynamics Corporation, received a contract for Atlas known as Strategic Missile 65. (Back in 1951 the Air Force had granted cruise and ballistic missile programmes a measure of respectability by designating associated projects numbers in the 'B' series denoting bombers officially contracted by the Department of Defence. In this series the Matador became the B-61, the Snark was the B-62 (short range tactical and long range strategic 'bombers' respectively), the Navaho became the B-64 (long range supersonic missile) and the Atlas was designated B-65 (intercontinental ballistic missile). The B-63 designation was applied to a glide bomb called Rascal, that would have been carried by a conventional bomber to within 160 km of a potential target and then released for free flight while the carrier-plane turned for home.)

Convair received its contract order in January and throughout the first eight months of 1955, the programme geared up with a high level of priority in Congress and the Pentagon. For almost ten years after the end of World War II, marked by the surrender of Japanese forces in September 1945, the United States had slowly come to recognize the important values accruing from possession of a strategic missile force and was now waking up to the full implications of past lethargy.

It has already been said that the naive assumption that the Air Force's mighty long range bomber fleet could satisfy all the strategic requirements of the United States, received a rude awakening with the rapid development of Soviet nuclear weapons. It was to receive an even greater prod from news that came in September 1955, but to appreciate the magnitude of the effort after this date, it is essential to trace the historical development of US army and Navy rocket projects in the period from 1945. All the ICBM work was firmly lodged with the US Air Force and this highlights the separation by category functions: in believing that all intercontinental bombing activities were under their prerogative, the Air Force confined their thinking to studies involving very long range missiles while the Army, with an almost exclusive hold on the captured German research effort, went their own way. Before 1955 there was little or no co-ordinated missile programme, each armed service seeking to exploit potential applications according to their respective roles for a projected war scenario.

Because the US Army moved quickly into the vast complex of rocket production facilities in the Bleicherode area, at the end of the Second World War, it was that service that obtained first call on the selected German engineers and technicians rounded up at the direct instigation of Colonel Holgar Toftoy. By August 1945, Toftoy had managed to obtain permission for the Army to secure the services of 127 top Germans, including von Braun, Eberhard Rees and Ernst Stuhlinger; the latter had been working at Peenemunde since 1943 following five years in the Berlin Institute of Technology and two years in the German Army. He would become one of the key figures in the American rocket research programme. Toftoy had intended to gain permission for picking up to 300 leading German rocket engineers, but the United States government allowed only 127, and even that number was only approved after an appeal to Congress.

Toftoy met with the selected cadre early in August at Witzenhausen and offered each one a contract which would last for one year and require them to move to the United States where they would be paid for their services while their families remained in Germany. All the costs of housing the dependents would be subtracted from their fees. By sheer weight of numbers, it can be said that the Russians received the larger share of the ex-rocket pioneers, but that would ignore the fact that the United States had carefully sifted out the more important members of the group from those that had less value to the old V-2 project. There is no doubt at all that the Russians were left without any major personalities upon which to base their post-war rocket programme and the components for 100 V-2 rockets had been sent to Antwerp docks during the last week in May. By the time Toftoy had negotiated for the services of the German rocket engineers, the operation had been code-named Overcast, although it will be remembered for its more popular and recognized title as Operation Paperclip, which it was retrospectively designated in 1946.

Developed at the Jet Propulsion Laboratory, the Corporal tactical battlefield missile would see extensive service with the US Army. The transporter/erector has just raised the missile 90° from the mobile position.

Before the 127 were shipped to the United States, Wernher von Braun was sent to Britain where he was interviewed by (Sir) Alwyn Crow at the Ministry of Supply. The first members of the group arrived in the United States toward the end of September 1945, and von Braun was seen by Army Ordinance Corps personnel in Washington before moving to the Army's Fort Strong in Boston, Massachusetts. Here, he met Major James P. Hamill, who had been assigned to retrieving V-2 equipment from the Nordhausen facilities, and was then delivered to the Aberdeen Proving Ground where the first members of the group could brief US Army and Intelligence experts on the mountains of documents fetched over from their location, where von Braun had hidden them before the end of the war. Major Hamill organized the arrival of the other rocket engineers and by the end of 1945 the trickle of V-2 experts began to supplement the vanguard, hurriedly brought over the previous September.

By this time Hamill had arranged for their transfer to Fort Bliss at El Paso, Texas, and it was from here that work would get under way on assembling the captured V-2 components into usable rockets. Within three months, by February 1946, almost all the 127 engineers were on hand at Fort Bliss and the Army began to build up the necessary facilities for active tests, which would be performed at the White Sands Proving Ground in New Mexico. The V-2, a product of the first precursor steps on the road to a ballistic missile fleet, had come to the place not far from where Robert Goddard first tested a liquid propellant rocket nearly twenty years earlier.

It will be remembered that the only promising rocket programmes then under development in the United States rested on the advanced work at the Jet Propulsion Laboratory and came as a direct result of the GALCIT project. Under contract to the Army Ordinance Corps (the Air Force had shown virtually no interest at all in rocket programmes), JPL moved ahead with work on the Corporal tactical ballistic missile although it would be more than six years before the first test flights began. When the German engineers arrived in the United States, however, the JPL team, under the general envelope of the ORDCIT programme, had begun tests with the Wac Corporal atmospheric sounding rocket.

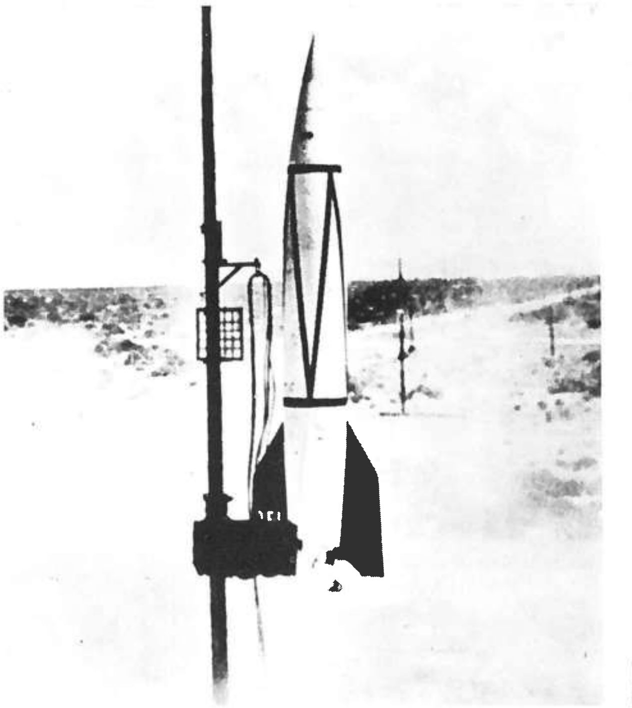
The first test programme of a US sounding rocket led to flights 73 km above the White Sands proving ground and it was with Wac Corporal that the newly arrived V-2 rockets would be combined in the so-called Bumper-Wac configuration. However, the first order of business was to assemble the basic V-2 and fly it in a series of experimental tests. On 14 March 1946, the first of these was static-fired at White Sands, almost a year since the V-2 had last been launched offensively in Europe, and this was followed on 16 April with the first flight. Soon, V-2 rockets were being launched with useful payloads and the adopted missile programme provided a solid basis for investigating the upper atmosphere and performing a variety of physical and biological experiments.

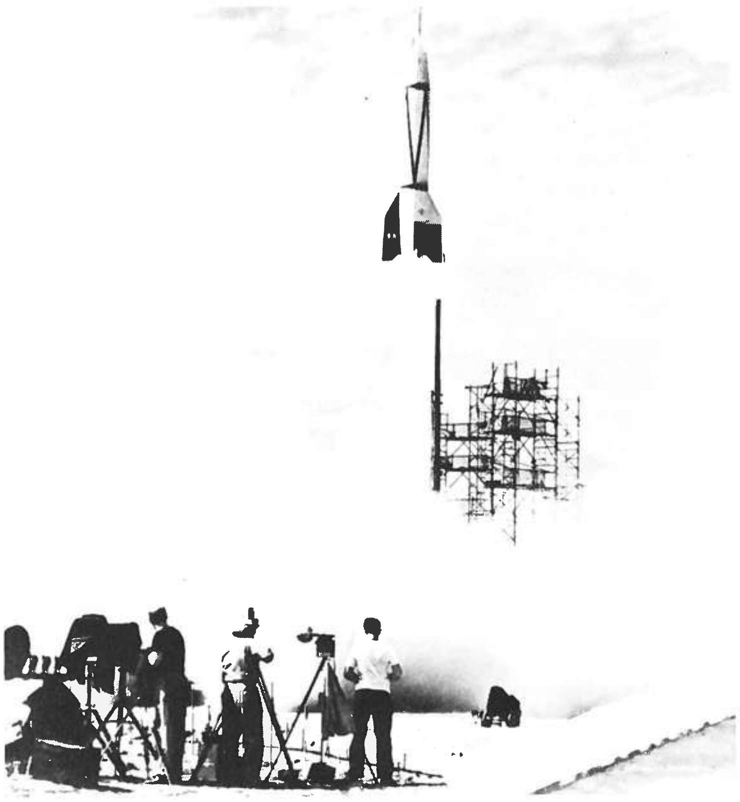
By 1947 the V-2 Upper Atmosphere Research Panel had been set up to co-ordinate an increasing number of proposed tests and the Army Ordinance Corps brought the General Electric Company in on a programme called Hermes, which would expand on the limited capabilities of the basic missile. Now, in the position of project director for guided missile development, von Braun was working on modifications to the V-2 and assisting with technical details for a planned US Navy test, which led to the first launch from a ship. This came under Operation Sandy and resulted in a flight from the deck of the aircraft carrier USS Midway in September 1947, prematurely terminated when the missile exploded at a height of only 1.5 km. Nevertheless, increasing Navy interest in the possibility of launching long range ballistic missiles from ships at sea, led Rear Admiral Daniel V. Gallery to further the experiment programme. In 1948, under the command of Lieutenant Commander W. P. Murphy, two V-2 rockets were intentionally blown up in tests to measure the amount of damage which would result if missiles exploded before launch.

But it was the Bumper programme that gave the V-2 its greatest performance achievements. In this, the Army placed a JPL Wac Corporal (again, not to be confused with the Corporal tactical missile) on top of the standard V-2 in a two-stage configuration designed to carry a small payload of engineering instruments to altitudes higher than were possible with the basic missile. In basic V-2 flights from the White Sands Proving Ground, flights were generally accomplished to an altitude of about 180 km at most. With Wac Corporal as the second stage, the assembly could reach a height of nearly twice this altitude and the first flight was performed on 13 May 1948. Not until the fifth flight, on 24 February 1949, did the assembly prove itself, when the Wac Corporal reached a height of 393 km. On the next flight, 21 April 1949, the Bumper configuration fell back to the ground when the V-2 engine cut out prematurely, 38 seconds after lift-off. The first six flights had been performed to satisfy the requirement of reaching extreme altitude, but now the Army wanted to use the assembly to test the aerodynamic characteristics of a low angle trajectory seeking range rather than height.

For this purpose the Bumper programme moved to the Long Range Proving Ground at a place called Cape Canaveral on the east coast of Florida. It was an historic move as later events will show. The first flight was made on 24 July 1950, and achieved a range of 322 km and the last Bumper firing, the second from Cape Canaveral, was performed just five days later. By 1950, therefore, the US Army had taken the V-2 and put German engineers and technicians to work in activities centred on wringing the last ounce of performance from the basic rocket. The US Navy had, meanwhile, moved ahead with plans of its own for development of high altitude sounding rockets with one of two projects based in large part on the JPL Wac Corporal.

Redundant V-2 rockets were brought to the United States and launched in a series of tests aimed at studying the missile's characteristics and for flights of scientific importance.





The first rocket launch from Cape Canaveral, later the site for the sprawling Kennedy Space Centre, 24 July 1950. The Bumper-Wac rose to a height of 16 km and then tilted 90° to fly parallel to the sea before impacting the Atlantic Ocean 322 km from the launch pedestal.

At the end of 1945, the Naval Research Laboratory set up its Rocket-Sonde Research Branch and by 1946 had embarked on the Viking and Aerobee programmes. The Viking specification required a company to develop a high altitude sounding rocket capable of lifting a useful payload to an extreme height, so that measurements could be taken from a stable position above the atmosphere, before the device fell back to the earth. One of the drawbacks with the V-2 research came when the motor cut out and the projectile tumbled uncontrollably as it lost all means of stability. Before the end of the year the Glenn L. Martin Company had received the Viking contract with the development of the propulsion system awarded to Reaction Motors Incorporated.

As design progressed the rocket matured into a single stage carrier about 14 metres long, weighing 4.5 tonnes and with a 9 tonne thrust motor fed with liquid oxygen and alcohol propellants. Static engine tests began in 1947 and the first Viking rocket was delivered to White Sands in January 1949. Under the watchful eye of Lieutenant Commander W. P. Murphy, who just a year before had directed the V-2 detonations on a US Navy test programme, the Viking 1 was readied for its first flight. Much of the engineering design on Viking had been obtained from the V-2 and this is yet another example of the effective marriage between German developments of the 1936–45 period and immediate post-war rocket projects in the United States. In no small measure the basic learning process was boosted by tests with the V-2, although the United States would soon develop advanced technologies far in excess of anything acquired at Peenemunde; the MX-774 work is a classic example of the early break-away branches on the evolving tree of rocket research.

The first static test of the fully assembled Viking 1 came on 11 March 1949, but a fire in the tail section brought this to a halt without serious damage. Following a successful static test on 28 April, Viking 1 was fired on its maiden launch on 3 May. Its engine burned for 54 seconds and the rocket reached a speed of 3,780 km/hr and a height of 80 km. The 9 tonnes of thrust from the Viking propulsion system was the highest of any US rocket of the day, comparing very favourably against the less than 0.7 tonnes thrust of the Wac Corporal and the 3.6 tonnes of the three MX-774 rockets tested in 1948. The next two Viking shots were equally successful, but the fourth,

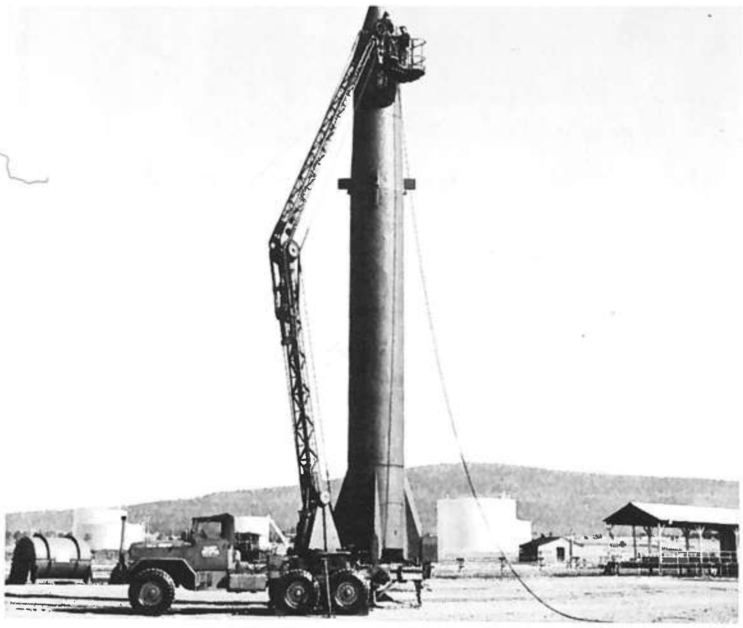
The Bumper-Wac configuration used a basic V-2 missile as the first stage to a liquid propellant Wac Corporal research missile. Note the stub-fins at the base of the V-2/Wac Corporal mating position.

on 11 May 1950, was flown from the deck of the USS Norton Sound, in the continuing series of Navy tests directed by Rear Admiral Gallery, aimed at evaluating the concept of launching rockets from ships at sea.

The second US Navy sounding rocket project, Aerobee, was conceived by the Naval Research Laboratory, ordered by the Navy Bureau of Ordinance and built by the Aerojet Engineering Corporation under the technical direction of the John Hopkins University. The original specification required a payload capability of 45 kg to a height of 120 km and much of the design owed its success to the earlier work performed on the Wac Corporal at JPL. To match the objective, Aerojet designed the Aerobee as a liquid propellant rocket fed with Red Fuming Nitric Acid (RFNA) and aniline, providing a thrust of 1.18 tonnes for 45 seconds. A single booster utilized solid propellants to provide a thrust of 9.5 tonnes for 2½ seconds; the assembly was to be launched from a tower nearly 43 metres in length and stability was effected by three fins at the base of the main rocket and three at the base of the booster, the two being mounted in tandem like a traditional two-stage rocket.

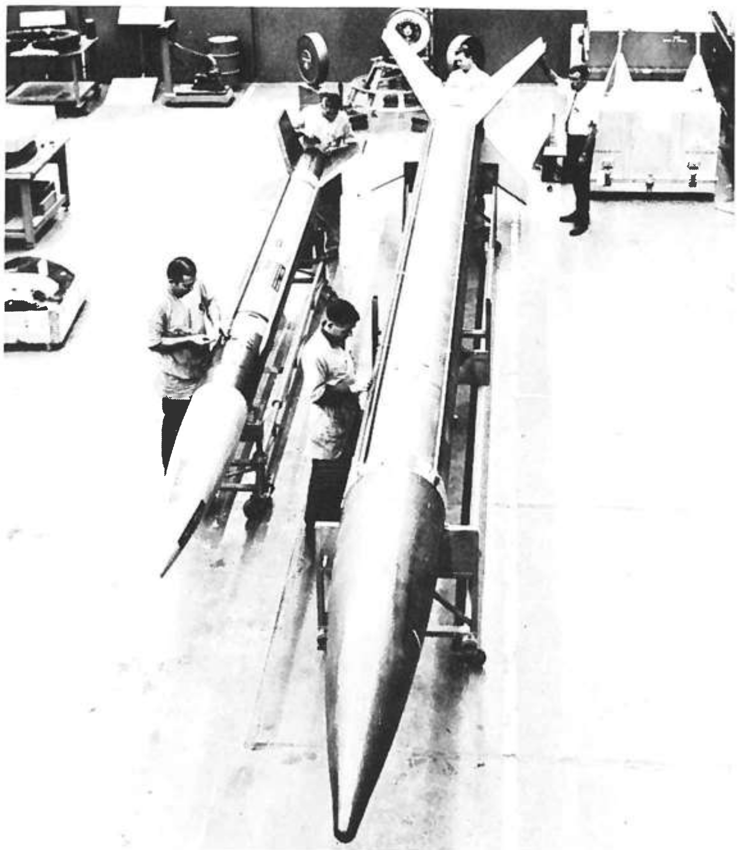
The first flight was successfully performed on 14 November 1947, and carried a load of 68 kg to a height of 120 km, well beyond the original design specification. Aerobee would be built in a variety of different configurations in the years to come and serve as one of the most useful US sounding rocket programmes, its derivatives operated by all three armed services and the civilian space agency of later years. So, with the Navy busy on its Viking and Aerobee projects and JPL operating the Wac Corporal, the Army was pressing ahead with more flights of the basic V-2 and its adapted configuration.

The true marriage of German technology and American ideas formulated under the name of Hermes, but it was becoming readily apparent that the Army would soon have to begin development of its own missile as stocks of the ballistic weapon were finite and required flights exceeded the number of rockets that had been returned from their assembly plants in the Harz Mountains. At first, modified components were tried out with the existing inventory of V-2 rockets and then new designs for guidance and control were built and tested. By 1948, General Electric were testing a new rocket motor for the Hermes A-1, with a thrust of more than 6 tonnes and this was used in a scaled-down V-2 with which five firing tests were performed between May 1950 and April 1951. The rocket carried fins at the rear and proved itself capable of reaching a height of 24 km and a speed of nearly 3,000 km/hr on the propulsion from its single liquid oxygen and alcohol motor.

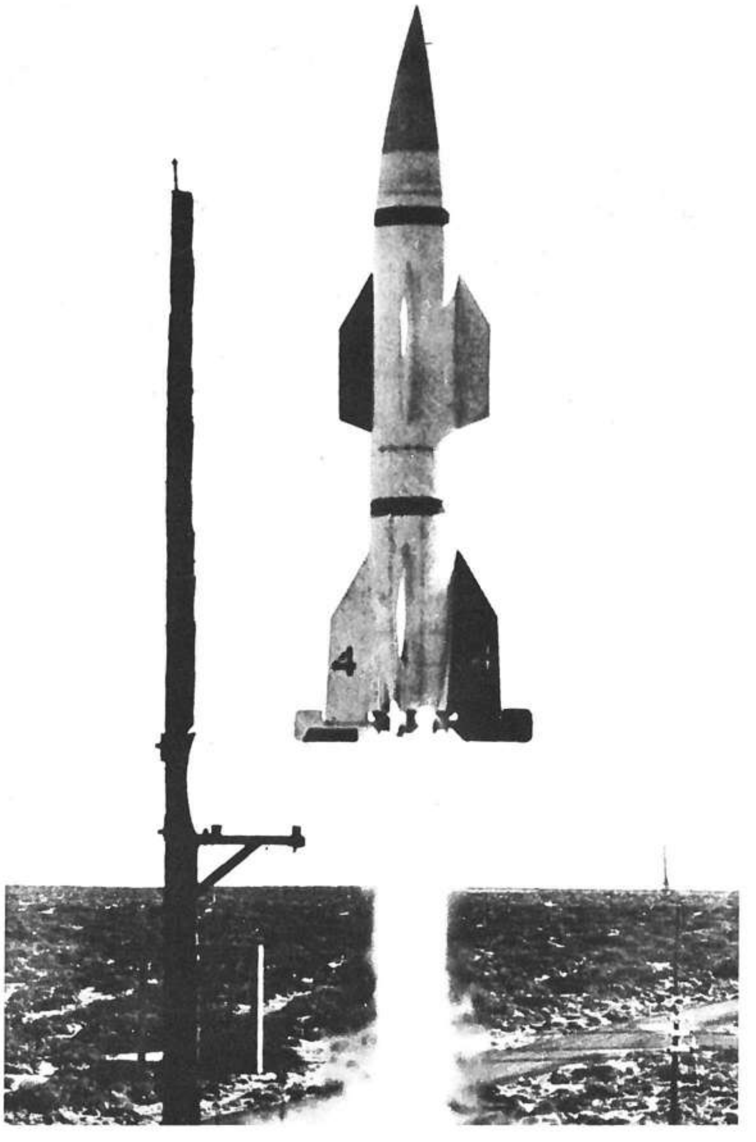


Technicians prepare a Redstone medium-range ballistic missile. Note the four short fins forward and the four aerodynamic fins and rudders at the rear.

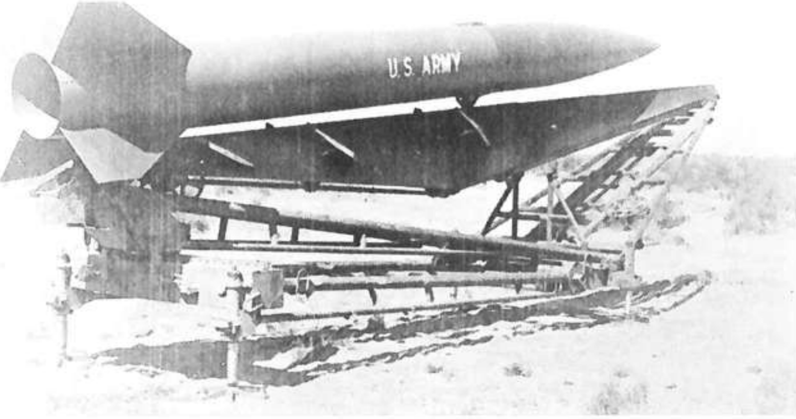
During the flight tests of A-1, General Electric perfected an A-2 model which would have used a solid propellant rocket engine produced by JPL and the Thiokol Chemical Corporation. Although much smaller than the V-2, like its predecessor, the A-2 bore superficial resemblance to its ancestor and tests with the motor were carried out beginning late in 1951. The A-2 never flew, but the propulsion unit continued under test and was eventually fired as part of the RV test vehicle series in 1953. Several other Hermes rockets were conceived and two, Hermes A-3A and -3B gave the Army and General Electric experience with testing new guidance systems and generally acquiring the data upon which later, more ambitious, rockets would be based. Despite its success, Hermes



A liquid propellant Aerobee 350 is checked out alongside the smaller Aerobee 150. Developed by the Navy and built by the Aerojet Engineering Corporation, Aerobee proliferated a successful family of atmospheric sounding rockets.

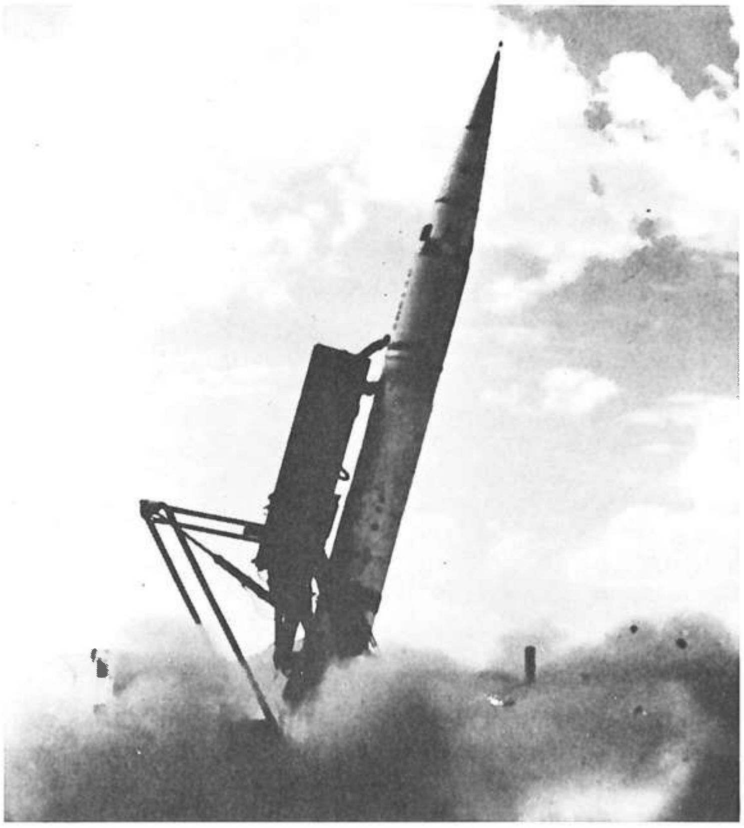


'The true marriage of German technology and American ideas formulated under the name of Hermes.' Here, modifications to a basic V-2 are carried out.



The Honest John tactical battlefield missile was phased in to service during the mid-1950s.

Sergeant succeeded Corporal in its command of battlefield capability. The missile was designed as a highly mobile, rapid-fire weapon and used a solid propellant rocket motor.



represents the first tentative post-War design tasks for the von Braun cadre and the C concept envisaged a three-stage rocket powered by a cluster of 6 liquid propellant engines delivering a total thrust of 272 tonnes.

Working under the supervision of Holger Toftoy, now a Colonel, von Braun worked on the design of a rocket capable of transporting a payload weighing 225 kg across a range distance of 800 km. This was designated Hermes C-1 and although it was an original design, it bore the unmistakable stamp of the Peenemunde team, carrying all the primary features of the post-V-2 genesis. Nothing at all came of the basic C model, with its over-ambitious thrust requirement and a third stage winged glider, but the C-1 did provide the Army with its first medium range ballistic missile (MRBM).

The growing demand for more rocket research facilities and the need to centralize theoretical studies at an accessible establishment, led the Army to search for more suitable quarters in which to conduct work that would lead to the first generation of US military missiles destined for operational use. On 28 October 1949, permission was granted for the Fort Bliss work force to move to the Redstone Arsenal, then under the command of Brigadier General Thomas Vincent, at Huntsville in the state of Alabama. By April 1950 the move was under way with more than 750 persons, many of them members of the original German contingent that had journeyed to the United States 4½ years earlier, migrating to the new Ordinance Guided Missile Centre. Colonel Toftoy had released Major Hamill from his post at the Ordinance Research and Development Division Rocket Branch in Washington to head the new unit; Wernher von Braun, his American star already in the ascendant, was named as Technical Director.

If the Korean War had only a modest affect on Air Force plans for ICBM work, the outbreak of hostilities in June 1950 was brought more fully home to the US Army rocket protagonists. No sooner had the Hamill–von Braun team moved across to Redstone and set up shop, than did the call come from Washington for studies of a ballistic missile capable of delivering a warhead across a distance of 800 km. It was only at the end of 1950, however, that real work could begin; the apparent lack of urgency and the slow migration of personnel and equipment from El Paso, contributed to the apparent hiatus between conception and initiation of design work. Nevertheless, as the conflict built up in importance and ferocity the Army pressed for ever more urgent attention on its first tactical battlefield missile.

Officially classed as a medium range ballistic missile (MRBM), the project was named Redstone on 8 April 1952, in honour of the new Guided Missile Centre. Also at this time (1950) the US Army placed a contract with the then Douglas Aircraft Company for a short range missile called Honest John, envisaged as a small 2 tonne solid propellant projectile with a range of less than 20 km. Throughout 1951 and 1952 work on the Redstone MRBM continued and the choice of propulsion systems was limited by the increasing urgency to come up with a viable missile. The department of North American Aviation created to perform design work on the engine for the Navaho I cruise missile booster, was chosen to design and build the Redstone motor and the Guided Missile Centre at Huntsville took the original Navaho booster engine design virtually intact and married it to the Redstone rocket. With more than 34 tonnes of thrust, the motor would be capable of matching the Army requirement for the projectile's specification, but because of changing views on the operational role of the missile, the range was reduced to some 320 km and this had the favourable affect of increasing the potential payload capability, moving it just inside the weight requirement for a nuclear warhead.

At this time the operations strategy was conceived whereby the Redstone would be placed in use as a highly mobile weapon, the transition from fixed-base launch site to a more flexible mode, being performed with more approval than had attended the earlier attempts in 1943–44 to get the V-2 accepted as a mobile missile! By 1953 the first missile was ready for launch and the initial flight was accomplished on 20 August with a flight over the minimal distance of 815 metres. Much had still to be done in bringing the Redstone up to operational levels, but the programme moved ahead smoothly and without undue hindrance from the Army. Nevertheless, recognizing the complex nature of this, the first major Army rocket research programme, it was decided to place production outside the government establishment, like the Air Force with their concurrent Atlas ICBM project, and Redstone was to be built in large numbers by the Chrysler Corporation.

Because of the Korean War, work picked up on the flagging Hermes project and models of the A-3 series were fired, seven of the A-3A and six of the A-3B type, before the work was completed in 1954. Now, with V-2 flights over, the American industrial machine was beginning to gear up for quantity production of two major missile programmes: the Redstone MRBM for the Army and the big Atlas ICBM for the Air Force. It was the delegation of production responsibilities out of US industry that gave the American missile effort valuable flexibility in future years. Many of the design innovations that would do so much for the space programme of later years, were built up on the practical experience of direct participation in these early days of military rocket development.

If there is any one year which can be recognized as the turning point in US missile programmes, it must surely be 1955. Before this time the Army, the Navy and the Air Force had gone their own ways, each service developing specifications from requirements generated by their own unique view of the potential applications. The Army had accepted the Corporal short range ballistic missile and was phasing in the Honest John. The former, with a range of 120 km, was the first

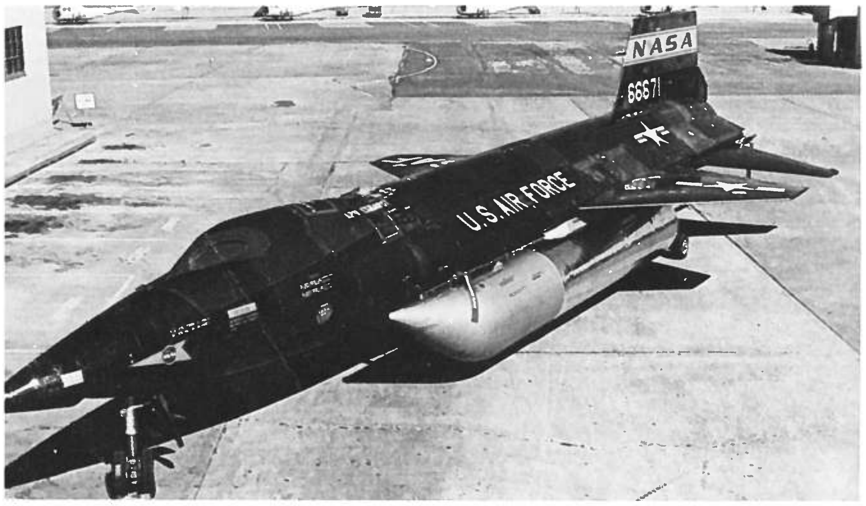
US military rocket to be brought to offensive readiness and the Honest John would be used for battlefield operations, its range being limited to cover very short-range requirements.

By 1955 the limitations placed upon Corporal flexibility were all too apparent and the Army was looking ahead to accepting the Sergeant, lighter in weight, and with at least an equivalent range capability. Corporal required some 250 persons to ready it for launch and a period of at least seven hours to erect and fire. Sergeant, on the other hand, was designed from the outset as a highly mobile, rapid-fire missile using a solid propellant motor which could be kept in a high state of readiness at all times. It was precursor to a family of surface to surface missiles that would demand increasingly mobile capabilities and brief preparation times.

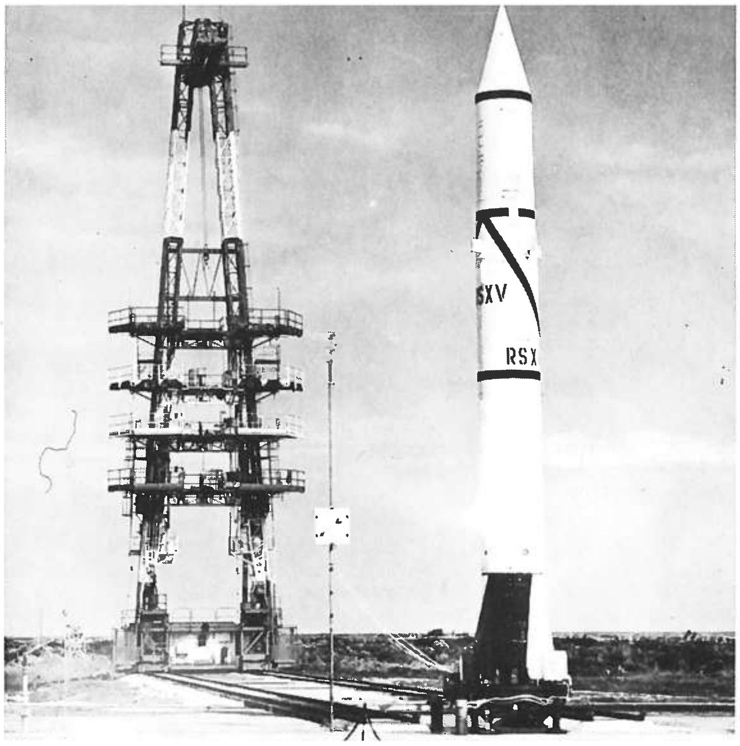
Now, the history of Army and Navy missile development can join with that already discussed for the Air Force for, after September 1955, it became almost impossible to separate the three services' interests. For the previous two years the military planners in the Pentagon had accepted an increasing possibility of Soviet progress which could threaten the dominant position held by the United States since World War II. The Hydrogen Bomb dropped by the Russians on test in August 1953 had sealed all thought of a broad technology gap between the two countries. Nevertheless, the Secretary of Defence, Charles E. Wilson, was reluctant to authorize a crash programme for missile development until a committee report on 13 September 1955, jettisoned the last vestiges of apathy from the Eisenhower administration. (The elections of November 1952 had brought Dwight D. Eisenhower from command of the Supreme Headquarters of Allied Powers in Europe to the Presidential seat, ousting twenty years of Democratic party domination in favour of a Republican administration.)

Eisenhower's special adviser on science and technology, James R. Killian, Jr., headed the committee and it heard news from intelligence sources of a massive Soviet endeavour to procure a viable ICBM fleet. The strategy of the European theatre dictated a potentially hostile situation as far as the Russians were concerned: with borders patrolled by NATO countries, the Soviet armed forces could expect to receive little warning of attack and although there was no justifiable reason why they should expect a pre-meditated assault, the lessons of the Second World War would remain an integral part of Soviet military thinking. The United States' bomber force, possession of the Atomic Bomb and the imminent availability of the thermonuclear Hydrogen Bomb in a deliverable size pointed out the inferior military stance of the Soviet Union.

In the event of another all-out war, the Russians would face civil and industrial disorder on a massive scale; without the ability to strike targets on the continental United States they would be prey to the long range nuclear strike aircraft based in America. The Soviet bomber force, or the lack of it, played hard on the politics of equal strength. In an attack from the west, bombers in the United States could fly across the Atlantic, deliver their weapons on Russian targets and fly the comparatively short distance back to friendly bases in western Europe and the United Kingdom, a total trip of less than 10,500 km. Soviet bombers, on the other hand, would be required to fly to the United States, drop their load on American targets and then fly the same distance back through potentially hostile air-space, a distance in this case of 17,000 km on the round trip.



Work by Reaction Motors Inc., on the MX-774 propulsion system led from work on the rocket engine used for the Bell X-1 research aircraft. The definitive US rocket powered aircraft – the X-15 – is seen here sporting cylindrical propellant tanks used for boosting performance.



Test and non-operational development models of the Redstone MRBM were serviced by a special tower mounted on rails and adapted from redundant oil derricks.

The Russians were painfully aware of the American preparations for total war: the big Boeing B-52 heavy long-range bomber was coming into service and although it could not manage the round-trip to the Soviet Union, it was capable of flying across the Atlantic and landing in European bases after delivering its load east of the Elbe; the Soviet Intelligence sources knew too of the intensified efforts to build up an ICBM fleet and of the high priority placed on the Atlas missile. Recognizing the advantages in building a delivery system which did not have need to return to home base, the Russians were rapidly acquiring the technology to develop their own intercontinental ballistic missile. By September 1955, they were well on the road toward completion of their first missile in this category.

It was with grim reality that the Killian committee spoke of a new escalation in the research and development programmes of Soviet munitions. Upon hearing the chilling news, Secretary of Defence Wilson ordered not only maximum priority for ballistic missile programmes already on hand, but put weight behind several other projects which had been conceived in the preceding months. Killian had advised the National Security Council that the Army should play a prime role in the development of an intermediate range ballistic missile which could find application with both the host service and aspirations on the part of the Navy for a ship-launched projectile. Consequently, on 8 November 1955, the Defence Secretary set up a Joint Army–Navy Ballistic Missile Committee to monitor the project, called Jupiter, and nine days later the Navy formed the Special Projects Office under Rear Admiral William F. Raborn.

Jupiter was to be developed at the Guided Missile Development Division at Redstone Arsenal under the capable tutelage of Wernher von Braun, by now a United States citizen. Its mission encroached on what had hitherto been thought to be Air Force ground, in that the range of 2,600 km placed it more in the category of a long range bombardment weapon than in the battlefield support role of previous Army missile programmes. It would, in effect, provide an IRBM function between the Army Redstone and the Air Force Atlas. Much of the technology of Jupiter A would be derived from existing work on the Redstone, a project which fathered another programme bearing the Jupiter name, but one which was more of a modified Redstone than anything radically new. Called Jupiter C, the missile would bear considerable resemblance to the Redstone, but with a lengthened tank section, more powerful engines and the addition of two upper stages, the project had a character all of its own.

Jupiter C was developed, beginning late in 1955, to test materials and structures which would be required to protect the nose cones of IRBM and ICBM vehicles when they slammed down into the atmosphere at the end of a long cruise to their targets. The tremendous heat which would build up on the outer surface of the warhead, by now the concept of a separable warhead was accepted practice, brought many new problems to all three services and with the flurry of new projects coming as a result of the Killian report, the Army had desperate need of a test vehicle which could be used to investigate the many unknowns associated with the phenomena. The tests would be performed by the first stage of the Jupiter C, basically a lengthened Redstone to all external appearances, propelling the upper two stages to a height from where they could fire sequentially to drive the nose cone back down into the atmosphere at the high speed experienced by a warhead carried by a long range missile.

As it turned out only three Jupiter C rockets were actually launched as part of the re-entry nose cone test programme, but the significance of this project would be greater than anything it accomplished, for the tasks it was designed to perform. Bearing the initial designation of Jupiter Composite Re-entry Test Vehicle the rocket would, in only moderately modified form, launch the first United States satellite little more than two years after its inception at the end of 1955 under the name of Juno I. But more on this later. As it was, within two months of the Killian report, the Army had organized, and gained high level permission for, two major new projects: Jupiter A and Jupiter C. Its interest in ballistic missile research accelerated from this point on, hence the investment in a research rocket for nose cones.

For its part, the Air Force too gained new projects from the Killian report and the good work it did in shaking the sleeping Defence Secretary. For several months the Air Force had been considering the development of an IRBM of its own and had come up with a requirement for a missile with similar range to the newly proposed Army design approved as the Jupiter A. The Air Force missile, called Thor, finally got the go-ahead in November 1955 and the following month a development contract was awarded to the then Douglas Aircraft Company. It would be designed to a specification which required a range of 2,600 km, close to that specified for the Jupiter IRBM. Thor was the more important missile authorized at this time, but the most visually exciting and spectacular was Titan, an Air Force creation that stemmed from recommendations of the Von Neumann committee.

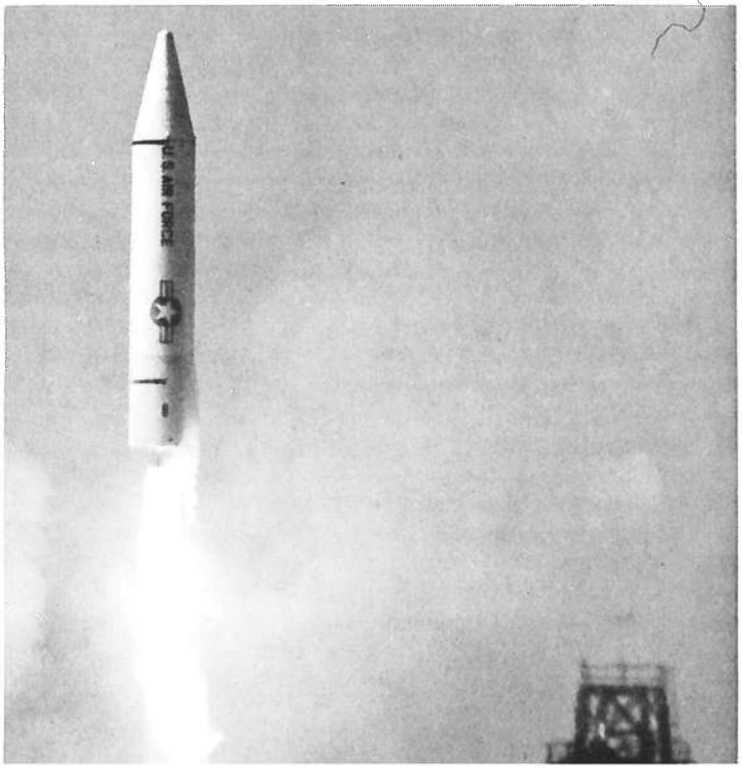
It had been observed that Weapon Sytem 107A–1, the Atlas ICBM, carried many novel design features which could lead to problems and resulting delays to the test programme and subsequent service introduction. The extremely light, thin-wall tank concept, married to the unique booster arrangement whereby the central sustainer engine was flanked by supplementary motors jettisoned on the ascent, seemed just too revolutionary to carry the same predictable assurance of success as did other, more conventional, approaches. Because of this, the Strategic Missiles Evaluation Committee of 1953–54 recommended Air Force development of a second ICBM based on existing and well-tried concepts of design.

Called Weapon System 107A–2, work progressed at a snail's pace until, again, the Killian report of September 1955 prized open Federal coffers and gave the Defence budget the money it needed to bring the project to fruition. Conceived as a back-up to Atlas, Titan was given a boost almost immediately the National Security Council met to approve the host of new missile projects and just a month after Killian the Martin Company (now Martin Marietta) were awarded a contract for final design and development. Whereas Thor, an intermediate ballistic missile, was developed as the only Air Force IRBM, Titan grew in importance to complement the role played by the Atlas ICBM. Both Thor and Titan would find expansive application as space boosters in later decades.

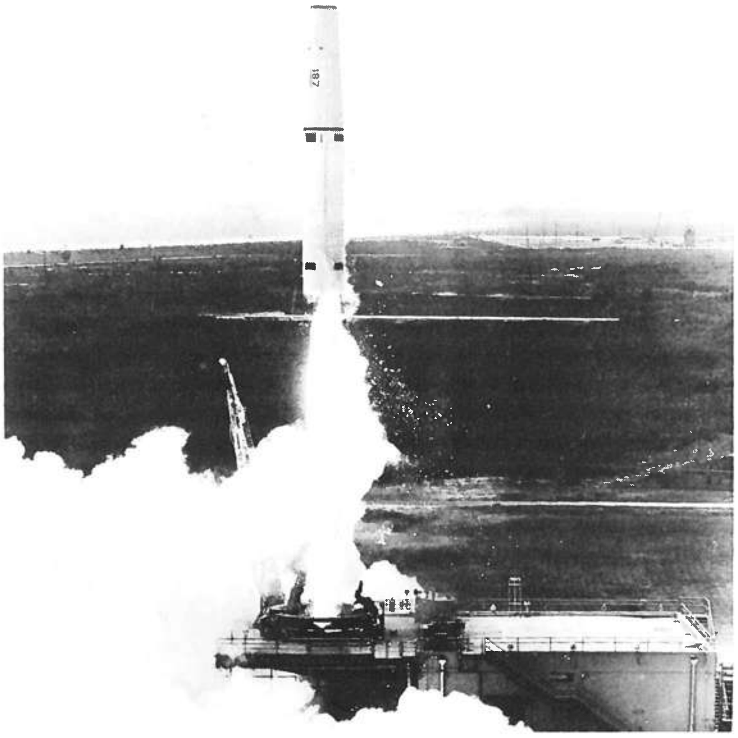
Just as the Army had been able to procure funds for a re-entry nose cone test vehicle, in the form of Jupiter C, so too did the Air Force begin development of its own research tool. Work on the so-called X-17 had begun in February 1955, but there was now a new urgency about the knowledge gap concerning re-entry nose cones and the programme accelerated toward a first flight in July 1956 as Army and Air Force IRBM and ICBM projects spewed forth their demanding requirements for information on terminal trajectories, high heat loads, thermal transfer rates etc. So, by the end of 1955, three new missile programmes had been added to the growing inventory of service development contracts: the Army was busy with Navy support, on the SM-78 Jupiter A IRBM, with a potential range of 2,600 km; the Air Force brought in its SM-75 Thor IRBM, with a similar range to that of Jupiter and moved ahead with development of the SM-68 Titan 1 ICBM, to supplement the Atlas, under way in fits and starts since 1946. At the bottom end of the scale, the Army was pursuing a vigorous test-launch schedule with the Redstone medium range ballistic missile and finalizing design details on the Sergeant short range tactical battlefield rocket, a proposed replacement for the Corporal.

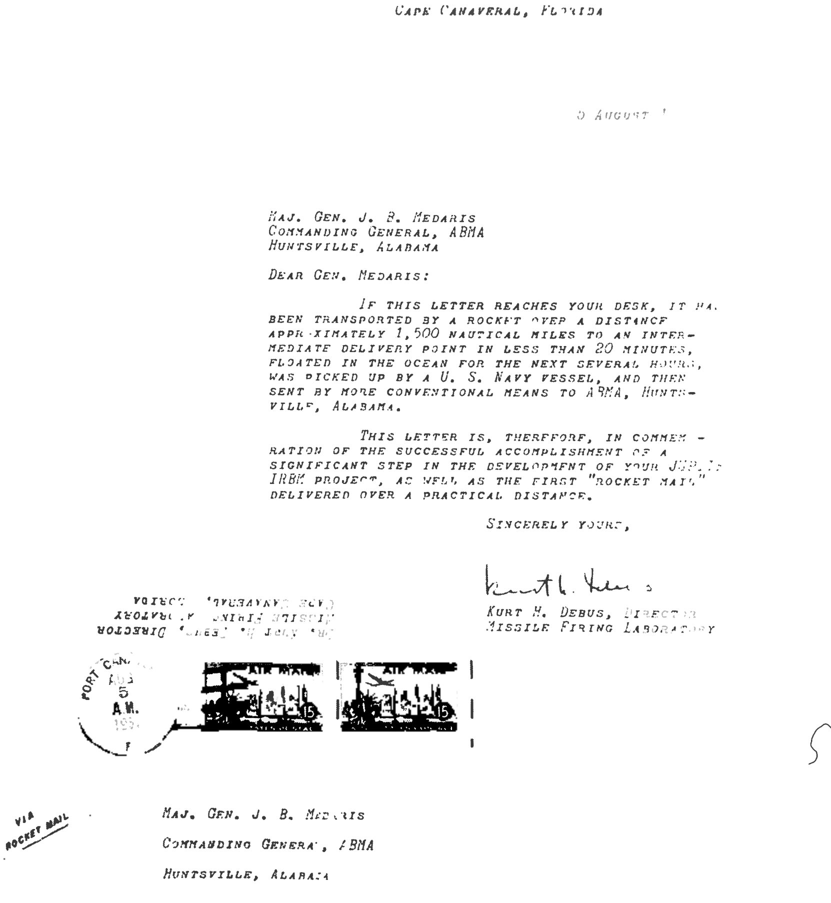
Activity reached an unprecedented level. Never before had so much emphasis been placed on the development of large ballistic missile systems and all three services would go through the usual, sometimes painful, stages of maturation with a technology that was still cluttered with many unknowns. In spite of confident assertions that the proposed missile programmes would fill the gap in tactical and strategic requirements, the dual Army–Navy project to fund

The Jupiter A was developed at the Guided Missile Development Division of Redstone Arsenal. This view was taken after the US Air Force took control of the project in November 1956.



The Thor IRBM was the US Air Force counterpart of the Army Jupiter and supports a characteristic flat-topped nose cone. The missile was eventually deployed in the UK.





CAPE CANAVERAL, FLORIDA

5 AUGUST

MAJ. GEN. J. B. MEDARIS
COMMANDING GENERAL, ABMA
HUNTSVILLE, ALABAMA

DEAR GEN. MEDARIS:

IF THIS LETTER REACHES YOUR DESK, IT HAS BEEN TRANSPORTED BY A ROCKET OVER A DISTANCE APPROXIMATELY 1,500 NAUTICAL MILES TO AN INTERMEDIATE DELIVERY POINT IN LESS THAN 20 MINUTES, FLOATED IN THE OCEAN FOR THE NEXT SEVERAL HOURS, WAS PICKED UP BY A U. S. NAVY VESSEL, AND THEN SENT BY MORE CONVENTIONAL MEANS TO ABMA, HUNTSVILLE, ALABAMA.

THIS LETTER IS, THEREFORE, IN COMMEMORATION OF THE SUCCESSFUL ACCOMPLISHMENT OF A SIGNIFICANT STEP IN THE DEVELOPMENT OF YOUR JUPITER IRBM PROJECT, AS WELL AS THE FIRST "ROCKET MAIL" DELIVERED OVER A PRACTICAL DISTANCE.

SINCERELY YOURS,

Kurt H. Debus

KURT H. DEBUS, DIRECTOR
MISSILE FIRING LABORATORY

PORT CANAVERAL
AUG
5
A.M.

VIA ROCKET MAIL

MAJ. GEN. J. B. MEDARIS
COMMANDING GENERAL, ABMA
HUNTSVILLE, ALABAMA

This letter was sent by Dr. Kurt H. Debus at the Cape Canaveral Missile Firing Laboratory by Jupiter rocket on 5 August 1957. It provides an interesting and historic comparison with similar efforts at rocket-mail transport conducted by Gerhard Zucker and Friedrich Schmiedl more than forty years earlier.

development of the Jupiter A for land and sea deployment, ran into problems almost from the beginning. When the Navy agreed to go into co-operative liaison with the Army, it already had its own ideas for long term missile development. While liquid propellant missiles might be suitable for land use, where the necessary launch support equipment could be built around the deployed rockets, the naval requirement had to make do with the limited services provided by conventional ships. There would simply be no room for the complex and elaborate support systems common to liquid propellant missiles.

Because of this the Navy put emphasis behind the concept of a solid propellant rocket for its own use and looked even harder at the possibility of placing ballistic missiles in submarines, specially built to contain vertical launch tubes within the hull. The handling, storage and preparation of liquid propellants was another problem facing naval deployment and with an eye on undersea applications, the Joint Army–Navy Ballistic Missile Committee was faced with conflicting requirements. If 1955 was the year in which the first generation IRBM and ICBM systems were authorized, 1956 was the year in which the lines of demarcation between Army and Navy tasks were defined with a degree of clarity essential to respective interests.

But first the Army had to strengthen its administrative control over the host of organizational tasks and set up a department for management of the many subcontractors who would be called upon to perform work on the missile programmes. On 1 February 1956, the Guided Missile Development Division at Redstone Arsenal was taken over by the Army Ballistic Missile Agency (ABMA), a new organization set up on that date, under the command of Major General John B. Medaris, late of the Industrial Division at the Ordinance Corp. With the Redstone missile already into its flight test programme, the ABMA was to be responsible for this and the new Jupiter rockets and with the increasing influence of Army control over the latter, ostensibly a *joint* venture, the Navy was ill at ease over the management of its own intrinsic requirements. From its inception, Wernher von Braun was named as Director of the Development Operations Division, with specific responsibilities to Redstone and Jupiter projects; the ABMA was well served with experienced rocket engineers from the V-2 days and with a commander (Medaris) who would do much for the build up of US ballistic missile programmes.

Just one month after the formation of the Army Ballistic Missile Agency the Navy gained permission from the Joint Committee for its own research into the feasibility of ship-launched rockets with performance capability up to intercontinental range. It coincided with a directive from the Ballistic Missile Committee at the Office of the Secretary of Defence for a study of the possible use of solid propellant missiles. The following month, April 1956, the Navy gave the then Lockheed Aircraft Corporation a contract to look closely at the idea of using a nuclear powered submarine as an underwater missile launcher. The breakthrough in submarine technology that led to development of an underwater vessel that could remain submerged almost indefinitely led, in turn, to thoughts about using such a boat for strategic defence. This was a significant turning point in the submarine's role and constitutes a story in itself, but suffice it to say here that the traditional role of 'hunter-killer' was now being transformed, in concept at least, into a weapon system that would have profound repercussions on the strategy of military deterrence a decade hence.

With nuclear power-plants, the new generation of submarines would lend themselves admirably to a marriage of extreme significance. But in 1956 the problems associated with placing an albeit limited number of rockets with ICBM range, inside the traditionally confined quarters of a submarine, were daunting. It was with no little concern for its future role that the Navy eagerly awaited the results of the feasibility study from Lockheed. For their part, the Navy were convinced that the apparently insurmountable barriers standing in the way of full scale development of a nuclear submarine equipped with long range rockets would be overcome and that, when they were, the oceans of the world would become the third dimension of strategic global conflict. In the immediate post-War period few could have foreseen the day when submarines would provide an even more effective platform for ICBM systems than Army or Air Force developments. Nevertheless, the cooperation between the Army and the Navy reached significant proportions as each service worked to honour the text of the agreement set up in November 1955 for joint development of the Jupiter IRBM.

Many of the problems associated with Jupiter guidance were met and resolved by close examination of the Ship Inertial Navigation System, SINS for short. Work at the Redstone facility on guidance equipment for the Jupiter tied in with the SINS equipment already in naval use and the rocket acquired a level of sophistication which would have been denied, but for the active participation of the US Navy. By mid-1956 the Scientific Advisory Committee at the Office of the Secretary of Defence urged that the Navy concentrate solely on the problems associated with solid propellant rocket delivery systems, echoing the Navy's sentiments expressed when they obtained permission from the Joint Committee for independent work on ship-launched missiles in the March.

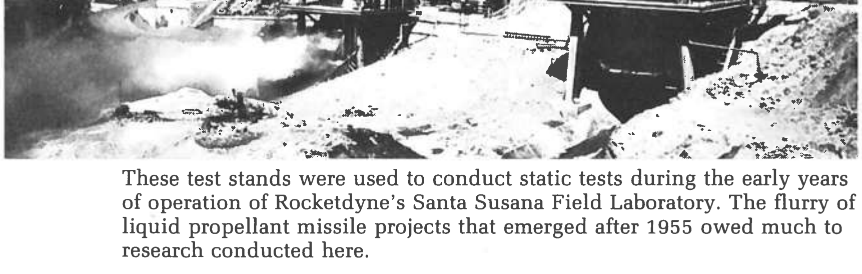
One of the two major stumbling blocks to full development of a Navy ICBM programme, was the excessive weight of nuclear warheads, which despite the improvements made in the past few years, were still too heavy to give consideration to their use on comparatively small, low thrust missiles of the type that could be carried, and fired, by a submerged submarine. Yet, earlier in 1956, the Atomic Energy Commission had prepared a Hydrogen Bomb that could be carried by a conventional aeroplane and this had been dropped from a B-52 bomber in May. By September, the AEC were confidently predicting that they would have nuclear warheads small enough to be carried by submarine launched missiles within eight years. The news of a breakthrough in nuclear technology brought by Dr. von Neumann to the Strategic Missiles Evaluation Committee in 1954, had been the single spur to full scale development of Atlas as a land based ICBM. Now, with news that the AEC could go even further with de-scaling thermonuclear bombs, a similar resurgence of interest surrounded the Navy proposal.

The second drawback to submarine missiles concerned their necessarily reduced size, but the Lockheed Corporation backed up the Navy assessment which concluded that a solid propellant design was both feasible and practicable. The writing was on the wall. Before 1955, and the shake-up brought about as a result of the Killian report, missile programmes were fragmented, developed within each service only as a result of needs expressed by either the Army, the Air Force or the Navy. In the rush to increase the technology gap between the United States and Russia, the combined services approach had gone too far. Jupiter, with its large size, its liquid propellant engine and its comparatively high weight penalty, never would be any use for the Navy. It was time to draw lines of distinction between the requirements, and the demands, of each service. Inter-service liaison would be retained only in so far as it prevented duplication, so that each service could develop the missiles it needed under the broad umbrella of total strategic requirements.

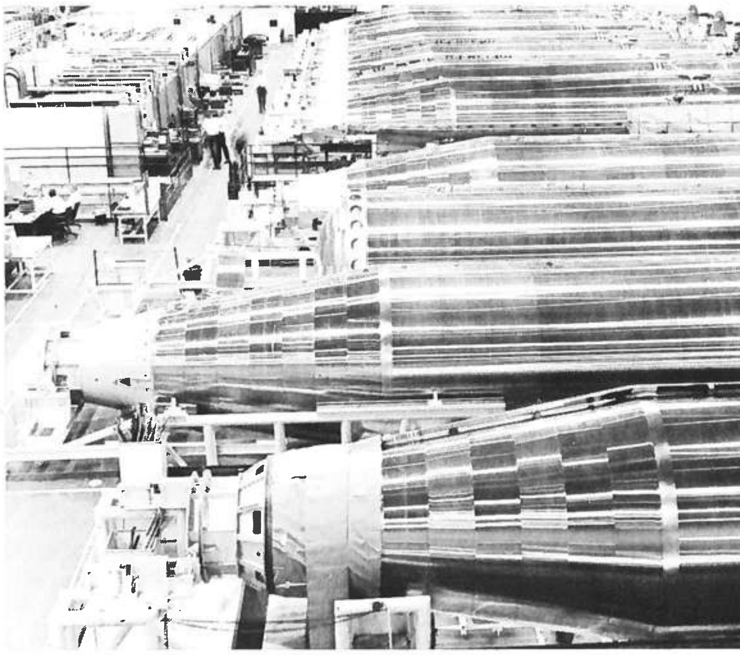
By the end of October 1956, the Scientific Advisory Committee pressed for a high priority investigation of the solid propellant missile, stressing its importance by comparing it to the important Jupiter programme. Events related to severing the restrictions on autonomous Navy missile work moved quickly. On 8 December, the Navy withdrew from the Army's Jupiter project and on 18 December the Joint Army–Navy Ballistic Missile Committee was abolished. The following day the Navy Ballistic Missile Committee was set up and the office hitherto authorized to control Navy interests in the Jupiter programme, under Rear Admiral William F. Raborn, turned its attention to the new strategies envisaged for a submarine launched solid propellant ICBM.

Shortly before this, on 26 November, the Secretary of Defence transferred development of the Jupiter IRBM to Air Force control, effectively removing all major missile projects of intermediate and intercontinental range from Army administration and funding. However, work on the Jupiter IRBM had reached an advanced stage of development and the first flight version was already nearing completion. In more respects than one the success of Jupiter, Atlas and Thor was directly attributable to the work performed by North American Aviation Incorporated to develop the liquid propellant booster engine for Navaho III. All three utilized variants of this basic motor and all variants used liquid oxygen and kerosene propellants with a theoretical specific impulse of 255.

Jupiter emerged for flight trials in 1957, as a single stage missile with cylindrical tank sections machined to a thickness of 0.1 cm with a tapered nose cone carrying the warhead. The S-3D propulsion system burned for 157 seconds and incorporated a turbopump for bringing the propellants into the combustion chamber at the rate of 277 litres per second. The gas generator, associated with the turbopump, discharged its exhaust through a swivelling nozzle which was used for fine adjustments to the speed of the missile and for control about the roll axis. In the forward section of the missile an inertial guidance system controlled the geometry of the trajectory after main engine shut down by way of a small solid propellant control motor. The entire package was developed by the ABMA and Ford Instruments so that the precise angle of the warhead could be adjusted immediately prior to its separation. From that point on the warhead would follow the pre-set course to its target, leaving the main body of the rocket to burn up in the dense layers of the atmosphere.



These test stands were used to conduct static tests during the early years of operation of Rocketdyne's Santa Susana Field Laboratory. The flurry of liquid propellant missile projects that emerged after 1955 owed much to research conducted here.



Atlas missiles in quantity production at the, now, General Dynamics, facility. Although these rockets are destined for use as space launch vehicles, the view puts emphasis on large scale production line orders placed in the late 1950s.

The first Jupiter flight came on 1 March 1957, when the missile successfully flew a distance of 96 km. Within two months it had demonstrated a range capability of 2,575 km. By this time, Jupiter was under the control of the US Air Force Strategic Air Command, having been removed from the Army aegis with whom it was conceived eighteen months before the first flight. The second missile to achieve flight status, in 1957, was the Atlas A, a development model of the SM-65, which carried only the two booster engines for propulsion. The third engine, the sustainer, would be fitted to Atlas B and subsequent models. Each LR-89 booster motor produced a thrust of 68 tonnes and the total launch thrust of 136 tonnes represented the most powerful liquid propellant assembly fitted to a ballistic missile at that time; only the Navaho III cruise missile, which had begun flight trials in November 1956, carried the more powerful cluster of three 61.2 tonne thrust booster motors, but this project was cancelled in July 1957.

The first Atlas A launch was performed on 11 June 1957. Shortly after liftoff from Cape Canaveral one of the two booster motors cut out and the missile began a series of violent manoeuvres resulting in the range safety officer having to send a command to blow the missile apart and thus prevent its wild gyrations from threatening the safety of nearby communities on the ground. Early in the development of powerful ballistic missiles, the need to rapidly terminate a 'rogue' missile had brought a requirement for explosive detonation of the propellant tanks, conceived by the premise that it was better to cause an explosion over unpopulated areas than to run the risk of it crashing to earth at random. The first Atlas flight had lasted but 60 seconds, yet the project had finally reached the hardware stage and confidence was high that the ICBM would live up to its expectations.

One of the most rapid development efforts of the period was, however, the Air Force Thor IRBM which was prepared for its first flight in January 1957, just thirteen months after the go-ahead. Thor had many features common to the Army Jupiter, it was after all a contemporary in both time and role, although its MB-3 liquid propellant rocket motor delivered a thrust of 78 tonnes versus the Jupiter's 68 tonnes and launch weight was slightly higher. In overall size, Thor was slightly longer and thinner than its Army counterpart, but both were designed for the IRBM duties stipulated late in 1955 and both had a potential range of 2,575 km with a 1.5 MT nuclear warhead. In its construction, Thor adopted the same concept of integral tanks manufactured from etched and milled aluminium with an interior 'waffle' pattern for structural stability. The first flight attempt came on 25 January 1957, but the missile rose only 15 cm and then blew up. Only the fifth flight, on 20 September, achieved the desired results and thus began a 27 month test period, before the Thor was declared fully operational.

By September a second Atlas A, again with only the two booster motors fitted, was ready on its launch pad at Cape Canaveral and again the missile ran amok and failed to fulfil its objectives. Launch Pad 14, the site of the first two Atlas shots, was getting a bad reputation. Nevertheless, the tremendous strides that had been made in the two years since 1955 had brought three missiles to the test stage: Jupiter, Atlas and Thor. It was a time for learning lessons, and for learning them quickly before the hectic pace of flight test and launch schedule repeated errors in succeeding attempts. A new technology was being forged and there were many who kept a suspicious eye on the optimistic assertions of Air Force protagonists, ever ready to seize upon failure as a justification for a less benevolent and forgiving attitude.

In many respects, Thor was seen as a scaled-down Atlas, albeit with a very different method of construction, using essentially the same propulsion system as that employed for each Atlas booster engine and designed to carry the same type of nose cone. Its rapid development phase owed much to the decade of work at Convair on the big ICBM. But if 1957 was a year in which the first generation ICBM and IRBM rockets tentatively flexed their capable muscles in the precursor flight tests leading to full scale production, it was also the year in which the US Navy defined its own ballistic missile project. Freed now from the limitations of the Joint Army–Navy Ballistic Missile Committee, and with a committee of its own to look after Navy interests, new roles were being forged that would lead to full scale development of an ocean-going ICBM capability.

On 12 January 1957, the Department of Defence approved formulation of the Polaris programme and within three months the specification for the submarine-launched ballistic missile had been laid down. By the middle of the same year the Chief of Naval Operations drew up a work and production schedule for fabrication of a new generation of submarines that would be especially designed to carry 16 Polaris missiles each. The basic mission of the Polaris programme was to provide a launch capability whereby nuclear-tipped missiles could be launched from unknown, and undetected, locations to back up the inventory of land-based ICBM's in the event of a major conflict. The sheer presence of these moving, underwater, launch platforms was thought to be a stabilizing influence in the balance of power, a formidable obstacle to nuclear blackmail from the east and one which could be used as a bargaining chip in the game of international politics.

Unlike the Atlas ICBM, Polaris would use storable solid propellants so that each missile would be in a 'ready' condition from the moment the submarine slipped its berth. Lacking the complexity of a liquid propellant motor, the submarine launched ballistic missile (SLBM) would be the ultimate answer in the never ending quest for simplicity, carrying with it an effective and deadly payload. The obvious vulnerability of a launch site on land, requires the missile to be fired before warheads from a hostile nation can reach these sensitive areas and destroy the ICBM's. By mid-1957 the first Atlas launch complex was under construction at the Vandenberg Air Force Base in California, in a system which required the missile to be backed up to the launch structure and then rotated through 90° to a vertical position. This, so-called, 'soft' launch mode was exposed to the ravages of weather and attack and a far cry from the protected environment of the submarine-launched ballistic missile of the Polaris programme. But even though Atlas was only just moving into the flight test phase, and the more conventional Titan 1 was still in the design stage, the obvious advantages of a solid propellant concept spilled over to Air Force attention as a second generation ballistic missile.

As early as 1956 the Scientific Advisory Committee had been asked to review plans developed at the Western Development Division of the ARDC (set up in July 1954 to handle Air Force ICBM work) for an intermediate range ballistic missile based on solid propellant technology. Liquid propellant ICBM's required a lengthy preparation time, the propellants could not be stored in the missiles, and the rapid-fire opportunity resulting from the use of storable propellants was too valuable an option to leave unexploited. In essence, the concept took the Polaris idea and adapted it to land application.

For two years prior to the 1956 plan, the Air Force Ballistic Missile Division had been studying the technology of solid propellant missiles and the view was hardening that the liquid propellant missile would be an effective stop-gap for the first generation ICBM's, but only a precursor to a more effective deterrent. Consequently, the Scientific Advisory Committee approved plans for contracted studies of the concept and in April 1956, the Wright Air Development Centre's Power Plant Laboratory moved ahead with analyses of the preferred configuration, based upon a growing knowledge of the chemical properties of suitable propellants.

By March 1957, the ARDC–WDD had drawn up the specification for a solid propellant IRBM. It was felt that benefits would accrue from reducing the size of the missile to a level where unit costs would be low, placing emphasis on quantity rather than lifting capacity. In this way, the big earth-shaking, multi-megatonne warheads would be assigned to the more vulnerable Atlas and Titan 1 missiles and the solid propellant design would be equipped with kiloton-equivalent re-entry vehicles, which could penetrate hostile air-space en masse. The basic simplicity of the solid propellant concept enabled costs to be kept lower than the big liquid propellant missiles and so more could be procured for a given financial sum. In any event, it was felt advantageous to swamp the enemy with a saturation blitz, rather than emphasize the more powerful warheads carried by a smaller number of ICBM delivery weapons.

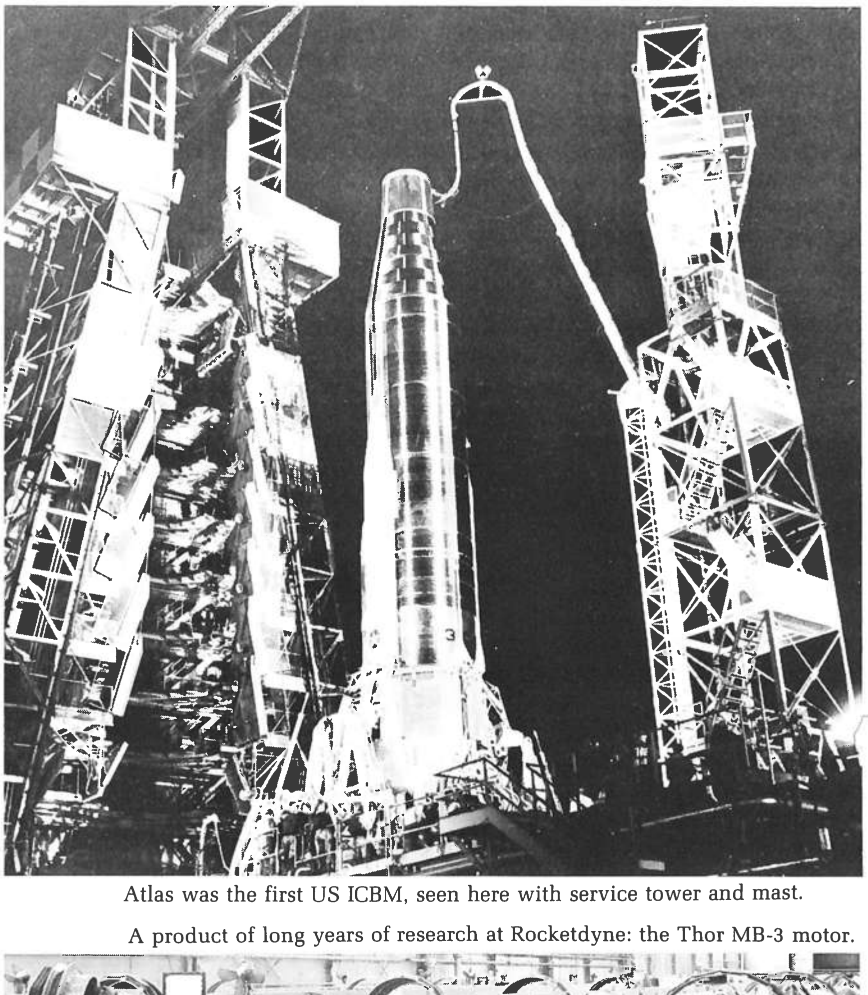
In July 1957, the Air Force settled on the final performance requirements and decided to build a solid propellant, second generation missile, with a range of 8,050 km. This was now an ICBM class project and the missile, called Minuteman (after the famous American guard that stood ready to go into action at a 'minute's' notice), was designed for launch from underground silos, so that even a close nuclear explosion would not damage the system's ability to respond. The biggest stumbling block had been removed, in theory at least. A large number of missiles held in constant readiness for attack, permanently fuelled for launch, would preserve the selective option of a retaliatory strike, even after the first wave of an incoming assault from hostile ICBM's. With Polaris carrying submarines patrolling the oceans of the world, lurking under water for months on end in undetectable locations, the effective strategy of nuclear annihilation was assured even after a pre-emptive attack from the Soviet Union.

In September 1957, Colonel Edward N. Hall headed a work group that defined the project requirements, established programme schedules and set up administrative networks to oversee the enterprise. Strategy was being defined with a clarity unknown hitherto. In 1955 the Killian report had sent Department of Defence officials scurrying through the shelves to re-open dusty files on military proposals that until this date had received little sympathy or support from Capitol Hill. By 1957, Atlas was the leading ICBM programme, Titan was coming along two years behind in development, Thor was showing its capabilities as an effective IRBM and the solid propellant Polaris and Minuteman projects were conceived as second generation weapon systems, that would hopefully propel the United States to undisputed leadership of operational missile systems.

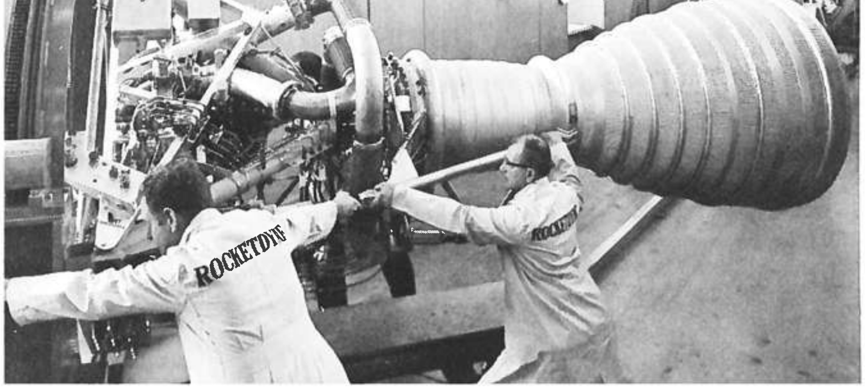
The industrial effort required to satisfy the hungry missile programme was increasing with each month. Across the United States, companies hitherto devoted almost entirely to large scale aircraft production, were setting up sophisticated laboratories and complex tooling facilities ready to secure the rewarding contracts from Federal coffers. An increasing proportion of the money allocated to rockets and missiles was going out to industry and corporate investment on the necessary facilities was insurance for the future. There seemed no end to the variety of roles and tasks envisaged for the rocket motor. Already, the Army, Navy and Air Force had coined acronyms unheard of just five years before with MRBM, IRBM and ICBM configurations signalling a new era in the eternal search for the ultimate weapon. Now, tentatively, discussions at the Pentagon broadened and a new acronym – ALBM – was heard around the corridors and halls of weapon establishments across the nation. This stood for 'air-launched ballistic missile', a concept that married the impressive bomber fleet of Strategic Air Command to a simplified solid propellant rocket.

Vulnerability, already seen to be a problem for proposed Atlas ICBM sites, had forced missile applications under ground and under sea, with programmes like Minuteman and Polaris respectively. Now, with the Air Force ever ready to integrate existing delivery systems into a new technology, discussion began on the possibility of using a giant B-52 to carry ballistic missiles to within a few hundred kilometres of the target from where they would be released for a rocket propelled flight, penetrating hostile airspace at high speed to carry a nuclear warhead to its destination. In 1957 this was only a vague idea, but it effectively broadened the spectrum of weapons capability, providing valuable time en route, during which the bomber could be called back before reaching the launch position; ICBM systems were committed within a few seconds after leaving the launch pad and gave no room for second thoughts about starting a thermonuclear holocaust. The air-launched concept would remain in the background to operational missile development for the following twenty years, as will be apparent in a later chapter.

The broadening scope for rocket engine applications, with missiles like Jupiter, Thor and Atlas demanding large scale production, had forced the prime motor supplier, North American Aviation, to set up a new division in November 1955. With the appropriate name of Rocketdyne, the group was headed by S. K. Hoffman who had responsibility to the vice-president in charge of missile operations, L. C. Waite. It has already been observed, that North American moved quickly into the field of rocket propulsion after World War II. In 1945 a nucleus of five engineers set about the task of examining the motor used by the German V-2 ballistic missile and were soon in the vanguard of studies on high performance engines. The Navaho requirements gave North American its first opportunity to add modifications to the basic V-2 motor and come up with a product that borrowed much from this German design.


Atlas was the first US ICBM, seen here with service tower and mast.

A product of long years of research at Rocketdyne: the Thor MB-3 motor.



Through the following years the company moved further away from the old technology and introduced novel features leading to successful development of the powerplants for Jupiter, Thor and Atlas. Up to 1947 test firings of experimental engines were performed at the East Lot of the Los Angeles facility, but this soon proved impracticable and the rocket motors were taken to a site in the Santa Susana mountains, 56 km away. From here the effort built in magnitude and secrecy, engines would be fired through daytime into the nocturnal hours and local residents debated the true intent of this elusive band of pioneers. Rumour abounded and even local press reports questioned the nature of the work, linking the strange flashes and the rumbling sounds with flying saucers and alien spaceships.

When Rocketdyne was formed in 1955, the facility grew in size and stature, resembling the structures beloved of science fiction writers. In the rocky moonscape of the Santa Susana area, test stands were set up in profusion and firing would start soon after dawn and last long into the night. The same problems that had faced earlier German engineers in producing not only a reliable power plant that worked, but one which could be produced in quantity, were met and overcome in the impressive California mountains. Administrative buildings were erected at nearby Canoga Park and a multishift work force grew in number, moving in van loads between test stand and research laboratory.

By 1957 more than 10,000 people were employed at Santa Susana on the motors for Jupiter, Thor, Atlas and a host of experimental projects far advanced on the military necessities of the day. The accomplishments of the Rocketdyne team had already embraced a combustion chamber delivering the unparalleled thrust of 136 tonnes, but there was little application then for such a powerful motor. Nevertheless, the technology necessary for its fabrication would stand the company in good stead a few years hence. The most urgent work centred on simplifying existing propulsion systems so that the likelihood of catastrophic failure was effectively minimized, reducing motor weight for maximum payload:mass ratio and demonstrating long duration firing sessions with, if possible, multiple re-start capability.

The demanding requirements of a production motor of the type used by Jupiter or Thor, drove Rocketdyne to exploit basic principles at the expense of sophistication and several manufacturing techniques were pioneered in an effort to reduce the number of components and increase the reliability. At the beginning of its work, Rocketdyne, then just a branch of North American Aviation, used separate propellant tanks for the fluids used in the gas generator by which the turbine would pump the main oxidizer and fuel to the combustion chamber. It fitted special oil lubricants in the turbopump mechanism and complex igniters in the gas generator and the main combustion chamber. Ingenious electrical circuits controlled pneumatic actuators attached to the main propellant flow valves and a host of redundant items ensured satisfactory operation in the event of a single component failure.

The MB-3 and SD3 engines, used in Thor and Jupiter respectively, were classic examples of the progress made towards simplification. Turbopumps were started by a simple solid propellant igniter, or by a spark plug type device which fired the gases, and propellant flow control valves were opened by discharged exhaust from the turbine, in a precise sequence known as a pressure-ladder. In this system the engine dispensed with complex pneumatic actuators and allowed the engine to move through pre-set operations once the turbopump ignited. Main combustion chamber ignition of the fuel and oxidizer brought down from the rocket's propellant tanks, was performed by a small quantity of hypergolic (contact ignition) fluid and the pump itself was lubricated by a supply of diluted fuel.

By 1957 Rocketdyne were exploring the possibility of removing the turbopump altogether by bleeding hot gases from the main combustion chamber and using these to spin the pump and drive the propellants down into the engine. Precise shut-down, essential for accurate trajectory angles, had traditionally required the use of verniers to compensate for the unpredictable thrust tail-off and this led Convair to use Bossart's idea and fit small rocket motors which could fine-tune the speed of the missile, after main engine propulsion. But Atlas was almost a generation behind the work on advanced propulsion at Rocketdyne and pyrotechnic squib igniters were used to slam shut the main oxidizer valve and thereby cut out the engine at a very precise velocity.

Thor and Jupiter profited by this development and only roll control was relegated to an exhaust duct bled from the turbine. Much of this simplification helped reduce the hitherto complex equipment needed for starting the engine and by combining many operations into a single function, the motor was cheaper to produce and more versatile in its application. Although missiles like Atlas, Thor and Jupiter were first generation rockets of their type, the engines they used were already second generation products, benefiting from several years' work on earlier designs.

The Redstone missile used a mixture of liquid oxygen and alcohol diluted with water, as the oxidizer and the fuel respectively. This had a limited specific impulse and proved less efficient than the later engines based on a mixture of liquid oxygen and kerosene. One of the main drawbacks with liquid oxygen is that its extremely low boiling point of −183°c makes it a difficult fluid to store for any appreciable length of time; the 'reaction' time of a ballistic missile is severely limited by this factor if it adopts liquid oxygen as the oxidizer, because the rocket must be filled with this liquid only minutes before launch. Rocketdyne were already thinking of substituting a storable propellant for the liquid oxygen and experimented with nitrogen tetroxide which can be kept for long periods of time, due to its high boiling point. But there were other advantages too.

The preferred fuel for nitrogen tetroxide was hydrazine and although the specific impulse theoretically obtained from this mixture was no greater than that for a liquid oxygen and kerosene combination, the density of the nitrogen tetroxide and hydrazine propellants combined was greater. This meant that a lower volume of propellant would be required for a given mass, the tanks could be smaller and the structural weight of the rocket would be reduced, thereby improving the propellant mass ratio. As for specific impulse alone (an effective measure of the efficiency of a given propellant mixture) the ideal combination was liquid oxygen and liquid hydrogen, but the extremely low density of hydrogen meant that the tank would have to be much larger than for other propellants. Moreover, liquid hydrogen boils at a temperature of −253°c and the necessary insulation required to prevent excess evaporation, compounded the existing problem of handling liquid oxygen with a boiling point of −183°c.

Nevertheless, Rocketdyne recognized the value of pressing on with basic technology, even though the military application of the liquid hydrogen and liquid oxygen engine was virtually non-existent. This energetic combination would find its niche in the demanding requirements of the space programme, where complicated ground equipment and long preparation times were less of a problem. Nevertheless, work on the liquid oxygen and kerosene engines reached a level from where Rocketdyne could match the production schedules demanded by the new military missiles. Efforts to reduce manufacturing time reached sophisticated proportions and, in one example among many, thrust chambers were fabricated from tubes brazed together and then covered with a resin and fibreglass impregnation. The brazing operation itself usually took about fifteen days, but Rocketdyne worked on a unique furnace technique which held great promise for reducing this.

By 1957, the technology of rocket engine manufacture had reached unprecedented heights and the evolutionary tree of missile development owes its initial success to the availability of research facilities and test laboratories operated by Rocketdyne. The increased flight activity associated with missiles like Jupiter, Thor and Atlas had already begun to transform the launch site – Cape Canaveral – into a precursor spaceport.

For eight years now the Eastern Test Range had been building in scope and importance – the then US President Harry S. Truman, had granted the Air Force permission to develop the facility on 11 May 1949 – and people joined rockets in the governmental and industrial migration to this Florida shore. After gaining permission from the British Government to use islands strung into the Atlantic Ocean as far as Ascension, the Air Force set up radar and tracking facilities to provide a testing range 8,000 km long. Air Force headquarters used the Naval Air Station 32 km away from Cape Canaveral as an administrative complex and promptly named it after the first chief of the Army Air Corps, Major General Mason M. Patrick. Patrick Air Force Base would continue to look after service interests on all military rocket flights.

It was in June 1950 that the first missile – a Bumper-Wac – arrived at the Eastern Test Range, under the control of Colonel Harold R. Turner, from White Sands in New Mexico. By 19 July the converted V-2 was ready for the first flight attempt, supported by a makeshift control centre in a redundant bath house with a painter's scaffolding pressed into service as an access ladder to various levels on the rocket. The initial attempt was unsuccessful, but five days later another Bumper-Wac rose majestically from the firing site to become the first liquid propellant rocket launched from Cape Canaveral. Trials with the Redstone, fabricated at the Huntsville Arsenal, bearing the same name, began in 1953 and on 20 September 1956, a Jupiter C nose cone test vehicle propelled its payload to a height of 965 km and a distance of more than 4,800 km. Another milestone was logged on 7 August the following year, when another Jupiter C fired a nose cone 2,400 km down the range; it was the first such cone recovered as precursor re-entry body to a new family of warheads scheduled for installation on operational missiles.

So it was that America put its political and military will on to the side of an expanding rocket programme, with little aim in view other than the possession, almost exclusively, of the most powerful weapons for war ever brought to fruition. Almost as an incidental side-show, the United States agreed to launch an artificial earth satellite as part of the International Geophysical Year, scheduled well in advance for the period 1957–58. In the wake of a massive effort to pull far ahead of the Soviet Union in the development of nuclear weapons, strategic delivery systems and missile technology, the United States viewed its satellite programme as a natural by-product of the rocket business.

No-one really appreciated the political prestige that would accrue from progress in the exploration of space and very few were really interested in the earth satellite project. It was just so much more icing on the cake. Public opinion in the United States had been steered to regard the armed services as unchallenged, unbeatable and possessing the best and most advanced equipment anywhere. Just twelve years after victory in Europe and the Pacific the American public were confident of their nation's unparalleled strength and, with the United States playing an increasing part in policing the world's trouble-spots, there was a growing awareness of strategic capability. With big bombers and big budgets, America, it seemed, could out-gun anybody, including the Russians.

But if the public had been influenced by the expert public affairs officers, the reality of the situation was already apparent to the few Pentagon officials who knew of the existence of a Soviet missile programme. This fact was brought fully into the open when, on 4 October 1957, Russian news agencies announced the launch and successful orbiting of Sputnik 1, a small satellite weighing 83.5 kg. Less than a month later, on 3 November, Sputnik 2 was sent into orbit with a weight of 508.5 kg. Inside, a dog called Laika became the first living animal to orbit the earth. It had been done. Not only had the Russians succeeded in sending the world's first artificial satellite into space; they had performed an engineering feat that was the single most effective demonstration of Soviet resolve to be a leading power. No other events had accomplished this as satisfactorily as Sputnik 1 and Sputnik 2. Within just a matter of weeks the United States had been made to realize how effectively a space programme would be in advertising national prestige. The 'cold war' between east and west had entered a new chapter in international affairs. From now on the two great super-powers would perform, as if on a stage, while the world watched and kept score. The price was high, and to come second in the game was to come last in the race.

Russian Challenge

Sergei P. Korolev (1906–1966). Schooled in the theories of Tsiolkovsky, he was a brilliant engineer serving aeronautics and rocket vehicle design from 1930 until his sudden death more than three decades later.

The development of the Soviet rocket programme in the years following World War II is shrouded in the secrecy that still prevails over military research programmes. In a society unified by a single-minded philosophy, where conflicting political and social ideals are considered to be a threat to the system, free discussion of technology and the evolution of a weapon system is all but moribund. It is a sad aspect of the prevailing situation that the country that has done more than most to pioneer the dawn of space exploration, considers it necessary to veil the origins of its engineering accomplishments. The Soviet rocket programme has been consistently associated with the requirements of national defence and for that reason alone the steps leading to the launch of Sputnik 1 are only loosely identified with fact. Nevertheless, the framework of the story is present if not all the details.

When the Soviet 19th Army moved in to the German rocket research facility at Peenemunde, they found the place empty of all the technicians, equipment and documents that were expected to be captured intact. They had received little immediate intelligence of the hasty move (in February 1945) to the Harz Mountains, but the place soon told its own story. Back in the Soviet Union, leading Russian aircraft and rocket engineers were preparing to visit Peenemunde, so that they could learn as much as possible about the successful developments that had given Germany the world's first ballistic missile: the V-2. One of those concerned with the progress achieved by the enemy, was Dr. Gregory A. Tokaty. Seeking refuge in Great Britain three years after the war, he would provide many of the details about Soviet rocket research in the period up to his voluntary move.

Tokaty was born in 1910, went to the Workers' Facility at the Leningrad Mining Academy, the Moscow Higher Technical College and from there to the Zhukovsky Soviet Air Force Academy in June 1932. A year later, Tokaty met Konstantin Tsiolkovsky and began a life-long enthusiasm for rocket research. During the war he worked on the development of several notable Russian aircraft and by 1945 was conducting tutorial work on aeronautics and the theory of rocket propulsion, including jet reaction. It was at the Zhukovsky Academy that Tokaty learned of the evacuation from Peenemunde that left the place virtually in ruins by the time the Soviet Army arrived. The first order of business was to isolate the facility and place a guard upon its shattered buildings so that Russian engineers would be able to piece together the story of its activity from the remaining equipment.

In June 1945 the first contingent of Soviet experts arrived at Peenemunde, Tokaty among them, under the authority of Zhukov and Sokolovsky, both Marshals of the Soviet Union. Tokaty recalls how shocked he was at the chaos caused by bombing raids on the research facility and by the total lack of any real evidence as to what had been going on in its many laboratories and buildings. Nevertheless, the team soon pieced together the purpose of several structures and partially re-opened the laboratories.

Before long, the Army collected some 3,500 personnel directly and indirectly involved with Peenemunde and although almost all the leading figures had gone over to the US forces, the Russians were able to gain the services of Helmut Grottrup, an engineer who had unique experience with the V-2 control electronics. Grottrup had elected to abandon his fate to the Soviet armed forces, the leader of a dissident group who saw little advantage in following Wernher von Braun across to the United States' Army. At the Nordhausen-Bleicherode area, where V-2 production facilities had been set up, the Russians found a more favourable situation. The American forces had removed much of the valuable equipment, but sufficient remained to form the basis of a full scale investigation of German progress. Of all the people rounded up by the Russians, Grottrup and some two hundred associates were the only truly knowledgeable technicians involved in the V-2 work and these formed the nucleus of Institut fur Raketenbetrieb Bleicherode, set up by the Red Army to conduct a post mortem.

Tokaty, by now Chief Rocket Scientist of the USSR in Germany, was convinced that what the Germans had achieved was more of a break-through in the production plants than anything especially significant in rocket technology; the Soviet Union, he mused, was not very far behind the V-2 design concept and would rapidly exploit innovative ideas in its own rocket programme. Moreover, it was possible to forecast likely stages of development by the United States, since Russia had acquired information about the advanced ideas put forward by von Braun. Before long the Russians had 'recruited' labour from the area of Nordhausen and began the tedious job of putting the Mittelwerke plant back into operation as a V-2 production facility.

On into 1946 the work force toiled. Every piece of information and practical experience that could be extracted from the Germans, was carefully noted and fed back to the Soviet Union. Later that year Tokaty summarized the situation thus: 'As we all know, immediately after the Potsdam Conference we gave to our Allies sectors in Berlin. They, in turn, allowed us to extend our zone of occupation to its present boundaries. Of course, the Americans and British first removed all they considered valuable to them. Trains loaded with aircraft, rocket and other equipment were leaving for the British and American zones from Dessau, Bleicherode, Nordhausen, Magdeburg, Jena and other places just before we arrived. Nevertheless, here we were more fortunate than in Peenemunde. Somehow, our men have managed to get hold of interesting objects, including several complete V-2 rockets. They have found very interesting scientific papers. But, again, not a single significant rocket specialist!

'There is, however, no ground for pessimism. What we really need is practical experience; and there are in our zone at least hundreds of ordinary technicians and workers, who will help us in one way or another. As to the loss of Dr. Wernher von Braun and his men, let me tell you that it will soon be adequately compensated by our own designers and theoreticians. We have the free or compelled cooperation of hundreds of German workers, technicians and second-rate scientists, whose experience could be of value to us. In the circumstances, I think the best thing to do is to organize all these into a group, in Peenemunde, to give it a set task, and to find out what it can do for us here in Germany.'

The last sentence refers to an already growing divergence of opinion about the location and fate of the German engineers, if not the work force, who were now demonstrating to the Russians the methods they used for large scale V-2 production. On the one hand a respectable body of opinion preferred to see the Germans remain in situ, with the details they could provide fed back to the Soviet Union, while on the other, several influential members of the Soviet political faction, among them Marshal L. P. Beria and Colonel General I. A. Serov, of the security force, wished to bring the work force back to Mother Russia under the umbrella of Party restrictions. Those opposing the move pointed out that although the Germans had much to teach the Russian rocket engineers, the whole idea of using V-2 technocrats was becoming something of an obsession which could lead to a void between existing knowledge, which had been brought to an effective halt by the end of World War II, and the demands of a new missile technology which would be necessary for future developments.

The Russian rocket engineers had made steady progress since the decade of the 1930's and already the leading figures in post-war Soviet missile technology were emerging. Glushko was recognized as an expert on liquid propellant motors and his contributions have been documented in an earlier chapter. Sergei P. Korolev, by now closely associated with analysis of the V-2, was one of those who would have preferred to keep the German workers at Peenemunde and already had ideas for a Soviet liquid propellant ballistic rocket. Pobedonostev too, was eager to embrace the technology of the V-2, but had independent ideas for a Russian missile. Despite the conflict of opinion over the fate of the German engineers, the security forces won the day and plans were laid to bring them to the Soviet Union.

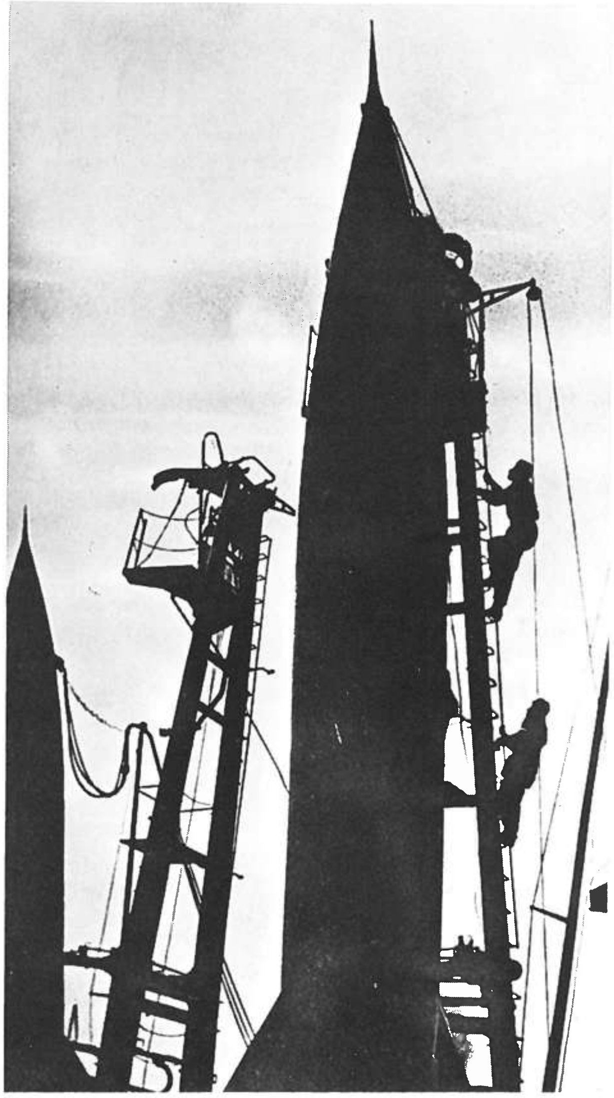
There was no question here of inviting the ex-V-2 people to work for the Soviet government under contract, no freedom of participation in Russia's missile programme similar to offers extended to the von Braun cadre by the United States. Suddenly, and without warning, Grottrup's men were told to pack their belongings and go with the security men for a trip lasting several days. They journeyed through war-torn Poland, uncertain as to their destination. Finally, the group arrived on the outskirts of Moscow, in a district known as Mytischi-Tchkalovskaya-Monino where most of the laboratories and test facilities for Soviet weapons development was located. It was 22 October 1946, and the German workers had been brought 2,000 km to the heart of a nation that, just eighteen months earlier, had battered the life out of the Third Reich. Feeling ran high against the immigrants; many opposed the ideas of accepting responsibility for people from a nation that had slaughtered more than twenty million Russians. Eventually the German engineers were moved to a small island, called Gorodomlya, in the middle of Lake Seliger more than 300 km north-west of Moscow. Around the lake, 45 km long and 20 km wide, lived simple Russian people who had experienced some of the worst fighting of the war. Feelings ran high and the teutonic work force was obliged to take care with their movements in the area, a more sure form of security than any other!

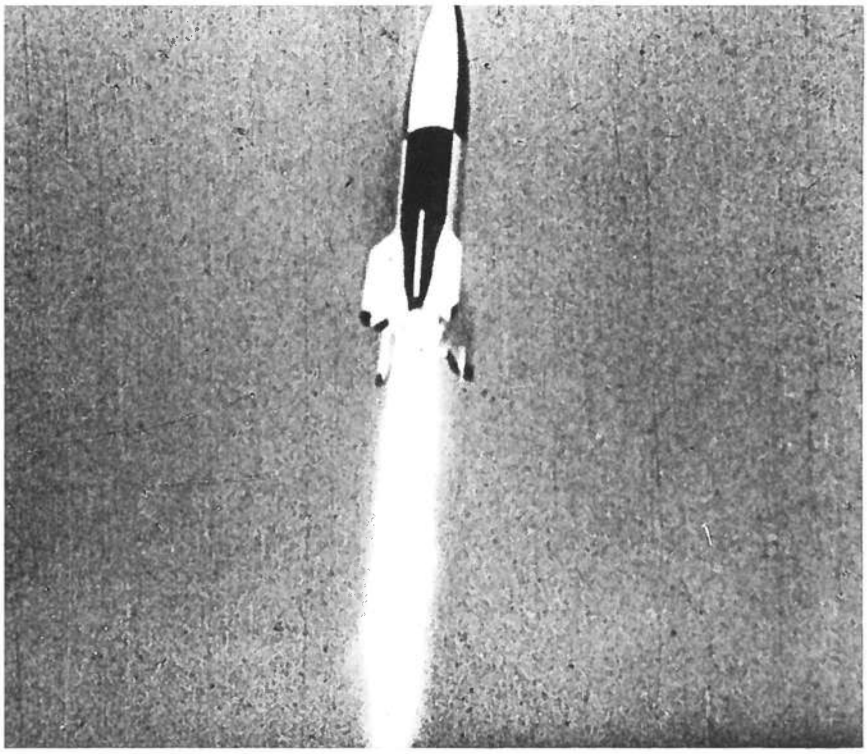
Soon, the team was busy working on a project to upgrade the performance of the V-2, indeed they had been moving toward refinement of the basic missile for several months, and the activity was coordinated under the capable direction of Yu. A. Pobedonostsev. It was essentially an attempt to provide the Soviet Union with a ballistic missile of its own, but one, nevertheless, which was based on German technology. This effort was organized under the project designation R-10, but many leading Russian engineers still preferred to strike out independently of the V-2 people. Careful examination of the V-2 design revealed a commonality of theoretical approach (the Russians had themselves anticipated many of the design concepts brought to fruition at Peenemunde) although it was generally accepted that the German production techniques provided many lessons for further exploitation. Separate from the Gorodomlya team, Russian engineers began to evolve a 'stretched' version of the basic V-2, under the designation R-14, or Pobeda (Victory). It had been instigated by a State Commission in March 1947, which sought to clarify the potential application of rocket technology to the needs of Soviet defence forces.

Russia had learned much from the terrible punishment suffered at the hands of the German Army. One of the reasons for Russia's lack of success in repulsing the enemy during the first eighteen months of war, lay in her reliance on ground forces. Battles had to be fought in a front-line conflict and the Russians had little or no capability for striking deep at the heart of Germany or, indeed, at the lines of supply that fuelled the spearhead units. It had been a war in which bloody encounter was the only means of engaging the enemy and owing to this fact, the Soviet armed forces had lost more men than any other nation throughout World War II. In evaluating the situation during 1946 and 1947, Soviet Marshals recognized the need to equip their forces with a long range strategic capability and the rocket seemed the most assured way of striking hard across intercontinental distances. It was not at that time known which direction rocket technology would take and the Soviet research had been prevented from exploiting the theoretical knowledge gained through several years of effort until now. It was apparent, however, that Soviet military needs would only be adequately met by a rocket of much greater potential than the V-2.

Tokaty recalls the words of Georgi M. Malenkov, Stalin's trusted lieutenant, when he addressed this issue in 1947: 'We have improved it (the V-2), we have more than reached the Peenemunde level of 1945, but, even so, it remains a blind, short-range, primitive weapon. Who, do you think, can we frighten with it? Poland? Turkey? But we are not going to frighten Poland. Our potential enemy is thousands of kilometres away. We must work on the development of long-range rockets. The importance of Sanger's project (see Chapter Six) must be seen in the fact that it can fly very long distances. And we certainly cannot wait until the Americans add Sanger's rocket-plane to their B-29 and Atom Bomb (see Chapter Seven).' The Russians were certainly very aware of the technology that had simply 'walked' across to the United States and the uncertainty as to western objectives cut deep into Soviet thinking on the whole issue of strategic arms.

Modifications made to captured German V-2 rockets provided the Soviet rocket engineers with valuable information about developments at Peenemunde and afforded opportunity for testing new ideas.





The launch of a captured V-2 conducted by Soviet engineers. The first such flight was performed on 30 October 1947.

Kruschev would write later, 'America was conducting its foreign policy from a position of strength. The Americans had the Atomic Bomb, and they knew we didn't. For the Atomic Bomb to be in our enemy's hands was bad enough. To make matters worse, the President at that time was Truman, who had neither an ounce of statesmanship nor a flexible mind and who was hostile and spiteful toward the Soviet Union.... The American 'flying fortress' (B-17) and 'super-fortress' (B-29) had played a big part in winning the war against Germany and Japan, and they were still unmatched by any other planes in the world. I would even say that America was invincible, and the Americans flaunted this fact by sending their planes all over Europe, violating borders and even flying over the territory of the Soviet Union itself, not to mention a country like Czechoslovakia.'

Russia consistently maintained the need for a massive land army capable of repulsing an attack from western Europe, but the intercontinental nature of America's big bomber fleet brought about reciprocal development of a Soviet capability. If Kruschev was fearful of the American Atomic Bomb, he was well aware of Russian attempts to enter the nuclear age. As early as 1942 the Soviet Union was working to perfect an Atomic Bomb of its own and nuclear reactors were in working operation by the end of 1946. Under Stalin, the Soviet armed forces were seen to require a new approach to defensive strategy, one in which the ability to strike first at the potential enemy's home-based army and air force was given priority. A cursory examination of the American bomber fleet has been given in Chapter Seven and there is little doubt that the enormous problems faced by the Soviet Air Force in developing a strategy for long range bombardment led to early acceptance of the ballistic missile as a counter to the advantageous strike capability possessed by the United States.

In 1947 the policy was laid down whereby Russia would move without respite toward production of the Atomic Bomb and, simultaneously, develop the necessary delivery system for its effective application as an instrument of war. Meanwhile, work on the Russian version of the V-2, the Pobeda, continued apace with a promised range capability of more than 900 km, while the German work force pressed ahead with their own variant of the basic V-2, the R-10. The first launch of a V-2 from Russian soil came on 30 October 1947, under the direction of Sergei Korolev. It was fired from the steppes of Kazakhstan, about 200 km from the old city of Stalingrad, across a distance of some 300 km. Two weeks later a second V-2 was launched, but the attempt ended in disaster when the rocket ran amok only 150 metres above the ground, due to a problem in the control system. The launch site would later become famous for flights into space and achieve world fame as the Kapustin Yar façility. In other areas of rocket technology the Soviet engineers pressed ahead with engines designed during the war years at the GDL-OKB.

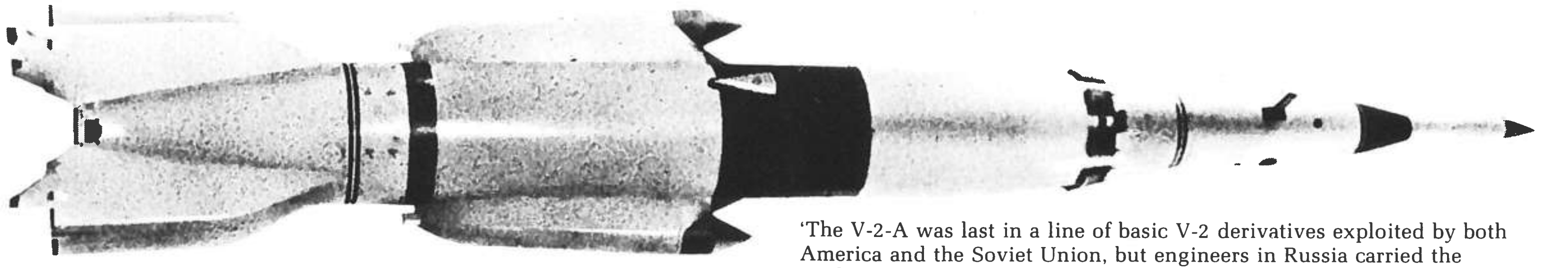
On 18 August 1946, the Lavochkin 120R single seat aeroplane took part in the fly-past at Tushino airport, equipped with the RD-1X3 rocket motor in the tail, thus becoming the first rocket-equipped aircraft to receive public demonstration. With a thrust of 300 kg, the motor was only one of the RD series developed from 1942 and put into quantity production in 1945. The Flight Test Institute reported that, 'The RD-1X3 engine can reliably be started at both starting and maximum thrust. The transfer from the starting to the operating duty is quiet. The combustion in the chamber of the RD-1X3 proceeds smoothly both at starting and in normal operation. The engine is simple to start up, control in operation, and shut down; the light indicators of engine operation are informative and convenient.' Although continued work at the GDL-OKB had been disrupted because of the necessary emphasis on restoring civil and social programmes at the end of the war, the RD series formed the basis for much of the work that led to the first Soviet ballistic rockets.

By the end of 1946 Academician, M. V. Keldysh, had been appointed head of the RNII (see Chapter Five) and activity here and at the GDL centred on the 100 series RD motors. The first of these, the RD-100 itself, was being developed for a liquid propellant rocket that could be used for military duties and double as a geophysical sounding probe into the upper atmosphere. Sergei Korolev gives a vivid account of the interest expressed by Stalin in the evolving technology, with not unmindful attention to the military capabilities of any new missile: 'At first he listened in silence, practically without taking the pipe out of his mouth. As he got more interested he began to interrupt now and then with terse questions. You felt he had a grasp of what rockets were about. He wanted to know about speed, distance, altitude of flight and payload. He was particularly concerned about accuracy of delivery. Outwardly, Stalin was restrained. I didn't know whether he approved of what I was saying or didn't, but that meeting played a positive role. Obviously, it had become clear to Stalin and his military advisers that the first experiments in building jet aircraft and rocket systems would have far reaching consequences. . .'

Now, at last, Soviet rocket experts were marshalling their resources again for an independent attack on the basic problems of large scale rocket programmes, quite apart from the German team who had been relegated to a supporting role. Working to perfect the RD-100, and a new more powerful motor similar to that employed by the V-2 and known as the RD-101, the GDL-OKB prepared the first truly Soviet sounding rocket in 1948. It is known by the English designation MR-1 (for Meteorological Rocket One) and was about 9 metres tall, with a diameter of 52 cm and a launch weight of 1 tonne. It would prove capable of lifting a payload weighing 112 kg to a height of 100 km. It was designed and built not as a purely military rocket, but one which would serve to stimulate the development of technology deemed necessary for future missiles and one which could simultaneously find application as a pure research tool for atmospheric physics.

The first flight was performed from Kazakhstan and Professor A. Kosmodemyansky remembers the incident with nostalgia: 'The first ballistic rockets created under the guidance of Korolev were embodied in metal in the first half of 1948 and in the autumn the firing trials began. Within two or three seconds of being switched on, the engine developed full power and the rocket gently and easily detached itself from the launching pad, flew for 70–80 metres straight up and then, gathering ever greater speed, 'lay' on course. The very first flight was successful. Korolev's closest assistants couldn't contain their excitement and started tossing him high up in the air. That clear autumn day in the steppes is engraved in my memory.' Three decades after that event, there is, today, a monument to this and later flights from the same site. The future course of Soviet rocket development was being mapped out by political incursions to what was, after all, a technical issue.

The first move to set up a valid design concept for a long range missile had been made when the military chiefs at the Kremlin decided to structure their requirements around the potential enemy across the Atlantic ('What we really need are



'The V-2-A was last in a line of basic V-2 derivatives exploited by both America and the Soviet Union, but engineers in Russia carried the application of this German-designed missile far beyond anything accomplished elsewhere.'

long range rockets of great reliability, capable of hitting targets on the American continent', said Marshal Zhigarev, Commander in Chief of the Soviet Air Force). This had been recognized in 1946 and on 15 March, the following year, Marshal Stalin addressed the Soviet Council of Ministers and pointed to the successful production facilities for the German V-2 and to the work of Dr. Eugene Sanger and his 'antipodal bomber' project. Clearly, this winged missile caught Stalin's imagination and, in the general atmosphere of increasing preoccupation with technical solutions, Russia was moving toward acceptance of the inevitable developments that led to the first intercontinental missiles. Up to this time the Soviet rocket research was too fragmented to present a consolidated front, but 15 March was the turning point.

Almost immediately the State Commission for long range rockets was set up, with Colonel General I. A. Serov, Professor Tokaty, Professor Keldysh, Professor Kishkin and Major General V. I. Stalin as initial members. With a considerable wealth of information on Sanger's orbital bomber already on hand, it was felt that the Viennese engineer should be brought to the Soviet Union and put to work on further developments. Accordingly, in August 1947, Professor Tokaty went to Germany in the hope of finding Sanger and bringing him to Moscow. The mission failed because Sanger was already in France. When Tokaty returned to the Soviet Union a new wave of change was already gathering force. Before the end of 1947 many of the Russian rocket engineers were arrested and put in prison and others, Tokaty among them, fled to the west. Within six months the Grotrupp team had been moved to Lake Seliger and their contribution became less effective. It was at this point that the R-14 Pobeda emerged as a more promising project over the R-10 and although the German team were directly responsible for stimulating Russian initiatives, they were deliberately excluded from its continued development.

During 1948 Grottrup's work was increasingly isolated from contemporary research performed by the Russians themselves; five years later the German team returned to their homeland and the association with Soviet developments was brought to an effective halt. In the period 1947–49 the Soviet rocket engineers developed several important sounding rockets which they would continue to use well into the 1950's and from the technology stimulated by such work, were able to move quickly ahead with the design of a large number of military missiles. The most successful adaptation of the V-2 followed conceptual lines similar to those which led to the Bumper-Wac configuration in the United States (see page 234) and Russian attempts to improve the performance of this ballistic missile paralleled those under way at the same time in America. Where the Russians possessed a decided advantage, however, was in the modifications they made to the basic engine developed at Peenemunde.

Using the so-called RD-101, the Russian engineers fabricated a sounding rocket known as the V-2-A and this would provide a performance capability in excess of any other V-2 derivative. The first flight was carried out in 1949 and the rocket could carry a variety of instrumented packages in the nose and strapped to the sides of the cylindrical tank section. For a while, intelligence experts in the west favoured the view that these external appendages were supplementary boost motors, but the V-2-A was strictly a 'geophysical' rocket and the additional 'boosters' were nothing more sinister than recoverable experiment pods. The V-2-A was last in a line of basic V-2 derivatives exploited by both America and the Soviet Union, but engineers in Russia carried the application of this German-designed missile far beyond anything accomplished elsewhere. In its developed form, the V-2-A was 20 metres tall, 1.66 metres in diameter and could carry a payload of 2.2 tonnes of which 860 kg was given over to scientific instrumentation, designed to explore many aspects of the physics of the upper atmosphere. At other times the rocket was used to conduct biological experiments and to carry various animals to high altitude where, after separation from the main body of the projectile, the payload would experience a few minutes weightlessness before plunging back into the dense layers of the atmosphere. The safe recovery of these biological payloads was inconsistent. In this way flights could be performed to a maximum altitude of 212 km and the V-2-A found extensive use as a scientific research tool, a valuable follow-on to the MR-1 which had a capability of taking 112 kg to a height of 100 km.

By the early 1950's rocket research, totally divorced now from any association with the two hundred or so members of the Grottrup team brought from Germany in 1946, began to develop a character in keeping with the overall objectives of the plan laid down by Stalin's State Commission. Research into high thrust engines was pointing to the day when a missile of intercontinental capability would be both feasible and practicable and one of the important milestones on the road to achieving this, was a series of short and medium range missiles placed in development during the final years of Stalin's life. As early as 1947 the Russians had deployed a small number of short range ballistic missiles, for use as tactical weapons, which today are known by the NATO codes SS-1 (Scunner) and SS-2 (Sibling). In essence, Scunner was a re-worked V-2 and used little in the way of innovative modification that was to characterize the Sibling descendants. This failed to appear in any large number, however, and both SS-1 and SS-2 represented maximum exploitation of extant technology, developed by the Germans. The relationship of SS-2 to the V-2-A is apparent in pictures of the rocket and highlights the dual nature of the development; Russian technology consistently tends to use a common design for multifarious roles, whereas several different designs are more frequently found to exist in western objectives.

When Stalin died in 1953, work was already well advanced on the RD-103 rocket motor at the GDL-OKB. Studies of the preferred chemistry for high performance motors had already indicated the need to switch from the alcohol used in the German V-2 to kerosene fuels mixed with liquid oxygen. The RD-103 had been in development for three years and although it borrowed much from the technology of the V-2 engine it was to prove the first wholly Soviet-developed motor to find application as a liquid propellant engine for military application. With a thrust of 35 tonnes, the RD-103 was the first major post-war creation of the GDL. It adopted the liquid oxygen/kerosene propellant combination and became precursor to a family of rocket motors that would emerge over the following decade. A suitable missile specification for the RD-103 was prepared between 1950 and 1953 and the medium range ballistic rocket that was to emerge, became known as the SS-3, or Shyster.

Between 1953 and 1955, the year that Shyster entered operational service, the philosophy of Soviet military strategy went through a change, brought about principally by the beliefs of Georgi Malenkov, who was both First Secretary of the Communist Party and Premier for the first few months after Stalin's death. It was the beginning of a transformation in post-Leninist doctrine whereby the inherent belief in an all-out struggle, leading in the most extreme of circumstances to global conflict, was gradually replaced by a reasoned philosophy that said that communism would achieve world unity of the working classes by peaceful co-existence with potentially hostile states until such time as the lower classes themselves could achieve freedom from capitalist bondage. It is important here to recognize the emphasis continually placed, since the days of Lenin, on the effective strength of a military liaison with political ideals. The armed forces and the state were seen as an inseparable bond working together in the cause of leftist dogma and it was a revolution of thought and concept to relegate the struggle to the internal politics of foreign nations.

Malenkov argued that in a nuclear age the 'all-out' struggle must be confined to civil change without military intervention and as such he was the vanguard of a more moderate and civilized line of communist expansion in the world at large. He was, perhaps, a couple of decades in advance of the Party line which continued to maintain that the Soviet Union would be increasingly challenged in the years ahead, by the threat of total war resulting from long range delivery systems carrying nuclear warheads. In the Stalin era, a period lasting nearly thirty years, Russia had experienced a devastating assault from fascist forces which had left the country wounded and bleeding at a time when social and civil change was gradually transforming the Soviet Union into a major world power. Opponents of the Malenkov view pressed for continued, even accelerated, development of a strategic missile capability so that the armed forces could protect the interests of the Party, and, presumably, the solidarity of the homeland, by conducting a pre-emptive strike at potentially hostile states. This implied that the Soviet Union would be prepared to go to war, by launching an all-out attack, if it felt its security threatened by the actions of another country. It was a disturbingly hostile attitude, a hard-line philosophy that sadly took little account of the interests of foreign peoples.

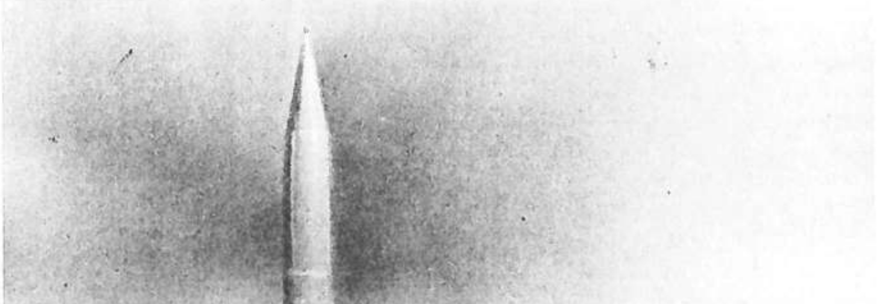
By February 1955, Malenkov was ousted from power by Party preference for the Bulganin–Kruschev view that favoured a stronger Russia with emphasis on military supremacy. The hard line attitude would moderate two decades later in favour of Malenkov's view that total destruction of civilization as a result of all-out nuclear war could be made to imbue a sense of deterrence through mutually assured annihilation.

However, the year of Malenkov's decline, saw the service introduction of the Shyster medium range ballistic missile. It is remarkable how similar this weapon was to the American Redstone rocket of the same period. It can be said that the Russians were first in the field with a medium range missile since development of the propulsion system, the RD-103, began as early as 1952, the very year that Redstone was authorized at the Huntsville Arsenal. When Shyster emerged in 1955, it had programme and structural characteristics almost identical to those of the Redstone: both missiles performed their first flights in 1953, both used a propulsion system developing a thrust of 35 tonnes and both were designed to a specification requiring a range of about 800 km. However, as observed earlier, Shyster had the more efficient combination of liquid oxygen and kerosene (versus the Redstone's liquid oxygen and alcohol) propellants and Shyster was the first to be deployed operationally; the world's first MRBM of the post-war period. In the current classification of short-, medium and long-range performance values, the German V-2 can be said to have been a short-range weapon.

Both Redstone and Shyster adopted similar methods of flight control, in that each had four triangular fins grouped at the base of the missile for stability and four movable control surfaces, one on each fin, together with four vanes placed in the exhaust efflux of the motor. As an operational missile, Shyster had a length of 21 metres, compared to Redstone's 19.2 metres, with a diameter of 1.7 metres, almost identical to that of its American contemporary. It could carry either nuclear or conventional warheads and was guided to its target by radio commands, a very potent weapon for its day and one of the emerging series of Soviet missiles that triggered reciprocal gestures on the part of the United States government during the Killian hearings discussed in Chapter Seven. It will be remembered that Jupiter, Thor, Polaris and Titan were authorized as a direct result of intelligence reports on Russian missile developments and that Atlas was accelerated on the evidence of Soviet flight tests. From the careful examination of sequential developments it is possible to affirm that the Soviet Union has been in the vanguard of missile operations, if not technology, since 1955. But just as the American first-generation MRBM – Redstone – was later to find application as a research tool for space operations, so too did the Russians use their own MRBM – Shyster – as a geophysical rocket and probe for upper atmosphere physics.

By 1954–55, the Shyster was being used to carry a payload weighing 1.3 tonnes to a maximum height of 512 km in a similar role to that performed by the V-2-A. Known in this guise as the V-5-V, the liquid propellant rocket carried many scientific instruments on several hundred research flights over the following years. Most of the experimental flights of this nature originated from the Kapustin Yar facility, the same area which, in 1947, was used for the first Russian launched

The nose cone of the V-2-A was used to carry scientific payloads for research into upper atmosphere physics. The petal flaps at the base serve as drag brakes to reduce speed prior to parachute deployment and recovery.



A contemporary of the US Redstone missile, this SS-3 Shyster was a medium range weapon using the RD-103 rocket motor and liquid propellants.

V-2 flight. Kapustin Yar was coming into increasing use now as a military test centre and would support several new missiles developed during the 1950's.

With some measure of truth it can be said that the Stalin era had provided the framework within which rocket development in the post-1953 period would mature and prosper, although several historians have credited Kruschev with setting in motion the expanding goals of the major rocket programmes that came to fruition under his leadership. Despite the fact that Scunner and Sibling, little more than re-worked V-2 missiles, were operational before Stalin's death in 1953, it was Shyster that represented the first fruitful product of an indigenous Soviet policy, deliberately structured by the State Commission, which Stalin had been instrumental in establishing. But the objectives of the Soviet missile programme did not stop at the limited capabilities of a medium range ballistic weapon. By 1954 the GDL were working on the development of two separate propulsion systems which would be employed by the Soviet Union's first intercontinental ballistic missile.

Whereas policy in America had stayed the design hand of rocket engineers until progress with the development of nuclear warheads reduced their size to a level which could be accommodated on comparatively small missiles, Russian plans were directed toward matching the required payload capability with a rocket large enough to carry the heavy warhead. This was the reverse of US philosophy. Atlas and Titan were kept waiting on the shelves of contractor industries until the 'breakthrough' in miniaturized warhead technology made them viable delivery systems. The first Soviet Atom Bomb had been detonated in August 1949, followed in 1953 by the first Hydrogen Bomb – dropped from an aeroplane – and it was with this bulky first-generation thermonuclear weapon technology, that the Russians moved ahead. Plans were laid to take the bull by the horns and size the missile to the dimensions necessary for carrying it across intercontinental distances.

There was no let up, no deliberate waiting around for the promised day when nuclear warheads would be small enough to put on medium size rockets. But the Russians were only too aware of the size that such an ICBM would have to be and were far from ready to move ahead with a rocket motor of necessary thrust to power the missile. A compromise was sought – and found. Instead of designing a rocket motor with a single combustion chamber of the stipulated thrust, a comparatively low-thrust motor would be developed, which could be used in clusters to power the big ICBM. But the performance requirement of the assembled missile would demand an unnecessarily large stage design and this augured well for a multi-stage approach, with two stages at least in tandem. So far, the Soviet engineers had used only single-stage designs and the problems that faced Karel Bossart at Convair in 1946, now set a potential obstacle for the Russians.

With no experience in the, then, complex process of igniting an upper stage within seconds of first stage shut-down, the missile would forge new and uncharted paths which could, conceivably, work to the detriment of reliability. Reliability was a prerequisite for missiles aimed at providing strategic defence. Already, the ICBM was seen to require a structure several times the size of anything yet built and to further complicate the issue by introducing a multi-stage design was stretching credibility too far. Sergei Korolev, already one of the leading figures in Soviet rocketry, headed the team that would design the big intercontinental missile and before long they adopted yet another compromise to satisfy the objective. It would, thought Korolev, be simpler to build a main rocket stage with its own propulsion system – the sustainer – and attach to it four boosters, each with their own clustered rocket motors, which could be jettisoned during the ascent.

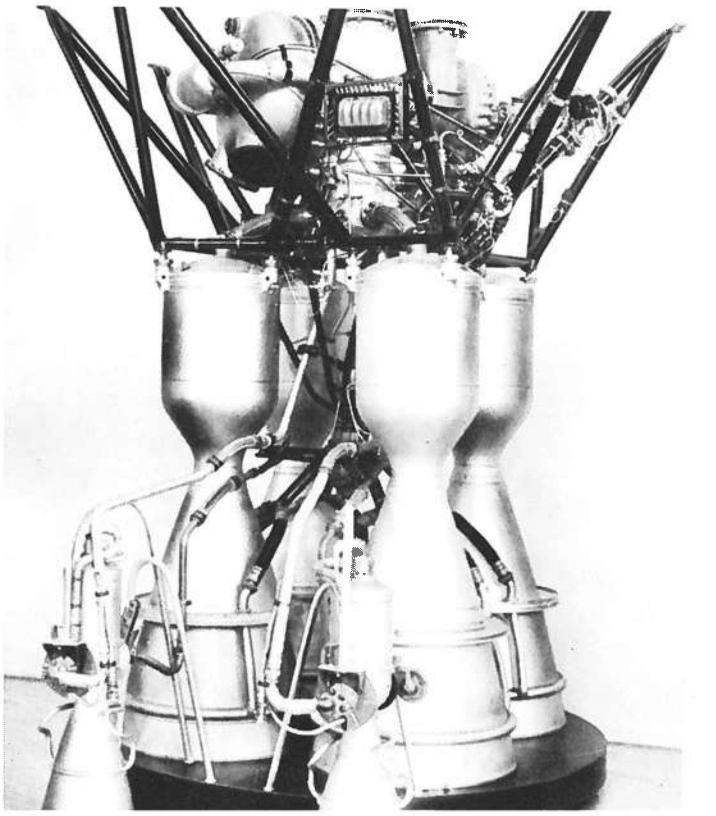
This was a variation on the concept pioneered by Bossart when he gave the American Atlas ICBM two separate booster motors in addition to the central sustainer. Korolev's solution provided separate propellant tanks for each booster, Bossart's on the other hand used the same propellant tanks for both sustainer and boosters. Again, as with Redstone and Shyster, similar problems of design were being met by parallel solutions in the race for missile supremacy. The Soviet ICBM would escape the problems of complicated 'staging' operations in similar fashion to the American missile; with boosters and sustainers ignited on the ground there would be no need for complex autonomous command sequences once the assembly left the launch pad. In support of the propulsive requirements for the Russian ICBM, the GDL-OKB moved ahead with development of the RD-107 and RD-108 rocket engines.

The RD-108 would employ four main combustion chambers grouped in a square pattern and four small vernier chambers also placed in a square. Each main chamber would operate with an internal pressure of 36.6 kg/cm^2 and the engine would provide a total thrust of 96 tonnes. This was the propulsion unit for the central sustainer. The RD-107 also employed four main combustion chambers, but had only two small vernier chambers and delivered a total thrust of 102 tonnes at a chamber pressure of 42.2 kg/cm^2. A single RD-107 unit would be attached to the bottom of each booster, four of which would be required for each ICBM. This was the most advanced rocket motor programme which the GDL had yet worked on, with an objective already mapped out when design began.

Glushko summarizes its main characteristics: 'The RD-107 is . . . fed from a single turbo-pump unit. With a multi-chamber design, the length of the engine can be reduced markedly, and this reduces the weight of the rocket. The turbo-pump has two main centrifugal pumps, one for oxidizer and the other for fuel, and two auxiliary pumps driven via a gear-up transmission to feed hydrogen peroxide to a gas generator and liquid nitrogen to the tank pressurization system. The turbo-pump unit also includes a heat-exchanger, heated by the turbine exhaust steam-gas mixture, which turns the liquid nitrogen into a gas. The turbine is actuated by the products of decomposition of hydrogen peroxide over a solid catalyst in the gas generator. The turbine exhaust steam-gas mixture is then expelled through a port outside the rocket, thereby supplying an additional thrust.

'The combustion chamber is a cylinder with a flat injector head. The cylindrical part of the main chamber has an inside diameter of 430 mm, and the nozzle throat is 166 mm in diameter. The engine chambers are of brazed-welded construction. The areas of the fire wall, under the heaviest thermal stresses, are made from heat-resistant bronze with milled fins brazed at the tips to the outer pressure jacket. The less stressed areas of the bronze fire wall are brazed to the jacket through a corrugated spacer that forms ducts for the propellant and replaces fins. With this arrangement, the chamber can be made extremely light in weight and capable of with-

The RD-107 propulsion unit had four main combustion chambers and two small vernier chambers for a total thrust of 102 tonnes. Each of the four boosters attached to the A-series launcher, initially developed as the SS-6 Sapwood ICBM, carried a single RD-107 unit.



standing fairly high pressures and appreciable heat fluxes.

'The bronze swirl-type bipropellant injectors provide for a nearly complete combustion. The chambers are regeneratively cooled by fuel and also by an internal curtain formed by the peripheral row of injectors. This combination of external and internal cooling and also the use of internal bronze walls of high thermal conductivity provides a reliable cooling for the chamber at a high temperature of combustion and under an appreciable gas pressure.

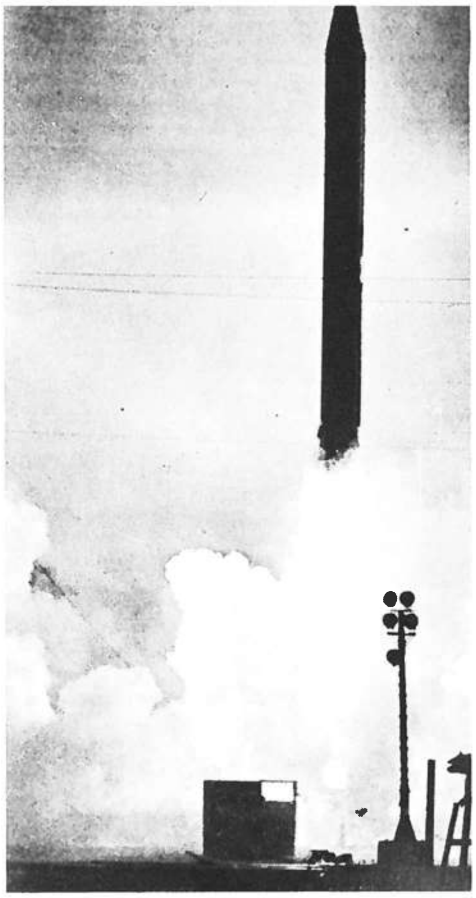
'The swivelling vernier chambers provide fine trajectory control. The engine is started, controlled and shut down fully automatically, by commands from the flight control system in the rocket. Ignition is by pyrotechnics, with electrical indicators and interlocks. At starting, the engine is first allowed to operate at an intermediate thrust, when the propellant is fed to the combustion chambers under the pressure maintained in the tanks by the pressurization system. Transfer to full thrust occurs automatically, as the gas generator is started. In flight, thrust and the oxidizer-to-fuel ratio are controlled by suitable controllers upon commands from the flight control and propellant-feed systems.

'The RD-108 engine . . . is similar in design to the RD-107. It differs in that it has four vernier chambers, modified control units because the engine is started and shut down differently, and a longer service life because the RD-108 is lit at launching simultaneously with the first stage engines.'

The RD-108 engine cluster would form the propulsion unit for the central sustainer which, with its two propellant tanks holding liquid oxygen and kerosene, would have a length of 28 metres. Each booster would be fitted with the RD-107 unit in a structure 19 metres long and 3 metres wide at the base. The four boosters were designed so that they fitted within the flared contour of the central sustainer, providing a total diameter of 10.3 metres including four fins facing outboard, one to each booster. At launch, the ICBM would ascend under the reactive influence of the 20 main combustion chambers and the 12 small vernier chambers, a collective assembly of 32 exhaust plumes, delivering a combined vacuum thrust of 504 tonnes. Compared to the 28 tonnes of thrust of the basic V-2, and the 35 tonnes of the Shyster, it was a colossus. But an efficient behemoth as well. The RD-107 unit would operate with a specific impulse of 314 seconds, while the RD-108 in the central sustainer element would achieve 315 seconds efficiency.

If the rocket itself was by far the largest project of this nature so far approved, the supporting facilities promised to command special consideration unique to the big ICBM. Flight tests would have to be performed over greater distances than hitherto obtained from existing Soviet rockets. About two years after the preliminary specification had been written up in 1953, engineers and technicians moved in to the Kazakh S.S.R. and planned the construction of a massive new launch complex. It was located close to the town of Tyura-Tam, about 350 km south-west of Baykonur and about 130 km east of the Aral Sea: the site proper was not far from the Syr-Darya river. From here the Soviet ICBM's would fly east across the Sayan Mountains, over the Sea of Okhotsk and impact designated test sites on the Kamchatka Peninsula, more than 6,000 km from the launch pad.

Events moved with smooth rapidity: the basic mission of the ICBM had been set up in 1953, work on the RD-107 and RD-108 engines picked up momentum in 1954 and by 1955 the sites had been chosen for launch operations. But, already, engineers at the GDL-OKB were working on another rocket engine which would be used to power an intermediate range ballistic missile – an IRBM equivalent to the American Jupiter and Thor programmes – and find application in the SS-4 Sandal. This missile leaned heavily on the technology developed in support of Shyster and would borrow many design details of the earlier MRBM class weapon. Sandal was required to carry a 1 MT warhead across a distance of more than 1,800 km. As a single stage missile like the Shyster, it bore considerable resemblance to the smaller MRBM with four triangular fins at the rear and a pointed nose section containing the lethal payload. Externally, Sandal was 2.5 metres longer, but in all other aspects of its appearance it was the same as its generic predecessor.



The SS-4 Sandal employed storable nitric acid and kerosene propellants and appeared ahead of the US Jupiter and Thor missiles of similar class.

Internally, the most important difference was to be found in the propellant combination. Shyster, and even the big ICBM project, employed non-storable propellants which required considerable preparation before launch and this comprised the necessity to keep the missile in a constant state of readiness. These problems had been recognized in the United States, and partly met by consideration of solid propellants for missiles such as Polaris and Minuteman, but the Russians retained the liquid propellant concept and used an oxidizer which would not boil away like the oxygen used in Shyster and the ICBM. The engine for Sandal was the RD-214 which would use a nitric acid/kerosene combination, propellants that had a less efficient specific impulse than the liquid oxygen/kerosene group, but with the promise of a rapid launch capability, these storable liquids gave an improved military posture.

Again, as with the RD-107 and RD-108, the RD-214 adopted a clustered concept whereby comparatively small combustion chambers are grouped together with a common turbo-pump assembly feeding all four motors. Thrust was of the order of 74 tonnes, with each chamber producing a unit thrust of 18.5 tonnes compared to a unit chamber thrust of about 25 tonnes for the clustered engines adopted for the ICBM. In 1974, Glushko spoke about its characteristic features: 'The RD-214 is a four-chamber engine with a single turbo-pump unit which combines a turbine, centrifugal pumps each for oxidizer and fuel, and a pump to feed hydrogen peroxide to a gas generator. The products of the catalytic decomposition of hydrogen peroxide in the gas generator, drive the turbine. The turbine exhaust steam-gas mixture is expelled through a nozzle, thus contributing to the rocket's thrust. The chambers are regeneratively cooled by fuel and also by an internal curtain produced by the peripheral injectors in the head of the combustion chamber.

'The combustion chamber has an inside diameter of 480 mm, and a throat diameter of 176 mm. The engine uses chemical ignition by a starting fuel which self-ignites upon contact with the main oxidizer; the starting fuel is fed into the main fuel line ahead of the fuel pump. The engine is brought up direct to full thrust (unlike the RD-107 and RD-108). In flight, thrust can be controlled by varying the flow rate of hydrogen peroxide to the gas generator. The engine can be shut down at the final stage.' Unlike the clustered engines on the ICBM, the RD-214 carried no vernier motors and flight control of the missile was to be effected by vanes protruding into the exhaust flow. This was similar in concept to the

Shyster. Work on the engine had matured through a variety of design studies embracing both ICBM propulsion systems, but the pressing requirement for an intermediate range ballistic missile caused an acceleration through 1955.

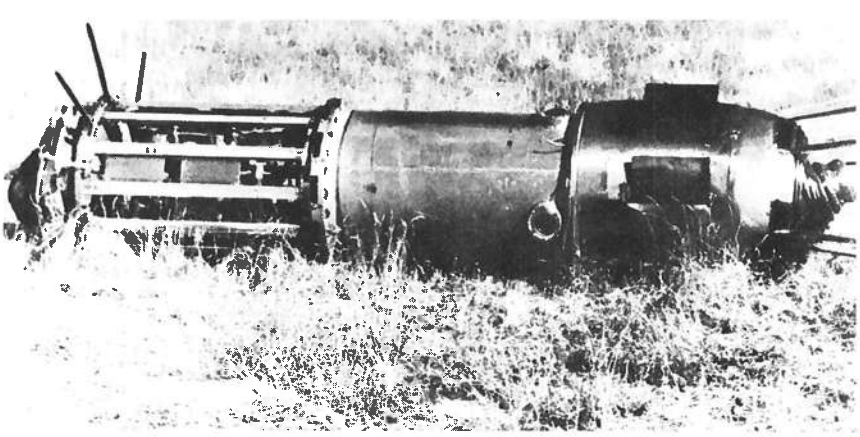
By 1956 Sandal was ready to begin flight trials, more than one year ahead of the ICBM, but contemporary with the American Jupiter and Thor IRBM class weapons. Here again the Soviet rocket engineers were ahead of their political rivals. When Sandal entered full operational service three years later, it would begin a service life extending through two decades of use, find application as a satellite launcher and create international tension by being one of the missile classes deployed in Cuba. But while the new leaders in the Kremlin were embracing a strategic capability, leap-frogging manned bombers by going for a strong missile force with the capability of striking targets in Europe and the United States, others saw the development of the big ICBM as being conducive to the philosophy of Konstantin Tsiolkovsky.

Ever aware of the difficulties facing them, protagonists of orbital flight were convinced that they could achieve the necessary conditions for journeys beyond the atmosphere. Success would need an effective guidance system and a lot of power; sufficient, in fact, for speeds of 8 km per second. Anything less and the probe would fall back to Earth. This is determined by the curvature of the Earth, which falls 4.9 metres in a straight-line distance of 8 km, and the pull of gravity. Subservient to this force, a device accelerated to a horizontal velocity of 8 km per second would similarly fall at a rate of 4.9 metres/sec, but the Earth's surface would curve away from the device at the rate of 4.9 metres in each second of flight. In this way, the satellite would fall towards the Earth, but move forward in each second at a rate comparable to the curvature of the planet. Above the atmosphere, there would be minimal drag to slow the satellite and it would remain circling the Earth for a long period of time.

Fifty years on from the early writings that gave Tsiolkovsky world fame for his proposed use of rockets for space exploration, the Soviet Union was developing the capacity to put his words into reality. Many of the engineers and scientists engaged on the ICBM project were more interested in the prospect of space travel than in the military and political equivalence it would afford. It was an idea that had first taken root shortly after the end of the Great Patriotic War with Germany and Professor Tokaty recalls that in 1947 he had discussed the possibility of using rockets to launch earth satellites with Academician S. A. Khristianovitch at the Zhukovsky Academy. The then Major General of Aviation, Vassilli I. Stalin (Marshal Stalin's son) had responded by telling Tokaty that, '. . . others may be wasting their time on abstract projects, but you are a service man, and you must be concerned with the practical needs of state defence. Can't you understand that we need jet-fighters, not a silly Sputnik!'

This view was prevalent among an essentially military orientated research community and even when initial design details of the Shyster MRBM opened, once again, the possibility of Soviet satellites Tokaty was warned that '. . . there is no time for abstract Sputniks.' Despite this apparent preoccupation with the military potential afforded by a vigorous missile development programme, some leading figures in the political faction approved of the idea and encouraged support for a Russian satellite. In the haste-filled rush to develop a strategic rocket force, the restrictions placed upon military projects found little time or sense for purely scientific research. For several years the proposal was little more than an idea, but the seeds had been sown and soon the Soviet scientific community began to make their voice heard. In 1953 Professor A. Nesmeyanov, President of the Soviet Academy of Sciences, spoke in Vienna of the timely emergence of a space programme aimed at putting satellites in orbit about the Earth and sending rockets to the Moon and the planets. As work progressed on the massive ICBM, the possibility of launching such payloads into space as could be accommodated by the rocket's performance, gradually emerged.

Sergei Korolev recalls that, 'In January 1956 the preliminary decision on building the first artificial earth satellite in 1957–58 was taken. Under the chairmanship of the Vice-President of the USSR Academy of Sciences, Mstislav Keldysh, a number of scientific conferences were held which brought together experts in different fields who in one way or another had a stake in space research. There was one question on the agenda – what could an artificial satellite do for science, what instruments should be placed on board and who would take on the job of producing them.' It was because of Korolev's confidence in the programme, that the Kremlin approved work on the development of Sputnik 1 and the Academy of Sciences put their weight behind the decision.


While work moved ahead toward the launch of Sputnik 1, other research projects were building up a valuable inventory of data about the atmosphere. This container is typical of the types used in ballistic flights to altitudes in excess of 200 km.

Then, from a posture of quiet preparation, the Academy announced at the conference held in Barcelona to plan for the coming International Geophysical Year, that the Soviet Union would prepare and launch an artificial earth satellite. The date, 11 September 1956, was to be remembered in the west as an object lesson in crass assumption; not until Sputnik 1 was bleeping its way around the Earth thirteen months later, could the west accept these words as truth. The sheer magnitude of the accomplishment was thought to lie far beyond Soviet capabilities and even military officials in the United States were largely unaware of the tremendous strides already being taken to provide the first ICBM. Korolev remembers the thoughts that ran through his mind when drawing up the design details of this first artificial satellite. 'It seems to me the first Sputnik must have a simple and expressive form, close to the shape of natural celestial bodies. It will forever remain in the consciousness of people as a symbol of the dawn of the space age. We cannot ignore the historic significance of the forthcoming experiment. The wavelengths of its transmitters must be such that radio hams throughout the world can pick up its signal. It is important that the orbit and the optical characteristics of the satellite are such that almost all people in the world will be able to watch its flight with their own eyes.'

Thus, with a bow to future generations who will look back on Sputnik 1 as a milestone in the evolution of the human species, this first satellite would be round like Earth and the planets, possess a highly polished surface for maximum reflectance of sunlight and transmit its call sign on frequencies that could be picked up by amateurs and professionals alike. Nobody really cared what the object carried into space – it was the first of its kind and as such could escape the scientific requirements of later probes. By the early summer of 1957 preparations reached a level where the Soviet authorities could be a little more informative about the satellite's capabilities. Starting in May, radio broadcasts warned amateur enthusiasts to prepare for satellite telemetry reception by constructing a special receiver, the frequencies of transmission were advertised and scientific communities discussed its impact on society and the pursuit of knowledge.

Outside the Soviet Union, heads turned a deaf ear to the talk about satellites. But Sputnik 1 was not the object of most attentions during that summer: the big ICBM that would make the launch of Sputnik 1 possible, was in itself a remarkable step beyond anything yet built. With more than twice the power of the Atlas and Titan missiles, projects which had yet to fly, the clustered missile was a product of the deep urgency instilled in the programme several years before. Without waiting for small nuclear warheads, the Soviet Union had propelled itself far ahead of anybody else in the rocket business and, unknowingly, given itself the tools by which to fashion the space race. The simple decision to build big for the big, primitive warhead, imbued a sense of scale and this would develop a capability for lifting thermonuclear payloads of a higher yield than contemporary US weapons; when warhead technology reached the point where size reductions were feasible, the much larger 'throw-weight' of the Russian missiles would afford the opportunity of increasing unit yield. However, by May 1957 the first ICBM, now designated SS-6 Sapwood, was in the final stages of preparation for its first flight attempt.

This came on 3 August, more than four months before the first successful Atlas flight, but the trajectory was strictly limited because engineers were more interested in measuring performance than demonstrating an operational capability. A few weeks later the Tass news agency announced that the ICBM had successfully flown its maximum range and that in the course of the ballistic path it, '. . . flew at a great, hitherto unattained altitude.' There now followed a rapid sequence of events designed to instill western respect for the accomplishments of Soviet rocket engine and missile designers and to demonstrate that Russian strategic capability was no longer a written objective, but one which had become an all too obvious reality. On 4 October, Sputnik 1 was sent into orbit about the Earth, followed on 3 November by the dog-carrying Sputnik 2. Just four days later examples of the SS-3 Shyster, the medium range ballistic missile, were trundled through the cobbled streets of Moscow and past the Kremlin walls as part of a military parade designed to mark the 40th anniversary of the Soviet revolution.

Although Sputnik was a remarkably successful advertising gimmick, sending its bleeping signals into countries that had, hitherto, sustained a somewhat remote association with the Soviet Union, the real nature of its presence admirably emphasized the steps that had been taken to acquire modern technology. There was no better way of demonstrating the serious intention of matching western progress and no better indication of the existence of a very large and very powerful carrier-rocket. In shaking apart the public and political apathy that prevailed in the west, SS-6 and Sputnik's 1 and 2 were an unparalleled exercise in snubbing the opposition. For Russia, it signalled the emergence of a new regime.

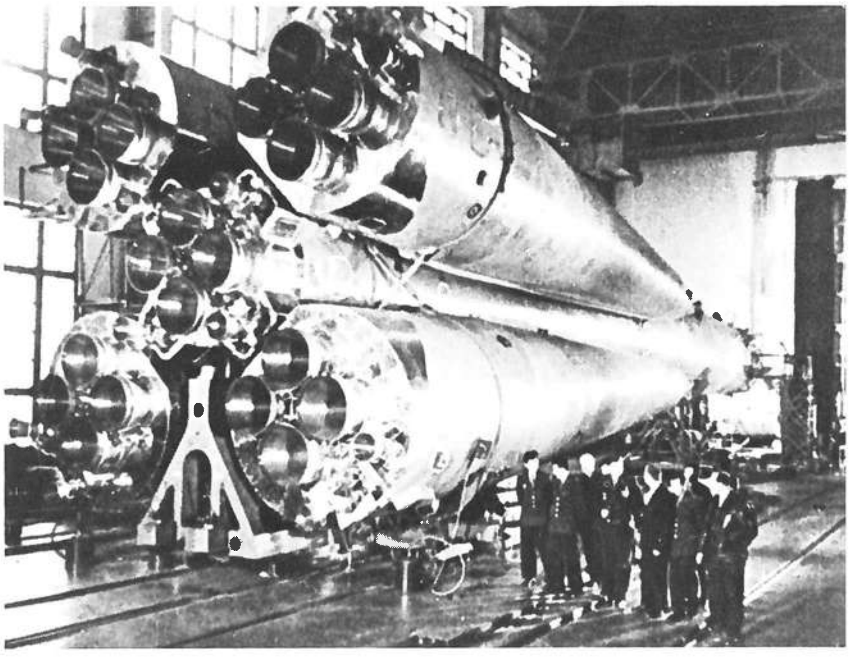
Since Stalin's death in 1953, Kruschev had been forging new roads of success, transforming the Soviet Union and replacing the old order controlled by a vicious security force, with one which would sweep aside the era of concentration camps and forced labour. There was an increasing emphasis on peaceful co-existence with states ostensibly hostile to communist rule and a growing awareness of the need to woo uncommitted countries. By 1956 the old Stalinist order was openly criticized, a measure of internal self-analysis that Russians had not seen for decades, and the pursuit of science and technology was unfettered from the constricting influence of extremism. Within this atmosphere, the able demonstration of Soviet prowess in modern technology was a useful tool for international politics. Countries which until now had been sitting on the fence of indecision, were prime targets for the new policy which sought to embrace diffident communities.

But if the Shyster, Sandal and Sapwood, MRBM, IRBM and ICBM, class weapons were in truth of wholly Russian design, taking little in the form of practical knowledge from the German immigrants, there were many parallels with V-2 design philosophy. The lengthy debate on a mobile capability versus one which relied on hardened concrete launch sites, was examined by the Russian military theorists during development of the Shyster MRBM and the advantage of a mobile concept was recognized to outweigh the fixed-base approach. This was acceptable for a missile that was little larger than the V-2 itself, but the big ICBM was quite a different matter altogether and there was little choice but to establish a fixed site which could support all the complicated equipment essential to its operational use. Without the advantages of storable propellants – both Shyster and Sapwood used liquid oxygen/kerosene – the time required to prepare the missile for launch was much greater than that afforded by a missile which could store its oxidizer and fuel for long periods of time. Sandal was a step in the right direction in that it used storable oxidizer, but the big ICBM was a prime target for enemy missiles in the opening hours of a major conflict.

Partly because of this, and partly because the lack of sophisticated computer technology stipulated a more direct means of examining the condition of the big missile, consideration was given to housing Sapwood in a specially prepared concrete shed, which could, at the very least, afford minimal protection from incoming warheads. In the United States the philosophy of launch preparation grew through a generation of small missiles and the availability of an increasingly sophisticated family of automated check-out equipment demanded that the missile should first be emplaced on its launch pad and then subjected to an electronic scrutiny that would clear the vehicle for flight. In the Soviet Union, on the other hand, engineers preferred to perform most of this otherwise on-pad checkout, in a protective enclosure, with the missile in the horizontal position mounted on a trailer, which was itself resting on a simple railway track. This was the method adopted for the Sapwood and is still in use today.

When the missile had been checked out to the satisfaction of the engineers, large doors would be opened at one end of the building and the rocket would be moved out, tail first, for a journey that would terminate at the launch pad. This was the accepted method of preparation for the German V-2, albeit on a much smaller scale and with a wheeled, rather than rail mounted, trailer called the Meillerwagen. When Sapwood arrived at the pad it would be hydraulically elevated to a vertical position by jacks located on the support trailer (again, like the German method) so that it could rest on the launch platform within a cradle. Four truss-type arms placed at 90° intervals around the base would then move in to restrain the missile at the forward end. These arms were counterbalanced so that when the missile rose from its cradle, the mass would unload the arms, causing them to swing back at the forward end away from the ascending vehicle. Pivoted at the base, they were an effective means of holding the Sapwood in a vertical position.

This, of course, was very different to anything tried on the V-2, but Sapwood was many times the size of the German ballistic missile and brought unique problems to the fore. With the Sapwood thus fixed to its launch platform, the trailer was moved back into the checkout building, where the missile had been assembled, to await the preparation of a second vehicle. In remarkable similarity to earlier problems experienced by the Germans between manufacture and launch of the V-2, Sapwood was required to be launched within twenty four hours of propellant filling; corrosive properties of fluids used in its propulsion system would degrade the integrity of critical components and feed lines if the missile remained unused for longer than a day. Weather had been the main reason for limiting the period between fabrication and launch of the V-2; chemistry was responsible for the limitations placed upon Sapwood operations. During



Russia's first ICBM – later code-named SS-6 Sapwood – comprised a central sustainer and four boosters, all using liquid oxygen and kerosene. The rocket was assembled in the horizontal position and delivered to the launch pad by rail.

the early phases of the development of Sapwood, this problem was not fully understood and several abortive attempts at launch were made before the problem was resolved.

In a further bow to German operating techniques, Sapwood was controlled in pitch and yaw during independent flight, the roll axis being fixed to reduce the complexity of the missile's guidance system. Even by 1957, the theoretical problems associated with automated flight control were awesome in the extreme and any facet of the design which boasted simplicity was to be preferred over more complex systems. This meant that the direction of the trajectory, or azimuth, had to be determined before launch and, like the V-2, Sapwood was placed upon its launch platform and the support structure was then swivelled to point in the precise direction of the target. The small platform used to launch the V-2 was cranked round by a hand-operated ratchet and although the process of careful azimuthal alignment was infinitely more complex for the Sapwood, the basic principle was identical. Once aligned on azimuth, pitch and yaw control ensured that the missile would follow its pre-set trajectory. Without this, the missile would have required guidance in all three axes. Tri-axial guidance systems would be essential in later, more complex, missile designs, but the pre-set azimuth removed one very complex aspect of long range flight.

So, with the missile placed upon its launch platform, most of the pre-flight sequence of checkouts and tests that kept contemporary American rockets sitting on their pads for many weeks, were avoided. The specially prepared checkout building would afford limited protection from blast generated by hostile warheads and the time required to wheel the missile from its preparation shed to the launch pad and prepare the vehicle for launch, was cut to a matter of hours. It is interesting to compare this approach with the preferred launch mode for the V-2, where Hitler personally intervened to champion the massive concrete pads built along the North Sea coastline. Sapwood was filled with liquid oxygen and kerosene within hours of the planned lift-off time, and of course, once filled had to be launched within twenty four hours or replaced, and when the time came to send it on its way, the big missile literally launched itself.

This was accomplished by first manually initiating the ignition of all five clustered engine units (each with four main combustion chambers). When the total thrust had, within the space of a few seconds, built up to a level where it equalled and then exceeded the mass of the rocket, the missile slowly rose under the reactive influence of its motors. It was at this point that the four massive arm structures swung on their base pivots and splayed outward to allow the missile to climb from the launch pad. This was in direct contrast to the mode adopted in the United States, where the rocket is held down past the point at which thrust equals the mass, so that electronic analysis of the missile's integrity is made before committing it to flight. During the second or so between the point that thrust exceeds the weight and the commit decision, the automated launch sequence can call off the flight and shut the engines down. But even in 1957, this technique was largely unexplored and only missiles of the calibre of Atlas and Titan were designed from the very outset to provide this sophisticated capability.

All in all, Sapwood was a basic vehicle with many aspects of its assembly, checkout and launch, fettered to first generation technology. It had a poor propellant:mass ratio, used crude methods of control and afforded little opportunity for sophisticated control techniques. With five clustered engine assemblies, it was a stop-gap project and in the ICBM role it was designed to perform, Sapwood forged no major breakthroughs in missile technology. But it worked. Its success was largely found to lie in the fact that it did not require complex and untried methods for launch and control although it would soon be replaced by more sophisticated rockets. In the role of satellite launcher it was a mass-produced tool that would serve as the mainstay of the Soviet space programme, truly a workhorse for heavy payloads during the decade after Sputnik 1 and then a medium-weight launcher, second only to the 'D' rocket, in the second decade of space exploration. In the closing months of 1957, however, it worked in more ways than that for which it was designed.

Unsure as to the precise level of technical development, the world outside the boundaries of the Soviet Union knew only that the Russians *had* succeeded in launching the world's first artificial satellite and that the armed forces had possession of a missile potentially capable of sending a thermonuclear warhead to the United States. The psychological threat was far worse than anything that could have been contrived by an efficient public relations team; without knowing the details of Sapwood, the west would have to accept a temporary gap in technical capability. In the eyes of the world, America was talking missiles, while the Soviet Union were actively launching satellites. It was recognition of the impact that such a feat would have on public opinion that finally tipped the decision scales in favour of a satellite programme. It was recognized in the Kremlin that Russia needed to capture the world's attention with a demonstration of unquestioned magnitude, that would leave the west at least, in no doubt as to the level of progress they were attaining in science and technology. A project, in short, that would do nothing to uncover the veil of secrecy about the precise nature of the particular technology, but one which would, nevertheless, instill a sudden respect for Soviet claims.

At a time when Russia was attempting to embrace the uncommitted nations of the world, a project that could raise its standard proudly above that of the United States *and* be seen to further the aims and objectives of peaceful scientific research, was one to be pursued as a priority. Thus, while elements of the Russian scientific community welcomed the new ears of approval that listened to their cry for a more benevolent use of rocket technology, the leaders in the Kremlin were, like their American counterparts a few years hence, bent on using the unexploited ocean of space to demonstrate their wares and impress the less affluent communities below. The idea of sending a satellite into space was taken up by the organizing body for the International Geophysical Year and along with sounding rockets, was thought to be an efficient way of obtaining data on the Earth. At a time when the western world was emerging from post-war austerity, the spectacular achievement of a satellite launch was thought to be an appropriate signal for a new and enlightened age embracing science and technology.

But there were few countries capable of spending the money necessary to achieve this and even less with the technical resources on hand: in France the Ballistics and Aerodynamics Research Laboratory had produced a liquid propellant sounding rocket burning a mixture of nitric acid and turpentine to generate a thrust of 4.1 tonnes and send a small payload to a height of 64 km, but their only contribution to the IGY was in the less sophisticated area of sounding rockets; Japan resumed rocket research in 1953 with theoretical studies at the Tokyo University Institute of Industrial Science and by 1957 had progressed through a series of test projectiles called Pencil and Baby to the Kappa rockets first fired in 1956, but here too the country was unable to consider the launch of an artificial earth satellite; in Canada, the Black Brant sounding rocket emerged a year before the IGY began, but research here had been limited to solid propellant motors and the country lacked the research base necessary to develop a potential satellite launcher; Italian interest in rocketry was almost wholly vested in the work of Prof. Robotti, but with the limited resources available he was only able to develop comparatively small research projects, albeit liquid propellant types, burning nitric acid and kerosene or aniline.

Only in Britain and the United States was there sufficient technical know-how *and* the necessary money to invest in a satellite launcher. One of these two countries would turn its back on development; the other would become a world leader in space exploration. In an earlier chapter it has been observed that much of the work on rocketry and space travel in the UK had been pursued by the British Interplanetary Society; only with the advent of hostilities in 1939 did the government lend moderate support to the development of rocket propelled weapons. Theoretical analysis of the possible configuration that rocket vehicles would take had already given the BIS substantial credibility, but with the outbreak of war the Society was disbanded. Elsewhere in the country, at Leeds and Hastings, other groups had formed only to be wound up in 1938 while in Scotland, J. D. Stewart societies. It was agreed that such as organization should be established and that another meeting should be held the following year in London, sponsored by the BIS. During the ensuing period proposals would be studied of suggested by-laws for a permanent federation. An ad hoc committee, headed by Dr. Eugene Sanger, was established to co-ordinate such proposals. Sanger was selected for this post for two reasons. Firstly, because he was a rocket expert of international renown. His brilliant preliminary study and experimental research on a globe-circling rocket bomber is well known. Secondly, Sanger represented no society. At that time, he was working for the French Department of Defence. Characteristic of this historic conclave, and at subsequent congresses, the business sessions were conducted in a spirit of friendliness and goodwill. Feelings of national pride or personal vanity were sublimated in the common interest behind these meetings – the development of astronautics.'

At the Second International Astronautical Congress, held in London in the week beginning 3 September 1951, representatives from the eight countries that had participated in the first Congress, assembled to approve proposals for the setting up of the International Astronautical Federation. In addition, delegates from Switzerland and the United States attended the meetings. During the summer of 1951, Kenneth Gatland of the BIS published a series of articles in the weekly magazine *Flight* summarizing the achievements to date in the field of guided missile development. A year later he wrote a book on the basis of these reports and discussed a recent study performed with the assistance of A. M. Kunesch and A. E. Dixon which set out the basic requirements of a 'close-orbit Earth satellite vehicle.'

The proposal envisaged a three-stage rocket, 18 metres tall weighing 161 tonnes and propelled from the launch pad by motors generating 200 tonnes of thrust. The first stage would consist of seven rocket motors of the type used in the German A-4 (V-2) augmented by no less than 175 solid propellant boosters, each delivering a thrust of nearly 2.3 tonnes. These booster motors would be operated on a staggered firing sequence, to lessen the shock of high acceleration. Combined thrust at lift-off would have been 427 tonnes and the first stage was expected to carry the assembly to a height of 99 km. The second stage, with its single 21 tonne thrust liquid propellant motor, would take over and burn for 79 seconds to raise altitude to 300 km. The final stage, also with a single motor, would have had a thrust of 1.5 tonnes and in a 79 sec burn, would lift itself and a 50 kg payload to a height of about 1,070 km and an orbital speed of 29,890 km/hr.

To quote from Gatland's book, 'In no case does the design exceed the limitations imposed by current engineering practice, and the propellant is taken conventionally as liquid oxygen and alcohol. The conservative nature of this study is emphasized for it seeks to show that, if ever we are allowed officially to think 'big' in terms of rockets in Britain, we could design orbital vehicles with a propulsion unit of no greater efficiency than the existing A-4 motor.' The 'close-orbit Earth satellite vehicle' had emerged before the Second International Astronautical Congress in 1951, but Gatland, Kunesch and Dixon prepared a paper for the week-long discussions outlining four potential satellite launchers.

The first, called Type A, was very much a 'minimum satellite vehicle.' It was proposed to have three separate stages with first, second and third stage thrust levels of 33.6 tonnes, 5.76 tonnes and 0.21 tonnes respectively. Overall, Type A would be 15.6 metres in length and weigh 16.8 tonnes. Type A was incapable, theoretically, of carrying a payload and the rocket was conceived as a test vehicle for tracking and radar tests, but one which would, nevertheless, place the third stage structure in Earth orbit at a height of 850 km.

Type B, capable of lifting a payload of 100 kg into an 805 km orbit, would have to be 20.5 metres long, weigh 62.4 tonnes and have first, second and third stage thrust levels of 124.8 tonnes, 21.4 tonnes and 1.05 tonnes, respectively. Five engines would be carried in the first stage and single motors in the second and third stages. It is convenient to use the design values for Types A and B, to show the significant increase in the mass of the launcher when a payload of only 100 kg was incorporated; because the weight of the launching rocket grew from the 16.8 tonnes of Type A *without* a payload to the 62.4 tonnes of Type B *with* a payload incorporated, it can be said that each kilogramme of unit payload increased the weight of the rocket by 456 kg. It is possible, through this example, to recognize the problems associated with providing a satellite launch capability. The enormous increase in weight of Type B over Type A was due, wholly, to the 100 kg payload to be carried by the former.

Kenneth W. Gatland, seen here on the left talking to Leonid I. Sedov from the Soviet Union at the Second International Astronautical Congress in 1951, repeatedly demonstrated that British participation in space was a feasible proposition.

Whereas Types A and B were proposed with virtually no consideration for sophisticated control equipment, Type C incorporated an additional guidance package weighing 75 kg. This resulted in a further increase in the total mass of the launch rocket to some 90.9 tonnes, with a length of 24 metres and a first stage thrust of 181.8 tonnes; second and third stage thrust levels were 31.2 tonnes and 1.68 tonnes respectively.

Finally, a Type D satellite launcher was considered with an expendable propellant tank construction. Although this was ostensibly a three-stage rocket, the second and third stages lay within the first stage. The single motor of the second stage was, therefore, at the centre of the cluster of first stage engines and would be used to supplement thrust from these motors. During the period from lift-off until separation of the first stage, the second stage engine would be firing also, drawing propellant from the stage 1 tanks. The actual propellant flow path would bring propellant through the existing second stage tanks and thus keep the latter full until the first stage separated and the second stage began to use the propellant in its own tanks.

Although somewhat complex in operation, the scheme was simple in concept and had similar beneficial characteristics to those possessed by a rocket stage, augmented by additional boosters strapped to the sides. It was very similar in efficiency to the method selected for the Russian SS-6 Sapwood ICBM several years later. The American Atlas ICBM was a variation on this idea, when engineers designed the two boosters operating in conjunction with the central sustainer to be jettisonable on the ascent. However, it was seen with the Gatland, Kunesch and Dixon Type D proposal, that a rocket with identical mass and launch thrust to that of Type C, would be able to lift more than twice the payload (220 kg in fact) to the same type of orbit. Also, because the three stages were mounted inside each other, the overall length of the rocket was reduced by 11.5 metres, or 48%, compared with the tandem arrangement of the Type C. Such was the calibre of theoretical studies into the problems of satellite launchers.

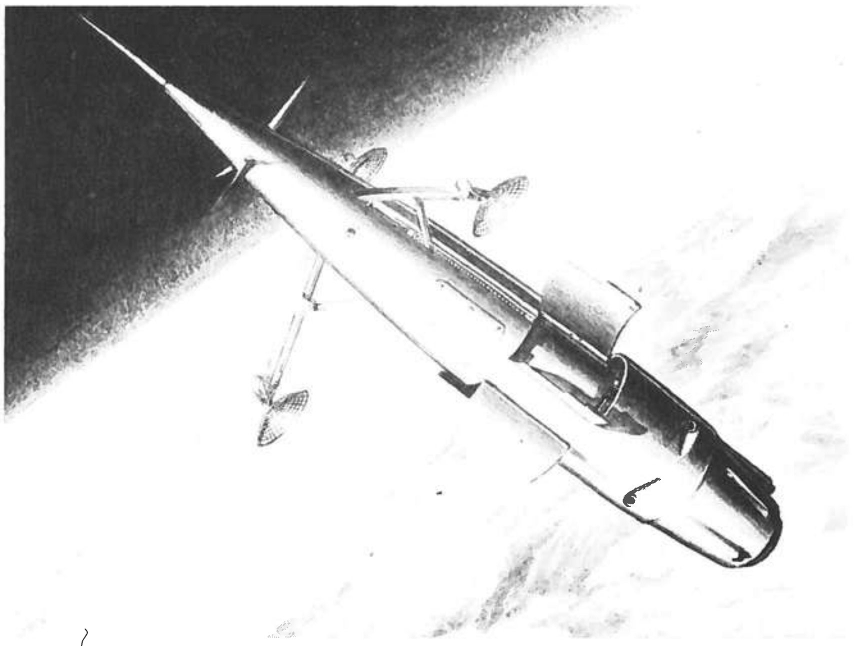
When the Second Congress reviewed the papers in 1951, it was generally accepted that the world was on the verge of a new age: an age in which rocket technology would breed a new generation of possibilities through the orbiting of artificial satellites. But governments throughout the technically advanced world were unmoved by all the apparently viable arguments put forward in support of further development. Societies throughout Europe, the United States, South America and, presumably, the Soviet Union continued to push, and exceeded the achievements which might have been thought possible from their meagre resources, with lectures, meetings and public debate on the vital issues concerning the future role of rocketry. In the suspicious aura of a potential confrontation, east and west found little time, at official level at least, for consideration of satellite launcher projects.

Yet a veritable host of small research projects continued to prosper after World War II. In Britain, one of the earliest standard 'test-beds' for experimental work on guidance and control techniques was known as the RTV-1. Developed at the Rocket Propulsion Department, Westcott, the projectile was 5.2 metres long with a diameter of 24 cm and four fins at the rear spanning 68.6 cm. With a weight of 118 kg, RTV-1 was propelled by a single liquid propellant motor burning a mixture of liquid oxygen and alcohol for a thrust of 450 kg and a burn duration of 25 seconds. Shortly after the introduction of this research tool, the RTV-2 was developed. This missile was almost twice the length of the earlier model and built a creditable reputation in pioneering design and operating techniques that would be applied to later missiles. By 1950 the British Government was ready to move ahead with the development of several operational projects and two of the most notable were dubbed Thunderbird and Bloodhound. Each was designed as a surface-to-air missile (or SAM) with the former going to the Army and the latter to the Air Force.

Work on Thunderbird originated in October 1948 when the Ministry of Supply engaged English Electric to assemble a team of engineers and technicians to work on the design of a guided anti-aircraft weapon. Mr. L. H. Bedford must receive credit for his strenuous efforts in bringing English Electric's Guided Weapons Division through its formative birth pangs and in setting up a liaison with another English Electric subsidiary, D. Napier & Son, then working on liquid propellant rocket motors. Through a variety of Ministry code names, including Red Heathen and Red Shoes, the missile project matured quickly and the first test firings with small scale motors were performed at Larkhill, in Wiltshire. In 1951 more than thirty engineers working at the Napier facility were transferred to English Electric in an attempt to centralize the development effort. The first full size development firing took place from the Royal Aircraft Establishment's test range at Aberporth, Cardiganshire, on 15 July 1951. As the missile emerged, it was a single stage solid propellant weapon, boosted during the ascent by four jettisonable solid propellant boosters. Each booster carried a large, rectangular fin and the main body of the missile supported four fins at the rear and four larger fins mid-way along the body. Thunderbird was 6.4 metres long, 53.3 cm in diameter and provided a range capability of 40 km. Final development activities were conducted by the Rocket Propulsion Establishment when it was re-named as an independent body; hitherto the group had been called the Rocket Propulsion Department of the Royal Aircraft Establishment.

Bloodhound, a contemporary of Thunderbird, was 8.46 metres in length, with a diameter of 55 cm and a range of 24 km. It differed from Thunderbird in that it used four solid propellant boosters for launch, but relied on two ramjet propulsion units for the cruise portion of ascent. The ramjet motors were strapped either side of the main body of the missile, one above and one below. The missile was developed by the Bristol Aeroplane Company, who chose to place the tank for the kerosene fuel in the aft section of the projectile's cylindrical body which was then introduced, via feed lines, to the two ramjet motors. Both Thunderbird and Bloodhound were fitted to hydraulically operated launchers, consisting of a circular pedestal supporting a ramp which could rotate from the horizontal position through 45° at selectable intervals, and both were operational by 1958.

In the field of air-to-air weaponry, the first notable British product was the Fireflash, a product of the Fairey Aviation Company's research division, originally set up toward the end of World War II, consisting of a central body containing guidance and the warhead and two solid propellant boosters strapped to the forward end and extending far ahead of the inert section. The Supermarine Swift Mk. 7 fighter was specially developed to carry four Fireflash missiles under its swept-back wings and each missile was guided to its aerial target by a beam 'laid' down on to the object under attack. During the mid-1950's de Havilland Propellers developed a second generation air-to-air missile called Firestreak, a considerable improvement on the earlier Fireflash in that it used a single body structure with integral solid propellant motor and stabilizing fins toward the rear and an infra-red homing guidance system, which caused it to follow and intercept the heated engine structure of an enemy intruder. One of the first applications of Firestreak was to the delta-winged Gloster Javelin all-weather fighter. With a length exceeding 3 metres, the missile packed a powerful punch and the weapon was in service with the Royal Air Force by 1958.



The Minimum Orbital Rocket, a concept that, like so many, was to fall on deaf ears and an indifferent British government.

Within twelve years of the end of hostilities in Europe, Britain had built up a creditable inventory of military missiles: at the top of the range was Blue Streak, an IRBM with a design range of 4,000 km capable of carrying a thermonuclear warhead yet to be developed, supported for technical research by the emerging Black Knight warhead test rocket; ground-to-air missiles of the Thunderbird and Bloodhound class promised to lay an effective anti-aircraft screen for hostile intruders into British airspace; fighter cover was supplemented by Royal Air Force squadrons equipped with Fireflash and Firestreak beam-guided and infra-red seekers respectively. Although it would still be several years before Blue Streak could supplement the manned bomber force, it had only emerged as a definitive project in 1955, the capability which it would afford ensured British participation in the advanced technology of long range ballistic weapons research.

Yet, throughout the period 1945–1957 there was no official approval for the many and varied proposals for a satellite launcher and it was left to private groups and organizations to rally support for a more scientific application of solid and liquid propellant rockets. The situation was just a little different in the United States. When Sputnik 1 ascended from the Tyuratam launch complex, the American armed forces had at least one project in the offing which promised to ensure that the Stars and Stripes would not be missing from orbital activities that suddenly appeared to be the exclusive preserve of the Soviet Union. The attempt to gain congressional approval for a United States satellite programme can be divided into two periods: the first between 1945 and 1949 and the second between 1954 and 1957. However, the earliest proposals were being formulated in 1943–44 when the Navy Bureau of Aeronautics responded to intelligence reports on German rocket developments, by studying the feasibility of pre-empting a suspected initiative on the part of the Peenemunde team with development of a US satellite launcher.

When Wernher von Braun was interrogated by the Army Ordinance Corp in May 1945 it was all too readily apparent that had they been given the chance to concentrate on more advanced projects, the Germans could have developed such a launcher within a few years. Several months later, in August 1945, Dr. Theodore von Karman prepared a report for the Army Forces Scientific Advisory Group and failed to impart a sense of urgency to proposals for long range ballistic missiles and satellite launchers. Recognizing the remarkable achievements of the Peenemunde team, he advised that it was, '. . . important for us to note that one element in their success was the fact that they had under a single leadership in one organization, experts in aerodynamics, structural design, electronics, servomechanisms, gyros and flight control devices, and propulsion; in fact, every group required for the development of a complete missile.' This was as much a recognition of the lack of a co-ordinated development team in the United States, as it was a commendation for the unified approach fashioned for German V-2 developments.

In the post-war years, the United States policy emphasized the need to reduce arms expenditure rather than to mobilize a new generation of weapons development; the existing emphasis on large bomber fleets and fission bombs was already taking a large amount of money from the defence budget and any new arm of the defence force was considered too inflationary. In October 1945 the Navy Bureau of Aeronautics set up the Committee for Evaluating the Feasibility of Space Rocketry (CEFSR) and by the end of the month had made recommendations on the structure of a programme aimed at development of the necessary hardware leading to a satellite launcher. By December the Guggenheim Aeronautical Laboratory were under contract to the Bureau of Aeronautics to conduct research in basic technology – embracing propellant combinations, motor design, structural specifications, etc. – necessary to implement the recommendations.

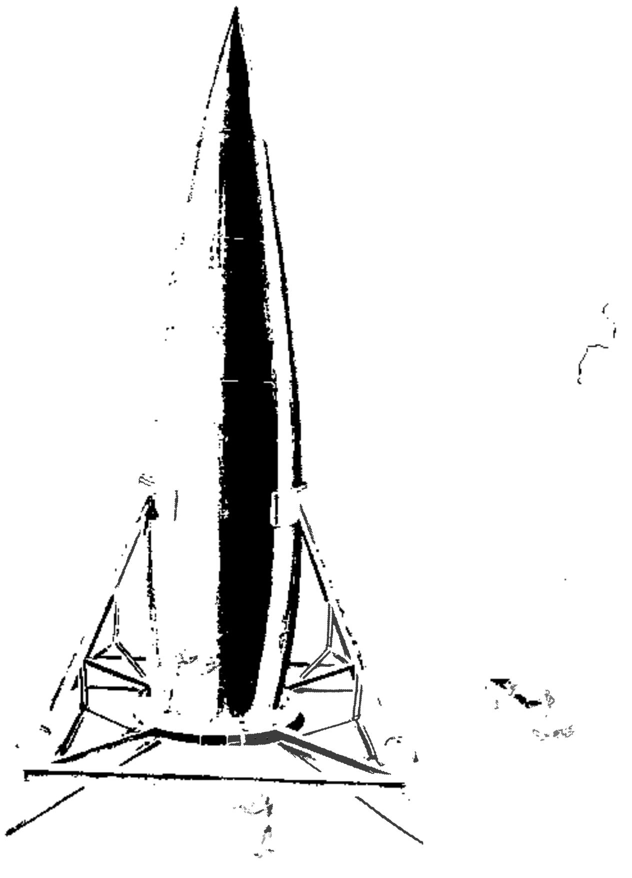
In the belief that a major project of this nature would stand a better chance of success with the cooperation of Army Air Force departments, the Navy took its proposal to the Army on 7 March 1946. Two representatives from the Navy, met with three Air Force generals, to obtain their support, but received only cursory interest. The idea would be taken before the Deputy Chief of Air Staff for Army Air Forces Research and Development, Major General Curtiss LeMay, but when the Navy staff met with LeMay it was to receive a rebuff, occasioned by open hostility at the prospect of other service interests eclipsing the existing projects on hand with the Army Air Force.

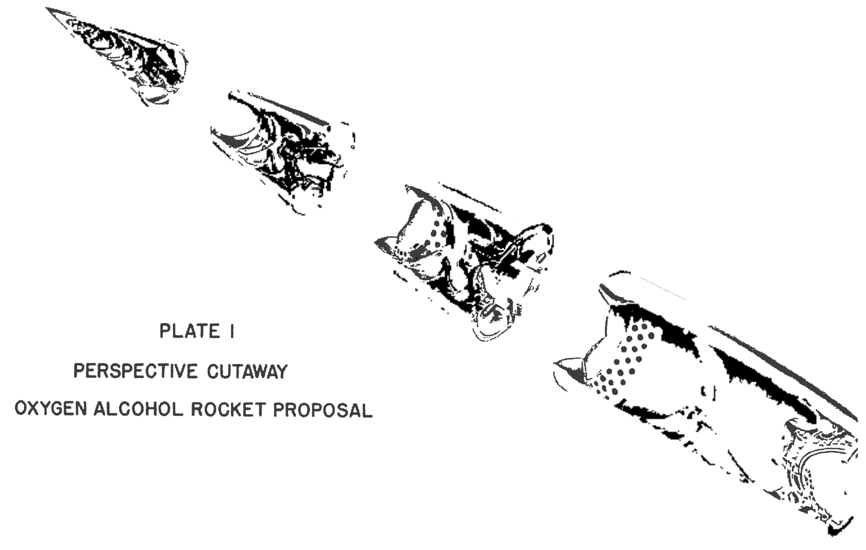
A few weeks later the Navy stiffened its resolve to pursue the satellite launcher project and requested an interview with Dr. Vannevar Bush, the Director of the Office for Scientific Research and Development, in the hope that he would endorse the proposal. Several months earlier, Dr. Bush had expressed opposition to the idea of long range rockets when, in testifying before the Special Senate Committee on Atomic Energy, he said that, '. . . such a thing is impossible for many years. The people who have been writing these things that annoy me have been talking about a 4,800 km high-angle rocket shot from one continent to another, carrying an atomic bomb, and so directed as to be a precise weapon which would land on a certain target such as this city. I say technically I don't think anybody in the world knows how to do such a thing and I feel confident it will not be done for a very long period of time to come. I think we can leave that out of our thinking. I wish the American public would leave that out of their thinking.'

The requested interview never took place due to Dr. Bush's reluctance to consider development of any major rocket proposal. But the Aeronautics Board, set up to prevent duplication of effort between the services, called for a meeting between Navy and Army Air Force personnel to consider the varied satellite launcher proposals. The Army Air Force responded by calling for a two-month postponement so that they could prepare a concrete design for consideration with the Navy and immediately requested Project RAND to submit a preliminary design. Project RAND had been in existence about eight months as an advisory and consultative board on military weapons development, formed principally by the Douglas Aircraft Company, but with the participation of North American Aviation and Northrop.

During the first week in May, the Army Air Force scrutinized the findings from RAND, which came in the form of Report Number SM-11827 entitled, *Preliminary Design of an Experimental World-Circling Spaceship.* The 'spaceship' was considered to require a four-stage assembly for delivering a payload weighing 227 kg into a circular orbit 480 km above the surface of the Earth. The complete vehicle would weigh 106 tonnes and each stage would use a single liquid propellant rocket motor of a similar technology to that used in the V-2. The selected propellants were liquid oxygen and alcohol, emphasizing the reliance on German experience, so recently captured as spoils of victory. RAND added that the project would probably require a committment of $150 million and could be in operational use within five years of a go-ahead decision.

The Navy proposal was somewhat different. Called the High Altitude Test Vehicle, or simply HATV, it consisted of a single stage vehicle, fabricated from stainless steel, with two large propellant tanks holding liquid oxygen and liquid hydrogen. These high-energy propellants were, of course, the most efficient chemical combination that could be used for a liquid rocket, but in 1946 the proposition that they be used for an early satellite launcher was bold and audacious. Very little consideration had been given to handling these cryogenic liquids and although engine efficiency was considerably enhanced, it was a doubtful venture if only for the lack of experience in engine design and operation with liquid hydrogen and liquid oxygen. The HATV design was 26 metres in length, 4.9 metres in diameter and weighed 46 tonnes. At the extreme rear of the launcher, a central rocket motor was expected to provide a thrust of 33 tonnes with eight 'peripheral' motors arranged in a circle around the central motor, each unit generating a thrust of 12.8 tonnes. Total thrust at launch would be, therefore, about 136 tonnes and the





The RAND proposal envisaged a single rocket motor attached to each of four stages, the complete assembly capable of sending 227 kg into orbit.

In May 1946, the RAND proposal for a four-stage liquid oxygen/alcohol 'World Circling Spaceship' was submitted to the US Army Air Force.

HATV would ascend, under the propulsive energy of the nine motors, to put itself into a 241 km high orbit.

Two horizontally opposed fins were located at the rear, for aerodynamic stability during the climb through the dense layers of the atmosphere, and several solid propellant vernier rockets were to be carried, for final velocity and altitude adjustment when the main engine shut down. This latter concept was adopted several years later for the Atlas ICBM, where it was felt desirable to have a more precise control over the terminal speed of the missile. Several companies were involved in the HATV concept, including the Glenn L. Martin Co., Aerojet Engineering Corp., and North American Aviation. Further work on HATV applications predicted a cost estimate of $150 million for twelve vehicles during a five year programme; the financial requirement and the gestatory period were identical to those proposed by the RAND study for the Army Air Forces.

Early in 1947, the RAND proposal was modified to accept the inevitable development of rocket motors burning liquid hydrogen as a propellant fuel and the increased efficiency thus provided by switching from alcohol reduced the weight of the 'World-Circling Spaceship'. The new concept required a rocket vehicle weighing 37 tonnes, but with a capability of achieving a circular orbit 563 km high. The cost, at $82 million, was nearly half that projected for the oxygen/alcohol model, but still far too high to sway adverse opinion on the value of such an undertaking. Shortly after the Aeronautical Board expressed moderate, but largely indifferent attitudes to the Navy HATV and the Army Air Forces RAND proposal, it was replaced by the Joint Research and Development Board set up to monitor and co-ordinate any future investment in military projects.

The Board's Committee on Guided Missiles was advised by the Technical Evaluation Group that studies had gone far enough to provide a future reference on necessary developments should the government wish to orchestrate a satellite programme, but that for the present, further work should cease. This was in mid-1946 and within a year the Army Air Force lost interest in its own proposals, while the Navy HATV was brought to a similar halt. As discussed in Chapter Seven, the Air Force became an independent service in July 1947 and three months later Clark B. Millikan's technical evaluation group reported to its superior body, the Joint Research and Development Board, that satellite launch vehicles should not receive special consideration until some obvious military advantage would accrue from an orbiting payload.

It was, in effect, a rebuff to what was considered a digressionary pursuit and this spurred the National Advisory Committee for Aeronautics (NACA), a government body set up in 1915 'to supervise and direct the scientific study of the problems of flight, with a view to their practical solution,' and to 'direct and conduct research and experiments in aeronautics', into a more attentive posture. Charged with responsibility for exotic aeronautical research projects, NACA felt itself the logical body to take up the challenge so recently thrown aside by the three armed services' coordinating Board.

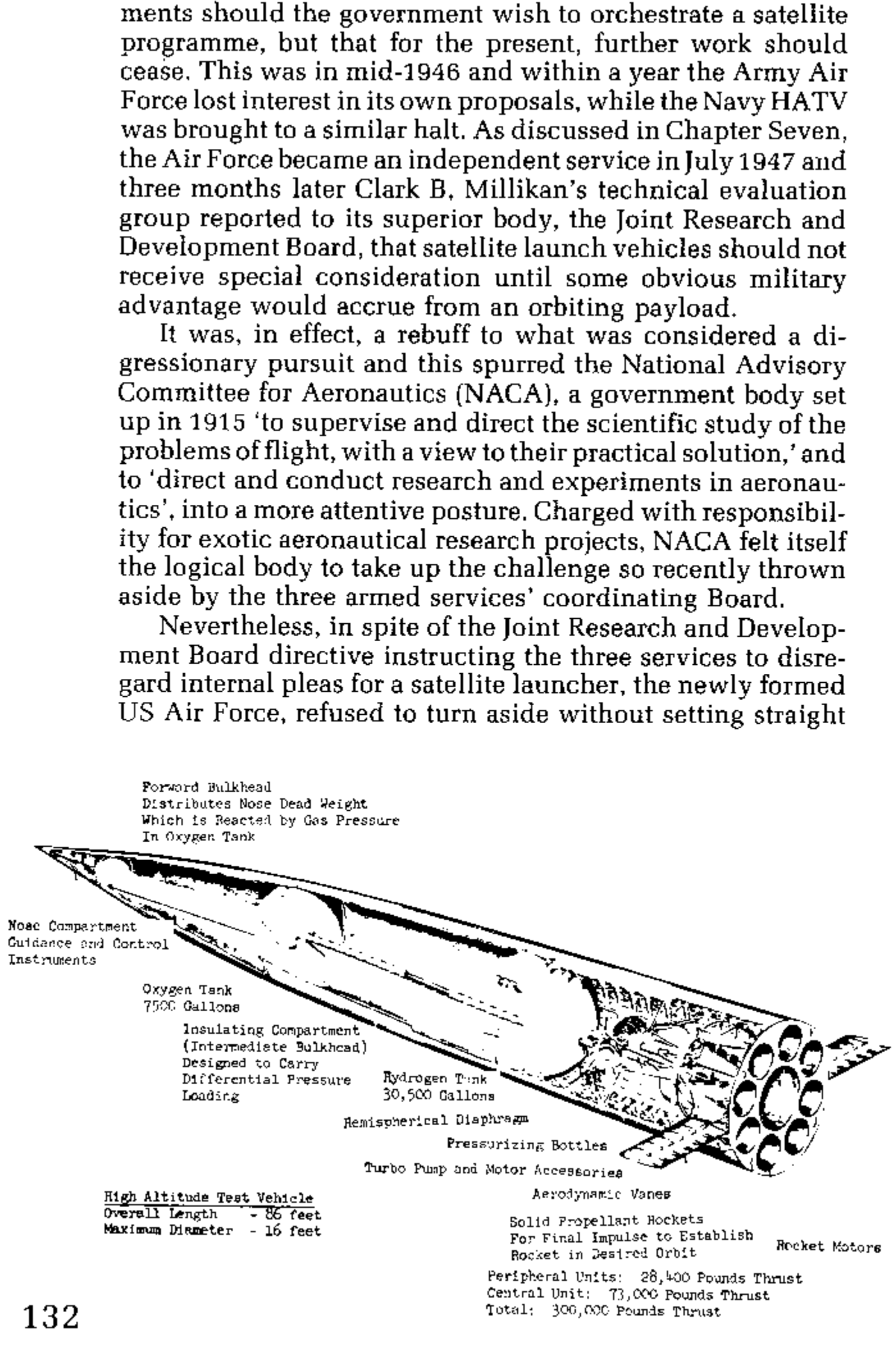
Nevertheless, in spite of the Joint Research and Development Board directive instructing the three services to disregard internal pleas for a satellite launcher, the newly formed US Air Force, refused to turn aside without setting straight the record as to just who it was had prime responsibility for such tasks – securing, in effect, its own lead position as and when the decision was, or may be, reversed. On 15 January 1948, Air Force General Hoyt S. Vandenberg issued a statement that said that, 'US Air Force, as the service dealing primarily with air weapons . . . had logical responsibility for the satellite.' In the end, despite their assertion to the contrary, the struggle to get the first American satellite into orbit would be a product of the contest between Army and Navy research teams, and not the Air Force at all.

As a last resort, in the face of official complacency, the Navy, late in 1948, solicited the assistance of the NACA in moving ahead with the development of its HATV proposal, re-shaping its objective as one which could enhance the studies into upper atmospheric physics. Both agencies of the Federal purse-string pursued the project, but received no support whatsoever from Washington and in the face of depleted funds for further work, the HATV died a natural death. Also in 1948, the first Annual Report of the Department of Defence issued the first official, and public, comment on talk about artificial satellite programmes by asserting that such a project may, at some time in the future, prove to be of useful military value. It went on to detail the studies performed by the Army, the Air Force and the Navy up to 1948. However, press reports of the statement brought an unfavourable response and charged the Pentagon with having concerned itself with a waste of public money; private citizens were outraged at the prospect of having to pay for such an extravagant indulgence which would surely have little value or return. As a last final attempt to re-structure its objectives, the Air Force asked RAND to find a military use for the artificial Earth satellite and so justify continued study leading towards development.

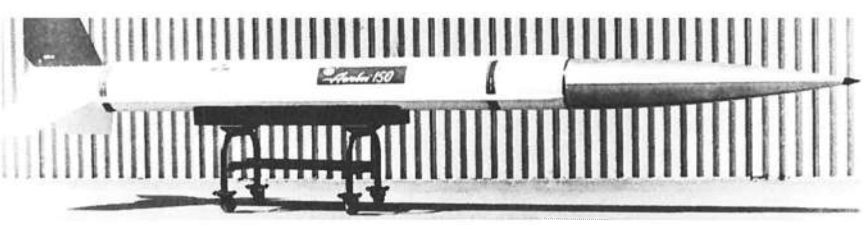
The report, when it emerged early in 1949, pointed out that reconnaissance and surveillance of a potential enemy could be more efficiently conducted from an orbiting satellite than by conventional methods. It also indicated the progress that could lead to development of a communications system using satellites to relay messages between distant points and stressed the psychological value of placing US hardware in space. Its findings can be summed up by the assertion that a satellite could be looked upon as 'an instrument of political strategy.' Throughout the following years continued updates to the RAND report would stress these advantages, but it would be a long time before the Air Force was allowed an autonomous satellite programme.

The period 1945 to 1949 had demonstrated the emergence of a momentum carried through from American and German rocket developments towards a natural conclusion that an enhanced technical competence would benefit from a broad research base. This lesson would have to be learnt afresh a decade later and not until 1954, does the evolutionary development of America's attempts at launching a satellite pick up once again. In 1951 the Russian rocket engineer M. K. Tikhonravov claimed that the Soviet Union would very soon have the capacity to launch an Earth satellite and, again, in 1953 A. N. Nesmeyanov declared, at the World Peace Conference in Vienna, that Russia 'has reached such a stage that . . . the creation of an artificial satellite of the Earth is a real possibility.' These voices were not heeded in the United States, which seemed oblivious to achievements of a strategic nature that began in foreign lands. Nevertheless, seven representatives from the Army and the Navy met in Washington on 25 June 1954, to consider the setting up of a Joint Army Ordinance Corps-Office of Naval Research project leading to the launch of a satellite. One member of the group, Wernher von Braun, would play a leading role in future events.

Von Braun was the only participant who had concrete association with a major missile project already under development as a medium range weapon – Redstone. It was this liquid propellant creation of the ex-Peenemunde man, that was adopted as launch vehicle for the proposed satellite. The idea that emerged from this meeting as Project Orbiter, envisaged a Redstone MRBM as first stage to a cluster of solid propellant Loki rockets as upper stages which would have the



The High Altitude Test Vehicle (HATV) was a bold proposal for the state of rocket technology extant in 1946. In selecting high-energy propellants the design team foresaw the development of such vehicles for application in the nation's space programme.



A candidate satellite launcher considered by the Naval Research Laboratory would have used an Aerobee sounding rocket as upper stage to a Viking rocket.

capability of placing a payload weighing 2.27 kg into a low Earth orbit. As an alternative concept, modified Sergeant solid propellant rockets could be clustered to give the launcher a 9 kg payload capability. The idea was reviewed by the Chief of the Office of Naval Research, Rear Admiral Frederick R. Furth, and given provisional approval. This led to a second meeting between the Army and the Navy, in August, at the Huntsville facility, set up four years earlier to conduct Army ballistic missile research.

In September, von Braun prepared the first formal document outlining the scheme conceived by the Joint Army–Navy team entitled, *The Minimum Satellite Vehicle Based Upon Components Available from Missile Development of the Army Ordinance Corps*. The prime theme of the concept was that the entire project could be brought to fruition using existing hardware, except, of course, for the satellite itself, and that objections arising from Department of Defence's reluctance to fund an entirely new satellite launcher could thus be avoided. A month later, on 4 October 1954, the committee of the International Geophysical Year met in Rome to establish a strategy for scientific research and encouraged participant countries to consider 'the launching of small satellite vehicles.' This was just what the Project Orbiter team wanted: an outside stimulus to shake Washington into action. It had the desired result. On 14 March 1955, the National Committee for the International Geophysical Year endorsed the Rome directive.

Meanwhile, in January, the Air Force was invited to join the Army–Navy team with a request to Donald A. Quarles, the Assistant Secretary of Defence. As it turned out, this request was to seal the fate of Project Orbiter: Quarles deferred the decision to an Advisory Group on Special Capabilities which now had the option of looking at Army, Navy and Air Force proposals. The Air Force were putting up the Atlas as a potential satellite launcher, but the big ICBM was still in the design stage and to divert a segment of the already complex research and development structure, to the task of using the missile to launch a satellite, was considered unwise. Although the Project Orbiter proposal had been stimulated by cooperation between the Army Ordinance Corps and the Office of Naval Research, the hardware was firmly established within the Army's bailiwick; the launcher was a modified Redstone and as such had little call on Navy projects. So it was that, with an eye on securing at least some of the credit, the Naval Research Laboratory proposed its own satellite launcher in competition with the Project Orbiter, Redstone based concept.

On 5 July 1955, a classified report was submitted to Quarles Advisory Group as an alternative scheme. Called simply, *A Scientific Satellite Programme*, the document outlined two separate Navy designs: the first would use a modified Viking sounding rocket, with two solid propellant upper stages; the second would again adopt the Viking as a first stage, but with an Aerobee-Hi second stage and a new solid propellant third stage. Both Viking and Aerobee had been conceived in 1946 as a Navy sponsored duo, capable of performing upper atmosphere research with different payload and altitude capabilities. The first concept would put a 18 kg satellite into orbit at a height of 347 km, the second would carry a similar load to a height of 488 km. The Naval Research Laboratory were confident of being ready to orbit the first satellite within two years of a go-ahead.

Four possible launcher configurations were now available: the Air Force Atlas, which never was a probable contender, the Army Redstone, actually the Jupiter C derivative conceived in the preceding months as a nose-cone test vehicle, and the two Navy proposals, each based on the Viking sounding rocket, flown successfully on eleven out of twelve attempts since May 1949. Meanwhile, on 29 July, President Eisenhower announced official approval for the launch of an artificial satellite as part of the US contribution to the International Geophysical Year.

By 9 September 1955, the Advisory Group on Special Capabilities had voted seven to one in favour of one of the two Navy proposals and killed Project Orbiter. The reasons were two-fold: the Army was moving towards several important new missile projects and the reasoning that eliminated the Air Force Atlas applied here too and President Eisenhower was intent on presenting the satellite project as one based on scientific application, using non-military hardware. Although Viking had been managed by the Navy, it was a pure research tool; Jupiter C, and its Redstone predecessor, were ballistic missiles fashioned to perform a hostile role. Several leading officials in the Department of Defence questioned the wisdom of this choice, but the decision held firm. The Army, with chief Project Orbiter protagonist von Braun, argued that it could get a satellite into orbit by January 1957 and 'since this is the date by which the USSR may well be ready to launch, US prestige dictates that every effort should be made to launch the first US satellite at that time.'

Perhaps the decision was made because the President believed that the satellite programme should be 'deliberately separated from our ballistic missile efforts in order, first, to accent the scientific purposes of the satellite and, second, to avoid interference with top priority missile programmes. . . . Our satellite programme has never been conducted as a race with other nations.' Perhaps the truth was expressed by the House of Representatives in a fiscal appropriations document which said that, 'The Vanguard (the name given to the Navy Viking based concept in 1956) programme was conceived in preSputnik 1955, in an aura of unwarranted, but nonetheless real, national complacency concerning the technical supremacy of the United States. It was planned as a comparatively low level, economical effort and was not to interfere with the ballistic missile development.'

Reports had consistently warned of the imminent availability to the Russians of a Soviet-built satellite launcher and Lloyd V. Berkner, once Chairman of the Space Science Board at the National Academy of Sciences, offered the view that, 'Our policy makers seem to have had no appreciation of the international reaction that would follow the accomplishment of the Scientific feat.' In this he was correct. Almost immediately the 9 September decision was made, von Braun conceived a four stage version of the basic Redstone, with the assistance of Major General John B. Medaris at the Guided Missile Development Division, Redstone Arsenal; just months later, Medaris would head the Army Ballistic Missile Agency when it formed on 1 February 1956. Actually, the von Braun–Medaris proposal was essentially a Jupiter C, three stage missile with a fourth, solid propellant, stage added.

The Office of the Chief of Ordinance informed the Quarles Advisory Group of their displeasure at selection of the Navy proposal which would, in effect, demand the development of a completely new launch vehicle, based only loosely on the existing Viking rocket. The Army already had three stages of a four-stage launcher in the form of Jupiter C and could, they said, prepare the necessary hardware in less time than it would take the Navy to send the first satellite into orbit. The new proposal was turned down yet again.

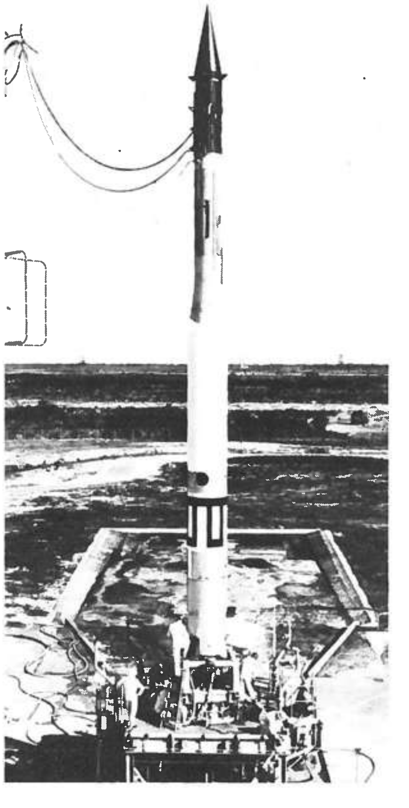
Shortly after announcing selection of the Navy project, the Department of Defence provided the necessary authorization to move ahead with development. By March 1956 the management structure, with John P. Hagen from the Naval Research Laboratory as programme manager and Milton Rosen from the Viking programme as technical director, was well established and the preliminary specification for Vanguard had been settled. The Martin Company would supply the first stage and General Electric would develop the single 12.7 tonne thrust rocket motor, an increase of 39% on the thrust of the basic Viking, with Aerojet-General contributing the liquid propellant second stage; the alternative NRL concept, whereby the Aerobee-Hi liquid propellant rocket would constitute the second stage, had been dropped. The Grand Central Rocket Company would develop the third stage in cooperation with the Allegheny Ballistics Laboratory and Minneapolis-Honeywell were responsible for guidance equipment. Thrust for the liquid propellant second stage and the solid propellant third stage was 3.4 tonnes and 1.4 tonnes respectively. The total assembly, 21.9 metres tall, would be capable of orbiting a satellite weighing 1.4 kg.

But still Medaris and von Braun hammered away at the Department of Defence for authority to go ahead with their own Jupiter C, four-stage concept and twice in 1956 were turned down. Washington had closed its ears to further discussion, let alone consideration, of the proposal and put its faith firmly in the hands of the National Academy of Sciences, who structured the programme, and the National Science Foundation, who contributed the funds. Vanguard was the only access route to space, and that was that. In a strange sequence of events the Army Ballistic Missile Agency forced the Pentagon to secretly confess its embarrassment at the prospect of administering the space orientated research programmes of the United States.

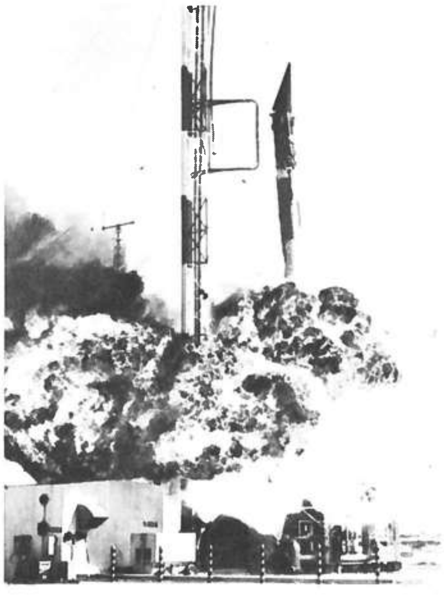
Without a clearly defined military objective for space, the Department of Defence felt itself to be a caretaker for somebody else's concoction and had it not been for the International Geophysical Year, it is doubtful if it would have allowed its institutions to work on the project. As it was, the Navy was in charge of Vanguard development, but direction and money came from civilian bodies, the National Academy of Sciences and the National Science Foundation, mentioned earlier. Then, on 20 September 1956, the first Jupiter C test vehicle propelled itself more than 4,800 km down the Eastern Test Range from Cape Canaveral. With an inert fourth stage, it would have been capable of placing a satellite in orbit; the performance was adequate for the task, only the trajectory was constrained by the need to conform to Pentagon wishes and make a purely ballistic flight.

Then, again, on 15 May 1957, a second Jupiter C got off the pad and with two successful launches in the bag, the ABMA kept up its pressure on the Department of Defence. Vanguard was still in the development stage, but Huntsville was already flying a potential satellite launcher. By this time the press was showing increased interest in the satellite project and ABMA representatives, spurred on by von Braun and Medaris, extolled the virtues of their Jupiter C. Although the two Jupiter C flights had been a part of the agreed development programme for testing nose cones that would be fitted to Thor and Atlas missiles, the successful performance seemed to irritate the Pentagon. The ABMA had been vocal on the possibilities of using Jupiter C as a satellite launcher and now the public were being shown how easy it would be to use the military project for space.

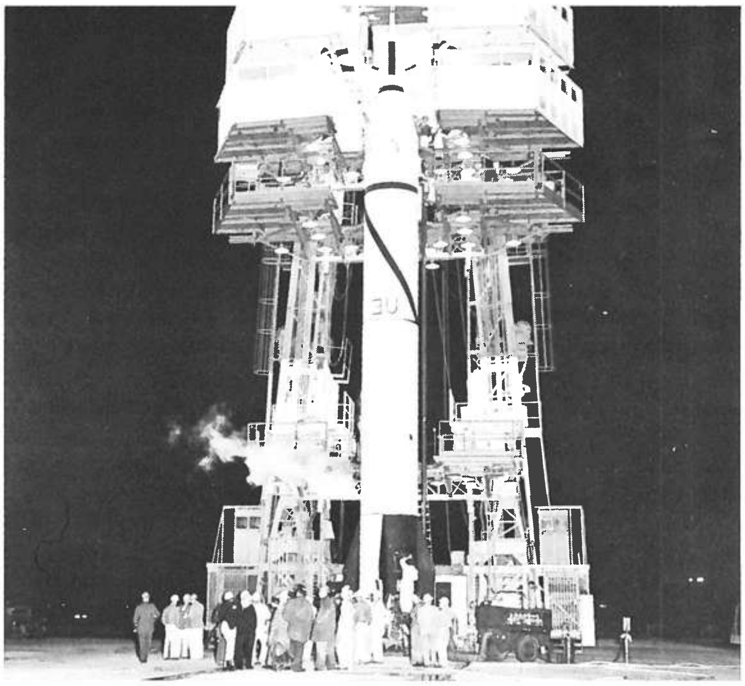
Consequently, on 29 July 1957, the Department of Defence issued an order to the three armed services: 'Recent news stories which have described certain projects as space flight projects have resulted in unfavourable reactions at DoD and congressional level. In any speeches or public releases planned by you or your staff avoid the mention or the discussion of space, space technology and space vehicles.' The Pentagon had been forced to affirm its displeasure.



Anticipation. 6 December 1957, and the US Navy Vanguard TV-3 stands ready for launch at Cape Canaveral during the attempt to place the first US satellite in orbit.



Disaster. Vanguard TV-3 explodes in its own ball of fire as the first attempt to place a US satellite in orbit fails seconds after ignition on 6 December 1957.



Success. A Jupiter C (Juno I) stands ready at Cape Canaveral shortly before placing the first US satellite in orbit on 31 January 1958.

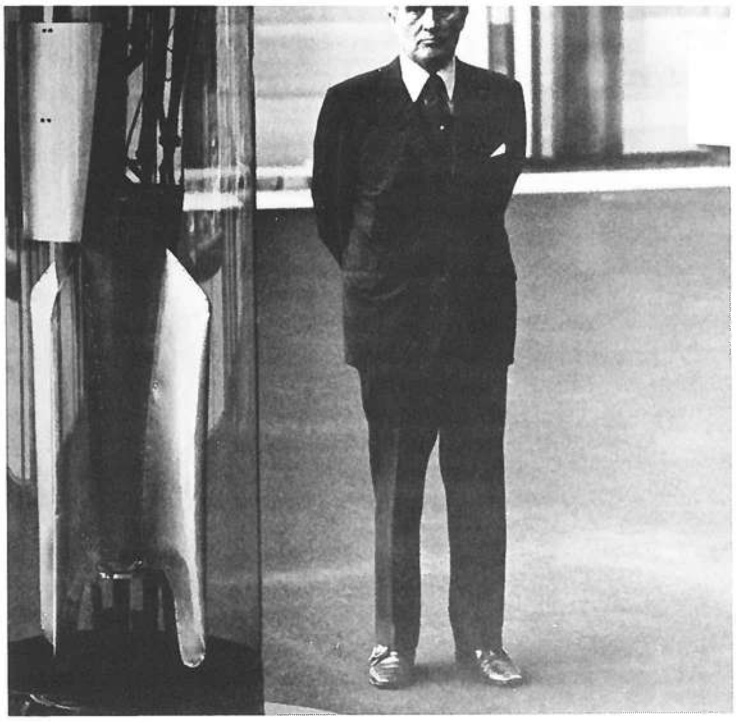
Meanwhile, the Vanguard programme moved ahead. Two flights with Viking rockets had been performed, one on 8 December 1956, the other on 1 May 1957, to check out equipment in support of the Vanguard satellite launcher. On 8 August, another Jupiter C shot succeeded in sending its payload down the Eastern Test Range, rubbing more salt into the wound. Then, on 23 October, less than three weeks after Sputnik 1 became the world's first artificial satellite, the first Vanguard launch was performed. It was a successful test of the first stage and prepared the way for the launch of an American satellite. On the same day a three-day meeting began at Fort Bliss, Texas, in which von Braun and Medaris, from the ABMA, discussed the prospects for a national space programme with the Army Scientific Advisory Panel. The product of these deliberations will be discussed in the following chapter. During its earlier attempts to get approval for adapting Jupiter C to a satellite launching role, the ABMA had proposed a six-vehicle programme and in the wake of the shock that moved through the nation as a result of the launch of Sputnik 1, the Secretary of the Army, W. M. Brucker, reasserted ABMA interest in the proposal.

Two days after the end of the Fort Bliss meeting, on 27 October, the Advisory Group on Special Capabilities, under Homer J. Stewart, approved Army plans for the launch of two artificial satellites using the modified Jupiter C, now, in its four-stage configuration, to be known as Juno 1 – a last gesture at dislodging its affiliation to a military rocket. The wave of change had broken over Washington and time was of the essence if the world at large was to see American technology at work. Sputnik 1 had been the final spur. Less than two weeks later, on 8 November, Secretary of Defence McElroy authorized the two-satellite programme with the first launch in March 1958. Before the end of the month the sum of $3.5 million had been authorized and the planned launch date had been pushed up to 30 January. The race for space was on. But as an ironic product of the lack of foresight displayed since the cancellation of Project Orbiter two years before, the event was staged between Vanguard and Juno I.

The first attempt to get the Navy project into space ended ingloriously on 6 December, when Vanguard TV-3 crumpled into a ball of fire at its Cape Canaveral launch pad. As the weeks ticked away, Redstone Arsenal erupted into a frenzy of activity. Calling upon the Jet Propulsion Laboratory for assistance, the ABMA organized a responsive team of assistants, drawn largely from its own resources, and moved toward the preparation of Explorer 1, the name given to the Army satellite, and the Juno 1 launcher. On 31 January, one day behind schedule, but just twelve weeks to the day since authorization by the Secretary of Defence, Cape Canaveral resounded to the rocket plume of the ascending launch vehicle and Explorer 1 was on its way into orbit. The space age had begun.

CHAPTER NINE.

The Race for Space



Dr. Wernher von Braun whose stoic determination gave him a leading role in the development of rocketry in two countries across four decades.

If America was slow to appreciate the propaganda value of satellites, it was quick to put its house in order and exploit the new frontier. Just two months after the launch of Sputnik 1, in October 1957, the Office of Research and Intelligence at the US Information Agency, issued a classified report summarizing the impact of the Soviet initiative on public attitudes in Western Europe. They found that in Great Britain, West Germany, France, Italy and Norway, all persons spoken to had heard of the successful Soviet satellite and that between 78% and 96% could name the vehicle. A second report, in February 1958, went further. In its foreword, the second document said that 'The surveys on which both studies are based were conducted between 15 November and 1 December 1957. High-speed preliminary reports of the major findings were provided to American representatives at the "summit" NATO conference in Paris in December, in time to be used as background for the negotiations in that conference. Timing of the surveys was advantageous for assessing the effects of the sputniks on public opinion. The surveys took place after both of the two Soviet satellite launchings (on 4 October and 3 November 1957), and long enough after the first one, to reflect considered judgements rather than first-blush reactions. At the same time, they occurred soon enough after these events to represent their effects in a relatively unmixed, unambiguous way, uninfluenced by later events such as the failure of the American Vanguard launching, the successful launching of Explorer, and the Paris meeting itself.'

Here, at last, was recognition of the fundamental role that satellites would play in structuring world opinion and influencing popular views on the ability of the United States to offer a protective umbrella in the absence of a national, autonomous, defence capability. The substance of this second report was centred on one simple question: 'At the present time, do you personally think that (survey country) should be on the side of the West, on the side of the East, or on neither side?' The findings were presented as a percentage part of the polled citizens that positively affirmed their confidence in siding with 'the West', which in this specific case meant the United States. The figures were examined for the period between May 1957, long before public opinion was ready to accept the imminent launch of any satellite, to November 1957, embracing the launch of Sputniks 1 and 2.

It was found that before the Russian satellites, 40% of West Germans approved of siding with the United States, while only 35% felt the same after the Russian launches. In Great Britain, opinion ran to little more than 10% in favour in May 1957 and to nearly 30% in favour by November. Norway and Italy were less sure, while France was publicly in favour of siding with the East. Although the spur to satellite development had undoubtedly come as a result of the International Geophysical Year, a period of scientific study of the Earth and its environment, the relationship of this ostensibly peaceful pursuit to significant military prestige was immediately apparent. The report concluded that '. . . from the standpoint of strengthening NATO the findings are far from encouraging. The situation could be described as a "crisis of confidence" rather than a continuation of a long-standing lukewarmness of attitudes toward NATO and lack of any real sense of urgency about the need to contribute to its strength.' It did, however, note that, 'Great Britain is the only country showing an increase in solidarity with the West during a six-month period that included the satellite launchings.'

Reports such as these would continue to influence policy-makers in Washington throughout the next decade of rocket developments. But the Army Ballistic Missile Agency at Redstone Arsenal, Alabama, had already moved far ahead of political initiatives, with proposals for a large rocket that could be used for sending heavy payloads into space. As early as 1956, principally at the behest of Wernher von Braun, the ABMA studied follow-on vehicles to the existing series of Redstone and Jupiter medium and intermediate range ballistic missiles. Recognizing that a space capability would probably require a unique launch vehicle developed apart from purely military rockets, the Alabama team put together a plan for using basic Redstone and Jupiter elements to build a large clustered-engine booster. Propulsion would be provided by four rocket motors of a type to be developed from the Rocketdyne engines previously designed for Jupiter and Thor missiles. With an increase in unit output, the launch vehicle would provide a first stage thrust of more than 680 tonnes, three times the power of the most advanced stage then under development.

It was an ambitious proposition and one that had little application to the military requirements for a ballistic missile. If built, the 680 tonne thrust rocket would serve as a satellite launcher and as such it represented one of the first

The Russian V5V research rocket, an example of early post-war interest in atmospheric science.

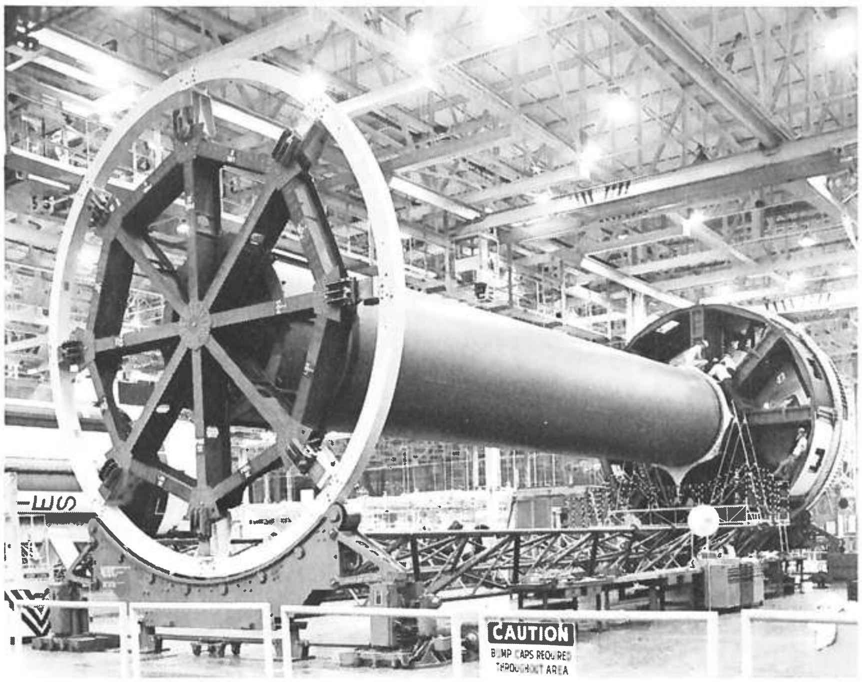
practical attempts to build a launch vehicle specifically intended for space operations; Juno 1, used to launch Explorer 1 on 31 January 1958, and Vanguard were outgrowths of the Redstone medium range ballistic missile and the Viking sounding rocket, respectively. But the singularly unique aspect of the proposal came not so much in the clustered engine concept, but rather in the manner in which it was designed to capitalize on existing developments; the concept envisaged a single liquid oxygen tank around which would be clustered eight more tanks of the same length , but smaller diameter, with four carrying liquid oxygen and the remaining four carrying kerosene fuel; the single tank in the centre would be fabricated from the same tooling used for the Jupiter IRBM, while the other eight tanks would use Redstone MRBM tooling. At the base, four Rocketdyne E-1 engines, each delivering a thrust of about 170 tonnes, would provide the energy.

The E-1 was first built in 1956 as a research development project at Rocketdyne. But it was a considerable advance on the 68 tonne thrust motor developed for the basic Jupiter and as such represented a major new development. By April 1957, the ABMA had begun to apply considerable effort to the von Braun proposal and it was one of the prime subjects of discussion at the three-day meeting, held at Fort Bliss, starting 20 October (see Chapter Eight). On 10 December 1957, the ABMA submitted a document detailing the essential characteristics of *A National Integrated Missile and Space Vehicle Development Programme*, pointing out the obvious advantages of the big clustered launch vehicle. The proposed development programme envisaged a funded start in 1958, followed by thirty test flights up to 1963, at which time the big rocket would be ready for operational use. The ABMA report concluded that 'Development of the large (680 tonne thrust) booster is considered the key to space exploration and warfare.' It is not too clear just how the massive vehicle could assist with national defence. The sheer size of such a behemoth would render it unsuitable for use as a quick-reaction missile capable of delivering a nuclear warhead.

Four days after the ABMA report was completed, General Medaris, its chief, testified before the Preparedness Subcommittee that, 'Unless this country can command 450 tonnes of thrust by 1961, we will not be in space. One of the great holes in the ballistic missile business today is that there is no big thrust ballistic engine or rocket engine under development.' This was certainly true. While America was still trying to get the Vanguard rocket off the launch pad and put its 1.4 kg payload in orbit, with the Juno 1 launcher now brought in as a second-shot contender with its own 14 kg satellite, the Russians sent up Sputniks 1 and 2 weighing 83 kg and 508 kg respectively. Although details of the Soviet launch vehicle were unknown at this time in the west, it was apparent that to put loads of this weight in orbit required a first stage thrust of at least twice that generated by the Atlas and Titan ICBMs.

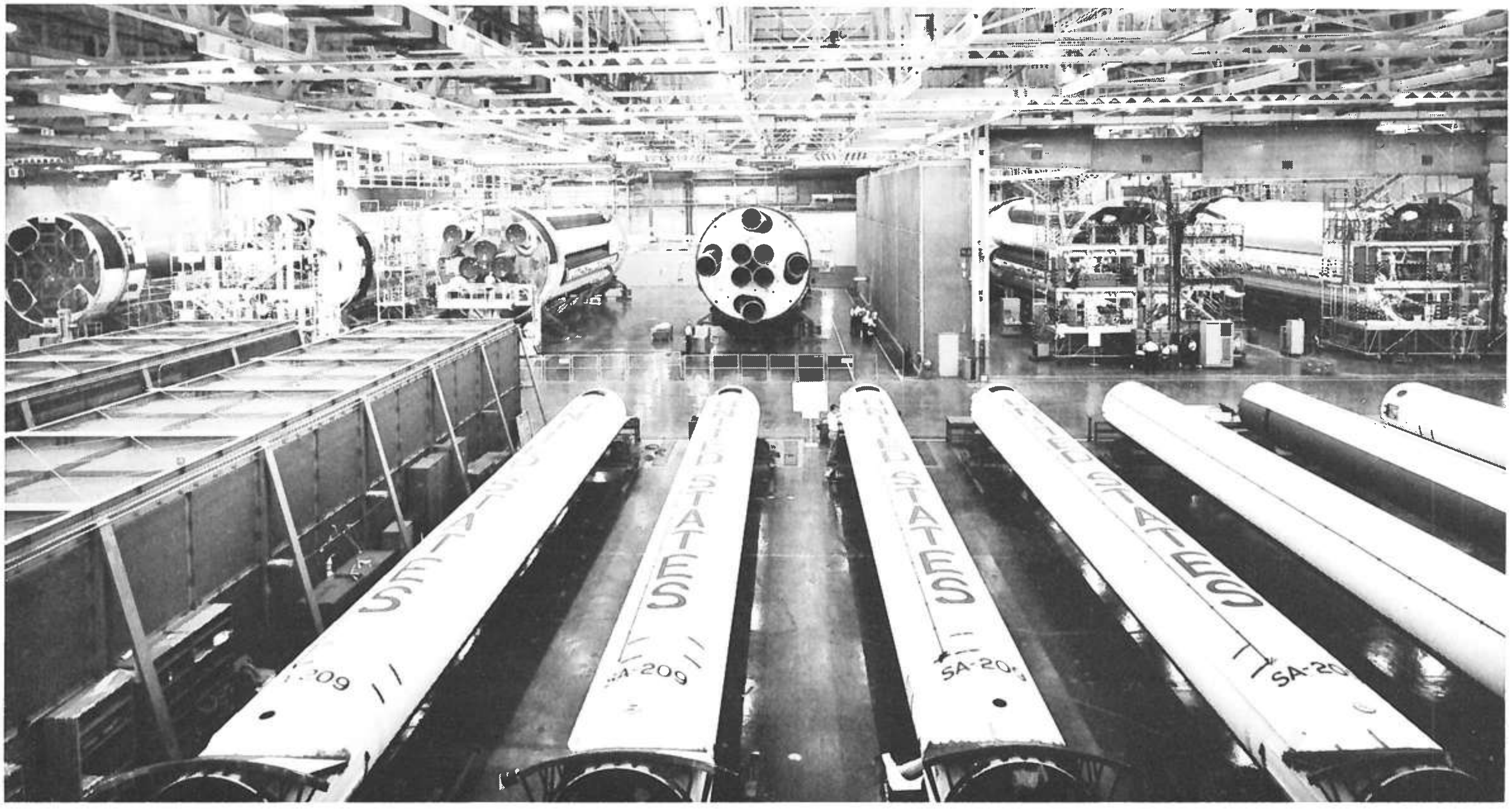
Von Braun added at the same meeting, 'Powerful rocket engines are a basic requirement for the conquest of space. We have pretty sound proof that the Russians have in single units, engines that are many times stronger than the most powerful engine we have in this country, and that they have an even more powerful engine under active development.' Turning to General Medaris, the Subcommittee asked for details of the Rocketdyne E-1, capable of delivering a thrust of at least 170 tonnes, and information as to why it had not been put on a higher priority rating. His response – 'It disappeared in the Department of Defence' – summed up the mood. No-one knew how to implement a vigorous programme aimed at improving the lifting capability of military rockets.

There was very little awareness of the military role in space and because of this it was left to individuals with foresight, to oil the wheels of machinery that could mobilize large programmes at government level. On 23 January 1958, just eight days before Juno 1 placed Explorer 1 in orbit as America's first artificial Earth satellite, the Preparedness Subcommittee completed its hearings on the recommended posture of the future space programme. In submitting its findings to the Senate, it urged immediate work towards the development of large liquid propellant rocket motors, pointed out the deficiencies in the methods used at that time



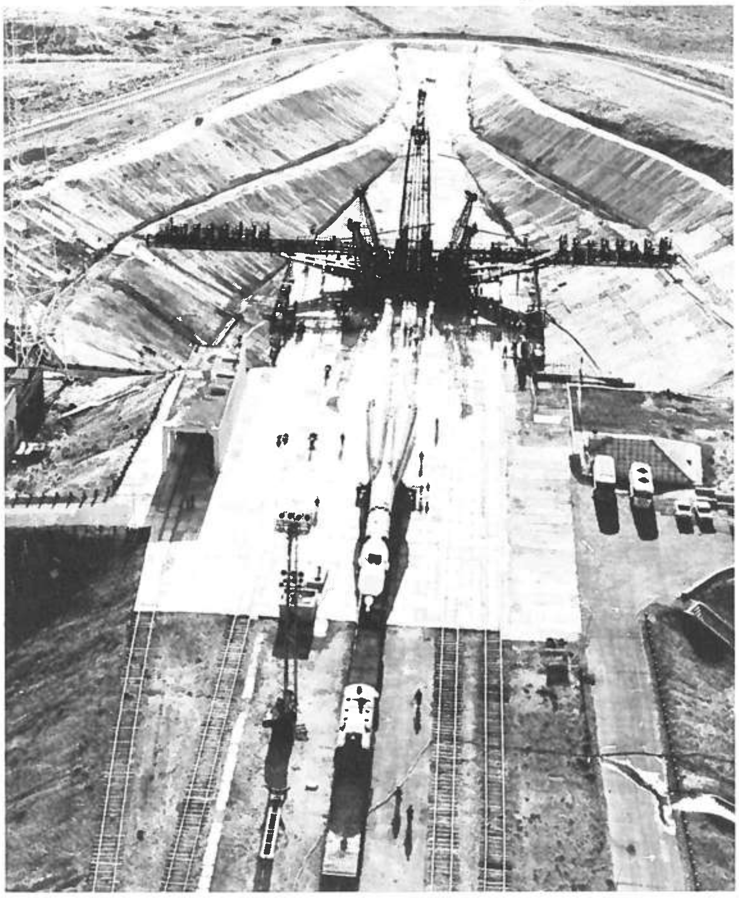
The clustered booster concept that envisaged a central liquid oxygen tank with a spider ring at one end and thrust structure at the other.

Eight cylindrical propellant tanks would surround the central oxygen tank in the clustered booster concept. In the foreground, several tanks are laid out preparatory to assembly. At back, assembled boosters are in a production-line sequence from left to right.



Service masts and access platforms surround this Soviet rocket launched for scientific research.

A Soviet A-2 launch vehicle is moved to the launch platform by rail.



to implement new government projects and concluded that the Department of Defence should play a more vigorous role in structuring long term goals. Just a few months earlier the concept of an Earth satellite was seen as the justification for orbital research. Now, with the Russians launching much heavier payloads than anything planned by the United States, weightlifting capability was the steering influence in future policy moves. Just as the prestige value of Earth satellites had provided able demonstration of creditable levels of technical development, so would the payload weight value demonstrate technical prowess.

Exactly one week after Explorer 1 rocketed into Space on the shoulders of the converted Redstone MRBM, the Secretary of Defence, Neil H. McElroy, authorized establishment of the Advanced Research Projects Agency (ARPA) to control and assume responsibility for the existing, and any future, space programmes. There had emerged from the Senate Preparedness Subcommittee hearings a suggestion that space activities should be controlled by a totally separate organization and Congress ratified the decision to form the ARPA, on the understanding that the Department of Defence would control space activities for a period not exceeding one year. This would give the House of Representatives and the Senate ample time to decide who should look after the nation's space programme. Already, feeling was running high in Congress that the DoD had mismanaged its affairs in letting the Soviet Union place Sputnik 1 in orbit before an American satellite. There was almost universal approval for a new, civilian controlled, organization and Washington strengthened its interest in structuring the decision-making process by setting up House and Senate space committees.

But already the urgency in structuring new directives for science and technology as a result of Sputnik 1 had, by December 1957, moved President Eisenhower to establish the Office of Special Assistant to the President for Science and Technology, taking the Science Advisory Committee from the Office of Defence Mobilization and placing it under the authority of the White House. This brought a name change and the SAC became the President's Science Advisory Committee, or PSAC, with James R. Killian, Jr., its first Special Assistant and, later, Chairman. This moved the programmatic control of space programmes nearer to Presidential responsibility and, with the ARPA serving as the Department of Defence outlet for space technology, ensured that Eisenhower could 'act promptly' to eliminate 'unnecessary delay in our development system.' The Office of Special Assistant to the President for Science and Technology had been urged upon the administration, by a privately funded body, called the President's Commission on National Goals. This had been set up in response to the Sputnik to recommend a strategy which would prevent further lack of goal orientation from exorcizing American prestige in like manner to that which made Explorer 1 second runner to Sputnik 1.

It was becoming abundantly apparent that a fundamental lack of coherent policy had forced America into second place. When Killian was introduced to Congress in this new role, Eisenhower said that he would 'have the active responsibility of helping me follow through on the programme of scientific improvements of our defences.' Congress responded to these organizational changes by increasing the budget appropriations to the National Science Foundation by 300%. Almost immediately upon formation of the PSAC, meetings with the President and the National Security Council resulted in formulation of a document titled *Introduction to Outer Space*, which set itself the task of defining the value of a space programme and structuring a broad set of objectives. It began by asking 'What are the principal reasons for undertaking a national space programme' and went on to cite the 'compelling urge of man to explore and to discover', the 'wish that space is not to be used to endanger our security', the belief that 'To be strong and bold in space technology will enhance the prestige of the United States' and the assumed fact that 'space technology affords new opportunities for scientific observation and experiment which will add to our knowledge and understanding of the earth, the solar system, and the universe.'

In short, it expressed a belief that national space programmes were a consequential outgrowth of a maturing society and should be embarked upon by the United States simply because it fell to that country to be in the vanguard of progress and technology. It was not a belief that had found wide support until Russian initiatives forced the hand of Congress; no-one was seemingly prepared to argue whether or not there should be a space programme at all, merely to debate the size of the operation. The PSAC document was published on 26 March 1958, and it was this august body, along with the Senate Preparedness Subcommittee, chaired by Senator Lyndon B. Johnson, that effectively moved for establishment of a new federal agency dedicated to future space projects.

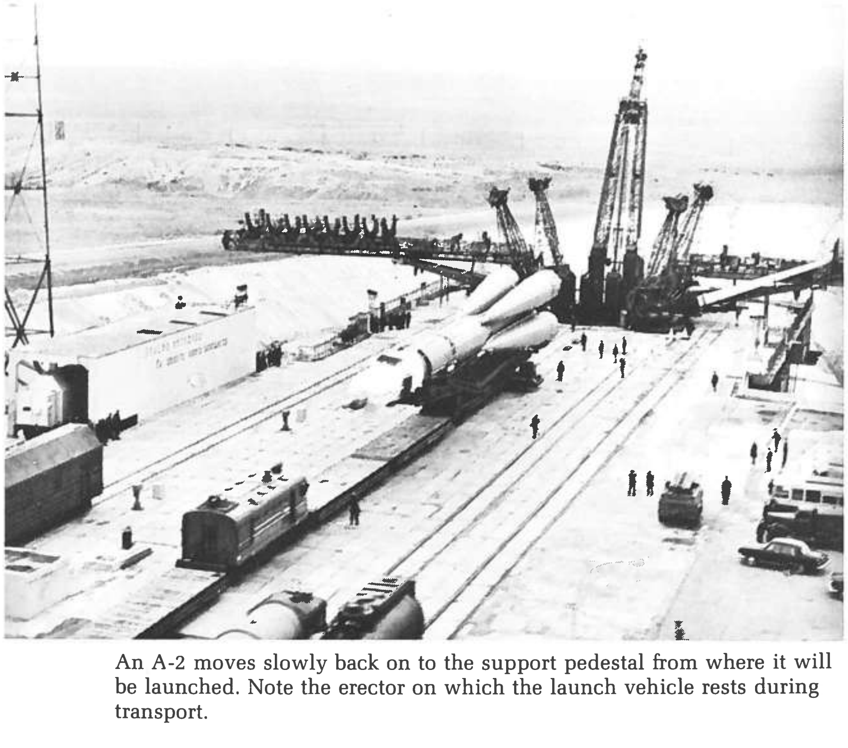
The principal reasons for developing a civilian agency were rooted in the politics of international relations. Already the proposed emphasis on space activities was seen as a valuable tool for propaganda and it was observed that the Russian effort had been inexorably tied to military developments. The American administration was not slow to realize that third-world influence would probably achieve higher levels of success, if an increasing committment to space technology was visibly related to ostensibly civilian objectives. Although it was argued that Russia would probably respect an American space programme based on military decisions more than one preoccupied with pure scientific research, the general concensus of opinion held the view that depressed communities thoughout the world, would more properly endorse peaceful goals in that they could identify with these more than national defence.

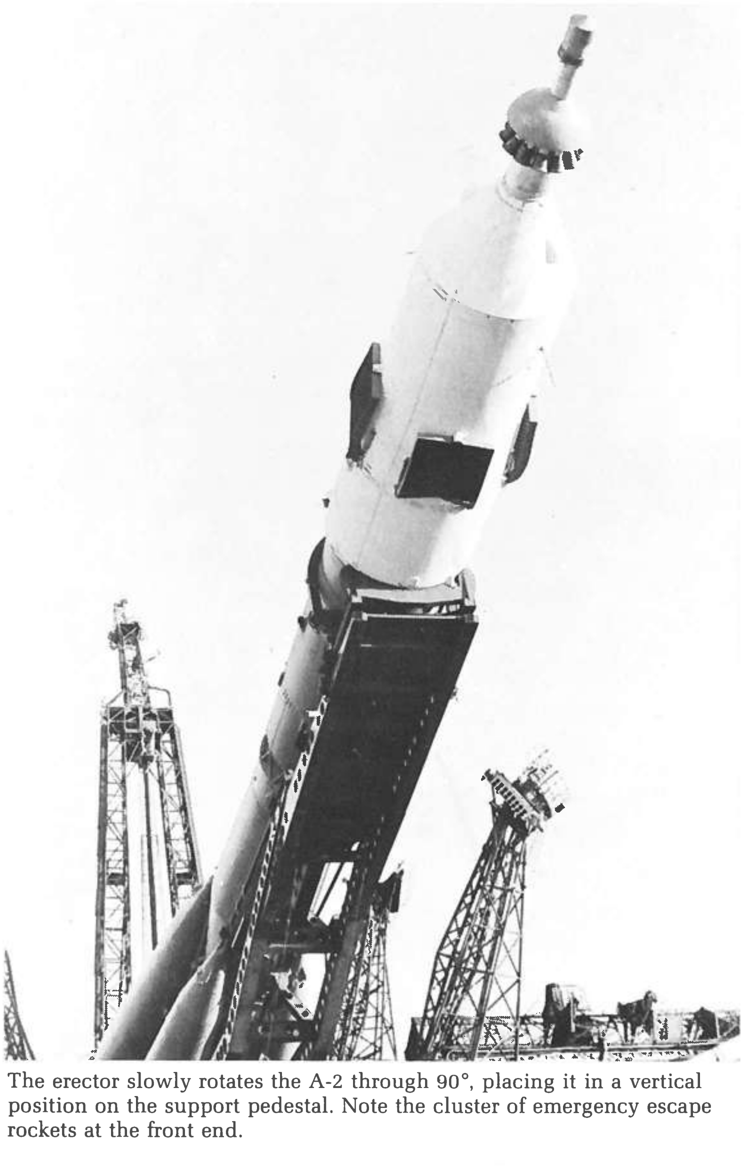
Both Johnson and the PSAC, the former chairing Senate hearings on legislation, unquestionably assumed that any emergent space agency would be civilian controlled and have non-military objectives. In effect, this would provide an instrument for public space spectaculars, while the Department of Defence conducted its own space activities in the background of reported events. But there were good reasons too for wanting space operations taken from the Department of Defence in all but those projects specifically developed for national security. President Eisenhower, personally committed to establishing a civilian space agency, pointed out that it would ensure 'the fullest cooperation of the scientific community at home and abroad' and that 'a civilian setting for the administration of space . . . will emphasize the concern of our nation that outer space be devoted to peaceful and scientific purposes.' He did not deny the importance of space for future military activities, although few could point to an obvious advantage for defence, other than the propaganda value, but felt that it would provide a better climate within which to mobilize the resources of the nation's scientists and engineers. Sensing that the argument over civilian or military orientation could rekindle the anguish expressed over development of the Hydrogen Bomb, Eisenhower firmly supported a peaceful goal structure to placate dissident scientists.

Accordingly, on 2 April 1958, the President presented the National Aeronautics and Space Act for ratification by the House of Representatives and the Senate. It envisaged transforming the existing National Advisory Committee for Aeronautics (NACA) into a National Aeronautics and Space Administration (NASA), the former chaired by James H. Doolittle and directed by Hugh L. Dryden. Almost immediately the Department of Defence called for clarity on the precise lines of demarcation between projects controlled by the proposed NASA and those to be administered by the armed services. Under the prevailing structure, NACA was responsible for conducting research, laboratory tests and scientific analysis, while the Department of Defence had firm control over funded programmes and adopted project authorization. Several leading figures at the Pentagon wanted to see this structure maintained, others were prepared to allow NASA to gain control of all projects which carried no immediate military potential. Moreover, argument broke out between the White House and the two Houses of Congress over the language of the proposed Act. Both Houses used their respective space committees, recently set up to play a steering influence in space affairs, to iron out the differences and it was left to a joint conference committee to approve the final text.

On 29 July, President Eisenhower signed into being Public Law 85-568, the National Aeronautics and Space Act of 1958, which effectively provided for termination of the old NACA and the establishment of the new space agency – NASA. But even this did not totally clarify the roles to be performed by the new civilian agency and the Department of Defence. It merely said that space programmes 'shall be the responsibility of, and shall be directed by, a civilian agency . . . except that activities peculiar to or primarily associated with the development of weapons systems, military operations, or the defence of the United States (including the research and development necessary to make effective provision for the defence of the United States) shall be the responsibility of, and shall be directed by, the Department of Defence.' There would be continued debate over who had responsibility for what in the first few years of NASA's existence.

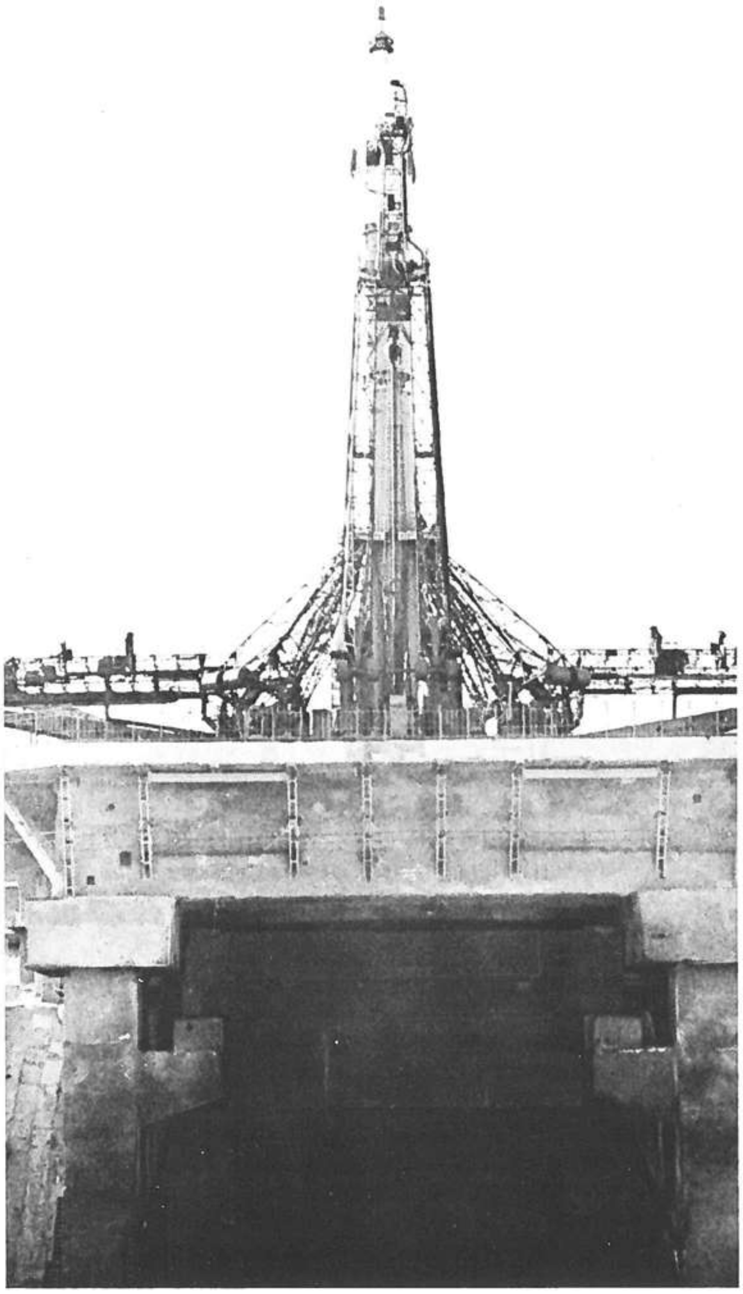
Before the Act became law, as early in fact, as April 1958, NACA Director, Hugh L. Dryden, asked Abe Silverstein, then assistant head of the NACA Lewis Laboratory, to take charge


An A-2 moves slowly back on to the support pedestal from where it will be launched. Note the erector on which the launch vehicle rests during transport.


The erector slowly rotates the A-2 through 90°, placing it in a vertical position on the support pedestal. Note the cluster of emergency escape rockets at the front end.

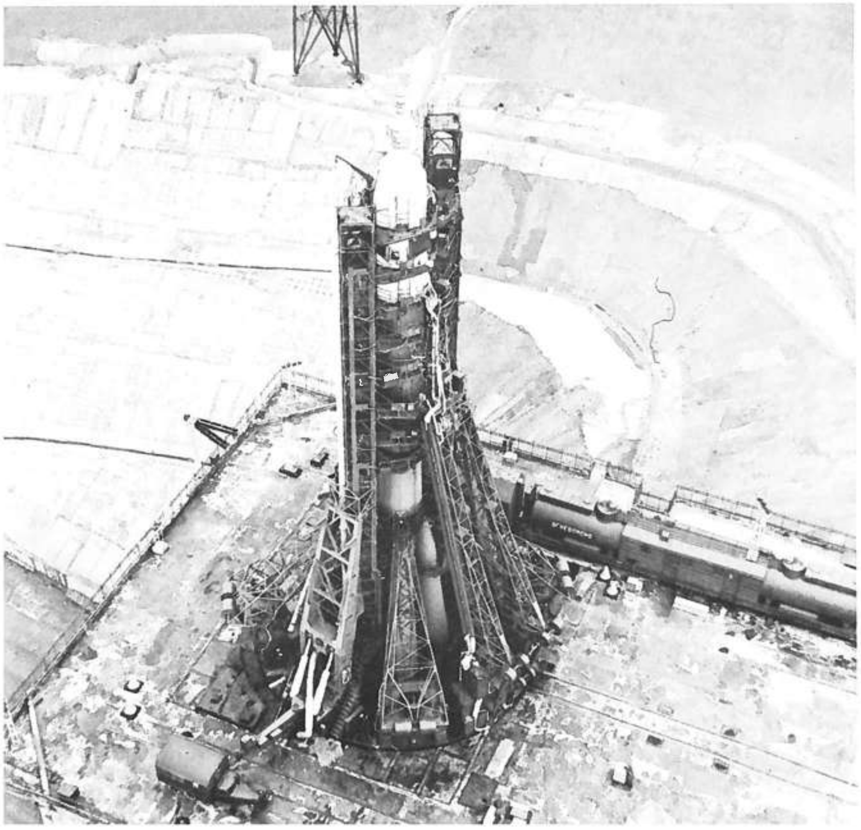
of structuring the transition and provide a new organizational pyramid for the agency. On 19 August, T. Keith Glennan, was sworn in as the first NASA Administrator along with Dryden who would act as Deputy Administrator. Glennan had been in charge of the Atomic Energy Commission and at the time of his new appointment was President of the Case Institute of Technology. On 1 October 1958, NASA formally replaced the NACA and took over the facilities at Hampton, Virginia, Moffett Field, California, Cleveland, Ohio, and Edwards Air Force Base, California, re-named as the Langley Research Centre, the Ames Research Centre, the Lewis Research Centre and the Flight Research Centre, respectively. NASA also had control of the launch site at Wallops Island, Virginia. In all, 8,040 personnel now embraced the NASA organization. At Headquarters in the Dolley Madison House, Washington, DC, Glennan addressed the 170 staff members and announced that, after forty three years, the NACA was no longer in existence and that a new mandate was written for vigorous pursuit of the nation's civilian space activities.

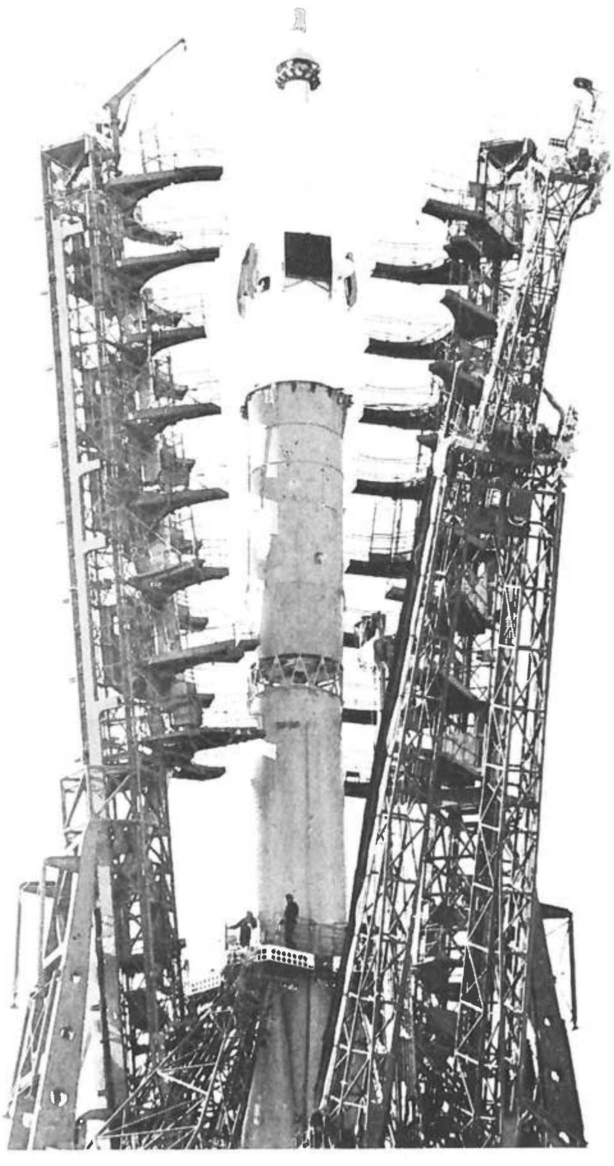
On the same day, the Executive Office of the President signed over control of the Navy Vanguard project and existing programmes from the Air Force and the Army. One of the first actions by Glennan was to hand back administration of these, so that NASA could organize its affairs before accepting responsibility. But the Army had already consolidated its own position to smooth development of new guided missile systems and on 31 March 1958, set up the Army Ordinance Missile Command (AOMC) with headquarters at Redstone Arsenal under General Medaris. Under the new Command, the Army Ballistic Missile Agency and the White Sands Missile Range in New Mexico were directly subservient to the



Support arms hold the A-2 in a vertical position while service masts extend along the full length of the launch vehicle. Work platforms are carried on the two horizontal arms that will soon be raised for final checkout.

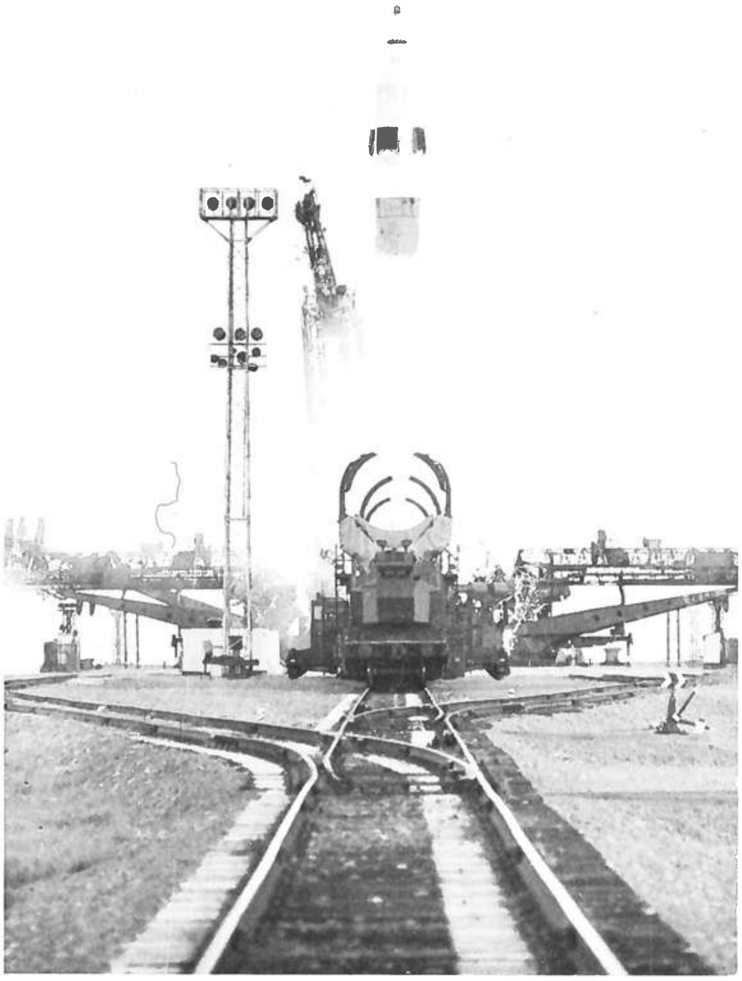
Service masts and work platforms cluster around the A-2 in the final hours before launch of a manned Soyuz spacecraft (covered by a white shroud). Note the hydraulic rams on the base of the work platform structure and the barrel-shaped counterweights on the support arms that grip the top of the first stage.



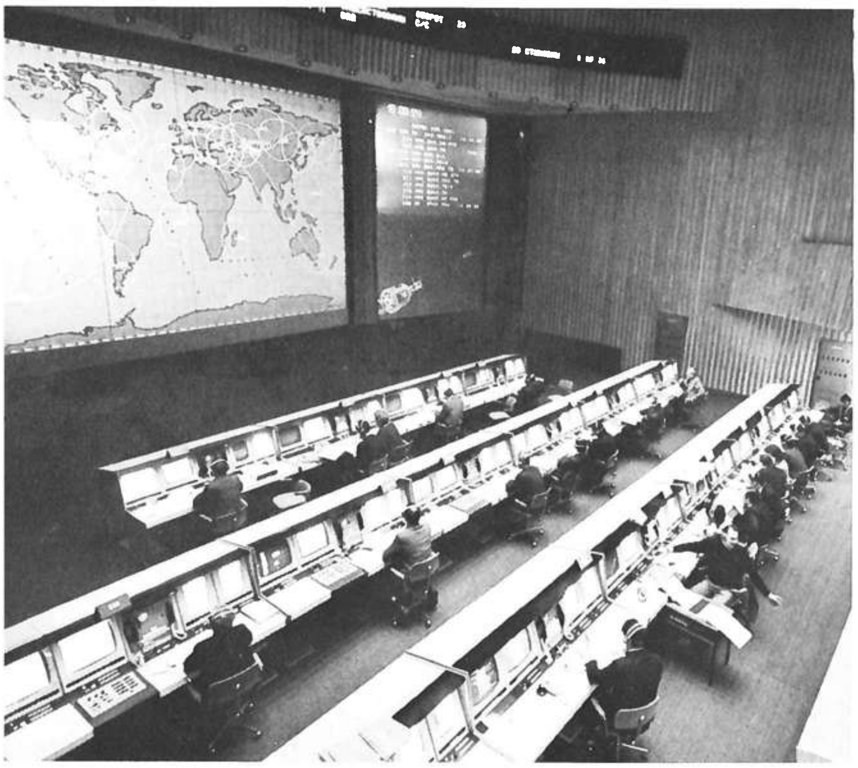


The single service mast, and the two work platform structures, are lowered shortly before an A-2 is launched. The top of the launch vehicle support arms carry small platforms on which two engineers can be seen. Note the truss structure that separates the first and second stages, the white shroud over the Soyuz spacecraft and the cluster of small rockets at the top that will wrench the spacecraft away from the second stage in the event of a malfunction.

Ignition! Work platforms and service mast are in the lowered position while, faintly visible amid the smoke and flame, support arms still hold the launch vehicle, seconds before lift-off.



A large plot-board dominates this view of the Soviet control centre.



AOMC. In addition, AOMC also embraced the Army Rocket and Guided Missile Agency (ARGMA) set up on 1 April. But if NASA was to fulfil its obligations and gain authority for the peaceful space activities of the United States, it would have to extract key organizations from under the custody of the Department of Defence. Project Vanguard had been transferred intact to NASA along with the Naval Research Laboratory's Upper Atmosphere Sounding Rocket team under Dr. John W. Townsend, Jr. The Army, for its part, had an effective and strong work force at the Redstone Arsenal where von Braun had developed Project Orbiter and, later, the Juno 1 launch vehicle.

The Army Ballistic Missile Agency had proved itself to be in the forefront of missile and satellite-launcher developments and had contracted the Jet Propulsion Laboratory in Pasadena, California, for assistance with the preparation of Explorer 1. NASA wanted both groups under its umbrella and on 10 October 1958, Glennan and Abe Silverstein visited the Secretary of the Army, Wilber M. Brucker. Their request was simple: direct transfer of those elements of the AOMC that were dealing with space projects and jurisdiction over the Jet Propulsion Laboratory. Brucker refused to make a decision and asked Glennan to prepare a written memorandum for review by the Secretary of Defence. This emerged five days later when the NASA Administrator reminded McElroy that 'As you know, the technical responsibility for the clustered-rocket project has not yet been decided. NASA should acquire at the earliest possible date a developmental and operational capability for large space vehicles. This capability exists at ABMA working with the Jet Propulsion Laboratory.'

The requirements foreseen by Glennan would not demand immediate transfer of the entire ABMA work force, but special mention was made of the Development Operations Division headed by von Braun. NASA would need about 2,100 scientists and engineers at ABMA, out of a total Army complement of 3,800 then working in ten facilities controlled by the Division. Brucker responded to this by claiming that if more than half the ABMA Development Operations Division was transferred to NASA, it would severely curtail Army missile programmes and retard the overall objectives of the space programme by two years. Instead, he proposed a 'cooperative agreement between the NASA and the Department of the Army' whereby the Jet Propulsion Laboratory would be taken over by the space agency, with an understanding that the relevant sections of the AOMC, particularly the ABMA, would assist NASA with its present and future objectives.

A day later, on 6 October, Glennan again met Brucker and handed him a copy of the letter issued to McElroy on the 15th. On 28 October, Brucker stiffened his opposition to an ABMA transfer, alleging that it would cause 'separation, division, and dissolution of Army facilities and personnel (which) would not be in the national interest.' The memorandum containing these words went to McElroy and the next day, the National Aeronautics and Space Council met to decide the fate of JPL and the von Braun team at Redstone Arsenal. The NASC had been formed under the 1958 Space Act and consisted of statutory members, the President of the United States as chairman, the Secretary of State, the Secretary of Defence, the NASA Administrator and the Chairman of the Atomic Energy Commission, together with no more than four others each appointed by the President. Its prime function was to convene and make recommendations to the President on strategic issues of space policy.

Exactly one week later, NASA officials met and discussed with the AOMC the machinery of the supposed transfer. At about this time, the then Bureau of the Budget, was structuring the language of the fiscal year 1960 budget request, which would go before Congress the following spring for ratification and/or modification so that it could be effective for the start of fiscal year 1960 on 1 July 1959. Under the American budget process operating at that time, the designated fiscal year began exactly six months in advance of the calendar year; when NASA came into formal existence on 1 October 1958, the United States was already in to fiscal year 1959. The fiscal year 1959 budget request, originally proposed in the spring of 1958 when the NACA was still operating, was for $106.7 million, but the supplementals inspired by the formation of NASA raised this to $405.8 million. In working out the fiscal year 1960 authorization, NASA tried to obtain funding for projects under development at the ABMA, in particular for work on the big clustered-engine launch vehicle described earlier in this chapter, but to no avail. The Bureau of the Budget had approved a request of $50 million for this project, but stipulated that it was still under the aegis of the Department of Defence and as such all funds should go to the Army and not to NASA. This was confirmed in a telephone call on 2 December from the Bureau of the Budget to Roy W. Johnson, head of the Advanced Research Projects Agency (ARPA) since its formation on 7 February 1958. Johnson had been particularly active in pressing for retention of funds for the clustered-engine launch vehicle. As it was, NASA would finally gain approval for fiscal year authorization of $490.3 million covering the period 1 July 1959, to 30 June 1960.

The National Aeronautics and Space Council meeting on 29 October had been unable to reach a final conclusion on the requested transfer of ABMA segments to NASA, although the Army's concurrence with the request for administration of the Jet Propulsion Laboratory was provisionally endorsed. A second meeting was called and this took place on 3 December, one day after the ARPA had secured Budget Bureau approval for the retention of funds for work on the clustered-engine rocket. Before the end of the day, Eisenhower had issued Executive Order 10793 transferring JPL, its facilities and the 2,300 personnel over to NASA. Glennan and Brucker signed an agreement approving full cooperation of the ABMA resources, but stipulating that control still remained with the Army through the AOMC. This made 'the AOMC and its subordinate organizations immediately, directly, and continuously responsive to NASA requirements.' For the time being NASA would have to accept jurisdiction of the JPL complex and forget administrative gains over the Army Ballistic Missile Agency.

Significant contributions had been made by the GALCIT and ORDCIT teams at JPL between 1936 and the end of World War II. These have been discussed in Chapter Five. But progress in solid propellant rocket technology continued at JPL in the postwar period and led to the first American radio-guided ballistic missile brought to operational status – Corporal. First, the JPL workers experimented with a polysulphide propellant, manufactured by the Thiokol company and used this as a replacement for an asphalt compound in attempts to produce a charge that would not crack under thermal stress. While early work on solid propellant motors required the charge to burn from the bottom end up, this brought a pronounced disadvantage in that as the charge was consumed, the casing became gradually exposed to more and more heat. Progress towards reducing the weight of the outer casing of the solid propellant rocket had already been achieved by increasing the strength of the charge, now it was necessary to devise a way in which the casing weight could be reduced still further and, at the same time, protect the cylindrical support tube from excess heat.

JPL developed the concept whereby the charge is first poured into the cylindrical mould and then hollowed out by a shaft sunk through the centre. When the propellant set hard, and the shaft was removed, the charge exhibited a hole of constant diameter running along its entire length, in effect turning the charge itself into a tube-like cylinder. Following emplacement in the support casing, and the attachment of external appendages such as nozzle, nose section and payload, the rocket burned along its entire length using the mass of the propellant as a heat sink for temperatures generated by the process of combustion. These two concepts have been called 'end-burning' and 'internally-burning' designs and adequately describe the operating functions discussed above.

Because only the exposed surface area of the solid propellant will burn the 'end-burning' concept allows a smooth steady thrust output as the combusting surface slowly moves toward the front end of the rocket. In the radial, or 'internally-burning' approach, however, the surface area increases as the internal hole gets larger with combustion. Because the measured thrust is proportional to the rate of combustion, and because the rate of combustion is directly related to the surface area, the thrust will steadily increase at a rate related to the increase in the surface area. Two major areas of technology had now advanced significantly on previous developments in solid propulsion. In the first, substitution of the asphalt propellant for a polysulphide compound, reduced the tendency to crack or break apart under stress and significantly lowered the internal chamber pressure; high chamber pressures in a solid propellant motor lead to thrust instability and, at worst, an explosion. In the second, the thickness of the motor case could be reduced because the burning surface only reached the case liner at the end of combustion.

Rocketdyne facilities in the mountains above California's San Fernando valley provide research stimulus for a new generation of US rocket engines.

But there was still the problem of thrust increasing as the surface area of the highly desirable 'internally-burning' concept grew larger. This was finally obviated by sinking a shaft in the form of a star-shaped mandril so that the surface area remained the same throughout the period of combustion. Instead of a hole of circular cross-section down the centre of the charge, a shaped burning area could be configured to not only precisely control the desired level of thrust (by altering the surface area of the star to suit specific requirements), but also to ensure a constant, or neutral burning, phase. Further developments at JPL led to the case-bonding method of propellant application, whereby the solid propellant is poured into a mould, the mandril inserted, left to dry into a solid charge and then placed directly within the case structure separated only by a liner instead of mechanical supports. Further advances led to the direct pouring of the propellant into the casing/liner assembly so that it could harden in situ.

In 1949, the Corporal E, a development test vehicle fired in 1947, was modified into a short-range ballistic missile (see Chapters Five and Seven). The Jet Propulsion Laboratory tested the Corporal from the White Sands range and set up a training establishment at the Pasadena facility. Production missiles were manufactured by the Firestone Rubber Company and the Corporal entered operational service with the US Army in April 1954. One of the major contributions from JPL came in the form of the Loki solid propellant anti-aircraft rocket, originally conceived as a liquid propellant device, but one which embraced the advances in solid propellant technology from 1951. Developed as an unguided, high-speed saturation weapon, Loki was fired in a test programme mounted at White Sands and was to play an important part in the Project Orbiter proposal of 1954. The considered concept would have required a spinning cluster of 37 Loki rockets mounted as upper stages to the Redstone MRBM, but JPL pointed out the advantages of using 15 Sergeant rockets to improve performance and increase reliability. The Sergeant rockets for Project Orbiter were to be smaller versions of the Sergeant tactical missile under development at JPL and eventually manufactured by the Sperry Utah Engineering Laboratory.

Toward the end of 1957, while the Army was preparing its Juno 1 launcher to place Explorer 1 in orbit, JPL studied the problem common to all solid propellant rockets of that period that prevented precise cut-off on command. Once started, the solid propellant would continue to burn until exhausted and this was a severe problem for accurate control of any large rockets or missiles that used the concept. By this time thoughts were turning to the use of solid propellants in big intercontinental ballistic missiles and precise shut-down at a pre-set velocity was an essential feature of weapons demanding an accurate trajectory. The method of control proposed by JPL, and incorporated in an experimental rocket called Shavetail, required the ejection of a portion of the nose section so that the payload at the front would separate just at the precise moment the thrust was reduced due to a loss of chamber pressure. The concept was not actively adopted, but it did lead to further developments for the control of solid propellant rockets.

So it was that when JPL was transferred to NASA on 3 December 1958, the space agency acquired a valuable research facility with an incredibly successful record – a facility that had already achieved twenty-two years of experience with liquid and solid propellant rockets.

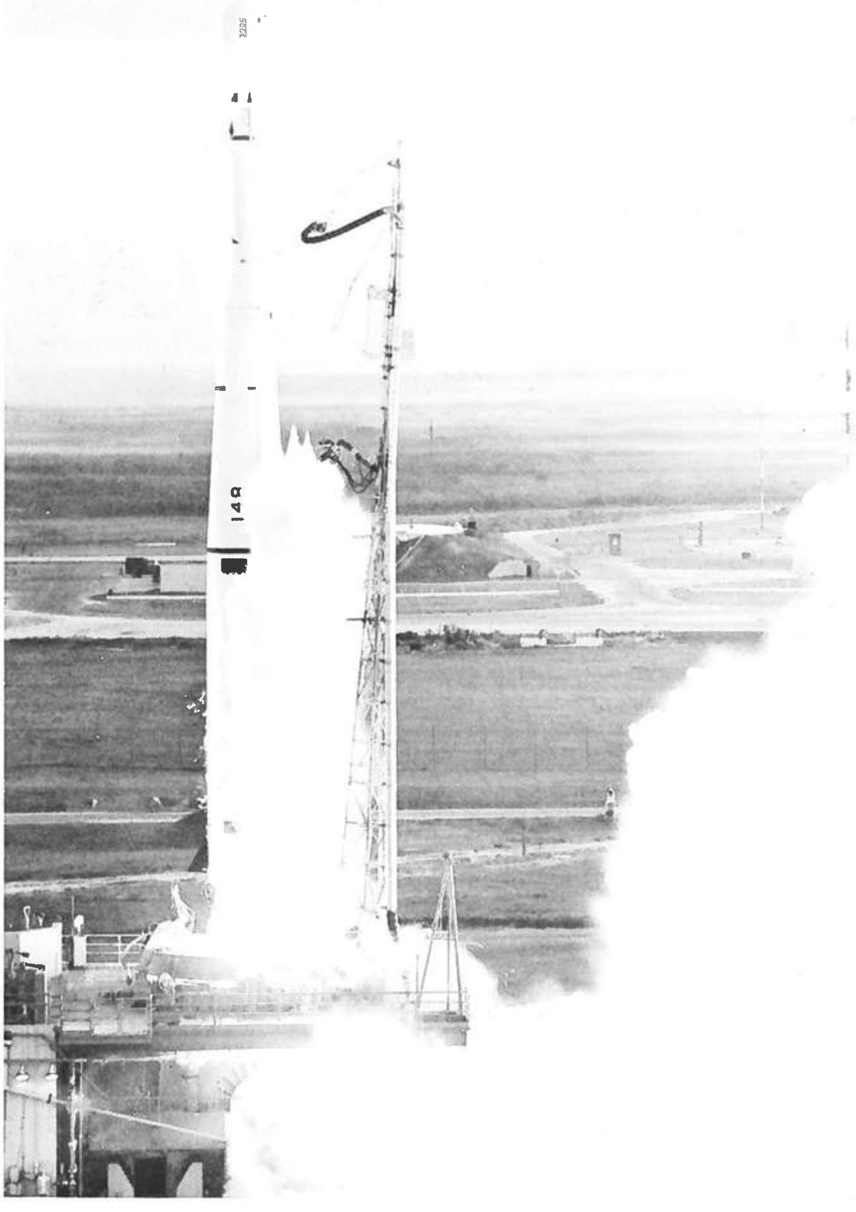
Throughout 1958 the United States moved ahead with a concerted programme of satellite launches that did more to provide information on launch vehicle performance than actually send payloads into orbit. Following on the heels of the unsuccessful attempt to send Vanguard into space on 6 December 1957, Explorer 1 was put into orbit on 31 January 1958, followed by a second Vanguard attempt on 5 February. This failed, due to a malfunction in the control system, but exactly one month later the second Juno I launch attempt suffered a similar fate, when the fourth stage failed to fire and the Explorer 2 payload ended up in the Atlantic. Twelve days later Vanguard scored its long-awaited first success, when the Vanguard 1 satellite began operations that would last for nearly six years. A third Juno I launch put Explorer 3 in orbit on 26 May but this was followed by three consecutive Vanguard failures due to problems with the second and third liquid and solid propellant stages. However, by mid-1958 three new projects were emerging under the separate auspices of the Air Force, the Army and the emerging NASA organization.

Work on the Douglas Aircraft Company's Thor IRBM had progressed rapidly from a go-ahead authorized in late December 1955. By early 1958 the missile had successfully demonstrated its full range potential and thoughts turned toward its application as the first stage of a carrier vehicle, that could be used to boost re-entry nose cones back into the atmosphere at high speed. The first successful flight of this vehicle – Thor-Able – came on 9 July. The second and third stages comprising the Able element were the same respective stages from the Vanguard launcher and this configuration was recognized as providing a viable launch system for placing Air Force payloads in space. Consequently, on 17 August, Thor-Able 1 was launched with the object of placing a Pioneer spacecraft on course for the Moon. Three weeks earlier, the fourth Juno I launch had broken the string of Vanguard failures by placing Explorer 4 in orbit, but the first Thor-Able space launch proved once again that there was no easy road to success, when it blew up only a few seconds after lift-off.

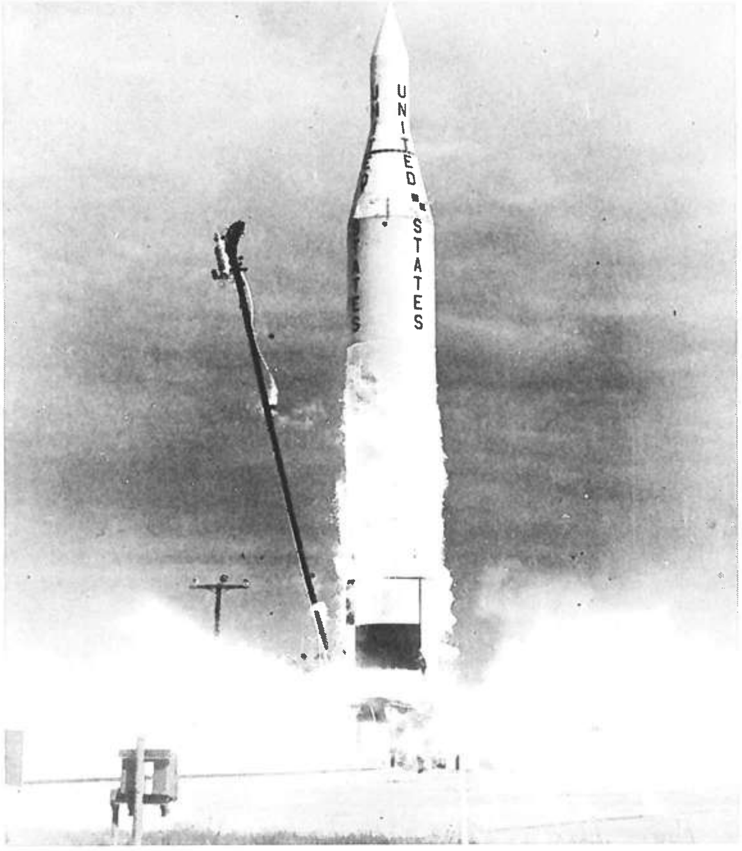
Two more failures followed in August and September when upper stages failed on Juno I and Vanguard launch vehicles respectively and a second Thor-Able flight was scheduled for 11 October. This was a partial success, in that the three stages placed the payload on course for the Moon, but with insufficient speed to escape Earth's gravity field and after reaching a height of nearly 114,000 km, the Pioneer 1 spacecraft tumbled back into the atmosphere. Following another Juno I failure on 23 October, the Air Force again tried to get a Pioneer off to the Moon on 8 November, but after successful operations with the first two elements of the launch vehicle, the third stage failed to fire. In the basic Thor-Able configuration for re-entry nose cone tests, the Able element consisted of only the liquid propellant second stage previously developed for the Vanguard; with a third solid propellant stage added, the same third stage used by Vanguard, Thor-Able 1 was seemingly too ambitious for these early days of trial and error. It would be nine months before the Air Force launch vehicle vindicated the confidence of its design team. Less than a month after the third Thor-Able failure, the Army began operations with its second candidate satellite launcher.

It may help here to briefly recap the sequential development of the first Army-JPL launcher. The Redstone medium-range ballistic missile, first flown in 1953, was fitted with solid propellant second and third stages, one placed inside the other, for re-entry nose-cone tests beginning in 1956. With a single solid propellant fourth stage, this Jupiter C, misleadingly named to imply a generic development from the Jupiter IRBM, became the Juno I satellite launcher, in essence a third generation development. The Jupiter missile, first flown in March 1957, was now seen as a promising first stage design for a more powerful satellite launcher.

Most of the work required to transform the basic Jupiter into a multi-stage space vehicle was performed by the Jet Propulsion Laboratory and envisaged the cluster of three solid propellant upper stages, previously adopted for Juno I, being situated on top of the more powerful Army missile. The Basic S-3D rocket motor of the Jupiter IRBM was retained, but the additional weight now placed on top demanded increased burn time and so the Jupiter's propellant tanks were lengthened by nearly 92 cm allowing the engine to continue firing for an additional 20 seconds, Also, JPL increased the thrust of the third and fourth stages and changed the titanium casing of the latter for stainless steel. With three upper stages, each a derivation of Juno I upper stages, the Jupiter missile was given the designation Juno II. It would be capable of lifting a weight of 230 kg into Earth orbit or of sending some



A Thor-Able launch vehicle lifts off from Cape Canaveral, one of the first successful Thor derivatives for space application, 1 April 1960.



13 October 1959, and Juno II sends Explorer 7 into orbit. Basically a liquid propellant Jupiter, Juno II carried solid propellant upper stages.

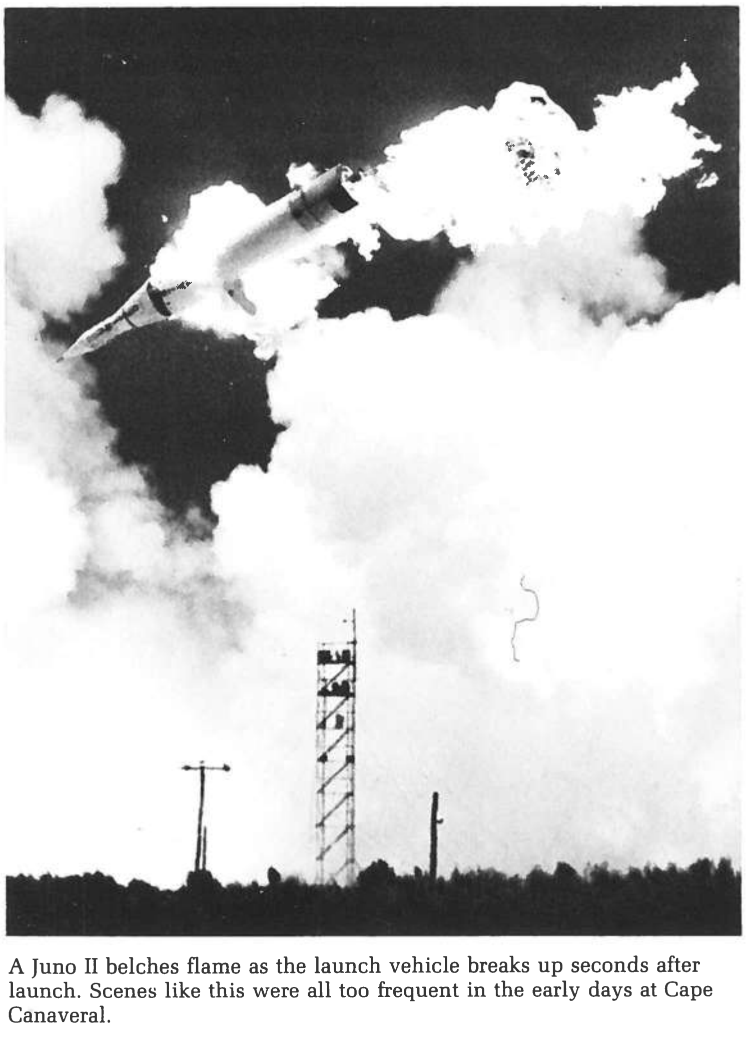
6.8 kg on an escape trajectory toward the Moon. Externally, the upper stages of the Juno II launcher were shrouded by a special fairing that covered the solid propellant rockets which were visibly exposed on the less powerful Juno I.

The first task assigned to this new Army satellite launcher required Juno II to send a tiny Pioneer spacecraft, weighing only 6 kg, on to an escape path that would take it past the Moon and hopefully secure the first pictures from space of the lunar surface. Unfortunately, the first stage shut down nearly 4 seconds too soon and the probe had insufficient speed to reach escape velocity. Designated Pioneer 3, the payload reached a height of 102,000 km and fell back to Earth. This launch, on 6 December 1958, was performed exactly one year after the first Vanguard satellite failure, but twelve days later, the Army completed launch operations for the year by sending an Atlas ICBM into orbit.

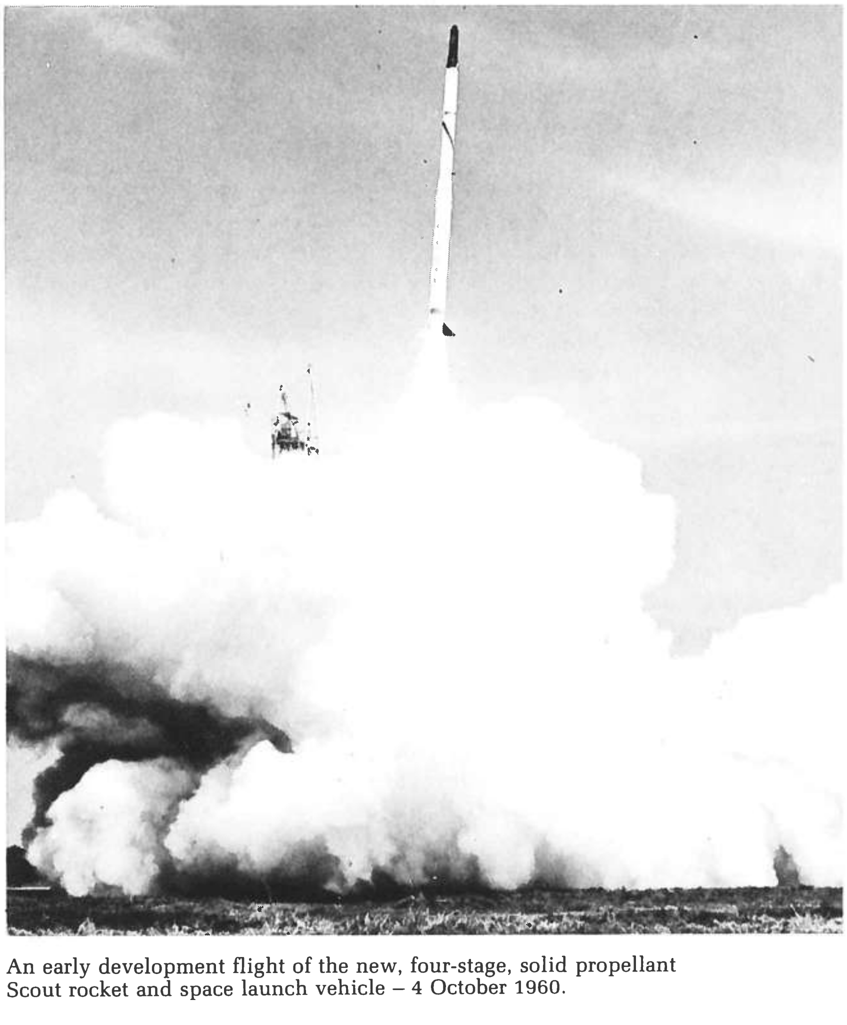
The first three-engined B-series Atlas had been successfully launched on 2 August and after six more attempts, of which only four were totally successful, a specially equipped Atlas B was launched into orbit on 18 December. Weighing nearly 4 tonnes, the empty Atlas carried a tape recorder which, on the 13th orbit of the Earth, broadcast a Christmas message from President Eisenhower in a public relations exercise designed to re-kindle support for American technology. Officially dubbed Project Score, and more popularly known as the 'talking Atlas', the flight did little to convince the public that the United States was confident about its future performance in the new frontier.

During 1958 the Russians launched only one successful satellite mission: Sputnik 3 on 15 May. With a weight in orbit of 1,327 kg it was a significantly heavier vehicle than the 508 kg Sputnik 2 (3 November 1957) or the 83 kg Sputnik 1 (4 October 1957). It represented the maximum payload lifting capability of the basic SS-6 ICBM adapted as a satellite launcher and described in Chapter Eight.

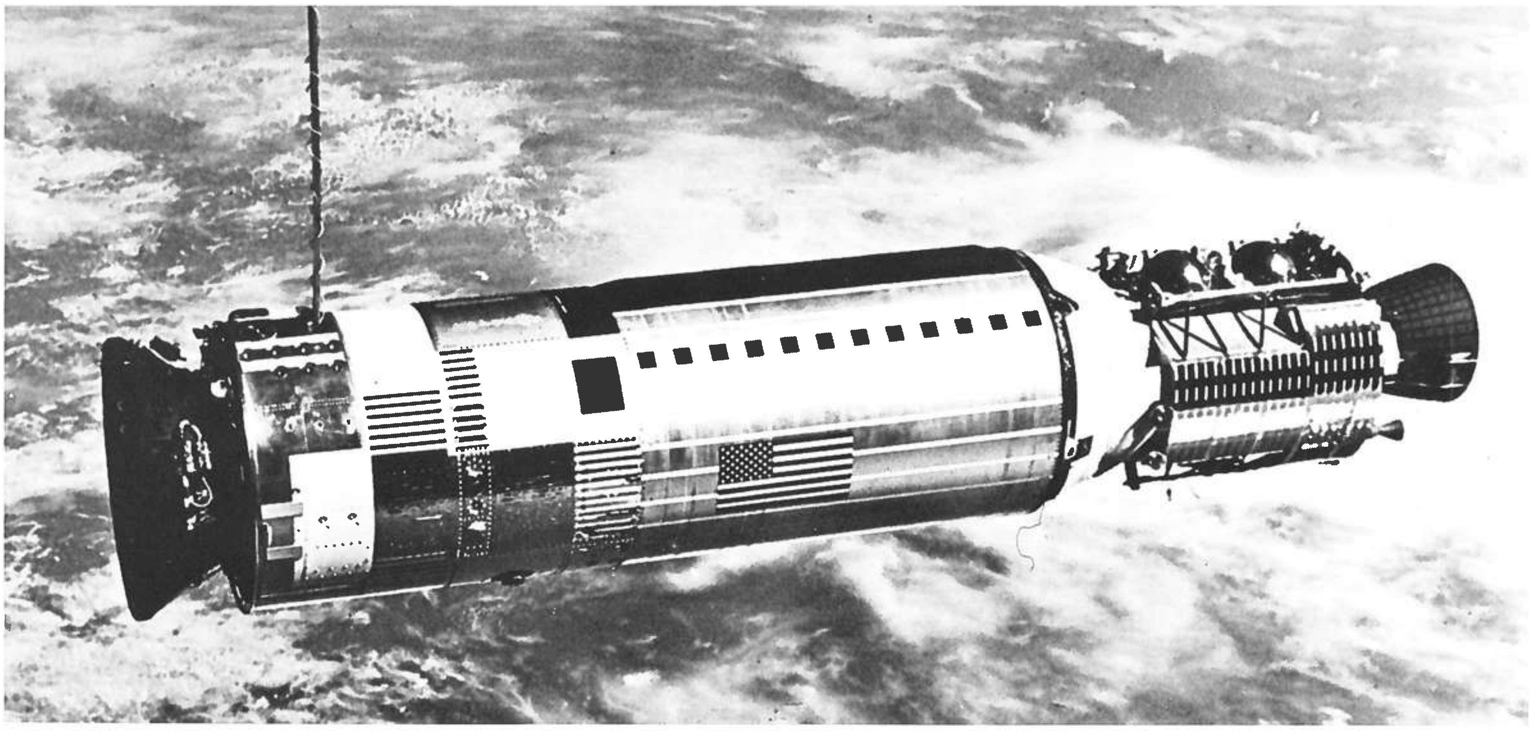
The third new American development of 1958 was the Scout solid propellant rocket programme, aimed at providing a reliable, simple, and efficient four stage launcher which could be used for probing the upper atmosphere, performing re-entry tests and sending small, low-weight, payloads into Earth orbit. Its design was placed with the Langley Aeronautical Laboratory, re-named the Langley Research Centre when NASA took over from the NACA in October 1958, Scout was to have a powerful first stage motor developing a thrust of 52 tonnes with much of the design fed across from the US Navy Polaris submarine launched missile programme (see Chapter Ten). The second stage would develop from the JPL Sergeant missile, the third stage was developed from the fourth and the latter was taken from the third stage of the Vanguard satellite launcher. Thus, Scout was an assembly of existing compo-



A Juno II belches flame as the launch vehicle breaks up seconds after launch. Scenes like this were all too frequent in the early days at Cape Canaveral.



An early development flight of the new, four-stage, solid propellant Scout rocket and space launch vehicle – 4 October 1960.



Agena D, seen here as a docking target for Gemini spacecraft in 1966, following launch by Atlas.

nents put together to provide NASA with its first development programme, but one which would continue to perform a useful function for at least the next two decades. The first Scout launch came in 1960 and the programme is still in use today for launching small payloads. It is the only programme begun before NASA officially came into being with a future still promising to require Scout rockets in the 1980's.

However, by the end of 1958, the orbital score card gave the Russians three successes and the Americans five. It is difficult to know exactly how many attempts were written off as failures in the Soviet Union, but there is good reason to believe that the problems experienced at Cape Canaveral were representative of the situation prevailing at Tyura-Tam. In all, the United States had attempted to launch 18 satellites and space probes during the fourteen months after Sputnik 1: a success rate of 28%; nearly three out of every four rockets launched in support of a space objective failed to carry out their mission. So far, the only successful launch vehicles had been the Army-JPL Juno I, the Navy Vanguard and the Air Force Atlas ICBM (adapted for a single unique launch into orbit). Thor was a potentially viable delivery system, Juno II had been struck by bad luck, and engineers singled out this Air Force IRBM as first stage for a progressive family of upper stage designs which would perform classified space missions for the Department of Defence.

Military aims and objectives in the new medium were now building towards a clarity that would stimulate many new projects in the following year; early doubts about the military value of an active space programme were now removed by the promise of new capabilities. Most of these were associated with orbital reconnaissance, 'spy in the sky' satellites, and surveillance of potentially hostile territory. One of the earliest programmes authorized by the US Air Force was the Discoverer series of orbital test satellites, conceived in 1958 and rapidly brought to fruition the following year. The project utilized a Lockheed Agena liquid propellant upper stage, launched by a Thor first stage. The payload section of the assembly was attached to the forward end of the Agena, both sections going into orbit together. Discoverer flights were launched from a complex on the Vandenberg Air Force Base in California and were programmed to go into polar orbit carrying experiments designed to investigate technical aspects of space flight operations.

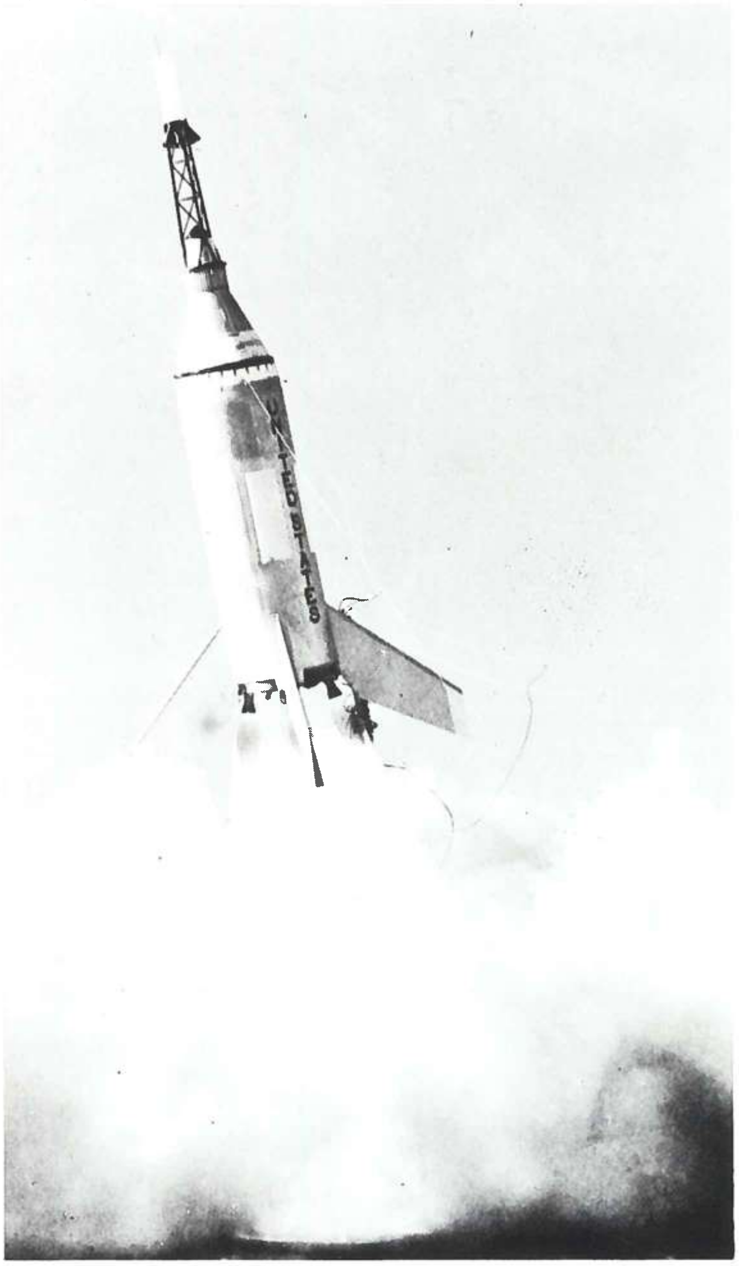
Early Discoverer class payloads weighed about 770 kg of which 88 kg was given over to a recoverable capsule which would separate from the main body of the Agena A stage after it had fired its engine to return through the atmosphere. Only the capsule was shaped and insulated to protect it from the searing heat of re-entry and the Agena A would burn up from the heat generated by atmospheric friction. The capsule would then return to the dense layers of the atmosphere, where a parachute would be deployed to slow its descent, so that aircraft, suitably equipped with a snare on the front end, could fly through the trailing wire and secure the capsule for analysis. Many capsules were expected to carry photographic equipment, infra-red sensors and other military payloads, but the entire programme was more a research and development venture than a fully operational surveillance operation. Nevertheless, by the end of 1958, the US Air Force was ready to begin flight operations.

As yet, the Thor-Able 1 configuration had failed to demonstrate a single success and it may be thought that introduction of another Thor derivative, Thor-Agena A, was too presumptive a move to augur well for success. It should be remembered, however, that problems with the Thor-Able 1 assembly were almost wholly limited to the upper stage units. Agena A was a very different development to that which led to the Thor-Able 1 configuration. Also by the end of 1958, the Department of Defence was studying the possibility of launching early-warning satellites into orbit. This programme would later emerge under the name Midas, as a series of experimental vehicles, with infra-red sensors, which were intended to watch for sudden increase of heat from the exhaust efflux of a military rocket. But even as the Air Force was increasing its attention to the value of earth satellite programmes, so was the nascent space agency embarking on a committment of monumental proportions: the launch of a human being into orbit from where he would circle the globe several times and return at will.

The concept of manned space flight is as old as the Chinese powder rocket and the full story of the development of manned space vehicles must be told elsewhere. Nevertheless, the pertinent aspects of the move to organize a man-in-space capability, is central to the evolving pattern of civilian launch vehicle development and as such must be considered a fundamental part of the story of rockets and guided missiles.

In the decade following the end of World War II any emergent space programme was considered to require human participation. Only when extraordinary developments in the field of radio communication, information transfer systems and data transmission modes obviated the apparent function of a man in space, did it become apparent that many of the tasks previously thought to require human participation, could in fact, be accomplished by automated vehicles. This suited the available inventory of candidate launch vehicles. Manned space flight would require large capsules weighing considerably more than the tiny unmanned satellites initially made available to the armed services and this in turn demanded large rockets with a substantial lifting capacity. Atlas and Titan were the only candidates and these were still very much in the development phase; the other launch vehicles were simply too small to carry manned satellites into space.

Little Joe I lifts a test model of the Mercury spacecraft on to a ballistic trajectory.



Nevertheless, as early as March 1956, the Air Force began studies of Project 7969 known as the Manned Ballistic Rocket Research System and work would continue for two years on the possibility of progressively scaling up the size of capsules which would ultimately provide a manned space flight capability. The Atlas ICBM was cited as the most suitable launch vehicle for this purpose, requiring only the addition of an Agena class upper stage. By January 1958, the Air Force had received proposals from 11 industrial contractors for participation in Project 7969, although the concept had not, as yet, received official sanction and was still restricted to limited design study.

On 29 January a three-day conference began at the Wright-Patterson Air Force Base, Ohio, at which Air Force and NACA officials discussed various ideas on the prospect of a manned orbital spacecraft. One of the concepts floated at the conference, proposed by Maxime A. Faget, envisaged a conical, high-drag, capsule with the pilot lying prone for re-entry and recovery. This would continue to be the preferred concept when NASA took up the programme later the same year. On 10 March 1958, the Air Force Ballistic Missile Division held a conference to discuss a request from Roy Johnson, head of the newly formed Advanced Research Projects Agency, that the Air Force prepare a plan for 'Man In Space Soonest'. Under the MISS programme the Air Force would move through a series of developments towards the early launch of a manned space capsule and it was expected that future work would lead to orbital space stations or a flight to the Moon. It was the intention of the ARPA to give the job to the Air Force, again because of the imminent availability of the Atlas ICBM which would have the necessary power to lift the large weight into space.

Just eight days later, the NACA published a report titled *Preliminary Studies of Manned Satellites, Wingless Configurations, Non-Lifting* and in June, the Langley Aeronautical Laboratory submitted a preliminary specification for a manned spacecraft. While much of the preliminary design work was being carried out by the NACA, the Air Force kept up its own internal effort, based on the requirements of the MISS programme, in the hope that it would get the work detail from congressional sanction. But the Army too was interested in developing a manned vehicle and on 8 August Wilber M. Brucker, the Secretary of the Army, sent Defence Secretary McElroy a memorandum promoting Project Adam, whereby a basic Redstone MRBM would be modified for a ballistic, suborbital flight with a man-carrying capsule. One month later the ARPA told the Army that there was little hope of the project receiving authorization.

Sprawling Launch Complexes at the Cape Canaveral site herald a new era. From bottom (foreground) to top: two Complex 36 pads connected by concrete support facilities (Atlas Centaur); Complex 11 (Atlas); Complex 12 (Atlas Agena); Complex 13 (Atlas Agena); Complex 14 (Mercury Atlas); Complex 15 (Titan); Complex 16 (Pershing); Complex 19 (Gemini Titan); Complex 20 (Titan); Complex 34 (Saturn IB); Complex 37A & B (Saturn IB).

By this time the Space Act of 1958 had written up a mandate for the new NASA organization and it was becoming increasingly apparent that manned space flight would be the responsibility of the civilian agency. MISS and Project Adam would be absorbed into any initiative proposed by NASA and separate development of manned spacecraft would be prohibited. For its part, the Navy had been working on a Project Mer proposal which envisaged the launch of an inflatable glider containing a human occupant, but this too went out with the dictates of the Space Act. Before NASA officially came into being, on 24 September, Robert R. Gilruth of NACA chaired a series of meetings designed to write up the requirements of a manned satellite programme and these were presented to NASA Administrator Glennan on 3 October. Just four days later, Glennan authorized development of a manned orbital capsule by pronouncing the now historic words, 'Let's get on with it.' Seven days old, NASA was planning to put a man into space.

By the end of 1958 it had been officially named Project Mercury and orders had been placed with the Air Force for Atlas ICBM's, which would be used to place the capsule in orbit. Initial suborbital flights with the Mercury spacecraft would be carried out with a Redstone missile and unmanned tests of the capsule would use a solid propellant booster with the name of Little Joe. This was assembled from Sergeant and Recruit solid propellant rockets. It would be a cheaper method of testing than that using the comparatively expensive Atlas or Redstone rockets. But, despite the remarkable progress achieved during the year following the successful launch of Explorer 1, the comparatively low weight lifting capacity of US rockets was already pointing to a deficiency in thrust output compared to that enjoyed by the Soviet Union. With the ready availability of the giant SS-6, the Russians succeeded in placing a total accumulated weight of 1,918 kg in orbit in the three Sputnik launches up to the end of 1958. In that same period the five successful American flights had placed a total weight of 139 kg in orbit. This figure included 68 kg of useful payload launched by the Project Score Atlas and while it could be said that the total weight of that configuration was nearly 4 tonnes, all but 68 kg was made up of the inert shell of the rocket; the Russian figures similarly exclude the weight of the inert structure that went into orbit along with the payload.

In its basic form, the SS-6 could lift nearly 1.4 tonnes into orbit; Atlas, the most advanced launch vehicle available in the United States at that time, could place a similar weight in space when fully developed, but it would not do so until September 1961. By that time additional upper stages were being used with Atlas to improve the efficiency of the system. But even as NASA was drawing up plans for the Mercury man-in-space programme, the Russians were developing an upper stage for their SS-6 that would appear early in 1959, with a capability of sending 400 kg to the Moon. This same upper stage, when used in conjunction with the SS-6, would put nearly 4.8 tonnes in Earth orbit and it did so for the first time on 15 May 1960, in a test run of the capsule design that would be used to place the first man in space eleven months later.

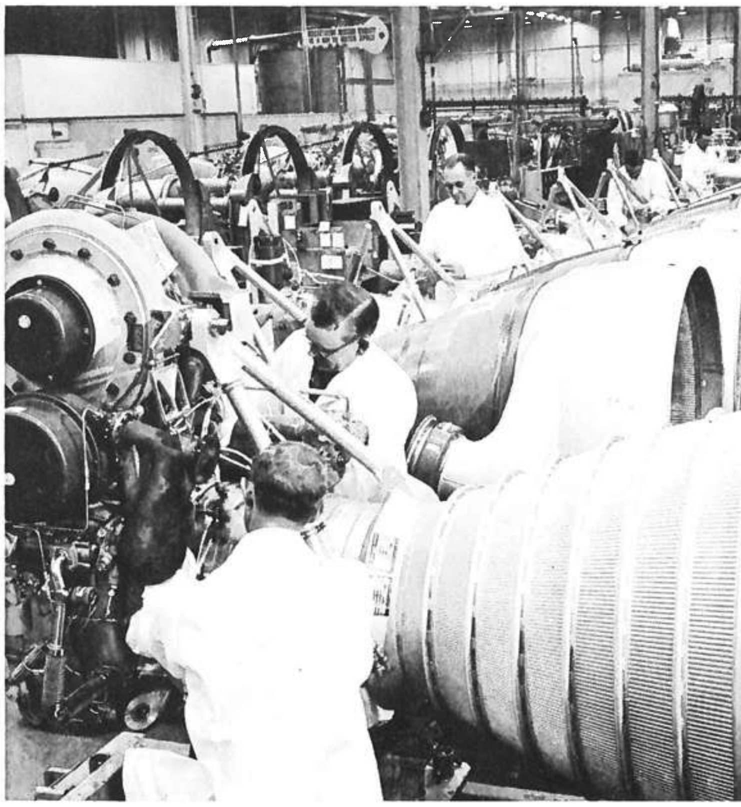
In 1958 the only hope of catching up with the weight lifting capability enjoyed by the Russian teams rested with the large clustered-engine proposal outlined at the beginning of this chapter. It was expected to make use of four Rocketdyne E-1 engines, a total stage thrust of 680 tonnes, and would use a cluster of eight propellant tanks surrounding a central tank fabricated from tooling laid down for the Jupiter IRBM. The project was provisionally designated Juno V – Juno III and Juno IV were single-engine developments of the basic Jupiter, which would never emerge from the drawing board – and enthusiasm generated by the ABMA was reflected in the second edition of the report *A National Integrated Missile and Space Vehicle Development Programme*, released on 1 April 1958.

But Juno V was not the ultimate space launch vehicle envisaged at this time. Three years earlier, in 1955, the Air Force Rocket Engine Advancement Programme had initiated feasibility studies into the possibility of building a single rocket motor with a thrust exceeding 450 tonnes and by 1957 full scale testing was under way leading towards fabrication of a working combustion chamber. This big single-chamber engine would conceivably find application to launch vehicles following on from the clustered, 680 tonne thrust, rocket. On 17 April 1958, General Medaris testified before the House Select Committee on Astronautics and Space Exploration, with an affirmation of the need for large rocket engines: 'The major breakthrough which must be effected before any national space programme can gain substantial impetus, is the development of engines of much greater thrust. I am convinced that we must have a well-tested capability of a minimum 450 tonnes thrust, either by a combination of multiplex engines or by a single engine.' At the same hearings, Medaris spoke of a potential application that today seems bizarre, but with hindsight, reflects the mood of the late 1950's: 'I believe that the US Army must make long range plans for the transport of small combat teams by rocket. I also believe that cargo transport by rocket is economically feasible. To accomplish these things an engine of greater thrust is necessary.'

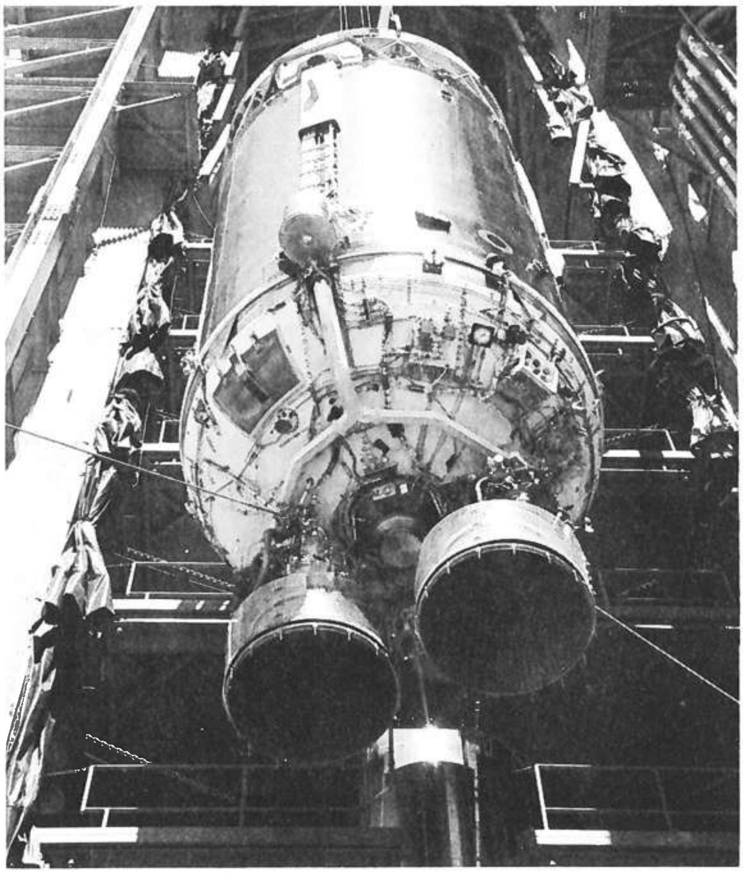
Beginning in May 1958, the ARPA studied the opportunities which would accrue from development of large boosters and conducted detailed work on the preferred configuration with representatives from the Institute for Defence Analyses. The IDA was a non-profit organization providing staff for the Department of Defence; a liaison division with the ARPA had been set up on 18 March, under Dr. Herbert F. York, this person also serving as the Chief Scientist at ARPA. Over the next three months the ARPA/IDA team proposed a change to the Juno V configuration whereby the four E-1 engines, yet to be developed and as such a potential risk to the programme, would be replaced by 7, 8 or 9 engines of the S-3D type used by the basic Jupiter, already fully developed and available 'off the shelf.' It was suggested that apart from reducing the magnitude of technical complexities that could threaten the early availability of Juno V, a cluster of 6 or more first-stage engines could provide a cross-feed capability so that if any one of the cluster failed, the remaining engines could burn longer and carry the launch vehicle safely into space, from where the upper stage(s) could take over as planned.

Towards the end of these meetings, the National Security Council gave their blessing to the clustered-engine concept and concurred with plans laid down for use of the Juno V. On 23 June the Air Force placed a contract with Rocketdyne for the preliminary design of the large thrust, single-chamber rocket motor, calling it the F-1, and approved plans to aim for a unit thrust of between 450 tonnes and 680 tonnes. On the one hand, the Army was pursuing the Juno V concept which would use a cluster of smaller thrust engines to achieve a total output of 680 tonnes and on the other was promoting development of a single chamber motor with a similar capability. The F-1, it was thought, could be similarly clustered to provide a launch vehicle thrust measured in thousands of tonnes. As yet, no clear mission had emerged for such a colossus; there was a determined will not to fall behind any future increase in Soviet lifting capability.

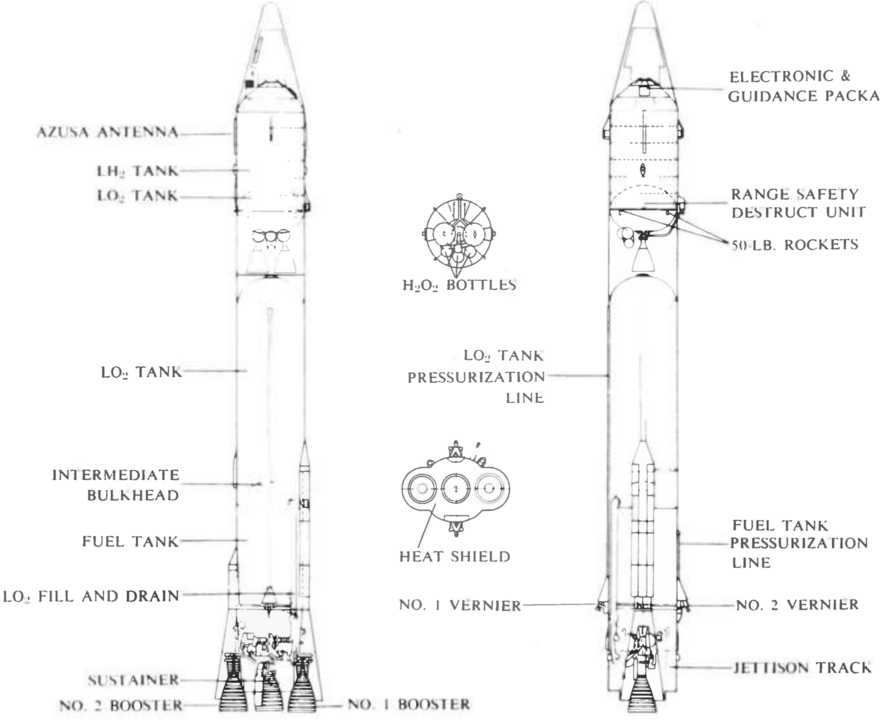
On 18 July 1958, the third edition of the *National Integrated Missile and Space Vehicle Development Programme* was sent to the NACA stressing the importance of the Juno V programme, but the document retained a preference for four E-1 engines, rather than 7 to 9 clustered engines of less thrust. On 7 and 8 August, the ARPA visited von Braun at the Army Ballistic Missile Agency and discussed funding requirements for Juno V. They approved cancellation of the Juno IV design so that funds could be transferred from this project to the Juno V. One week later the Army Ordinance Missile Command formally requested permission to start the Juno V programme with immediate release of funds totalling $10.5 million. A day later, on 15 August, the ARPA Director, Roy Johnson, issued Order No. 14–59 to the AOMC at Huntsville with the following relevant text: 'Pursuant to the provisions of DoD Directive 5105.15, dated 7 February 1958, you are requested



Developed from the Rocketdyne S-3D used by Jupiter, H-1 engines would be used in clusters of eight to power Saturn I and IB launch vehicles. Note the many tubes through which propellant would flow to cool the nozzle.

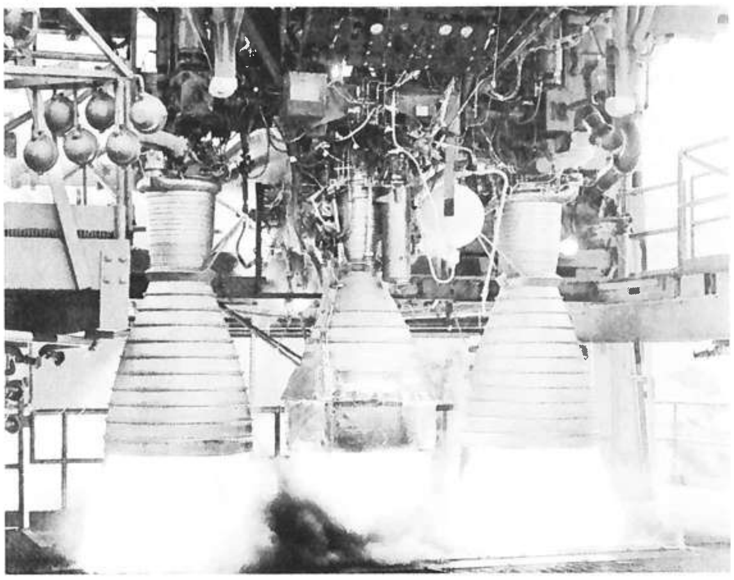


The Centaur, developed as an upper stage for Atlas, shows off its two hydrogen/oxygen engines.



Major Atlas-Centaur systems are shown in three-way view.

While design work progressed with exotic and powerful launch vehicles, first-generation launchers bore the brunt of space activity. Here, the three engines used by Atlas are seen under test.



to proceed at once on behalf of the Advanced Research Projects Agency with the project specified below. Initiate a development programme to provide a large space vehicle booster of approximately 680 tonnes thrust based on a cluster of available rocket engines. The immediate goal of this programme is to demonstrate a full-scale captive dynamic firing by the end of calendar year 1959. The Order makes available \$5 million . . .'. The 7 February DoD directive was issued both to set up the ARPA and to empower that agency to deal direct with the Army Ballistic Missile Agency without going through the decision-making process at Army Staff level. It specifically mentioned the Juno V project and represents an attempt to smooth the administrative plans for work authorization.

Within two weeks of getting the go-ahead, the AOMC received word that the ABMA would be allowed to spend \$15 million in getting the programme off the ground – nearly \$5 million more than initially requested. But Juno V was only the first stage of what was conceived as a multi-stage launch vehicle and on 28 August, the Air Force received authority from the ARPA to develop a new upper stage, using the highly efficient combination of liquid hydrogen and liquid oxygen propellants to achieve efficiency values denied to earlier launch vehicles using kerosene fuel. This new upper stage was called Centaur and had originally been proposed as an upper stage for the Atlas ICBM, effectively transforming the military missile into a viable space launcher for the orbiting of payloads weighing 4 tonnes.

It is interesting to note that the SS-6, with its first upper stage development, designated A-1 in the role of satellite launcher, had about the same capability. Atlas-Centaur, with a first stage thrust of about 33% that of the A-1 first stage, would lift 83% of the payload weight carried by the A-1. Later developments raised the Atlas-Centaur weight lifting capability to 4.5 tonnes, or 94% that of the Russian launcher. Such are the virtues of using high-energy propellants with increased specific impulse (about 444 seconds in the case of Centaur). However, while Centaur was still expected to find application with the Atlas, it was being viewed with increasing interest as an upper stage contender for Juno V.

During September, the contest over how many engines to use in the base of Juno V, four E-1 engines or seven to nine smaller, existing, motors, was finally resolved. On the 11th Rocketdyne were requested to develop the S-3D design used with Jupiter into an H-1 model, which would provide an initial unit thrust of nearly 75 tonnes, with a development potential of eventually increasing this to 85 tonnes. Eight H-1 engines would be attached to each Juno V, providing an initial stage thrust of 600 tonnes, with a potential increase to 680 tonnes when the more powerful H-1's were ready. Rocketdyne had already been working on a development of the 68 tonne thrust S-3D used by the Jupiter IRBM and the performance increase (10% in thrust) was no problem. In addition, the company incorporated several unique features that would substantially reduce the number of components and this had the desired effect of simplifying the design and improving reliability.

So far, the Juno V launcher programme had been authorized for feasibility development up to and including the completion of a full scale model which would perform and demonstrate a static firing during 1959; this had been expressed in the language of ARPA Order 14–59 mentioned above. On 23 September Roy Johnson from the ARPA, General Medaris from the ABMA, and other officials met to discuss the future requirements and signed a letter of agreement increasing the magnitude of the programme by adding three more boosters to the contract. The second would follow captive tests with the first by demonstrating a propulsion test in flight and the third and fourth Juno V's would make extra flights to more properly evaluate the technical requirements for a fully operational system based on this launch vehicle. No specific attention was yet to be given to upper stage configurations and the requirements for flights 3 and 4 would concentrate on proving the capabilities of the basic stage.

US Air Force Thrust Augmented Thor Agena prepares for launch.

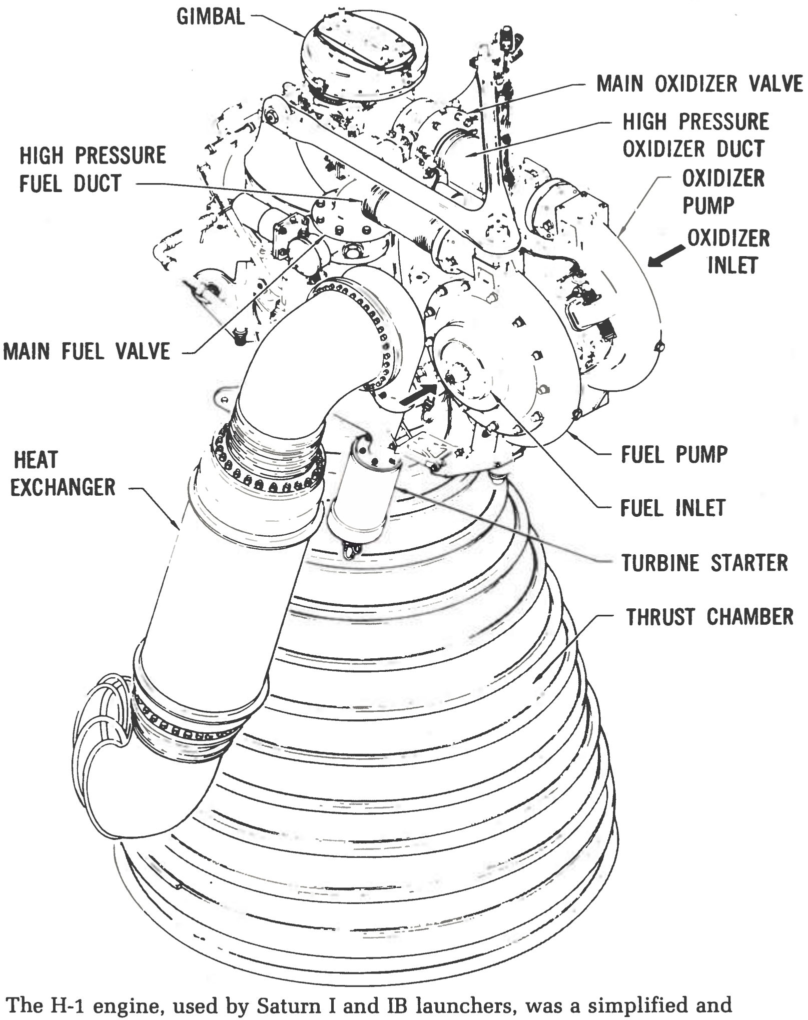
However, on 13 October publication of the *Juno V Space Vehicle Development Programme* pointed to the urgency in selecting second stages for flights 3 and 4 and suggested that a decision should be made 'within 3 months on the second stage to be used.'

Despite the initial enthusiasm that had attended approval of the project, proposed funding levels were being cut back in a severe and debilitating move to reduce unnecessary expenditure. The ABMA plan expected captive tests with the first booster to be completed by December 1959, with the flight test of the same vehicle in September or October 1960. Vehicle number 2 would be flown in January 1961 followed by 3 and 4 in June and October 1961, respectively. The Development Programme document pointed to the dangers of insufficient funding and expressed the view that, 'Funding limitations make this programme a compromise from a desirable development programme required to meet the national need at the earliest possible date.' It was at about this time that the contest over who should administer the Juno V project was being fought and the efforts by NASA to secure control of the Development Operations Division of the ABMA did little to project an aura of certainty, a necessary feature for reliable funding requests. In one specific instance, on 21 October 1958, ARPA were denied funds from the Budget Bureau to modify engine test stands for Juno V until a firm decision had been made as to who would be the 'responsible agency.'

During this month the ARPA decided that the Juno V would use either Atlas, or the first stage of the two-stage Titan ICBM, as the second stage and adopt a Centaur as the third stage; the Air Force had by now contracted Convair Astronautics to build Centaur and requested the development of Centaur engines from Pratt & Whitney. Two LR-115 liquid hydrogen, liquid oxygen engines, each delivering a thrust of 6.8 tonnes, would be carried by the Centaur for a total stage thrust of 13.6 tonnes. By November, changes in the development plan required the assembly of five Juno V launchers: one for static tests and four for flight tests. Still the funding problem prevailed and repeated attempts to get additional money for the project failed to open federal coffers; the AOMC wanted $60 million for fiscal year 1960 (effective for twelve months from 1 July 1959), but the Budget Bureau cut this to $50 million. Weeks later on 9 December, the Secretary of Defence refused a request to place Juno V on a top priority, DX, rating. This would have given the project first call on material and supplies from government contractors providing metals and fabricated components.

But if the development of the Juno V booster was slowing down, the work at Rocketdyne on the H-1 design progressed quickly to the first firing at full power on 31 December 1958. It had, perhaps, been more a labour of love than just another engine development programme. Rocketdyne had long wanted to perform modifications to the S-3D used by Jupiter and the necessary drawings and design details were already drawn up when the H-1 contract arrived. Using the same liquid oxygen and RP-1 (kerosene) propellants, the engine adopted a solid propellant gas generator for ignition and incorporated features that promised to greatly improve the operating efficiency. One significant design change required re-location of the turbopump. On the earlier LR-79 and S-3D engines the pump had been fitted to the fixed portion of the engine mounting so that when the engine was gimballed for flight control, flexible pipes, carrying high pressure propellant, were required to transport the fuel and oxidizer to the injector on top of the combustion chamber. On the H-1, the turbopump was mounted to the main combustion chamber itself, below the gimbal block, so that the flexible pipes carried only low-pressure propellants from the delivery lines to the pump inlets; re-location of the turbopump placed all engine elements on the moving platform of the combustion chamber.

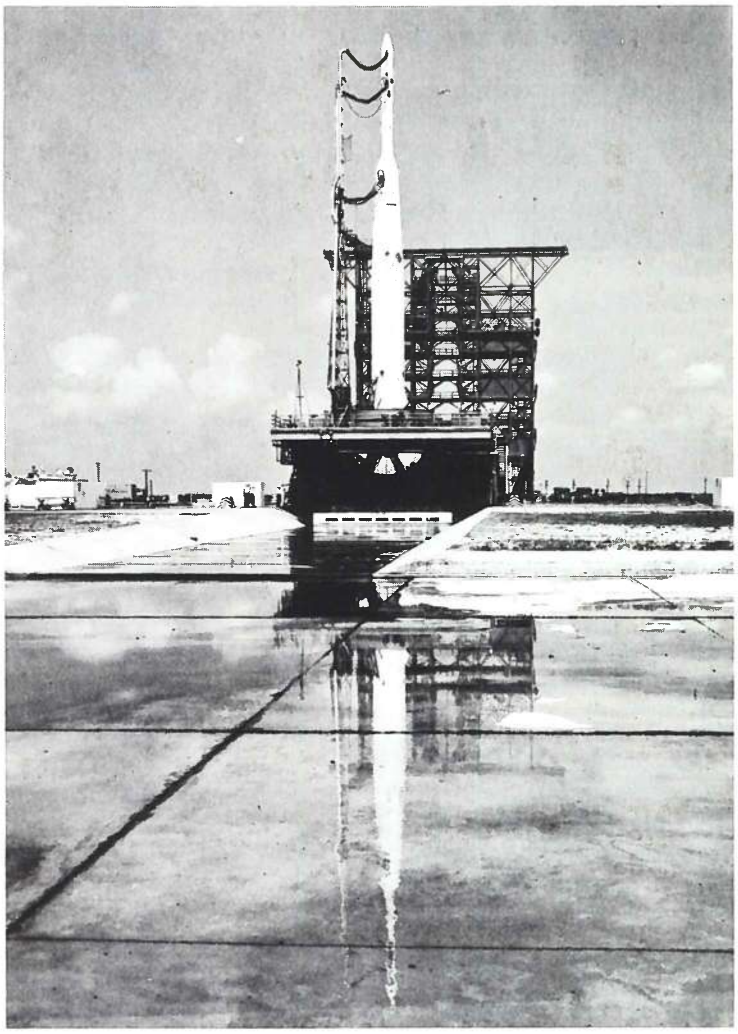
In operational emplacement, four H-1 engines would be fixed to the base of the Juno V in a square pattern with a second set of four, forming another square. Only the four outer engines would be gimballed for flight control; the inner set would be fixed in the downward firing position. It is doubtful if the Juno V booster would have been feasible without the extensive programme of modifications that simplified the starting procedures, a programme that began when Rocketdyne recognized the steps that could be taken to improve



The H-1 engine, used by Saturn I and IB launchers, was a simplified and much improved version of the engine used by Jupiter and Atlas.

27 March 1969. An Atlas Centaur launches Mariner VII toward Mars from Launch Complex 36 at the Kennedy Space Centre. Note the large, cylindrical liquid nitrogen pressure vessel in the foreground and the two small vernier motors firing to left and right of the base of the Atlas.

A Delta launch vehicle prepared to launch the British satellite Ariel 1 into space on 26 April 1962.



the same basic engine that was being applied to Jupiter, Thor and Atlas. The complex pre-start and ignition sequence demanded by the S-3D, would have been multiplied to an intolerable degree with eight such motors attached to one launch vehicle: all eight engines would be required to ignite within fractions of a second of each other and the whole operation was something akin to launching eight Jupiter missiles at exactly the same time from the same launch pad!

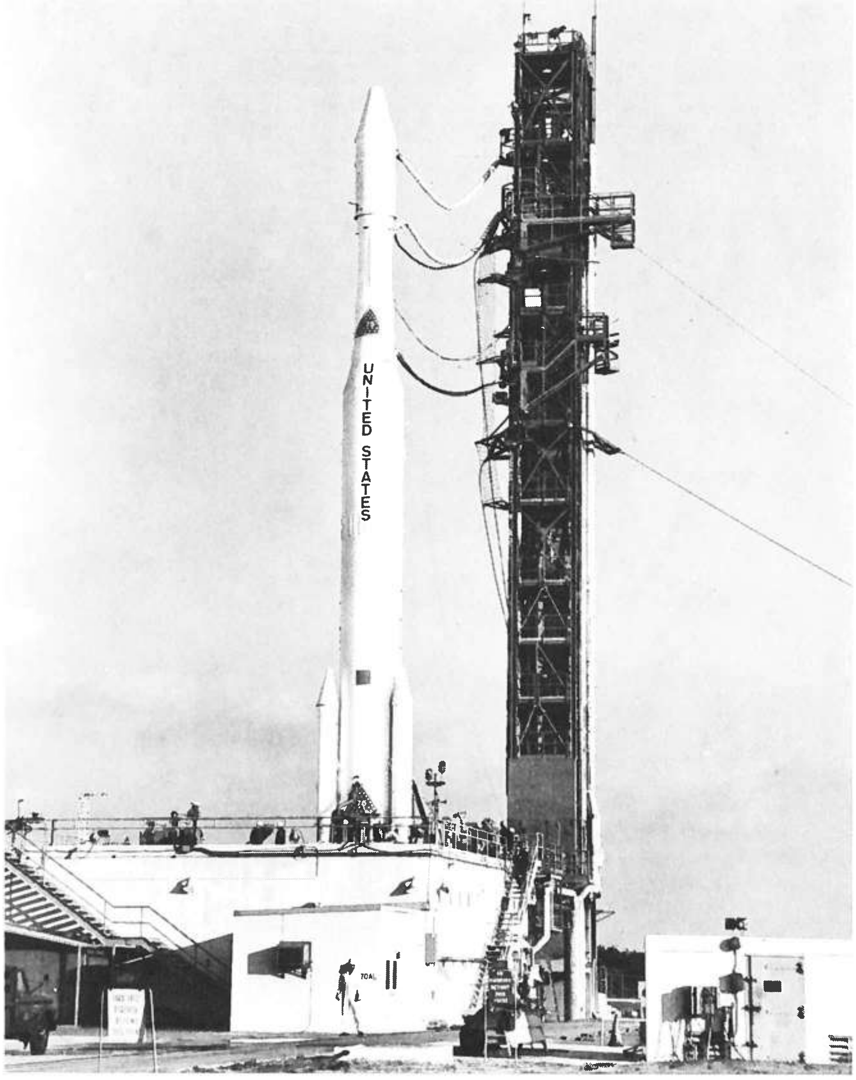
During the closing months of 1958, Wernher von Braun suggested that the Juno V designation be changed to Saturn and on 2 February 1959, the Army officially sought recognition of the new project title. Roy Johnson approved this a day later. Then, on 6 February the ARPA asked the AOMC to review the possible extension of the Saturn programme and a week later AOMC responded by proposing that 16 Saturns be built for flight tests. ARPA held a meeting with the National Aeronautics and Space Council at which the President was presented with three possible configurations; Saturn A would use either the first stage of the Titan ICBM or a cluster of smaller engines for the second stage and adopt the high-energy Centaur as third stage; Saturn B would use a cluster of four H-1 engines in a second stage, four 6.8 tonne thrust liquid hydrogen/liquid oxygen engines in the third stage and adopt Centaur as the fourth stage; Saturn C would use various configurations of Centaur engines in three upper stages. All Saturn models proposed would use the same basic first stage with its cluster of eight H-1 engines burning liquid oxygen and kerosene.

The urgent need to select an upper stage configuration for Saturn remained in the forefront of launch vehicle planning decisions and on 13 March the AOMC issued its 'Saturn Systems Study', requested three months earlier by the ARPA, in which it stressed that, 'An immediate decision by ARPA as to choice of upper stages on the first generation vehicle is mandatory if flight hardware is to be available to meet the proposed Saturn schedule'. Upon receiving a copy of the document, Roy Johnson set up an ad hoc committee from NASA and the Department of Defence staff to provide recommendations. While early attempts by the space agency to procure control of the ABMA Development Operations Divisions had proved inconclusive, it was universally recognized that NASA would be a prime customer for Saturn launch vehicles. But the Army retained its enthusiasm for space operations and on 20 March, a task force began to study the possibility of setting up a manned colony on the Moon. Headed by General Medaris, and conducted with cooperation from the von Braun team, the effort was named Project Horizon.

During May 1959, the ad hoc committee recommended use of the first stage of Titan as the second stage of Saturn and this decision was endorsed by Johnson at the ARPA. When the ARPA reviewed the financial state of the programme, however, it learned that if fiscal year 1960 funds remained at $50 million, the initial flight programme, with four vehicles, would not be completed before July 1962, nine months later than originally planned. Moreover, projections for fiscal year 1961, effective from 1 July 1960, implied that the Saturn programme could expect to receive only $130 million versus $250 million required to keep the schedule on course. It was to prove a year of switchback decisions: on 29 July the ARPA ordered a halt to work on the Saturn second stage studies due to 'a new requirement to relate Saturn second stage planning to other Department of Defence programmes.' In other words, the future role of the Saturn was so ill-defined that the Department of Defence were not even sure the Titan would fill all potential payload lifting requirements.

The Army were certainly in need of a military mission for the Saturn. To retain control of the programme, and vindicate their protestations over attempts by NASA to embrace the ABMA, it was essential to demonstrate that Saturn was a key element in Army plans for future satellite projects. Shortly after this decision, Dr. York, Chief Scientist at the ARPA and Director of Defence Research and Engineering at the Office of the Secretary of Defence, since 24 December 1958, issued a crippling statement: 'I have decided to cancel the Saturn programme on the grounds that there is no military justification . . . on the grounds that by the cancellation the Department of Defence will be in a position to terminate the costly operation being conducted at ABMA.' Dr. York went on to say that existing military requirements could be accommodated by the Titan-C, a derivative of the basic Titan ICBM that the Air Force had proposed as a heavy-weight launch vehicle in open competition with Saturn. In actual fact the announcement was tempered in favour of further review by a Booster Evaluation Committee.

Meanwhile, at the ABMA facility at Huntsville, the last production Jupiter missile was completed on 27 July, in Building 4707 and as the vehicle was moved off the assembly line, engineers began converting jigs and tooling for the Saturn SA-T, the static test model that would be used for engine runs in the clustered configuration. Authority to build the SA-T was granted by the ARPA. But the fate of the entire project hung in the balance, and the scales were to be loaded and weighed by the Booster Evaluation Committee between 16 and 18 September 1959; York and Hugh L. Dryden were co-chairman. It was found that while the documents used to select Saturn or a Titan derivative optimistically revealed that the former would cost $218 million more than the latter, cost predictions for Titan engine development had been underestimated and that no funds had been allowed for flight testing the Titan. Moreover, it was recognized that the Saturn launch vehicle held greater promise for future evolutionary development and that it would possess enhanced versatility over the Titan. The Titan programme had provided a valuable addition to the ICBM fleet (see Chapter Ten), but this new derivative was ill-suited to the somewhat different demands of the space programme – military or civilian. Consequently, the Committee judged Saturn as the most acceptable programme and work was allowed to continue.



Improvements to the basic Delta, with extension of the first stage tanks and the use of three Castor strap-on rockets, gave this Delta L launcher enhanced payload lifting capability.

Throughout 1959 NASA re-asserted its claim to management of the sprawling facilities at Huntsville and with much of the administrative teething toubles now behind it, the space agency renewed efforts to obtain the ABMA. There was good reason for this line. If NASA was to carry out its mandate effectively, it must have control of all the major launch vehicle programmes under one coordinated plan and the legacy of a fragmented development posture, whereby each of the three armed services retained control of their own in-house projects, would do little to stimulate an effective schedule for long range planning. As early as 20 January 1959, only a few weeks after the President had allowed transfer of the Jet Propulsion Laboratory to NASA and retained the ABMA under the Department of Defence, the Assistant to the NASA Administrator, Wesley L. Hjornevik, sent a memorandum to Glennan with the following assertions: 'I for one believe we should move in on ABMA in the strongest possible way. Both because I believe this is the course which will best enable us to obtain ABMA by transfer, but also because it is becoming increasingly clear that we will soon desperately need this or an equivalent competence . . . We will have to be willing to force an issue if necessary to the point of embarking on an alternative means of doing the job if ABMA won't play ball right down the line . . . Continuation of present levels of negligible monitoring is not an acceptable solution.'

Then, on 2 October 1959, Homer J. Stewart, the Director of the NASA Office of Programme Planning and Evaluation, sent Glennan a review of future agency launch vehicle requirements and considered the availability of several existing projects which threatened to duplicate performance capabilities. For some time now NASA had been working on Project Vega, a launch vehicle configuration that would have adopted the Atlas as first stage to new second and third stage designs providing enhanced lifting capabilities, and the agency was considering the use of Agena and Centaur upper stages, thus eliminating the need for new developments. Before the end of the year, Vega would be cancelled in favour of Agena and Centaur as upper stage vehicles to the Atlas.

Before this decision, on 20 October 1959, President Eisenhower considered the latest moves by NASA to obtain the von Braun team and thereby secure authority over the Saturn programme. A day later, the President announced that he approved of the transfer and would bring this before Congress for ratification within the next few months. Two days earlier General Medaris announced his resignation from the ABMA and von Braun was quoted as saying that he too would leave government work if the Saturn project was cancelled. Von Braun pointed to the large launch vehicle available in the Soviet Union and suggested that within a very short time the Russians would have the capability of placing 'a busload of astronauts' in orbit. Moreover, 'If we continue at this leisurely pace we will have to pass Russian customs when we land on the Moon.' The transfer of 5,000 workers from the Development Operations Division would do more than provide NASA with the Saturn launch vehicle, with its 680 tonne first stage thrust and a potential for placing up to 10 tonnes in orbit with appropriate upper stages. The big F-1 liquid oxygen and kerosene engine under development at Rocketdyne was itself a candidate for much larger vehicles.

Plans for an advanced Saturn, called Nova, envisaged clusters of up to eight F-1's and this would provide a first stage thrust of more than 5,400 tonnes with a capacity for placing nearly 200 tonnes in orbit. A payload capability of this magnitude would be required for Moon landings and flights to the very edge of the solar system. Missions, in effect, that would have only scientific value and, as such, structure objectives totally divorced from any military needs. Now that the basic Saturn, albeit a veritable behemoth by contemporary standards, would be developed by NASA the long awaited decision on upper stage configurations could be addressed, and suitable missions for the Saturn could be selected and put into effect.

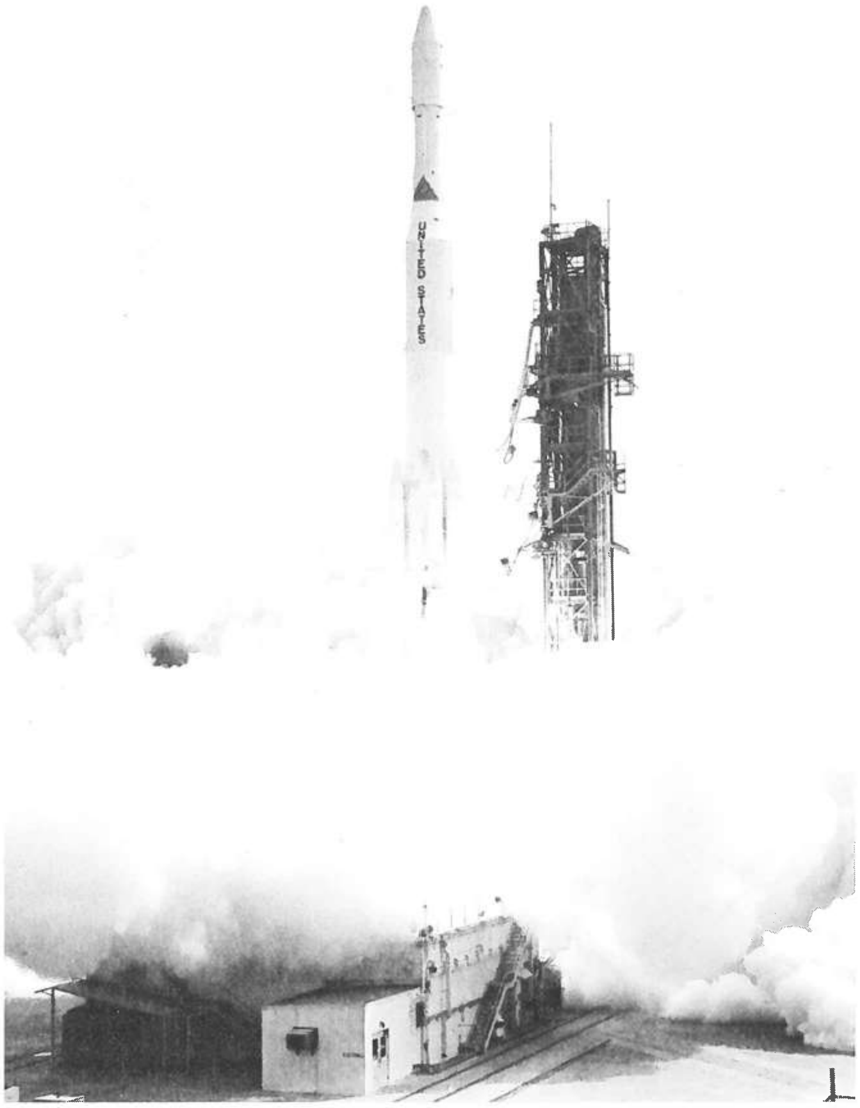
By the end of 1959, NASA and the ARPA had consulted the Huntsville team on the preferred configuration of potential upper stages and the latter carried out engineering studies that pointed to the desirability of having the second stage provide a thrust of 36 tonnes from four clustered motors burning liquid hydrogen and liquid oxygen. The third stage would use two modified LR-115 engines of the type fitted to the Centaur, but providing a thrust of 18 tonnes. On 15 December the Saturn Vehicle Committee, formed a month earlier and also known as the Silverstein Committee, recommended adoption of this three-stage design as the first Saturn configuration. Under the earlier classification of A, B and C derivatives it was known as the C-1 and would be able to send more than 4 tonnes to the Moon. On 18 January 1960, the Saturn launch vehicle development programme received the long-awaited DX rating, placing it in the category of one of the nation's most important projects. This allowed contractors and government establishments alike maximum access to raw materials necessary for sustaining the programme. Two days later NASA issued its 10-year plan and immediately outlined the differences that would mark the new space agency.

Whereas its predecessor, the National Advisory Committee for Aeronautics had been essentially a research organization, NASA would conduct operational missions to both further the space aims of the nation and collect basic data about the physical environment of Earth and the planets; Earth orientated research and operations would concentrate on the remote sensing of atmospheric phenomena and incorporate studies of the near-space medium. All this activity required a reliable and efficient inventory of launch vehicles by which to gain access to the new and unexplored domain. At the bottom end of the scale would come the Scout solid propellant four-stage rocket. It would be used to launch small satellites and conduct atmospheric research. Next, the Thor IRBM would be adopted and used as the first stage for a variety of upper stage designs that could place medium-size payloads in orbit. Flights to the planets, and the launch of larger satellites about the Earth, would use the Atlas together with upper stages such as Agena and Centaur. For manned missions to the Moon and unmanned flights to the planets with large spacecraft, NASA would use the Saturn C-1 which, although not expected to achieve operational status before 1963, would eventually be fed into the launch vehicle inventory. For the heaviest payloads of all, probably manned Moon landings versus the simpler 'fly-by' missions with the C-1, the agency would phase in the Nova using clusters of F-1 engines with each delivering a thrust of 680 tonnes. Nova was expected to support manned landings on the Moon sometime in the 1970's.

The fiscal year 1961 budget, ironed out during the closing months of 1959, envisaged a sum of $967 million, nearly double the $490.3 million finally authorized for fiscal year 1960. It would run for twelve months from 1 July 1960, and reflect the increasing emphasis on funding new and expensive space activities. Congress would finally raise the fiscal year 1961 allocation to $972.7 million.

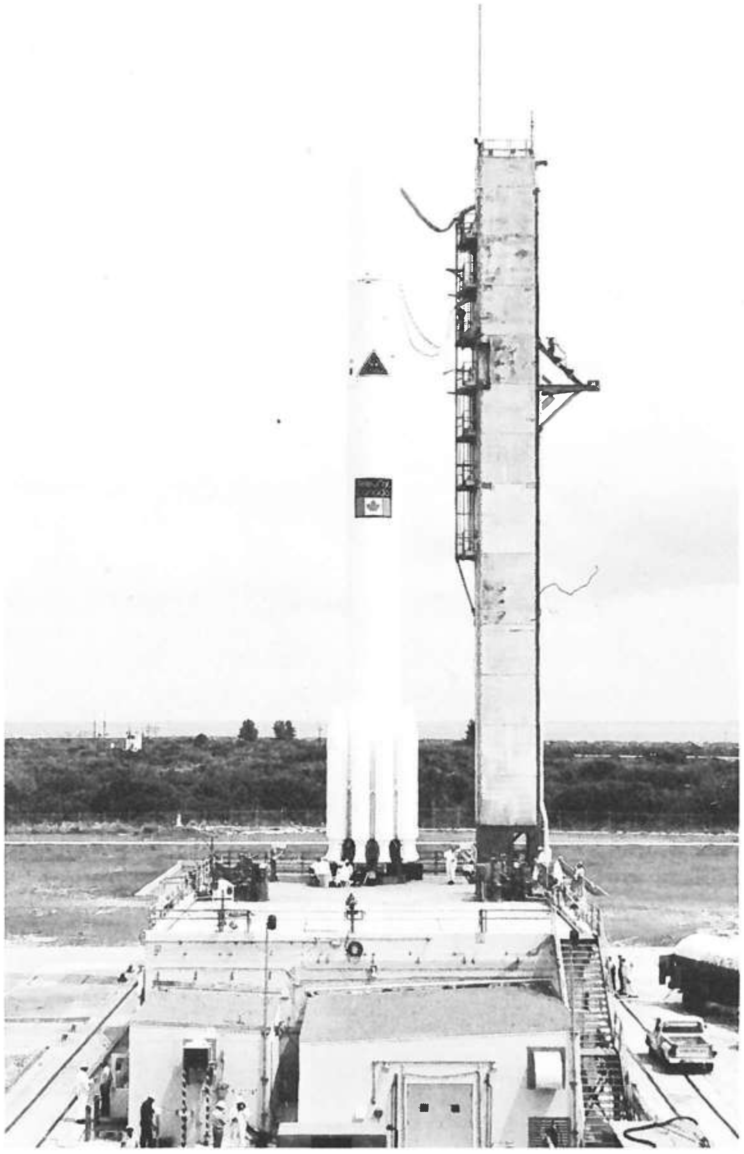
NASA was already thinking of improving the basic Saturn C-1 by adding more efficient upper stage configurations; as early as 15 December 1959, the Saturn Vehicle team had recommended development of a 90.72 tonnes thrust J-2 by Rocketdyne using high-energy liquid hydrogen/liquid oxygen propellants. At that time it was felt likely that the stage would be a candidate addition for later Saturn developments, effectively building on the large thrust ouput from the eight clustered H-1 engines so that future derivatives could provide a 'bridge' between the basic C-1 and the large Nova class vehicles. NASA was certainly mindful of the need to develop a heavy lift capability at the earliest opportunity. On 22 January, the Director of the US Information Agency gave evidence before the House Science and Astronautics Committee that opinion polls taken in several countries, indicated general acceptance that the United States was between five and ten years behind the Soviet Union in the field of space technology.

Four days later a bidders conference was held, at which the ABMA, still winding up its administrative surveillance of the Saturn project, briefed thirty-seven potential contractors for the second stage of the C-1. It would be called the S-IV and comprise four 9 tonne thrust rocket motors, burning liquid hydrogen and liquid oxygen for a total thrust of 36 tonnes. On 3 February 1960, prospective bidders were briefed on an S-II



Continued improvements to Delta were manifest in the M-6 variant with six Castor strap-on boosters.

With improved upper stage and nine strap-on boosters, Delta 1914 was a proud descendant of the basic launcher.

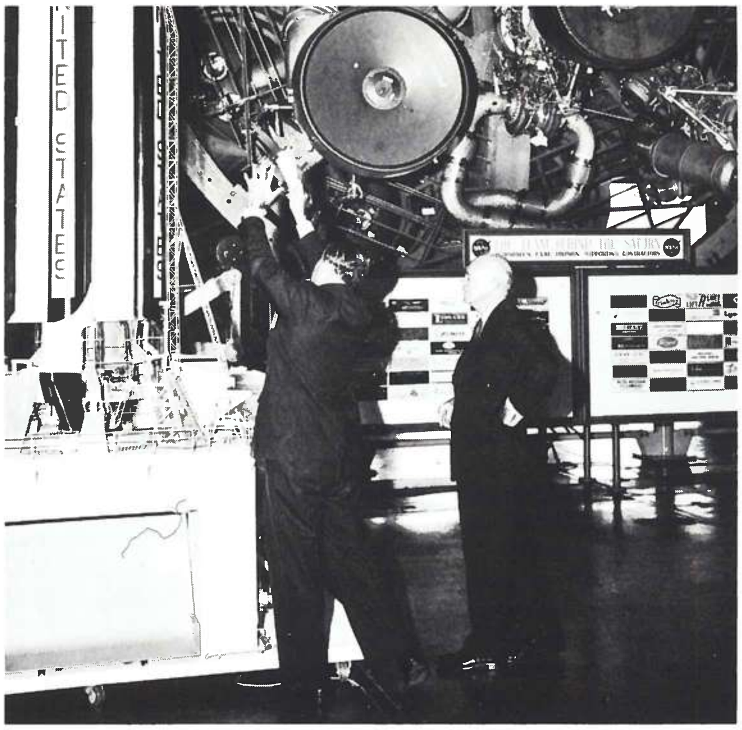


stage which would use high-energy propellants and a cluster of Rocketdyne J-2 engines; money for the J-2 had been provided two days before. During February the Huntsville team reviewed the Saturn development plan in the light of a generous increase in money for rocket research, provided by order of President Eisenhower. From now on the financial deficiencies of the previous two years changed into a progressively more favourable situation and this provided the stimulus to increase the work effort on future upper stage configurations.

Beginning on 28 March 1960, the ABMA carried out a series of engine tests designed to prove the operating principle of clustered H-1 motors. First came ignition of two H-1 engines for a duration of 8 seconds and then, on 6 April, four engines were fired for 7 seconds. These were followed by the first simultaneous ignition of all eight H-1 engines on 29 April, in an 8 second burn; additional tests in the weeks ahead raised the burn time to 121 seconds. Events were now moving toward fabrication of the first Saturn C-1 and the programme picked up momentum. Organizational changes, resulting from the transfer of the von Braun team at Huntsville, prompted President Eisenhower to re-name the recently acquired NASA facility the George C. Marshall Space Flight Centre, effective from its formal transfer date of 1 July 1960. The Missile Firing Laboratory at Cape Canaveral would become part of this new Centre on the same date and be absorbed by the MSFC Launch Operations Directorate. Less than two years later is would become a Space Centre in its own right.

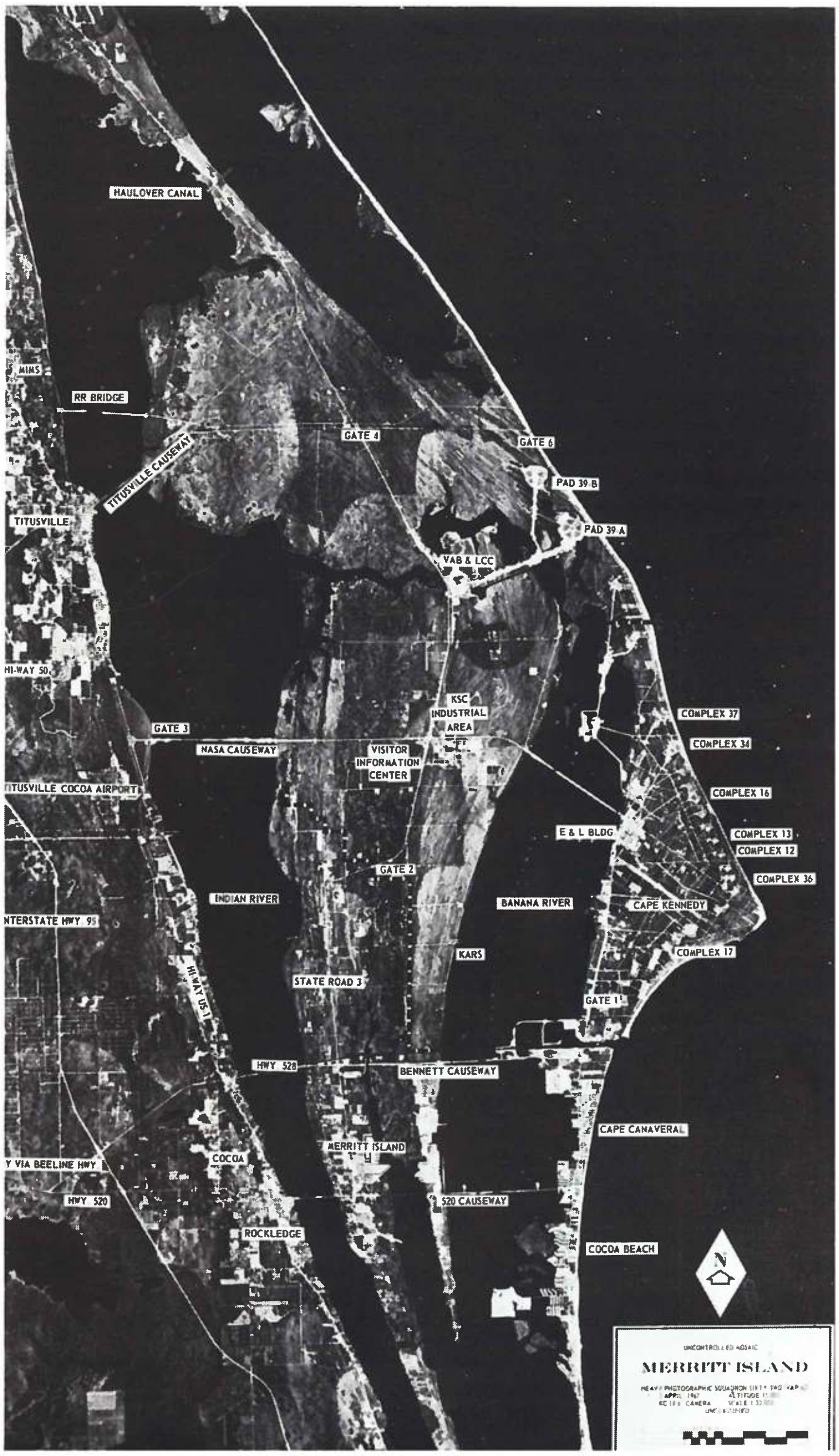
By the end of May, 1960, the first flight version of the Saturn rocket was in the assembly phase at Huntsville, designated SA-1, and Rocketdyne were formally requested to develop the J-2. On 8 August, Pratt and Whitney were issued a contract to start work on the LR-119 liquid oxygen/liquid hydrogen engine for use in Saturn upper stages. Each engine would deliver a thrust of 7.9 tonnes. By October the preliminary Saturn development schedule envisaged flights beginning in mid-1961 followed by tests with a two-stage configuration early in 1963 and three-stage flights a year later. Ten research and development tests with the C-1 would qualify the launch vehicle for operational missions.

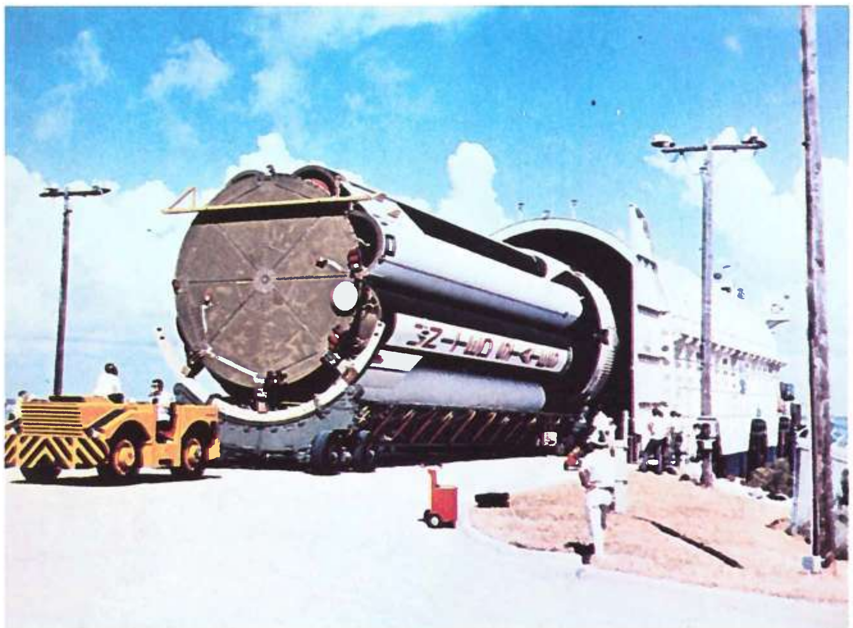
By the end of 1960 America had been to the polls and elected John F. Kennedy as the new President; he would assume office early in 1961, replacing the Republican President Dwight D. Eisenhower for a term of Democratic rule. On 27 December 1960, Kennedy made known his displeasure over the protracted emergence of a US space programme and warned of the dangers resulting from a Soviet lead. Two weeks later Kennedy issued a report, compiled by a committee, chaired by Jerome B. Wiesner, which called for substantive changes to the administrative layout of NASA, a more effective use of the National Aeronautics and Space Council and a more unified coordination of military projects controlled by the Department of Defence. For his part, Eisenhower proffered caution when addressing the Congress before leaving office; 'Further testing and experimentation will be



President Eisenhower, here seen at the formal dedication of the NASA Marshall Space Flight Centre, is shown a one-tenth scale model of Saturn I. At back two of the eight H-1 engines in the first stage give scale to the launcher. Von Braun describes principal features on the model.

Aerial mosaic of the Kennedy Space Centre at Cape Canaveral. Pads 39 A and B would be used for the massive Saturn V; Pads 34 and 37 for the Saturn I series.





Saturn I first stage units arrived by barge at the Kennedy Space Centre.

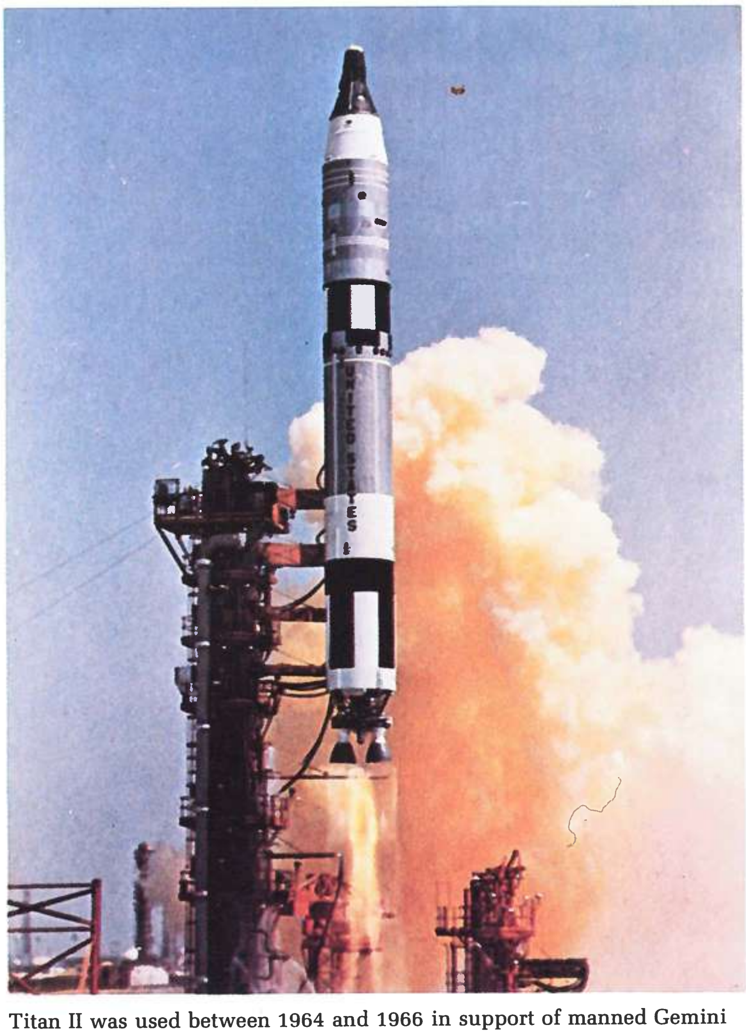
necessary to establish whether there are any valid scientific reasons for extending manned space flight beyond the Mercury programme.' NASA had already done its homework on the future of manned space flight and fully one year before had come up with Project Apollo, at that time conceived as a progressive step beyond Mercury which would provide a capability for long duration flights in Earth orbit, culminating in flights around the Moon and back. It had no specific timetable and the Saturn programme was seen as an integral part of post-Mercury plans.

One of the last functions required of the out-going President was preparation of the fiscal year 1962 budget request, effective from 1 July 1961. In his submission, Eisenhower asked for $1,110 million on behalf of NASA, but this was eventually raised to $1,855 million in a series of supplemental additions introduced by the new Kennedy administration. The increase in available resources had been enormous; since its inception on 1 October 1958, the space agency budget had grown more than fourfold and manpower levels now stood at more than twice that originally placed on the payroll. Between the end of 1958 and the end of 1960, NASA and the Department of Defence had attempted 48 launches, of which 21 had failed for various reasons. This represented a success level of 52%, a considerable improvement on the 28% success rate achieved during calendar year 1958. By the end of 1960 the Thor IRBM was forging for itself a record of versatility with upper stages like Agena, Able-Star and Delta providing a reliable series of launch vehicles capable of placing payloads of up to 450 kg in Earth orbit. Atlas, with Able or Agena upper stages, could put 2,200 kg in orbit. By May 1960, however, the Russians were demonstrating a capability of lifting weights in the order of 4,800 kg into space by attaching a single upper stage to the existing SS-6 and the gap between American and Russian lifting potential prompted Kennedy to consider major new initiatives in the race for supremacy.

During the early months of 1961 the initial series of Saturn launch vehicle configurations was established. Three basic stages were involved; S-I, with its cluster of eight H-1 engines providing a total thrust of more than 600 tonnes, the S-IV, with four LR-119 engines providing a total thrust of 31.7 tonnes, and the S-V with two LR-119 engines and 15.8 tonnes of thrust. The S-IV and S-V upper stages burned liquid oxygen and liquid hydrogen, while the big S-I stage burned liquid oxygen and kerosene. The Pratt and Whitney LR-119 was a projected development of the LR-115 being prepared for the Centaur upper stage and would produce a unit thrust of 7.9 tonnes.

The Saturn C-1 launch vehicle would consist of S-I, S-IV and S-V stages, one above the other; a proposed C-2 derivative would use the same S-I first stage, but adopt the S-II, a liquid hyrdogen/liquid oxygen development carrying four J-2 engines for a total thrust of 363 tonnes, as the second stage and the S-IV, with its four LR-119 engines providing 31.7 tonnes of thrust, in third stage position. An even more powerful four-stage version would place an S-V on top of the S-I, S-II and S-IV assembly. The C-1 would be capable of placing 10 tonnes in Earth orbit, while the C-2 would carry a payload of up to 20 tonnes. So far, no formal contracts had been issued for the projected S-II stage, but following the submission to Congress of a substantially improved budget by President Kennedy, the NASA Administrator authorized full scale development of the C-2.

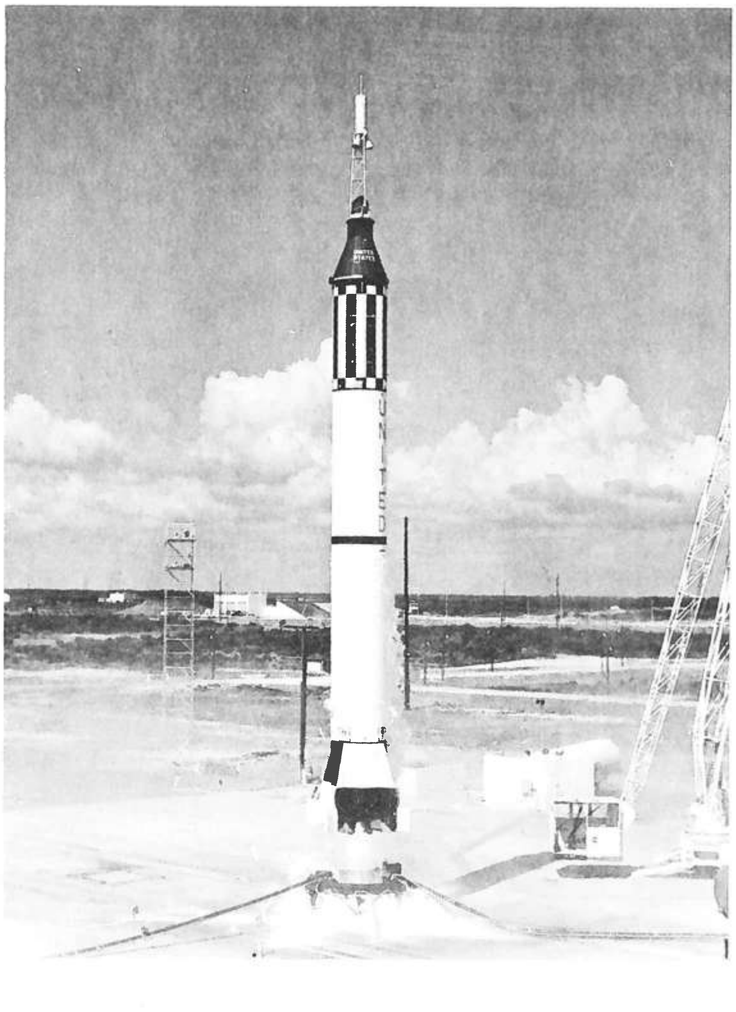
Earlier, Glennan had resigned his position with the agency and NASA had a new head: James E. Webb, with a well earned reputation for blunt and aggressive administration, having held government posts as Undersecretary of State and Director of the Budget Bureau. Then, on 23 March 1961, the Marshall Space Flight Centre made recommendations that resulted in a configurational change. Instead of using four LR-119 engines in the S-IV stage, engineers preferred the logic of adopting the basic LR-115 already being developed for Centaur and placing six of these units in the



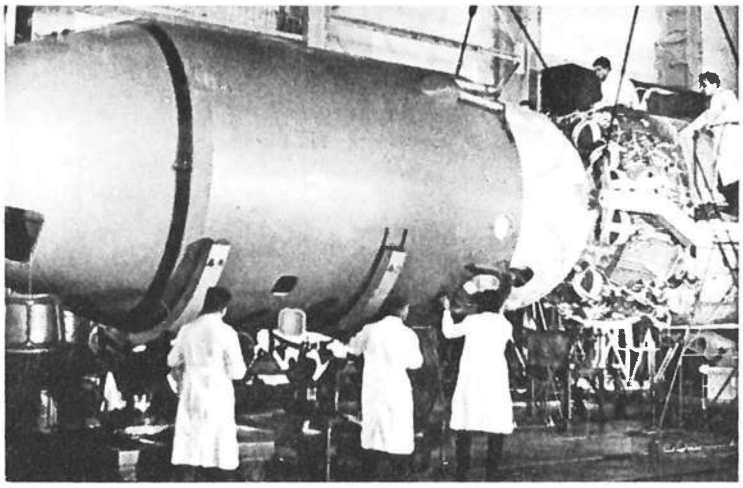
Titan II was used between 1964 and 1966 in support of manned Gemini flights, seen here on 3 June 1965, sending Gemini IV into orbit.

An Atlas Agena lifts off the Kennedy Space Centre in March 1966. The slim Agena upper stage was placed in orbit so that a Gemini spacecraft could rendezvous and dock with it.

NASA Administrator James E. Webb (left) is here seen with his deputy, Dr. Hugh L. Dryden. Webb's dynamic leadership did much to keep the NASA ship on course during the period of Democratic administration between 1961 and 1968.



A Redstone rocket lifts Alan Shepard on a 15 min sub-orbital flight, 5 May 1961. Note the single escape rocket on top which would be used to wrench the spacecraft from the booster in the event of trouble during the ascent.



Yuri Gagarin's Vostok 1 spacecraft, at right, prepares to receive its aerodynamic shroud. The encapsulated vehicle will then be mated to the second stage of the A-1 launch vehicle.

S-IV, resulting in an increase in thrust from 31.7 tonnes to 40.8 tonnes. Also, the Saturn C-1 would be relegated to a two-stage vehicle, using only the S-I and the S-IV, since performance would be adequate for research and development purposes and the ultimate availability of the larger Saturn C-2 would fill requirements for a heavy weight-lifting capability.

NASA was already considering potential missions for the Saturn family of launch vehicles and tailored the preliminary requirements of unmanned Moon explorers and robot spacecraft to the planets, around the known performance of the C-1 and the C-2. The agency formally approved the configuration change on 7 April, and decided that the first three Saturn C-1 launches would be with live first stages only; dummy upper stage structures would take the place of S-IV units until two-stage flights began from the fourth mission. With S-I and S-IV stages, Saturn C-1 would be able to place a payload of 5 tonnes in orbit. But the C-1 was being seen more and more as merely a development vehicle for C-2 and subsequent variants, with ten launches between late 1961 and early 1964. Trimmed down to carry just an S-IV upper stage. The basic C-1 would be capable of placing in orbit a load similar to that lifted by an Atlas-Centaur. The first Atlas-Centaur was expected to fly in May 1961, a month after the formal Saturn configuration change, but not until 1964 or 1965 would the C-2 be available with a capacity of lifting 20 tonnes into space.

The Russians already had a launch vehicle regularly sending weights of 4.5 tonnes into orbit. On 12 April 1961, they used this capability to place cosmonaut Yuri Gagarin on a trajectory that took him once around the globe and back to Earth. The first man in space. At this time the Mercury programme was still moving towards final proving flights and it would be ten months before an American got into orbit. Nevertheless, tests of the Mercury spacecraft incorporated, two ballistic flights that would carry Alan Shepard and Virgil Grissom on fifteen minute flights into space and back, without going into orbit. The first of these, on 5 May, did little to hide the tremendous gap between the American and Russian space programmes. The President, John F. Kennedy, was particularly disturbed by events that clouded the opening months of office and the sentiments expressed at the Inaugural Address for a new wave of change and national resolution seemed far from possible. It would need new hands at the helm; a physical transformation of purpose and will. Toward this end, he instructed the Vice President, Lyndon B. Johnson, to seek out ways by which the United States could overtake the Soviet Union and demonstrate a superior American technology in full view of every nation on Earth.

NASA had written up only preliminary requirements for the future Apollo programme and saw, as an end objective, the possibility of sending men around the Moon. Nothing concrete had yet emerged from the studies, because the agency felt it prudent to finish Project Mercury and then consider further initiatives in manned space flight. It became clear that the Russian space programme may soon acquire the capability of mounting a manned circumlunar flight and that public pronouncement of this as a NASA objective would lead to open condemnation of the new administration, if the Soviet Union got there first. Other possible space goals, such as the establishment of a large Earth-orbiting space station, were too imprecise a measure of national capability. It would need dedication to objectives which would demonstrate a clear cut lead for the United States. Finally, it was decided that only a manned landing on the surface of the Moon was sufficiently in advance of contemporary Soviet accomplishments to give the space agency a fighting chance of getting there before the Russians.

Consequently, on 25 May 1961, President Kennedy went before Congress and called for a massive new committment to space exploration: 'Now is the time to take longer strides – time for a great new American enterprise – time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth. I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long range exploration of space; and none will be so difficult or expensive to accomplish.' At last, after centuries of speculation filled with dreams of treading the dusty soil of another world, a national goal had been set that would bring to life the words of Konstantin Tsiolkovsky, Hermann Oberth and Robert Goddard. But in the mood of the moment it was a brilliant stroke of political genius, effectively welding the nation's resolve behind a clear and defined objective that threw down the glove of challenge to a determined Soviet administration.

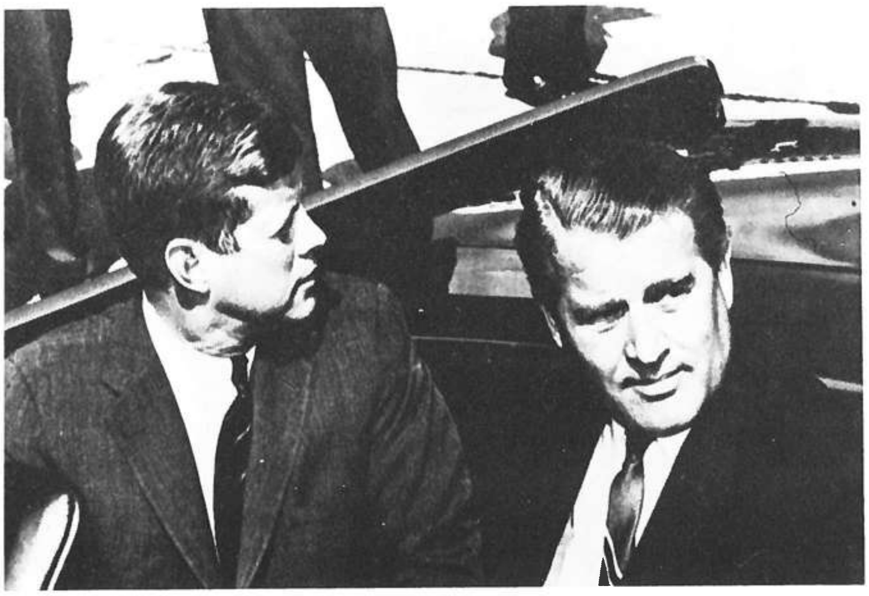
Two days after the congressional address, Wernher von Braun, for years working towards the day when Man would visit other worlds in the solar system, announced a third derivative of the Saturn launch vehicle: the C-3. The first stage would use two mighty F-1 engines to produce a combined thrust of 1,360 tonnes, the second stage would be the S-II, with four J-2 engines delivering 363 tonnes of thrust and the third stage would be the S-IV, with six LR-115's providing 40.8 tonnes of thrust. It would have a capacity for lifting payloads weighing 45 tonnes into Earth orbit. Launch vehicles of this size would be essential for landing men on the Moon and the Kennedy committment provided the spur for more advanced design concepts.

On 5 June, an historic milestone was passed, with the dedication of Launch Complex 34 at Cape Canaveral, built by the Army Corps of Engineers for the Saturn C-1. The Area was to the north of the launch pads, built in the early days of the missile programme and, like its neighbours, occupied a strip of land flanked by the Atlantic Ocean to the east and the Banana River to the west. Quite naturally, it was the largest launch facility that had emerged at the Cape and boasted awe-inspiring proportions. Complex 34 comprised a concrete launch pad 133 metres in diameter on which was situated a pedestal, 8 metres tall, which would support the rocket for launch. A central cut-out would allow exhaust gases from the eight H-1 engines to flow into a blast deflector that would channel the direction of escape. To facilitate erection of the complete Saturn C-1, a massive steel structure weighing 2,845 tonnes would be wheeled into position over the pedestal. It consisted of two towers, each one measuring 21.3 metres by 11.3 metres, standing 17 metres apart and surmounted by a steel bridging piece. In all, the tower assembly was 94.5 metres high and incorporated two twin-storey buildings at the base containing launch checkout equipment.

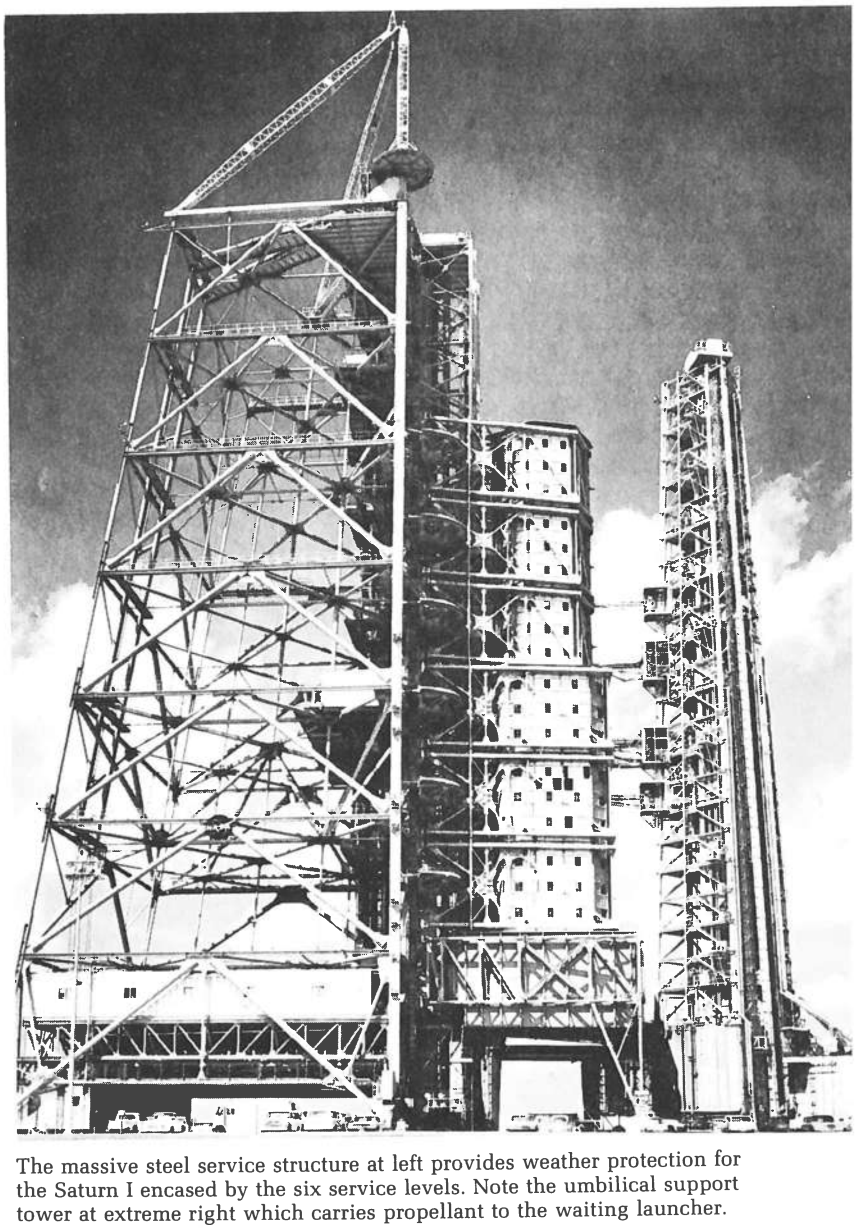
This massive service structure would be driven to a point 183 metres from the launch pedestal, before launch, to prevent damage. Underneath the launch pedestal, engineers built a room 65 metres long and 11.6 metres wide to house more checkout equipment, the essential power supplies and a distribution facility for routing, measuring and data transmission lines. Some distance away from the launch pad, the control centre, or 'blockhouse', ensured adequate command over all the functions required to prepare the Saturn for flight. It had walls nearly 3.7 metres thick, a door weighing 24 tonnes and 929 square metres of floor space divided between two levels. Propellant for the big Saturn was to be provided from four tanks: the two kerosene vessels were 290 metres from the launch pad and the two liquid oxygen containers were 198 metres away. Another 36 storage vessels were also provided for nitrogen and helium used in preparing the vehicle for ignition. Despite the abundance of peripheral support equipment, the launch site was dominated by the huge service tower – a structure that would embrace the launch vehicle with floors and collapsible walls, supporting 350 engineers and technicians, as the mighty rocket was readied for flight.

The first flight model of the Saturn C-1, designated SA-1, arrived at Cape Canaveral aboard the barge, Compromise, on 15 August 1961, two months after the dedication of Launch Complex 34. To the north, engineers were still working on a

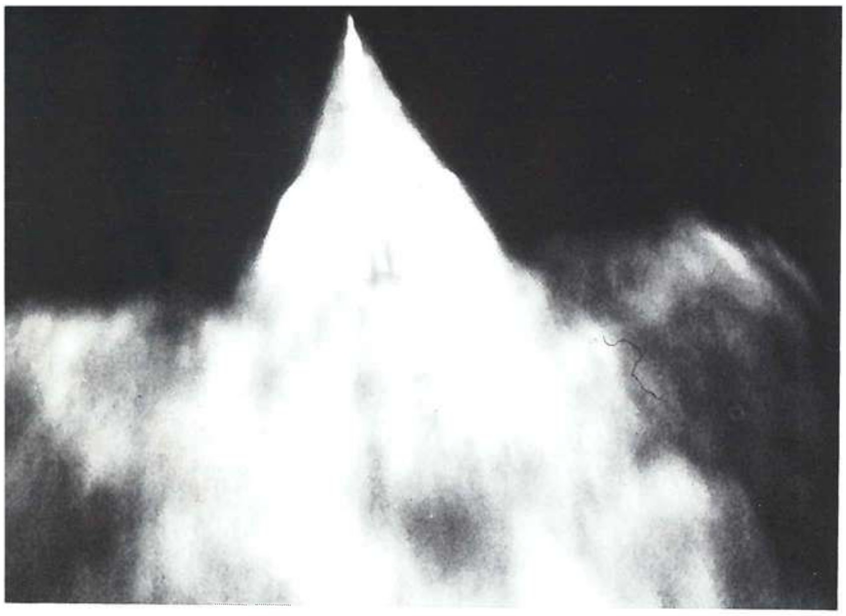
Launch control centres such as this example at Cape Canaveral were familiar sights in the early days of the space programme. They provide interesting comparison with the Launch Control Centre used for Saturn V and Shuttle missions.



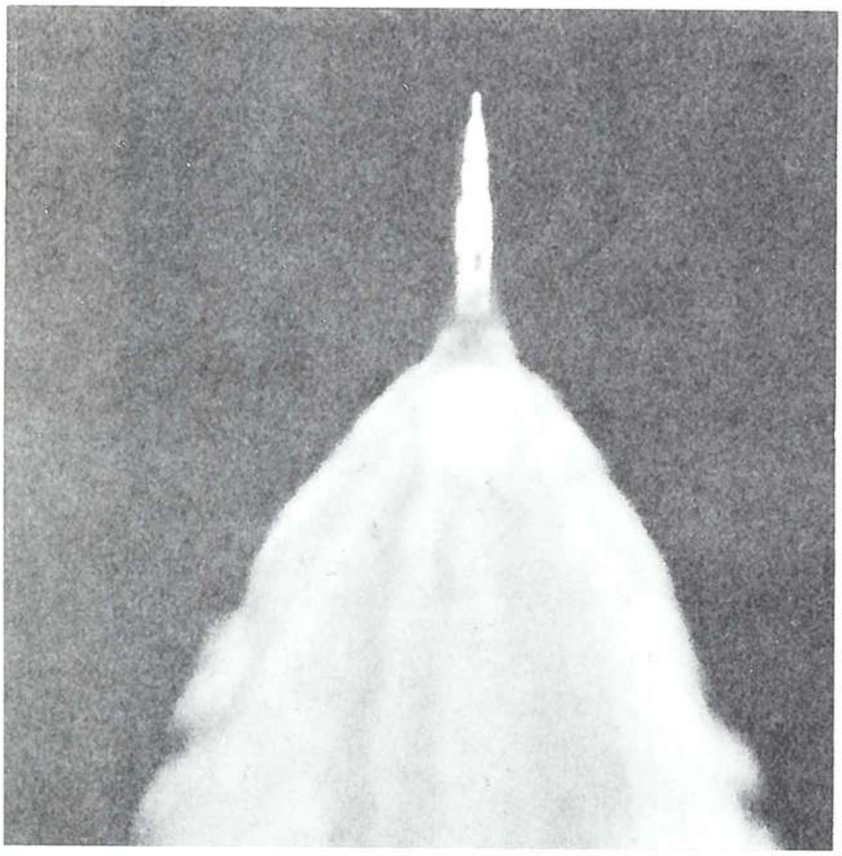
Political architect of the Apollo Moon landing programme, President Kennedy (at left), with Wernher von Braun who provided the technical stimulus to build the hardware.



The massive steel service structure at left provides weather protection for the Saturn I encased by the six service levels. Note the umbilical support tower at extreme right which carries propellant to the waiting launcher.

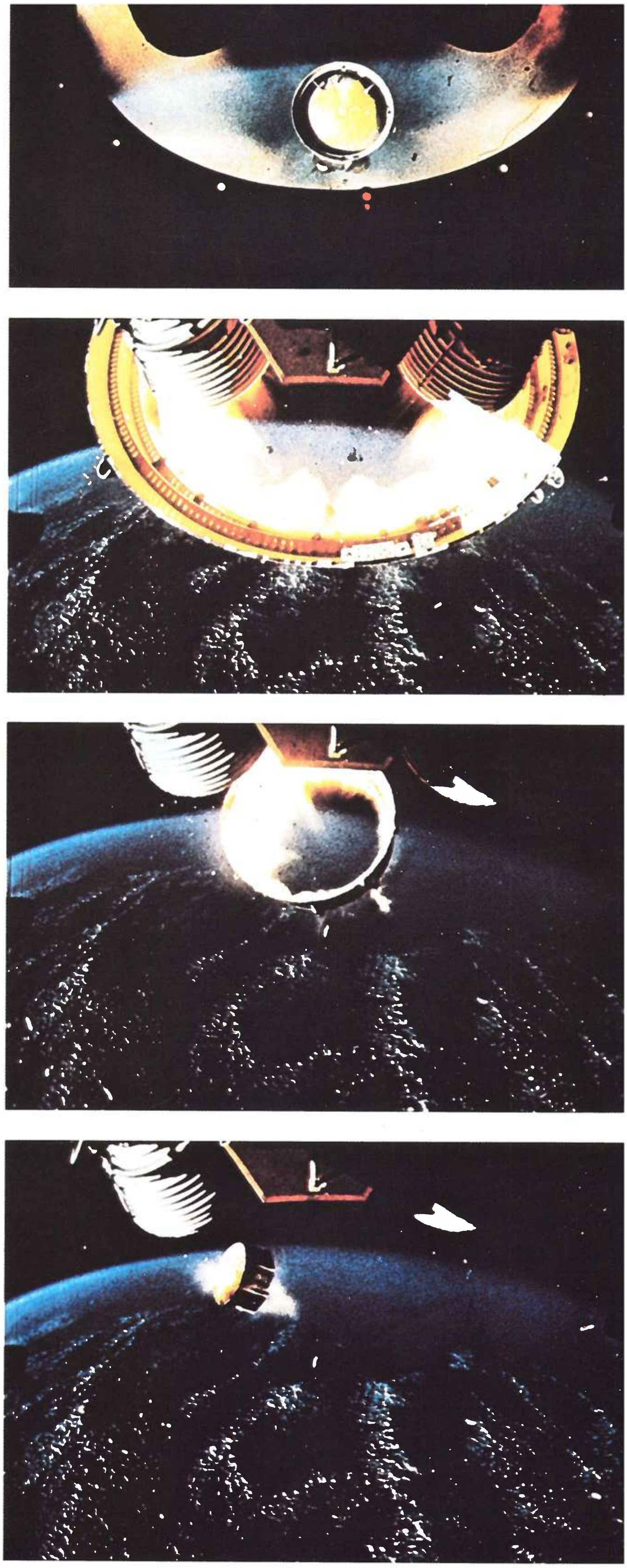


The instant of first-stage separation. Solid propellant rockets fire to retard the forward momentum of the stage and thus prevent re-contact with the upper stages of the Saturn V, momentarily enveloping the launch vehicle in a brilliant fire-ball.



An ascending Saturn V nears the end of the first-stage burn and the flame plume billows out unconstrained by atmospheric pressure found at lower levels.

Near disaster strikes Apollo 12 as an electrical discharge grounds to earth down the exhaust plume of the ascending Saturn V. Note the steam boiling from the launch umbilical tower, heated by the launch vehicle's motors seconds before.



First stage separation of a Saturn V as viewed from a 16 mm film camera placed in the engine bay of the second stage, looking aft. The top of the frame in all four views is filled by two of the five J-2 second stage engines. At top, the first stage can be seen falling away; at mid-upper, the separation structure linking first and second stages is jettisoned; at mid-lower, the separation structure is seen tumbling; at bottom, it continues to fall beneath the ascending second stage.

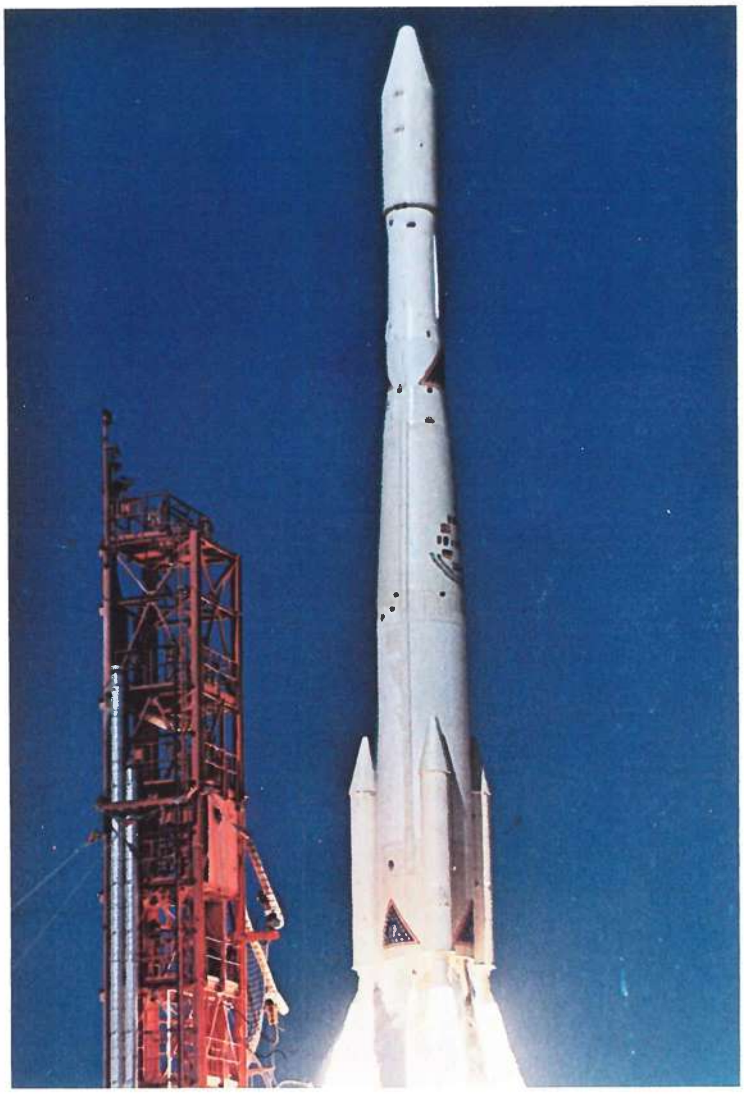
second Saturn facility, Launch Complex 37, that would be ready by the end of 1962. In the weeks that followed delivery of SA-1, technicians placed the vehicle on the pedestal at Launch Complex 34 and fitted dummy upper stages that would simulate live stages planned for later flights and smooth the air flow over the assembled rocket. In a coincidental bow to its ancestry, SA-1 incorporated the empty shell of a Jupiter IRBM as the extreme forward nose section.

On 27 October 1961, at 10:06 a.m. Eastern Standard Time, the powerful first stage thundered into life, with a thrust of nearly 599 tonnes and the eight H-1 engines burned for 116 seconds and then shut down as planned. In a flight lasting less than seven minutes, SA-1 flew to a height of 136.5 km and came down into the Atlantic Ocean 345.5 km from Launch Complex 34. The thrust generated by this first Saturn C-1 was almost four times greater than the Titan, at that time America's most powerful rocket.

During the second half of 1961, the Saturn development programme began to take on the shape it would eventually display for support of the ambitious landing on the Moon. No other launch vehicle was either available or proposed and the C-1 was seen as the predecessor of a new range of heavyweight rockets that could fill all the requirements of the space agency for the next decade or so. Five versions, each one larger and more powerful than its predecessor, were considered for development. The Huntsville team had the ideas, the Kennedy administration provided the money and NASA was charged with its objectives. Never before had the road to manned exploration of the planets been cleared of so many key obstacles. Nothing, it seemed, could now stop the machinery of space exploration.

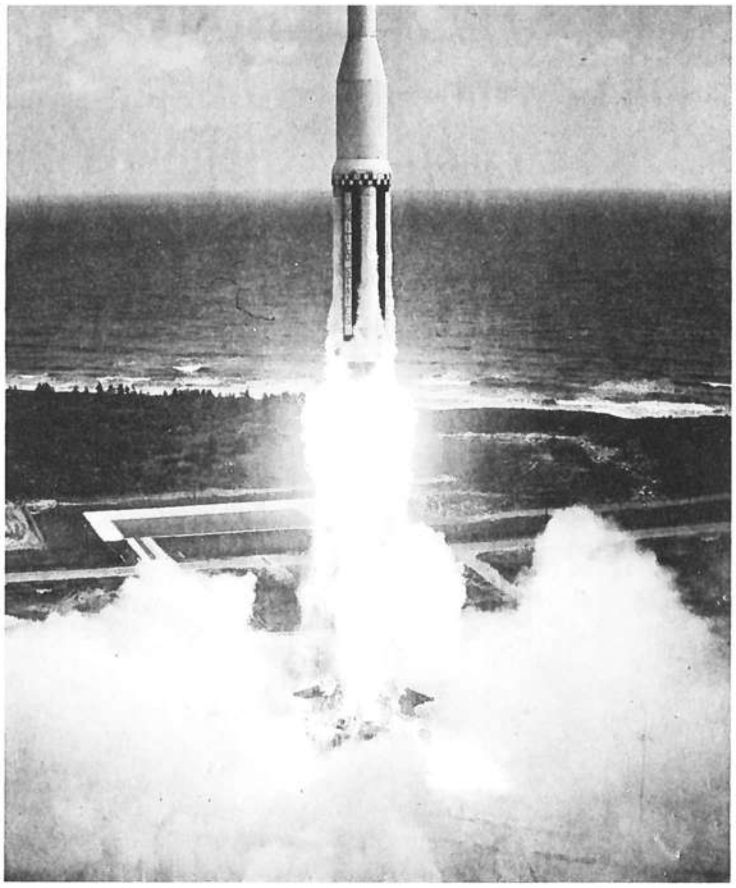
The formal transfer of the ABMA Development Operations Division to NASA had been effected on 1 July 1960, and Wernher von Braun was appointed Director of the new Marshall Space Flight Centre at Huntsville from that date. On 7 September 1961, NASA chose a redundant facility at Michoud, Louisiana, as the site for production of large Saturn launch vehicle stages. It would be operated by contractors working on the design and assembly of the various stages and would be known simply as Michoud Operations, directly responsible to the Marshall Space Flight Centre. Two days before the first flight of the Saturn C-1, NASA selected its third major Saturn installation in the south-west corner of the State of Mississippi, from where large Saturn engines would

Although used only as a research and development vehicle, the Saturn I pioneered the technology that led to successful operations with Saturn IB and Saturn V.



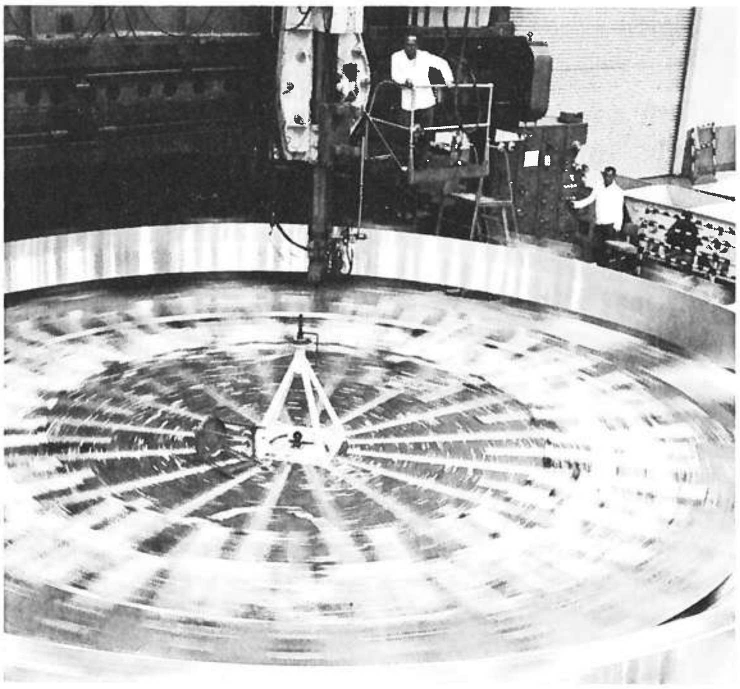
Developments with the basic Delta launch vehicle centred on new and improved upper stage configurations and the addition of three or more Castor solid propellant boosters attached to the base of the first stage at 120° intervals.

The first manned launch of a Saturn IB came with the flight of Apollo 7, the first manned Apollo, in October 1968. The launch vehicle was a successful development of the Saturn I research launcher.



On 27 October 1961, the first Saturn I launch vehicle ascended from Cape Canaveral on a suborbital test of the first stage; upper stages were inert.

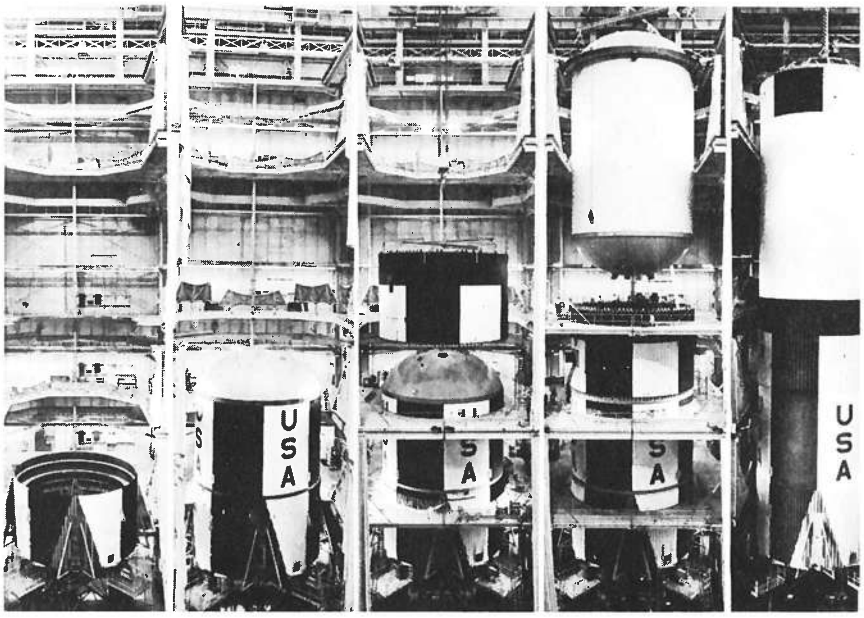
Construction of the Saturn V began with fabrication of tank sections. Here, a Y-ring used for joining cylindrical tanks is being milled.



be test fired before installation of the completed assembly on respective launch pads at Cape Canaveral. Called simply Mississippi Test Operations, it would be more popularly known as the Mississippi Test Facility, or MTF for short. Like the Michoud Operations complex it too was directly controlled by the MSFC.

The five Saturn configurations now being considered for support of the Apollo moon landing project, upgraded to a programme involving flights to the surface by the Kennedy decision announced 25 May, were known as C-1, C-2, C-3, C-4 and C-5. All but the last two have been described earlier in this chapter. C-4 proposed the use of four F-1 engines, each delivering a thrust of 680 tonnes, in the first stage for a total lift-off thrust of 2,720 tonnes. The second stage would be the S-II and its four J-2 engines in the same configuration as that proposed for the C-3. It would provide 363 tonnes of thrust. Above the first and second stages would be a third, the S-IV, delivering a thrust of 40.8 tonnes from six LR-115 engines. This three-stage assembly would be able to lift 90 tonne loads into Earth orbit compared with 45 tonnes for the C-3, 20 tonnes for the C-2 and 10 tonnes for the C-1. An incredible performance envelope considering that the most powerful civilian space launcher then available was the Atlas-Agena, with a 2.2 tonne payload capability; Atlas-Centaur, still in the development stage, would increase this to more than 4 tonnes, however.

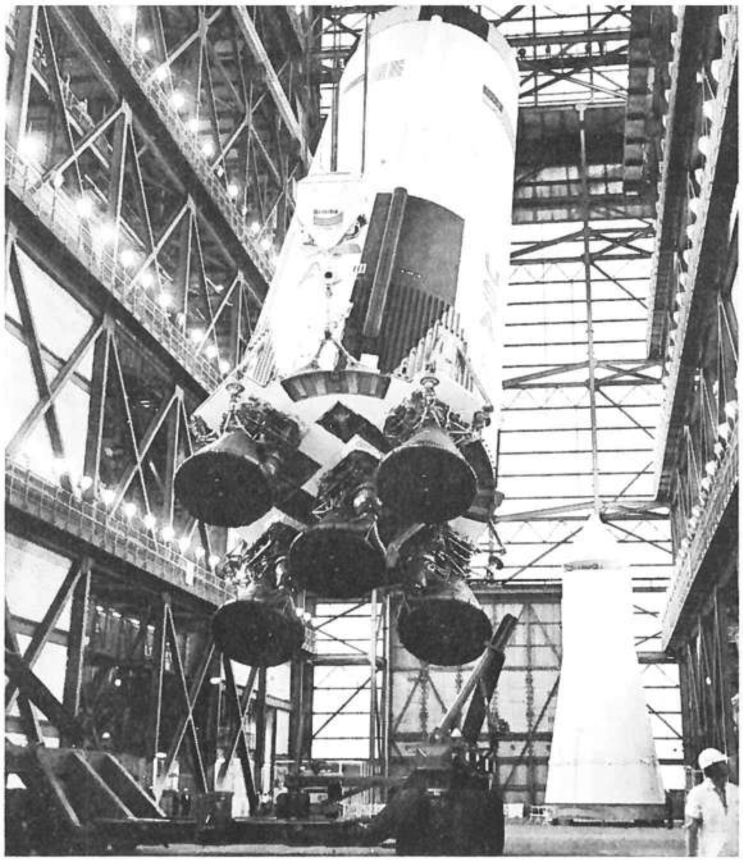
The most ambitious Saturn derivative seriously considered as a candidate launch vehicle for Apollo objectives was the C-5. It would carry five F-1 engines in the first stage, delivering a total thrust of 3,402 tonnes, use the same S-II adopted by the C-2, C-3 and C-4, and carry the S-IV stage provided for all derivatives. This configuration would be able to place 113 tonnes into orbit and was considered a likely contender for the early development stages of Apollo. By the end of 1961 the method to be used for sending men to the Moon was still the subject of much debate and engineers suggested using the C-5 for flights around the Moon and back as the precursor mission to the actual landing itself. A much larger rocket would be required for actually landing on the Moon and for this objective NASA would use the Nova, which was essentially a Saturn C-6, although it was never known by that designation. Nova would support eight F-1 engines at the base of the first stage, providing a launch thrust of more than 5,400 tonnes, use two engines in the second stage for a thrust of 1,360 tonnes, adopt the 363 tonne thrust S-II as the third stage, place the six-engined S-IV as fourth stage, with a thrust of 40.8 tonnes and use two LR-115 engines producing a combined thrust of 13.7 tonnes in a fifth stage.



Assembly of the first (S-IC) stage of Saturn V. Left to right: the thrust structure to which will be attached five F-1 engines; the kerosene tank; the intertank structure; the liquid oxygen tank; the forward cylindrical skirt. Note the personnel on the centre platform in second photo from right.

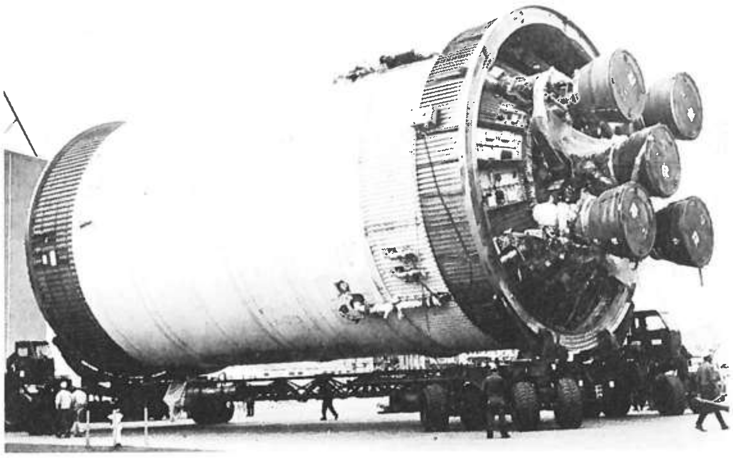
This gargantuan launch vehicle would be able to put a payload of 205 tonnes into orbit, more than enough to carry the Apollo spacecraft off to the Moon.

Nova, then, was proposed as the launch vehicle necessary for achieving the manned lunar landing objective by the so-called 'Direct Ascent' mode. This envisaged a large Apollo spacecraft travelling to the Moon under the impetus of the thrust provided by Nova, turning around so that its base pointed in the direction of flight landing softly on the lunar soil with the aid of braking rockets located between landing legs. The Saturn C-5 vehicle would not have the lifting potential to send Apollo to the Moon with sufficient propellant for a landing. It could boost a load of 45 tonnes out of Earth's gravitational pull, while the Nova vehicle would be capable of sending 70 tonnes on the same trajectory, a figure more closely matched to the projected weight of the 'Direct Ascent' Apollo at this time. But rationalization of the development programme suggested that the C-2 and the C-4 were not necessary to the aims of the space programme and toward the end of 1961 a trimming process was set in motion to pick out most beneficial launch vehicle concepts and eliminate the rest. Moreover, deepening uncertainty as to the best means to



The Saturn V first stage (S-IC) with its five F-1 engines is here seen being lifted in the Vehicle Assembly Building at the Kennedy Space Centre. A mock-up of the Apollo payload is at back.

The S-II, second stage of Saturn V, carried high-energy liquid hydrogen/liquid oxygen propellants.

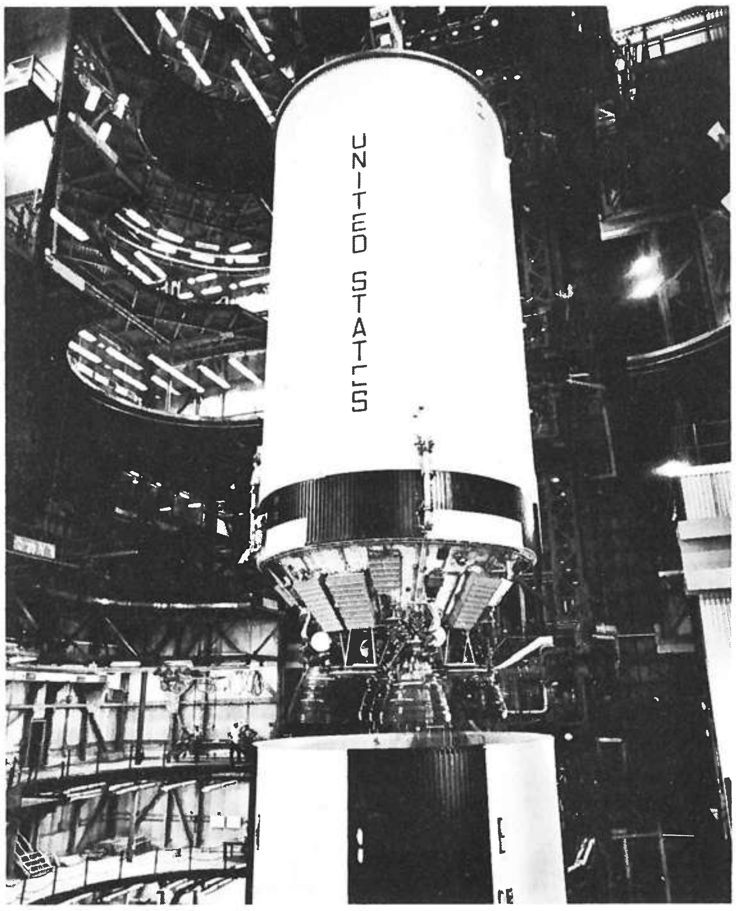


be employed in reaching the Moon, did little to focus programme plans on the preferred launch vehicle.

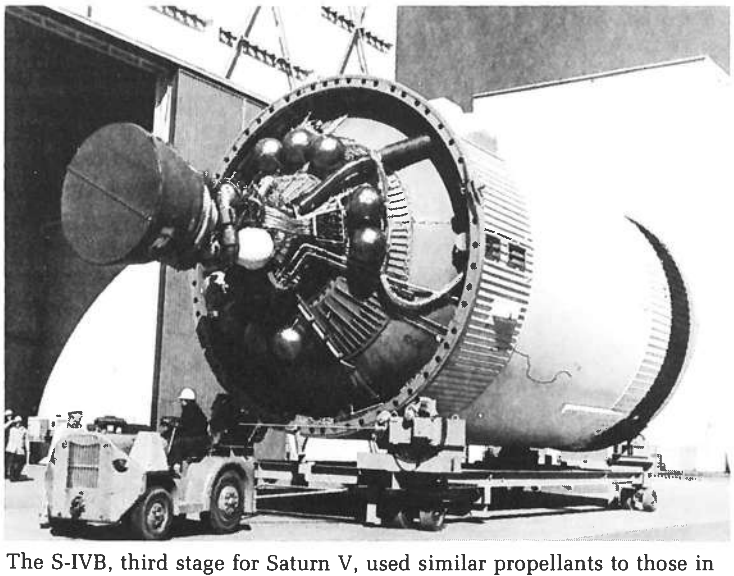
John C. Houbolt at the NASA Langley Research Centre proposed adoption of a so-called Lunar Orbit Rendezvous mode, whereby the main Apollo spacecraft would go first into lunar orbit and then dispatch a separate space-craft for the actual descent and landing. Thus, propellant sufficient for landing the smaller vehicle would reduce the overall weight of the payload that would have to be fired out of Earth's gravity field. For the LOR method, Saturn C-5 would suffice. Also, in an alternative approach, an Earth Orbit Rendezvous mode was proposed whereby Saturn C-5 vehicles would lift all the elements of the Nova-class Apollo into Earth orbit first, from where they could be assembled before leaving for the Moon and a direct descent. Thus it was that with three possible ways of reaching the Moon, Saturn engineers progressed with C-3, C-5 and Nova design studies, so that when the final decision was made, the appropriate launch vehicle development programme would be available.

NASA headquarters had decided to support the Earth Orbit Rendezvous plan, but von Braun's Huntsville team favoured the Direct Ascent method with Nova. Gradually, however, they too came over to the EOR concept. Houbolt, long time prophet of the simpler Lunar Orbit Rendezvous technique, was infuriated by persistent emphasis on Earth Orbit Rendezvous. In a mood of truculence he wrote a letter to Robert Seamans at NASA pointing out the deficiencies in the other concepts, protesting at the continued lack of support for his ideas and urging the agency to take a more benevolent look at the single-launch approach. By 28 November 1961, the North American Aviation Space and Information Systems Division had been awarded the contract to build the spacecraft that would land men on the Moon. As then envisaged it would consist of three sections: one, at the forward end, where the crew would live and work; beneath this, an instrument and equipment section would provide all the systems for keeping the crew alive and carrying out the mission, together with a set of rocket motors that would be used to lift the vehicle off the Moon; the section that would decelerate the entire vehicle and place it on the lunar surface, was situated below the two upper sections and provided landing legs for supporting the entire assembly.

This design reflected emphasis on the Direct Ascent and Earth Orbit Rendezvous modes; the Lunar Orbit Rendezvous plan would use a separate vehicle to actually land men on the lunar surface. Houbolt had sent his angry letter to Seamans on 15 November, going over the heads of immediate superiors, in an attempt to shake reason from NASA administrators;



The second stage is being mated to the interstage adapter which itself rests upon the first stage and provides sufficient volume to accommodate the five J-2 engines at the base of the S-II.



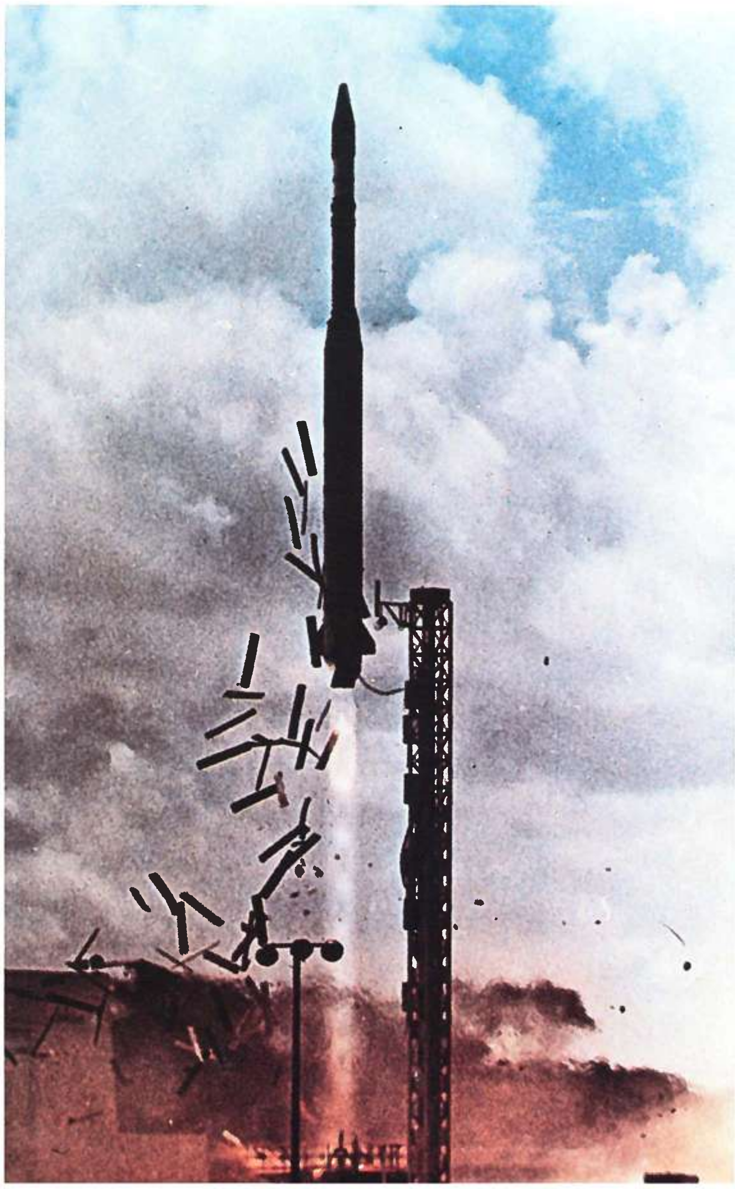
The S-IVB, third stage for Saturn V, used similar propellants to those in the second stage and carried a single J-2 engine capable of multiple re-start in space.

Seamans was Associate Administrator and as such directly responsible to James Webb. Houbolt was a fervent believer in Lunar Orbit Rendezvous, leaving no stone unturned in efforts to get it accepted. This abrupt approach from the Langley engineers impressed Seamans. He immediately turned the letter over to Brainerd Holmes, head of NASA manned space flight at headquarters, who in turn passed it to Joseph Shea, a newly appointed deputy to Holmes. Seamans was not so convinced about the desirability of choosing between the Direct Ascent and Earth Orbit Rendezvous methods as other personnel at headquarters; many had already made up their minds and allowed little room for flexibility. Maxime Faget, head of engineering at the Space Task Group set up to handle the simpler Mercury project, had openly declared his support for Direct Ascent. By now, most people were in favour of the Earth Orbit Rendezvous mode, but Faget still battled on and pressed hard for the Nova approach.

Doubts on the ultimate availability of Nova weighed heavily against Direct Ascent and there were fears that the enormous costs involved in its development would drive it under the axe of cost-conscious appropriations committees in Congress. Nevertheless, despite all the obvious criticism, Direct Ascent had gained a lot of support and even by late 1961 boasted influential advocates. But the Earth Orbit Rendezvous concept had gained sophistication, in that the large number of C-5 vehicles required to lift all the elements of Apollo into Earth orbit were cut to just two, by way of the tanker method. In this refined model, the first C-5 would lift the third stage and Apollo spacecraft into orbit. A second C-5 would then be launched to rendezvous with the empty third stage and spacecraft and transfer propellant so that it could fire its engine and send Apollo to the Moon. Landing on the Moon would still require the three modules of the Apollo, described earlier for the Direct Ascent method. Thus, the Saturn C-5 could be used to send the crew and equipment sections of Apollo on a precursor flight around the Moon and two Saturn C-5's could perform Earth Orbit Rendezvous for the actual landing attempt. This was the system favoured by most headquarters' staff and von Braun got the order to start work on the development of the C-5 on 10 January 1962.

A mighty Titan III-E/Centaur lifts off from the Kennedy Space Centre. Used primarily for sending unmanned spacecraft to the planets, this launcher is the penultimate development from the Titan stable.

The Europa II launch vehicle, seen here ascending on a test flight, was developed from the British Blue Streak long range ballistic missile.



Diamant B leaps away from its launch stand, testimony to the successful development of this French national satellite launcher. Flying debris is a part of the base shroud.

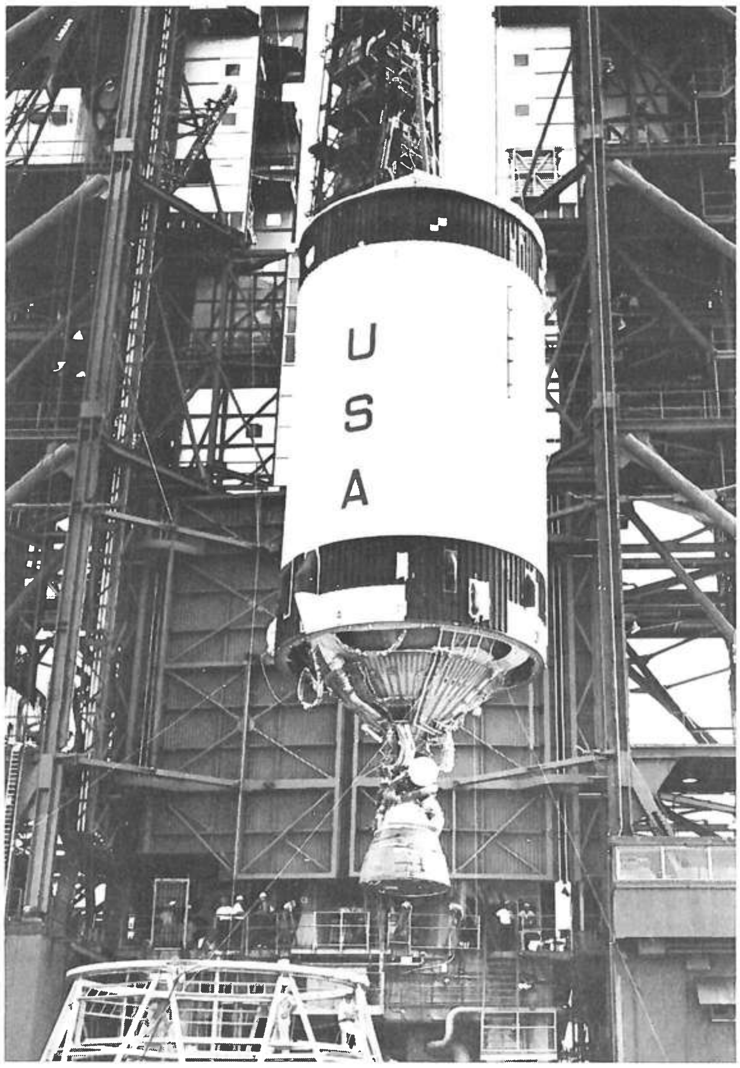
In the preceding months certain changes had been made to the design whereby the second stage, the S-II, would have five J-2 engines providing a total thrust of 454 tonnes. Also, a new stage, the S-IVB, would be developed using a single 90.8 tonne thrust J-2, instead of the six LR-115 engines in an S-IV stage. The first stage, with five F-1 engines delivering 3,402 tonnes of thrust, would be called the S-IC.

Back at headquarters, Houbolt's irate letter, now in the hands of Joseph Shea, had prompted second thoughts on the Earth Orbit Rendezvous mode. If his calculations were correct, Houbolt had found a way to mount the landing operation with just one Saturn C-5 launch. For more than a year Houbolt had plied back and forth from committee to government study group trying to get the idea acknowledged. Suddenly, things began to take a new turn. Shea immediately left for the Langley Centre in Virginia to get a first-hand briefing on this Lunar Orbit Rendezvous method. Suitably impressed, he returned to Washington and commissioned a private firm to analyze the work. By 15 January 1962, an Apollo Spacecraft Project Office had been set up at the new Manned Spacecraft Centre being built outside Houston, Texas, for control of all future manned space operations. North American Aviation were now well into the design stage and NASA was pressed for a decision: Earth Orbit Rendezvous or Lunar Orbit Rendezvous. It had to decide one way or the other and NASA was fully aware of the situation. If the Lunar Rendezvous method was selected, it would mean developing a new landing module separate from the basic Apollo vehicle; if the Earth Rendezvous method was selected, North American could proceed as planned with the design of the three-section module, the landing section being an integral part in this case.

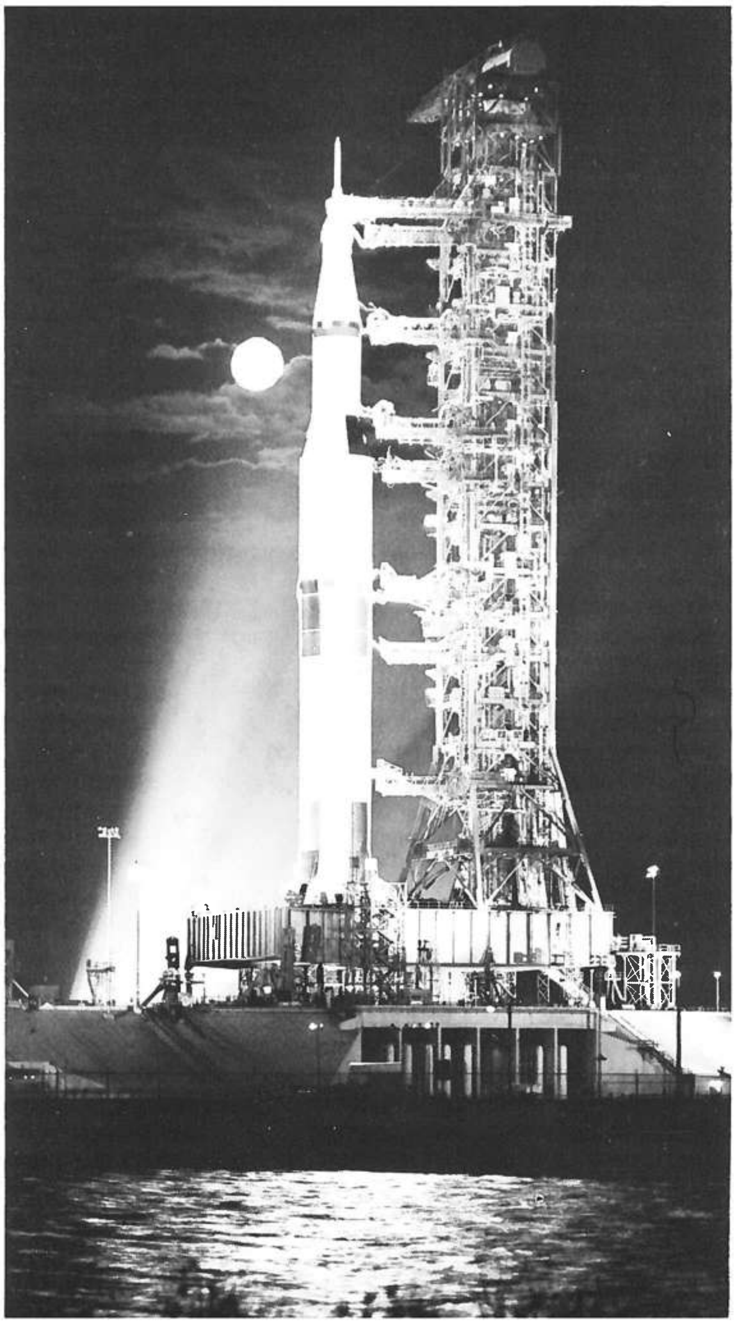
On 13 February 1962, NASA began a series of formal meetings by holding a three-day conference on Earth Orbit Rendezvous. This idea for the meetings had come from Shea and he pulled in executives from most NASA centres to air their views. Its basic mandate was to decide on the problems associated with Earth Orbit Rendezvous and this was followed by a second conference beginning 2 March. This time, Lunar Orbit Rendezvous was under evaluation and the basic concept was laid down under the guiding influence of John Houbolt. Many aspects of the technique were considered and problems ironed out. The general feeling at NASA was to support the Earth Orbit Rendezvous approach and von Braun himself was undeterred by Houbolt's effort to turn the tide of opinion. But doubts existed and the Manned Spacecraft Centre slowly came round to the Lunar Orbit Rendezvous concept.

On 16 April, representatives from MSC held a formal briefing at von Braun's Marshall Space Flight Centre in an attempt to convert the Saturn diehards. North American Aviation were still pressing NASA for a decision and expressed concern over the lack of direction. Work on the integrated landing section would have to begin soon if they were to keep up to schedule. By the end of April, the Apollo Project Office had been won over. In May, representatives briefed Brainerd Holmes and Robert Seamans on Lunar Orbit Rendezvous and got their support. It was now a question of converting von Braun at Marshall, but even amid this unofficial concurrence for Houbolt's idea, there still existed a general unwillingness to come out openly in favour of the single launch technique.

Watching all this activity with not a little interest, North American Aviation began to fear the consequences of a switch from Earth Orbit Rendezvous. If the Houbolt method were chosen, it would bring in another prime contractor for the Lunar Excursion Vehicle, the ferry craft needed to take the crew from Moon orbit to the surface. The basic Apollo spacecraft would be relegated to a supporting role, playing host to the Moon landing vehicle, and the attendant loss of prestige



The S-IVB was also used as the second stage to the smaller Saturn IB and is seen here being lifted on to the first stage of that launch vehicle.



A fully assembled Saturn V stands ready for launch, illuminated from the ground by searchlights and from the sky by reflected light from its target: the Moon.

would be a bitter pill to swallow. When the contract had been awarded, North American Aviation were working on recommendations that saw their Apollo spacecraft as the mighty landing vehicle alone. Now, sensing the impending switch, they were to express their feelings and gather support in an attempt to hold on to a hitherto unchallenged role. North American Aviation had an influential ally in Jerome B. Wiesner, the President's science advisor, and he in turn influenced the Science Advisory Committee away from Lunar Orbit Rendezvous. They quickly drew up a report condemning the concept and urged further analysis of Direct Ascent and Earth Orbit Rendezvous concepts.

The situation was explosive and with pressure building up for a decision, NASA was thrown into confusion. Headquarters and the Manned Spacecraft Centre at Houston were coming out in favour of Lunar Orbit Rendezvous, while North American Aviation and the President's Science Committee favoured the approach that required the complete Apollo spacecraft to land on the Moon: Earth Orbit Rendezvous. North American Aviation were reluctant to concede and the Marshall team under von Braun lent their support. However, not being motivated by corporate pride, they were less vitriolic in their statements, continuing to appraise the situation from a more rational standpoint. In an attempt to reach a decision, Holmes asked two conflicting NASA centres to draft schedules and cost predictions for the opposing techniques. For their part, the Manned Spacecraft Centre drew up an additional schedule, one that would permit a contract to be let for a Lunar Excursion Vehicle, the ferry for their Lunar Rendezvous mode.

By 22 June 1962, Joseph Shea had received the recommendations of the opposing factions. But by then even von Braun's Marshall team had gone over to the Lunar Orbit Rendezvous method. On 7 June, headquarters staff had gone to Marshall to brief von Braun on the concept. There was no indication of his support until at the end of the day he came out strongly in favour of the Houbolt plan. NASA was now presenting a consolidated front to North American Aviation and the Science Committee. With the draft reviews to hand, Shea sent a copy to the Manned Space Flight Management Council. One point stood out clearly from the rest: Lunar Orbit Rendezvous was the most dangerous of the three concepts. The figures showed a discrepancy between the verbal approval given to Lunar Orbit Rendezvous by NASA administration and the technical considerations evidenced by the report. Wiesner heard of this and went immediately to James Webb, the NASA administrator, with accusations of attempted whitewashing of his plans. Puzzled by this, Webb called Shea over on the evening of 3 July, to look at the figures again and calm Wiesner.

On re-checking the calculations, Shea found that a simple arithmetical error had crept in. When corrected, it left Lunar Orbit Rendezvous no more dangerous than the other concepts. By the end of June, Webb and Seamans had been advised of the Manned Space Flight Management Council recommendation. Lunar Orbit Rendezvous was the best way of getting to the Moon and design studies on a Lunar Excursion Vehicle should begin immediately. NASA officially announced their concurrence on 11 July, one week after Wiesner had made a last-ditch attempt to turn the tide of opinion. LOR was better, they said, because it had a higher probability of success, could be accomplished several months earlier than competing modes and would cost approximately 10–15% less. But Wiesner and his staff still hounded NASA seizing every opportunity to destroy confidence in the selected mode.

The bitterness finally exploded in September 1962. President Kennedy was paying a visit to the Marshall Space Flight Centre to see for himself how preparations were going, when von Braun began to discuss the Lunar Orbit Rendezvous plan. Moving closer to the group, Wiesner could contain himself no longer. 'That's no good', he shouted, creating an embarrassed silence. Kennedy drew away leaving Wiesner and von Braun to engage in heated debate. Kennedy was disturbed by this apparent dissention and immediately ordered Webb to make a firm decision one way or the other. By the end of October, Webb had written to Wiesner and detailed the reasons for his selection of the Lunar Orbit Rendezvous mode. On 7 November 1962, NASA announced that the Grumman Aircraft Engineering Corporation had been awarded a contract to build the Lunar Excursion Vehicle. The decision was irrevocable. Men would land on the Moon by way of two separate spacecraft, launched on top of a single Saturn C-5.

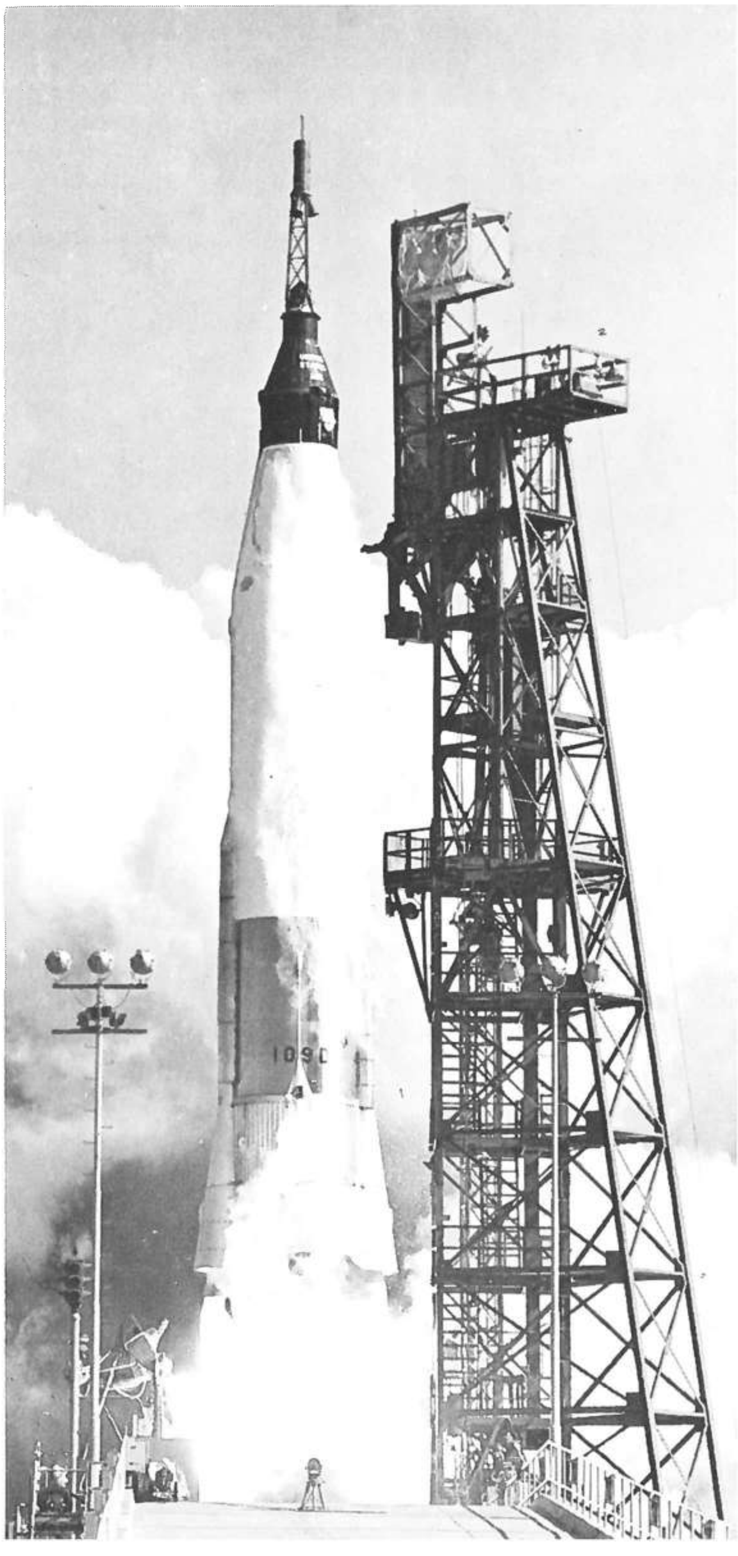
In 1961 and 1962 the United States launched exactly 100 spacecraft into space of which only 19, 41% in the first year and 12% in the second, were classed as failures. There was clear evidence for an increasing competence and the many problems associated with the launch of comparatively complex rocket vehicles, were slowly being eliminated. In 1958, 1959 and 1960 the first three years of the American effort, failure rates were 59%, 42% and 45% respectively. Money, too, was flowing faster than ever before. Fiscal year 1963,

Saturn V required a launch team of 450 persons housed in the Launch Control Centre at Launch Complex 39. Inset: Robert Goddard waits for the lift-off of one of his experimental rockets, securing a ghostly presence in this photo-montage.

President Lyndon B. Johnson (third hand on console from left) accompanies Dr. Kurt Debus (to his left), Director of the Kennedy Space Centre, and Ludwig Erhard (to his right), Chancellor of the Federal Republic of Germany, as they listen to Astronaut James A. Lovell, Jr., in the Launch Complex 19 'blockhouse' where Gemini-Titan launches were controlled.

While large liquid propellant launch vehicles in the Saturn class were being developed, Lockheed Propulsion test a 3.96 metre diameter solid propellant rocket motor consuming 317 tonnes of propellant in 55 secs and producing 1,360 tonnes of thrust.

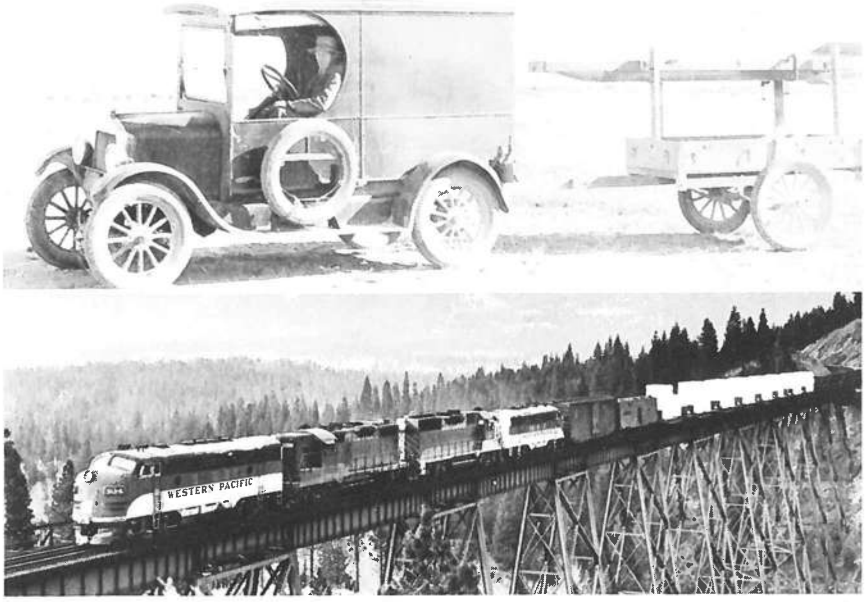
'The most creditable success in manned space flight came with the launch of John Glenn on 20 February 1962, aboard the Friendship 7 Mercury spacecraft.'



arranged at the end of calendar year 1961 and effective from 1 July 1962, provided NASA with $3,744 million or an increase of 102% over the previous year. But fiscal year 1964, settled as a formal request at the time NASA was deciding between alternative Lunar landing concepts, provided the agency with $5,350.8 million. In its first year of operation, NASA had a budget of less than $406 million. Five years later it was commanding a sum more than thirteen times that figure. However, seen in perspective, this represented only 4½% of total federal outlays for fiscal year 1964. So far, most of the NASA money had gone on the expensive preparations for flight of systems that had yet to emerge in reality and this trend would continue for several years more.

In 1961 and 1962 NASA phased in the small Scout solid propellant launch vehicle and moved ahead with the further development of Thor based rocket assemblies. Atlas-Centaur was still in the development phase and severe problems encountered during the first attempted flight on 8 May 1961, would inhibit further test flights for 2½ years. The United States was still restricted by the poor lifting capabilities of its launch vehicle inventory and the most powerful rocket – Atlas-Agena – could lift only 2.2 tonnes into orbit, versus the 4.8 tonnes provided by the SS-6 and a single upper stage. Nevertheless, achievements in space were notching up a creditable list of successes for the United States. Mariner 2, the first interplanetary spacecraft, flew past the planet Venus and returned useful data on 14 December 1962, more than three months after launch by Atlas-Agena. Discoverer class satellites continued to return their recoverable capsules to the Earth in flights by Thor Agena launch vehicles. Weather satellites were contributing to the meteorological surveillance of the atmosphere in flights that began with the launch of Delta rockets using the Thor as a first stage.

The most creditable success in manned space flight came with the launch of John Glenn on 20 February 1962, aboard the Friendship 7 Mercury spacecraft. Circling the Earth three times, he was the first American to go into orbit and was followed with two more flights in 1962, all of which used the Atlas D launch vehicle procured from the Air Force. The weight of the Mercury capsule was about 1,350 kg, truly a minimum-size vehicle compared with the two elements of Apollo that would weigh around 40 tonnes. Early in 1962, NASA decided that it would need the services of an intermediate spacecraft by which successive teams of astronauts could rehearse the many complex operations demanded by the Moon landing. It would have to be available by 1964, carry two astronauts and possess the capability of staying in orbit for up to fourteen days; Mercury was limited to flights lasting no more than thirty-five hours. Called Gemini, after the twin stars Castor and Pollux in the constellation of the same name, the vehicle would weigh about 3.8 tonnes and require a launch vehicle larger than any so far used for space operations.

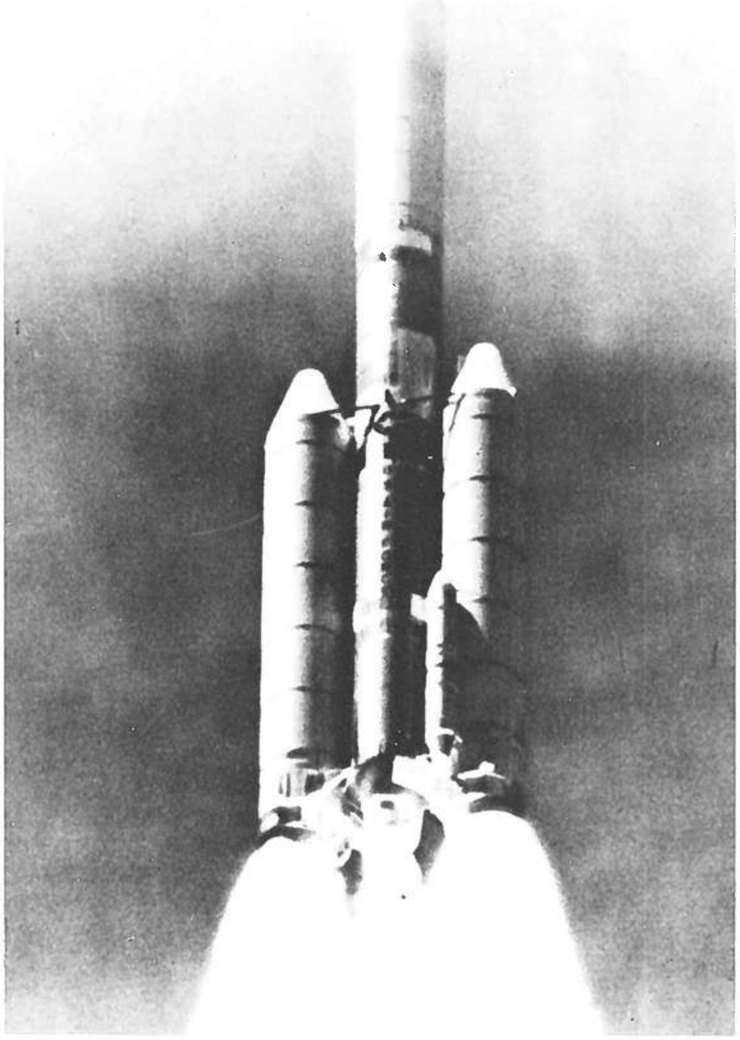


More than three decades span these contrasting modes of transport. The inset shows Robert Goddard transporting his experimental rockets by road in the early 1930's while, in the mid-1960's, a Western Pacific locomotive hauls separate segments of the solid propellant boosters used with Titan III.

NASA finally decided on the Titan II, a military ICBM that had never been used to place payloads in orbit, but one which could be readily adapted for this purpose. With a first stage thrust of 195 tonnes from two Pratt and Whitney LR-87 motors at its base, and a single second stage LR-91 motor delivering a thrust of 45.5 tonnes, the rocket used nitrogen tetroxide and aerozine-50 propellants. Further developments of the Titan led to use of the Transtage upper stage and in this configuration the vehicle was known as the Titan III-A, its first successful flight taking place in December 1964. Seven months later the Air Force began testing the Titan III-C, a much improved delivery system employing two large solid propellant motors strapped either side of the basic rocket. With a combined thrust of 1,088 tonnes, the two solid propellant boosters increased the payload carrying capacity of the launch vehicle to more than 13 tonnes, with a suitable upper stage. This was in excess of the lifting capability of the Saturn C-1, since January 1963 known simply as the Saturn I, and compared favourably with the existing fleet of Soviet launchers.

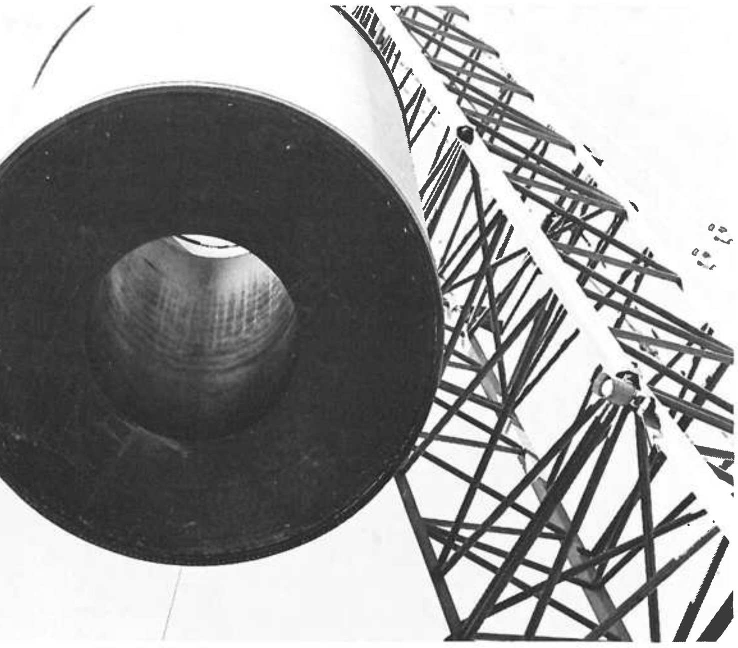
Each Titan III-C solid propellant booster was made up from five segments 304.8 cm in diameter and 3.2 metres tall. The segments were separately cast and incorporated synthetic rubber and aluminium powder as the fuel, with ammonium perchlorate as the oxidizer, separated from the motor case by a silica rubber insulation and a rubber based liner. Fabrication was carried out by the United Technology Centre of United Aircraft Corporation and segments were transported to the launch area by rail where they were assembled into a 25.9 metre long structure. Flight control was maintained via a thrust-vector system that obviated the need for flexible nozzle extensions to simulate the gimbal operation used by liquid propellant engines. Nitrogen tetroxide was fed to the base of the solid propellant motor and injected into the exhaust stream. This had the effect of creating a shock wave which deflected the exhaust plume by the desired amount. Commands from the guidance equipment would dictate the precise amount of fluid injection necessary to change the direction of flights; it was a principle that substituted the exhaust vanes of early rockets with a working fluid.

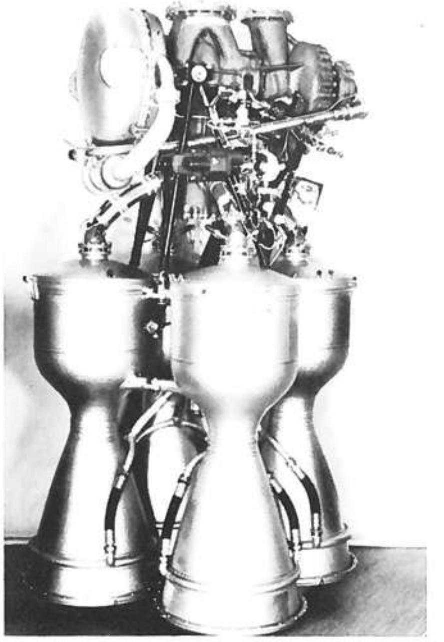
Up to early 1962 the Russian space programme relied on the A series launcher developed from the SS-6 ICBM; with a payload capability of up to 4.8 tonnes, the two stage A-1 configuration was used to place 6 Vostok manned spacecraft in orbit between April 1961 and June 1963. Beginning in 1961, a new upper stage configuration was in use for launching planetary spacecraft on flights to escape velocity, but although theoretically capable of putting 7.5 tonne satellites into Earth orbit, it was consistently used for missions to other worlds. The first new satellite launcher emerged in March 1962. Developed from the SS-4 Sandal IRBM, it was adopted for the space programme with a new upper stage using a single-chamber liquid propellant rocket motor, designated RD-119. The first stage used the four-chamber RD-214.

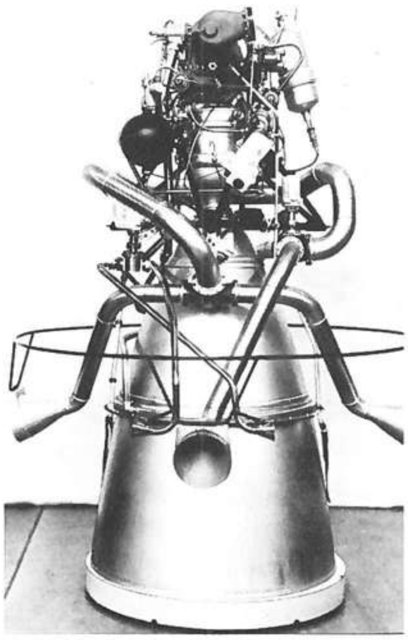

A Titan III-D lifts off under the power of its two solid propellant boosters. This class of Titan was specially developed to launch the Big Bird military reconnaissance satellites.

In its role as a satellite launcher, the two-stage vehicle is designated as a B-series rocket, being the second new launcher to the existing A-series, and can place weights of up to 420 kg in low Earth orbit.

V. P. Glushko describes the RD-214 as 'the first Soviet quantity-produced powerful engine operating on high-boiling-point nitric acid as oxidizer and kerosene products as fuel. The engine has the highest specific impulse of all known engines in this class using nitric acid as oxidizer and hydrocarbons as fuel.' Glushko describes the main characteristics of the RD-214 as follows: '(It) is a four-chamber engine with a single turbo-pump unit which combines a turbine, centrifugal pumps each for oxidizer and fuel, and a pump to feed


The circular grain configuration on the interior of a solid propellant booster segment is seen to good effect as a crane lifts it on top of other, similar, segments.


The RD-214 liquid propellant rocket motor used in the first stage of the Russian B-series launcher.


A single-chamber RD-119 motor powered the second stage of the B-series launch vehicle.

A ground camera captures the instant of booster separation as a Titan III ascends toward orbit.

Boosters from a Titan III tumble away from the main stages of the launch vehicle.

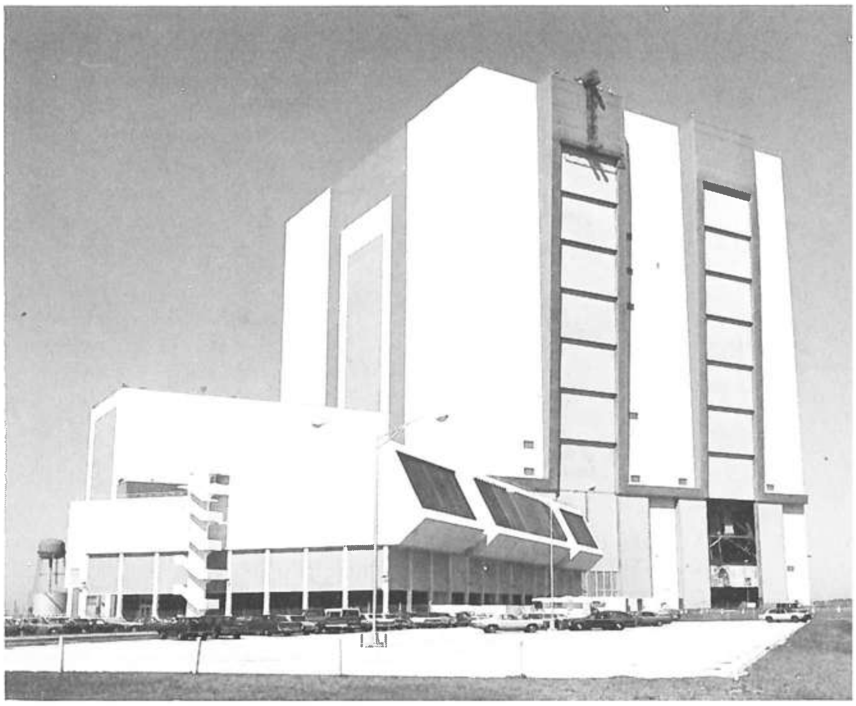
Engineers give scale to the massive strap-on boosters of a Titan III. Note the cone-topped nitrogen tetroxide container attached to the booster at right which would be used as a fluid injection control system.

hydrogen peroxide to a gas generator. The products of the catalytic decomposition of hydrogen peroxide in the gas generator drive the turbine. The turbine exhaust steam-gas mixture is expelled through a nozzle, thus contributing to the rocket's thrust. The chambers are regeneratively cooled by fuel and also by an internal curtain produced by the peripheral injectors in the head of the combustion chamber. The combustion chamber has an inside diameter of 480 mm, and a throat diameter of 176 mm. The engine uses chemical ignition by a starting fuel which self-ignites upon contact with the main oxidizer; the starting fuel is fed into the main fuel line ahead of the fuel pump. The engine is brought up direct to full thrust (74 tonnes). Vector control is effected by means of gas vanes.' The RD-214 operates at a chamber pressure of 46.5 kg/cm^2 and provides a specific impulse of 264 seconds.

The single-chamber RD-119 in the second stage, used a combination of unsymmetrical dimethylhydrazine propellants to produce a thrust of 11 tonnes, a chamber pressure of 82.7 kg/cm^2 and a specific impulse of 352 seconds. Flight control of the upper stage was effected by four vernier motors placed around the main exhaust nozzle discharging gases from the single turbo-pump unit.

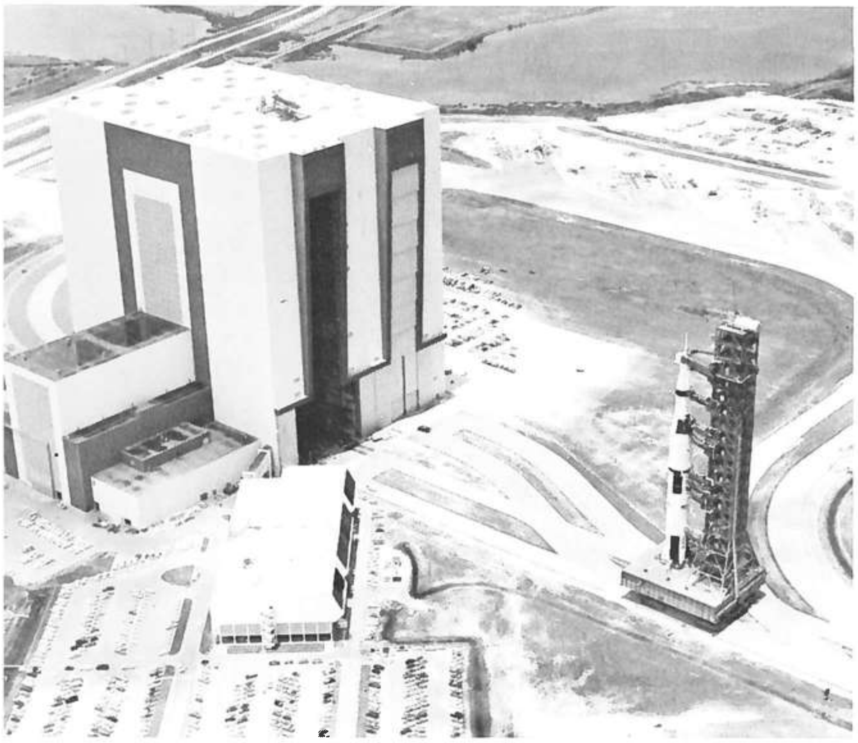
More than two years after the appearance of the B launcher, a third new delivery vehicle began space operations. This was a derivation of the SS-5 Skean IRBM and in a two-stage configuration, could launch weights of 1 tonne in to Earth orbit, more than twice that of the B series. It was immediately classed as the C series satellite launcher and provided a payload lifting capability between the B and A series. As early as 1961 the GDL-OKB began design work on a rocket engine that would be used in the most powerful Soviet launch vehicle ever brought to operational status. Known as the D series launcher it used RD-253 engines and first appeared in July, 1965. With various upper stages it can be tailored to missions in Earth orbit or to the planets and probably has a maximum payload lifting capacity of about 22 tonnes.

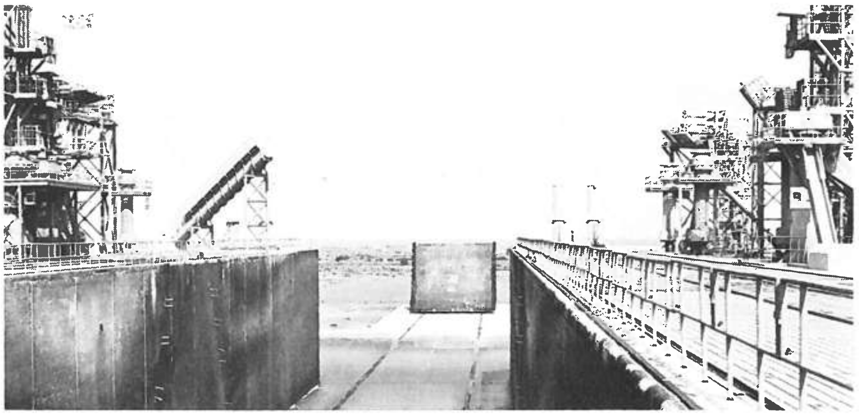
Meanwhile, progress with plans for the Apollo Moon landing moved ahead with the design of a new spaceport, that would be built at the NASA Launch Operations Centre (renamed from the Launch Operations Directorate of the Marshall Space Flight Centre in 1962), Cape Canaveral. Following the assassination of President Kennedy in November 1963, President Lyndon B. Johnson formally announced a further name change; from now on the Launch Operations Centre would be known as the John F. Kennedy Space Centre. By this time engineers and contractors had finalized design details of a completely new facility that would be essential to the satisfactory handling and launch of the massive rocket stages, developed for the Saturn programme. Unlike previous launch vehicles, the big Saturns would have to be assembled in a vertical position, remote from the launch pad itself and then physically moved to the pad by a surface vehicle of monstrous proportions.



The barn-like Vehicle Assembly Building was set up at Launch Complex 39 to house Saturn V Moon rockets; the Launch Control Centre is in the foreground.

In this aerial view of the Vehicle Assembly Building and Launch Control Centre, connected by a covered walkway just discernible, a Saturn V has been assembled on its Mobile Launch Platform. It is being transported by the Crawler Transporter with tracks just visible underneath (in shadow).





The blast trench at Launch Complex 39A into which the Saturn V would release its exhaust products. The Mobile Launch Platform, complete with Saturn V, would straddle this 18-metre-wide trench and rest on support pedestals seen to the left and right in this view. Note the inverted 'V' shaped deflector which will be moved in before launch and the inclined escape tube through which astronauts could escape in the event of a threatened explosion in the Saturn V.

The flame deflector – 18 metres wide and 13 metres high – that would channel the Saturn V's exhaust products through the blast trench. It is covered with a volcanic ash aggregate.

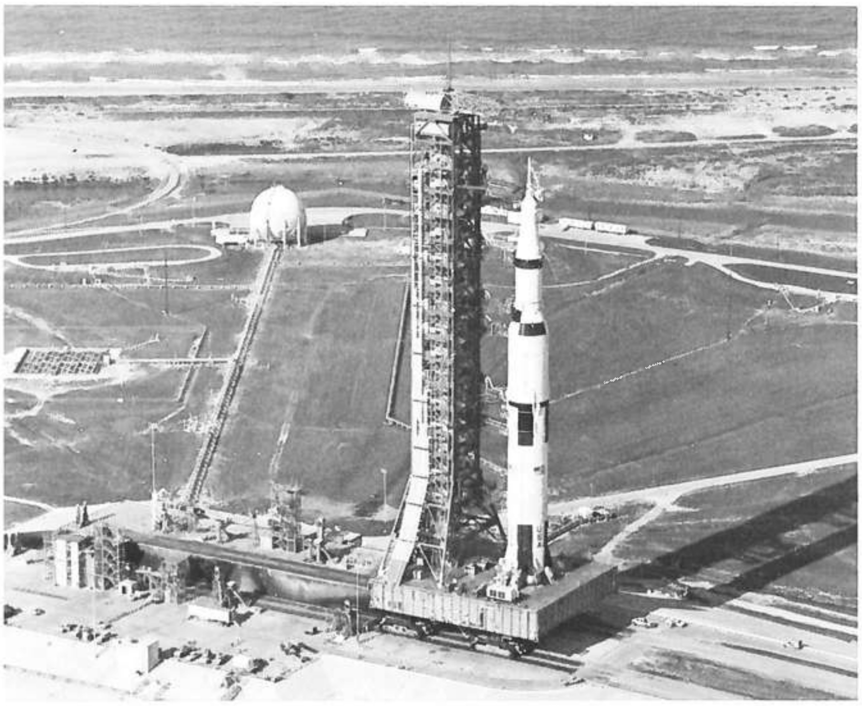
The structure that housed engineers and technicians, employed in the assembly of Saturn launch vehicles, was called the Vehicle Assembly Building. From there the rocket would be transported a distance of more than 4½ km, set up on its launch pad and finally checked. The site was known as Launch Complex 39 and the selected area was north of Cape Canaveral, on the marshy land of Merritt Island. Before construction could begin, it was necessary to raise the surface from 46 cm to 2.1 metres above sea level by dredging the Banana River, simultaneously excavating a channel for the barges bringing the large rocket stages and digging out a 'turning basin' where they could be off-loaded. In all, some 1.15 million cubic metres of soil was brought up and spread out across the area where the VAB would stand. Having prepared a surface upon which to work, the engineers had to provide a secure anchor for the box-like building that would rise from the Florida marshes like some gigantic square-shaped hat box; without secure foundations, high winds could lift the building and fracture its supports. To insure against this, it was necessary to sink 4,225 steel pilings, each 40.6 cm in diameter, down through limestone and silt into bedrock more than 46 metres down. The emplaced pipes were then filled with sand and capped off in clusters of between 6 and 20 with concrete. The floor of the Vehicle Assembly Building was then laid and more than 23,000 cubic metres of concrete poured over the site.

Next, the skeletal structure went up with more than 61,000 tonnes of structural steel providing support for 93,000 square metres of insulated aluminium and 6,500 square metres of plastic panels. In all, the VAB consisted of a large box-structure 160 metres high, with a second, smaller box-structure, joined to the side, 64 metres high. In total, the Vehicle Assembly Building was 218 metres long and 158 metres wide. The large box-structure had two doors at the front and two at the rear, through which the completed Saturn launch vehicles would pass on their way to the launch pad. Each door was in the form of an inverted 'T', 134 metres tall, with the first 34 metres providing a width of 45 metres and the upper 100 metres only 22 metres wide. Four massive door panels closed out the wider bottom section, while the upper section carried seven panels that would open by sliding vertically to the top of the frame.

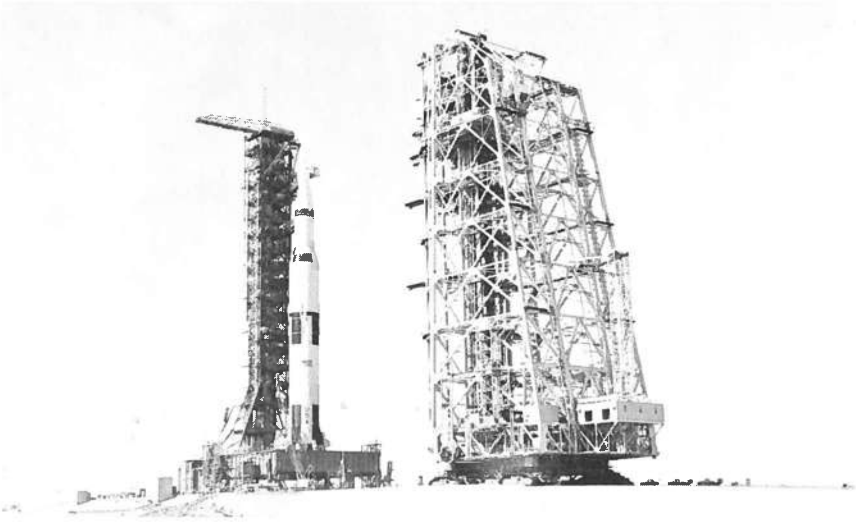
Inside, four high-bay areas were positioned adjacent to the door openings where the Saturns would be assembled. Each bay was provided with five pairs of work platforms, each platform supporting a floor area of 324 square metres, which could be moved up and down or in and out for positioning against specific sections of the launch vehicle. With a requirement for moving very large rocket stages about the interior of the VAB, it was necessary to provide 141 lifting devices: the largest could lift 227 tonnes, the smallest about 900 kg. The special demands placed upon these lifting devices brought a new sophistication to the art of precision positioning. Cranes were required to hold maximum load for fifty minutes with less than 8 mm movement and to move at speeds as slow as 2.5 mm per minute, while aligning the position to within 0.2 mm. Around the interior of the VAB, 16 elevators afforded access to the highest levels, where the electronic equipment was housed that would check out the launch vehicle. On the roof, 125 ventilators provided a complete change of air every hour. Fed from 9,100 tonnes of air conditioning equipment, they would prevent fog or clouds forming inside the 3.67 million cubic metre building. As Max O. Urbahn, head of the architectural design team, said, 'The structure is not so much a building to house a Moon vehicle as a machine to assemble a Moon craft.'

The building that would carry engineers, technicians and computers essential to the final countdown and launch of a Saturn rocket was located alongside the VAB. Known as the Launch Control Centre, it consisted of a four-storey structure (with a height equivalent to eight conventional storeys) with four firing-rooms on the third floor. The LCC was connected to the Vehicle Assembly Building by an enclosed corridor 18 metres above the ground. It represented a new dimension in monitoring capability. From here, electronic computers could plug in to the respective high-bay area in the VAB and follow the assembly, checkout and transfer of each Saturn to the launch pad. Once at the pad, the dedicated firing-room could orchestrate the complex and exacting task of test, preparation and launch, continually observing events throughout the full length of the 2,900 tonne Saturn.

When the decision to use the Lunar Orbit Rendezvous mode had been made in July 1962, it all but sealed the fate of the C-3 and C-4 Saturn designs. The Saturn C-5, known simply as the Saturn V from February 1963, would be the launch vehicle built to transport the Apollo mother ship and the lunar ferry vehicle into Earth orbit and then on to a trajectory from the Moon. Consequently, the Launch Complex 39 facilities were built around the requirements of the Saturn V, but with sufficient scope for handling larger launch vehicles so that it would not compromise any future rocket designs that might emerge. Assembly of the separate stages and spacecraft would be carried out in the VAB, using a Mobile Launcher that would serve as a base upon which the rocket could be set up and as a firing platform upon which it would sit at the Launch pad. Once erected, the Saturn V would not leave the Mobile Launcher until it lifted off into space. It would serve as an assembly platform and as an interface between the Saturn V and ground servicing equipment. Each Mobile Launcher was 48.8 metres long, 41.1 metres wide and 7.6 metres tall, with interior work compartments and facilities for routing cables and plumbing to the Saturn V. A centre cut-out, 13.7 metres on each side, provided an opening through which the hot exhaust plume could escape when the mighty F-1 engines ignited for launch. On top and to one side was situated a massive steel tower extending 121.3 metres above the top deck of the Mobile Launcher. The Saturn V would be 110.6 metres tall and require service arms to provide it with electrical power, fluids and propellant. Together, the assembly platform and the service tower were 129 metres tall and weighed a phenomenal 5,450 tonnes.


The Crawler Transporter is seen here moving the Mobile Launcher and a Saturn V to its position over the blast trench. Note the scorch marks on the inside wall of the trench from previous use.

The Mobile Service Structure, weighing 4,800 tonnes, is brought up to the Mobile Launcher and the Saturn V by Crawler Transporter.



When a Mobile Launcher was brought in to the Vehicle Assembly Building for preparation of a Saturn V, it was placed on six pedestals 6.7 metres tall; a similar set of pedestals was built in to the launch pad and, with a full load of propellant on board the Saturn V that it supported, the combined weight exceeded 8,300 tonnes. The vehicle that had responsibility for moving the Mobile Launcher, with or without a Saturn V installed, was known as the Crawler Transporter. It was 40 metres long, 35 metres wide and 6.1 metres high with four sets of double tracks, two at each corner of the vehicle, providing mobility for the Crawler and its load. Two diesel engines provided the power for four, 1,000 kilowatt generators serving 16 traction motors. Another two generators operated the levelling, jacking and steering equipment. Because the Crawler would have to roll uphill to the launch pad, the load-carrying deck had to remain in the horizontal position by means of hydraulic rams at either end. It was so efficient, that the top of the Saturn V, 135.7 metres above the ground, was never out of vertical alignment by more than 30 cm.

Altogether, the Crawler weighed 2,700 tonnes, moved at 1.5 km/hr, with a fuel consumption of 350 litres per kilometre, carried six radiators each with a capacity of 1,900 litres and could be driven by one man to within 5 cm of the desired position. With the Mobile Launcher and an empty Saturn V on its back, the Crawler assembly would walk to the launch pad weighing a phenomenal 8,165 tonnes. The road way, specially built for the Crawler, was nearly 40 metres wide and consisted of 6 million cubic metres of dredged fill, laid to a depth of 75 cm and covered with 1 metre of crushed rock. Asphalt was then laid over the rock and covered with Alabama river stone 15 cm deep. The launch pads, three, were designed, but only two built, consisted of an octagonal concrete structure reinforced to take the weight of the Mobile Launcher, the Crawler Transporter and a Mobile Service Structure, or more than 12,900 tonnes. It was a hardened facilities and support area, into which the Mobile Launcher was 'plugged' to route these services to the Saturn V on its back. A central flame trench was built into the pad, 18 metres wide and 13 metres high, through which the exhaust products would flow from the five F-1 engines at the base of the Saturn V.

The pad itself contained computer connection rooms with electronic monitoring, gas storage and emergency escape rooms. Although most of the complex checkout procedure was accomplished after the assembly in the VAB, there was still a considerable amount of work that had to be accomp-


By road. . . . A Saturn V second stage begins its journey to Florida.


By sea. . . . Saturn first stages move past the New Orleans skyline at the start of their journey to the Marshall Space Flight Centre for tests. Barge Poseidon, at left, carries the first-stage for the first Saturn V; barge Promise carries a Saturn IB first-stage.

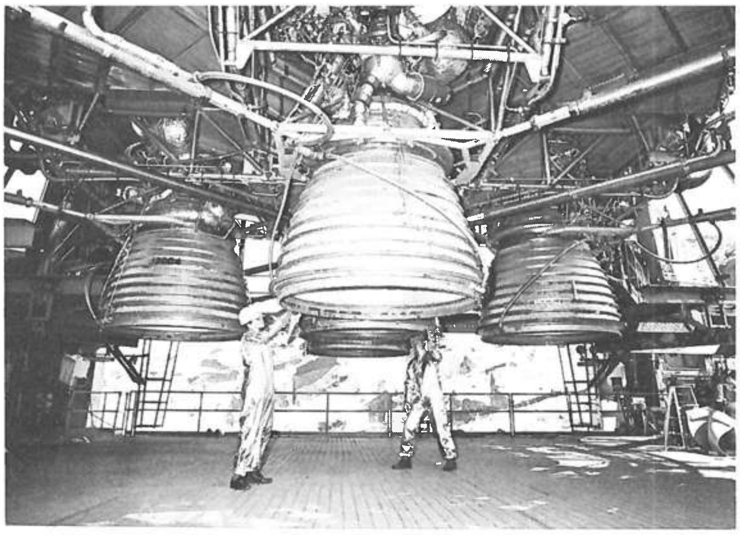
lished before the vehicle could be released for flight. The Mobile Service Structure, a steel framework weighing 4,800 tonnes, was built to facilitate access to any desirable level along the entire length of the Saturn V. It was brought to the launch pad by Crawler Transporter and placed on stilts adjacent to the Mobile Launcher and its progeny. This enormous structure – it was 41 metres long by 40 metres wide at the base – rose to a height of 125 metres and was removed from the pad several hours before launch.

From all across the nation, manufacturing and facilities assembly plants prepared the long list of hardware and sent it via special test stations to the Kennedy Space Centre in Florida. North American Aviation built the S-II second stage at Seal Beach, California, and brought it down the west (Pacific) coast of North America, through the Panama Canal and then across the Gulf of Mexico to New Orleans by barge. From there it was moved around between the Marshall Space Flight Centre, Michoud Operations (since July 1965 known as the Michoud Assembly Facility) and the Mississippi Test Facility by canal transport. When static firings had been completed, the S-II was loaded aboard the barge again and floated to the receiving dock at Cape Canaveral, a distance of more than 3,500 km. The S-IVB third stage units were built at Huntingdon Beach, California, by the Douglas Aircraft Company (later McDonnell Douglas), flown to the Mississippi Test Facility in Louisiana and from there to the Kennedy Space Centre. First stage units, designated the S-IC, were assembled by Boeing at the Michoud Assembly Facility, test-fired at the Mississippi Test Facility and then moved by barge to Launch Complex 39 at the Kennedy Space Centre.

But large launch vehicles are more than just an assembly of propellant tanks and rocket engines: Saturn in particular was required to know exactly where it was going, what it was expected to do next and how it could coordinate its operational plan to most effectively use the available resources. In short, it needed a brain: the so-called Instrument Unit which was placed at the top of the third, S-IVB stage. This consisted of a ring exactly the same diameter as the S-IVB and only 91.4 cm tall, upon which was mounted the inertial platform, electrical power systems, accelerometers, telemetry systems, radar systems, communications equipment and the all-important guidance command system.

During the early portion of its ascent, the Saturn V would follow a pre-programmed course and then switch to a specially formulated guidance profile when it was clear of the dense region of the atmosphere. As the launch vehicle climbed through turbulent air, or came under the influence of high winds, it would be blown slightly off course. Measurements obtained through the guidance computer would send signals to apply corrective gimbal motions to the main engines, thus restoring the programmed flight trajectory so that when the time came to begin the guidance profile, the launch vehicle would be at the designated point in space and time. Early Saturn V launch vehicles were equipped with 22 telemetry systems, two tracking systems and several motion picture cameras to record critical events as they happened. In all, nearly 3,000 measurements were taken from the three stages and Instrument Unit, compared with up to 1,378 on the Saturn I, 150 on the Jupiter IRBM and 75 on the Redstone. In all respects, Saturn V was a new dimension in launch vehicle operations and the sprawling facilities set up on the Merritt Island marshes, dwarfed anything built elsewhere at Cape Canaveral. Kennedy Space Centre Administrator, Dr. Kurt Debus, first began to consider the layout of Launch Complex 39 in 1962 and by 1967 the $800 million site was ready.

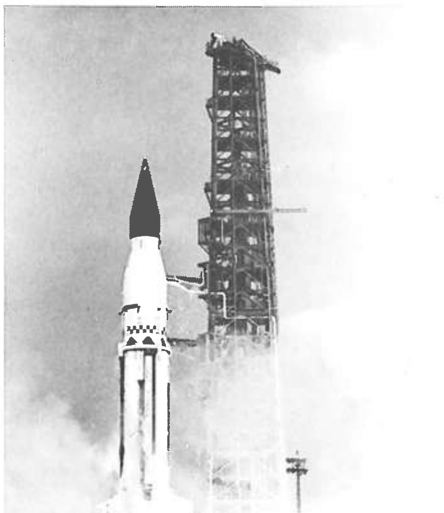
Between October 1961 and July 1965, NASA launched ten Saturn I launch vehicles from Complexes 34 and 37. It was considered a development vehicle for a more powerful version known as the Saturn IB. The first four Saturn I launches, SA-1 to SA-4 inclusive, used clusters of eight Rocketdyne H-1 engines, each one of which delivered a nominal thrust of 78.4 tonnes. This provided a total stage thrust of 598.7 tonnes. The last six Saturn I vehicles, SA-5 to SA-10, adopted a slightly more powerful H-1 which raised the total stage thrust to 682.2 tonnes. An S-IV second stage was flown on flights SA-5 to SA-10 also; the first four flights were with the Block 1 vehicle, the last six with the Block 2 configuration. The S-IV used six LR-115 (also known by the later designation RL-10) liquid hydrogen engines for a total thrust of 40.8 tonnes. Maximum payload capability of the basic two-stage Saturn I was only 9 tonnes, although this was twice the value of the Atlas Centaur which was successfully flown in 1963.



Engineers prepare five J-2 engines for test in a layout similar to that in which they will be employed as propulsion for the S-II, second stage for Saturn V.

Because it was felt desirable to place early Apollo spacecraft in Earth orbit before starting operations with the mighty Saturn V, a second version, the Saturn IB, was introduced in 1966. This consisted of a modified Saturn I first stage, using a third development of the basic H-1 which produced 90.7 tonnes of thrust for a total stage output of nearly 726 tonnes. It also carried, as a second stage, the S-IVB under development for Saturn V. With a single J-2 engine, burning liquid hydrogen and liquid oxygen, it could produce a thrust of between 91 and 102 tonnes depending on the mixture ratio. With a more powerful first stage and the highly efficient third stage, payload capability was raised to 18 tonnes – just sufficient to lift the Apollo mother-ship into Earth orbit on test flights, insufficient to carry both the Apollo and the lunar landing vehicle; that dual lift capability was bequeathed to Saturn V. But the development of the J-2 was central to the success of both Saturn IB and V programmes. Five J-2 engines would be employed in the second stage of Saturn V and one in the third, or S-IVB, stage. Only the first stage of Saturn V, the S-IC, used the comparatively low energy mixture of liquid oxygen and kerosene and without the enhanced efficiency of

First of the Block 1 Saturn I launch vehicles, SA-5, lifts off from Complex 37B on 29 January 1964, with a live S-IV upper stage in the first two-stage Saturn I flight.

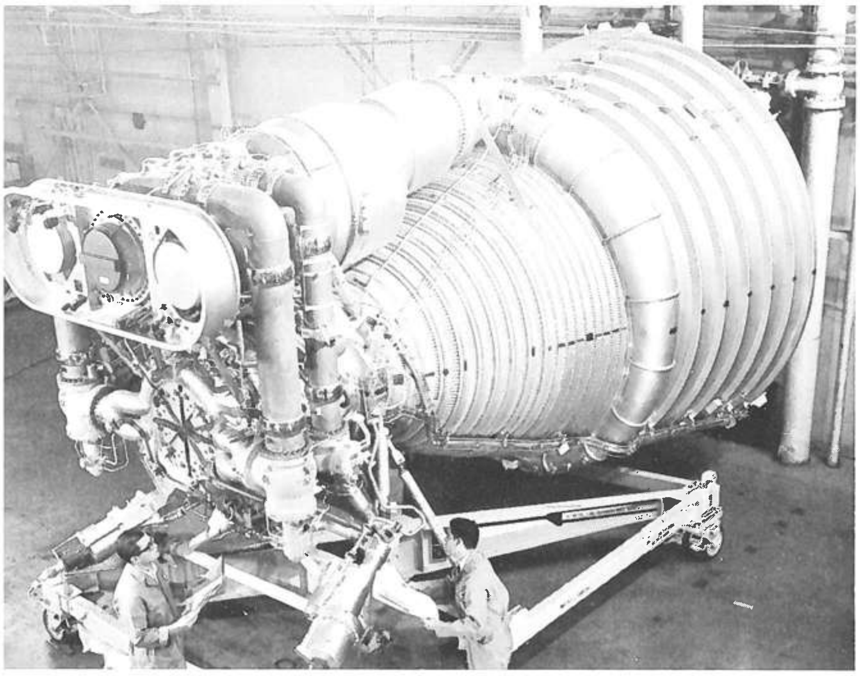


The second variant of the Block 2 Saturn I lifts off with a mock-up of the Apollo configuration on top. Launched on 30 July 1965, SA-10 was the last of 10 Saturn I flights. ↑

second and third stages burning hydrogen fuel, the weight lifting capability of the entire vehicle would have been reduced dramatically.

Adopting the philosophy engineered by the H-1, Rocketdyne built the J-2 to carry all its major assemblies on the main combustion chamber, thereby reducing the problem of carrying high-pressure propellants across a flexible interface; the J-2 was required to gimbal for effective stage control. The engine was regeneratively cooled by passing gaseous fuel through thin stainless steel tubes brazed together to form a single unit. Propellant was introduced to the combustion chamber by way of 614 oxidizer posts with fuel nozzles installed over the posts to provide a concentric orifice.

The fuel turbopump was driven by hot exhaust products from a gas generator at a speed of 27,000 rpm which delivered hydrogen to the injector at about 37 kg/sec. The oxidizer turbopump was mounted to the main combustion chamber block on the opposite side and derived its power from the same gas generator as that used for the fuel pump, the two being mounted in series so that gases from the fuel turbine moved to the inlet manifold of the oxidizer pump. The oxidizer pump operated at a speed of 8,600 rpm and moved oxygen to the injector posts at 204 kg/sec. After passing through fuel and oxidizer turbopumps, the redundant exhaust products from the gas generator are fed through a heat exchanger and join the main exhaust flow from the combustion chamber at a point half-way down the inside of the expansion nozzle. High-pressure helium was used to operate the propellant flow valves and a hydrogen tank was attached for providing initial power to the turbine. The J-2 operated with a main combustion chamber pressure of 53.6 kg/cm^2 and provided a specific impulse of 424 seconds. An important feature of the J-2 was that it was required to re-start in space after first placing its Apollo payload in Earth orbit. A second start capability was essential for boosting the spacecraft on to a trans-lunar trajectory.



The most powerful liquid propellant single-chamber rocket motor ever brought to operational status: the Rocketdyne F-1 used in the first stage of Saturn V.

Although only loosely related to the Saturn programme, NASA's largest liquid hydrogen/liquid oxygen engine project was placed in the capable hands of Aerojet-General in April 1962, when the agency foresaw a need for powerful high-energy first-stage engines of extreme power. Called the M-1, it initially aimed for a thrust of 544 tonnes, but changes to the specification increased this to 680 tonnes. Studies of a post-Saturn launch vehicle envisaged the use of M-1 in a cluster of 12 engines delivering a lift-off thrust of 8,160 tonnes. With a single M-1 engine in the second stage this would have generated sufficient power to place payloads of up to 450 tonnes in Earth orbit – almost twice that of the basic Saturn V. By 1965 the project had been scrapped.

Despite the efficiency of high-energy liquid hydrogen/liquid oxygen engines, the most spectacular rocket motor developed for Saturn V was the 680 tonne thrust F-1. With five F-1 engines in the first stage, it would generate a combined thrust of 3,400 tonnes. Like the J-2, all the prime assemblies were located on the main combustion chamber which had a regenerative cooling capability and gimbal struts for flight control. Unlike the J-2, the fuel and oxidizer turbopumps were mounted in a common assembly together with the turbine and the turbine exhaust heat exchanger. Propellants fed to the gas generator provided the energy to drive 788 kg of RP-1 (kerosene) and 1,789 kg of oxygen into the injector head each second.

The injector itself contained copper fuel and oxidizer rings, with radial and circumferential baffles installed within a stainless steel body. The gas generator was located to one side of the turbine, both of which were mounted below the fuel and oxidizer pumps and exhausted gases moved to a manifold that discharged into the interior of the expansion nozzle half-way down its length. The F-1 was the largest liquid propellant rocket engine built, with a height of 5.8 metres and a nozzle diameter of more than 3.7 metres. It

Framed by the glare from 74 searchlights, a Saturn V stands poised for launch while, at right, the Mobile Service Structure is moved away from the pad area.

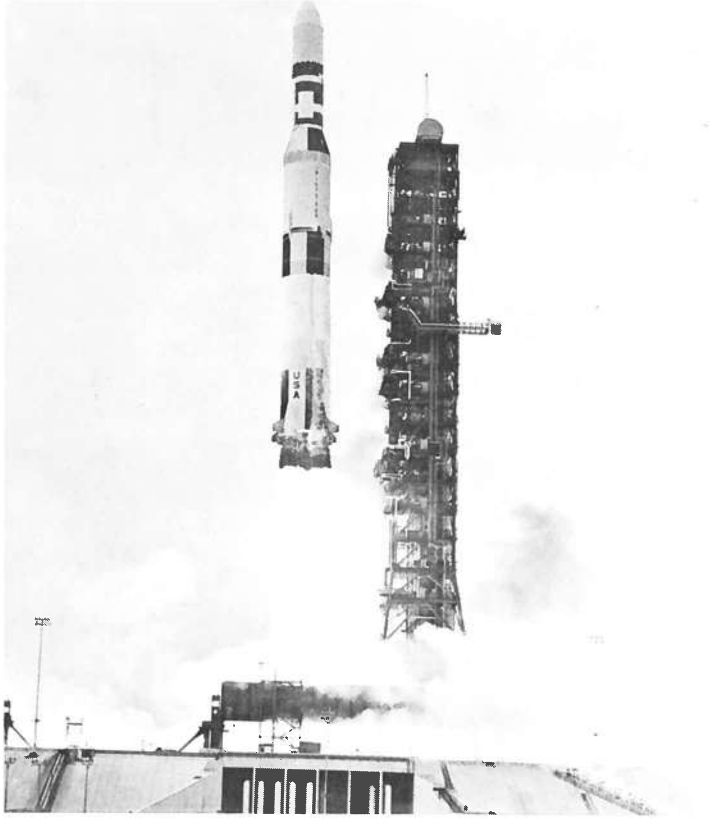
Continued adaptation of existing launch vehicles, like this Atlas-OV (Orbital Vehicle) configuration, was sustained throughout the 1960's while Saturn class vehicles came and went.

weighed 8.4 tonnes and provided a specific impulse of 260 seconds at a chamber pressure of 67.8 kg/cm^2.

Saturn V represented a new era in rocket technology and its specutacular proportions brought visitors from all over the World when the first such vehicle began its maiden flight in November 1967. Tears of emotion rolled down the cheeks of pressmen 5½ km away as the mighty cluster of F-1 engines thundered into life. Nothing like it had ever been seen before and it was in truth a monster befitting the fantastic goal of landing on the Moon. Less than two years later, it supported that objective by propelling three astronauts out of Earth orbit on a path that would place Neil Armstrong and Edwin Aldrin on the dusty lunar surface. Saturn V represented the climax of a story that began when the young Wernher von Braun first joined rocket enthusiasts at a disused patch of waste ground outside Berlin. Nearly four decades had passed and the aspirations of the German Society for Space Travel had been brought to fruition.

Between 1963 and 1969 the success rate of American rockets increased. In 1963 only 18% of all attempted satellite launching failed; in 1969 that value was down to less than 2½%, although this figure has fluctuated between 3½% and 12% in the years since 1969 and only in 1972 were there no failures at all. But the period between 1963 and 1969 were the busiest for the American space programme. In all, 369 space vehicles were sent into space on missions that took men into Earth orbit, astronauts to the Moon, robots to the Moon, Venus and Mars and a host of 'applications' satellites circling the globe. For their part, the Russians continued to extend the flexibility of A-, B-, C- and D-series launch vehicles, with an ever increasing array of upper stages, tailored to ever more ambitious flight objectives.

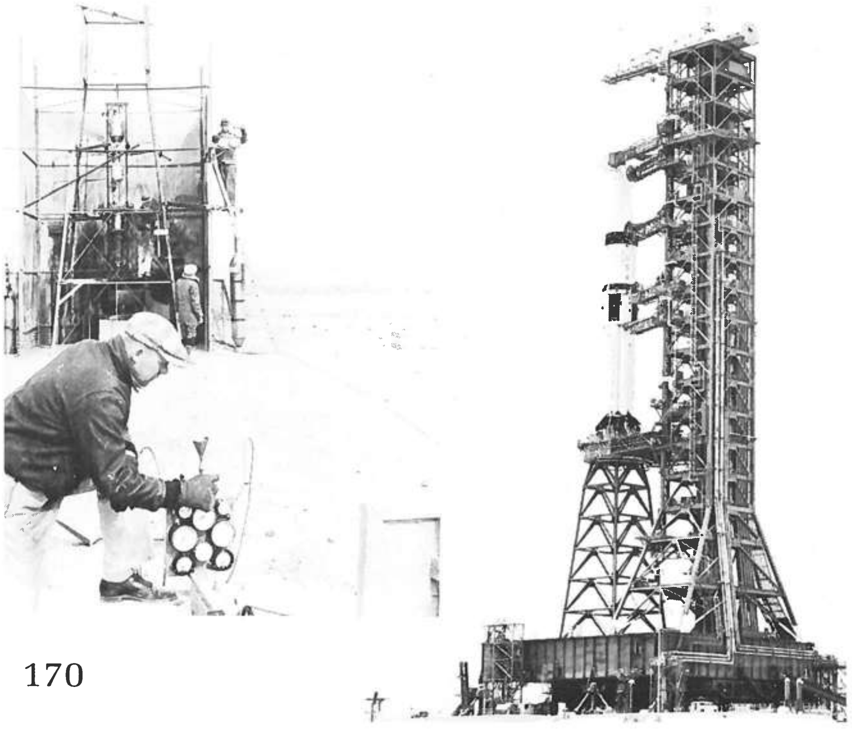
The peak year for American activity came in 1966, when NASA and the Department of Defence attempted to launch 74 payloads, but thereafter the annual launch rate declined to a level where just 41 flights were attempted in 1969. The Russians, slow to match the rapid build-up of American launch records (probably reflecting a high failure rate since only successful missions are announced publicly) began to strengthen the scope and magnitude of their space programme and by 1969 had built up to a record 80 flights, passing the US level by a handsome margin. By the time Armstrong and Aldrin were walking on the Moon in July 1969, the public mood had changed and a new President was at the helm; Richard M. Nixon. Suddenly, the new view of Earth, presented by globe circling astronauts, brought an awareness of the fragile nature of the planet and all around the world environmental issues were brought to the fore. It was as if the very technology that provided the means by which earthlings could seek identity with the Universe was being held responsible for increasing pollution and diminishing fossil fuels. Plans to build on the achievements of the first decade of the space age were now in direct conflict with more down-to-earth problems and many saw the expensive and time-consuming attention to ambitious space exploration as the very antithesis of cultural growth.

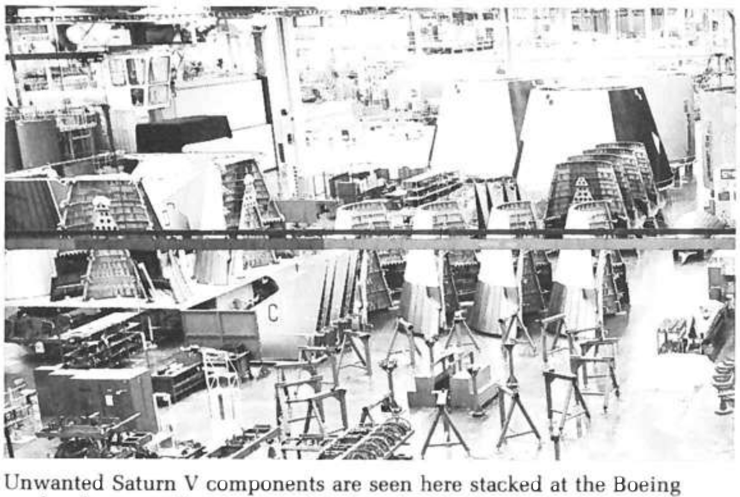


The 13th, and last, Saturn V lifts off from Launch Complex 39A with the Skylab space station on 14 May 1973.

NASA funds began to decline after fiscal year 1964 and by the end of the decade was down from its peak of $5,350.8 million to $3,768 million (in fiscal year 1970). In 1969 it was felt that the space agency had all the lifting power in Saturn V that it needed, and indeed the payload capability of that launch vehicle was five times that of the Russian D-class rocket. But the Saturn V was an expensive launcher and could find application only with lunar or planetary mission objectives. With a capacity for sending more than 115 tonnes into Earth orbit, it was far ahead of the Saturn IB with a payload capability of 18 tonnes, or the Titan III-C with 13 tonnes. Between 1967 and 1973 thirteen Saturn V's were launched into space, spanning a period during which it became obvious that a second national space objective, equal to that made by President Kennedy, would be impossible to structure.

In the early years of the 1970's public disinterest in repeated Moon landings sealed the fate of this massive launch vehicle; the nation was just not prepared to finance another major goal in space. Increasingly, the need for small Earth-orbiting payloads pointed to Saturn V as a redundant dinosaur, lingering on from an age when it really had seemed necessary to beat the Russians to the empty wastes of the Moon. And so, when the last Saturn V rose from Launch Complex 39 in May 1973, it was in support of an Earth orbiting space station, precursor to a new age for space travel, in which exploration of the far-off frontiers of the solar system would be relegated to the province of unmanned robots





Unwanted Saturn V components are seen here stacked at the Boeing works after cancellation of the big launch vehicle in May 1971.

Nearly four decades separate these contrasting scenes: a Saturn IB prepares to send a trio of astronauts to the Skylab space station and (inset) a Goddard rocket is prepared for static test in November 1935.

launched by smaller and less costly vehicles. Thus it was that the capability of sending 115 tonnes in to orbit died with the Saturn V, a launch vehicle built for a purpose that had no place in the stringent economic environment of the 1970's.

A similar fate awaited the Saturn IB. In 1973 three such launch vehicles were used, to send Apollo astronauts to the Earth Orbiting Skylab space station sent up by the thirteenth Saturn V, and in 1975 it made its last flight into space, when another Apollo went to rendezvous with a Soviet Soyuz spacecraft. No more American astronauts would go into space for the next four years.

Beginning in 1973 the Russian space programme supported more than 100 flights a year, while the annual American launch rate dropped to between 25 and 30. One of the reasons for the low US figure is related to the development of an entirely new launch vehicle – the Space Shuttle – which is fully described in Chapter 11 and the Compendium. In an attempt to reduce the expensive costs associated with conventional launch vehicles, where each rocket is used only once, much of the NASA budget has gone on the technology for a reusable delivery system to low Earth orbit. During the first two decades of the space age, America has sought to continually modify its existing fleet of light and medium-weight payload launchers and a host of Delta, Thor, Atlas and Scout derivatives have satisfactorily met programme requirements.

By 1977 Delta and Atlas-Centaur launch vehicles had established a creditable record of success, with repeated flights in support of Earth orbit and planetary missions. The last launch vehicle derivative to be introduced was the Titan III–E/Centaur and this has successfully sent Viking spacecraft to the planet Mars and Voyager spacecraft on fly-by missions to the outer planets. It represented a successful marriage between the Air Force Titan, used primarily for classified payloads funded by the Department of Defence, and the Centaur originally built for the Atlas. With a capability of sending 3.7 tonne payloads to the outer planets, versus the 258 kg of Atlas-Centaur, it first flew in 1974 and was retired after the two Voyager launches in 1977. All future planetary missions will use the Shuttle and a family of solid propellant boost stages developed for use with this reusable launch vehicle.

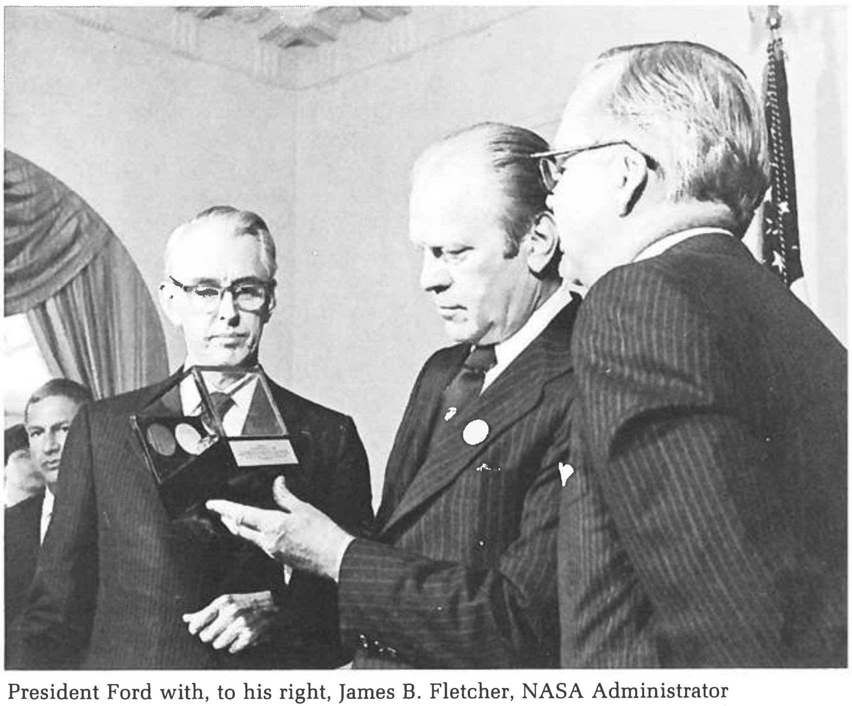
If the 1960's were a period in which increasingly more powerful launch systems were developed and tested, the 1970's will surely be seen as a time during which existing launch vehicles were applied to every conceivable facet of their performance envelope before the totally revolutionary Shuttle system became operational in the 1980's. But America and Russia were not the only countries interested in developing a satellite launch capability.

France made an early committment to rocket vehicle development and by 1961 was testing the Agate solid propellant test vehicle, used later in a slightly different form as a sounding rocket for upper atmospheric research. This project was followed by Topaze, also used as a sounding rocket, and in 1964 Rubis and Emeraude were flown as precursor steps leading to assembly of a small satellite launcher. Rubis was essentially an Agate rocket with a new upper stage, designated P-07, built by Sud Aviation; Emeraude would be the first stage of the Diamant satellite launcher, powered by a rocket motor generating 28 tonnes of thrust and burning white fuming nitric acid and turpentine. With a second stage consisting of the Topaze solid propellant rocket, the assembly was known as the Saphir and preliminary flight trials were carried out in July 1965. Thrust for the Topaze P-2 stage was rated at 14.5 tonnes. The third stage of the Diamant launcher was taken from the 5 tonne thrust Rubis and in this configuration, the first French satellite was successfully placed in orbit in November 1965. The payload capability of the Diamant A was limited to 80 kg, but further development led to the use of a more powerful first stage, burning nitrogen tetroxide and unsymmetrical dimethyl-hydrazine and, with this replacing the Emeraude, payload capability for Diamant B was doubled. It first flew in March 1970 and led to development of the Diamant B/P-4, with the Rita 1P-4 stage replacing Rubis, and a payload capability of 200 kg.

In Britain, satellite launchers were a cause for considerable debate and public scrutiny. Throughout the late 1950's and early 1960's the British Interplanetary Society urged the implementation of an autonomous national launch vehicle and plans centred on two likely candidates: the Blue Streak missile and the Black Knight test vehicle as one approach and the Black Arrow, developed from Black Knight, as the second. When Blue Streak was cancelled early in 1960, it was proposed as the first stage to a multi-stage launch vehicle, developed in cooperation with other European countries. Britain was in the forefront of plans to set up a European Launcher Development Organisation (ELDO) and although this meant dropping tentative studies on the Blue Streak/Black Knight scheme the transfer of an autonomous launch capability to one embracing several nations, was considered the most economical means by which member states could acquire access to space; more money would be spent in the long run, but each participant country would pay less for a given capability.

ELDO was formed in 1962 and plans were laid for an ambitious series of satellite launchers based on the Blue Streak as first stage to upper stages developed by other European countries. Six years later Britain announced that it intended withdrawing from ELDO in 1971 and this move effectively sealed the fate of a European launcher. On 11 February 1970, Japan became the fourth nation to launch its own satellite when a Lambda 4S four-stage rocket lifted into space. Little more than two months later China used the CSS-2 missile to put its national satellite into orbit. Meanwhile, further work on the Black Arrow three-stage launcher led to a British satellite in space when it performed its only operational launch on 28 October 1971. Plans to use Black Arrow for further flights into space were cancelled and the programme was dropped.

In the face of a total lack of national resolve, continually beset with political reverses and vacillating governments, Britain is the only country to have developed a satellite launch capability and followed this by wilful disregard of the inherent technology. As such, it provides a unique, albeit sadly negative lesson that has no parallel in the history of rocket development. Since 1971 Britain, and other European countries, have, with the exception of France, had to rely on American launch vehicles under agreements laid down to provide re-imbursable services. By 1980 Europe expects to have its own launch vehicle, but revenue that may have accrued from selling the services of a competitive launcher are lost along with the technology applications generated by ELDO and the British aerospace industry. Since 1975 a large proportion of NASA launches have been in support of foreign satellite programmes and the ready availability of Scout, Delta and Atlas-Centaur launchers has provided European and third-world states with an access to space that would otherwise have been denied. It is against that background that the next major developments in American rocketry are being forged.



President Ford with, to his right, James B. Fletcher, NASA Administrator from 1971 to 1977, looking at a segment of an indium-antimonide crystal grown in space aboard the Skylab orbital station.

CHAPTER TEN:

Strategic Rocketry

This night shot shows the first Atlas (12-A) to achieve a successful flight. Launch came on 17 December 1957.

The third quarter of the 20th century of the Christian era has seen major changes in national and international affairs resulting from the remarkable discoveries and inventions that have re-structured attitudes and objectives to the point where mankind is faced with a new challenge in space exploration or the finality of total annihilation. After several million years of development, human innovation and aggression Man has reached the point of technological expertise where he can not only dominate his environment, but totally destroy all other living forms on Earth. Since 1957, the space programme has forged new hopes for the better, and more benevolent, management of existing planetary resources; in the same period, powerful political factions have arraigned a horrific force for destruction unlike anything conceived before. Central to both paths of human development, the rocket portends both alpha and omega – the beginning *and* the end. Rocket propelled space vehicles have the potential for providing a new start for Man beyond Earth's thin veil of atmosphere, or they can be instruments of nuclear war writing finis to the upward thrust of human evolution. In truth, the development of strategic rocket delivery systems, since 1957, has led to a more awesome potential than that which separated conventional high explosives of World War II from the first operational fission bomb dropped on Hiroshima.

When Soviet Russia announced the presence of an ICBM, in the form of the SS-6, in August 1957, the United States had only one configuration to parallel this development anywhere near the flight test stage: Atlas. The Titan was still in the design stage, sea-going Polaris was not much more than an idea and the Air Force had yet to make up its mind on the final configuration of Minuteman. Using liquid oxygen and kerosene, Atlas was limited in operational roles by the nature of the propellant, the complexity of launch preparation and the sophisticated ground-support equipment essential to its success. When the programme officially got under way in January 1955, little thought had been given to the missile's vulnerability; standing exposed on the concrete launch pad it would be a relatively simple target for Soviet ICBM's should Russia decide to authorize a pre-emptive strike.

Development of the Titan was given approval by the desirability of having two ICBM programmes, ensuring that at least one type of missile would move rapidly to operational status. Only when it became apparent that the mere possession of a retaliatory strike force was not enough, did the Pentagon officials begin studying the possibility of affording moderate protection. However, recognizing the need to consolidate the administrative orchestration of existing and future ICBM projects, the Air Research and Development Command's Western Development Division was renamed the Air Force Ballistic Missile Division in June 1957; ARDC-WDD had been set up on 15 July 1954 under General Bernard A. Schriever. It was one of a series of moves that would culminate in the Air Force being given full responsibility for all military space programmes in 1959, ending a multi-service participation that had led to the orbiting of Explorer 1 in January 1958.

With the sure knowledge that Russia was fast catching up with the operational deployment of missile defence systems, the Atlas programme moved ahead on an ambitious schedule. Instead of pursuing a development philosophy that introduced all the many associated elements and systems in a sequential fashion, each tailored to definitive lessons learned from tests with the former, the Air Force proceeded to develop the entire system – missile, support equipment, launch pads – at the same time. Concurrent development would be a key feature of the emerging US missile industry and these early moves by the Air Force were a bold departure from accepted practice. The A-series Atlas was introduced as a test bed for the integrated system. Without the central sustainer engine, and powered only by the two booster units, it was charged with proving that the missile could be built, effectively transported to the designated launch site, erected on the pad and fired. In all, eight Atlas A vehicles were launched from Cape Canaveral between 11 June 1957, and 3 June 1958. They all left the launch pad without problem, but only four were partially successful in carrying out their assigned test objectives.

The Atlas B, a further development model leading toward the fully operational configuration, carried the central sustainer engine and provided the first opportunity to check out the trio of rocket motors that would power subsequent versions. It also carried the General Electric Mk. 1 nose cone, precursor to a later series of developments that would seek to maximize the efficiency of the weapon by incorporating a high velocity warhead. Flights with Atlas B would demonstrate the booster release mechanism, test out the radio-inertial guidance system and provide an opportunity to separate the nose cone from the main body of the missile. The first Atlas B launch came on 19 June 1958, but the mission to test the booster release system and separate the warhead failed shortly after lift-off. On the second B flight, however, the missile took off cleanly from the launch pad, separated its two booster motors as planned, flew on under the continued thrust from its single sustainer engine and released the nose cone on schedule. The date of this flight, 2 August 1958, is one of the more memorable in the diary of Atlas events, since it was the first time that all primary elements of the system had been tested in flight. But the attempt had been intentionally conservative, with the missile flying only 4,000 km down range from Cape Canaveral, and it was left to a subsequent flight to prove the fully specified range: 8,850 km.

This was achieved on 28 November, during the seventh Atlas B flight, and was followed three weeks later by a flight into Earth orbit under Project Score (see Chapter Nine). There were only two more flights with the series-B model; one, on 1

January 1959, was only partially successful while the second, on 4 February, flew nearly 5,500 km out into the Atlantic Ocean. In all the ten Atlas B flights, only two had failed and six had been totally successful. The third developmental model was, appropriately, the Atlas C series, of which six types were flown between 23 December 1958, and 24 August 1959. As a weapon system, Atlas was proving to be more capable than the basic specification intended, as witnessed by the full range flight of a B-series model. Only with the C model did all the many operational refinements come together in a missile thoroughly representative of the definitive variant: the aft skirt sections surrounding the boost engines was fabricated from chemically milled steel, much of the weighty test instrumentation was deleted and the vehicle carried an all-inertial navigation system. With a much improved mass-ratio value the Atlas would double the originally designated range potential of 8,850 km.

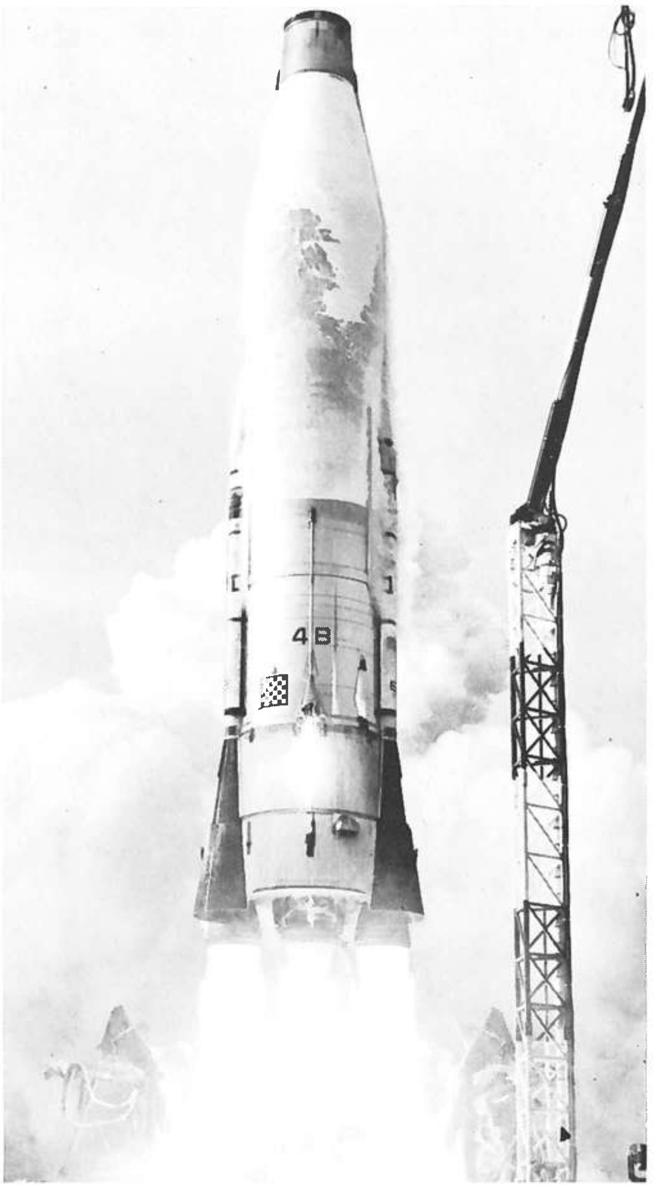
The B series model had carried a guidance system adopting a hybrid matrix of radio command and inertial control, a concept based on the transmission of data to receiving stations on the ground which, when processed through a Burroughs computer, sent refined signals up to the missile's command system for flight control. Later in the flight, the inertial control system would take over and command all functions up to and including separation of the nose cone. Parallel development of guidance and command systems for the Titan led to the adoption of the Bosch Arma all-inertial equipment on Atlas C, so that it could be proven in flight in advance of the Titan development trials and lead to accelerated preparation of the operational version of Atlas. By switching to an all-inertial guidance system, Strategic Air Command launch teams would possess the capability of launching more than one missile at any given moment and prevent enemy interference with command signals, which would otherwise be sent with the dual control mode. Once launched, the missile would be on its own and require no further instruction from the ground.

The first Atlas C flight got off on 23 December 1958 and in five subsequent tests, only one total failure was recorded, three being completely successful. Yet for all its apparent success, only 54% of all Atlas A, B and C models flown had operated as planned in all essential respects. This was too biased a value to argue a case for immediate operational deployment and more tests were necessary to qualify the missile as a viable addition to the American strategic arsenal. Flights with the operational version, the Atlas D, began on 14 April 1959 and resulted in a catastrophic failure, when the missile went askew shortly after lift-off. Nevertheless, the D-series model was expected to go into use at the end of 1959 and progress with eliminating the troublesome faults, led to a successful flight on the fourth attempt at the end of July.

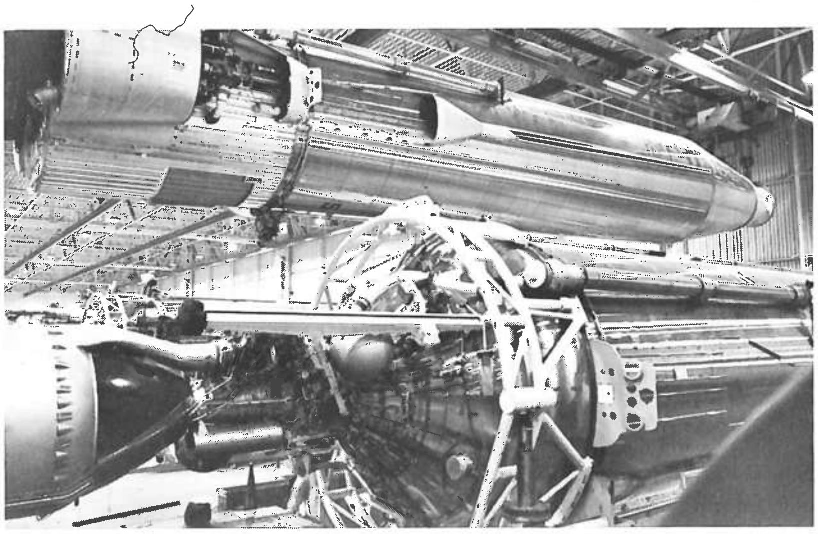
So far, all Atlas models had used the Mk. 2 nose cone, developed by the Space Vehicle Department of General Electric. It was essentially a heat-sink device, fabricated from a slab of copper by Wyman-Gordon to a diameter of 171 cm weighing 624 kg. The Mk. 2 was the first generation nose cone fitted to Thor IRBM vehicles. But it had serious disadvantages. Because the material from which it was constructed was particularly heavy, the available weight for incorporating a nuclear warhead was considerably reduced. Moreover, high drag occasioned by the blunt profile, effectively reduced its impact velocity; atmospheric pressure seriously retarded its progress through the dense layers of air and caused the cone to leave a long trail of ionized gas, which could provide a fix for enemy radar scanners. It was, however, the first nose cone to be operationally deployed and initial success had been recorded in May 1958.

Working in concert with the Army Ballistic Missile Agency, contractors developed a new ablative nose cone for use on the Atlas ICBM. This was manufactured by General Electric as the Mk. 3 and the material from which it was constructed incorporated an outer layer, designed to burn away, or 'ablate', as the cone descended through the dense

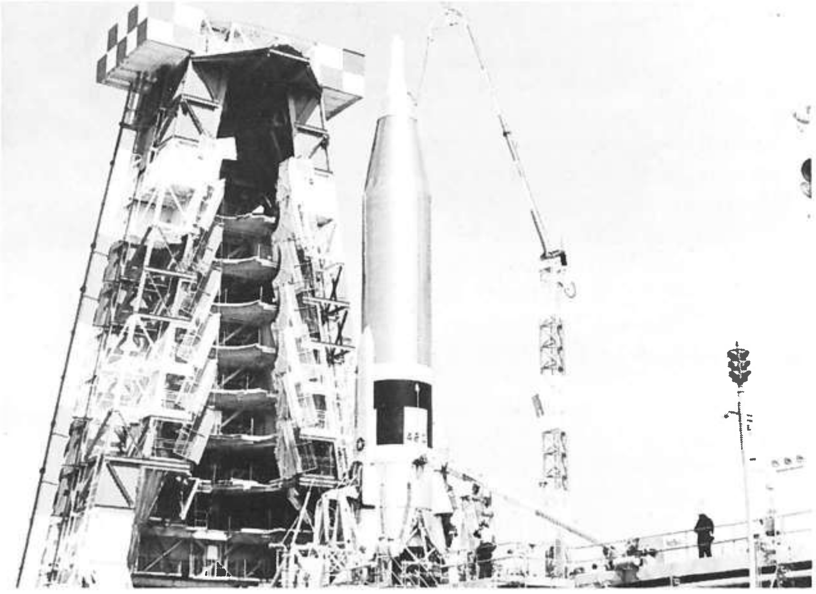
Atlas 4-B, actually the second flight of a 'B' vehicle, was launched on 2 August 1958, and flew 4,000 km down range. Note the corrugated transition section at the top, developed to support the General Electric Mk. 2 warhead.



This view of the final assembly area at Convair, now General Dynamics, shows a closeup of the single sustainer engine carried by Atlas while, above, another Atlas has received its twin booster motors and fairings.



This series 'D' Atlas was sent on a successful flight from Cape Canaveral on 3 August 1960, with a simulated Mk. 3 nose cone. Note the large service tower at left, removed before launch.



layers of the atmosphere. Whereas the Mk. 2 would decelerate to subsonic speed because of the high drag coefficient, the Mk. 3 possessed a substantially higher impact velocity and greatly improved accuracy. As the cone entered the atmosphere and began to heat up through friction, the plastic surface layers would vaporize and provide a protective boundary layer to inhibit thermal transfer and provide effective insulation. Many of the materials used with ablative nose-cone research were variations of a basic phenolic resin compound, reinforced with glass-cloth, nylon and asbestos. The Mk. 3 was about 3 metres in length, but with a comparatively slim body shape that flared to meet the top of the Atlas structure. It was capable of carrying a nuclear warhead with a yield of 2 MT (two megatonnes equivalent TNT yield), or 100 times the explosive yield of the Hiroshima bomb.

The first test of the Mk. 3 re-entry vehicle came with the ninth attempted Atlas D launch, on 6 October 1959. It was completely successful and resulted in a later flight that demonstrated a 16,740 km range capability with a similar nose cone and test instrumentation weighing an additional 450 kg. The enormous increase in range resulted from close examination of the flight trajectories flown hitherto. A reprogrammed guidance profile provided more efficient management of the Atlas' propulsion system and more accurately exploited the energy inherent in the system. It was a process of careful calculation, trial, sometimes error, and ultimate success. No one had launched missiles of this size across the distances now being sought and the 'concurrency' approach was bringing an increasing sophistication along a wide front of technical objectives.

It had been hoped that the first operational Atlas base would be flight-ready by 1 September 1959, but that was too optimistic a date and while construction of the 576th Strategic Missile Squadron facilities at Vandenberg Air Force Base in California was on schedule, the missile was not. Nevertheless, considering that full scale development had begun less than six years before, progress had been outstanding. More and more of the problems were being ironed out and concerted efforts by government-industry teams produced increasingly productive results. Strategic Air Command, with its incongruous motto, 'Peace is our Profession', was charged with operational responsibility for the Atlas and the 576th SMS was set up as a training establishment for SAC crews converting to the ICBM. Trading wings for rocket motors, their efforts would produce the first cadre of missileers from which the first American strategic ICBM defence force would emerge.

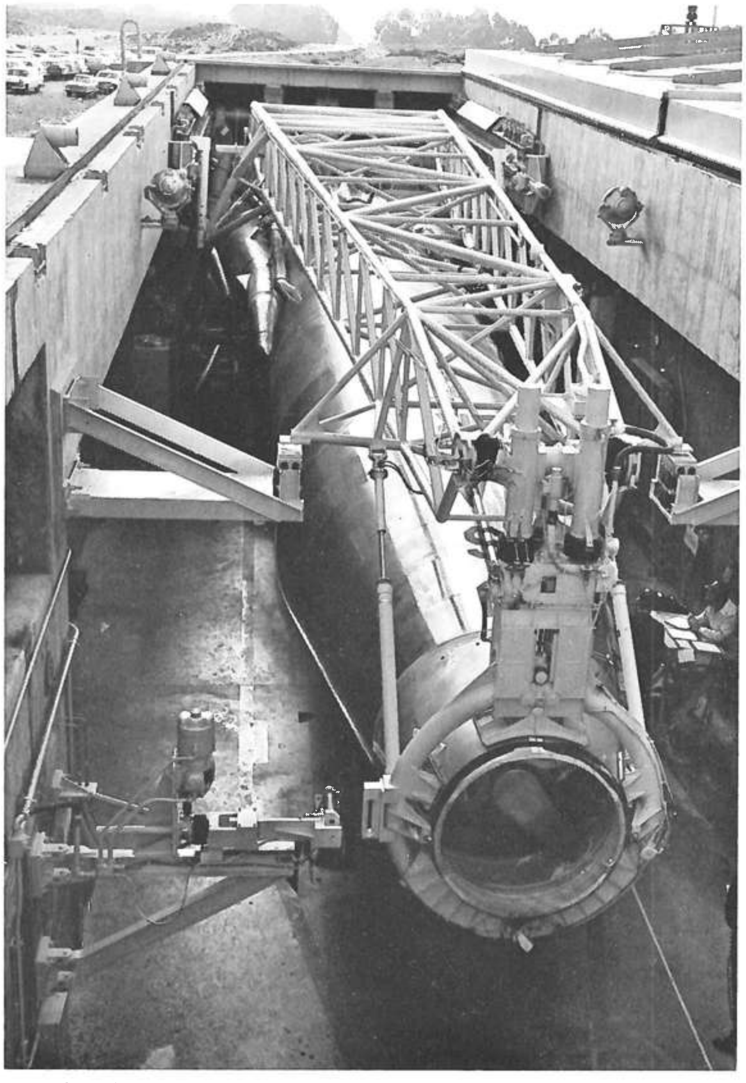
The first truly operational combat-ready unit was to be the 564th SMS, one of three Squadrons that would occupy sites within 93 km of the Francis E. Warren Air Force Base, Cheyenne, Wyoming. The 564th had authority over 6 emplacements, all located within a single complex, whereas the other two Strategic Missile Squadrons at Warren would have 9 missiles apiece. The first firing by SAC crews came on 9 September 1959, from the Vandenberg Air Force Base, when the seventh D model so far launched flew away from its pad on a perfect mission. The first Atlas to arrive at Warren AFB was delivered in the October and on 10 November missile transportation adopted the Lockheed C-133B aircraft instead of the surface mode used previously. This resulted in a much speedier delivery service and a substantial saving in costs.

The six Atlas missiles assigned to the 564th SMS were set horizontally in protective emplacements which afforded shelter from inclement weather. An end-sliding roof section was removed, so that the missile could be rotated through 90° for launch. The second and third SMS units to occupy Warren AFB, the 565th and the 549th, each had control over 9 missiles and used slightly different emplacement facilities. The 565th used a 'soft' launch mode similar to the 6 operated by the 564th, but with cover panels that slid sideways to expose the missile for vertical erection. The 549th SMS adopted a 'semi-hard' coffin emplacement for its 9 missiles, whereby the top of the sliding roof was level with the surrounding ground, thereby affording a certain degree of protection from bombs or warheads falling close by. It was only an interim measure, but it did represent the first attempt to harden the launch facilities against surprise attack.

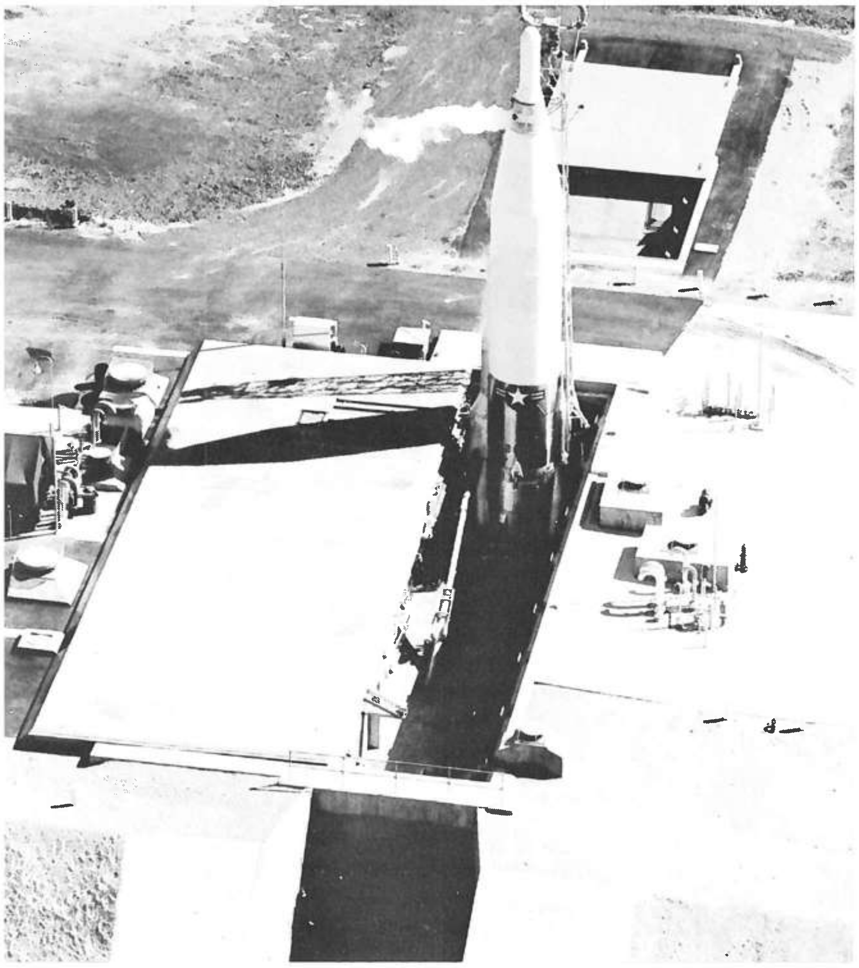
The soft emplacements of the type constructed for the 564th and 565th SMS's were to be the only unprotected facilities ever built for American ICBM's. The semi-hard emplacement, pioneered by the installations used by the 549th SMS, would be able to withstand pressures of 1.7 kg/cm². The first demonstration of an operational capability came with the 9 September 1959 launch of an Atlas D from Vandenberg, but the 576th SMS at that location was in all respects a training Squadron and while it could have effectively launched its missiles in anger, the reaction time would have been several hours at least. It was essential to speed up the time lag between alert warning and actual launch and to provide a hardened facility affording less vulnerability to hostile attack. At Warren Air Force Base, and other Atlas launch sites, missiles could react to a launch alert within fifteen minutes, or halt the countdown eight minutes before launch and remain in this holding posture for some considerable time. Consequently, in May 1960, the American Machine and Foundry company were awarded a contract to build hardened Atlas launch emplacements, which took the missiles underground in vertical silos covered by concrete doors.

But if Atlas represented the potential heavyweight punch that would serve to deter the escalation of local war into global conflict, it was only one part of the strategic nuclear strike force that was beginning to assemble with calculated precision. By 1960 the British Royal Air Force had brought up to strength all 60 of its Thor Intermediate Range Ballistic Missiles and distributed them across widely separated sites in Yorkshire, Lincolnshire and East Anglia. It was the product of an intensive two years, during which more than 1,200 RAF personnel were trained in the United States to effectively provide a front-line force against the day that Soviet ambitions moved outside their territorial domain.

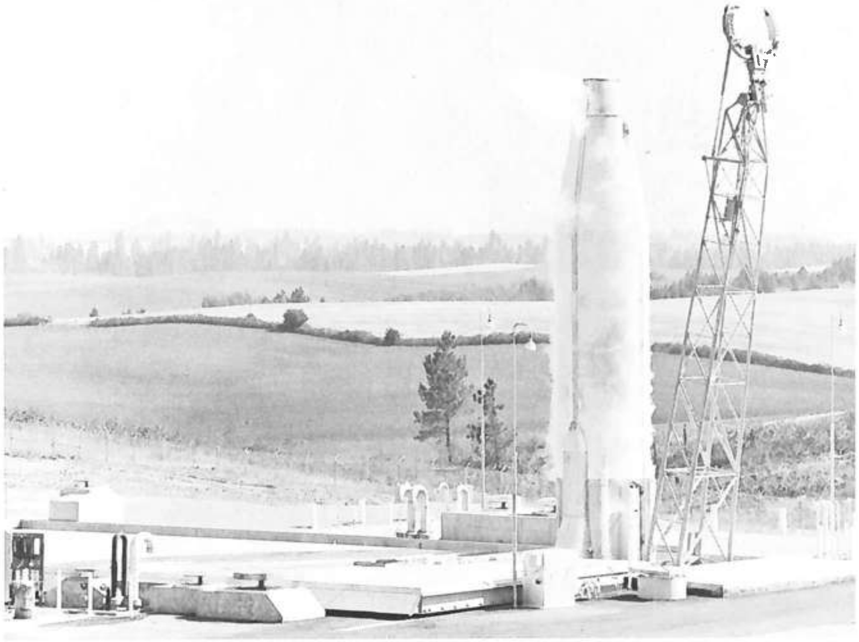
With a range of more than 2,400 km, the Thor would serve as deterrent with performance to spare. Familiarization courses for RAF personnel began in 1958 when forty-five



An Atlas of the 576th Strategic Missile Squadron at Vandenberg Air Force Base is seen hanging from its erector assembly in a 'semi-hard' coffin emplacement.



Atlas E ICBM's were placed in 'semi-hard' coffins and raised to a vertical position for launch. Note the large horizontal concrete close-out door and, behind, the smaller horizontal door moved back to expose the exhaust duct.



An Atlas E ICBM shortly before launch, when the missile is filled with propellant. Note the buildup of ice around the liquid oxygen tank and the erector assembly, here placed in standby mode.

airmen arrived in the United States to learn key aspects of the missile's design and operation. They would form the nucleus of the first Thor unit in the UK: 77 Squadron, RAF Bomber Command. First the course required an initiation session at the Douglas Aircraft Company's training school at Tucson, Arizona, operated by Douglas for the US Air Force Air Training Command. From there the students went to several key contractors working on Thor engineering and production and received briefing on propulsion, guidance, control, subsystems design, etc. Next came a visit to Cook Air Force Base in California for crew training and launch instruction and the participants learned the philosophy behind deployment strategy and operating techniques, traditionally somewhat different from the text-book dictates.

By early 1959 the procedures for graduation to actual launch tests were completed and the RAF gradually moved toward autonomous command of countdown and firing. The British launch team was under the tutelage of the 392nd Missile Training Squadron, an element of the 704th Strategic Missile Wing of the 1st Missile Division. This US Air Force Squadron was one of three providing training facilities for American crews: The 576th covered Atlas and the 395th was devoted to Titan. The 1st Missile Division had been formed as an arm of the Air Research and Development Command (ARDC) in April 1957 and was transferred to Strategic Air Command in January 1958. The first RAF launched Thor IRBM was sent up on 16 April 1959, from its Vandenberg Air Force Base launch pad. Several postponements had forced a delay in preparations for launch, but under combat conditions the missile could have been fired on the originally planned date, two days earlier than the actual launch. Additional flights were accomplished in June and August and a procedure was established whereby RAF crews would fire Thor missiles from Vandenberg before assuming launch control from bases in the United Kingdom.

Transport to Britain of Thor missiles and support equipment was provided by C-124 Globemasters and on 10 March 1960, the last of 60 rounds was delivered from Dover Air Force Base, Delaware. The Royal Air Force set up four squadrons operating from Feltwell, Driffield, North Luffenham and Hemswell and training activity required the appropriate RAF crew to receive the missile at their home base and then take it back to California for flight. Another round would then be supplied to replace the one used in training. Full operational capability with UK based Thor missiles was achieved in mid-1960, although none were fired from British soil because of the geographical location of the four bases.

On site, the Thor was stored in a horizontal position, resting on an erector holding the missile at the rear and at the forward end by clamps that would release it for flight. The erector-launcher was emplaced on a fixed concrete bed and covered by a hangar-like shelter that protected the missile from the severest British weather. Mounted on rails, the shelter would be rolled back from the concrete pad within twenty minutes of an anticipated launch. With less than fifteen minutes to go, the missile would then be moved to a vertical position by hydraulic rams on the erector, filled with propellant and brought to a state of readiness. With only minutes to go, the erector assembly would be lowered to a horizontal position once again, leaving the missile alone on its pad, and the final countdown could move towards launch.

For the first 100 seconds of the flight, control would be provided from a pre-set programme, but instructions on the precise nature of the desired trajectory would then have come from the inertial control system for a further 65 seconds. Less than three minutes after launch, the warhead would be separated from the missile so that it could fly to its target in Soviet Russia or territories of the Warsaw Pact countries. All the warheads used by the Royal Air Force Thor squadrons were of the General Electric Mk. 2 type under the control of US Air Force authority. Because of the design of the soft launch sites, the missile was exceptionally vulnerable to attack, but the presence of a forward-based deterrent was one important element of the West's strike capability. In 1959 the US Department of Defence decided to cancel its deployment of Thor and rely wholly on the missiles based in England, at the same time drawing up final plans for site location of the Army IRBM: Jupiter. With a similar performance to Thor, Jupiter control had been transferred to the Air Force's Strategic Air Command in 1957 and the 864th Strategic Missile Squadron was established at Redstone Arsenal. Like Thor, it would be deployed overseas.

By 1959 plans embraced a squadron of fifteen missiles based in northern Italy and a second squadron operating from sites in Turkey. In all, ninety IRBM class missiles would be strung out across a line stretching from the British Isles to the southern flank of the Soviet Union and this front-line deployment was to cause much consternation at the Kremlin. In April 1960, the British Government elected not to pursue development of the Blue Streak Long Range Ballistic Missile, a class providing a range capability mid-way between IRBM and ICBM types. If deployed, Blue Streak would have had a performance capability only marginally below that of the American Atlas ICBM: its propulsion system would have

Soviet missile buildup began in the late 1950's and a high-speed shutter 'freezes' this Frog shortly after launch.

delivered a thrust of 136 tonnes (versus 163 tonnes) and it would have carried a thermonuclear warhead across an operational distance of 5,500 km.

But even as Atlas was in the process of maturing towards operational status, the United States Navy was preparing to put to sea with the first of her nuclear powered ballistic missile submarines. As early as January 1957, the Department of Defence had authorized full development of the Polaris system whereby powerful, fast, submarines would be equipped with 16 solid propellant missiles that could be fired on command from any concealed underwater location on Earth. The political ramifications of deploying such a system seem not to have had the anticipated repercussions on international affairs, but the SLBM – Submarine Launched Ballistic Missile – effectively opens up more than 60% of the surface of the planet for use as a patrol area. While international waters are not exclusively the preserve of any one nation, by virtue of international law, the deployment of strategically offensive weapon systems has consistently proved to be a sensitive area. Most countries accept the presence of naval vessels for the protection of sea-routes and civilian shipping owned or operated by the host state; the transfer of a strategic retaliatory strike force, totally devoid of application to protective pursuits, from the territory of one nation to the open ocean is but one further example of the demolition of traditional barriers.

Nevertheless, progress with the technology of solid propellants, and considerable improvements in the miniaturization of nuclear warheads, made the concept look exceedingly attractive in 1957, when the programme was accelerated. At that time the Secretary of the Navy proposed development of a missile of 2,250 km range that could be in operational service by the end of 1960. On 9 December 1957, the Secretary of Defence authorized more positive progress towards the implementation of Polaris objectives and work began on the first of several submarines adapted to carry the weapon. The USS George Washington was to be the first of these, its keel having been laid down on 1 November 1957, for a submarine named Scorpion. When authority was received from the Department of Defence, Scorpion's hull was cut in two and a 40 metre long missile tube section added, converting it into the new SSBN ('B' for ballistic and 'N' for nuclear) vessel. At this time the Navy planned to achieve operational status by the end of 1963, a notably pessimistic date as events would show.

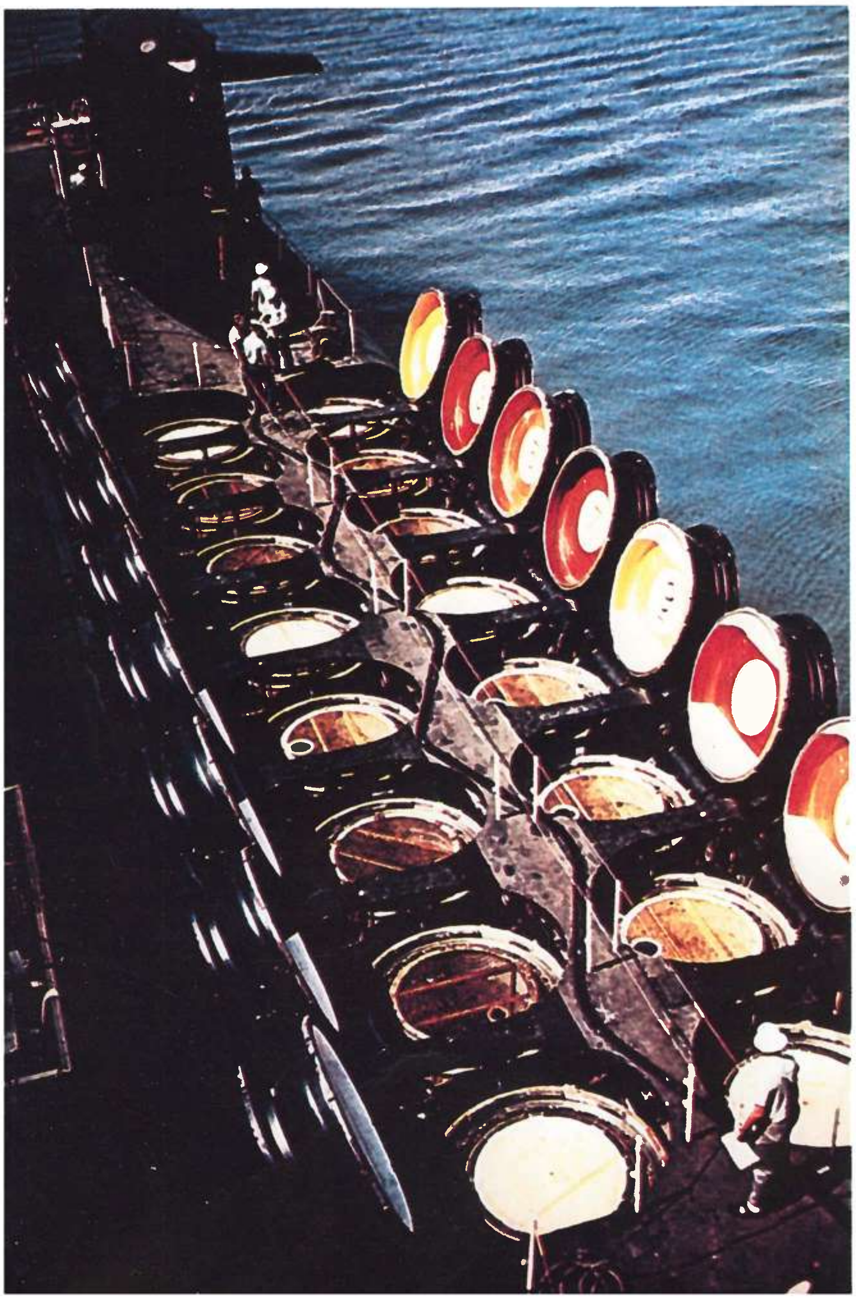
If Polaris was simple in concept, the many operating problems were daunting in practice. Unlike any other missile system yet developed, the device would have to remain in a position affording only limited inspection for several months at a time, be capable of ejection by compressed air from the appropriate launch tube, move rapidly to the surface under the influence of the momentum imparted at release, and ignite its solid propellant motor within milliseconds of clearing the surface. The hydrodynamic properties of Polaris would be a new consideration for missile designers and the enormous changes in pressure experienced as the missile rose to the surface, would have to play an important part in the selection of an optimum configuration. In effect, Polaris would be required to move efficiently in two environments and operate in three: the first being a changing hydrostatic medium, with a variety of surface sea-states, the second being the atmosphere, and any air turbulence on the ascent, and the third, operating environment, the vacuum of space during the time between leaving the atmosphere and separating the nose cone.

Much of 1957 was spent in laying out the essential requirements of the test programme and dividing the project into functional areas such as the Polaris missile itself, the SSBN launcher and the interfacing systems involving the two. The first experiments with launch methods began late in 1957, at Hunters Point, in San Francisco Bay under Operation Peashooter. Large trunks from Californian Redwood trees were fashioned into dummy projectiles that could be ejected by compressed air from simple launch tubes set up on the shore. Later, cylindrical blocks of concrete weighing 12 tonnes, suitably placed inside a container simulating the missile, provided an opportunity for checking mass distribution and weight characteristics. These too were flung out of the dummy launch tubes, on occasion reaching a height of more than 30 metres before falling back into the Bay.

Tests of the interaction of solid propellant projectiles and suitable launch tubes got under way as part of the Polaris-jg (Junior Grade) programme, whereby shapes approximating that of the definitive missile were fired from Cape Canaveral. From January 1958, the full scale testing of underwater launch models was under way at Point Mugu, California, as a part of Operation Pop-up. This effectively demonstrated the feasibility of a sub-surface ejection with projectiles leaping into the air to a height of 30 metres before falling back into the sea to be caught by a large net just below the water. But this method of testing the system was limited in that it required the projectile to drop back down into the water unlike operational procedures with the fully developed Polaris. A way had to be found whereby the projectile could be prevented from falling back. The problem was resolved at the San Francisco Navy Yard and involved the large travelling crane domiciled at that facility. The unpowered test vehicles would be ejected from underwater launch tubes while attached to lines linking the projectile with the crane head. As the device shot upwards through the surface, the lines would reel in and hold the projectile in suspension when it reached the top of its trajectory. As long as the test vehicle was not expected to reach a height exceeding that of the crane head, the system would work. And it did.

For other tests the Navy built a 30 metre square barge on which was constructed a derrick, 57 metres high, with a similar reel-and-catch system adopted earlier. This series was known as Operation Fishhook. By mid-1958 the prime contractor on the Polaris programme, Lockheed, delivered live test rounds similar in every respect to the final product. These formed the AX series of test flights and required the vehicle to demonstrate ignition, first stage flight and separation, followed by second stage ignition. The first AX flight was attempted on 24 September 1958, from Cape Canaveral and led to a series of test launches that did much to improve the success of the programme. Many of the AX series came to grief, but considerable knowledge was gained about the system's design potential.

On into 1959 the programme moved ahead with striking rapidity. At Cape Canaveral the Naval Ordinance Test Unit worked with Lockheed to prepare test vehicles and conduct live firings. Pad 25A was used for propulsion tests with its support rig well clear of the ground for continued monitoring of motor performance. Pad 25B was a ship-motion-simulator set up on the ground so that hydraulic rams could move the launch tube at any angle from the vertical, while simultaneously moving it up and down. This enabled engineers to test the ejection procedures under conditions representative of different sea states. Meanwhile, the USS Compass Island, an ageing cargo ship specially adapted for the Polaris programme, put to sea to test and evaluate the Ship Inertial Navigation System (SINS) that would be used by the new class of submarines equipped with the SLBM.



The Polaris equipped submarines would each carry 16 missiles, placed in single launch tubes aft of the sail. The two rows of launch tubes were capped with individual doors, each door opening in turn to allow the missile to be ejected.

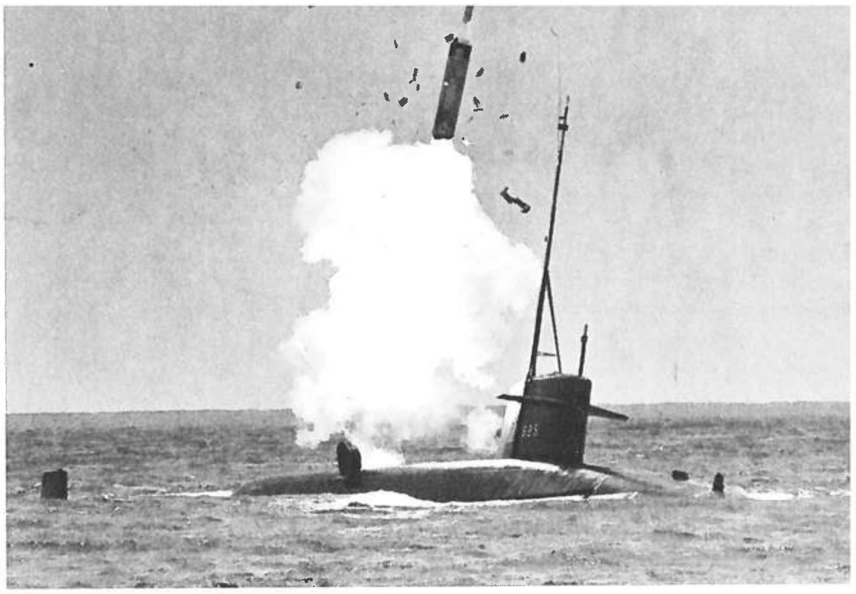
By April 1959, the AX series of test vehicles had successfully flown distances of up to 480 km leading toward final tests with an AIX configuration fully typical of the definitive Polaris. The first flight of an AIX came on 21 September 1959, with a success that heralded the fortunes of the programme from this point on. The first night firing was accomplished on 15 December, from Pad 25A and by February 1960, several AIX models had flown more than 1,600 km down the Atlantic Missile Range. Tests of the all-inertial navigation system were proving fruitful and on 18 March, a live Polaris missile was fired from the ship-motion-simulator in demonstration of air-ejection and solid propellant ignition. Another successful flight came a week later and on 14 April, the first underwater ejection of a live missile was performed off the coast of San Clemente, resulting in a 23 second flight, limited only by the reduced load of solid propellant. Just eleven days later, an AIX achieved a flight range of more than 1,900 km.

Meanwhile, the first SLBM vessel, the SSBN-598 George Washington, had been launched on 9 June 1959, and commissioned six months later. The final tests could now begin. During the first half of 1960, the George Washington had been performing trials with dummy projectiles to check out the tube-launch mechanism before committing the vessel to active tests employing live missiles. On the night of 9 July 1960, two fully loaded Polaris missiles were slowly lowered into two vertical launch tubes on the George Washington while it lay moored at Port Canaveral. Early the next day, with 307 picked crew on board, the submarine quietly slipped its berth and put to sea. Just 3½ years after the programme got under way, the first pre-operational tests were about to begin. About 48 km off shore, the George Washington met the USS Observation Island with instrumentation on board for checking important aspects of the test. Submerging to a depth of 27 metres, the George Washington began the firing run at a speed of little more than 2 km/hr. Before launching the first Polaris missile, a green coloured smoke float was released to mark the spot for observers on the surface. The countdown progressed and Navy technicians waited for the final call to 'launch'.

Somewhere along the flat aft section of the submarine's hull, a circular door swung vertically open and a flurry of bubbles poured from the exposed launch tube. Inside, the Polaris missile responded to the force of compressed air and shot upwards towards the surface. Clearing the water at an angle of 20° from vertical, the missile seemed almost to have come to a halt, when suddenly the solid propellant charge ignited and a blast of white smoke gouged furrows in the boiling water. Within seconds the guidance system restored the missile's attitude to a near vertical stance as it sped away from its subsurface launcher, gradually pitching over on course for a designated target area nearly 2,050 km away. It had worked; a fearsome new dimension had been added to strategic warfare. Exactly 2 hrs 53 mins later the second missile was fired, duplicating the performance of the first. In further tests of the complete system, George Washington was joined by SSBN-599, Patrick Henry, and this second SLBM launcher successfully fired off four Polaris A1 missiles in an operational combat environment between 15 and 18 October 1960.

As a weapon, the Polaris missile packed an incredibly efficient punch into a surprisingly small package. With a specified range and weight lifting capability not too far below that of the Air Force Thor and the Army Jupiter, it was expected, and designed, to be 57% shorter and weigh 74% less. Nevertheless, it was required to carry a warhead with an explosive yield of 500 KT (about 25 times the explosive yield of the Hiroshima bomb) and with 16 Polaris missiles apiece, the nuclear powered submarines would provide a concealed launch environment for nose cones that collectively would equal four Atlas ICBM class launchers. By late 1960, the Department of Defence had authorized construction of 21 SSBN vessels with a projected requirement for 45 in total. As it turned out the Navy would eventually get 41 submarines of this class, with a total capability for launching 656 missiles, a collective explosive yield equal to 164 Atlas ICBM weapons.

But the A1 model was only a first generation Polaris that would be replaced by the A2 and the A2 in turn would be relinquished in favour of an A3 version. All three models were two-stage missiles with four exhaust nozzles in each stage, but improvements in the chemistry of the propellant substantially increased the range: A1 could fly 2,220 km; A2 had a range of 2,780 km and the A3 would reach targets fully 4,630 km away. Development of the A2 was already in hand by late 1960, but it would be two years before serious work could begin on the A3. It was a project heralding radical new concepts for submarine-launched missiles and as such represented a major step beyond the A1 and the A2. On 10 November 1960, the Patrick Henry fired one in a series of A2 test vehicles and successfully achieved a flight range exceeding 2,590 km. On 15 November, the George Washington moved out from Charleston, South Carolina, on the first operational patrol, with 16 Polaris A1 missiles. It was a historic moment for the programme: the original objective of operational status by 1963 had been broken by a handsome margin. On 30 December, the Patrick Henry joined the George Washington on patrol with a similar load of 16 A1 missiles.



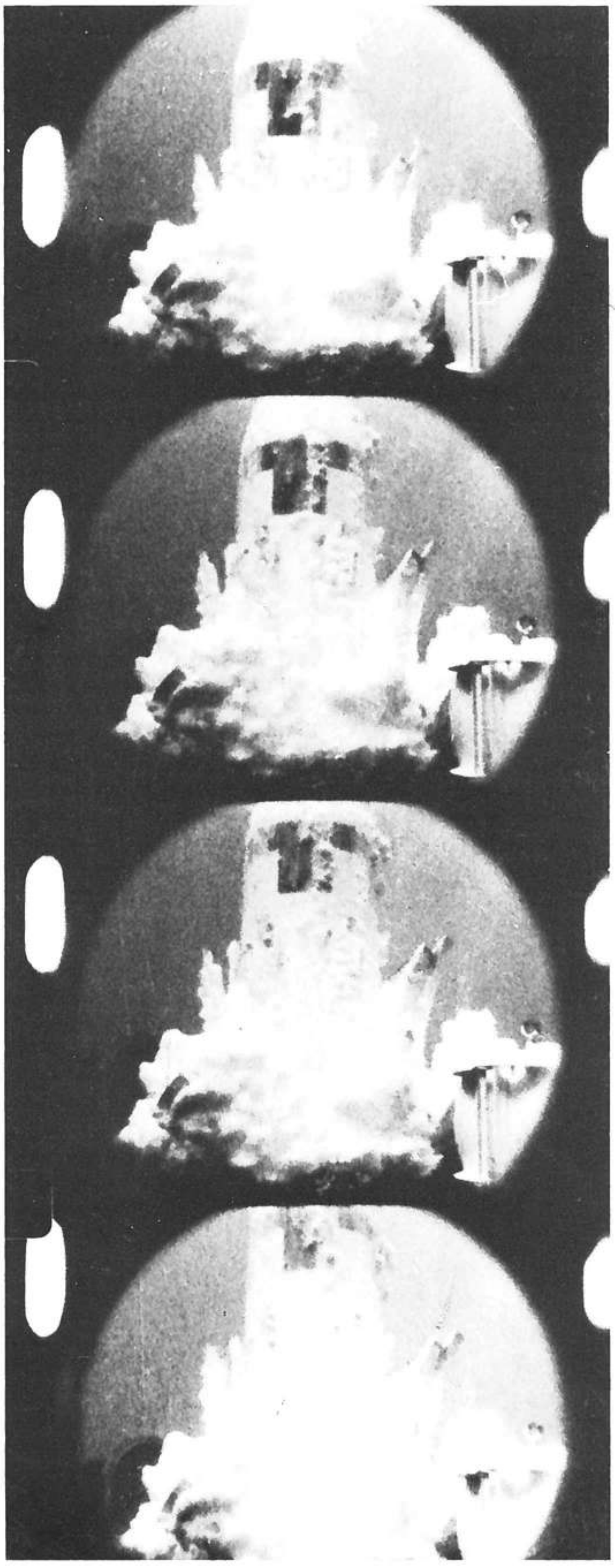
Just thirty minutes after launching a Polaris missile from underwater, the USS Henry Clay surfaced and launched this A2 version while performing a turn to starboard at speed, demonstrating an on-surface ejection capability for the first time on 20 April 1964. Note the telemetry mast (mounted to the sail for test only) and the debris from adapters carried between the missile and its launch tube.

In the fifteen years that spanned the end of World War II and the service introduction of long-range ballistic missiles like Atlas, Thor and Polaris, development of other, less spectacular, missiles continued. In 1958 the Matador short-range, surface-to-surface missile (see Chapter Seven) was replaced on the production line by Mace. With a single turbojet engine, the winged bomber was capable of flying 1,000 km, while a developed version had twice the range. Mace was launched from an inclined ramp using a solid propellant Thiokol boost rocket to propel it into the air, with a thrust of 45 tonnes. In 1959, Mace was operational with the 38th Tactical Missile Wing in West Germany and by the early 1960's units were equipped with the missile throughout Europe and the Pacific.

Work on the development of a US anti-aircraft missile, more popularly known by the acronym SAM (Surface-to Air-Missile), began in June 1945 when Boeing received a contract from the then Army Air Force to study a range of potential design configurations. Called GAPA, for Ground-to-Air Pilotless Aircraft, they comprised a solid propellant first stage, with different upper stage propulsion units employing solid or liquid propellant rocket motors or a ramjet engine. The last GAPA missile was fired on 15 November 1949, and the programme led to the successful Bomarc missile, an operational SAM, first flown in February 1955. Altogether different from GAPA, Bomarc was a pilotless interceptor employing two ramjet engines following launch by a single solid propellant booster. The missile was 15 metres long and carried aerodynamic control surfaces for flight at between Mach 2 and 3 (two and three times the speed of sound). Developed versions proved capable of intercepting targets at altitudes in excess of 30 km and a range of 800 km. By 1958, air-defence units were operational with Bomarc and the missile was eventually used by the Royal Canadian Air Force.

In other developments, the US Army organized a vigorous programme of SAM systems in the so-called Nike project: Nike Ajax had a range of nearly 50 km, Nike Hercules could reach targets 140 km away and Nike Zeus was effective up to 400 km from its launch site. Nike Zeus was accelerated into flight by a Thiokol solid propellant booster, delivering a thrust of 204 tonnes and could reach altitudes in excess of 45 km, making it the most lethal SAM of its day.

In the category of air-to-air missiles, the Firestreak had by 1960 entered squadron service with the Royal Air Force, while in the United States the Sparrow family was equipping supersonic interceptor units at home and abroad. At the bottom end of the scale, anti-tank and ship-launched missiles were being developed in abundance and in a variety of configurations.

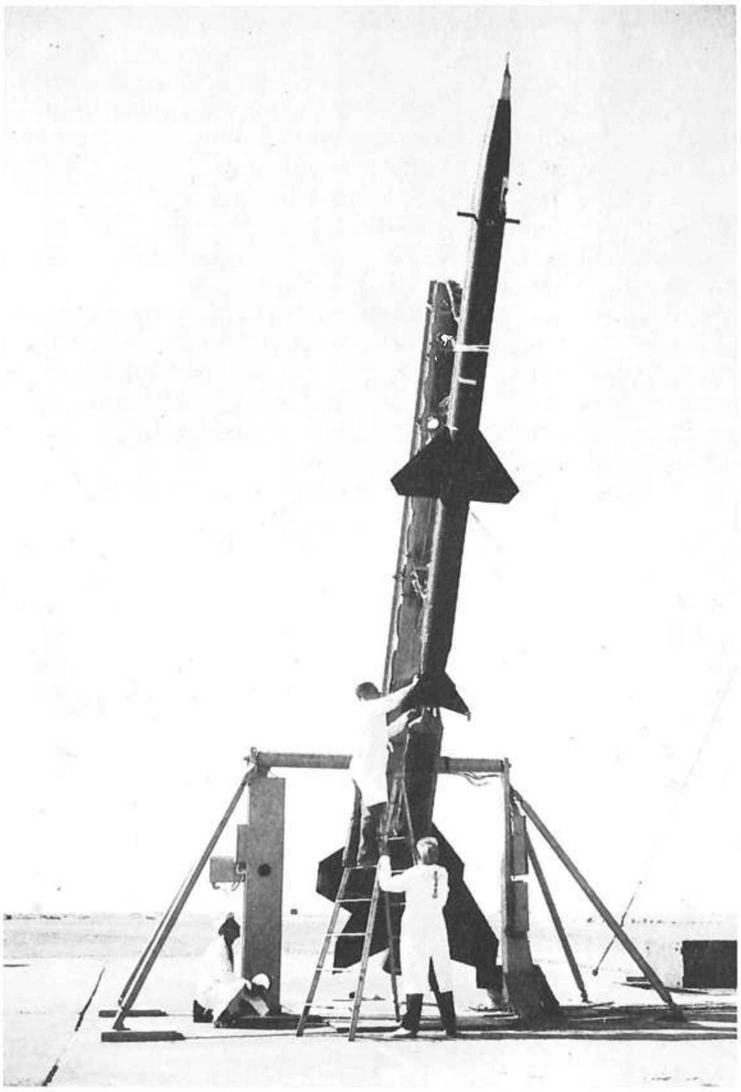


In this remarkable series of photographs, a Polaris missile is seen in the process of ejection from an underwater launch tube on the USS Theodore Roosevelt. Note the flurry of gas bubbles accompanying the ascending missile.

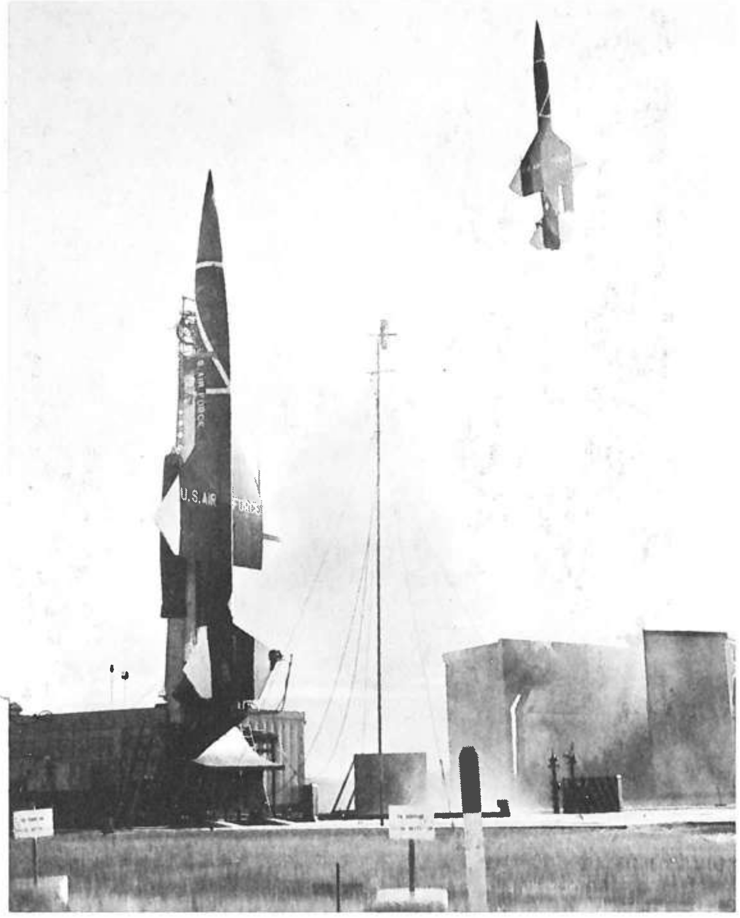
The strategic nuclear deterrent was also building in force. Atlas missiles were going into soft and semi-hard coffins at Warren Air Force Base and more were planned for installation at other ICBM sites. Thor IRBM weapons were stationed in England as a front-line force and Jupiter would soon be deployed in Asia Minor and southern Europe. At sea, the SLBM force was a major development in the concept of strategic warfare and although it initially had a range capability less than that of intermediate ballistic missiles, the mobility of the launcher – SSBN submarines – provided the ability to sneak up close to Soviet borders and fire deep into the Russian heartland. However, good as Atlas was in the role of a first generation land-based ICBM, it had several drawbacks that led to the accelerated development of the second Air Force heavy-weight delivery system: Titan.

Originally conceived as the insurance policy for a flagging Atlas programme, the new missile would rely on conventional design concepts for a simple and reliable weapon system that could supplement the strike force in soft sites and at sea. Weapon System 107 had embraced both Atlas and Titan from the latter's authorization in 1955 and it was this second missile that would pioneer the concept of in-silo launch. This feature was an integral part of the Minuteman programme, but more on this later. With the Martin Company building the missile and Aerojet-General working on the LR-87 propulsion system, Titan 1 evolved as a two-stage liquid propellant weapon that would be housed in a vertical silo until it was in the final stages of a countdown to launch. Within minutes of the planned lift-off time, the missile would be elevated so that its first stage engines were clear of the surrounding ground. In this way, the ICBM could be kept in a protected environment until it was required to seek out targets in Soviet Russia. As a strategic concept emerged at the end of the 1950's, Titan was seen as the heavy punch in the American arsenal. With a warhead capable of a 5 MT explosive yield, each missile would carry a single nuclear charge equal to 250 Hiroshima bombs. It would seek out and destroy 'hardened' Soviet installations or be employed as a 'city-buster' of awesome potential.

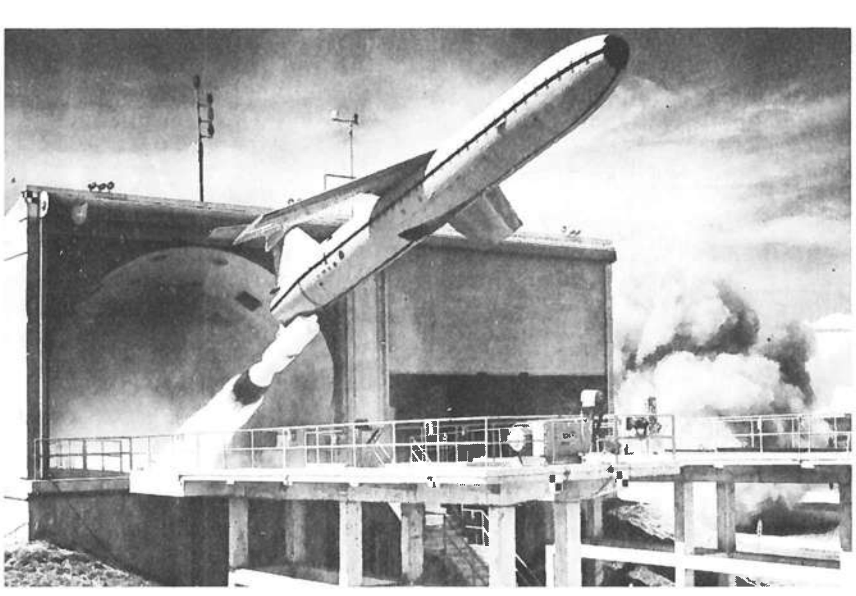
Titan 1 was designed to use liquid oxygen and kerosene (RP-1) propellants in both first and second stages, the first employing two LR-87 engines for a combined thrust of 136

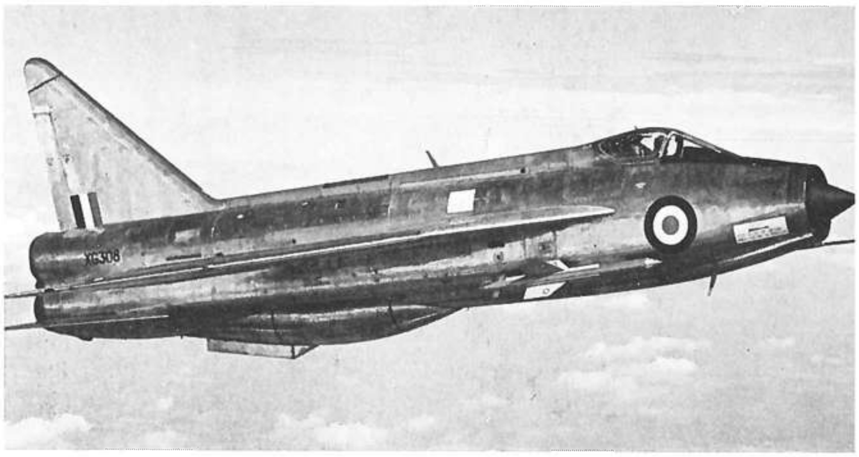


Precursor to the Bomarc surface-to-air missile, the Boeing GAPA is seen during launch preparations.



Bomarc missiles participate in a dual test launch on 27 January 1959, from Cape Canaveral. Note the concrete shelter.





A Royal Air Force Lightning interceptor sports a Firestreak air-to-air missile, behind and below the RAF roundel.

A test version of the Martin Mace surface-to-surface missile is seen leaving its Cape Canaveral shelter on 21 September 1960. Mace was 13.4 m long, boosted into the air by a 45 tonne thrust booster in the ventral position from where a turbojet engine would take over and provide a range capability of 2,200 km.

tonnes and the second adopting the LR-91 engine with 27 tonnes of thrust. With a launch weight of nearly 100 tonnes, the missile was lighter than Atlas and was expected to send its deadly warhead a distance of 14,800 km. One of the drawbacks with the non-storable propellants required the missile to be filled with fuel and oxidizer shortly before launch, complicating and extending the reaction time from first alert to launch at the top of the silo. A similar problem attended Atlas deployment. Originally, Titan was expected to use the all-inertial Bosch Arma system, transferred to Atlas missiles, but the first flight versions were prepared with an initial post-launch guidance system based on radio command updates. This was a limiting factor in operation, since the missiles would have had to be launched singly rather than in salvo. Later Titans carried an all-inertial guidance package developed by AC Spark Plug.

In every respect Titan was a missile built to conventional principles that contrasted sharply with the sophisticated engineering of the unique Atlas. It had two separate stages mounted in tandem, a frame built up from stretch-formed and chemically milled, high-strength, light alloy and was designed from the outset for silo emplacement. The first attempt at getting Titan 1 into the air failed on 20 December 1958, and again on 3 February 1959. Three days later the missile rose into the sky from Cape Canaveral and proved that the first stage worked; the second stage was filled with water ballast to simulate the mass and weight distribution of a live stage. On this first flight the second stage was not separated, but on 4 May, another Titan took off and demonstrated good stage separation prior to further tests resulting in live first *and* second stage ignition. Not for some time would Titan fly from the top of a silo and the initial series of trials was performed from a conventional concrete launch pad. The missile was brought to the launch site in the horizontal position and then elevated 90° by a massive erector that was lowered to the surface, again prior to launch; a large service mast formed from structural steel remained alongside the missile to top up the propellant tanks.

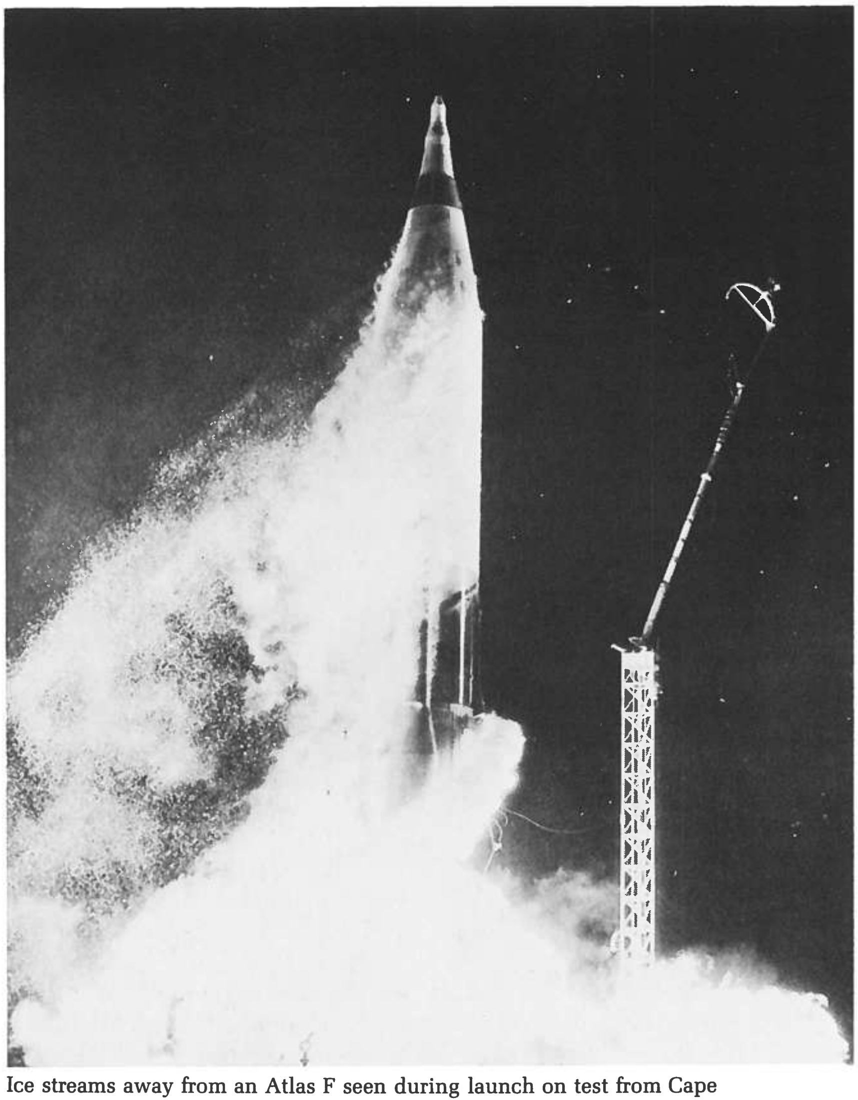
By the middle of 1959, the drawbacks resulting from use of non-storable propellants and the exposed nature of the soft launch site came to the fore and a decision was made to expand upon the promising technology of Titan 1 and use it as the basis for a new version. Called Titan 2, it would use storable liquids for the fuel and the oxidizer so that the missile could stand ready for almost instantaneous launch for extremely long periods of time. Moreover, Titan 2 would be designed to ignite its first stage engines at the bottom of the silo and so reduce, even further, the exposure time inherent in the Titan 1 which had to be raised to the surface before launch. With similar engines in both first and second stages to those employed on Titan 1, the new version would use nitrogen tetroxide as the oxidizer and a mixture of hydrazine and unsymmetrical hydrazine as fuel. Both fluids could remain in the respective tanks for a considerable period of time without damage to the delicate plumbing and valve systems essential to all liquid propellant engines.

No sooner had this decision been taken, than a series of spectacular disasters struck the development programme. On 14 August 1959, a Titan 1 leapt away from its launch pad hold-down clamps before service lines connecting the missile to the service tower had been properly released. The big missile promptly received a signal warning its control system of a suspected malfunction, which shut down the two first stage engines, causing it to collapse back down into a ball of fire. On another occasion, a Titan 1 liquid oxygen tank imploded when oxidizer flowed too quickly into the interior and met a volume of warm air inside. Another tank ruptured while being airlifted to Cape Canaveral. Then, on 2 December, a Titan 1 stood ready for the first flight attempt with two live stages. Seconds after launch the control system picked up unusual oscillations in the body of the missile and interpreted this an an indication that the vehicle was in serious trouble. As required under such circumstances, the control system ordered the missile to blow itself up and thus prevent further deviations that might take it over populated areas. As it turned out the sensors were placed in too sensitive a location and the flight would have progressed normally had the destruct system not been called in to dramatically terminate the mission.

Finally, after more than nine months of successive failures, the first flight test of both first and second stages came off as expected on 24 February 1960. Moreover, the missile carried full guidance equipment and its operational Avco Mk. 4 nose cone and flew a range distance of some 8,050 km. But such are the attendant fortunes of missile engineers that only rarely does a success lead to sustained perfection. On 8 April, a repeat test of the successful 24 February shot resulted in failure, when the second stage engine shut down too soon and brought the assembly prematurely back to earth. On the same day the Reuter newsagency reported: 'An Atlas ICBM blew up on its launching pad last night, sending out flames that illuminated the sea and beaches for miles around. When the countdown was completed – for a test of a new guidance system – flames suddenly engulfed the whole rocket. The fire raged for several minutes. It was the second consecutive test of the nation's only operational ICBM which ended with an explosion on launching.'

Lessons were being learned the hard way – but the only way. Throughout the intensive build-up in flight tests that characterized the emergence of an efficient ICBM force, failures were frequent, and often spectacular. For no apparent reason a missile would explode on the launch pad, veer off course or blow up unexpectedly high in the upper reaches of the atmosphere. As the first Titan 1 missiles were being fed across to the 395th Strategic Missile Squadron at the Vandenberg Air Force Base, it seemed that most of the unknowns had been charted. Then, on the night of 4–5 December 1960, during a routine propellant loading operation in support of a planned test flight down the Pacific Missile Range, the Titan 1 suddenly blew up in its silo and virtually demolished the facility. The bill for damages came to $5 million. There was a good reason for the accident, but one which had to be found out after the event.

So it was with most missile development programmes: some blew up, a few flew successfully, and while the casual observer would think that rocketry was stumbling along an unsure path, the reality was very different. Each accident was analysed with deft precision; every explosion was discussed



Ice streams away from an Atlas F seen during launch on test from Cape Canaveral with a Mk. 5 nose cone.

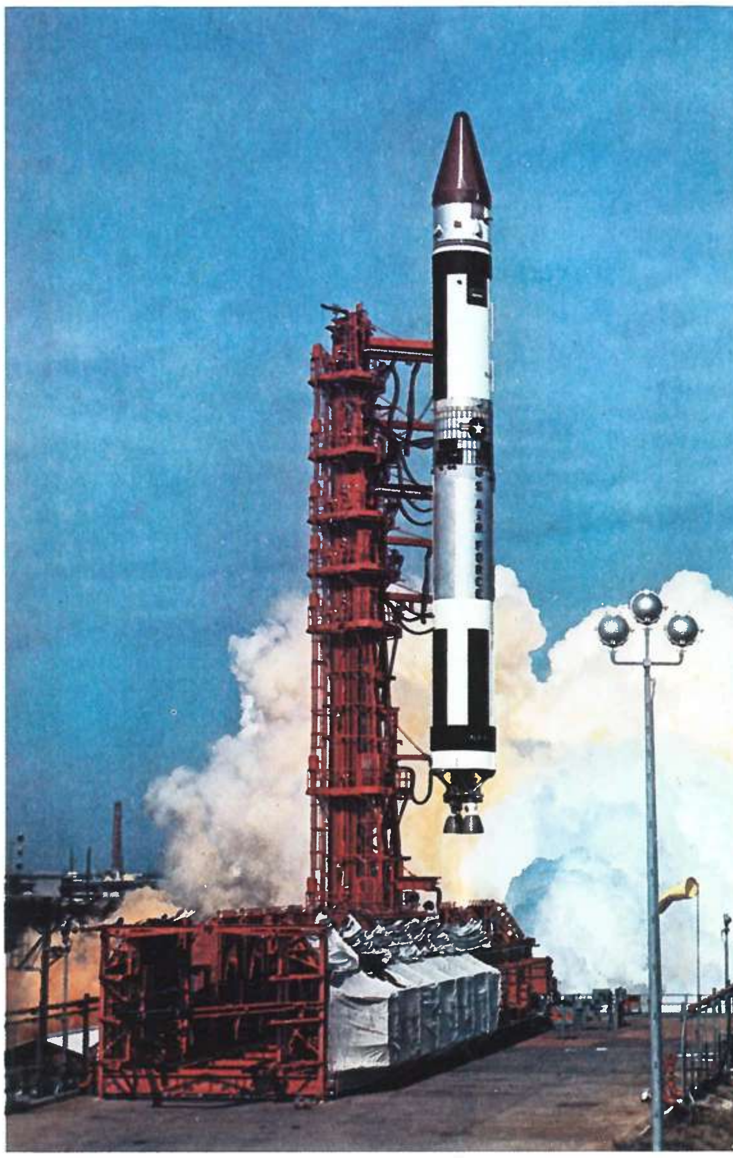
and a reason found for its cause. Step by step the lessons were learned, sometimes re-learned, but always applied and fed back into the programme, making the next flight just that little percentage part more likely to provide a satisfying result. In time, the accidents diminished and the success rate increased, but not yet awhile. The very essence of 'concurrency' implied that the many untried facets of a programme all had to be tackled at the same time and slowly the collective assembly of elements and sub-elements converged towards efficiency.

By the end of 1960 work was well under way on the design of all three classes of launch facility: soft, semi-hard and hard. Atlas D would be emplaced in soft launch pads at Warren Air Force Base only and three squadrons operating 21 missiles would back up other sites. These were to comprise four additional Strategic Missile Squadrons, with each Squadron operating 9 missiles, at: Forbes Air Force Base, Topeka, Kansas; Offutt AFB, Omaha, Nebraska; Fairchild AFB, Spokane, Washington; and the training facility at Vandenberg AFB, California. All 36 Atlas E missiles operated by the four Squadrons would employ semi-hard coffins whereby the projectile was housed in the horizontal position, protected from lateral blast by partially burying the erector/missile assembly in concrete walls level with the surrounding ground. Atlas F was to be employed in vertical silos, or hard sites, that would afford considerable protection while the missile was in storage, but render it liable to destruction in the closing minutes before launch.

Convair had worked long and hard to come up with a means by which the Atlas could be fired from the bottom of the silo, but studies proved that this was impossible. The only conceivable compromise for this type of missile was the silo-lift concept. In this approach, the missile was contained within a silo 53 metres deep and nearly 16 metres in diameter. It would rest on a shock absorbing cradle and be surrounded by a gantry secured to the walls of the silo so that engineers and technicians could gain access to any desired level up the full length of the missile. At its base, the cradle was supported by a flame deflector bucket and a crib assembly which was itself secured by hydraulic rams that could lift the entire assembly, missile included, to the surface of the silo for launch. In this way the damaging effect of the rocket's hot exhaust products would escape from the flame bucket out across the top of the silo. Massive concrete doors pivoted open to allow the missile to emerge from its subterranean cavern. This was the time when the Atlas would be most vulnerable to attack, but it was the best compromise between the open and exposed soft site facility and the impossible concept of an in-silo launch.

The 6 squadrons set up to operate Atlas F in its hard emplacements, with each squadron operating 12 missiles, were to be located at: Altus AFB, Altus, Oklahoma; Dyess AFB, Abilene, Texas; Lincoln AFB, Lincoln, Nebraska; Plattsburg AFB, Plattsburg, New York; Scilling AFB, Salina, Kansas; and Walker AFB, Roswell, New Mexico. This then, was the fully operational complement of the 72 Atlas F models in silos and the 57 Atlas D and E models in soft and semi-hard launch facilities. It will be noted that there is a discrepancy between the number of missiles in soft and semi-hard emplacements at Warren AFB quoted here and the figure used earlier in this chapter. It had been planned to install 24 missiles, but three pads were never used. Consequently, Warren AFB had 21 operational missiles and the four Atlas E squadrons employed 9 missiles apiece to result in the grand total of 57 for D and E versions.

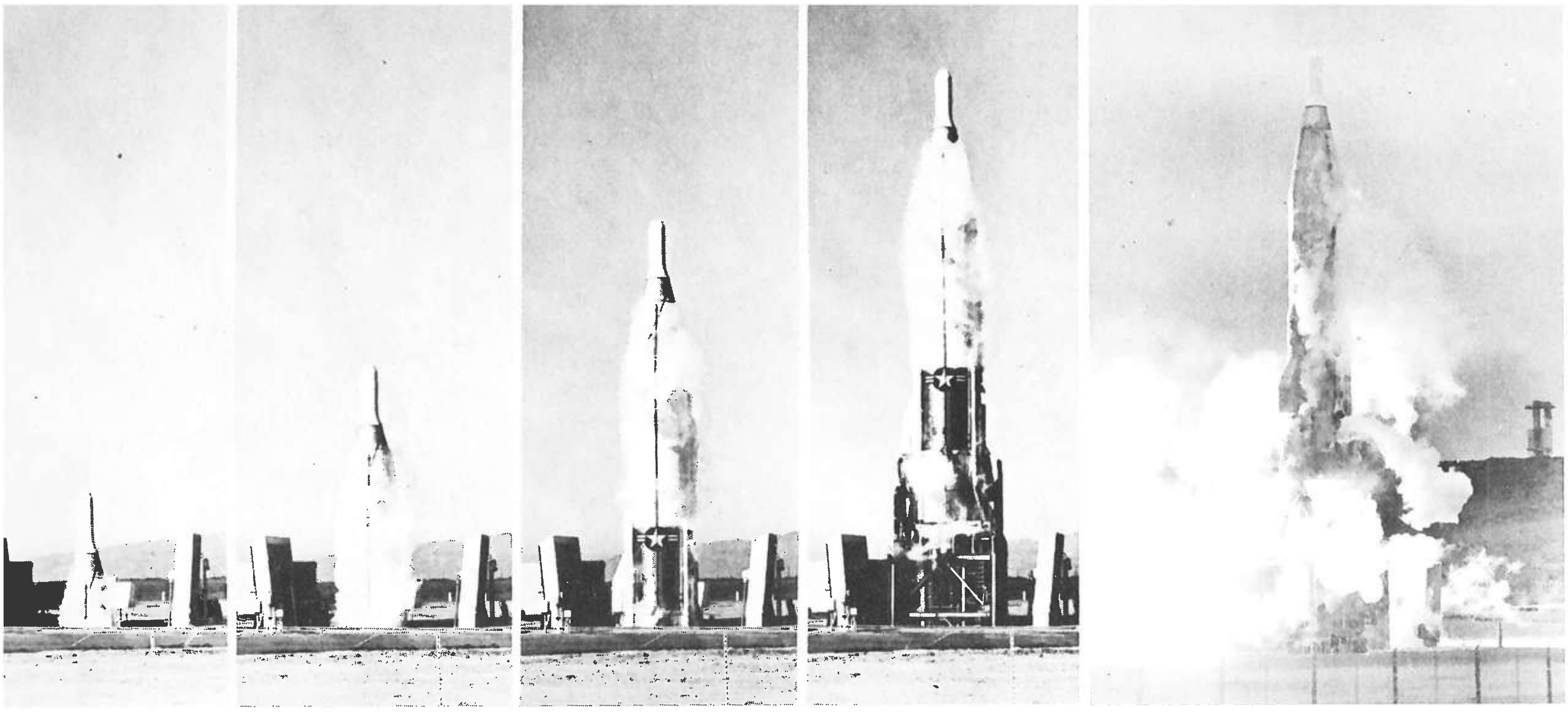
Concurrent with the planned deployment of 129 Atlas missiles, Strategic Air Command drew up plans for Titan activation at 5 locations. The Titan 1 model would adopt a similar storage and launch concept to that used for Atlas F in hardened silos. The design and construction task was very different, however. Instead of installing a set of individual silos, site engineers for Titan 1 would prepare an elaborate complex supporting three missiles in vertical silos. The complex would provide living accommodation for 200 personnel and be required to environmentally isolate the troglodytic workers long after the air and surrounding land became uninhabitable through radiation and blast destruction. The entire structure of domicile buildings, silos, support facilities and launch centre would be buried underground, with interconnecting tunnels affording access to the various elements.


Test models of the Titan 2 were launched from surface pads, as seen in this view of the massive ICBM ascending.

At each Titan 1 complex, some 700,000 cubic metres of earth was to be removed and the space filled with 96,000 cubic metres of concrete, 22,000 tonnes of steel and storage vessels for 227,000 litres of water. Power generating facilities for a continuous supply of 4,000 kw of electricity were to be installed along with liquid oxygen storage vessels, fuel storage tanks, nitrogen tanks, diesel reservoirs and air filtration facilities. Tunnels would link the various sections of the underground facility and provide opportunity to service the air filtration facility, the powerhouses, the chemical waste clarifier and the sewage unit. Each silo was designed to the same general principles as those employed in the construction of the silos for Atlas F: the Titan 1 missile would rest on a cradle and be elevated to the surface just before launch. Two enormous doors made from compacted concrete, each weighing 18 tonnes, protected the missile from pressures up to 7 kg/cm^2, thus affording protection from a nuclear blast comparatively close to the silo.

To quote from a publicity handout prepared by the Martin Company, contractors on the Titan missile programme: 'The Titan, in its underground fortress, can be lifted to the surface and fired during the few minutes after any enemy missile has been launched and before it strikes. Or if there is no warning, the Titan hard base can withstand a near miss of a nuclear bomb. Even though the surface of the land is seared, the giants in the earth still could deliver their answering megatonnes of death.'

The Titan 1 deployment sites were located at: Beale Air Force Base, Marysville, California; Lowry AFB, Denver, Colorado; Larson AFB, Moses Lake, Washington; Ellsworth AFB, Rapid City, South Dakota; and Mountain Home AFB, Idaho. One strategic Missile Squadron was set up at each of these five primary locations, except for Lowry AFB which had two.



In this series of five photographs, an Atlas F is seen demonstrating the silo-launch mode whereby the missile is stored in a vertical silo underground and raised to the surface in a crib assembly. Note the vertical concrete doors in the open position which would afford protection for the missile during storage in the silo.

Each Squadron had authority over 9 missiles in three triple complexes of the type described above. In all, the six squadrons commanded 54 Titan 1 ICBM's. Titan 2, designed from the outset to use the in-silo launch technique, had greater potential than its predecessor. With improved performance from both first and second stage engines and an increased volume for second stage propellants, the missile was capable of sending a 20MT warhead across a distance of 15,000 km. This equivalent explosive yield was 1,000 times that of the Hiroshima bomb and the Titan 2 ICBM would be the most powerful strategic weapon ever brought to operational status by the United States.

Installed in triple-silo complexes, not unlike those designed for Titan 1, it could be launched within a reaction time of just one minute. The storable propellants were hypergolic and as such dispensed with the complex ignition systems employed by other liquid propellant missiles. Small wonder then that the Strategic Air Command was keen to move towards operational deployment of this mighty Titan – named, appropriately, for class as well as deed. Considerable research had been conducted by Aerojet-General, makers of the two engines in the first stage and the single engine in the second, on the method to be employed in igniting the missile from the bottom of its silo. The problems were daunting. Not only would the missile have to survive its fiery ascent past the lined walls of the silo, but it would also have to endure the thundering shock waves generated by acoustic reflection. The vibration levels would be enormous as the missile, generating a thrust of 195 tonnes, rose more than 40 metres between its base and the lip of the silo. In tests to more fully define the thermal and acoustic environment, experiments were made using small scale models ignited at varying levels of a mock silo tube.

Much of the preparatory work was undertaken by Space Technology Laboratories and various materials and shock-absorbing compounds were developed in the search for a satisfactory design. In its definitive form, the silo provided a flame deflector at the bottom so that exhaust products from the Titan's powerful engines would be deflected either side of the area immediately below the engines. From here the flame and smoke would be channelled upwards through two ducts, one each side of the silo, and released to the atmosphere either side at the top. With the base of the silo more than 44 metres underground, the sudden release of the fiery inferno would be a spectacular prelude to the slowly ascending missile moving up past the silo doors. A major re-design was authorized on the doors themselves, when it became apparent that the hinged covers used for Atlas F and Titan 1 silos would be less able to withstand a nuclear explosion, than doors constructed to slide sideways across the top of the silo. Additional protection would be provided by horizontal movement, so that at no time in the operation, would the doors present a perpendicular surface to the shock waves of a Hydrogen Bomb.

Despite efforts to maintain the letter and the intent of 'concurrency', Titan development fell behind preparation of the first hot-launch silo and it was necessary to use a Titan 1 for demonstration tests. As would be expected, the first silos were emplaced at the Vandenberg Air Force Base training facility and on 24 April 1961, a Titan 1 was fired, for a run at full power, from the bottom of one of these. Restrained by secure clamps, it was the first missile operated from a subterranean hiding place. On 2 May, the same Titan 1 was used to demonstrate a complete sequence of ignition, launch and ascent. With a dummy second stage the missile was expected to fly for little more than two minutes, reaching a height of 76 km and a down-range distance of 85 km, at which time the Navy would send a signal to activate the destruct mechanism. All operations were carried out as expected and the test was a complete success, proving for all to see that a large liquid propellant missile could be fired from the bottom of a suitably configured silo.

It would be two years before the first Titan 2 unit was operational, but plans envisaged formation of 6 Strategic Missile Squadrons with two at each of the following three locations: Davis Monthan Air Force Base, Tucson, Arizona; McConnell AFB, Wichita, Kansas; and Little Rock AFB, Little Rock, Arkansas. Each Squadron would support three complexes of three launch silos for a total Base complement of 18 Titan 2 missiles. An additional complex was planned for installation at Griffiss Air Force Base, New York, but this was eventually cancelled. Meanwhile, the flight tests of Titan 1 continued and on 23 September 1961, Vandenberg AFB successfully achieved the first launch from the top of a silo lift, characteristic of the type of facility the missile would be called upon to operate from.

The first Titan 2 launch was conducted on 6 March 1962, following static firing tests at the end of 1961, and the missile successfully flew 9,000 km from its Cape Canaveral launch pad. Early development flights were made from conventional concrete launch pads. The last Titan 1 development flight was performed on 29 January 1962, followed by qualification of the Titan 2 on 9 April. In a series of 33 attempted launches, Titan 2 had been successful on 73%. By this time Titan 1 was going operational at its 5 designated locations, but not until June 1963 was the first of 3 Titan 2 sites declared ready for active use. By the end of that year all 108 Titans were in their silos and ready to go; Weapon System 107A-2 was fully operational. But while the strategic Air Command was justifiably proud of its fleet of 129 Atlas and 108 Titan missiles, Air Force chiefs were divided on their opinions relating to the level of effectiveness that such an ICBM force could wield.

In a future thermonuclear war the very presence of these mighty monoliths would be a reassuring boost for morale and operational flexibility alike. But the central problem remained: how much emphasis to place on the automated ICBM and how much attention to give to a manned bomber force. By the early 1960's Strategic Air Command had a formidable inventory of heavy bombers – production of the giant B-52 alone totalled more than 700 aircraft – and this arm of the United States Air Force was generally considered to be the most flexible force for deterrence. Proponents of a strong manned bomber force pointed to the 'recall' capability, whereby a weapon system can be called back before delivering its lethal load, as insurance against spontaneous escalation. It would take several hours to reach the strategic targets in Russia or Warsaw Pact countries and during that time diplomatic discussions would have an opportunity to get under way and avert unrestrained retaliation. With a capacity for carrying a nuclear weapon load exceeding that of even the Titan 2 ICBM, the B-52 fleet had a built-in temporal interlude and this, it was argued, ensured that a major war would only start if all other alternatives were eliminated. Also, with men at the controls all the way to the target, the bombers would exercise a degree of selectivity denied to the pre-programmed ICBM's.

The big Atlas and Titan missiles were regarded as last-ditch strike elements, without recall capability beyond the first few minutes after launch (up to which time they could be ordered to blow themselves up), with multi-megatonne warheads that left little room for a flexible war scenario. If hostilities reached the point where the use of Atlas and Titan were essential for national survival, the conflict would move to a global posture with irrevocable consequences. As early as 1954, when strategic missiles were a whim of industrial think-tanks, General Curtiss LeMay, head of Strategic Air Command, urged the Department of Defence to draw up plans embracing a manned bomber to replace the B-52. This eight-engined aeroplane was still a year away from entering service, but LeMay wanted insurance against the day that Soviet development of a long-range bomber fleet challenged the dominant posture of the United States. As a result of this, the Air Research and Development Command issued two specifications: WS-110A and WS-125; the former for a 11,000 km range jet-powered bomber, the latter for a nuclear-powered manned delivery system.

WS-110A would be expected to cruise close to the speed of sound, en route to hostile territory, go supersonic, and dash up to 1,800 km to its target at the highest speed possible. Competitive tussles followed as leading aircraft manufacturers sought ways of matching the ambitious specification. Finally, in December 1957, North American Aviation got the contract to build WS-110A as the B-70. It would be designed for flight at three times the speed of sound during a supersonic dash across enemy air space. In December 1959, the project was dramatically reduced in budget cuts that almost condemned the B-70. For the previous five years, ever since the Strategic Missiles Evaluation Committee decided that an ICBM fleet was both feasible and desirable, the tussle between the manned bomber and automated missile had gathered momentum, until the boiling furore broke into hostile argument.

By early 1961, John F. Kennedy, now President of the United States, had formulated his policy and decided to step up development of the strategic missile force. Secretary of Defence, Robert McNamara, had little argument with this approach although Congress disagreed and injected additional money into the B-70 programme. In the light of a new strategy being forged in the White House, emphasis would go on missile strength to the detriment of the manned bomber. But there was still the strategic niche into which neither manned bomber nor strategic ICBM would fit: what to do if Soviet initiatives deemed it necessary to inflict a limited counter-strike? Before answering that it was necessary to assess the potential war scenario.

Russian ambitions were clearly linked to the emerging strength of Warsaw Pact countries and it was felt more likely that the Soviet armed forces would move into central and western Europe before launching an all-out assault on the United States. Because of this interpretation the Eisenhower administration had boosted funds for large numbers of small tactical battlefield missiles that could be deployed in European NATO countries. With the threat of a large number of such missiles before them, the Soviets, reasoned Einsenhower, would be deterred from initiating a pre-emptive strike. If they ignored the consequencies of a pre-emptive strike, the Russians would face retaliatory action from the more than 200 Atlas and Titan ICBM's based on the continental United States and the several hundred Polaris missiles at sea. The daunting question arising from the need to match a measured initiative, with a reciprocal assault, led to the concept of measured force retaliation.

With very large numbers of inexpensive and reliable ICBM's, the retaliatory strike could be shaped to the magnitude of the Soviet initiative. Consequently, Atlas and Titan would be the precursor force leading to a second generation weapon that could be produced in large numbers for structuring a reciprocal attack based upon the size and magnitude of the pre-emptive strike. With several hundred land-based ICBM's in hardened silos, the Russian people would be faced with casualty levels far beyond the tolerable limit for an organized society. So went the reasoning of the Kennedy administration. With a few, very large missiles, the United States could rapidly find itself involved in total war. With a massive ICBM fleet composed of somewhat smaller missiles, the United States would be in a position to hit several hundred targets simultaneously. The balance of deterrence required the Soviet Union to recognize that a pre-emptive strike would bring catastrophic results, and this was the basis of the American argument; all-out war was impossible to survive and even more impossible, to win. If, however, a limited war broke out in Europe, presumably according to the American view because of Soviet incursions across the German frontier, there would be time to negotiate a peace. At most, the Russians would receive a warning of the ultimate consequence with a partial bombardment from a few of the many ICBMs based in the United States. Nowhere, in the White House, could the administration conceive of a situation where the Soviet Union would push forward to the point where all-out strike was necessary.

That belief, in the futility of global nuclear conflict at the ultimate level, dominated American strategy, but there is no reason to think that the Russians held the same view. It was an argument based entirely on presumptive conclusions about Soviet military intentions. Nevertheless, in the light of a dedicated commitment to development of the second generation ICBM, the B-70 was eventually reduced to a research and development status. Fifteen years later, a similar decision – bombers or missiles – would have to be made by another President fresh to the Executive Office. The second generation missile in question was called Minuteman. It was a radical departure from the Atlas and Titan land-based ICBM's and would bring a new and unheralded sophistication to the science of strategic conflict.

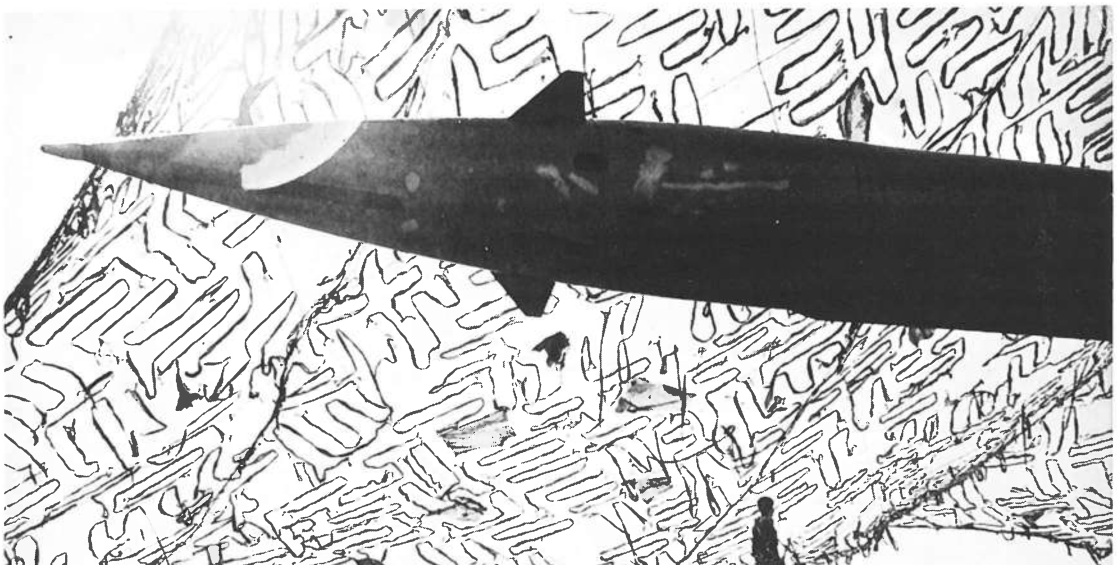
An Honest John surface-to-surface battlefield missile thunders away from its launcher during joint US Army and Air Force exercises in May 1963.

The first positive steps leading to development, began in September 1957 when Colonel Edward N. Hall wrote the specification for Minuteman as a functional part of the new ICBM concept: Weapon System 133A. Unlike Atlas and Titan, Minuteman would use a solid propellant motor in each of three sequential stages to provide an efficient and storable missile, ever ready to depart on its calculated mission. Atlas and Titan 1 used liquid oxygen as the oxidizer and this had to be fed to the propellant tanks of respective vehicles after a launch alert, necessitating a 15 min lag between the order to fire and engine ignition; Titan 2, with its storable liquid propellants, was fuelled up in constant readiness and could respond within 60 seconds of a launch order. Minuteman had none of the complex equipment and support facilities demanded by a liquid propellant rocket and could be launched within 31 seconds of an order to fire. Moreover, the simplicity of a solid propellant design dramatically reduced the number of personnel required to support a Minuteman complex and this ensured a minimum work force with the consequent increase in operating efficiency. Skilled engineers and technicians would be employed in further and continued refinements of the Minuteman design, but the launch crew were required to perform a standby role; Atlas and Titan employed a large work force at all times.

Another advantage of the solid propellant, silo-launched, Minuteman arose from the reduced cost brought about as a result of the simpler design. Large numbers could be deployed in several hundred launch tubes like artillery rounds residing in the breech of a field gun. Although each missile would carry a smaller warhead than that employed by either Atlas or Titan, its cost, at only one-fifth the price of the big liquid propellant ICBM's provided a much greater number for a given financial committment in the defence budget. Also, it offered the opportunity of saturation bombing which would confuse Soviet early warning systems and ensure the destruction of a greater number of targets.

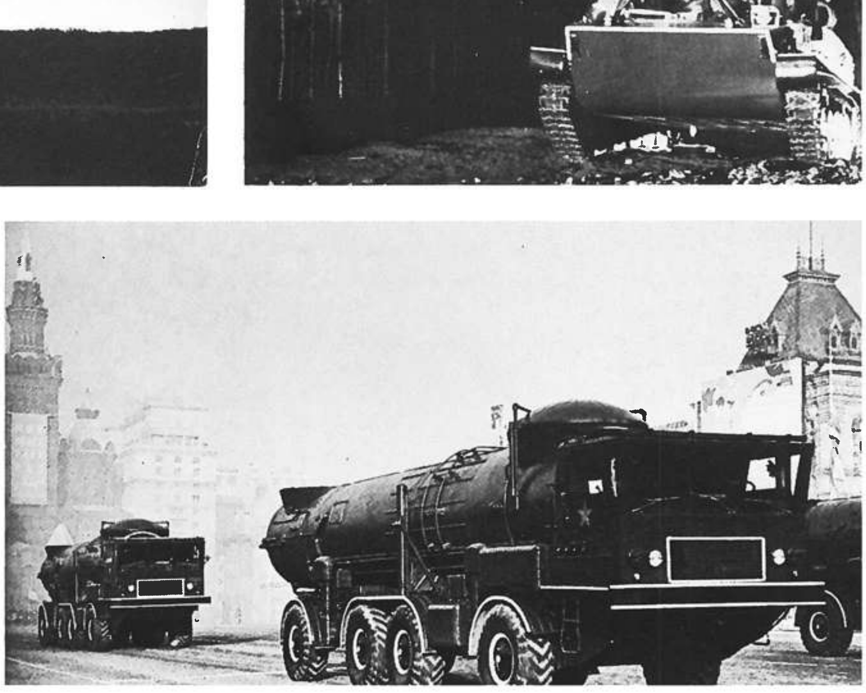
Most of the early work on defining Weapon System 133A was conducted at a small facility, established at Inglewood, by the Air Force Ballistic Missile Division. By the end of 1957, the initial task force had convinced the Pentagon that the system would work and should be implemented with all haste. The Ballistic Missile Division went back and prepared its plans and submitted these to the Air Force on 15 February 1958. Final approval was granted just thirteen days later. The Air Force was back in business with development of the second generation ICBM that, with the large numbers envisaged, would keep it in the forefront of missile production for a decade and more. It was for them, a particularly pleasing prospect. With the Navy moving ahead on the Polaris programme, a certain degree of friction had been generated; the Air Force felt that strategic deterrence was its preserve alone and chafed at having to share this responsibility. Now, at last, there was a secure niche for sustained ICBM development.

During the first half of 1958, the Air Force invited bids from prospective contractors on the Minuteman system. The full design configuration had yet to be decided, but industry would have to be in on the early development phase so that consideration could be given to fabrication and production needs. There were certainly many problems confronting the engineers. Solid propellant rockets had decided advantages for a ballistic missile system, but as yet no one had considered their use for an ICBM of Minuteman size and weight. Technology development for the two-stage Polaris was only just getting under way and Minuteman would be a three-stage weapon, twice the length and double the weight of the Navy missile. The new silo-based ICBM would be the largest solid propellant vehicle yet built and possess more than four times the range of Polaris. It would be difficult enough to pioneer new applications for solid propellants, but the attendant problems brought by the definitive nature of the Minuteman



Soviet surface-to-air missiles stood guard on the Russian frontiers from the early 1960's. Note the camouflage net and how the photographic angle grossly distorts the size of the missile.

Short-range mainstay of Soviet assault troops, a Frog missile is seen caught in searchlights during exercises in a wooded area typical of an operational scenario.



Soviet missile support systems on parade.

mission, compromised smooth and accessible termination of the early design problems.

One major area of concern centred on the fabrication of large diameter rocket cases. Tests and experimental activity had revealed serious deficiencies with existing technology, although much of the work conducted at the Jet Propulsion Laboratory had direct bearing on the issue. The successful fabrication of a solid propellant charge housed in a lined case was no mean task for propulsion engineers and the sheer size of the missile, made the assignment more difficult. Also, there was contention over the preferable method to be employed in flight control: vanes placed in the exhaust efflux, gimballed nozzles that would re-align the thrust vector, or fluid injection to create shock waves and move the plume within a fixed nozzle (see Chapter Nine). By the end of 1958, the primary contractors had been selected and Boeing received authorization to perform the final assembly and test phases of Minuteman production. Over the next two years, Thiokol would be brought in to manufacture the first stage, Aerojet-General would produce the second stage and the Hercules Powder Company would build the third stage. Flight control of the missile would be delegated to the Autonetics Division of North American Aviation.

No sooner had the programme been officially approved, than the Air Force began serious moves to improve not only the status of the project, but its size as well. The Commander in Chief of Strategic Air Command, General T. S. Power, was particularly vocal about the pressing requirements of the prime deterrent in the coming decade. All this would be picked up later by the new President, John F. Kennedy, when he came to the White House early in 1961. However, technical development of the Minuteman moved ahead rapidly and the Thiokol Chemical Corporation performed tests with a solid propellant precursor to the definitive first-stage design on 13 April 1959. Exactly one month later, Aerojet-General had tested a development version of the second stage and by the end of May, the Hercules Powder Company had demonstrated satisfactory combustion with several preliminary third stage units.

Definition of the basic design details was emerging with a clarity unseen in earlier missile programmes and this was not entirely due to the simplistic nature of the concept, but rather to the enhanced development procedures pioneered by Thor, Jupiter, Atlas and Titan. Learning from the inherent mistakes of previous years, missile activity was acquiring a new sophistication and several lengthy and inefficient management techniques had been replaced by new operating modes that promised to accelerate the period between conception and fabrication. On 15 September 1959, the first in a series of five development tests was performed from a special silo at the Edwards Air Force Base in California. In these, the first stage contained sufficient propellant for launch from the vertical tube, but second and third stages were dummy configurations, as was the nose cone.

The test missiles were designed to qualify the basic design of the silo and to prove that a solid propellant vehicle could be launched from the bottom of the facility. Like Titan 2, which was itself designed to be flown from the bottom of a silo, Minuteman would remain hidden until the moment of ignition. This concept was known as the hot-launch technique and required the space between the missile case and the silo wall to be sufficient for escape of exhaust products and flame out the top of the silo. Titan 2, of course, had channeled ducts facilitating release of the heated products but the Minuteman would rise from a silo bathed in the searing flame of its own exhaust. Because of this, the silo could be much simpler than those designed for Titan 2 and the large number of Minuteman missiles planned for deployment made this a desirable feature of the programme. If costly Titan 2 silos had been deemed necessary, the project would have carried a serious cost penalty detracting from the economic viability of the concept. Moreover, because the missile itself was so much simpler to build and, once fabricated, could be stored with very little servicing requirements, it would lend itself to a more fruitful application than the big liquid propellant missiles of Atlas and Titan class.

The concept of a silo-launched ICBM was certainly a considerable step beyond the operational limitations imposed by soft and semi-hard emplacements, but Strategic Air Command also wanted a measure of concealment beyond that provided by fixed launch sites. While Minuteman, and Titan 2 for that matter, would be protected from all but a direct hit, the precise location of individual silos would be well known to a potentially hostile country. In future developments the Soviet Union could assign large numbers of missiles to the physical destruction of each silo and reduce the magnitude of the deterrent by disabling Minuteman rounds before they could be launched. SAC wanted a more flexible operating scenario where it would be impossible for incoming ICBM warheads to know the exact location of the retaliatory strike force. In the overall strategic arsenal, the Navy could provide an effectively concealed launch position; with Polaris missiles carried in nuclear powered submarines the Soviet Union would be unable to monitor the movements of the mobile launch stations. On land, the large ICBM force would be difficult to hide, but a mobile ICBM could so confuse an enemy that it would be unable to keep track of daily dispositions.

For this reason, Strategic Air Command developed a plan whereby Minuteman would be fired from specially prepared trains, using existing lines laid down as a part of the more than 400,000 km of track across the continental United States. Operational deployment of about 450 silo-based missiles would be supplemented by five squadrons, operating 10 Minuteman trains each. Each train would include between three and five missile launch cars, a launch control car, a power car to generate and distribute electrical energy, a single environmental car for missile environmental control and several personnel cars for transporting the launch crew and a limited number of service engineers.

Each launch car would contain a single Minuteman missile stored horizontally on an erector assembly. When the time came to launch the missile, the train would be brought to a halt and the roof of the launch car would open so that the ICBM could be rotated through 90° to a vertical position. Because the missile would be required to know exactly where it was in relation to the designated target, the geographical location of the launch position would have to be surveyed and fed into the Minuteman guidance system. This could be

Minuteman was developed as a simple and reliable ICBM which could be stored for long periods in underground silos before launch.

speeded up by designating assigned areas surveyed in advance although in times of emergency, when the train could not reach the appointed place, missiles could be fired from other areas with only a slightly reduced operating accuracy. The main advantage would remain: Soviet intelligence would be unable to follow the daily movements of the Minuteman trains and only a few privileged military officials would know the assigned launch areas in advance of a call to fire. Moreover, Minuteman trains could hide in tunnels and receive a measure of protection from nuclear warheads falling on open land areas until it became expedient for them to pull out of the tunnel and fire their missiles.

In the plan formulated during the early technical development of Minuteman, Strategic Air Command would deploy about 75% of its second generation ICBM force in fixed-base silos, with the balance going into mobile units on fixed track. By the end of 1961, however, the costs and resources necessary to implement the train-mounted concept were deemed too high for the advantages that would accrue and the idea was dropped in favour of a full silo-based deployment. Little more than a decade later the concept of a mobile ICBM force would re-emerge with more assured validity.

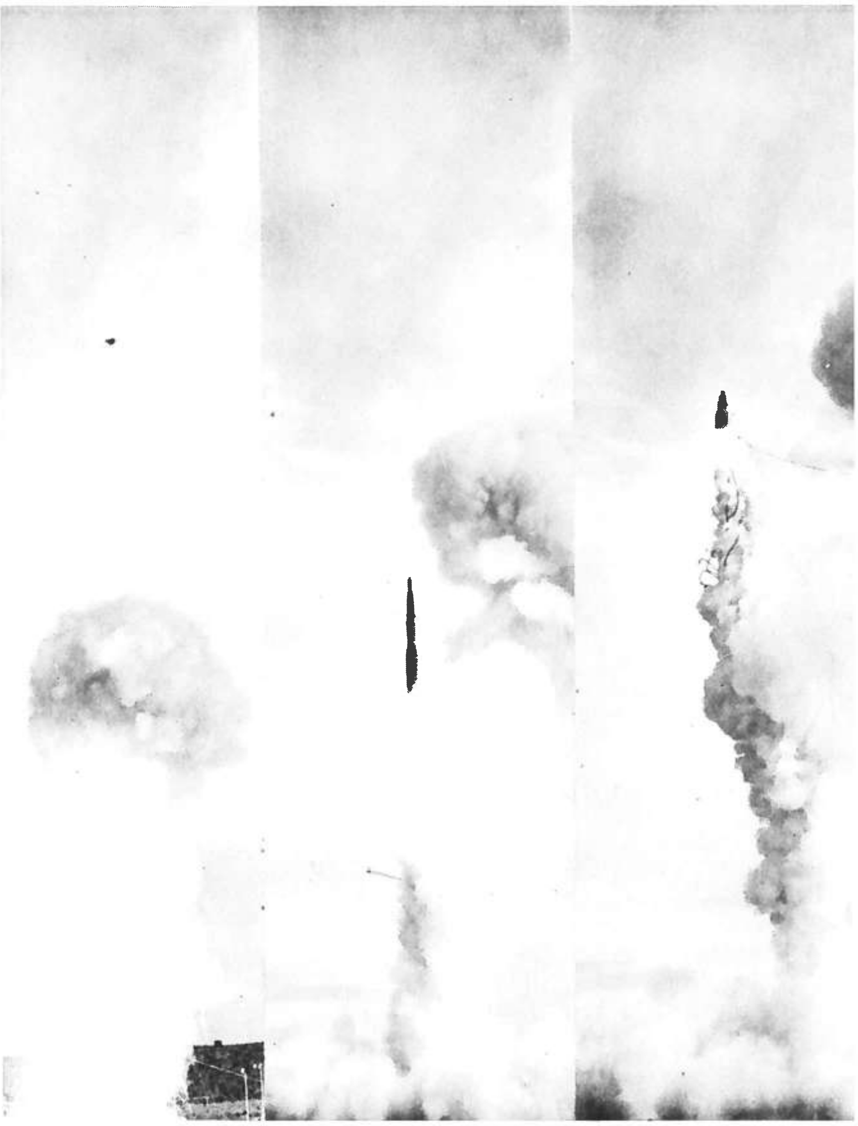
Following the five silo test flights of a mock Minuteman configuration from Edwards Air Force Base, between September 1959 and February 1960, the first prototype missile was fired from the same facility on 4 March. It carried only a live first stage and was tethered by a nylon cable 610 metres long so that when the missile flew away from its underground launch tube it was restrained from falling on surface buildings; the first stage carried sufficient propellant for a limited ascent only and the stage burned out before it reached the full height afforded by the cable. But even at this stage, consideration was being given to the inherent flexibility of the design and plans emerged for smaller and larger versions of the basic missile. The original specification for Minuteman had stipulated a design range goal of 10,200 km; a smaller version called Midgetman was conceived, with a range of 1,850 km and a much larger version, Mightyman, was proposed with a potential range of 22,200 km. Like the train-launched concept, these too went the way of other adaptations and were never funded.

During 1960 plans were laid down for silo deployment and it was agreed that the 394th Strategic Missile Squadron would be employed for Minuteman training at the Vandenberg Air Force Base and that the first operational site would be located at Malmstrom Air Force Base, near the town of Great Falls in Montana. But Malmstrom, originally a refuelling field for Strategic Air Command, would be only the field headquarters for the 341st Missile Wing and its 150 silos. Stretched out over 12% of the entire land area governed by the state of Montana, this Missile Wing would have authority over dispersed silo emplacements located in rolling hills and rich farm land, unlike the clustered approach adopted for Atlas and Titan emplacement. The Missile Wing would be broken down into three squadrons and each squadron would have five flights of 10 missiles. A single launch control facility would administer the 10 silos under its command, compared with a maximum three silos for each buried Titan 2 complex. Simplicity was the keynote of Minuteman and this enabled fewer people to control more than three times the number of silo positions. From Malmstrom AFB, 8 km due east of Great Falls, silos stretched 195 km along the southern edge of the Missouri river, fanning south toward Roundup and White Sulphur Springs. In the other direction, past the town of Great Falls, other silos stretched nearly 100 km due west for a total spread of more than 290 km. This was deployment on a grand scale. By the end of 1960 it was expected that Strategic Air Command would operate three missile wings, each with about 150 silos, but this number would be more than doubled under the improvements authorized by the Kennedy administration.

During September 1960, General Thomas D. White, US Air Force Chief of Staff, unveiled Minuteman at the Air Force Association Convention in San Francisco and publicly displayed the 18 metre long missile for the first time. It was an impressive addition to an already expanding strike capability; one element of the triad comprising land-based missiles, submarine-launched missiles and manned bombers that would go into action only on orders from the White House. To speed development of Minuteman and move through the essential stages of flight test and systems qualification, management decided on a bold strategy for sequencing the various elements of the programme. Whereas previous work on earlier missile programmes had required each stage of the definitive product to be tested separately, it was decided quite early in the Minuteman programme that all three stages would be fired live from the very first launch attempt.

It is interesting to recall that Atlas was tested first without the central sustainer engine and that the first Titan flights were conducted with only the first stage live. Atlas and Titan moved ponderously through satisfactory flight trials with individual stages, until the full system could be flown as a complete assembly. Not so with Minuteman. The entire three-stage configuration would be set up for flight from the beginning of launch tests. A key figure in this 'all-up systems testing' philosophy was George E. Meuller and, at Meuller's instigation, the concept was applied to the NASA Saturn programme from 1964 onward. Saturn V, specially developed for boosting Apollo to a lunar trajectory, was flown from the first flight with all three stages live and operating and the success of this civilian launcher owed much to the all-up approach pioneered in the early stages of the Minuteman programme. It was a strategy for launch vehicle qualification that would remain a key feature of later civilian and military launcher development programmes.

Consequently, in direct conformation with this philosophy, the first flight-rated Minuteman missile was assembled at Cape Canaveral for its maiden flight on 1 February 1961. In little more than three years the second generation ICBM had been designed and developed to the launch pad for active trials leading to operational deployment. Concurrency, whereby the various elements of the missile, ground support equipment and silos were developed at the same time, had been acquired from the Atlas and Titan programmes. All-up testing was a further refinement in compressing the interval between conception and delivery. The first flight went exceptionally well in 'the most successful (flight) ever accom-



plished in United States missile history', according to the Boeing Company. Leaping away from its surface launch pad, the Minuteman streaked a distance of 8,500 km, fired all three stages in turn and separated its Avco Mk. 5 warhead as planned. The design goal of 10,200 km would not be met until later Minuteman developments brought refinements to the technology employed.

Nevertheless, LGM-30A Minuteman 1, was seen to be a successful product from the radical design criteria set up for Weapon System 133A. The first stage was the largest solid propellant propulsion unit built at that time and used a mixture of polybutadiene acrylic acid with an ammonium perchlorate additive as the oxidizer. A small quantity of an aluminium compound was provided to smooth the combustion process. The manufacturing process began with preparation of the outer case formed from double vacuum-melted steel, followed by placement of a coated liner to separate the propellant from the walls of the outer case. The propellant itself was then fed into the lined case under pressure and in the fluid state. A six-point, star-shaped mandril ensured a combustion profile that would consume propellant from the inside out towards the case liner, along the full length of the stage. The extreme rear end of the motor was capped by a hemispherical enclosure to which was attached four nozzles designed to pivot in pairs for a gimbal motion that would be employed to steer the rocket. Each nozzle had a potential motion of ±8° from the centre-line. An igniter was situated at the forward end and the entire first stage was nearly 7.4 metres in length, with a diameter of 165 cm and a launch weight of about 20.8 tonnes.

The second stage motor was manufactured by Aerojet-General, contractors on the Polaris programme, and employed the same polyurethane and perchlorate propellant combination, with an aluminium additive. Minuteman's second stage was 3.2 metres long 112 cm in diameter and adopted a four-point, star-shaped cross section for stable combustion. Four exit nozzles were fitted to the rear end, each one with a gimbal capability of ±6°. The third stage was 2.3 metres long, 94 cm in diameter and adopted a propellant configuration comprising nitrocellulose, nitroglycerine, ammonium perchlorate, triacetin, nitrodiphenylamine and aluminium. The four exhaust nozzles had a gimbal capability through ±4°. The guidance system employed for Minuteman was the most advanced of any ICBM electronic unit up to that time and carried a limited capability for autonomous check-out, coupled with a built-in power supply from batteries and an auxiliary power unit using solid propellant charge. Flight control was inertially based and once the missile left the silo it was fully automated. The Avco Corporation was responsible for the warhead and the Mk. 5 re-entry vehicle. Final assembly was carried out by Boeing at a special facility set up at Hill Air Force Base, Ogden, Utah, at US Air Force Plant 77.

After a successful first flight, the programme moved rapidly ahead. A second version of Minuteman 1, the LGM-30B, was developed for silo emplacement at sites other than the initial inventory of 150 missiles at Malmstrom and this had a range of 9,260 km. Several modifications were introduced, including a longer guidance and navigation section, a more advanced Avco Mk. 11 warhead, and a change from steel to titanium for the second case. The LGM-130B moved closer toward the definitive expectations of the original specification, but this too would be replaced by more advanced models during the 1960's. Meanwhile, the second flight of an LGM-130A was performed on 19 May 1961, but the missile had to be destroyed after second stage ignition, due to a failure in the guidance system. The third flight, another success to parallel the first, came off on schedule on 27 July 1961, from Cape Canaveral.

Air Force development facilities at Cape Canaveral included two surface pads and two silos and the first attempt at launching a live missile from its underground tube brought disastrous consequences. The flight, fourth in a series of development trials, was performed on 30 August 1961, but shortly after leaving its silo, the missile blew up in mid-air and totally destroyed itself. Success was coming in fits and starts. The fifth test launch, again from a silo at Cape Canaveral, got off on time and as expected on 17 November, followed on 18 December 1961 by another successful flight. A major milestone in the Minuteman programme was passed on 12 April 1962, when Boeing completed the first production version at its Hill AFB facility. In addition to the training facility at Vandenberg Air Force Base, Minuteman dispersal would follow the lines adopted for Malmstrom AFB with

Construction workers prepare the underground control facility for a flight of ten Minuteman missiles at Warren Air Force Base. The flat sided vertical structure at back is the lift shaft affording access from the surface. At completion, the facility will be filled in to ground level.

This sequence of photographs shows a Minuteman development model during tests of the in-silo launch method. The missile was limited to first stage burn lasting only a few seconds and steel hawsers restrain the upward ascent, causing the vehicle to fall back to earth.

other wing sites at Ellsworth AFB. South Dakota, Minot AFB, North Dakota, Whiteman AFB, Missouri and Warren AFB, Wyoming.

The first two flights of Wing 1, at Malmstrom AFB, were declared operational with their 20 missiles on 11 December 1962. As mentioned earlier, minimum strength at any one wing location would be 150 missiles with 3 squadrons operating 5 flights, each with authority over 10 missiles. Each flight had a single control facility from where the 10 missiles would be launched. Unlike the massive complexes built for Atlas and Titan, the Minuteman launch control facility was a separate underground command post linked to its charges by cable; Minuteman missiles would be several miles away from the central control facility. 18–24 metres underground, the Missile Combat crew would spend 12 hours at a time at this level and comprised two launch control officers, two cooks and three policemen; on the surface, small wooden buildings looking more like frontier farm shacks than access points to a missile firing room, covered a vertical lift-housing that would take personnel down to the underground control facility.

At the bottom, a massive concrete door afforded access to a room measuring 6 metres by 3.6 metres. The entire floor section was mounted on shock absorbers to isolate the structure from seismic disturbances brought about as a result of nuclear bursts and two swivel chairs provided spartan comfort for the two launch control officers. The walls of the launch facility were 1½ metres thick and were designed to withstand all but a direct hit. A contingency escape chute, filled with sand until required, provided secondary access to the surface. To fire a missile, each launch control officer had to move through a precise sequence of steps designed both to prevent accidental firing and to ensure that inexperienced personnel would be unable to articulate the essential steps in the sequence. Status lights displayed the condition of each of the 10 missiles administered by the facility and a launch control officer would request additional information on the nature of a suspected fault from the same console. He would then have to decide if the anomaly required engineering attention and call up technicians accordingly. The latter would then drive to the affected silo and conduct necessary adjustments under the supervision of the military police. Each fire control officer carried a pistol at his hip and was expected to shoot and kill unauthorized persons coming through the door, or his colleague, if the latter exhibited insane tendencies.

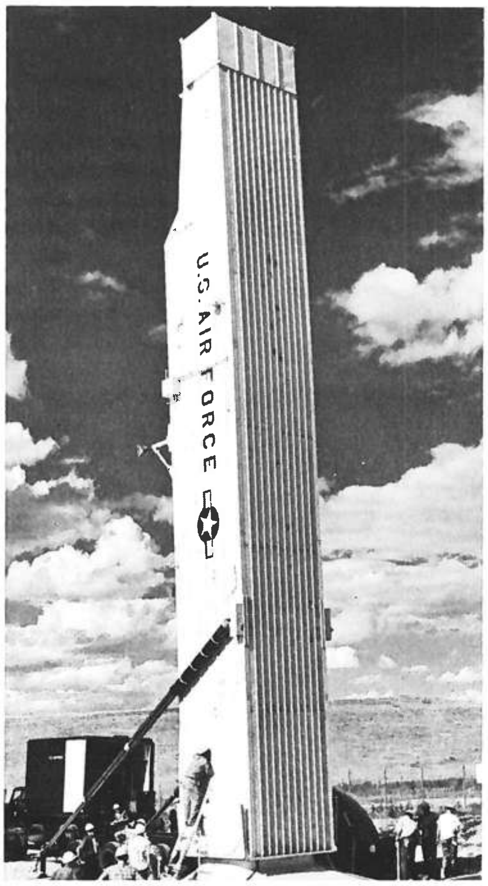
Such was the lot of the two men with a combined responsibility for launching up to 10 missiles. Shifts were arranged for 12 hours on and 24 hours off. Each silo was designed to afford environmental protection, and total isolation, for a single Minuteman missile and took the form of a simple tube sunk into the ground and linked to a facility, also unmanned, 15 metres away, where power equipment was installed. The walls of the silo were formed from a steel liner sunk into the excavated hole with a concrete base on to which was mounted a shock-absorbing ring for missile support. At the top of the silo, a reinforced concrete door, 1.2 metres thick, afforded protection against shock waves of up to 21 kg/cm². It was designed to slide horizontally away from the silo just 12 seconds before launch. Only then was the missile exposed to the potentially hostile environment of incoming warheads. As missiles were built up at the Ogden facility, they were loaded on to a special transporter and then flown to the appropriate base by C-133 transport aircraft. From there they would be moved by road to the designated silo and rotated to a vertical position so that they could be gently lowered into the underground tube.

By July 1963 the first Minuteman wing, with 150 missiles, was operational at Malmstrom, followed in March 1964 by activation of a second wing at Ellsworth. Five months later a third wing was added at Minot. By this time substantial improvements to the basic missile resulted in a re-written specification designated Weapon System 133B and this embraced the LGM-30F (originally LGM-30C). So different was -30F from the earlier A and B models that it was designated Minuteman II and with a range of more than 10,000 km, represented a considerable improvement on the initial capability. The principal difference resulted from a change in the steering control mode employed by the second stage.

Whereas Minuteman I had used four exhaust nozzles designed to swivel for changing the axis of thrust, compared to the centre of mass, the second stage of Minuteman II adopted a fluid injection concept, outlined in Chapter Nine, for booster guidance on the Titan III. By injecting a fluid, which in the case of Minuteman II was freon, a shock wave is created in the exhaust plume causing it to deflect as though the nozzle itself was in the process of being swivelled. By combining the exhaust plumes from the four nozzles of Minuteman I into a single nozzle for the second stage of Minuteman II, the process was simplified. Four freon injection ports located at 90° intervals around the single nozzle would operate in conjunction with the guidance system to respond to directional commands and so keep the missile on its assigned trajectory. Other improvements to Minuteman II led to a higher standard of micro-miniaturization, with substantial reduction in the number of guidance and control elements.

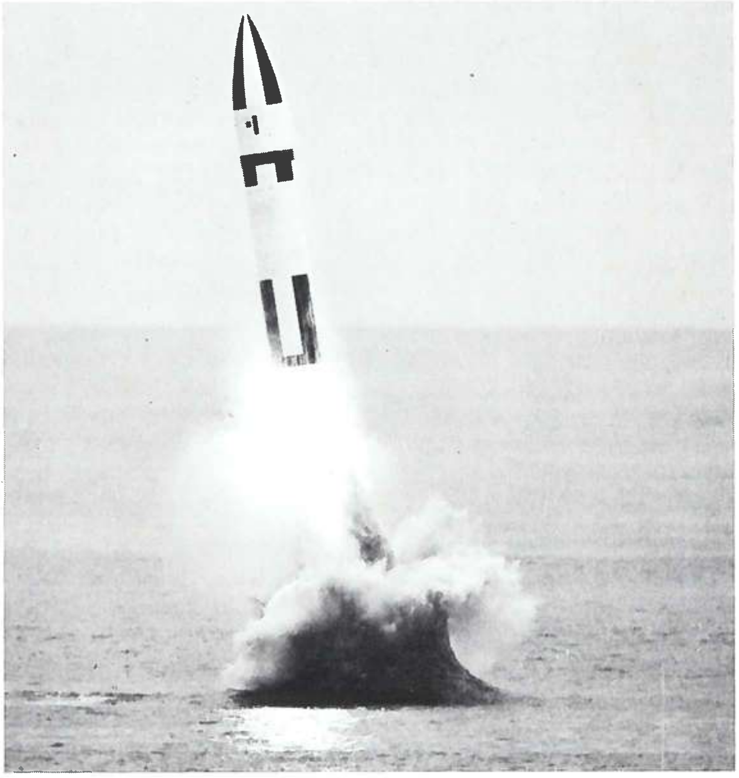
Following establishment of Wings I to III at Malmstrom, Ellsworth and Minot Air Force Bases between July 1963 and August 1964, Wing IV was operational at Whiteman AFB in

The size of this LGM-30F Minuteman II belies its powerful punch – equal to 50 Hiroshima Atomic Bombs across a range of 10,000 km – as it approaches completion at Plant 77, Hill Air Force Base, Utah, operated by Boeing.

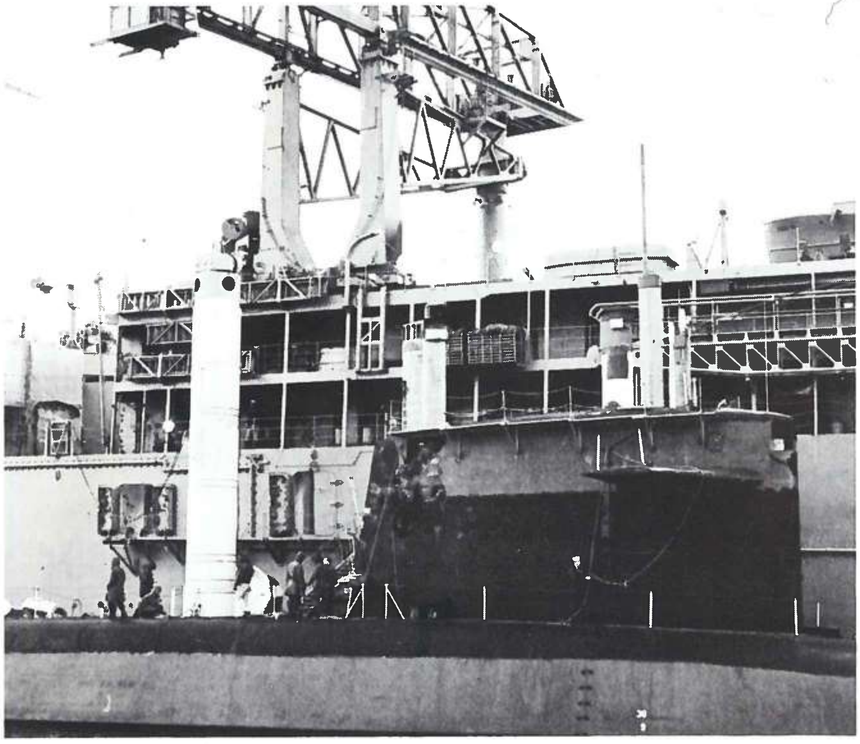


Minuteman missiles are loaded into their respective silos by this transporter-erector which, when raised 90°, allows the ICBM to be placed vertically into its firing tube.

1965, with Wing V at Warren AFB and Wing VI at Grand Forks AFB. Early in 1967 a fourth squadron of 50 missiles was added to Wing I; Wing V had four squadrons also, the remainder supporting three each. In all, 1,000 Minuteman missiles were operational within ten years of the programme go-ahead. A remarkable lesson in efficiency and project management, paralleled to perfection by the US Navy Polaris programme. By 1967, all 41 fleet ballistic missile submarines had been commissioned with a collective total of 656 missiles to add to the 1,000 Minuteman rounds based on land. By this time all the Atlas and Titan 1 missiles had been de-activated, with many Atlas models going for modification to adapt them as satellite launchers (see Chapter Nine), and only the Titan 2 was still emplaced in its 54 silos at Davis Monthan, McConnell and Little Rock Air Force Bases. In all, the United States had 1,710 missiles deployed operationally: 1,054 on land and 656 at sea. It was a formidable force to be reckoned with and one that had a reaction time measured in seconds.



A Polaris A3 variant ignites its solid propellant first stage motor following ejection from the launch tube on a submerged submarine. Each A3 carries an explosive yield equal to 30 Hiroshima Atomic Bombs, each submarine carrying 16 missiles.



The support ship USS Hunley off-loads a Polaris missile from the USS Thomas A. Edison at Holy Loch, Scotland, while Navy personnel re-paint the submarine's sail.

This Polaris A3 is seen seconds after leaving the water at the start of a test flight. Virtually undetectable, the submarine ballistic missile fleet is a formidable deterrent to unwarranted aggression.

Although the first use of rocket propulsion for transporting nuclear warheads across intercontinental distances had emphasized the land-based mode, simply because the logical adoption of the more flexible liquid propellant concept required large and heavy missiles, the sea-going ballistic missile was becoming a potentially more effective deterrent. Rapid developments in the technology of solid propulsion meant that performance would grow commensurate with strategic requirements. The first Fleet Ballistic Missile submarine – the USS George Washington – returned from the first operational patrol with its 16 Polaris A1, 2,220 km range missiles on 21 January 1961. Already it was breaking records. The vessel had spent 66 days and 10 hours submerged out of 67 days at sea, proving the validity of Navy expectations. There was simply no way of keeping track of its movements and still less chance of disabling the vessel before it unleashed an offensive load; SSBN vessels were groomed in the art of firing on the run and only a lucky strike from a conveniently placed surface ship would prevent the submarine from accomplishing the assigned mission. With more than half the surface area of the world to roam in, the nuclear powered submarine could stay hidden for exceptionally long periods of time, limited only by the feeding requirements of its human crew.

But Polaris A1 had a comparatively short range and the submarine would have to sneak up close to potentially hostile land areas to get within striking distance of strategic targets. On 1 November 1960, the British Prime Minister, Harold Macmillan, announced to Parliament that he had concluded an agreement with the United States which would allow the US Navy to use a base at Holy Loch on the Firth of Clyde for servicing and re-supplying the Polaris equipped submarines. It was understood that US submarines using the base would only fire their missiles after consultation with the British Government, but the exigencies of war would have made that a doubtful precursor to reciprocal action in the face of a pre-emptive first strike. Early in 1961 the USS Proteus docked at Holy Loch to act as a depot ship and on 8 March, the Fleet Ballistic Missile submarine, USS Patrick Henry, anchored alongside. It had journeyed nearly 20,400 km and exceeded the submerged endurance record set up by the USS George Washington by twelve hours, firing off eight Polaris A1 missiles en route; these two vessels would be part of Submarine Squadron 14 (or Subron 14) comprising 10 submarines, with a total complement of 160 missiles. Later Subron units would use the port of Rota, Spain, for patrols in the Mediterranean. Each submarine carried two crew, called Blue and Gold, of about 130 officers and men and would alternate at command posts during the long operational patrols.

By this time the newly installed President John F. Kennedy had authorized an increase in the construction rate of new nuclear powered submarines. Under the planned authorization of the outgoing Eisenhower administration the US Navy were preparing to build 21 Fleet Ballistic Missile boats. During his State of the Union message, on 30 January 1961, Kennedy announced that he had 'directed prompt action to step up our Polaris submarine programme. Using unobligated shipbuilding funds now, will build and place on station at least nine months earlier than planned substantially more units of a crucial deterrent – a fleet that will never attack first, but possess sufficient powers of retaliation, concealed beneath the seas, to discourage any aggressor from launching an attack on our security.' On through 1961 the steady flow of newly commissioned submarines slipped out of home ports and set sail for secret destinations. The USS Robert E. Lee started its first operational run on 2 May, followed by the USS Theodore Roosevelt on 19 July and the USS Abraham Lincoln on 28 August. Throughout the year, development of the Polaris A2 model moved rapidly to completion of the first operational rounds.

The first A2 test vehicle had been launched on 10 November 1960, from Cape Canaveral and on 23 October 1961, the USS Ethan Allen fired an A2 while submerged. Physical characteristics of the A2 were very similar to the prescribed parameters of the A1, except that it ws 76 cm longer and weighed 1,680 kg more than its predecessor. But other, more subtle, changes brought a range increase of 25%. The first stage was virtually the same as that employed by the A1, but the second stage adopted a glass fibre casing instead of the steel used earlier. Also, the second stage carried four rotatable nozzles for flight control, but retained the jetevators on the first stage; both stages on the A1 used jetevators, or vanes situated so that the exhaust products impinged on their surfaces. There were certainly strict limitations on the development potential as far as the launch system was concerned. The 16 launch tubes carried by each Fleet Ballistic Missile submarine were a tight fit, even for the comparatively small A1 model. With submarines rolling down the slipways at frequent intervals, any subsequent variant would have limited size growth capability. Because of this the basic A1 diameter of 137 cm remained constant for all Polaris models.

Nevertheless, the A2 was only a moderate step beyond the A1 and its development history went quickly through test and trial designed to wring every conceivable anomaly out of the system. The last production A1 was delivered on 7 December 1961, and on 26 June, of the following year, the USS Ethan Allen put to sea with a full complement of the A2, the first such patrol with the 2,780 km range missile. As built, only the first five fleet Ballistic Missile submarines were limited to using the A1, but these were modified to take the A2 as and when they returned from deep water operations. During 1962 Lockheed moved ahead with the development of an A3 version that would exhibit a substantial improvement in performance over the A1 and the A2. Both earlier Polaris missiles had retained four fixed nozzles in the first stage, using jetevators to deflect the exhaust products and so achieve the desired level of control during the initial stages of flight. This had a considerable penalty in that jetevators added to the weight of the missile and exercised a limiting constraint on the type of propellants used in the solid propellant motor. Propellants were available which promised to increase the efficiency and performance of the missile, but they also brought higher exhaust temperatures which would vaporize the material used in the fabrication of the jetevators. Consequently, it was decided to relinquish the four vanes in favour of gimballed nozzles and this reduced excess weight and made it possible to select more efficient propellants.

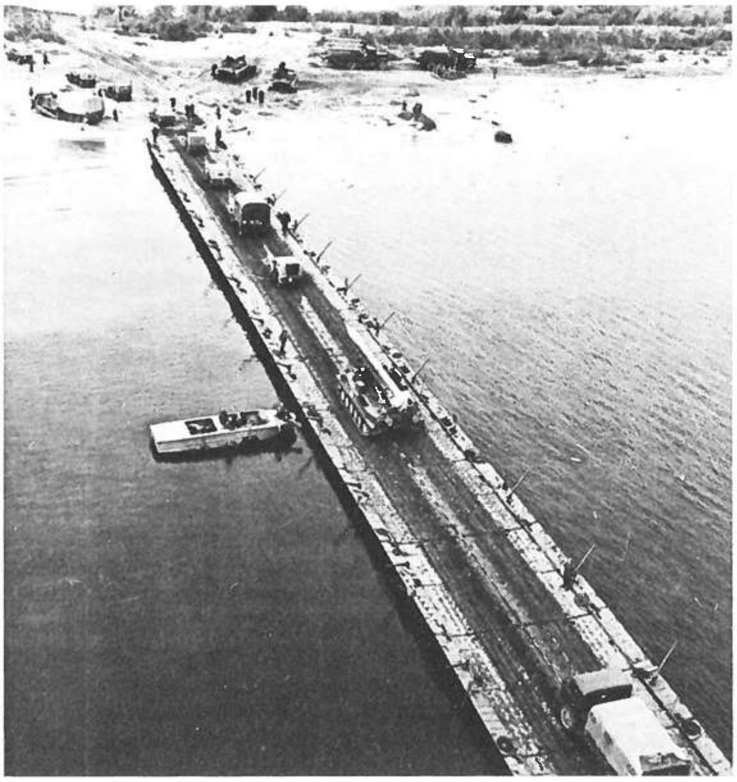
The first stage itself, built by Aerojet General like both stages of the A1 and the A2, was built up from glass filament-wound material on the experience with the second stage of the A2. The second stage was contracted to the Hercules Powder Company and also adopted a glass fibre casing, making Polaris A3 the first missile to use these materials in all stages. Polaris A1 and A2 used a combination of polyurethane and ammonium perchlorate in both stages, but the A3 was designed to use a mixture of nitrocellulose, nitroglycerine and ammonium perchlorate in the new second stage, like the third stage of the Minuteman ICBM. The progression from jetevators to gimballed nozzles had been made with the second stage of the A2 and now an even more sophisticated, albeit highly efficient, system was introduced for the second stage of the A3.

Instead of moving the nozzles to realign the thrust vector, the four expansion chambers would be fixed and use a Freon injection system through ports in the engine bell to create shock waves and achieve the same result. This concept has already been described for Titan III (in Chapter Nine) and for Minuteman II (earlier, this Chapter). Overall, Polaris A3 was 8 cm longer than the A2 and weighed an additional 1,360 kg. So far, the basic missile had grown nearly 10% in length and nearly 24% in weight, but the most notable difference lay in the use of a completely new warhead exhibiting a pointed, hemispherical profile. Earlier Polaris models supported a nose cone not unlike the Mk. 4 carried by Atlas. But it was range that gave the A3 its greatest advantage over the A1 and the A2. With a capability of sending a nuclear charge 4,630 km from the launch submarine, it was capable of striking targets deep inside the Soviet Union.

The first flight of an A3 came on 7 August 1962, followed 14½ months later by a sub-surface launch from the USS Andrew Jackson. It was fired from a depth of 30 metres and flew a distance of 3,685 km. The concept of all-up systems testing was being applied with similar success to that enjoyed by the land-based Minuteman programme. During 1963 operations with nuclear powered, Polaris-armed submarines were temporarily disrupted by the loss of the USS Thresher and its crew and one Fleet Ballistic Missile boat, the USS Thomas Jefferson, was held back from a scheduled operational patrol while suitable modifications were made in the hope of preventing further accidents of a similar nature. More Polaris A3 tests followed and the USS Daniel Webster sent two rounds down the Atlantic Missile Range from an underwater location off Cape Canaveral within 45 minutes of each other on 25 May 1964.

Operational deployment got under way before the end of the year and by June 1967 the US Navy had a total of 41 Fleet Ballistic Missile submarines in operation. Of this number, thirteen were equipped with the A2 and the remaining twenty eight were fitted with the A3; the A1 had been phased out of operation. Encouraged by the success of the Polaris programme, the Navy studied the possibility of using the sea for larger and more powerful missiles than could be carried by submarines. Surface vessels were far too vulnerable to vie as candidate launch platforms for all but ship-to-ship defence systems. In a programme called Advanced Sea-Based Deterrent, or ASBD, the Navy asked Lockheed, well versed in sub-surface launch techniques from their work on Polaris, to perform a feasibility study for very long range missiles that could be set up in fixed bases on the sea bed. The Navy proposal envisaged a series of fixed launch sites spaced at intervals off shore with provision for moving the missiles from one location to another. Unseen by prying eyes on the

Short range battlefield missiles like this Little John were deployed in their thousands with NATO forces in Europe during the 1960's.



A Soviet Frog surface-to-surface missile trundles along a metal bridge across the Dnieper during military exercises, carried on a modified PT-76 light amphibious tank chassis.

This Frog missile adopts a threatening pose as it is raised to maximum elevation, ever ready to support armoured thrusts into enemy front line positions.

surface, ICBM size projectiles would be moved from one location to another so that the enemy would never know the precise location of the offensive pad position. The idea was certainly novel, but the existing inventory was considered adequate for strategic deterrence.

Between 1961 and 1967 the United States had moved quickly to a force posture that left the NATO armies strongly reliant on the threat of all-out nuclear war to deter Soviet ambitions. Comparatively small, tactical battlefield missiles, in the form of Honest John and Sergeant were deployed in their thousands, with European armed forces operating under the NATO flag. Medium range ballistic missiles, like Jupiter and the limited number of Thors, were now backed up by Polaris operating from the Mediterranean and the Atlantic to cover the western borders and from the Indian Ocean to protect the southern flank across Asia. In silos across the United States, Titan 2 and Minuteman stood ready to deliver the massive retaliatory strike that completed the missile inventory with several hundred B-52 bombers ready at all times to back up the offensive strategy. It was an effective umbrella, structured in tiers that conformed to Kennedy's measured force retaliation concept; in a limited European war the land-based missiles in Western Germany, the Low Countries and Great Britain would be expected to stem the tide of a Soviet invasion while the strategic deterrent was held back awaiting further escalation or political bargaining.

By the time the first generation ICBM – Atlas – was being deployed in its soft emplacements, the Soviet Union had rationalized their position and recognized the severe limitations of the SS-6 Sapwood. With non-storable liquid propellants and a lengthy preparation and countdown, the missile would be unable to respond with the required degree of rapidity. Moreover, the sheer size of the missile prevented it from being a likely candidate for hardened launch complexes and the exposed nature of the surface pad, from which it would be prepared, would engender a degree of vulnerability unacceptable to the armed forces. No sooner had the missile demonstrated its power by sending the first satellite into orbit, than it was decided, at the behest of Kruschev, that more suitable ICBM configurations would be essential to Soviet defence requirements. Superb in its role as a satellite launcher, Sapwood was relegated to providing a heavyweight lifting capability for the nascent space programme.

In the year that Sputnik 1 was launched – 1957 – the first Soviet short range battlefield missile was put into operation. It would be designated 'Frog' by NATO forces. The missile had a warhead capable of carrying a nuclear charge with greater equivalent yield than the Atomic Bomb dropped on Hiroshima. The 1.2 tonne payload had a range of up to 32 km and would be utilized as a highly mobile front-line weapon system, integrated with infantry assault lines and armoured thrusts. Also in 1957, the Scud A medium range ballistic missile entered service with a nuclear or conventional warhead and a range of up to 130 km. Like the Frog series, Scud was launched from a mobile platform and utilized a tracked vehicle developed from a tank chassis. Unlike Frog, Scud utilized liquid propellants for a role similar to that pursued by the Corporal short range ballistic missile.

While the second half of the 1950's was characterized in Soviet missile development by the introduction of short- and medium-range battlefield weapons, it was also notable for the service introduction of the world's first submarine-launched ballistic projectile. Unlike the emerging Polaris design, the SS-N-4 Sark was carried in a special housing on the deck of the submarine and had to be fired from the surface after a period of preparation. It did utilize solid propellants, like Polaris, and had the capability of lifting a thermonuclear warhead of 1 MT yield (equal to 50 Hiroshima bombs) across a distance of nearly 600 km. The first Sark units were deployed in 1956, but the missile was never considered to possess a strategic potential and could only have been used after the parent submarine had moved close to enemy territory. Nevertheless, by the time the Eisenhower administration injected the necessary life into America's missile programme, the Soviet Union had moved ahead into almost every major area of potential application: ICBM, MRBM, SLBM and battlefield support roles.

Adjustments are made to a Frog missile by Soviet rocket troops.

Between 1955 and 1960, the first five years of the restructured post-Stalinist regime (1953–55 had been a period of transformation for the government) saw a new philosophy about communist objectives. No longer did Soviet leaders talk of conflict as an inevitable consequence of the march towards world rule. Instead, an increasingly well equipped force structure was rising to meet and match the hitherto dominant posture held by NATO and the United States. The prospect of deterrence by way of the threat of mutual annihilation would fabricate an aura of acceptability in the minds of Western leaders. Kruschev was committed to strengthening the Soviet armed forces and placed great faith on the generation of rocket powered missiles then coming into production. A future war would be fought with more decisive results than contemplated at the end of World War II and parity in weapons potential would stay the hand of capitalist doctrine; so went the argument. Russia would never again fall prey to fascist invasion. The threat was seen to parallel that from Nazi Germany nearly two decades before and Russian leaders were prepared to accept future conflict as an integral part of the struggle for world communism.

On 7 May 1960, the Strategic Rocket Forces were set up as a separate arm of the military oligarchy and under Marshal K. S. Moskalenko would command deployment and operation of ballistic missiles with a range greater than 1,000 km. Missiles of less ambitious potential would fall under the control of the Army, the Navy and the Air Forces. Dissatisfaction with the Sapwood ICBM led to development of the SS-7 Saddler, a two-stage liquid propellant missile capable of sending a 5 MT warhead across a range distance of more than 10,000 km. By the time Saddler was beginning to enter service late in 1961, the total number of Sapwood ICBM's was probably no more than 10 or 15, its lack of exploitation being due to poor accuracy, vulnerability and lengthy preparation time outlined earlier. From the Soviet view of international politics there was good reason to step up development of long range missiles. In August 1960, Francis Gary Powers went on trial in Moscow after being captured when his U-2 spy-plane crashed on Russian territory. At the end of a long public trial at the old Palace of the Tsars, Powers was given a ten-year prison sentence, but the repercussions of the incident hardened Soviet attitudes toward the West.

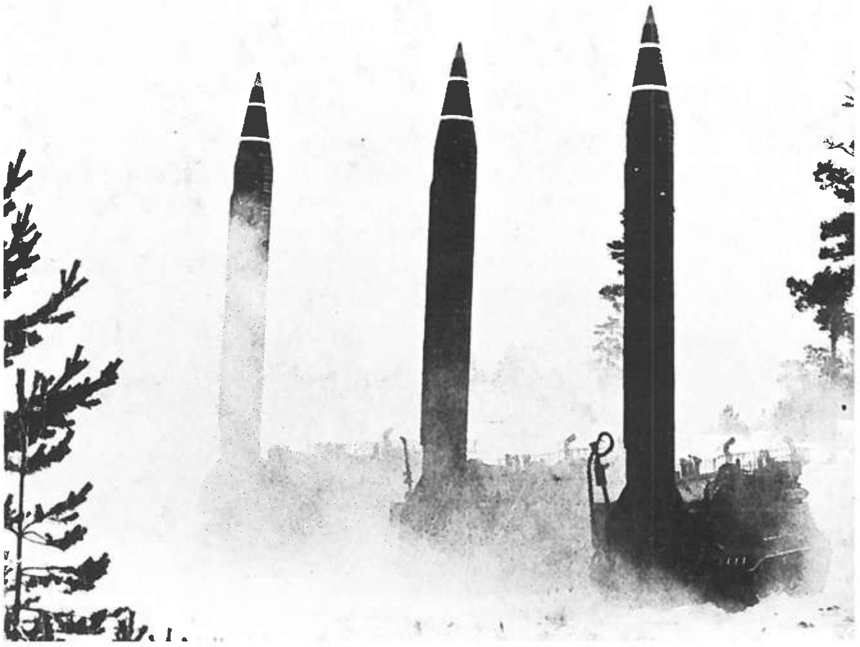
Two years later, in October 1962, the cold war between America and Russia threatened to spill over into conflict when US intelligence learned of the deployment of several Sandal intermediate range ballistic missiles on the island of Cuba. Moreover, construction sites were photographed showing preparations for emplacing Skean IRBM's and, if deployed, these missiles would have threatened areas as far north as Quebec and as far west as California. Without an effective ICBM in any adequate number, the Russians would have strike potential from the IRBM class weapons set up under an agreement with Fidel Castro, close to the continental United States. From Washington, President Kennedy ordered an immediate blockade of Cuba and put the armed forces on alert at home and in Europe. Throughout the world, soldiers, sailors and airmen prepared for an all-out war, while the President took a firm line with his Soviet counterpart and demanded the immediate withdrawal of Russian arms and personnel. It was a dramatic confrontation, a testing time calling for bold decisions. Kruschev finally backed down and agreed to dismantle the Sandal sites and stop work on Skean emplacement. It was not, however, a concession born of generosity.

In 1961, the total land-based ICBM force provided the Americans with 63 launchers against 50 set up by the Soviet Union. In 1962, there were 294 ICBM's and 144 submarine launched Polaris missiles, against the Soviet Union's 75 ICBM's. Sark was still the only Russian submarine launched ballistic missile, but its short range placed it at a decided disadvantage in the force parity game. Kruschev was aware that his 75 long range missiles compared unfavourably with the 438 ballistic launchers threatening Soviet lands. Added to this was the impressive fleet of several hundred B-52's and B-47's of Strategic Air Command. The outcome was inevitable but the lesson was learned: the Soviet armed forces would move steadily toward parity on most levels of defence and superiority wherever it could.

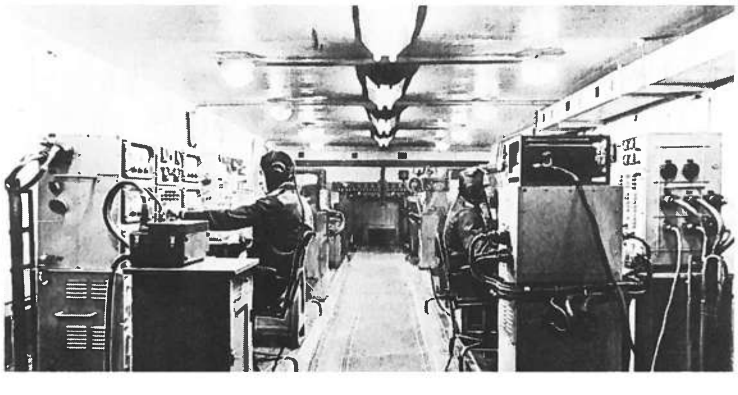
From 1961, Saddler was deployed in increasing numbers and the storable nature of its liquid propellants, made this two-stage missile an effective second generation ICBM. Within two years it was joined by the SS-8 Sasin, similar in range and lifting capacity to Saddler, but smaller in both length and diameter. Although the first generation Soviet ICBM, Sapwood, had little application to the exacting demands of strategic deterrence, Saddler and Sasin represented a considerable improvement both in flexibility and deliverable warhead accuracy. The use of storable propellants in both missiles ensured their ready availability by permitting technicians and launch personnel to hold the launcher in a state of readiness for long periods of time. This paralleled development of the Titan missile in America and, like its counterpart, Saddler was eventually deployed in underground silos, albeit in limited numbers. Sasin became operational in 1963, a year which also heralded the introduction of the SS-N-5 Serb submarine launched missile.

Serb adopted liquid propellants, setting a precedent for future Soviet SLBM projectiles, and had a range twice that of the first-generation Sark missiles, but little more than half that of the Polaris A-1. By the time Serb was entering service, the US Navy were preparing to deploy the Polaris A-3 with a range four times that of the Russian missile. Much emphasis was now going on to missile forces at the expense of the conventional equipment using armour and infantry. At the end of World War II, the Soviet armed forces boasted 11.4 million officers and men, but by 1948 this number had been reduced to less than 2.9 million and to counter a suspected threat, increased again to 5.7 million in the early 1950's. By 1958 the total stood at 3.6 million, but a planned reduction to 2.4 million in 1960 was deferred because of the worsening situation with the United States. Steps were taken to reduce the possibility of an all-out arms race with the test-ban treaty signed in August 1963. This effectively prohibited the testing of all nuclear weapons in the sea, in the atmosphere and in space and by the end of the year more than 100 'potentially nuclear' nations around the world had become signatories to

Scud A, a tactical battlefield weapon, was carried on a JS-111 tank chassis, as seen in this view taken during winter exercises. The missile had a range of 130 km.



'Throughout the world, soldiers, sailors and airmen prepared for all-out war . . .' A Soviet missile control centre.



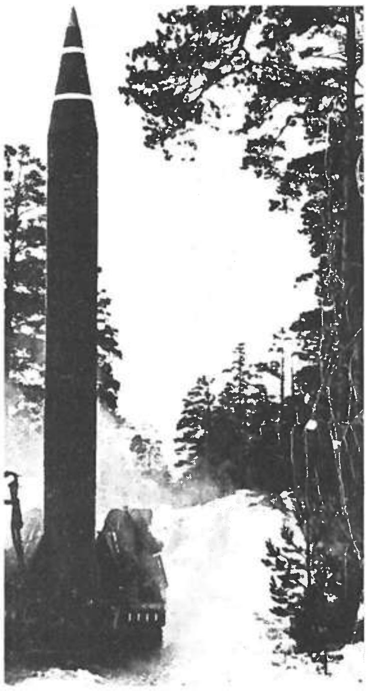
the agreement; only France and China declined to ratify this treaty.

But little could now stop the escalation of strategic weapons. While Saddler and Sasin were being deployed, work was increasing on the biggest ICBM so far contemplated; the SS-9 Scarp. While Saddler and Sasin, both destined for concurrent deployment along with the SS-9, could send a 5 MT nuclear charge across a distance of between 10,000 and 11,000 km, the Scarp would provide a throw-weight capability more than 4½ times as great, with a range of 12,000 km. With a capacity for sending a warhead weighing 5.5 tonnes across the full operational range, Scarp could bombard the continental United States with nuclear charges of 25 MT. A single Scarp warhead would have an explosive yield equal to 1,250 Hiroshima Atomic Bombs. Much attention had been given to high megatonne-yield thermonuclear charges and these reached a peak in 1961, with the test of a device generating an explosive yield of 58 MT; equal to a staggering 2,900 Hiroshima bombs. However, there was little military application for weapons of such devastating potential and the ability to place charges of less potential accurately on target, was a much more desirable proposition.

Much secrecy still surrounds Scarp, but it is thought to have been introduced into service as a two-stage missile, or with a third (terminal) stage used for final trajectory corrections before warhead separation. Either way, a four-stage version, designated Mod 3, appeared in 1966, a year after Scarp became operational. It was related to a series of tests designed to demonstrate a capability that has since become known as the Fractional Orbital Bombardment Satellite (FOBS) concept. Whereas ballistic missiles are required to fly a trajectory that takes the final stage and warhead out into space before the pull of gravity causes it to fall along a curving path to the designated target, FOBS vehicles were actually placed in orbit. This required the terminal stages(s) to reach a speed of more than 28,000 km/hr at a height above the atmosphere where they would not be retarded by air molecules and dragged back prematurely. Once in orbit, the terminal stage and warhead would prepare for the re-entry phase and an additional propulsive thrust against the direction of flight would reduce the speed of the assembly and cause it to fall toward its target. This would be carried out before completion of the first Earth orbit and so avoid the otherwise flagrant contravention of an agreement signed in 1962 that prohibited the orbiting of weapons of mass destruction.

To simplify, instead of moving along a ballistic, sub-orbital, trajectory, the warhead would first go into orbit and, before the completion of one revolution, return to Earth at the location of the designated target. This had a certain advantage in that Scarp could dispatch its warhead along a path that took it south-east over the Indian Ocean, close by the Antarctic continent and back up across the Pacific to the United States. In other words, sneak in through the west coast approaches to America in the opposite direction to that expected for a conventional ballistic trajectory. The throw-weight capability enjoyed by Scarp was so great that it could trade payload for speed and perform the FOBS mission. The first precursor tests got under way late in 1966 and the initial series of trials began on 25 January 1967. FOBS was a viable military development if America had possession of an alert network tied to anti-ballistic missile defence systems, or rockets that could intercept an incoming warhead. In that eventuality, the United States would be forced to deploy adequate radar coverage to include attack warning from any possible direction. Although FOBS testing went on until 1971, the Russians decided not to deploy the system as an operational weapon. Nevertheless, Scarp was employed on the launch of target vehicles for tests with a killer satellite, beginning in 1968 and these have continued to refine a system designed to seek and destroy US satellites placed in orbit for early-warning and radiation monitoring roles.

While Scarp was being deployed in 1965, Soviet rocket engineers were in the final stage of development with the SS-10 Scrag, a somewhat ambivalent missile, in that it was the longest ICBM ever built, with a very ambitious performance envelope, but one which adopted non-storable propellants. It was paraded publicly for the first time in 1965, but failed to secure a lasting niche in the inventory of Soviet missiles. With three separate stages joined by open truss structures, Scrag was expected to send a multi-megatonne warhead across a distance of 12,000 km. It was never deployed and soon disappeared from comment and view. It is



The SS-10 Scrag, obsolete because of non-storable propellants, was the longest ICBM ever developed. Note the truss structures separating the three stages and the four large motor nozzles in the first stage; upper stages had a single motor each.

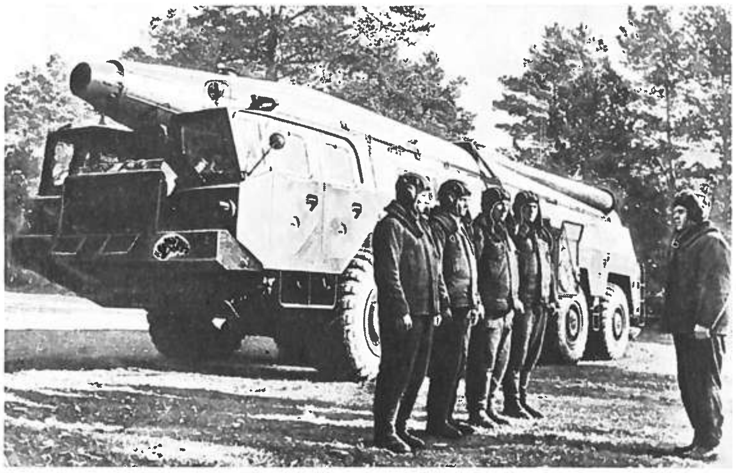
Two SS-9 Scarp heavyweight ICBM's, each carrying an explosive yield equal to 1,250 Hiroshima Atomic Bombs, are followed by two defunct SS-10 Scrag missiles.

a lasting surprise that at a time when Russia was moving ahead with storable propellants on ICBM's, Scrag emerged with liquid oxygen and kerosene engines.

By 1967 the United States had achieved its full complement of 1,710 land and submarine launched missiles with 54 Titan 2, 1,000 Minutemans and 656 Polaris A-2 and A-3 variants. Since the Cuba crisis of 1962, the United States strategic missile deployment had persistently outstripped that of the Soviet Union. In 1963 the United States had 668 strategic missiles operational, compared to 200 for the Soviet Union and in 1964 the numbers were 1,250 versus 320 respectively. The following year, American deployment figures boasted a total of 1,350 while the Soviet Union could field 390. The massive government/industry effort in the United States continued to move ahead and in 1966 America had 1,496 strategic missiles against 425 in the Soviet Union. By the end of 1967 Russia had increased the figure to 590, little more than one-third the US force level. From this year on, with American deployment frozen at 1,710 missiles of strategic quality, the Soviet Strategic Rocket Forces would slowly build and exceed this figure by 1971. However, it should be remembered that Strategic Air Command had an effective airborne fleet of manned bombers unlike the Soviet Union.

While ICBM developments had provided Russia with a growing inventory of second-generation land-based missiles, work continued to produce an effective equivalent to the Polaris fleet. In 1968 the SS-N-6 Sawfly began to equip Yankee class submarines and provide a more efficient strike force than the existing Sark and Serb equipped vessels. Each Yankee class submarine would carry 16 Sawflys and each missile could carry a 1MT warhead across a distance of 2,400 km. The nuclear charge was about twice that carried by Polaris and the range was little more than half that of the A3. But it represented a committment on the part of the Soviet Union to follow in America's steps and fully exploit the submarine launched concept.

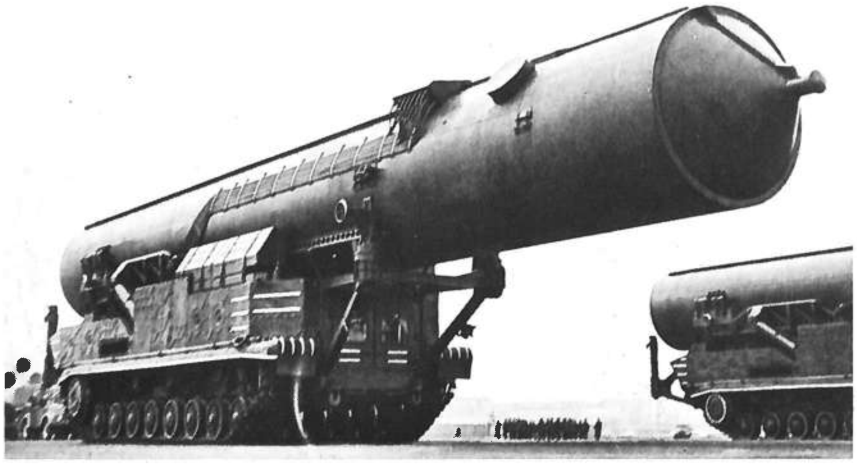
By 1968 the Strategic Rocket Forces were equipped with the SS-11 Sego, a missile that would be produced in greater numbers than any other Russian ICBM and one that filled a category between the tactical battlefield weapon and the larger Saddler, Sasin and Scarp. Using storable propellants, Sego had a range capability, at 10,500 km, similar to that of the 'big three' second generation ICBM's, but a warhead with an explosive yield equivalent to the US Minuteman. The throw-weight capability was only half that of Saddler and Sasin and only 13% that of Scarp, but it provided adequate growth capability for subsequent adaptation that was to be an integral feature of the new Russian hardware. Developed in parallel with Sego, the SS-13 Savage was the first land-based ICBM to employ solid propellants. It entered service in 1968, but like its contemporary, it had a poor target accuracy and only 60 were ever deployed in silos.



The solid propellant SS-12 Scaleboard had a range of 700 km and is seen here carried by a MAZ-543 transporter-erector.

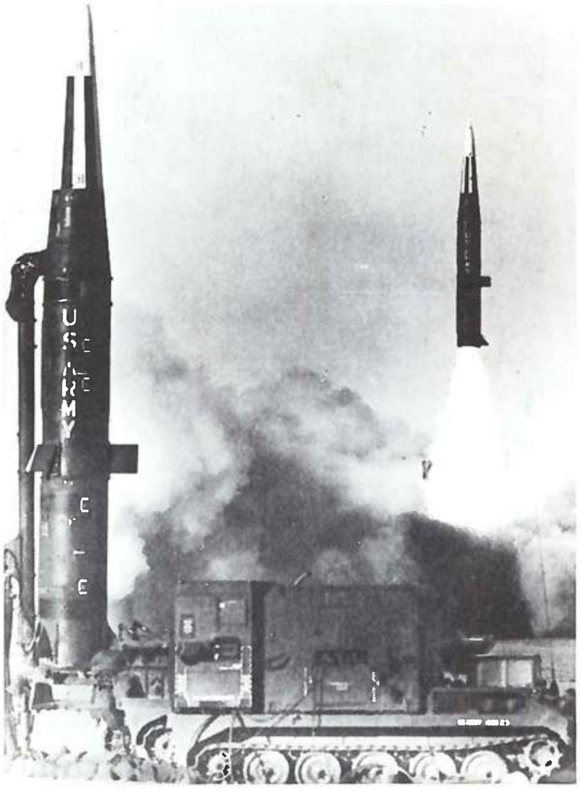
A single SS-10 follows a single SS-8 Sasin and two SS-13s, the first Soviet ICBM to employ solid propellants, in this May Day parade through Moscow's Red Square in 1966.

Also deployed, from 1968, was the SS-12 Scaleboard medium range missile with solid propellants and a range of 700 km. This was the first new MRBM since the SS-3 Shyster of 1955 and it was transported on a specially adapted vehicle for full mobility. It provided a role capability between the Scud and the Sandal, operational from the early 1950's and 1959 respectively. Yet another new appearance in 1968 was a missile that filled the operational gap between Scaleboard and Savage: the SS-14 Scapegoat. Scud A, with a range of 130 km, had been replaced by Scud B which could hit targets across a distance of 280 km and the Scaleboard complemented Scud B units with an action radius of 700 km. For more distant targets, there was the new Scapegoat with a range of between 2,000 and 4,000 km depending on the warhead selected for use. Paired with Scapegoat came the SS-15 Scrooge, first deployed in 1969, developed from Savage and with a performance greater than Scapegoat. Scrooge can hit

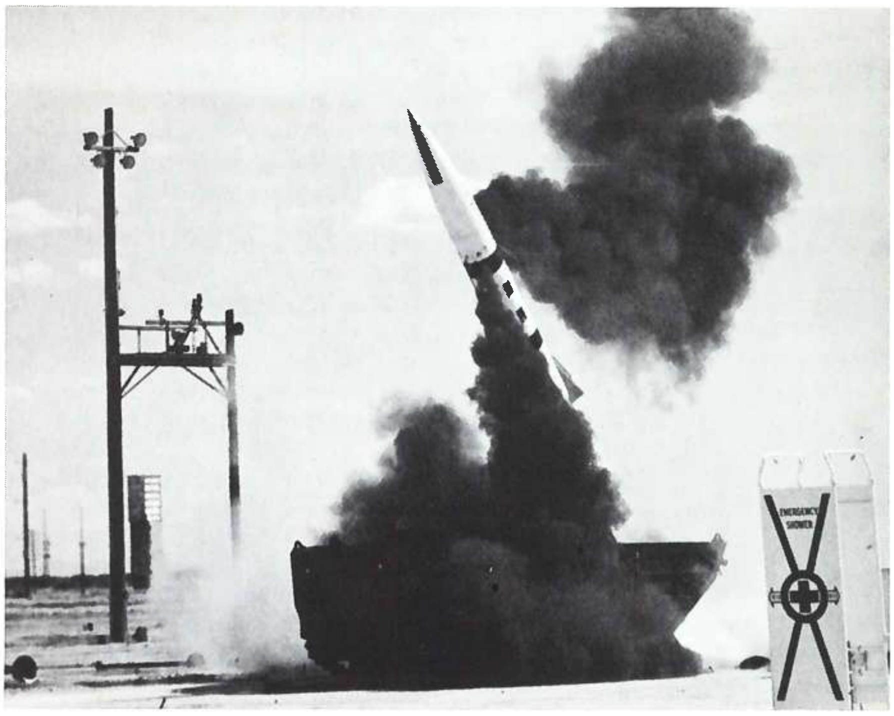


With a range capability of up to 4,000 km, the SS-14 Scapegoat is here carried in a container-erector mounted on a tracked transporter.

Concealed by its container in this view, the SS-15 Scrooge has a range of 5,500 km. Mobility is a key feature of medium range missiles like this and the SS-14.



Two US Pershing missiles are seen during firing trials at Fort Bliss, Texas, following erection from their tracked transporter-erector vehicles.



A Lance missile leaps from its mobile launch platform on a tracked vehicle during flight trials.

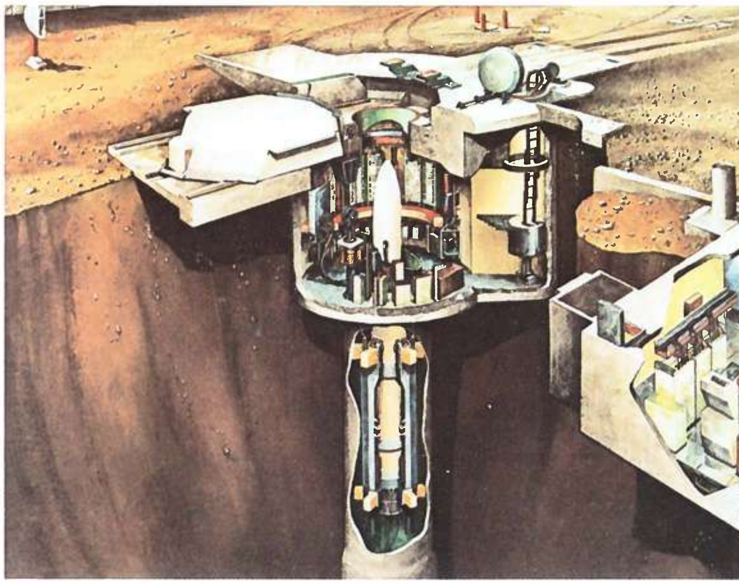
targets 5,500 km away and is carried in a special container with an integral erection and launch structure. Scud was the only tactical missile to employ liquid propellants; Scaleboard, Scapegoat, and Scrooge all used solid propellants. All four short and medium range missiles were mounted on mobile platforms comprising either adapted tank chassis or special wheeled vehicles.

Thus, by 1969, the Soviet forces were equipped with missiles capable of selective use at ranges of 130 km, 280 km, 700 km, 2,000–4,000 km and 5,500 km, all available for a fast moving army on the advance. At the bottom end of the scale, Frog (Free rocket over ground) derivatives provided coverage between 19 km and 60 km, exact distance depending on the variant selected and the warhead carried. At the upper end of the range, the Sego filled a strategic role equivalent to the Minuteman and was complemented by the lesser numbers of Saddler and Sasin while Scarp continued to present a 'heavy punch' role with multi-megatonne warheads. Savage and Scrag were never effectively utilized except for a limited number of the former.

When America froze its missile inventory at 1,710 in 1967, the Soviet Strategic forces had 590. It did not include missiles of the tactical battlefield class and was relevant to land-based ICBM's. In 1968 the force level had risen to 930 and by 1969 some 1,210 missiles were operational. A year later the number stood at 1,580 and in 1971 reached and exceeded the American figure to total 1,950. These figures do include an increasing number of submarine launched missiles although it is arguable as to whether the Sark, Serb and Sawfly could be classed as strategic weapons. Nevertheless, they carried nuclear warheads and could, admittedly only under the most favourable of circumstances, strike targets on the continental United States. If submarine launched missiles are discounted, for both American and Russian figures, total land-based ICBM deployment in Russia exceeded the 1,054 missiles emplaced in the United States by 1970, when a force strength of 1,300 was achieved.

While the Soviet Union was gathering a prolific inventory of tactical battlefield support missiles, the American Honest John and Sergeant soldiered on until Pershing, a development from Martin Marietta, began to go into deployment in 1969 as a replacement for the Redstone MRBM. The missile was a two-stage solid propellant weapon carrying a conventional warhead or a nuclear charge across range distances of between 160 km and 650 km. A replacement for Honest John and Sergeant was still in the development stage, but when it emerged as the Lance, it would have a range capability of between 70 km and 120 km. The hitherto well defined lines separating tactical from strategic and conventional from nuclear theatres were becoming blurred with a dangerous inconsistency. Nuclear weapons were once the ultimate strategic deterrent, delivered in the first decade after Hiroshima by aircraft and then in the second and third by ICBM class systems. By the early 1960's, however, increasingly sophisticated techniques for reducing the size of a nuclear charge had opened the possibility of deployment on small, mobile launchers and nowhere was this capability more fully exploited than in the array of Soviet tracked and wheeled vehicles fitted with battlefield missiles. Nuclear warfare was no longer the all-consuming holocaust signalling the end of the world. Massive warheads of multi-megatonne yield were still growing in number with the armed forces of the United States and the Soviet Union, but many more tactical weapons were being deployed to effectively re-shape the format of battle operations.

In a generation of new developments, the role of conventional artillery had largely been replaced by highly mobile missile launchers, a concept pioneered by William Congreve in the 19th century, but one which failed to keep pace with gun improvements at the time. From entrenched concepts of attrition through mutual bombardment in World War I, to the flexible running battles of World War II, where air power became an effective element during ground operations, the science of tactical warfare had been revolutionized. Missile forces were seen as the prime strike element of defence and retaliation and a host of light rocket propelled weapons began to replace conventional arms from the late 1960's. But it was in the prolific availability of small nuclear charges, that the defence of Western Europe rested.



Minuteman III is stored in individual silos on a special shock-absorbing cradle. Note the massive concrete door that slides back to expose the missile, seconds before launch.

As a direct result of strategic policies engineered by the Kennedy administration, NATO forces came to rely more on the saturation bombardment of armoured tank columns. Where once it had been considered unlikely that any major power would accept inevitable escalation to nuclear war, policy was now coming to rely on the immediate use of tactical nuclear weapons, deployed in their thousands across the European mainland. Missile technology had moved into every conceivable theatre of war and now the lines separating conventional from nuclear conflict were indistinct and dangerously reliant on the weapons that had originally been thought to provide a separate category of military commitment. While it had been convenient to list the total number of ICBM variants of each country up to the late 1960's and thereby judge the relative force strength of each side, new developments at the turn of the decades injected a subtle transformation in the equation.

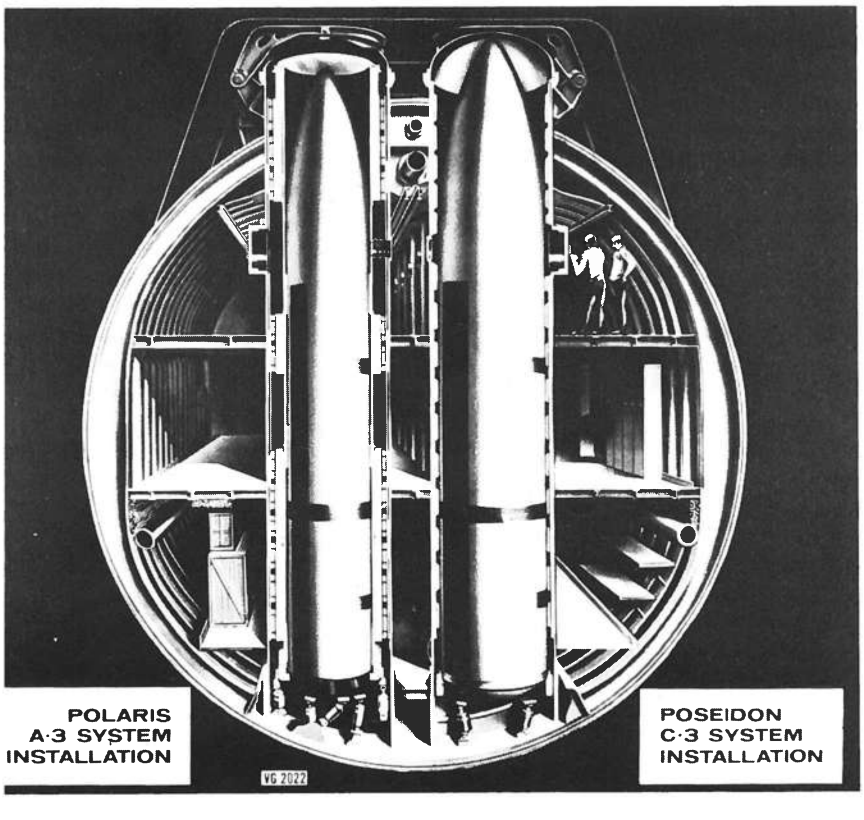
Up to 1971 each ICBM (Titan and Minuteman) carried a single thermonuclear warhead and, therefore, each missile was a separate entity with the assigned mission of seeking the destruction of a single target. This was a tidy numbers game whereby a missile count would reveal the potential number of targets that could be expected to receive attack in the event of an all-out war. But dramatic improvements in miniaturized warheads, experience with shaped re-entry vehicles designed to protect the warhead as it descended through the atmosphere to its target and the design of new forms of lifting bodies that could be pre-set to follow a programmed trajectory in the atmosphere, led the United States toward development of two new warhead configurations: MRV and MIRV.

The first of these, the Multiple Re-entry vehicle, envisaged a cluster of several thermonuclear charges carried within a common warhead which would separate to fall within a few hundred metres of the terminal co-ordinates of the trajectory. The second concept, the Multiple-Independently-targeted Re-entry Vehicle, is a logical progression from the MRV principle. Here, a cluster of separate nuclear charges is carried in a dispenser which also accommodates decoys and other devices to confuse enemy radar. As the terminal re-entry vehicle begins its descent to the target area, individual warheads are released along with the decoys with each nuclear charge falling to a specific target, which can be several tens of kilometres from its neighbour. In the final minutes before the high-velocity charges reach their respective targets, the enemy alert network is, theoretically at least, unable to filter the dummy warheads from those carrying a live charge. Thus, any anti-ballistic missile screen would be required to pursue and destroy the many incoming targets to ensure high-altitude destruction of the few live charges.

In strategic terms, it means that one ICBM, or submarine launched ballistic missile, can attack several targets simultaneously as long as they are not too far apart. This provides a not inconsiderable expansion of the effective role played by each missile and adds a second dimension to the established criteria employed for measuring force parity. Each MRV or MIRV nuclear charge would obviously have reduced yield, but improved accuracy and this also means that a lower yield can accomplish the same destructive objectives as a large charge carried in a single re-entry vehicle. By 1971 the United States began fitting its Polaris A-3 with a MRV capability. In a Lockheed re-entry vehicle designed to carry three nuclear charges of 200 KT yield, the final Polaris derivative would complement the A-2 model with its single 500 KT warhead. Meanwhile, work had been progressing rapidly on a further development of the LGM-30 Minuteman which remained at a force strength of 1,000 rounds in Mk. I and Mk. II variants.

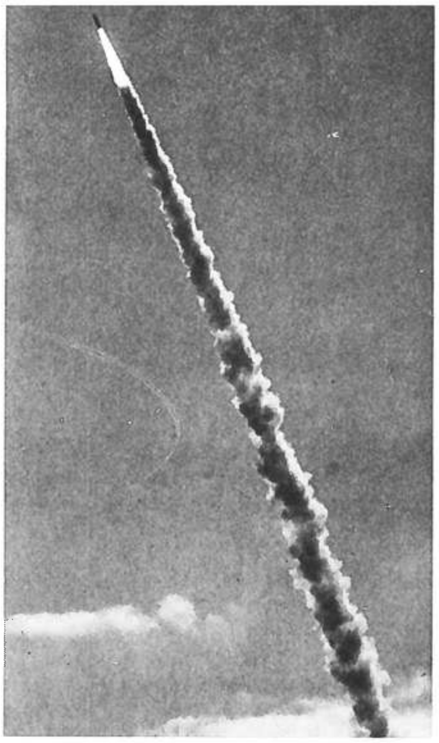
The new model, designated LGM-30G Minuteman III, had the same first and second stages as the Minuteman II, but the Hercules Powder Company third stage was replaced by a new development built by Aerojet-General using a solid propellant motor manufactured by Thiokol. This third stage also carried a single exhaust nozzle with a fluid injection control system in like manner to the second stage of Minuteman II and the second stage of Polaris A-3. Before the first Minuteman III model was ready for flight, it was decided to prepare the missile for operational use with a fully MIRVed warhead. Unlike the single nuclear charge carried by the first two models, Minuteman III would support a Post Boost Control System, or PBCS, equipped with three 200 KT charges, chaff, and decoys in various configurations. The PBCS was essentially a fourth stage for Minuteman, providing a guidance and manoeuvring system designed to perform trajectory changes before and between separation of the nuclear charges and decoys. It was produced by Bell Aerospace.

The first Minuteman III got away on test from Cape Canaveral during August 1968 and for two years the development programme went ahead from this location and the Vandenberg Air Force Base. With a range of more than 13,000 km, each missile would carry a warload of three nuclear charges, each of which had an explosive yield 10 times that of the Atomic Bomb dropped on Hiroshima. The warhead was a General Electric Mk. 12 design with a target accuracy of about 370 metres at full range distance. The first Minuteman III's became operational at Minot Air Force Base in January 1971, a month after the final delivery to a Strategic Missile Squadron at that facility. Over the next 4½ years Minuteman III would replace Minuteman II models which in turn were replacing the Mk. I version. Yet Minuteman III was not the only new strategic development of the late 1960's.



With little modification to the launch tube, Lafayette class submarines accommodated the new Poseidon SLBM as seen in this illustration which gives scale to this and the Polaris A3 missile.

A Poseidon SLBM accelerates away from the surface following launch aboard the submerged USS James Madison.



A Poseidon test missile flies straight and true from Pad 25C, Cape Canaveral, during development trials.

A Royal Navy Polaris ascends on test. Britain is the only foreign country to purchase a US Strategic missile system.

In 1964 President Lyndon B. Johnson, successor to Kennedy from the latter's assassination in late 1963 to early 1969, authorized full programme preparation of the Poseidon submarine launched ballistic missile. Poseidon was officially known as the UGM-73A, the 'U' standing for under, the 'G' implying ground or surface and the 'M' for missile: an under surface missile. The LGM designation for Titan 2 and all Minuteman models adopted similar acronyms with the 'L' referring to the low-underground launch mode whereby missiles in this category were fired from the bottom of their respective silos. Atlas F and Titan 1 were in the HGM class; missiles stored in a hardened silo and raised to the surface for launch. Atlas E was retrospectively referred to as a CGM type, where the missile was contained within a coffin on the surface, and the Atlas D was said to be a PGM missile because it was set up and launched on a soft pad. All Atlas models and the Titan 1 were, of course, deactivated in the mid-1960's when Titan 2 and Minuteman took over. Polaris was part of the UGM-27 programme with models A-1, A-2 and A-3 being designated UGM-27A, B and C respectively.

Poseidon was a considerable improvement over the Polaris A-3, with a two-stage solid propellant configuration and, for the first time since it was set by the Polaris A-1, a larger diameter. Length too was increased over the Polaris A-3 and the launch weight was about twice that of the existing SLBM. These factors brought problems to the Navy planners, but careful tailoring of the basic design ensured that with little modification to the launch tubes in Lafayette submarines, the existing boats of that class would be able to carry Poseidon without major problems. The two solid propellant stages each carried a single gimballed exhaust nozzle and although Poseidon had the same range (4,600 km) as the Polaris A-3, it had twice the throw-weight of its predecessor. From the beginning, Poseidon was seen as a supplementary addition to a small force of Polaris A-3 missiles which would be retained on George Washington and Ethan Allen class submarines. But whereas Polaris A-3 would retain three 200 KT nuclear charges in each MRV, Poseidon would be fitted with full MIRV capability. This took the form of an Mk. 3 re-entry vehicle carrying 10 nuclear charges, each with an explosive yield of 50 KT. An alternative configuration could adopt 14 nuclear charges of similar yield and, with this maximum throw-weight ability, range was the same as Polaris A-3; with 10 charges range was found to exceed 5,200 km.

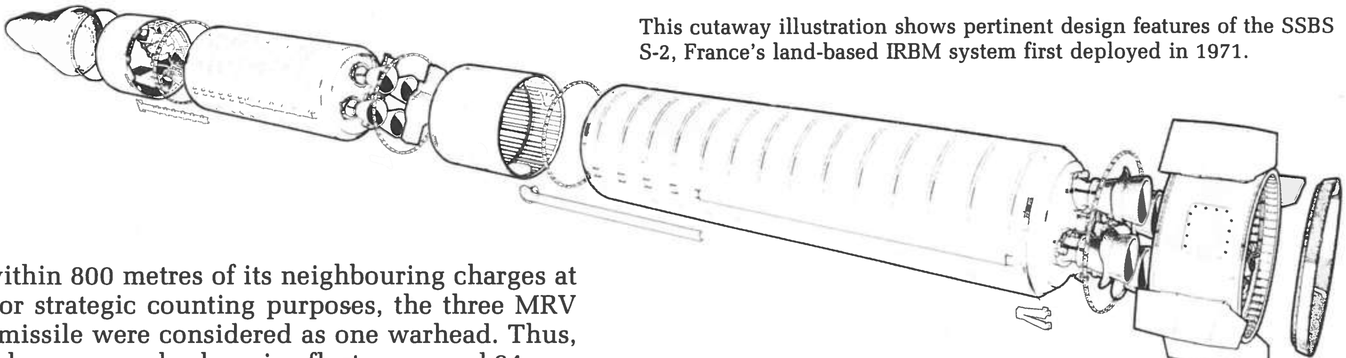
The first flight trials with Poseidon began in August 1968 and brought a successful flight from underwater two years later. In March 1971, the first Poseidon equipped submarine slipped its berth and put to sea. Over the next seven years the US Navy would move towards a force establishment of 10 Polaris A-3 and 31 Poseidon boats, each of which carried 16 missiles. While the United States was building up its force of Minuteman III land-based ICBM's and Poseidon SLBM's, the Soviet Union was preparing to deploy a third generation SLBM of its own. It first became operational in 1973 and was designated the SS-N-8. For five years the Soviet Navy had proudly operated the SS-N-6 Sawfly which had a range capability only two-thirds that of the Polaris A-3, but a single 1 MT warhead with twice the effective yield of the US counterpart. Later development with Sawfly had demonstrated the use of three nuclear charges in an MRV warhead across a range of 3,000 km.

The SS-N-8, a considerable improvement over Sawfly, could carry a similar load across a range distance of more than 7,500 km and soon the Russians were testing a SS-N-8 derivative with a fully MIRVed warhead. During at least one test the SS-N-8 demonstrated a range capability of 9,200 km – nearly twice that of Poseidon – but it is unclear as to whether this model carried a full warload or merely light-weight test instrumentation. But the two super-powers were not the only nations to develop and deploy a strategic missile capability. Britain, France and China make up the balance, although the contribution from each is small compared to the massive throw-weight of the United States and the Soviet Union.

For its part, Britain played a continually changing game of selection and re-selection; first going for an ICBM in the form of Blue Streak, cancelling this because of a political ploy, deciding to adopt a nebulous American air-launched ballistic missile (about which, more later), finding this unavailable due to cancellation and eventually opting to buy Polaris A-3 missiles to fit four Royal Navy submarines. From the Blue Streak conception to operational deployment with Polaris missiles, fifteen years of incredible hostility to indigenous development caused the eventual demolition of the considerable talent that had brought success with early post-war rocket projects. The decision to procure Polaris missiles was ratified in December 1962, but less than two years later the Polaris Sales Agreement came under fire in the House of Commons when questions arose concerning the purchase of fissile material from the United States.

Under the language adopted for open debate on Polaris procurement, Members of Parliament had been led to understand that the British missile force was to represent an 'independent deterrent' for integration with NATO requirements, but wholly responsive to British moves in foreign relations. On 17 December 1964, Harold Wilson clarified the situation by saying that the warheads adopted for Polaris would use materials supplied by the United States and that 'this programme would only work on an interdependent basis and not on an independent basis . . . the fact is that there is no independent deterrent because we are depending on the Americans for the fissile material for the British warhead.' Between 1968 and 1969 four Royal Navy submarines – Resolution, Renown, Repulse and Revenge – were equipped with the Polaris A-3 with 16 missiles to each boat.

When the Multiple Re-entry Vehicle emerged in 1970–71, the Royal Navy Polaris fleet was equipped with three 200 KT nuclear charges per missile, but again it should be stressed that this was not a full MIRV capability and each charge



This cutaway illustration shows pertinent design features of the SSBS S-2, France's land-based IRBM system first deployed in 1971.

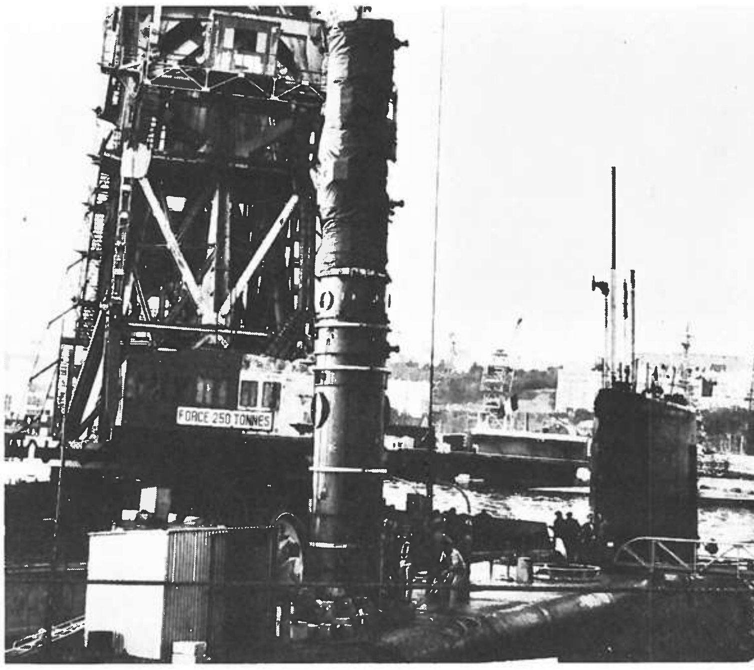
would fall within 800 metres of its neighbouring charges at the target. For strategic counting purposes, the three MRV charges per missile were considered as one warhead. Thus, the Navy nuclear-powered submarine fleet possessed 64 sea-launched ballistic missiles and this represents the total strategic missile force operated by Britain. The UK is the only non-American NATO country to deploy a strategic missile capability and makes up less than 4% of the total available number of ICBM and SLBM delivery systems in the West. The total strategic missile strike force is, therefore, 1,774 launch vehicles made up from 1,710 operated by the United States and 64 operated by the UK.

When the strategic nuclear deterrent was emerging in the United States during the early 1960's, France was a NATO member and officially committed to the deployment of weapon systems in concert with the combined requirements of the other member states. But from 1960, France was concerned at the developing philosophy of standardization; it felt that the United States was too keen to orchestrate an arms market in Europe which would lead to dependence on American technology and systems development. The political ramifications of this were in conflict with those of the French government and studies began on the proposed development of an autonomous capability, whereby French industry would develop French strategic weapons for the French defence forces. Between 1960 and 1963 the fundamental criteria were established and in the latter year the government, with General De Gaulle as President, approved the assembly of an independent nuclear strike force based on an Intermediate Range Ballistic Missile (IRBM) for the Air Force and an SLBM for the Navy. Moves on the part of the United States to tempt France into purchasing Polaris missiles had failed, as had a similar plan to develop a new NATO 2,400 km range ballistic missile with American technology.

Most of the development work for the French IRBM and SLBM systems relied on a series of existing rockets in the Agate, Topaze and Emeraude classes already discussed in the preceding chapter. The land-based IRBM, or SSBS (Sol-Sol Balistique Stratégique), was ready for operational deployment by 1971 and consisted of a two-stage solid propellant missile, the S-2, employing a quartet of gimballed exhaust nozzles in each stage. The S-2 has a range of 3,000 km and carries a single warhead with a yield of 150 KT (equal to 7½ Hiroshima bombs). By the end of 1971 two groups of 9 missiles had been set up in silos dispersed on the Albion Plateaux at Haute Provençe for a combined force of 18 IRBM's.

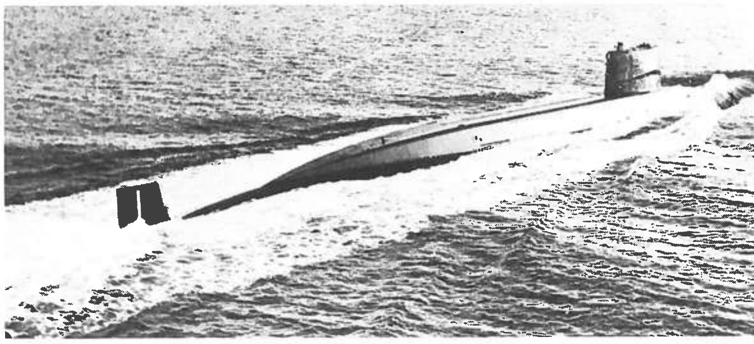
France's submarine launched ballistic missile, the MSBS (Mer-Sol Balistique Stratégique), was deployed in the specially built boat, Le Redoutable, in 1971. Called the M-1, it was a two-stage solid propellant missile with the first stage adapted from the second stage of the S-2 IRBM. The M-1 had a range of 2,500 km with a 500 KT nuclear charge, similar in performance and throw-weight to the Polaris A-1 first deployed with the United States Navy in 1960. In 1972 Le Redoutable was joined by the second MSBS boat, Le Terrible, also equipped with the M-1. Two years later a more advanced version of the missile had emerged and, called the M-2, was fitted to the third submarine, Le Foudroyant. This missile had a range of 3,000 km with the same type of warhead as that fitted to the M-1, equivalent to the Polaris A-2.

In 1976 yet another version, the M-20, emerged and this was fitted to the fourth submarine, L'Indomptable. It had a similar performance to the M-2 and differed only in the nature of the warhead: M-20 carries a single 1 MT re-entry vehicle equivalent to 50 Hiroshima bombs. By 1976 the French SLBM fleet numbered four submarines with a combined force of 64 missiles and remained at that level until the planned introduction of Le Tonnant in 1979 and L'Inflexible by 1983. With the four submarines and 18 IRBM delivery systems in silos, France reached an operational deployment of 82 strategic missiles within five years. Foreign policy of the De Gaulle administration ran counter to sustained involvement with NATO and on 7 March 1966, the President informed the United States that France was withdrawing from the alliance. Isolated politically, and even more so for military issues, the French nuclear deterrent is a wholly autonomous and independent force within Europe. The rapid development of missile technology secured third place in the space programmes of the world and fourth place in the list of nations possessing missile delivery systems with nuclear warheads.



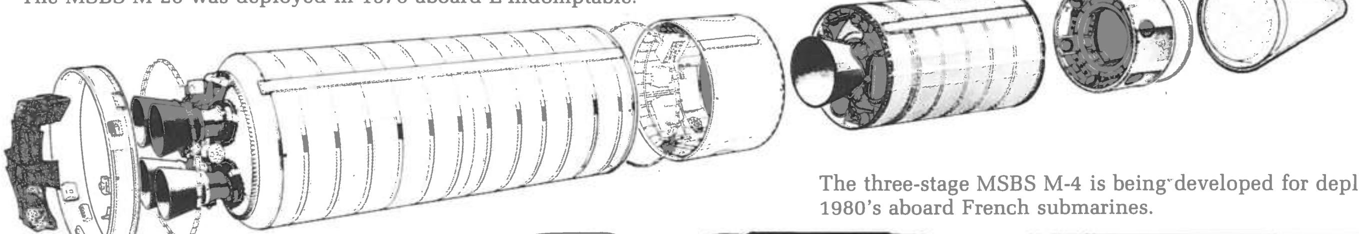
A submarine launched ballistic missile is placed in the tube of the test vessel Gymnote in Cherbourg harbour.

The first French ballistic missile equipped submarine Le Redoutable. Like all French SNLE, it can carry 16 missiles.

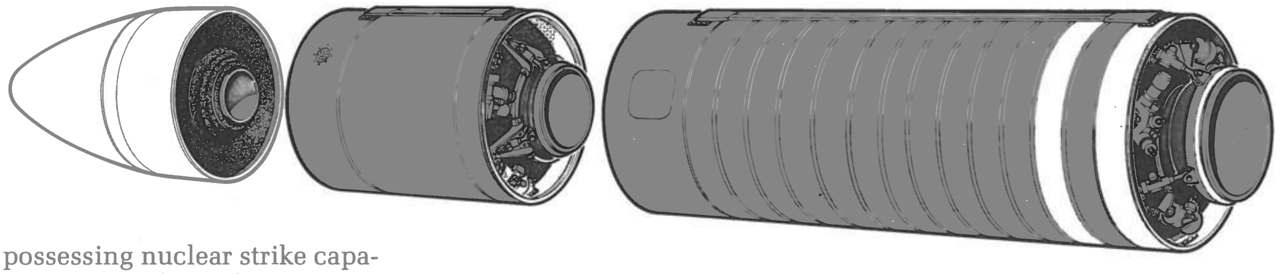


Tactical defence was supported by the introduction of the Pluton battlefield missile in 1974, a flexible delivery system capable of sending a 25 KT nuclear charge (more effective than the bomb dropped on Hiroshima) across a distance of up to 120 km. Sixty rounds were eventually deployed with five regiments. Although it is by no means certain that France would readily join NATO forces in repelling a Soviet assault on Western Europe, if only because it retains a strongly independent policy uncoupled from reliance on the massive nuclear umbrella of the United States, it is even more obvious that France would be loathe to support Russian ambitions regarding territorial incursions. With a strong proviso that France is indeed an independent military state, its 82 strategic missiles can, for the purpose of this analysis, be included with those of the US and the UK to provide a total strategic delivery arsenal of 1,856 ICBM, IRBM and SLBM delivery systems.

The MSBS M-20 was deployed in 1976 aboard L'Indomptable.



The three-stage MSBS M-4 is being developed for deployment in the 1980's aboard French submarines.

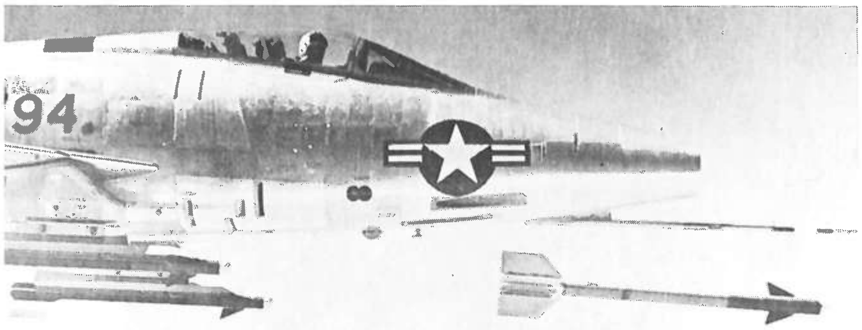


Fifth in the list of nations possessing nuclear strike capability is China, unequivocally divorced from the political ambitions of America, Russia or France. The detached, introspective philosophy of China's foreign relations have cut the country off from the integrated involvement in global strategy and while adopting a divergent form of communist rule, it has fallen out of favour with other socialist states, notably the Soviet Union. But this was not always the case and shortly after the end of World War II China obtained several Sandal missiles from Russia. From this came the first truly strategic Chinese rocket, designated CSS-1 in NATO nomenclature, with a possible range of up to 2,000 km, placing it in the category of a Medium Range Ballistic Missile. There are indications that China was deploying this weapon as early as 1966, but so far numbers have totalled less than 100. The geographical location of China ensures that missiles of this range can threaten most of India and South-East Asia, while posing little concern to the Soviet Union.

Throughout the 1960's and the early 1970's, however, friction with Russia emphasized the need for a longer range missile that could serve as a deterrent to Soviet initiatives. This resulted in the CSS-2, an IRBM class weapon with a range of up to 4,000 km carrying a 1 MT warhead. By the mid-1970's, only a few had been set up and the missile was seen as merely a precursor development leading to a truly intercontinental weapon designated CSS-3. This latter development was pursued concurrently with the CSS-2 and has a range of about 6,500 km. Deployed in the Sinkiang Province, it threatens all of the Indian sub-continent, the entire Soviet Union and most of Western Europe. The missile has a warhead in the megatonne range, but has so far been deployed in only limited numbers. Tests with an ICBM capable of reaching the United States began in 1976, but it will be several years before the weapon reaches production status.

By 1977 the concept of a turbojet powered, surface-to-surface missile, had been replaced by tactical battlefield weapons like the US Pershing and Lance, the Soviet Scud and France's Pluton. Mobility, high velocity and extreme accuracy ran counter to the performance of winged missiles like the Matador and Mace types described earlier in this chapter. But one applied development – the surface-to-air missile – increased in capability and importance throughout the 1960's and the 1970's. In 1960 the US armed forces began using the Hawk low altitude solid propellant SAM. With a two-stage propulsion system, the missile was effective against targets at a height of up to 12 km and a developed version, the Improved Hawk, had a kill ceiling of 18 km. By the mid-1970's the missile was in operation with the armed forces of the United States, Germany, France, Italy, Denmark, Holland, Belgium, Sweden, Israel, Spain, Japan, Saudi Arabia, Korea, Greece, Iran, Thailand and Kuwait. Hawk is guided to its target by two acquisition radars which cover low and high altitude objectives. In Britain, the Bloodhound and Thunderbird missiles continue to provide long range and high level air defence, while the Rapier, a very low level SAM system, has emerged as an efficient and highly effective weapon adopted for use by Iran, Zambia, Oman, Abu Dhabi and Australia. Carried in converted Land Rovers, the Rapier has been developed for use with a tracked vehicle based on a US design.

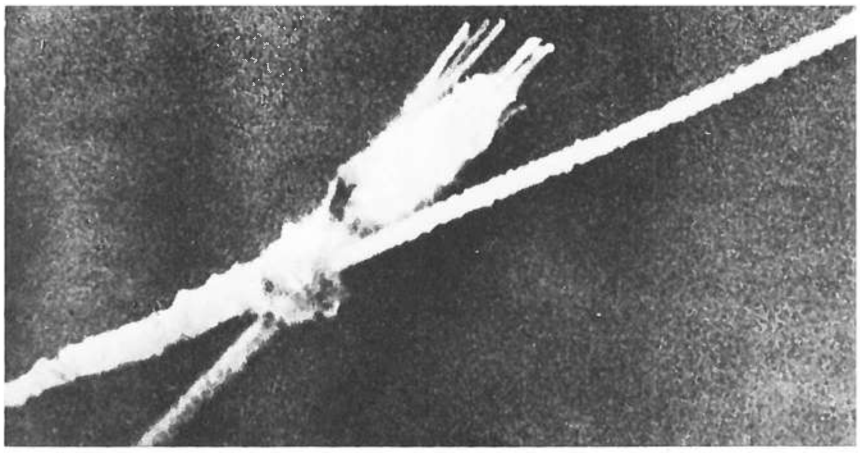
Soviet interest in SAM development stems from their geographically vulnerable position and by the mid-1950's the National Air Defence Command (NADC) began deployment of the first-generation, surface-to-air missiles: SA-1 Guild, a solid propellant weapon with a ceiling of 20 km. The next SAM development, SA-2 Guideline, has been deployed extensively at home and abroad with more than 12,000 rounds delivered to the NADC. It has a ceiling of 28 km and can carry a small nuclear charge. Developed concurrently with Guideline, the SA-3 Goa has seen service in Vietnam and the Middle East. It is designed as a low altitude defence system. The SA-4 Ganef is a mobile system effective against medium-altitude targets and employs ramjet propulsion, with four strap-on solid propellant boosters. As a replacement for the Guideline, SA-5 Gammon employs solid propellants for a kill ceiling of 30 km and a slant range of up to 200 km. SA-6 Gainful is the second Soviet SAM to employ ramjet propulsion and is used for low level air defence with a radar-homing capability. The SA-7 Grail is a solid propellant missile fired from the shoulder, with a length of 1.3 metres and a weight of 9 kg. It has infra-red homing and a slant range of nearly 4 km. (Infra red rays being emitted from a heat



A Sidewinder is caught milliseconds into its flight following launch from an F-100 Super Sabre during air superiority training exercises.

A Phoenix missile is seen here attached to the wing of an F-111B in a hangar at Edwards Air Force Base.

Air Defence troops sprint toward a Soviet SA-2 Guideline surface-to-air missile during an exercise in 1965.



The destructive capability of a surface-to-air missile is visibly demonstrated in this Soviet view of a direct hit during tests in 1965.

source such as the exhaust of a jet aircraft or even a stationary metal structure, standing in a relatively high ambient temperature.) Mobile air defence is the key to surprise attack from unknown launch positions and SA-8 Gecko and SA-9 Gaskin are carried on vehicles for low level, short-range interception.

There has been little opportunity to observe the operational viability of battlefield weapon systems in the SAM category – Korea broke into conflict before the extensive deployment of surface-to-air missiles and the technological imbalance in South-East Asia prevented military equivalence in Vietnam. The Middle East, however, had provided a classic example of how effective a SAM system can be in changing the fortunes of war. During the Six-Day war of June 1967, Israeli air strikes on Egyptian defence positions proved decisive. Only a limited number of Soviet Guideline SAM's had been deployed and low level attack on Egyptian airfields, coupled with rapid thrusts across the Sinai by ground forces, disabled the enemy and cleared the skies; in the first two days more than 400 Arab aircraft were destroyed before they could take off. Six years later, when Egypt and Syria took the initiative and attacked Israel, the situation was very different.

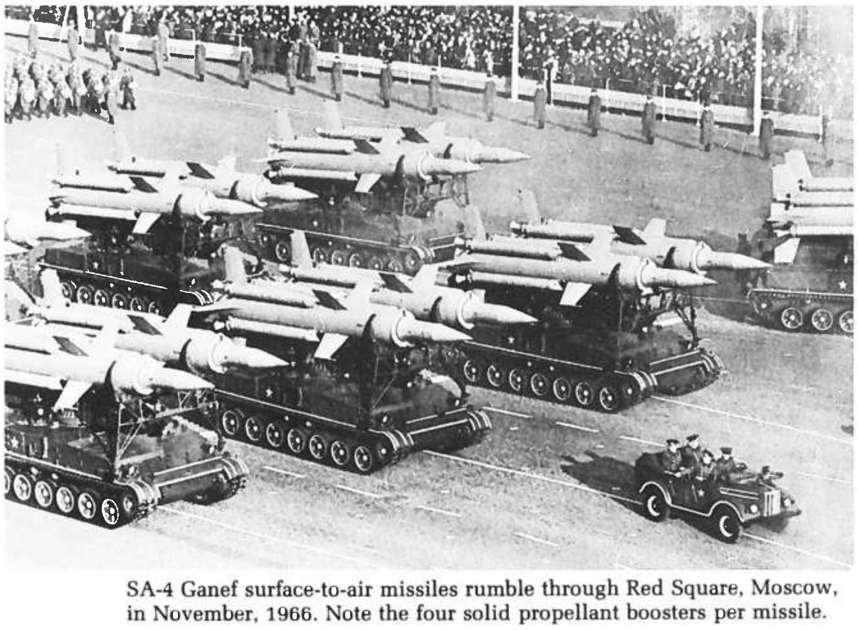
Large numbers of SA-2, -3 and -6 SAM's had been set up on the west bank of the Suez Canal and Egyptian forces moved rapidly across the Canal and into Sinai under the umbrella of missile cover. Denied the air supremacy they had so efficiently exploited in the Six-Day war, Israel was hard pressed to repulse the Arab armoured columns thrusting east from Egypt and west across the Golan Heights from Syria. It was a classic case of an efficient weapon system frustrating superior fighting qualities and the lessons from the October 1973 war have been applied by many developing nations to their emerging defence capabilities. An important requirement for the 1980's will be the development of an anti-SAM capability whereby an intruder can suppress hostile SAM sites before coming within range of the offensive ground based defence system.

Development of air-to-air missiles has provided enhanced capabilities epitomized by the Hughes Phoenix. With a range of more than 200 km, Phoenix is standard equipment on the Grumman F-14 carrier-based fighter. Operated in conjunction with a unique fire-control system, the F-14 can observe and track up to 24 separate airborne targets simultaneously and fire 6 Phoenix missiles at 6 independent targets. In the mid-1950's many experts felt that manned fighter aircraft would be obsolete in an age of missiles. Instead, the developments of the past two decades have demonstrated a successful marriage between the missile and conventional aircraft.

While much attention has been given in public to the development and deployment of strategic missiles in the MRBM, IRBM, ICBM and SLBM categories, there is one class of rocket powered weapons that plays an equally important role and yet seems to have been largely ignored by both the popular press and the public at large. This is the air-to-surface missile which has been called a stand-off bomb and an Air Launched Ballistic Missile (ALBM) according to specific characteristics of the design envelope. Development of the first two stand-off bombs got under way in the United States and Great Britain in 1957 under the project names Hound Dog and Blue Steel respectively. The former was a turbojet powered missile carried under the wings of a B-52 bomber. It could cruise at Mach 1.6 (1.6 times the speed of sound) to its target more than 1,000 km away with an impressive warhead containing a 4 MT nuclear charge. Blue Steel was designed for the emerging generation of V-bombers and employed a Bristol Siddeley Stentor rocket motor burning peroxide and kerosene. The missile carried aerodynamic control surfaces and like Hound Dog, would fly a horizontal course in the atmosphere after release. Blue Steel had a range of about 350 km and, like Hound Dog, went into service in 1960.

But these two developments were the precursor to a more sophisticated concept proposed by the United States, called Skybolt, a truly Air Launched Ballistic Missile. Preliminary studies on this solid propellant two stage missile indicated that extant technology could produce a weapon with a range of 1,850 km carrying a 2 MT warhead at Mach 9. Contracts went out to industrial companies, but within five years the project had been scrapped. Changes in strategic policy dictated that the manned bomber was unlikely to survive deep penetration of hostile airspace at high altitude; the US Air Force had failed to keep pace with current thinking on deep penetration capabilities and while Skybolt had an impressive performance, it was designed to be carried by the subsonic B-52 at high altitude. Considerable effort had gone into the development of strategic delivery systems like Atlas, Titan, Minuteman and Polaris at the expense of the third arm of the triad: the manned bomber force.

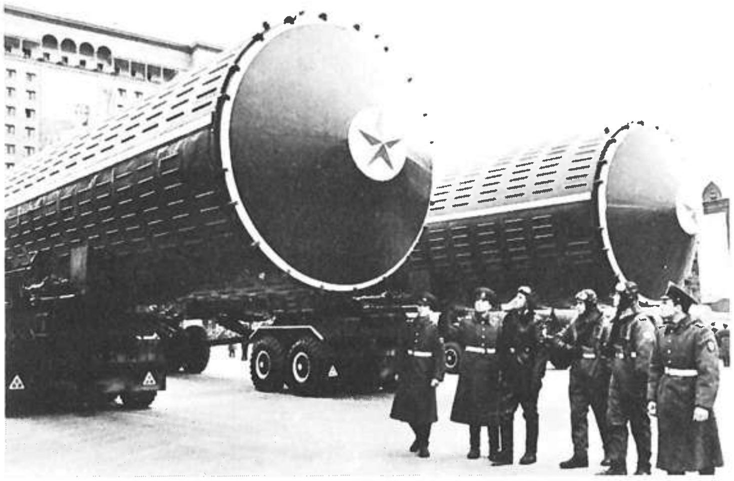
By the mid-1960's the US Air Force had come to terms with the new requirements and in October 1966, the Boeing



SA-4 Ganef surface-to-air missiles rumble through Red Square, Moscow, in November, 1966. Note the four solid propellant boosters per missile.

SA-5 Gammon surface-to-air missiles employ solid propellants throughout with each missile carried on an articulated trailer.

A Guideline surface-to-air missile is given scale by the soldier in the foreground and should be compared with the view on page 184.



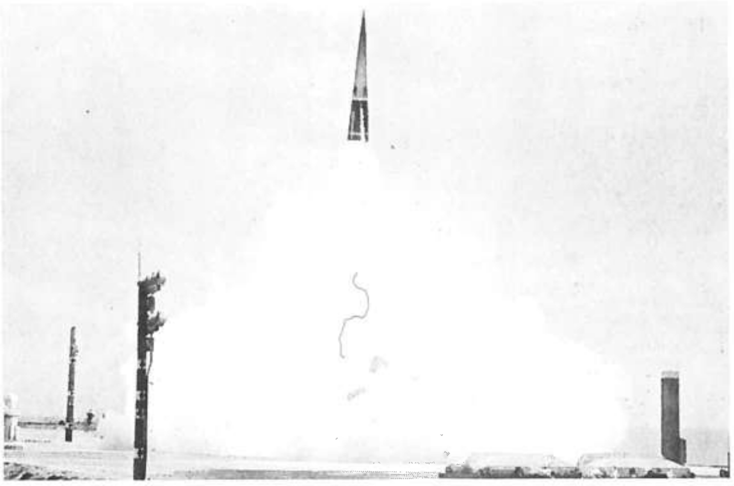
Inside these ribbed containers are Soviet ABM's code-named Galosh. There are 64 such missiles in site locations around Moscow.

Company was awarded a contract for design and development of the so-called short Range Attack Missile, or SRAM, a weapon which would have a range of 160 km and carry a 200 KT nuclear charge. Designed from the outset to follow a variety of possible trajectories from a low-flying B-52 approaching, and penetrating, hostile air defences, SRAM was tested in powered flight for the first time in July, 1969. By March 1972, the first production model was delivered to the Air Force and within less than 3½ years, all 1,500 rounds had been deployed for use on B-52 and FB-111 aircraft. The B-52 can carry a maximum of 20 SRAM's while the faster FB-111 has provision for six.

Although the Boeing AGM-69A SRAM is only 4¼ metres long and weighs a mere 1 tonne, it contains a unique propulsion system designed to accommodate a two-phase burn cycle. The first period of burning, or pulse, is fixed for all types of SRAM trajectory and is terminated by a thermal barrier. If the missile is programmed to fly a ballistic trajectory, similar to that employed by larger missiles launched from the ground or submarines, the second period of burning begins 1½ seconds after termination of the first; if the SRAM is required to fly a low, shallow profile to the target, the second pulse can be delayed for up to 80 seconds. This concept is akin to a two-stage missile with conventional technology, but it is the only restartable solid propellant rocket motor currently in operation, with both charges placed in tandem within a common case.

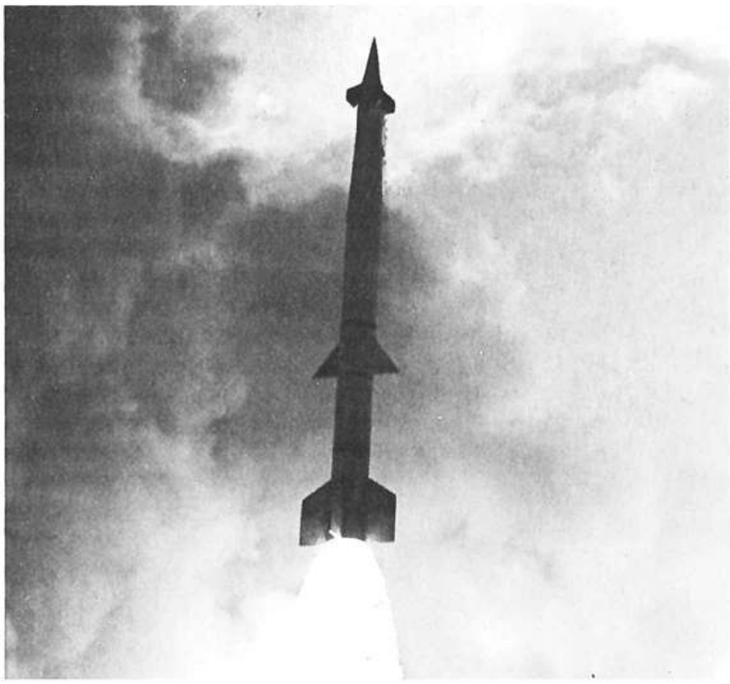
SRAM can be employed to penetrate prohibitively effective air defence screens and reach strategic targets, because it carries an all-inertial guidance system, making it almost impossible to stop, and a terrain-avoidance radar for very low level flight at speeds in excess of Mach 3. It can also be used to saturate heavy air-defence screens so that other B-52 and/or FB-111 bombers can penetrate Soviet airspace and deliver other SRAM's, or free-falling bombs, on selected targets. Alternatively, a mixed load of SRAM and other weapons can be employed to provide the B-52 with a capability of clearing defence systems from its path; SRAM can be programmed to fly left or right of the carrier aircraft, or to fly fast ahead of the subsonic bomber and clear away the anti-aircraft networks. The retention of a viable and effective manned bomber force is an important, if not essential, element of modern strategic warfare and an enhanced survival capability ensures full flexibility. The manned bomber, armed with SRAM or some other equally effective saturation weapon, presents a formidable problem to potentially hostile countries and ensures that measured response to a fast moving war scenario can harass and obstruct the strategic intentions of an enemy. Moreover, manned weapon systems have an efficient recall capability and a capacity for flexible response denied to the denizens of total war, buried in silos and submarines.

It is the very essence of nuclear deterrence that global war is seen to be both unwinnable and totally destructive for the host as well as the recipient; automated systems can be overcome by technical means, but the manned weapon system is both cunning and responsive in the face of a rapidly changing mode of conflict. Soviet developments in this field began with the introduction of the AS-1 Kennel in the early 1960's, but the missile used a turbojet propulsion unit and had a range of only 100 km. Employed on anti-shipping duties, it was followed by the AS-2 Kipper with a range of about 200 km, but still employing a turbojet as did the AS-3 Kangaroo with a range of 650 km. The AS-4 Kitchen appeared in 1967 and adopted a liquid propellant rocket motor with a range of at least 300 km. With inertial guidance it is a much more effective weapon than any of its predecessors. The AS-5 Kelt is employed as a replacement for the Kennel and adopts a liquid propellant motor for a range of 320 km at subsonic speeds. The final air-to-ground weapon of strategic importance employed by the Soviet Union, the AS-6 Kingfish, uses a solid propellant motor to achieve a range of 220 km at speeds of Mach 3 for strike missions against targets on land or at sea.



With an acceleration of 100g, a Sprint ABM is seen leaving its silo. The missile was designed to destroy warheads that escaped interception by Spartan and as such was an endo-atmospheric weapon.

The most ambitious application of a surface-to-air role was the antiballistic missile concept. Here, a US Spartan missile accelerates away during a test launch. It would provide exo-atmospheric defence against incoming warheads.



B-52 bombers of the US Air Force Strategic Air Command can carry 20 Short Range Attack Missiles, 8 internally and 12 under the wings. SRAM is an impressive extension of the bomber, itself only one element of the triad comprising manned aircraft, land-based missiles and submarine launched missiles.

By early 1972, the Russians indicated a genuine willingness to discuss the terms by which an agreement could be drawn up to limit the further expansion of the strategic weapons inventory held by the Soviet Union and the United States. After considerable negotiation under the terms of the Strategic Arms Limitation Talks, the President of the United States, Richard M. Nixon, and the Secretary General of the Communist Party, Leonid Brezhnev, signed the SALT-1 accord on 26 May 1972. In eight years of power, Brezhnev and Kosygin had transformed the military preparedness of the Soviet Union and exerted remarkable efforts to provide the armed forces with a truly global capability. Exploiting the prolific array of new missiles which appeared between 1965 and 1969, the Strategic Rocket Forces rose to new levels of importance and influence. Technical developments toward the end of the 1960's had improved the accuracy of ICBM class weapons, posing a direct threat to the Titan and Minuteman missiles stored in silos in the United States.

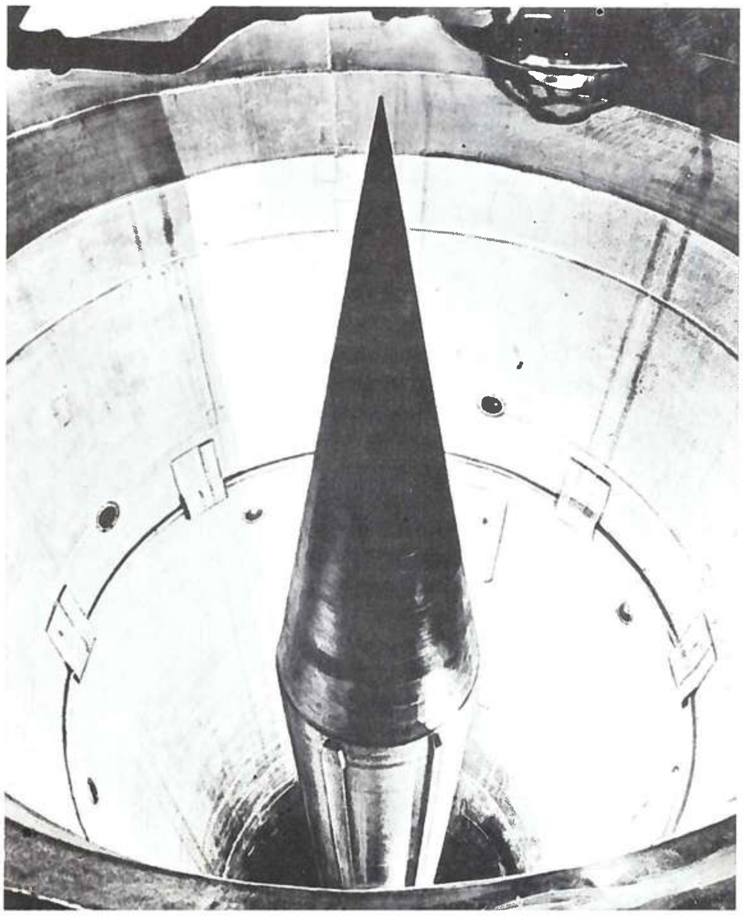
As the recipient of a considerable amount of money from the early 1960's, one missile category was seen to flounder on the colossal expense associated with its deployment: the Anti-Ballistic Missile, or ABM. The concept envisaged a network of solid propellant missiles that would be capable of intercepting incoming warheads. Two missiles were developed in the United States – Spartan for long-range defence and Sprint for short-range interception – but the SALT-1 accord limited deployment to two sites, each equipped with 100 missiles. Cost was an even more debilitating factor and the last ABM site was deactivated in 1975. The Russians, meanwhile, deployed 64 ABM missiles of the Galosh type around Moscow. Full details of US and Soviet ABM equipment is contained in the Compendium.

Although not as accurate as the US ICBM's, Soviet throw-weight was increasing with alarming haste. Nearly 300 Scarp heavyweight ICBM's were deployed, along with more than 100 Saddler and Sasin missiles. All three were in the Titan 2 class and capable of carrying warheads with 5–25 MT yield; deployment of 54 heavyweight Titan 2 ICBM's had been frozen several years before. Not only had the Soviet Union continued to deploy strategic missiles while the US total had been restrained; tests with MRV warheads were threatening to presage development of a Soviet MIRV capability. But haste on the part of the negotiating team, led to US concessions that should never have been approved, leaving the United States in an inferior position with respect to the Soviet Union.

Under the terms, each side would be limited to the number of ICBM missile launchers it had in construction as of 1 July 1972. This left the United States with the 1,054 reached in 1967, while the Russians could proceed to emplace up to 1,500. It was said that the technical superiority of American ICBM's, with more sophisticated MIRV warheads and greater accuracy ensuring a higher probability of silo destruction, compensated for the superiority in numbers presented by the Soviet force. The Russians did not argue the point and proceeded to introduce a range of technical improvements in the years after SALT-1. With regard to submarine-launched ballistic missiles, Kissinger had agreed to permit Russian force levels to grow to include a maximum 950 SLBM's on no more than 62 submarines; the total deployed force prior to SALT-1 was about 450 missiles. For their part, the US SLBM force was constrained to 710 missiles on 44 submarines and existing totals were already 656 Polaris A-3 and Poseidon in 41 boats.

In the language of the accord, both sides would be limited to 2,400 launchers, which included ICBM's, SLBM's and manned bombers in this number. Because of the agreed limitation on silo numbers, it was felt that this would effectively prohibit continued expansion of force capability, but imme-

This Soviet ICBM in its underground silo amply demonstrates the hot-launch concept, where the engines are ignited at the bottom of the silo. A cold-launch capability, where the missile is ejected by compressed gases before ignition, could be provided by installing a larger missile in the same silo.



diately after the treaty was signed, the Russians moved ahead with development of a cold-launch concept. Whereas existing silo-launched ICBM's used the hot-launch technique, with ignition of the first stage at the bottom of the silo, the cold-launch method ejected the missile with compressed air for ignition above the surface. This meant that existing silos could accommodate bigger missiles because there would be no need to provide space between the sides of the missile and the walls of the silo for the escape of hot gases from the exhaust nozzles of the rocket motor. In this way the Russians were able to upgrade the throw-weight of their ICBM's, allowing larger warheads or more MIRV charges to be carried by each delivery system, while staying within the limitations of the agreement. Moreover, because a silo would not receive the damage incurred by the hot-launch technique, ICBM's could be stored in discrete locations and loaded into the same silo within hours of the first launch. This opened up the possibility of secretly increasing the actual number of available ICBM's, while retaining the number of emplaced silos allowed by the agreement. It was a flagrant violation of the intentions of SALT-1, but one which remained within the legal language of the accord. Also between 1973 and 1976 the Russians introduced a range of third-generation strategic missiles which considerably enhanced the throw-weight and the accuracy of respective categories analyzed during the SALT-1 negotiations.

By 1973 the SS-16 appeared as a mobile replacement for the Savage, first deployed in 1968 in small numbers as a silo-launched ICBM. The SS-16 was capable of adapting to mobile or silo roles, but it had twice the throw-weight of Savage and a performance capability in range and warhead yield closely approximating that of the American Minuteman missile. Also, in 1973, the Soviet Navy began deployment of the SS-N-8, discussed earlier, which upset the force assumptions used during SALT-1 when US negotiators permitted more Russian SLBM launchers than retained by the American Navy.

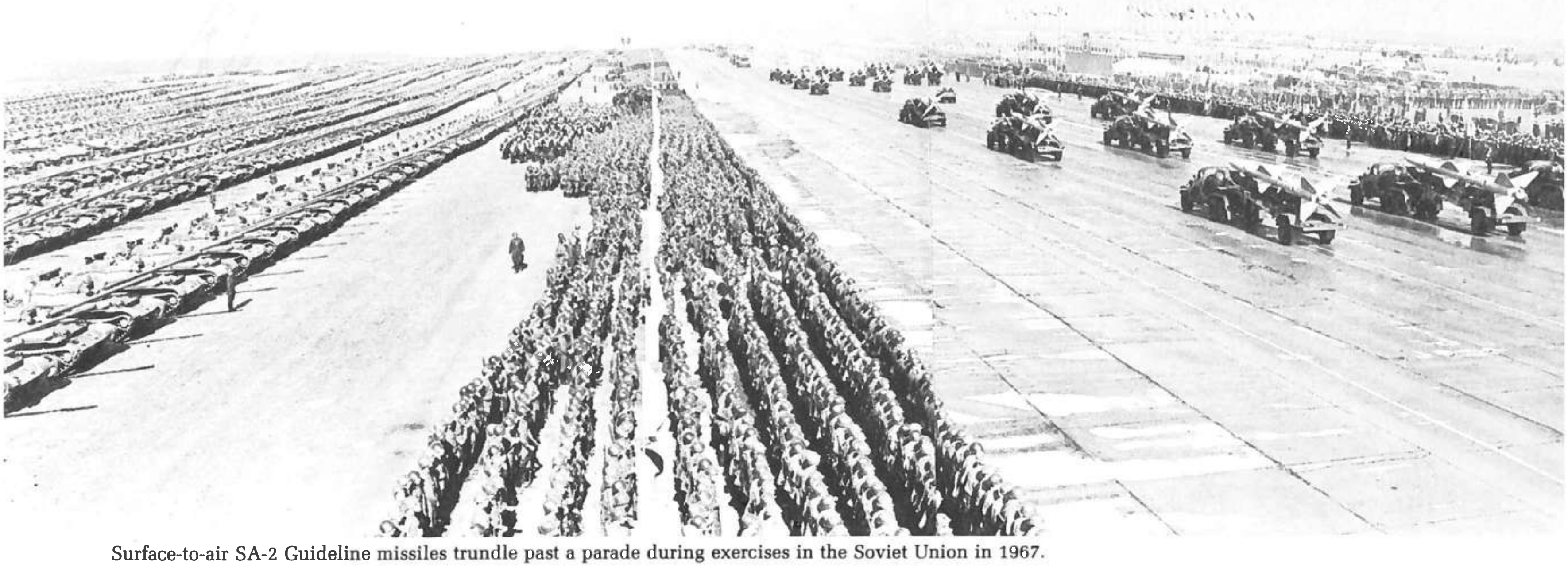
In 1975 the SS-17 was introduced as a replacement for the Sego, the latter accounting for 75% of the land-based strategic missile force. But SS-17 had three times the throw-weight of Sego and carried four MIRV charges, making it a more formidable weapon than Minuteman. Using the same silos employed for Sego, the SS-17 adopts the cold-launch method and thereby moves to deployment in the existing facilities allowed under SALT-1.

A year after SS-17 emerged from clandestine development, the Strategic Rocket Forces began to replace their super-heavyweight ICBM, the Scarp, with the SS-18. This is designed for cold-launch from existing Scarp silos and has an incredible throw-weight capability. Whereas Scarp can carry a single 25 MT warhead or up to 3 RV's of 5 MT yield each, the SS-18 can carry up to 10 fully MIRVed charges each with an explosive yield of 2 MT. Accuracy is also improved from a c.e.p. (circular error probability, or the radius of a circle centred on the target within which 50% of warheads are expected to fall) of 2.8 km for Scarp, to just 450 metres for the SS-18. Even a 1 MT warhead will destroy a silo if it detonates within a distance of 650 metres.

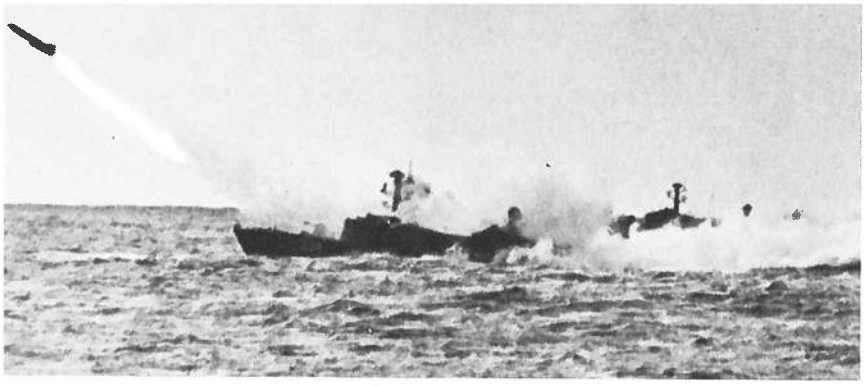
A nuclear warhead is gently lowered to the upper stage of a missile already emplaced in an underground silo. Soviet views of this activity are rare.

By the time SS-18 was moving into Scarp silos, the SS-19 was brought into operational use as a companion to the new S-17, both of which fill a strategic role hitherto played by the Sego. But whereas Sego has a c.e.p. of 1.3 km, the SS-19 is accurate to within 450 metres and has a throw-weight more than four times that of the missile it is designed to replace. In each case, the new generation of ICBM's introduced only after the SALT-1 accord had been ratified, substantially improve the role of respective categories; the incredible burst of technological activity evidenced by SS-16 to SS-19 had its origin in the years immediately preceding SALT-1 and only after the agreement had been signed, did the Soviet Union rapidly deploy these new missiles, remaining within the language of the accord, but boldly contravening the intent.

The most subtle product of this new and expanding phase of technical development is the SS-20, a missile made up from the first two stages of the three-stage SS-16. It is designed to operate as a mobile weapon, but a decision as to whether it ranks as an intermediate or intercontinental range missile depends on the selected choice of warhead. With a single 1.5 MT warhead it can cover every corner of Western Europe and the Middle East or, with a 50 KT warhead, could fly to the United States. It is arguable whether the SS-20 could be covered by strategic arms talks as the Soviets claim that the missile is an intermediate range weapon and consequently outside the scope of such negotiations. Apart from the mobile SS-16 and SS-20, all third-generation Soviet ICBM's have the



Surface-to-air SA-2 Guideline missiles trundle past a parade during exercises in the Soviet Union in 1967.



A Soviet patrol boat launches a Styx missile. Missiles of this class were used to sink the Israeli destroyer Eilat in 1967 and have been used by the Chinese in engagements off South Vietnam and by Arab forces in the October 1973 war.

ability to carry fully MIRVed warheads, with each charge deployed to a target several tens of kilometres from its neighbours. Before SALT-1, not a single Soviet missile had a MIRV capability and yet within four years of the agreement, six replacement missiles had been introduced, including the SS-N-8 SLBM, four of which were designed to accommodate multiple independently targeted warheads.

Poised to exploit the advantages of MIRV technology, the Russians have demonstrated a pronounced disregard for the containment of strategic capability. The important issues centre on the MIRV problem, since warheads, not rockets, would be responsible, for target destruction; within the agreed maximums relevant only to specific numbers of missiles, SALT-1 left open the question of warhead numbers. That void is being fully exploited by the Soviet Union, while the United States maintains existing numbers. By early 1977 the growth in Soviet strategic capability had reached ominous proportions. With the largest naval force ever assembled in history, and conventional forces equipped with weapon systems far beyond the range necessary for pure defence, Russian aspirations were seen to embrace the global capability envisaged by Brezhnev and Kosygin when they came to power in 1964. Cursory examination of the force levels maintained by America and Russia incite alarming conclusions.

In the heavyweight ICBM class, the United States maintains 54 Titan 2 missiles each with a 5–10 MT warhead: 54 nuclear charges with a c.e.p. of about 920 metres. As of early 1977, the Soviet Union had 140 Saddler, 19 Sasin, 264 Scarp, 36 SS-18 and 100 SS-19 missiles in the heavyweight ICBM class: 1,059 warheads (on 559 missiles) with c.e.p. accuracy from 2.8 km down to 450 metres. Put another way, total US heavyweight ICBM explosive yield was 540 MT (27,000 Hiroshimas) compared with a Soviet total of 8,595 MT or 429,750 Hiroshimas. Thus the combined explosive yield of the US heavyweight ICBM force is only 6.3% that of the Soviet Union.

In the category of medium to light land-based ICBM's, the United States has 450 Minuteman II's, each of which carries a 1 MT warhead, and 550 Minuteman III's each with 3 MIRV charges of 170 KT. This provides a grand total for the 1,000 missiles of 2,100 nuclear charges with a combined explosive yield of 730.5 MT (36,525 Hiroshimas). In the same category, as of early 1977 the Soviet Union had 910 SS-11, 60 SS-13 and 20 SS-17 missiles: 990 launchers, 1,050 nuclear charges and a combined explosive yield of 1,896 MT or 94,800 Hiroshimas. Here again, the combined explosive yield of US ICBM's, in the light to medium category, is much lower than that of the Soviet Union: the US total being only 38.5% that of Russia. But although the Russians have 99% of the number of missiles in this class deployed by the United States, they have only 50% the equivalent US number of nuclear charges. This is a direct result of the late introduction of a Soviet MIRV capability and will alter significantly as fourth generation ICBM's are introduced by the early 1980's.

Grouping all the land-based ICBM's of the two classes together, however, shows that the United States has 1,054 missiles with a total of 2,154 separate nuclear charges and a combined explosive yield of 1,270.5 MT (63,525 Hiroshimas). The Soviet Union, on the other hand, has 1,549 missiles, 2,109 nuclear charges and a combined explosive yield of 10,491 MT or 524,550 Hiroshimas. Thus with only 50% more missiles and slightly fewer warheads, the Soviet throw-weight equivalent for the land-based ICBM force is more than eight times that of the United States. But, as related earlier, the number of multiple warheads will grow as SS-18 replaces Scarp, the former carrying up to 10 separate charges versus the single warhead used by Scarp. The United States is already inferior to the Soviet Union in the number of missiles and the combined throw-weight; it will not be long before the available number of warheads are substantially less than those possessed by the Soviet Union. Since warhead numbers equate to potential targets the consequences are obvious.

But force levels do not stop at land-based ICBM's and one area where the United States is still superior is in the physical number of submarine-launched warheads, although here too the combined megatonne yield, as well as missile number, is dramatically inferior to the Soviets. By early 1977 the Soviet Navy was equipped with 18 SS-N-4 (range 1,300 km), 60 SS-N-5 (range 2,400 km), 544 SS-N-6 (range 3,000 km) and 220 of the new SS-N-8 (range 7,800 km) missiles. Each carries a single warhead, or a cluster of 3 MRV's at most, of about 1 MT yield so the total Soviet SLBM force boasted 842 missiles, 842 warheads and a combined explosive yield of 842 MT or 42,100 Hiroshimas. By comparison, the US Navy operated 208 Polaris A-3 (range 4,600 km) and 448 Poseidon (range 5,200 km) missiles, or 656 in total. Each Polaris was fitted with three 200 KT warheads in a Multiple Re-entry Vehicle which is classed as a single unit, because they fall as a cluster on one target. The Poseidon, however, carries 10 MIRV warheads of 40 KT yield, an earlier plan to fit 50 KT warheads having been dropped. With each MRV cluster counting as a single warhead, and the Poseidon MIRV's counting as separate warheads, the total US SLBM warhead count equals 4,688 with a combined explosive yield of 304 MT (15,200 Hiroshimas). In the category of submarine-launched ballistic missiles, the Soviet Union had nearly three times the equivalent explosive yield as the United States with 28% more launchers but only one-fifth the number of warheads.

The grand total for all land-based and submarine-launched ballistic missiles of a strategic nature reveals that the United States has 1,710 missiles, 6,842 warheads with a combined yield of 1,574.5 MT (78,725 Hiroshimas); the Soviet Union has 2,391 missiles, 2,951 warheads and a cumulative yield equal to 11,333 MT or 566,650 Hiroshimas. When combined with the four Royal Navy Polaris boats, the NATO force level increases to 1,774 missiles, 7,226 warheads and a combined yield of 1,589.86 (79,493 Hiroshimas); each Royal Navy Polaris is now fitted with 6 MIRVed warheads yielding 40 KT.

In a total war situation, the NATO forces would have authority over 42.6% of the missiles, 71% of the warheads, but only 12.3% of the yield available to both sides. The Soviet Union would be substantially better off in the potential destructive power of its strategic strike force, have a superiority in the number of missiles it could lose and still be left with, yet hit only 41% of the number of targets that the United States could hit. The two areas where the United States is seen to be inferior – number of missiles and throw-weight – are the most expensive to redress by conventional force increase criteria: both would require costly new development programmes and a substantial committment to larger and more powerful missiles.

The area where the Soviet Union is inferior, however, is comparatively easy to change. By progressively phasing in MIRV warheads, the total warhead count goes up and, with a larger number of missiles available in the first place, the potential number of targets rises accordingly. The only reasonable alternative to continued escalation is the availability of a missile system which can never be destroyed, even by a pre-emptive first strike. The argument in favour of large numbers of missiles and warheads cites the example that in a first strike situation the hostile nation would be in an advantageous position to knock out the silos of the enemy before he could launch in retaliation. But if the recipient of a first strike had a totally impregnable inventory of launchers, a first strike would be foolhardy and pointless since it would do nothing to degrade the opportunity of the recipient to fire back with his full force of missiles. This sounds like a utopian scenario where strategic deterrent is literally just that, instead, the current situation makes it increasingly plausible for the Soviet Union to initiate a pre-emptive first strike and win.

Nevertheless, studies under way in the United States have proved the feasibility of a concept which promises to make invulnerable a large part of the land-based strategic missile force.

This is a part of the MX Advanced ICBM Technology Programme which began in the early 1970's and originally envisaged air-launched ballistic missiles or simply replacement rounds using more advanced technology than that employed by the Minuteman force. Several modernization programmes have been introduced since Titan 2 and Minuteman were first introduced: the Titan 2 silo design has been changed to one where the big missile vents its exhaust through a single tunnel, dispensing with the need for two channeled exhaust ports, and Minuteman silos have been strengthened to resist a close nuclear detonation. In spite of these improvements the decreasing c.e.p. value of Soviet ICBM and SLBM types causes grave concern for the future survivability of the US land-based force. MX is now envisaged as a deployed system coming close to the concept of total concealment, essential in the light of Soviet developments.

Two methods are under analysis. In the first, called the shelter-based concept, MX missiles would be moved by transporters doubling as launchers between a number of widely dispersed shelters. Other shelters would be filled with dummy missiles so that a first strike would have to eliminate every known shelter to ensure the destruction of the live rounds – an almost impossible situation to accommodate in any conceivable strategic plan. The second method, called the trench-based concept, would utilize an underground tunnel dug a few metres beneath the surface and running for between 18 km and 30 km along a circuitous route. A track on the floor of the tunnel, suitably lined with moderate 'hardening' to resist earth movements generated by nuclear detonation, would support a cylindrical transporter consisting of a horizontal MX missile, hydraulic jacks and blast protective plugs at each end. While the Soviets would be able to accurately chart the route of the tunnel, possibly during excavation, they would never know at what point along the tunnel the missile was located. When the order came to fire, the hydraulic jacks would raise the forward end of the cylindrical transporter containing the missile, break through the earth and erect the weapon for immediate launch. In this way the MX system would ensure that a pre-emptive first strike had very little chance of eliminating the encapsulated missiles, thereby rendering it a less viable proposition.

An objective analysis of the potential war scenario for the mid-1980's, the earliest time that an MX system could be in place and operational, shows that the Soviet strategic missile force will probably total 900 heavyweight ICBM's, all equipped with MIRV warheads. Based on a matrix of ICBM's, SLBM's and manned bombers operated by the United States, the balance between an obvious advantage in striking first and a certain disadvantage in an undeclared assault, evens out when each side has 200 MIRVed missiles. But this assumes no MX deployment and further extrapolation reveals that the strongest incentive for a Soviet first strike comes when each side has between 700 and 850 MIRVed launchers – the number the Russians are expected to have by 1985. If MX is factored into the equation, however, it reveals a strong incentive for the Russians to strike first with anything less than 100 of the new missiles. Beyond a force level of about 300 the United States has a decided advantage in a first strike situation and so the obvious conclusion is drawn that a deployed force of between 100 and 300 missiles of the mobile MX type will ensure that neither side has the advantage of a first strike option throughout the 1980's.

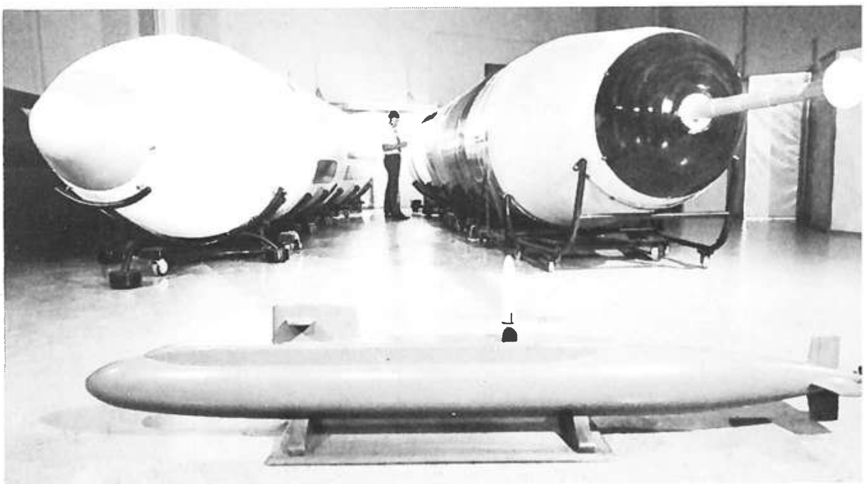
As it is, in the period up to at least 1985, the United States would have to expend 75% of its ICBM force to destroy half the Soviet strike capacity based in silos. For its part, the Soviet Union could now disable half the US ICBM force with only 15% of its own land-based inventory and, with expected growth brought about as a result of the new range of Soviet ICBM's, by 1985 Russia would be required to use only one-third of its total ICBM force to virtually eliminate the US land-based strike capability. If discussions between Soviet and American negotiators are ever to provide a climate within which the strategic offensive capabilities of the two superpowers can be reduced, and the threat of total war eliminated, it can only start from a posture of force parity. Several incidents in the decades since the end of World War II have made it all too obvious that, but for the threat of escalation into nuclear conflict, the machinations of extremist groups would have moved toward major conflict resulting in millions of dead.

Concerted efforts by the Soviet Union to protect its citizens from the ravages of nuclear war have brought about a situation where, if full evacuation to shelters is accomplished, Soviet dead would number less than 10 million in the event of total war. Against this the United States would expect to suffer more than 160 million dead in a Soviet strike aimed at industrial sites. This figure rises to more than 170 million US dead in an attack aimed primarily at the population. Without shelter or adoption of the active civil defence activities developed by the Russians, Soviet dead would number about 150 million in a total nuclear war. It is not possible to withdraw from the reality of these figures if the implications are to be avoided. Only by turning away from the sad facts of strategic rocket development will the situation continue to move towards a dangerous imbalance where the Soviet initiatives become not only plausible, but inevitable.

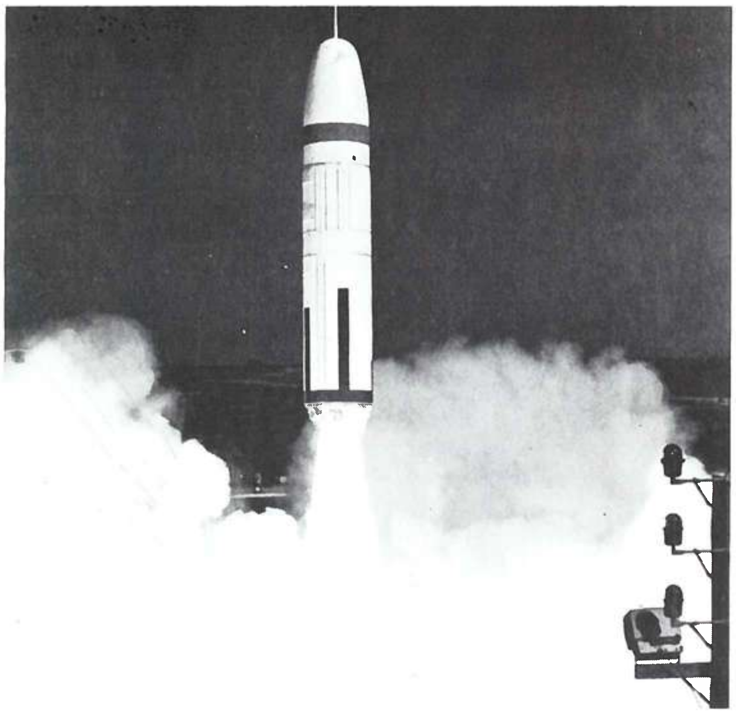
Political control of the defence budgets of the United States has been hampered by the democratic process of public accountability, where the tax-payer demands full and unexpurgated access to the products of his or her social investments. The Soviet Union has no such responsibility to its people and the steady 3–5% growth in weapons development and procurement over the past few years, is an example of indigenous resource manipulation by a few politicians. It would be foolish to believe that the Russian people would readily accept nuclear war as an inevitable product of the ideological ambitions of a few leading personalities; it would be equally foolish to accept the notion that foreign policy structured in the Kremlin eliminates the possibility of threatening less powerful states to the point where military intervention becomes inevitable.

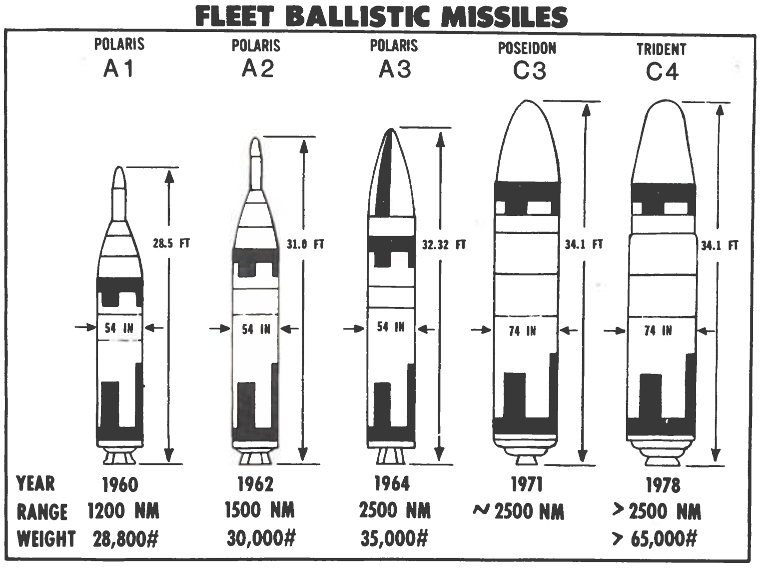
The past ten years have seen a dramatic upward surge in the force strength levels of the Soviet Union and based on the lessons of the past, where no major military development has been left unused, it is axiomatic that the day will come when the strategic nuclear arsenals are no longer left as pure deterrents. It is imperative that force equivalence is maintained, at least until agreement can be reached on the limitation of total strategic offensive capability.

Planned developments for the early 1980's will provide the United States with an enhanced capability in the field of submarine-launched ballistic missiles. Called Trident, the programme encompasses new missiles and new submarines, with each boat carrying 24 Trident I SLBM's for an effective strike range of about 7,800 km, equal to the SS-N-8 introduced into the Soviet Navy in 1973. Each Trident I will carry 8 warheads of 100 KT yield in a manoeuvrable independently targeted re-entry vehicle, (MARV) assisted by a Post Boost Control System of the type fitted to Minuteman III. MARV is a further sophistication of warhead technology where the reentry vehicle can perform a set of evasive manoeuvres during the terminal stages of the trajectory. Soviet tests with MARV technology have already been observed.



Poseidon (right) and the new Trident, seen here as a structural mock-up, give scale to each other. In the foreground, scale models of a Poseidon SLBM and the USS Ulysses S. Grant.





This configuration chart shows the relative dimensions of all five US fleet ballistic missiles.

The first test launch of the Trident SLBM came in January 1977 from a surface pad at the Cape Canaveral Air Force Station.

The new submarines developed for Trident missiles will be a considerable improvement on existing Polaris A-3 and Poseidon boats, although the Trident force will replace the current generation of submarines rather than supplement them and thereby maintain the current level of US SLBM's. In the wake of Soviet third-generation missile developments, the US Navy has increased its planned procurement level from an original 10 boats to a maximum of 30. If current plans move to fruition, the Navy expects to begin operations with a very much improved Trident, the Mk. II (two), late in the 1980's. Deployment would be accompanied with the introduction of an improved submarine, but by mid-1977 the Soviet Navy was believed to be building the Trident II equivalent, the Typhoon class submarine, at shipyards near Murmansk. By this time an improved Delta class boat had been observed carrying 20 SS-N-8 SLBM's, each equipped with a 1.5 MT warhead.

Nevertheless, Trident I represents a major committment on the part of the Defence Department to redress the alarming imbalance in projected SLBM force levels by the early 1980's. As such, it modifies one important arm of the triad, but on a time scale that will keep the US Navy in pursuit of Russian developments, rather than providing an equivalence posture. Land-based missile development takes hold of improvements in the field of solid propellant chemistry and the MX ICBM is expected to emerge, if approved by Congress, with a capability of carrying about 10 × 400 KT charges in a MARV warhead. With a launch weight about 2½ times that of Minuteman, it will emerge for operational deployment, more than a decade after the initial flight trials with the Soviet mobile ICBM's, SS-16 and SS-20. Whether deployed in shelters or trenches, emphasis is on a concealed mobile mode and as such it represents a vital deterrent without which the strategic imbalance would continue to move in favour of the Soviet Union.

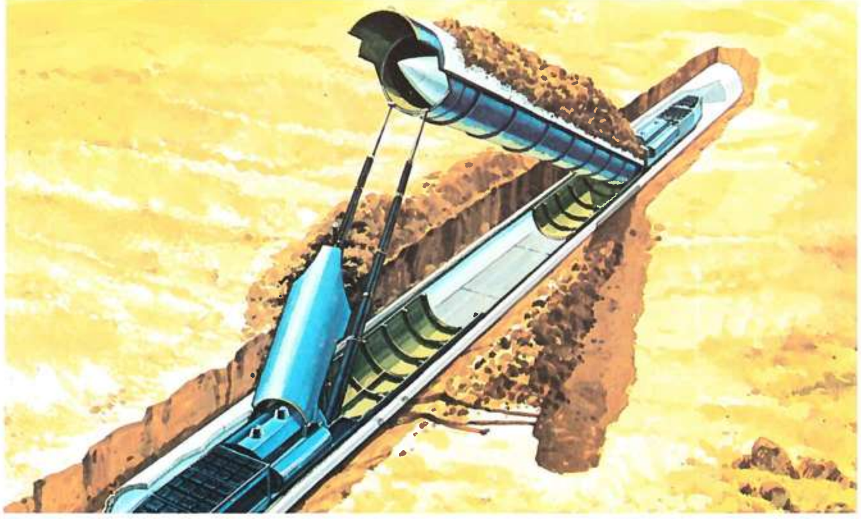
The third arm of the triad, manned bombers, has received a new credibility from the development of the so-called Cruise Missile. This is a subsonic, winged vehicle using a single turbojet engine for propulsion. As such it has no direct link with the development of rockets, but the repercussions of a decision in 1977 to proceed with its deployment directly impinge on the prospects for concurrent procurement of the MX mobile ICBM.

The Air Launched Cruise Missile, or ALCM, is only about 4.3 metres long with folded wings that deploy after launch to a span of 2.3 metres. Carried by heavy bombers like the B-52 or the proposed B-1, the ALCM would perform a role similar in several respects to the Short Range Attack Missile described earlier. But, with only 85% the weight and a size no greater than the SRAM currently deployed with B-52 and FB-111 units, the cruise missile would have ten times the range of the SRAM and possess a capability unlike anything yet developed for operational use.

With inertial navigation systems and a terrain comparison computer, the ALCM would be released by a parent aircraft and follow any one, or combination of, trajectories programmed into the vehicle before flight. A pre-programmed flight path would carry information on the terrain over which the cruise missile was expected to fly and this would permit the vehicle to use radar inputs, sampled periodically, to compare the information in its memory with that coming in during the flight. In this way, the cruise missile follows specific terrain features and thus avoids enemy defence networks to weave a circuitous route through to strategic targets. Or, it can follow a confusing path, winding around hilly ground, until it homes in with the aid of high-speed radar updates on tactical or air-defence targets.

The range of the cruise missile is dictated by the size of the fuel tank it carries and with a capability to fly 2,500 km at an average speed of 660 km per hour a pattern of such vehicles dropped by a manned bomber could selectively knock out a large number of ground targets. Each B-52 could carry up to 20 cruise missiles, while a modified wide-body transport aircraft like the Boeing 747 or the DC-10 would provide space for up to 90. One of the advantages of the cruise missile is that while it can carry a 200 KT warhead, with a target accuracy far beyond any other delivery system, it enhances the role of the manned strategic bomber and improves the flexibility inherent in the third arm of the triad. Aircraft could carry a full load of cruise missiles, a mixed load of cruise and SRAM vehicles or a combination of different types of cruise missiles tailored to a specific inventory of targets. But the most flexible element enjoyed by a cruise missile force would provide a capability for a carrier plane to fly to the designated release coordinates, or stand-off point, and loiter for several hours without committing its load to a hostile attack. With each cruise missile carrying an effective explosive yield equal to 10 Hiroshima bombs, the capacity to evade air defence networks en route and an accuracy at the target measured in metres, the weapon is an ideal choice for improving the posture of the bomber force operated by Strategic Air Command.

MX missiles in buried tenches would be capable of escaping destruction in a pre-emptive first strike from the Soviet Union by continually changing their location.



The Boeing Air Launched Cruise Missile is one of the most potent, yet compact, defence systems to be developed. Powered by a turbofan engine it could provide a similar deterrent threat to that posed by the MX system. Wings are folded until the missile is launched.

Studies on the impact of deploying a force of MX ICBM's has shown that with between 100 and 300 such missiles, a stable situation would exist whereby neither the United States nor Russia would gain a strategic advantage from first strike attack, as related earlier. Parallel studies have similarly shown that the same situation would exist with a force of 2,500 cruise missiles. In both cases, the equation assumes that MX or cruise missile launchers would replace existing elements of the Minuteman force. So, the future options available to the United States centre on one or other of these two alternatives: MX land-based mobile ICBM force of between 100 and 300 missiles with an aggregate warhead total of 1,000 to 3,000 (because each MX would carry 10 nuclear charges of about 400 KT yield) or Air Launched Cruise Missile force of 2,500, each with a 200 KT charge.

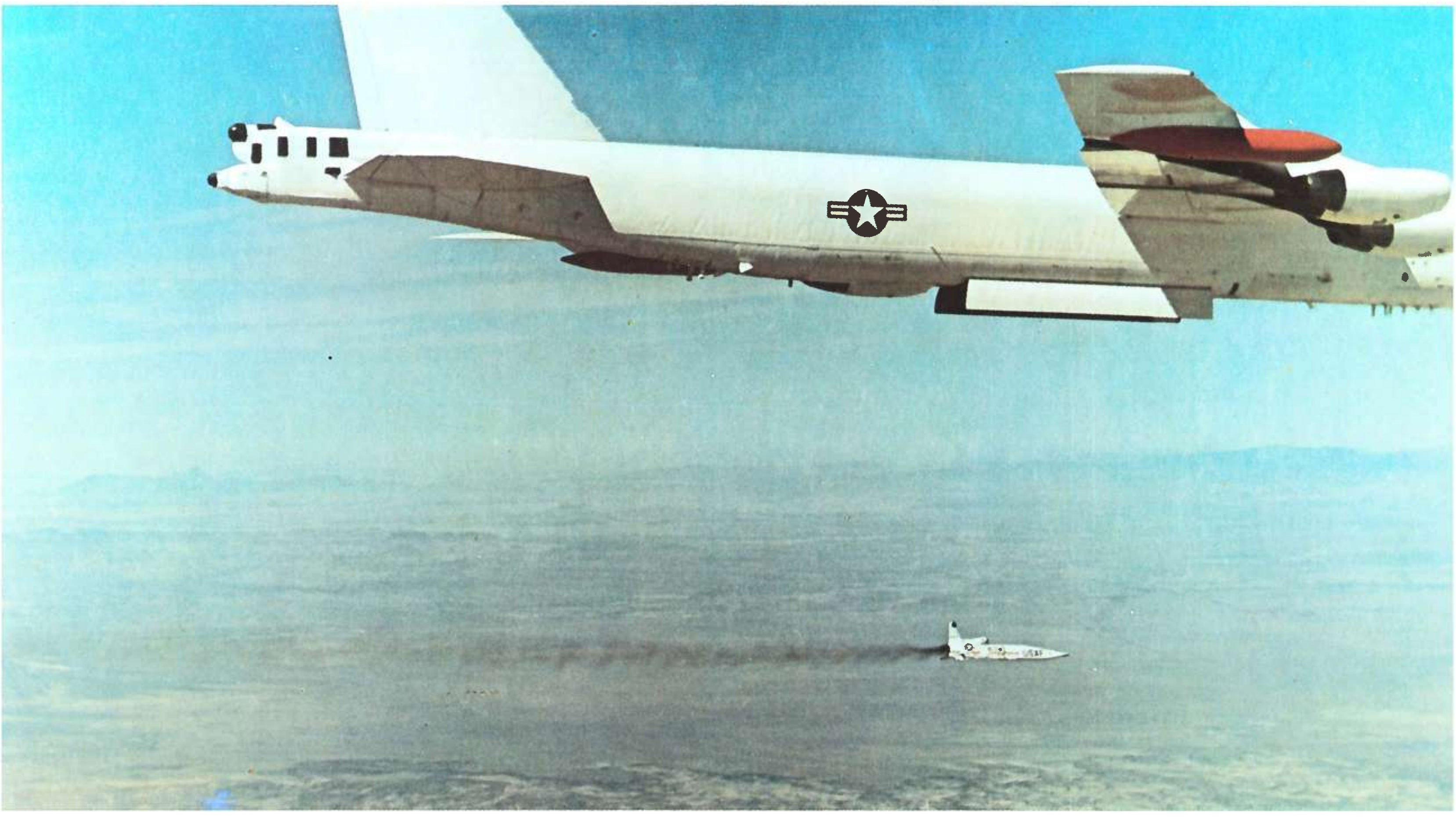
But, while MX missiles would be relatively invulnerable to a pre-emptive first strike, because the Soviet Union would expend more warheads than they could hope to destroy, the cruise missile force would face increasingly effective air-defences capable of eliminating a substantial number before they reached their targets. On the other hand, MX would be a final solution without capability of measured retaliation or recall, while cruise missiles would provide a time-lag between the onset of hostilities and the point of launch. Also, large wide-body transports converted to carry a massive potential strike force of cruise missiles would present a visible threat to an enemy who just might have second thoughts in time to begin negotiating.

Irrespective of these factors, the most important, indeed vital, necessity for the 1980's will be to ensure that neither the United States nor the Soviet Union assumes it has a pre-emptive first strike capability. While it is difficult to see US foreign policy moving toward the use of strategic force for territorial gain, it is not difficult to appreciate the ramifications of a Soviet belief in massive US potential. Threatened by a superior military might, the Soviet Union would not become the first nation in history to fly in the face of statistical defeat and launch a pre-emptive strike in the hope of eliminating a presumed enemy. But that situation does not exist and is not likely to emerge in the closing decades of this century.

The more important issue at hand is how to counter an increasingly effective Soviet strategic capability so that any lead which may be present is eliminated with the least cost and smallest degree of provocation. Some would argue that the steady and unyielding build-up in Soviet rocketry is a product of having lived for too long with an inferior strategic capability. That situation is reversed today and others would say that the United States has waited too long before awakening to the awesome potential that now exists for all-out war. Military leaders have watched the sustained build-up in Soviet capability for more than a decade, but only in the mid-1970's did political awareness spring to life. Missile development has too often fallen prey to crash programmes born out of haste as a product of vacillation. Such a situation must never be allowed to contribute a second imbalance and the future development of strategic rocketry is more closely allied to political will than at any other time.

Strategic Arms Limitation Talks are not an end in themselves, or a vehicle by which the Soviet Union can, or should, expect to gain political ground. They are a point from which to structure a beginning, beyond which the two super-powers must move if civilization is to be allowed a common ground for confronting challenges to all mankind. The strategic nuclear-armed rockets of today are a far cry from the V-2, but they have provided an awesome umbrella under which the major nations have exercised restraint. It would be naive to expect this situation to continue indefinitely and by their sheer presence the arsenals of the United States and the Soviet Union may yet be the instigators of a more morally benevolent philosophy than that which structured their birth.

Air Launched Cruise Missiles would follow long and unpredictable paths to their targets if launched in anger. Here, a Boeing ALCM on test drops from the bomb bay of a B-52.



CHAPTER ELEVEN.

Window to the Twenty-First Century

Throughout the long and protracted history of rocket engine development, the principles of chemical combustion have been applied to increasingly efficient propulsion systems, based on the simple law, first written down by Isaac Newton, that to every action there is an equal and opposite reaction. From the Chinese firecracker of a thousand years ago, to the complex and demanding requirements of a modern high-performance liquid propellant motor, the same basic principle has been employed by weapons of war and tools for the exploration of space. But for all the drama and pomp that surrounded early endeavours beyond Earth's atmosphere, it is a sobering reality that Man has hardly stepped beyond his own back door into the hostile void that spans the Universe. In terms of distance, the astronomical landmarks are daunting. No longer is it possible to measure length in the conventional values adopted for Earth. Using the speed of light itself, 299,700 kilometres per second, as a convenient unit for comparison, Earth and Moon are separated by less than 1½ seconds, while the nearest planet – Venus – is never less than about two minutes away. Travel from Earth to the most distant planets in the solar system would require a light-speed journey lasting four or five hours, while the nearest star is more than four years away.

But Man has not wrought such technological wonders that speed at the velocity of light is even a conceivable probability. The highest speed attained by a rocket propelled launch vehicle, departing Earth orbit for the outer planets, is about 90,000 kilometres per hour, or about 0.008% the speed of light. But this relates to the velocity of a small payload sent on its way by a large and powerful rocket; the fastest speed achieved by a manned vehicle is still no more than 40,000 kilometres per hour. At that rate it would take several years to reach the nearest planets and a staggering 27,000 years to arrive at the vicinity of the nearest star. Such is the magnitude of space. For all practical purposes the Sun and its nine planets represents the limit of human exploration.

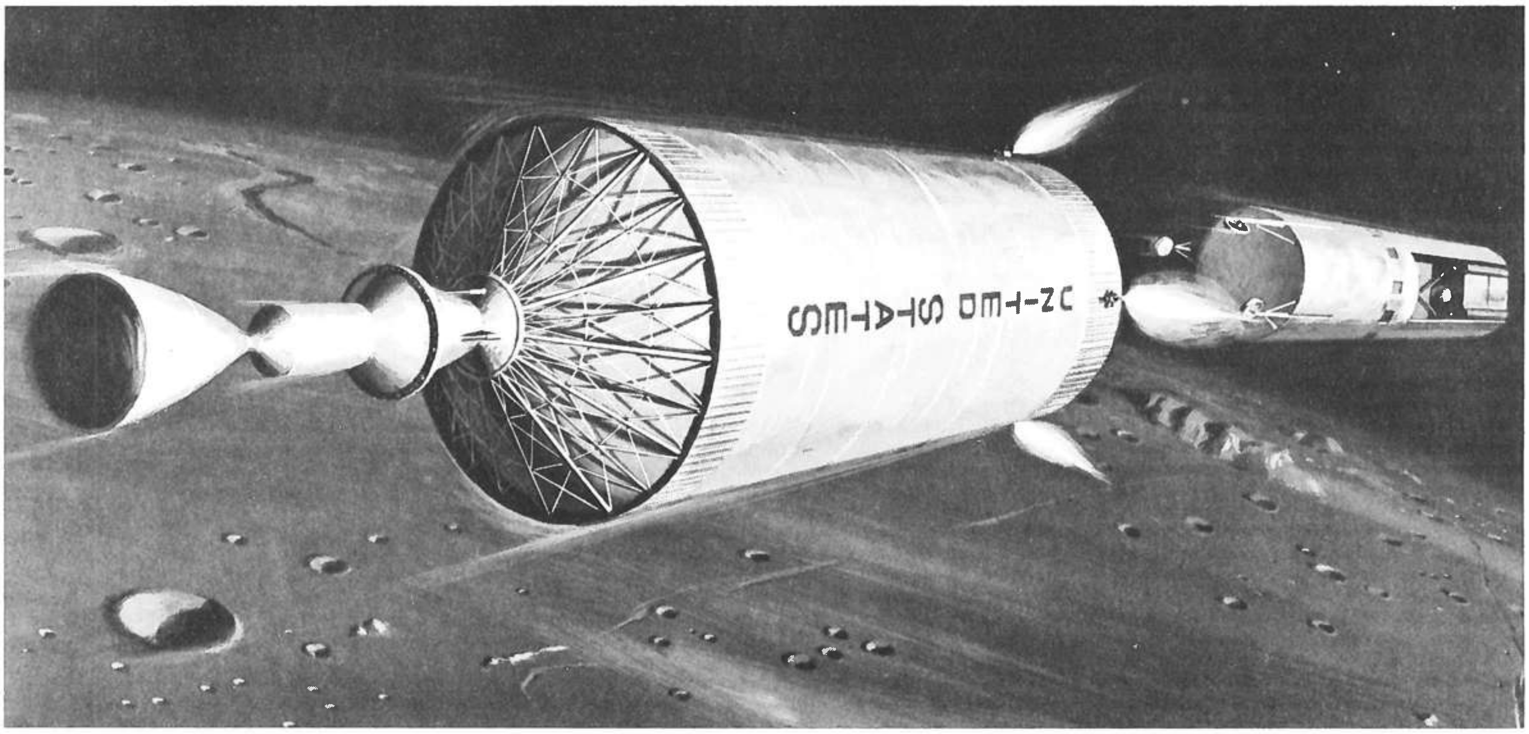
The realization that Man is bound by the physical laws that structure his very existence, comes hard to civilizations fathered on the aspirations of generations that spoke and wrote about the dawning age of true space travel. With the development of liquid propellant rockets in the first half of the 20th century a ray of hope shone down through the pillars of history, a sudden realization that flights to the Moon and beyond, may indeed become a reality. They did, but only for a very brief few years. Political pressure orchestrated by partisan causes cut those aspirations in two and distributed the product among Earth-based technologies, that offered little for the philosophical dreams of future generations. Instead of building on the accomplishments of the past and providing a true interplanetary capability, the space programme was turned diametrically to face and join combat with Earth-based problems, common to all mankind. But even as plans were being formulated for the first landing on the Moon, engineers and technicians joined scientists to develop exotic forms of propulsion that would find application with the giant planetary spaceships that they thought must surely follow.

Faced with limiting factors resulting from the physics of chemical combustion, physicists worked to perfect a nuclear rocket that would transcend the barriers dictated by conventional chemistry. The argument was simple and convincing, although not always seen with the clarity of hindsight: increase the specific impulse, by eliminating the weighty molecules associated with the oxidizer. Because the thrust produced by a rocket motor is proportional to the velocity of the exhausted gases, there is a limiting factor inherent in the principle of chemical combustion, which effectively constrains the speed of the escaping particles and, hence, the value of the reaction. Put simply, it means that increased exhaust velocity means a higher thrust from a given unit mass of propellant.

Chemical engines are limited by the heat of combustion per unit mass of propellant. Nuclear engines are limited only by the thermal barriers of materials used in their construction. Instead of using a process of combustion to generate the heat necessary for imparting a high velocity to the molecular components of the propellant, a separate heat source transfers thermal energy to the working fluid. Without combustion there is no need for an oxidizer and the molecular mass can be reduced accordingly. From fire-stick to liquid propellant rocket, chemical combustion has dominated the practical development of reaction motors. With the nuclear rocket, no such combustion takes place and the propellant becomes a simple fuel.

A clear distinction should be drawn here between the application of nuclear power to rocket propulsion and the development of thermo-electric generators. The conversion of thermal energy to electrical power requires a source of heat obtained from the fission of uranium or plutonium isotopes. Nuclear generators have been developed by the United States and the Soviet Union to provide electrical energy on missions where solar cell panels or batteries are prohibited, either because of extreme distance from the Sun or weight penalties. Apollo Moon landing vehicles transported nuclear generators to the lunar surface where they were left to power scientific instruments for several years after the crew returned to Earth. The aborted flight of Apollo 13 in 1970 required the Lunar Module, carrying a small nuclear generator, to serve as a lifeboat back to the vicinity of the Earth. Discarded shortly before re-entry, it burned up in the atmosphere leaving the nuclear power source to sink to the bottom of the Pacific. Protected by a strong graphite cask it presented no environmental hazard. Similarly, in January 1978, the Russian spacecraft Cosmos 954 unexpectedly re-entered the atmosphere as a result of malfunction and discarded its nuclear generator to a remote area of northern Canada.

In principle, the nuclear rocket works because of the fissionable properties of uranium-235, whereby a neutron causes the uranium nucleus to split into two separate parts, releasing energy and additional neutrons. Contained within a suitable case, this is known as the reactor, with the thermal energy produced at the core, a region containing the critical mass of U-235. Encased by a pressure shell, the reactor would be controlled by graphite rods moderating the fission rate; graphite has the desirable property of slowing down the neutrons. The reactor takes the place of the combustion chamber normally used for chemical engines and contains tubes through which the working fluid will be pumped. A nozzle at the base of the reactor provides a path of escape for the gases. While it was considered possible to use any one of several working fluids, the most obvious choice was hydrogen. With the lightest molecular structure, it had decided advantages over the alternatives. Hydrogen would be used to cool the exhaust nozzle before passing up the outside of the reactor and then down into the reactor pressure vessel. As the gas flowed through the reactor tubes it accepted heat from the fission of uranium-235 and was accelerated out through the convergent-divergent nozzle. From quite early in the theoretical design of a viable nuclear rocket, it seemed feasible to plan for a gas temperature of 2,500°c and with hydrogen as the working fluid, this would provide a specific impulse of nearly 1,000 seconds – more than double the value theoretically obtainable from the most efficient chemical combustion process, using high-energy hydrogen/oxygen propellants. This was the one area where engineers saw remarkable



A Moon landing vehicle (right) separates from a nuclear powered rocket stage that has transported it into Moon orbit in this hypothetical representation.

advantages. With increased exhaust velocity, and a higher specific impulse, propellant mass flow would be halved and effective power doubled for a given thrust output. In terms of performance, it meant that if a nuclear rocket engine was carried as the propulsion unit for a third stage to conventional two-stage launch vehicles, the payload could be almost doubled.

The first tentative proposals for a nuclear powerplant came in 1944, just two years after the first induced chain reaction, when Stanislaus Ulam and Frederick de Hoffman considered using nuclear power for spaceships. But there was no suitable mission for a nuclear rocket and the project awaited development of large missiles. By 1946, however, the then North American Aviation Inc., and the Douglas Aircraft Company studied the possibility of using nuclear rocket motors for long range ballistic missiles and this led to several military developments in the 1950's. In 1948 and 1949, A. V. Cleaver and L. R. Shepherd, two British protagonists of inter-planetary space travel, outlined the vital equation in the Journal of the British Interplanetary Society. By 1952, Kenneth W. Gatland, who had already proposed the concept of Lunar Orbit Rendezvous that would be used by NASA in Project Apollo seventeen years later, was recommending the use of a fission reactor for space flight.

Developments in the technology of guided missiles, led the US Atomic Energy Commission and the US Air Force to authorize work, in 1955, on a programme aimed at exploring the application of nuclear power to intercontinental missiles. Project Rover, as it was called, lasted just two years and by 1958 all work on nuclear power rockets had been absorbed into the new space agency – NASA. Work was concentrated at the Los Alamos Scientific Laboratory and at the Lawrence Livermore Radiation Laboratory. Following initial feasibility tests and a lot of calculation, the first working models were built under the group name Kiwi; an apt simile for the bird that cannot fly! The first Kiwi-A reactor test was performed on 1 July 1959, at the Nevada facility, operated by the Los Alamos Laboratory and just a year later, the Space Nuclear Propulsion Office was set up by NASA and the AEC.

When President Kennedy came to office early in 1961, he urged emphasis on the application of the nuclear rocket motor to space activities and the NERVA (Nuclear Engine for Rocket Vehicle Application) came into being. Aerojet-General and the Westinghouse Electric Corporation were contracted for development of an engine capable of delivering a thrust of 24.9 tonnes, with a specific impulse of 760 seconds. By 1962, the Marshall Space Flight Centre brought Lockheed in on a programme aimed at producing a stage for use on Saturn class launch vehicles with a NERVA propulsion system. As work progressed with engine tests through the early and mid 1960's, missions engineers were matching the promised performance to objectives envisaged for the post-Apollo period. In 1966 plans were laid for a NERVA derivative that would produce a thrust of 90.7 tonnes and the basic engine to be used as the precursor for the fully operational design was uprated from 24.9 tonnes to 34 tonnes in 1968.

On 20 March 1969, the first firing tests with the NERVA-XE engine began and a Presidential appraisal of the future posture of the US space programme endorsed full development of a nuclear powered upper stage. But the XE engine was only a research and development model and although it was never intended to fly, it did reproduce all the anticipated design features of the definitive product. With a length of 6.9 metres and a diameter of 2.6 metres, the XE weighed 18 tonnes and consisted of a graphite reactor within an aluminium case. At the top of the reactor, at the opposite end to the exhaust nozzle, a special shield was attached to protect systems from radiation.

But NERVA had one drawback that would ultimately lead to its demise: it was only suitable for use as an upper stage and as such was applicable to moving very heavy payloads across vast distances in the solar system. The sheer weight of the engine, plus the contamination from radiation, meant that it was unsuited to use as the first or second stage of a multi-stage launch vehicle. NERVA could operate for comparatively long periods of time and would accelerate attached payloads to high velocity. With only moderate thrust, compared to the developed technology of chemical combustion engines, the NERVA was the perfect answer for deep space operations; its lengthy 'burn' duration made up for deficiencies in sheer thrust and the high specific impulse made it very efficient.

By 1969, ambitious plans embraced the use of NERVA as third stage to the first two stages of a Saturn V and in this configuration the nuclear engine was considered a valuable addition to the inventory of existing liquid propellant rocket motors. It would be used to shunt large payloads between Earth orbit and Moon orbit, send teams of astronauts off to Mars, or ply back and forth between the planets carrying survey parties and their supplies. By September 1970, NASA was asking approval for planned expenditure in fiscal year 1972 and requested a sum of $50 million for further work on NERVA, leading towards a first flight in the late 1970's. Several weeks later the Office of Management and Budget (OMB) returned the proposal with a ceiling on the total NASA budget that forced acting Administrator, George M. Low, to re-structure priorities. With the new set of figures on hand, OMB promptly set about establishing their own internal ceilings on NASA programmes, deleting all funds for the nuclear rocket. NASA took its case to the White House and under pressure from Senator Cannon of the Senate space committee received assurances that 'as of this date 23 November 1970, support for this programme will be continued in the 1972 budget.'

As it turned out, NASA was allowed to request $15.4 million for the NERVA programme in the fiscal year 1972 appropriations. As soon as the figure had been officially announced, Senator Clinton Anderson, Senate space committee chairman, called the Joint Atomic Energy Committee to hearings held 23–24 February 1971, in an effort to find out who was responsible for the cutback. Top government and industry officials were consulted to determine in what areas the NERVA programme could be salvaged and, more important, to place the nuclear engine more in line with realistic planning. NASA was firm in its view that the reduced funding would cripple the programme. At the February hearings both NASA and OMB officials anticipated a delay of 'several years' in the face of rising commitments to other space programmes and even the most optimistic proponents could not see the government-industry team holding together for more than a year.

By this time the role of NASA was being modified to one which emphasized limited exploration and concentrated instead on Earth orbit flights which could benefit mankind at large. Gone were the days when giant spaceships were planned for manned landings on Mars. Little more than two weeks after the February hearings, the President received a letter from twenty-one signatories calling for a confrontation with Congress. Senator Anderson led support for the nuclear rocket and co-ordinated operations. An arrangement was made to meet with the Director of the OMB, George P. Schultz. On 24 May 1971, Senator Anderson voted against the US supersonic transport and Schultz, sensing a rebuff to the administration, cancelled the meeting the following day. Six weeks later, Anderson's special assistant, Frank DiLuzio, met with officials from the White House and tried to establish a firm commitment from the administration. Several times talks with the OMB were suspended, with the OMB refusing to give approval.

Meanwhile, proponents of the nuclear engine in the House of Representatives and the Senate had closed ranks and re-instated the full amount originally requested by NASA, with recommendation that $58 million be spent on NERVA in 1972. On 21 July 1971, the Conference Committee, formed of members from both Houses, endorsed the figure. But the writing was on the wall. Without a clear mission for the nuclear engine, NASA was fighting a losing battle. Already, production of the giant Saturn V had been halted and there would be no more Moon landings after the end of 1972. NERVA had relied on the Saturn V to lift it into space and the grand plans for Moon bases and expeditions to Mars, were fast disappearing. Studies conducted at the Marshall Space Flight Centre had proven the theoretical worth of a NERVA propulsion system attached to a reusable stage that could be used many times to ply between Earth and the Moon. From a parking orbit above Earth, the nuclear stage could be re-fuelled with hydrogen for successive trips to deep space destinations, but without the requirement for such ambitious tasks, NASA had no mission for the efficient engine. Even before the end of 1971, the space agency had revised its thinking on the nuclear rocket and reduced the planned thrust level from 38 tonnes, down to just 6.8 tonnes.

The only conceivable mission for a nuclear engine, in the light of dramatic changes in space priorities, lay within the range of unmanned planetary exploration vehicles that would continue to receive funds on a limited basis. These payloads would be small compared to the massive man-carrying spaceships that were envisaged when NERVA development got under way in 1961. It was the only possible way to incorporate the nuclear engine in future mission goals and the 6.8 tonne thrust variant would be adequate for sending mechanical robots to the outer reaches of the solar system. But even this was soon seen as too great a strain on the financial resources of the space agency and on 5 January 1973, NASA issued a statement that said 'work on nuclear propulsion will be discontinued.' It was as simple as that. In nearly two decades of sustained activity, NASA and the Atomic Energy Commission had spent almost $1,400 million on nuclear rocket technology. The principles had been sound and the many successful tests showed that nuclear propulsion would be a valid proposition for a vigorous and expanding space programme requiring the transfer of large loads across great distances. But in the climate of increasing emphasis on space applications, rather than exploration, the system had no use. Instead, there was a growing awareness of the paradoxical situation where the large launch vehicles, that had done so much to advance the state of the technological art, were themselves increasingly seen as the limiting factor in future space policy.

The sheer cost of building rocket stages was staggering in itself; compromised by the fact that each assembled rocket could only be used once, the solution was obvious. Reusability had to be a key feature of any further developments in the peaceful application of space technology. But the problems were enormous. Because rocket stages were essentially large propellant tanks held together by a supporting structure, with one or more rocket engine assemblies fixed to the bottom end, they would be required to maintain structural integrity during the long plunge back down through the Earth's atmosphere. Dynamic and stress loads were calculated for a launch vehicle ascending under the imparted thrust of its own engines and not for the unloaded descent that would be necessary for recovery. Also, the complex design of liquid propellant rocket motors was unsuited to the stress and strain of free-fall and thermal considerations demanded a configuration optimized around the requirements dictated for ascent. When a large rocket stage fell back into the atmosphere it would experience severe heating due to friction and considerable protection would have to be provided to prevent it burning up. Additional insulation, small rocket motors for stability, recovery parachutes for slow and retarded descent, all added up to a considerable increase in weight and additional cost. Nevertheless, attempts were made to solve these problems when very large launch vehicles of the Saturn class began to emerge in the early 1960's.

In the early days of the space programme, NASA enjoyed limitless horizons and assumed it would move positively toward colonization of the solar system. Consequently it was felt desirable to determine the feasibility of recovering the big Saturn rockets. These would be the space-freighters of the future, with an anticipated launch rate running to between ten and twenty each year. A moderate effort aimed at re-using the expensive hardware was expected to ensure a good financial return on the investment. By 1967, however, NASA was seen to be increasingly reluctant to plan for major programmes beyond the first few Moon landings, preferring to wait until lunar operations got under way, before setting new goals in space. This caused a somewhat confused environment, in that congressional proponents wanted clearly


End of an era. A Saturn V lifts off from Launch Complex 39 at the Kennedy Space Centre on the last manned lunar landing flight, December 1972, and the only night launch by a vehicle of this class.

Viewed from Cocoa Beach, about 40 km from the launch pad, the night launch of the Saturn V taking Apollo 17 to the Moon illuminates the sky and dominates artificial lighting on the ground.

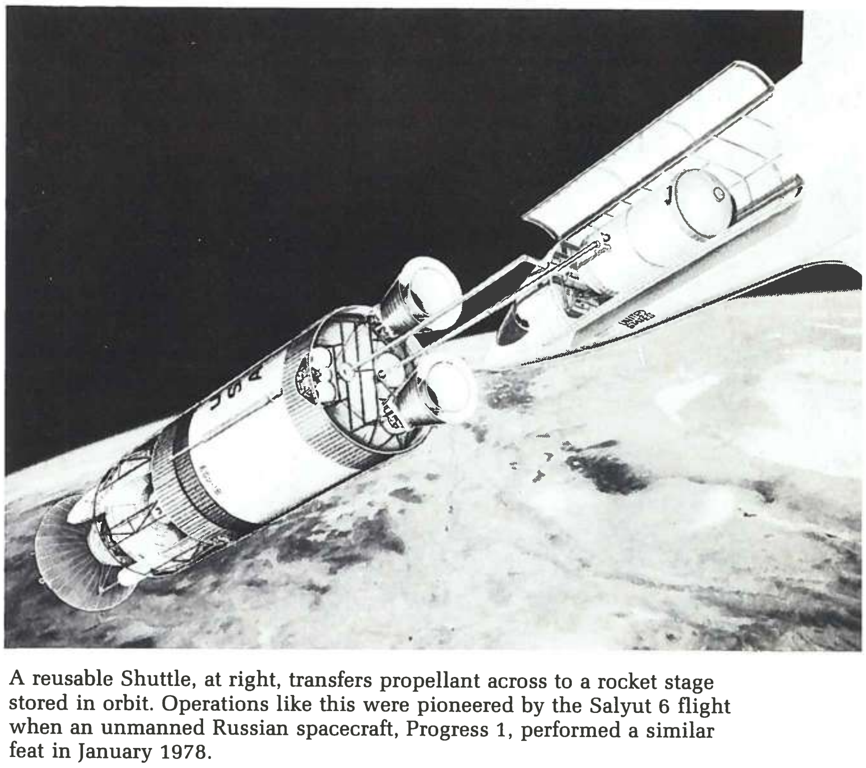
defined objectives with which to sustain the momentum built up under President Kennedy (1961–1963). No one individual at NASA knew for sure just how effective the big Saturn rockets would be and it was expected that fifteen Saturn V's would be necessary to test all the many complex and integrated procedures for a Moon landing.

As it turned out, only two unmanned test flights and three manned precursor missions were required, before the first Moon landing attempt in July 1969. This left a lot of Saturn V launch vehicles, already in production, with which to perform additional landings. Coupled with the decreasing space budget, the agency was unable to support more than one or two landing attempts per year and in a climate of economic restraint, brought about by domestic upheaval and a war in Vietnam, the production line was shut down. From an anticipated launch goal of twenty Saturn V's per year, NASA was reduced to a maximum of four Saturn V flights in 1969, one in 1970, two in 1971, two in 1972 and one in 1973. Clearly, launch rates as low as this rendered the additional development cost of recovery and re-use, a wholly untenable proposition. The plain and simple fact emerged with undisputed clarity: a recoverable booster would have to be designed from the outset, for return and re-use.

In many respects this highlighted the difference of opinion that prevailed when Eugene Sanger first proposed a practical design configuration for rocket powered launch vehicles, based on aerodynamic principles, rather than ballistic considerations (see Chapter Six). Apart from the Saturn series, every operational rocket propelled missile had been designed to a specification dictated by a military requirement. These usually demanded that the missile transport a useful warhead across a specified distance and left little room for aerodynamic considerations such as would be required by a civilian launcher. Only the family of small sounding rockets were built for a scientific task and here the objectives required a ballistic flight profile without lift characteristics.

During 1968 and 1969, NASA prepared an ambitious plan for the space programme of the future, based on the availability of a new generation of launchers then expected to receive funded development status. The programme was expected to involve several critical items that would serve as the nucleus of an expanding commitment to space activity, but one which could be sized according to the national goals. First, a Space Shuttle would be developed as a recoverable freighter which would be responsible for sending cargo, or satellites, into Earth orbit and then return to a landing, like a conventional aircraft. This would be the standard reusable launcher. Expendable launch vehicles, with a much larger payload capacity, probably of the Saturn V class, would be used from time to time on missions that would place modules of a space station in orbit. These orbital facilities would be manned by teams of astronauts brought up by the Shuttle and equipped with supplies and a host of scientific experiments carried in the Shuttle's cargo bay.

As requirements dictated, the size of the space station could be expanded by attaching additional modules. Eventually, a space base supporting up to one hundred persons would provide an orbital research facility from where unique experiments could be conducted. It would also serve as the stepping stone to colonization of the Moon. As the programme gathered momentum, a vehicle called the Space Tug would be developed and used for shunting cargo and supplies between separate orbital space stations or between the Shuttle and any one station. This would take the form of a propulsion module to which would be attached a crew module and a teleoperator system, the latter comprising a set of arm-like manipulators operated by personnel in the crew module. The Tug would be carried into space by the reusable Shuttle and returned to Earth by the same vehicle for use on a subsequent mission.



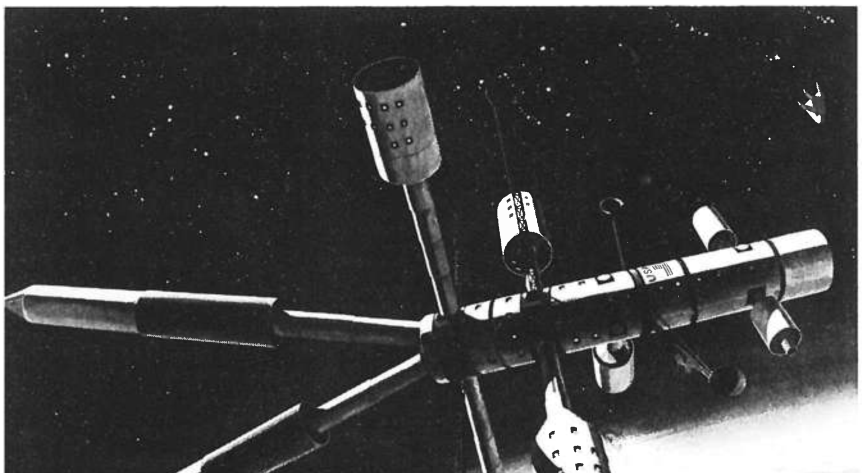
A reusable Shuttle, at right, transfers propellant across to a rocket stage stored in orbit. Operations like this were pioneered by the Salyut 6 flight when an unmanned Russian spacecraft, Progress 1, performed a similar feat in January 1978.

Meanwhile, the Nuclear rocket motor – NERVA – would be coming along in the development stage and, suitably configured as the propulsion unit for a unique rocket stage launched by two stages of a Saturn V, find application for deep space penetration. The first application would be as the propulsive element necessary to send space station modules from Earth orbit to Moon orbit; the Nuclear Shuttle, as it was called, would return alone to Earth orbit and await subsequent tasks. From the Lunar Orbit Station, specially adapted Space Tugs would visit the surface and serve as Lunar Shuttles for the first permanently manned Moon base.

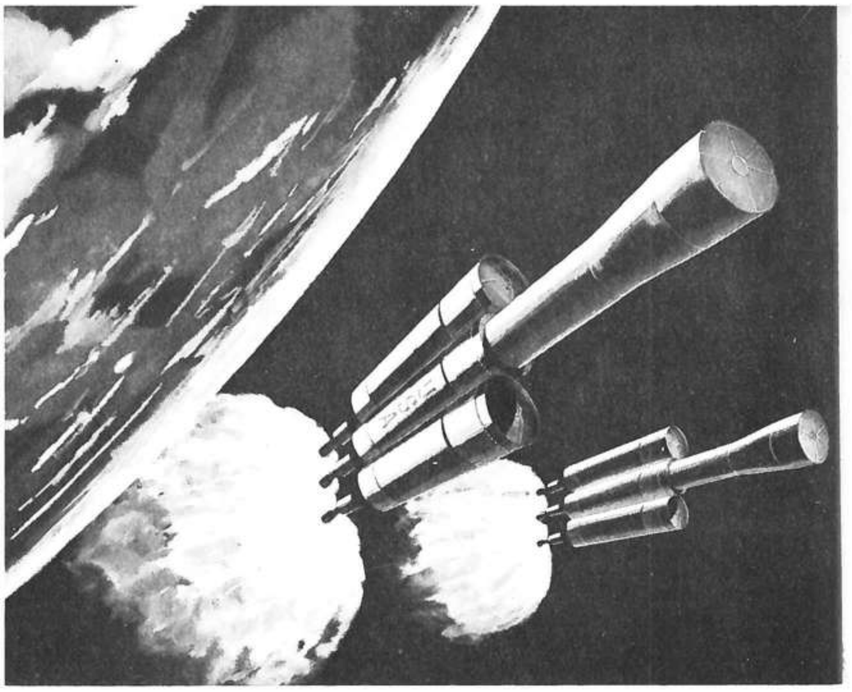
Still later in the evolution of this 'integrated space programme', Nuclear Shuttles would be strapped together in Earth orbit and mated with a separate, but standard, space station module. This configuration would then depart Earth orbit and journey to the planet Mars, going into orbit about this barren world after a trip of perhaps a year. The standard space station that would serve as living quarters for the Mars crew during the journey, would also carry a Mars Excursion Module, or MEM. This vehicle would be used to carry a few crew members down to the surface of Mars and return them to the orbiting station, after a few weeks of exploration. Later, other Nuclear Shuttles would bring more personnel to set up the first permanent base on Mars. Initially, the Mars expedition would return to Earth on the energy imparted by a single Nuclear Shuttle still attached to the station.

The Mars flight would require three Nuclear Shuttles: two for boosting the station and MEM out of Earth orbit and on to a course for Mars and one for decelerating into Mars orbit, firing out of Mars orbit and decelerating back into Earth orbit. The two Nuclear Shuttles, used for departing Earth orbit in the first instance, would separate from the third and its payload and return to Earth orbit so that they could be used again. In this way, all the expedition's hardware would be reusable, except for the bottom section of the MEM, that would serve as a launch base on Mars for returning the upper section and crew back to Mars orbit. Once back in Earth orbit, the associated crew would transfer to an Earth orbiting space station and wait for a Shuttle to return them to the surface.

Commonality and reusability were to be key features of this integrated space programme and with development of just a few separate elements (Shuttle, Nuclear Shuttle, Space Tug, Space Station and Mars Excursion Module) a vigorous assault on the solar system would be maintained and exploited. Such were the plans of NASA in 1969. With heavy traffic plying between the surface of the Earth and near-space, the Space Shuttle was a necessary, if not essential, element in the matrix of new hardware. Because each Shuttle would be used many times, each flight would cost only a small fraction of the price involved with a fleet of expendable launch vehicles. In this way, the NASA budget would profit by eliminating the requirement for building a new launcher for each flight. A single Saturn V, with a lifting capacity of 135 tonnes to Earth orbit, cost around $200 million; NASA was confident that a reusable Shuttle would send 30 tonne loads into orbit for about $10 million. In other words, the unit cost and launch charge for a Saturn V averaged $1,480 per kilogramme of payload weight, compared with $333 per kilogramme for the Shuttle.



'Eventually, a space base supporting up to 100 persons would provide an orbital research facility from where unique experiments could be conducted.'



Clustered Nuclear Shuttles leave Earth orbit for a hypothetical flight to Mars. The habitable sections of the payload, essentially converted space station modules, are at the forward end.

The three years between 1969 and 1972 were critical for the future development of the reusable Shuttle. In that period the basic configuration was defined resulting in the award of a fabrication contract to Rockwell International, formerly North American Aviation and North American Rockwell. But it was also significant for bringing about the demise of the integrated space programme and its manned space stations, colonization of the Moon and trips to the planet Mars. It became increasingly obvious that NASA could not afford concurrent development of the Shuttle and the space station and since the former was essential to any future space programme, it alone was retained. In 1972 the space agency lost out in the long and often bitter fight to bring the Nuclear rocket to flight status and the Space Tug, without a space station to serve, never got off the ground. Without the Nuclear Shuttle, flights to Mars with teams of explorers were an even more remote possibility. There had been just one glimmer of hope, in 1969, when President Nixon informally announced that it would be a goal for NASA to land men on Mars by the end of the century, but under the total umbrella of that administration, the money was not forthcoming.

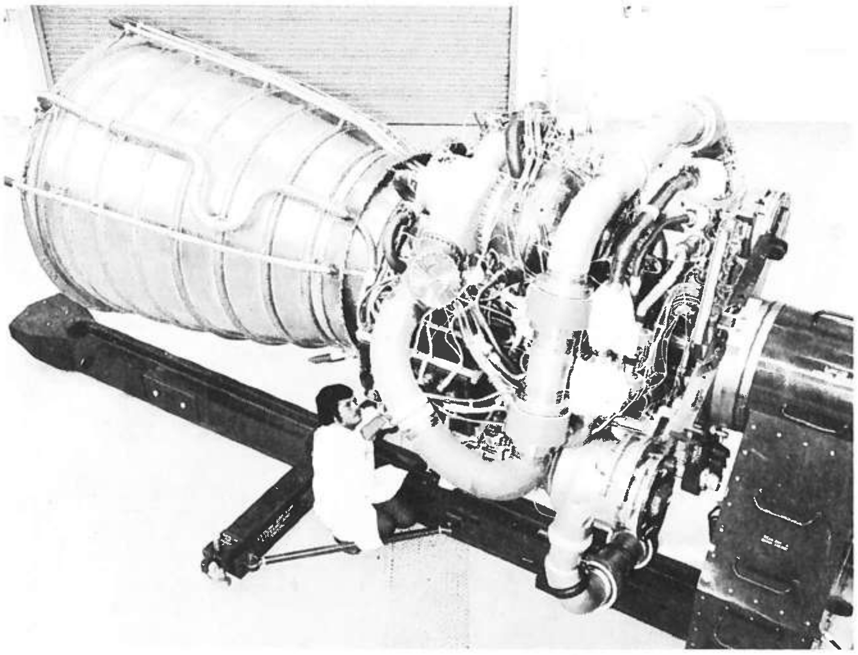
In March 1970, Dr. Wernher von Braun, approaching his 58th birthday, left the Marshall Space Flight Centre where he had spent nearly ten years as Director and went to Washington and the NASA Headquarters, to work on future programmes. On 1 July 1972, he left Government service and joined Fairchild Industries as Vice President for Engineering and Development. Little more than two years later, on 9 October 1974, Dr. Kurt H. Debus, Director of the Cape Canaveral launch facilities retired and began life as a consultant to industrial corporations. But the life that had consistently produced astoundingly successful results, was extinguished, when Wernher von Braun died in a Virginia hospital, in June 1977. In nearly a full half-century of outstanding endeavour, von Braun had played an instrumental part in the development of the German A-4 (V-2), the first US satellite, Redstone and Jupiter rockets and the entire family of Saturn launch vehicles.

Between 1972 and 1977, the role of the space agency was transformed from one that had prime responsibility for space exploration, to one that would open new opportunities for regular flights between Earth and space. The full development history of the Shuttle is given elsewhere in this book, but it is important to recognize in the reusable launch vehicle the very essence of the transformation in space policy. So many beneficial applications have been identified for the space programme that the reduced launch cost promises to open a new era in accessibility. The Shuttle will carry unmanned satellites into Earth orbit as expendable launch vehicles have been doing for two decades, but the flexibility of operation and the lower cost per kilogramme of payload, will open up space operations for many nations on Earth. It is the first manned launch vehicle designed to send payloads into orbit and as such, provides an opportunity for specialists and non-astronauts to use the Shuttle if their work is deemed worthy of access to space. With very little additional physiological stress over that experienced by a flight in conventional aircraft, the Shuttle will provide an opportunity for more than one thousand people to journey into space in the decade of the 1980's. It is, in short, a commuter service that fully profits from the massive technology base built up over the previous decades.

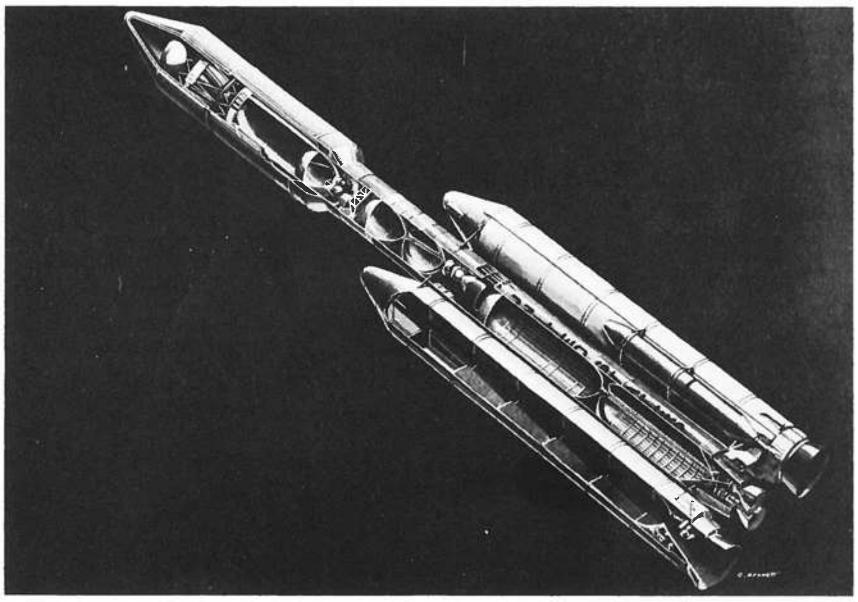
It is also one that ensures maximum returns from financial investment. The reusable transportation system will be open to use by any interested group or corporate body, as well as foreign governments. From 1979 the Shuttle will fly an increasing number of missions designed to place in orbit a host of scientific and applications satellites. NASA expects to launch up to sixty missions each year from the mid-1980's and a fleet of four or five operational vehicles are expected to suffice into the 1990's. Each Shuttle will fly into space more than one hundred times with a variety of payloads and manned laboratories in its cargo bay. Throughout the last few years of the expendable era, NASA has maintained launch operations with four prime categories of launch vehicle: Scout, Delta, Atlas-Centaur and Titan III. Only the solid propellant Scout will be retained in the 1980's, for the obvious reason that it still competes favourably as a launcher for small unsophisticated payloads.

Additional propulsion units, all using solid propellant, will be available for sending payloads beyond the operating ceiling of the Shuttle. These will be carried first into low Earth orbit by the Shuttle and then released so that they can fire their payloads into the required trajectory. The most powerful unit, called the Upper Stage, will be used by the US Air Force in the last expendable launch vehicle development funded by the Washington administration. Using the Titan III as the basic delivery system, the new launcher will be designated Titan 34-D and replace earlier configurations for sending military payloads into space. Eventually, the Air Force will integrate several military payloads with Shuttle flights, but there is considerable interest in retaining an autonomous launch capability. The Department of Defence is concerned

Dr. James C. Fletcher, then NASA Administrator, is accompanied by his deputy, Dr. George M. Low, and Associate Administrator for the (then) Office of Manned Space Flight, Dale D. Myers, at the historic March 1972 press conference that announced selection of the Shuttle configuration. An early model of the Shuttle is in the foreground.



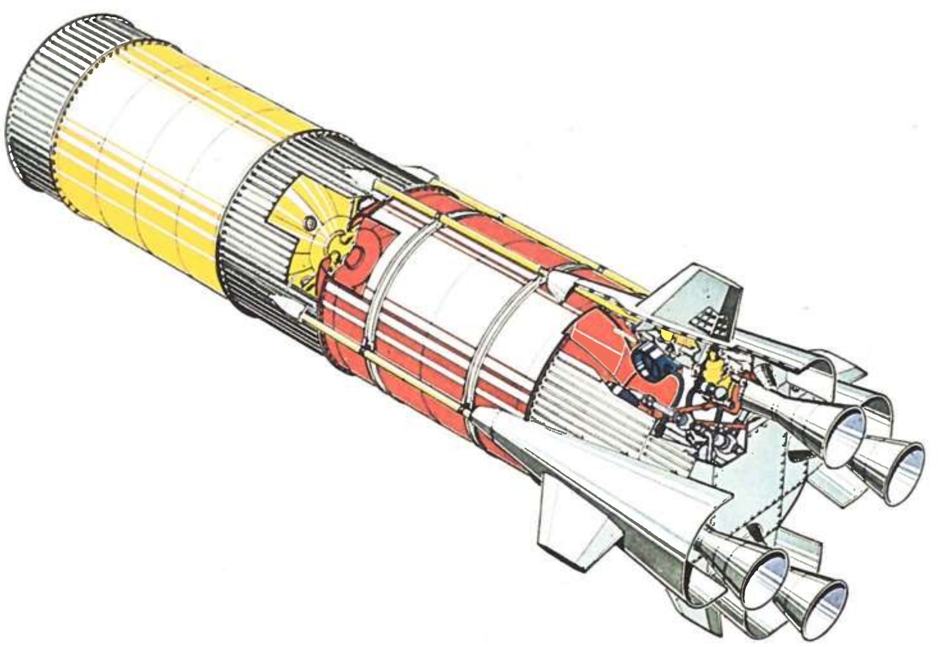
The Space Shuttle Main Engine, or SSME, is the most efficient liquid propellant rocket motor ever developed. With a chamber pressure of 208 kg/cm² and a specific impulse of 455 sec, burning liquid hydrogen and liquid oxygen.



'The last launch vehicle derivative to be introduced was the Titan III-E/Centaur and this has successfully sent Viking spacecraft to the planet Mars and Voyager spacecraft to the outer planets.'

Space Shuttle main engine injectors are being fabricated at Rocketdyne in preparation for the first thrust chamber test late in 1974. The injectors feed liquid hydrogen and liquid oxygen to the combustion chamber.

The European Space Agency is developing the Ariane liquid propellant satellite launcher for European payload users and other interested customers.



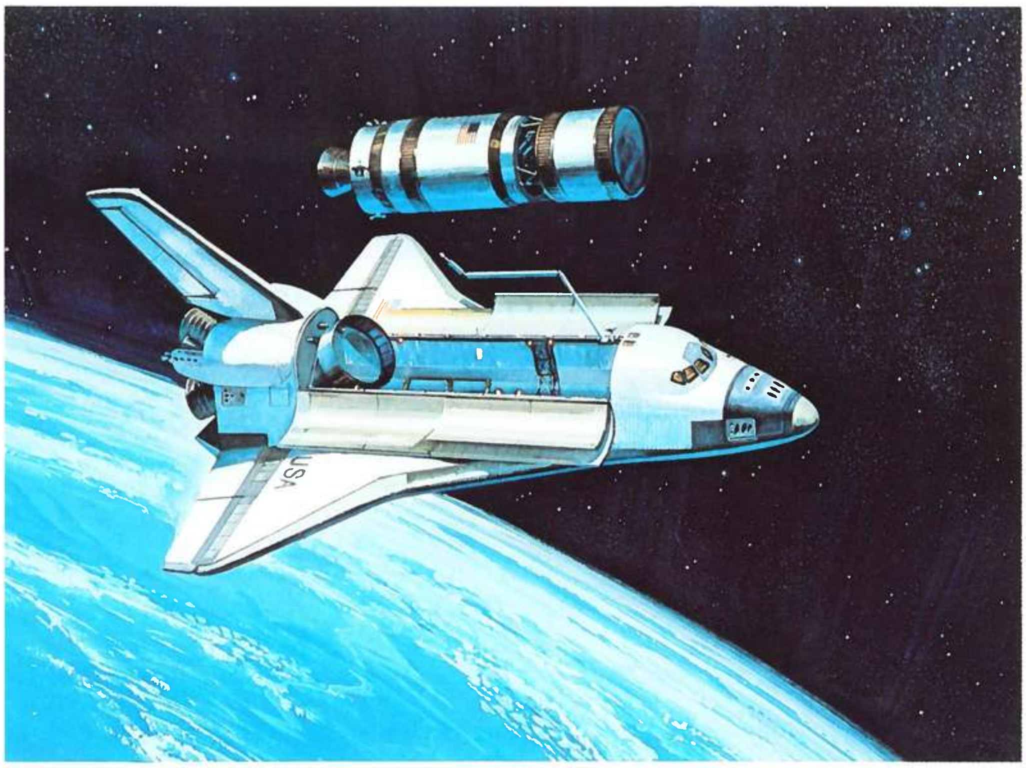
The first stage of Ariane will consume 145 tonnes of propellant in the four Viking-2 engines. Ariane has an equivalent capability to that of Atlas Centaur operated by NASA.

that in the event of hostilities, the Shuttle launch pads would be easy targets for enemy missiles. Consequently, work is progressing to perfect a launch credibility that would extend into an era of global nuclear war. It is proposed that the Minuteman ICBM could be used to launch essential military satellites into space from underground silos and so provide a degree of protection absent from the complex of surface sites. Ultimately, in the mid-1980's, Minuteman missiles may replace existing Titan derivatives for purely military satellite launches.

Expendable launch vehicles have obvious limitations, not least of which is the enormous cost associated with each flight. In the United States, public scrutiny of federal programmes compromises the continued use of such systems and this is one reason why the Shuttle has received congressional support. In the Soviet Union there are no such constraints on the use of government money and Russia continues to support an increasing launch rate each year, based on conventional and expendable launchers. There is no indication yet that the Soviet Union has developed a fully operational rocket stage using high energy oxygen-hydrogen propellants. Yet the higher specific impulse value of this low-temperature combination, makes it a highly desirable feature of any space launcher. While the United States has chosen to halt manned space flights and spend a considerable portion of its financial resources on the development of a reusable Shuttle, Russian cosmonauts have continued to exploit the technology of their existing space programme.

There is sustained interest in the use of Earth orbiting space stations and Russia has developed a small, but effective production line for Salyut laboratories launched by D class rockets. Visiting cosmonauts are launched on the A series launcher and perform rendezvous and docking operations to occupy the space station for extended visits. However, there are indications that the Russians too are interested in a reusable launcher and the United States may find that it is not the only space-faring nation to develop a recoverable transporter.

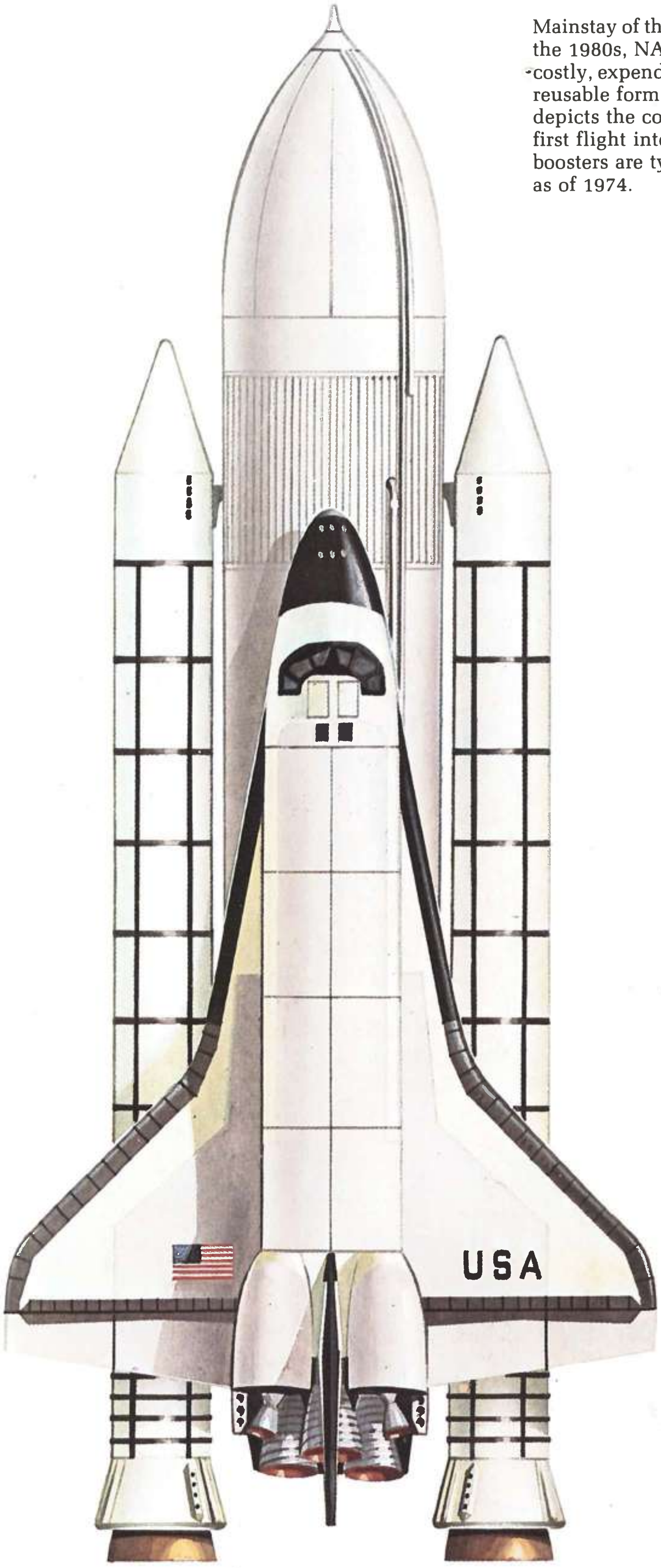
Elsewhere, the European Space Agency expects to provide a competitive launch service to the Shuttle when the

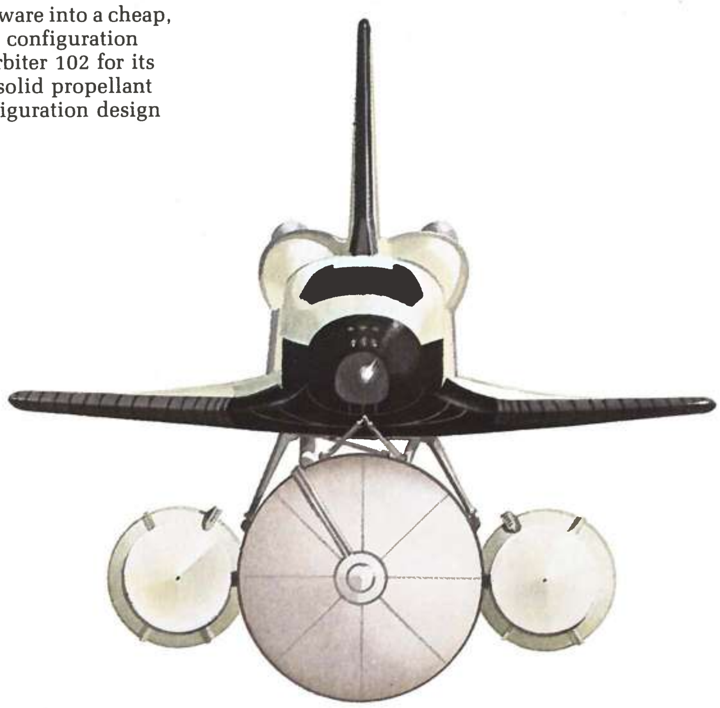


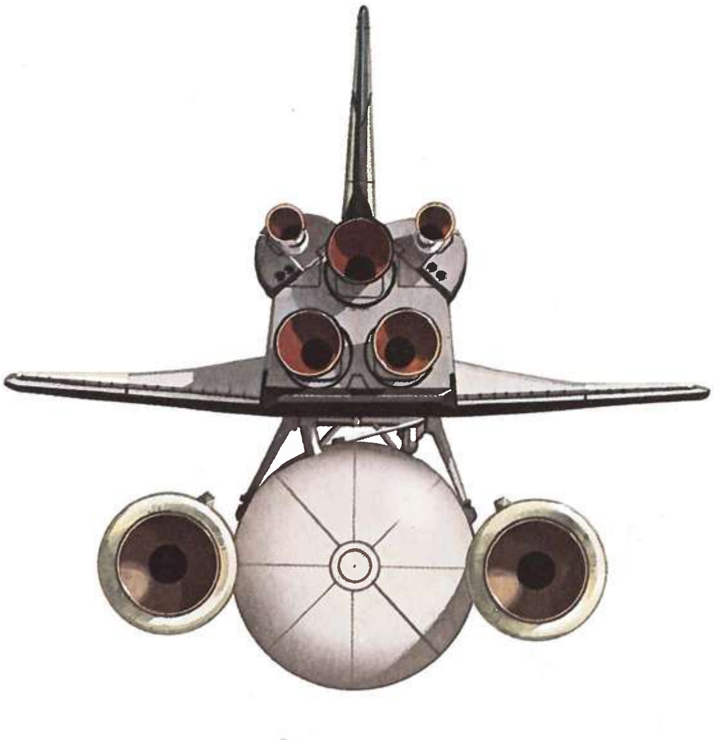
The functional adaptability of the Shuttle will be the mainstay of US space operations throughout the 1980's. Here, a separate rocket propulsion unit is backing out of the Shuttle's cargo bay with a payload destined for high orbit. Note the manipulator arm used for removing or placing payloads from or into the cargo bay.

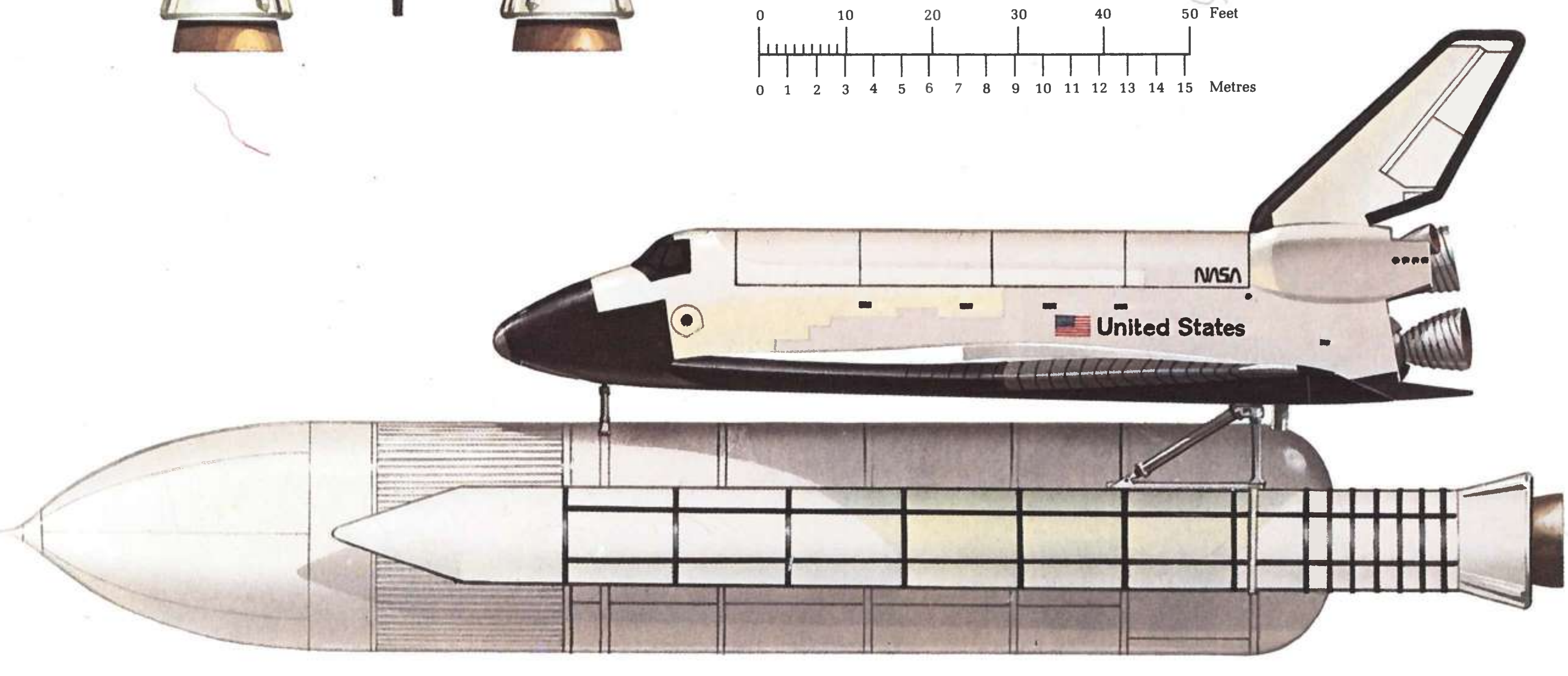
The massive External Tank that will be used to provide propellant for the Shuttle's three main engines is moved slowly by barge to the test site.

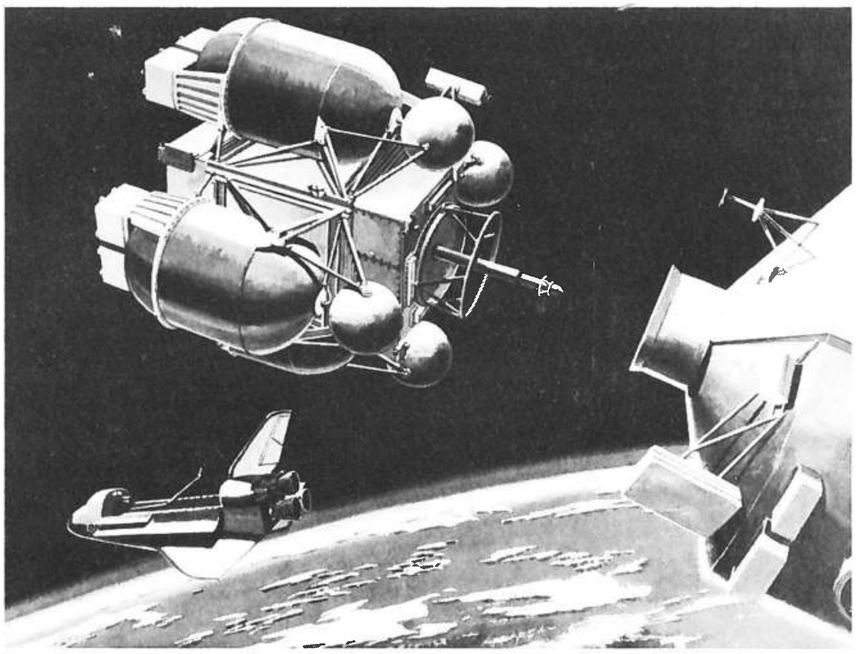
Mainstay of the US space programme throughout the 1980s, NASA's Space Shuttle will transform costly, expendable launch hardware into a cheap, reusable form of delivery. This configuration depicts the colours worn by Orbiter 102 for its first flight into space; the two solid propellant boosters are typical of the configuration design as of 1974.











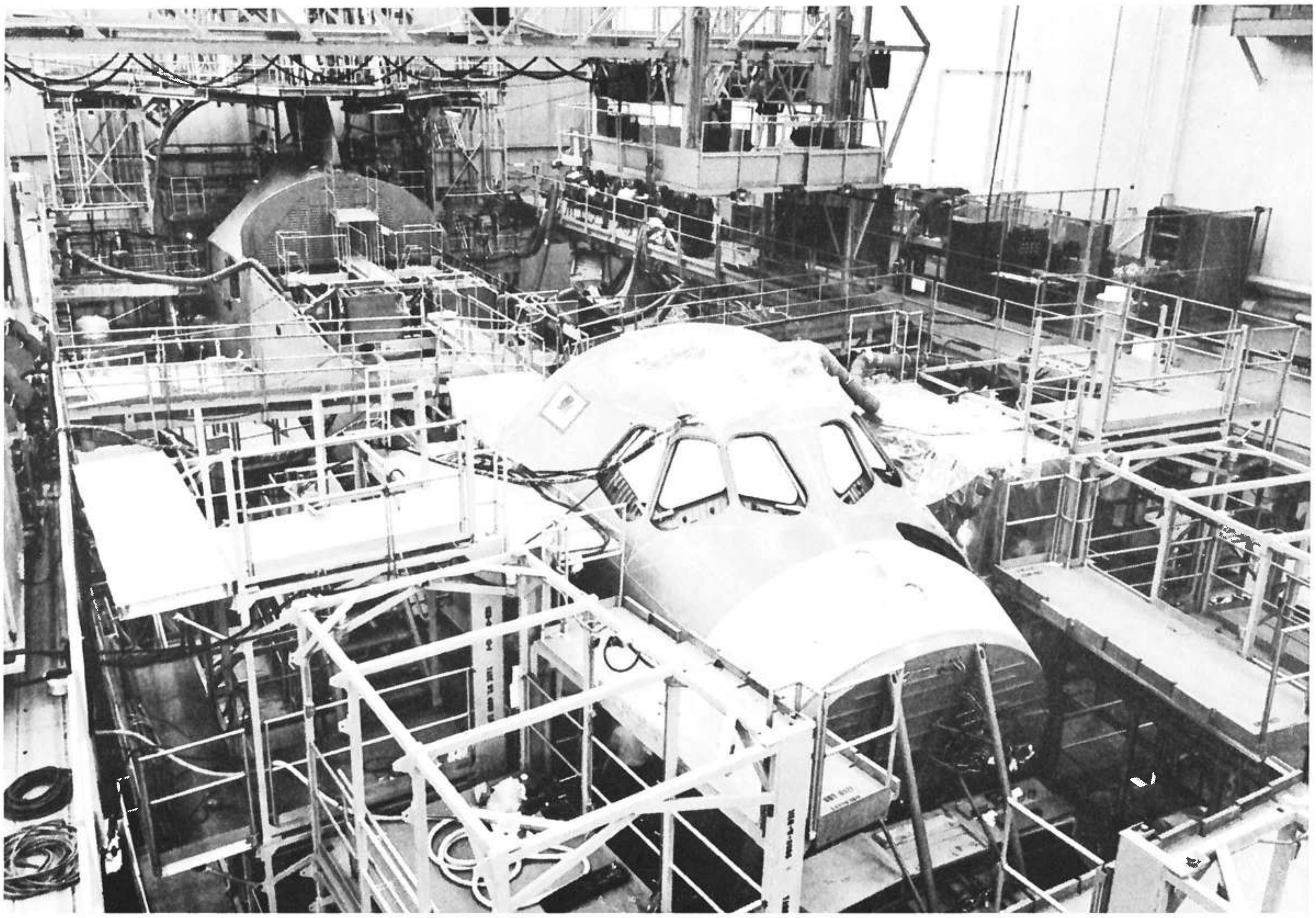
A Teleoperator Retrieval System, such as that shown in this illustration, will be used for manoeuvring payloads in orbit and can be recovered by the Shuttle for re-use. It will be used late in 1979 to boost the Skylab space station into a higher orbit and thus prevent it decaying into Earth's atmosphere.

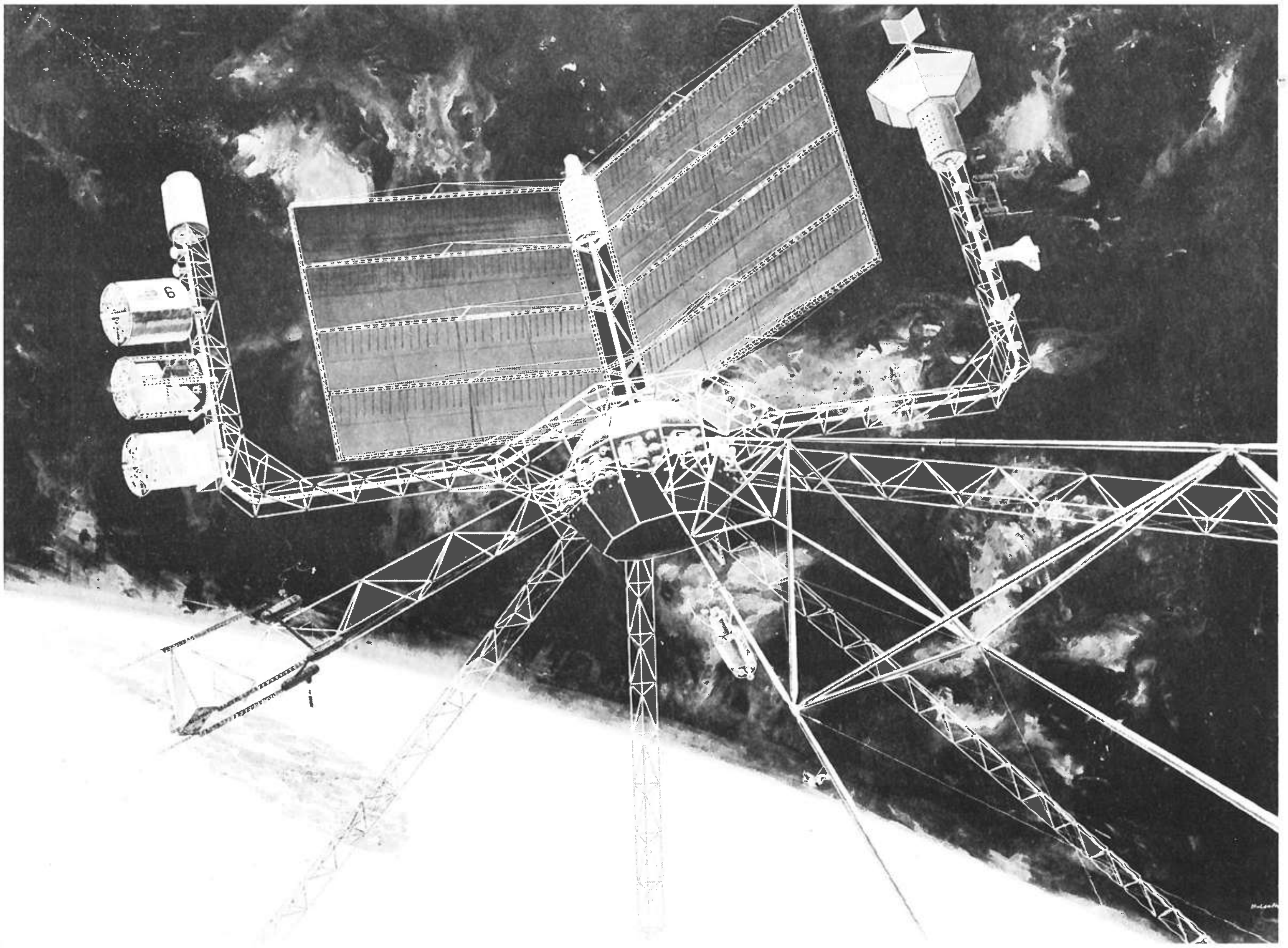
Astronauts Fred Haise (left) and Gordon Fullerton on the incomplete flight deck of a Shuttle Orbiter. These two pilots were at the controls of the first Orbiter when it was flown from the back of a Boeing 747 in the first of five drop-tests beginning in August 1977.

Ariane becomes operational in 1980. Ariane has been funded by several European countries as the definitive version of a design that began life as the L3S, a French proposal arising from the demise of the European Launcher Development Organisation (see Compendium). The launcher carries a range of technical improvements made possible by advanced developments in the field of rocket propulsion and will adopt a liquid hydrogen/liquid oxygen third stage motor to provide a capability comparable to the Atlas-Centaur used by NASA.

High energy propellants will be a feature of the proposed launcher development programme pursued by Japan, where the N-series vehicle promises to secure adequate payload carrying capability for the next generation of Japanese satellites. While the Soviet Union, Europe and Japan continue to pursue national objectives with their own indigenous delivery systems, many programmes organized by less affluent countries will rely on the reduced launch costs associated with the Shuttle. But while there is abundant opportunity for using space as a platform for applications satellites designed to enhance Earth-based activities, there is growing concern that more daunting problems face mankind than those that

A Shuttle Orbiter is seen here in an advanced state of assembly at the Palmdale facility of Rockwell International, prime contractor for this reusable launch vehicle.





One possible objective for launch vehicles in the 1980's and 1990's is the construction of a Solar Power Satellite. In this Boeing artist's illustration, workers are fabricating the primary structure. When completed, the facility could provide unlimited supplies of electrical energy beamed down to Earth on microwave links. Note the Shuttle at upper right, moored to one of the steel towers.

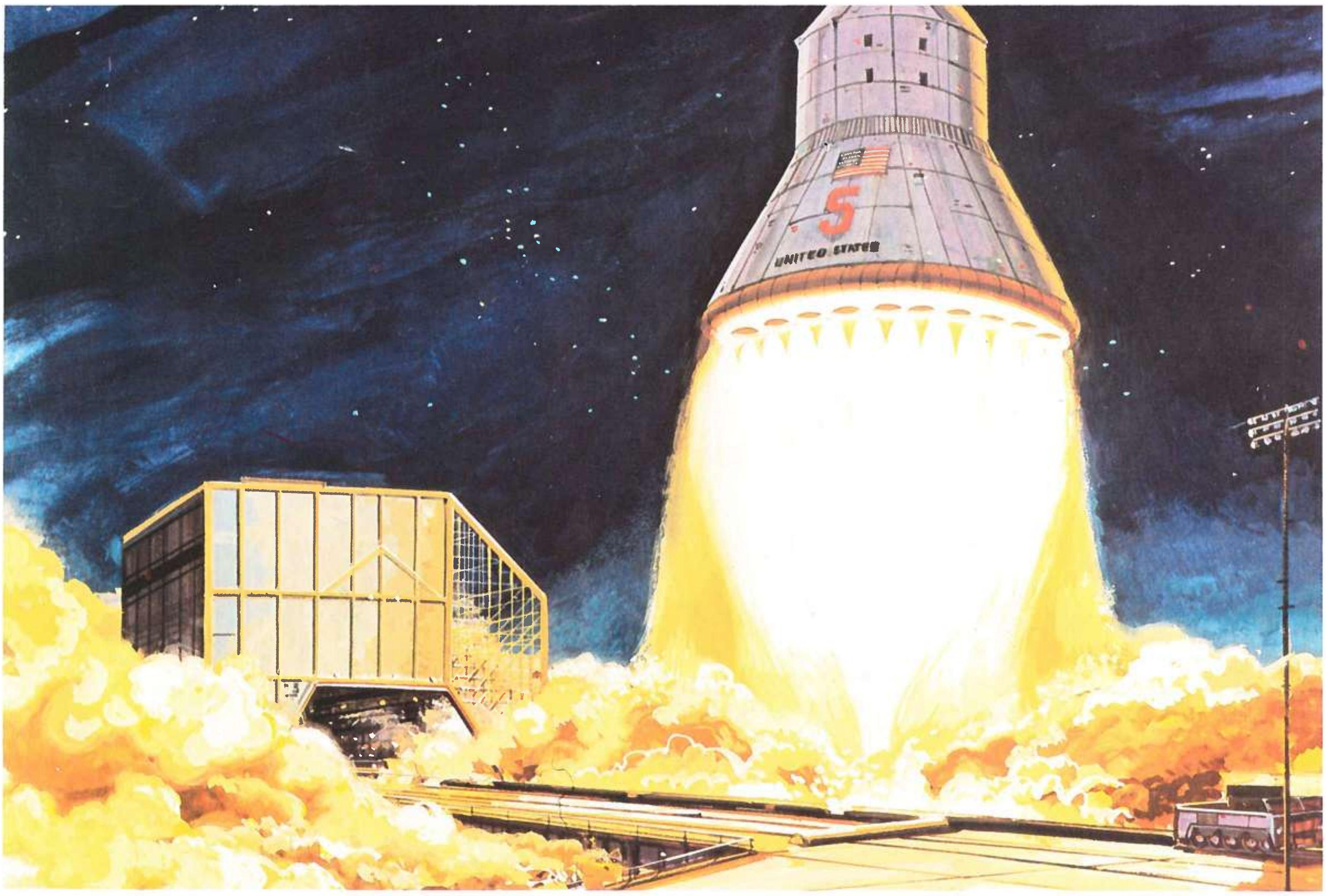
structure national objectives. There is little doubt that within the next one-hundred years the industrial societies of the world will be required to find and exploit new forms of energy production; the rapid depletion of fossil fuels runs counter to sustained growth and if civilization is to expand and prosper it will only be as a result of using hitherto untapped resources.

Because space technology and the concurrent development of operational delivery systems has provided an advancing base for sophisticated orbital operations, options are available which would have seemed remote a few decades ago. Studies conducted in the United States and the Soviet Union point to the desirability of exploiting solar energy as a viable means of driving our societies in the 21st century. Several aerospace corporations in the United States have performed feasibility studies for the Government which lead to the conclusion that a solar-power satellite is capable of providing sufficient energy for global needs. In one concept, the Boeing Company has proposed development of a solar-power satellite that would generate 10,000 megawatts of electricity and beam it down to the surface of the Earth on microwave links. Many of these facilities would be built in orbit to cover the energy requirements of the United States and it would be a logical product of this idea to expect other nations to participate in a cooperative endeavour that would bring benefits to the rest of the world.

But the solar-power satellite is a very different proposition to those that embrace the current generation of Earth-orbiting payloads. Each facility would be several tens of kilometres in diameter and require construction tasks impossible with the projected launch systems available in the near future. Several hundred million tonnes of material would have to be lifted into orbit so that large work forces could build the structure. This calls for a heavyweight launch system unlike anything yet brought to fruition. Moreover, with a requirement for several hundred launches each year, the delivery transporter would have to be reusable so that costs could be kept to reasonable levels.

Several times in the decades of the space programme, private studies performed at Boeing, Chrysler, McDonnell

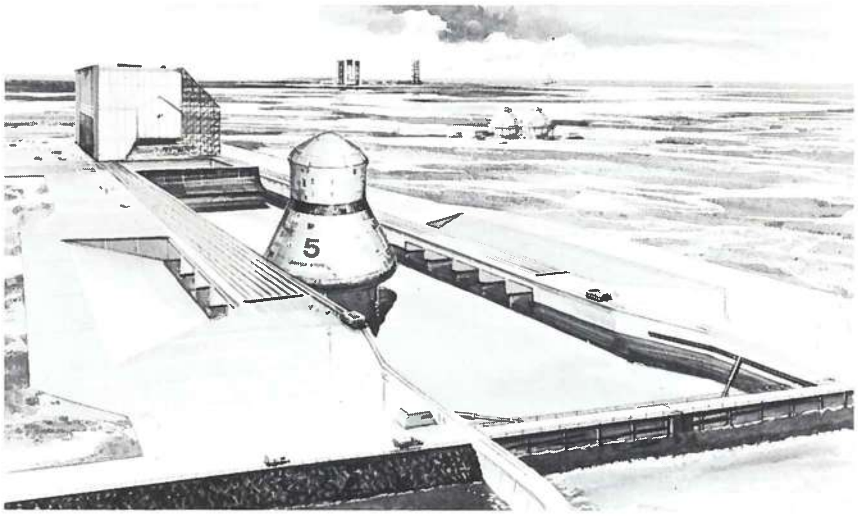
When Shuttle Orbiters are moved from one location to another they will be carried on the upper fuselage of a converted Boeing 747, as in this view taken during the drop-tests in 1977.



Assembly of a massive Solar Power Satellite in orbit would require large heavyweight freighters such as that seen during take-off in this Boeing view.

Returning from orbit, the heavyweight freighters would descend, base first, toward a large water-filled receiving pond and splashdown. Note the circular rectenna, which would receive microwave links from the Solar Power Satellite, at the top of the picture.

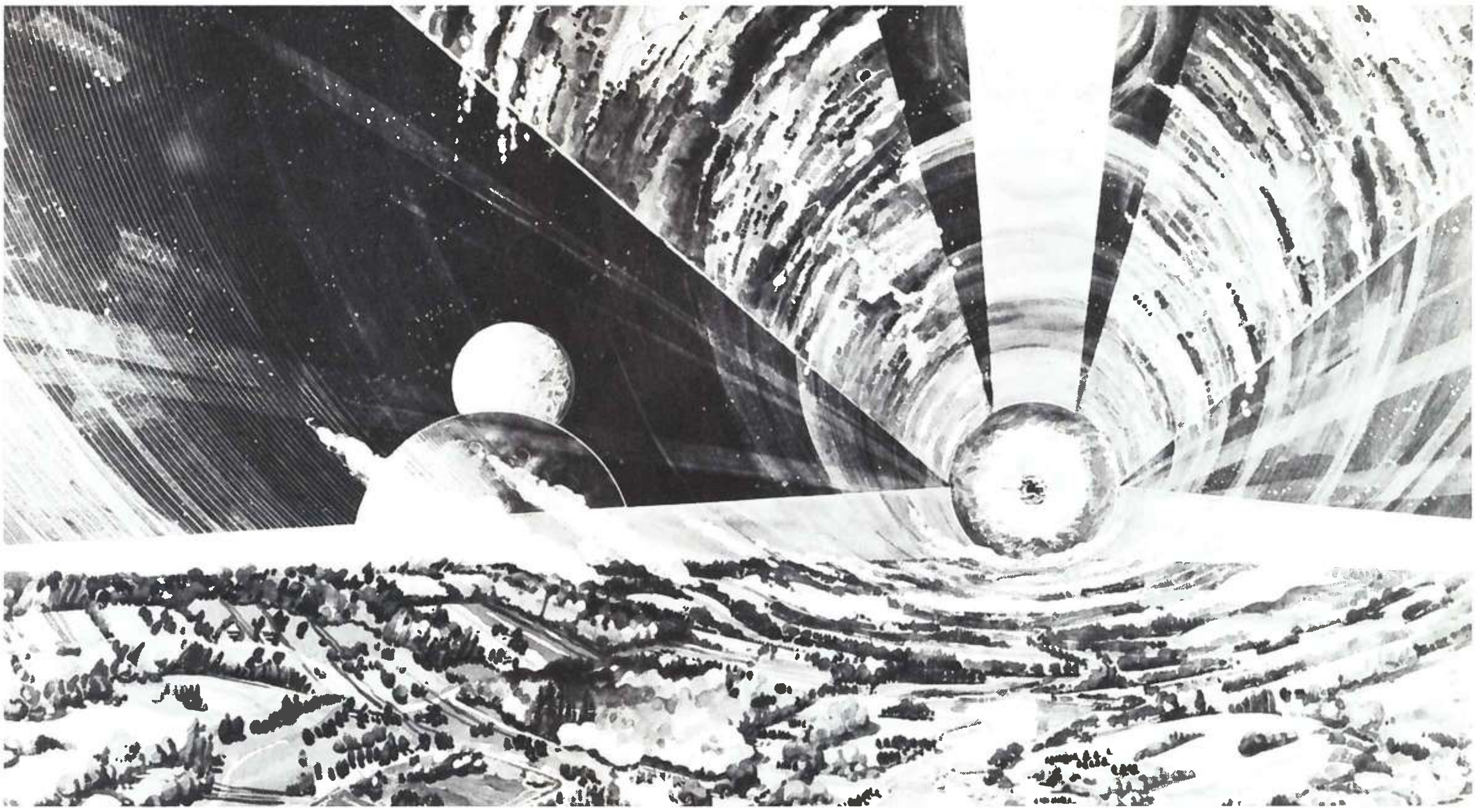
After splashdown, the freighters would be towed to a dry-dock facility at the periphery of the receiving pond from where water would be pumped out in readiness for re-launch into orbit after taking on more materials and supplies.



Douglas and other aerospace corporations have addressed the requirements of a heavy-lift launcher and all have agreed that a revolutionary approach to booster design is fundamental to the projected availability of such a system. But there has never been a more significant role for the heavyweight launcher than that which comes as a result of the search for more efficient and longer lasting sources of energy. The Boeing Company has performed a preliminary design study of the SPS Freighter which it believes will solve the enormous problem of lifting vast quantities of material into orbit, from where the solar-power satellites can be built. Space factories would provide employment for several hundred workers at a time and the logistics problem can only be circumvented by a regular and reliable transport system operating as efficiently as possible.

The heavyweight freighter, which would conceivably fill the assumed role would, as proposed by Boeing, use water as the recovery medium, unlike the Space Shuttle which lands on a runway, like an aircraft. Because of the colossal payload capability, the sheer size of the SPS Freighter would dwarf the Shuttle and recovery would be effected by a combination of retro-rockets and water impact to cushion the landing. The SPS Freighter would be about 73 metres tall and take the form of a truncated cone 39 metres in diameter at the base and about 20 metres in diameter at the top. A cylindrical section, 20 metres in diameter and about 23 metres long, would form the top of the vehicle with a hemispherical dome at the upper end. The SPS Freighter would actually consist of two staged sections with the bottom, or booster, section carrying sixteen rocket motors, burning liquid oxygen and kerosene for a unit thrust of nearly 886.4 tonnes. With the sixteen motors arranged around the lower periphery of the conical vehicle, launch thrust would equal 14,181 tonnes – more than four times the launch thrust of the Saturn V.

This booster section would carry the complete assembly through the atmosphere and then separate to fall back down towards the water recovery area. Six liquid oxygen/liquid hydrogen engines, of the type used in the Shuttle, would be situated, facing downward, at the centre of the flat base, to provide a total thrust of 1,279 tonnes. These would fire, close to impact, to cushion the shock of landing and provide for booster recovery and re-use. Meanwhile, the upper stage continues on into orbit under the impetus of eight Shuttle type engines, with a combined thrust of 1,700 tonnes. At launch the SPS Freighter would weigh 10,464 tonnes and carry a payload weight of 405 tonnes. The eight Shuttle engines in



Window to the 21st century? In this view, several hundred thousand people would populate an orbiting space colony. Essentially a cylinder 32 km long and 6.4 km in diameter, the earth-like colony resides on the inner face of the 'tube' which slowly rotates and provides artificial gravity. Transparent strips separate the populated areas so that mirrors can reflect sunlight to the interior, pressurized with an earth-like atmosphere. Having freed Man from fossil fuels, by building Solar Power Satellites in orbit, rocket vehicles will one day forge a new umbilical: one that connects planet Earth with manmade colonies in space.

the upper stage would be used to return the section back to Earth and re-ignition of the motors would cushion the impact in a similar fashion to the method employed by the booster stage.

Large fleets of SPS Freighters would be required for lifting the enormous loads necessary in building the orbital power stations and at a use rate of ten freighters per day, each flight would cost about $7 million, or $17.3 per kilogramme of payload weight. This is a cost-per-kilogramme value equal to less than 6% that of the Shuttle, which is itself capable of sending payloads into space at roughly one-seventh the rate charged with expendable launch vehicles. Assuming the launch of ten SPS Freighters per day, or 3,125 each year, at least one new solar-power satellite could be built per annum. The Boeing Company believe this to be an acceptable traffic rate, assuming that the necessary resources could be made available to mount such a large scale operation, saying that the daily cargo load (4,050 tonnes) could be flown with a cumulative freighter mass, similar to that operated at a major airport every day. Moreover, with the required flights necessary for building up to six solar-power satellites annually, the total energy consumption would represent only 10% of that already used by the commercial airline fleets. Clearly, such an ambitious concept is ripe for exploitation and total costs involved are predicted to be actually less than that spent on the entire Apollo Moon landing programme. If approval for such a system is given by the early 1980's, the first solar-power satellites could be operational in the 1990's, leading towards full use of the Sun's energy, for all domestic needs, early in the 21st century.

A decade ago this book would have ended on the visionary note that within a few years massive fleets of interplanetary spaceships would be coursing their way to remote destinations in the solar system, carrying the banner of human progress to the distant regions of the solar environment. Instead, humanity is assured that the problems it faces today and the future development of advanced rocket propulsion systems are inextricably united in an assault on objectives that will free Man from the finite resources of planet Earth. One day, perhaps in the not too distant future, Man will turn his evolving technology towards the stars, for having gone so far along the road of progress, he can never turn back. In the words of H. G. Wells: 'For Man there is no rest and no ending. He must go on, conquest beyond conquest, and when he has conquered all the deeps of space and all the mysteries of time, still he will be but beginning.'

This dramatic view of the launch of Apollo 14 in 1971, the ninth Saturn V flight, epitomizes the dramatic alternatives facing humanity: international cooperation in the exploration of space or global nuclear destruction. Both use the rocket as their fulcrum.

Compendium of Launch Vehicles and Ballistic Missiles

All Rocket silhouettes are
in proportion and to a scale of
approximately 1 mm:1 m.
Rockets under 10 m height, not illustrated.
**Accurate visual data not available.*
Comparative Rocket types: pages 123–125
(foldout)

In this section the reader will find a comprehensive and detailed review of 98 military missiles and space launch vehicles covering the period from the first V-2 tests to the impending Space Shuttle, due to make its operational debut in mid-1980 following a year of tests. Nearly four decades of ballistic missile history are outlined and to avoid confusion, the various projects are listed alphabetically by country of origin and then by type name.

In the Soviet section, the United States intelligence codes are used for military missiles (SS-) with letter designations for the civilian space launchers (A, B, C, D, F & G) borrowed from the format laid down by Dr. Charles S. Sheldon at the Library of Congress, Washington. Launch vehicles A, B, C and F are designations applied to SS-6, SS-4, SS-5 and SS-9 respectively when these primarily military missiles are used for 'non-military' space duties and they can be found under the section dealing with rockets, designated SS-.

In several cases space launch vehicles developed from military missiles are given a separate descriptive text. For instance, the Delta was developed from the Thor missile and can be found under 'Delta', but the family of upper stage configurations carried by Thor are to be found under 'Thor'. In this case the complete history of Thor derivatives will be found spread through both 'Thor' and 'Delta' headings and the reader should bear this in mind and look for notice of other sections which relate to essentially the same vehicle.

In other cases, where it would be confusing to separate a descriptive text into several categories, a generic development is grouped under one heading. For instance Titan I, II and III were military missiles and space launch vehicles, each very different from its predecessor, but they are all grouped under one heading because of the strong historical flow from one to the other. The opposite applies to Saturn I and IB, essentially the same launch vehicles, but with different upper stage configurations, and the Saturn V, a very different launch vehicle, found under a separate heading.

Sometimes, as in the case of 'Kappa' and 'Mu', several projects are listed under titles which relate to the overall series of design configurations, it being too confusing to list each specific type change under a separate heading. For these multifarious reasons an index is provided, with a list of main project names, so that readers can simply look up the particular vehicle in question to find the page which deals with that project or derivative. For instance, Centaur will be found under 'Atlas' and 'Titan', because both of these launch vehicles use the Centaur upper stage. As a final aid to cross-reference, page numbers are varied in the index, Compendium page numbers being in brackets.

In the case of the Shuttle, description attention has been paid to the historical development of concepts which led to selection of the final design. Political and economic ramifications of particular projects are dealt with in Section 1, but it has been found too confusing to retain that format for the Shuttle. This exception, then, combines both a technical history and an insight on the programmatic decisions which led to its development.

The categories within which the 98 descriptions fit, cover ballistic missiles and space launch vehicles, excluding air-to-ground, anti-ship, anti-submarine, surface-to-air, air-to-air and anti-tank missiles. Summary data on all these small rocket-powered devices (comparing some 389 different types) can be found in table form.

The criteria for inclusion in this section demands that the missile must either place payloads in space, be used for probing the upper atmosphere, transport warheads across continents or between continents or be used as a tactical ballistic battlefield weapon. Every such device which has entered service is included, together with those which are in an advanced stage of development and expected to be deployed, operationally, in the future. Some projects, such as the nuclear rocket, never reached operational status and are discussed in their historical context in Section 1. The index at the end of the book lists all projects which are not covered by this Section of operationally deployed systems.

CANADA

Black Brant:

As a result of responsibilities placed upon the Canadian Armament Research and Development Establishment (CARDE) for the production of rocket probes for atmospheric sounding, the Black Brant series of solid propellant rockets emerged in 1956, named after a well known Arctic goose. The motor for Black Brant 1 was produced by the Bristol Company in the UK and the rocket was 7.4 m long with the capability of sending a 45 kg package to a height of 160 km.

By 1960 industry had taken over development of improved versions and Canadair produced the Black Brant 2 which was first fired in 1960. This could send 70 kg to an altitude of more than 200 km and a further variant, Black Brant 3, appeared in 1962 as a result of further collaboration between CARDE of Canada and Bristol in the UK. This was a shorter model and had a capability of taking 23 kg to a height of 160 km.

The next variant adopted the Black Brant 2 as first stage for the Black Brant 4 and had a boost of 9.1 tonnes for 23 sec using the Black Brant 3 as second stage. The two-stage rocket, 11.3 m tall, could send a payload weight of 20 kg to a height of 1,000 km. The 8.2 m long, 43 cm diameter, Black Brant 5 was produced in three principal versions: the 5A designed to match altitude rather than weight carrying capabilities, the 5B with double thrust of the Black Brant 2 and designed to conduct scientific experiments above 350 km and the 5C with a capability of placing 200 kg at a height of more than 300 km.

The 5C achieved distinction in being part of the NASA Skylab manned space station programme, when two were launched during each of the three separate periods of astronaut occupation in 1973–74.

CHINA*

CSS-1:

The development of the Chinese medium range ballistic missile originates from early acquisition of the Soviet SS-4 Sandal. The liquid propellant, single stage CSS-1 was originally deployed in 1966 and probably carries a 20 KT fusion warhead across a range of up to 2,000 km. There are probably less than 100 deployed rounds, with most missiles seeing service along the north-eastern border and in Tibet aimed at key Soviet supply and transport routes in the east and northern areas of the USSR.

The CSS-1 design seems to adopt a basic technology reminiscent of first generation Soviet MRBM engineering and there is evidence to believe that the Peoples Republic of China is concentrating more fully on the updated versions of the CSS-2 and CSS-3 and on the potential capabilities of the new CSSX-4.

CSS-2

In October 1966, the fourth Chinese nuclear weapon test was performed, with a first generation MRBM taking the warhead to the target area. From this development came the CSS-2 intermediate range ballistic missile, which was known to have been deployed in 1971, following its use as a space launcher, when it put the first Chinese satellite into orbit on 24 April 1970. Launched from Shuang-ch'eng-tzu, the vehicle probably used the basic CSS-2 first stage, with adapted upper stage configurations, tailored to the requirements of the launcher role, in much the same way that early US satellite launchers were composites of military main stages and unique upper stages.

The CSS-2 has a probable range of 4,000 km and by 1972 was entering service in the western areas of China, to serve as a defence system on the Sino-Soviet border. The missile was tested in 1970, when it achieved a near design range performance demonstration from the launch site in Manchuria used for the satellite launching.

With a 1 MT warhead, the single stage liquid propellant IRBM deployment includes about 20 rounds. It appears that earlier US estimates of more than 100 rounds, reaching operational status by the mid-1970's, are unfounded and emphasis seems to be going on the CSS-3 and CSSX-4 ICBM's.

The first two satellites launched by the Peoples Republic of China (PRC) on 24 April 1970 and 3 March 1971, weighed about 173 kg and 218 kg respectively and probably represented the maximum payload capability of the basic launcher using the CSS-2 first stage. China 1, the first satellite, carried a recorded song *The East is Red*, broadcast by a small transmitter. Beginning in 1975, the PRC launched a series of satellites into elliptical orbits averaging 180 km by 470 km, with each vehicle weighing 3.5 tonnes. This probably adopted first stage technology originally developed for the CSSX-4, but details are unknown.

CSS-3

Although development of a Chinese ICBM is known to have been underway since the late 1960's at least, it is difficult to assess the operational development of the total system and only fragmentary evidence exists. However, it is known that tests of a first generation ICBM did take place in 1970 and from a variety of intelligence sources have come reports that several ICBM's were deployed in the Sinkiang area, with a range capability of 6,500 km.

The missile is probably a liquid propellant device with at least a 3 MT warhead and is expected to operate in conjunction with the very much larger and more powerful CSSX-4, now anticipated for operational deployment in the mid-1980's, probably from a silo launch site.

C-SLBM:

By late 1974, US intelligence reports indicated the imminent development of a new submarine-launched ballistic missile and spoke of a submarine under construction which could carry the missile(s) within its hull for possible sub-surface launch and with probably IRBM range. In 1977 the US Department of Defence considered it likely that the SLBM system would be brought into service in 1980, but further details are lacking.

C-SRBM

A short range ballistic missile based on the Soviet Frog battlefield weapon, has been deployed for at least a decade in large numbers along the Sino–Soviet border. With a highly mobile role, the C-SRBM is thought to be of original design but heavily influenced by the early Frog models which were first put into service by the Soviet Union in 1957. Several hundred rounds are thought to be in readiness, although the number of launchers and transporters is unknown. The C-SRBM is known, however, to carry a low yield nuclear charge.

CSSX-4:

It is very difficult to assess the evolutionary development of China's second generation ICBM, but certain aspects of the system are known to be operational, although it may be many years before the rocket poses a significant threat to potentially hostile nations. The Chinese have never released details of their ICBM research, but they have had a long and successful association with first generation Soviet rockets of limited range.

In February 1970, the US administration expressed belief in reports that indicated Chinese interest in establishing itself as a major nuclear power and the then Secretary of Defence, Melvin Laird, commented to the effect that he believed China could deploy a fleet of between 10 and 25 ICBM's by 1975. This was, he concluded, sufficient to cause as many as twelve million US fatalities; the missile was believed to have a range of about 9,700 km, with a thermonuclear warhead of up to 3 MT yield. It was known that considerable effort had been expended at Shuang-ch'eng-tzu during 1965 toward the establishment of a ballistic missile testing base, with a period of rebuilding in 1970, the same year a missile was observed to fly from the north-west Manchurian test area to western Sinkiang for a distance of 3,550 km.

At that time the US Department of Defence believed that tests of a longer, 5,640 km range, ICBM were imminent and predicted the operational deployment of a 3 MT yield missile with a probable range of 9,650 km from three or four liquid propellant stages. By 1974 and 1975 it was apparent that China was moving towards test flights of a much larger ICBM than that anticipated in earlier years and the intermediate ICBM tested in 1970 was thought to have been a step in its generic development.

The large ICBM, CSSX-4, probably has a higher performance than either US Titan II or Soviet SS-9 missiles and would have a range of about 12,000 km with a multi-MT warhead carried in two-stage liquid propellant rockets. The earlier missile has probably not been deployed and had led instead to development of the new and larger version which will probably enter operational service in the early 1980's.

EUROPE:

Ariane:

With a view to providing an autonomous European launch capability, the European Space Agency (ESA) has taken over development of the Ariane launch vehicle to enter operational service in 1981. Conceived in 1972 as the L3S, Ariane will be able to place a 1,700 kg payload in a geostationary transfer ellipse, or place 950 kg in geosynchronous orbit. It is a three-stage liquid propellant vehicle, stands 47.4 m tall with a maximum diameter of 3.8 m.

The first stage carries 145 tonnes of propellant, the second stage 33 tonnes, and both use the Viking rocket engine: four Viking-2 engines in the first stage, one Viking-4 engine in the second. Both first and second stages use a combination UDMH/N_2O_4 propellant. The third stage is powered by a single HM7 LOX/LH_2 engine with 8 tonnes of propellant in the tanks. Thrust levels for first, second and third stages are 249.5 tonnes, 72.4 tonnes and 6.1 tonnes respectively. The total assembled weight is 207 tonnes.

In a normal mission, the first stage burn lasts 143 sec, followed by separation and second stage ignition, 6 sec later. This burns for 124 sec and then it too is jettisoned, before third stage ignition, for a 570 sec burn, taking the payload on to a geosynchronous transfer ellipse. The standard cylindrical payload shroud has an interior dimension of 3 m by 4 m in length.

ESA will launch Ariane from the Guiana Space Centre near the equator on the first of four development flights in 1979, followed by a final three qualification launches in 1980. In the first few years of operational service, the Ariane expendable launch vehicle will be competing with the NASA Space Shuttle for customers planning to send payloads into space, all other heavy US launch vehicles being retired shortly after the introduction of the reusable Shuttle.

Europa:

A series of launch vehicle developments was proposed leading to an efficient and competitive delivery system for European satellites. Conceived by the European Launcher Development Organization (ELDO) following its inauguration in March 1962, the Europa project used the Blue Streak long range ballistic missile as the first stage. Blue Streak was developed between 1955 and 1960 by de Havilland in a response to British government plans to deploy a missile delivery nuclear weapon system with a range of 4,000 km. Because of the obvious vulnerability of large rockets standing unprotected on fixed launch pads, the concept was cancelled in April 1960.

Britain, France, Germany, Italy, Belgium and the Netherlands formed the ELDO group and as first stage of the Europa I launch vehicle, Blue Streak provided a thrust of 136 tonnes from two Rolls Royce RZ.2 liquid propellant motors. The total stage was 18.7 m tall, with a diameter of 3 m and a launch weight of 94.7 tonnes. The second stage of the Europa I launch vehicle was developed by the French and provided 27.9 tonnes of thrust from four liquid propellant motors burning UDMH and N_2O_4. The third stage was of German origin and produced a thrust of 2.3 tonnes from a single rocket motor, using the same propellants as the second stage. Originally called ELDO-A, Europa I would be capable of putting a 1,000 kg satellite into low earth orbit, a similar payload capability to that considered by the British government in 1959 when it looked at the possibility of using the Black Knight rocket as the second stage to a Blue Streak with a new solid propellant third stage.

In 1963 ELDO proposed a Europa-C model, with four RZ.2 engines in the Blue Streak first stage, uprating the thrust to 250 tonnes and fitting new LOX/LH_2 engines in the second and third stages. This would be capable of putting a 6,000 kg satellite into low earth orbit and provide Europe with the capacity to launch a manned space vehicle.

On 5 June 1964 Blue Streak was launched for the first time from the Woomera Rocket Range in Australia and reached a height of 177 km and a speed of 10,300 km/hr before impacting 966 km from the launch stand. In a second test on 20 October 1964, Blue Streak F.2 reached a height of 241 km and impacted 1,609 km downrange. The first test of the French Coralie second stage was attempted in August 1967, but failed to ignite on separation from the Blue Streak first stage. Later the same year, a second attempt ended when the stage failed to separate from Blue Streak.

The flight test sequence included: Phase 1, with three first stage launches; Phase 2, with two launches in 1966, using dummy upper stages and the unsuccessful two attempts in 1967 with live first and second and dummy third stages. Phase 3 would consist of four attempts with all three stages operating.

The unsuccessful test of the Coralie second stage came only months before Britain announced its intention to withdraw from ELDO by 1971 and the next scheduled flight, with all three stages live, was similarly unsuccessful, when the third stage fired for only 7 sec. An Italian satellite planned for orbital insertion was unable to achieve its objective due to insufficient velocity. European interest in a follow-on launcher stemmed from a decision in 1965 to go for a Europa II vehicle using the basic Europa I, but with a perigee/apogee stage for placing satellites in geosynchronous orbit and orginally known as ELDO-P/AS. A Europa III was proposed with high energy upper stages and a Europa IV which would have used two additional Blue Streak rockets strapped either side of the Blue Streak first stage of Europa III. This would have given Europa IV a launch thrust of 408 tonnes, with a 2,000 kg payload capability to geostationary orbit.

In 1969 and 1970 the Woomera site was used by Blue Streak for the last time, with two Europa I launches, which were also unsuccessful in sending a satellite into orbit. Trouble with the third stage prevented the objective from being met. While British financial participation was withdrawn from ELDO, Blue Streak rockets were still made available to the consortium and the first Europa II Blue Streak was fired from the Kourou range in Guiana on 5 November 1971. This was the 11th launch of a Blue Streak and it ended in catastrophe when the rocket blew itself up 150 sec after liftoff. A failure in the third stage electronics had prevented operation of the French second stage, German third stage and the French fourth stage.

A year later France proposed development of an entirely new first stage for Europa III and called the design the L3S (see Ariane) employing cryogenic propellants in the third, terminal, stage and by early 1973, Germany had agreed to co-operate on this project, effectively sealing the fate of Blue Streak purchase beyond Europa II flights.

The second launch attempt for Europa II was to have been made on 1 October 1973, followed by a further development flight in 1974 and launch of a Franco-German communications satellite at the end of that year. On 27 April 1973, however, the Europa II project was cancelled and ELDO was subsequently disbanded, having unsuccessfully attempted to launch a satellite into orbit. The only successful Europa I flights were the first five tests with Blue Streak only and the one Europa II flight had ended in disaster. European rocket development continued with the L3S, later re-named Ariane.

FRANCE:

Diamant:

The first French national satellite launch vehicle, was developed as a result of a decision made in December 1961, to use experience with earlier liquid propellant sounding rockets. It successfully placed the first French satellite in orbit four years later, from the Hammaguir launch site in Algeria. Diamant was based on the VE-231 Saphir military research rocket, which itself consisted of the VE-121 Emeraude as first stage and the VE-111 Topaze as second stage. Emeraude was a single-stage liquid propellant rocket, with a thrust of 28.4 tonnes burning nitric acid and turpentine, stabilized with four fins and controlled by a gimbal nozzle. Topaze was a solid propellant, single stage rocket, utilizing four steerable nozzles which could carry 100 kg to a height of 160 km.

The marriage of Emeraude and Topaze into the Saphir design effectively provided the French Ballistic Missile Design and Construction Company with the first two stages of a potential satellite launcher. With a third stage specially developed, called Rubis, containing 635 kg of solid propellant and delivering a thrust of 5.3 tonnes, it became the Diamant with a total length of 18 m and a payload capability of 115 kg to low earth orbit.

The first Diamant launch put the first French satellite into orbit on 26 November 1965 and by February 1967, three more Diamant rockets had been successfully fired from Hammaguir. The Centre National d'Etudes Spatiales (CNES) had control of the project and authorized the development of an improved version, Diamant-B, which would be capable of placing a 160 kg payload in low earth orbit. The first launch came on 10 March 1970, when France put two satellites in orbit with the one vehicle from the Guiana launch site, developed by France, when it was required to vacate the Hammaguir, Algeria, facility in 1967.

Diamant-B had a length of 23.17 m and a first stage thrust of 40.3 tonnes. A second satellite launch was performed by this rocket in December 1970 and a third in April 1971, but the fourth and final launch of the second generation rocket ended in disaster when, in December 1971, the second stage malfunctioned and the satellite failed to achieve orbit. In 1972, CNES decided to approve a third development, called the Diamant-B-P4. The first stage of the Diamant-B was retained, but the second stage was replaced by the P-4 (Rita), the second stage of the MSBS submarine-launched ballistic missile, producing 18.4 tonnes of thrust. The third stage of the -B was retained for the -B-P4 and this, with the shorter second stage, resulted in a total Diamant length of 21.4 m.

The first launch of the uprated version came on 6 February 1975, followed by a dual satellite launch the following month. The improved performance provides the Diamant-B-P4 with a capability to place 200 kg in a low equatorial earth orbit. Developed rapidly on the successful results of earlier ballistic rockets, the Diamant programme provided France with a reliable launch vehicle for national satellite projects and as such has been a singular success in itself.

MSBS:

The Mer-Sol Balistique Stratégique submarine-launched ballistic missile, is similar to the silo-launched SSBS design and is developed by Aerospatiale in a continuing series of refinements. First tests were performed in 1966 from the Hammaguir launch centre in Algeria and followed in 1967 with live firings from underwater rigs off Toulon. First submarine-launched tests were performed from the Gymnote in 1967 and continued at the Centre d'Essais des Landes (CEL) near Biscarosse in 1968. The prototype operational MSBS was fired from France's first nuclear powered submarine, Redoubtable, in 1969 and the first operational MSBS-M-1's were fitted to this vessel in 1971, followed by installation aboard Le Terrible in 1972.

An uprated version, the MSBS-M-2, was fitted to Le Foudroyant in 1975 and a further variant, the MSBS-M-20 was installed in L'Indomptable when it joined the other three vessels in 1976. Le Tonnant and L'Inflexible will be in service with the MSBS-M-20 in 1979 and 1983 respectively and eventually Redoubtable, Le Terrible and Le Foudroyant will be retro-fitted with the MSBS-M-20. The six nuclear powered missile launching submarines (Sous-marin Nucleaire Lance-Engins, or SNLE) are each 128 m long, manned by 142 officers and men, have a top submerged speed of around 46 km/hr and carry 16 MSBS nuclear armed missiles in two rows of eight.

The MSBS-M-1 is 10.4 m in length, 1.5 m in diameter and weighs 18 tonnes. It was capable of carrying the 500 KT nuclear warhead a distance of 2,500 km and used a first stage, almost identical to that employed as the second stage, of the SSBS silo-launched ballistic missile. The second stage, Rita 1, was 2.6 m long and produced a thrust of 18 tonnes, compared with 45 tonnes for the first stage. The first and second stages have burn durations of 50 sec and 55 sec respectively.

The MSBS-M-2 was introduced in 1974 and has a second stage length of 3 m with a thrust of 32 tonnes. This stage is the same as the second stage fitted to the SSBS-S-3 (see SSBS) with a 52 sec burn duration, but the first stage is the same as the -M-1. The increased length of the MSBS-M-2 second stage over that of the -M-1 is compensated by a shorter interstage section and the uprated variant has the same external dimensions as the earlier version. It does, however, have a 3,000 km range, with the same type of 500 KT nuclear warhead. Solid propellants in the first and second stages of the -M-1 and the first stage of the -M-2 consists of aluminium and ammonium perchlorate in a polyurethane binder, while propellant in the second stage of the -M-2 is a butalane compound.

The MSBS-M-20 is physically identical to the -M-2, but with a 1 MT MR-60 thermonuclear warhead and, as noted above, all six submarines will have this device by 1983. Further developments include changing the MR-60 warhead for the lighter MR-61 and retrofitting the six submarines with 16 MSBS-M-4 missiles each. This version will be a three stage, solid propellant rocket, weighing 35 tonnes versus the 20 tonnes launch weight of the -M-2 and carry six and seven multiple independently targeted re-entry vehicles of 150 KT yield each. Trials are expected to begin in 1979 and L'Inflexible, due in service by 1983, may be fitted with the -M-4 immediately on commission, rather than with the currently planned -M-20/MR-60 warhead combination. Total force strength of France's nuclear powered submarines will be 96 warheads (16 on each of the six vessels) by 1983 or, eventually, 672 150 KT devices if all 96 MSBS's are deployed with seven re-entry vehicles each.

Pluton:

Conceived in 1965, Pluton is a mobile tactical ballistic missile capable of delivering a nuclear warhead anywhere between 10 km and 120 km from the launch position, at the selective discretion of the operator. It began test trials in 1969 and was introduced into operational service in 1974. The French Army originally planned a complement of 120 Plutons, but that figure was subsequently reduced to 30 and it is currently deployed with five regiments: the 3rd at Mailly, the 25th at Suippes, the 60th at Laon-Couvron, the 74th at Belfort and the 32nd at Hageunau. Each regiment is assigned six launchers with a single missile per launcher. The warhead can carry either a 25 KT nuclear charge for air or surface burst against rear troop and/or equipment concentrations or a 10 KT nuclear charge for surface burst against enemy troops in the vicinity of friendly forces.

With a launch weight of 2.4 tonnes the Pluton is 7.6 m long, with a diameter of 65 cm and a fin span of 1.41 m.

SSBS:

The Sol-Sol Balistique Stratégique solid propellant strategic ballistic missile, was developed from a series of precursor rockets in the 1955–1965 period with the intention of providing France with an independent nuclear deterrent. Official go-ahead was given in 1963, replacing a plan to develop a NATO missile capable of carrying a 272 kg US nuclear missile warhead a distance of 2,400 km. Aerospatiale has project lead for the SSBS at five space and missiles centres throughout France.

The first tests were performed in 1965 from the Centre d'Essais des Landes (CEL), near Biscarosse, when the SSBS-S-112 design was sent on seven flights toward the Azores and tracked by a station on Flores Island and modified aircraft and ships. Underground silos were used in these tests, which ended in 1967, replaced by a second series, using the SSBS-S-01 between 1967 and 1968.

The SSBS-S-1 consisted of two P-10 solid propellant stages, each producing a thrust of 45 tonnes, but this was never deployed, being superseded by the SSBS-S-2 with the same second stage as the -S-1, but with a more powerful P-16 first stage producing 55 tonnes of thrust. Each of the two stages carry four gimballed nozzles. The first stage carries 16 tonnes of propellant and four fins on the aft skirt, which has a diameter of 1.51 m. Resin-impregnated cork protects the aft end from the intense heat and the entire first stage is stiffened with circumferential rings. The P-10 second stage carries 10 tonnes of solid propellant and supports an equipment section on the forward end for automatic flight control. The 150 KT fission nuclear warhead is a double cone re-entry vehicle, weighing 2.2 tonnes and cooled during descent through the atmosphere by a ceramic and resin-impregnated plastic coating.

The 31.9 tonne, 14.8 m long missile, has a range of 3,000 km and was deployed operationally in 1971. A total of eighteen SSBS-S-2 missiles are deployed in two squadrons 5 km apart under the control of the Armée de l'Air 1er Groupement de Missiles Stratégiques in the Haute Provençe region of France. The silos are under the control of command posts at Reilhannette and Rustrel and can react to firing commands in 3 min. These eighteen missiles will be replaced by the SSBS-S-3 in 1979–1980, each carrying a 1.2 MT fusion warhead. The second stage will adopt the 32 tonne thrust P-6 fixed-nozzle motor, developed by Aerospatiale.

First and second stage burn times for the existing -S-2 are 76 sec and 50 sec respectively; burn times are the same for the first stage of the -S-3, but 2 sec longer for the second stage. Stages for both versions use aluminium-ammonium perchlorate-polyurethane isolane propellants. The 23.8 m deep silos are hardened to withstand an overpressure of 21.1 kg/cm² and the 1.4 m thick doors are moved horizontally to expose the hot-launch fire tube. The SSBS missiles rest on a pedestal suspended from cables secured to pulleys and four cylinders on the floor. The fire control centre is 400 m underground, with two fire control officers on duty at any one time.

Véronique:

The first French atmospheric sounding rocket originated at the Ballistics and Aerodynamics Laboratory at Vernon in 1949. The project was named Véronique as an amalgam of Ver and ronique from Vernon électronique and resulted in a liquid-propellant single stage rocket producing 4 tonnes of thrust for 35 sec from nitric acid and turpentine propellants. It could carry a 63.5 kg payload to a height of 64 km and provision was made for lowering the instruments to the ground by air-brake discs and parachute.

A second, elongated version, appeared in 1954 which could reach a height of 128 km and a speed of 4,800 km/hr. It was 6 m long with a diameter of 56 cm and weighed 985 kg at launch.

A third version was introduced, for the International Geophysical Year (1957–1958), although it was 1959 before this appeared, with a capability of reaching a height of 200 km. The Véronique 61, introduced in 1964, could lift 130 kg to 290 km and a sub-variant, the 61M, was first launched in 1966, with the capacity to send 300 kg to an altitude of 185 km.

The basic Véronique 61 formed the basis for a new sounding rocket in 1965 called Vesta, with a payload capability of 1,000 kg to 212 km. Vesta had a weight of 5 tonnes, versus the 1.95 tonnes of Véronique 61. In a series of successive developments, the basic Véronique of 1949 has resulted in the Vesta variant with a thrust of 14.5 tonnes and developed the technology to fabricate France's first satellite launch vehicle.

GERMANY

Rheinbotte:

The Rheinmettal-Borsig company developed the Rheinbotte solid propellant surface to surface missile in 1944, from a German Army requirement, for a more versatile and mobile weapon system than the V-2, but with similar duties. The Rheinbotte was 15 m long, carried a 40 kg explosive charge a distance of 220 km and reached a speed of 5,800 km/hr. It consisted of four separate stages, each with a set of stabilizing fins, and went into production late in 1944. Although effective, it had too low a payload capability to be really decisive and, appearing in 1945, came on the scene too late to compete with other well-tried weapon systems.

It weighed 1.7 tonnes and was launched from an inclined ramp. Some 220 Rheinbotte models were produced and fired before the end of World War II. An advanced version, a 9.7 m long five stage model, was conceived in the spring of 1945 but could not be built before the end of the war in May.

V-2:

Although designated V-2 for the purposes of this compendium, the rocket is more properly referred to as the A-4; the appellation 'V-2', standing for Vergeltungswaffe zwei (Revenge Weapon 2), was coined by Nazi Propaganda Minister Dr. Josef Goebbels in verbal retaliation for the Allied bombing raids on Germany. The A-4 is well known, as the V-2, and for that purpose its less complimentary title suffices for classification in this Section.

The first A-4 launch attempt was on 13 June 1942, followed by a second on 16 August. Both were failures and the first successful demonstration flight was launched on 3 October 1942. This test resulted in an impact 201 km from Test Stand VII at Peenemunde on the Baltic coast, with a lateral deflection of only 4 km. Further tests followed and Allied detection of the Peenemunde research and test facility resulted in a 300-bomber, Royal Air Force raid, on 17 August 1943. The V-2 operation was then moved to Nordhausen and a production line was set up there in the Hartz Mountains where a substantial level of protection was provided.

The first V-2 assault was mounted on 6 September 1944 against the city of Paris and before the end of World War II more than 4,000 rockets had been launched, primarily against targets in England. The weapon was a highly mobile system and could be set up within a matter of hours in any clearing which had sufficient room for support vehicles and a vertical ascent.

The A-4 was 14.02 m in length and 164.6 cm in diameter, with four large aerodynamic fins on which the missile was supported for launch with a span of 353.57 cm. Empty, the A-4 weighed 3.99 tonnes and it could carry 8.96 tonnes of propellant and a 998 kg warhead for a total launch weight of 12.93 tonnes. Its pointed nose contained a 752 kg high-explosive charge and the propellants were a 75%/25% ethyl alcohol/water mixture with liquid oxygen as the oxidizer. The propellants were brought to the combustion chamber by a pump, capable of delivering 127 kg/sec powered by the action of sodium permanganate (Z-stoff) and hydrogen peroxide in a gas generator. The propellants burned with a combustion chamber temperature of 2,700°c and a pressure of 15.968 kg/cm^2. At liftoff, the A-4 delivered a thrust of 28 tonnes and the propellant was consumed in a burn lasting 65 sec, at which time the rocket was delivering a thrust of 32.7 tonnes.

The selected trajectory envisaged the A-4 reaching a speed of 5,790 km/hr at burnout, a maximum height of between 80 km and 95 km and a range of 322 km. Control was effected by four vanes mounted to the four fins protruding into the exhaust efflux operated by signals from two gyroscopes in the forward section of the missile. The missile had a flight time of 5 min and impacted the target area at a speed of 3,540–4,025 km/hr, surviving a re-entry temperature of 680°c. During the first moments the acceleration was about 1.9 g with a 6 g load at burnout.

Although the A-4 saw only six months and three weeks operational service – the last German launch was on 27 March 1945 – nearly 100 rockets, either complete or in component form, were taken to the United States and set up for flights from White Sands, New Mexico. The first US firing was on 16 April 1946 and in a series of about seventy flights up to 1952, the rocket was used for atmospheric research tests as developed by the Upper Atmosphere Research Panel. During these flights a maximum range of 179 km, maximum height of 214 km and a speed record of 6,534 km/hr were attained on separate flights during the six-year programme. In other tests between 1948 and 1950 a series of eight flights was accomplished with varying degrees of success incorporating a WAC Corporal research rocket in the nose for high altitude sounding duties (see Bumper).

INDIA

Rohini:

The Rohini series of solid propellant rockets is the mainstay of India's atmospheric and near-space sounding programme, with developments leading to the first all-India satellite launcher. The first in the family, RH-75, was developed in 1969 as a single stage vehicle capable of sending a 1 kg payload to a height of 9 km. This was followed by the RH-100, used for research into the technology of solid propellant rocket design and capable of sending more than 3 kg to an altitude of 14 km.

Most of India's sounding rockets are launched from TERLS (Thumba Equatorial Rocket Launching Station) which is controlled by the Indian Space Research Organization (ISRO) under the government's Department of Space. Several multi-stage designs have emerged in recent years, including the Rohini-560, a two-stage solid propellant vehicle, 7.6 m long weighing 1.39 tonnes at launch and capable of taking a 100 kg payload to a height of 330 km.

The Space Science and Technology Centre (SSTC) at the Vikram Sarabhia Space Centre (VSSC) is planning to launch a satellite with a four-stage rocket called Rohini SLV-3. With this India hopes to put 30 kg in to a 400 km orbit. The SLV-3 will be 19.4 m long, weigh 17.3 tonnes and be launched from the Sriharikota Range 100 km from Madras. The facility contains its own solid propellant fabrication plant. 10 tonne segments can be cast here and the SLV-3 launch complex includes sufficient flexibility for accommodating a follow-on to the planned satellite launcher. This will probably be sized around India's objective of putting 800 kg satellites into geostationary orbit sometime in the 1980's.

JAPAN

Kappa:

Based on work carried out by Professor Hideo Itokawa between 1954 and 1956, the Kappa series of sounding rockets were developed at the Tokyo University Institute of Industrial Science. The first rockets developed by Japan, immediately after post-World War II restrictions were lifted, were named Pencil and Baby, the former, a 23 cm long solid propellant design, utilized through more than one hundred flights to test technical details related to rocket size, fin size, etc. The Baby was a two-stage 130–150 cm long solid propellant rocket, capable of boosting instruments to a height of 5 km, launched from a test centre at Michikawa in the Akita Prefecture on the Sea Of Japan.

The Kappa series was developed in support of a sounding rocket programme instigated by the International Geophysical Year (1957–1958). The first, the two-stage solid-propellant Kappa-5, was initially fired in 1956 and could send a 20 kg payload to a height of 50 km. Kappa-6 was a composite, solid-propellant, two-stage design, with an altitude capability of 60 km and 13 were launched during the IGY.

Further developments ensued with the Kappa-8 (1960) capable of reaching 160 km and the Kappa-9L (1961) reaching 354 km. Other variants, Kappa-8L (1962), Kappa-9M (1963) and Kappa-10 (1965) appeared with the final development, Kappa-10S appearing in 1966. The latter, and most advanced Kappa rocket, could carry a 18 kg scientific package to a height of 740 km. Many of these variants are still in use and several have been exported.

Lambda:

Originally conceived in 1961, the Lambda series of sounding rockets was first launched in 1963 and a development, the L-4S, was used to place the first Japanese satellite in orbit in 1970. Lambda was designed at the Tokyo University Institute of Industrial Science and the first engine tests were performed in 1962 at the new Noshiro Testing Centre. Lambda-2, a 16.5 m long, two-stage, solid propellant rocket, employed four steerable nozzles in the first stage. The first launch, on 24 August 1963, failed when the second stage refused to ignite, but the second attempt, with an L-2 vehicle, was successful and the rocket reached a height of 402 km.

Lambda-3, is a three-stage assembly of basic Lambda and Kappa components. The first flight was made in July 1964 and the design is capable of sending a 100 kg payload to a height of 1,000 km on flights lasting 17-18 min. L-3 is 19.1 m long and weighs 7 tonnes at launch. The first example of this variant used the new Kagoshima Space Centre, a 430,000 m^2 facility set up in hilly, wooded land in Uchinoura to replace the older Akita Rocket Range used for launching earlier rockets. The latter was unsuited to high altitude ballistic shots due to the danger of rockets falling on to the Chinese mainland with disastrous political consequences.

In 1964 the space technology section of the Institute of Industrial Science and the Aeronautical Research Institute both departments of Tokyo University were amalgamated to form the Institute of Space and Aeronautical Science (ISAS). Lambda-3 made a significant contribution to the COSPAR organized International Year of the Quiet Sun (IQSU) in 1964–1965.

The final variant, L-3H, appeared in 1966 and carries two strap-on solid propellant boosters with a payload capacity of up to 300 kg. In basic configuration the L-3H is 16.3 m long and with a launch weight of 8.4 tonnes can send a 70 kg payload to a height of 2,000 km. The first stage diameter of 73.5 cm is increased to 1.35 m with the addition of the boosters. Because of difficulties with the development of the Mu-4, intended to send Japan's first satellite into orbit in 1968, it was decided to develop the Lambda series further to test out a spherical fourth stage designed to provide the final velocity for orbit insertion; a Lambda would be used as a technology development rocket, getting the job of putting Japan's first satellite in orbit, but Mu-4 would be used for subsequent orbital flights.

The Lambda-3H was selected and the spherical 48 cm diameter terminal stage was placed in the top of the Lambda's third stage, turning it into a Lambda-4S satellite launcher. The first attempt to launch a 24 kg satellite into orbit failed on 26 September 1966, when the attitude control thrusters failed in the spherical fourth stage. Additional attempts on 20 December 1966, 13 April 1967 and 22 September 1969 were similarly unsuccessful.

Finally, on 11 February 1970, Lambda-4S-5 put the 23.6 kg Osumi satellite into orbit. This is the only time a Lambda rocket has been used to orbit a payload. All Lambda series rockets have four fins around the base of the first stage and four fins around the base of the second stage for stability and the L-4S carried the two first stage boosters similar to those employed by the L-3H.

Mu:

The Mu series rockets were designed by the Institute of Space and Aeronautical Science (ISAS) with the object of placing Japan's first satellite in orbit in 1968. A Lambda-4S, four-stage, solid propellant rocket was, however, used instead, placing Osumi in orbit on 11 February 1970, and the first Mu launched satellite was put into space on 16 February 1971.

Conceived in 1963, the Mu-4S was designed as a four-stage, solid propellant, satellite launcher with a weight of 43.6 tonnes, an overall height of 23.6 m and a first stage thrust of 85 tonnes, with the capability of placing a 120 kg payload into a 500 km orbit. Controlled by radio commands, the first three stages were stabilized by fins and spin motors and the 2.7 tonne fourth stage was only 78 cm in diameter. First stage thrust was augmented by eight 31 cm diameter, 5.8 m long solid propellant boosters of the type fitted to the Lambda-3H and -4S launch vehicles. During ascent the first stage would fire for 61 sec, assisted by the eight solid propellant boosters for the first 8 sec, whereupon the second stage would provide 29 tonnes of thrust for 42 sec. The third stage then took over for 42 sec with a thrust of 13 tonnes and the fourth stage would burn for 40 sec with a thrust of 2.7 tonnes to put the payload in orbit.

The launch site was the Kagoshima Space Centre at Uchinoura on the southernmost extremity of Japan, 200 m above sea level, with a radar tracking station 2 km away and an optical tracking station 12.5 km to the south-west. The first stage motor, the M-10, was test fired at the Noshiro Testing Centre in March 1965 but technical problems delayed development with the fourth stage orbit insertion motor and the Lambda-4S rocket was used to put the first Japanese satellite in orbit.

Test flights of the Mu design were conducted in the period 1966–1969, but the first satellite launch attempt with a Mu-4S came unsuccessfully on 25 September 1970, when the fourth stage failed to fire. Eventually on 16 February 1971 the second Mu-4S put the Tansei satellite into a 1,000 km circular orbit.

In 1973 work began on a three-stage variant, the Mu-3C, with a virtually identical first stage (uprated to produce a thrust of 88 tonnes), a lengthened second stage, which increased the burn duration to 69 sec and a new third stage, providing 6 tonnes of thrust for 53 sec. The second stage carried a thrust vector control system and the first launch attempt of a Mu-3C came on 16 February 1974 when the 65 kg Tansei-2 satellite was put into a 280 × 3,130 km orbit.

Further developments, called the Mu-3H and the Mu-3S, have been under way since 1975. The Mu programme is under the continued control of the ISAS.

N:

Development of the N-series liquid propellant rocket had its origin prior to the establishment of the National Space Development Agency (NSDA) in October 1969. This agency is now responsible for its use and continued development. In 1967 the National Space Development Centre (NSDC, formed in 1964 from the Space Development Office of the Science and Technology Agency) proposed government support for two rocket development programmes, leading to the Q and N series satellite launchers.

The four-stage Q rocket would have weighed 40 tonnes at launch, stood 25 m tall and employed solid propellants, except in the third stage which was to have used liquid propellants, to place a 85 kg payload in to a 1,000 km orbit. The Q rocket was regarded as a technology development vehicle for the N rocket which was tied to the ultimate objective of placing a 100 kg satellite in a geostationary orbit. Both projects would use the Tanegashima launch site, already under construction, 45 km from the Kagoshima Space Centre used by the Institute of Space and Aeronautical Science for the launch of Lambda and Mu rockets on scientific flights.

In 1969 the NSDC was re-named the NSDA and became Japan's national space agency with responsibilities embracing satellites, rockets, tracking facilities and the development of scientific and applications missions. In 1970, after an exhaustive study of the future pattern of Japan's space developments, the government decided to cancel the Q rocket and proceed instead with development of the more efficient, and better suited, N rocket. The third and fourth stages of the Q rocket (liquid and solid propellant respectively) would form the second and third stages of the N rocket.

The first stage for the N would be obtained through acquisition of Thor MB-3 stages from McDonnell Douglas in the United States, with Castor solid propellant boosters strapped to the first stage (see Delta). Essentially a Thor-Delta, the N rocket emerged with a Japanese second stage using liquid propellants, and a third stage, using the solid propellant Thiokol TE-364-3, from the United States, but licence-built at the Nissan Motor Company.

The first launch was successfully conducted on 9 September 1975 when it put a 85 kg Kiku satellite in to a 975 × 1,100 km orbit. The N vehicle is 32.6 m long with a launch weight of 90.2 tonnes and a first stage thrust, from the single MB-3 motor, of 78.5 tonnes. It burns for 230 sec, assisted during the first 39 sec by the solid propellant strap-on boosters, and then falls away leaving the MHI LE-3 second stage (of Mitsubishi design) to fire for 250 sec producing 5.4 tonnes of thrust before it too is discarded and taken over by the 4 tonne thrust solid propellant third stage with a burn duration of 42 sec.

Capable of placing a 600 kg payload in to a 1,000 km orbit, or 130 kg to geostationary orbit, the N vehicle will be replaced by the N-2 with retrospective re-designation of the N to the N-1. This is an improved version of the basic N described above, or N-1 as it is now called, and will employ a longer first stage, increasing the burn duration and nine strap-on boosters. A larger second stage will be developed by Ishikawajima-Harima Heavy Industries. The first launch of the N-2 is planned for 1981, when it will be used to launch an engineering test satellite followed by a geosynchronous meteorological satellite in 1982.

NSDA is currently developing a LOX/LH$_2$ second stage engine for a proposed N-3 rocket. Using the same basic N first stage, it will have the capability of placing a 500 kg payload in to geosynchronous orbit and is expected to be available for use from 1983 or 1984.

SOVIET UNION

D-1:

Developed in the early 1960's the D-1 is Russia's largest and most powerful operational launch vehicle, designed purely for space operations. It is the only large rocket produced in the Soviet Union which has no military application apart from payloads launched into space, which may carry military equipment.

Based on technology in liquid propulsion developed by the GDL-OKB between 1961 and 1965 and relying heavily on improved engine performance resulting from novel technical innovations, the first stage consists of six cylindrical boosters 30 m long and 3.1 m in diameter each carrying a rocket motor producing slightly more than 250 tonnes vacuum thrust. The second stage is about 31 m long and 4.2 m in diameter and is situated in the centre of the boosters which are clustered round the second stage in a configuration much like the four boosters clustered round the core (sustainer) stage of the A-series developed from the SS-6 Sapwood ICBM (see SS-6). Whereas the four boosters and the central sustainer of the 'A' launch vehicle all ignite for launch, and require all five propulsion units to be referred to as the first stage, only the six boosters surrounding the core of the D-1 ignite at launch and constitute the first stage in their own right. The core vehicle, with its 400 tonne thrust propulsion system, is only ignited when the boosters separate at an altitude of approximately 40 km.

The six boosters and the central core, are stages 1 and 2 respectively, because although they are all clustered together, they fire sequentially: stage 1 consisting of the six boosters and stage 2 the central core vehicle. Stage 3 is mounted to the top of the central core stage (stage 2) by an open lattice structure and is observed to be 12 m long by 4.2 m in diameter and to have a thrust of 100–105 tonnes. The total height of the configuration is about 43 m and for the first few flights, a payload shroud about 7 m long was carried, producing a launch assembly 50 m tall with a diameter of nearly 10.5 m across the six rockets which constitute the first stage.

The first successful flight came on 16 July 1965, when more than 1,500 tonnes of thrust from the six engines of the first stage lifted a payload of 12,200 kg away from the Tyuratam launch site. In the first few launches only the six boosters and the central core stage (stage 2) were assembled (addition of the third stage came later) and on the first successful flight, the D launcher placed the Proton-1 satellite in to a 218 × 722 km orbit. This was immediately recognized as the heaviest Soviet payload put into space up to that time and the then unknown launch vehicle was dubbed the 'Proton Launcher', a name which has remained in halls of astronautical scholarship.

In line with Soviet practice, the development of a launch vehicle through to its design potential, comes in a series of sequential steps and so it was with the D-1. The designation 'D' implies the two-stage version, and 'D-1' refers to the three-stage version. The estimated lifting capacity to low earth orbit, with the three-stage D-1, is about 20,000 kg, but the launch vehicle was not primarily developed to exploit its basic earth orbit capabilities.

On 10 March 1967 a new version of the D-1 appeared with a fourth stage added to the top of the third in place of the payload which was now relocated above the new propulsion unit. Designated D-1-E, the four-stage stack was developed to take payloads out of earth's orbit to the Moon or the planets. Ascent to orbit would utilize the first three stages, while the fourth would accelerate the payload to escape velocity (11 km/sec). The fourth stage is estimated to be 6 m long, 3.8 m in diameter and to carry a propulsion system with a thrust of 17 tonnes. The complete four-stage assembly is nearly 60 m long and is capable of sending a 6,000 kg payload to the Moon or 5,000 kg to the near planets.

In support of the unmanned exploration of the Moon, the D-1-E was first used to launch Luna 15 on 13 July 1969 and has since been used to launch all circumlunar, lunar orbit, lunar sample-return and lunar surface-rover missions. The first Mars flight attempt was on 10 May 1971 and the first D-1-E launched mission to Venus began on 8 June, resulting in the first TV pictures being returned from the surface of that planet by Venera 9.

On 2 December 1970, another variant of the D vehicle appeared, this time with the 'escape' or E stage removed and another installed to supplement the first three in putting very heavy loads in Earth orbit. This is the D-1-H and to date has been used solely to launch the Salyut space station with the third stage relinquishing its orbit-insertion role, held hitherto to the new 17 tonne fourth stage. In this mode first, second and third stages fall away leaving the 7 m long, 4.15 m diameter, fourth stage to put Salyut in orbit. With the Salyut space station attached, the D-1-H stands about 72 m tall on the launch pad. By 1977 six Salyut stations had been launched since the first in April 1971, each having a maximum weight of about 18,500 kg. There is considerable speculation as to whether the fourth stage discussed here is actually part of the payload, which is superfluous to gaining speed or altitude for orbit insertion. However, the stage does exist, but may play only a minor role, such as providing the payload with an on-orbit propulsion system. The payload lifting capability of the D-1-H is conceivably as high as 25,000 kg and this is in line with statements that the Salyut space station is to be upgraded in the near future. The Salyut is usually manned by two cosmonauts, launched separately by an A-2 launch vehicle, in the Soyuz spacecraft.

The fourth and most recent variant was used to launch Cosmos 637 into orbit on 26 March 1974. It has all the basic four stages of the D-1-E, plus a fifth stage which could be used to apply manoeuvres or velocity changes to a payload in Earth orbit. In one application it can circularize a satellite in geostationary orbit after having accelerated from a low parking orbit, or it may be used to change the orbital altitude or inclination of a payload which has been taken out of the original orbit. This five-stage configuration is able to place 3,000 kg in geostationary orbit and although some sources designate it D-1-E-e, it should more properly be referred to as D-1-E-m, for 'manoeuvering' capability.

At least one student of Soviet military rockets considers that the D vehicle technology emerged from a potential requirement to develop a rocket capable of delivering a 100 MT thermonuclear warhead in the late 1950's. When strategic studies revealed the undesirability of furthering this work, the Proton Launcher was developed from that existing technology base, to provide a heavyweight launch vehicle for space work. However, there is little or no evidence to support this speculation, although the unique nature of its conjecture merits consideration.

All D class vehicles have been launched from Tyuratam and there is no indication of its use from either Plesetsk or Kapustin Yar. By 1976 the vehicle, in all its variants, had launched more than forty unmanned flights into space. The D vehicle has never been publicly displayed and since 1965 it has been the heaviest Soviet launcher to reach operational status.

Frog:

The Frog series of short range battlefield support missiles, first emerged in 1957 and all versions comprise one or two stage solid propellant boost with supplementary thrust from annular nozzles. Frog 1 and Frog 2 entered service in the same year and provided range capabilities of 32 km and 20 km respectively, with warheads of 1,200 kg and 550 kg. The Frog 1 could carry a nuclear charge of up to 25 KT yield and the Frog 2 was deployed with chemical or high explosive heads.

The Frog 3 had a similar payload capability to the Frog 2, but with two separate stages increasing the range to 45 km, the missile was also able to carry a nuclear warhead while the Frog 4, with similar propulsion, could reach targets 50 km away.

The most popular variant is the Frog 7, which first appeared in 1965, and has a single stage solid propellant motor, with a range of 60 km carrying a 500 kg warhead of either nuclear, chemical or high explosive charge. Unlike earlier Frog models, the '7' is used with a transporter-erector capable of rapidly changing rounds after each launch. Support vehicles carry batteries of additional missiles and a selection of warheads to suit the preference of battle commanders.

Recently a new and very much improved weapon, the Frog 9, has been tested and this is expected to replace the Frog 7 by 1980. All Frog variants to date have carried four fins in a cruciform arrangement and warhead configurations have provided a variety of forward area contours according to the dimensions of the particular charge carried. Frog rockets are spin stabilized and unguided (hence the Frog, Free Rocket Over Ground, acronym) and operate with Soviet and East European forces in a highly mobile mode, with the SS-1B and -1C (Scud A and B) missiles to bombard front line troops or battle tank concentrations, complementing the Scud and Scaleboard (SS-12). These latter missiles are designed to saturate rear echelons and/or supply dumps.

Frog missiles have been used by the USSR, Bulgaria, Czechoslovakia, Egypt, E. Germany, Hungary, Iraq, N. Korea, Poland, Romania and Syria. Egypt has the largest number of export Frog launchers and by 1977 the army was equipped with at least 50 launchers. Syria has acquired approximately 40 and was expecting to exceed the total employed by Egypt by 1980. Syrian Frog rockets were fired in anger against Israeli forces during the 1973 conflict. In all, forces outside the USSR control 300 launchers, all equipped with conventional warheads.

G-1:

This enigmatic launch vehicle, designed to launch very heavy earth-orbit payloads, has been a source of contention since the mid-1960's. Although it has yet to accomplish one successful flight, it does exist, has been launched at least twice and is expected to emerge as a super-heavyweight satellite launcher sometime in the early 1980's. No hint of its existence has been officially endorsed, although the G-1 has been studied by a number of specialists under a variety of assumed name designations.

Because of the valuable work contributed by Charles P. Vick, the name he appended to this project – Lenin – has been adopted in recognition of his valuable intelligence work. As a result of intensive analysis and study performed by Vick and others, it is possible to gather a reasonably accurate events diary, and to draw some tentative conclusions as to the performance and capabilities of the G-1.

The engines of the G-1 probably date back to 1963 and a committment for attempted Soviet lunar landings in the early 1970's. This was possibly responsible for early design work on the G-1 and it seems that by mid-1966 US reconnaissance satellites spotted test facilities under construction at Tyuratam. By 1967 NASA Administrator, James E. Webb, was publicly voicing warnings about the impending availability of a Soviet heavy booster and since that year it has been referred to as 'Webb's Giant'.

By 1968 static test models had been built and between March and April a full size version was moved from its fabrication area to the launch pad and back, in tests of the transport and logistics procedures. Early in June 1969 the G-1 was going through a sequence of rehearsals for a test launch. The first stage had been filled with propellant, the second stage almost completely filled and third stage loading was under way, when a massive leak developed from the second stage which poured propellant over and down the sides of the rocket, around the base and across the launch pad area. A fire quickly developed, enveloping the first and second stages and causing the propellant tanks to rupture. In the ensuing explosion the entire rocket was ripped apart and US reconnaissance satellite photographs taken shortly after the incident apparently showed a large amount of debris around the area where the launch pad had been located.

There is contention as to whether the G-1 was in a series of tests or rehearsals for an actual launch attempt, which would have come later, or being fuelled for a live countdown and launch. All that is known for certain is that photos taken on 3 June showed the G-1 on its pad, while others taken on 14 June carried abundant visual evidence of the explosion. The magnitude of the fire was understood by examining evidence from earth-scanning satellites in orbit, which observed the effects; the local consequences need little imagination.

By 1971 a second G-1 was ready for launch and late in June, an attempt was made to get it off the ground, but engines failed during the ignition sequence and the attempt was aborted. Undeterred, Soviet engineers accomplished a successful liftoff during the last two weeks in August 1971, but catastrophe struck when the rocket had ascended to a height of 12 km as the giant rocket literally shook itself to pieces, probably due to some propulsion failure in the first stage.

The third attempt at full flight testing came on 24 November 1972 and this time the G-1 ascended past the point where the previous vehicle had failed, but shortly thereafter a problem developed and less than two minutes after launch, the rocket had to be destroyed, by range-safety command, from the ground control centre. No other launches have been recorded to date, but it is believed that the G-1 is still in late stages of development and may yet be applied to heavy-lift duties in the Soviet space programme.

It is impossible to know for certain the exact dimensions or capabilities of the G-1 and indeed, it may have evolved through a variety of configurations even during the unsuccessful period of flight attempts between 1969 and 1972. However, careful examination of all the available evidence, consideration of NASA expectations and, again, with careful scrutiny of Charles Vicks's analytical studies, it is possible to conclude that a three-stage configuration would have a height of 110 m (including the payload) and exhibit a launch weight of 3,450 tonnes.

Liftoff thrust, consistently agreed by all sources since 1967, is about 4,750 tonnes and the rocket probably has a diameter of 23.5 m. Other students of the G-1 suggest that it is a two-stage vehicle, but the weight and performance characteristics are comparatively well established and not subject to as much speculation as engineering details, which always depend on specific patterns of technology utilization.

Although the G-1 is enormous by any standard, with a liftoff thrust more than 50% greater than the largest launch vehicle yet put into operational service – Saturn V (see Saturn V) – the payload capability is probably not as great as it would be if high energy propellants were used in the upper stage(s). Nevertheless, the G-1 should be capable of placing 155 tonnes in low earth orbit, sending 63 tonnes to the Moon or between 20 tonnes and 27 tonnes to the near planets Mars and Venus.

At a time when the only nations engaged in heavy space launch vehicle programmes, the US and European members of ESA, are placing increasing emphasis on reusability and modular build-up of large structures in space via multiple launch by smaller rockets, it is unclear exactly what Soviet intentions are regarding expendable, heavy-lift, launch vehicles. In spite of mounting evidence to the contrary, it is difficult to see any future requirements which would call for continued development of such a colossal behemoth. Latest intelligence from US sources, however, confirms the sustained availability of the G-1 launch complex, with considerable activity around the assembly facilities.

Galosh-1:

Deployed in 1970, the Anti-Ballistic-Missile-System continues to use the ABM-1 Galosh rocket for defence of Moscow against ICBM attack. The Galosh was first publicly displayed in a 19 m long cylindrical container, 2.7 m in diameter and open at one end to reveal four exhaust nozzles attached to the missile inside. Resting on a single eight-wheel bogie the assembly, first rolled through the streets of Moscow in November 1964, is pulled by an eight-wheel tractor with an enclosed cab.

Galosh is probably a two-stage rocket with a slant range of 300 km, designed to intercept and destroy incoming missiles before they re-enter through the dense layers of the atmosphere. So far, four ABM sites have been set up around Moscow, with each complex operating 16 missiles in co-operation with Try-Add engagement radars comprising Chekhov target-tracking radars and two guidance and interception radars. Phased array units in the vicinity of Moscow (Dog House) acquire and track the target on information received from other phased array radars (Hen House), which provide early warning.

The missile is most probably launched at a high inclination from the container in which it was first displayed and all 64 ABM's have been modified to counter Chinese ICBM's which are expected to be capable of reaching Moscow. Under the code name SH-4 a new missile is believed to have been tested if not already deployed with the capability of stopping and re-starting a terminal manoeuvering platform to give ground-based radars sufficient time to discriminate between warheads and decoys. Capable of exo-atmospheric interception, the SH-4 was tested from Sary Shagan in 1974.

A new high acceleration, mobile missile is thought to be under development capable of destroying incoming short-range attack missiles within the atmosphere. (See Spartan/Sprint for details of the US ABM system.)

SS-1 (Scunner):

Considerable speculation surrounds the very existence of this rocket, but it is generally regarded as a development of the German A-4 (V-2), having approximately the same dimensions, but with additional payload in the nose section. This could have been either a very small solid propellant boost motor, or an instrumented package without propulsion, for the purpose of obtaining atmospheric data.

SS-1 appeared in 1947 and since this was two years prior to the introduction of a Soviet nuclear charge, the rocket is more likely to have been a precursor tactical ballistic surface-to-surface weapon, if indeed it did play a military role. It is more likely that SS-1 was a high-altitude sounding rocket used for gathering precise air temperature and pressure data as a preliminary step to acquiring the information for later technical developments.

SS-1B/-1C (Scud A/B):

Developed in the early 1950's the SS-1B is a medium range tactical ballistic missile, with a 130 km range and a high explosive or nuclear warhead with mobility provided by a tracked vehicle modified from a World War II tank chassis. Transported in a horizontal position, the missile is erected for launch by raising it to a vertical position, access to various sections along its 10.7 m length being gained by a supporting ladder framework which is lowered preparatory to ignition.

The single stage liquid propelled Scud A (SS-1B) is probably controlled by a tracking system which permits the operators to shut down the motor by single radio command. Control during flight would be affected by movable vanes in the exhaust efflux; four fins are carried at the base of the 85 cm diameter missile, but these are attached to the rocket and show no localized strengthening such as would be required for pivot points, etc. Propellant for the Scud A is an unsymmetrical dimethyl hydrazine/inhibited red fuming nitric acid combination, with the oxidizer tank at the front end of the missile.

Scud A entered service in 1957 and was replaced by the Scud B (SS-1C), very similar to the Scud A, but with a 0.5 m increase in length to facilitate an increase in propellant capacity and reverse positioning of the tanks. This variant weighs 1.9 tonnes more than the Scud A and has a range of 280 km with a cutoff velocity (at 1,500 m/sec) 400 m/sec more than its predecessor.

Some specialists have identified a third, interim, variant displaying the structural characteristics of the Scud A, but with the increased length of the Scud B. Apart from service with the forces of the USSR, Scud B is used by Bulgaria, Czechoslovakia, E. Germany, Egypt, Poland, Romania and Syria. The Scud B warhead weighs up to 860 kg versus 680 kg for Scud A, and the missile is transported on a modified eight-wheel MAZ-543 twin-cab vehicle, with a protective casing removed prior to erection. Scud rockets were fired operationally by Arab forces during the 1973 Yom Kippur War.

A fourth variant, capable of hitting targets at a range of 450 km, is reported, but its existence remains unconfirmed. Scud is the only Soviet long range battlefield ballistic missile to have been fired in anger (but see Frog for details of short range activity).

SS-2: (Sibling):

A somewhat obscure development, the Sibling was evident in Soviet photographs released in the late 1950's and seems to have taken the form of a modified SS-1 Scunner. It appeared to display longer propellant tanks than the V-2, to which it may have been a successor, with similar design and construction, and recoverable pods for safe return of atmospheric data. Although used by military forces, it was probably responsible for gathering more data on the upper atmosphere and reaching higher altitudes than the Scunner. Only a few were developed and when Soviet sources displayed photographs of the Sibling, it was said to be a 'geophysical rocket'.

SS-3 (Shyster):

This strategic ballistic missile was first revealed publicly during the military parade in Moscow on 7 November 1957 and consists of a single stage liquid propellant rocket, with a warhead of nuclear or high explosive charge. The rocket motor is a single chamber development of the RD-103 which was first tested in 1952 using oxygen and kerosene propellants.

In service by 1955, Shyster had a range of up to 900 km and owes its success to an earlier model of unknown designation. It was probably controlled by radio guidance and the base area of the missile supports four triangular fins with movable aerodynamic control surfaces and four vanes in the exhaust efflux. This latter mode of control is reminiscent of the SS-1, SS-2 and SS-1B/-1C, all of which matured from technical dissection of the German V-2.

With a length of 21 m, Shyster was the first operational Soviet strategic missile, capable of reaching targets in London and Paris from E. Germany. It was transported on a mobile launcher pulled by a tracked vehicle which, at the 1957 Moscow parade, carried twenty personnel.

SS-4 (Sandal):

Operational in 1959 as the standard Soviet intermediate range ballistic missile, Sandal was derived from Shyster (SS-3) and is a single stage liquid propellant rocket with the same diameter but length increased by 12%. It can carry high explosive or nuclear charge, the latter up to 1 MT, and it has an effective range of 1,800 km, twice that of the SS-3 from which it was developed. Sandal currently uses an inertial guidance system which in recent years has replaced the radio command control used earlier.

The flared aft skirt supports four triangular fins with aerodynamic control surfaces and vanes which project into the exhaust efflux (see Shyster). The propulsion system is a variant of the RD-214 rocket motor, with four fixed combustion chambers and a thrust of 72 tonnes at liftoff. The propellants are nitric acid and kerosene and the motor operates at a specific impulse of 264 sec with chamber pressures at 46.51 kg/cm^2. The motor was developed by the GDL-OKB between 1952 and 1958.

Sandal has found military use as both a mobile and fixed base rocket, with about 500 operational in the USSR and along the Chinese border. It is being replaced by the SS-20. Its most memorable claim to fame came in late 1962 when Fidel Castro accepted Soviet basing of the Sandal in Cuba. If it had remained operational from sites on the island, the rocket could have reached all the southern States of the US south and east of a line drawn from Houston to Washington. American pressure forced the Soviets to withdraw the Sandal.

Beginning in 1958, the GDL-OKB developed a single-chamber rocket motor developing 11 tonnes of thrust and burning liquid oxygen and unsymmetrical dimethyl hydrazine, with a specific impulse of 352 sec. This motor, the RD-119, was used as the propulsion unit for a stage which could be placed above the basic Sandal, thus enabling the two-stage configuration to deliver payloads of more than 400 kg to a low earth orbit. The advanced nature of the engine from this early period is indicated by its high chamber pressure of 82.7 kg/cm^2. The second stage was attached to the first (Sandal) stage by a truss structure and the entire assembly is 32 m long with a diameter of 1.65 m.

In this configuration the two-stage vehicle is known as the B-1 satellite launcher and it was first employed successfully on 16 March 1962 when it launched the first in the Cosmos series of satellites from the Kapustin Yar launch site. The Cosmos series is used to develop satellite technology and to perform military tasks in space; more than 1,000 Cosmos satellites have been launched to date. Cosmos 1 was the first satellite to be launched from Kapustin Yar, a site used exclusively for B-1 flights until the Plesetsk site on 16 March 1967, when Cosmos 148 was sent aloft. The last B-1 flight from Kapustin Yar was made on 19 April 1973 when Interkosmos 9 was sent to orbit. Since that time Plesetsk has been used exclusively by this rocket. To date more than 150 satellites have been launched by the B-1 and it continues to be used as the rocket employed for orbiting small payloads.

SS-5 (Skean):

Developed in the late 1950's, the Skean entered operational service in 1961 and consisted of a single-stage, long range IRBM, probably using liquid propellants to feed two GDL-OKB RD-216 rocket motors. The RD-216 is a twin-chamber engine and provides the Skean with a first stage thrust of about 178 tonnes and a range of 3,500 km carrying at least a 1 MT warhead. The latter has a distinctly rounded-nose section, signifying a more developed re-entry vehicle to those used with the SS-3 and SS-4.

Guidance is by inertial control and flight stabilization and tracking uses vanes protruding into the exhaust from the four rocket nozzles. There are no fins on the flared aft skirt, but the rear section is reminiscent of that on the much smaller SS-4, of which Skean is probably an advanced first generation derivative. Length is uncertain and various sources have indicated it to be anywhere between 24.4 m and 26 m, but there are intelligence reports which seem to confirm a basic length of 24.5 m. The SS-5 may also have been used to test a variety of multi-megaton warhead configurations, but such a combination has never been deployed operationally.

In 1962 the Russians prepared what appeared to be SS-5 launch sites on the island of Cuba, with the co-operation of Fidel Castro, but the missile was never actually set up there (see SS-4). Most of the 100 Skeans deployed in the western USSR are located at surface sites, but a number have been fitted to hot launch silos like the Sandal. The missile's large mass prevents it from being a mobile weapon and there are indications that it is in line for replacement by the SS-20.

The Skean was first displayed publicly at the November 1964 parade in Moscow and although it is considerably more powerful, with a 94% increase in range, than the SS-4 it has not, as expected at that time, totally superseded the Sandal and continues to play a complementary role.

Seeking a satellite launcher capable of placing medium weight payloads in earth orbit at a size and mass range between the B-1 (lightweight) and A series (heavyweight) launchers (SS-4 and SS-6 derivatives respectively), the Russians developed a multi-stage vehicle based on the SS-5. First used successfully on 18 August 1964 to launch three Cosmos satellites (see SS-4), no's 38 to 40, the configuration is classed as the C-1 satellite launch vehicle and consists of the SS-5 and a 8.4 m long liquid propellant second stage for a total vehicle length of 31.6 m.

The first few launches were from the Tyuratam site, but flights from Plesetsk began with the launch of Cosmos 158 on 15 May 1967 and from Kapustin Yar

(Cosmos 546) on 26 January 1973. Flights from Tyuratam ceased with the launch of Cosmos 236, on 27 August 1968, and all subsequent flights, to date, have been from the other two sites. The C-1 is capable of placing a 1,100 kg payload in low earth orbit, but it is rarely used this way; most C-1 flights transport single or multiple payloads to high inclination orbits.

SS-6 (Sapwood):

Developed in the early to mid-1950's the SS-6 was a strategic answer to the US manned bomber force and comprised a central liquid propellant sustainer stage to which was attached four liquid propellant boosters. The engines used by the sustainer, also known as the core stage, and the engines developed for the boosters, were produced for the specific requirements which led to fabrication of the SS-6. At the time this was by far the most powerful rocket under development anywhere in the world.

It was first flown on 3 August 1957 and followed up with a full range test on 27 August. On 4 October 1957 it was used to place the world's first artificial satellite, Sputnik 1, in a 227 × 946 km orbit inclined 65° to the equator. As the first operational Soviet ICBM, it had a range of more than 8,000 km, but its huge size made it a strategically obsolete weapon before very long and only a dozen or so were ever deployed, and these only up to the early 1960's.

The sustainer stage is 28 m long and supports a RD-108 rocket motor comprising four combustion chambers, a single-shaft turbine and four steerable vernier motors, the total thrust being 96 tonnes. Each booster carries a RD-107 rocket motor with four combustion chambers and two steerable verniers for a thrust of 102 tonnes per booster. The 19 m-long boosters are 3 m in diameter at the base, support a single triangular-shaped fin each and taper to a cone at the forward end, where they fit flush to the side of the contoured sustainer stage. The SS-6 has a base diameter of 10.3 m across the fins.

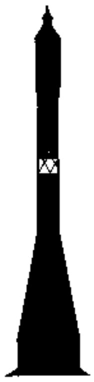
At launch, all five rocket motors are ignited, making a total of 20 main and 12 vernier combustion chambers in simultaneous operation to produce a thrust of 504 tonnes. Ignition normally comes 4 sec before liftoff and the boosters fall away when their propellant is expended after 120 sec of flight, leaving the central sustainer to continue thrusting for an additional 150 sec. Sustainer and boosters use the same liquid oxygen/kerosene propellant.

When the SS-6 was used to place the first Soviet satellites in orbit in 1957 and 1958, it displayed a capability of lifting up to 2,000 kg and because the central sustainer went into orbit along with the payload, this resulted in an on-orbit mass of some 8,000 kg. When used as a space launch vehicle, the SS-6 is re-designated A. On 2 January 1959 an upper stage was brought into use when Luna 1 was launched on a flight past the Moon. The upper stage was 3.1 m long with a diameter of 2.58 m, attached to the top of the central sustainer by an open truss structure. This variant, called the A-1, gave the launch vehicle a payload capability of 4,800 kg to low earth orbit or more than 400 kg on an escape trajectory to the Moon.

Flights of the A-1 began from Tyuratam with the ascent of Luna 1 in 1959 and from Plesetsk in 1966. A-1 flights from Tyuratam ended in 1967 and from Plesetsk in 1971.

Meanwhile, another variant, called the A-2-e, had been introduced in 1961 when, on 4 February 1961, Sputnik 7 was sent into orbit using a basic A launch vehicle with a still more powerful second stage and a new third, or escape, stage. The more powerful second stage was 8 m long, 2.58 m in diameter with a thrust of 30 tonnes and the new escape stage was on top of that, 2 m long and 2 m in diameter. The A-2-e configuration could put 7,500 kg in low earth orbit or send 1,200 kg to the planets. Up to 1970 all A-2-e flights originated from the Tyuratam launch site, but on 19 February of that year Molniya 1 (communications satellite) was launched from Plesetsk and since that date both launch sites have supported flights with this configuration. In operational procedures the second stage takes over from the boosters and first stage to achieve orbit and at some time after that, the third stage separates and accelerates the payload to high altitude, or escape velocity, as the mission dictates.

Yet another variant, called the A-2, was in use by 1964, but some observers have speculated on its application to a Cosmos series launch in November 1963. Nevertheless, the first certain successful flight was on 6 October 1964 when Cosmos 47 was put into orbit using the basic A-2-e vehicle without the escape stage. Capable of placing 7,500 kg in earth orbit, the A-2 had been used at both Tyuratam and Plesetsk launch sites, the latter beginning in 1966. More A-2 vehicles have been launched than any other variant of the SS-6, with about 66% of the total launch record being claimed by this type.



In 1967 the A-2 began its most ambitious role: that of launching the Soyuz manned spacecraft which, with a payload shroud length of more than 13 m, increases the length of the A-2 to 49.3 m – the longest of all the A series variants. Between 1963 and 1970 various flights were observed which appeared to employ a unique form of manoeuvering stage and these, somewhat speculatively, have resulted in the appended designations A-m, A-1-m and A-2-m, but there is little evidence to support the view that a major new development has emerged.

To date nearly 600 A, A-1, A-2-e and A-2 derivations of the Sapwood have been launched into space, claiming fame for having launched all Soviet manned space flights, many lunar and planetary exploration vehicles and a host of scientific and applications satellites, in addition to many military reconnaissance and technology development flights. It has been the mainstay of heavy payload delivery to space from Sputnik 1, until the D series (see D-1) vehicle was available in 1965 and has continued to play a prominent role as the Soviet space programme's standard workhorse.

SS-7 (Saddler):

Developed as a direct result of the improved technology in thermonuclear engineering that came in the mid-1950's and dramatically reduced the weight of a nuclear charge, the SS-7 Saddler emerged as the first successful Soviet ICBM. In service by 1961, much secrecy surrounded this missile and it has never been publicly displayed. It is known that the SS-7 is a two-stage liquid propellant missile capable of carrying a 1,200 kg 5 MT warhead to targets 10,500 km from the launch site.

The missile is 32.5 m in length with a diameter of 3.1 m. In 1963 an improved version, Mod 3, entered service and by 1967 nearly 200 SS-7's had been deployed at various locations and in a variety of modes. Some were installed in underground silos and the balance were set up at surface launch sites which, being vulnerable to attack, are obsolete. The SS-7 is being replaced by submarine-launched ballistic missile of more recent design and because of its less sophisticated technology, the warhead is accurate to only 1.4 km, but the missile does use inertial guidance. Used for a wide variety of tests and development flights in support of other missile technologies, the Saddler has been shown capable of carrying a nuclear charge of 25 MT. All existing SS-7 missiles, currently only half the peak number, will be replaced by the early 1980's.

SS-8 (Sasin):

Superficially similar to the SS-5 Skean, Sasin is a two-stage liquid propellant ICBM with a range of 11,000 km and a 5 MT nuclear warhead. It was deployed operationally in 1963, but only 200 were ever in service at one time. The SS-8 was first displayed at the military parade in Moscow in November 1964, when the missile was transported on an articulated conveyance with a fully enclosed tractor cab. The rear of the missile was enclosed within a cover and the control functions make use of vanes in the exhaust efflux, but without any stabilizing fins, the absence of this latter feature are necessary due to the silo launch mode.

The first stage probably carries four rocket motors (or supports a single motor with four combustion chambers) and both stages feature separate systems tunnels. The second stage has a smaller diameter to the 2.9 m diameter of the first stage and the warhead nose cone has the same spherical cap as first demonstrated on the SS-5 Skean. The error radius on impact is probably less than 2 km, but the nuclear charge and re-entry vehicle is probably the same as, or a later derivative of, the warhead fitted to the SS-5. Although bearing a technological resemblance to the SS-5, it played a complementary operational role to the SS-7 much as the SS-5 did to the SS-4.

SS-9 (Scarp):

Although displayed publicly for the first time at the 7 November 1967 Moscow parade, Scarp is known to have been operational since 1965. A certain amount of speculation has arisen over the precise number of stages incorporated in the design of this missile, but it now appears that a two-stage system is adopted using liquid propellants. The first stage is 3.4 m in diameter and carries six rocket engines fixed within the base section, complemented by an additional four verniers for flight control and trajectory changes.

The enormous length of the missile was seen to good effect at its debut in 1967 and in the configuration displayed at that time, the SS-9 is 34 m long with a constant diameter across the first stage where it flares to the reduced diameter, 1.15 m, of the terminal stage and warhead assembly. Earlier, observers suggested three stages separated at the 51% and 74.5% positions along the length of the missile from the base. Typical of the second generation ICBM, and indeed the first operational example, Scarp is a dramatic improvement over its predecessors the SS-7 (1961) and the SS-8 (1963).

Capable of carrying a 25 MT nuclear charge over a distance of 12,000 km, Scarp has a throw-weight capacity of 5.5 tonnes, compared with 1.2 tonnes for each of its two strategic predecessors. Using storable propellants, it is launched from a silo site and controlled in flight by an inertial guidance system with an impact error radius of 0.5 km.

So far five different versions of the SS-9 have been recognized. Mod 1 carries a 20 MT nuclear charge in a single entry vehicle and Mod 2 supports a 25 MT charge with a similar performance; sequential upgrading to match the technical capabilities of a basic design has been consistently applied throughout the development of Soviet rockets and missiles and rarely is the full performance potential exploited for some time. Mod 3 appeared in 1967 and has been re-designated F-1-r to indicate that it has an orbital capability. This variant, with unidentified upper stage, can lift a 4,500 kg payload to low earth orbit and has been used exclusively, between 1967 and 1971, to demonstrate a FOBS (Fractional Orbit Bombardment System) role.

The tests conducted between 1967 and 1971 employed an upper stage, about 8 m long and 2.5 m in diameter, with a payload in a structure 8 m long and 2 m in diameter placed in a low orbit and returned through the atmosphere before completion of the first earth revolution. This displays a capability to use a depressed trajectory or low orbit insertion which keeps the flight path below the US radar screens, thus enabling the operators to mount a surprise attack and/or reduce the warning time of an approaching missile.

If used operationally, the FOBS technique would place the warhead in a low earth orbit with retro-fire initiated some distance uprange of the target. In the fourteen tests conducted between 1967 and 1971, the orbits were between 130 km and 300 km, considerably below the 1,500 km altitude of a conventional ballistic missile on an arching trajectory. In the latter case the missile rises above the horizon well in advance of its re-entry and subsequent impact. There have been no FOBS tests since 1971 and the system has not been deployed operationally, probably because one of the advantages of the technique, sneaking in from over the South Pole on a part-orbit trajectory, has been negated by the installation of defence alert radar networks on the southern flank of the United States.

The SS-9 Mod 4 variant was first tested in 1969 and provides a capability of carrying three multiple re-entry vehicles with a warhead yield of 5 MT. The Mod 4 was deployed operationally in 1971 and two years later a further set of tests were conducted as part of Soviet MIRV (Multiple Independently targeted Re-entry Vehicle) developments. This concept however, was not deployed as part of the SS-9 system.

Mod 5 was demonstrated in 1968 when SS-9 was used to send a satellite to inspect the target vehicle, move away and explode. This intercept and destroy capability used the two-stage Scarp plus a third orbit-insertion stage and a fourth manoeuvering vehicle with the payload. The third stage is thought to be similar in size to that employed on the F-1-r and the manoeuvering vehicle is probably 5 m long with a 2 m diameter. In this configuration the SS-9 Mod 5 is re-designated F-1-m, signifying an orbital capability. Satellite intercept and destroy tests continued until 1971, ceased, then began again in 1976. The last flights in 1971 and the latest series starting in 1976 adopted the C-1 launch vehicle (derived from the SS-5) for placing the target in orbit.

All F-1-r and F-1-m flights originate from the Tyuratam site and the F-1-m has been used additionally to deploy ocean surveillance satellites. More than 50 F-1 launches have been recorded and the rocket is the only space launch vehicle not used to send up civilian payloads in addition to military functions. In all, some 250 SS-9 Mod 1 and Mod 2 missiles were deployed with 38 Mod 4 variants between 1970 and 1975, but the missile is being replaced by the SS-18 and only 210 were in service by 1977.

SS-10 (Scrag):

Developed in parallel with the SS-9, Scrag was publicly unveiled at the 9 May 1965 parade in Moscow as a long range ICBM. It has not been deployed operationally and the missile was deleted in favour of the SS-9. Scrag is a three-stage rocket supporting four large rocket engines in the first stage and may have had a similar design objective to that adopted for the SS-9; a commentator at the May Day parade said that missiles of the SS-10 type could 'find their targets literally from any direction'. A descriptive portrayal of the type of trajectory flown by the FOBS test vehicles in 1967–1971 (see SS-9).

One reason for the early demise of the SS-10 may have been because of the liquid oxygen/kerosene propellants. These are not storable and require lengthy preparations for launch. The SS-9 uses storable fluids, as did all subsequent liquid propellant ICBM's, to facilitate a rapid countdown and launch. Nevertheless, as built, the Scrag had a range of 12,000 km and with a length of 38 m represents the tallest ICBM to date. The first stage was 18.2 m long with a diameter of 3.4 m, the second stage was 7.7 m long and 1.8 m in diameter and the third stage and warhead was 6.4 m long with a 2.4 m diameter. Each stage was attached to its neighbour by a truss structure and a systems tunnel shroud connected to all three stages in a continuous cable run.

SS-11 (Sego):

Developed in utmost secrecy and never publicly displayed, Sego has been seen shrouded by its cylindrical container 20 m long and 3 m in diameter, but there are indications that it is a two-stage liquid propellant missile using storable fluids, feeding four rocket motors in the first stage.

Deployed in 1966, the SS-11 continues the exploitation of updated ICBM techniques first demonstrated by the SS-9 in 1965 with the introduction of storable propellants. Sego is thought to adopt the cold-launch technique whereby initial release of the silo-launched missile is effected by gas-expulsion prior to ignition. With the missile ejected from its launch tube by compressed air, the silo need provide no accommodation for the hot exhaust of rocket engines and additional hardening of the silo ensures its survival in the event of a close detonation such as may be inflicted from an incoming warhead. Once clear of the silo, the missile's engines ignite and carry it forward along its trajectory.

There is debate as to whether Sego actually exploited this advantageous approach; retrofitting of SS-11 silos with the larger diameter SS-17 and SS-19 seems to indicate that Sego was deployed with sufficient room in the silo to vent rocket exhaust, such as would be required with the hot-launch technique necessitating ignition inside the silo.

Sego has been deployed in three known variants. Mod 1 was introduced in 1966 and by 1971, 970 had been put into service. Carrying a single 1–2 MT charge, it had a range of 10,500 km with an error radius at the target of 1.5 km employing inertial guidance. By 1976 about 50 Mod 1 versions had been replaced by the improved Mod 3 and the total force was converting to the new SS-17 and SS-19. Several Mod 1 variants have been set up among ICBM forces in the western USSR and this had led to speculation that the SS-11 has found application, itself, as an intermediate range weapon. In this application it would carry a heavier warhead and exhibit improved accuracy because of the reduced range.

Mod 2 was a test development and not operationally adapted to service requirements. Mod 3 appeared in 1973 and became the first Soviet ICBM to carry multiple re-entry vehicles (MRV's) in an operational mode. Each missile carries three 500 KT warheads with a target error radius of less than 1 km. Some 66 missile silos have been prepared and this effectively uprates the warhead complement to 198 if all applicable silos are installed with the Mod 3. All variants have a throw-weight of nearly 0.7 tonnes.

SS-12 (Scaleboard):

First displayed publicly at the November 1967 Moscow parade, Scaleboard is a medium range tactical missile employing a storable solid propellant single stage design and was in extensive service by 1969. Normally housed in a ribbed container, the missile is about 10.5 m long with a diameter of 1.4 m and a range of more than 700 km.

Like the SS-1B and -1C it is transported on a MAZ-543 vehicle and erected for launch at will. The transporter has two cabs on opposing sides at the front and with inertial guidance and extremely good accuracy, the SS-12 can send a warhead of up to 1 MT to its battlefield support target. The missile would be rapidly deployed to destroy support and supply stores at the rear of front line or battle troop positions.

SS-13 (Savage):

As the first solid propellant ICBM to enter operational service, the SS-13 has achieved a certain historical distinction, but very little else about its operational deployment is complimentary. First displayed publicly at the 1965 May Day parade in Moscow, it is a three-stage missile, 20 m in length with a diameter of 1.7 m. The Savage first entered service in 1968 and to date only 60 silo launched models have been deployed, all around the Plesetsk area.

With a range of 8,000 km the missile normally carries a single warhead of at least 1 MT yield, although conflicting reports indicate that for a time some of the 60 SS-11's carried a multiple re-entry vehicle (MRV) configuration housing three 300 KT charges similar to the design fitted on the SS-11 Mod 3 missile. With a throw-weight of nearly 0.5 tonnes, the missile has a target error radius of 1.3 km. The SS-11 will eventually be replaced by SS-16 models.

SS-14 (Scapegoat):

Publicly displayed for the first time at the November 1967 military parade in Moscow, Scapegoat is a solid propellant intermediate range ballistic missile, comprising the second and third stages of the SS-13, an idea conceivably stimulated by earlier American plans to convert the Minuteman ICBM into a medium range missile by using the top two stages, a scheme which was never actually adopted.

When it was revealed on its trailer transporter in Moscow, it provided observers with the first look at the missile that had hitherto been shrouded by a cylindrical container; from its first appearance in the 1965 May Day parade, the transporter/container, utilizing a modified JS 111 tank chassis, had provided only tantalizing suspicion of its content.

In the missile/transporter/container configuration, the system is given the code name Scamp. Scapegoat is nearly 11 m long and can carry a 1 MT warhead a distance of 4,000 km. An unknown number have been deployed, but its most prolific deployment seems to have been along the Sino–Soviet border where it complements the SS-15, a missile which appeared later than Scapegoat and may have replaced it in increasing numbers.

SS-15 (Scrooge):

This solid propellant ICBM first appeared publicly at the 1965 November military parade in Moscow, when its 19 m long, 2.2 m diameter cylindrical container was displayed on the converted JS 111 tank chassis used six months earlier to show the SS-14 container. With a range of 5,500 km the missile is thought to be a three-stage solid propellant derivative of the SS-13 ICBM. However, the 20 m length and 1.7 m diameter of the SS-13 is greater than that of the SS-15 container and substantial modification is indicated.

The transporter/container system carries an elevating and erection capability with two large hydraulic jacks, one either side of the JS 111, at the rear. The missile is erected and fired from the container, permitting a high level of mobility. Scrooge would probably be used against western Europe and the UK in the event of a strategic European conflict and a considerable number are deployed in outer Mongolia along the Sino–Soviet border. Several SS-14 units may have been re-equipped with the Scrooge, but although it first appeared in service in the late 1960's, it is, itself, in for replacement by the SS-20.

SS-16:

Developed, but not as yet deployed, the SS-16 first appeared in 1972 and represents the first in a series of third generation ICBM systems designed to considerably upgrade and advance the capability of the USSR to engage hostile forces with the most up-to-date equipment technology can provide.

Believed by some to be slightly smaller than the SS-13 which it is designed to replace, the three-stage solid propellant ICBM has twice the throw-weight (nearly 1 tonne) and improved range, capable of reaching targets 9,600 km from the launch site.

In tests the SS-16 has used a multiple re-entry vehicle (MRV) carrying three warheads, but in the deployed configuration it may carry a multiple independently targeted re-entry vehicle system, where each charge can be sent to a different location within a given radius. Like all other third generation ballistic missiles, it uses a post-boost manoeuvering vehicle with an on-board computer capable of trimming errors from the trajectory and separating warheads along the descent path.

In a silo launched mode, ascent is effected via the hot fire technique (see SS-11), but the SS-16 can be deployed in a land mobile system which would undoubtedly be called upon to carry heavier payloads over a shorter distance. SS-16 has already been deployed in small numbers in the mobile configuration and specialists believe this may be its most lethal application.

SS-17:

Developed in the early 1970's as a long range ICBM capable of destroying hardened missile silos, the SS-17 was conceived along with the SS-19 as a successor to the SS-11 Sego. It first flew in 1972 and has since been tested with a variety of new warhead configurations, including a triple payload multiple re-entry vehicle and independently targeted thermonuclear charges (MIRV).

The SS-17 is about 24 m long, has a diameter of 2.5 m and provides a throw-weight of 2 tonnes. With a potential range of 10,500 km, it can deliver four separately targeted warheads each of which has a yield of 1 MT and it displays a target accuracy of 600 m. Excluding the manoeuvreable payload propulsion unit, it has two stages using storable liquid propellants. From 1975 the SS-17 began to replace the Sego in existing S-11 silos and this casts doubt on the suspected cold-launch technique adopted for Sego (see SS-11). A larger silo is needed for the hot-launch technique and this would suggest that existing SS-11 silos are large enough to accommodate the increased volume of the SS-17 in a cold launch mode of operation. The alternative conclusion is that the SS-11 was made unnecessarily voluminous to support the Sego as a cold-launch vehicle. Since the cold-launch method requires a close fit of the missile to the silo, so that compressed air can achieve the necessary pressure to eject the device, the Sego would have required a container from which it could be fired out of the silo. This may have been the container which shrouded the SS-11 when it first appeared in a Moscow parade: it is the only non-mobile ICBM to have been displayed in a container.

The SS-17 is replacing the Sego and by 1977 20 missiles of this type had been emplaced, each carrying four 200 KT warheads.

SS-18:

With a requirement to provide the technology for a first strike capability, the SS-18 has been produced as a replacement for the ageing SS-9. It was developed in 1972–1974 to be a versatile heavyweight ICBM capable of carrying a very high yield thermonuclear charge for destroying cities or missile silos. It can also carry a multitude of independently targeted warheads for concussion attack, penetration to generate a seismic disturbance (earthquake) or multiple attack on industrial areas as required.

The SS-18 is the heaviest and largest ICBM built with a length of 36 m, a diameter of more than 3 m and a throw-weight of 7 tonnes – more than 30% greater than the Scarp it was designed to replace. The Mod 1 version can carry a single thermonuclear charge of up to 50 MT, but its most flexible application is with a warhead of 18 or 25 MT enabling an improved terminal guidance system to improve the accuracy and increase the penetration velocity. The Mod 2 variant can carry up to 10 independently targeted warheads with an effective yield of 2 MT each, but for some time Soviet engineers have been developing a new lightweight warhead which can be carried as part of a cluster of independently targeted heads. With a yield of around 5 MT the 8 such warheads that may ultimately be fitted to the Mod 2, make the SS-18 a very formidable missile, capable of achieving first-strike pre-eminence.

A Mod 3 variant has not yet been sufficiently developed to enter operational service, but work is continuing on it to further refine the accuracy of a single re-entry vehicle which would have the capability of placing a 25 MT warhead virtually on top of any specific missile silo in the United States. Target accuracy is to within a radius of 550 m for the Mod 1 and to within 450 m for the Mod 2.

The SS-18 is a two-stage liquid propellant, cold-launch rocket utilizing storable propellants, gimballed nozzles for flight control and the very latest guidance and control electronics. By 1977 the Russians had declared 40 SS-18's operational in SS-9 silos.

SS-19:

In companion development with the SS-17, the SS-19 has enjoyed singular success in all its design trials and production activities. More favoured than the SS-17, it is a long range ICBM replacement for the Sego and is currently being deployed in that role on a one-to-one basis.

SS-19 is a two stage rocket employing storable liquid propellants with a length of 27 m, a diameter of 2.5 m and a range of 10,000 km – the same as the SS-11, but with a throw-weight nearly four times greater. In its preferred configuration, the SS-19 carries six independently targeted re-entry vehicles (MIRV's) of 200 KT yield each, but the missile is capable of carrying six warheads of 400 KT yield each. With inertial guidance and control, the re-entry vehicle can emplace warheads with a target error of only 450 m, assisted by the terminal propulsion vehicle and third generation electronics.

The missile uses a cold launch technique similar to the SS-17 and SS-18 and was deployed operationally from 1975. Currently, more than 100 rockets of this type have been installed. Although it utilizes a less sophisticated technology than the SS-17 (which accompanied it through the design and development phase), the SS-18 could probably be used against hardened targets such as missile silos in the event of hostilities necessitating a strategic response.

SS-20:

With the service introduction of this missile in 1976, the Soviet Union had acquired a land mobile weapons system of true ICBM proportions. Developed from the first two stages of the three-stage solid propellant SS-16, the SS-20 has the capacity to deliver a 50 KT nuclear charge across a range of 7,500 km or, in its operationally more flexible role, send a 1.5 MT warhead a distance of 2,800 km. This latter application has important repercussions for the strategic balance in Europe; with the SS-20 deployed in large numbers, every part of Europe, the Mediterranean, N. Africa and the Middle East would be within range and the mass of the warhead lifting capacity endorses the missile as a considerable improvement on existing mobile intermediate range ballistic missiles.

The SS-20 is expected to replace the SS-4, about 500 of which are deployed on mobile transporters in the western USSR and eastern Europe, and others may take over from the SS-5 (Skean). Although operational deployment is still awaited, tests have been carried out in the Kamchatka Peninsula and they may be used to replace SS-4 missiles on the Sino–Soviet border.

SS-X- :

At least three fourth generation missiles are currently under development and the Strategic Rocket Forces of the USSR are expected to begin trials with one of these in 1978. Although there is no accurate indication as to what form these developments might take, it is becoming increasingly clear that future long range missiles of the ICBM class will come to rely more on satellite guidance than current generations of rocket. Also, there is increasing emphasis on the kill capacity at hardened targets and increasingly accurate guidance systems will be employed to ensure a first-strike capability. This area of improvement, however, will probably result in refined modifications to existing missiles with the new vehicles employing higher energy propellants and sophisticated penetration aids.

SS-N-4 (Sark):

This was the first submarine-launched ballistic missile developed for the Soviet Navy, appearing and equipping Zulu, Golf and Hotel class submarines between 1955 and 1960. The missile is of single stage liquid propellant design, with a length of 15 m, a diameter of 1.8 m and a launch weight of 19 tonnes. The Sark was first publicly displayed at the 7 November 1962 Moscow parade. It has a moderately effective range of 600 km with a 1 MT warhead and carries first generation inertial guidance. SS-N-4 was the world's first SLBM and was considered operational in 1956. Very few are still in use and the missile is now playing a secondary, reserve role.

The seven Zulu V class submarines carried two Sarks each, the Golf and Hotel classes were equipped with three each. The Zulu class submarine has a displacement of 2,200 tonnes, a length of 90 m and a beam of 7.3 m. A total of 35 vessels were built between 1951 and 1955 and seven were converted to carry the Sark by extending the sail rearwards. The Soviet Navy currently operates only one Zulu V equipped with the Sark.

The Golf 1, with a displacement of 2,800 tonnes submerged, length of 97.5 m and beam of 7.6 m, was specially built from 1957 to carry the Sark and 22 were eventually operational. Like the Zulu V conversions, the Golf class carried their missiles in extended sails. Service phase-out was under way by 1976.

The Hotel class first emerged in 1958, with a submerged displacement of 4,100 tonnes, length of 115 m and a beam of 8.6 m. Each vessel carried three Sark missiles in extended sails and 15 submarines were commissioned.

Nine Hotel and eleven Golf class submarines were converted to carry the SS-N-5 from 1963 and 1967 respectively. In all cases the Sark could only be launched after the submarines surfaced.

SS-N-5 (Serb):

First deployed operationally in 1963, the SS-N-5 is a single stage liquid propelled SLBM with a range of 1,200 km. The missile, with a length of 10.7 m and a diameter of 1.5 m, is smaller than the Sark which it replaced and this was decidedly advantageous to the role it performed. With a weight of 18 tonnes it was slightly lighter than Sark, a not too inconsiderable saving, when three missiles equip each submarine.

The Serb was first displayed publicly at the Moscow parade in November 1964, when it was thought to be a solid propellant missile. The missiles are launched by a cluster of 18 cold-gas generators located on the base of the first stage and when the rocket reaches maximum achievable height, the generator package is jettisoned and the first stage ignites in mid-air. The first submarines to be equipped with the Serb were nine Hotel class vessels beginning in 1963, three missiles being installed in the three vacated SS-N-4 tubes forming the rear section of the sail. From 1967 11 Golf class submarines were retrofitted with the Serb (see SS-N-4). Six SS-N-5 equipped Golf class submarines were observed to move in to the Baltic in November 1976, thereby becoming the first SLBM vessels to enter those waters.

SS-N-6 (Sawfly):

Beginning in 1968 the Soviet Navy introduced their first SLBM system of truly IRBM range when Sawfly was fitted to the then new Yankee class vessels to provide a Polaris equivalent strike force (see Polaris). The SS-N-6 is the first two-stage SLBM deployed by the Soviets and like its predecessors, the SS-N-4 and the SS-N-5, it uses storable liquid propellants.

Three variants have been identified so far. The Mod 1 could carry a single 1 MT warhead a distance of 2,400 km, the Mod 2 (first introduced in 1974) could transport a single warhead some 3,000 km and the Mod 3 employs three re-entry vehicles with a range of 3,000 km. Although the Mod 2 and Mod 3 variants are being installed aboard Mod 1 equipped submarines in place of the earlier variant with limited range, it is thought that the Soviet Navy is using the single 1 MT warhead of the Mod 2, rather than the low yield triple warhead multiple re-entry vehicle of the Mod 3.

The probable target error of the Sawfly is rather high, at nearly 2 km, with three multiple re-entry vehicle charges and even worse, 2.8 km, with the single 1 MT warhead. However, the more effective destructive capability of the MT yield warhead more than compensates for the decreased accuracy and results in a higher probability of target kill than would be the case with the separated warheads of low yield. With improved target error capability from the SS-9, -17, -18 and -19, pin-point accuracy is more properly relinquished to the land-based ICBM fleet in favour of a higher explosive yield with the submarine launched SS-N-6.

The Yankee class submarines are the first in the Soviet Navy to adopt the US system of burying the vertical missile launch tubes in the hull aft of the sail, rather than having them built in to an extension of that structure. Beginning in 1968, the Soviet Navy built up Yankee class submarine production to reach a maximum in-service inventory of 34 boats, carrying 16 missiles apiece by 1973. Total Sawfly operational inventory has remained at 544 since that year.

The Yankee class submarine is 130 m long, with a beam of 10.7 m and a submerged displacement of 9,000 tonnes. With a pressurized-water nuclear reactor, the boat has a top submerged speed of nearly 56 km/hr and carries eight 53.3 cm diameter torpedo tubes in the bow for defence.

SS-N-8:

If slow to exploit the application of concealed underwater positions to nuclear deterrence, the Russians have recently instigated a programme of dramatic modernization for their sea-borne force and included in this category is the SLBM.

First of the third generation submarine launched ballistic missiles was the two-stage liquid propellant SS-N-8 with a length of 17 m and a diameter of 1.8 m, representing a considerable advance on existing SLBM capabilities first employed. The SS-N-8 was first deployed in 1973 and had demonstrated a capability of sending a useful payload more than 7,800 km. With a target error of probably no more than 1.4 km, the Mod 1 version can carry a single 1 MT warhead. The Mod 2 can carry three re-entry warheads in the kiloton range and the Mod 3 is expected to carry several independently targeted charges.

Tests have been performed with the SS-N-8 displaying a range capability of 9,200 km, but it is uncertain as to whether this missile carried a full warhead load. Nevertheless, it has a range which exceeds current US SLBM's and only the Trident C.4 will match it in performance, and this not expected to enter operational service with the US Navy before 1981. Only the Trident C.5 will exceed it in performance and this will not be available until the mid to late-1980's. With a stellar-inertial guidance system, the SS-N-8 has an improved probable target error of 500 m, but the Soviet Navy has so far only deployed the Mod 1 version with its single 1 MT warhead.

By 1977 ten Delta I class submarines and five Delta II class boats had been fitted with the SS-N-8, but increased shipyard production potential indicates a commissioning rate of 10 boats per year in the near future. The Delta class submarines are produced at the Severomorsk shipyards and the Delta I class has a length of 130 m with a 10.7 m beam and a submerged displacement of 10,000 tonnes. Each Delta I carries 12 vertical SS-N-8 firing tubes in two rows of six aft of the sail, with each tube 15 m long. The Delta II can carry 16 SS-N-8 missiles in two rows of eight.

Although these submarines are the largest in the world, improvements are still being made and boats capable of carrying 18 or 20 SS-N-8 missiles apiece are under construction (see SS-NX-17 and -18). Existing Delta I and II class submarines are powered by pressurized-water nuclear reactors and provide the boats with a submerged speed of 56 km/hr.

SS-NX-17:

No details are currently available for publication, but the SS-NX-17 is a single-stage solid propellant missile representing a fourth generation SLBM. It has a range of 3,200 km with a post-boost re-entry vehicle capable of carrying multiple independently targeted warheads, probably in the kiloton range. The development of this missile, the first solid propellant SLBM yet tested for operational deployment by the Soviet Navy, is probably tied in with the strategic requirements of a localized conflict and lacking the range of the existing SS-N-8 SLBM, probably fills a defence niche hitherto carried by surface ships.

SS-NX-18:

Tests with a fourth generation strategic SLBM began in the mid-1970's as a follow on to the SS-N-8/Delta submarine system and although tests were still under way in 1977, the SS-NX-18 is known to be a two-stage rocket employing liquid propellants in storable formula. With a range of more than 11,000 km, the missile can carry multiple independently targeted re-entry vehicles (MIRV's) in the kiloton range. It is most probably designed for placement aboard the already unparalleled Delta II class submarines, each of which can carry 16 missiles.

A new post-Delta submarine of even greater displacement is under development, capable of carrying up to 20 strategic ballistic missiles and the SS-NX-18 will possibly find application in this new design. With very long range and extremely high accuracy, the MIRV/SS-NX-18 equipped submarine fleet will be a formidable component of the Soviet strategic missile force and by 1980 these developments may be entering front line service with the Soviet Navy.

UNITED KINGDOM

Black Arrow:

Conceived in 1963, the Black Arrow grew from Black Knight experience to be Britain's first space launcher, when the fourth flight succeeded in placing a 66 kg satellite in orbit in 1971.

The rocket was a three-stage vehicle standing 13.2 m tall with a launch weight of 18.2 tonnes. The first stage was powered by eight Bristol Siddeley BS 606 rocket engines fed with hydrogen peroxide and kerosene propellants, each quartet of motors using one pump. The second stage and the first stage used the same propellants. The second stage carried two BS 625 motors to produce a thrust of 5.7 tonnes, essentially the same engines as those employed in the first stage, but with extended nozzles to increase the expansion ratio pressure for more efficient operation in a vacuum. The first and second stages carried 13.15 tonnes and 3.17 tonnes of propellant respectively.

The third stage was a solid propellant rocket containing a 317 kg charge and ignited at apogee to secure orbital insertion for the payload. The second stage would have placed the third stage and payload on to a transfer ellipse, the apogee of which would represent the desired orbit insertion altitude.

The Black Arrow was developed from a UK government decision in 1964 to use the rocket to place a British satellite in orbit, then expected during 1968. The first flight attempt was made on 28 June 1969, but an electrical failure in the first stage forced the range safety officer to destroy it, one minute after launch. On the second attempt, in March 1970, the sub-orbital flight was a success and the vehicle flew 3,057 km down the range from Woomera in Australia. This was followed by an attempt to place a small test satellite in orbit in September 1970 which failed, when the second stage engines shut down too early, and the vehicle failed to gain the necessary velocity.

On 29 July 1971, the UK government announced its intention to abandon the Black Arrow programme after X-3 had been sent into orbit on the next attempted launch. This came on 28 October 1971 when X-3 (Prospero) was put into a 537 × 1,593 km orbit. The first stage accelerated the payload to a height of 45 km, the second stage to a height of 200 km and the third stage fired for 40 sec when it reached its 560 km apogee ten minutes after launch.

The Black Arrow programme was controlled by Bristol Siddeley and all four launches were made from Woomera. The availability of the ESA Ariane launch vehicle (see Ariane) renders it unlikely that Britain will develop its own satellite launcher, thus Black Arrow represents the only successful launch vehicle produced by the United Kingdom.

Black Knight:

Design work on Black Knight began at the Saunders-Roe company in the UK in 1955 in response to a government requirement for a development vehicle for Blue Streak and to complement existing technology research. Blue Streak was the only ICBM produced by the UK, although it was cancelled, as such, before the first flight, and Black Arrow would test out re-entry warheads and nose cone materials, etc.

Originally fitted with a four-chamber Armstrong-Siddeley (later Bristol-Siddeley) Gamma 201 rocket motor producing a thrust of 7.44 tonnes and burning hydrogen peroxide and kerosene propellants, the first Black Knight was fired from Woomera, Australia on 7 September 1958. It reached a height of 483 km and flew 96.5 km down range. The single stage rocket was 10.2 m long with a diameter of 91 cm, weighed 5.4 tonnes at launch and carried four fins for stability at the base of the first stage with a span of 2.13 m.

A more powerful variant, using the four-chamber Gamma 301 engine of 9.52 tonnes thrust, was introduced with Black Knight No 13 and consideration was given to using this rocket as the second stage to a Blue Streak (see Europa), thus enabling the combination to place satellites in orbit. This was dropped, however, and a two-stage Black Knight emerged in which the basic rocket, with a Gamma 301 motor, was retained as the first stage and a second stage developed from the solid propellant Cuckoo motor added (see Skylark).

The first two-stage Black Knight launch was made on 24 May 1960. Following cancellation of Blue Streak in 1960, this variant of Black Knight was used for warhead re-entry studies and it had a length of 11.6 m with the second stage capable of accelerating the instrument warhead (simulated) to a speed of 14,000 km/hr. Launch weight for the two-stage variant was 6.35 tonnes and the solid propellant, second stage could be used either to fire a simulated warhead back down through the atmosphere from a height of 805 km, or to boost a scientific package of instruments to a height of 3,220 km.

The re-entry research programme went under the name of Project Dazzle and the last Black Knight launch was on 25 November 1965 when the second stage carried a Dazzle payload to a height of 644 km. All twenty two flights had been 100% successful and Black Knight technology was used from 1964 to develop the Black Arrow small satellite launcher.

Jaguar:

Developed at the behest of the British government in the late 1950's and designed by the Royal Aircraft Establishment at Farnborough, UK, the Jaguar was a co-operative venture between them and the RAE Weapons Research Establishment at Woomera in Australia. It was responsible for studying aerodynamic heating effects of high-speed atmospheric re-entry.

The first solid propellant stage accelerated three upper stages to a speed of 3,300 km/hr with the Rook motor, a development of the Raven used later for the Skylark sounding rocket. Coasting on to a height of 24.4 km, the remaining stages were pointed down toward the atmosphere and fired in sequence to accelerate the payload to a speed of 11,000 km/hr, so that measurements could be made of the heating effects as the payload plunged towards the ground. The first stage motor burned for 6 sec from a ramp launcher inclined 20° from vertical.

Jaguar could also be used as a scientific research rocket and in this application could take a 9 kg payload to a height of more than 800 km. The Australian Weapons Research Establishment had earlier developed two stage solid propellant rockets: Long Tom, capable of sending 59 kg to a height of 167 km, and Aeolus, with a payload of 14 kg to 74 km. Jaguar is no longer in use.

Petrel:

Originally developed for the UK Science Research Council and first flown on 8 June 1967, the two stage solid propellant sounding rocket was capable of sending a 15 kg payload of scientific instruments to a height of 150 km or 30 kg to 87 km. The main sustainer was the Lapwing motor with a thrust of 454 kg, assisted in the latest version by four boosters delivering 2.041 tonnes thrust for 0.2 sec which gave it a capability of sending 25 kg to a height of 140 km.

So far more than 100 Petrel rockets have been launched on scientific and atmospheric sounding flights.

Skua:

Developed in the early 1960's as a high altitude atmospheric sounding rocket, the British Skua 1 was a two-stage solid propellant rocket with a length of 224 cm, diameter of 12.7 cm and a weight of 57 kg. The first flight came in 1962 and to date more than 900 Skua rockets have been purchased by 6 foreign countries and launched from 11 launch sites.

The Skua 2, which appeared in 1965, had improved performance, raising the 5 kg payload altitude from 75 km with Skua 1 to 100 km. The most recent development is the Skua 4 which can transport a 7.4 kg load to a height of 140 km with up to 32 sec flight time above 100 km. This version appeared in 1972 and the basic Skua, in all three variants, is capable of lowering the payload to the ground by parachute for safe recovery. The two stage Skua 4 is the same size as Skua 1 and Skua 2 and weighs 83.3 kg.

Skylark:

Originally conceived in the mid-1950's, Skylark 1 first flew in February 1957 and to date more than 300 types have been used in six countries. Skylark is a two-stage solid propellant atmospheric and earth resources sounding rocket, using a Raven motor in the first stage and developments of the Cuckoo (see Black Knight) in the second. Skylark 1, of which there were seven launches, had only one stage and could send a 100 kg payload to a height of 175 km. Skylark 3 appeared in February 1965 and with its two stages, could lift the same weight to 290 km.

Skylark 4 was ready in 1972, with a payload capability of 100 kg to 330 km, although Skylark 6 had already appeared in 1969 capable of taking a 100 kg load to 380 km. With several other variants, the Skylark provides a wide range of capabilities to match the requirements of operators pursuing unique avenues of research and the most recent development, Skylark 12, is one of the most powerful sounding rockets available in Europe. Using a solid propellant apogee motor as a third stage, it carried a 138 kg payload to a height of 800 km on 21 November 1976 and will be capable of lifting 181 kg to this altitude if required.

The first Skylark 12 flight was in October 1975 and maximum altitude is 1,500 km with a 75 kg payload. Skylark payloads are returned to earth by parachute for recovery.

UNITED STATES

Aerobee:

Developed in 1946 at the request of the US Navy, Aerobee was designed and built by the then Aerojet Engineering Corporation under an initial contract for 20 sounding rockets, under the guidance of the John Hopkins University. The name was selected by Dr. James A. Van Allen, the director of Aerobee planning, and the rocket emerged as a two-stage vehicle weighing 540 kg and capable of sending a 60 kg payload to a height of 125 km.

The basic Aerobee was propelled by a 1.2 tonne thrust liquid propellant motor burning nitric acid/aniline propellants for 45 sec, boosted by a 9.5 tonne thrust solid propellant motor for the first 2.5 sec. Without the booster, Aerobee was 5.74 m long and 38 cm in diameter with four fins at the rear of the booster and three at the rear of the sustainer.

In 1952 the Air Force and the Navy requested development of a more powerful version called Aerobee-Hi so that intensive studies of the upper atmosphere could be conducted. The first flight came two years later and an improved version was designated Aerobee 150. This had a capability to send a 68 kg payload to a height of 275 km and with four fins attached it became the 150A. The 9 m tall rocket employed liquid propellants and with a solid propellant booster it became the Astrobee.

Many variants were produced and representative examples are the Aerobee 200, carrying a 227 kg payload to 290 km and the Aerobee 300, taking 3 kg to a height of 500 km. The Astrobee 200, with its solid propulsion could transport 57 kg to 320 km, while the Astrobee 1500 could boost a payload of 136 kg to an altitude of 1,200 km. Aerobee had been a development of the Wac Corporal and was usually launched from a 43 m tall tower, but the later versions were set up on an inclined ramp, in effect a support beam. Several flights were made in the early days with mice and monkeys to a height of 64 km, followed by recovery and examination of the live payload.

Arcas:

In 1959 the Atlantic Research Corporation produced the Arcas as a cheap atmospheric sounding rocket and with a wish to perpetuate the company initials (A, R and C), chose the name Arcas as an acronym for 'All purpose Rocket for Collective Atmospheric Soundings'. The comparatively small, 2.43 m tall, rocket had a single solid propellant stage and four cruciform fins in the tail. It was launched from the inside of a firing tube and was capable of boosting 5.4 kg to a height of 64 km.

Further developments of the Arcas called Arcon and Iris were also developed by the Atlantic Research Corporation. Arcon was 3.4 m long and could send 18 kg to a height of 400 km and Iris stood 5.7 m tall and could carry a 45 kg payload to an altitude of 320 km.

Argo:

Developed by the Aerolab Company, which was subsequently taken over by the Atlantic Research Corporation (see Arcas), the Argo was conceived in the late 1950's as one of America's largest and most powerful carrier rockets for sounding probes. The name originates from the ship used by Jason in Greek mythology when searching for the Golden Fleece; a ship he had chosen to name after its builder, Argus. The Argo rocket is a development of the Jason, originally designed and built by Aerolab.

The D-8 Argo, named Journeyman, using the initial letter from the word 'Jason', was a four-stage version capable of boosting 70 kg to a height of 2,400 km. The first stage was 79 cm in diameter and produced a thrust of 54.9 tonnes while the second and third stages had sequential thrusts of 21.3 tonnes each. The fourth stage produced a thrust of 1.4 tonnes and the complete assembly stood 18.9 m tall.

The Argo D-4 Javelin, again with a J from 'Jason', continued in service after the retirement of the D-8 from NASA service in 1965. It had a capability of sending up to 70 kg to a height of 1,100 km, but was also used with the Nike as a first stage.

Aries:

Unlike other atmospheric sounding rockets, the Aries utilized redundant second stages from an ICBM programme – the Minuteman silo launched missile. Developed in 1974 in co-operation with the Naval Research Laboratory, Sandia Laboratories and West Germany, NASA produced the Aries to fill a requirement for improved weight lifting capability and increased periods of weightlessness during the brief few minutes outside the atmosphere. The original name of Fat Albert, taken from a US television character, was felt to be excessively flippant and Bob Arritt of the Naval Research Laboratory selected the name Aries after his birth sign and because the rocket was to conduct research in various aspects of astronomy.

Adopting the Aerojet-General second stage of the Minuteman missile, the Aries can lift up to 900 kg of scientific equipment and reach altitude in excess of 300 km. A distinct advantage of this solid propellant sounding rocket is in the generous 11 min of weightlessness it can provide on carefully adjusted trajectories, thereby enabling NASA to conduct experiments in materials processing during this time.

Asp:

First launched in 1955, the solid propellant sounding rocket, named Asp, an acronym for Atmospheric Sounding Projectile, has been used by NASA and other agencies for gathering data at extreme altitude. The 3.6 m long rocket can boost a 14 kg package of experiments to a height of more than 40 km and was originally conceived and developed by the Cooper Development Corporation for the US Navy.

Its maximum payload lifting capacity was 36 kg and an attempt was made to improve the performance by placing it as an upper stage to the basic Nike sounding rocket. Such a configuration was actually tested by NASA in 1960, but there was little practical application and further work was halted, leaving the Asp to live out its days as a sounding booster in its own right.

Atlas:

The first true US ICBM was conceived as a result of work carried out under an MX-774 concept developed in 1946 toward the design of a missile capable of carrying a warhead across a range of 8,000 km. It was not until early 1951 that the project was named Atlas, when Karel J. Bossart, head of the Consolidated Vultee Aircraft Corporation (Convair, later the Convair division of General Dynamics) working on the successor to MX-774, called the MX-1593, selected the title to represent the Greek god reputed to support the world on his shoulders. Also, Convair was owned by the Atlas Corporation and after submission of the name to the Air Force Department of Defence Research and Development, the Committee on Guided Missiles approved the proposal in August 1951.

Atlas had grown to provide a copious range of military derivatives and has been adopted by NASA as the first stage to a multi-stage satellite launcher, still in service and likely to remain so until the early 1980's when it, along with Delta and Titan, will be replaced by the reusable Shuttle. By 1954 the Atlas project envisaged a 27.4 m long, 3.6 m diameter, missile powered by five engines, producing a liftoff thrust of 295 tonnes.

Studies from the Strategic Missiles Evaluation Committee agreed with conclusions from the Rand Corporation that by 1960 the United States would have acquired a lightweight thermonuclear warhead and because of this the proposed missile was reduced in height and diameter to 22.86 m and 3.05 m respectively. With less mass in the warhead, the design could be smaller and still achieve the same performance objectives. Toward this end, two of the five engines were deleted and the design progressed on this basis from the end of 1954. This concept was approved by the Department of Defence. Convair, re-named as a division of the General Dynamics Corporation in 1953, were awarded a contract in January 1955.

Nine months later it was given the highest priority rating and peripheral side effects of a disturbing report on military developments in the Soviet Union, spurred this programme, as well as prompting development of the Titan ICBM and the Thor IRBM.

The first models, designated Atlas A, B, C and D, adopted the Rocketdyne MA-2 propulsion system, which had been developed from a cancelled cruise missile programme called Navaho. It would find application in Redstone, Thor and Jupiter programmes. The propulsive concept for Atlas was, and still is, quite unique for a large missile and warrants some description. While most rockets of one (or more) stage(s) adopt either one engine or a cluster of motors all fixed to the base of the respective stage(s), Atlas utilized a boost/sustainer concept. In this approach, three rocket motors are arranged in a row at the base of the stage with the central motor called a sustainer and the outer two motors called boosters. All three use propellant contained in the main body of the stage proper and ignite simultaneously at launch. However, in the case of Atlas, at 145 sec into the flight the boosters are shut down. The two boosters, connected by a common structure that surrounds the sustainer, are jettisoned by sliding the cage and its two motors rearward and away from the ascending missile. Meanwhile, the sustainer continues to burn for an additional 125 sec and remains attached to the stage tanks throughout.

This concept, sometimes called the 1½ stage design, ensures that all engines can be ignited on the launch pad and removes the possibility of an upper stage failure from an in-flight ignition. The author takes the view that it is misleading to refer to this as a 1½ stage concept, since a 'stage' should more properly be thought to have its own dedicated motor and propellant tanks; with Atlas the single sustainer and the two booster motors use propellants from the same source. It is suggested that confusion is avoided by referring to this as a 'slave-booster' concept; that is, 'boosters' serving the same function as strap-on boosters to, for instance, the Thor, Delta or Titan III but 'slaved' because they bleed propellants from the tanks supplying the central sustainer. This may help the readers unfamiliar with the concept to understand the functional role played by the various elements.

The MA-2 propulsion system comprised two Rocketdyne LR-89 boosters each generating a thrust of 68.04 tonnes at sea level and a single LR-105 sustainer delivering 25.85 tonnes thrust. Pitch and yaw control was governed by movement of the booster and sustainer engine exhaust nozzles with gimbal actuators and roll was controlled by two 454 kg thrust vernier motors located on the rear opposing sides of the main tank structure of the first stage, but forward of the fairing containing the boosters, released at booster shutdown. Although the main structural body of the missile was a constant 3.05 m in diameter, the three rocket motors mounted in line across the base exceeded this value and required two straight sided fairings to emerge from a point just below the vernier motors to smooth aerodynamic effects.

The fairings, booster, support structure and relevent plumbing were all released at booster shutdown and the central sustainer was accommodated within a central cutout. Because it was attached to the base of the first stage proper, the sustainer remained with the Atlas while booster engines, fairings, etc., slid past the thrusting engine.

The design of the main stage was quite revolutionary, especially for 1955, in that it used a pure monocoque construction. Instead of the conventional former and stringer concept used by the V-2 and other missiles, whereby the propellant tanks are supported by a rigid frame, Atlas was the propellant tank in itself. In this fashion the walls of the first stage are the actual walls of the oxidizer and fuel tanks with a hemispherical dome separating the two chemicals. Moreover, because of the pure monocoque construction, the stage must be kept pressurized at 689 g/cm^2 above atmospheric pressure to prevent buckling.

The cylindrical stainless steel tank sections are fabricated from 91.4 cm wide bands with the two ends welded to form the required ring shape and then welded to each other to form the main stage. Thickness varies, but is never more than 1 mm. The nose section is in the form of a straight-sided cone, tapered to a diameter of 1.22 m with a hemispherical dome and the payload is carried forward of this section. Liquid oxygen is carried forward of the RP-1 (fuel) tank, which occupies the rear section, to which is attached the semi-monocoque boost section with external stringers to stiffen the structure. Two broad cable fairings run up opposing sides of the stage from the point where the flared booster engine fairings meet the tank; one is longer than the other. Retrorockets on the forward section of the cable fairings ensure that when the warhead is separated, the massive stage can be moved back, thereby preventing any re-contact or 'shunting'.

The stage, with a Mk. 2 warhead, is 23.13 m long, 304.8 cm in diameter and 4.87 m wide across the base of the booster fairing. With a Mk. 3 or 4 warhead, the missile is 25.15 m long, or 24.1 m with the Mk. 5. At liftoff Atlas weighed 115.67 tonnes and produced a thrust of 162.84 tonnes from the central sustainer, the two boosters and the two vernier motors. In a normal flight profile the boosters burn out and are separated 145 sec after liftoff, reducing weight by 3.6 tonnes, followed by sustainer and vernier engine shutdown 270 sec after ignition. At this point the vehicle is travelling at a speed of about 25,750 km/hr, climbing at an angle of 70°. The warhead/nose cone assembly is released followed by a 1 sec burst from the two Atlas retrorockets to move the stage back from the payload until it reaches a peak altitude of 1,480 km and begins to curve back down, towards the atmosphere, finally reaching the target more than 8,000 km from the launch site. Whereas the warhead is designed to survive re-entry, the massive structure of the Atlas ICBM is destroyed through friction when it reaches the atmosphere.

Guidance was initially planned to adopt a semi-inertial system co-operating with ground stations for corrective information, but Atlas E and F models used an all inertial system ensuring that unlike models A to D, more than one Atlas could be launched by the same missile complex at any one time. The improved Azusa tracking system, developed by Convair as a part of the MX-774, project had a reported accuracy of 3 cm at a distance of 500 km. In just four years from 1958 the improved guidance system had been reduced in weight from 110 kg to 15 kg, a fair indication of the level of progress extant at this period of rapid electronic development.

Fabrication of the first monocoque tanks began in San Diego late in 1953 under a General Dynamics subcontract to the Solar Aircraft Company and by October 1954 GD had received the structure for tests at the Point Loma facility. The first model, Atlas A, was purely a research and development precursor to the operational variants to follow and did not carry the central sustainer engine, thereby reducing weight and lowering the liftoff thrust to about 136.1 tonnes. The first flight attempt was made with Atlas number 4A on 11 June 1957 from pad 14 at Cape Canaveral. It was a failure and so was the second try with Atlas number 6A on 25 September of the same year. On the third try, Atlas 12A ascended from pad 14 on 17 December 1957 and performed a near perfect maiden flight.

Without the central sustainer, range was limited to less than 1,000 km and within three months all eight 'A' models had been flown: only three were successful and the last came on 6 March 1958. Atlas B, with all three main motors and a separable nose cone installed, had its first flight on 2 August 1958 following an earlier failure the previous month, and successfully flew a downrange distance of more than 4,000 km. After three more successful flights with Atlas B, the full design range was exceeded in a 9,660 km flight on 28 November 1958.

This was followed by a daring publicity exercise of remarkable audacity when, after only seven successful flights in 16 attempts, a specially stripped down Atlas put itself and 55 kg of communications equipment into an orbit of 185 × 1,471 km about the earth. Its purpose was to broadcast a recorded Christmas message from President Eisenhower to the world, which it did for thirteen days. But the real message was far clearer than the taped voice: America had the capacity to send thermonuclear warheads across intercontinental distances and could match the Soviet initiatives demonstrated by Sputnik 1 more than a year before. Called Project Score, the Atlas B weighed 3,970 kg and because of its low orbit and high surface area it decayed into the atmosphere and was destroyed on 21 January 1959.

With specified performance a reality, the Atlas C series got off the ground on 23 December 1958 to test ablative nose cone technology and investigate the effects and problems associated with a high speed dash back through the atmosphere, generating temperatures of up to 8,300°c. The last Atlas B flight was launched on 4 February 1959 and of the ten attempts only six had been successful. In all, there were six Atlas C flights attempted of which only three were successful. The last came on 24 August 1959. Four months earlier the first Atlas D, the operational version, had been launched unsuccessfully and not until the fourth attempt, on 28 July, were all flight objectives met. On 9 September the Atlas D was declared operational in its ICBM role as the first successful firing from the Western Test Range under Strategic Air Command control. It was the first in a series of tests that continued on into 1960 and demonstrated an effective range potential of 16,000 km, 100% greater than the original specification required.

Meanwhile, mindful of the exposed nature of a fixed launch site, Air Force and General Dynamics engineers had developed the E and F versions which could be fired from underground silos, hardened against nuclear attack by massive concrete doors. The non-storable propellants meant that the earlier Atlas D would have to wait in a horizontal concrete bunker on the surface and be elevated to an exposed vertical position for rapid fuelling and launch. This procedure would take 15 min and while all Atlas models ever built had this drawback, at least the E and F models could achieve a measure of protection while being fuelled. The full refinement of these developments, whereby a missile is filled with storable propellants at all times, as well as being contained within a hardened silo, would await introduction of the Minuteman ICBM.

The Atlas E and F models used a more powerful propulsion unit called the MA-3, whereby the two jettisonable booster motors had an uprated thrust of more than 74.84 tonnes each, versus the 68.04 tonnes of the MA-2 system used in Atlas A to D. This provided the vehicle with a total launch thrust of 176.45 tonnes, an increase of more than 8%, enabling it to send a 2.8 tonne warhead a distance of 8,000 km. The first successful E series flight came on 24 February 1961 after a succession of three failures beginning four months earlier. The first Atlas F was launched successfully on 8 August. By this time Strategic Air Command Atlas D tests had consistently demonstrated a range capability of 15,000 km and this was accepted as the operationally assured kill radius.

By 1965 Atlas missiles were being replaced by the second generation Minuteman system and its military strike role was over. But Atlas had demonstrated its superior potential over other multi-stage rockets and was America's conceptual answer to the Soviet SS-6 Sapwood, which became the A series satellite launcher. It too was a single stage vehicle assisted by four boosters released at extreme altitude and the 'slave booster' Atlas design had already demonstrated its potential with the successful flight of Project Score.

In 1959 the Air Force extended this capability to a true payload lifting operation, with the addition of an Able upper stage. Able had been developed in 1958 to ride on top of the Thor IRBM for re-entry nose cone tests (see Thor) and delivered a thrust of 3.4 tonnes from a liquid propellant motor. The first Atlas-Able flight was on 26 November 1959, but the payload shroud broke away 45 sec after liftoff and prevented the Pioneer spacecraft from flying to the Moon as intended. A second attempt, ten months later, also failed as did the third and last Atlas-Able mission on 15 December 1960, when the Atlas stage blew up 70 sec after launch.

The first successful upper stage adaptation was with Agena, a stage developed by the Air Force in support of the Discover programme (see Thor). The Atlas–Agena A was 26.87 m tall and weighed 124.74 tonnes at launch. An uprated MA-2 propulsion system provided 69.85 tonnes of thrust from each booster engine in the Atlas and this provided a total Atlas thrust of 166.47 tonnes. The Agena A stage was 6.7 m long, 1.5 m in diameter and weighed 3.35 tonnes with a single 4.6 tonne thrust engine burning inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine propellants for about 120 sec.

The first Atlas–Agena A flight, on 26 February 1960, was unsuccessful when the second stage failed to separate, but the second on 24 May was a success and resulted in the 2.27 tonne payload going into orbit. The next flight was another failure, but the fourth and last mission with this configuration put Samos 2 into orbit on 31 January 1961, three years to the day after the launch of America's first artificial satellite. Atlas–Agena flights had been in support of the Air Force Samos and Midas programmes.

During this time a concerted effort had been applied to adapt the basic Atlas ICBM for launching the first US manned spacecraft. Selected for the Mercury Programme at the end of 1958, Atlas was required to lift the 1 tonne vehicle into low earth orbit and orders were placed by the then Space Task Group at NASA for nine missiles in December 1958. Whereas the Little Joe booster was conceived to test various aspects of spacecraft design under stress, the ready-made Atlas would be required to first prove it could successfully send a Mercury vehicle into space at 28,900 km/hr orbital speed. The demonstration would be called Big Joe and help to determine whether ablative materials under development for the Mercury heat shield could be safely applied to the spacecraft itself.

After numerous delays, the Big Joe flight was accomplished on 9 September 1959, the very day that another Atlas would lift off from the Western Test Range and qualify the missile for its ICBM role with the Air Force. The NASA flight was a failure, when the two booster engines remained with the stage after shutdown, which lowered the attainable altitude to 107.9 km, although the boilerplate spacecraft separated and was subsequently recovered. A boilerplate spacecraft is only a simulated structure of the actual vehicle and in this case it had no launch escape tower which would be carried by orbital Mercury–Atlas flights in the event that the spacecraft would have to be fired away from the Atlas if it malfunctioned in some way. The successful demonstration of ablative heat shield materials qualified the flight as a success, however, and a second Big Joe shot was cancelled.

The Mercury–Atlas-1 (MA-1) flight, so named because it used a production spacecraft, was a dismal failure when the Atlas broke up at a height of 9.7 km on 29 July 1960. The MA-2 attempt on 21 February 1961, successfully demonstrated good performance, as it cut off, intentionally, at a speed of 5,500 km/hr to expose the Mercury spacecraft to a high altitude abort test. The standard Mercury Atlas launch vehicle adopted the improved Rocketdyne MA-2 propulsion system, which produced a booster thrust of 69.85 tonnes, first used in the Atlas–Agena flights, and the configuration was 29.06 m tall and weighed 117.9 tonnes. The MA-3 and subsequent launchers had a stiffened tank section in the forward area to prevent buckling, but the flight was aborted only 40 sec after liftoff on 25 April 1961, when the inertial guidance system failed.

MA-4 was the first orbital flight of a Mercury spacecraft and got off the Cape Canaveral launch pad on 13 September 1961 to put the payload on a single orbit flight before re-entry and recovery. MA-5 took chimpanzee Enos on a two-orbit flight on 29 November and successfully qualified all systems for the four manned Mercury flights, MA-6 to MA-9, on 20 February, 24 May and 3 October, 1962, and 15 May 1963. In a programme which culminated in sending the first four US astronauts on earth orbiting space flights, Atlas had been launched ten times with 3 launch vehicle failures.

Meanwhile, US Air Force development for unmanned orbital operations had got under way with the Agena B upper stage. This configuration varied slightly according to the specific mission it was supporting, but a typical Atlas–Agena B assembly was 31.5 m tall, weighed 124.74 tonnes and generated a first stage thrust of 176.45 tonnes with the same MA-3 propulsion system (not to be confused with Mercury Atlas) fitted to the E and F ICBM versions in 1961. The Agena B was 6.7 m long with a diameter of 1.5 m, had a loaded weight of 8.2 tonnes and generated 7.27 tonnes of thrust for 240 sec burning inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine propellants.

The first Atlas–Agena B flight was launched on 12 July 1961 and successfully placed the Air Force Midas satellite in orbit. The second launch was in support of the NASA Ranger programme, an unmanned lunar exploration project which envisaged soft landing capsules sending data back from the surface, but it failed during flight on 23 August 1961. The last Atlas–Agena B flight was launched successfully on 6 June 1966 when it sent a NASA scientific satellite into orbit; the final Air Force launch of this configuration had been successfully conducted on 18 July 1963 and it would have been retired then, had it not been for a NASA requirement to send more Ranger vehicles to the Moon in 1964 and 1965, the last three of which successfully televised views of the surface up to impact.

In all, 29 Atlas–Agena B missions were flown, of which 7 had been failures. It is interesting to see how increasing design and operating experience was enhancing the success rates between 1959 and 1966. The consecutive Atlas–Able, Atlas–Agena A and Atlas–Agena B configurations exhibited failure rates of 100%, 50% and 24%. Atlas–Agena B had achieved fame for launching the first successful NASA planetary spacecraft, the 203 kg Mariner 2 for a flight close to Venus, but the next three planetary missions would use a more powerful Atlas–Agena D combination.

The first flight of this configuration came on 6 September 1963 and the Agena D and payload shroud was 11.9 m long, 1.65 m in diameter with a thrust of 7.26 tonnes for 240 sec. On 14 August 1964 the new SLV configuration became standard and this was the first major change in the Atlas structure. In later developments the first stage was extended by 3 m to a total length of 24.35 m, providing volume for an additional 21 tonnes of propellant, with a liftoff thrust of 179.17 tonnes. This was designated SLV-3A, the prefix SLV denoting the new Standardized Launch Vehicle concept whereby interchangeable kits of subsystems replaced the earlier custom-built approach.

Atlas–Agena D vehicles achieved success in launching five Lunar Orbiter spacecraft to the Moon in 1966 and 1967, sending the first successful fly-past of Mars on course and putting up a host of NASA and Air Force satellites. The configuration had a capability of lifting 4,000 kg in low earth orbit, or sending 1,240 kg to synchronous orbit transfer. In addition, the Agena D was modified to serve as a target vehicle for the manned Gemini spacecraft, a programme which sent two-man crews into earth orbit in 1965 and 1966 to follow the highly successful Mercury missions of 1962 and 1963. In this role Atlas sent an Agena D into orbit to await the launch of the Gemini spacecraft. Following rendezvous operations the crew moved the nose of their spacecraft into a special docking collar on the Agena in a rehearsal of docking operations anticipated for the Apollo Moon landing programme. In all, six Gemini–Agena Target Vehicles (GATV's) were sent up by Atlas launch vehicles with two failures. A specially built Augmented Target Docking Adaptor (ATDA) was launched in lieu of one of the failed GATV flights and it was essentially the forward docking section of an Agena, but without the mass of the Agena tankage and motor. The ATDA weight was within the payload-to-orbit capability of the Atlas, so it did not require propulsion, other than provided by the basic Atlas.

By 1965 yet another variant had been brought to operational readiness using the FW-4S as a solid propellant second stage. In this configuration the assembly was 30.27 m long using the basic D series Atlas with the SLV/3A stage extension and the second stage had a diameter of 213.4 cm. This assembly was called the SLV-3A/OV1 and could place 2.5 tonnes in low earth orbit and the OV1 (Orbital Vehicle One) could accommodate two satellites within its payload shroud. It has been used solely by the US Air Force for sending military payloads to space. Refurbished Atlas E and F models following ICBM de-activation in 1965 have formed the basis for many of these configurations. In 1968 a basic Atlas was used with a 4.5 tonne thrust Burner II as second stage.

The most effective civilian variant emerged in 1962 when it was married to the General Dynamics Centaur. This high energy variant was the first general purpose liquid oxygen/liquid hydrogen upper stage applied to a standard expendable launch vehicle. These cryogenic propellants had been used in the S-1V stage of the Saturn 1, but they were launch vehicles tailored to a specific objective and their entire sequence of operations spanned a few months; Atlas–Centaur will have seen nearly 20 years of service by the time it is retired.

Centaur consists of two propellant tanks and two RL-10 engines producing a total thrust of 13.6 tonnes. The engine was a precursor to the J-2 used in Saturn IB and V upper stages. In the initial Atlas-Centaur configuration used operationally in 1966, the total vehicle had a height of 34.44 m and a liftoff weight of about 137.35 tonnes. The propulsion system carried boosters with a thrust of 74.84 tonnes and a standard sustainer of 25.85 tonnes thrust. This resulted in a launch thrust of 176 tonnes.

The first Atlas-Centaur flight was launched on 8 May 1962 and by 30 May 1966 the first operational mission sent Surveyor 1 to a soft landing on the Moon. On 8 September 1966 an improved version entered service by sending Surveyor 5 to the Moon and this configuration incorporated a 1.22 m extension in the Atlas stage. The height was 35.67 m and launch weight grossed 147.42 tonnes with the extra propellant. The MA-5 propulsion system provided a thrust of 179.17 tonnes, with booster and sustainer burn durations of 153 sec and 249 sec respectively.

Still further development resulted in enhanced performance and the current, and probably last, configuration change is designated the SLV-3D-1AR, with a length of 40.84 m and a liftoff weight of 148 tonnes. The uprated MA-5 propulsion system provides each booster with a thrust of 83.92 tonnes and a sustainer producing 27.22 tonnes for a gross liftoff thrust with verniers of nearly 195.64 tonnes, a creditable improvement on the 162.84 tonnes of the first versions in 1957.

With this performance the SLV-3D-1AR can send more than 4,500 kg into a low earth orbit, 1,880 kg on to a geosynchronous transfer or 910 kg to the planets. Most applications now use the geosynchronous transfer orbit capability and the Atlas–Centaur has become, and will remain until the reusable Shuttle enters service, the standard workhorse for this type of mission.

On a typical mission, the two boosters are shut down at a height of 57 km and a speed of nearly 9,000 km/hr, 139 sec after launch. From this point the central sustainer and the two verniers, producing a total thrust of nearly 30 tonnes due to the enhanced efficiency at altitude, carry the assembly to a height of 144 km and a speed of 13,000 km/hr, 247 sec after launch. Nine seconds later the Centaur/payload combination has separated from the Atlas, leaving it to come back down to the atmosphere and be destroyed through frictional heat build-up, and ignite to produce a constant thrust of 13.6 tonnes.

About 350 sec later the Centaur shuts down, having taken itself and payload to a height of 189 km and a speed of more than 28,000 km/hr. With the combination still gaining altitude, the Centaur engines are re-ignited after a cruise duration of 14½ min and a height of 560 km has been achieved. The second and final Centaur burn lasts for a mere 85 sec and puts the combination on a trajectory which will bring it to a geosynchronous altitude of 35,900 km several hours later. When the Centaur shuts down for the second time it is at a height of 630 km and a speed of nearly 33,900 km/hr. About 135 sec later the spacecraft separates from its housing above the Centaur, nose fairing panels having been jettisoned at 271 sec into the flight, and the launch vehicle's job is over. The Centaur, now useless, stays in this highly elliptical orbit, but the spacecraft will fire its own small solid rocket propulsion system to circularize itself at geosynchronous altitude.

This complex and demanding sequence of operations is in marked contrast to the first operational launcher techniques extant at the dawn of space-borne activities and serves to endorse the conviction that a great deal of technical sophistication still attends seemingly routine operations.

By the end of 1977 more than 430 Atlas rockets had been launched on ballistic flights and space missions, with an overall success rate of about 80%, but this figure is of course heavily biased by the extensive problems encountered during the early phases of not only this programme, but the entire rocket industry. Atlas–Centaur will be replaced by the manned reusable Shuttle soon after it enters operational service in 1980. Nevertheless, the basic Atlas has, as a main stage, experienced less change in the prolific variety of alternative configurations brought into use than any other major launch vehicle and this is probably the greatest tribute that can be applied to its obituary, when after a quarter-century of use it finally relinquishes its role to the new reusable transporter system now under development.

Bumper-Wac:

Essentially comprising a redundant German V-2 ballistic missile and a US Army Wac Corporal, the Bumper-Wac programme was implemented as part of the Hermes project between 1948 and 1950. The US Army Ordnance Department had contracted the General Electric Company to integrate operations associated with V-2 tests. With a need to study the technical problems of separating rocket stages in flight, determine the possible instability of high altitude flights in the rarefied atmosphere and evaluate the techniques for high altitude ignition, the Army conceived a marriage between V-2 and Wac Corporal, with the latter mounted on the nose of the V-2 so that it could reach greater altitudes than the single stage V-2 alone.

Wac Corporal was used without the solid propellant booster normally fitted to this sounding rocket (see Wac Corporal) and in this configuration it had a length of 4.8 m and a diameter of 30.4 cm. The 14 m long V-2 provided a first stage boost of 25 tonnes at liftoff and about 29.6 tonnes at altitude. In a typical flight the V-2 would carry the Wac Corporal on its nose for 60 sec of main engine burn, shut down and separate from the Wac Corporal which would then fire its liquid propellant motor for 45 sec with a thrust of 68 kg. The Bumper-Wac combination stood nearly 18.9 m tall and weighed 13.12 tonnes at liftoff.

The first flight was launched from White Sands, New Mexico, on 13 May 1948, but an early cutoff with the Wac Corporal limited the altitude to 127 km and a speed of 4,410 km/hr. On the second flight, in August of that year, the V-2 shut down prematurely and the assembly reached a height of only 13 km while the Wac Corporal failed to ignite at all, on the third flight in September 1948, although the V-2 did carry the combination to a height of 150 km.

The fourth attempt, in November 1948, ended in disaster when the V-2 exploded, but the next flight in February 1949 was successful and the Bumper-Wac reached a height of 393 km and a speed of 8,288 km/hr. The sixth flight in April, was another flop when the V-2 cut off prematurely. The last two flights were launched from the Long Range Proving Ground at Cape Canaveral on trajectories which required the V-2 to fly a low angle trajectory after liftoff, gaining horizontal range at the expense of altitude.

Both flights were launched in July 1950, the last on the 29th of that month, and succeeded in travelling a range distance of 322 km. The eight Bumper-Wac flights had been only moderately successful, although one flight had achieved all its assigned objectives. On a point of historical nostalgia, it is interesting to note that the two Bumper-Wac launches from Cape Canaveral were the first flights from what later became known as the Kennedy Space Centre, Florida.

Corporal:

Developed in 1944 as the US Army's first generation short range ballistic missile, the Corporal was a contemporary of the German V-2 and adopted several technical approaches reminiscent of that rocket. The guidance was by radio beam with control effected by graphite vanes in the exhaust plume. The rocket was 14 m tall, a constant 76.2 cm in diameter before converging in a straight-sided cone to the pointed nose, and weighed 5.4 tonnes at launch. It used red fuming nitric acid/ethylanilene propellants to produce a thrust of nearly 9.1 tonnes. Four elongated fins were attached to the base of the single stage rocket and the missile had a normal range of about 120 km.

Corporal saw service with the US Army in Europe and was delivered to UK Missile Regiments of the Royal Artillery in 1957. The exceptionally simple design was, nevertheless, complex to operate in a battle situation and several hours were necessary to prepare it for launch. The Corporal was gradually replaced by the Sergeant in the early 1960's, although the Royal Artillery contined to operate the missile until the end of 1966, 22 years after it was conceived.

Delta:

A projected requirement for an intermediate weight satellite launcher led NASA to approve development of an improved upper stage configuration for the basic Thor IRBM in 1959 which would serve to send civilian payloads into earth orbit until more sophisticated and capable launch vehicles became available. Reference to Thor rocket history will remind readers that in 1959, less than than a year after the formation of the civilian space agency, the Army had already adapted the basic IRBM to military satellite launches, by placing the upper stages of the Vanguard rocket on to the Thor and calling it the Thor–Able satellite launcher. In essence, the Air Force had taken components of the Vanguard and applied it to military duties in a marriage with their own IRBM. Now NASA re-worked the upper stages of Vanguard and married this to the Air Force Thor, calling it the Thor Delta, as the much needed interim launcher capable of sending civilian payloads to orbit until more advanced launchers became available.

In all respects the Thor Delta was yet another upper stage adaptation of the basic Thor IRBM, but whereas upper stage configurations outlined under 'Thor' references were utilized almost exclusively for military duties, the Thor Delta began life as, and remains to this day, primarily a civilian launcher and as such began a long line of developments warranting this separate descriptive section.

Historically and chronologically it emerged as a concept while the Air Force/Navy teams were using the first Thor launcher, Thor–Able, and came into operational use with NASA at about the same time as the Air Force was changing over to the Thor-Able-Star and Thor-Agena A configurations. Selection of the suffix 'Delta' was made to imply that it was the fourth Thor-based upper stage adaptation (after Able, Able-Star and Agena A), 'D' being the fourth letter of the alphabet. The name was given by Milton Rosen in January 1959 when contracts were signed for fabrication of the Delta upper stages. Although beginning life as Thor Delta, preserving the established procedure of separating the names of first and upper stages, it has gradually become known simply as the Delta, with letter or numeral suffix identification for subsequent improvements. This conveniently provides easy access to prime function: Thor-based derivatives for military use were designated the 'Thor' title as a prefix, whereas the one Thor derivative for primarily civilian application uses the prefix 'Delta'. To avoid confusion subsequent discussions will refer to this launcher by its more recent title – Delta – rather than Thor Delta.

The first stage of the Delta launch vehicle was, of course, a modified Thor with a length of 18.2 m and a diameter of 2.44 m. With the Block 1 MB-3 engine, it produced a thrust of 68 tonnes from the combustion of liquid oxygen/RJ-1 propellants for a duration of between 146 and 162 sec, depending on the specific mixture ratio. The second stage consisted of an Aerojet-General AJ-10 series engine producing a thrust of 3.5 tonnes from the inhibited red fuming nitric acid/unsymmetrical dimethyl hydrazine propellants contained in a structure 6.3 m long and 81.3 cm in diameter. The third stage was a solid propellant ABL-X-248 motor 1.52 m long and 45.7 cm in diameter, producing a thrust of 1.25 tonnes. Radio guidance was carried on the first two stages and the solid propellant third stage was spin stabilized at 140 rev/min. Second and third stages fired for 170 sec and 42 sec respectively. The height of the configuration depended on the size of the payload shroud, but was typically 27.4 m with a launch weight of 52 tonnes.

In a typical flight profile, the Thor first stage would take the assembly to a height of 66 km followed by separation and ignition of the second stage. About 40 sec later the payload shroud was jettisoned and after second stage shutdown, the assembly coasted on up to an altitude of about 260 km. The third stage was then spun up to 140 rev/min, the second stage was separated and the third stage ignited to provide the necessary speed to reach orbital velocity. Following these procedures the satellite was separated from the now inert third stage and the responsibilites of the launch vehicle were over. The orbital capability ensured a maximum payload weight of 270 kg or 45 kg on to a geosynchronous transfer orbit (that is, an elliptical trajectory which would carry 45 kg to a high point of 36,000 km).

The first Delta launch came on 13 May 1960, but a second stage malfunction prevented the intended payload from reaching orbit. On the second try, on 12 August, the Delta performed as required and put the inflatable Echo 1 passive communications (reflector) satellite in orbit. The prolific varieties of successive Delta developments are far too numerous to detail in a truly comprehensive manner, but the following generalities cover all the variants that were subsequently brought to operational status.

The basic Delta, as outlined above, was used between 1960 and 1962, successfully launching Echo communications satellites, Tiros weather satellites, scientific research satellites and the first UK satellite Ariel 1, in a series of twelve flights. In October 1962, the Delta A was introduced, with the uprated MB-3 engine in the first stage increasing thrust to 78 tonnes (see Thor) in two launches of Explorer class satellites. The uprated Thor first stage improved the payload capability to a maximum 320 kg.

Delta B also appeared in 1962, with second stage propellant tanks increased by a total 91 cm and a modified AJ-10 motor, this increasing the payload capacity to 375 kg. Improved guidance and electronics were also introduced and the variant achieved fame in nine flights up to 1964 by, such feats as, launching the first synchronous orbit payload, the 39 kg Syncom 1, on 14 February 1963. Retention of the long-tank second stage and modification to improve the performance of the third stage motor, led to the Delta C of 1963, which could put 410 kg in low earth orbit; among the thirteen flights at various times up to 1969 were: Explorer scientific satellite missions, solar observatories, weather satellites and the first polar orbiting meteorological satellite.

On 19 August 1964, yet another variant was introduced, when the first Delta D put the Syncom 3 communications satellite in geosynchronous orbit. This version of the Delta used three solid propellant Castor 1 boost rockets to increase total first stage thrust to some 150 tonnes, in like manner to the Thrust Augmented Thor–Agena D combination, introduced by the Air Force 19 months earlier (see Thor). The civilian Delta D equivalent was also dubbed, Thrust Augmented Delta, or Tad. Solid propellant Castor boosters fitted around the base of the first stage would be used in all subsequent Delta variants, but the Delta D version was used only twice: once in 1964 to launch Syncom 3 and again in 1965 to launch Early Bird, the first operational civilian communications satellite.

With the supplemental first stage boost, Delta D had a capability of placing 580 kg in low earth orbit, or of sending 104 kg on to a geosynchronous transfer trajectory. This and future vehicles also made use of the uprated first stage engine, the Block 3 MB-3 which produced a thrust of 79.4 tonnes. Just 4 years and 3 months after the first flight, Delta payload capability had more than doubled and it was obvious that considerable potential was inherent in the basic design. This did much to ensure continued use of Delta for civilian launch duties and further developments would double the payload capability yet again.

In 1965 NASA introduced the Delta E, a derivative which would be used more than any other variant. The principal difference about this vehicle was that it used a virtually redesigned second stage. Delta and Delta A models had used a 6.3 m long, 81.3 cm diameter second stage, producing a thrust of 3.5 tonnes for 170 sec, increased in length to 7.2 m for Delta B, C and D. The new Delta E second stage was 3.96 m long, 138.9 cm in diameter and produced a thrust of 3.54 tonnes for 380 sec. The stage could be re-started in space and used the upgraded AJ-10-118E engine. The third stage was also changed at this point in Delta evolution and instead of the Thiokol X-258, the United Aircraft FW-4 was used, increasing the thrust from 1.25 tonnes to 2.75 tonnes and reducing the burn time from 42 sec to 32 sec: the 24% decrease in burn time was more than offset by the 118% increase in thrust. The new FW-4 solid propellant motor was 1.52 m long and 50.8 cm in diameter.

An optional two-stage version, called Delta G, was available and a more powerful TE-364-3 third stage could be used instead of the standard FW-4 and in this configuration, the assembly was designated Delta J. The additional development effort put into upper stage design called for a more descriptive reference and whereas Delta D, introducing the three Castor first stage strap-on boosters was called the Thrust Augmented Delta, Delta E was designated the Thrust Augmented Improved Delta or TAID for short. The assembly was about 28 m tall, weighed 68 tonnes and, with the Castor assisted first stage, had a launch thrust of 151 tonnes.

In a typical flight profile, the Delta E could lift a payload of 735 kg to low earth orbit or place 550 kg into geosynchronous orbit. In a series of twenty six flights, between 1965 and 1971, NASA used the Delta E to launch Explorer class satellites, weather satellites, communications satellites and solar orbiting vehicles in the Pioneer series. This latter role called for the payload to reach escape velocity so that it could free itself of earth's gravity and, like the earth itself, orbit the Sun at less distance than the home planet. To accomplish this, a new application for Delta, the first stage was accelerated to a height of 103 km and a speed of 16,500 km/hr; Castor boosters will have been jettisoned after their 39 sec burn at a height of 26.7 km. The second stage boosts the payload to a height of 375 km (but by this time the arching trajectory has taken the vehicle more than 2,000 km from the launch site) and a speed of 30,000 km/hr. The third stage takes over to achieve a height of 460 km and a speed of 44,000 km/hr and shuts down leaving the payload to coast on free of Earth's gravity.

While Delta E series were used variously up to 1971 for selected payloads requiring the capability afforded by this variant, a new model emerged in 1968 called the Delta L. It was, essentially, a Delta E with a lengthened Thor first stage and improved Mark II Castor boosters. The increased length of the first stage, now 21.3 m, followed on from the similar increase applied to the military variant called Thorad (see Thor) from 1966. With the additional length came a new constant diameter of 243.8 cm instead of the inward taper at the forward end of the basic Thor, which had been used for all Delta variants up to the L model. Thus the Delta L was dubbed Long Tank Delta (LTD) or Long Tank Thrust Augmented Delta (LTTAD), both applying to the same vehicle.

The first stage of Delta L weighed 84.4 tonnes, loaded with propellant, and produced 78 tonnes of thrust for 220 sec, supplemented for the first 39 sec by 69.4 tonnes of thrust from the three Castor II rockets clustered around the booster. With a similar upper stage configuration to that of the Delta E, described earlier, the assembly had a height of 32.3 m and a launch weight of nearly 90 tonnes. With an FW-4D third stage, the vehicle was designated Delta L, with a TE-364 third stage it was the Delta M and in a basic two stage configuration, it was the Delta N. NASA launched 20 vehicles of the Delta L (M,N) types between 1968 and 1972 and the assembly could place 1,000 kg in low earth orbit or send 350 kg on a geosynchronous transfer.

Still more improvements came with the Delta M-6 and N-6 variants used four times between 1970 and 1971. These were the same as the basic M and N variants (three and two stage configurations respectively), but with six Castor strap-on first stage boosters instead of the three adopted for the Delta D, E, L, M and N versions. In a typical flight with the M-6, only three Castors ignited with the first stage at liftoff, producing a total thrust of 147 tonnes, followed 31 sec later by ignition of the remaining three Castors. This had the effect of increasing booster burn duration by sequentially firing the two sets of Castor rockets. The two stage N-6 was similar in operation, but had only one upper stage instead of the two upper stages on the M-6. Payload capability was increased to nearly 1,300 kg by this method. Despite the incredible five-fold increase in payload lifting capability from the basic Delta of 1960 to the M-6 of 1971, still more variations were to emerge and secure the Delta launch vehicle as the true work-horse for medium weight satellite flights under NASA aegis.

In 1972 and 1973 the space agency launched five Delta 900 series rockets and these differed from the L, M and N and their associated sub-variants in having nine Castor first stage boosters and improved guidance electronics. The second stage was also improved with adoption of the AJ-10-118F engine burning nitrogen tetroxide and aerozine-50 producing a thrust of 4.4 tonnes, 1 tonne more than the second stage of Deltas E, L, M, and N. Basic length with payload was still 32.3 m and the sequence of operation required six Castors to ignite with the first stage at launch and produce a total thrust of nearly 218 tonnes for 39 sec. At burnout the other three were ignited for a further 39 sec, at the end of which they shut down leaving the first stage to continue producing 78 tonnes of thrust until completion of the burn 220 sec after liftoff.

The first stage is separated 8 sec later followed by a 4 sec coast to second stage ignition. Where the required orbit necessitated a double burn from the second stage, the first period of thrusting would continue for about 320 sec followed by shutdown and a 48 min period of coasting to the high point of an elliptical orbit and circularization, with a second burn for 11 sec or so. The two stage Delta 900 could take a 1,680 kg payload to low earth orbit and the Delta 904, with the addition of a TE-364 solid propellant third stage, could lift 635 kg on to a geosynchronous trajectory.

In 1972 further refinements were made to the Delta launch vehicle with the introduction into NASA service of the 1000 series. These adopted an extended long-tank configuration where the 243.8 cm diameter first stage was maintained throughout the full length of the vehicle, providing a 243.8 cm diameter forward shroud necessary for payloads then in the planning stage. An optional TE-364-4 solid propellant third stage was produced providing a thrust of 7 tonnes for 44 sec from a structure 1.4 m long, 1 m in diameter and weighing 1.1 tonnes. By comparison, the earlier FW-4 solid propellant third stage had produced a thrust of 2.7 tonnes for 32 sec. This new configuration could place 1,840 kg in low earth orbit or send 680 kg on to a geosynchronous transfer ellipse.

It should be pointed out that the constant external diameter of 243.8 cm was carried forward from the first and the small second and the third stages were located inside the extended walls of the first stage, thus the actual upper stage diameters are correct, but viewed from the exterior the sidewalls maintained a constant width of 243.8 cm. This version and subsequent variants utilizing the constant 243.8 cm diameter throughout, except for the Castor boosters clustered round the first stage, are sometimes referred to as the 'straight 8' configuration. This refers to the 8 ft diameter in English units equivalent to 243.8 cm in metric measurements.

The Delta 2000 series was introduced in 1974 and adopted a much more powerful second stage, using a modified version of the rocket motor first fitted to the Apollo Lunar Module for landing on the Moon. Called the TRW-201, it is 6.4 m long, 1.5 m in diameter and weighs 6.2 tonnes. With nitrogen tetroxide as the oxidizer and aerozine -50 as the fuel, the TRW-201 produces a thrust of 4.3 tonnes for 355 sec. Readers will note that the long line of developments in Delta second stage design, up to 1974, used the Aerojet-General AJ-10 engine burning inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine propellants producing 3.5 tonnes of thrust for 380 sec. A switch in second stage design to the TRW-201 engine demanded a 13% reduction in burn time, but a 23% increase in thrust; the net gain is self evident.

On top of the new second stage was the now standard TE-364-4 third stage described as optional for the 1000 series Delta and parameters outlined there apply to the 2000 series here, but both upper stages used an uprated Thor first stage. This was the first major change, in first stage design, since the basic Thor was extended in length, allowing more propellant to be carried and increasing the burn time from about 150 sec to 220 sec, with the Delta L in 1968. The new 2000 series used the Rocketdyne RS-27 engine developed from the H-1 used in the Saturn 1 and 1B launch vehicles and it produced a thrust of 93 tonnes using the same liquid oxygen/RJ-1 propellants for 228 sec. This was a considerable improvement over the MB-3 engine, which had been used to power the Delta first stage since 1960; developments in that engine had increased thrust from 68 tonnes in 1960 to 79 tonnes with the Delta D introduced in 1964. Now, with the new RS-27 liquid propellant engine and 6 Castor II solid propellant boosters all firing at liftoff, maximum thrust was 234 tonnes compared with 221 tonnes for variants beginning with the Delta M and its Block 3 MB-3 motor. This motor had been used since Delta D in 1964, but Delta M introduced the cluster of six Castors, or nine with only six firing at launch.

As with the 1000 series Delta, the 2000 series shrouded the 1.5 m diameter second stage and 1 m diameter third stage within a constant 234.8 cm extension of the first stage. The much changed 2000 series had a total height of 35.4 m, but the appearance of the launch vehicle belied its relationship to the much simpler Delta of 1960. The extended walls of the first stage completely transformed the vehicle and with its constant diameter along its entire length the Delta of 1974 bore no resemblance at all to the basic Delta of 1960, with its capability of placing 270 kg in a low earth orbit. With nine Castor II strap-on boosters and the first two main stages, the Delta 2910 had a liftoff weight of 134 tonnes and could place 2,000 kg in low earth orbit. The three stage Delta 2914 could send 703 kg to a geosynchronous transfer.

On variant, the Delta 2310, appeared superficially identical to a 2910 or a 2914 with an obviously similar length. However, the third stage was deleted and a support cage occupied the vacated volume within the constant-diameter shroud. Also, the first stage was assisted by only three Castor II boosters and this resulted in a total configuration weight of only 106 tonnes and a maximum liftoff thrust of 164 tonnes. One Delta was a strange hybrid and consisted of a basic 18 m long first stage using the Block 3 MB-3 engine, producing 79 tonnes thrust with the TRW-201 second stage, with the exterior wall 2.4 m in diameter to give the 'Straight 8' appearance. The first stage was assisted by the addition of four Castor II solid propellant rockets and this produced a total assembled weight of 110 tonnes and a maximum thrust of nearly 174 tonnes.

A typical flight to synchronous orbit for a Delta 2914 would begin with ignition of six Castor II rockets and the first stage RS-27 liquid propellant motor. At 38 sec the six Castors burn out and are followed by a 38 sec burn of the remaining 3. About 87 sec into the flight, at a height of 24 km and a speed of 4,270 km/hr the nine Castor II's are jettisoned and 3 min 48 sec after liftoff the first stage has consumed its propellant and the assembly is at a height of 106 km and a speed of 18,700 km/hr.

Just 8 sec after first stage shutdown, the upper stages separate and the second stage ignites at 4 min 1 sec into the flight. It burns for 4 min 20 sec and increases the speed to 27,980 km/hr at a height of 170 km. At second stage shutdown, elapsed time of 9 min, the configuration is in a low earth orbit which must be transformed into an ellipse with geosynchronous altitude (35,800 km) at the high point. Some 22 min 30 sec after liftoff the second stage is re-ignited for a 9 sec burn at a height of 180 km followed, 1 min 2 sec later, by separation of the stage.

At 24 min 22 sec, the solid propellant TE-364-4 third stage ignites for a 44 sec burn with the assembly at a height of 203 km and a speed of 36,775 km/hr. The trajectory is now an ellipse with the high point 35,800 km above the equator and 1 min 13 sec after the third stage shutdown, the spacecraft separates from the upper stage and coasts on along its elliptical path round the earth. Sometime later, perhaps at the high point of the fourth orbit, a propulsion system on board the satellite is fired to circularize the orbit at geosynchronous altitude. While this is only a typical sequence of events, it does amply demonstrate the level of development achieved with the Delta 2000 series.

Basic configurational selections provide the user with a choice of either three, four, six or nine Castor II strap-on boosters and a two or three-stage launcher. While the Delta 2000 represented the last intended development of the launch vehicle as far as NASA was concerned, a commercial requirement emerged for a further increase in performance. This was occasioned by the need to place heavier loads into geosynchronous orbit than could be handled by the 2000 series, but not sufficiently heavy to justify use of a more powerful type of launch vehicle such as Atlas–Centaur; the costs would be prohibitive and since more than one proposed payload fell into this category, it was felt desirable to finance development of a Delta 3000 series launcher.

Nevertheless, however desirable this may have seemed, NASA was reluctant to finance major expendable launch vehicle developments at a time when it was heavily committed to developing the reusable Shuttle. But the Shuttle would not be ready for operation until 1980 and the space agency could use the enhanced capability of a Delta 3000 series vehicle, so it was agreed that private industrial development of the launcher would be officially blessed by NASA and, if it lived up to expectations, be purchased by the agency without government money going on the development. So emerged the Delta 3914 and in 1975 it was used to send the RCA commercial satellite, Satcom 1, into geosynchronous orbit.

Basically the 3914 differs from the 2914 described earlier in the adoption of larger and more powerful solid propellant boosters, the Castor IV which is 11.1 m long, 1 m in diameter and produces a unit thrust of 38 tonnes. As with the 1000 and 2000 series Delta nine Castors could be carried, but the 65% increase in thrust of the Castor IV required only five to ignite at launch with the first stage, to prevent excessive acceleration on the assembly, instead of six. Maximum thrust after liftoff was, therefore, 286 tonnes from the RS-27 main stage engine and the five Castor IV solid propellant rockets compared with 234 tonnes for the RS-27 and six Castor II's on the Delta 2914. The remaining four Castor rockets on the 3914 were ignited at burnout of the five ignited for launch. Maximum liftoff weight is 190 tonnes and the Delta 3914 is capable of placing 930 kg on to geosynchronous transfer, compared with 703 kg for the 2914.

A final version, the Delta 3916/PAM, provides an improved third stage using the Thiokol Star 48 rocket motor, producing a thrust of 5.9 tonnes with a larger, 1.22 m, diameter than the TE-364-4 used for Delta 1000/2000 series launchers and the 3914. Length remains the same, but launch weight is 192 tonnes. The improved third stage, or Payload Assist Module (PAM), provides a capability for the Delta 3916 to place 1,040 kg in geosynchronous transfer.

With NASA launch operations converting to the reusable Shuttle for sending satellites and spacecraft into space, and preserving only the Scout rocket for very small payloads, the days of the Delta are numbered, but the phased transition to Shuttle operations will keep this launch vehicle in business through to the early 1980's. In the period between 1960 and mid-1977 the Delta vehicle has been launched on 130 flights six of which had reached orbit but suffered some malfunction which prevented the satellite reaching the expected parameters and five were total failures resulting in an abort or explosive disintegration. Some 119 flights had been totally successful, resulting in a reliability value of 91.5% and a total failure in only 3.9% of all attempted flights. It is interesting to compare the first Delta with the most recent, and probably final, version. In 1960 the Delta weighed 52 tonnes and provided a first stage thrust of 68 tonnes with a payload capability of 270 kg to low earth orbit or 45 kg to geosynchronous transfer. The latest and most powerful versions, weigh 192 tonnes, generate a maximum potential thrust of 286 tonnes and have a capacity to put 2,000 kg in low earth orbit or 1,090 kg on to geosynchronous transfer; earth orbit capability has increased more than seven-fold, geosynchronous capability more than 24-fold.

This is the most significant growth potential demonstrated by any civilian space launcher in the world and although the Delta 2000 and 3000 series variants are far removed from the basic Thor first stage which initially put a Delta vehicle in space on 12 August

1960, the generic development consistently applied over seventeen evolutionary years, has ensured the continued success of this versatile launch vehicle. All 130 Deltas (up to June 1977) had been, and will continue into the early 1980's, to be used for NASA flights from the Kennedy and Vandenberg launch sites.

Honest John:

Developed as a first generation tactical battlefield missile, Honest John was designed in 1950 as a solid propellant spin stabilized weapon and first saw service in 1954 with the US Army. Development responsibility was given to the Douglas Aircraft Company in association with Emerson Electric and it emerged as a 7.9 m long, 76.2 cm diameter weapon, with a launch weight of 2.1 tonnes.

Honest John was characterized by a pronounced bulbous nose terminating in a sharp point and with three large triangular fins at the rear. Three short stub-fins were located just aft of the bulbous nose and the rocket was stabilized in flight by spin motors and the aforementioned fins. The Hercules Powder Company rocket motor provided a missile range of 19 km and the 680.4 kg warhead could be equipped with either high explosive or nuclear charge. The original MGR-1A was replaced by the -B, which had higher performance and more refined launch procedures.

Honest John was normally launched from a rail, mounted on a wheeled truck. By the late 1960's the missile had seen extensive service with the US, UK, French, German, Italian, Belgian, Dutch, Danish, Greek, Turkish, South Korean and Taiwanese forces. It was replaced by the Lance and Pluton from 1974, although units were still operating the Honest John in 1977.

Jupiter:

The Jupiter A originated from a joint Army-Navy decision in 1955 to develop the first US intermediate range ballistic missile for both services (see Polaris) and towards that end work started in 1956 on a modified Redstone design, with the first test launch on 1 May 1957.

Jupiter was a single stage liquid propelled missile, 18.4 m long and 266.7 cm in diameter, utilizing a Rocketdyne S-3D motor producing a thrust of 68 tonnes from combustion of a liquid oxygen/kerosene propellant combination to lift the 50 tonne vehicle to an altitude of 660 km and a range of 2,500 km. The engine bore considerable resemblance to the LR-79-NA-9 adopted for the Thor IRBM and carried a turbopump delivering propellants at the rate of nearly 17,000 litres per minute. The gimbal-mounted main chamber was assisted in the flight control mode by a combined vernier and roll control jet discharging exhaust from the gas generator on the turbopump.

The missile was constructed of aluminium alloy with a stiffened tail section and carried a nose cone attached to the forward end of the propellant tanks with a 27° taper to a tip radius of 30.5 cm. The nose cone was secured by explosive bolts and could carry either a nuclear or high explosive charge in the warhead. By mid-1957, Jupiter had demonstrated its full design range and the twenty nine development flights had been successfully completed by February 1960. The operational variant had been delivered to the US Air Force in August 1958 and service firing trials began in 1959. In 1960 operational deployment got under way and the missile was subsequently sent to Italy and Turkey where up to 60 were installed for border defence of West European countries.

On 13 December 1958 US Army tests got under way with the launch of a South American Squirrel Monkey and after a 15 min flight, the capsule and its contents were lost in the Atlantic Ocean. Again, on 28 May 1959, a live payload was sent on a ballistic trajectory when a Rhesus Monkey, Able, and a Squirrel Monkey, Baker, were sent 2,600 km down the Atlantic Missile Range. Satisfactory recovery preceded confirmation that the test subjects had not suffered unduly from their flight, during which they had experienced punishing accelerations of up to 40 g and 9 min of weightlessness.

Militarily the Jupiter enjoyed a peaceful and undistinguished life, before retirement by the mid-1960's, in favour of home based ICBM's and ocean going SLBM's which were coming into service in large numbers. However, the Jupiter design was used as the basis, and indeed the first stage of, the Juno II space launcher, with 10 such vehicles being launched between 1958 and 1962.

In support of Juno launched satellite missions, the Jupiter was lengthened by nearly 1 m so that with the same 68 tonnes of thrust, the burn duration could be increased from 162 sec to 182 sec. The basic Jupiter IRBM could reach a speed of 14,500 km/hr, but with the longer burn time of the Juno II configuration this was increased to 17,700 km/hr, enabling the upper stages (with a total velocity increment of 11,200 km/hr) to reach orbital speed of 28,900 km/hr. The modified Jupiter IRBM, now designated stage 1 of the Juno II satellite launcher, was 16.84 m long and carried nearly 50.6 tonnes of propellant in the extended tanks. Stage two consisted of 11 solid propellant Baby Sergeant rockets, burning a polysulphide-perchlorate mixture to generate a total thrust of 7.484 tonnes (with each motor developing a thrust of 680.4 kg) from a specific impulse of 220 sec. The 11 rockets were arranged in a ring 96.2 cm in diameter and 1.37 m tall with a combined weight of 454 kg. Stage three was made up from three Baby Sergeant solid propellant rockets, but with each delivering a thrust of 816.48 kg (specific impulse of 235 sec) for a total of nearly 2.45 tonnes and arranged in a cluster inside the 11 rockets of stage two. The diameter of this inner ring was 34.3 cm and the three rockets weighed a total of 136 kg. Stage four consisted of a single Baby Sergeant of the type used in stage three and it delivered a thrust of 816 kg. Height was the same as the rockets in the clustered second and third stages and diameter was 15.9 cm.

In this configuration Juno II was 23.34 m tall, weighed 55.3 tonnes, could lift 50 kg to low earth orbit or send nearly 7 kg to escape velocity. The mode of operation required the first stage to take the upper stages and payload to orbital altitude and a speed of 17,700 km/hr, separate by explosive bolts and fire small deflection rockets which moved the booster to one side of the upper stages thereby avoiding re-contact. The upper stages were situated in a tub which spun all three upper stages and the payload, at a rate of nearly 400 rev/min for stabilization.

Shortly after the separation of the first stage, the nose cone was jettisoned and after coasting for 5 min the second stage fired, which caused the cluster to pull free of the tub. Third and fourth stages fired in rapid succession with stages two to four burning for 6.5 sec each. The rapid fire of the three solid propellant upper stages provided the necessary velocity to reach orbital speed or head for deep space, depending upon the pointing angles and the payload weights. The total height at launch was 23.3 m with a liftoff weight of 54.88 tonnes and the three upper stages were 'borrowed' from the Juno I launch vehicle (see Redstone) which carried a similar configuration.

The first launch of a Juno II came on 6 December 1958 when an attempt was made to send a 6 kg satellite close to the Moon and obtain photographs, in addition to other scientific information. However, the first stage shut down 3.7 sec early, which resulted in the payload (Pioneer 3) falling back to the earth from a distance of 102,319 km, little more than 38 hrs after liftoff. The second attempt on 3 March 1959 was similarly unsuccessful when the Pioneer 4 payload was taken off the nominal trajectory by a longer burn than planned from the second stage. On the third Juno II launch, on 16 July 1959, the vehicle went off course and had to be destroyed by the range safety officer 5½ sec after liftoff. The payload had been Explorer S1, intended to go into earth orbit for solar and magnetospheric studies.

For the fourth launch, on 14 August 1959, Juno II was used in a three stage configuration with the single Baby Sergeant fourth stage rocket removed; the 4.5 kg payload could be placed in orbit with only the first three elements of the launch vehicle. Again, failure in the first and upper stages resulted in the payload ending its days in the Atlantic. Next in line came the Explorer 7 earth orbit launch, on 13 October 1959, with the four stage Juno II placing the payload on station as planned.

Following another Juno II failure, on 23 March 1960, Explorer 8 was put in orbit on 3 November 1960 with another failure on 24 February 1961. The last successful Juno II launch got off the ground on 27 April 1961, when Explorer 11 was put into earth orbit, followed by a failure on 24 May. No further Juno II missions were attempted and the ten planned flights since 1958 displayed a success rate of only 30%.

The extended-tank Juno II formed the basis for the central propellant tank in the Saturn I and IB launch vehicles and the S-3 liquid propellant rocket motor led to design of the H-1 liquid oxygen/kerosene engines used in the Saturn I, IB and Delta launch vehicles, the latter application seeing service into the early 1980's.

Jupiter C:

Based on the Redstone medium range ballistic missile, Jupiter C was developed as a test vehicle for use in evaluating the performance of various nose cone materials. It was necessary to find the most suitable configuration of materials and shapes from which to fabricate thermonuclear warheads that would be fitted to medium range and intercontinental range ballistic missiles then in development and toward this objective Jupiter C emerged with an appearance almost identical to the Redstone. However, the additional energy required to drive test cones back through the atmosphere after ascent into space, necessitated additional stages and these were provided in the form of a ring of 11 Baby Sergeant solid propellant rockets constituting stage two and an inner ring of three Baby Sergeants as stage three.

The configuration had a length of nearly 20 m and a first stage diameter of 177.8 cm. The first stage was basically a lengthened Redstone booster and an uprated main engine, capable of delivering a thrust of 37.6 tonnes. Propellants were a combination of unsymmetrical dimethyl hydrazine/diethylene triamine and, as such, a different type to those used in the basic Redstone. The second stage comprising the 11 solid propellant rockets was 96.2 cm in diameter and 1.37 m tall and, with each rocket providing a thrust of 680.4 kg, total stage thrust was nearly 7.5 tonnes. The third stage was located inside the ring of 11 rockets forming the second stage and comprised three Baby Sergeant rockets uprated to deliver a unit thrust of 816 kg for a combined thrust of 2.45 tonnes. These two upper stages, one within the other, were spun before launch and the rotation rate ensured a spin-stabilized flight path when the time came for them to take over from the first stage.

On an operational flight, the modified Redstone booster, comprising the first stage of the Jupiter C, would lift the upper stages and payload through the atmosphere and into near space, whereupon the second and third stages would fire the payload back down through the atmosphere at high speed in two 6.5 sec sequential bursts. Tests could then be conducted to determine the effects of high speed re-entry on different nose cones.

Work on the project began in 1955 and the first Jupiter C (Composite re-entry test vehicle) was launched on

20 September 1956, sending the payload to a record altitude of 1,100 km and a down range impact distance of nearly 5,500 km. The second flight, on 15 May 1957, carried a 136 kg scaled-down model of the nose cone to be fitted to the Jupiter IRBM (see Jupiter), but it landed off target and was not recovered. On the third flight, 8 August 1957, the payload was accelerated to a height of 600 km and an atmospheric entry speed of 19,300 km/hr. The nose cone came down by parachute 2,140 km from the launch site and within the prescribed 400 m diameter target circle.

This was the last Jupiter C flight, but on 4 October 1957, a modified Russian SS-6 ICBM put the world's first artificial satellite in orbit and when President Eisenhower went on American television to issue comment, he displayed the recovered nose cone of this last mission. US efforts to place an American satellite in orbit were centred on a Navy project (see Vanguard), but in order to enhance the probability of success Wernher von Braun was given the go-ahead on 8 November to convert the Jupiter C into a satellite launcher by adding a fourth stage.

Re-named Juno I, the basic Jupiter C carried a single Baby Sergeant of 816 kg thrust mounted on top of the combined second and third stages. This cluster of three solid propellant upper stages was later applied to the Juno II launcher (see Jupiter) and differed in appearance in that on Juno I they were encased within a protective shroud. Juno I had a total length of 21.7 m and a liftoff weight of 29 tonnes. The satellite launch attempt came on 31 January 1958 and Juno I successfully placed the 14 kg Explorer 1 in a 360 × 2,549 km orbit. Data was returned up to 23 May 1958 and the satellite re-entered the atmosphere and was destroyed on 31 March 1970.

A second launch attempt (Explorer 2) failed on 5 March 1958 and the third attempt, on 26 March, put Explorer 3 in orbit followed by Explorer 4 on 26 July. The last two Juno I launches (Explorer 5 and Beacon 1) failed on 24 August and 23 October. In a total of six launches, Juno I had been successful on three flights. Juno II missions, with the same upper stage configuration mounted within a shroud, began on 6 December 1958. To avoid confusion, it is important to note that most references refer to the Juno I satellite launcher as the Jupiter C, but the name Juno was selected by Dr. William Pickering in November 1957 from the Roman goddess, sister of Jupiter the King among gods.

The Army Ballistic Missile Agency (ABMA) at Huntsville, under Dr. von Braun who developed the rocket, applied a designation system for numbering Redstone rockets, whereby each individual letter of the word HUNTSVILLE represented a separate numeral with the second 'L' deleted for clarity; progressive letters of HUNTSVILLE were assigned numbers one to nine so that 'H' was one and 'E' was nine. The first Juno I, adapted from the basic Redstone, carried the letters UE on the side and readers who may see photographs of the Explorer 1 launch, can decode this to show that it was the 29th Redstone rocket produced, because 'U' and 'E' correspond to two and nine. As a further note of historical interest Juno I was the only space launcher to retire from successful service before NASA came into existence in October 1958. The last launch on 23 October 1958 was a failure.

Lance:

Developed as a short range ballistic missile replacement for the Sergeant, Honest John and little John battlefield tactical missiles, Lance was conceived in 1962 by the US Army Missile Command. The Ling-Temco-Vought Aerospace Corporation received a development and fabrication contract in November and a research, test and engineering supplement was appended in January 1963.

The first firing was in March 1965 and at that time the missile was designed to provide an effective range of between 4 km and 40 km, using storable liquid propellants and guided by an inertial navigation system. By 1966 LTV were working on an Extended Range Lance (XRL) using an improved propulsion system with greatly increased performance capability. This concept replaced the earlier version, with its maximum range of 40 km and employed two concentrically mounted storable liquid propellant rocket motors. In this design the outer concentric rocket provides high thrust boost for launch and initial climb, while the central sustainer continues to operate at low thrust to put the missile on course. This approach had been used with the original concept, but improvements promised to extend the range.

Procurement funds were approved in 1970 and 55 test and training models were produced in 1971 with full production getting under way in that year. The MGM-52C Lance entered service with German based units of the US Army in 1973. Because Lance is designed to fill a support role to the longer range Pershing, mobility is the key to its successful operation in battlefield conditions and the missile is transported on a M688 vehicle which also serves to load it on to the M740 or M752 launcher, the latter being a modified M113 vehicle of the type used for the Pershing.

Lance is 6.1 m long with a diameter of 56 cm and carries four elongated triangular fins at the rear with a span of 1.4 m. The 1.5 tonne missile has a range of up to 120 km, or 70 km with a 450 kg warhead, and uses inhibited red fuming nitric acid/unsymmetrical dimethyl hydrazine storable propellants. The outer, boost, propulsion system delivers a thrust of 19.3 tonnes from the Rocketdyne P8E-9 motor and the central sustainer delivers 2.04 tonnes of thrust. Guidance and control is effected with a simplified inertial system and fluid injection to a single nozzle respectively.

The US Army Lance is equipped with a 10 KT nuclear charge in the 210 kg warhead with which the missile has a range of 120 km. One of the earliest export applications came in 1975 when Israeli forces received the Lance missile as first delivery in an order for more than 100 rounds. The Israeli missile uses a 450 kg warhead carrying the Honeywell XM251 dispenser which releases more than 830 bomblets, each weighing 0.5 kg, on target from a height of 0.8 km. The bomblet spread covers a scatter pattern nearly 400 m across on the ground and would be effective against surface-to-air missile sites.

The US Army were interested in acquiring more Lance missiles to be fitted with terminally-guided-sub-missile (TGSM) warheads. These are free-fall bombs released from a dispenser during descent and retarded in a nose-down attitude by a ballute-type parachute. Infra-red seekers in the nose of each bomb home on to specific targets, such as heat producing vehicles or tanks, and each Lance would be capable of carrying up to nine such bombs per warhead. The German Army has so far ordered 175 Lance missiles and other countries in line for delivery are the UK, Italy, Belgium and Holland. So far the US Army has failed to gain congressional approval for the purchase of additional non-nuclear rounds and all export orders, so far totalling nearly 400, are designed to carry high explosive or bomblet charges in the warhead.

A Lance 2 is under consideration and will probably employ solid propellant propulsion with advanced guidance, control and terminal targeting. The improved missile may appear in service by the mid-1980's and replace existing Lance MGM-52C rounds. Currently, the missile is playing a support role to the longer, 160–650 km, range Pershing and thereby contributes to bombardment potential in the tactical battlefield role from 70 km to 650 km according to specific requirements.

Little Joe:

Developed in 1958 as a solid propellant booster for tests with the Mercury spacecraft, the first US manned space vehicle, Little Joe was designed to take unmanned capsules out of Earth's atmosphere so that Mercury systems could be checked and tested prior to committing the spacecraft to manned flight. Originally conceived as part of the 'High Ride' test phase, Little Joe, as it was re-named, comprised a cluster of four Castor and four Recruit solid propellant rockets, each type delivering a unit thrust of 24.9 tonnes and 14.9 tonnes respectively. The Castors burned for 25 sec and the Recruits for 1.5 sec and in a normal flight two Castors and the four Recruits ignited followed 20 sec later by the remaining two boosters. In other configurations, two of the Castors were removed and all 6 remaining rockets ignited at launch. For less demanding flights, four Pollux solid propellant rockets, delivering 20.4 tonnes each, replaced the Castors.

Whatever the combination, Little Joe contained the solids in a cylindrical structure 9.5 m tall, 2 m in diameter and with four large tail fins spanning 6.1 m. With the Mercury spacecraft on top, height was 16.7 m with a total loaded weight of 18.4 tonnes. Thrust depended on the type of rockets carried and can be computed from the above data (e.g. two Castors and four Recruits generated a thrust of 49.8 tonnes and 59.6 tonnes respectively, the latter burning for the first 1.5 sec only).

The first test, scheduled for 21 August 1959, would take the Mercury spacecraft to altitude so that the launch escape system could be tested, this being a solid propellant rocket mounted to the top of the capsule by a lattice tower and designed to wrench the spacecraft free of a malfunctioning booster. About 30 min before the planned launch time for LJ-1, however, the escape rocket suddenly ignited and whisked the Mercury spacecraft off the top of the Little Joe booster carrying it to a height of 600 m. The next attempt (with a dummy rocket!) used the same Little Joe booster and was successfully accomplished on 4 October 1959, when it fired the Mercury spacecraft to a height of 60 km and a downrange distance of 115 km. About 2½ min into the flight the assembly was intentionally blown up in a rehearsal of the destruct mechanism which would be fitted to Redstone and Atlas boosters in the event that they flew off course and threatened to endanger populated areas – after the escape system had removed the spacecraft.

Re-designated LJ-6, the first flight was followed by LJ-1A on 4 November 1959 in another escape system test. LJ-2 was launched exactly one month later and took Rhesus Monkey Sam on a flight to 30 km followed by separation of the spacecraft, a coast on up to 85 km and 3 min of weightlessness before splashdown and recovery. The next shot, on 21 January 1960, used only two Pollux motors and this time took a female Rhesus Monkey called Miss Sam to a height of 14 km and a speed of 3,200 km/hr, whereupon the escape rocket was intentionally fired to free the monkey and its capsule for a descent and splashdown 18 km away.

On 8 November 1960 the LJ-5 launch ended 16 sec after liftoff when the Mercury escape rocket fired, but the spacecraft failed to separate and the entire assembly plunged back to earth and an inglorious impact. The fifth Little Joe booster, LJ-5A, was a repeat test of LJ-5 and came on 18 March 1961, but problems developed with the precise sequence of separation commands and although the Mercury capsule was successfully recovered, proving that the system worked, it was not deemed a great success.

The last of the 6 Little Joe boosters, LJ-5B, was a further attempt at full Mercury escape system qualification and came on 28 April 1961. However, one of the Castors failed to fire for the first 5 sec and took the capsule on a much lower trajectory than planned.

although good separation and recovery was demonstrated.

Less than eighteen months after the Mercury support flights NASA was planning a Litte Joe II design, which would be used to test the launch escape system on the Apollo spacecraft. The first model was ready by August 1963 and the completely re-designed booster incorporated seven Algol 1-D solid propellant rockets for a maximum liftoff thrust of 141 tonnes. The first test, on 28 August 1963, used a dummy payload to simulate the Apollo it would normally be called upon to carry and was intended as a qualification test of the new booster. The flight reached a height of 7.3 km and a downrange distance of 14.3 km.

The second Little Joe II flight came on 13 May 1964, when a structural mockup of the Apollo was carried to a height of 5.2 km whereupon the booster was intentionally destroyed so that the launch escape system could demonstrate a safe recovery of the command module under conditions of operational stress, which it did to perfection. The parachute recovery system brought the spacecraft back to earth 7½ min after launch and from the 7.3 km altitude that the escape system had boosted the Apollo to when it wrenched free of the Little Joe II. A similar test was conducted on the third Little Joe flight on 8 December 1964 using another boilerplate Apollo model.

The fourth flight, third in support of Apollo, was to have carried the payload to a height of 35 km in 89 sec so that the launch escape system could fire and demonstrate safe recovery of the spacecraft from high altitude. In the event, when launch came on 19 May 1965, the Little Joe II split apart just 25 sec after liftoff at a mere height of 5 km. The launch escape system on Apollo functioned perfectly, retrieving the spacecraft, but denying high altitude test objectives. The final Little Joe II was launched on 20 January 1966, but on this occasion an actual flight-rated spacecraft was used, instead of a mockup, to demonstrate an ability of the launch escape system to return the vehicle in safety from a medium altitude abort. In a successful demonstration of this capability, the fifth Little Joe II sent Spacecraft 002 to a height of 24 km before recovery.

All Little Joe flights had been conducted from the White Sands Missile Range and out of 5 attempts only 1 had been a failure.

Little John:

The US Army Materiel Command began development of the Little John tactical support weapon in 1956, so named because it serves as a small scale version in design and role to the Honest John missile. The solid propellant weapon is highly mobile, only 4.4 m long and 31.7 cm in diameter, and can be transported by helicopter or jeep.

By 1961 two battalions were each equipped with four launchers. The 354 kg Little John is spin-stabilized by four square fins at the rear and the warhead can carry high explosive or nuclear charge across a range of 16 km. The missile was being phased out by the mid-1970's in favour of the Lance.

Minuteman:

In a major shift to strategic planning the US Air Force Strategic Air Command prompted and administered development of a solid fuel, silo-launched ICBM called Minuteman in the late 1950's and early 1960's. The missile's genesis lay in the recognized superiority of the US Navy's Polaris programme, whereby solid propellant missiles were placed in vertical launch tubes on nuclear powered submarines, effectively converting them into moveable underwater arsenals, very difficult to detect and almost impossible to track.

The Air Force, with a profound feeling of exposure, sought ways to bury their own missiles beneath the ground and if not make them undetectable, at least insulate them from destructive impacts. The Titan I and Atlas A to D models required a launch site on the exposed surface of an open land area and with fuelling and preparation times in excess of the warning limit, it was all too obvious that these first generation ICBM's would be destroyed before they could be fired in retaliation. Atlas E and F models went some way toward improving the situation in that they could be emplaced in vertical underground launch silos and reside protected until fuelled and sent on their destructive trajectories.

Titan II, with its storable liquid propellants, could be similarly silo-launched, but the enormous complexity of fuelling the missiles and carrying a sophisticated system of plumbing aboard the vehicle rendered it less efficient than desired. In any event, Titan was a heavyweight ICBM carrying an enormous procurement cost and could only be efficiently used as a nuclear armed 'blockbuster'; Atlas had compound problems of non-storable propellants and a heavyweight payload capability which made it even less adaptable to improvements along the path required by the Air Force. Consequently, a work group was set up to define a totally new missile design which could incorporate all the desired objectives and headed by Colonel Edward N. Hall, Weapon System Q emerged in September 1957.

The new missile would have to be silo-launched, carry storable propellants, have a range of at least 9,700 km and be sufficiently cheap to allow procurement of several hundred rounds. Unlike Atlas and Titan the new concept envisaged a relatively low yield warhead and because it would be installed in great numbers provide a saturation threat. The sheer magnitude of the number involved would require almost all the Soviet missile force to be assigned silo targets in the hope that the opposing forces could be diverted from civil and industrial objectives.

As the design emerged it was dubbed Minuteman after the American guard that boasted a 1 min readiness for combat; the missile would improve still further on its optimistic title. By 15 September 1959, the first Minuteman tests began in earnest when the live stage 1 assemblies were fired, tethered, from silos at the Edwards Air Force Base, California, and the first operational missile was fired 6,920 km away from Cape Canaveral on 1 February 1961 in what has been proudly claimed to be the most successful maiden flight of any missile programme.

The Boeing Company had received the Minuteman assembly contract on 10 October 1968 and played a creditable role in bringing the system to operational status. After an unsuccessful attempt to launch a Minuteman from an underground silo, the first successful flight from the sub-surface launch pad flew away from Cape Canaveral on 17 November 1961. Less than five months later, the first missile was rolled out from the Boeing assembly facility at Hill Air Force Base in Utah.

The LGM-30A Minuteman I carried many of the then new improvements in guidance, control and warhead design and emerged as a 29.48 tonnes three stage solid propellant missile with a 90.72 tonne thrust stage 1 solid propellant motor firing through four gimballed nozzles for guidance and control. These were by far the largest gimballed solid propellant rocket nozzles fabricated at that time. The Minuteman was 16.38 m long with a first stage diameter of 187.9 cm. Second, third and warhead stage diameters were progressively smaller and the missile could achieve a speed of 24,130 km/hr and a range of 8,370 km.

When the first two Minuteman flights were declared operational on 11 December 1962 at Malmstrom AFB, the missiles were designed to carry the Avco Mk. 5 warhead with a nuclear charge of 1 MT yield. The missiles were contained within silos 24.38 m deep and 3.66 m in diameter, steel-lined and with two adjacent equipment rooms 8.5 m below the surface. Launch control facilities were similarly buried underground and arranged so that each twin-chamber launch control position had authority over 10 missile silos.

By June 1965 the initial planned deployment of 800 missiles had been declared operational. These comprised five separate Wings, each of which had either three or four Squadrons with each Squadron totalling 50 missiles. Each of these Squadrons were divided into five Flights with a further breakdown into 10 individual silos under the control of one Launch Control Facility per Flight. Thus there were, in all, 80 Launch Control Facilities serving the five Wings, with two missileers manning each one together on 12-hr shifts. Wing 1 was located at Malmstrom AFB, Montana, Wing II at Ellsworth AFB, South Dakota, Wing III at Minot AFB, North Dakota, Wing IV at Whiteman AFB, Missouri, and Wing V at Warren AFB, Wyoming. Wings I to IV operated 3 Squadrons, each with five flights and a total of 50 missiles under their command, for a total of 150 Minutemans per Wing. Wing V had 4 Squadrons with a total of 200 Minutemans.

Wings I to IV operated the LGM-30A Minuteman while Wing V, the last to be deployed, had a slightly modified 17.04 m long Mk. 1 designated LGM-30B. This had a range of 8,850 km and could carry the improved Avco Mk. II warhead with a 1MT yield.

The 80 Launch Control Facilities supporting the 800 silos are separated by at least 18 km and each silo is at least 7 km from its neighbour. This ensures minimum loss of operational capability, since only a direct hit would disable each silo with its heavy concrete doors and the 800 silos and 80 Launch Control Facilities would force a hostile opponent to dedicate 880 ICBM's to eradicating the land-based component of the US strategic nuclear strike force, since a separate ICBM would have had to strike each silo cover and its grouped launch facility. There are alternative methods of launching the Minuteman missiles in the event a Launch Control Facility is destroyed.

By 1964 Boeing had produced an improved Minuteman, called the LGM-30F Mk. II and on 24 September that year, a flight from the then Cape Kennedy, carried the missile successfully down the Atlantic Missile Range on its first attempt. On 18 August 1965 an operational demonstration flight carried the Minuteman II away from a Vandenberg AFB silo and qualified it for service use. With a 34% increase in propellant capacity, an improved guidance system capable of selecting pre-programmed targets en route and an eight-fold increase in accuracy, the missile began to replace Minuteman I's at Wing IV, Whiteman AFB, in February 1966.

By 7 December 1966 a new Wing, number VI, had been set up at Grand Forks AFB, North Dakota, with 3 Squadrons of 150 missiles divided into a total of fifteen Flights each operating 10 silos. By 21 April 1967, a fourth Squadron of 50 missiles had been activated at Wing I, Malstrom AFB, bringing the total Minuteman I and II force to 1,000 missiles. Wings I and V now had 200 missiles each, with 150 under the control of Wings II, III, IV and VI.

Minuteman II is 18.24 m long, 187.9 cm in diameter and possesses a launch weight of 31.75 tonnes. The effective range is in excess of 10,100 km and at the time of initial deployment, the missile carried a single Avco Mk. II warhead with a MT yield. The first stage has a thrust of 90.7 tonnes with a 27.5 tonne thrust second stage and a 16 tonne thrust third stage. The first stage uses a combination of ammonium perchlorate and polybutadiene acrylic acid propellants and the second stage adopts polyurethane and ammonium perchlorate. The third stage uses a nitrocellulose, nitroglycerine and ammonium perchlorate mixture.

On 16 August 1968, the first of a new and very much modified Minuteman, the LGM-30G Mk. III, was successfully fired from Cape Kennedy. By February 1969, the last of the original LGM-30A missiles had been removed from Wing I and the total Strategic Air Command Minuteman inventory now consisted of the LGM-30B and the LGM-30F. Minuteman III has the same first and second stages as the Mk. II, but the third stage is considerably improved with a new enlarged motor and a much greater payload capability. The missile is 18.24 m long, 1.8 m in diameter and has a launch weight of 34.47 tonnes.

With improvements to the third stage, in the form of a fluid injection control system to the single efflux nozzle, the warhead can be carried a greater distance and the Minuteman III range potential is in excess of 13,000 km with a re-entry vehicle capable of ensuring high target accuracy. On 14 December 1970 a Minuteman III was launched from Cape Kennedy in the last such firing from that site and the facility was closed down after nearly 10 years of Minuteman tests; by this time more than 340 Minuteman missiles had been fired from Cape Kennedy and the Vandenberg AFB.

The first Minuteman III Squadron was set up at Wing III, Minot AFB, North Dakota, on 29 December 1970 and full force modernization was completed on 8 July 1975 at which time Strategic Air Command reached the planned total of 450 Mk. II's and 550 Mk. III's. Today the Minuteman II carries the Avco Mk. IIC re-entry vehicle carrying a 1 MT thermonuclear warhead which is hardened against electro-magnetic pulse effects and can demonstrate a target error of only 550 m. Minuteman III carries a Mk. 12 manoeuvrable independently targeted re-entry vehicle with 3 nuclear charges each of 170 KT yield. The target error probability is 370 m.

Strategic Air Command is in the process of fitting the improved Mk. 12A which can carry 3 warheads each with a yield of 350 KT to a target circle probability claimed to be less than 200 m. It is expected that about 55 Minuteman III's will have this improved re-entry vehicle. All Mk. III's, however, carry a Propulsion System Rocket Engine capable of dispensing decoys and warheads in a variety of combinations to confuse radar and upset anti-ballistic missile activities.

With each of the 450 Minuteman II's carrying a single 1 MT warhead and the 550 Minuteman III's armed with 3 warheads of at least 170 KT each, the total inventory permits operational use of 2,100 warheads broken down into 1,650 warheads up to 400 KT and 450 of 1 MT yield. Added to this are the 54 Titan II, 5–10 MT, warheads to provide a total land-based ICBM inventory of 1,054 launchers and 2,154 warheads. Wing establishment is the same as that mentioned earlier with 200 missiles at Wing I, 150 at Wing II, 150 at Wing III, 150 at Wing IV, 200 at Wing V and 150 at Wing VI.

Possible future use of the Minuteman includes a US Air Force proposal to exploit the silo-launched mode for placing military satellites in orbit during periods of hostility when the existing space launch complexes at Cape Canaveral and the Vandenberg AFB may be destroyed. In this way the Air Force retains the option of putting payloads in space when all surface launch sites are disabled. The enhanced performance capabilities of the Minuteman III would enable it to place low-weight packages in earth orbit of the type essential to long distance military communications, space-borne early-warning tasks and navigational positioning, such as would be required for cruise missiles travelling to their respective targets.

MX:

The Air Force Rocket Propulsion Laboratory and Hercules Incorporated are studying the possibility of advanced development of a missile designed to replace Minuteman ICBM elements in the late 1980's. While Minuteman deployment in the early 1960's provided an effective capability for retaliatory strike, giving the United States protection against force depletion by surprise attack, the improved accuracy of Soviet ICBM re-entry vehicles has rendered the existing inventory less effective.

The new generation of Soviet ICBM's have a capacity for destroying individual silos and within the next decade will be able to effectively neutralize a large percentage of the land-based ICBM stock. Because of this, the Department of Defence considered two possible modes of deployment, both of which were aimed at reducing the ability of the Soviet Union to knock out individual missiles before they were launched.

In one concept the missile would be placed within an underground tunnel system containing a few silo stations with access and exit to and from each one. From the surface it would be impossible to determine which particular silo contained the missile and as the missile would be moved from silo to silo via the underground tunnel, its movement could be shrouded from any observer on the surface. The connected silos would be separated by sufficient distance to ensure that the concrete covers could only be disabled by a thermonuclear detonation that would leave the others intact. Thus, a great number of warheads would be required to strike each silo and thereby ensure the destruction of the MX missile.

The second proposal considered by the Air Force envisaged an air-launched ballistic missile carried within a large transport aircraft and pulled rearward horizontally from its canister through large doors with the aid of a drag parachute. The missile would then ignite and pitch up to begin its guidance programme enabling it to set course for the target. In 1974 several tests were performed in air-drop exercises aimed at simulating the concept, but the MX programme has centred on the underground launch mode as being more practicable, strategically more desirable and with a higher probability of success.

The new MX system is a mobile concept with a transporter/launcher moving from site to site, each site containing the launch shelter necessary to get the missile on course to its target. The missile leans heavily on developments in guidance and work has been given priority on elements such as the Advanced Inertial Reference Sphere. MX components have been under test since late 1976 and the propulsion system uses a more efficient solid propellant motor configuration with a new extendable nozzle shaping the exhaust plume so as to extract maximum performance from the potential system capabilities. Also, tests are being conducted which will evaluate the effects of explosive detonation on shelters and system elements. The new missile will weigh about 75 tonnes, have about twice the throw-weight capability of Minuteman and be sized to a diameter of about 2.3 m. The MX system is expected to enter operational service in the mid-1980's, to partially replace existing Minuteman rounds.

Nike:

The Nike series of sounding rockets were developed from the anti-aircraft missile of the same name, itself the first guided missile to be put into series production. The Nike originated at the Hercules Powder Company for US Army Ordnance in 1945 and used a nitric acid/gasolene liquid propellant with a solid rocket booster. As a sounding rocket it has been used with Cajun, Apache, Malemute and Tomahawk upper stages, names derived from Indian association with the State of Louisiana which contained the fabrication facilities.

The Nike-Cajun (Cajun being a group of Louisiana inhabitants of mixed blood) was a derivative of the Decon motor developed as a solid propellant rocket during World War II. It could carry a 35 kg payload to a height of 160 km. Nike-Apache provided a 6 sec second stage burn compared with the 4 sec duration of Cajun and could take 34 kg to a height of 210 km. Nike-Cajun and Nike-Apache had the same appearance and dimensions. Tomahawk was a solid propellant rocket 2.7 m in length which could, by itself, accelerate a 20 kg payload to 160 km. The Nike-Hawk adopted the US Army Hawk anti-tank missile as second stage and the first flight came in May 1974, with the promise of a payload capability which could take 90 kg to a height of 160 km. On its own the Hawk could lift 90 kg to a height of 57 km or send 45 kg to 80 km. The Hawk is 2.5 m long and 36 cm in diameter, with three tail fins inclined rearward.

Also developed in 1974 was the Nike-Malemute, again the basic Nike as the first stage with the Malemute, named after Alaskan inhabitants of the same title, providing a 90 kg lifting capability to 500 km. All upper stage variants used solid propulsion designs and one version used the four-stage Argo D-4 with the basic Nike first stage (see Argo).

Pershing:

Developed and built by the then Martin–Orlando Company of Baltimore, Pershing is a medium range ballistic missile conceived in the mid to late-1950's as a replacement for the Redstone MRBM. Development work began in 1958 with the objective of applying a measure of mobility and quick response time which would enhance the military value of Pershing over the fixed-base Redstone.

Martin–Orlando were awarded a development and fabrication contract in 1959 and the first test firings began a year later. The extensive test and qualification phase resulted in an operational deployment in 1964 to replace Redstone missiles emplaced by US Army and West German forces in Europe. The MGM-31A Pershing has emerged as a two-stage solid propellant MRBM with a length of 10.5 m and a diameter of 101.6 cm with a sheet steel airframe.

The configuration has a long conical nose section terminating in a sharp tip, with four triangular fins at the base and four square stub-fins about one-third along the length toward the nose. Guidance is by inertial reference with exhaust deflection in the first stage and aerodynamic control via the four stub-fins for the second stage. The guidance and stabilization system uses the Bendix Eclipse-Pioneer system and the missile can carry either a high explosive warhead or a nuclear charge of 60–400 KT yield. The first stage is powered by a Thiokol XM-105 solid propellant motor delivering a thrust of 12.1 tonnes and the second stage consists of a Thiokol XM-106 producing 7 tonnes of thrust, with both stages using radar correlation with the inertial guidance system.

Pershing is designed to satisfy tactical battlefield requirements in addition to medium range bombardment against rear supply units and has a variable range of between 160 km and 650 km selected at the discretion of the operator. For training purposes a special MGM-31B version was developed which is in all respects identical to the version outlined above.

Mobility was the key element in Pershing design and the missile is transported by four modified M113 light armoured personnel carriers and designated XM474. The missile is broken into four elements: the erector/launcher carrying the missile, the warhead, the communications equipment and the fire control/power supply modules. The four elements are carried in the four tracked vehicles and can be rapidly assembled for quick-fire launch. The high degree of mobility is enhanced by the capability to roam 320 km moving 60 km every hour, cross shallow water and climb steep inclines. At other times Pershing can be moved, by fixed or rotating wing aircraft, to or from battle areas.

In 1966 Martin–Marietta, previously Martin–Orlando, began development of a new mobility system whereby the missile is supported by four wheeled vehicles based on the XM656 2.3 tonne truck. This enhanced rate of mobility, preparation and firing, became standard from 1970 and uses the IEL (Improved Erector-Launcher), essentially an articulated truck/trailer combination, which also carries the missile and its warhead, a programmer and test vehicle, a firing control vehicle and a radio command vehicle with inflatable antenna. The four-vehicle combination is considerably more efficient than the earlier MX474 based system and is designated Pershing 1A, although the design of the missile itself remains unchanged.

During 1974–75, operating units in the US and West German Army's were equipping their Pershings with the new Azimuth Reference System, replacing the need to survey the launch site and so enhancing the launch response time accordingly. Pershing, fired from its near vertical launcher, can be aggressive within minutes of arriving at a forest clearing or any suitable launch area.

By 1977 Martin–Marietta were well into development of the Pershing II, which like the 1A is more an uprating and refinement of operational capability with the same basic missile and plans to incorporate terminal guidance in the warhead, which will improve accuracy and reduce peripheral effects of a nuclear blast marginally off target. Also, the Goodyear radar area-correlation guidance system will be installed, which permits the missile to compare the approaching terrain with pre-recorded images of the target area. Further refinements may come in the form of an earth-penetrator warhead, which increases the blast effect at the target, but restricts lateral blast effects from a nuclear charge.

Pershing is expected to remain in front line service until the 1990's.

Polaris/Poseidon:

Development of the first US submarine-launched ballistic missile (SLBM) originated when the Navy broke away from joint development of the Army sponsored Jupiter IRBM project in December 1956. A Navy Ballistic Missile Committee was formed on 19 December to take over the direction of that service's interest in solid rocket missile operations which, it was envisaged, could be mounted from surface vessels and then submarines. As early as April 1956, a Navy industrial contract had sought answers to problems associated with launching a long range missile from a submarine and the company involved, the Lockheed Aircraft Corporation, recommended a two-stage solid propellant concept that would emerge as the definitive Polaris design.

On 12 January 1957, the Polaris programme was officially authorized whereby the recommended Lockheed missile would be placed aboard specially built nuclear-powered submarines effectively providing an operational Fleet Ballistic Missile (FBM). The sheer pace of programme definitization and progress was, and still is, unparalleled in rocket development history and by March 1957, the specification for Polaris had been drawn; three months later the design of the new type of submarine necessary for launching the missile had been completed and on 9 December the project was given accelerated blessing by the Secretary of Defence.

Construction of the first three submarines, named George Washington, Patrick Henry and Theodore Roosevelt, got under way a month later, just one year after the project's official go-ahead. From the Office of the Chief of Naval Operations Guided Missile Division came a classified memorandum in February 1958 outlining the benefits to accrue from adoption of a submarine-launched ballistic missile fleet. The then emerging concept of a storable propellant contained within a weapon system was recognized to have decided advantages over the conventional systems, using non-storable fuels and launch readiness was assured from the moment of emplacement. Also, the roaming Polaris armed submarines would pose a serious threat from unknown directions and force the Soviet strategists to develop a comprehensive 360° alert network at considerable expense.

The Fleet Ballistic Missile would be a continually moving target, but one that could not be defined in advance, if indeed its location was determined at all. Being less vunerable than land based systems, the FBM can be deployed throughout half the world's surface area, at undetermined positions, and remove the need to negotiate land rights on the US continent or abroad, or to guard against political reversal on foreign territory supporting US or NATO arsenals.

The first Polaris, designated AX-6, was set up for a test launch on 24 September 1958, but the attempt was unsuccessful and the first effective demonstration came on 20 April 1959, when AX-6 flew 483 km as precursor to the more advanced A1X tests. The first Polaris flight came on 7 January 1960, six months after the SSBN George Washington had been launched (on 9 June 1959). The submarine was commissioned in December and on 20 July 1960 submerged for the first underwater Polaris launch. The following November the George Washington slipped its berth, carrying 16 Polaris missiles and began the first operational cruise mission less than four years after the project officially got under way.

The UGM-27A Polaris A1 was nearly 8.69 m long, 137.16 cm in diameter and weighed nearly 12.48 tonnes. The first stage had a thrust of 36.23 tonnes and used a polyurethane ammonium perchlorate solid propellant as did the second stage, with both propulsion systems manufactured by the Aerojet-General Corporation. Guidance and control had been a problem due to the comparatively unstable nature of the launching platform and considerable effort by the Navy and a North American Autonetic Division/Sperry team in refining the Ship Inertial Navigation System, ensured that the motion of the submarine would be accurately displayed as a bias in the Polaris guidance system.

Westinghouse and the Massachusetts Institute of Technology developed the missile's launch programmers and advanced the concept whereby each missile would be ejected from its vertical launch tube on the submarine by high pressure gas, literally shooting it to the surface where the first stage would ignite and immediately employ its inertial navigation system to control the flight trajectory and fly to the target. Much of the development in the Ship Inertial Navigation System came from the Army's work on the Jupiter IRBM guidance platform and was a very real product of the co-operative work undertaken by the Navy, when in 1956 it studied Jupiter as a possible answer to the service's requirements.

The Polaris A1 could provide a range of 2,220 km carrying a Lockheed warhead with a 500 KT yield. The first five SSBN vessels were of 6,270 tonnes displacement, had a length of 116 m and carried the Polaris A1. The first of these, the George Washington, had set sail for duty in November 1960, the same month that the first of five improved SSBN's was launched, represented by Ethan Allen with a displacement of 7,730 tonnes, a length of 125 m and a new hull design.

In October 1961 the first UGN-27B Polaris A2 was successfully fired from a submerged submarine. The A2 had a length of 9.45 m, a diameter of 137.16 cm and a launch weight of 13.6 tonnes. The missile had a range of 2,780 km, an improvement of 260 km on the A1, and in May 1962, the first of 31 Lafayette class SSBN vessels was launched. These had a displacement of 8,120 tonnes, a length of 129.5 m and followed the 10 earlier vessels in production. On 7 August of the same year the first UGM-27C Polaris A3 was successfully launched followed by a submerged test on 26 October 1963. The A3 had a length of 9.52 m, a diameter of 137.16 cm and a launch weight of 15.6 tonnes, but with improvements in the second stage, which now housed a nitrocellulose-nitroglycerine-ammonium perchlorate propellant mixture. The missile demonstrated a range of 4,630 km, representing a 1,850 km increase over the A2. The Polaris A3 was deployed from September 1964 and by October 1965 all A1 models had been withdrawn in favour of the A2 and A3 after less than 5 years of service.

By the end of 1967 the SSBN fleet had been brought up to strength with 5 vessels of the George Washington class, 5 of the Ethan Allen class and 31 of the Lafayette class. Each submarine had 16 Polaris missiles located in vertical firing tubes aft of the sail. Of the 41 vessels, 13 were equipped with the A2 and 28 had the A3 for a total of 656 missiles. Operating bases were used at Holy Loch in Scotland, Rota in Spain, Charleston on the continental United States and Apra Harbour on Guam Island in the Pacific. The US Navy built up an operating procedure whereby each SSBN could fire 14 of its 16 missiles all of the time and 16 for 95% of the time.

In December 1962, the then President of the United States, John F. Kennedy and the then UK Prime Minister, Harold Macmillan signed a contract whereby the US Navy would provide missiles under the Polaris Sales Agreement. The first two Polaris A3 equipped Royal Navy submarines, HMS Resolution and HMS Renown, became operational in 1968 followed by Repulse and Revenge in 1969. All four submarines are of the Lafayette class and operate out of Faslane on the Clyde in Scotland. The Royal Navy ensures that 50% of the Fleet is operationally available at any one time and with each submarine carrying 16 missiles, the service maintains the only 64 thermonuclear launchers controlled by the United Kingdom; the Royal Air Force relinquished its role of nuclear deterrence by missile in 1968.

Production of Polaris missiles ended in 1968, after some 1,409 rounds had been delivered. By 1969 the US Navy inventory of 13 SSBN vessels equipped with Polaris A2 and 28 with the A3 began to shift as modifications were made to the submarines to accept the second generation SLBM: Poseidon. By 1971 Poseidon development had introduced the missile to operational deployment, using the specially adapted launch tubes of the existing SLBM submarine fleet, and gradually moved toward a planned reduction in the Polaris inventory to just 10 submarines carrying 160 Polaris A3 missiles. The other 31 submarines would then be fully equipped with Poseidon.

In 1971 and 1972 the US Navy began to fit its Polaris A3 with a new Lockheed multiple re-entry vehicle which could carry 3 nuclear charges, each with a yield of 200 KT; the A2 with, less performance, retained the single 500 KT warhead. Later, the Royal Navy also equipped their 64 Polaris missiles with the Lockheed triple warhead re-entry vehicle. Because the three charges carried by each missile would impact in a cluster only 800 m apart, it is not unusual to count them as separate warheads. This is the MRV (Multiple Re-entry Vehicle) and unlike independently targeted warheads which move considerably away from each other before detonation, do not rightly constitute a division.

In 1974 the Royal Navy began a Polaris Improvement Programme in which it equipped its Polaris A3 fleet with independently targeted warheads carrying 6 separate charges of 40 KT yield each. By 1978 the programme was completed and the British Polaris SLBM fleet carries 64 launchers and a total of 384 warheads, albeit each one with a low yield. All 6 warheads per missile can separate by up to 70 km and so are considered as separate numbers in the total count, unlike the simpler and less sophisticated MRV system outlined above.

Meanwhile, the US Navy was progressing with a run-down in the numbers of Polaris missiles, begun in 1971 during Poseidon build-up, and by 1978 had established the SSBN fleet at 10 submarines equipped with the Polaris A3 and 31 with Poseidon. The Polaris A3 still carried a re-entry vehicle with 3 warheads of 200 KT yield and a target probability claimed to be 900 m. The US Navy has established its 160 Polaris missiles in the 10 George Washington and Ethan Allen class vehicles; Poseidon has gone into the Lafayette class with modifications.

In 1964 the then US President Lyndon B. Johnson, authorized a go-ahead for the second generation Poseidon SLBM. The new missile would be larger than Polaris, yet be capable of using the same submarines with modified launch tubes. From the beginning, a mixed Polaris/Poseidon fleet was envisaged and by 1966 it had been agreed that 10 submarines would retain Polaris with a gradual build-up to 31 equipped with Poseidon. The first test launch was successfully accomplished on 16 August 1968.

On 31 March 1971, the USS James Madison went to sea with the new UGM-73A Poseidon C-3, originally called Polaris B3. The first submerged launch had been performed on 3 August 1970 and during the following year 16 test flights were accomplished from Cape Canaveral. In 1973 a Poseidon Operational Test Programme showed up several deficiencies which were successfully circumvented during the following two years. By 1978 all 31 SSBN submarines scheduled to be fitted with the Poseidon C-3 had been declared operational, joining the 10 existing Polaris equipped submarines.

The missile is 10.36 m long, 188 cm in diameter and weighs 29.5 tonnes at launch. The first stage is powered by a Thiokol/Hercules solid propellant rocket and the second stage adopts a Hercules solid propellant unit to provide a range capability of 4,630 km, with double the throw-weight capacity of Polaris A3. With a Mk. 3 multiple independently targeted re-entry vehicle, carrying 10 separate warheads of 50 KT each, the missile can reach targets up to 5,200 km away or with 14 separate warheads of 50 KT each, a distance of 4,000 km. The preferred configuration of the entry vehicle carries 10 separate 50 KT warheads in the nose and this is the configured deployment as of 1978.

The 31 Poseidon submarines carry a collective total of 496 launchers (16 per submarine) with a total of 4,960 separate warheads (160 per submarine). The multiple independently targeted re-entry vehicles provide a probable target accuracy of only 550 m. Altogether, the US SLBM fleet operates 41 submarines carrying 656 missiles (Polaris and Poseidon) grossing 5,120 warheads in the 50 to 200 KT range. It should be noted here that although each Polaris missile carries 3 200 KT warheads in a manoeuvrable re-entry vehicle, they are classed as one warhead because of the minimal 800 m separation at contact with the target; the manoeuvrable re-entry vehicle (MRV) readjusts the trajectory up to the point of warhead release, whereas the manoeuvrable independently targeted re-entry vehicle (MIRV) fitted to Poseidon, releases its separate warheads sequentially, so that they fly, independently, to targets many tens of kilometres apart.

Redstone:

Developed in response to growing requirements for a US Medium Range Ballistic Missile, Redstone was designed and built by the Army Ballistic Missile Agency at Redstone, Alabama. Wernher von Braun had a considerable contribution on Redstone and the Redstone Arsenal, so named because of the soil in that area, later became the Marshall Space Flight Centre. ABMA, then called the Ordnance Guided Missile Centre, moved to Redstone in 1950 and on 8 April 1952 the project for a US MRBM was officially named, 18 months after work began on the design.

Basic objectives initially centred on a missile capable of placing a useful warhead accurately on a target 800 km from the launch site, but with pressure building up as a result of the Korean War, the requirements were changed and a battlefield weapon with a range of no more than 320 km was deemed most urgent. By this time design details for the Redstone had matured considerably and, in order to save time and reduce costs, the liquid propellant motor originally designed for the Navaho cruise missile, formed the basis for the Redstone propulsion system. With the range requirement reduced, the missile would be capable of carrying a nuclear warhead and this improved its potential application to military needs.

When the MRBM emerged it was about 19.2 m long, 177.8 cm in diameter and carried a single 35 tonne thrust rocket motor. Of single stage design, Redstone used a liquid oxygen/ethyl alcohol propellant combination, with the fuel consisting of 75% ethyl alcohol and 25% water; in the stage design the liquid oxygen tank was located to the rear of the fuel tank. Aerodynamic control was effected from four movable vanes on the forward section below the nose cap and warhead and four fixed fins on the tail supporting a single movable vane each. Vector control was provided by four vanes in the exhaust flow and the deflectors were moved on pivots, located on the inner face of the aft fins. Guidance equipment and electronics were carried on the forward face of the fuel tank, immediately below the payload.

Redstone was supported on a pivoting, circular stand with a cone-shaped exhaust deflector in the centre. The entire configuration of the test stand was very like that used by the V-2 of German origin and reflected influence from the earlier design team in the Redstone missile. In flight, the missile would burn for 130 sec and reach a speed of 5,300 km/hr to travel a downrange distance of 320 km. The first launch was performed on 20 August 1953 and the 7,300 m flight began the Cape Canaveral test series that would culminate in quantity production for the US Army.

Between 1953 and 1958 a total 37 research and development flights were made; Redstone Arsenal built 16, and the remaining 21 were constructed under contract by the Chrysler Corporation. The missile entered field service in Germany in June 1958 and continued in this role up to the early 1960's when it was replaced by Pershing. Conceived in 1950, Redstone was the first US MRBM and drew heavily on the practical experience of V-2 engineers, the prominent member being Wernher von Braun. The missile, although achieving only moderate fame as America's first real attempt at a reliable medium range ballistic missile, provided a thoroughbred from which grew many of the early developments in support of an emerging US space programme: Jupiter C, a Redstone adaptation originally designed to test re-entry warhead nose cones, first flew in 1955 and achieved fame as the first US satellite launcher when the fourth model (re-named Juno I) put Explorer I in orbit on 31 January 1958 (see Jupiter C); Jupiter A, a completely re-designed Redstone developed as an IRBM between 1956 and 1958 and later adapted as a satellite launcher, when it was fitted with upper stages and became Juno II (see Jupiter), itself achieving recognition as the launcher which first sent a US payload past the Moon.

Again, in 1957, Redstone was proposed as the precursor step to a new concept, whereby eight Redstone rockets would be clustered round a single Jupiter A stage to form the first stage of a space launch vehicle capable of lifting payloads of 10 tonnes to earth orbit. This was called Juno V, later re-named Saturn I, and the basic Redstone (which inspired Jupiter A) was the direct ancestor of the Saturn I and IB family.

Probably the most direct and prominent use of a Redstone was in its application to, and support of, Project Mercury, the first US manned spacecraft. Although the Atlas ICBM was selected as the only launch vehicle capable of lifting Mercury into orbit with its human occupant, Redstone was used to boost the spacecraft on ballistic trajectories which took it out of Earth's atmosphere on tests in 1961 and this significantly contributed toward the Mercury test phase, proving that the tiny conical vehicle could sustain life in a vacuum and safely return a man through the atmosphere.

The idea required a Redstone, chosen because of its own comprehensive test programme and proven reliability, to carry a Mercury spacecraft on top of its propellant tanks in the location normally reserved for the warhead. In a flight lasting 15 minutes, Redstone would boost the spacecraft to a height of more than 160 km, separate the Mercury and tumble back down toward the earth while the manned capsule itself re-entered the atmosphere, protected by its heat shield to an Atlantic Ocean splashdown. This would qualify the spacecraft prior to an orbital attempt with a modified Atlas ICBM. To accomplish this task the Redstone MRBM was extended by 1.8 m so that more propellant could increase the burn time to 150 sec and increase the speed and altitude. About 800 engineering changes were necessary to qualify the booster for manned flight, but the Redstone A-7 was basically the same as that used by the standard Redstone. In the Mercury–Redstone (MR) configuration the assembly was 25.3 m tall and weighed more than 29.9 tonnes.

The first launch attempt came on 21 November 1960, but seconds after the ignition the Mercury escape rocket (a device carried by all Mercury vehicles to lift the capsule free of the booster if problems developed early in the flight) suddenly fired off for no apparent reason and the Redstone settled back on to its pedestal. The booster used for this test had been a modified Redstone MRBM, rather than the fully developed Mercury–Redstone vehicle and it was felt that the lighter propellant tanks, in decreasing the all-up weight, had provided too high a liftoff acceleration thus causing the anomaly.

The ten centimetre flight of MR-1 was followed by a second attempt, this time with a fully developed Mercury–Redstone booster, on 19 December 1960 and the MR-1A launch achieved a speed of 7,813 km/hr taking the Mercury capsule to a height of 211 km and a range of 378 km at splashdown. The next test, MR-2, was made on 31 January 1961 and took a Chimpanzee Ham on a flight to 249 km and a speed of 8,100 km/hr before separating the capsule, which came down 676 km from the Cape Canaveral launch pad. A further test, MR-BD (Booster Development) was performed with an empty spacecraft, like MR-1 and -1A, on 24 March 1961, where an altitude of 185 km and a range of 500 km was achieved, but this time without spacecraft separation and recovery; this was merely a final qualifying mission for the Redstone and did not include any spacecraft test objectives which necessitated its return intact.

On 5 May 1961, MR-3 successfully took astronaut Alan B. Shepard on a 15 min 22 sec flight into space. Maximum altitude was 186.2 km, speed at burnout was 8,304 km/hr and the capsule came down into the Atlantic 486 km from the launch pad. Although suborbital, with only minutes of weightlessness, an American astronaut had been into space. The final shot was successfully flown on 21 July 1961, when astronaut Virgil I. Grissom rose to a height of 190 km and a speed of 8,545 km/hr to splash down 488 km away. The flight lasted 15 min 37 sec and although the capsule sank after the astronaut had been recovered, the mission was so successful that plans for MR-5 and MR-6, repeat flights similar to the first two manned missions, were cancelled.

Saturn I/IB:

In April 1957 the US Army Ballistic Missile Agency (ABMA) studied the possibility of securing a heavy launch capability by clustering existing rockets together, so that large payloads could be sent into space. It is important to remember that at this time the only development programme associated with placing objects in orbit was the US Navy three-stage Vanguard, still 6 months away from its first flight, capable of putting 11 kg in earth orbit and with a first stage thrust of 12.7 tonnes.

The ABMA, under the enthusiastic tutorship of Dr. Wernher von Braun, head of its Development Operations Division, proposed a cluster of Jupiter and Redstone rocket stages, fitted with modified MB-3 motors of the type used in the Thor IRBM, to provide a first stage thrust of 680 tonnes. This was considerably in excess of the largest rockets then under development represented by Atlas with 163 tonnes of thrust and Titan with 131 tonnes of thrust, but neither had yet flown and Titan was only at the very beginning of its development. Nevertheless, the plans matured through 1957 and on 15 August 1958 the Advanced Research Projects Agency (ARPA), authorized development of what was called Juno V.

The 'Juno' designation had begun with Juno I, when the Jupiter C nose-cone test rocket was converted to a space launcher. Juno II was a direct application of the Jupiter medium range ballistic missile to space missions and both Juno models owed much to the Redstone missile which fathered their generic development. Juno's III and IV were conceptual designs expected to follow on from Juno II but were never adopted. Juno V was originally conceived to use four Rocketdyne E-1 engines, producing 149.7 tonnes thrust each, but by the time of the August 1958 go-ahead, the Rocketdyne MB-3 engine had been selected with a unit thrust of 68 tonnes. These had been used in other missiles and had proven reliability.

In October 1958, Dr. von Braun proposed that the name 'Juno' be dropped in favour of 'Saturn'. Saturn was the next planet out in the solar system to Jupiter (a name that had been applied to the proposals preceding Juno V) and appeared brighter than a first magnitude star, was the name of a Roman god and would therefore be in keeping with Army custom. A variety of different configurations had been developed using the powerful Juno V as a base and the entire series appeared to be maturing into a new family of launch vehicles, thus warranting a completely new designation. The name Saturn was finally approved by the Advanced Research Projects Agency (ARPA) on 3 February 1959 and the designation Juno V was dropped.

Throughout 1959 a wide range of stage configurations was considered by the Silverstein Committee, composed of NASA, ARPA, Department of Defence and Air Force personnel. On 21 October 1959, President Eisenhower ordered Saturn work to be transferred to NASA along with the ABMA Development Operations Division. NASA had been brought into existence one year before so that it could control and develop the nation's civilian interests in space and since Saturn was applicable to launching satellites and space probes, with no application to military ICBM roles, the move was a logical progression.

The Silverstein Committee, more properly known as the Saturn Vehicle Evaluation Committee, grouped the many and varied stage configurations into concepts A, B and C. The 'C' concepts included proposals to use high energy liquid oxygen/liquid hydrogen engines in their upper stage and it was felt that this was the most efficient way to use the enormous lifting capabilities of the clustered Saturn first stage. It is important to recognize that the concerted efforts applied to heavy booster development came as a result of the achievements in Soviet space projects at the end of 1957 and during 1958. In fact, the original Juno V was just a proposal, until Sputnik I was launched and accelerated the concern about US lethargy in building up a space launcher development programme. A liquid propellant rocket motor with 680 tonnes thrust had been proposed as a result of this concern and it was incorporated into plans to eventually adopt a much more powerful booster than the clustered Juno V. This would be called Saturn V and the story is told under that designation.

With approval of the high energy LOX/LH_2 upper stage concept, the Saturn C series moved ahead in development through 1960. A variety of different stage configurations, some using clustered engines developed from the MB-3 motor and some using the powerful 680 tonne thrust engine, were outlined and the first of these, the C-1, would use a three stage assembly. The political and programmatic evolution is discussed in historical terms in Section 1 covering C-1 to C-5 concepts.

By early 1961, the development programme had been decided and the C-1 would have a first stage cluster of eight H-1 engines, delivering a total thrust of 598.75 tonnes, a second stage called the S-IV burning a LOX/LH_2 combination through four LR-119 engines, delivering a total thrust of 31.75 tonnes, and two similar engines in the third stage, called the S-V, with a combined thrust of nearly 15.88 tonnes. By the end of March, NASA decided to change the LR-119 for the RL-10A-3 with 6 in the second stage and 2 in the third stage. Each RL-10 produced a thrust of 6.8 tonnes, compared with 7.94 tonnes for the LR-119 and the change now envisaged second (S-IV) and third (S-V) stage thrusts of 40.82 tonnes and nearly 13.61 tonnes respectively. The RL-10, a product from Pratt & Whitney, was originally developed for the Centaur high energy upper stage and is used to this day with Atlas as a first stage (see Atlas).

On 1 June 1961, a major change was approved when NASA ordered cancellation of the third (S-V) stage for Saturn C-1. The original plan laid out on 25 October 1960 envisaged 10 Saturn C-1 development flights starting with launches in mid-1961, using just a live first stage and dummy upper (S-IV and S-V) stages, two-stage flights and a dummy third stage in 1963 and full three-stage flights before the end of that year. All 10 research flights would be completed by early 1964, clearing the way for missions using the more powerful C-2 rocket in 1965. Von Braun had pressed for deletion of the S-V stage so that the 10 Saturn C-1 flights could be seen as a natural progression to the more powerful models: he was concerned that if the C-1 was seen to be too efficient as a space launcher, the more advanced variants would be cancelled. Under the new plan, the first few C-1 flights would use a live first stage with dummy upper stage, while the remainder would use live first and second stages. These would be called Block 1 and Block 2 respectively.

By October 1961 the Saturn C-1, launch vehicle SA-1, was ready to make its first test flight on a ballistic trajectory from Cape Canaveral's Launch Complex 34. The first stage, called the S-1 stage, consisted of eight cylindrical tanks, fabricated from tooling laid down to produce the Redstone MRBM, clustered around a central tank using tooling from the Jupiter A programme (see Redstone and Jupiter). The central 266.7 cm diameter tank and four of the eight clustered 177.8 cm diameter tanks carried liquid oxygen, the remaining four clustered tanks carrying kerosene. All 9 tanks were fabricated from aluminium, with integral stiffening rings to ensure rigidity.

The tanks were secured at the forward end by an eight-legged 'spider' beam arrangement, supporting 48 spherical nitrogen tanks used for pressurizing the four fuel tanks. The oxygen tanks were pressurized by gaseous oxygen from heat exchangers on the rocket motors. At the base of the tanks a rigid thrust frame provided a platform on which to mount the eight H-1 engines, arranged in a pattern of two squares of four each, one square inside the other. An aerodynamic fairing shrouded the outer engines with a firewall covering the bottom of the thrust frame. At one time, in 1960, it had been proposed to place eight retro-rockets on the thrust structure in a position so that they could all fire in a forward direction at once and decelerate the booster as it fell toward a splashdown, so ensuring minimum damage and enhancing the chances of recovery for later re-use. These were never actually carried however.

The H-1 engine was a simplified and compact version of the Rocketdyne MB-3 used in Jupiter and Thor and burned liquid oxygen/kerosene propellants to provide a thrust of 74.84 tonnes each for a combined first stage thrust of 598.75 tonnes. The four inboard H-1 engines were rigidly fixed in a downward direction canted 3° outboard, but the outer four motors were canted 6° outboard and could be gimballed for flight control. The Block 1 S-1 stage was 24.99 m long, 6.55 m in diameter and the first two vehicles carried 272.2 tonnes of propellant for a total stage weight of 317.52 tonnes. For the first four missions of the Saturn C-1, the upper stages were ballasted dummies with the nose section comprising an inert Jupiter missile shell for aerodynamic qualities. The total vehicle weighed 419.58 tonnes and was 49.38 m tall.

On 27 October 1961, Saturn SA-1 was successfully launched on a 6 min 48 sec flight from Cape Canaveral, reaching a maximum height of 136.5 km and a downrange distance of 345.5 km. The second flight came on 25 April 1962 in a similar ballistic test, but on this flight the water ballast (107 tonnes) was explosively released from the dummy upper stages at the apex of the trajectory (105 km) and the SA-2 ended its journey with splashdown 80 km from Cape Canaveral. This was Project High Water I, a bid to gain data on ionospheric physics. The first two Saturn C-1 flights, SA-1 and SA-2, had provided first stage engine burns of 116 sec and 117 sec respectively, due to lower propellant loading than the stage was designed to accommodate. The next two flights, also suborbital, exploited the full 340.2 tonne propellant capacity, raising the weight of the first stage to 385.5 tonnes and the weight of the total vehicle to 486.6 tonnes.

SA-3 was launched on 16 November 1962, as part of Project Hight Water II, followed by SA-4 on 28 March 1963. This last ballistic flight, all four of which were designed to qualify the first stage S-1 booster, incorporated an early cutoff of one inboard engine at 100 sec after launch, to test the ability of the flight control system to recover from an anomalous situation. One month before the last ballistic flight the NASA Project Designation Committee changed the Saturn C-1 designation to Saturn I and henceforth all vehicles would be known by this simplified number.

The last six flights, SA-5 to SA-10, were flown between 29 January 1964 and 30 July 1965 and the performance figures can be found on an accompanying chart. SA-5 was the first to use the S-IV second stage and was only the second mission to use high energy liquid oxygen/liquid hydrogen propellants after the Atlas–Centaur launch on 27 November 1962. The S-IV, used on all the last 6 Saturn I flights, was 12.6 m long, 5.5 m in diameter and weighed 50.58 tonnes with 45.36 tonnes of LOX/LH_2 on board. Its six Pratt & Whitney RL-10 engines each delivered a thrust of 6.8 tonnes for a total stage thrust of 40.82 tonnes.

In the Block II configuration the Saturn I carried mock-up Apollo spacecraft on top of the second, S-IV, stage, but these were merely structural shells with ballast or other weight simulation. The first, SA-5, did not carry a mock-up when it flew on 29 January 1964, sporting instead a nose configuration similar to that used for the first four ballistic Saturn I flights mentioned earlier. However, SA-5 succeeded in placing the second stage, payload adaptor and nose cone into orbit and with a combined weight of 17.1 tonnes, was 12.3 tonnes heavier than the previous US record set up by the Atlas–Centaur two months and two days earlier. This new record was equivalent to a payload lifting capacity of 9 tonnes, when the S-IV weight is deleted representing an enormous improvement on other existing launch vehicles.

Flights SA6 to SA-10 carried the dummy Apollo structure and in this configuration the Saturn I weighed 499 tonnes and was 51.8 m tall. Vehicles SA-5 to SA-10 used lengthened propellant tanks with a total capacity of 385.6 tonnes which raised the stage weight to 430.92 tonnes and each carried four large fins at the base of the first stage, interspersed with four small stub-fins. These last six Saturn I's also used uprated H-1 first stage engines and produced a total thrust of 682.2 tonnes; each H-1 generated nearly 85.28 tonnes, an improvement of 14% over the Block I engines used with SA-1 to SA-4.

The SA-6 flight, on 28 May 1964, threatened to bring the only failure to the Saturn programme, when one of the 8 H-1 engines shut down unexpectedly 26 sec early, but the guidance system kept the other 7 engines running to compensate and adjusted the ascent trajectory so that the orbit was very close to that desired. SA-7, on 18 September, was a perfect success, putting 17.7 tonnes into orbit (equivalent to a true payload capability of 9 tonnes when the weight of the S-IV stage is discounted) and fully qualified the Saturn I by completing all the test objectives three flights early. Because of this, the last three flights carried Pegasus satellites into orbit inside the dummy shells of the Apollo spacecraft, numerically out of sequence, because SA-9 was ready before SA-8.

The last flight, SA-10, on 30 July 1965, completed the research and development phase which Saturn I had been built to demonstrate and with 100% success displayed a unique record of achievement. Saturn I had been the largest rocket built at that time and adopted a unique clustered tank and engine philosophy which had paid off handsomely.

Several years earlier, in June 1961, just four months before the first Saturn I flight and one month after President Kennedy made it a goal of the United States to land men on the Moon by the end of the 1960's, development centred on more powerful Saturn derivatives. It will be remembered that Saturn versions were designated C-1 to C-5 and that the first, Saturn C-1, was built to provide the 10 development flights and this became simply Saturn I in February 1963. Saturn C-2 would use the same first stage as the 10 development vehicles but Saturns C-3 to C-5 adopted the very powerful 680 tonne thrust rocket motor called F-1 in clusters of 2, 4 and 5 respectively (see Saturn V).

When Saturn C-2 was cancelled (it never actually got off the drawing boards) in June 1961, work centred on the C-3 and the C-5, but as history would record only the C-5 was actually built, becoming the now famous Saturn V in February 1963. However, it was recognized that NASA would need a more powerful rocket than the Saturn I, if it was to test out Apollo spacecraft in orbit, early enough to send astronauts to the Moon on the C-5. But the C-3 was still several years away and so an intermediate vehicle was proposed in 1962 which would use the basic S-1 stage of the then C-1 and put a higher thrust second stage on top, more powerful than the S-IV.

Thus was born the Saturn C-IB, changed to Saturn IB in February 1963, to be developed for early flight trials with Apollo spacecraft. The designation was changed to Uprated Saturn I on 9 June 1966, at the suggestion of Dr. George Meuller, then NASA Associate Administrator for Manned Space Flight, but 18 months later this was changed back again to simply Saturn IB. For the purposes of clarity, the following discussion will retain the title Saturn IB irrespective of dates.

The Saturn IB would be a two-stage vehicle and obtain its first stage from improvements and increased performance developed from the first stage of Saturn I. The second stage would be the liquid oxygen/liquid hydrogen S-IVB developed for the Saturn V and whereas Saturn I could put a payload of 9 tonnes into orbit, Saturn IB would double this to 18 tonnes. This was sufficient to lift the Apollo spacecraft or the Lunar Module, but not both together, so the Saturn IB was seen as a launch vehicle capable of testing both elements of the Moon landing programme; Apollo would carry the three astronauts, put itself and the Lunar Module into Moon orbit and bring the three men home, while the Lunar Module would be able to take 2 men to the lunar surface and return them to Moon orbit. Only the Saturn V could put the two spacecraft in rbit together, or send them off toward the Moon.

The S-IB, first stage of the Saturn IB, was built by the Chrysler Corporation to a contract which originated when Chrysler built the last two S-1 stages for the Saturn I. In appearance, it is almost indistinguishable from the S-1, but a weight improvement programme had considerably enhanced its performance: the weight of the stage had gone down and the power of the H-1 engines had gone up. With a dry weight of 39.1 tonnes compared with 45.4 tonnes for the Saturn I first stage, the S-IB could hold 399.8 tonnes of liquid oxygen and kerosene for a total weight of 445 tonnes representing a weight reduction of 11% on the Saturn I's S-1 stage.

Like the S-I, the S-IB was 24.99 m long with a diameter across the clustered tanks of 6.52 m. The eight H-1 engines were uprated to provide a unit thrust of 90.72 tonnes for a combined stage thrust of 725.76 tonnes. Eight elongated fins were situated around the base thrust structure and spanned 12.4 m. Arranged in a swept-down configuration, they carried the support beams on which the vehicle would rest during its time on the launch pad.

The second stage, the S-IVB, carried a single Rocketdyne J-2 engine which delivered between 91 and 102 tonnes of thrust, the exact value depending on the propellant mixture ratio. Development of the J-2 engine originated in 1959 when NASA was examining possible types of high energy upper stage engine. Rocketdyne were contracted to build the J-2 in June 1960 and the system was built from the outset for manned space vehicles to support a variety of C-2 to C-5 configurations. Engine tests began in January 1962 and the engine had proved its planned performance by November 1964. The S-IVB was 17.9 m long including the thrust structure and the J-2 engine, was 6.5 m in diameter and weighed 116.12 tonnes with liquid oxygen/liquid hydrogen propellants on board.

The 5.7 m long cylindrical adaptor, which connected the first and second stages, is included in the 17.9 m length of the S-IVB, but the adaptor itself remained with the first stage at separation. It carried four solid propellant rockets producing a total thrust of 66.6 tonnes to back the S-IB away from the second stage after separation. The S-IVB carried three solid propellant 'ullage' rockets producing a combined thrust of 4.7 tonnes for 4 sec. These were mounted on the outside of the aft skirt and provided positive acceleration during the period between first stage shutdown and second stage ignition to prevent gaseous bubbles getting into the propellant feed lines to the J-2 engine. They were jettisoned 15 sec after stage separation. The S-IVB also carried two Auxiliary Propulsion System modules located 180° apart on the aft skirt. Each had three 68 kg thrust attitude control motors for stabilizing the S-IVB/payload structure after reaching orbit. (Note: see Saturn V for different S-IVB ullage and APS motor arrangement).

A 6.5 m diameter ring was fixed to the top of the S-IVB, 91 cm high, and this was known as the Instrument Unit. It carried all the electronic command, control and guidance equipment to direct all launch vehicle functions during the ascent. The Apollo spacecraft, its adaptor which linked it with the Instrument Unit and the launch escape system on top, presented a combined length of 25.3 m. The launch escape system consisted of a solid propellant rocket on top of a lattice tower which would be used to wrench the Apollo command module and crew away from the Saturn IB if the launch vehicle lost control or ran amok. In total, the Saturn IB was 69 m tall.

The first Saturn IB was launched on 26 February 1966 from Launch Complex 34 at Cape Canaveral carrying the first Apollo spacecraft on a ballistic trajectory to a height of 493 km and a range distance of 8,690 km. The 20.82 tonne Apollo had more propellant in its own tanks than it could have had to allow the Saturn IB to put it in orbit – orbit weight capability for Saturn IB was 18 tonnes – but this was just a ballistic suborbital flight and was not required to reach orbital speed. At launch the configuration weighed 597.8 tonnes and the mission was designated AS-201: 'A' for Apollo, 'S' for Saturn and 201 representing the first mission with the second version of Saturn I.

The flight had contrived to test the Apollo engine that would be used on Moon flights to put the combined Apollo/Lunar Module in lunar orbit and to fire the crew out of that orbit for return to Earth. The unmanned AS-201 flight had shown that the engine could be controlled, re-started and operated in a precise sequence of commands. In addition, the Apollo engine burns were used to drive the command module back into the atmosphere at high speed to test out the heat shield. In putting the Apollo spacecraft in a long arching ballistic trajectory the first, S-IB, stage burned for 149 sec while the second, S-IVB, stage fired for a duration of 453 sec.

The next flight, confusingly out of sequence and designated AS-203, had the objective of putting the S-IVB in orbit so that engineers could perform a strenuous series of tests by remote control. No Apollo was carried and the vehicle was 52.79 m long with a liftoff weight of 538.26 tonnes including a special shroud in place of the Apollo. The object of the test, the S-IVB stage itself, fully qualified the Saturn IB for all anticipated requirements. Launched on 5 July 1966, AS-203 was followed by the third flight on 25 August. Called AS-202, it was essentially a repeat of the Apollo engine and heat shield tests performed on the first Saturn IB flight and with the spacecraft weighing 25.8 tonnes, represented the heaviest payload a Saturn IB would ever be called upon to lift, albeit on only a ballistic suborbital trajectory.

The three tests in 1966 had spurred confidence in the new Saturn IB and coming concurrently with five successful Titan II flights putting two-man Gemini spacecraft in orbit, gave high hope for the first manned Apollo flight early in 1967. The plan was to dedicate AS-204 to sending astronauts Grissom, White and Chaffee on a 14-day flight in earth orbit to fully test the spacecraft. If this was a success, launch teams would put another manned Apollo up and then a day later launch a Saturn IB carrying an unmanned Lunar Module. The Apollo already in orbit would dock with the Lunar Module and fully check out all systems before separating and coming back to Earth. This would clear the way for a full dress rehearsal of the Moon flight with the more powerful Saturn V.

Plans to launch AS-204 had been delayed because of problems in the Apollo environmental control system, but by mid-January 1967 all seemed ready for a launch attempt the following month. On 27 January 1967, the launch vehicle and spacecraft was on the pad at Launch Complex 34. The scheduled crew had been in the Apollo for several hours performing tests on the spacecraft systems when, at 6:31 p.m. local time, an electrical short circuit ignited inflammable materials and caused a flash fire in the pure oxygen environment. Grissom, White and Chaffee died as a result of asphyxiation in a tragedy that caused a 20-month delay in the first Saturn IB/Apollo manned inaugural flight. Plans for the dual Saturn IB flight were cancelled, but NASA made use of the lost time spent in re-designing the Apollo interior by sending up a Lunar Module on the Saturn IB that had supported the burnt out Apollo.

The AS-204 flight was launched on 23 January 1968 and the payload shroud was specially configured to encase the unmanned Lunar Module. The assembly was 55.2 m tall, weighed 584.4 tonnes at launch and took the 14.38 tonne Lunar Module 1 (LM-1) into orbit. A comprehensive series of tests put the LM through its paces with several engineering tests and engine firings using motors which would be used to put astronauts down on the Moon and take them off again. The tests ended when the last burn put the vehicle on to an intercept trajectory with the atmosphere, where it was destroyed through friction 8 hours after launch.

The next Apollo support flight was the first manned Apollo mission and put Schirra, Eisele and Cunningham into orbit on 22 October 1968 for a 10-day test of the re-designed spacecraft. Called the AS-205, the Saturn IB performed well and introduced a new system of indexing adopted earlier that year. After the fire the three unmanned Saturn IB flights in 1966 were retrospectively designated Apollo 1 to 3, the first Saturn V flight at the end of 1967 became Apollo 4 and the AS-204 Lunar Module flight was Apollo 5. A second Saturn V flight in 1968 became Apollo 6 and the first manned Apollo mission, flight AS-205, was Apollo 7. This was the last Saturn IB flight for nearly 4½ years and in the intervening period 10 Saturn V/Apollo flights, including 6 Moon landings, kept the manned space flight teams occupied with more ambitious efforts than earth orbit launches.

Then, in 1973, Saturn IB launch vehicles were brought out of storage to support the Skylab space station programme. The H-1 engines were also uprated to produce a thrust of 92.99 tonnes each which generated a total first stage thrust of 743.9 tonnes. AS-206 launched 3 astronauts and an Apollo spacecraft to earth orbit on 25 May 1973, followed by AS-207 and a second three-man crew on 28 July. When it appeared that this second Skylab crew may need a rescue flight to return them from the Skylab, because of an indicated failure in control rockets on their waiting Apollo, AS-208 was rolled out to the launch pad early on 14 August. It had been decided that a rescue capability would exist with the Skylab operations and launch teams were prepared to accelerate preparations for the next vehicle in line, should the need arise.

It seemed that it did and so AS-208 was placed on the pad in a standby role that would await further results from tests being carried out to determine the validity of the rescue call; safe inside Skylab there was no danger to the astronauts while the Apollo was playing a passive role docked to a port on the outside. Tests showed that the Apollo, already docked to Skylab, could be safely used to bring the crew back at the end of their 59-day sojourn in space and AS-208 was left on the launch pad ready for the third and last Skylab visit. Just 4 days before the planned liftoff on 10 November 1973, cracks were discovered in the fins located at the base of the S-IB stage and a decision was made to replace them, postponing the launch by 6 days to 16 November. When liftoff came, the eight-year-old Saturn IB functioned perfectly and put the crew in orbit for the final Skylab visit which would make space history by lasting 84 days. The back-up to this last Skylab flight was Saturn IB AS-209 and with its Apollo spacecraft was rolled out to the launch pad just in case it was needed for a rescue. It was not and the launch vehicle was returned to the Vehicle Assembly Building at the Kennedy Space Centre at the end of the Skylab mission.

The last Saturn IB flight, with AS-210, came on 15 July 1975 as the US component of the joint docking flight with two Soviet cosmonauts called the Apollo–Soyuz Test Project (see SS-6). AS-210 was more than eight years old, but performed flawlessly to end a successful 9½ years of operations, during which time 9 Saturn IB's had been sent into space and 5 three-man astronaut teams had gone into orbit.

Due to closure of the Launch Complex 34 and 37 facilities, Saturn IB operations supporting Skylab and the Apollo–Soyuz Test Project originated from the Launch Complex 39 site, hitherto used exclusively for Saturn V flights. So as to make the smaller Saturn IB compatable with the old Saturn V launch tower the smaller launch vehicle was set up on a 37 m tall pedestal, surely the most incongruous position ever occupied by a major launch vehicle.

In the 18 months following launch of the last Saturn IB, NASA held two launch vehicles of this type in storage at the Vehicle Assembly Building, but on 16 December 1976, NASA Administrator James B. Fletcher announced that they would be released to museums and historical institutions. Between 1961 and 1975 19 launch vehicles of the Saturn I family had served to rehearse Moon landing flights and support major manned space flight programmes in their own right. Their legacy is left in the form of 22 unused first stage H-1 engines, handed over for use in the first stage of Delta rockets (see Delta).

Saturn V:

Development of the world's largest operational launch vehicle was instigated by the May 1961 committment for America to land two astronauts on the Moon by the end of the decade. When President Kennedy set that goal as the prime objective of the nation's space programme, the task was beyond definition and without structure. Not until the end of 1962 could work begin in earnest, so many and varied were the design concepts and configurations that emerged from government and the industrial sector. At that time NASA was considering development of two launchers: the C-3 and the C-5. The precise launch vehicle which would be most suitable depended on the way NASA would fly to the Moon, land and return. That story, as far as it influenced development of the major launch vehicles of the day, is told in Section 1 and suffice it to say here that the C-5 design was given the go-ahead in January 1962 in preference over the C-3.

As then envisaged the Saturn V, as it was known from February 1963, would be powered by five Rocketdyne engines in the first stage, producing a liftoff thrust of 3,400 tonnes, a second stage with five Rocketdyne J-2 engines generating 520 tonnes of thrust and a third stage with a single J-2 producing 95 tonnes of thrust. The massive assembly would be capable of putting a payload weight of 115 tonnes into low earth orbit or of sending 45 tonnes to the Moon. The performance was enhanced by a decision to use liquid oxygen/kerosene in the first stage and liquid oxygen/liquid hydrogen in the two upper stages.

Boeing was selected as the contractor for the first stage, the S-1C on 15 December 1962. It would be 46.1 m tall, 10 m in diameter, carry five huge F-1 engines at the base and hold 2,038 tonnes of propellants. This was the largest single rocket stage ever brought to operational status. The liquid oxygen tank was located above the fuel tank which was in turn above the thrust structure to which was attached the F-1 engines. The 1¼ million litres of liquid oxygen was brought down to the engines by five suction pipes running through the fuel tank below and each pipe was 43 cm in diameter and capable of delivering the oxidizer at more than 7,600 litres per second. A massive intertank structure separated the tanks and provided a rigid frame, stiffened with external hat section stringers. The fuel tank held 769,000 litres of kerosene and delivered this to the engines at a rate of 5,110 litres per second through 10 suction lines. The total delivery rate of 12,710 litres per second kept the five F-1 engines running for about 2½ minutes with a total stage consumption of 12.9 tonnes of LOX/kerosene every second of flight.

The F-1 engine was developed from the outset as a 680 tonne thrust rocket motor capable of independent operation or serving large launch vehicle requirements in a clustered configuration. The engine was 5.8 m tall with a maximum diameter of 3.6 m across the exhaust cone. Although using basic technology and adopting a chamber pressure of about 67.8 kg/cm^2, the F-1 was required to perform a very basic, unsophisticated function and did this admirably.

The second stage contract went to the then North American Aviation (now Rockwell International) on 11 September 1962. Called the S-II, it was very different in construction from the first stage and employed high energy cryogenic propellants carried in two tanks divided by a common bulkhead, unlike the S-IC which incorporated two tanks each with separate hemispherical domes. The S-II was 24.9 m long in diameter and carried a propellant load of 428 tonnes, or 1.3 million litres. Special forms of insulation were developed to preserve the cryogenic nature of the liquid oxygen/liquid hydrogen propellants. The five J-2 engines were mounted in a four-square pattern with a central J-2 fixed firing downwards. All other engines in all three stages were gimballed for flight control.

The third stage, the S-IVB, was contracted to McDonnell Douglas (then the Douglas Aircraft Co.) on 8 August 1962. It was 17.9 m long and 6.5 m in diameter carrying 103.4 tonnes of liquid oxygen/liquid hydrogen, or 314,200 litres. Like the S-II, the S-IVB had propellant tanks separated by a common bulkhead and the single J-2 produced a thrust of about 91 tonnes depending on the propellant mixture ratio. The J-2 was developed by Rocketdyne from work that began in 1959 and the engine was specifically designed to be re-startable in space. That is, it could be shut down after its initial work of putting a payload into orbit and then started again several hours later to accelerate to escape velocity. This was the method of operation called for when Saturn V supported manned Moon flights. The engine itself was 3.38 m tall, with an exhaust cone diameter of 1.95 m. It consumed propellant at a rate of about 241 kg/sec and had a specific impulse of 424 sec compared with the F-1 at 260 sec.

Above the S-IVB was located the 6.5 m diameter Instrument Unit, 91 cm tall and carrying control and guidance electronics for command of the vehicle functions. The two interstage adaptors, separating the first and second and the second and third stages, were 5.5 m and 5.7 m tall respectively. The adaptor separating the first and second stages was a constant cylinder 10 m in diameter, while the upper adaptor was in the form of a truncated cone connecting the 10 m diameter second stage to the 6.5 m diameter third stage.

Above the main launch vehicle stages and Instrument Unit was another adaptor 8.53 m tall, also adopting the

form of a truncated cone and fitted to connect the 6.5 m diameter Instrument Unit to the 3.9 m diameter Apollo spacecraft. This was divided into four separate panels, 2.06 m up from the base, so that they could be rotated outward through 45° and jettisoned to reveal the Lunar Module supported at four points to the inside of the lower section. With the Apollo spacecraft on top and a launch escape motor fitted to a lattice tower, the payload above the launch vehicle was 25.3 m tall. In total the Saturn V/Apollo was 110.62 m tall and weighted with a full launch load the configuration grossed 2,820 tonnes.

A full test of the launch facilities was performed with a full size mock-up on 25 May 1966 and the first fully equipped Saturn V, AS-501, was launched from pad 39A on 9 November 1967 in an unmanned test of the complete assembly. In a typical flight plan, the first stage F-1 engines are ignited 6 sec before liftoff and the centre engine is shut down 135 sec into the flight followed by the four outer engines 15 sec later. One second later the first stage is separated from the upper stages and simultaneously fires eight retro-rockets. These are located in pairs facing forward and enclosed within large fairings over each of the four outer F-1 engines at the base. They produce a total thrust of 40.2 tonnes for 0.7 sec and retard the forward momentum of the stage at separation so as to prevent it bumping the adaptor on the base of the second stage. Aerodynamic stability during stage 1 flight is maintained with the help of four fins, spanning 20 m, fitted to the cone-shaped fairings. At separation the assembly is at a height of about 62 km and a speed of 9,850 km/hr; the first stage plunges back down through the atmosphere and falls to the Atlantic Ocean, 630 km from Cape Canaveral.

About one second after stage separation, eight solid propellant rocket motors mounted on the adaptor, which is still attached to the second stage, fire in a downward direction for 4 sec to produce a combined thrust of 82 tonnes. This is called the ullage manoeuvre and it is performed to produce a positive acceleration to the assembly and ensure that the propellants will be settled at the feed outlets when ignition of the second stage is commanded. The term 'ullage' is actually an old brewers name for gases that collect at the top of a liquid and refers here to the small quantity of liquid oxygen and liquid hydrogen that boils off before use. While the ullage motors are still firing, the five J-2 engines on the second stage ignite, followed about 30 sec later by release of the cylindrical adaptor at the base. This slides out past the J-2 engines on rails and tumbles back down toward the atmosphere and 6 sec later the Apollo launch escape tower is released. Up to this point it could be used to free the Apollo command module if the Saturn V ran amok, but from here the big Apollo engine could fire, if needed, and take the vehicle to safety away from the launch vehicle.

After a 365 sec burn the S-II stage shuts down, its propellant expended, and separates from the third stage and its payload. At the same time four forward-firing solid propellant motors, located in the conical adaptor on the front face of the S-II stage, burn for 1½ sec to produce a combined thrust of 63.5 tonnes. These prevent the S-II from buffeting the S-IVB, which still has a job to do by putting itself and the payload in orbit, by retarding the forward momentum of the stage at separation. The assembly is now at an altitude of about 185 km and a speed of 25,250 km/hr.

Its work done, the S-II second stage tumbles back down and impacts the Atlantic Ocean 4,260 km from Cape Canaveral. Immediately upon separation two solid propellant ullage motors, located 180° apart on the aft skirt of the S-IVB, fire for 4 sec to produce a total thrust of 3.1 tonnes to settle the propellants. Just 3 sec after separation, the single J-2 is ignited on the third stage and 9 sec later the ullage motors and their protective cases are jettisoned and left to fall back to Earth. After a burn duration of 142 sec the S-IVB shuts down and the assembly is in orbit at a height of about 190 km and a speed of 28,200 km/hr.

The S-IVB carries two Auxiliary Propulsion System (APS) modules located 80° apart on the aft skirt of the third stage. Each module has three attitude control motors, each with a thrust of 68 kg and one ullage motor delivering 32 kg thrust. All four motors in each pack use a nitrogen tetroxide/hydrazine liquid propellant stored in separate tanks. The ullage engines are fired at the end of the J-2 engine burn to ensure that the main liquid oxygen/liquid hydrogen propellants settle properly and the attitude engines keep the assembly stabilized while in orbit. (Note: see Saturn I/IB for different S-IVB ullage and APS motor arrangement).

On a flight to the Moon, the S-IVB is re-ignited on the second or third orbit to accelerate the assembly out of earth's gravity field. This operation begins with ignition of the two small ullage motors to settle the propellants again in a 77 sec burst and the J-2 engine is fired for (typically) 345 sec to increase speed to about 39,000 km/hr. The ullage motors are fired again for 280 sec to move the S-IVB away from Apollo and the Lunar Module which would have separated from the third stage shortly after main engine shutdown. A variety of trajectories are possible with this manoeuvre and several S-IVB stages were deliberately sent on a collision course with the Moon to trigger a shock wave from the impact which seismometers on the lunar surface used to map internal layers. On other flights out of earth orbit, the S-IVB was put on a trajectory which takes it into deep space.

The complex sequence of operations, involving 41 rocket motors on the three stages, represent a triumph of engineering achievement and at a time when rocketry was in its infancy, the design of such a colossus was profoundly significant for future developments.

The first flight on 9 November 1967 went well and was followed by a similar test run on 4 April 1968. Called AS-502, the Saturn V Apollo 6 mission, it was intended, like its predecessor, to place the Apollo spacecraft on to a highly elliptical orbit so that after separation the main Apollo engine could be tested. The adopted system of nomenclature designated the first Saturn V AS-501 ('A' for Apollo, 'S' for Saturn, '5' for Saturn V and '01' for the first flight of the series). It was also Apollo 4, Apollo's 1 to 3 being flights with the smaller Saturn IB in the AS-200 series; Apollo 5 was another Saturn IB flight followed by Apollo 6 using the second Saturn V, AS-502. Shortly after separating from the first stage, two of the five J-2 engines in the second stage shut down earlier than planned, but the other engines kept firing to compensate and the third stage and payload finally got into orbit 87 sec late, but in a safe condition. However, when a planned S-IVB re-ignition failed to occur, it brought doubts to engineers on the ground that the Saturn V would be ready to carry astronauts on the next flight as intended.

Nevertheless, extensive tests in the ensuing months restored confidence and plans moved ahead to send three astronauts to the Moon on only the second manned Apollo flight and the third Saturn V mission which would also be the first with men aboard; the first, Apollo 7, was launched to earth orbit by a Saturn IB in October 1968. Saturn V AS-503 and subsequent vehicles carried only four solid propellant ullage rockets on the adaptor, linking the first two stages and this reduced the total ullage thrust to 41 tonnes for the 4 sec burn to settle the second stage propellants. It also reduced weight and modifications like this consistently increase the payload capability. Changes had been made to the Saturn V second stage to prevent recurrences of the premature shutdown experienced with AS-502 and on all future flights, the centre F-1 engine on the first stage would be shut down 125 sec after liftoff, leaving the remaining four to burn until an elapsed time of 154 sec. The time would vary a little on subsequent flights, but the staggered shutdown was retained to limit acceleration to 4 g and prevent vibration detected on the first two flights.

AS-503 (Apollo 8) was launched on 21 December 1968 and placed Borman, Lovell and Anders in Earth orbit before re-ignition of the third stage and a flight into Moon orbit, where they remained for more than 20 hrs before returning home. The Saturn V performed well and proved that the launch vehicle could fulfil its responsibilities in sending heavy payloads first to Earth orbit and then on toward the Moon. Nevertheless, it had been a daring exercise, being the first manned Saturn V flight, only the second manned Apollo mission, the first use of Saturn V hardware to send anything to the Moon, the first time men had gone further than a few hundred kilometres from Earth and the first time an Apollo command module had survived a return flight from lunar distance at nearly 40,000 km/hr through the atmosphere. But it paid off.

AS-504 (Apollo 9) was the first of the operational Saturn Vs, the first three being development vehicles carrying a host of film cameras and instrumentation to record critical events as they happened. Uprated F-1 engines were used in the first stage for a total liftoff thrust of 3,500 tonnes and normal ignition weight was now up to around 2,940 tonnes. AS-504 was launched on 3 March 1969, carrying a Lunar Module (for the first time) and an Apollo spacecraft into Earth orbit from where the two vehicles rehearsed the kind of manoeuvres they would be called upon to make for a Moon landing. After separating from the Lunar Module/Apollo configuration the S-IVB was put through a demanding series of tests requiring two further periods of J-2 engine firing, the result of which was to send the stage out of Earth orbit and into deep space.

The next vehicle, AS-505, carried still more change to Saturn V operating procedure. In order to avoid vibrations in the second stage, the five J-2 engines would be shut down at staggered intervals with the centre engine burning for only 297 sec and the four outer J-2's firing for 389 sec. Formerly, all five engines had fired together for about 365 sec, but the new procedure would remain standard for subsequent vehicles.

AS-505 was a full dress rehearsal of the planned Moon landing flight and took Apollo 10 out of Earth orbit to lunar orbit, where the Apollo and Lunar Module tested all the systems necessary for a descent without actually landing. Launched on 18 May 1969, the Saturn V performed well and the S-IVB was sent into deep space out of the way.

Apollo 11, launched by AS-506 on 16 July 1969, proudly sent two astronauts to the surface of the Moon while a third waited in lunar orbit. The seventh Saturn V, AS-507, was launched on 14 November 1969 and was twice struck by lightning. The Saturn V performed well, however, sent three Apollo 12 astronauts to the Moon and discharged the S-IVB toward deep space. Errors in the guidance system prevented the stage from achieving the proper trajectory and it stayed in a 163,000 × 861,800 km orbit about the Earth, moving more than twice as far out as the Moon and returning to the 'low' point of its strange orbit once every 42 days.

AS-508 was launched on 11 April 1970 on the fateful Apollo 13 flight. The first stage performed well and separated, but severe oscillations in the second stage liquid oxygen system caused the centre J-2 engine to shut down 164 sec after ignition. It should have burned for a planned duration of 297 sec, which would have been followed by shut down of the other four engines at a second stage elapsed time of 392 sec. Because of this the outer four J-2's kept firing until all the propellant was depleted, finally shutting down at an elapsed time of nearly 427 sec. Nevertheless, speed was down by 245 km/hr on that which it should have achieved during normal operations and the third stage was required to burn for 163 sec instead of a planned 144 sec to put the payload in orbit.

This resulted in more propellant being consumed by the S-IVB than had been intended and left little margin over that which would be required to head for the Moon. The re-start was performed as expected, however, and the Apollo sped toward the Moon while the S-IVB was re-targeted for an impact with the lunar surface at a speed of 9,290 km/hr and a force equal to 13 tonnes of TNT. Apollo suffered an explosive depressurization in one of its oxygen tanks, rupturing a second and disabling the spacecraft. Sheltering in the attached Lunar Module the crew swept round the Moon and came straight back to Earth for a splashdown 6 days after launch.

Following a delay for basic changes in spacecraft design, which would prevent a similar failure to that experienced by Apollo 13, Apollo 14 was launched on 31 January 1970. The AS-509 launch vehicle performed as planned and the S-IVB was sent to destructive impact with the lunar surface after putting the Apollo/Lunar Module assembly on course for Man's third Moon landing.

Another launch vehicle change came with the next Saturn V, AS-510, so that more weight could be trimmed off and a heavier Apollo/Lunar Module carried as payload. The basic Apollo/Lunar Module had weighed a maximum 44.5 tonnes, but the last three lunar missions would carry extra equipment (such as a Lunar Roving Vehicle) and increase this to 47 tonnes. By carefully looking at previous Saturn V operations and studying the engineering results, it seemed possible to dispense with the four ullage rockets mounted to the adaptor separating first and second stages. There had originally been eight ullage rockets and four had already been removed from the AS-503 on.

Engineers felt confident that the S-II second stage could start without ullage acceleration and so the last remaining four were taken off from AS-510 and subsequent vehicles. Also, four of the eight forward firing retro-rockets fixed to the engine fairings at the base of the first stage, were taken out. This left just four retro-motors producing 20.1 tonnes of thrust for 0.7 sec to prevent the S-IC from shunting the upper stages immediately after separation; sufficient to do the job and adequate for the task. The last three Apollo/Saturn V flights would all fly with this configuration and the three launch vehicle stages now carried a total of 29 solid and liquid propellant motors, versus the 41 carried by the first two Saturn Vs.

The AS-510 flight got off the ground on 26 July 1971 and sent Apollo 15 to the Moon and its third stage to a lunar impact. This was followed by an equally successful Apollo 16 launched by AS-511 on 16 April 1972 and a lunar impact for the S-IVB, AS-512, the last three stage Saturn V flight was launched as Apollo 17, the last Moon landing, on 7 December 1972. A 2 hr 40 min delay due to technical trouble, prevented the Saturn V getting off on time on what was the only night launch of this massive rocket. The sheer spectacle of this launch eclipsed previous flights and made other records too, by being the heaviest launch vehicle successfully sent into space with the heaviest payload ever carried to the Moon.

On the pad AS-512 weighed a phenomenal 2,962 tonnes including a 46.78 tonne Apollo/Lunar Module payload. At launch the big F-1 engines generated a total thrust of 3,477 tonnes increasing to a maximum 4,100 tonnes before the centre engine shut down. Apollo 17 flew successfully to the Moon and the third stage went to a lunar impact.

Despite troublesome irregularities, the 12 Saturn V launches had been remarkably successful when viewed in the light of the complexity represented by the basic design. Designed to send 45 tonnes to the Moon, it had exceeded this value by a handsome margin and although experiencing problems with the second stage, had proved itself sufficiently adaptable to correct, in flight, its own irregularities and go on to satisfy assigned objectives.

When originally ordered it had been thought that as many as 15 flights would be necessary to fulfil the goal of landing two astronauts on the Moon. As events showed, it needed only two flights to qualify it for sending men to the Moon and only three flights beyond that to check out Apollo and Lunar Module systems. Consequently, a lot of hardware was left for more Moon flights and a Skylab space station was developed for obtaining knowledge about the Earth from space. The Skylab space station was adapted from a redundant S-IVB stage and AS-513 was configured as a two-stage vehicle to launch it into orbit. The assembly was 99 m tall and weighed 2,856 tonnes at ignition.

At launch on 5 May 1973 the first stage engines burned for 152 sec, with the centre F-1 engine shut down 18 sec earlier, and the second stage burned for 429 sec with the centre J-2 cutting off after 154 sec. This put the second stage and Skylab into orbit at a height of 442 km. About 2 sec after getting into orbit the forward firing retro-rockets on the conical adaptor on the front of the second stage fired to move the S-II back away from Skylab, but damage was caused to structures on the space station. Also, during the ascent, the adaptor on the base of the second stage failed to separate, as it was intended to do, 30 sec after ignition of the five J-2 engines. Nevertheless, despite these difficulties the Skylab workshop went on to support three separate teams of astronauts sent up by Saturn IB launch vehicles and the inert S-II stage re-entered the atmosphere and was destroyed.

Between 9 November 1967 and 5 May 1973 – just 5½ years – thirteen Saturn V class launch vehicles took 12 astronauts to 6 Moon landing and sent the Skylab space station into Earth orbit. This is almost certainly the largest launch vehicle that will be built in the United States this century and its place in the annals of rocket history is assured.

Hardware for two Saturn V vehicles were held in storage for 3½ years after the last flight, but on 16 December 1976 NASA Administrator, James B. Fletcher, announced that they would be released to museums. Several schemes had been proposed for the continued use of Saturn V and variants developed in concept from the three-stage vehicle. These are to be found in the relevant paragraphs to Section 1.

Scout:

In 1958, when most space launcher development programmes were centred on the expensive and powerful missiles in use or pending introduction to the Army or the Air Force, NACA began studies to determine the optimum approach toward production of a small, low weight and inexpensive satellite launcher. While considering possible names for the project, William Stoney decided on 'Scout' and the rocket has remained under that title since it first entered operational use.

When NASA was formed out of the old NACA in 1958, the Langley Research Centre had management control of the project and the vehicle was seen to be a solid propellant four-stage launcher which could be used for high altitude sounding tasks, in addition to its prime role of placing low-weight satellites in orbit. Solid propellants were stipulated due to the high level of confidence in this type of propellant, to avoid complex storage, preparation and countdown procedures and to simplify the basic design.

In April 1959 the Astronautics Division of Ling-Temco-Vought, a member of the Chance Vought Corporation, were contracted to develop the Scout, oversee subcontractor activities and provide launch support services. A year later the first Scout was ready for launch. The first stage was 9.4 m tall, 101 cm in diameter and carried 8.65 tonnes of propellant which would be consumed in a 40 sec burn delivering 52.2 tonnes of thrust. Four fins of triangular configuration were grouped around the base of the first stage which weighed 10.7 tonnes fully loaded. The second stage was 6.3 m long, 78.7 cm in diameter and burned 3.3 tonnes of propellant in 39 sec at a thrust of 22.7 tonnes. The total second stage weighed 4.3 tonnes. The third stage had a length of 3.38 m, a diameter of 76.2 cm and a loaded weight of 1.22 tonnes including 930 kg of propellant. The third stage developed nearly 6.2 tonnes of thrust for 39 sec. Stage four was only 1.83 m long and 45.7 cm in diameter, but its 206 kg of propellant produced a thrust of nearly 1.4 tonnes for 38 sec.

The four stages, in sequence first to fourth, were named: Algol, Castor, Antares and Altair after stars in the constellation. The first stage, Algol, was controlled by aerodynamic fins, in effect movable outer tips of the four fixed stabilizer fins, and four vanes, so situated that exhaust products would impinge upon their surfaces. Algol was the largest solid propellant motor then available and came from a Polaris missile while the second, Castor, stage originated as the Sergeant rocket. The Castor was used in clusters with the Little Joe booster and, later, in clusters of three for the Air Force Thor satellite launcher and clusters of 3, 4, 6 or 9, for the Delta satellite launcher used by NASA. Stabilization on the second stage was by hydrogen peroxide jets. The fourth stage, Altair, began life as the ABL X-248, was the third stage of the Vanguard satellite launcher developed in 1957 and employed a very lightweight construction method whereby a glass fibre filament-wound case supported the propellant. Later, the ABL X-248 became the third stage of NASA's Delta launch vehicle and served in this capacity until 1965 when it was replaced by a more powerful motor. The third stage, Antares, was an uprated version of the X-248 serving as fourth stage and in the uprated adaptation was designated ABL X-254.

Thus did all four stages of the Scout converge from three separate, earlier programmes, to provide the civilian space agency with a low-cost, low-weight satellite launcher. The entire configuration, with payload shroud, was 21.9 m tall and weighed 16.6 tonnes at liftoff. The vehicle's two top stages were encased in a glass fibre shield which included the payload shroud and the mechanism to spin the fourth stage for stabilization; stages 2 and 3 used hydrogen peroxide jets for guidance and stability. The basic mission objectives, which promoted the Scout vehicle, required a capability, which the resulting design met, to place a 23 kg payload on to a ballistic trajectory of 13,700 km or place a 70 kg satellite in low earth orbit.

The first Scout launch was successfully achieved on 1 July 1960 when only the first three stages were live, the fourth being inert. On 4 October, in the same year, the full four-stage configuration was launched with a 57 kg payload to a height of 5,800 km, but an attempt to orbit the 6.3 kg Explorer S-56 satellite on 4 December 1960 failed when the second stage refused to ignite. Finally, on 16 February 1961, a four-stage Scout successfully put the 6.8 kg Explorer 9 in a 636 × 2,583 km orbit, the orbital debut of a launch vehicle that would outlast every other expendable rocket developed by NASA.

Meanwhile, in 1960, attention had focused on development of several Air Force variants which could be used to conduct experiments in ballistic and orbital flights. The principal variants at this time were: XRM-89 Blue Scout 1, XRM-90 Blue Scout 2, XRM-91 Blue

Scout Junior and the XRM-92 Air Force Scout. All four versions were developed by the Air Force Systems Command, Space Systems Division.

Blue Scout 1 was merely a three stage Scout, with the fourth stage removed and the 178 kg payload mass was carried by the rocket to decrease launch weight to 16.27 tonnes. The first launch came on 7 January 1961, when the three stage launcher took its load to a height of 1,600 km and a downrange distance of 1,930 km on a ballistic trajectory.

The Blue Scout 2 was identical to the four-stage NASA Scout, but was adapted to carry a 166 kg payload on a ballistic trajectory. Launch weight was 16.87 tonnes and the first flight came on 3 March 1961, when an altitude of 2,540 km and a range of 3,220 km was demonstrated.

The Blue Scout Junior was more than a simplified rearrangement of capabilities and deleted the first and fourth stages of the NASA Scout, so that the Castor and Antares, second and third stages, now became the first and second stages of Blue Scout Junior. Readers are referred to the earlier discussion of these elements and that data is consistent with the re-worked application. The only change here was that Castor and Antares had four fixed triangular fins at their aft ends. The new Alcor third stage was 1.37 m long, 45.7 cm in diameter and produced a thrust of 3.6 tonnes for 30 sec. The new Cetus fourth stage was 50.8 cm long and a spherical 43.2 cm in diameter, that is to say, the actual propellant case and bonding was a sphere contained with a cylindrical structure 50.8 cm long. The stage had a thrust of 408 kg. In this configuration, with first to fourth stages comprised of Castor, Antares, Alcor and Cetus mounted in tandem, the Blue Scout Junior was 12.3 m long and weighed 5.8 tonnes. First stage thrust was, of course, the 22.7 tonnes rating of the standard Castor normally utilized as the second stage of the NASA operated Scout.

The Blue Scout Junior was unguided, spin-stabilized and launched from a beam previously used for the Sergeant missile. Spin rockets in the second stage were firing at liftoff and achieved a spin rate of about 3 revolutions per second by the time first and second stages had expired in succession. This was sufficient to keep the unspun third and fourth stages on course and on one flight, in August 1961, the US Air Force launched a Blue Scout Junior to a height of 225,000 km with a 8 kg payload designed to probe Earth's radiation belts.

The fourth Air Force variant, the XRM-92 Air Force Scout was in all respects the same as the basic four stage NASA Scout and earlier details of that configuration can be applied to this model. Later, a Scout B was developed with more powerful stages. In this development the Castor II and Altair III second and fourth stages produced thrusts of 27.5 tonnes and 2.7 tonnes respectively, increases of 21% and 93% on the basic Scout. This resulted in a payload increase providing the Scout B with a capability of putting 145 kg in low earth orbit. The stage dimensions were virtually the same as the Scout A.

In 1972, NASA introduced the Scout C, with a 48.6 tonne thrust capability for 82 sec, twice that of the basic Algol. The new stage was 1.14 m in length and the total vehicle weighed 21.5 tonnes at launch and could place 188 kg in earth orbit.

In June 1974, a new five-stage variant was introduced to place a scientific satellite in a highly elliptical orbit. The Scout was in basic model C configuration with the addition of a Hercules BE-3 solid propellant motor called Alcyone IA, a name which like others applied to Scout stages, was taken from a well-known star. The fifth stage had a thrust of 2.7 tonnes for 9 sec. The payload for the first five-stage Scout flight was the Hawkeye magnetospheric satellite weighing 27 kg. Design orbit was 499 × 28,750 km, but the launch orbit was 3,450 × 201,600 km. This new derivative was designated Scout E. The basic Scout D in use now, has the Algol 3 first stage producing 48 tonnes of thrust, the Castor IIA second stage of 28 tonnes thrust, the third stage Antares IIB with a 12.7 tonne thrust and the Altair III (FW-4) with a thrust of 2.6 tonnes. The configuration is 22.9 m long and weighs 21.4 tonnes at liftoff. The payload capability is 188 kg to low earth orbit.

The Scout has consistently provided a reliable launch capability for small, low-weight satellites and as such is the only NASA launch vehicle expected to remain in service when the reusable Shuttle becomes operational in 1980; the heavy lift capability of this new manned launcher will render it uneconomic to dispense with a cheap and effective rocket at the bottom of the weight-lifting scale. Now moving toward its third decade of use, it has been launched on more than 100 missions with a high reliability rate in that less than 5% of total launches have ended in failure. A commendable performance for the demanding tasks the vehicle will continue to face.

Sergeant:

In pursuit of a replacement for the Corporal short range ballistic missile, the US Army developed the Sergeant during the early 1960's and introduced it to operational status in 1962 so that it could supply short range cover to the longer range Pershing. So named because of its progressive operational role to Corporal, the Sergeant emerged as a single-stage, solid propellant rocket with a length of 10.5 m and a diameter of 78.7 cm. The forward section was an elongated cone with straight sides converging to a point and four aerodynamic fins for stability clustered round the base.

With an airframe of steel sheet, the missile was guided by a Sperry Rand inertial navigation system operating through elevators on the trailing edge of the fins. The Thiokol XM-100 rocket motor produced a thrust of 20.4 tonnes and launch weight was around 4.58 tonnes. The missile was transported by air to the battle front and contained within four storage sections comprising the warhead, the guidance unit, the main solid propellant motor section and the aft control surface unit. The US Army boasted a capability for readiness which required only 6 personnel and a few minutes warning to place the missile on its launcher and fire it toward its target. The launcher incorporated its own erector which positioned the missile at a near vertical angle for firing.

With inertial guidance, the SRBM was relatively safe from the countermeasures equipment operated by Warsaw Pact forces at that time and could carry either a high explosive or nuclear warhead across a selected operating range of between 40 km and 120 km. In its prime role, it was a front line battlefield weapon capable of hitting advancing tank squadrons or a rear support missile aimed at supply depots or stores supporting advancing enemy forces.

Operated in conjunction with the much larger Pershing, which had an effective range of more than 700 km, Sergeant was deployed with US Army units in Germany from 1963 and went out of production in 1967, although operating refinements continued with the retrofitting of advanced guidance equipment and battle procedures. Operated by West German forces in addition to US Army units, the former with high explosive warheads, the Sergeant was being replaced with Lance missiles in 1972 but some units still operated the weapon as late as 1977.

Shotput:

A grouping of basic and readily available solid propellant rockets in 1959, resulted in the so-called Shotput composite rocket to launch a series of test packages on ballistic trajectories outside the atmopshere. The test payload was a packaged precursor of the Echo communications satellite, essentially an inflatable balloon, which was expected to be placed in Earth orbit by a Delta launch vehicle. Tests would be carried by bouncing radio waves off its spherical surface. Before this could be introduced operationally it was felt desirable to test the sequence of inflation by boosting a test model to high altitude and performing the inflation sequence before it fell back into the atmosphere.

Instigated by NASA, the Shotput configuration was so named because its mission was thought to be akin to the familiar sport of that name. The selected rockets were the solid propellant Sergeant, Recruit and ABL X-248 designs. The Sergeant provided the first stage and was boosted by two Recruit rockets with a second stage consisting of the X-248. In essence the configuration resembled a four stage Argo D-8 Journeyman sounding rocket without the second and third stages.

In the Shotput configuration the Sergeant produced a thrust of 22.7 tonnes for 27 sec and the two Recruits delivered a combined thrust of 31.7 tonnes for 1.9 sec. Maximum thrust at liftoff was 54.4 tonnes. The Sergeant had been originally designed as a short range ballistic missile and the Recruit was applied to the Little Joe booster. The second stage X-248 motor produced a thrust of 1.4 tonnes for 42 sec and was used as the third stage of the Delta launch vehicle between 1960 and 1965 and as the fourth stage of the Scout low-weight satellite launcher.

In this Shotput configuration the assembly was 78.7 cm in diameter with a length of 8.3 m exclusive of the payload. In 1959 and 1960 the Shotput was used in 5 launches during Echo balloon inflation tests, boosting the payload to a height of 400 km. Shotput was also applied to tests of the Italian-funded satellite project, San Marco.

Shuttle:

Designed as a revolutionary new concept for launching payloads into space, the Space Shuttle will replace most current NASA and Air Force launch vehicles by the mid-1980's. NASA currently operates Scout, Delta, Atlas-Centaur and Titan IIIE/Centaur launch vehicles for sending satellites and space probes on flights ranging from Earth orbit to the planets and beyond, and these provide a payload capability from 180 kg to Earth orbit for the Scout to more than 3,500 kg to the planets for the Titan with Centaur upper stage. Only the Scout will remain in the launcher inventory to complement the Shuttle, by launching lightweight payloads into unique Earth orbits. The Air Force currently operates Titan III derivatives with various upper stages, and these too will be replaced by Shuttles from early in the 1980's.

Whereas all previous and existing launch vehicles are expendable, in that the stages are launched only once and then discarded during the ascent to space, leaving the last, or terminal, stage to enter the same orbit or escape trajectory as the payload, the Shuttle will be largely reusable so that only a few need be produced to cover several years' operations. This, essentially, is the conceptual philosophy of moving launcher services from many different types of expendable rocket to one, reusable, launch system. Peripherally, launch costs would be dramatically reduced because of the reduced hardware needed to support a launch capability and payload costs would be reduced, in some cases by up to 50%, because the Shuttle could perform repair tasks in space or return expensive satellites to Earth for periodic servicing and refit, thereby reducing the number of critical items required to support a given objective.

Although the Shuttle concept is not new, potential space-faring nations have sung the virtues of a reusable transporter system for more than 30 years, the NASA project now reaching fruition, began in a different mode to the role it now waits to fill. In 1968 NASA was engaged in planning long term objectives for the so-called Post-Apollo space programme, in effect setting a strategy for the development of an increasingly viable manned presence in orbit beyond the finite number of lunar explorations using Apollo type spacecraft launched on massive Saturn V type expendable rockets.

Central to the expanding use of manned space flight was a large space station continually housing between 12 and 24 people on shifts and periodic visits from where scientists could study the characteristics of the Earth, survey its land and ocean reaches for new mineral resources, evaluate the long duration effects of weightlessness on the human body, set up unique manufacturing facilities and provide an engineering and operations base from which flights to Mars could be attempted.

Because of the heavy demand on a logistics system, made necessary by the space station, a study of potential traffic requirements between the surface of the Earth and orbiting space stations displayed a need for some form of reusable transportation system which would, by virtue of its reusability, provide cheap and routine access in both directions, with the capacity to carry large supplies of materials to keep the station in business.

Thus was born the Shuttle and on 31 January 1969, four industrial contractors were given NASA money to study possible configurations of such a rocket, called the Integrated Launch and Re-entry Vehicle or ILRV. A host of reusable, semi-reusable and only partially reusable concepts were studied by the NASA Space Shuttle Task Group. When the four companies reported back to the space agency on 1 November 1969, there was wholehearted recommendation for a fully reusable two-stage approach. Between November 1969 and the end of January 1970 NASA set out its basic requirements for a vehicle based on the engineering studies performed during the four ILRV industrial feasibility studies.

During these few months the name 'Space Shuttle', more a definition of purpose than the philosophical or mythical title usually given to rockets, had become firmly ensconsed in NASA terminology and when industry was asked to bid for definition contracts on 18 February 1970, the Space Shuttle was seen as a manned reusable two-stage launcher, which would probably enter service in about 1977. On 12 May 1970 two companies were chosen to perform competitive design studies which would lead to selection of a single contractor to begin development and fabrication in 1971: North American Rockwell (now Rockwell International) and McDonnell Douglas.

But several persons close to the developing Shuttle programme had doubts about the desirability of choosing a two-stage concept and alternative configurations were looked at in a new set of 11 month contracts which went to Grumman/Boeing, Lockheed and Chrysler in June. Rockwell and McDonnell Douglas, meanwhile, pressed ahead with definition work on the preferred concept.

This envisaged two winged vehicles, one smaller than the other, with the smaller mounted on the back of the larger and set up in a vertical configuration for launch. The larger vehicle would sit tail-end down on the launch pad called the Booster, and ignite a cluster of downward firing rocket engines in the rear to lift the smaller vehicle to a height of about 80 km. When the Booster had expended the propellants in its fuselage, the smaller vehicle, or Orbiter, would fire off from the side of the ascending Booster and use its own rocket motors to reach orbit. A large portion of the Orbiter's fuselage would be given over to a cargo bay, with doors on the top of the fuselage, and it would be manned with a forward-facing crew on a flight deck similar to that of a conventional aircraft.

The Booster meanwhile would reach the top of its arching trajectory, pitch over and re-enter the denser layers of the atmosphere before starting turbofan engines so that it could fly the several hundred kilometres to a runway close by the launch site and land like an ordinary aeroplane. The Booster was little more than a conventional rocket stage with wings, a tail and a forward area, housing a flight crew for manned operation. The Orbiter would also have wings, a tail and a cockpit and when, at the end of its mission, it came back down to Earth the wings would generate lift, permitting it to glide into dense layers of the atmosphere, extend a group of internally housed turbofan engines and land just like the Booster on its undercarriage.

Propellant for the Orbiter's own rocket engines, used only for lifting off of the Booster and ascending to orbit, would be carried in tanks either side and forward of the cargo bay, whereas propellant for a set of smaller engines would be carried in the tail section and be used for reducing orbital speed, causing the vehicle to fall toward the atmosphere in like manner to a manned spacecraft of Mercury and Gemini type. Unlike earlier space vehicles, however, the Orbiter would fly a controlled lifting entry profile instead of the ballistic entry path of earlier space vehicles. Also, because the vehicle would be reusable, it would have to be covered with a special heat-sink material that could preserve the nature of the insulation rather than burning off like ablative compounds used as heat shields for Mercury, Gemini and Apollo spacecraft.

Both vehicles would look like aeroplanes because they required aerodynamic surfaces to fly back to their bases, becoming hypersonic powered aircraft in the atmosphere. When ILRV work had been under way in 1969, preparatory to the selection of the two-stage reusable configuration, it had been observed that the shape of the Orbiter's wing would substantially influence the so-called cross range of the descending vehicle as it came back down through the atmosphere. Cross range was defined as the distance to left or right that the Orbiter could reach by using its wings to change the amount of lift versus drag that was adopted by the profile of the lifting surface. In short, a high-lift configuration allows the descending vehicle to fly farther than a low-lift profile and this applied to the shape of the Orbiter's lifting surface, or wing.

It should be remembered that while the Orbiter would encounter the atmosphere at a vertical altitude of 120 km it would still have to fly several thousand kilometres to the runway. Cross range was defined as the distance to left or right of this groundtrack; there would be sufficient energy in the vehicle to permit it to make these manoeuvres since it would be entering the atmosphere at a speed of 28,900 km/hr. With a delta wing configuration, the Orbiter could achieve a cross range of 2,040 km and only 370 km with a straight wing configuration.

When the original specification had been written early in 1970, the space agency required a vehicle that would be capable of carrying a payload weight of 11.34 tonnes to a circular orbit 500 km above the Earth inclined 55° to the equator. By the end of the year, six months after definition studies had been started at Rockwell and McDonnell Douglas, a change was made to the basic concept of the Shuttle's intended role.

Since late 1969 these two aerospace companies had been conducting competitive evaluation of the proposed 12-man space station and early predictions on the anticipated cost of the project, left doubt as to whether NASA would be able to finance concurrent development of both this and the Shuttle. With severe cuts in the NASA budget, and considerable analysis of the monetary allocation expected in future years, the space agency approached a serious time of decision: what to do about retaining a manned capability in space, for if the space station was to be cancelled in Congress, it would be difficult to justify development of the Shuttle, since this was, at that time, the raison d'être of the reusable transporter. Moreover, a meeting between NASA and the Air Force at Williamsburg, Virginia, in January 1971 had re-defined the performance requirements and in addition to lifting 11 tonnes to an orbit of 500 km inclined 55° to the equator the Shuttle was now required to send 29.484 tonnes to a 185 km due east orbit.

The higher payload to a lower orbit was not a natural equivalent to the lower payload weight to the higher orbit and brought certain constraints to any thought of reducing the size of the Shuttle as an economic move. The high cross range capability of 2,040 km to left or right of the groundtrack was also stipulated as mandatory and that kept the design at a sophisticated level, bringing high temperature requirements to the heat-sink thermal insulation due to the increased thermal loads imposed by a maximum cross range re-entry. The conditions had been laid down by the Air Force who had special requirements which demanded these uprated technical specifications; Air Force participation in the Shuttle programme was becoming more and more important, as NASA concluded a generic re-think on its own role.

As 1971 moved to its spring, contractors previously studying the big space station moved to a modular concept whereby segments of a space station would be sent into orbit by the Shuttle. Originally, the space station had been thought of as a multi-deck structure launched into orbit by a two-stage version of the Saturn V. It would be capable of growing to a fully developed space base supporting 100 personnel by additional segments also launched by heavy lift rockets, such as Saturn V and see 10 years of continuous operation before replacement.

The enormous cost of this fully fledged on-orbit research station was simply too great to contemplate and the modular space station concept looked more and more favourable. The Shuttle would still be needed for transporting supplies and could, therefore, be justified before Congress. It was from this scale down in space station objectives that the definitive function emerged for Space Shuttle operations. NASA reasoned that if the Shuttle could be used for sending segments of the space station into orbit, replacing the function of the large Saturn V, and dock these sections together month by month, it could also send other satellites into space and if it could replace the Saturn V it could also replace other NASA rockets.

For a while this promised to provide a fall-back reason for development of the Shuttle because if, at worst, it was found to be impossible to get Congress interested in even a small modular space station, NASA could justify the Shuttle on the grounds that it would provide a more economical day to day launcher for everything sent into orbit. Before very long this 'fall back' role would be seen as the only role by which to justify the new reusable transporter.

Meanwhile, studies went ahead on a modular space station in the hope that both station and Shuttle could be financed concurrently but, as NASA already realized, this would mean severe limitations on the development cost of the transporter, if there was to be sufficient money for both to be built together within the projected funding ceiling expected in future years. However, the Williamsburg Conference in January 1971 had set the performance firmly at the upper end of the potential spectrum and with a payload lifting requirement of nearly 29.5 tonnes to low earth orbit, there was little room for technical adjustments to lower the development cost; the cargo bay had been set at 18.29 m in length by 4.57 m in diameter and this would remain sacrosanct along with the performance capabilities.

The initial definition contracts to Rockwell and McDonnell Douglas ended in June 1971 and both companies announced projected development costs more than twice the value set by NASA. With an expected cost of $10,000 million through research, development, fabrication and test, the fully reusable Shuttle was obviously too expensive to take before Congress for approval, even though this was less than half the cost of Apollo development and 6 Moon landings, neither the White House nor Congress would look favourably at another expensive commitment to several years of high funding.

On 1 July 1971 NASA issued four-month contract extensions to Rockwell and McDonnell Douglas so that industry could evaluate technical changes necessary to cut the development cost. There were four primary areas that could possibly lead to the reduction. The first concerned the Booster. If the Shuttle could be developed initially with the Orbiter riding on a conventional expendable Booster, the manned reusable winged Booster could be introduced at a later date when funds permitted. The Booster was a very large element in the dual configuration and if the Orbiter could leave the Booster at a lower altitude and less speed than proposed in the definition studies, thermal problems with the Booster coming back down through the atmosphere would be reduced with a consequent reduction in the size of the Booster structure.

In rockets, as in aircraft, metal costs money and this was a good way to reduce the development bill as well as reducing the stress on Booster thermal protection requirements. Reduced Booster demands was the second potential area for financial manoeuverability. The third concerned the Orbiter.

While recognizing that both its own interests and those of the Air Force could only be served in the long run by operational availability of the full size Orbiter, it was proposed that NASA could initially develop a Mk. I vehicle which had limited capabilities in the form of a reduced size and payload capability and decreased potential in orbit. A fully fledged Shuttle, or Mk. II, could then pick up the original specification yet phase in the costs of the expensive and necessary model.

This was essentially a similar type of treatment to that proposed for the Booster: execute a phased development approach and spread the development cost over several years. It had the advantage of bringing down peak-year budget requirements, a desirable feature of many aerospace programmes as far as the US Office of Management & Budget (OMB) were concerned. The fourth and final area for candidate re-modelling was concerned with the propellant carried within the Orbiter for use in its own rockets from Booster separation to orbit. Readers will recall that the basic Orbiter design had required propellant to be carried in tanks either side and forward to the voluminous cargo bay. It had already been decided that the engines used in the Booster and the Orbiter would have to use high-energy propellants in the form of liquid oxygen and liquid hydrogen and the very cold temperatures necessary to keep them in a liquid state, brought severe, and again expensive, technical difficulties to the design. With liquid hydrogen and liquid oxygen retained at −217°c and −147°c respectively the exterior surface of the Orbiter would increase in temperature during the ascent, a problem common to all rockets using these cryogenic fluids, but to have them contained within the Orbiter where areas such as the crew compartment would have to be kept at 21°c compounded the technical problems.

Partly for this reason, but also because the Orbiter was required to be excessively large just to accommodate propellant tanks that would only have to be used during the few minutes between Booster separation and reaching orbit, NASA asked the contractors to look at the possibility of taking these tanks out of the Orbiter and putting them in an external tank configuration which could be discarded as the vehicle reached orbit. As early as spring 1971, while the original definition studies were still under way, NASA had given Rockwell and McDonnell Douglas extra funds to study the possibility of taking the liquid hydrogen tank out of the Orbiter and placing it on top of the wings for use during the ascent before jettisoning their empty cases.

This had been seen to provide a valuable cost saving bonus in that it reduced the overall size of the Orbiter, without changing the size of the cargo bay or reducing performance capabilities. Through the definition contract extension between July and September 1971, NASA worked with the two prime teams headed by Rockwell and McDonnell Douglas to seek and find a configuration that would lower the projected development cost. In addition, parallel study contracts went out to a Grumman/Boeing team and to Lockheed in the July in a massive government/industry tie-up, not seen in a civilian space project since a 1961 decision by President Kennedy marshalled resources for a Moon landing by the end of that decade. Five big names in aerospace were converging on a common problem instigated by reluctance on the part of the Office of Management & Budget to give its blessing to another high cost investment in space technology.

It should be said, at this point, that the most economical approach to low-cost space transport, with every element reusable, was the manned Booster/Orbiter approach that reached its nadir with early definition studies at the beginning of 1971. It promised to lower launch costs to just $135 per kilogramme sent into orbit, but at $10,000 million the development bill for this advanced concept was not acceptable to OMB, the branch of the US Executive which has responsibility for federal expenditure. At $135/kg the transport cost was just one-tenth of the existing cost of sending up payloads by expendable throw-away rockets. Trade-offs in the form of selected compromises discussed earlier would increase the launch cost away from the best achievable value, but the saving in development cost would more than offset the slightly less rewarding approach. This was the important criteria established by the OMB which forced NASA to seek a cheaper concept.

In September 1971, inspired by NASA thinking on a phased approach to Booster selection, whereby an existing expendable rocket would be used initially, Boeing proposed a modified Saturn V first stage, the S-IC, to cut costs and satisfy the financial arguments. The idea envisaged use of the basic S-IC but with wings and a tail added together with a forward crew compartment. An Orbiter could be attached to the side of the modified S-IC with external hydrogen tanks jettisoned before getting into orbit. Boeing also proposed a still cheaper concept whereby the expendable S-IC could be used as it came off the production line, but with a cylindrical tank on top of the stage carrying the Orbiters propellants. The Booster would separate at a height of 70 km leaving the Orbiter and the cylindrical tank locked together so that the Orbiter could extract hydrogen and oxygen from the tanks in the cylinder and burn these in its own engines. As developments matured, this would be closer to the final design concept than anything yet proposed.

Without delay, NASA saw great promise in this design which had gradually slipped away from providing a unique manned Booster with wings and turbofan engines for literally flying back to its base to one in which the booster was a conventional off-the-shelf design, unmanned and expendable. The space agency had already decided the previous month (August) to take the propellant tanks out of the Orbiter design and place them in some sort of jettisonable pod, albeit a pod that would be longer than the Orbiter itself. With tanks in the Orbiter as originally envisaged the vehicle was required to be about 63 m in length, with the tanks removed to an exterior location the Orbiter need be only 38 m long yet still retain its capability of taking 29.48 tonnes to low earth orbit in a cargo bay 18.29 m long and 4.57 m in diameter. In effect the proposal to put wings, tail and a crew compartment on the basic Saturn V first stage (called RS-IC for Reusable S-IC) and provide two Orbiter mounted pods for the liquid hydrogen was a last ditch attempt to come up with the semblance of a configuration that held on to the original concept.

With NASA now committed to an external tank for both liquid oxygen and liquid hydrogen Orbiter propellants, and looking toward some form of unmanned booster, concepts rolled fast and freely from the aerospace companies busily trying to seek a compromise between development cost and launch cost. Boeing had already proposed a basic S-IC stage, but these used comparatively low energy propellants (LOX and kerosene) and would be too inefficient for the requirements. Apart from this the S-IC Saturn V first stage used technology already a decade old and carried a higher unit production cost than that which would be required for the Shuttle.

On 7 October 1971, NASA issued further extensions to the definition studies being performed by Rockwell, McDonnell Douglas, Grumman/Boeing and Lockheed. The original contract had ended in the June and a four-month extension from the beginning of July to the end of October had resolved certain areas of the technical re-direction; this latest extension would go from the beginning of November 1971 to the end of February 1972 with a further two month option beyond that. Its purpose was to select a booster which would be compatible with the performance specification, while at the same time providing reduced development costs, and low launch costs.

Two basic concepts had emerged: parallel burn and series burn. In the parallel burn approach the engines on the Orbiter would be ignited at the same time as those on the booster, a new philosophy for the Shuttle, but a concept that had been applied to other, albeit expendable, launch vehicles. It was, in effect, like the Delta rocket with strap-on boosters: all four engines ignite at liftoff and the boosters are discarded when their propellant is expended. The only real difference lay in the continued burn requirement for the Shuttle Orbiter engines which would have to fire all the way into orbit unlike the Delta which relinquishes its first stage role to other stages on top.

The price to be paid here, of course, was that the external propellant tank feeding the Orbiter engines with liquid hydrogen and liquid oxygen would have to be commensurately larger since the motors would be firing from the ground up instead of igniting at altitude. But this was not considered a drawback. It would have been had the Orbiter's propellant tanks still been integrated with the structure of the winged vehicle, but that was now reduced to its minimum feasible size and growth in the size of the external tank would have no impact on the size of the Orbiter – the most sensitive element as far as cost was concerned.

The exact type of booster needed for the parallel burn proposal was the subject of the contract extension and NASA asked the industrial teams to look at very large solid propellant boosters, never before used for a manned vehicle, medium sized solid propellant boosters and liquid propellant boosters using a pressure-feed system to reduce costs. Two large solid propellant or pressure-fed boosters would be needed. If the small solid propellant booster design was seen to be in favour the Orbiter and its external tank would need four.

The other concept, series-burn, was similar to other multi-stage rockets in that the Orbiter and its large external propellant tank would be mounted on top of the booster taking over only when the booster had expended its propellant. Candidates here were clustered solids, an uprated cluster of liquid propellant F-1 engines of the type used in Saturn V, liquid propellant high-pressure engines or the pressure-fed liquid propellant engine mentioned earlier for the parallel burn concept.

As 1971 drew on toward Christmas, NASA was determined to find a way of reducing the development cost. Everything was now focused on the results of the definition contract extension and the space agency would decide on the parallel burn or series burn concept as a result of the engineering analyses, choosing among the five alternative booster configurations according to which revealed the highest technical value and the lowest projected development cost. NASA was acting on an ultimatum from the Office of Management & Budget: find a Shuttle configuration that would cost no more than 5,000 or 6,000 million dollars to develop, or forget the idea.

The space agency was all but stymied. The only hope lay within the concerted studies developing among the industrial contractors and they simply had to find a cheaper booster programme if NASA was to retain a manned space flight capability beyond the time when Apollo equipment ran out. The Orbiter design was now small and as cheap as it could be made to be and everything hinged on a cheap booster to get the programme off the ground. It now seemed very clear to even the most optimistic planner, that the phased approach which had forced NASA to look at an interim unmanned booster before proposing development of the manned, winged transporter was the only one that would be approved by the OMB or Congress. It was proving to be a tough and unrelenting struggle just to get the cheap system introduced. Whatever NASA settled for in the way of a booster, would be the only one it would get.

Because of this it was recognized that the booster would have to be reusable as well as the Orbiter and along with their evaluation of the different concepts and configuration, industry was also asked to propose a method by which the booster could be used again. This would keep launch costs low enough to make the project worth while. If the unmanned booster was to be replaced by a fully reusable manned booster the agency could afford to delay full reusability until the definitive article could be introduced, but there was little or no confidence that the agency would be allowed to get the desirable booster it wanted and had planned for a year ealier. Whatever it settled for now would have to last and that meant making it reusable to preserve the economics.

Meanwhile, NASA had called upon an independent company, Mathematica, to conduct an economic and statistical study of the Shuttle and to come up with figures which could help the agency to decide if the Shuttle could be used for other duties than supplying a space station. It had seemed apparent to the space agency that the performance capability of the Shuttle would enable it to replace existing expendable rockets and launch satellites into orbit. This, at one time a bonus capability, was now becoming more apparent as the possibility of a manned space station became more and more remote.

Consistently, the studies showed that a space programme based on the Shuttle would require less money than one accomplishing the same objectives, but using expendable rockets. NASA took hold of these studies and pushed hard on the door of Congress bringing testimony not only from Mathematica, a private analytical organization openly vetted by the agency to publicly display impartiality, but figures from Dr. Oscar Morganstern a leading US economist, Aerospace Corporation the West Coast engineering analysts and Lockheed Missiles & Space Co., the aerospace evaluation team. Never before had NASA grouped so many financial experts to an independent assault on the domain of the Office of Management & Budget.

The first Mathematica study had been handed to OMB in August 1970 and this had been the product of a NASA generated analysis, but by the autumn of 1971 the agency brought its experts into open and public battle with what had hitherto been the function of the OMB, to contest OMB ruling on a financial decision. The fight had evolved on two fronts and in this battle the more fronts NASA could stimulate, the greater its chances of proving a need for the Shuttle. On the one hand were definition extensions delving deep into technical means for lowering the projected development cost and on the other it was fighting OMB at its own game and showing a public need for the Shuttle in that launch costs would be dramatically reduced. All attention now turned to proving the Shuttle's worth as a satellite launcher, capable of sending payloads into space at a fraction of the cost demanded by expendable rockets. NASA knew it would not gain immediate acceptance of this reusable transporter as a supply vehicle for space stations because congressional reluctance to approve two major new thrusts into space had already dimmed the prospect for a manned orbital facility.

Late in 1971 Mathematica, headed by economist Oscar Morganstern, now working with Klaus P. Heis, were asked to dig deep into the financial prospects for the Shuttle as a replacement for existing rockets. Again the figures came out in favour of the NASA plan. But still the OMB was unmoved and demanded a technical solution that could be examined in its entirety; NASA pointed out that it would still be several months before the definition contract extensions could provide the solution and decide on the best configuration.

During the period between September and November each year, the US government agencies liaise with the Office of Management & Budget to agree on budget allocations for the financial year starting in the following summer. Late in 1971 NASA was concerned to get budget funding for an actual start on the Shuttle, but OMB, reluctant to agree to money being allowed before the technical studies were complete, refused to go along with the request. It wanted time to review the definitive design to see that the economic arguments really held true. But, if they waited, another year would go by before a contractor could be selected to build the Shuttle and in the meantime the industry would lose confidence, teams would start to break up and second thoughts in Congress might kill the project.

In an unprecedented move NASA began a series of behind-the-scenes steps to go to a higher authority and overrule the Office of Management & Budget's procrastinating reluctance to provide the funds for a start on the project. In December, top executives at NASA, acting under the instructions of Administrator James B. Fletcher, sought a meeting with President Nixon. Delays and a travelling US President brought in a new year and time was running out. The President would go before Congress in late January and present the federal budget which would run for the 12 months beginning 1 July. If NASA failed to get Shuttle funds requested before Congress, it would be 18 months before the next budget year began on 1 July 1973.

Telephone calls and continued pressure from NASA finally got the White House executives to schedule an audience with the President, but the NASA chiefs would have to fly to California to catch Nixon at his San Clemente office. They did and on the morning of 5 January 1972, the President spent 45 minutes with James Fletcher, head of NASA, and George Low, deputy chief, while the argument was put. It was a token meeting. Nixon had already reviewed the Shuttle papers, been in letter communication with Fletcher and made up his mind.

At 11:15 a.m., local time, a press conference was convened at the San Clemente Inn. President Nixon's statement read, 'I have decided today that the United States should proceed at once with the development of an entirely new type of space transportation system designed to help transform the space frontier of the 1970s into familiar territory, easily accessible for human endeavour in the 1980s and 90s.'

The decision had been announced just 19 days before the next budget would be presented to Congress. Now emphasis turned toward resolving the technical problems and, in the immediate future, choosing a booster concept and configuration that would be compatible with the lowest development cost. By the end of January 1972 Mathematica had presented its final report to NASA, indicating that either a pressure-fed liquid propellant system or a solid propellant booster in parallel or series burn configuration, was to be economically preferred.

On 22 February, NASA's Office of Manned Space Flight reviewed technical studies from the contractors and looked specifically at the results of engineering analyses, but with more than an interested eye on the economics and proposed costs for the different configurations. The two most economical proposals were for the liquid propellant pressure fed boosters, in either parallel or series burn configuration, and the parallel burn solid propellant booster. The pressure-fed booster would render a total Shuttle development cost of $7,000 million with each flight costing $220/kg of payload weight. The parallel burn solid propellant configuration would cost $5,500 million to develop, but raise the payload cost per kilogramme to $356.

Little more than two weeks later, on 15 March 1972, NASA announced its decision to go for development of a parallel burn solid propellant booster configuration. There were good technical reasons to believe that the boosters could be recovered and used again, although this had never been tried before, and of course the Orbiter was totally reusable with a promise that each winged vehicle could provide between 100 and 500 flights before retirement. Only the large external tank carrying propellant for the Orbiter would be expendable.

At last industry had its specification and government had given its approval to development and testing. On 17 March, NASA asked industry to submit their proposals for the Orbiter by 12 May and four companies responded: Rockwell, Grumman, McDonnell Douglas and Lockheed. They were charged with producing documents supporting their own specific proposals for the design of the Orbiter with consideration to the concept and configuration selected by NASA. Manpower proposals, subcontract distribution, annual funding requirements and the overall development cost estimate were important aspects of the documentation.

As with most space projects, about 90% of the federal expenditure would go to industry, stimulating the private sector and contributing toward the nation's technology base. Separate contracts would be let for the external propellant tank and the solid rocket boosters, but as these would not require as long a development time as the Orbiter they would be awarded in mid 1973 and late 1973 respectively. There would be separate contracts for the Orbiter, its tank and the solid rocket boosters going to separate companies.

Although the official go-ahead for full Shuttle development had not been granted until January 1972, the enormous problems associated with the propulsion system had pressed NASA to award a contract to Rocketdyne for main engine development in July 1971. This had been one of the reasons for concern when, later in 1971, NASA had a confrontation with the OMB. There would have had to be a reduction in engine development schedules if NASA had failed to get a funded start on the Shuttle proper in 1972 and this would have resulted in stagnated work on the engine and an increase in the associated costs; many economists fail to recognize the need to maintain momentum in a high technology project, thus avoiding a prime cause of inflated development costs and it is often necessary to spend more in the peak years to sustain original estimates.

As a result of the re-modelled technical specification associated with the Shuttle system, the engine requirements were finally settled in April 1972. Basic technology for the Space Shuttle Main Engine (SSME) had developed between the dates of contract award and the final specification. The SSME requirements were far more demanding than encountered hitherto. Not only would the engine have to introduce a new technology in that it was required to operate at very high internal pressures, but it would also have to be capable of at least 100 re-uses for a total life of more than 13 hours. Each flight would require the three engines to burn for less than 9 minutes, but the accumulated duration was far in excess of anything asked of a major propulsion unit before. No large rocket engine had yet been built to fly back and forth through the atmosphere, the only real competitor for that record being the X-15 (see Section 3, X-15).

The SSME would have to provide a vacuum thrust of 213.19 tonnes at a chamber pressure of 209 kg/cm² and yet be throttleable for precise thrust control during the ascent. The pressures were three times that normally adopted for a liquid propellant engine and the propellants would be fed to pre-burners before combustion in the main chamber. This provides a high level of performance from the liquid oxygen/liquid hydrogen propellants and hot gases generated in the pre-burners operate high pressure turbopumps which drive the propellants into the main chamber. The SSME is designed to operate at thrust levels of between 106.5 tonnes and 232.38 tonnes according to the throttle setting, with a vacuum specific impulse of 455 sec.

Before long it was considered technically expensive to retain the original objective of 100 flights and 13 hours of accumulated operation and the SSME design settled for a flight life of 7½ hours with 55 flights accumulated before replacement.

Meanwhile, the four aerospace companies responding to a request for Orbiter proposals, provided documentation to NASA on 12 May 1972 outlining their individual, and highly secret, estimates for consideration. The winning submission was announced on 25 July, when Rockwell International's Space Division officially got the contract to build the Orbiter and integrate development of the overall system. Readers are referred to page 215 for views of the configuration as it stood from June 1972.

In this first really definitive concept the two solid rocket boosters (SRB's) would ignite together with the three liquid oxygen/liquid hydrogen engines in the tail of the Orbiter providing a launch thrust of 4,254 tonnes. If anything went wrong during the first few minutes of ascent two Abort Solid Rocket Motor (ASRM) assemblies, strapped to the Orbiter's tail would ignite to lift the Orbiter free of the Boosters to an altitude from where it could turn round and fly back to a landing. At a height of 40 km and a speed of 4,320 km/hr the boosters are separated and fall away to be recovered from Atlantic or Pacific Ocean splashdown points and used again.

Meanwhile, the Orbiter carries on toward orbit and shuts down its three main engines before releasing the External Tank (ET). Because the ET provides the propellant for the Orbiter to put itself into space, it too goes into orbit, but a small forward-firing rocket motor in the nose of the ET would be fired to slow the tank and bring it back into the atmosphere. Unprotected from the severe heating effects of friction the ET breaks up and is destroyed. This is the only element in the system to be expended, but the design provides a production line supply at minimal cost; the expensive rocket motors are carried in the tail of the Orbiter and are recovered after each flight.

When the Orbiter returns to Earth two rocket motors in the tail produce 2.27 tonnes thrust each to reduce the velocity and cause the vehicle to fall toward the atmosphere. These same engines could be used for adjusting the orbit or performing rendezvous with a passive satellite, etc., during the orbital life of the vehicle. After re-entering the atmosphere and using the lifting surfaces to fly a controlled descent, the Orbiter lands at the pre-designated runway like a conventional aircraft. Two turbofan engines would be mounted on the rear of the cargo bay so that it could be ferried from landing site to launch site, although landings from space would usually be made at the launch site.

This was the design concept as it stood in mid-1972. By the end of the year the Abort Solid Rocket Motor assemblies had been deleted in favour of a so-called Return-to-Landing-Site (RTLS) routine whereby the Orbiter itself jettisons the boosters and uses its three SSME engines to provide the available 510 tonnes of thrust to lift it clear and then return to a landing site after jettisoning the external propellant tank. Further design changes were to follow and in February 1974, NASA changed the concept whereby two turbofan engines would be fitted to the rear fuselage so that, like an aircraft, the Orbiter alone could be flown at subsonic speed from the assembly plant to the launch site or from a remote landing area back to its base.

Instead of flying itself on cross-country delivery, the Orbiter would be carried on top of a large transport aircraft like the Lockheed C-5A Galaxy or the Boeing 747 Jumbo Jet. By the end of 1974 NASA decided to purchase a Boeing 747 for this purpose. The first flight of this dual configuration would come in 1977 during aerodynamic trials when the first Orbiter would be taken to a height of about 9,000 m and flown off the top of the carrier plane in simulated descent tests of the actual landings coming at the end of later flights from space. This would provide an opportunity to rehearse the critical handling manoeuvres necessary to get the 82-tonne Orbiter back down on the ground before committing it to space flights.

The 1970 concept of turbofan engines extended in the atmosphere for powered descent had been changed in 1971 and the space agency felt sufficiently confident of its ability to land the Orbiter without power, that it relegated the vehicle to perform the role of a glider, using the energy from its 28,900 km/hr entry to the atmosphere to steer an accurate course to the runway.

On 16 August 1973 the third big contract was let, after Rocketdyne for the SSME in July 1971 and Rockwell for the Orbiter in July 1972, when Martin Marietta was appointed to build the external tank (ET). The ET would be set up on a production line because this was the only element which would not be re-used, necessitating a separate article for each flight. Nevertheless, the ET represented the largest single propellant tank structure yet built for a rocket, despite the fact that it carried no engines, its purpose being to feed liquid hydrogen and liquid oxygen to the Orbiter where they would be consumed in the three SSME motors in the tail of the winged transporter.

A decision in March 1973, five months before the contract went to Martin Marietta, had deleted the small forward-firing rocket motor which would have been located in the nose of the ET so that it could be brought out of orbit and destroyed in the atmosphere. The three Orbiter SSME motors would shut down shortly before reaching orbital speed, rapidly followed by release of the big external tank which, with insufficient velocity to go into orbit, would fall back to the Earth by itself. The Orbiter, meanwhile, would fire up its two manoeuvering engines delivering 2.27 tonnes thrust each and nudge itself up to orbital speed. In a final change these engines would be uprated to 2.7 tonnes thrust each.

On 20 November 1973, NASA awarded the last major Shuttle contract by selecting the Thiokol Corporation to build the large solid rocket boosters (SRB's). These too were larger than anything of the type built before with a capacity to deliver up to 1,497 tonnes thrust each, considerably higher than the two big solid rocket motors used with the Titan III, each one of which produces a thrust of 544 tonnes. However, a protest from Lockheed held up work until NASA Administrators reviewed the petition and endorsed Thiokol as contractor on 27 June 1974.

Rockwell International's Space Division began work on the first Orbiter, vehicle 101, on 4 June 1974 and by the end of 1975 all the major sub-contractors had delivered wings, cargo bay doors, vertical fin, centre fuselage, etc., and roll-out from the hangar at Palmdale in California was celebrated on 17 September 1976. From here the Orbiter was rolled a short distance to the NASA, Hugh L. Dryden, Flight Research Centre at Edwards Air Force Base from where it would spend all of 1977 performing tests with the Boeing 747.

On 18 February the Boeing carried Orbiter 101 on its back during a 2 hr 5 min flight to test the air-worthiness of the dual configuration and by 2 March, the five so-called captive-inert tests had been completed; a sixth was cancelled as being unnecessary in the light of success with the test schedule. The captive-inert series implied that the Orbiter remained attached to the Boeing during flight and was not manned by a crew. This was followed in mid-June by the first of three captive-active flights. The Orbiter still remained with the carrier-aircraft, but two astronauts on the Orbiter's flight deck powered up various systems and checked out communications and other vital functions necessary for the drop tests.

Next came the free-flight tests in which the Orbiter was separated from the Boeing 747 by its crew and flown down to a dry salt runway at Edwards Air Force Base, qualifying the vehicle for descent flights in the atmosphere and clearing the way for missions into space. These will begin with the second vehicle, Orbiter 102, during the first half of 1979, but no earlier than March 31 of that year. The much used Orbiter 101 meanwhile performed static tests at the Marshall Space Flight Centre in Alabama and played a useful part in qualifying the basic structure of the assembly.

As the Shuttle stands on the pad, it has a launch weight of nearly 1,996 tonnes making it the heaviest launcher yet brought to operational status with the exception of the unique Saturn V. A typical flight begins from the Shuttle launch pad at the Kennedy Space Centre, actually a re-structured pad used originally for Saturn V, with a liftoff thrust of 2,960 tonnes from the two solid rocket boosters and the three Orbiter liquid propellant motors. Maximum thrust is reached about 26 sec into the flight and can be as high as 3,242 tonnes pushing the Shuttle in a nearly vertical ascent. About 122 sec into the flight, the two solid rocket boosters expend their propellant and are separated from the external tank.

Four small solid propellant rockets in the nose and four in the tail of each booster fire for 1½ sec to move them aside from possible re-contact with the Orbiter external tank.

At separation, height is between 41.2 km and 45.6 km and speed is around 5,000 km/hr. With the boosters gone only the three SSME engines are left to carry the Shuttle into space. With a thrust of almost 696 tonnes the Orbiter continues to ascend, gradually pitching over until it is at a height of 115.7 km and a speed of 26,670 km/hr about 7 min 41 sec after launch. The SSME motors are shut down and, their job complete, the external tank is separated 30 sec later, whereupon the two smaller Orbiter engines are fired in a 65 sec burst producing a combined thrust of 5.44 tonnes. This gives the Orbiter additional speed, bringing it up to 26,750 km/hr, and puts it into a 121 × 160 km elliptical orbit.

The tank, meanwhile, has insufficient speed to gain orbit and falls back on a long arching trajectory to burn up in the atmosphere and reach the sea 3,550 km from the launch site. When the Orbiter reaches the highest altitude in its elliptical path around the globe the two manoeuvring engines are ignited briefly to circularize the path at this height and ensure a stable orbit.

The boosters, after separating at a height of about 43 km, continue to curve upwards on their ballistic trajectory and from a height of 68 km begin to fall back toward the atmosphere, 75 sec after leaving the ascending Shuttle. At the top of the trajectory the bottom section of the exhaust cone is released and this burns up during the descent. About 1 min later the boosters are within the atmosphere and plunging toward the Atlantic Ocean, but their design and fabrication ensures survival from the ensuing heat and at a height of 5,500 m a sequence of operations is triggered which will put the boosters safely back down on the water for recovery.

About 232 sec after separating from the external tank, the forward nose cap on each booster is separated and a small 3.5 m diameter pilot parachute is released which in turn drags out a drogue parachute into a reefed (semi-inflated) position. After about 7 sec the drogue is allowed to inflate with air to its full 16.46 m diameter size, reducing the speed of the booster's fall from 570 km/hr to 470 km/hr. At a height of about 2,895 m, some 248 sec after separation, the forward nose section on the booster is severed causing the drogue to pull out the three main parachutes. The drogue and nose section float down separately and reach the water at a descent rate of 66 km/hr. When the three main parachutes are pulled free they are inflated to the 17% open position after 3 sec delay and then to the 40% open position after a 5½ sec delay at a height of 1,800 m. Five seconds after reaching 40% inflation they are fully disreefed so that each opens to its normal 37.49 m diameter at a height of 1,460 m.

By the time the booster reaches the water, 310 sec after separation, 7 min 12 sec after launch, speed is down to 93 km/hr. When they impact, about 261 km from Cape Canaveral, sea-water fills 75% of the interior and the boosters float vertically with the nozzle at the bottom and the upper few metres out of the water; trapped air in the top 25% ensures good flotation characteristics. The boosters are expected to land in the water in an assigned area 11 km by 17 km and shortly after impact a retrieval ship, waiting on the edge of this ellipse, moves to within 150 m of the floating hulks to deploy a remotely controlled plug adaptor. This manoeuvres underwater to the exhaust nozzle, plugs itself in, and then pumps in air, expelling the sea-water in the process. Gradually, the booster in question rights itself and floats on the surface from where it is towed back to Cape Canaveral for flushing and propellant reloading. The separated drogue parachute and nose section is recovered by the surface ships.

During the first Shuttle flights one booster will jettison its three main parachutes at splashdown, while the other retains the parachutes so that recovery teams can determine the least damaging approach. At liftoff each solid rocket booster was 45.45 m long, 3.71 m in diameter and weighed 586.5 tonnes. After its 7 min flight to 68 km and back, the booster is 38.84 m long and weighs 72.2 tonnes on the water. The decrease in length is due to the jettisoned bottom section of the exhaust cone and the jettisoned nose section at release of the parachute. Weight loss is due to propellant consumption. Each booster is expected to make twenty flights using an ammonium perchlorate and aluminium powder combination with iron oxide for improving burning qualities.

In space the Orbiter settles down to its scheduled orbital activities, either releasing satellites, performing experiments or manning a laboratory installed in the cargo bay and called Spacelab. This is being developed for NASA by the European Space Agency and will provide sufficient room for two persons to work comfortably inside after transferring through from the Orbiter's crew compartment via a pressurized tunnel. Spacelab represents a co-operative programme begun early in 1973 with a view to capturing many of the tasks hitherto planned for a separate space station, but with funds only running to development of the Shuttle the space agency has had to make do with a compromise design.

Although Spacelab will always remain inside the cargo bay, it does provide a unique opportunity for carrying out research which would be impossible otherwise and NASA expects to fly about 20 Spacelab missions each year. In no small way can it be said that the space station, which originally was to have inspired the reusable space transporter, has itself been consumed by the Shuttle and although NASA is keen to start work on a manned orbital facility that can be left in space for long periods of time, it is not likely to emerge before the end of the 1980's at the earliest. Instead, and as a follow on to the joint Apollo–Soyuz Test Project in 1975, NASA expects to send up a Shuttle to dock with the Russian space station called Salyut in the early 1980's as a further demonstration of co-operative research and scientific activity.

Normally, the Shuttle carries a crew of four: two pilots, a mission specialist and a payload specialist on the flight deck. The pilots fly the Orbiter up and bring it back down at the end of its stay in space, the mission specialist is responsible for controlling all functions of the vehicle while it is in space and the payload specialist looks after the cargo or whatever has been transported into orbit. Up to three additional payload specialists will be carried in the living area beneath the flight deck for a maximum complement of 7 persons. The living area provides sleep accommodation, eating and toilet facilities and provides access through into an airlock situated in the cargo bay. From here, suited astronauts can leave the Shuttle or, if Spacelab is carried, move on along to its pressurized interior. In an emergency 3 more persons can be carried in the living area, but this would only be necessary if a 7-man Orbiter was disabled and had to have its crew rescued by a 3-man Shuttle.

Pilots and mission specialists are crew members on permanent astronaut duties, while payload specialists will be brought from earth-based laboratories or research institutes to accompany their own payloads. In this way the Shuttle system not only affords opportunity for launching off-the-shelf hardware, but also off-the-shelf humans. At no time during ascent or descent will accelerations go beyond 3 g and this goes a long way to making it possible for untrained personnel to fly into space. As built, the Shuttle will be capable of supporting its crew for 7 days in space, but kits will be provided that extend this to 30 days; all gases, temperatures and pressures will duplicate the environment at the surface of the Earth and additional 'consumables' are needed for the longer flights, missions which will almost wholly be dedicated to flights with the Spacelab in the cargo bay.

While NASA is solely responsible for all the development costs associated with the Shuttle, the Air Force is planning to make use of this reusable transporter and phase out its current inventory of Titan III derivatives and there may well be military missions which will use the 30-day capability. In basic form the Shuttle can lift 29.48 tonnes to a maximum circular orbit of 400 km or, with the low point at 185 km, a maximum elliptical altitude of 830 km. With additional propellant for the small manoeuvring engines on the Orbiter, the maximum circular orbit that can be reached is about 1,200 km, but here the payload weight suffers and with extra propellant must come a decrease in the weight carried in the cargo bay so that to get into a circular 1,200 km orbit the payload weight is down to about 4 tonnes.

In basic form the Shuttle provides a very heavy weight-lifting capability into low earth orbit. But most of the satellites and space vehicles which are developed for commercial applications need a launch vehicle which can send payloads into geosynchronous orbit at 35,890 km and the Shuttle simply cannot reach such high altitudes, as will be seen from the examples above. Also, missions to the planets, although demanding a very low and infrequent launch rate, do constitute a launch vehicle requirement which must be met if the Shuttle is to replace all existing NASA rockets of a class capable of supporting such objectives.

Awareness of the Shuttle's inadequacy in meeting high-altitude or escape velocity needs stimulated early concepts for a rocket stage which could be attached to the payload and lifted into space by an Orbiter. The Orbiter would release the stage, move away and then remotely fire it so that the necessary speed could be applied to the payload. In 1968 and 1969, when NASA was planning to use the Shuttle for servicing a manned space station, the agency developed a concept known as the Space Tug. This would take the form of a reusable liquid propellant rocket motor which could carry a crew module on top and be used for literally shunting large experiment modules around in space, taking them between stations and into different orbits or collecting redundant space station modules and bringing them back to the Shuttle for return to Earth in the cargo bay.

As the 1970's came in with a more realistic approach to near term objectives the Space Tug was pushed further into the future, but when the Shuttle was sold to Congress as a cheaper way of launching ordinary satellites, a need arose for some form of supplementary booster to fill the gap between availability of the Shuttle and availability of the Tug. The solution was a cheap, solid or liquid propellant rocket of the type already used on rockets such as Atlas, Titan, Thor and Delta. By taking an upper stage straight from an existing production line the development cost could be avoided.

This was called the Interim Upper Stage, or IUS, and several aerospace companies proposed stages such as Centaur, Agena, Transtage and Burner II. Most of these stages were small compared with the big 18.29 m long cargo bay in the Orbiter and could easily be carried inside the Shuttle attached to a payload. In orbit the assembly would be removed and the stage could take the payload to the desired altitude or speed. Then it became clear that, along with the space station, NASA would be hard pressed to gain approval for a Tug if it already had a valuable, albeit interim, boost stage. NASA argued that the Tug, specially designed to be large enough to carry sufficient propellant to return to the Orbiter and be brought back to Earth, was reusable and therefore more economical than the proposed expendable IUS. Nevertheless, hopes faded for early introduction of the reusable Tug and NASA concerned itself with getting the best possible performance and economics out of the IUS design.

Negotiating with the Air Force, a prominent enthusiast for the IUS, the space agency got an agreement for the Department of Defence to provide the money for this boost stage and in several thorough and concentrated studies decided that a solid propellant concept would be efficient and technically desirable, simplifying the design and improving the reliability. Accordingly the Air Force Space & Missile Systems Organization (SAMSO) issued a request for industrial proposals and on 16 August 1976, announced that Boeing had been selected from four other competitors to start work on the solid propellant IUS. This was fortunate for Boeing since its production line for Burner IIA upper stages used with expendable launch vehicles was coming to a close and much of the experience developed as a result of work on this, and its predecessor Burner II, contributed toward anticipated confidence in developing a reliable boost stage for the Shuttle.

Within a few months the name was simplified to Upper Stage, or US, in pessimistic recognition of the fading likelihood of ever getting a manned Space Tug authorized. Boeing completes its preliminary design phase in February 1978 and by January 1980 will deliver the first Upper Stage to NASA at the Kennedy Space Centre. Because each US will be used only once, there will be production opportunities for several years to come and according to the NASA Shuttle traffic model, about 200 flights will be required between 1980 and 1992. Boeing is designing the US so that it can be tailored to individual customer requirements according to the specific type of orbit necessary for the Shuttle. It is useful for the following description to remember that the Shuttle's cargo bay is 18.29 m long and can lift 29.48 tonnes to low earth orbit.

The basic two-stage US is 4.5 m long and weighs 14.5 tonnes. The rear stage is a 9.7 tonne solid rocket motor generating a thrust of 19.3 tonnes and the forward stage weighs 2.7 tonnes and provides 7.9 tonnes of thrust. An uprated version is provided with two of the large aft stages instead of one large and one small. This weighs 22 tonnes, is slightly greater in length at 5.4 m and of course both stages produce 19.3 tonnes of thrust in sequence. These two optional dual-stage designs are intended to support high earth orbit and geosynchronous orbit payload delivery. The reader will see that even with the more powerful version, the Orbiters lifting capacity leaves more than 7 tonnes available for the weight of the payload which would be attached to the front of the US and carried inside the cargo bay.

For missions which require a boost from Earth orbit to escape velocity from Earth's gravity, such as flights to the planets, Boeing is providing special 3 and 4 stage configurations. The three-stage model would put a 2.7 tonne motor on top of the uprated two-stage version providing sequential thrusts of 19.3, 19.3 and 7.9 tonnes respectively. It would weigh 25 tonnes in a length of 8.3 m.

The four-stage US is the same as the three-stage version but with a Thiokol TE-M-364-4 motor for a total weight of 26.4 tonnes and a combined length of 10.1 m. The Thiokol motor produces a thrust of about 7 tonnes and has been used with the Delta launch vehicle as an upper stage to that expendable rocket. In all cases, except the small Thiokol motor, the US stages are nearly 3 m in diameter and are mounted in tandem like a conventional multi-stage rocket. It will be seen that the 3 and 4 stage versions have margins of 4.4 tonnes and 3 tonnes respectively, obtained by subtracting the weight of the US from the Shuttle's lifting capability. This is the effective margin available for payload and may be critically low for future generations of planetary spacecraft. Available space is little or no problem; even the largest US, the four-stage version, occupies only 10.1 m leaving more than 8 m for the payload at a constant cargo bay diameter of 4.57 m.

Future missions may require a much heavier lifting capacity and this can be provided by putting two Shuttles in orbit: one with the payload and one with multiple US stages. These would then be docked together so that a large US could take the payload to its designated orbit. In this way the Shuttle is seen to be an integral part of what has come to be called the Space Transportation System, employing a range of upper stage configurations carried in the Orbiter's cargo bay, with a capacity to fill all the anticipated requirements of the remaining decades in this century.

At the bottom end of the performance scale NASA has obtained agreements for industrial development of cheap solid propellant boosters which would be carried in the cargo bay like the US configurations. Unlike the US, however, they would be spin-stabilized and because of this only apply to payloads which are suitable for a less sophisticated launcher. On 6 December 1976, McDonnell Douglas signed a memorandum of understanding with NASA to the effect that the company would provide its own money, and do all the work, to produce a Solid-Spinning Upper Stage (SSUS) capable of taking payloads to geosynchronous orbit hitherto launched by Delta rockets. Called the SSUS-D (for Delta-equivalent payload) it would put satellites weighing up to 1,110 kg into a geosynchronous transfer trajectory.

A similar agreement, signed on 18 February 1977, covered work on a slightly more powerful stage capable of sending 2,000 kg on to geosynchronous transfer. Called the SSUS-A, it would provide a capability now covered by Atlas–Centaur launch vehicles. Under these agreements McDonnell Douglas does all the work, provides the money and builds the SSUS configurations. NASA, for its part, agrees to use these specific designs when they become available in the 1980's and not to purchase other models that may be produced by a competitor without agreement. With the four Upper Stage configurations and the two Solid Spinning Upper Stage designs, NASA will have a variable payload launch system tailored to the requirements of individual customers; the Air-Force-funded Upper Stage will carry payloads which require an attitude-stabilized booster. The Boeing Company, contractor for the US, has also negotiated for SSUS development under a similar type of agreement to that undertaken with McDonnell Douglas and may seek SSUS design for a payload category hitherto ignored.

Launch and landing facilities for the Shuttle will be placed at the Kennedy Space Centre and at the Vandenberg Air Force Base. These will cover orbital flights up to an inclination of about 55° and polar orbits respectively. The land mass to the north of Cape Canaveral restricts the ascent azimuth to one which constrains the orbital inclination and the Vandenbery AFB provides opportunity for the Shuttle to fly south over the Pacific Ocean and clear any land mass. Strict regulations prevent flights over land which may be populated and the two launch sites have developed over the years primarily because of that fact.

The massive launch facilities at the Kennedy Space Centre prepared for the Saturn V flights have been adopted for Shuttle operations and two launch pads are being modified for flights into space from 1979. A 4.57 km long runway has been built which will receive Orbiters coming back from space and it provides radar tracking facilities for co-operative liaison with the Orbiter. Following touch-down the Orbiter is towed to a processing facility where it can be emptied of corrosive and dangerous chemicals and liquids before inspection of the thermal insulation and other important aspects of the vehicle which may need minor attention before the next flight.

After this it is brought to the Vehicle Assembly Building, the 3.7 million cubic metre building once used to erect the various stages of the Saturn V, and mated to the external tank which is itself supported by the two solid rocket boosters. From here the Shuttle is rolled out the huge 45-storey high doors to the launch pad – Complex 39A. A second pad, 39B, will be ready to support Shuttle flights from October 1982 and the Vandenberg Air Force Base will be operational from the beginning of 1983. NASA and Air Force traffic models anticipate a requirement for five Orbiters and following the first in 1979, the space agency expects to have the remaining four vehicles in service at intervals between 1981 and 1984.

By the mid-1980's the full Space Transportation System fleet will be up to strength and capable of taking responsibility for launching every satellite and space probe through the atmosphere, with the exception of very small payloads which will continue to be launched by the Scout expendable rocket (see Scout). The first 6 Shuttle flights between March 1979 and March 1980 will be test and development missions, designed to explore every possible operating procedure and to qualify the elements and systems for operational use. Thereafter, NASA and the Air Force expect to build up to between 25 and 60 flights each year with that level of activity emerging by 1984. The Shuttle system will need to be replaced by the early 1990's and future reusable transporters are expected to operate more economically and with even greater efficiency.

Spartan/Sprint:

In response to pressure from the Department of Defence for a viable anti-ballistic-missile screen to protect civilian and military sites against ICBM attack, the McDonnell Douglas Astronautics Company developed Spartan as an exo-atmospheric interceptor capable of destroying or disabling incoming warheads. Secretary of Defence, Robert S. McNamara, gave the go-ahead for the Sentinel ABM programme on 18 September 1967 which at that time envisaged long range Spartan and short range Sprint missiles to be deployed for defence of the western United States against Chinese ICBMs, then thought to be in an advanced stage of development.

On 14 March 1969, the ABM programme was re-named Safeguard and was modified to provide radar equipment which could detect submarine-launched ballistic missiles, defend Minuteman ICBM launch complexes and provide protection for bomber bases.

The Spartan was developed as a three-stage solid propellant missile 16.46 m long with a diameter of nearly 3 m over the rear fins. The 12.97 tonne missile would be guided to its target outside the atmosphere by the command network from Missile Site Radar with a tracking range of 1,600 km. The MSR, located adjacent to the missile site, employs a phased-array system which discriminates between warheads, decoys and balloons from its hardened concrete structure 70 metres square. A 23 m tall turret contains 3.9 m diameter radar faces set into all four sides and the MSR would take over control of missile launch operations and send the Spartan on an intercept trajectory followed, if necessary, by Sprint missiles to kill the target after it had entered the atmosphere on a descending trajectory.

MSR alert is triggered first by information from the Perimeter Acquisition Radar, which can detect a 1 metre square target at a range of more than 4,200 km with a 90% probability factor. A fake alert from the PAR to the MSR was estimated to be only one in a million. Spartan has a slant range of 740 km and the first stage lifts off with a thrust of 226.8 tonnes. Interception was planned to take place at a height of up to 480 km and the third stage Thiokol TX454 solid propellant motor is designed to respond to terminal commands which allows the stage to manoeuvre as it closes on the target, thereby allowing last minute discrimination between decoys and the incoming warhead.

The Spartan warhead has a 5 MT nuclear yield and would be detonated in the vicinity of the incoming target, so producing high intensity x-rays which would bombard the hostile warhead, evaporate the ablative re-entry vehicle and cause it to burn up through friction as it entered the atmosphere. Total reaction time is claimed to be no more than 30 sec. The first Spartan firing was on 30 March 1968 with the first successful interception of a dummy target on August 28, 1970, when a Minuteman 1 ICBM was launched from the Vandenberg Air Force Base. The Spartan was sent up from Kwajalein Atoll in the Pacific and it closed on the ICBM's re-entry body at an altitude of 160 km after the Minuteman had flown 6,760 km along its trajectory.

As a result of the terms of the 1972 Strategic Arms Limitation Talks (SALT) the US is restricted to two ABM sites equipped with 100 Spartan/Sprint combinations apiece. However, only the Minuteman ICBM complex at Grand Forks AFB North Dakota was equipped with ABM systems and a proposed site near Washington was deleted, due to congressional pressure to restrict expenditure.

The Sprint missile was developed by Martin Marietta which was, like McDonnell Douglas, under subcontract to the Bell Telephone Laboratories who had prime management of the Safeguard ABM system. It is designed to be a short range, high velocity, endo-atmospheric interceptor, capable of knocking out warheads which get through the altitude gate policed by Spartan. Sprint by name and sprint by nature, the two stage solid propellant missile accelerates with a force of 100 g after launch from a vertical silo. On command from the MSR network Sprint is ejected from its firing tube by a gas-driven piston pushing the missile through a retentive membrane.

Immediately it leaves the silo the first stage engine ignites to produce a thrust of 294.8 tonnes and carry the 3.4 tonne missile on an intercept trajectory. The 8.2 m long missile has a diameter of 1.37 m at the base and takes the form of a flat-sided cone, control being effected by fluid injection to the single first stage nozzle and small aerodynamic fins. Within 15 sec the missile has intercepted its target and detonated a nuclear charge in the low kiloton range. With launch delayed so that the MSR can select the incoming warhead from among possible decoys, interception can take place anywhere between 1.5 km and 30.5 km; the Sprint has a slant range capability of 46 km and because of prior discrimination can fly straight to the already selected target.

Apart from physically destroying an incoming warhead by the blast from its own thermonuclear explosion, Sprint bombards the area with neutrons which enter the hostile warhead and distorts the fissile material to prevent detonation. The first Sprint development contract went out in October 1962 and the project go-ahead came in 1963. A series of 38 development tests were fired from the White Sands Missile Range, New Mexico, and the first intercept came when a Minuteman was fired on 23 December 1970. A Sprint went up from Kwajalein Atoll in the Pacific and successfully demonstrated a kill capability. A Sprint II model was under development in the early 1970's, but funds were deleted for further work.

The one and only Safeguard site, at Grand Forks AFB, was deactivated in 1975 and the Sprint and Spartan missiles have been removed from their locations. The Soviet Union currently operates 64 ABM missiles around Moscow to defend the city against attack from US or Chinese ICBMs; readers are referred to ABM-1 Galosh for further details.

Thor:

The Thor intermediate range ballistic missile and space launch vehicle has had one of the most consistently successful histories of any rocket developed for use anywhere in the world and has found application in a variety of configurations and upper stage assemblies for more than 20 years. For purposes of clarity the reader is requested to note that this section should be read in conjunction with that describing the Delta launch vehicle; both Thor and Delta originate from the same stable, but each has spawned a prolific variety of developments.

The Thor IRBM was conceived as a US Air Force project, essentially a US Air Force equivalent to the Army's Jupiter A missile, and the Ballistic Missile Division of the Air Research & Development Command signed a contract with the then Douglas Aircraft Company in December 1955 for hardware design, development and fabrication.

Assembled at the Santa Monica, California, Facility, the Thor emerged as a liquid propellant single stage missile employing a motor similar to that built for the Atlas ICBM, with a thrust of 68 tonnes and a launch weight of nearly 50 tonnes. The missile was designed to provide a range capability of 2,500 km and the first flight attempt was made on 25 January 1957. Seconds after ignition, the Thor rose 15 cm from its launch pad and promptly exploded. This test was followed by three more similarly unsuccessful trial launches in April, May and August of the same year. After a series of modifications, the fourth flight vehicle successfully flew nearly 1,600 km down range on 20 September, followed by a special aerodynamic test in October where the missile attained a range of 4,500 km, but this was with a lightened frame and under special conditions.

In December 1957 the first guidance equipped Thor flew on course down the Atlantic Missile Range and by February 1958 nose cone tests had qualified the design concept. Following a nose cone recovery flight in June 1958, the Thor IRBM was declared operational and a year later the Royal Air Force began equipping squadrons with the US missile and from 1960 about 60 rounds were deployed in the United Kingdom.

In its IRBM role the Thor was 19.75 m long and 266.7 cm in diameter. It contained 45.6 tonnes of liquid oxygen and kerosene propellants and burned for 146 sec. The cylindrical lower and centre sections of the missile narrowed to a diameter of about 163 cm at the top with the LOX tank at the bottom and the fuel tank in the forward section. Construction was of waffle stiffened integral propellant tank fabrication, with pressurized gas for support when empty, much like the Atlas, but with less critical collapse margins. The Rocketdyne motor of the MB-3 type was gimballed for flight control and the combustion chamber was surrounded by a cylindrical skirt of similar diameter to the main LOX tank. Four aerodynamic fins were mounted on the fairing and the missile had a similar weight to the Jupiter A IRBM.

By 1958 it had become apparent that Thor could be effectively utilized as the first stage of a space launch vehicle and with upper stages under the group name Able, the first launch was performed successfully on 9 July 1958, but not for a space mission. Developed to test re-entry nose cone design for MRBM and ICBM applications, the first launch was in support of military applications, but Thor–Able 1, on 17 August 1958, carried the 38 kg Pioneer spacecraft designed to fly to the Moon and go into lunar orbit. The upper stages of Thor–Able 1 comprised a liquid propellant second stage delivering a thrust of 3.4 tonnes and a solid propellant 1.1 tonne thrust third stage spun up to 120 r.p.m. to fire the payload and fourth stage to escape velocity toward the Moon. The fourth stage had a thrust of 1.36 tonnes and would be used to accelerate the Pioneer spacecraft on course for the Moon. The Able second and third stages were the same as the respective stages on the Vanguard launcher (see Vanguard).

This first attempt failed when the 26.8 m tall assembly blew up 17 sec after liftoff, following a rupture in one of the main Thor propellant tanks. The second attempt on 11 October 1958 also failed, when the third and fourth stages could not provide sufficient velocity for escape speed and the Pioneer B payload fell back to Earth from an altitude of 114,000 km. Again, on 8 November 1958, failure struck, when the second stage refused to fire and the Pioneer 2 spacecraft plunged back from a height of 1,600 km.

After this, the fourth stage was removed and Thor–Able flights were applied to earth-orbit satellite launches with Explorer 6 on 7 August 1959, Transit 1A on 17 September 1959, followed by the last Thor–Able launch placing the Tiros 1 weather satellite in orbit on 1 April 1960. Before this, a four-stage configuration had sent Pioneer 5 successfully into deep space on 11 March. In all there had been 7 Thor–Able launch attempts of which 3 (Explorer 6, Pioneer 5 and Tiros 1) were completely successful.

Meanwhile, another configuration had emerged with the designation Thor–Able Star, confusing because of the similar terminology to Thor–Able using upper Vanguard stages and described above. Thor–Able Star was a two-stage space launcher capable of placing 410 kg in a low circular earth orbit, compared with 135 kg for its predecessor Thor–Able. The first stage was a modified Thor IRBM, 18.45 m long with a weight of 48.7 tonnes, and the second stage was 5.3 m long, 162.5 cm in diameter and weighed 4.67 tonnes of which 3.88 tonnes was propellant. Fuelled by inhibited red fuming nitric acid (or inhibited white fuming nitric acid) and an unsymmetrical dimethyl hydrazine oxidizer, the Aerojet-General AJ-10 series liquid propellant motor delivered a thrust of 3.5 tonnes in a total burn time of 296 sec, which was utilized in a continuous burn. The complete Thor–Able Star assembly was 24.13 m tall and weighed 53.5 tonnes at launch.

The first flight came on 13 April 1960 when Transit 1B, a navigation satellite, was put into orbit, followed on 22 June by the first launch of two satellites by one rocket: Transit 2A and Solrad 1, the latter a solar science satellite. The first triple satellite launch was claimed by Thor–Able Star on 29 June 1961, although one failed to separate in orbit, and 5 satellites were launched together on 24 January 1962, but these failed to get into orbit at all. The first launch of 6 satellites on one flight was successfully accomplished on 13 August 1965 bringing to an end more than 5 years of Thor–Able Star operations for the Air Force and Navy, during which time 18 launches had been attempted with 6 failures.

In 1959 a third variant, Thor–Agena A, had been introduced. With an Air Force requirement for a reliable upper stage which could be applied to military duties in space, the Agena A was first in a line of Agena upper stage developments which would find application on a variety of launch vehicles. However, the Agena A was developed by the Air Force to support the Discoverer programme which required the upper stage to remain attached to the payload in orbit and for the payload to eject a separate capsule which would re-enter the atmosphere and be recovered. The classified objectives of the Agena A and its payload embraced measurements of various forms of radiation in space, reconnaissance of potentially hostile countries, missile early warning techniques and alert networks.

The Agena A upper stage was 5.28 m long, 152.4 cm in diameter and weighed 3.8 tonnes loaded with inhibited red fuming nitric acid/unsymmetrical dimethyl hydrazine propellants. The Bell Hustler 8048 rocket motor delivered 7 tonnes of thrust for 120 sec and the Thor–Agena A configuration, was 23.9 m tall, weighed more than 53 tonnes and could put a 136 kg payload in low earth orbit. The first launch, Discoverer 1, came on 28 February 1959 and although the vehicle was not stabilized when it got into orbit, the mission did achieve fame as the first satellite to go into polar orbit, where the angle of inclination of the orbital path was 90° to the equator. The last Thor–Agena A launch was that of Discoverer 15 on 13 September 1960 and in the 15 flights since February 1959 two failed to reach orbit and only two re-entry data capsules were successfully recovered from space of the other 13. There were four Agena A vehicles launched by Atlas making 19 Agena A flight attempts in all (see Atlas).

Discoverer flights after no. 15 used the next Thor variant designated Thor–Agena B, essentially an Agena A with re-start capability so that initial orbits could be changed by firing the upper stage engine, still attached to the payload, a second time. The Agena B was adopted by the Atlas launch vehicle and relevant details, with the heavier and more powerful booster, are outlined under that section. Agena B was 8 m long, 152.4 cm in diameter and it weighed 7.2 tonnes with 5.58 tonnes of a similar propellant to that carried by Agena A. The motor, a Bell Hustler 8096, produced a thrust of 7.26 tonnes for 240 sec either in a single full burn or two periods totalling that duration. The complete Thor–Agena B configuration was 24.79 m tall, weighed 55.79 tonnes and could put 725 kg in a low earth orbit compared with 136 kg for Thor–Agena A.

The first launch came on 26 October 1960 when Pioneer 16 was sent aloft, but failed to get into orbit due to separation failure from the Thor first stage. On the third launch Discoverer 18 had the advantage of an uprated propulsion system in the Thor; this and subsequent boosters produced a thrust of 78 tonnes. The last Thor–Agena B flight came with the successful mission of Discoverer 38 on 27 February 1962 and of the 23 launch attempts only 7 had failed to reach orbit.

Launch vehicle performance was a considerable improvement over that demonstrated by the earlier Thor–Able and –Able Star combinations, with a success rating of nearly 70%. By the end of Discoverer flights in 1962 Thor boosters had been launched on 64 attempts in –Able, –Able Star, –Agena A and –Agena B upper stage configurations of which 19 had been failures. It is interesting to note that a satellite put into orbit for the use of amateur radio enthusiasts, Oscar 1, rode with Discoverer 36 on 12 December 1961. One Thor–Agena B launch supported a classified US Air Force mission outside the published objectives of the Discoverer programme and went into orbit on 21 February 1962. After the Discoverer flights a further 15 Thor–Agena B missions were mounted successfully with the last US Air Force launch on 24 November 1962.

More than a year later, on 25 January 1964, NASA launched the first wholly civilian payload put up by a Thor–Agena when it sent Echo 2 into orbit. Nimbus 1 followed on 28 August and the last Thor–Agena B launch was a dual satellite flight on 28 November 1965. In all, 42 Thor–Agena B flights had been attempted, 3 of these in support of NASA projects, and only 7 had failed to reach orbit.

So far Air Force requirements had generated the evolution from Agena A to B with the latter providing engine re-start opportunities and greater lifting capacity. However, there was still a need for a common upper stage design which could be assembled to a specific plan and adopted for any of the payloads likely to be carried by the vehicle. Up to now Agena stages had been tailor-made for a specific flight, but with increased launch rates and a wider range of payload options a standardized upper stage was essential. In 1962 the Air Force began using the Thor–Agena D, specifically designed to meet these criteria.

The new design used a development of the Aerojet-General AJ-10 series first applied to the Able Star stage and comprised propellant tanks for inhibited red fuming nitric acid and unsymmetrical dimethyl hydrazine feeding a single 7.26 tonne thrust motor with a 240 sec burn time. The storable propellants were also used to feed a secondary propulsion system which could perform five orbital adjustments and minor velocity corrections (see Atlas). The complete Thor–Agena D system was about 23.25 m tall with a second stage diameter of 12 cm and a liftoff weight of approximately 55.8 tonnes. First stage thrust was, at 78 tonnes, similar to the uprated Block II MB-3 engine fitted to all Thor boosters after December 1960 and the two stage assembly was capable of placing 725 kg in a low earth orbit.

By February 1971 the US Air Force had launched 25 Thor–Agena D vehicles on military flights to earth orbit. In 1965 a new Thor upper stage emerged: the ABL X-248 Altair, fourth stage to the Scout launcher (see Scout). With a length of 183 cm, diameter of 45.7 cm and a weight of 238 kg the single solid propellant upper stage produced a thrust of 1.4 tonnes for 38 sec. Between 18 January 1965 and 30 March 1966 the Air Force launched 6 Thor–Altair configurations, of which only one failed to reach orbit.

Starting on 15 September 1966 the Thor–Burner II was introduced and by 17 August 1973 a total of 14 such configurations had been launched, all of them successful. Burner II was developed by the Boeing Company in April 1965 and the solid propellant upper stage produced a thrust of 4.1 to 4.5 tonnes from a TE-364 motor. Separation from the Thor first stage, all attitude control manoeuvres in space and minor velocity corrections, were accomplished with a mono-propellant system feeding four 9.98 kg thrust reaction jets and cold-gas nitrogen jets adjusted to fire final payload orientation and alignment bursts.

A new, two-stage, version of the upper stage called Burner IIA appeared in 1974, with a first launch on 16 March. The first stage was similar to the basic Burner II, but the new second stage produced a thrust of 3.6 tonnes. About two Burner IIA flights are launched by Thor each year, usually to send military weather satellites into orbit.

The eight upper stage additions to the Thor booster (Able, Able Star, Agena A, Agena B, Agena D, Altair, Burner II and Burner IIA) progressed between 1958 and 1974 with the same basic first stage design that had been adapted from the missile when it was an IRBM. With improvements in upper stage performance, it was felt necessary to uprate the liftoff thrust to effectively maximize the theoretical payload capability. This resulted in the addition of three solid propellant Castor 1 rockets at the base of the Thor first stage, increasing the liftoff thrust from 78 tonnes to nearly 152 tonnes. Each Castor I produced a thrust of nearly 24.5 tonnes for a total boost increment of 73.5 tonnes which, added to the liquid propellant Thor first stage engine, considerably increased the ascent lifting capacity and maximized the payload return.

The Castor solid propellant rockets used a combination polybutadiene acrylic acid co-polymer/ammonium perchlorate mixture and each motor was 6 m long, 80 cm in diameter and weighed 4.4. tonnes. The overall height of the configuration was dictated by the upper stage selected for use and the designation for the first stage was now appropriately, Thrust Augmented Thor or simply TAT. Between 28 February 1963 and 3 November 1968 the US Air Force launched 63 TAT-Agena D vehicles and in this configuration, height was nearly 23.8 m, diameter was the same at 2.4 m and liftoff weight was 62.6 tonnes. The combination payload capability was 1,140 kg to a low earth orbit, a 57% increase over that provided by the basic Thor–Agena D without solid propellant boosters. Two flights were successfully accomplished, one for the Air Force in 1963 and the other for NASA in 1966, using the TAT-Agena B, but this was a somewhat inefficient combination and little application accrued.

In 1966 yet another configuration matured to operational acceptance: the Thorad, so named because there was a Thor addition in the form of a lengthened tank structure. This concept has been referred to as the Long Tank Thor (LTT) for just such a reason. Basically the Thor was lengthened to 21.64 m, increasing the propellant capacity which extended the first stage burn duration to 216 sec, an improvement of 70 sec on the burn time of previous Thor vehicles. The most noticeable change was the adoption of a constant 2.44 m diameter throughout the length of the Thor first stage, unlike all previous Thor stages, which had tapered to a 1.63 m diameter from a point just over half-way up.

Thorad vehicles were used with Agena D stages and 20 were launched at irregular intervals, principally by the Air Force, but 3 by NASA, between 9 August 1966 and 20 December 1972. The Thorad–Agena D did not carry supplementary boost in the form of solid propellant Castor rockets and launches came sporadically – for instance there was a gap of 18 months between the first and second flights yet during a 9-month period beginning in 1969 six such assemblies were launched. When Castor first stage boosters were fitted to the Thorad–Agena D it became known as the Long Tank Thrust Augmented Thor–Agena D, or LTTAT–Agena D, and flights began in May 1967 with 16 launches up to the last one of such a configuration in September 1971.

An extended tank, thrust augmented, Thor was used on 7 August 1968 as the first stage to a Burner II second stage and this LTTAT-Burner II configuration was in support of US Air Force projects, but the only such flight on record.

The Thor configurations had extended to the use of eight upper stages (Able, Able Star, Agena A, Agena B, Agena D, Altair, Burner II and Burner IIA) with three basic Thor first-stage modifications (TAT, Thorad and LTTAT) in addition to the Thor IRBM and the Thor stage in an unmodified configuration when used with earlier upper stage assemblies. In support of these assembled space launcher configurations, the Air Force and NASA had mounted 234 launches between 17 August 1958 and 20 December 1972 when a US Air Force satellite was put into orbit. In the 14 years of operation with these eight upper stage designs, only 14 launches were under NASA auspices, the remaining 220 being in support of Air Force or Navy objectives, usually carrying classified payloads.

But, just as the various Thor configurations had been almost exclusively reserved for launching military payloads into space between 1958 and 1972, the Thor–Delta had emerged as a prominent civilian space launcher and used as such by NASA, it continues to serve an important role as the most popular launch vehicle in use by the US space agency. Readers are again reminded to refer to Delta for the continued story of the multitude of configurations flown under that designation.

Titan I/II/III:

During the early stages of development of the Atlas ICBM design, the Air Force acted on reports of suspected deficiencies by initiating conceptual studies for a simpler and more efficient missile. There were critics of the Atlas and its slaved-booster concept, whereby the two outer boost engines in a row of three at the base of the missile are jettisoned during the ascent. The advantage of ground ignition prevented failure of an upper stage at extreme altitude and the separate boosters had the same effect as an independent stage, in that they reduced the structural mass in a positive incremental step.

In 1955 the Martin Company (now Martin Marietta) was awarded a contract to design and develop a two-stage liquid propellant rocket which could serve as a back-up to the Atlas, at that time in the final design stages, and parallel the operational role performed by Atlas as a flight-rated ICBM. Joe Rowland, the Public Relations Director at Martin, was asked by the Air Research and Development Command to select a suitable name for the missile and, thinking the Greek mythological giants that dominated the Earth provided an apt simile, chose the name Titan.

When Titan got the go-ahead in 1957, Martin had already finalized all the major design aspects and settled on a specification compatible with the Air Force mandate. By 1959 the first model was ready and Titan appeared as a 99.79 tonne missile, 27.4 m long and 304·8 cm in diameter. The two liquid propellant stages burned liquid oxygen and kerosene and the first stage provided a thrust of nearly 136.1 tonnes with the second stage developing 27.2 tonnes of thrust.

The first flight of a Titan came successfully on 6 January 1959 with only the first stage live, the second stage being inert. Subsequent tests displayed a range capability of 9,650 km and the missile entered service with the Strategic Air Command in April 1962. The HGM-25A Titan would see only three years of service before it was replaced by its successor, the LGM-25C Titan. For simplicity the first design became Titan I and the second was called Titan II. There were considerable and fundamental differences between the first and second designs which would probably have stimulated a new project name had not the original teams performed the transition.

Titan I used non-storable liquid propellants like Atlas and had to be set up into a vertical launch position before the missile could be fuelled and sent on its way. This was the very antithesis in concept of the strategic requirements of the day: a retaliatory strike force that would not be totally disabled by a pre-emptive attack. In other words, the missile had to preserve a threat of reciprocal attack under the severest bombardment. With these paradoxical problems at hand, the Strategic Air Command pressed for a long range ICBM with storable propellants in a design concept which would permit separate rounds to be housed in hardened underground silos, protected from nuclear attack by massive concrete doors which would be pulled back to expose the firing tube only seconds before launch.

The LGM-25C Titan II filled these requirements. The two-stage missile carried a combination of nitrogen tetroxide and aerozine-50 as storable propellants and considerably advanced the technical state of the art: enhanced efficiency and realistic reliability accrued from a reduction by 134 of the 245 moving parts in each Titan I first stage propulsion system. Also, power control operations on Titan II were only 21 compared with 107 on its predecessor. In many respects the Titan II benefited from the increasing sophistication in electronics during the early 1960's and significantly applied improved engineering concepts to a missile that would see at least two decades of operation.

The rocket itself was 31.39 m tall, 304.8 cm in diameter and consisted of a 21.5 m long first stage developing 195 tonnes of thrust and a 8.23 m long second stage producing 45.36 tonnes of thrust carrying a 1.7 m long warhead. Launch weight was 149.7 tonnes and the missile had an effective range of 15,000 km. First stage thrust was provided by two Aerojet-General YLR-87 motors burning propellant at a rate of 590 litres/sec for more than 2 min. The second stage employed a single YLR-91 motor, essentially a scaled-down version of the two first stage units, each one of which delivered a thrust of 97.5 tonnes.

The first stage carried the missile to a height of 70 km and a speed of 9,700 km/hr and the second stage would then take over to produce a terminal acceleration of 7 g at 29,000 km/hr in a burn duration lasting more than 180 sec. As an operational ICBM, Titan II entered service with Strategic Air Command in 1963 and in 1965 all HGM-25A Titan I's had been withdrawn from service. The Titan II's went to the Davis–Monthan Air Force Base in Arizona, the McConnell AFB in Kansas and the Little Rock AFB, Arkansas and the full complement of 54 rounds had been emplaced by 1965, by which time the six Titan I squadrons had been deactivated. The Titan II is still in service with Strategic Air Command at the same launch complexes as America's heaviest ICBM capable of carrying a higher yield nuclear warhead and traversing greater distances in flight than any other missile in the US arsenal.

The 54 Titans can each carry a warhead with a 20 MT warhead in a single nuclear charge, but the optimum operational deployment prefers a single 5 to 10 MT warhead in a General Electric Mk. 6 re-entry vehicle, which, along with the most powerful nuclear charge carried in any US missile, also boasts a veritable bus-load of decoys and electronic penetration aids. With only 54 heavyweight ICBM's compared to more than 500 on the Soviet side, the US strategic posture relies on a very high rate of probable target emplacement. All Titans must get through to their targets and if both potential adversary and home forces understand that fact, the weapon is a true deterrent in that any level of bombardment and counter-manoeuvres will fail to deter the chain of launch, flight and impact procedures.

Recognition of this fact, that the missile is preserved in a hardened silo and can be expected to reach its target, moves tactical escalation into strategic nuclear conflict toward the realm of unpredictable insanity and places the logical selection of war as a means to gain territorial or ideological advantage beyond the bounds of reason. Hence, the 54 Titan II's play an exceptionally important role in the fabric of strategic deterrence and are a considerable threat to civilian order in a potentially hostile country; the warheads each have a capacity to destroy individual cities and the acceptance of hostile retaliation, which endangers public order is another important part of defence. With the currently fitted warheads the probable target error is 0.9 km.

When NASA decided to progress beyond the first manned orbital flights of the Mercury Programme, (1962/63) with a two-man vehicle capable of remaining in space for up to 14 days, conducting experiments in rendezvous, docking separate vehicles and generally advancing the pool of knowledge concerning physical responses in the human body to prolonged weightlessness, Titan II was selected as the only proven rocket capable of sending the vehicle into space. Called Gemini, the spacecraft would weigh 3,600 kg and be required to achieve a 185 km orbit about the Earth. In this configuration, with Gemini on top of the second stage, the total assembly was 33.22 m tall and the spacecraft itself had been tailored to the size and weight-lifting capacity of the Titan II. The maximum diameter of the base of the spacecraft was the same 304.8 cm as that of the second stage to which it was attached for launch and the weight of the Gemini was kept to just below the certified lifting capacity of the Titan II.

The first flight was performed on 8 April 1964 and the second stage and boilerplate spacecraft (essentially a structural mock-up) went into a 160 × 330 km orbit where it remained until re-entry and atmospheric burn-up a few days later. Known as GT-I (Gemini–Titan I), the first flight was followed by GT-2 in January 1965 before the first manned Gemini flight to earth orbit on 23 March 1965, when astronauts Grissom and Young spent 4.9 hours in their new two-man spacecraft. By 11 November 1966 GT-12 was leaving pad 19 at the Kennedy Space Centre, Cape Canaveral, and the last Gemini spacecraft was put into orbit for a successful 94.6 hour flight. In twelve successful flights in the months between April 1964 and November 1966, the Air Force Titan II had provided US astronauts with docking operations, the experience of 14 days in space and several periods of activity outside their spacecraft.

On 1 September 1964 the first of a special line of Air Force satellite launches got off the Launch Complex 20 firing pad at Cape Canaveral, when Titan III-A made its debut, albeit ingloriously. The first two stages fired as planned, but a premature shutdown in the new third stage prevented the 1.7 tonne dummy payload from reaching orbit. The new third stage, called Transtage, is a liquid propellant design capable of delivering a thrust of 7.1 tonnes from a combination of nitrogen tetroxide and unsymmetrical dimethyl hydrazine storable propellants. The Transtage structure is 304.8 cm in diameter and 4.57 m in length.

The first successful flight came on 10 December 1964 when the Transtage and a test payload reached orbit. After a period of coast the 2.38 tonne third stage expelled a 1.7 tonne cylindrical dummy satellite and qualified the operational procedures developed for Titan III-A. Transtage had a multi-burn capability and went on to demonstrate this with launches of test satellites in the final two missions, the last of which occurred on 6 May 1965. Out of four flights, three had been successful.

On 29 July 1966, the Air Force introduced the combination that was to become the standard medium-weight launcher for military payloads: the Titan III-B, usually flown with an Agena D. The first stage was 23.77 m long and delivered a thrust of 210.1 tonnes for 162 sec from two uprated YLR-87 motors. The 9.14 m long second stage delivered 46.4 tonnes of thrust for 208 sec from its uprated YLR-91 engine and, like Titan II, both stages were 304.8 cm in diameter. The third, Agena D, stage was 6.4 m long, produced a thrust of 7.6 tonnes for 240 sec and had a diameter of 1.52 m. The total height varied according to the selected payload and could be anywhere between 43.9 m and 52.7 m. The Titan III-B/Agena D could place 3.5 tonnes in to a polar orbit or put 450 kg on to a geosynchronous transfer trajectory.

By the end of 1976, a total of 52 such configurations had been flown with only one failure in the previous 10½ years. The most recent variant adopts an uprated first stage propulsion system which delivers a launch thrust of 235.87 tonnes for a liftoff weight of 169.9 tonnes.

One year before Titan III-B operations began, the Air Force introduced a very different concept to Titan launch operations, when two very large solid propellant boosters were attached to opposite sides of the first stage; the solids would be ignited at launch followed by ignition of the liquid propellant main stage when the solids had been jettisoned and because of this, the solid propellant boosters became stage 1 with the two-stage Titan contributing stages 2 and 3 and a Transtage upper element comprising stage 4. This was the most massive and powerful launch vehicle up to that time and the first launch was performed successfully on 18 June 1965. The total vehicle weighed 635 tonnes and had a height of 39.6 m. The two solid propellant boosters were each 25.9 m long, 304.8 cm in diameter with a weight of 299.97 tonnes and a unit thrust of about 544.32 tonnes. This stage 1 assembly had a combined weight of nearly 600 tonnes with a total liftoff thrust of 1,088 tonnes and continued to burn for 120 sec. At this point the two strap-on boosters of stage 1 expended their propellant and were explosively released from the sides of stage 2 (first stage of the basic Titan II) by 16 small rockets designed to move the massive boosters away from the ascending Titan. Stage 2 now ignited, a duo of engines that had lifted Titan off the launch pad in earlier configurations, and produced a thrust of 210.1 tonnes for a further 137 sec. This was then discarded and the third stage took over, producing 46 tonnes of thrust for 207 sec. Following this, about 9 min after launch, the Transtage fired its own 7.12 tonne thrust motor for a further 2 min and put the 13,000 kg test payload in orbit about the Earth.

This launch vehicle system, essentially an uprated Titan III-A (two basic Titan stages plus Transtage) with two massive solid propellant boosters lifting it to altitude before ignition, was designated Titan III-C and by the end of 1976 the Air Force had launched 24 during the previous 11½ years. The current version of Titan III-C uses an uprated stage 2 propulsion system of 235.87 tonnes, the same as the bottom Titan stage in the III-B/Agena D configuration. The assembly can place more than 13,000 kg in low earth orbit or put 1,500 kg in geosynchronous orbit.

In 1971 the Air Force began space operations with the Titan III-D, a basic two-stage Titan with two solid propellant boosters of the type fitted to the III-C as stage 1. All details of stage performance and sizing discussed for the III-C apply to the 'D' model, except that launch weight is reduced and a variety of payload shrouds can be used. The payload capability is the hightest for any earth-orbit launcher with a maximum potential of 13,600 kg, or 10,890 kg into polar orbit. By the end of 1976 fifteen Titan III-D vehicles had been launched and all were successful in accomplishing their objectives.

Like previous Titan configurations the III-D is used exclusively for military space operations rather than civilian and the high payload weight-lifting capability of the III-C and III-D versions make them extremely useful workhorses for launching surveillance satellites and reconnaissance vehicles into orbit. The Titan III-D is the launch vehicle specially adapted to the unique role of lifting Big Bird reconnaissance satellites into space.

The final, and possibly the last, variant is the Titan III-E/Centaur configuration. This has been developed for use as a civilian space launcher under NASA aegis and has the demanding task of lifting planetary and interplanetary vehicles on to earth-escape trajectories. The two solid propellant boosters of stage 1 have the same characteristics as those already described for the Titan III-C and the basic two-stage Titan is also of a similar configuration. However, stage 4 is the highly successful Centaur developed for the Atlas launch vehicle and still used with that medium/heavy NASA satellite launcher.

The Centaur D-1T is 9.1 m long and 3 m in diameter like the two liquid propellant stages of the Titan. The Centaur tanks are integral with the stage walls at a nominal thickness of 0.035 cm with pressure stiffening maintaining structural integrity in like manner to the basic Atlas launch vehicle (see Atlas); a special cradle supports the empty Centaur in storage when not attached to the Titan. A single hemispherical bulkhead separates the two propellant compartments with an insulation of double-wall vacuum construction to inhibit thermal conductivity. Centaur uses high energy cryogenic liquid oxygen/liquid hydrogen propellants, feeding two RL-10 engines delivering a total thrust of 13.6 tonnes and weighs 16.1 tonnes empty.

Twelve small hydrogen peroxide thrusters are used for attitude control and for applying a moderate increase in speed, when the stage is coasting, to settle the propellants and permit an engine re-start; weightless coasting between burns allows the liquid to 'float' away from the exit ports and could cause cavitation or temporary propellant starvation. The payload shroud carried on the front of the Centaur is unusual in that it has a greater diameter than the stage itself and is connected to a Centaur shroud which is attached to the top of the stage below the Centaur. This results in the Centaur having an external appearance of being much larger than it actually is and photographs readily display this 'hammer-head' effect. The two liquid propellant stages of the Titan are a constant 3 m in diameter along their entire 29.8 m length, but the Centaur stage and payload shroud is 4.27 m in diameter. The two halves of the Centaur shroud are severed about 1 min after ignition of the third stage when the assembly is already more than 100 km above the Earth. At liftoff a typical configuration is 48.77 m tall and weighs 640.8 tonnes.

The first Titan III-E/Centaur launch was on 11 February 1974 and although the flight was only a test mission to qualify the new configuration, it did carry a small satellite which was unfortunately lost when the assembly went out of control and had to be destroyed by the range safety officer at Cape Canaveral. Then, on 10 December 1974 a second III-E/Centaur successfully put the solar probe Helios A on course for a close pass with the Sun, followed on 20 August and 9 September by the launches of Viking 1 and 2 respectively. These latter vehicles successfully soft-landed on Mars in 1976 and sent back the first detailed study of the surface of that planet.

Early in 1977 a second Helios solar probe was launched and later in the year two III-E/Centaurs put two planetary spacecraft on course for Jupiter. These vehicles called Voyager will reach Jupiter in 1979, fly past the ringed planet Saturn in 1981 and one of the two will probably reach Uranus by 1986 and may go on to Neptune. There is a strong possibility that these are the last Titan III-E/Centaur missions, due to the availability of the reusable Shuttle for all satellite and space probe launch tasks from 1980.

Since 1974 this expendable heavyweight launcher has been in the NASA inventory for sending the heaviest payloads into space. With a capacity to put 3.63 tonnes into a geosynchronous transfer ellipse, Titan III-E/Centaur is unequalled in the US and apart from the uniquely developed Saturn V vehicle, which served only specialized duties with the Apollo and Skylab programmes before retirement, it is the heaviest space launcher ever brought into use by either the Air Force or NASA.

In a typical planetary launch mission, in this case the Viking Mars mission, the two solid propellant boosters ignite for liftoff producing a total thrust of about 1,088 tonnes. About 110 sec later, when the assembly is at a height of 39 km and a speed of 4,960 km/hr, the second stage engines, at the base of the Titan, ignite and contribute additional thrust. From this point on for 11 sec total thrust can peak to 1,300 tonnes and while the solid propellant boosters of the first stage separate and fall away at 122 sec into the flight, the second stage liquid propellant engines continue to produce 236 tonnes of thrust until they shut down at 256 sec and a height of 109 km; they had burned for 135 sec and taken the assembly to a speed of 14,500 km/hr.

Stage 3 now takes the vehicle to a height of 164 km and a speed of 23,200 km/hr in a burn lasting 202 sec. About 16.5 sec after stage 3 shutdown, the Centaur fourth stage ignites and in a 127 sec burn, builds up speed to 26,600 km/hr at a height of 603 km. The assembly is now in a parking orbit and 20 min later the Centaur engines are ignited a second time to take itself and the payload out of Earth orbit and on to a Mars trajectory. At shutdown 320 sec later, speed is 41,230 km/hr with the assembly climbing through an altitude of 310 km.

About 3½ min after Centaur shutdown, the spacecraft is separated and 14 min later the Centaur blowdown operation begins. This vents excess propellants, imparts a velocity increment and literally knocks the inert stage off course so that it will gradually get further away from the spacecraft. Blowdown ends about 250 sec later and, 57½ min after launch, the launch vehicle has accomplished its part of the mission.

By the end of 1976 exactly 100 Titan III-A, -B, -C, -D and E/Centaur orbital flights had been attempted since 1 September 1964, of which 4 had been classed as failures. Added to these 12 successful Gemini-Titan II flights were orbital and 1 was a ballistic shot. Titan III-B, -C, -D and -E/Centaur will retire in the early 1980's as the NASA Shuttle takes over responsibility for placing designated payloads in space. However, the Air Force is keen to retain some of its heavyweight fleet in the event of delays or accidents with the Shuttle launch schedule and may use the occasional launch vehicle of the Titan class up to the end of the 1980's. So far Titan III-B and -D launches are fired from the Vandenberg Air Force Base with III-C and -E/Centaurs leaving from Cape Canaveral.

Trident:

In 1969 the United States Navy developed proposals for an Undersea Long-range Missile System (ULMS) conceived to provide an integrated third generation submarine/SLBM force to at least partially supplement the existing Polaris/Poseidon fleet. At this point the reader is advised to refer to Polaris/Poseidon for a resume of historical milestones associated with the first and second generation SLBM developments.

The ULMS proposals envisaged two concepts: ULMS-1 would adopt existing Poseidon-equipped submarines and would lean heavily on Posiedon technology for development of the SLBM; ULMS-2 would adopt a totally new missile design and require production of submarines about twice the size of the current Lafayette-class boats with each one capable of carrying between 20 and 24 missiles instead of the 16 carried by Polaris/Poseidon boats to date.

The basic objective behind the ULMS concept was to provide a missile which would have about twice the range of the Poseidon and be carried by submarines that would remain close to the continental shelf instead of roaming the oceans of the world. This would have an advantage in that foreign shore bases could be contained in those qualifying as US territory. Also, improvements in submarine technology could be applied to providing a quieter mode of operation; the US Defence Department was worried about the capacity of Soviet tracking equipment to detect the comparatively noisy operations involved in running motive engines, etc.

By 1972 a decision had been made to develop a missile based on theoretical studies of a three-stage Poseidon and originally called Expo, for Extended range Poseidon. Designated the C-4, the missile was named Trident I (C-4) and because it used the first two stages of Poseidon could, and would be, fitted to existing Poseidon firing tubes in Lafayette-class submarines; special Trident submarines would be built later. In 1973 tests with Poseidon showed deficiencies in performance which, although receiving corrective attention, did have an impact on the development schedule for Trident. A year later the procurement plan for the 10 new Trident-type submarines was reduced from a planned 3 boats per year to 2 per year and an intermediate submarine was proposed which would carry only 16 Trident missiles and provide an option for the Navy to make a choice between the two designs. Also, 10 existing Poseidon-type Lafayette-class submarines would be retrofitted with the Trident I (C-4).

By the beginning of 1975 procurement of the 10 new submarines had been reduced still further from 2/year to 3/2 years, with the first becoming operational in 1979. Then, during 1975, it became apparent that Soviet strategic arms developments warranted more than the initially planned procurement of 10 Trident submarines and the US Navy adopted a plan whereby it would continue to order the new boats on a 1-2-1-2 basis each year, ensuring the previously agreed quota of 3 new submarines every two years, up to a possible total of 30. The exact number could be tailored to future requirements in the light of Strategic Arms Limitation Talks and the prevailing relative defence posture between the US and USSR as time progressed.

The first Trident submarine was ordered in 1974 followed by 2 in 1975, 1 in 1977 and 2 in 1978. The first five would be followed by additional procurements in successive years. Early test failures of the UGM-93A Trident I C-4 in 1974 and 1975 hampered development progress for a while, but the first successful flight was accomplished on 18 January 1977 although the first underwater launch will not be performed before 1979.

The Trident missile is 10.36 m long, 188 cm in diameter and weighs 32 tonnes at launch. The three stages use solid propellants (see Poseidon for the propellants in the first two stages) with the third stage employing a Hercules Powder Company rocket motor. A Post Boost Control System ensures a high level of terminal manoeuvrability and the missile uses an all inertial guidance and navigation system to transport 8 warheads of 100 KT yield in a Mk. 4 manoeuvrable independently targeted re-entry vehicle. Trident has a range of about 7,800 km with this payload.

The first Trident submarine, SSBN Ohio, will be operational in 1979 and in 1980 ten Poseidon Lafayette-class submarines will begin retrofit with 16 missiles apiece. The new Trident submarine, of which up to 30 may eventually be commissioned, has a submerged displacement of 18,700 tonnes, a length of 170 m, will carry 24 Trident I missiles and operate from a base at Bangor in Washington. If a second base is needed, it will probably be built at Kings Bay, Georgia. With Trident I having a carrying capacity, and an explosive yield, twice that of the Poseidon C.3 the new missile will provide effective support for an increasing emphasis toward SLBM deterrence.

A new version, Trident II (D-5) may be introduced for service toward the end of the 1980's using Trident I launch tubes in the new 24-missile submarines. The missile would weigh about 57.5 tonnes and provide a range capability of about 11,000 km. Whereas Polaris and Poseidon boats have adopted names of famous American personalities, unlike earlier US submarines which adopted the names of fishes, the Trident boats use State names such as Ohio and Michigan. If 30 Trident submarines are built the total fleet would carry 720 Trident rockets with a collective total of 5,760 warheads of 100 KT yield each.

Vanguard:

Developed in response to President Eisenhower's approval of plans to launch US earth orbiting satellites, in support of the 1957–58 International Geophysical Year, on 29 July 1955, Vanguard had an inglorious career, but left a distinguished legacy. Much of the technology for Vanguard, conceived as a three-stage launch vehicle capable of placing a weight of 23 kg in a low earth orbit, came from the Viking atmospheric sounding rocket and was directed by the US Navy. The name Vanguard has been associated with both the launcher rocket and the satellites it attempted to place in orbit and as such implies a project name with the same designation applicable to the two elements involved.

Vanguard genesis began on 5 July 1955 when the Naval Research Laboratory issued a report titled 'A Scientific Satellite Programme' outlining the advantages, problems, methods of launch and tracking requirements for placing a small payload in orbit. It recommended adoption of the Viking research rocket as the basis for the launcher with upper stages consisting of either two solid propellant rockets in tandem or one liquid propellant Aerobee with a solid propellant third stage. Aerobee was a liquid propellant sounding rocket and the Viking-Aerobee-solid propellant stage concept, much favoured by Milton Rosen, who later became technical director to the project, was selected a month later. Rosen's wife Josephine chose the name 'Vanguard' and it was approved on 16 September 1956.

Charged with taking care of development, the Department of Defence authorized the project on 9 September 1955 to the Naval Research Laboratory with scientific tasks under the guidance of the National Academy of Sciences. By March 1956 design details had been finalized. The first stage would burn a liquid oxygen/kerosene propellant combination for 142 sec, delivering a thrust of 12.7 tonnes, the second stage would burn inhibited white fuming nitric acid and unsymmetrical dimethyl hydrazine to produce 3.4 tonnes of thrust and the third stage would be a solid propellant rocket with a thrust of about 1.4 tonnes.

The satellite would be contained within a shroud on top of the third stage and the total vehicle was 21.9 m tall with a diameter of 114.3 cm and a liftoff weight of 10.25 tonnes. The first flight associated with Project Vanguard, came on 8 December 1956 when a Viking sounding rocket carried equipment for checking tracking and telemetry equipment at Cape Canaveral. This was the 13th launch of a Viking and the rocket reached a height of 203 km and came down 295 km from the launch pad. The experiments, designated TV-0 (Test-Vehicle Zero), was followed by TV-1 on May 1, 1957, when Viking No. 14 took the Vanguard third stage on a test flight across a range distance of 724 km.

The first Vanguard launch, TV-2, came on 23 October 1957 with a full test of the first stage carrying a dummy upper stage section. This was satisfactory and the first attempt to put a satellite in orbit was made on 6 December with all three stages of the Vanguard TV-3 and a 1.4 kg satellite. However, 2 sec after ignition the first stage malfunctioned, thrust was lost and after rising just a metre or so, the rocket fell to one side, broke up and exploded in a ball of fire.

On the next attempt, on 5 February 1958, Vanguard TV-3BU (for Back-Up) went off course and broke up at a height of 5.5 km. Then, on 17 March, TV-4 successfully put its 1.4 kg payload, Vanguard 1, into orbit. The last of the five Vanguard research and development flights was made on 28 April 1958 when the third stage of TV-5 failed and the 10 kg satellite could not get into orbit.

Satellite Launching Vehicles (SLV) -1, -2 and -3, the fully operational rockets, similarly failed in May, June and September 1958 during upper stage trouble which prevented any of these payloads reaching orbit. On 17 February 1959 SLV-4 put Vanguard 2 into orbit followed by SLV-5 and -6 which failed the following April and June; again upper stage problems, this time with 10.4 kg payloads on board. Finally, on 18 September 1959, SLV-7 put Vanguard 3 into orbit and the operational programme came to an end.

In all 11 attempts to orbit payloads, only 3 had been successful, but 4 of the Vanguard rockets operated perfectly and the hardware developed for the project found application in the upper stage designs applied to the Delta, Atlas and Scout launch vehicles.

Viking:

Designed to accommodate a US Navy requirement for an upper atmosphere research tool, Viking was a direct successor to the V-2 although it was the product of a totally separate technology. The Naval Research Laboratory conceived Viking in 1946 and an industrial competition resulted in the contract going to the Glenn L. Martin Company who eventually fabricated 14 rockets of this type. The 9.1 tonne thrust rocket motor, developed by Reaction Motors Inc., used liquid oxygen and alcohol propellants and by October 1947 the engine test programme got underway in the first of three consecutive programmes leading toward full thrust firings.

By September 1948 engineers had demonstrated a thrust of 9.5 tonnes and this was mated to the first Viking rocket in December. Because of the experimental nature of rocketry in the late 1940's no two Vikings were the same; each successful or unsuccessful flight provided experience from which the next could benefit and the Viking series can be divided into two separate phases. During Phase 1 the Viking was generally between 12.8 m and 14.6 m in length, depending on the type of nose cone fitted, and 81.3 cm in diameter.

In the first flight on 3 May 1949, Viking 1 reached the then creditable altitude of 81 km and a speed of nearly 3,800 km/hr. Viking 4 was fired from the Pacific based USS Norton on 11 May 1950 in a test called Project Reach and Viking 5, launched 21 November 1950, soared to a height of 50 km and a speed of 5,650 km/hr from the White Sands Missile Range, New Mexico. The last of the Phase 1 Vikings, No. 7, was launched in August 1951 to a height of 219 km and a speed of 6,400 km/hr. The basic Phase 1 rocket had a burn duration of between 49 and 72 sec with a propellant load of between 4.3 tonnes and 5.1 tonnes.

With 6 out of 7 flights successful, the NRL team spent the first half of 1952 uprating the Viking capabilities and, by increasing the diameter of the single stage to 114.3 cm, increased the propellant weight to about 6.62 to 6.82 tonnes and the burn duration to around 100 sec. The first Phase 2 Viking, No. 8, left the launch stand of its own accord on 6 June 1952 when it tore free of the restraint points during a static engine test, careered to a height of 6.4 km and crashed to the floor 8 km away. The next attempt was a scheduled flight (!) and three more successes with the enlarged Viking completed the basic programme by February 1955.

In twelve flight attempts only one had suffered failure (Viking 6 in December 1950) excepting the one surprise flight with Viking 8. On 8 December 1956 and 1 May 1957, Vikings 13 and 14 respectively, flew support missions to test tracking networks for the Vanguard programme (see Vanguard) effectively completing the Viking project. Maximum altitude and speed was achieved on 24 May 1954 when Viking 11 reached a height of 254 km at 6,920 km/hr and the heaviest payload – 435 kg – had been lifted by Viking 4 on 11 May 1950, from the ship-launch performed in the programme. Apart from this flight, and No's 13 and 14 from Cape Canaveral, all other launches were from White Sands.

Wac Corporal:

Developed by the Jet Propulsion Laboratory at the California Institute of Technology, the Wac Corporal (not to be confused with the Corporal surface to surface missile) was inspired by a US Army Signal Corps requirement, processed through the Ordnance Department, for an atmospheric sounding rocket capable of reaching a height of 30 km with a 10 kg payload. Work began in 1944 and the then Douglas Aircraft Company co-operated with the Guggenheim Aeronautical Laboratory to produce the rocket. A scale model, dubbed Baby Wac, was tested in July to study characteristics of the design concept which incorporated a main sustainer section 4.8 m long and 30.4 cm in diameter, producing a thrust of 680 kg for 45 sec.

The sustainer received initial impetus from a 1.5 m-long booster producing 22.7 tonnes of thrust for 0.6 sec and called Tiny Tim. The solid propellant booster weighed 247 kg and the liquid propellant sustainer – comprising the entire forward section of the 6.4 m tall rocket – weighed 54 kg. The propellants used in the sustainer were a nitric acid/anilene combination and the complete assembly reached a maximum speed of 4,500 km/hr during ascent.

The Wac Corporal carried three clipped, triangular fins at the booster stage and formed part of the Upper Air Research Programme when in October 1945 one example flew to a height of 70 km with a 10 kg payload. The rocket was launched from a 31 m tall tower with lattice structure and a guide rail, so configured that by the time it left the top of the rail sufficient velocity had been achieved to ensure its stabilized flight as air pressure impinged on the fins. The Wac Corporal was later married to captured German V-2 rockets to form the Bumper Wac assembly and went on to form the design basis for the Aerobee sounding rocket (see Bumper Wac and Aerobee).

A Compendium of Rocket Powered Aircraft

The following section describes all 8 major rocket powered aircraft projects and discusses 13 specific types. The generic characteristic of an aircraft as distinct from a rocket-powered missile is that the former is capable of sustained lift through the use of aerodynamic control surfaces. There are many examples of rocket-assisted aircraft and these are mentioned elsewhere in the text. The Japanese Baka commands a border-line status, but it errs on the side of a rocket-powered missile in the sense that it was only marginally capable of sustained lift. Unlike the alphabetical order by nation and then name, the aircraft types are arranged in order of chronological development. This was felt necessary because of the special and unique nature of rocket-powered aircraft which is best understood by using the section as a reference text for the generic development of these projects.

This section covers all rocket aircraft projects brought to operational status and includes discussion of the X-24C, which has yet to appear as a contracted programme, but for which there is great hope concerning development. The reader is advised to use the 8 project designations as a historical narrative and it is further suggested that a good understanding of how rocket aircraft projects have evolved will be had by starting at Me 163 and reading through to X-24C.

It should be pointed out that the M2-F2, M2-F3, HL-10, X-24A and X-24B Lifting Body vehicles are grouped under 'Lifting Body' because of the special nature of that category and that the Me 263 is similarly displayed under Me 163. A pictorial survey of major rocket-powered aircraft developments appear on pages 67 to 70.

Germany

Me 163:

The historical genesis of the world's first operational rocket-powered fighter had its beginning in the late 1920's and early 1930's when Dr. Alexander M. Lippisch studied various concepts of rocket propulsion which could be applied to aeronautical designs of revolutionary concept. Among his many innovative designs was the tailless aircraft which was to receive attention from the Reichsluftfahrtministerium (RLM, or German Aviation Ministry). The RLM Research Department brought in the second member of what would come to be the second Me 163 requirement when, in 1936, Helmut Walther was asked to supply small 40 kg thrust rocket motors for aeronautical research.

Soon, a 400 kg thrust liquid propellant rocket motor had been produced to power the Heinkel 176 experimental aircraft, with flight trials beginning in early 1938 from a modified He 112. This first rocket motor was designated TP-1 and used T-stoff and Z-stoff propellants. T-stoff was 80% hydrogen peroxide with phosphate or oxyquinoline and Z-stoff was a solution of sodium or calcium permanganate. A modified version of this motor, the TP-2, was used in the He 176 and Erich Warsitz first flew the aircraft on 20 June 1939, thus initiating the flight of the world's first aircraft designed from the beginning to use rocket propellants.

Meanwhile, Dr. Lippisch was asked by the assistant to the head of the RLM Research Department, Dr. Lorentz, to design a suitable airframe for testing a rocket motor at speeds of around 508 km/hr. At this time Lippisch was working for the Deutschen Forschungsinstitut fur Segelflug (DFS), or German Research Institute for Sailplanes, and had already achieved merit for his tailless aircraft and rocket-assisted glider projects. The first such device had been launched on 11 June 1928, for a 35 sec flight, piloted by Friedrich Stamer and powered by two Sander solid propellant rockets delivering an approximate total thrust of 40 kg. The glider was built in conjunction with Fritz von Opel, the noted automobile manufacturer.

Lippisch was asked to design the high-speed airframe in 1938 and the potential research aircraft was given the designation Project X. Based on the DFS-40 – a delta-wing tailless research project with down-swept wing tips – DFS-194 matured in shrouds of secrecy and emerged as a 1,600 kg test bed for the airframe. On 2 January 1939 Lippisch left DFS and joined the Messerschmitt factory at Augsburg, simultaneously re-designating Project X as Me 163. By this time the German Army had built up a military research establishment at Peenemunde on the Baltic coast, having purchased the area in April 1936, and in mid-1939 the DFS-194, research tool for the Me 163, was transferred there from Augsburg.

Doubtful results from the tests of Heinkel's He 176 nearly killed the project, but the Walther R-1-203 liquid propellant rocket motor was fitted to the DFS-194 at Peenemunde in place of the piston engine it was originally designed to carry. This would enable it to qualify the rocket-powered system as well as the basic dynamics of the tailless airframe concept. The DFS was 6.4 m long with a 10.7 m wingspan and a potential speed of up to 300 km/hr, with its Walther motor delivering 400 kg of thrust. With test pilot Heini Dittmar flying the DFS-194 from Peenemunde and Lippisch working on the definitive Me 163 at Augsburg, news came of the new Walther R-11-203b liquid propellant motor providing 750 kg of thrust. The motor had originally been developed to help assist heavy aircraft into the air, but its potential for adaptation to the Me 163 fired enthusiasm for developing the rocket research aircraft into a high-speed fighter. The plan was then adopted to develop an operational interceptor called the Me 163B after initial flight trials with the experimental Me 163A, or Anton.

The first of three Me 163A types, the VI (not to be confused with the flying bomb of that designation), was unpowered and made its first flights from a towed launch behind a Messerschmitt 110 in early 1941. Existing military operations had pleased Adolph Hitler to such an extent that he thought existing weapons were adequate for any future campaigns and signed an order restricting expenditure on the ME 163A. The first marriage of an Me 163 and the Walther R-11-203 rocket motor came in May 1941 when a wooden airframe received a test bed trials engine followed by the first acceptance tests in July.

Heini Dittmar took the first Me 163A into the air from Peenemunde West on 13 August 1941 and tests continued until Ernst Udet approved a plan for 76 production Me 163B's in November; the Me was slowly regaining favour. Udet was to shoot himself a month later and his successor Erhard Milch was less enthusiastic, despite his order bringing Hauptmann Spate from the Russian front to oversee production and service introduction.

As fitted to the 163A, the Walther rocket motor provided 4½ min of powered flight from 441 litres of T-stoff and Z-stoff. With a weight of 2,400 kg the Anton models were 5.57 m long, with a wingspan of 9.32 m. A series of spectacular explosions led to the introduction of a new catalytic fuel called C-stoff for the production engine. It was a 57% methyl alcohol, 30% hydrazine hydrate, 13% water combination with potassium cuprocyanide to catalyze the hydrogen peroxide T-stoff for combustion. The new T-stoff/C-stoff combination would be used in the Walther R-11-211, which would be used with the Me 163B as the HWK 109-509A. This was expected to produce a thrust of about 1,700 kg and with performance figures to hand, an operational role for the Me 163 came into sharper focus.

The aircraft would be accelerated into the air by its rocket motor, running along the ground on a two-wheel trolley until takeoff when it would be jettisoned. The Me 163 could climb to a height of 12,000 m in a 3 min burn at full thrust. The engine would be throttled back for a 30 min flight, before running out of propellant. The aircraft would then dive from 12,000 m through a bomber formation and with its guns inflict damage before gliding to a landing on its nose skid and tail wheel. This anticipated performance requirement was equal to 12 min powered flight at full throttle, based on a T-stoff consumption of 1.4 kg/sec. This was soon seen to be overly optimistic as the actual consumption rate of 2.7 kg/sec limited full throttle time to less than 6 min.

The operational Me 163B construction programme began in December 1941, with delivery of the first plane in April 1942, followed by subsequent models at frequent intervals. As with so many projects, the propulsion system proved more difficult to develop than the airframe and for more than a year glide tests with unpowered airframes provided opportunity for developing flight tactics and flying lessons with the unique tailless aeroplane.

By mid-1942 Wolfgang Spate, drawn in to form an operational test unit, began to gather together the pilots who would serve as test crew and staff Erprobungskommando 16 (Test Commando 16) which would wring out technical and operating difficulties and discover methods by which the Me 163 could achieve tactical pre-eminence. The basic role of the rocket-powered fighter still envisaged a high speed dive through enemy bomber formations from high altitude, the theory being that extremely high speed, coupled with an unparalleled take-off and climb rate, could effectively offer a viable screen against slower hostile aircraft. In July 1943 the first Walther rocket motor arrived at Peenemunde and was installed in Me 163B V2. The following month Rudolph Opitz took the aircraft into the air for 2 min of powered flight, but problems developed and Opitz needed all his skill to get the aircraft back on the ground. This was only a foretaste of the consistent and sometimes horrifying characteristics which plagued the tiny aircraft throughout its life.

By this time Allied intelligence was gathering information about the activities at Peenemunde West. On the night of 17/18 August nearly 600 Royal Air Force bombers struck Peenemunde killing more than 700 personnel and inflicting severe damage to the test installations. After this Test Commando 16 was moved to an airfield near Bad Zwischenahn and training with the Me 163A got underway until the definitive article – the Me 163B – could be supplied in quantity. Several new pilots had been recruited to serve with Test Commando 16 and during the autumn of 1943 many of these arrived at Bad Zwischenahn to fly the 'A' model in familiarization trials designed to introduce the new methods of operating the temperamental aircraft.

The pre-production Me 163 V or Ba-1 series were assembled at the Messerschmitt Regensburg plant, but the operational Me 163B-1a was assembled by Klemm Technik G.m.b.H. in the Black Forest and then transported to the Luftwaffe airfield at Lechfeld. From here they would be moved to Bad Zwischenahn for the use of Test Commando 16 which, was expected to define the flying tactics and operating roles most effectively maximizing the aircraft's potential. Later, the unit would serve as a sort of operational conversion base for fighter pilots going on to operational groups.

Delays and myriad technical modifications hampered early delivery of the 'B' series and Test Commando 16 concentrated on flying the Me 163A as the onset of a severe winter caused further delays due to poor flying conditions. In December 1943 the first Me 163B-0 models were moved to Lechfeld and by January 1944 Wolfgang Spate had developed plans to set up a ring of airfields which could use the rocket powered fighter to repel Allied bombers. Now the much coveted 'B' series began to arrive and operational trials started in earnest.

The aircraft was 5.7 m long, 2.5 m tall and carried a wing span of 9.3 m. The fuselage was of circular cross-section, with a pointed nose terminating in a small propeller for the generator, which gave the entire structure a distinctly bulbous profile. A large fairing under the fuselage contained a central skid which was lowered for landing and retracted for flight (the retraction sequence after takeoff released the trolley). This fairing continued toward the tail and enclosed the rear fuselage wheel which was partially retractable. The 22 ° swept wings had a large surface area for the size of the aircraft, necessitated by the gliding role it was called upon to perform at the end of powered flight, plus the high lift-to-drag ratio demanded by the basic operating plan. They had a high thickness/chord ratio and supported two ailerons and two flaps, with fixed slots on the leading edge.

Two small stub fairings close to the wing tips prevented damage when the aircraft tilted to one side after losing speed at the end of its landing run. The rear fin supported a single-piece rudder which faired in to the top of the fuselage to form a subtle dorsal bulge between the tail and the cockpit. This gave the fuselage the appearance of an oval cross-section. The cockpit itself was heavily armoured for pilot protection with a 9 cm thick armoured glass plate above the instrument panel, securing the gunsight. A bulbous plexiglass canopy was side-hinged for pilot access.

Propellant was contained within the fuselage and wings: two C-stoff tanks in each wing with a capacity of 204.4 litres/wing; an 866.8 litre T-stoff tank behind the pilot's seat; two 49.2 litre T-stoff tanks either side of the cockpit between the seat and the instrument panel. The 1,374 litres of propellant would be delivered to the HWK (Helmuth Walther Kiel Kommandogesellschaft) 109-509A rocket motor for controllable thrust between 100 kg and 1,500 kg. The T-stoff was essentially an oxidizer and combustion exhibitor for the C-stoff fuel, but an additional purpose was served by using it to generate steam for the turbine pumps to drive the propellants into the engine. Also, T-stoff was passed over porous stones impregnated with calcium permanganate and potassium chromate to induce a head of steam and drive the pumps which would move C-stoff into the walls of the combustion chamber for cooling.

The motor itself weighed 166 kg and was situated in the centre fuselage. Access was gained by propping the fuselage at the wing root and removing the tail unit as a single piece. The rear fuselage would then slide out past the engine and its combustion chamber. The highly volatile and extremely dangerous propellants caused many deaths due to familiarity and lack of caution, until mechanics and pilots acquired a healthy respect for the lethal chemistry involved in their make-up. The T-stoff propellant would ignite on contact with any organic substance and even buckets or containers previously used for one, would explosively erupt if a quantitiy of the other were poured inside. This demanded precautions of an unparalleled kind. From time to time propellant lines would rupture inside the aircraft and dangerous chemicals leak into the cockpit, which produced toxic odour and suffocating fumes. At worst, and not on a few occasions, the leaking propellant gushed into the cockpit in sufficient quantity to literally dissolve the pilot alive; twice a Test Commando 16 officer opened the canopy of a Me 163 to find protruding skeletal bones instead of a face.

Armament for the initial batch comprised two 20-mm cannon located in the wing root, but this was later changed to two 30-mm cannon in the same location. Empty, the aircraft weighed 1,777 kg and with 2,018 kg of propellant and the necessary armament and pilot, weighed 3,950 kg; maximum landing weight was 1,900 kg. The Me 163 had a theoretical speed limit of 900 km/hr and a ceiling of about 12,000 m, although one actually reached a height of 15,100 m. During takeoff the Me 163 would gather speed to about 280 km/hr, ascend from the runway, drop its two-wheeled trolley and climb at a speed of about 710 km/hr to altitude.

Because of the 5 min full throttle operating time, the rocket motor was required to provide height, whereupon the fighter would dive fast and furious into bomber formations at about 900 km/hr. In a head-on attack, closing speed with the hostile bombers, probably cruising at a height of 7,500 m, could be as much as 300 m/sec and this dictated a preferred attack from the rear where approach speed relative to the target could still be as high as 150 m/sec, leaving little time for aiming the cannon, which itself had a range of only 590 m. The operational plan for interception required the Me 163 to be tied to an alert network which could provide clear information as to where the approaching bombers were to be found in the closing minutes before reaching the vicinity of the airfield. This ensured that the limited duration of the Me 163's flight potential maximized the operational effectiveness and with a climb time of 191 sec to 10,000 m the aircraft had no need for much advanced warning before it could be on station.

It is interesting to compare this phenomenal performance figure with the Focke Wulf 190D, a popular fighter of the day, which took 1,008 sec to reach 10,000 m, and the famous Me 109G which took 720 sec.

During the first half of 1944 Test Commando 16 received 'B' models in greater numbers and the first operational sortie was flown by Wolfgang Spate on 13 May in his all-red Komet, as the aircraft had come to be called. Only the previous month the Luftwaffe had stopped all development testing and given the go-ahead for full series production and, also in May, the first operational unit was set up at Wittmundhafen with several personnel going across from Test Commando 16 at Bad Zwischenahn. The unit, 1./JG 400 (Staffel 1 of Jagdgeschwader 400) moved to Brandis near Leipzig in July 1944 to counter Russian aircraft on the eastern front.

The following month 2./JG 400 joined Staffel 1 at Brandis for a combined force of 30 Komets. In September, Test Commando 16 vacated Bad Zwischenahn, it had received increasingly heavy air attack, and joined the two Staffel of Fighter Group 400 at Brandis under the command of Hauptmann Thaler; Spate had been required to re-join conventional fighter units. Also at this time, a training unit was set up at Udetfeld known as Erganzungsstaffel/JG 400, ultimately comprising Staffeln 13 and 14 of III/JG 400 (that is Squadrons 13 and 14 of Wing 3 under Fighter Group 400).

In November, 3. and 4./ JG 400 (Squadrons 3 and 4 of Fighter Group 400) were set up at Stargard in Pomerania, changed to Staffeln 5 and 6 to form the first elements of II/JG 400 (Wing 2 of Fighter Group 400) in December. By then Spate had been brought back to command JG 400. By the end of the war only Wing I had been brought to operational effectiveness and the limited radius of action had severely curtailed hopes, by the German High Command, that the rocket fighter could repulse the Allied onslaught.

Too few in number, the Me 163B was a difficult aircraft to handle and many pilots lost their lives when rocket motors blew up without warning and airframes collapsed during the precarious landing operation. Only 279 Me 163B models were produced up to February 1945 when assembly ceased due to the Allied offensive. In 1944 a two-seat trainer, the Me 163S was used, with the second cockpit behind the original, in the position normally occupied by the main T-stoff tank. A slightly larger version with bubble canopy for all-round vision and additional propellant for longer range, the Me 163C, was designed, but only three were ever built.

A Japanese version, the Mitsubishi J8M1 Shusui, was built, but only 5 were completed with the Japanese equivalent of the HWK 509A rocket motor, the Toku Ro. 2 (Kr-10). First flown on 7 July 1945 the J8M1 rose only 400 m before the rocket motor stopped and the aircraft crashed; the J8M1 came too late for an operational version to be completed.

Meanwhile, a complete re-design of the Me 163B had emerged at Messerschmitt, called the Me 163D, with a new fuselage and a HWK 509C-4 rocket motor producing 1,700 kg of thrust from the main chamber and 300 kg from an auxiliary chamber. Propellant capacity was increased to 2,032 litres (from 1,374 litres in the basic Komet) and this promised a speed of 1,000 km/hr, a range of up to 160 km and a 180 sec climb to 15,000 m. The two rocket motor chambers would be used together for a total thrust of 2,000 kg or in sequence, with the high thrust chamber providing boost during ascent and the second chamber, cutting propellant consumption, for an extended cruise to the target. The only common structure was the wing, everything else being a complete re-design incorporating a tricycle undercarriage with in-flight retraction.

By mid-1944, the project was turned over to Junkers due to pressure of work at Messerschmitt and the design was temporarily re-designated Ju 248, but reinstated as the Me 263 at the insistence of the RLM. The only model ever built, the Me 263 VI, performed unpowered and powered flight trials late in 1944 and was eventually captured by the Russians and tested, in modified form, as the I-270 (ZH) after the war.

Developed as the world's first rocket-powered fighter, the Me 163 had the notorious credit of killing more German than Allied personnel, but the sheer daring with which it was brought to operational status continues to capture the imagination and certainly gain respect from historians of aeronautics and rocket propulsion alike.

Bachem Ba 349:

In a memorandum submitted to the Technical Office of the German Ministry of Aviation (Reichsluftfahrtministerium Technischen Amt) in July 1939, Dr. Wernher von Braun proposed a rocket propelled aircraft which could be launched vertically to intercept hostile aircraft. attaining an altitude of 8,000 m from a liquid propellant motor delivering 22 tonnes of thrust. For more than five years the idea was considered to be impractical, until the fortunes of war reversed and Allied troops landed on mainland Europe.

At the personal request of Heinrich Himmler, a consistent campaigner, Dipl.-Ing. Erich Bachem, was asked to take up the idea and develop the interceptor to production level. Bachem had kept in constant touch with von Braun and modified the basic concept according to the technical status of the art as it advanced in the early 1940's. A small factory was established at Waldsee in the Black Forest and in August 1944, the project, designated Bachem Ba 349 Natter, got under way.

The aircraft emerged as a cylindrical tube, 6 m long, with a 4 m wing span and an offset cruciform tail. This consisted of two rectangular fins, one above the rear fuselage and one below. with a horizontal tailplane fitted to the upper fin above the fuselage. A twin-chamber Walther HWK 509C rocket motor was situated in the rear fuselage and would produce a total thrust of 2,000 kg or 1,700 kg and 300 kg from sequential use of each chamber. The propellants, T-stoff and C-stoff, were in tanks forward of the motor and with 882 litres on board, the Ba 349 was expected to reach a speed of 1,000 km/hr or cruise at 800 km/hr with a maximum range of 60 km. The interceptor would have an endurance of between 3 and 4 minutes and weigh 2,232 kg including four Schmidding solid propellant rockets delivering a total thrust of 2,000 kg for 10 sec.

Launched vertically from a rig with guide rails, the Natter would jettison its four boosters at burn-out and continue on up to a height of 10,000 m, whereupon it would cruise until the liquid propellants were depleted and then dive on enemy bomber formations. The nose cap would then be jettisoned revealing 24 Hs 217 Fohn missiles which could be fired at the target simultaneously. The pilot would then jettison the entire forward section of the interceptor, at which time a parachute would automatically deploy and wrench him from the main fuselage section for a slow descent to the ground.

The first tests of the Ba 349 got underway in November 1944 when the prototypes were towed behind a Heinkel III, but firing tests were hampered by accidents. In December, the Chief Development Commission cancelled all further work in favour of Me 262 (jet fighter) and 263 (see Me 163) production. This order was ignored and the first manned flight was delayed until rocket motors arrived, and then only the HWK 509A, with 1,500 kg thrust, was available. Piloted trials began on 25 February 1945 ending in disaster, but three more successful tests followed.

In a proposed Ba 349B version, the four solid propellant boosters were replaced by two units of different design delivering 1,000 kg each; only three were ever built. In all, 36 Ba 349 interceptors were assembled, 24 were flown and 7 had a pilot in the cockpit. In April 1945, a detachment of 10 'A' Natters was set up near Stuttgart to wait for approaching bombers, but in the event, Allied ground armour moved in and destroyed the lot before they could be launched. It was an inglorious end to a bizarre project.

United States

X-1:

Conceived in 1943 as a rocket powered research aircraft, designed to achieve Mach 1 (the speed of sound) in level flight, the X-1 (originally XS-1) project got under way the following year. The Bell Aircraft Corporation received a contract to build the aircraft in a congressional decision to approve funds for two high speed aircraft. The second was to be the Douglas built, D-558-I, a jet aircraft which led to the rocket-powered D-558-II, described elsewhere in this Section.

The X-1 was to provide much needed information on the transonic region and in evaluating these high speed areas, be the first aircraft to reach the speed of sound in level flight. It was also designed to fly to extreme altitude (for the day) and serve as a test vehicle for several flight routines which, in the absence of practical experience at Mach 1, were essentially theoretical. When it emerged, the X-1 was a conventional mid-wing aeroplane with straight wings and a circular cross-section fuselage supporting a dorsal extension of the fin along to the top of the cockpit. The cockpit was essentially the forward section of the fuselage with no protruberances or fairings. Glazed sections, with metal frames, afforded a reasonable degree of forward vision and the side hatch provided access to the cramped cockpit.

The X-1 was 9.45 m long, 3.3 m tall to the tip of its fin and rudder, with a wingspan of 8.53 m. The then Reaction Motors Inc., provided an XLR-II, four chamber rocket motor with each chamber delivering a thrust of 680.4 kg or a total thrust of 2.7 tonnes for 100 sec. This approach was made so as to provide a range of selectable thrust levels, but without the complexity of a throttleable engine. The 3.72 tonnes of ethyl alcohol and liquid oxygen propellants were carried in the fuselage for a total X-1 weight of 5.9 tonnes.

In flight the X-1 was carried to altitude, strapped in the modified bomb bay of a B-29 heavy bomber. In this configuration only the lower section and wings were visible beneath the aircraft. The X-1 was hoisted in to the B-29's bomb bay by first wheeling it down an inclined ramp in to a pit. The B-29 was then moved over the pit into a position from where the X-1 could be winched up to the carrier plane. The X-1 was released from its location for a free fall, followed seconds later by ignition of the XLR-II rocket engine. After the brief powered portion of the flight, the X-1 would glide down to a landing at Edwards Air Force Base from where most flights originated.

The desert conditions and dry salt lake bed had provided plenty of room for manoeuvrability far removed from urban areas or other aircraft. Test flights were made fron Pinecastle Air Force Base in Florida. For landing the X-1 used a retractable undercarriage like a conventional aircraft. Flights from Pinecastle were simple glide tests in 1946 shortly after the first of three X-1 aircraft was delivered. Although in all respects an Air Force project, the High Speed Flight Station at Edwards, then called Muroc, worked with NACA engineers to extract aerodynamic data from successive drops.

Powered flights began in October 1946 and on October 14, 1947, Charles E. (Chuck) Yeager became the first man to fly an aircraft through the sound barrier. In all the three X-1 rocket-powered aircraft made 156 flights, including the 10 from Pinecastle, between introduction in 1946 and retirement in 1951. The maximum recorded speed was Mach 1.45 (1,540 km/hr) and maximum achieved altitude was 21,916 m. In November 1951, X-1-3 (the third basic X-1) blew up and was destroyed. All X-1 flights, except one, were drop tests from the B-29 and this one mission provided the only ground takeoff performed in the programme.

Throughout 1952 work progressed on modified X-1 designs and the X-1A was rolled out at the end of that year ready to make its first flight in February 1953. This and subsequent derivatives were 1.5 m longer than the three basic X-1's of 1946–51 and had increased forward visibility from a raised cockpit roof and forward windows. The X-1A had been designed to explore flight regimes higher and faster than the basic X-1 and the longer fuselage provided additional propellants for the XLR-II engine. On 12 December 1953, it reached a speed of Mach 2.435, or 2,594 km/hr, and the following June reached a height of 27,566 m. Although not first to go through Mach 2, that distinction had fallen to the Douglas D-558-II in November 1953, the performance figures represented the maximum ever reached by an aircraft of the X-1 series. In all, the 21 X-1A flights spanned two years from 1953 to 1955.

The X-1B was essentially the same as the -1A, but with special equipment for investigating heating properties at different flight conditions. It flew 27 missions between 1954 and 1958, the first flight being performed in October 1954, and among its many test objectives was the evaluation of a reaction control system of the type that was fitted to the X-15 (see X-15).

Next in line, the X-1C, was cancelled before completion and the X-1D was destroyed by fire in August 1951 during its second flight, slung under the B-29; only one unpowered test glide had been performed. The X-1E appeared in 1955, re-built from X-1 number 2, and was essentially similar to the -1A and -1B variants, but with a new, thin, high-speed wing. With the enlarged propellant capacity of the 'A' and 'B', X-1E was assigned to explore flight dynamics close to Mach 2 and the first powered flight was performed in December 1955. In a series of 26 flights between 1955 and 1958 it reached a maximum speed of 2,367 km/hr and a maximum altitude of 22,390 m.

But X-1E had been intended from the outset as a research tool rather than a record breaker and while the D-558-II and X-2 made speed and altitude claims, the ageing X-series soldiered on probing the mechanics of supersonic flight. Early in the NACA research programme the X-1A had been destroyed in a near catastrophe that threatened to take the lives of crew members in the B-29 carrier-plane. NACA had taken possession of the X-1A and -1B in 1954 from Air Force custody that eased the aircraft into service, but in August 1955, while still strapped to its B-29, the X-1A caught fire and had to be jettisoned. As feared, the tiny rocket aircraft full of propellant, pitched up sharply toward the B-29 and in a near collision, swept vertically upward, before plunging down to the desert floor.

Out of six X-1 series rocket-powered research aircraft, three (X-1-3, X-1A and X-1D) were destroyed. Paradoxically this was a creditable record for such revolutionary designs. Participating in operational tests in the 12 year period between 1946 and 1958, the X-1 series retired to give way to the hypersonic X-15 which would appear in 1959. In all there had been 231 flights, gathering a wealth of valuable data on high speed/high altitude flight.

D-558-II:

In 1950 the US Navy converted the D-558-II high speed research aircraft into a rocket powered test vehicle for supersonic flight. The D-558-II Skyrocket had first appeared in 1948 as a more or less conventional aircraft, specifically designed to investigate high subsonic speed regimes and contribute to knowledge on aerodynamics concerned with future jet-powered combat aircraft. An earlier project, the D-558-I, had first flown in March 1947 with a General Electric TG-180 jet engine delivering a thrust of 1,814 kg enabling the aircraft to reach a speed of 1,046 km/hr and a height of 12,200 m.

The original D-558-II was very different, with a 35 ° wing sweep instead of the straight wing fitted to the D-558-I and a sharply pointed nose, terminating in an air-data boom, instead of a circular air intake fitted to its predecessor. The then Douglas Aircraft Company were responsible for both the D-558-I and -II. In February 1948, the D-558-II (hereafter referred to by its more popular name: Skyrocket) made its first ground takeoff with a Westinghouse J-34 turbojet engine and this was later changed to a J-40 for extra power.

The second Skyrocket configuration incorporated a Reaction Motors Inc., LR-8-RM-6 rocket motor with 2.7 tonnes of thrust for high speed flight trials. The aircraft carried 946 litres of aviation gasoline for the jet engine, which was expected to get the Skyrocket off the runway so that the rocket engine, with 1.36 tonnes of propellant, could provide additional thrust for higher speed. Designed from the outset as a research aircraft, it carried 284 kg of instrumentation crammed into every conceivable vacant space to monitor performance and the aerodynamic qualities.

Late in 1950, Douglas completed Navy funded modifications which removed the jet engine and transformed it into a potential Mach 2 research tool, at a time when the Bell X-1 series were still the only aircraft capable of reaching Mach 1.5. The Skyrocket was 13.7 m long, 3.3 m tall and had a wingspan of 7.6 m. The new configuration provided a maximum weight of 6,800 kg and the aircraft was to be launched from beneath the fuselage of a B-29 bomber previously used in the X-1 programme so that it could ignite its rocket at altitude and gain height and speed advantage. The LR-8-RM-6 engine could fire for 200 sec with the additional propellant contained in space hitherto occupied by the jet engine.

In January 1951 the all-rocket Skyrocket arrived at Edwards Air Force Base, California, the home of all high speed research aircraft and by April the first drop test and powered flight was successfully accomplished after three months of captive flights. Although the first Skyrocket air-drop had been performed in June 1950, the configuration at that time incorporated the jet and rocket propulsion systems. In August 1951, toward the end of a protracted series of Navy tests before handing it over to NACA, the Skyrocket reached a speed of Mach 1.89 and a height of 24,080 m.

In 1953 the Air Force hoped to celebrate the 50th anniversary of the first powered flight with an attempt to reach Mach 2 in the new Bell X-1A, then in the hands of Charles Yeager. The Navy responded by bringing ex-D-558-I pilot Marion Carl to Edwards for a similar bid with the Skyrocket, then performing NACA research tasks. Temperamental and exacting to handle, the Skyrocket failed to reach the magic goal in two flight attempts during August 1953. Spurred on by the Navy failures, Yeager prepared for a Mach 2 run. Then NACA test pilot Scott Crossfield approached the Navy liaison officer at Edwards with the proposal that he should be allowed to make an attempt, since he had been familiar with the Skyrocket's peculiarities during extensive research flights.

The flight attempt came on 20 November 1953 and Scott Crossfield, later famous for his pioneering flights in the X-15, rocketed to Mach 2.005 (2,078 km/hr) and a height of 21,945 m. Three weeks later, on 12 December, Charles Yeager took the newly delivered X-1A on to a speed record of Mach 2.435 (2,594 km/hr), just days before the Wright Brothers Memorial Dinner and gave the Air Force a self induced fillip. Nevertheless, the ageing Skyrocket, which had been designed seven years earlier, became the first rocket-powered aircraft to probe Mach 2. It made a creditable height record as well when, during one of the two failed attempts at Mach 2 by the Navy in August 1953, Marion Carl took the Skyrocket to an altitude of 25,065 m. Less than a year later the X-1A eclipsed this with a flight to more than 27,000 m.

By 1956 the D-558-II Skyrocket had been retired and attention was turning to the protracted and ill-fated X-2 programme. Between 1948 and 1956 the Skyrocket had made 161 flights, of which 87 were with the all-rocket configuration and, of the total, 27 had been made from a ground takeoff instead of air-borne drop. Some 89 flights were made by NACA pilot, Scott Crossfield, following 17 missions in the earlier jet-powered D-558-I Skystreak. For several years the Skyrocket had provided a reliable research tool for the scientific examination of flight and aerodynamic phenomena which did much to build up a viable data base leading to the 'Century-series' fighters in the mid and late 1950's.

X-2:

In May 1945 the availability of German technical research papers on high speed flight pointed out certain advantages of a swept-wing design for aircraft in supersonic regimes. By October the Bell Aircraft Corporation, then working on the X-1 research aircraft conceived in 1943, proposed to the Air Force development of a follow-on to the straight wing design which would incorporate a swept-back wing and fly to Mach 2 (twice the speed of sound). In February 1946, the Air Force authorized Bell to develop the concept, known as the X-2, and produce a rocket engine which would be capable of accelerating the aircraft to high speed, after release from beneath the fuselage of a B-50 bomber. Other research aircraft (X-1 series and D-558-II) used the B-29, but the increased weight of the X-2 demanded the use of the B-50, a more powerful version of the B-29 Superfortress.

Toward the end of 1946, responsibility for developing the rocket engine was taken from Bell and given to the Curtiss–Wright Corporation. Between 1946 and 1951, the X-2 was beset by a variety of technical problems which delayed completion and stretched the programme far beyond the original schedule. The first X-2 was ready for drop tests from the B-50 in 1952 and arrived at Edwards Air Force Base, California, in October. Edwards had been the home of Air Force, Navy and NACA flight testing for several years and its flat landscape provided the degree of remoteness necessary in advanced high speed/high altitude flying; the vast expanse of dry salt bed afforded ample runway space.

The X-2 was 11.28 m long, 3.35 m tall and had wings swept back 40 °, spanning 9.75 m. The landing gear comprised a nose wheel, a rear ventral skid and two 'whisker' supports which, along with the wheel and skid, would be deployed just before touchdown, to prevent the wings from contacting the ground, a potentially disastrous event at 270 km/hr. The propulsion system was unique in that it was designed from the outset as a throttleable rocket motor burning through two combustion chambers. The XLR-25 motor would use 6.35 tonnes of alcohol/liquid oxygen propellants driven into the chambers by a pump at 2,270 litres/min to produce a thrust of between 2.27 tonnes and 6.9 tonnes. The X-2 weighed 11.8 tonnes fully fuelled for a thrust/weight ratio of 0.6:1 compared with 0.46:1 for the X-1. At the end of the rocket burn thrust/weight ratio would be 1.27:1 compared with 1.24:1 for the X-1 and this meant that the X-2 could reach higher speeds than its predecessor and probably attain Mach 3 plus.

Electrical power was provided by a 136 kg lead-acid battery with a life of 30 minutes. Because of the high speed anticipated, the X-2 was built with a fuselage of copper and nickel alloy and stainless steel wings. With work on the engine still moving ponderously toward completion, the first X-2 made its inaugural drop test from the B-50 in October 1952 with Skip Ziegler, Bell's chief test pilot, at the controls. A second successful drop test followed and then a third by Air Force test pilot Frank K. Everest. The X-2 was then flown back to Buffalo for installation of the long-awaited rocket engine and flown to Lake Ontario for a drop test and powered flight in May 1953.

The pilot, Skip Ziegler again, was in the bomb bay of the converted B-50 when a massive explosion ripped through the X-2, killing Ziegler and a Bell engineer in the process. All but blown apart in the sky, the B-50 limped home, but was so severely damaged that it could not be used again. More than a year went by while a second X-2 was prepared at Bell and another B-50 converted for carrier-plane duties. They arrived together at Edwards AFB in July 1954 for Frank Everest, now the Air Force X-2 test pilot, to attempt a series of unpowered descents – the second engine was still months away from completion.

The first descent was performed on 5 August 1954, but a problem with the frail landing gear necessitated its return to Bell factories for further modification. Back at Edwards in February 1955 the second drop test was made on 8 March 1955, followed by a third on 2 April. Again problems brought near disaster on landing and again the X-2 was sent back to Bell Aircraft, this time with plans to install the second Curtis–Wright rocket motor. The programme had now dragged on for 10 long years, completely destroying the first X-2, killing two experienced personnel and with only 6 unpowered descents to show for it. The Air Force announced that if the first powered flight could not be demonstrated before 31 December 1955, the project would be cancelled.

With engine installed and a modified landing gear supplied by Bell, the Air Force decided to try a powered flight on the first drop test with motor and propellant on board, a risky venture spurred on by the approaching deadline. On 25 October 1955 Everest slipped away from the B-50, but a problem in the rocket motor prevented ignition and transformed the flight into the seventh X-2 unpowered descent, the fourth with the second aircraft.

Moderate success came with the next attempt on 18 November, but a fire in the rocket motor and repeated attempts at ignition failed to get more than intermittent operation and a speed of Mach 0.95. But this was sufficient to get a stay of execution and while the Air Force had stipulated a powered flight by the end of the year, it recognized that progress had been made and the programme was allowed to continue; NACA was the real customer who would put the X-2 to work in sustained high speed flight trials and conduct much needed research between Mach 2.5 and whatever the aircraft could do above Mach 3. After the engine fire, the X-2 was returned to the maintenance hangar for analysis. Only three months earlier the X-1A had blown up while still attached to its B-29 carrier-plane following the destruction of the first X-2 in May 1953 and the third X-1 in November 1951. These in-flight explosions gave cause for concern and a concerted effort to trace the cause, effectively grounded operations for several months.

In the air again on 26 March 1956, Frank Everest took the X-2 to Mach 0.91 and then through the sound barrier to Mach 1.4 the following month. Suddenly, the dark clouds of ill fortune seemed to have dissipated and in May 1956 Everest made three flights going from Mach 1.5 to Mach 1.8 and then to Mach 2.5, to marginally exceed Yeager's record flight of Mach 2.4 in the X-1A, nearly 2½ years earlier. In May, Frank Everest selected Ivan Kincheloe and Melburn Apt to succeed him and take the X-2 to its maximum speed and altitude capability before handing the aircraft over to NACA on 1 November for extensive aerodynamic research.

Kincheloe made his first flight in the X-2 on 25 May with Everest watching over the flight from a following aircraft. Before leaving Edwards AFB, Everest made two more X-2 flights. On 12 July 1956, the X-2 was dropped from the B-50 for a high speed run, but the engine cut out at Mach 1.5 leaving Everest to bring it down to a glide landing. Then, on 23 July, Everest reached Mach 2.93 breaking his own record Mach 2.5 flight and left the programme. Kincheloe made three more flights going for an altitude record to eclipse the 27,566 m flight of the X-1A in June 1954. On the last attempt he reached 38,466 m, a record that would stand for nearly 4 years until broken by the X-15.

In September 1956 Melburn Apt, who had never flown the X-2 before, rocketed to a speed of Mach 3.2 (3,370 km/hr), but when the motor shut down the aircraft went into a frightening tumble and forced Apt to eject. The X-2 had been fitted with a nose section which could be jettisoned from the main body of the aircraft, following which the pilot had to scramble out and deploy his parachute. With the nose section detached, Mel Apt was unable to get out and died when the capsule slammed into the desert floor. It was the end of the X-2 programme, terminated before NACA could even begin to use it for aerodynamic research.

The first X-2 had made only 3 unpowered descents at the end of 1952 before blowing up and killing two people in May 1953. The second X-2 had made 17 descents, of which 13 had been under power from the rocket engine, between August 1955 and September 1956, finally being destroyed in the air and causing the third death of its inglorious career. For 11 years the project had dragged on through delay after delay, finally securing an altitude record and making the first flight through Mach 3, on its last two descents, in September 1956.

It was the end of an era at Edwards Air Force Base during which X-1 series, D-558-II and X-2 rocket research aircraft, all conceived between 1943 and 1945, had performed drop tests from converted B-29 and B-50 bombers. In just 9 years, between September 1947, when the X-1 became the first rocket propelled research aircraft to become available for record attempts, and September 1956 when the second X-2 crashed, speeds had gone from 1,047 km/hr to 3,370 km/hr in flights that destroyed 5 aircraft and killed three people. Only the X-1B and X-1E were left to carry on with NACA research work before retirement in 1958 and the introduction of the X-15 in 1959.

X-15:

In April 1952, the NACA moved a directive instructing its laboratories to study the potential problems of manned space flight and by May 1954 had drawn up plans for a high altitude, high speed manned research aircraft with which it could evaluate the theoretical resolutions then being worked out. Two months later the National Research Airplane Committee, representing the NACA, Air Force and Navy interests, decided to approve the NACA proposal which would be financed by the two Services. In December 1954, industrial contractors were asked to bid for the competitive distinction of building the X-15, as it was designated, and four responded with proposals along with four potential engine contractors.

North American Aviation Inc., now North American Rockwell, were selected as airframe contractors in the September; three aircraft would be built. Following a protracted evaluation of engine proposals the then Reaction Motors Inc., were chosen in February 1956 to build a 25.8 tonne thrust, single chamber rocket motor which could be throttled between half and full power and operate in a constant 90 sec burn. To support the flights, which envisaged the X-15 being launched from beneath the wing of a converted B-52 carrier-plane, a special tracking and communications network was set up at Edwards Air Force Base in California. This area had been consistently associated with high performance aircraft tests and with dry salt lake beds for runways and a deserted, flat landscape the site was an apt choice.

By January 1958 it seemed likely that the propulsion system would not be ready in time, airframe manufacture having commenced the previous September and it was thus decided to use the XLR-II for initial flight trials with the X-15. This is a four chamber rocket motor developing 3.63 tonnes of thrust and two would be carried by the new hypersonic aircraft until the XLR-99, with 25.8 tonnes of thrust, was ready.

The X-15, as it emerged, had a potential performance capability of Mach 6 (six times the speed of sound) at a height of 50 km with a very high altitude capability constrained only by the aerodynamic and heat loads imposed on the vehicle when it came back into the denser layers of the atmosphere. The fuselage was designed to be of oval cross-section, with large fairings along either side and stubby wings of a modified trapezoidal plan form. The tail supported wedge-shaped dorsal and ventral fins and two swept elevons with pronounced dihedral (downward sweep). When fully operational, the XLR-99 engine would be fed with 5,470 litres of anhydrous ammonia and 3,796 litres of liquid oxygen, stored in two tanks, for a burn duration of 90 sec and a thrust of nearly 26 tonnes. The cylindrical propellant containers were mounted in the fuselage between an equipment bay aft of the cockpit and the rear-mounted rocket engine, with the LOX tank, forward of the fuel tank.

Hydrogen peroxide attitude control thrusters were located near the wing tips and in a cluster in the forward section of the nose. The X-15 would be required to fly to extreme altitude where air pressure would be too low to control the attitude of the vehicle by conventional means (ailerons, elevons and rudder). These jets would serve to stimulate operational experience with the so-called reaction control system, forerunner of a similar technique that would be used on manned spacecraft in orbit.

For launch, the X-15 would be carried under the wing of a B-52, but its descent to the dry salt beds of Edwards Air Force Base would require an undercarriage. This was provided in the form of two extendable skids mounted in the rear fuselage, either side of the wedge-shaped ventral fin and only deployed shortly before landing. A nose-mounted retractable two-wheel leg provided front support; this too would only be deployed for touchdown. Helium tanks were used to provide the gaseous product by which the propellant tanks were pressurized and an Auxiliary Propulsion Unit (APU) provided electrical power and hydraulic power.

The materials used in the construction of the X-15 were important because of the extreme heating conditions that the vehicle would experience. An Inconel-X skin was used for the exterior with a primarily stainless steel and titanium structure. Inconel-X alloy was a product of the International Nickel Company and was widely used in hot, stressed environments. The alloy was required to withstand temperatures of 820 °c on the leading edges of the wing and fins and 730 °c on certain wing panels, but metallurgists were confident that the Nickel-X skin could survive for short periods at 870 °c.

During a normal mission, the X-15 would drop from the B-52, fire its rocket motor for either high speed or high altitude flight and, as it descended, jettison the lower section of the ventral fin. This large, wedge-shaped structure was required to be larger than the ground clearance of the rear fuselage provided for, so to land on its rear skids, the vehicle had to modify its rear shaping. The basic X-15 was 15.09 m long, 4 m tall and had a wing span of 6.8 m. Empty, the aeroplane weighed 7.76 tonnes and about 22.5 tonnes in the launch condition.

Rollout of the first X-15 (X-15-1, serial number 56-6670) was in October 1958, just 11 months after construction began. The second vehicle (X-15-2, number 56-6671) was delivered in March 1959. North American Aviation test pilot Scott Crossfield was the first to fly the X-15-1 on 8 June 1959, after a series of captive flights under the starboard wing of the parent B-52, starting 19 March. The first powered flight, using X-15-2, followed on 17 September with the two XLR-II rocket engines on temporary stand-in for the much awaited XLR-99. Tragedy nearly struck on 5 November when engine failure caused a temporary fire and X-15-2 broke its back on landing; it was, nevertheless, back in the air three months later.

In April 1960, the XLR-99 arrived and this was installed in X-15-2 for a flight under power on 15 November. Earlier, the XLR-99 engine, fitted to X-15-3, (serial number 56-6672) blew up in a ground test and demolished the tail unit necessitating a return to North American Aviation for re-building.

Between mid-1960 and the end of 1961, aeronautical flight research moved more quickly through speed records than any project had demonstrated hitherto. It was an almost incredulous assault on Mach number after Mach number, beginning on 12 May 1960, when Joe Walker cruised the powerful X-15, up to Mach 3.19, to equal the existing record set up by Mel Apt in the X-2 more than 3½ years before. By August, Walker had broken through to Mach 3.31 and then, on 4 February 1961, test pilot White hurtled to Mach 3.5. Little more than three weeks later White accomplished the incredible in exceeding this by almost one whole Mach number. The flight came on 7 March 1961, in X-15-2 and before it was over had demonstrated Mach 4.43. It stood for just six weeks until the same pilot raised it to Mach 4.62.

The first flight through Mach 5 was made by

White on 23 June when the X-15 rocketed to a speed of 5,798 km/hr (Mach 5.27). Petersen and Walker followed this in September and October with flights to Mach 5.3 and 5.74 respectively, nudging ever closer toward the magical Mach 6, for which the impressive rocket plane had been designed. Success was achieved on 9 November 1961, when X-15-2, again with White at the controls, reached Mach 6.04 (6,587 km/hr).

When the X-15 had made its first flight on 8 June 1959, the altitude record stood at 38,466 m, set up by Ivan Kincheloe in the X-2 during September 1956. This was exceeded on 12 August 1960, in a flight to 41,605 m, at the skilled hands of Robert White and exceeded again on 30 March 1961, when Joe Walker reached 51,694 m. By the end of 1961 White had flown to 66,142 m, followed in April 1962 by fulfilment of the design goal, when Walker attached X-15-3 to a record 75,194 m. By July a new world altitude record had been set at 95,936 m in X-15-3.

It is important to appreciate the paucity of information about high speed flight in excess of Mach 2.5 gathered earlier by X-series research aircraft, when the X-15 was designed. Only the X-2 had probed regions above the record Mach 2.4 set up by Yeager in the X-1A on 12 December 1953 and then in just a few quick record-making attempts. The X-2 crashed before it could provide NACA with aerodynamic data associated with Mach 3 flight. While Mach 3 had been attained in September 1956, there was virtually no solid data base beyond Mach 2.4, making the Mach 6 achievements of the X-15 design all the more creditable.

The fastest speed achieved with the basic X-15 design was on 27 June 1962, (6,605 km/hr) and the all time world altitude record was set on 22 August 1963, when X-15-3 reached a height of 107,960 m. Nine months earlier, X-15-2 had crashed on landing, injuring the pilot, and in May 1963 it was decided to modify the vehicle so that additional propellant could be carried in to cylindrical drop tanks under each fuselage fairing. This resulted in an increase in length to 15.72 m and an extended XLR-99 burn time to 135 sec.

The re-modelled vehicle was designated X-15 A2 and made its first flight on 25 June 1964, more than 18 months after the crash on 9 November 1962. In the summer of 1967, the A2 was covered with a new ablative insulation which would permit the X-15 to fly faster than attempted hitherto and on 3 October 1967, claimed the unchallenged world speed record at Mach 6.7 (7,274 km/hr). Meanwhile, the other two X-15s had performed a variety of scientific and engineering flights taking many unique forms of practical test to high speed or high altitude flight regimes.

The 191st X-15 drop on 15 November 1967, resulted in the death of Michael Adams, bringing the only operational fatality to the programme. During a flight to Mach 5.2 and a height of 81 km, attitude errors resulted in the X-15-3 re-entering denser layers of the atmosphere and turning fully 90 ° to the flight path. Aerodynamic forces broke the aircraft apart at a height of 19 km and the pilot, unable to eject, probably due to excessive damage, died on impact with the ground. Wreckage was spread over a 16 km area.

The last X-15-A2 flight, on 3 October 1967, had been the record-breaking mission. Finally, on 24 October 1968, X-15-1 made a flight to Mach 5.38 and a height of 77.7 km to conclude the research programme begun more than 9 years earlier. In that period, 199 flights had been achieved, bringing to an end 22 years of high performance rocket research tests since the X-1 of 1946. At one time the X-15 was thought a likely candidate for flights into orbit, boosted by an expendable launch vehicle, but Project Mercury eclipsed this when, in 1958, the achievements of Soviet space engineers spurred the newly formed NASA to press ahead with a new form of ballistic re-entry spacecraft. Nevertheless, the X-15 laid the foundations for a research base that would lead to the Lifting Body series of winged vehicles and in turn to the concept of a reusable space transporter, now called the Shuttle.

Lifting Bodies:

In the late 1950's and early 1960's NASA conducted theoretical research on the aeronautical problems associated with controlled descent from space. Recognizing the need to perform practical research on a variety of different shapes and configurations, the agency procured and tested three specific designs from industrial contractors. The programme required these unconventional shapes to be carried into the air beneath the wing of a larger aircraft, from whence they could be released for independent flight. In this way the handling characteristics could be determined and, on later drops, rocket engines in the tail would enable the vehicle to reach greater speeds and altitudes than would be possible with a gravity drop.

Because a vehicle returning from space is travelling at great speed, it was felt desirable to eliminate the wings and so avoid potential areas of excessive thermal loading. In a redesigned body shape the vehicle would generate sufficient lift to provide flight manoeuvering qualities necessary for reaching a runway from a variety of situations. The programme named these shapes 'Lifting Bodies' for the obvious definition of their function. Without wings, all lift would be generated by the contoured shape of the body and flight stability would be effected by short stub fins at the rear, with control surfaces providing pitch, roll and yaw functions.

The first such Lifting Body to be built was designated the M2-F1, 'M' and 'F' referring to manned flight, and was 6.1 m long, 3.9 m wide and 3 m tall to the tip of its two vertical fins. The semi-conical body supported a single place cockpit and a fixed undercarriage for a total weight, in flight, of only 517 kg – pilot included. Control of the M2-F1 was effected by the use of rudders, flaps (at the rear of the body) and elevons. There was no propulsion and the vehicle had to be towed by another aircraft to a height of 3,650 m from where it was released, reaching a maximum speed of 210 km/hr on the glide, down to a landing at 145 km/hr. The unpowered M2-F1 was a very simple vehicle consisting of steel tubing and plywood oversheets, but it showed that wingless vehicles could be controlled to a safe landing and pioneered the way for the next more definitive designs.

The first operational lifting body was the M2-F2 built by the Norair Division of the Northrop Corporation. It was 6.75 m long, 2.92 m wide and 2.7 m tall with a weight of 2,720 kg. Unlike the M2-F1, the -F2 had four hydrogen peroxide rockets in the tail, with a throttleable thrust of up to 725 kg total and these would be used during the landing approach, if the pilot was required to test out low-level manoeuvres or simply re-align the vehicle for touch down. Also, the M2-F2 had provision for a single Thiokol XLR-II rocket motor, with a thrust capability of 3.63 tonnes for 100 sec. This was a much modified version of the rocket motor that had powered the Bell X-1 during Chuck Yeager's sound-breaking flight in 1947.

The propellants for the XLR-II were carried in the Lifting Body's two main cylindrical tanks: one contained 882 litres of the ethyl alcohol/water fuel and the other carried 795 litres of liquid oxygen. Two independent hydraulic systems provided power for the flight controls fed into rudders, flaps and elevons in the tail area. A ram-air turbine provided back-up power in the event of a failure in the electrical power which was provided by 6 silver-zinc batteries. If the M2-F2 did get out of control, the pilot could eject from his cockpit. The undercarriage was retractable and adopted from off-the-shelf items available for existing aircraft.

The mode of operation required the M2-F2 to be lifted to a height of 13,700 m under the wing of a B-52 (operated by NASA as a research aircraft carrier plane) and there released at a speed of 720 km/hr. On an unpowered descent, the M2-F2 would reach the runway after 3½ min of free flight, at a speed of about 320 km/hr. With the XLR-II rocket motor it was expected to reach speeds of over 1,600 km/hr and heights of 24,000 m.

Since August 1963 and more than 100 drop tests with the plywood M2-F1, the metal-skinned -F2 was released for first descent on 12 July 1966 with NASA test pilot Milton O. Thompson at the controls. All Lifting Body flights originate from the NASA, Hugh L. Dryden Flight Research Centre, at Edwards Air Force Base, California where vast expanses of desert terrain, dry salt beds and reasonably stable climate, provide ideal conditions for exotic research projects.

By May 1967 pilots Thompson, Peterson, Sorlie and Gentry had flown 15 unpowered descents and progress was being made toward powered flight when, on the 10th of the month, drop test number 16 ended in disaster. As is normal practice a rescue helicopter was in the air during the descent of the M2-F2. Fears of a collision, plus compound problems with unexpected rolling, caused the pilot to approach an unmarked section of the dry salt lake bed. A high sink rate caused the Lifting Body to hit the ground before the landing gear could be extended and the vehicle slid, rolled and bounced to a stop, causing severe facial injuries to the pilot, Bruce Peterson. Film of this crash was used by a television company to introduce the adventure series entitled 'Six Million Dollar Man'. The M2-F2 was completely wrecked and NASA decided that in re-building the vehicle, it would add a third vertical fin at the rear of the Lifting Body.

Called the M2-F3 it made its first drop test on 2 June 1970, more than three years after the accident, with test pilot William Dana at the controls. The first powered flight using the XLR-II engine was on 25 November 1970 and the last of 27 M2-F3 descents came on 20 December 1972. An accompanying table provides details of the speed and altitude records achieved by the Lifting Body's. In all, 43 M2-F2/M2-F3 flights had been achieved in a period of less than 6½ years.

The second Lifting Body to fly was called the HL-10 ('H' and 'L' being an acronym for horizontal landing) also built by the Norair Division of Northrop, but to a different profile from that adopted for the M2-F series. Whereas the M2-F was semi-conical in shape, the HL-10 displayed a delta-shaped profile flat on top and rounded underneath. The three vertical fins provided stability with control, provided through a complex arrangement of elevons, rudders and flaps and a split rudder on the centre fin which could act as an air-brake if needed. Hydraulics and back-up ram-air intake were provided, along with a retractable undercarriage and an ejector seat for the pilot.

Electrical power was provided from 6 silver-zinc batteries and two hydrogen peroxide engines, producing a total thrust of 450 kg which were situated in the tail in case power was needed during the landing phase. Provision was made for an XLR-II rocket engine producing 3.63 tonnes of thrust for 100 sec, fed by 863 litres of ethyl-alcohol/water fuel mixture and 798 litres of liquid oxygen. The HL-10 was 6.75 m long, 4.6 m wide and 3.48 m tall at the top of the dorsal fin, weighing 2,720 kg in flying condition. The first HL-10 drop test was made on 22 December 1966, followed by a powered flight on 23 October 1968. During a succession of rocket-propelled tests a variety of thrust levels were tried out. The XLR-II rocket engine has four combustion chambers, each delivering a thrust of 907 kg and two or three-chamber firings were made to evaluate performance with different test objectives. The last HL-10 flight came on 17 July 1970 concluding 37 successful drops, flown by test pilots Peterson, Gentry, Manke, Dana and Hoag.

While the M2 and HL-10 series Lifting Body vehicles had been developed at the instigation of NASA, the Air Force produced its own test vehicle called the X-24A built by Martin Marietta. This displayed a rounded delta shape, flattened underneath, with three vertical fins at the rear. It was 7.47 m long, 4.2 m wide and 3.15 m tall, weighing 4.99 tonnes fully fuelled. The propulsion systems were the same as the HL-10, but the XLR-II engine was supplied with a fuel load of 1,287 litres and an oxidizer capacity of 1,098 litres. Four batteries supplied electrical power and the X-24A carried a retractable undercarriage and an ejector seat in the cockpit.

The first drop test was launched on 17 April 1969, followed on the 10th descent, by the first powered run with the XLR-II motor on 19 March 1970. The last X-24A flight was successfully achieved on 4 June 1971: test pilots Gentry, Powell and Manke had made a total 28 descents.

On 15 December 1971, the X-24A left the Flight Research Centre on board a transport aircraft which delivered it to Martin Marietta at Denver, Colorado, for modifications to the design profile which would test new flight regimes and give the vehicle improved flying qualities. When it emerged from re-work, the vehicle was re-designated X-24B. The fuselage had been lengthened to 11.43 m, the width had been increased to 5.84 m and the height remained unchanged at 3.15 m. The new aerodynamic shape gave the X-24B a fuelled weight of 5.9 tonnes and three times the manoeuvrability of its X-24A shape.

In several respects the new configuration was similar to that which it was believed would be adopted for some future hypersonic transport aircraft, boosted out of Earth's atmosphere and brought back to a landing several thousand kilometres away. The first X-24B flight was launched on 1 August 1973 followed by a powered flight on the 15 November. The last drop flight from the B-52 carrier-plane, used for all Lifting Body missions, was flown on 26 November 1975 with Manke, Love, Dana, Enevoldson, Scobee and McMurtry, having performed a total of 36 descents.

Between July 1966 and November 1975 the NASA/Air Force Lifting Body programme had generated 144 powered and unpowered drop tests from the B-52, contributing valuable flight research results important to the Space Shuttle satellite launcher and future hypersonic transport aircraft. It also marked the end of nearly 29 years of operation with rocket-powered research aircraft, under the auspices of the Air Force, Navy, NACA and finally NASA.

X-24C:
In May 1974 the US Air Force and NASA set up a study group to examine the possibility of jointly developing a hypersonic, rocket-powered research aircraft, for the 1980's. Thirteen months later, a report entitled *Joint USAF–NASA Study of a High-Speed Research Airplane for the 1980's (X-24C)* proposed basic guidelines controlling the specification and project objectives.

As envisaged, the X-24C would be required to fly materials and test propulsion systems at Mach 6 (ie six times the speed of sound), and study aerodynamic qualities of the configuration at sustained hypersonic speeds. Although the project designation implies a strong generic tie with the X-24B Lifting Body, it would bear only superficial resemblance to the earlier transonic research vehicle and would constitute more of a marriage between the Lifting Body concept and the propulsive capabilities of the still earlier X-15.

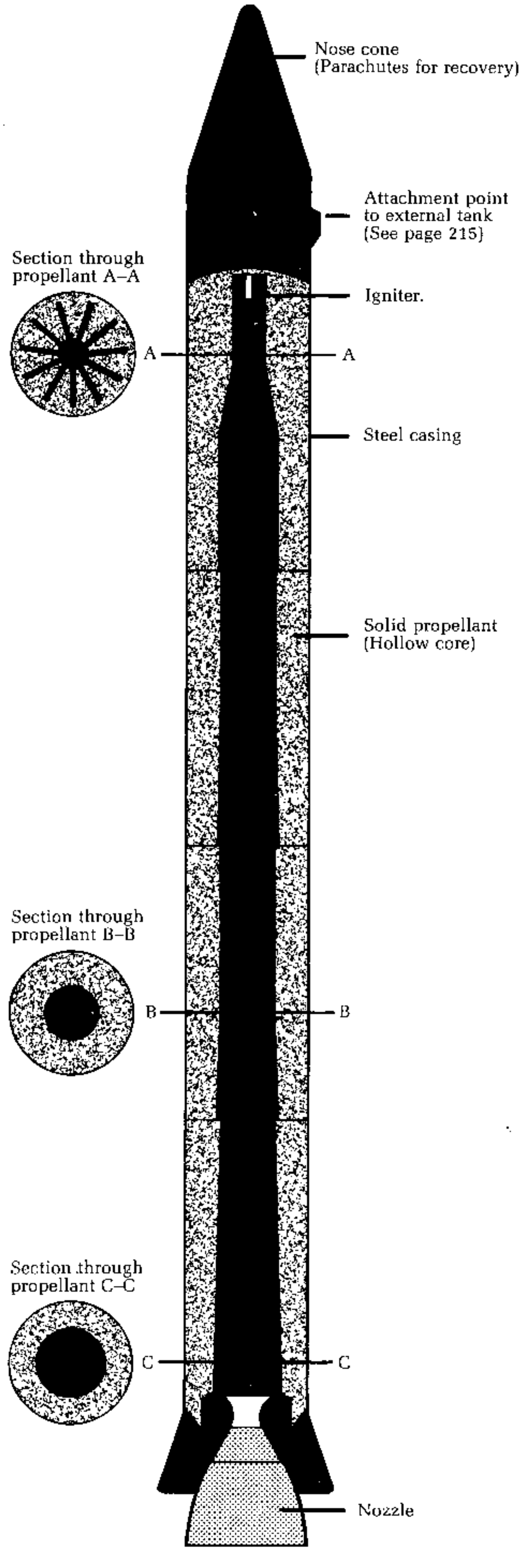
Although final design details have yet to emerge, the X-24C is expected to appear with a semi-conical body, a flat undersurface, two blended lifting surfaces and three fins. Its anticipated length will be 14.8 m, with a span of 7.4 m and weigh 25.1 tonnes of which 17.8 tonnes would be propellant. The preferred propulsion system is a modified Thiokol XLR-99, of the same basic design as that used for the X-15, but delivering a thrust of 27.7 tonnes for a thrust/weight ratio at ignition of 1.1:1. This would permit the X-24C to reach speeds of Mach 7.4 (about 8,000 km/hr). Alternatively, the LR-105 engine with 27.2 tonnes of thrust could be used.

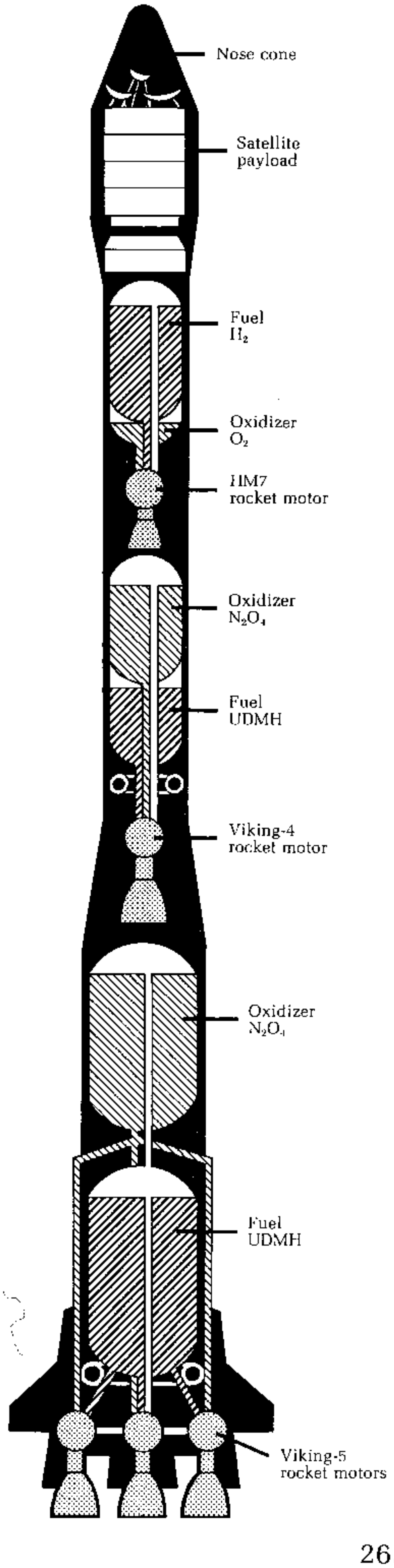
Basically a test bed for future hypersonic configurations, the X-24C, would be used to measure air flow and temperature patterns around simulated intakes for hypothetical ramjets, test a variety of thermal insulations and gather data which could lead toward definition of a civil hypersonic transport and a Mach 6 interceptor, both areas where respective agents are concerned about future developments. If the programme receives approval, the X-24C will be flying, launched from under the wing of a B-52, in the mid-1980's.

Basic solid and liquid propellant technology

Shuttle solid rocket booster:
The propellant is electrically ignited and the resulting flame ignites the main propellant segments, which burn from the centre outward, for about 124 seconds. The exhaust gases escape at a temperature of 1,861°C and at a speed of 1,571 m/sec., a higher velocity than that achieved by any operational fighter aircraft (3 times faster than a bullet) and creates sonic waves from the supersonic flow. Maximum thrust, at more than 1,360,000 Kg, is equal to the thrust generated by 16 Boeing 747 Jumbo Jets at takeoff.
Although specifically designed for the Shuttle programme, the SRB is typical of the solid propellant rocket. Exhaust temperature and velocity quoted are generally similar to those obtained for a liquid propellant rocket.

Ariane liquid propellant rocket:
A liquid propellant launch vehicle works on the principle that fuel and oxidizer are contained in separate tanks and brought to the combustion chamber by forced-delivery or by turbopump. The example shown here, Ariane, is a three-stage rocket optimized around the requirement to place a payload in Earth orbit. Each stage carries one or more rocket motor(s) in which fuel and oxidizer are ignited to combust the propellants and discharge the resulting gases through a bell shaped nozzle, otherwise known as an expansion skirt. The temperature of the liquid hydrogen will go from −253°C to 1,600°C within a few seconds. Alternative modes of operation for this class of propulsion are included in the Glossary.





Glossary of terms

Accelerometer. An instrument that measures components of motion in the xyz axis of the acceleration of a vehicle.

Apogee. The high point of an orbit about the Earth.

Ballistic missile. A device which is propelled at a speed less than that required to place it in orbit. That is, an object travelling at a speed of less than 7km/sec.

Bipropellant. Two separate propellants stored apart from each other until the moment of combustion.

Combustion chamber. The chamber in a rocket engine where propellants are ignited and burned and in which the resulting build up in pressure provides thrust by exhausting the products of combustion through a nozzle.

Cryogenic propellant. Propellant that has a boiling point considerably below the freezing point of water.

Escape velocity. The minimum velocity at which a body must move to escape from a gravitational field. In Earth's case, 11.2km/sec.

Exhaust nozzle. A bell or cone shaped duct through which combusted propellant is exhausted and controlled in velocity by the shape of the duct.

Exhaust velocity. The speed of the gases escaping from the exhaust nozzle of a rocket engine.

Expansion ratio. The ratio of the nozzle outlet area to the throat area.

Geosynchronous orbit. An orbit which provides the satellite with a revolutionary period exactly equal to the period of the Earth's rotation and which, if placed over the equator, will seem to station the satellite over one spot. In Earth's case, a satellite placed on, and in the plane of, the equator at a height of 36,000km (and a speed of 3.1km/sec.) will take 23hrs 56 min to perform one orbit, exactly equal to Earth's rotation period.

Hypergolic. Propellant that ignites spontaneously on contact.

Injector. A device, usually a perforated plate supporting access tubes, through which fuel and oxidizer is introduced to the combustion chamber at a controlled and pre-determined rate.

Launcher. A space rocket which carries a usable payload intended for prolonged or sustained flight.

Liquid propellant. A rocket propellant consisting of one or more liquids, usually two.

Mass ratio. The ratio of the total mass of a rocket to the mass remaining when all the propellant in question has been consumed.

Missile. A vehicle whose prime purpose is to transport its payload on a ballistic trajectory to a terminal point on the Earth's surface.

Mixture ratio. The ratio of the masses of the oxidant to the fuel at any given time.

Monopropellant. Fuel and oxidizer combined in a single substance, a term usually applied to liquid propellants to distinguish them from Bipropellants.

Newton. A unit of force which induces in 1kg an acceleration of 1metre/sec^2.

Orbital velocity. The velocity necessary to overcome the gravitational pull from the primary body to which it is referred. In Earth's case, 7.8km/sec at an altitude of 160km.

Perigee. The low point of an Earth orbit.

Pressure-fed. A Bipropellant propulsion system in which propellants are forced into the combustion chamber by pressure usually exerted by a gas acting on the propellant.

Pump-fed. A Bipropellant propulsion system in which propellants are forced into the combustion chamber by a pump.

Regenerative cooling. The circulation of fuel as a coolant through a jacket or tubes around the combustion chamber and sometimes around the exhaust nozzle as well.

Rocket. A device producing reactive thrust which carries its own fuel and oxidizer. Unlike a jet engine, which takes in air as it moves forward.

Servo. A device to reinforce, or multiply, a small force or movement.

Solid propellant. A rocket propellant consisting of a solid substance called a grain.

Sonde. A package of instruments designed to transmit information about the upper atmosphere.

Specific impulse. The thrust of a rocket, measured as the value per unit rate of propellant given in pounds weight per second per pound.

Stage. An assembly of propellant, rocket engine(s) and the necessary control devices for autonomous flight. A multi-stage rocket is a collection of several such stages placed in tandem for sequential operation.

Telemetry. A system for transmitting information about the condition of a launch vehicle, missile or satellite to receiving stations on the ground.

Throat. The point between the combustion chamber and the open area of the nozzle.

Thrust. The measured product of exhaust gases of a rocket expressed in kilogramme form, i.e. in order to ascend, the thrust of a rocket must measurably exceed its mass.

Thrust vector control (TVC). A system whereby a liquid is injected into the fixed exhaust nozzle of a rocket motor, deflecting the gases by action of a shock wave.

Abbreviations

c.e.p. Circular Error Probability, or the radius of a circle within which 50% of targeted warheads are expected to fall.

cm. Centimetre.

kg. Kilogramme.

km. Kilometre.

KT. Kilotonne, equal to 1,000 tonnes.

m. Metre.

MT. Megatonne, equal to 1million tonnes.

TNT. Trinitrotoluene, a highly explosive crystalline solid made by the nitration of toluene.

tonne. 1,000 kilogrammes.

Representative mixture ratios for typical propellants:

Fuel	*Oxidizer*	*Mixture ratio (Oxidant/Fuel)*
Hydrogen	Fluorine	9.4
Hydrazine	Fluorine	1.9
Hydrazine	Hydrogen peroxide	1.7
Hydrazine	Nitrogen tetroxide	1.0
Hydrogen	Nitrogen tetroxide	11.5
Turpentine	Nitrogen tetroxide	4.7
Ammonia	Oxygen	1.2
Ethyl alcohol	Oxygen	1.5
Hydrazine	Oxygen	0.8
Hydrogen	Oxygen	2.9
Kerosene	Oxygen	2.3
Methyl alcohol	Oxygen	1.1
Hydrazine	Red fuming nitric acid	1.2
Ethyl alcohol	Red fuming nitric acid	2.5
Aniline	Red fuming nitric acid	3.0
Hydrazine	White fuming nitric acid	1.2
Hydrogen	White fuming nitric acid	12.6
Methyl alcohol	White fuming nitric acid	2.4

Representative specific impulse values for typical propellants:

Fuel	*Oxidizer*	*Specific impulse*
Hydrogen	Oxygen	390
RP-1	Oxygen	300
Ethyl alcohol	Oxygen	280
Hydrogen	Fluorine	410
RP-1	Fluorine	320
Unsymmetrical dimethylhydrazine (UDMH)	Fluorine	340
Hydrazine	Nitrogen tetroxide	290

World Rocket and Missile Inventory

Tables 1, 3 and 4 list every development in their respective categories while the rest provide a representative selection of all the more important developments. Introduction dates are omitted in 2 as this deals with rockets which are, in the main, derivatives and combinations of other programmes (see Compendium).

ABBREVIATIONS:

ABMA	Army Ballistic Missile Agency
Ae-50	Aerozine 50 (50% hydrazine; 50% UDMH)
cm	Centimetre(s)
CNES	Centre National d'Etudes Spatiales
DNA	Defence Nuclear Agency
DoD	Department of Defence
ELDO	European Launcher Development Organisation
ERDA	Energy Research & Development Administration
ESA	European Space Agency
FBM	Fleet Ballistic Missile
FBMS	Fleet Ballistic Missile Submarine
GO	Geosynchronous Orbit
G.P.	General Purpose
GTE	Geosynchronous Transfer Ellipse
H.E.	High Explosive
Hp	Hydrogen peroxide
ICBM	Inter-Continental Ballistic Missile
IR	Infra Red
IRBM	Intermediate Range Ballistic Missile
IRFNA	Inhibited Red Fuming Nitric Acid
ISRO	Indian Space Research Organisation
ISAS	Institute of Space and Aeronautical Sciences
IWFNA	Inhibited White Fuming Nitric Acid
Kg	Kilogramme
Km	Kilometre
KT	Kilotonne
L	Liquid
LH_2	Liquid Hydrogen
LOX	Liquid Oxygen
LRBM	Long Range Ballistic Missile
MIRV	Multiple Independently-targeted Re-entry Vehicle
MO	Meteorological Office
MoD	Ministry of Defence
MRBM	Medium Range Ballistic Missile
MRV	Multiple Re-entry Vehicle
MT	Megatonne
Na	Nitric Acid
N/A	Not applicable
NASA	National Aeronautics & Space Administration
NASDA	National Space Development Agency
N_2O_4	Nitrogen Tetroxide
NIPR	National Institute for Polar Research
NRC	National Research Council
PIHM	Polish Institute for Hydrology and Meteorology
R	Ramjet
RJ-1	Kerosene
RP-1	Kerosene
R/R	Rocket and ramjet combined
RV	Re-entry Vehicle
S	Solid
Sat.	Satellite
SL	Storable Liquid
SLBM	Submarine Launched Ballistic Missile
SRC	Science Research Council
T	Turbojet
Tu	Turpentine
TV	Television
TVC	Thrust Vector Control
UDMH	Unsymmetrical Dimethyl Hydrazine
UK	United Kingdom
US	United States
USAF	United States Air Force
USN	United States Navy
USSR	Union of Soviet Socialist Republics (Russia)
* (Table 1)	Date of first flight of first stage; upperstages later
** (Table 1)	In configuration used for Mercury manned spaceflights
* (Table 3)	First displayed publicly; not deployed
–	Not applicable
?	Classified information or unknown

The terms 'strategic' and 'tactical' have been applied in their contemporary usages. Thus the V-2 is designated 'strategic' whereas in the light of today's weapons system performance it would be regarded as tactical, bearing in mind its range and throw weight capability. The term 'tactical' denotes a more localized use analogous to a single battlefield scenario in World War II.

TABLE 1: SPACE LAUNCH VEHICLES

	Name	User	Launch wt. (Tonnes)	Length (Metres)	Diameter (Metres)	Stage Thrust (Tonnes)/Propellant Type 0	1	2	3	4	Orbital Payload (Tonnes)	Escape Payload (Tonnes)	First Flight
EUROPE:	Ariane	ESA	207	47.4	3.8	—	249/UDMH; N_2O_4	72/UDMH; N_2O_4	6/lox; LH_2	—	4.5 (1.7 GTE)		1979
	Europa 1	ELDO	104	31.7	3.0	—	136/lox; kerosene	28/UDMH; N_2O_4	2/UDMH; N_2O_4	—	1.0		1964*
FRANCE:	Diamant A	CNES	18.4	18	1.4	—	28/Na; Tu	14/solid	5/solid	—	0.115		1965
	Diamant B	CNES	24.5	23.2	1.4	—	35/UDMH; N_2O_4	14/solid	5/solid	—	0.16		1970
	Diamant B/P4	CNES	26.3	21.4	1.4	—	35/UDMH; N_2O_4	18/solid	5/solid	—	0.2		1975
JAPAN:	Lambda-4S	ISAS	9.1	16.5	0.7	19/solid	37/solid	12/solid	7/solid	0.8/solid	0.02		1966
	Mu-4S	ISAS	43.6	23.6	1.4	78/solid	85/solid	33/solid	13/solid	3/solid	0.1		1970
	Mu-3C	ISAS	41.6	20.2	1.4	78/solid	88/solid	28/solid	6/solid	—	0.2		1973
	Mu-3H	ISAS	52	25	1.4	78/solid	97/solid	28/solid	6/solid	—	0.27		1977
	N	NASDA	90.2	32.6	2.4	72/solid	78/lox; RP-1	5/UDMH; N_2O_4	4/solid	—	1.0 (0.13 GO)		1975
UK:	Black Arrow	UK	18.2	13.2	2.1	—	23/Hp; kerosene	6/Hp; kerosene	/solid	—	0.12		1969
US:	Atlas**	NASA	117.9	29	3	140/lox; kerosene	27/lox; kerosene	—	—	—	1.0		1959
	Atlas-Agena A	USAF	124.7	26.9	3	140/lox; kerosene	27/lox; kerosene	5/IRFNA; UDMH	—	—	2.5		1960
	Atlas-Agena D	USAF/NASA	124.7	31.1	3	140/lox; kerosene	27/lox; kerosene	7/IRFNA; UDMH	—	—	4.0 (1.3 GTE)	0.4	1963
	Atlas SLV-3D	NASA	148	40.8	3	168/lox; kerosene	27/lox; kerosene	14/lox; LH_2	—	—	4.5 (1.9 GTE)	0.9	1962
	Delta	NASA	52	27.4	2.4	—	68/lox; RJ-1	3.5/IRFNA; UDMH	1.25/solid	—	0.27		1960
	Delta D	NASA	65	28.3	2.4	71/solid	79/lox; RJ-1	3.5/IRFNA; UDMH	1.25/solid	—	0.58 (0.1 GTE)		1964
	Delta E	NASA	68	29.2	2.4	71/solid	79/lox; RJ-1	3.5/IRFNA; UDMH	2.7/solid	—	0.7 (0.2 GTE)		1965
	Delta M	NASA	103	32.4	2.4	141/solid	79/lox; RJ-1	3.5/IRFNA; UDMH	6.8/solid	—	1.3 (0.45 GTE)		1970
	Delta 900	NASA	125	32.3	2.4	211/solid	79/lox; RJ-1	4.4/Ae-50; N_2O_4	6.8/solid	—	1.7 (0.63 GTE)		1972
	Delta 1000	NASA	134	32.3	2.4	211/solid	79/lox; RJ-1	4.4/Ae-50; N_2O_4	6.8/solid	—	1.84 (0.68 GTE)		1972
	Delta 2914	NASA	134	35.4	2.4	211/solid	93/lox; RJ-1	4.4/Ae-50; N_2O_4	6.8/solid	—	2.0 (0.7 GTE)		1974
	Delta 3914	NASA	190	35.4	2.4	348/solid	93/lox; RJ-1	4.4/Ae-50; N_2O_4	6.8/solid	—	2.2 (0.93 GTE)	0.7	1975
	Delta 3916/PAM	NASA	192	35.4	2.4	348/solid	93/lox; RJ-1	4.4/Ae-50; N_2O_4	6/solid	—	2.3 (1.1 GTE)	0.75	1978/79
	Juno 1	ABMA	29	21.7	1.8	—	38/lox; UDMH	7.5/solid	2.5/solid	0.8/solid	0.018		1958
	Juno II	NASA	55.3	23.3	2.7	—	68/lox; kerosene	7.5/solid	2.5/solid	0.8/solid	0.05		1958
	Saturn I	NASA	499	51.8	6.6	—	682/lox; kerosene	41/lox; LH_2	—	—	10		1961
	Saturn IB	NASA	598	69	6.6	—	744/lox; kerosene	102/lox; LH_2	—	—	18		1966
	Saturn V	NASA	2,960	110.6	10	—	3,470/lox; RP-1	528/lox; LH_2	100/lox; LH_2	—	95	48	1967
	Scout	NASA	16.6	21.9	1.0	—	52/solid	23/solid	6/solid	1.4/solid	0.07		1960
	Shuttle	NASA/DOD	1,996	56	N/A	3,000/solid	640/lox; LH_2	5.5/MMH; N_2O_4	—	—	29.5		1979
	Thor-Able	USAF	52	26.8	2.4	—	78/lox; RJ-1	3.4/IRFNA; UDMH	1.1/solid	1.4/solid	0.13	0.04	1958
	Thor-Able Star	USAF	53.5	24.1	2.4	—	78/lox; RJ-1	3.5/IRFNA; UDMH	—	—	0.41		1960
	Thor-Agena A	USAF	53	23.9	2.4	—	78/lox; RJ-1	7/IRFNA; UDMH	—	—	0.14		1959
	Thor-Agena B	USAF/NASA	55.8	24.8	2.4	—	78/lox; RJ-1	7.3/IRFNA; UDMH	—	—	0.7		1960
	Thor-Agena D	USAF	55.8	23.25	2.7	—	78/lox; RJ-1	7.3/IRFNA; UDMH	—	—	0.7		1962
	LTTAT-Agena D	USAF	62.6	23.8	2.4	73.5/solid	78/lox; RJ-1	7.3/IRFNA; UDMH	—	—	1.14		1963
	Titan II	NASA	136	33.2	3	—	195/Ae-50; N_2O_4	45/Ae-50; N_2O_4	—	—	3.7		1964
	Titan III-A	USAF	140	37	3	—	195/Ae-50; N_2O_4	45/Ae-50; N_2O_4	7.1/UDMH; N_2O_4	—	3.6		1964
	Titan III-B	USAF	179	44–53	3	—	210/Ae-50; N_2O_4	46/Ae-50; N_2O_4	7.6/IRFNA; UDMH	—	4 (1.0 GTE)		1966
	Titan III-C	USAF	635	39.6	3	1,089/solid	238/Ae-50; N_2O_4	46/Ae-50; N_2O_4	7.1/UDMH; N_2O_4	—	13 (1.5 GO)	1.7	1965
	Titan III-D	USAF	635	47.2	3	1,089/solid	238/Ae-50; N_2O_4	46/Ae-50; N_2O_4	—	—	13.6		1971
	Titan III-E	NASA	639.5	48.8	3	1,089/solid	238/Ae-50; N_2O_4	46/Ae-50; N_2O_4	13.6/lox; LH_2	—		3.7	1974
	Vanguard	USN	10.25	21.9	1.1	—	13/lox; kerosene	3.4/IWFNA; UDMH	1.4/solid	—	0.012		1958
USSR:	A	USSR	?	29	3.0	408/lox; kerosene	96/lox; kerosene	—	—	—	2.0		1957
	A-1	USSR	?	33	3.0	408/lox; kerosene	96/lox; kerosene	18/lox; kerosene	—	—	5.0	0.4	1959
	A-2	USSR	326	39–49	3.0	408/lox; kerosene	96/lox; kerosene	30/lox; kerosene	—	—	7.5	1.7	1961
	B-1	USSR	?	32.1	1.6	—	72/Na; kerosene	11/lox; UDMH	—	—	0.42		1962
	C-1	USSR	?	31.6	2.5	—	178/liquid	?/liquid	—	—	1.0		1964
	D-1	USSR	?	53	4	1,500/lox; UDMH	400/lox; UDMH	?/lox; UDMH	—	—	20	6 (with third stage)	1965

TABLE 2: RESEARCH ROCKETS

	Name	User	Weight (Kg)	Length (Metres)	Span (Metres)	Diameter (Cm)	No. of Stages	No. of Motors	Prop. Type	Total Thrust (Kg)	Payload Weight (Kg)	Payload Altitude (Km)	Remarks
AUSTRALIA:	Corella	Military	—	—	—	—	—	—	S	—	45	200	Research
	Kookaburra 1	Military	50	3.44	—	—	1	—	S	5,300	45	82	
	Lorikeet 1	Military	167	5.58	—	—	—	—	S	21,410	21	85	Two stages
BRAZIL:	Sonda 1C	Military	54.5	1.49	0.36	15.24	1	1	S	2,722			Weather research and meteorology
							2	1	S	454	5.5	68	
	Sonda 2A	Military	385.5	2.93	1.04	30.48	1	1	S	3,764	35	113	
	Sonda 2B	Military	548.9	3.96	1.00	30.48	1	1	S	5,897	50	235	
CANADA:	Black Brant 4A	US; NASA; NRC	1,388	12.2	0.94	27.5	1	1	S	11,340			
							2	1	S	4,090	38	925	
	Black Brant 5B	USAF; NRC; USN	1,520	10.4	1.5	42.7	1	1	S	9.075	270	250	
	Black Brant 6	NASA; NRC	52	2.8	0.3	12.2	1	1	S	752	3	85	Exclusively meteorology
	Nike-Black Brant 5B	NASA; NRC	2,120	14	1.6	42.7	1	1	S	22.680			
							2	1	S	7,710	275	340	
FRANCE:	Belier III	CNES; ESA	412	4.9	—	30.48	1	1	S	—	91	75	Also 30 kg to 150 km
	Belisama	CNES	128	4.6	—	—	1	1	S	—	10	85	Also 6 kg to 100 km
	Centaur	CNES; ESA	545	6.4	—	30.4	1	1	S	—			
							2	1	S	—	109	75	Also 30 kg to 177 km
	Dauphin	CNES	1,170	5.8	—	54.9	1	1	S	—	250	100	Also 130 kg to 150 km
	Dragon III	CNES; ESA	1,306	8.3	—	54.9	1	1	S	—			
							2	1	S	—	50	600	Also 110 kg to 400 km
	Emma	CNES	70	3.87	—	12.2	1	1	S	—			
							2	1	S	—	5	70	
	Eridan	CNES	2,225	10	—	54.9	1	1	S	—			
							2	1	S	—	420	180	Also 360 kg to 210 km; 140 kg to 400 km
	Grannus	CNES	194	5.25	—	—	1	1	S	—	30	124	Also 18 kg to 172 km
	Tibere	Defence	4,540	16.15	—	65.5	1	1	S	—			
							2	1	S	—			
							3	1	S	—	544	480	Also 170 kg to 1,350 km
	Veronique 61M	CNES	2,155	9.25	1.8	54.9	1	1	L	5,490	200	260	Also 300 kg to 185 km
	Vesta	CNES	5,489	9.5	2.4	100.6	1	1	L	14,425	500	370	Also 1,000 kg to 212 km
INDIA:	Menaka I	ISRO	25.9	2.89	—	10	1	1	S	—			
							2	1	S	—	4	58	
	Menaka II	ISRO	58.8	3.79	—	12.2	1	1	S	—			
							2	1	S	—	3.5	100	
	Rohini 75	ISRO	10	1.5	—	7.5	1	1	S	—	1	9	
	Rohini 100	ISRO	24.6	2.0	—	10	1	1	S	—	3.2	14	
	Rohini 125 and 100	ISRO	51	3.69	—	12.2	1	1	S	—			
							2	1	S	—	3.2	100	
	Rohini 300	ISRO	420	4.85	—	31.6	1	1	S	—	40	100	
	Rohini 560	ISRO	1,390	7.64	—	56	1	1	S				
							2	1	S	—	100	334	
JAPAN:	JCR	NASDA	2,227	10.24	1.89	51.8	1	1	S	10,000	—	—	Science research
	Kappa-5	Tokyo Univ.	—	5.6	—	—	1	1	S	—			
							2	1	S	—	20	50	Test vehicle
	Kappa-6	Tokyo Univ.	270	5.6	—	—	1	1	S	3,500			
							2	1	S	1,900	25	60	
	Kappa-8	Tokyo Univ.	1,500	10.8	—	42	1	1	S	10,000			
							2	1	S	3,500	50	200	Also 90 kg to 170 km
	Kappa-9M	Tokyo Univ.	1,497	11.12	1.80	42.7	1	1	S	11,204			
							2	1	S	4,400	85	305	
	Kappa-10	Tokyo Univ.	1,750	9.9	1.80	42.7	1	1	S	4,600			
							2	1	S	4,600	170	250	
	Lambda-2	Tokyo Univ.	7,000	16.5	—	73.5	1	1	S	42,000			
							2	1	S	10,000	180	500	
	Lambda-3	Tokyo Univ.	—	19.1	—	73.5	1	1	S	42,000			
							2	1	S	10,000			
							3	1	S	1,600	145	1,000	
	Lambda-3H	Tokyo Univ.	9,490	16.6	2.9	73.1	1	1	S	37,195			
							2	1	S	11,750			
							3	1	S	816	200	1,930	
	LS-C	NASDA	2,540	11.2	—	60	1	1	S	17,780			
							2	1	S	3,380		58	Engineering tests
	MT-135P	Met. Agency	70.3	3.29	0.55	12.2	1	1	S	798	10	51	
	S-160JA	NIPR	108.9	4.12	0.26	15.2	1	1	S	1,089	16	80	Polar research
	S-210JA	NIPR	258	5.18	0.73	21.3	1	1	S	2,200	41	96	Polar research
POLAND:	Meteor 1	PIHM	32.7	2.56	0.43	12.2	1	1	S	1,400	0.6	35	Exclusively meteorological
	Meteor 2K	PIHM	419.6	4.3	1.1	34.1	1	3	S	5,200	10	100	Atmospheric research
	Meteor 3	PIHM	64.9	4.3	0.46	12.2	1	1	S	1,400			
							2	1	S	1,400	0.5	55	Exclusively meteorological
SWITZERLAND:	Zenit	ESA	763.9	6.49	—	42.7	1	1	S	6,795	45	185	Also 100 kg to 131 km
	Zenit and Cuckoo	ESA	1,175	7.93	—	42.7	1	1	S	7,850			
							2	1	S	6,795	45	310	Also 200 kg to 150 km
UK:	Fulmar	SRC	454	7.47	1.1	24.4	1	1	S	10,886			
							2	1	S	1,700	40	340	Also 60 kg to 270 km
	Petrel 1	SRC	113.4	3.35	0.52	18.3	1	3	S	6,124			
							2	1	S	454	20	130	Also 16 kg to 145 km
	Petrel 2	SRC	120.2	3.5	0.52	18.3	1	3	S	6,124			
							2	1	S	454	20	160	Also 16 kg to 185 km
	IWTA 255	UK	333	6.12	—	—	1	1	S	—			
							2	1	S	—	28	136	
	IWTA 300	UK	454	7.28	1.1	24.4	1	1	S	10,887			
							2	1	S	1,700	35	402	Also 50 kg to 301 km
	Skua 1	MO; SRC; NRCC	38.6	2.26	0.43	12.2	1	1	S	2,040			
							2	1	S	181	8	60	Also 6 kg to 70 km
	Skua 4	MO; SRC; NRCC	41.3	2.56	0.43	12.2	1	4	S	8,164			
							2	1	S	181	9	90	Also 7 kg to 126 km
	Skylark 12	SRC; MOD; ESA	1,905	12.8	1.9	42.7	1	1	S	19,505			
							2	1	S	8,164			
							3	1	S	3,629	150	805	Also 75 kg to 1,500 km

US:	Advanced Terrier Malemute	NASA; ERDA; USAF	1,512	7.2	1.52	45.7	1	1	S	26,310	91	708	Also 68 kg to 708 km
							2	1	S	6,350			
	Advanced Terrier Tomahawk	ERDA; DOD	1,270	9.45	1.52	45.7	1	1	S	26,310	79	418	
							2	1	S	4,990			
	Aerobee 200	NASA; DOD	1,476	13.1	1.52	38.1	1	1	S	22,090	113	328	
							2	1	L	2,300			
	Aerobee 350	NASA; USAF	3,007	15.24		54.9	1	1	S	22,090	272	325	
							2	4	L	7,440	5.4	64	
	Arcas	NASA	.	2.43	—	—	1	1	S	---	18	400	
	Arcon	NASA	---	3.4	—	—	1	1	S	—			
	Argo D-4	NASA; USAF	3,311	14.63	2.62	61	1	1	S	39,010			
							2	1	S	22,090			
							3	1	S	22,090			
							4	1	S	1,406	45	700	
	Aries 1	NASA; DOD	6,350	8.5	—	112.8	1	1	S	19,505	181	725	Also 907 kg to 290 km
	Aries 2	USAF; USN	7,711	10.97	—	112.8	1	1	S	19,505			
							2	1	S	8,618	136	1,610	
	Asp	NASA		3.6	.	....	1	1	S	—	14	40	
	Astrobee 1500	NASA	5,213	10.4	---	79.56	1	1	S	25,855			
							2	1	S	3,629	23	3,220	
	Astrobee D	NASA; USN; USAF	82.1	3.6	0.61	15.24	1	1	S	1,973/890	14	120	
	Astrobee F	NASA; USAF	1,383	8.5	1.4	38.1	1	1	S	17,237/3,629	102	346	
	Athena	DOD	7,212	15.24	3.38	79.25	1	1+2	S	24,450+2@ 30,845			High velocity re-entry tests at 7,315 metres/sec for research on ballistic missile warheads
							2	1	S	25,946			
							3	1	S	4,536			
							4	1	S	2,676	136	160	
	Athena H	DOD	14,016	18.35	2.74	100.6	1	1+4	S	38,563+4@ 61,690			High velocity re-entry tests at 9,145 metres/sec for research on ballistic missile warheads
							2	1	S	9,843			
							3	1	S	4,672			
							4	1	S	2,676	363	320	
	Bumper-Wac	US Army	13,117	18.3	3.58	165	1	1	L	27,200			
							2	1	S	680	10	400	
	Castor 1	DNA	5,443	12.19	3	79.25	1	3	S	54,432	907	200	
	Honest John Hydac	DNA	2,313	11.28	2.65	57.9	1	1	S	39,010			
							2	1	S	5,443	91	250	
	Honest John Nike	Army	2,478	5.49	2.62	57.9	1	1	S	39,010			
							2	1	S	22,090	113	80	
	Honest John Nike Hydac	USAF; Army; DNA	2,783	14.39	2.65	57.9	1	1	S	39,010			
							2	1	S	22,090			
							3	1	S	5,448	45	563	Also 136 kg to 338 km
	Honest John Mike Javelin	USAF; Army; DNA	2,690	13.4	2.65	57.9	1	1	S	39,010			
							2	1	S	22,090			
							3	1	S	19,051	91	322	
	Hydac	USAF; Army	277	5.58	0.85	22.9	1	1	S	5,448	45	97	Also 136 kg to 48 km
	Javelin 3	DNA; USAF	180	4.51	0.7	22.9	1	1	S	19,051	45	48	
	Little Joe I	NASA	18,140	9.5	6.1	200	1	4+4	S	4@99,600+4@59,600	1,000	85	Project mercury tests
	Little Joe II	NASA	—	—	—	305	1	7	S	141,000	4,000	75	Project apollo tests
	Loki Dart	USAF; USN	15.6	2.96	0.13	7.62	1	1	S	989	0.9	66	Exclusively meteorological
	Nike Apache	NASA; Army; USN	680	10.4	1.52	42.7	1	1	S	22,090			
							2	1	S	2,395	23	241	
	Nike Cajun	NASA; Army; USN	680	10.4	1.52	42.7	1	1	S	22,090			
							2	1	S	3,992	23	145	
	Nike Malemute	ERDA; NASA; USAF	1,291	6.83	1.52	39.62	1	1	S	22,090			
							2	1	S	6,350	91	483	Also 68 kg to 640 km
	Nike Tomahawk	ERDA; NASA; USAF	884	7.31	1.52	40.54	1	1	S	22,090			
							2	1	S	4,990	45	402	
	Paiute Tomahawk	USAF	635	8.84	1.1	38.1	1	1	S	14,515			
							2	1	S	4,536	73	322	Also 39 kg to 483 km
	Sandhawk Tomahawk	ERDA	1,372	16.4	1.3	33	1	1	S	8,437			
							2	1	S	4,990	72	554	
	Sergeant	DNA	4,617	10.4	3.5	78.6	1	1	S	19,051	771	113	
	Sergeant Hydac	DNA	4,536	13.4	3.5	79.2	1	3	S	38,556			
							2	1	S	5,448	363	209	
	Shotput	NASA	—	10	—	78.7	1	1+2	S	1@22,700+2@31,700			
							2		S	1,400	10	400	
	Strypi 7R	ERDA	5,493	11.89	3	78.6	1	3	S	55,339			
							2	1	S	4,536	45	61	
	Super Chief 2	USN	6,796	12.2	3	76.2	1	1	S	49,896			
							2	1	S	24,494	544	381	
	Super Loki Dart	NASA; USAF	28	3.1	0.21	10	1	1	S	2,608	2.5	100	Exclusively meteorological
	Swik B	USAF; Army	6,169	13.1	3.38	79.25	1	1+2	S	24,449+2@ 30,845			
							2	1	S	9,843	450	725	
	Percheron A1	NASA; USAF	5,494	10	2.86	79.25	1	1+2	S	24,131+2@ 30,845	450	378	
	Percheron D	Army	5,461	11.22	2.86	79.25	1	4	S	1@ 24,131; 1@ 35,392; 2@ 30,845	450	365	
	Talos Castor	DNA	6,804	14.3	1.83	79.25	1	1	S	58,968			
							2	1	S	27,216	907	300	
	Talos Sergeant	DNA	5,897	14	1.83	79.25	1	1	S	58,968	907	201	
	Talos Sergeant Hydac	DNA; USAF	6,804	16.76	2.1	78.6	1	1	S	58,968			
							2	1	S	20,412			
							3	1	S	5,443	136	805	
	Tater	ERDA; USAF	3,171	12.28	2.56	79.2	1	1	S	51,484			
							2	1	S	26,309			
							3	1	S	16,330	64	3.2	
	Terrier Nike	ERDA	1,724	10	1.98	45.72	1	1	S	26,309			
							2	1	S	22,090	136	3.2	
	Ute Tomahawk	USAF	544	8.1	1.14	38.1	1	1	S	6,804			
							2	1	S	4,990	54	257	Also 36 kg to 321 km
	Viking	USN	6,777	14.6	—	81.3	1	1	L	9,300	15	260	
	Viper Dart	USAF; USN	106	4.2	0.54	16.46	1	1	S	3,856	4.5	129	Exclusively meteorological
	Wac Corporal	US Army	302	4.87	—	30.48	1	1	S	680	20	71	
USSR:	V2A	—	—	20	—	166	—	—	—	—	2,195	211	
	V5V	—	—	23	—	166					1,297	510	

TABLE 3: STRATEGIC & TACTICAL BALLISTIC MISSILES

Origin	Name	Category	Weight (Tonnes)	Length (Metres)	Diameter (Metres)	Stage Thrust (Tonnes)/Propellant Type				Range (Km)	Warhead Type	MIRV Yield (KT)	Total Yield (MT)	Service Intro' (Year)	Retired (Year)
						0	1	2	3						
FRANCE:	MSBS M-1	SLBM	18	10.4	1.5	—	45/S	18/S	—	2,500	Single RV	—	0.5	1971	1977
	MSBS M-20	SLBM	20	10.4	1.5	—	45/S	32/S	—	3,000	Single RV	—	1.0	1976	—
	MSBS M-4	SLBM	35	11	1.9	—	70/S	30/S	?/S	4,000	6–7 MIRV	6–7× 150	0.9–1.05	1983–85?	—
	Pluton	Tactical	2.4	7.6	0.65	20–22/S	10–16/S	—	—	10–120	Single	—	0.01 or 0.025	1974	—
	SSBS S-2	IRBM	31.9	14.8	1.5	—	55/S	45/S	—	3,000	Single RV	—	0.15	1971	—
	SSBS S-3	IRBM	25.8	13.7	1.5	—	55/S	32/S	—	3,000+	Single RV	—	0.5	1980?	—
GERMANY:	V-2	Strategic	12.9	14	1.6	—	28/L	—	—	320	Single	—	H.E.	1944	1945
US:	Atlas D	ICBM	115	23.1	3	140/L	26/L	—	—	14,800	Single Mk 2	—	2	1959	1964
	Atlas E	ICBM	121	25.1	3	150/L	27/L	—	—	16,700	Single Mk 3	—	2	1960	1965
	Atlas F	ICBM	118	25.1	3	150/L	27/L	—	—	16,700	Single Mk 4	—	4	1961	1965
	Corporal	Tactical	5.4	14	0.7	—	9/SL	—	—	120	Single	—	Nuclear or H.E.	1953	1966
	Honest John MGR-1B	Tactical	2.7	8.3	0.76	—	41/S	—	—	20-50	Single	—	Nuclear or H.E.	1954	1978
	Jupiter	IRBM	50	18.4	2.7	—	68/L	—	—	2,800	Single RV	—	1.5	1958	1961
	Lance	Tactical	1.5	6.1	0.56	—	21/SL	—	—	70–120	Single	—	Nuclear or H.E.	1973	—
	Little John	Tactical	0.3	4.4	0.37	—	?/S	—	—	18	Single	—	Nuclear or H.E.	1961	—
	Minuteman I (LGM-30A)	ICBM	29.48	16.38	1.88	—	91/S	?/S	?/S	8,500	Single RV		1 MT	1963	1969
	Minuteman I (LGM-30B)	ICBM	29.48	17.04	1.88	—	91/S	?/S	?/S	9,260	Single RV	—	1 MT	1964	1975
	Minuteman II	ICBM	31.75	18.2	1.88	—	91/S	27.5/S	16/S	11,000+	Single RV	—	1 MT	1966	—
	Minuteman III	ICBM	34.47	18.2	1.88	—	91/S	27.5/S	15.5/S	13,000+	3× MIRV	3× 170	0.51	1971	—
	Minuteman III	ICBM	34.47	18.2	1.88	—	91/S	27.5/S	15.5/S	13,000+	3× MIRV	3× 350	1.05	1978	—
	MX	ICBM	85	21.5	2.3	—	?/S	?/S	?/S	10,000+	10× MIRV	10× 400	4.0	1985?	—
	Pershing 1A	MRBM	4.5	10.5	1	—	12.1/S	?/S	—	160–650	Single RV	—	0.06–0.4	1964	—
	Polaris A1	SLBM	12.5	8.7	1.37	—	36.2/S	?/S	—	2,220	Single RV	—	0.5	1960	1965
	Polaris A2	SLBM	13.6	9.45	1.37	—	36.2/S	?/S	—	2,780	Single RV	—	0.5	1962	1973
	Polaris A3	SLBM	15.6	9.52	1.37	—	36.2/S	?/S	—	4,630	3× MRV	—	0.6	1964	—
	Poseidon C3	SLBM	29.5	10.4	1.88	—	?/S	?/S	—	4,630+	10× MIRV	10× 40	0.4	1971	—
	Redstone	MRBM	27.7	21	1.78	—	34/L	—	—	370	Single	—	Nuclear or H.E.	1958	1965
	Sergeant	Tactical	4.6	10.5	0.79	—	20/S	—	—	40–140	Single	—	Nuclear or H.E.	1962	—
	Thor	IRBM	47.6	19.7	2.67	—	68/L	—	—	2,780	Single	—	1.5	1958	1962
	Titan I	ICBM	99.8	27.4	3.05	—	136/L	27/L	—	9,650	Single	—	4.0	1962	1965
	Titan II	ICBM	149.7	31.4	3.05	—	195/SL	45.4/SL	—	15,000	Single	—	5–10.0	1963	—
	Trident I C4	SLBM	32	10.4	1.9	—	?/S	?/S	?/S	7,800	8× MIRV	8× 100	0.8	1981?	—
	Trident II D5	SLBM	57.5	10.4	1.9	—	?/S	?/S	?/S	11,000	?	?	?	1988?	—
USSR	Frog 1	Tactical	3.1	10.2	0.6	—	?/S	—	—	32	Single	—	Nuclear or H.E.	1957	—
	Frog 2	Tactical	2.5	9.5	0.3	?/S	?/S	—	—	20	Single	—	Chemical or H.E.	1957	—
	Frog 3	Tactical	2.3	10.5	0.4	?/S	?/S	—	—	80	Single	—	Nuclear or H.E.	1959	—
	Frog 4	Tactical	2.0	10.2	0.4	?/S	?/S	—	—	100	Single	—	Nuclear or H.E.	1959	—
	Frog 5	Tactical	—	9.5	0.4	?/S	?/S	—	—	50	Single	—	Nuclear or H.E.	1961	—
	Frog 6	Tactical	—	—	—	—	—	—	—	—	—	—	—	1965	—
	Frog 7	Tactical	2.5	9.0	0.6	—	?/S	—	—	60	Single	—	Nuclear or H.E.	1965	—
	SS-1 Scunner	Strategic	13	14.5	1.6	—	28/L	—	—	350	Single	—	H.E.	1947	1955
	SS-2 Sibling	Strategic	—	—	—	—	?/L	—	—	450?	Single RV	—	H.E.	1948	?
	SS-3 Shyster	MRBM	—	21	1.7	—	?/L	—	—	900	Single RV	—	Nuclear or H.E.	1955	?
	SS-4 Sandal	IRBM	—	23.5	1.7	—	72/SL	—	—	1,800	Single RV	—	1.0	1959	—
	SS-5 Skean	LRBM	—	24.5	2.6	—	178/L	—	—	3,500	Single RV	—	1.0–5.0	1961	
	SS-6 Sapwood	ICBM	—	29	3.0	408/L	96/L	—	—	8,500	Single RV	—	5.0–10.0	1957	1962
	SS-7 Saddler	ICBM	—	32.5	3.1	—	?/SL	?/SL	—	10,500	Single RV	—	5.0	1961	—
	SS-8 Sasin	ICBM	—	25.5	2.9	—	?/SL	?/SL	—	11,000	Single RV	—	5.0	1963	—
	SS-9 Scarp	ICBM	—	34	3.4	—	?/SL	?/SL	—	12,000	Single RV	—	18.0–25.0	1965	—
	SS-9 Scarp Mod 4	ICBM	—	37	3.4	—	?/SL	?/SL	—	12,000	3× MRV	—	12.0–15.0	1971	—
	SS-10 Scrag	ICBM	—	38.5	3.4	—	?/L	?/L	?/L	12,000	—	—	—	1965*	—
	SS-11 Sego	ICBM	—	19	2.4	—	?/SL	?/SL	—	10,000	Single RV	—	1.0–2.0	1966	—
	SS-11 Sego Mod 3	ICBM	—	19	2.4	—	?/SL	?/SL	—	10,000	3× MRV	—	1.5	1973	—
	SS-12 Scaleboard	MRBM	—	10.5	1.4	—	?/S	—	—	750	Single RV	—	1.0	1968	—
	SS-13 Savage	ICBM	—	20	2.0	—	?/S	?/S	?/S	8,000	Single RV	—	1.0	1968	—
	SS-14 Scapegoat	LRBM	—	11	1.4	—	?/S	?/S	—	4,000	Single RV	—	1.0	1968	—
	SS-15 Scrooge	LRBM	—	18.5	2.0	—	?/S	?/S	?/S	5,600	Single RV	—	1.0	1969	—
	SS-16	ICBM	—	20	2.1	—	?/S	?/S	?/S	9,500	3× MRV	—	1.0?	1977	—
	SS-17	ICBM	—	23	2.6	—	?/SL	?/SL	—	10,500	4× MIRV	4× 200	0.8	1975	—
	SS-18	ICBM	—	36	3.4	—	?/SL	?/SL	—	12,000	Single RV	—	18.0–25.0	1976	—
	SS-18 Mod 2	ICBM	—	36	3.4	—	?/SL	?/SL	—	12,000	8–10× MIRV	8–10× 2,000	16.0–20.0	1977	—
	SS-19	ICBM	—	27	2.8	—	?/SL	?/SL	—	10,000	6× MIRV	6× 200	1.2	1975	—
	SS-20	LRBM	—	11.5	1.8	—	?/S	?/S	—	5,700	Single or 3 MRV	—	1.5	1976	—
	SS-20 (variant)	ICBM	—	11.5	1.8	—	?/S	?/S	—	7,500	Single RV	—	0.05	1976	—
	SS-1B Scud A	Tactical	4.4	10.7	0.85	—	18/SL	—	—	130	Single	—	Nuclear or H.E.	1957	1976
	SS-1C Scud B	Tactical	6.3	11.2	0.85	—	25/SL	—	—	280	Single	—	Nuclear or H.E.	1965	—
	SS-N-4 Sark	SLBM	19	15	1.8	—	?/SL	—	—	600	Single RV	—	1.0	1955	—
	SS-N-5 Serb	SLBM	18	10.7	1.5	—	?/SL	—	—	1,250	Single RV	—	1.0	1963	—
	SS-N-6 Sawfly	SLBM	19	13	1.8	—	?/SL	?/SL	—	2,400	Single RV	—	1.0	1968	—
	SS-N-6 Sawfly Mod 2	SLBM	19	13	1.8	—	?/SL	?/SL	—	3,000	Single RV	—	1.0	1974	—
	SS-N-6 Sawfly Mod 3	SLBM	19	13	1.8	—	?/SL	?/SL	—	3,000	3× MRV	—	0.9?	1974	—
	SS-N-8 Mod 1	SLBM	20+	17	1.8	—	?/SL	?/SL	—	7,800	Single RV	—	1.0	1973	—
	SS-N-8 Mod 2	SLBM	20+	17	1.8	—	?/SL	?/SL	—	7,800	3× MRV	—	0.9?	?	—
	SS-N-8 Mod 3	SLBM	20+	17	1.8	—	?/SL	?/SL	—	7,800	?× MIRV	?× MIRV	0.8?	?	—
	SS-NX-17	SLBM	20?	17?	1.8?	—	?/S	—	—	3,200	?× MIRV	?× MIRV	?	?	—
	SS-NX-18	SLBM	?	?	?	—	?/SL	?/SL	—	8,000+	?× MIRV	?× MIRV	?	?	—

TABLE 4: ANTI-BALLISTIC MISSILES

Origin	Name	Weight (Tonnes)	Length (Metres)	Diameter (Metres)	Finspan (Metres)	Stage Thrust (Tonnes)/Propellant Type			Range (Km)	Intercept altitude (Km)	Warhead Yield	Service Intro' (Year)	Retired (Year)
						1	2	3					
US	Spartan	12.97	16.46	1.07	3	227/S	?/S	?/S	740	Up to 480 km	2–5 MT	1973	1975
	Sprint	3.4	8.2	1.37	—	295/S	?/S	—	46	1.5–30.5 km	KT size	1973	1975
USSR	Galosh	?	18.5	2.4	—	?	?	—	300	?	MT size	1970	—

TABLE 5: AIR-TO-GROUND MISSILES

Origin	Name	Weight (Kg)	Length (Metres)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop Type	Range (Km)	Control	Guidance	Warhead Type	Service Intro'	Remarks
BRAZIL:	Carcara	45	1.22	42.7	12.5	1	S	?	?	TV	?	?	Currently in stages of development
FRANCE:	AS.12	72.6	1.86	64	21.3	2	S	8	Aerodynamic	Wire	H.E.	1968	Adapted from surface-to-surface design
	AS.20	143	2.6	80	25	2	S	3–7	Thrust Def'	Radio	H.E.	1962	
	AS.30	520	3.8	100	34.2	2	S	2–12	Thrust Def'	Radio	230 kg GP	1962	Operational with French, S. African, Swiss, UK, German and Peruvian AF's
	AS.30L	380	3.9	90	34	2	S	?	Thrust Def'	Radio	115 kg H.E.	1975	
GERMANY:	Jumbo	1,150	5.24	125	50	1	S	35–40	Aerodynamic	Inertial; TV	800 kg H.E.	—	Developed for MRCA (Tornado); abandoned in 1975
	Kormoran	580	4.4	100	34.3	2	S	37	Aerodynamic	Inertial; IR	H.E.	1977	Developed initially as air-to-ground; see Table 8
UK:	Blue Steel	?	10.6	394	172	1	L	370	Aerodynamic	Inertial	Nuclear	1961	Phased out in mid 1970's
UK/FRANCE:	AJ168 Martel	550	3.87	120	40	2	S	30	Aerodynamic	Radio; TV	150 kg	1970	Possible candidate for export market (see AS.37)
	AS.37 Martel	530	4.12	120	40	2	S	30	Aerodynamic	Radio	150 kg	1970	Production completed 1977 (see AJ168)
US:	AGM-12B Bullpup A	260	3.2	95	30.5	1	L	11	Aerodynamic	Radio	114 kg H.E	1959	
	AGM-12C Bullpup B	810	4.1	118	44	1	L	14–16	Aerodynamic	Radio	454 kg H.E.	1962	
	AGM-12D Bullpup	?	?	96.5	33	1	L	?	Aerodynamic	Radio	Nuclear or H.E.	1962	
	AGM-45 Shrike	177	3.05	91.4	20	1	S	16	Aerodynamic	Radiation seeker	H.E.	1964	Used in Vietnam and by Israeli's during 1973 war
	AGM-53A Condor	958	4.21	135	43.2	1	S	110	Aerodynamic	Radio; TV	286 kg	—	Development began in 1965, flight tests began in 1970; cancelled 1976
	AGM-65 Maverick	210	2.46	71	30.5	1	S	22.5	Aerodynamic	TV, laser or IR	59 kg	1972	For use against hardened fortifications
	AGM-69A SRAM	450	4.25	?	45	1	S	60–160	Aerodynamic	Inertial	200 KT nuclear	1972	Carries terrain avoidance capability
	AGM-78 Standard ARM	816	4.57	109	30.5	1	S	25	Aerodynamic	Radiation seeker	H.E.	1967	
	AGM-83A Bulldog	272	2.98	96	30.5	1	L	10	Aerodynamic	Laser seeker	114 kg H.E.	—	Development began in 1969; unlikely to enter service
	AGM-88A HARM	350	4.17	113	24	1	S	16+	?	Radiation seeker	H.E.	—	First flown in 1976
	ASALM	1,225	4.27	53.3	53.3	1	RR	—	—	—	—	—	Advanced strategic air launched missile
	Hornet	56.7	3.0	—	18.3	1	S	?	—	Laser; TV	—	—	Test vehicle
USSR:	AS-4 Kitchen	6,000+	11.3	248	50	1	L	300	?	Inertial	?	1966	Carried by Tu-22 Blinder
	AS-5 Kelt	?	10	490	100	1	L	320	Aerodynamic	Radar seeker	H.E.	1969	Carried by Tu-16 Badger
	AS-6 Kingfish	5000?	9.0	3.2	90	1	L	200	?	Inertial	?	1970	Carried by Tu-16 Badger and Backfire
	AS-7 Kerry	1,200	?	?	?	1	?	10	?	?	?	?	Carried by Su-7B Fitter
	AS-8	?	?	?	?	?	?	8	?	Inertial	?	?	Helicopter borne

TABLE 6: SURFACE-TO-AIR MISSILES

Origin	Name	Weight (Kg)	Length (Metres)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop Type	Range (Km)	Altitude (Km)	Control	Guidance	Warhead Type	Service Intro	Remarks
FRANCE:	Crotale	85	2.89	54	15	1	S	0.5–8.5	0.05–5	Aerodynamic	IR + beam	15 kg	1971	Carried on wheeled vehicle
	Masurca 2	2,080	8.6	77	40.5	2	S	45	0.03–23	Aerodynamic	Radar	120 kg	1967	Ship defence
	Roland	65	2.4	50	16	2	S	0.26–6.2	0.02–3	Deflectors	IR + radar	6.5 kg	1977	Mobile system for France and Germany
	Shahine	90	3.0	54	15	1	S	?	?	Aerodynamic	IR + beam	15 kg	1980?	Ordered by Saudi Arabia as Crotale on tank chassis
ITALY:	Indigo	120	3.3	81.3	19.5	1	S	1–10	0.015–5	Aerodynamic	Radar	22 kg	1972	Operated from towed or self-propelled launcher
SWEDEN:	RBS70	15	1.3	32	10.6	2	S	5	3	Aerodynamic	Laser	1 kg	1976	Operated by one man; highly portable
SWISS:	Micon	800	5.38	3	42	1	S	35	22	Aerodynamic	Command	H.E.	—	
UK:	Bloodhound 2	2,350	7.75	282	55	4 + R	S + R	80+	0.3–23	Aerodynamic	Radar	—	1958	Date of original service introduction with Mk. 1
	Blowpipe	?	1.4	25.4	7.6	2	S	3	1.5	Aerodynamic	IR + command	2.2 kg	1975	In service with British army
	Rapier	42.5	2.24	38	12.7	1	S	0.5–7	3	Aerodynamic	Radar	0.5 kg	1968	Low level air defence
	Seacat	65	1.47	65	19	1	S	5+	?	Aerodynamic	Radar	—	1963	
	Seadart	550	4.36	91	42	1 + R	S + R	80+	25	Aerodynamic	Radar	—	1968	
	Seaslug 2	?	6.0	144	41	4 + 1	S + S	45+	15	Aerodynamic	Beam	135 kg	1962	Date of Mk. 1 service introduction, used from surface ships
	Seawolf	82	2.0	56	19	1	S	5	?	Aerodynamic	Radar + TV	14 kg	1979?	Defence system for ships
	Thunderbird	?	6.4	162	53	4 + 1	S + S	80+	?	Aerodynamic	Radar	—	1958	Mobile field missile
US:	Bomarc A	7,030	14.25	554	87.5	2 + 1	R + L	425	1.5–21	Aerodynamic	Command + radar	Nuclear	1958	Also used by Royal Canadian Air Force; retired in 1965
	Bomarc B	7,271	13.7	554	87.9	2 + 1	R + S	704	30	Aerodynamic	Command + radar	Nuclear	1959	Used by Royal Canadian Air Force
	Chaparral	84	2.9	64	12.7	1	S	3+	?	Aerodynamic	IR	5 kg	1967	Carried on a self-propelled tracked vehicle
	Hawk	584	5.08	120	37	1	S	30	0.3–12	Aerodynamic	Radar	45 kg	1958	First of the class to cover down to zero height
	Improved Hawk	625	5.08	120	37	1	S	40	0.3–18	Aerodynamic	Radar	54 kg	1974	
	Nike Ajax	1.043	10.6	134.6	30.5	1	L	48	1.5–18	Aerodynamic	Command	3× H.E.	1953	More than 20,000 rounds produced
	Nike Zeus	10,342	14.7	206	116.8	2	S	370	152	Aero' + jet	Command	Nuclear	—	Developed as anti-ballistic missile leading to Spartan (see Table 3)
	Nike Hercules	4,800	12.7	266	88	4 + 1	S + S	30–150	6–30	Aerodynamic	Command	Nuclear or H.E.	1959	Capable of intercepting tactical missiles
	Patriot	1,000	5.18	92	41	1	S	?	?	Aerodynamic	Radar + command	?	1979?	Replacement for Nike Hercules and improved Hawk
	Redeye	8.2	1.22	14	7	1	S	3.4	2.5	Aerodynamic	IR	—	1965	Combat area defence carried by one man
	Sea Sparrow	205	3.65	102	20	1	S	18	?	Aerodynamic	Radar	30 kg	1970	Ship launched version of air-to-air missile (see Table 7)
	Standard ER	1,050	8.23	157	35	1 + 1	S + S	55	20	Aerodynamic	Radar	—	1982?	Ship defence
	Standard MR	595	4.57	107	35	1	S	20	20	Aerodynamic	Radar	—	1982?	Ship defence
	Stinger	15.1	1.52	9	7	1	S	?	14.8	Aerodynamic	IR	Frag	1979?	Replacement for Redeye
	Talos	3,175	9.53	290	76	1 + R	S + R	120	27+	Aerodynamic	Radar	Nuclear	1959	Defence system for surface ships
	Tartar	680	4.6	107	35	1	S	16+	0.3–12	Aerodynamic	Radar	H.E.	1961	Defence system for small ships
	Terrier	1,360	8.23	157	30.5	1 + 1	S + S	35	20	Aerodynamic	Beam + radar	Nuclear	1956	Defence system for large ships
USSR:	SA-1 Guild	3,000	11.5	270	60	1	S	32	20	Aerodynamic	Radio	?	1954	First public display in 1960
	SA-2 Guideline	2,300	10.7	220	70	1 + 1	S + R	50	28	Aerodynamic	Radio	Nuclear or H.E.	1957	First public display in 1957
	SA-3 Goa	600	6.7	150	70	1 + 1	S + S	35	0.2–15	Aerodynamic	Radio	H.E.	?	First public display in 1964
	SA-4 Ganef	1,000	9.0	260	80	4 + R	S + R	70	25	Aerodynamic	Radio	H.E.	?	First public display in 1964
	SA-5 Gammon	9,000	16.5	396	100	1 + 1	S + S	60–250	30	Aerodynamic	Radar	Nuclear or H.E.	?	First public display in 1963
	SA-6 Gainful	550	6.2	152	33.5	1	R/R	35	0.1–15	Aerodynamic	Radio + radar	80 kg	?	First public display in 1967
	SA-7 Grail	9.2	1.35	?	7	1 + 1	S + S	3.6	1.5	Aerodynamic	IR	2.5 kg	?	Infantry weapon used in Vietnam
	SA-8 Gecko	195	3.2	64	21	1	S	8.0	6	Aerodynamic	Command + IR	50 kg H.E.	1977	First public display in 1975
	SA-9 Gaskin	30	1.8	32	11.5	1 + 1	S + S	4	—	Aerodynamic	IR	H.E.	1976	First public display in 1975

TABLE 7: AIR-TO-AIR MISSILES

Origin	Name	Weight (Kg)	Length (Metres)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop Type	Range (Km)	Speed (Mach No.)	Control	Guidance	Warhead Type	Service Intro'	Remarks
FRANCE:	Word AA.20	133	2.6	80	25	2	S	4	1.7	Aerodynamic	Command	23 kg	1957	Limited capability. Precursor to R.530. Project start in 1953
	R.511	180	3.1	100	26	2	S	7.4	1.8	Aerodynamic	Radar	25 kg	1956	Development began in 1951; terminated
	R.530	195	3.28	110	26	2	S	18	2.7	Aerodynamic	Radar	27 kg	1965	Equipped Mirage III squadrons
	Super 530	205	3.54	90	26	2	S	35	4.5	Aerodynamic	Radar	—	1979?	Replaced R.530
	R. 550 Magic	90	2.74	66	15.7	1	S	0.3-7	2	Aerodynamic	IR	12.5 kg	1975	Replaced Sidewinders on French aircraft
ISRAEL:	Shafrir	93	2.47	52	16	1	S	5	?	Aerodynamic	IR	11 kg	1969	Used in 1969–70 during war of attrition
ITALY:	Aspide	220	3.7	100	20.3	1	S	50–100	4	Aerodynamic	Radar	35 kg	1977	Replaces licence-built Sparrows
JAPAN:	AAM-1	76	2.5	50	15	1	S	5	?	Aerodynamic	IR	?	1968	Replaced Sidewinders on F-86 and F-104 fighters
	AAM-2	74	2.2	50	16	1	S	5	3.5	Aerodynamic	IR	?	1973	Replaced AAM-1
SWEDEN:	Rb72	112	2.6	60	17.5	1	S	?	?	Aerodynamic	IR	H.E.	?	Development began in 1975
UK:	Firestreak	136	3.19	74.7	22.2	1	S	8	2	Aerodynamic	IR	23 kg H.E.	1958	Development began in 1951
	Red Top	150	3.27	91.4	22.2	1	S	11	3	Aerodynamic	IR	31 kg	1965	Initially equipped RAF Lightning and Sea Vixen
	Sky Flash	193	3.66	102	20.3	1	S	50	4	Aerodynamic	Radar	30 kg	1978	Arms RAF Phantoms for air defence
US:	AIR-2A Genie	373	2.92	100	44	1	S	10	3	None	None	Nuclear	1958	Equipped Sabre and Voodoo squadrons
	AIM-4D	61	2.0	50.8	16.25	1	S	10	?	Aerodynamic	IR	H.E.	1965	
	AIM-7E Sparrow	205	3.6	100	20	1	S	25–50	4	Aerodynamic	Radar	30 kg	1964	Sparrow first used operationally in 1958
	AIM-7F Sparrow	228	3.6	100	20	1	S	100	4	Aerodynamic	Radar	40 kg	1964	
	AIM-9B Sidewinder 1A	75	2.84	60.7	12.7	1	S	1.1	2	Aerodynamic	IR	H.E.	1958	Exported in large numbers. Operational since 1956
	AIM-9D Sidewinder 1C	84	2.91	63.5	12.7	1	S	3.7	2.5	Aerodynamic	IR	4.5 kg H.E.	1965	US Navy use
	AIM-9H Sidewinder	86	2.87	63	12	1	S	18	2.5	Aerodynamic	IR	10 kg	1968	US Navy use
	AIM-26A Falcon	91	2.14	64	28	1	S	10	2	Aerodynamic	Radar	Nuclear	1960	Development began in 1947. Earlier models in use 1954
	AIM-26B (Rb27)	115	2.1	62	29	1	S	10	2	Aerodynamic	Radar	H.E.	1961	
	AIM-54 Phoenix	380	3.96	91.4	38	1	S	200	5+	Aerodynamic	Radar	—	1974	Equips F-14 Tomcat shipboard interceptor
USSR:	AA-1 Alkali	90	1.9	58	18	1	S	8	2	Aerodynamic	Radar	—	?	Armed MiG-17
	AA-2 Atoll	70	2.8	53	12	1	S	6	?	Aerodynamic	IR	—	?	Equips MiG-17, MiG-21 and MiG-23
	AA-3 Anab	275	3.8	135	30	1	S	18	?	Aerodynamic	IR or Radar	—	?	Equips Fishpot C, Su-11, Su-15 and MiG-23
	AA-5 Ash	200	5.5	130	30	1	S	30	?	Aerodynamic	IR	—	1962	Used by Tu-28 and initial versions of Foxbat
	AA-6 Acrid	800	6.3	225	40	1	S	45	2.2	Aerodynamic	Radar	100 kg H.E.	1975	Two carried by each Foxbat
	AA-7 Apex	330	4.3	1.0	24	1	S	30	2	Aerodynamic	Radar or IR	40 kg H.E.	1975	Two carried by MiG-23
	AA-8 Aphid	55	2.1	52	13	1	S	8	2	Aerodynamic	IR	6 kg H.E.	1975	Carried by MiG-23

TABLE 8: ANTI-SHIP MISSILES

Origin	Name	Weight (Kg)	Length (Metres)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop Type	Range (Km)	Speed (Mach)	Control	Guidance	Warhead Type	Service Intro'	Remarks
FRANCE:	MM.38 Exocet	735	5.21	104	34.8	2	S	5–45	0.95	Aerodynamic	Radio/radar	165 kg	1974	Ship-to-ship missile
	AM.39	650	4.63	104	34.8	2	S	70	0.95	Aerodynamic	Radio/radar	165 kg	1979?	Firing trials began in 1976. Air launched
	MM.39	650	4.63	104	34.8	2	S	50	0.95	Aerodynamic	Radio/radar	165 kg	?	Ship-to-ship missile
	MM.40	735	5.21	100	34.8	2	S	70	0.95	Aerodynamic	Radio/radar	165 kg	?	In development as uprated MM.38
GERMANY:	Kormoran	600	4.4	100	34.4	2	S	35	0.95	Aerodynamic	Radio/radar	160 kg	1977	Designed for launch from fighter-bomber
ISRAEL:	Gabriel 1	400	3.35	138.5	32.5	2	S	20	0.65	Aerodynamic	Radio/radar	150 kg	1970	For use on fast patrol boats
	Gabriel 2	500	3.35	138.5	35	2	S	40	0.65	Aerodynamic	Radio/radar	150 kg	1970	For use on fast patrol boats
ITALY:	Airtos	191	3.9	85.7	20.6	1	S	3–11	1.9	Aerodynamic	Seeker/radio	35 kg	?	Licence development for unspecified customer
	Otomat Mk. 2	730	4.9	125	46	2 + 1	2S + 1T	100	0.9	Aerodynamic	Radio/radar	65 kg	1979?	Ordered by several foreign names, missile is fired from truck
	Sea Killer Mk. 2	300	4.7	99.9	20.6	2	S	25+	300 m/sec	Aerodynamic	Beam/command	70 kg	1972	Ship-to-ship missile
	Sea Killer Mk. 3	548	5.3	109	32	1 + 2	S + S	45+	290 m/sec	Aerodynamic	Radio/radar	150 kg	?	Proposal for future development
JAPAN:	ASM-1	590	?	?	?	1	S	45	0.98	?	Radio/radar	140 kg	1980	Launched from transport aircraft
NORWAY:	Penguin	340	3	140	28	1	S	30	0.9	Aerodynamic	Inertial/IR	Frag.	1972	Launched from patrol boats
SWEDEN:	RLO4E	600	4.45	204	50	1	S	?	0.8	Aerodynamic	Radio/seeker	—	1971	Launched from subsonic aircraft
	RLO5A	305	3.6	80	30	1	L	?	?	Aerodynamic	Radio	—	1971	Launched from aircraft
	RLO8A	1,215	5.72	301	67	2 + 1	2S + 1T	150	0.8	Aerodynamic	Seeker	225 kg	1965	
UK:	Sea Skua	200	2.8	67	22.2	1	S	14	0.96	Aerodynamic	Radar	37 kg	?	Under development
US:	AGM-53A Condor	958	4.2	135	43.2	1	S	110	?	Aerodynamic	Autopilot+command	286 kg	1973	Air-launched
	AGM/RGM-84A Harpoon	667	4.58	91.4	34.3	1 + 1	S + T	110	0.85	Aerodynamic	Inertial/seeker	227 kg	1977	Air-launched
	GD Standard Active	635	4.6	107	30.5	1	S	?	?	Aerodynamic	Inertial/seeker	?	?	Built in 1974 for test and evaluation
USSR:	SSC-1 Shaddock	11,790	13.8	210	100	2 + 1	T + Jato	450	2.5	Aerodynamic	Radio/radar	Nuclear or H.E.	1962	Coastal defence from wheeled transporter
	SSC-1/SS-N-3 Shaddock	11,790	13.8	210	100	2 + 1	T + Jato	800	2.5	Aerodynamic	Radio/IR	Nuclear or H.E.	1962	Launched from submarines or surface cruisers
	SSC-2B Samlet	3.100	7	500	120	1 + 1	S + T	180	0.9	Aerodynamic	Radio/radar	H.E.	—	Coastal defence replacing 130-mm gun
	SS-N-1 Scrubber	6,000?	7?	400?	130?	1 + 1	S + T	240	0.9	Aerodynamic	Radio/IR	H.E.	1958	Mounted on cruisers
	SS-N-2A Styx	3,000?	6.5?	275	75	1 + 1	S + T	42	0.9	Aerodynamic	Radio/IR	400 kg H.E.	1960	Mounted on fast patrol boats
	SS-N-2B Styx	?	?	?	?	?	?	8–40	?	Aerodynamic	Radio/IR	400 kg H.E.	1961	On patrol boats
	SS-N-7	?	6.7	?	?	?	?	55	1.5	Aerodynamic	Radio	?	1969	Submarine (underwater launch) missile
	SS-N-9	?	9.1	?	?	?	?	275	?	Aerodynamic	Radar	H.E.	1969	On corvettes
	SS-N-11	?	6.4	?	?	1 + 1	S + T	50	0.9	Aerodynamic	Radio/IR	H.E.	1968	Replacement for SS-N-2 on fast patrol boats
	SS-NX-13	?	?	?	?	?	?	750	4	?	Sat. updates	Nuclear	?	Underwater launch. Anti-aircraft carrier or FBMS

TABLE 9: ANTI-SUBMARINE MISSILES

Origin	Name	Weight (Kg)	Length (Metres)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop Type	Range (Km)	Control	Guidance	Warhead Type	Service Intro'	Remarks
AUSTRALIA:	Ikara	?	3.43	153	?	2	S	?	Aerodynamic	Command	Torpedo	1967	Carried by destroyers. Torpedo descends by parachute
FRANCE:	Malafon	1,450	6.1	330	65	2	S	2–13	Aerodynamic	Command	Torpedo	1961	Ramp launched from surface vessel
US:	Alfon	227	2.59	—	32.38	1	S	0.82	Aerodynamic	None	H.E.	1952	Tube launched from surface vessel
	Asroc	450	4.65	76	32	1	S	2–8	None	None	Torpedo	1961	Carried by surface vessels in 8-round launcher
	Subroc	1,814	6.7	—	54.9	1	S	50	TVC	Inertial	Nuclear	1965	Submarine launch, atmospheric flight. Delivers depth charge
USSR:	SS-N-14	?	?	?	?	?	S	55	?	?	Nuclear	1975?	Winged missile carried by cruisers and destroyers. Delivers torpedo
	SS-N-15	?	?	?	?	?	S	40	?	?	Nuclear	1975?	Submarine launch, atmospheric flight

TABLE 10: ANTI-ARMOUR MISSILES

Origin	Name	Weight (Kg)	Length (Cm)	Span (Cm)	Diameter (Cm)	No. of Stages	Prop' Type	Range (Metres)	Speed (m sec)	Control	Guidance	Warhead Type	Service Intro'	Remarks
AUSTRALIA:	Malkara 1A	100.7	196.8	79.4	20.3	2	S	460-3,600	179	Aerodynamic	Command	26 kg	1959	Vehicle mounted. Used by British army
FRANCE:	AS.11/SS.11	29.9	121	50	16.4	2	S	350-3,000	100-190	Deflectors	Command	Various	1956	Air or ground launch
	AS.12/SS.12	74.2	187	65	21	2	S	800-8,000	260	Deflectors	Command	28.6 kg	1962	Air or ground launch
	SS.10	15	86.1	74.9	16.25	2	S	302-1,600	80	Aerodynamic	Command	5 kg	1955	Superseded by AS.11/SS.11. Used by infantry
	Entac	12	82	37.5	15	1	S	400-2,000	85	Aerodynamic	Command	4 kg	1962	Fired from a wheeled vehicle
	Harpon	30.4	121.5	50	16.4	2	S	500-3,000	190	Deflectors	Command	2.6 kg	1970	Vehicle mounted
FRANCO-GERMAN:	Hot	23.5	127.5	31	13.6	2	S	75-4,000	250	Deflectors	Command	6 kg	1968	Vehicle mounted
	Milan	11.9	77	26.5	9.0	2	S	25-2,000	200	Deflectors	Command	3 kg	1973	Shoulder or ground launched
GERMANY:	Cobra 2000	10.3	95	48	10	2	S	400-2,000	85	Aerodynamic	Command	2.7 kg	1961	Launched from the ground
	Mamba	11.2	99.5	40	12	2	S	300-2,000	140	Aerodynamic	Command	2.7 kg	1976	Replacement for Cobra
ITALY:	Mosquito	14.1	111	60	12	2	S	360-2,300	90	Aerodynamic	Command	4 kg	1959	Purchased by Japan
	Sparviero	16.5	138	?	13	2	S	75-3,000	140	Aerodynamic	IR	4 kg	1980's?	Ground or helicopter use
JAPAN:	KAM-3D	15.7	100	60	12	2	S	350-2,000	85	Aerodynamic	Command	H.C.	1963	Infantry weapon
	KAM-9	?	155	33	15	2	S	2,000	?	Aerodynamic	Command	1.9 kg	1975	Launched from transporter storage tube
SWEDEN:	Bantam	7.6	84.8	40	11	2	S	230-2,000	90	Aerodynamic	Command	?	1962	Ground operated: could be used by helicopters
UK:	Swingfire	38	106	39	17	1	S	150-4,000	185	TVC	Command	6.8 kg	1969	Fired from armoured vehicle
	Vigilant	14.75	98.5	27	13	1	S	230-1,375	120	Aerodynamic	Command	5.4 kg	1962	Infantry launched
US:	Dragon	6.17	74.5	33	12.7	2	S	60-1,000	100	Thrusters	Command	2.44 kg	1972	Replaced the US Army 90-mm recoilless rifle
	Shillelagh	27	114	29	15.2	1	S	4,500	?	Thrusters	Command	6.8 kg	1967	Tube launched, optically tracked, wire guided
	TOW	24.5	118.1	34	14.75	2	S	65-3,750	Subsonic	Aerodynamic	Command	3.6 kg	1971	Infantry launched
USSR:	AT-1 Snapper	22.3	113	78	14	1	S	500-2,300	90	Aerodynamic	Command	5.2 kg	?	Vehicle mounted
	AT-2 Swatter	25	90	66	15	1	S	300-2,200	150	Aerodynamic	Command+ IR	?	?	Vehicle mounted
	AT-3 Sagger	11	87	46	12	1	S	500-3,000	120	Jetevator	Command	2.7 kg	1966	Vehicle mounted
	RPG-7V	2.5	?		8.4	1	S	300	300	None	None	2 kg	—	Fired from an over-shoulder launcher

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