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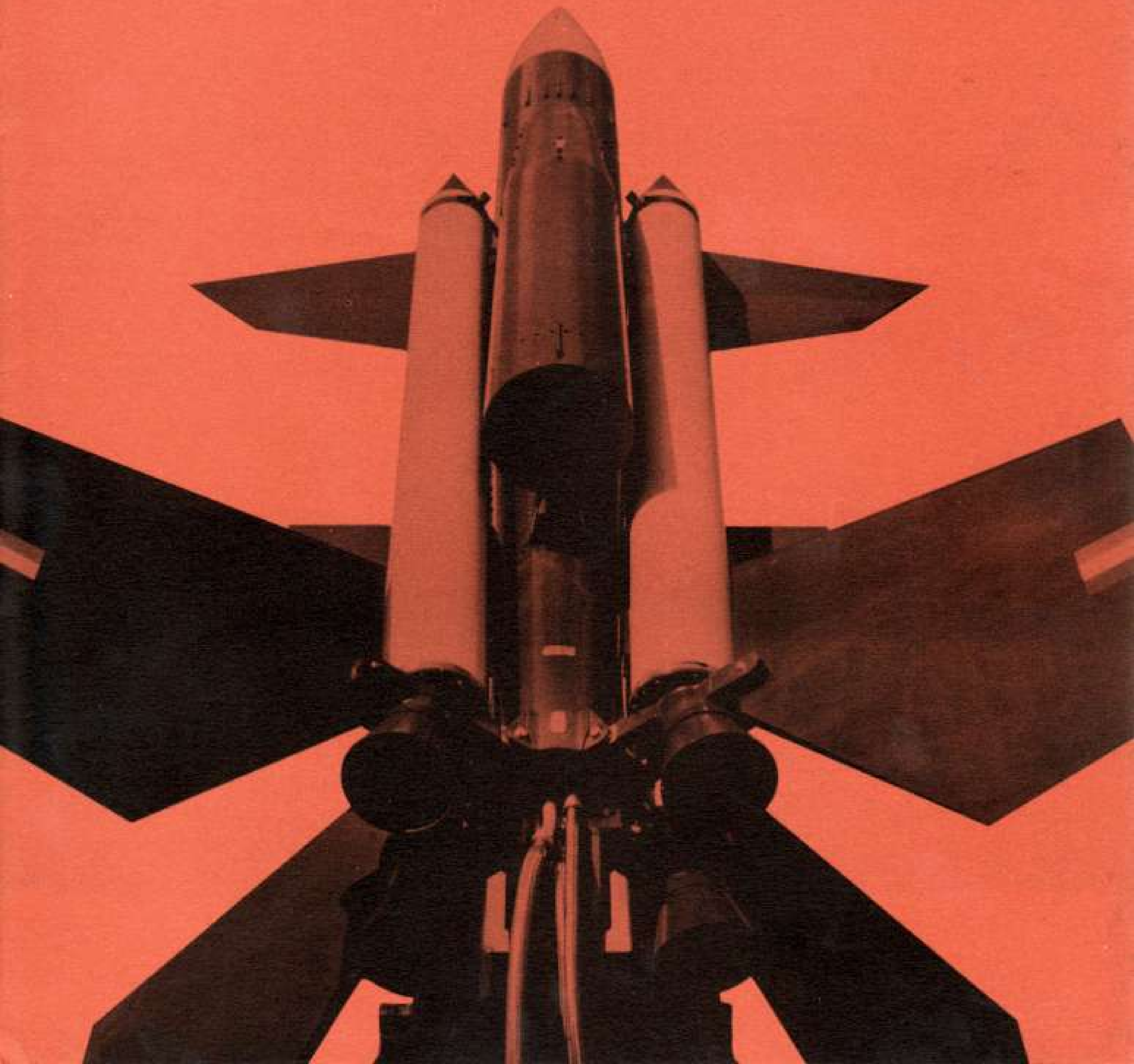
BLOODHOUND



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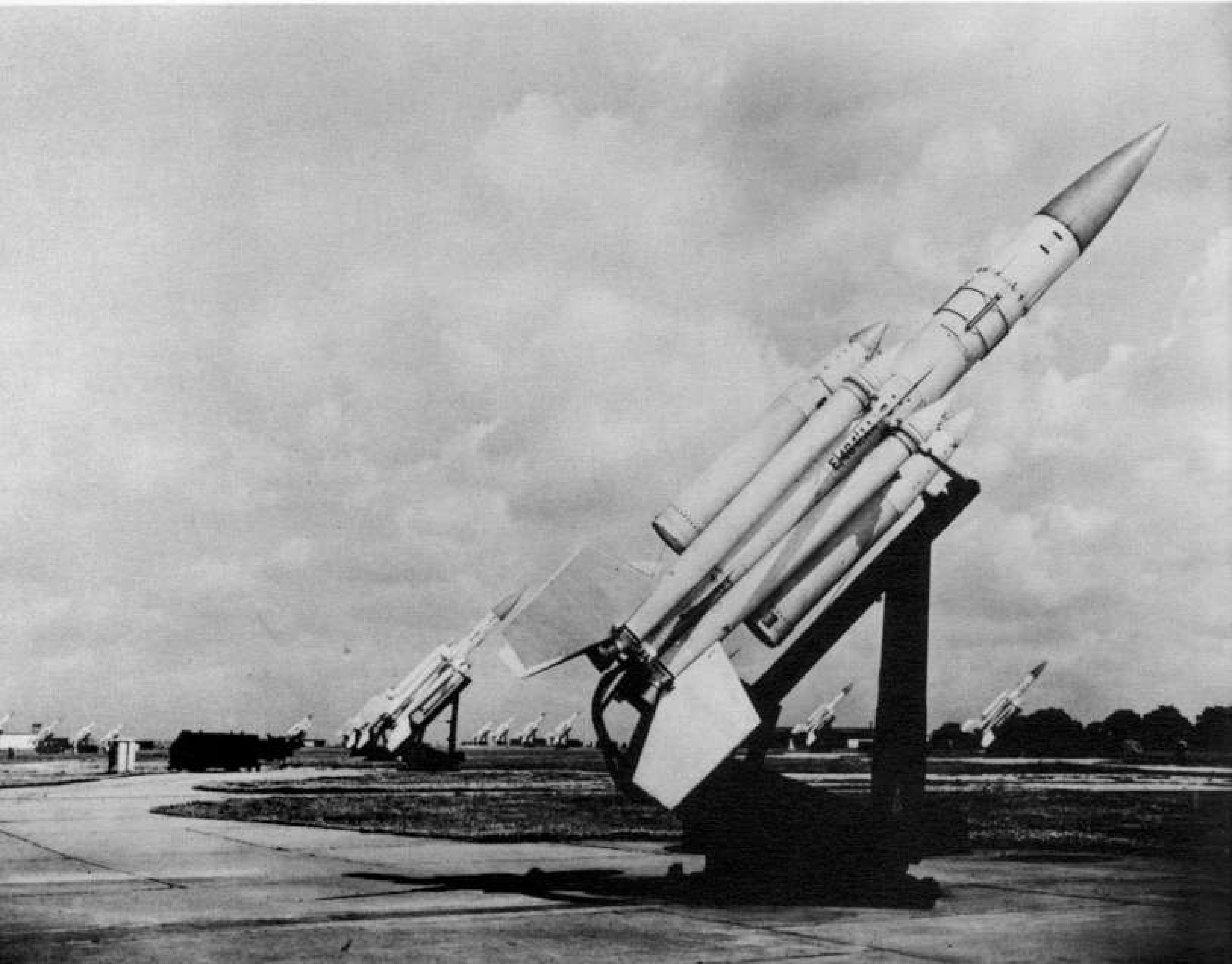


BLOODHOUND

By D. J. Farrar, O.B.E., M.A., F.R.Ae.S. Chief Engineer, Guided Weapons, Bristol Aircraft Limited.

With the announcement in July of a substantial order from Sweden for the Bristol/Ferranti *Bloodhound Mark 2* and with the decision of the Swiss Federal Council to recommend its adoption for the defence of Switzerland, the *Bloodhound* was clearly confirmed in its position as Europe's most important guided weapon system.

Bloodhound 2 is already on order for the British Royal Air Force, while the earlier *Mark 1* version is deployed in very considerable strength in the United Kingdom and has been adopted, on a smaller scale, by Sweden and Australia.

No other European missile system has gained acceptance on such a scale, and the decisions of the Swedish and Swiss authorities to adopt *Bloodhound 2* are particularly significant, as neither country is committed by external treaty obligations, and thus each could base its selection of defence equipment in the sole criterion of technical merit. Their choice is therefore a clear-cut vindication of the basic concept of the sophisticated *Bloodhound* system.

Many aspects of the Mark 2 *Bloodhound* surface-to-air missile system cannot yet be told. It is, of course, a direct development of the Mark 1 which has been in operational service with the RAF for the past three years. The intensive development programmes of the past few years are reflected in all-round improvement of performance, deriving chiefly from the adoption of continuous wave radar guidance in place of the pulsed radar system used in *Bloodhound 1*.

The adoption of CW radar guidance has not only enabled *Bloodhound's* operational range to be significantly increased, but also given it great lethality against all types of target from high altitude down to very low levels, even in the face of highly sophisticated electronic counter-meassures. The ground radar set developed for use in the Mark 2 system is, in fact, the most accurate and advanced in the world.

Bloodhound 2's efficacy against the low-flying attacker—hitherto the Achilles' heel of air defence—has been demonstrated during firing trials. Details released of one the many successful test flights already carried out revealed that it resulted in the interception and destruction, by an unarmed missile, of a fast jet target flying at less than 1,000 feet.

In the field of tactical control, other improvements have been made. The launch control post—the main operational link between the battle control centre and the missiles themselves—is built around a compact digital computer, with a consequent gain in speed of response and operational flexibility.

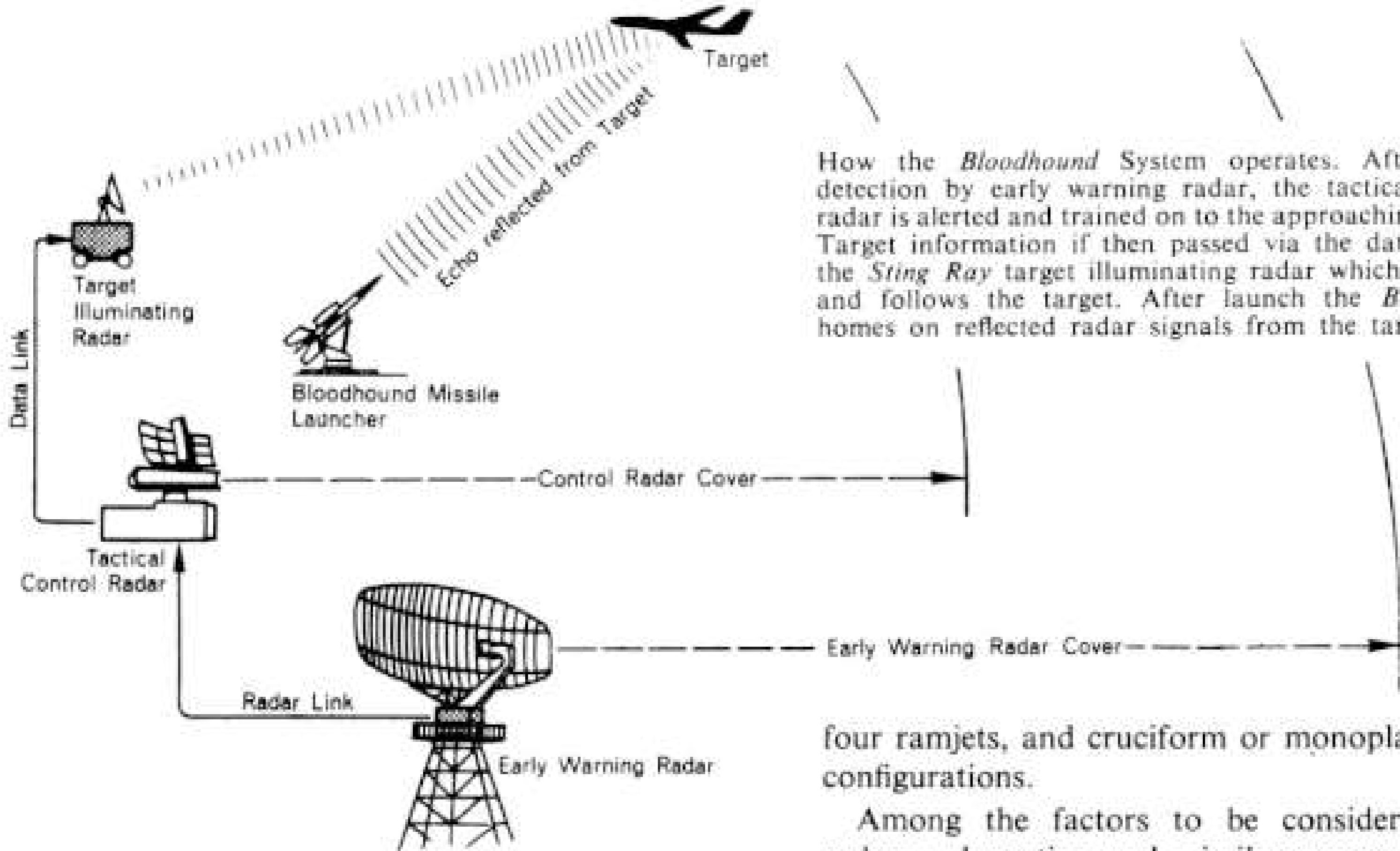
A new version of the Bristol Siddeley *Thor* ramjet gives the missile even better range and altitude performance; full advantage has been taken of recent technological advances, and of the experience gained with *Bloodhound 1*, to improve still further the efficiency, reliability, and serviceability of the weapon system as a whole. Fundamentally, however, the roots of its outstanding performance and reliability are to be found in features which have been basic to the design concept since its earliest days.

The most important of the general requirements behind the choice of a semi-active homing guidance system were those of high fire-power and the use of tracking radars which would not impose major radar development problems. To achieve long range, the guidance system had to be one that would permit much of the missile flight to be at high altitudes; for accuracy of interception, the use of homing was essential.

All these requirements were met by employing semi-active homing from launch. In this system, the target is illuminated by a ground radar, while a receiver in the missile is locked on to the reflected signal from the target. The missile is not then constrained to follow a "line-of-sight" trajectory, and fire power not limited by the number of radars available.

The target illuminating radar used in *Bloodhound 1* is the *Sting Ray* radar, a very accurate automatic, pulse-radar system developed by Associated Electrical Industries Limited. At that time, while the advantages of continuous wave radar were appreciated, development had not reached a stage where the potential benefits outweighed the immediate availability of highly efficient pulse-radar systems.

The need for long range also helped to influence the choice of the method of propulsion. Even at short ranges, the ramjet appeared to be competitive with the rocket. Over longer ranges, it held distinct advantages, and, because of its lower



How the *Bloodhound* System operates. After target detection by early warning radar, the tactical control radar is alerted and trained on to the approaching enemy. Target information if then passed via the data link to the *Sting Ray* target illuminating radar which locks on and follows the target. After launch the *Bloodhound* homes on reflected radar signals from the target.

propellant consumption, it offered the prospect of achieving further extensions in range without major re-design of the airframe. These considerations, plus such other factors as the ease of handling and storing the simple and familiar kerosene fuel, led to the adoption of ramjet propulsion, despite the fact that—at the time the decision was taken—ramjet experience was limited and supersonic ramjet propulsion had not been achieved in Britain.

When a second working party was formed to study possible airframe configurations, therefore, two requirements had already been established. Many possible configurations were studied, and it was a year before a final decision was taken. There is no doubt that this period of relatively unhurried study at the most formative stage of the project made a decisive contribution to the subsequent progress through development and into production and service.

One of the first questions the "engineering working party" had to answer was "How many ramjets?" The choice was a multi-ramjet configuration versus a single-ramjet configuration employing either an intake in the missile nose or intakes in the side of its body. Both single-intake versions were eventually ruled out, the first because it gave insufficient space for the guidance equipment and raised vibration problems, the second because of the lack of experience with such a configuration in interceptor missiles.

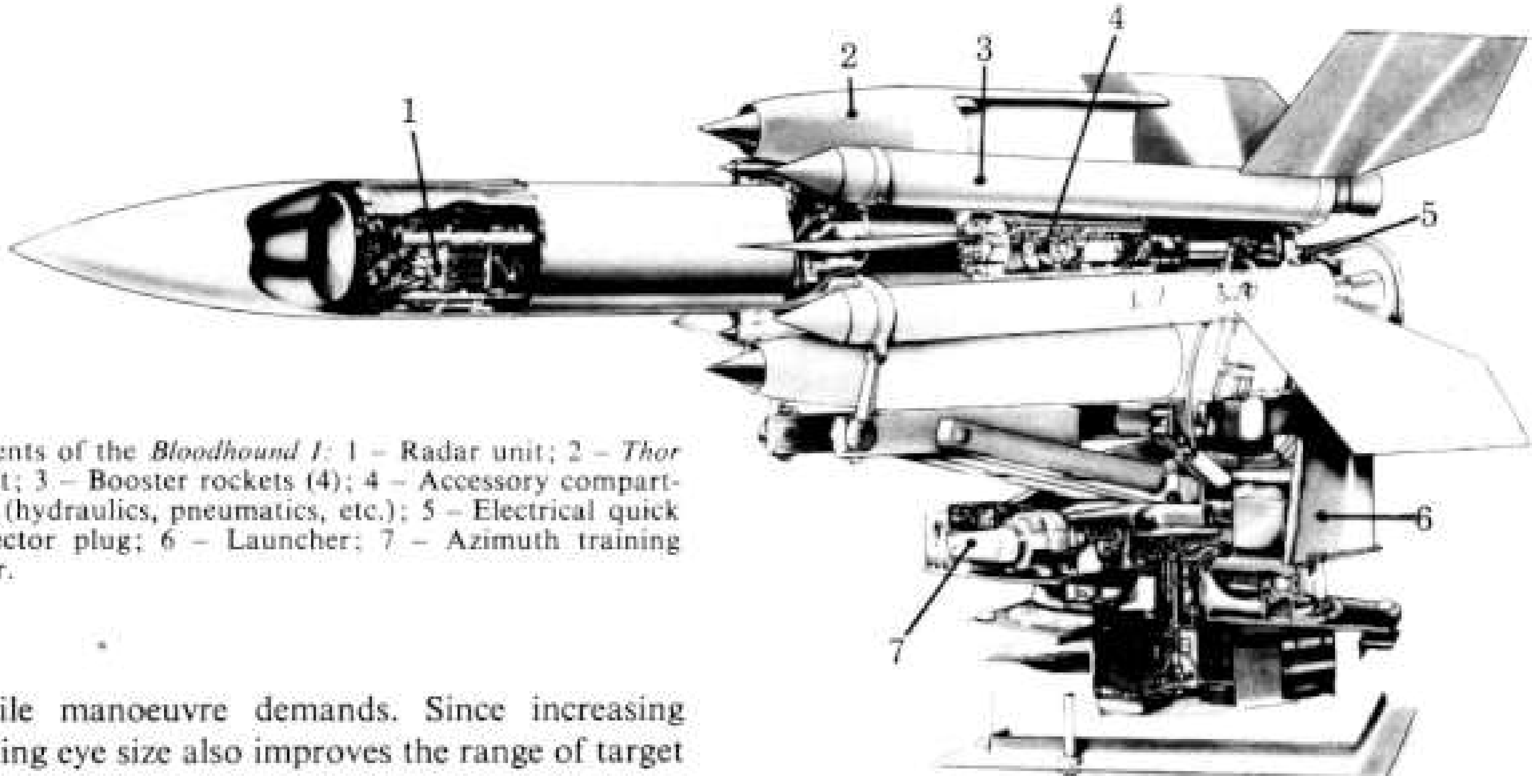
Once the multi-ramjet concept was accepted, there remained the question "how many wings?" and whether fixed or moving. Comparative studies were made of a number of "paper designs," combining fixed or moving wings with two or four ramjets, and cruciform or monoplane wing configurations.

Among the factors to be considered were radome aberration and missile manoeuvrability, particularly at high altitude. These were to some degree inter-related and inter-acting, and the good high-altitude performance of *Bloodhound* depended on them.

A supersonic missile which flies for any distance must, if weight and cost are to be economic, have a streamlined radome in front of the homing eye or dish. This radome causes distortion of the radiation reflected from the target, which manifestes itself in an erroneous line of sight. If the radome is rotated in space, the line of sight erroneously rotates as well, conveying to the missile false steering signals which could have a very serious effect at high altitude. Careful control of radome manufacturing methods will, of course, do much to minimise the distortion but will not entirely eliminate it.

As regards manoeuvrability, the main problem in an interceptor missile is to strike the right compromise between available manoeuvre and time required to develop that manoeuvre, especially at high altitude. Abrupt and violent changes in body incidence as the missile changes its attitude in response to manoeuvre demands can also have unwelcome effects on the ability of the homing eye to "hold" its target.

An example of the conflicting demands which are made by the requirements of guidance efficiency and missile manoeuvrability is the compromise necessary between wing size and guidance eye size. The former obviously governs manoeuvrability at altitude, but on the other hand increased homing eye size will give better target position information which will, in turn, decrease



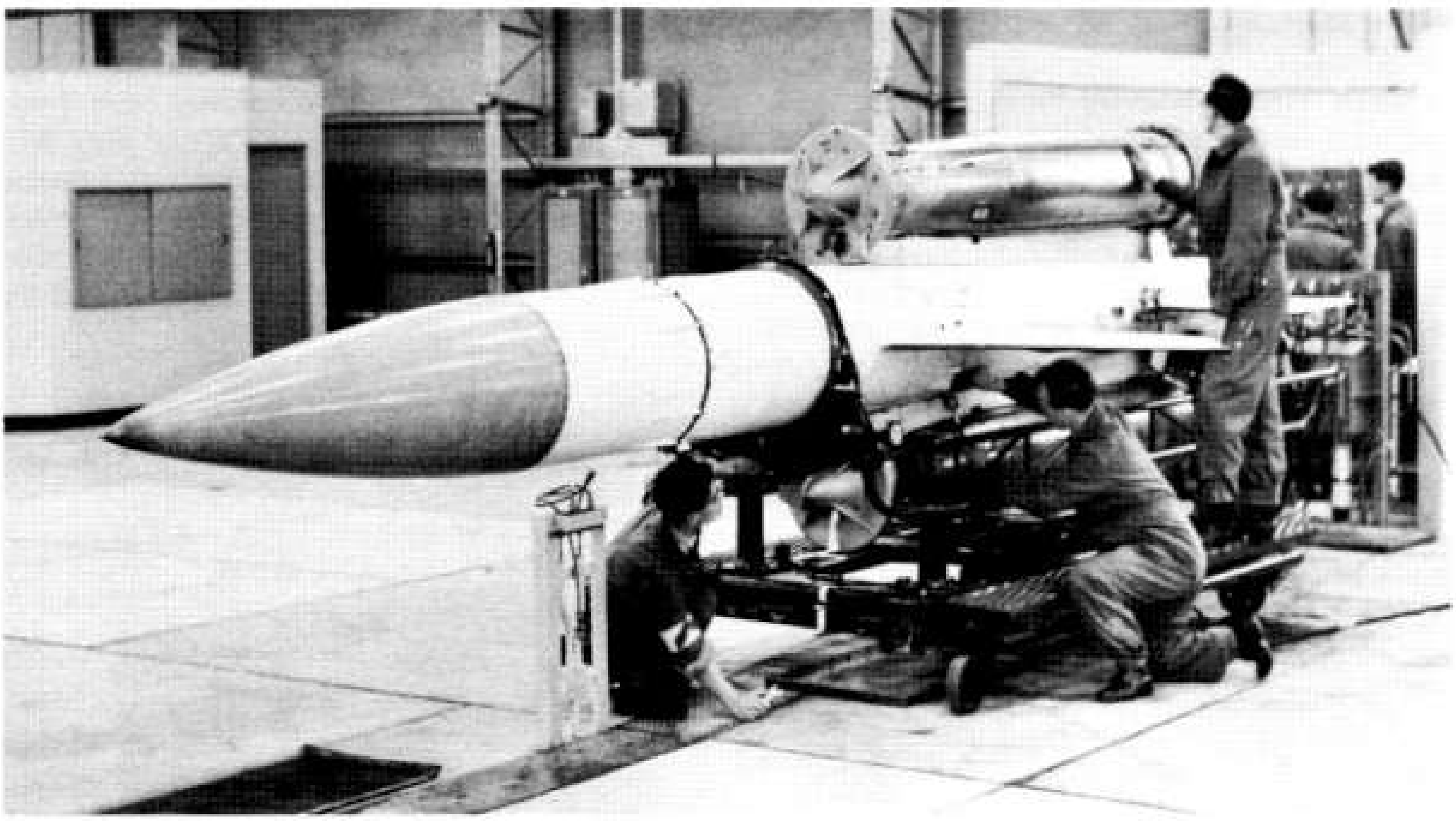
Elements of the *Bloodhound I*: 1 – Radar unit; 2 – *Thor* ramjet; 3 – Booster rockets (4); 4 – Accessory compartment (hydraulics, pneumatics, etc.); 5 – Electrical quick connector plug; 6 – Launcher; 7 – Azimuth training motor.

missile manoeuvre demands. Since increasing homing eye size also improves the range of target detection, the policy on *Bloodhound I* was to favour, so far as possible, the demands of the guidance dish.

Comparison of the various paper designs showed that, for a given missile weight, the number of ramjets made little difference to performance. On the score of available manoeuvre, the monoplane fixed wing gave the best results, with little to choose between the cruciform fixed wing and monoplane moving wings. Moving wings gave much shorter response times, however, and the fixed wing designs suffered more from radome aberration effects.

The choice of a monoplane configuration for a guided missile was undoubtedly unorthodox. All other British missiles of that time had fixed, cruciform wings and moving rear control surfaces. There were, however, substantial arguments in favour of adopting the "twist and steer" method implicit in the monoplane configuration.

Technicians of the Royal Air Force service a *Bloodhound*. The missile is seen in its flight configuration with the rocket boosters detached. Two of the forward shoes, which allow the booster cases to detach when the thrust diminishes, can be seen by the leading edge of the wing.



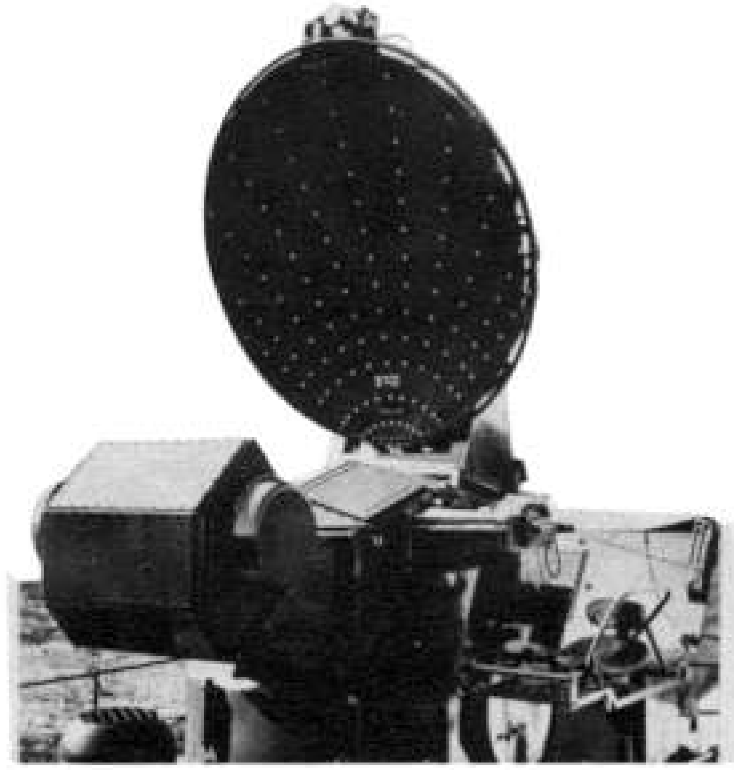
A Cartesian missile manoeuvres so as to achieve a collision course in each manoeuvre plane. A twist and steer missile rolls so as to align the normal to the wings with the vector direction in which manoeuvre is required and then develops that manoeuvre by pitching. In the Cartesian missile, miss distance can be increased by missile response lags and by cross couplings, such as those between pitch and yaw affecting the roll stabilisation upon which the system fundamentally depends. In a twist and steer missile, the only major cross couplings are gyroscopic forces.

The twist and steer arrangement—which is that found in birds—also possesses the advantage of being redundant, in that a failure of either pitch control or roll control can still permit some sort of interception course, whereas failure in one plane of a Cartesian missile is catastrophic.

The three basic characteristics of the first *Bloodhound* missile were now established: semi-active homing guidance, propulsion by twin ramjet engines, and a moving-wing monoplane configuration. Design and development could now begin and, although difficulties were encountered, the basic conception proved sound and the *Bloodhound 1* was brought into full production.

The missile flies a proportional navigation course (i.e., one in which the rate of turn of the missile flight path is proportional to the rate at which the sight line of the homing eye to the target changes). Thus, although the homing receiver dish always points directly at the target, the missile axis does not normally do so, but points at an interception point some way ahead of the target.

Radar signals reflected from the target are collected by the receiver dish, and the receiver ensures that the dish locks on to and tracks the target and that a signal is sent to the wing servo to move the wings and steer the missile on an interception course. It does this by resolving the signal received into pitch and yaw components, which are then compared to obtain the roll signal. (All the computation involved is, naturally, automatic within the missile). This signal operates the wing differentially to roll the missile to the

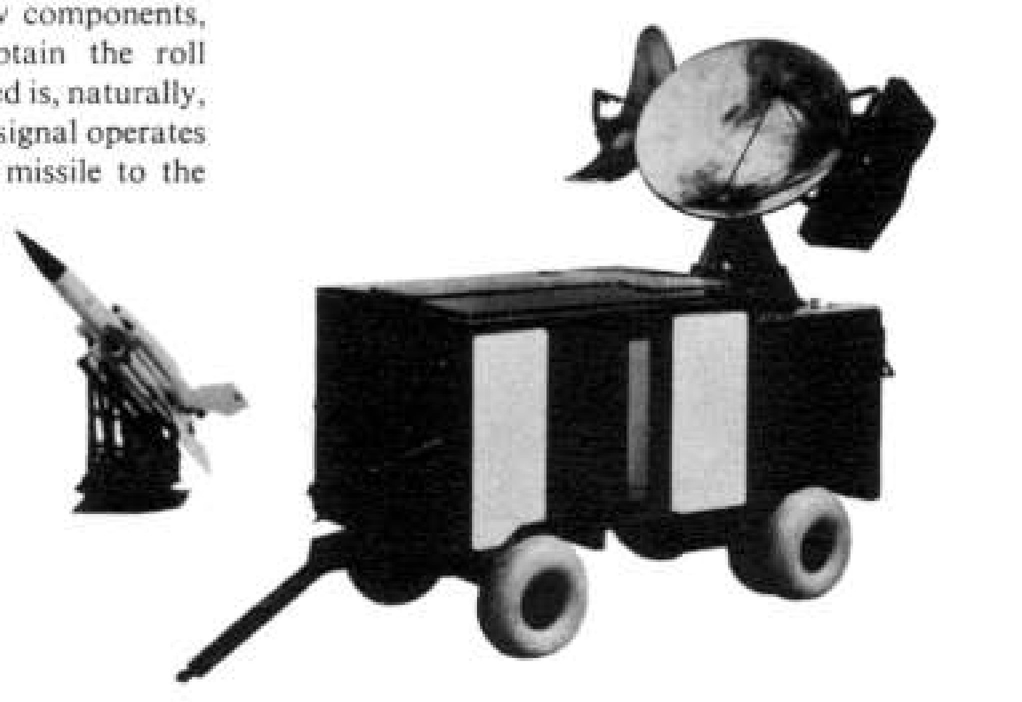


The *Sting Ray* radar, produced by Associated Electrical Industries. The radar dish and horn tilt as a complete unit and the pedestal is mounted on a rotating base.

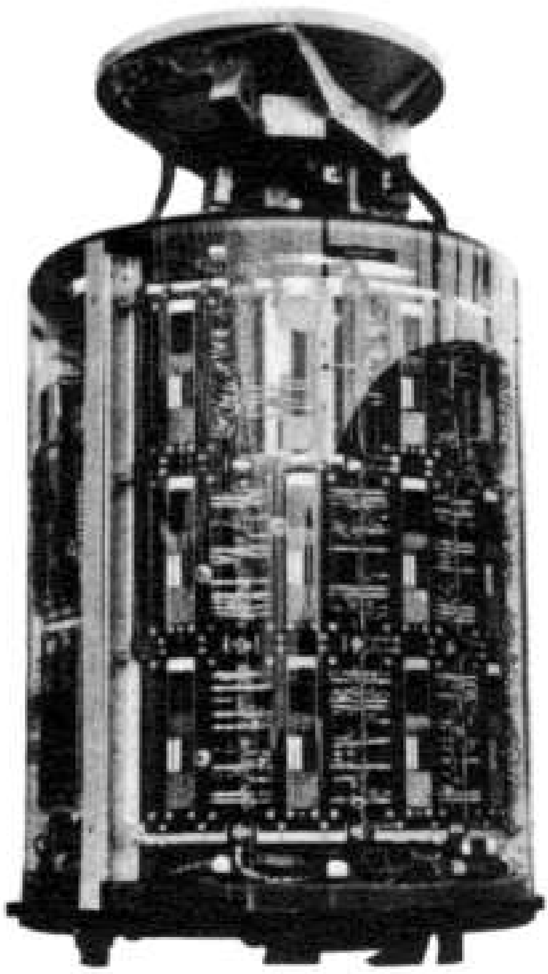
required attitude, and the pitch signal is applied to the wing servo in the same sense to operate the wings symmetrically and pitch the missile on to its computed interception course. The two manoeuvres take place simultaneously, of course, and are constantly corrected as the missile closes with its target.

Early flight trials proved that *Bloodhound 1* could satisfactorily counter evasive action on the part of its target, and indeed it is the essence of a homing system that the accuracy of information available for interception increases as the distance between missile and target decreases.

The response of the missile to manoeuvre demands is, as has been mentioned, very quick. The basic interval of response of the pitch loop is the time needed for the powerful wing servos to put on a wing angle, and response speed is therefore very fast. In roll, very powerful roll moments are applied by the differential operation of the



The *Bloodhound Mk2* weapon system in model form. The radar trailer carries the antenna of the continuous wave target illuminating radar.



The radar dish and guidance set of the *Bloodhound*, developed by Ferranti Ltd. The sub-unit construction is clearly to be seen.

wings. Since the roll moment of inertia is of a much smaller order than the pitch and yaw moments of inertia, very high roll accelerations and rates can be achieved. Since there is no stability problem analogous to weathercock instability, the roll system can in practice be made much faster then the pitch system. Moreover, by altering the gain of the roll loop with altitude, the roll response of the missile can be maintained almost independent of height.

Since the centre of gravity of the missile and the centre of pressure of wing lift are very close together, little body motion is induced by the manoeuvres of the missile, which alters course with a minimum change of body incidence so that guidance receiver dish is not forced to contend with violent changes in the line of sight to the target.

Many hundreds of test firings, plus a considerable number of RAF firings under operational conditions, have proven *Bloodhound I's* ability to maintain precision of control and accuracy of homing out to very long range and at very high altitudes. Frequent RAF and NATO exercises have demonstrated the reliability and speed of response of the weapon system as a whole, and have proven that this sophisticated weapon system is capable of being fitted into any modern scheme of air defence.

In the Mark 2, *Bloodhound's* capabilities are still further extended. The radars, electronic equipment, and other elements of the *Mark 2* system have already completed arduous test programmes, and development is advanced.

In lethality, speed of reaction, and flexibility of operation *Bloodhound Mark 2* is a formidable anti-aircraft defence system, capable of countering any threat by enemy aircraft for years to come.

A Mainstay for Switzerland's Anti-aircraft Defences

On July 14th, 1961, the Swiss Federal Council asked Parliament to approve a bill providing Sfr 300 million for the acquisition of the Bristol/ Ferranti *Bloodhound Mk. 2* ground-to-air guided missile, and a further Sfr. 150 million for medium-calibre AA guns. As already published, *Bloodhound Mk. 2* missiles can effectively attack targets up to an altitude of about 60,000 ft; range is some 70,000 yds. Two Swiss AA artillery regiments, each of four units, are to be equipped with this missile.

On September 19th, 1961, when the Swiss Parliament approved these appropriations, Divisional Colonel Etienne Primault, Chief of Aircraft and Anti-Aircraft weapons, made the following statement on the value of *Bloodhound:* "The choice of *Bloodhound* by our experts is certainly the best we could have made, with regard to both the number of batteries which can be at present established with present resources and the role which we require of this weapon. Its long range compensates for the disadvantage of fixed location. Admittedly, in the case of the employment of anti-aircraft guided missiles there is much dead ground, especially in the mountains. The task of the AA guns and aircraft will, therefore be to complement the guided missiles."

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