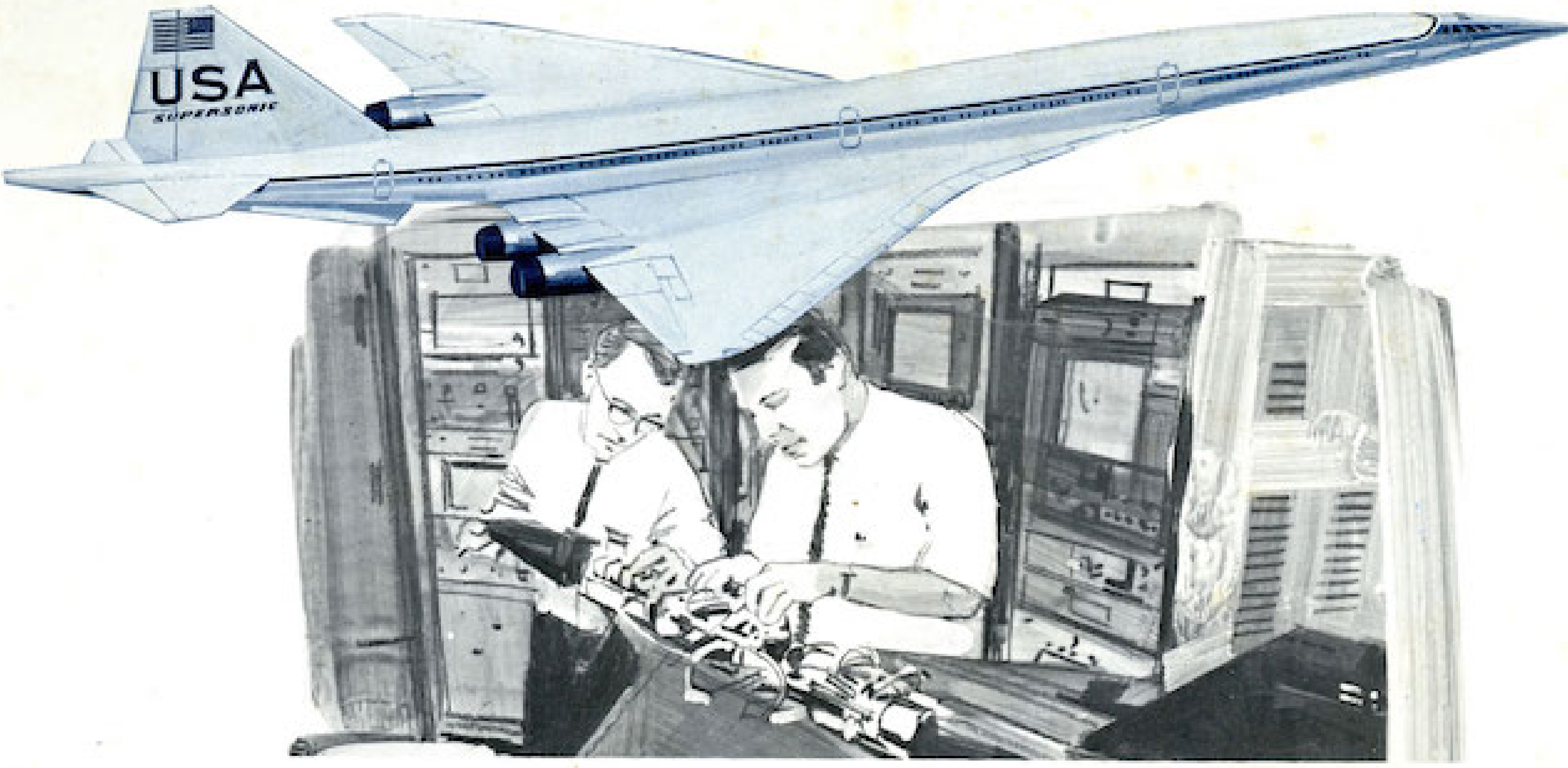
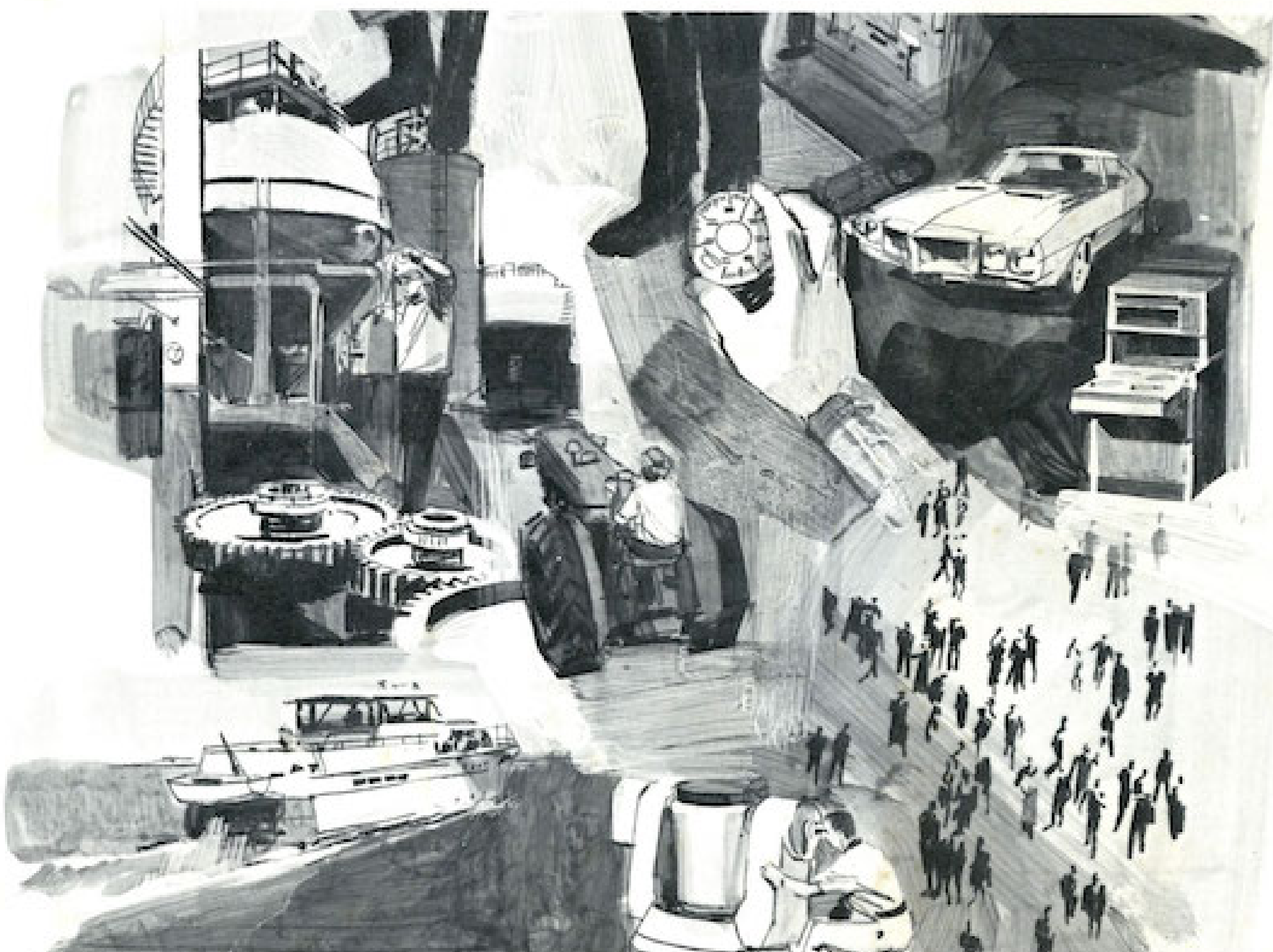
MORE THAN AN AIRPLANE



SST TECHNOLOGY BENEFITS



JULY 1970

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July 1970

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*THE **BOEING** COMPANY COMMERCIAL AIRPLANE GROUP SUPERSONIC TRANSPORT DIVISION*

"Continuing technological progress is necessary to maintain leadership in every field; history proves there can be no resting on the oars. Although the Wright brothers invented the airplane, there was little subsequent support in America. As a result, during World War I American pilots flew only French and British planes; there was no ready U.S. aviation industry.

"In the Second World War, the Me 262 jet fighter was operational while America was still testing prototypes. The British flew the first jet transport; the first supersonic transports will be Anglo-French Concorde and the Russian Tu 144. International competition in aviation is intensifying. More than national commercial interest is at stake in a strong aerospace industry; it is today a matter of national survival."

"The importance of aerospace to the United States can be put into another perspective: It is now America's largest manufacturing industry, employing 1.3 million people with a $14 billion annual payroll. This industry does an annual business of $27 billion – and last year had a $28 billion backlog. U.S. exports of aircraft and parts climbed from $1.1 billion in 1964 to $2.9 billion in 1969. The aerospace industry is thus one of our great producers of national wealth. America would not have this vital industrial capacity, competence, and output today had we not made continuing technological investments in the past. This will hold true even more so in the economic equations of the future."

Statement by Dr. Thomas O. Paine to Senate Committee on Aeronautical and Space Sciences, April 6, 1970, quoted from the Congressional Record.

INTRODUCTION

The United States has more at stake in the SST program than the building of a successful commercial supersonic transport airplane. While this is the major objective, the additional technical achievements provided by the program are essential to maintaining the aviation leadership and industrial capability of this country.

Two qualities enable U.S. products to compete in world markets against foreign competition: advanced technology and superior producibility. These qualities are also essential in maintaining the superiority of U.S. military weapons. The SST program has already provided advancements in engines, aerodynamics, materials, processes, and systems. Many current military and commercial programs have already benefited from SST developments. The full potential of benefits to be derived is still to come.

This booklet contains a description of some of the progress already made and the impact that this progress has had on existing programs. It describes other advances and possible applications to military, industrial, and consumer products. This information is only a partial listing of the total progress that may be expected; however, it demonstrates conclusively that technical benefits from the SST program will improve American industrial capability and provide for new products, improved transportation systems, more jobs, and greater tax return to the government.

THE CHALLENGE

The United States SST will be designed and produced at a time when man is more concerned about his environment than ever before. As a result, the SST must meet a much more demanding set of requirements than any transportation system built thus far. Because the critical nature of the problems requires unique solutions, the SST program will be a rich source of technical improvements for other applications.

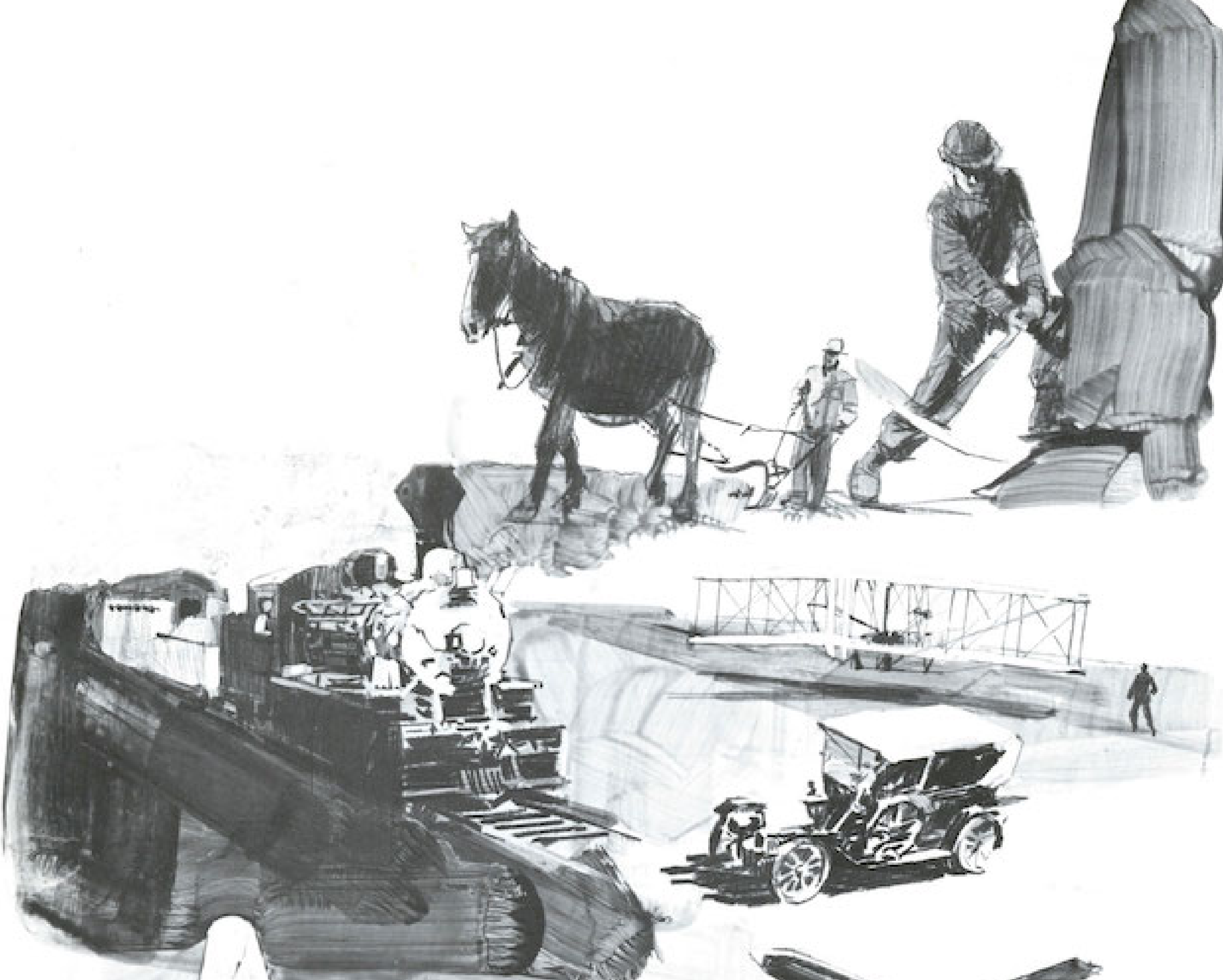
THE CHOICE

It is inevitable that there will be a substantially increased international market for passenger travel in the 1980's, and that this market will be served by the world's airlines using supersonic transports. The increase in the world's population and the demand for improved travel services provides the market demand. The supply of supersonic travel will be provided to meet this demand. The British, French, and Russians have already demonstrated their intention to serve this market.

The alternatives to the United States SST program are unacceptable. Arbitrarily restricting airline operation so that the market can only be served with subsonic jets requires a larger number of aircraft and more flight hours because of slower speeds. The resulting total effect on man's environment in terms of noise, air pollution, and airport congestion is greater. For example, it would take 1200 747's to carry the passengers carried by 500 SST's. Serving this market with foreign made supersonic aircraft will cause serious deterioration in the U.S. balance of payments and cause the U.S. to lose its present position of world leadership in aviation.

The present financial structure of the program provides the government with complete return on all monies invested. The total return including taxes will be 124 percent of the government's investment. The additional return resulting from the technical benefits will be provided in many ways, through many channels. Existing products will be improved, and new products will be developed. It is clear that the United States through the SST program is making an investment in industrial progress and in the well-being of the Nation as a whole – more than an airplane.

Man's Progress in the Control of Energy and Materials



SUMMARY

Technical advancements resulting from the SST program will bring about improvements in products used by consumers and industry in the future, just as investments in research and development made in previous years have paid off in the products in use today.

The widespread use of aluminum as a common material in automobiles, building materials, and consumer products was made possible through the development of this material for aircraft structure in the 1930's and 1940's. The SST will make possible similar exploitation of titanium where high-strength light-weight high-temperature materials are required. Industrial uses will include high temperature processing equipment in food, petroleum, and chemical industries; components for internal combustible engines on tomorrow's automobiles, such as afterburners in the exhaust systems to reduce the level of pollutants; improvements in home and industrial heating equipment; and marine applications.

Titanium has been available for some time in small quantities for special applications. Its use has been limited by manufacturing technology and relative cost. The knowledge necessary to economically form and fabricate titanium has been developed and is available today. Its use in the SST and the increasing demand for the material will cause a reduction in price which will make it economically attractive for use in common applications.

Man's progress has been paced by the development, control, and efficient use of energy. The progress from animal power, to steam power, to the internal combustion engine and finally to the high performance aircraft engines in use on today's jet aircraft has made possible man's achievement in many other areas. The use of light-weight high-energy producing equipment has brought about the development of man's present transportation systems.

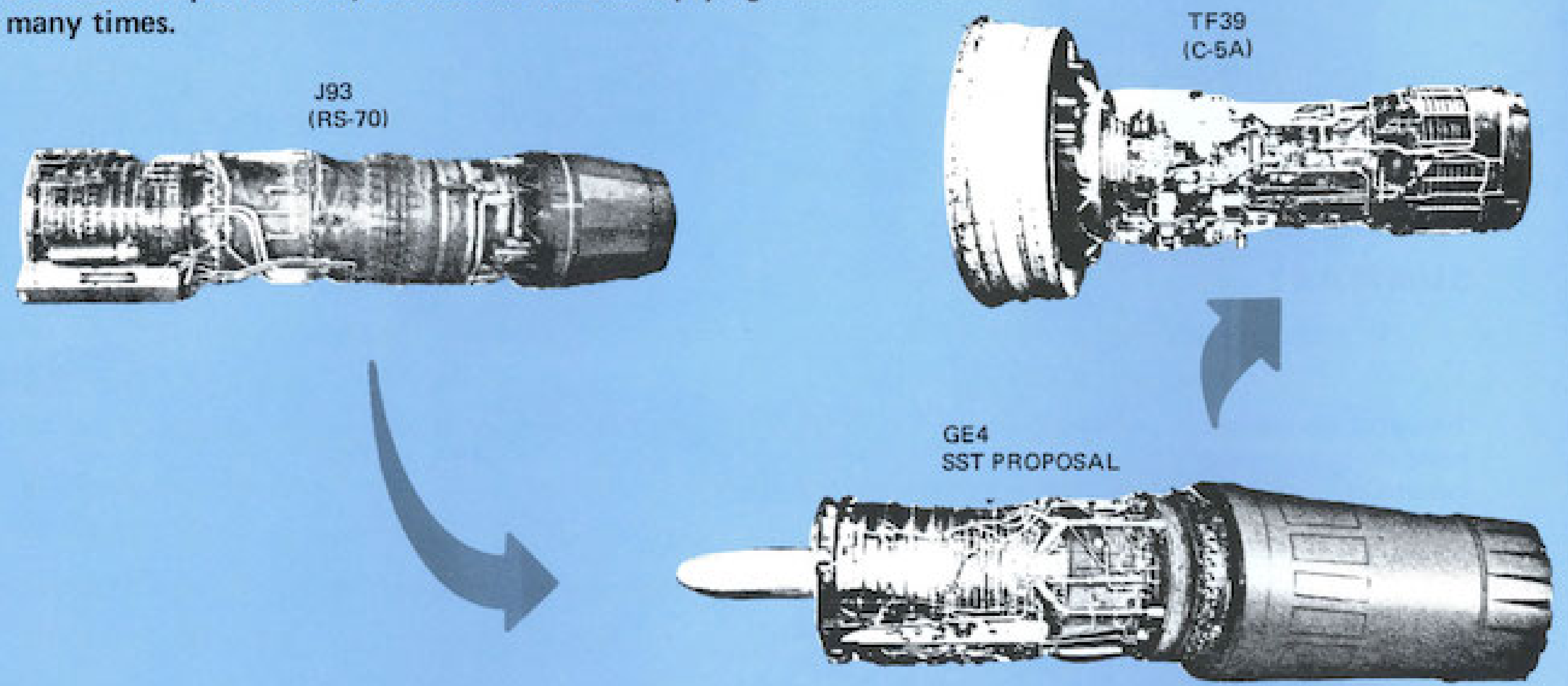
Improvements in aircraft engines for the SST will be reflected in similar improvements in many other types of engines and energy producers. The improved burner technology resulting in the high thermodynamic efficiency of the GE4 engine will make possible more efficient, smokeless powerplants.

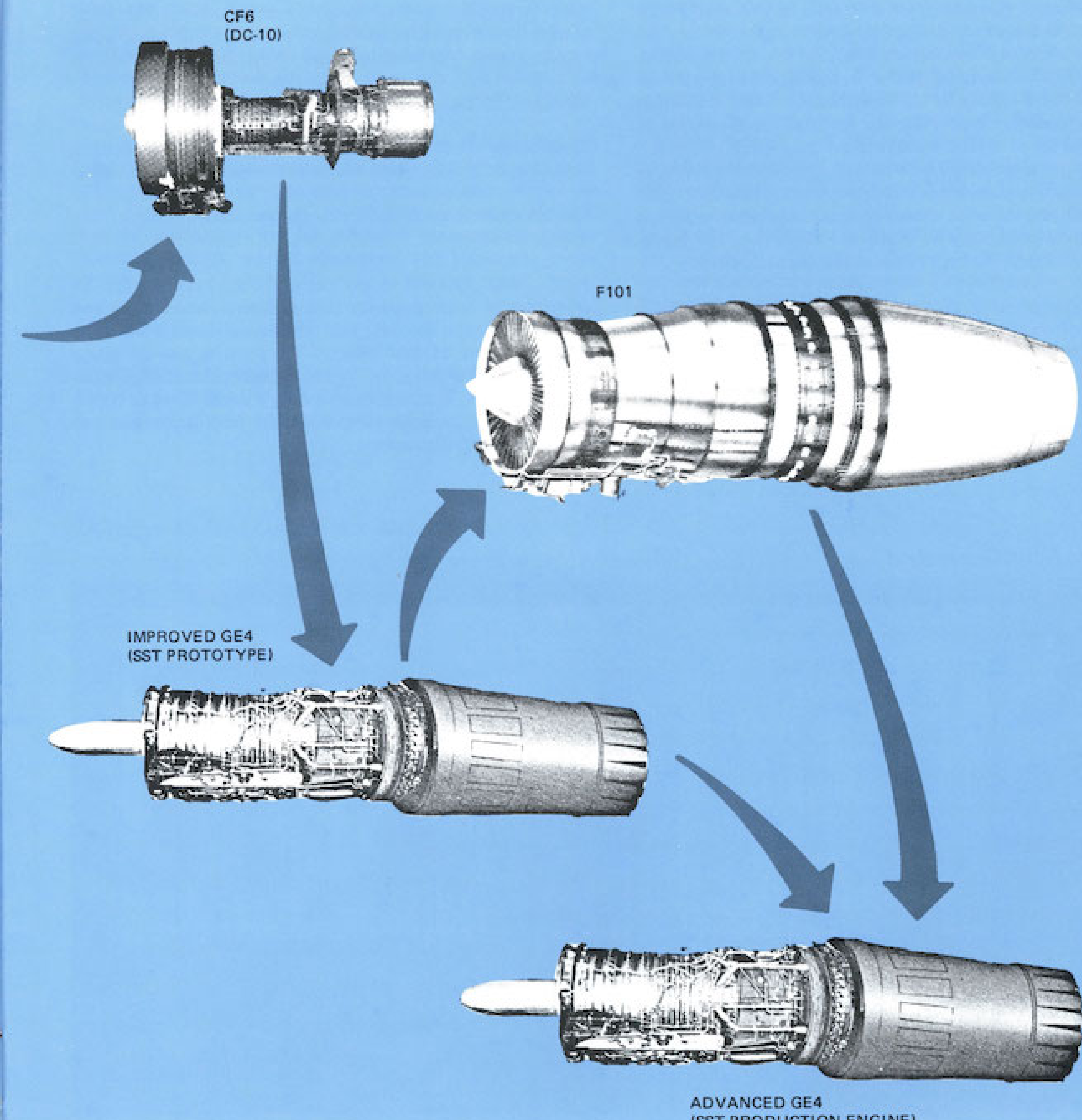
The development of automated flight control systems and air traffic systems for use with the SST will provide a significant improvement in air traffic control, and reduction of air traffic congestion. The same technology for control of vehicles in high density traffic areas will make automated control systems possible for automobile and truck traffic of tomorrow's cities.

The total scope of the advancements of technology resulting from the SST program is only beginning to be realized. The effect of the benefits of these improvements in technology will soon be felt in other parts of the U.S. economy.

The long term benefits are impossible to predict at this time. However, past experience has shown that the ingenuity of American industry in the application of technological improvements is virtually unlimited. The technical benefits resulting from advancements made possible through the SST program will contribute to the well-being of American industry and the people of the U.S. as a whole for many years to come.

The flow diagram shows a simple example of the interrelated effects of improvements that are developed for a specific application, and how other programs benefit from these improvements. This example illustrates only the General Electric engine program. The effects on other companies and other programs are not shown, but the benefits are multiplied by these other applications. In the case of a material such as titanium where hundreds or thousands of companies may find ways to use the improvements, the total of this multiplying effect is increased many times.





The latest concepts and technology from General Electric's J93 military engine (used on the RS-70 Mach 3 bomber) provided a base to launch the initial GE4 design. But performance and fuel economy demanded for the SST Phase II competition with Pratt and Whitney forced General Electric to use higher turbine temperatures for the GE4. This required improved turbine blade cooling and better materials in the SST competition hardware.

This work on the GE4 enabled General Electric to use this new GE4 turbine technology for their TF39 to power the Air Force's C-5A, which in turn provided hardware for more extensive turbine development tests. The TF39 basic design was then adapted to the CF6 engine for the McDonnell-Douglas DC-10. This improvement in technology next enabled General Electric to define a more advanced GE4 for the SST production engine design and to build five test engines for the current Phase III prototype program. (These GE4 engines have set a new world record for thrust and have already exceeded their thrust and fuel-consumption contract requirements to be obtained by 1973.) Using cross-fertilization from the TF39, CF6 and GE4, General Electric has proceeded to a new military family of F101 engines.

INFORMATION ON ENGINE IMPROVEMENTS IN THIS SECTION WAS PROVIDED BY GENERAL ELECTRIC.

ENGINES

ENGINE NOISE SUPPRESSION

The total noise of the installed aircraft engine is a combination of the turbomachinery noise (fan, turbine, and compressor) and the noise of the exhaust jet. This total noise contains both high and low frequency components. At the same sound pressure level measured in decibels (db) the higher frequencies tend to be more annoying. However, the high frequencies are dissipated more rapidly in the atmosphere. The most efficient sound suppressors convert the low frequency components to high frequency so total noise is reduced more quickly with distance from the airplane. New sound suppression techniques include absorption materials and quiet inlets. These SST techniques will provide noise characteristics comparable to or less than existing wide body jet transports under the same conditions, even though the engines are producing more thrust.

The technology made available through exploration of these noise suppression techniques can be used to reduce the noise levels of other aircraft engines and will be available for noise suppression in non-aircraft applications.

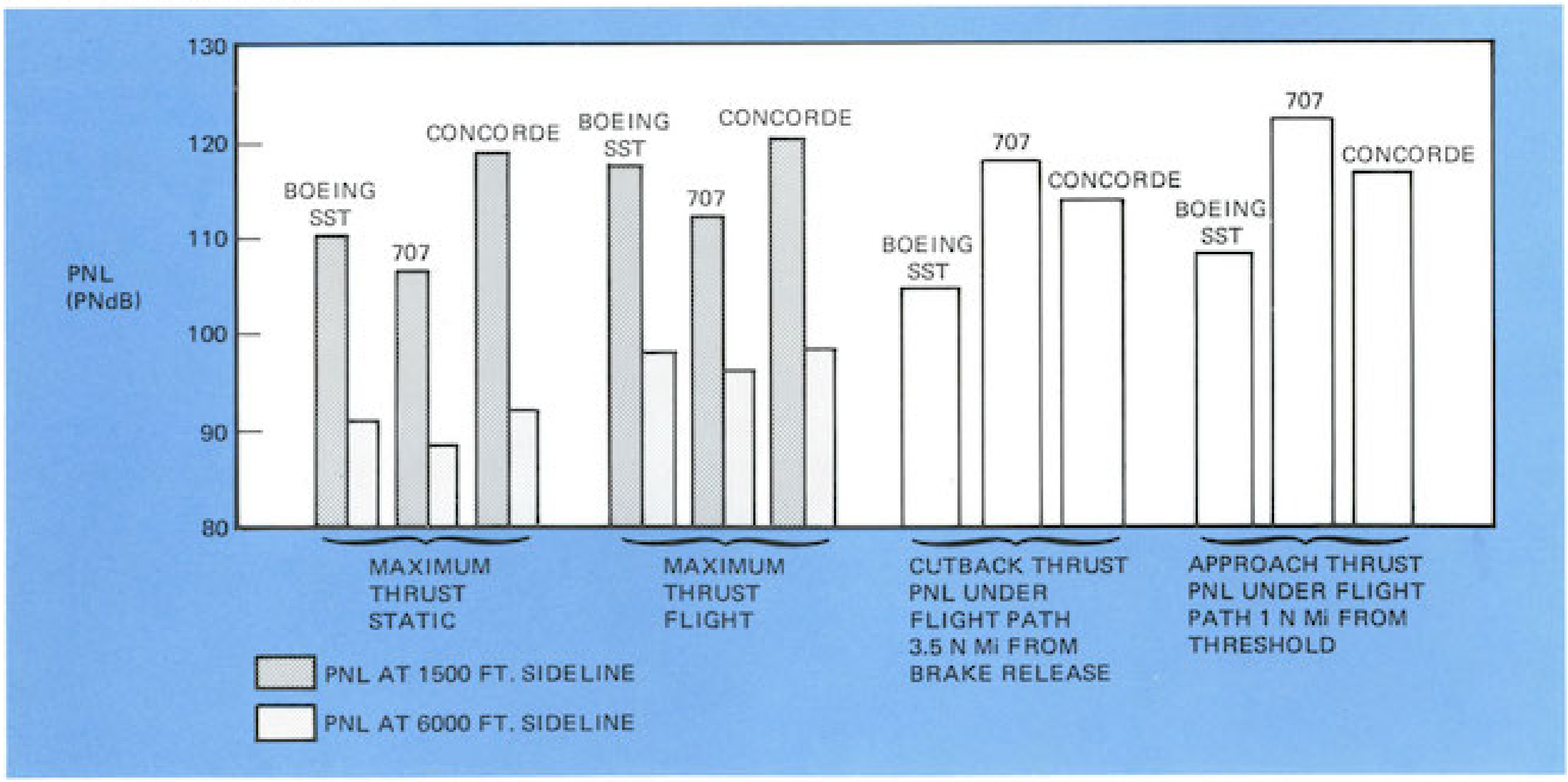
In most cases, the muffling of machinery noise requires large amounts of absorbing material and reduction of efficiency. These techniques are not acceptable for aircraft because of loss of thrust and increased weight. The light weight noise suppression technology applied to consumer products will mean quieter power mowers, outboard engines, chain saws, automobiles, trains, and other common equipment.

FUNDAMENTAL JET NOISE PREDICTION

Technology: During the SST jet noise program, considerable work has been conducted on an analytical/empirical method to improve the accuracy of predicting jet noise, especially at low velocities. Improvements to the standard technique have been defined.

Applications: This will be applicable at low jet velocities to the definition of noise goals for future subsonic commercial and military transport aircraft. For commercial aircraft the accurate prediction of low velocity jet noise is also of prime importance in defining an engine cycle consistent with minimal total noise, attaining an optimum balance between turbomachinery and jet noise components for both suppressed and unsuppressed configurations.

Airplane Noise Comparison



CHOKED INLETS

Technology: The engine inlet on the SST will be equipped with a movable centerbody. During periods when the engine is operating at low power settings, the centerbody will be moved to reduce the inlet area. This choking action reduces the turbo-machinery noise because the velocity of the incoming air is increased to approach the speed of sound. This prevents the noise from propagating forward.

Applications: This suppression device can reduce forward propagated turbo-machinery noise up to 10 PNdb and is applicable to variable inlet geometry configurations on which the inlet Mach number can be set at 0.85 or greater. Possible specific applications are for proposed commercial transonic transport aircraft, marine equipment, and stationary power plants.

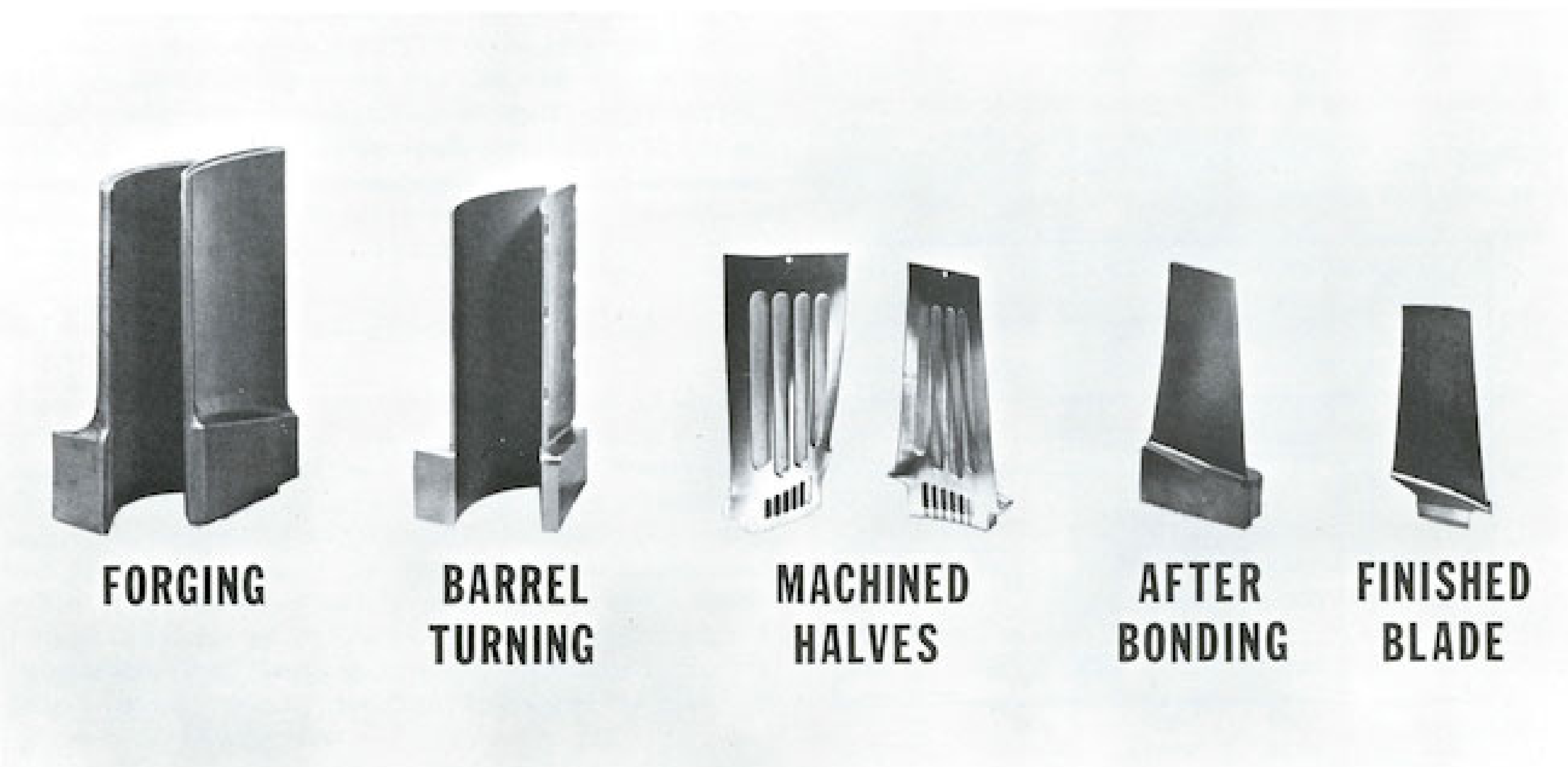
TURBINE BLADE DESIGN

Technology: The high-temperature turbine could not operate efficiently enough for the SST without air cooled turbine blades. The SST developments significantly raised the temperature and increased the blade life 2 to 5 times.

Blades are under development which combine film and impingement cooling. Fabrication of the blade from three separate castings is necessary to provide this means of cooling. A joining process was required which could achieve strength in excess of 70 percent of the base metal. A diffusion bonding process activated by a temporary molten phase was developed to satisfy the requirement. The development was a marriage of advanced brazing and diffusion bonding technology. Continued development is expected to achieve 100 percent of the base metal properties in the bonded joints.

Applications: This new blade technology is being applied to the CF6, F101, and other advanced turbines for future military and commercial applications. The automotive industry is interested in these advanced concepts because of the importance of developing high turbine temperatures in proposed automotive turbines. The use of turbine power in land transportation can improve efficiency and reduce pollution emissions and noise.

Diffusion Bonded Compressor Blade

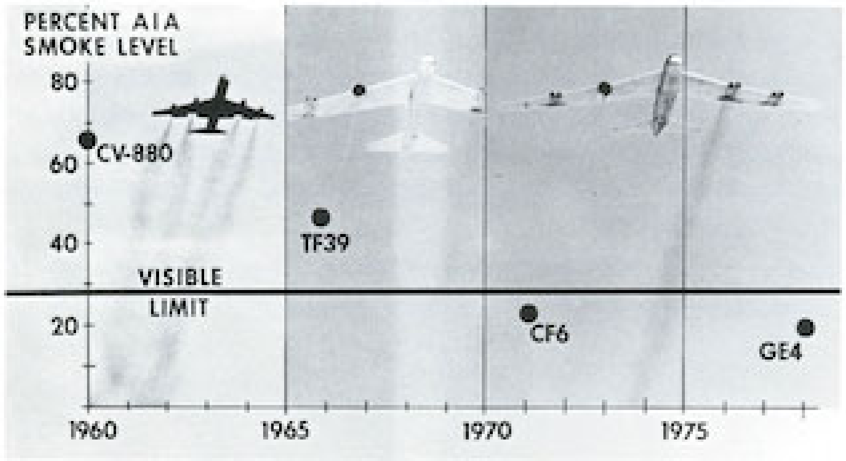


General Electric

ENGINE EXHAUST EMISSIONS

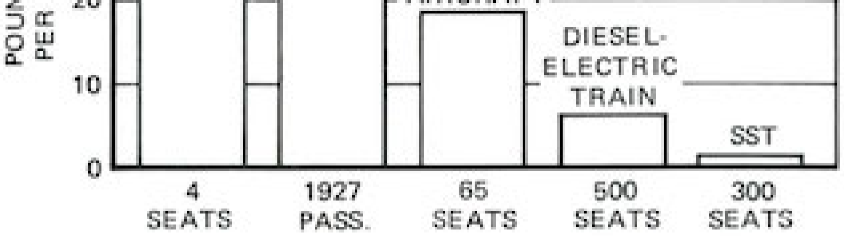
Technology: Development work on aircraft engines in recent years has emphasized the reduction of engine exhaust emissions. Improved methods of introducing and mixing the fuel and air in the combustor have eliminated visible smoke from the engines on the SST. This technology being developed by General Electric jointly on the SST and CF6 programs is a significant advance in the reduction of exhaust emissions for aircraft engines. This work is continuing to reduce the non-visible emissions. It should be noted that the quantity of exhaust emissions from aircraft turbine engines is significantly less than for piston engines used in trucks and automobiles.

Progress in Engine Smoke Control



General Electric

Comparison of Pollution Effects of Transportation Systems



Applications: Application of the improved knowledge of fuel-air mixing and combustor design can improve the efficiency and reduce the exhaust emission level on other types of combustion engines and combustion heating devices. The low level of emission from turbine engines will influence an increase in their use in other forms of land transportation. This means the total quantity of exhaust emissions released into the atmosphere can be reduced as a result of the improved technology. An additional benefit is the development of a standardized technique for measuring exhaust emission levels as described below:

STANDARDIZED MEASUREMENT PROCEDURES FOR SMOKE EMISSION LEVELS

Technology: Within the past few years extensive efforts have been carried out within the aircraft turbine engine industry to develop and define adequate means of measuring the smoke emission levels of aircraft engines. These emissions are now commonly measured through the use of an AIA/SAE smoke measurement procedure, which has recently been adopted as an industry standard. This method determines the concentration of smoke particulate matter in the engine exhaust gases, in terms of an index which is related to the visibility of the engine exhaust plume. General Electric was a major contributor in the development of this method. To a considerable extent, General Electric's efforts to develop this system were a part of the GE4 engine combustor smoke reduction investigations.

Applications: This smoke measurement method is suitable for use with any type of turbine engine and is adaptable for use with other types of power plants. Currently the use of this procedure to determine the smoke emission levels has been extended to a variety of marine and industrial turbine engines, as well as various types of aircraft turbine engines.

SYSTEMS

The SST, even though it will fly higher and faster than any existing commercial transport, will be designed to use existing airports and facilities that will also serve existing and future subsonic aircraft. The new flight control and flight management systems being developed for the SST will enable improvement of navigation, display, airplane control, and traffic control systems. This will improve the total capability of the transportation systems to handle increased volume of traffic and to operate under poor weather conditions.

The development of automatic flight management for the SST by integrating information processing, computation, and display functions will substantially reduce the workload on the pilot and crew. An area navigation system and automatic landing system will provide continuous updating of the necessary position information and flight control for safe flight in the highly congested areas adjacent to airports. They will also provide all weather landing capability at those airports around the world served by the SST.

Additional systems designs are being developed to improve the display of information to the flight crew on the ambient conditions surrounding the aircraft, and the weather conditions along the flight track. Improved onboard test equipment and area surveillance spark detection systems will provide greater safety of operations through detection and control of potential failures.

The development of these systems to improve the safety of the SST and the efficiency of the crew, will also make the same benefits available to other commercial and military aircraft. These same systems or derivatives are applicable to high speed ground transport systems, control of surface traffic congestion, military systems, and all types of ships from fishing boats to submarines, ocean liners and yachts.

AUTOMATIC FLIGHT MANAGEMENT

Technology: The flight time compression due to SST speeds and the increased number, and complexity of the navigation and control systems could cause higher peak workloads for the flight crew. However, the crew workload will be substantially reduced by integrating computation, information processing, and display functions in an automatic flight management system. The benefits of such a system include higher safety through reduction of crew workload, better pilot command information, more timely and accurate knowledge of the airplane's position, velocity, and flight status, and the ability to achieve better flight profiles.

Applications: Full development of computer controlled automatic flight management is an essential step toward a fully automated computer controlled traffic flow system for use in traffic congestion areas. This will provide central computer controlled and monitored movement of vehicles along paths in the control area to achieve maximum flow rates with reduced delays and improved safety. This type of system can be used for automotive and marine traffic.

AUTOMATIC LANDING SYSTEM

Technology: An automatic landing system called "Autoland" will provide all-weather automatic landing capability at all major SST airports. The system contains those elements of navigation, flight control, velocity, attitude, flap, and ancillary systems to provide safe, controlled landings under all weather conditions. Work has been proceeding on this system for several years. The impetus provided by the SST requirements will force the completion of the development to meet SST schedules. Data gathered from a number of aircraft systems and navigational aids are collected, conditioned, subjected to algorithm routines, and checked for error and trend. Instructions and signals are initiated into the proper flight and control systems. Update of the data takes place continuously from multiple source transducers that have self check and loop checks that detect any malfunctioning or inaccuracy anomaly.

Applications: The automatic landing system is directly applicable to aircraft and manned re-entry vehicles required to operate in visibility and ambient light conditions where a normal visual approach cannot be accomplished.

AREA NAVIGATION SYSTEM

Technology: The area navigation system will provide the SST pilot with an instrument which will permit more efficient point-to-point navigation, provide worldwide magnetic heading, and provide data input at the required data rate for the Automatic Flight Control System (AFCS). The data is constantly updated and signal conditioned, displayed, and distributed to the associated systems. This system is a significant advance in area navigation instrumentation display and provides the pilot better position information than that available in today's aircraft. The added navigational capability will improve safety of flight and provide a fundamental improvement during landing approach, holding patterns, and flight in congested air traffic control zones.

Applications: The area navigation system is directly applicable to all commercial, military, and general aviation uses. Techniques of data processing, analysis, and display are applicable to such diverse areas as marine navigation, orbital re-entry and landing, oceanographic research vessel guidance, and other applications where precise position control is required.

MULTI-FUNCTION DISPLAY

Technology: The multi-function display (MFD) provides information such as Mach vs. altitude, pictorial navigation, position of surrounding navigational aids, and topographic features. This advanced flight instrument will enable the SST pilot to

The Multi-Function Display Replaces a Number of Conventional Flight Instruments

obtain any specified flight altitude and aircraft velocity condition with accuracy and within a minimum time period. This instrument also enables the flight crew to predict the control actions required to capture and maintain any speed schedule.

Applications: The MFD can be applied to all high performance civil and military aircraft and for other applications where multiple information display must be generated within one display device. Possible uses of this instrument are for oceanographic research vessels, chemical and petroleum process control, and metalworking industries. A possible future development is the application of such a display to high speed truck and automobile traffic to provide instantaneous information on relative speeds and closing rates on other vehicles to assist in accident prevention.

FLIGHT CONTROL SURFACE ACTUATION AND ENGINE CONTROL BY ELECTRIC SIGNALS

Technology: Present aircraft in operational service use mechanical cables to move all flight control surfaces and engine controls. As aircraft size increases, the control cables become longer and unduly complex due to the number of systems required for reliability. The SST will use a multiple, highly reliable electric signal system to control the engine and flight control surfaces. This provides complete independence of the relative location of the flight deck to the control surface. The airplane design is not restricted to the physical distribution of cable runs, location and rigging of tension devices and the pulley system. Besides saving a considerable amount of weight, the "fly by wire" system conserves a large usable volume on board the airplane.

Applications: The obvious application of this system is for large aircraft of all types. Further applications are for naval and merchant vessels, for fishing boats (both vessel and fishing equipment control), and larger, more complex farm equipment.

WEATHER RADAR SYSTEM

Technology: The SST will be equipped with an advanced weather radar system to insure comfortable aircraft ride and to provide economical diversions from turbulent localized weather conditions. Storm centers and weather front identification will be possible at distances which will enable the flight crew to obtain necessary air traffic approval and correct their flight path. A unique new feature will provide for cloud top height measurements and will allow the SST to fly over some weather cells with sufficient clearance to prevent turbulence.

In addition, the comfort of the flight will be greatly improved because the flight crew can seat and secure passengers and reduce the aircraft speed if storm areas cannot be avoided. The aircraft structure fatigue life will be increased with reduced exposure to turbulent high load conditions.

Applications: The SST advanced weather radar system can provide economic benefits when applied to all transport aircraft, both civil and military.

SOLID STATE WORD RETRIEVAL SYSTEMS

Technology: The need for many different kinds of warning devices has far surpassed the use of bells, horns, sirens and lights. The SST will incorporate a solid-state word memory and retrieval system, coupled with detection and warning devices, to provide the pilot with audible word data to alert him to a problem and to give him instructions on what to do.

Applications: This type of system can be used for any military vehicle that requires pre-programmed information. It can also be used by the entire transportation industry and other commercial applications to provide effective warning and instruction data on emergency situations. Hospitals and doctors can also use this type of equipment for intensive care monitoring.

AREA SURVEILLANCE FIRE DETECTION SYSTEM

Technology: The SST will be equipped with ultraviolet sensors that are capable of detecting even the smallest spark located in the most remote section of the engine compartment or nacelle. This provides the capability to sense ignition sources and take corrective action prior to actual fire.

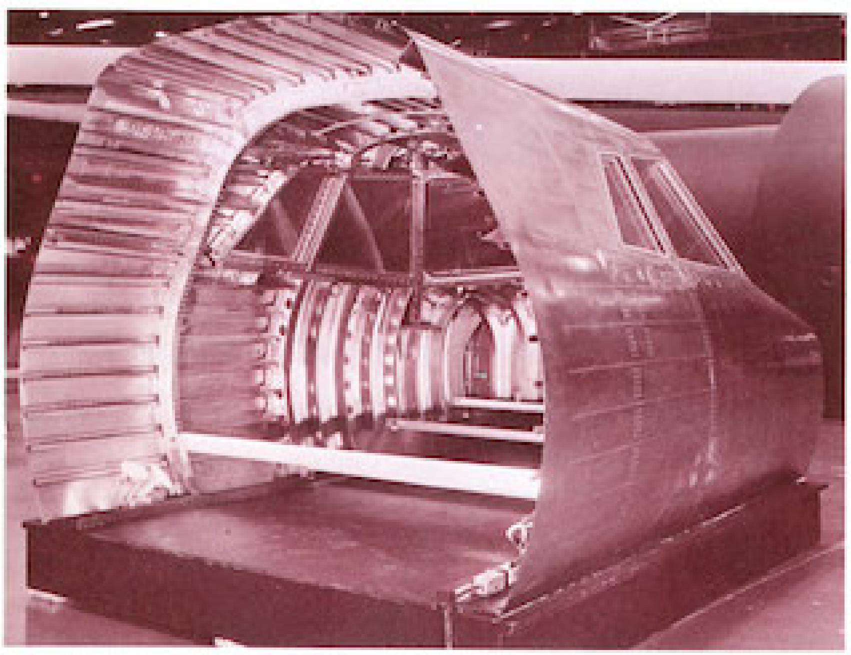
Applications: This new ultraviolet sensor can be easily retrofitted to all commercial, private, and military aircraft, thus enhancing overall flight safety. Furthermore, this sensor can be used wherever combustible fuel-air mixtures can exist and potential ignition sources must be controlled. This is directly applicable to ship's compartments, buildings, and processing areas in petroleum refining and chemical industries.

ADVANCED MATERIALS

The development of knowledge on exotic or advanced materials on aircraft structures or power plants has, historically, been followed by the dissemination of this knowledge into commercial fields and the widespread use of these materials in consumer goods. Aluminum, once an expensive material used sparingly in aircraft to save weight, is now found in all segments of industry. As its use in aircraft production increased, its price dropped, and interest in other fields such as civil structures and ground transportation grew. Now it is in common use for boats, beverage cans, lawn furniture, building materials – the list is endless.

Titanium, an element almost as abundant on the earth's surface as aluminum, is now in the embryo stage of development in the structure of airplanes. To meet the high temperature requirements of the SST, titanium will be used throughout its airframe. The development of titanium technology for the SST is a major addition to the aerospace industry technology and will be a major addition to the technology of the nation's commercial enterprises. As a result of government/industry effort during the 1930's, the knowledge of aluminum's properties and uses were expanded. Now the joint government/industry effort in titanium is developing an even stronger base for the use of titanium on transportation and consumer goods of the future. Gross weight of aluminum commercial aircraft of the 1930's approximated 15 tons; the SST will use five times this amount of finished titanium per airplane. Thus we will have a firm base on which to expand the use of titanium into many industrial, commercial and military applications such as petrochemical, desalinization, ground transportation, and marine systems.

Airplane Cab Section – Titanium Development



As propulsive efficiencies in aircraft jet engines have been improved, the intake temperatures have increased. This leads to the requirement of ever increasing material temperature capability throughout the engine. The development of materials for the SST General Electric GE4 engine have shown this increase not only in titanium alloys, but in the super alloys, generally nickel based dispersion-strengthened alloys with useful temperatures above 1600°F. With the development of these alloys and dissemination of information, their use in other improved engines and other applications will increase.

Some materials are found to have a cyclic development. The high strength, high modulus filaments have this type of development. Carbon and boron fibers developed for aircraft usage and now in the early stage of flight testing in subsonic and low supersonic aircraft have found commercial applications in such diversified fields as sports equipment and molded gears. These uses require only moderate temperature resistant matrices to be efficient. Projected uses in the SST will require matrices with long-time high-temperature capability. In addition, the attention to design detail necessary for the required efficiency will lead to a large increase in knowledge of the theory and practice of composite structure. This additional knowledge will allow the recycling of use of the material in commercial and advanced aircraft. These uses will no longer be restricted to low-temperature applications but may be used on high-temperature military aircraft, spacecraft, and other commercial supersonic aircraft.

These materials should find numerous civil and mechanical engineering applications as the manufacturing technology is improved during SST development. There should be a direct parallel with the development of adhesive bonded aluminum sandwich materials in military products and its acceptance in construction of mobile homes, school buildings, and multi-storied curtain wall building construction. High-temperature materials have advantages in fire walls, structural walls, doors and partitions in moderate temperature (450° - 700°) baking ovens, heat treatment facilities, and specialized tooling.

COMPOSITE MATERIALS

Technology: Further development of boron and carbon filament high strength composite materials will be carried out during the structural development of materials for the production SST. This will be done by improving the knowledge of design and analysis of these unique materials and in improving the matrix materials for encapsulating the high strength filaments. Through the use of composite materials, light weight wing skin materials, control surfaces, and stiffened body panels will be designed and fabricated.

Applications: This type of material may be used in structures needing, or benefiting from, high strength-to-weight ratio –

Airplane Flap Made of High-Strength Composite Materials

such as: commercial and military aircraft, building trusses and beams, bridge trusses, bailey bridges, prefab structures, road machinery, trailers and trucks, cranes, boats, trains, and buses. Composite materials have been used in small quantities in small boats, gears, golf club shafts, and other sporting equipment.

HIGH TEMPERATURE SOLID LUBRICANTS

Technology: Lubricants suitable for a wide range of temperatures ranging from sub-zero to 500°F will be developed for metal-to-metal and elastomer-to-metal contact. The SST with its high content of titanium fasteners and structural joints requires dry lubricants to prevent galling action and seizure problems. With the long structural life of the titanium airplane, the lubricant requires trouble free, consistent performance throughout the life of the part.

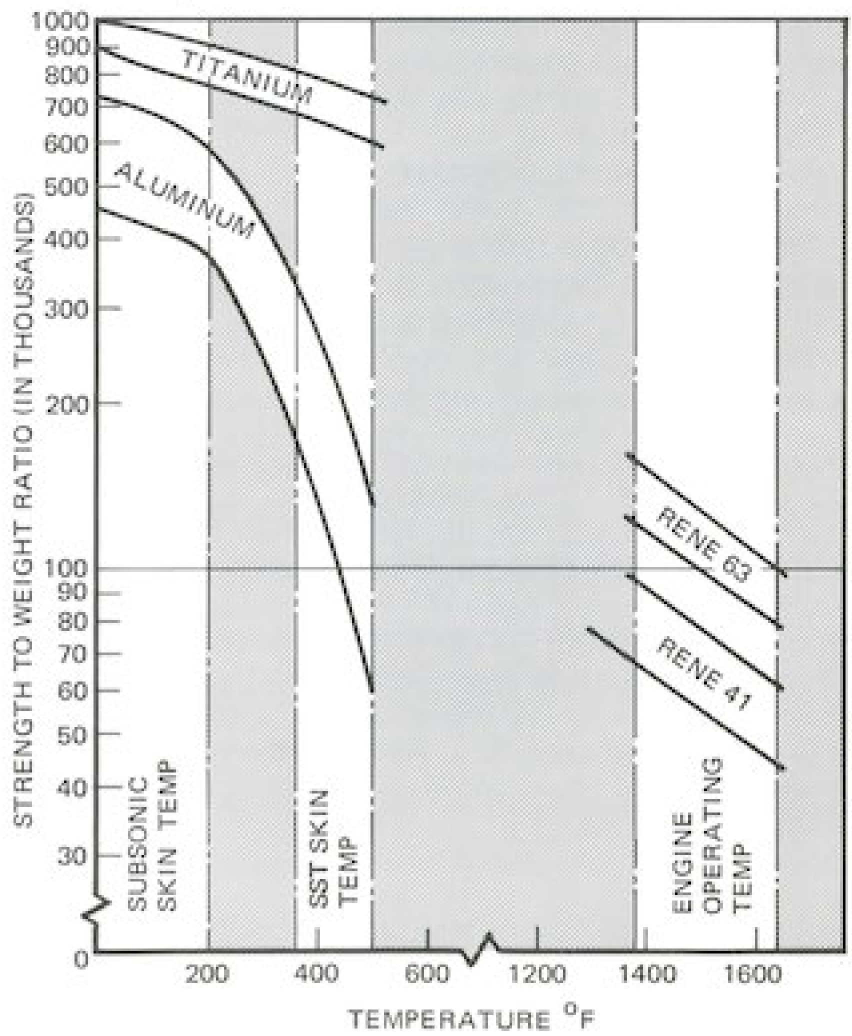
Applications: Long life solid dry lubricants are applicable to all mechanical systems where direct physical contact either through rubbing, rolling, sliding, impacting, or pivoting action takes place. Applications will apply to all industries for new equipment, for maintenance and repair functions, and equipment overhauls.

COMPOSITE SEALS

Technology: Efficient aircraft performance requires aerodynamic seals between movable components at the SST operating temperatures. At 450°F elastomeric seals used previously have excessively high wear rates and creep or harden, thus losing their sealing ability. This problem has been solved by the development of a new family of composite seals. Improved high temperature elastomers enable the seals to conform to surface irregularities while metallic spring elements support the elastomer to maintain sealing pressure. Application of glass or teflon fabrics to the seal provides wear resistance.

Applications: These seals are applicable to any piece of equipment operating at elevated temperatures, such as ovens or chemical process units in which doors or other movable sections must be sealed during operation.

Temperature Ranges and Comparative Properties for SST Materials



TI 6-2-4-2 HIGH-TEMPERATURE TITANIUM ALLOY

Technology: When a laboratory development composition containing 6% Al – 2% Sn – 4% Zr – 2% Mo appeared attractive for GE4 compressor components, the alloy was scaled up to production size ingots and full scale GE4 compressor disks, rotor blades, and stator vanes were produced and evaluated. Its high temperature properties resulted in a considerable weight savings since higher density nickel-base alloys were the alternative to Ti 6-2-4-2.

Applications: Since its, application in the SST engine, Ti 6-2-4-2 has been applied to several other advanced commercial and military engines both by General Electric and other engine manufacturers. The alloy is now the first choice titanium alloy for application at temperatures above 400 or 500°F, based on its very successful scaleup and engine performance in the SST. Moreover, the alloy also is now a standard commercial grade available from all titanium vendors.

NICKEL

Technology: Three new nickel-base alloys of the Rene series, Rene 63, Rene 80, and Rene 95, have been developed for the SST program. Rene 63 is a sheet alloy for use in highly stressed jet engine ducts and frames fabricated by welding. This alloy offers a significant stress rupture advantage over Rene 41 at 1700°F. Its use will result in a weight savings of approximately 35 percent for these parts. Rene 80 is a cast alloy which will provide long life turbine blades for the SST. Without sacrificing high-temperature strength, Rene 80 offers vastly improved hot corrosion resistance and resistance to thermal cycling over competing alloys. Rene 95 has been developed for use as turbine and compressor disks. This alloy is expected to offer a major strength advantage over others available. Its use will result in a weight savings of 200 pounds per engine.

Applications: All these alloys will be used in newly developed jet engines. Rene 80 has already gained acceptance and service experience in aircraft engines including the J79, TF34, T58 and CF6. Its high corrosion resistance also makes Rene 80 a likely candidate for shipboard and land based turbines. Rene 63 is the best of several alloys being evaluated for firebox construction in home heating plants. Compressor and turbine rotor material for the F101 and J97-J1A5 engines will be Rene 95. Its very high strength at elevated temperatures makes its application in the petroleum, chemical, and metal-working industries probable.

TD NICKEL-CHROMIUM FOR HOT COMPONENTS

Technology: The flame-holders and spraybars of the afterburner of the SST engine operate at temperatures in excess of 1800°F. To provide the life needed for SST production engines, TD nickel-chromium was chosen. The SST engine has supported the development of scaleup of the alloy as sheet in production quantities, joint, coating, and development of a process for the production of tubing.

As a result, the vital hot afterburner components have operated successfully in SST engine tests.

Applications: TD nickel-chromium material uses will be those consistent with the requirement of a metal with high strength in the 1800°F regime. Possible applications of the technology of the usage of TD nickel-chromium include the chemical processing industry, smelting of ores, steel industry, automotive exhausts and air pollution control, glass industry, and refractories.

TD nickel-chromium will be utilized in the F101 engine in various low stressed components in the hottest temperature zones. Its unique high temperature properties make it applicable to all future engines where extremely high combustion temperatures and limited cooling are inherent.

BETA PROCESSING

Technology: In order to fully utilize the many desirable properties of titanium, it was necessary to improve fracture toughness and stress corrosion resistance, particularly in thick sections.

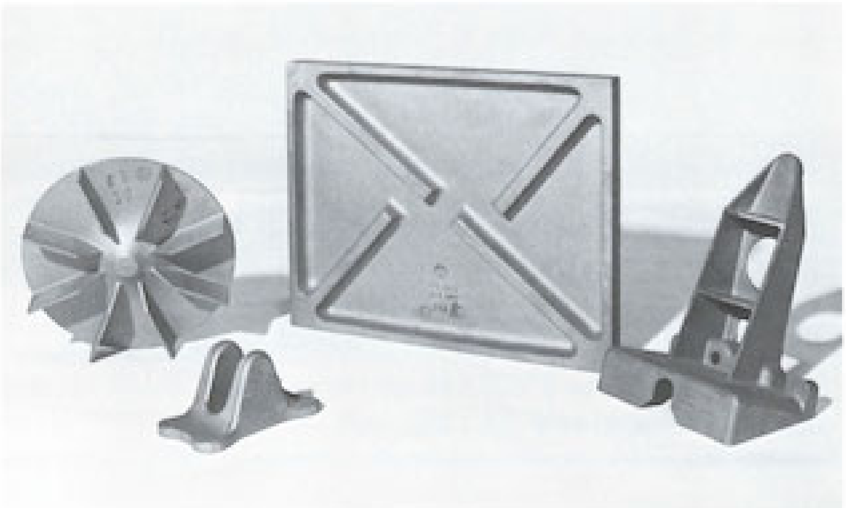
This goal was achieved through development and improvement of techniques for rolling and forging thick sections at elevated temperatures which encompass the range at which the "Beta" form of titanium predominates. Exploitation of these "Beta Processing" techniques improves the fracture toughness and stress corrosion resistance of the resultant product by as much as 50 percent, while allowing the forging of more complex shapes.

Applications: Improved fracture toughness and stress corrosion resistance will be beneficial in many titanium structures in the form of weight savings, simplified design, improved reliability, and longer life. This technology is presently being applied in new aircraft such as the F-14 and F-15 and jet engines.

TITANIUM CASTINGS

Technology: Titanium is of great interest in design because of its high strength at elevated temperature, light weight, and corrosion resistance. Because of its extreme reactivity in the molten state, it has never been cast into complex shapes. The SST has supported efforts to develop precision casting technology for titanium alloys. As a result, the SST will be the first aircraft to utilize a significant number of precision titanium castings in several areas.

SST Titanium Casting Development



Applications: This technology will provide a great amount of weight reduction in future aircraft of all kinds. There will also be thousands of applications of titanium precision castings in many industries, including dairy, food, chemical, medical, marine, and transportation.

ELEVATED TEMPERATURE TITANIUM HONEYCOMB SANDWICH

Technology: Titanium's high strength/density ratio and the high structural efficiency of honeycomb panels have spurred the development of titanium honeycomb sandwich. Two methods of fabrication have been developed for SST applications: aluminum brazing and polyimide adhesive bonding, with the former used as primary structure and the latter in secondary structure. These panels offer high strength and stiffness with low weight for efficient operation at the elevated temperature of the SST.

The aluminum brazed, titanium honeycomb panel process was developed on an FAA sponsored research program at Aeronca Inc.

Applications: Engine manufacturers are presently evaluating aluminum brazed titanium honeycomb sandwich for use as engine cases. Significant advances in state-of-the-art for cleaning, processing, and inspection will enhance wider use of brazed honeycomb and the application of aluminum brazing for joining other forms of titanium hardware.

HIGH TEMPERATURE PACKAGING DESIGN FOR ENGINE CONTROLS

Technology: Advanced concepts for high-temperature long-life packaging design have been developed for the SST electrical controls. These advancements include heat transfer improvement by improved encapsulation materials and techniques, improved thermal design of electrical sub-assemblies, and improved capability to transfer internal heat to the cooling media (fuel). They also include improved heat isolation capability in the form of titanium mounting with heat isolation barriers and lightweight insulation.

Applications: The operating temperatures around the engine are similar to those around furnaces, refineries, and industrial heating systems. This technique can be used in operation of high temperature exhaust systems and pyrometrics for closer control of combustion to reduce pollution and improve efficiency.

OXIDATION RESISTANT COATINGS

Technology: The turbine blades and vanes of the SST engine operate at some of the highest temperatures experienced in long life-expectancy engines. These complex, air-cooled components are subject to oxidation and erosion effects which might seriously affect their performance in fatigue thermal cycling or steady stress. These unique requirements of the GE4 gave impetus to the development of coating processes for applying Aluminum-base coatings to both internal and external surfaces of blades and vanes. The coatings which have been developed promise to markedly increase blade and vane service life.

Applications: The severe temperature and life requirements of the SST have yielded protective coatings that are also being applied in the TF39, CF6, TF34, F101 and other advanced engines. These coatings also have been found to improve the life of turbines used for industrial and marine applications where hot corrosion is a major problem.

COMPACT BEARINGS AND BUSHINGS

Technology: Improved bearing lining material is available for use on the SST due to the development of Molalloy. This is a powder metallurgical material formed by compacting a mixture of high temperature lubricants and refractory metals under high temperature and pressure. Bearings made using Molalloy offer superior performance in high temperature and high contamination areas.

Applications: Compact bearings are currently being tested for possible applications on the 737 and 747 in areas where conventional bearings were unsatisfactory due to temperature or contamination. Molalloy is also being used as brushes for electrical motors operating at high temperatures in a vacuum where graphite is unsuitable.

HIGH TEMPERATURE FUEL TANK SEALANTS

Technology: Polymeric materials developed for fuel tank sealants on the SST have long life, the ability to operate within a wide range of temperatures from subzero to +500°F, remain pliable within these temperatures, and are not affected by exposure to various liquids and gases.

Applications: Many of the sealants and adhesives in common use today are a direct result of research and development work necessary for missiles, rockets, and subsonic commercial and military aircraft. The stringent requirements imposed by the SST for polymer materials will provide a family of sealants applicable to industrial and commercial purposes in high temperature conditions.

HIGH TEMPERATURE RADOME

Technology: Radomes with stringent material and predictable long term characteristics will be used on the SST aircraft. Radome materials with high dielectric strength, microwave transmissibility, ability to tolerate a wide range of temperatures and withstand impact of rain, hailstones, and lightning strikes will be required.

Applications: Advanced radome material applications can be transferred directly to all high speed aircraft, high temperature space probes, and for commercial uses such as components for microwave ovens, autoclaves, and dielectric heating systems.

MANUFACTURING DEVELOPMENT

VACUUM CREEP FORMING

Technology: Vacuum creep forming uses fluid pressure on titanium assemblies held at elevated temperature to generate the proper contours. A die is prepared to the final contour desired. The die also contains the heating elements to maintain the elevated temperature required. The part is placed on the die; covered with insulation to help maintain uniform temperatures on heating; a flexible membrane is placed over the part and the insulation; an inert atmosphere replaces the air surrounding the part so that the titanium remains uncontaminated; and then a vacuum is drawn to force the part into conformity with the die. After the part has completed the heat cycle, in which temperatures up to 1500°F are achieved, it will retain the shape of the die on cooling to ambient temperatures.

The process is applicable to the shaping of complex parts including flat, tapered, welded, or sculptured panels which may require either simple or compound contours. Parts ranging from 0.020 inch up to 2 inches thick have been produced by this method, including the forming of a one-inch thick panel to a radius of 30 inches. Vacuum creep forming will be used in many applications on the SST including the forming of wing skins and leading edges to simple and compound contours.

As-received plate from the mill has previously had waviness conditions as great as 3/8 inch in one foot of length. This required a wasteful and costly surface machining operation to reduce the surface to reasonable flatness before the material could be handled in conventional vacuum chucks for further, more precise machining operations. Vacuum chucks require the flatness tolerance to be about ±0.025 inch. An industry-wide effort was initiated in April 1969 by the AIA MC-52 Ad Hoc Committee. As a result, vacuum-creep-forming techniques are now available to process flat stock before shipping it from the mill. One producer can now furnish "flat" titanium plates up to 35 feet in length; and another producer has designed and is building a facility to provide a similar capability in the near future.

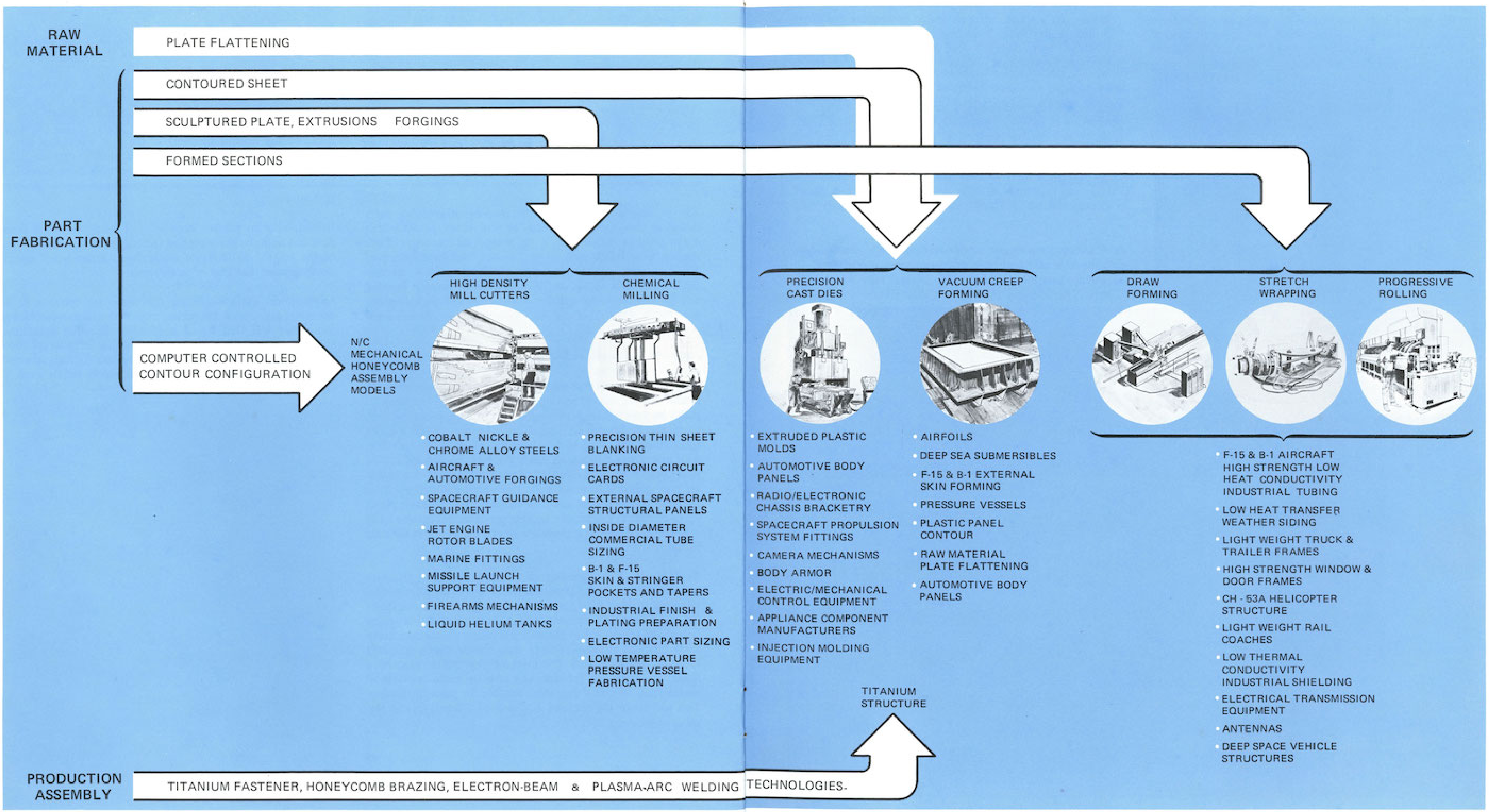
Applications: The capability of the mills to deliver titanium plate of the required flatness for vacuum chucking in the conventional manner is of great value. Wastage of time and material to pre-machine the plate surface is eliminated. Flattening operations conducted at the mill will utilize the vacuum creep form facilities more effectively than similar widely-scattered facilities maintained by the users of the mill stocks. As a result, titanium mill products can now be made available to commercial users in a condition suitable for parts fabrication. This will make the material available to a much greater segment of industry.

IMPROVED CUTTERS AND DRILLS

Technology: Techniques for machining of titanium have been improved greatly by recent investigations. For example, in one study it was found that reducing the edge-margin on the flute of a drill from 0.050 inch to 0.010 inch increased tool life in drilling of titanium assemblies by more than seven times for a particular manufacturing sequence. In another study, a new endmill cutter was developed utilizing helical carbide inserts which can be positioned and clamped in the cutter body without brazing or subsequent machining. The inserts may be resharpened and repositioned in the body of the cutter to maintain the original diameter of the tool. Numerous similar improvements now make it possible to machine titanium using metal removal rates ten times greater than rates previously feasible, and at the same time to provide an improvement in part quality.

In fact, with the present knowledge of the properties of titanium, and with the materials and techniques of the current state of the art, the difficulty of machining titanium is not significantly greater than that of many steels.

Applications: Since machining operations are common to all the metal fabrication industries, improved titanium machining techniques will find broad application in other industries. Some applications include the manufacture of internal combustion engines, breech and bolt mechanisms for high-powered rifles, fittings, bracketry, pumps, and valves widely used in chemical plants and marine applications.


RAW MATERIAL
PLATE FLATTENING
CONTOURED SHEET
SCULPTURED PLATE, EXTRUSIONS FORGINGS
FORMED SECTIONS
PART FABRICATION
COMPUTER CONTROLLED CONTOUR CONFIGURATION
N/C MECHANICAL HONEYCOMB ASSEMBLY MODELS
HIGH DENSITY MILL CUTTERS
CHEMICAL MILLING
PRECISION CAST DIES
VACUUM CREEP FORMING
DRAW FORMING
STRETCH WRAPPING
PROGRESSIVE ROLLING
· COBALT NICKLE & CHROME ALLOY STEELS
· AIRCRAFT & AUTOMOTIVE FORGINGS
· SPACECRAFT GUIDANCE EQUIPMENT
· JET ENGINE ROTOR BLADES
· MARINE FITTINGS
· MISSILE LAUNCH SUPPORT EQUIPMENT
· FIREARMS MECHANISMS
· LIQUID HELIUM TANKS
· PRECISION THIN SHEET BLANKING
· ELECTRONIC CIRCUIT CARDS
· EXTERNAL SPACECRAFT STRUCTURAL PANELS
· INSIDE DIAMETER COMMERCIAL TUBE SIZING
· B-1 & F-15 SKIN & STRINGER POCKETS AND TAPERS
· INDUSTRIAL FINISH & PLATING PREPARATION
· ELECTRONIC PART SIZING
· LOW TEMPERATURE PRESSURE VESSEL FABRICATION
· EXTRUDED PLASTIC MOLDS
· AUTOMOTIVE BODY PANELS
· RADIO/ELECTRONIC CHASSIS BRACKETRY
· SPACECRAFT PROPULSION SYSTEM FITTINGS
· CAMERA MECHANISMS
· BODY ARMOR
· ELECTRIC/MECHANICAL CONTROL EQUIPMENT
· APPLIANCE COMPONENT MANUFACTURERS
· INJECTION MOLDING EQUIPMENT
· AIRFOILS
· DEEP SEA SUBMERSIBLES
· F-15 & B-1 EXTERNAL SKIN FORMING
· PRESSURE VESSELS
· PLASTIC PANEL CONTOUR
· RAW MATERIAL PLATE FLATTENING
· AUTOMOTIVE BODY PANELS
· F-15 & B-1 AIRCRAFT HIGH STRENGTH LOW HEAT CONDUCTIVITY INDUSTRIAL TUBING
· LOW HEAT TRANSFER WEATHER SIDING
· LIGHT WEIGHT TRUCK & TRAILER FRAMES
· HIGH STRENGTH WINDOW & DOOR FRAMES
· CH - 53A HELICOPTER STRUCTURE
· LIGHT WEIGHT RAIL COACHES
· LOW THERMAL CONDUCTIVITY INDUSTRIAL SHIELDING
· ELECTRICAL TRANSMISSION EQUIPMENT
· ANTENNAS
· DEEP SPACE VEHICLE STRUCTURES
TITANIUM STRUCTURE
PRODUCTION ASSEMBLY
TITANIUM FASTENER, HONEYCOMB BRAZING, ELECTRON-BEAM & PLASMA-ARC WELDING TECHNOLOGIES.

PRECISION CAST DIES

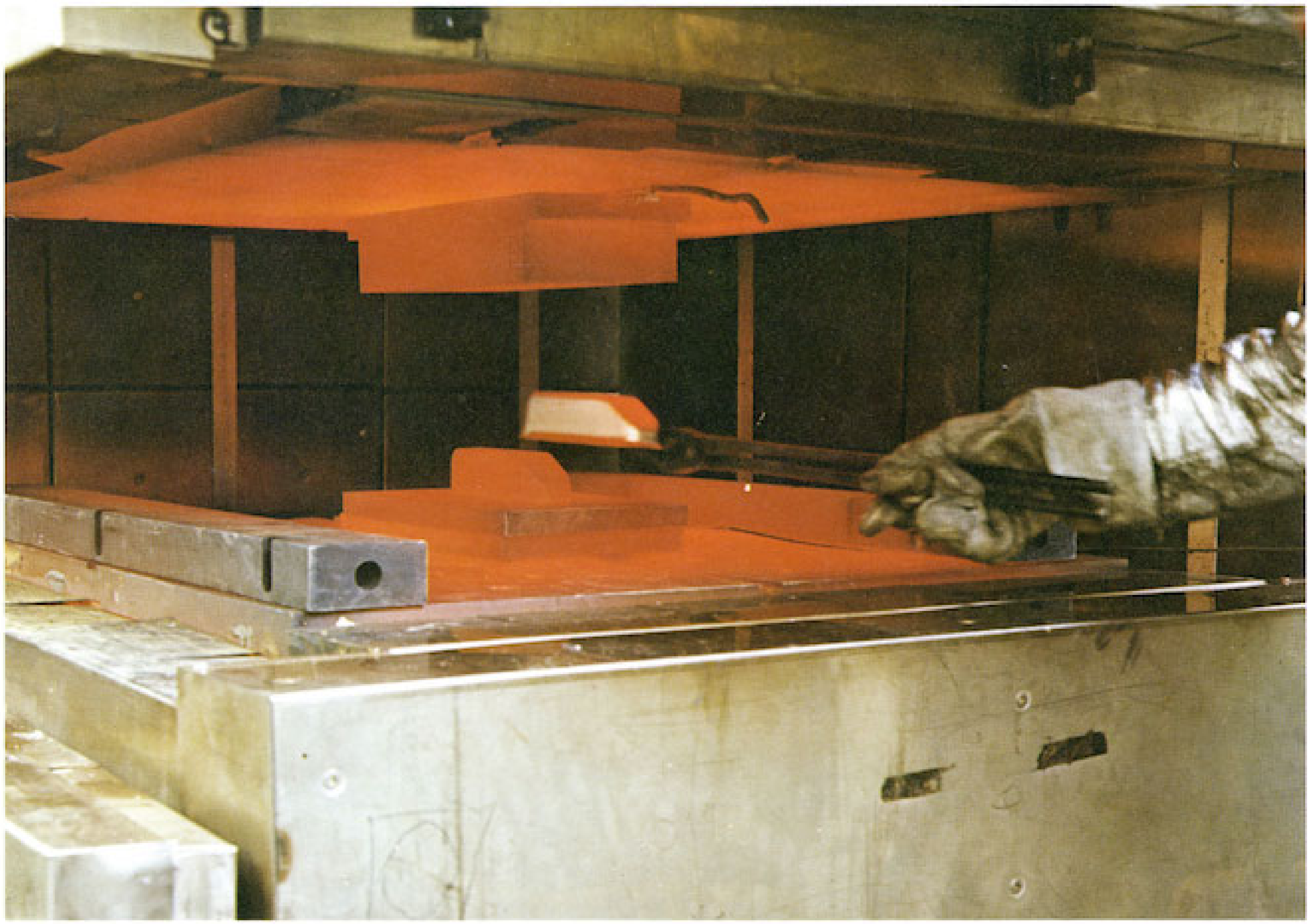
Technology: Because titanium can best be formed at elevated temperatures, production of titanium airframe structure would normally require large numbers of hot sizing dies made from stainless tool steels. Producing these dies by conventional machining processes would be extremely time consuming and costly. To overcome this problem, a new technique was developed for precision casting of dies to close tolerances. Only hand cleaning on the working surfaces and a small amount of machining on certain simple planar surfaces is required.

Applications: The precision casting process can be applied to producing dies for any commercial or military program requiring the use of elevated temperature for forming or sizing of detail parts.

New die-casting techniques and improvements in part-heating techniques have effectively increased capability to form titanium. As a result, airframe design options are less restrictive and permit using conventional facilities with relatively light-weight and nominally sized dies. These can be exploited with dramatic reduction in costs.

Forming process technology improvements will benefit the production of military equipment, i.e., body-contoured armor, helmets, and combat vehicles, as well as consumer products, including gas and liquid vessels, tanks and containers, large diameter ducts, tubes and pipes, shipping containers, and automobile mufflers.

Precision Cast Heated Forming Die



DRAW FORMING AND STRETCH STRAIGHTENING

Technology: Various metal parts in the shape of tees, zees, hats, angles, and channels have been used in every airframe design from the B-17 through the 747. The SST also uses these same members in the monocoque body structure; but rather than the cold-worked or extruded aluminum sections which rarely exceeded 24 feet in length, the SST will use titanium members in lengths up to 40 feet. These can be formed in a three step operation: first the shape is initiated by incremental forming at room temperature using a brake press; the preformed section is then draw-formed to net size in a single-stage operation at a temperature of 1300 to 1400°F; and the part is finally stretch-straightened at 1250°F. A 40 foot Zee of 0.090 gage titanium was an industry "first" in the last quarter of 1969.

Applications: Parts in these various shapes are standard items of construction in many applications requiring strength combined with light weight. With titanium forming techniques reduced to commercial practice, the unique advantages of titanium are now available to potential users for applications outside the aircraft industry.

PROGRESSIVE ROLLING OF TITANIUM SECTIONS

Technology: Titanium sections with tight bend-radii can be formed in one continuous operation from the raw material coil to the finished section, using 6Al-4V titanium or similar alloys. The process uses elevated temperatures maintained with banks of quartz lamps. Bend radii of 1.5 times the thickness of the raw material are achieved, with mold-line tolerances of ±0.010 inches and angular tolerances of ±1 degree. This process, best suited to the production of large quantities of standardized parts, is a major accomplishment in achieving a cost-effective all-titanium airframe.

Applications: The ability to produce large quantities of standard parts makes this a useful process for the product. Possible users include the automotive industry, producers of heating equipment, and manufacturers of structural parts for specialized construction.

RESISTANCE, INDUCTION, AND RADIANT HEATING OF PARTS

Technology: Resistance heating, induction heating, and radiant heating have certain advantages in applying heat to titanium parts in high-temperature forming processes. Resistance heating is an excellent means to achieve elevated temperatures in sections such as hats, angles, zees, tees, etc., for stretch forming or for stretch-straightening. Induction heating, on the other hand, is advantageously applied to draw-forming operations; here, the preformed section is simply passed through the induction heating zone as it passes into the jaws of the die. Radiant heating has proved to be a versatile means of applying heat to a wide variety of parts such as those subjected to progressive rolling operations. Radiant energy is also useful to heat large skins, as in stretch forming, for example.

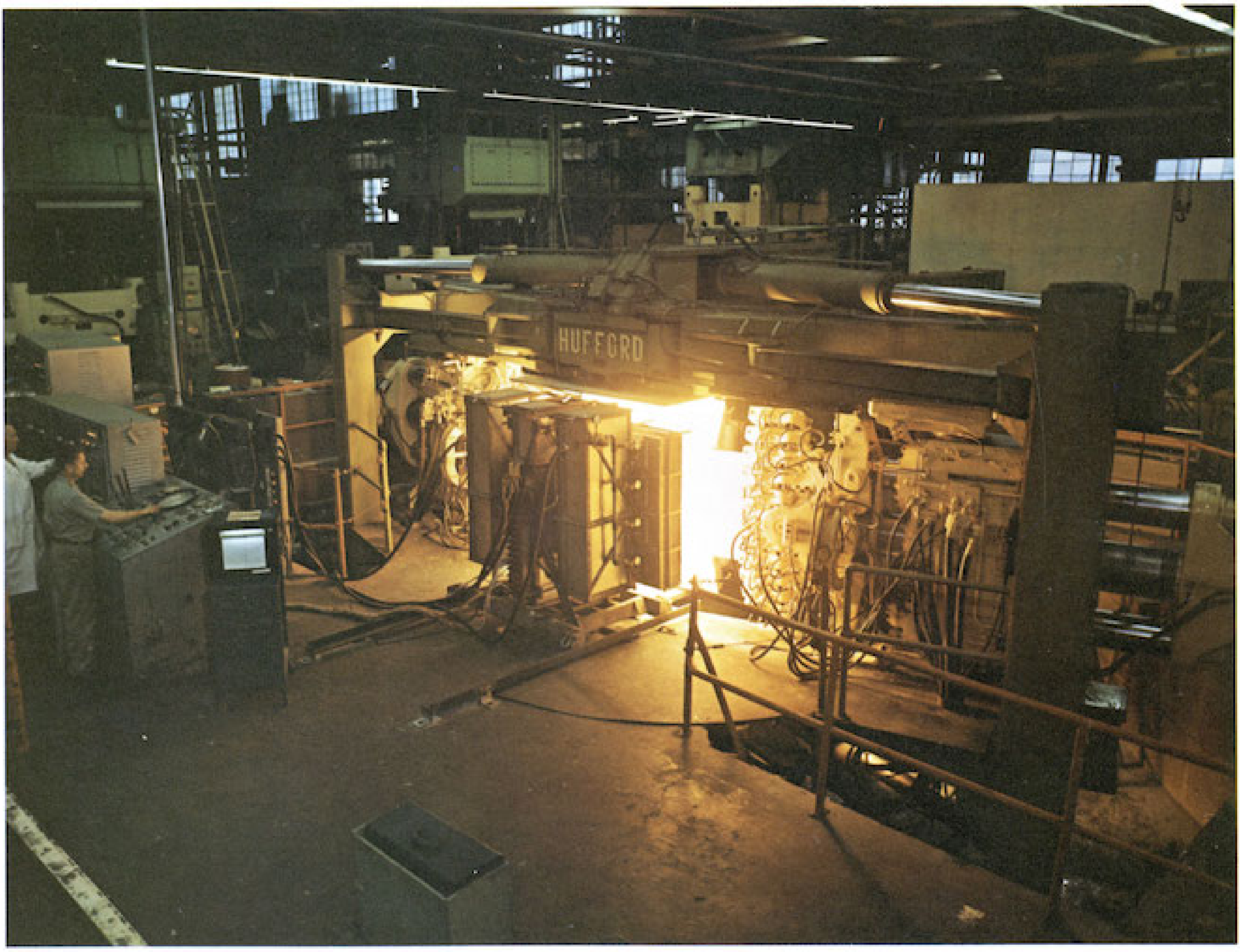
Special techniques have been developed for these heating methods to make it possible to convert standard presses for stretch forming and joggling (originally designed for the room temperature forming of aluminum) to the forming of titanium at elevated temperatures. Innovations which made the conversions possible include the development of an electrically nonconductive abrasion-resistant thermal barrier composed of aluminum and titanium oxides which isolate and protect the die surfaces from the resistance-heated workpiece. The oxide coating, which must be flame sprayed onto the die surfaces, also serves to prevent heat losses from the workpiece to the forming die, and to lubricate the interface between die and part to prevent galling.

Hot Rolling of Titanium Parts

Resistance heating also proves useful in making minor changes to the contour of the frames in the monocoque structure which vary slightly from station to station as a consequence of the "coke bottle" shape of the SST fuselage. The basic frames are built on a nominal number of stretch-form blocks, and are then brought into their widely varying final contours by means of relatively inexpensive contour-correction fixtures that incorporate resistance heating.

Applications: The specialized techniques for use of these heating methods can be applied to materials other than titanium which can utilize elevated temperatures to improve forming capability.

Hot Stretch Forming of Titanium Skins

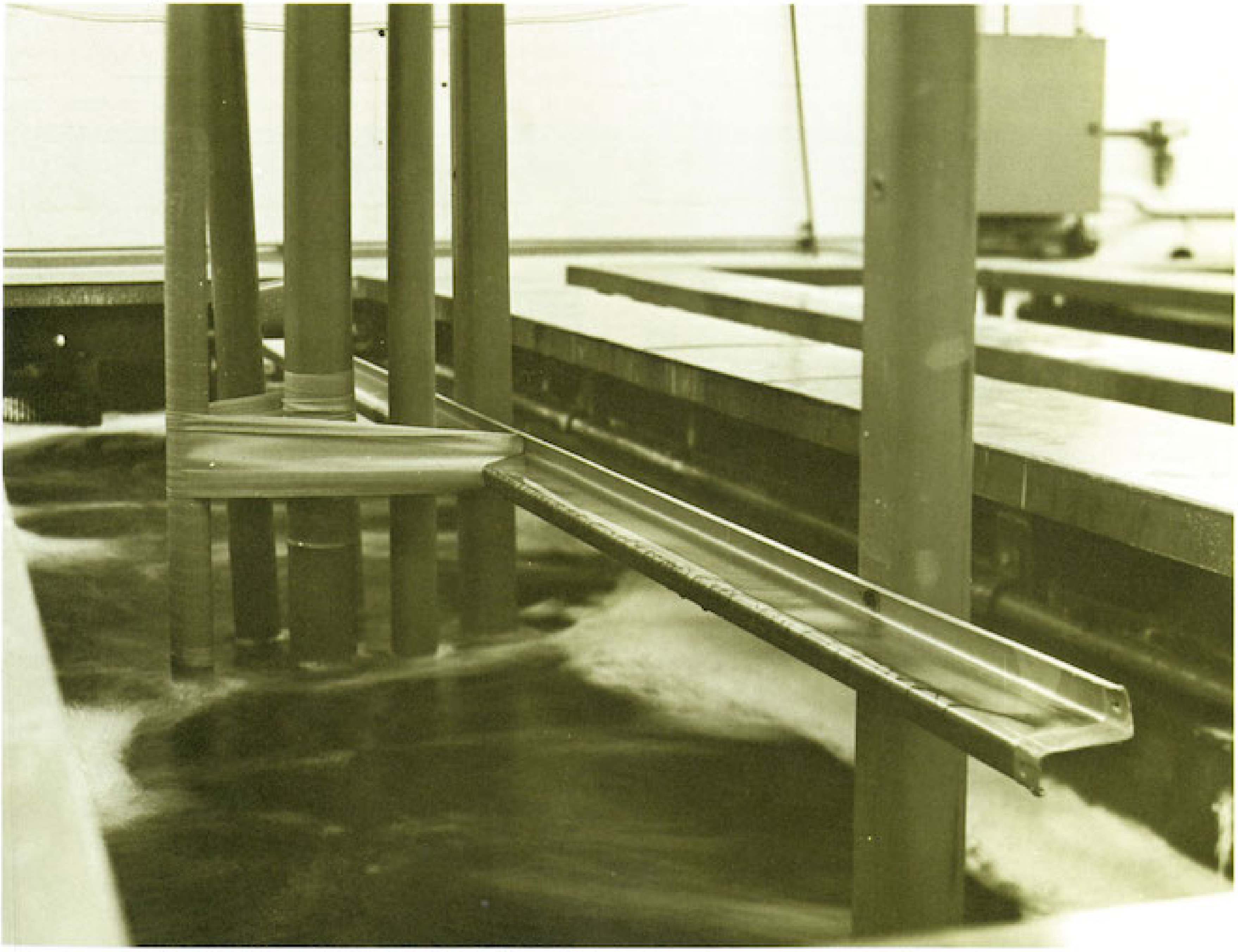


CHEMICAL MILLING OF TITANIUM

Technology: Chemical milling processes have been developed as a complementary process to machining. The chemical milling process permits tapering and pocketing of large skins with a modest investment in facilities, replacing very costly machine tools. Parts can be chemically milled to close tolerances as a follow-up to forming, welding, or heat-treating operations. The process does not stress the workpiece, so thin parts are not distorted. All surfaces of parts can be processed at one time. Chemical milling will generally improve the surface of as-received titanium for subsequent operations by removing micro-cracks, or oxygen-embrittled surface layers or the alpha case layer which complicates machining operations. Standard gage titanium can be reduced overall to a special required thickness, and by this means avoid the cost of a special mill to produce the stock. The thickness variation of as-received stock can be reduced to provide parts with more favorable strength-to-weight ratios.

Applications: Chemical milling can be used in a broad range of industrial applications. The application of the process to titanium is not unique, but does broaden the technological base upon which many industrial processes depend. Its application to the forming of tapers is especially interesting because it performs in a unique manner which cannot be duplicated by mechanical removal of excess metal.

Progressive Strip Chem-Milling of Titanium to Produce Tapered Parts



A direct commercial usage of the above process is currently being investigated for the manufacture of cameras. The high strength and toughness of titanium and its low thermal conductivity makes it highly competitive with aluminum or magnesium in camera bodies, lens retainers, shutters, and other mechanisms. Chemical milling now allows the efficient precision machining of titanium for the complex shapes of cases or the thin foils of focal plane or leaf shutters. This application also leads to use in other portable equipment where ruggedness and light weight are coupled with intricate mechanisms.

LIGHT-WEIGHT MASTER AND ASSEMBLY MODELS

Technology: The many complex contours which are required to shape aerodynamic and other aircraft surfaces are computed or developed from design drawings. These are then converted to surfaces, or models, which can be used to form or check the desired contours of the many production assemblies that comprise the final aircraft shape. These models have traditionally been fabricated from plaster.

A dramatic improvement in model fabrication developed for use on the SST uses very low density aluminum honeycomb material coated with an extrudable low-density epoxy-base foam. The foam is shaped to final contour using numerical-control machining techniques. The models are extremely stable, strong, and lightweight. These properties provide the following benefits: accuracy of .0025 inch can be achieved on the machined contour and scribed lines which then remain unaffected by the environment; handling is simplified; and storage requirements are reduced. Initial cost of these models is 1/2 that of plaster models; the weight 2/3 less; and can be stored in 1/3 the space required for plaster models because they can be stored upright.

Applications: This process has direct application in the manufacture of the complex shapes of automobile bodies, boat hulls, sheet metal ducts for heating and air conditioning plants, and fiberglas and other plastic parts for many consumer products.

Riveting of Titanium Structure

RIVETING

Technology: Advancements in riveting of titanium include the development of a procedure to drive fatigue-resistant rivets, and the development of a titanium alloy which permits hand driving of high performance rivets.

"Fatigue-resistant riveting" is an installation technique in which the rivet is expanded radially during the "upset" process to a diameter greater than that of the drilled hole. The radial compressive stress developed in the material around the rivet is instrumental in achieving longer fatigue life in the structure so joined. In this process it is necessary to apply high squeeze forces to the parts to be joined, and clamp force must be applied and controlled separately from the squeeze force applied to the rivet. Cavity dies are used to limit plastic deformation of the rivet button to aid in generating the high squeeze force necessary to this process.

Beta III titanium alloy rivets possess exceptional properties that combine ease of fabrication with unusual toughness and strength. The Beta III alloy can be cold-formed quite easily. This permits hand driving of rivets of this material. Subsequent heat treatment will develop strengths up to 200,000 psi in the part which will also show great toughness, stability in elevated temperature service, and resistance to stress-corrosion cracking. These rivets will be one of the principal fastener materials used on the SST and represent the first production use of the Beta III alloy.

Applications: Riveting is a common method of joining metal parts and the availability of good riveting methods is a fundamental requirement for the use of titanium in many applications. The development of squeeze riveting and the use of the Beta III rivet provides fastening processes that make titanium a natural selection for high-temperature high-strength sheet metal applications.

WELDING

Technology: A "complexity factor," which relates the difficulty of welding titanium to the difficulty of performing the same welding operation on aluminum, permits meaningful estimates of titanium welding requirements based upon the broad experience of the aerospace industry with aluminum fabrication. This complexity factor has been reduced from approximately 4 in 1965 to about 1.7 in 1969 due principally to advancement of welding technology as a result of studies in support of the SST.

The refinement of automatic fusion welding facilities, equipment, and processes are exploited in SST assemblies constructed of titanium which, though large in size, are lightweight and cost effective. Examples of these refinements include:

- Precision alignment of electron beams.
- Precision electron beam focus control and measurements.
- Time defined linear slope on all weld functions.
- Advanced weld-seam tracking systems allowing use of inexpensive details and tooling.
- Reliable mechanized Plasma-Arc welding equipment.
- X-Ray equipment for the examination of inplace-welded tubing joints which permits inspection of a weld within the same restricted space required for the welding head.

Applications: Automatic equipment incorporating the improvements developed for the SST establish the welding process as an attractive alternative to mechanical fasteners in broad classes of applications. Welding can be economically applied to tube, pipe, and duct assembly for desalination plants, atomic reactors, submarine and ship plumbing; vehicles such as trains, busses, automobiles, rapid transit systems, hydrofoil boats; and in the textile, food, and chemical industries.

MORE THAN AN AIRPLANE

THE BOEING COMPANY COMMERCIAL AIRPLANE GROUP SUPERSONIC TRANSPORT DIVISION