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Review of General Operating Experience with a Jet-Lift VTOL Research Aircraft (Short S.C.I.)

by

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REVIEW OF GENERAL OPERATING EXPERIENCE WITH A JET-LIFT VTOL RESEARCH AIRCRAFT (SHORT S.C.1)

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SUMMARY

In the course of the research investigations on the S.C.1, considerable experience has been obtained on the general operating characteristics of VTOL aircraft. The aircraft has been operated from normal runway surfaces as well as from a special platform, and the associated ground suction, erosion, re-circulation and other effects are discussed. A detailed description of the aircraft and its equipment is included, and the serviceability and maintenance record of the aircraft is reviewed, with better results than might have been expected for an aircraft of the complexity of the S.C.1.

Replaces R.A.E. Tech. Note No. Aero.2913 - A.R.C. 25515.

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1 INTRODUCTION

The pioneering experience with the "Flying Bedstead" VTOL reseach vehicle[1] demonstrated the feasibility of achieving satisfactory stability and control during hovering and low speed flight. Because of the absence of any aerodynamic surfaces, this vehicle could not be used to study the transition to conventional flight. Further, although the importance of autostabilization was established in principle, the system used on the "Bedstead" had inherent characteristics, such as lag, etc which were known to have an adverse effect on flying qualities.

The Short S.C.1 aircraft was designed and built to exploit the experience gained with the "Bedstead" and to explore those areas of interest which the "Bedstead" could not cover. Briefly, the original research aims for the S.C.1 were:-

(a) To investigate the behaviour of the aircraft during the transition between hovering and conventional flight.

(b) To determine the optimum and minimum assistance required from the autostabilizer during these manoeuvres.

(c) To study the problems likely to arise during the operational use of such aircraft, including operations into and out of restricted spaces, and in conditions of both good and poor visibility.

(d) To develop such equipment as proved necessary for the assistance and guidance of the pilot in these operations, leading to the development of an all-weather approach and landing system.

This broad programme still stands, though in execution it is convenient to separate it into two parts. The first, covering Items (a), (b) and some of (c), is concerned with the pure aerodynamics and flying qualities and with operating techniques. The second, covering Item (d) and part of (c) involves the development of such systems and equipment as are shown to be necessary to meet the objective.

Two aircraft were built. The first, XG 900, made its initial conventional flight on 2nd April, 1957. The second, XG 905 started tethered hovering trials on 26th May, 1958 and made its first unrestrained hover on 25th October, 1958.

To date, fourteen pilots have flown the aircraft. In addition to the training effort associated with this aspect, a considerable amount of demonstration flying has been done, including an overseas flight to the Paris Air Show.

The present Note is concerned with general operating experience on the S.C.1, and is not specifically related to the research programme outlined above. The first of a series of notes reporting on specific research tests on the aircraft has already been issued[2].

2 DESCRIPTION OF THE S.C.1 AIRCRAFT

2.1 Aircraft and engine installation

The Short S.C.1 is a small single-seat tailless delta aircraft of about 8000 lb AUW. Leading particulars are given in Table 1, and a photograph of the aircraft appears in Fig.1. A 3-view general arrangement drawing is given in Fig.2, while Fig.3 is a cut-away illustration of the interior layout of the aircraft.

Four RB108 light-weight jet-lift engines are mounted vertically, in side-by-side pairs, in a central bay, around the centre of gravity. These pairs of engines can be tilted, about transverse axes, from 23° in the accelerate sense to 12° decelerate, relative to the normal. The original design range was ±30°, but the above restriction arose from the need to fit baffles, separating the upper and lower parts of the engine bay, to prevent the recirculation of hot exhaust gases up between the engines during take-off.

A fifth RB108 engine is installed in the rear fuselage, with an intake under the leading edge of the fin, and provides propulsive thrust.

The tricycle undercarriage has twin wheels with heat-resisting tyres, safe to 200°C. The gear is non-retracting, but the pilot can select either of two alternative positions for the main legs. The forward position brings the main wheels close to the C.G., and is used for all conventional or short take-offs and landings. The aft position ensures that the aircraft will not tip backwards if landed and braked with some rearward velocity, in VTOL operations.

The cockpit layout, Fig.4, is conventional, but somewhat complicated by the large number of systems which the pilot has to monitor. The only additional primary control lever is the common throttle lever controlling the four lift engines. This operates in a similar manner to a helicopter collective pitch lever, and carries a twist grip which is used to control the propulsion engine throttle during jet-borne flight.

2.2 Lift engine intake

The critical case in the design of this intake was the starting of the lift engines in flight. Compressed air from the propulsion engine, applied to the turbine discs, gives the lift engines their initial acceleration, but to ensure that adequate rotational speed would be achieved, it was necessary to avoid an adverse pressure gradient between top and bottom of the engines. Also, the flow into the individual engines had to be sufficiently uniform to avoid surge and vibration problems.

After considerable wind tunnel and flight development work, the present intake system was evolved, and is shown in Fig.5. The forward part of the intake carries a set of 7 gills, hinged at their rear edges, which open about 25° to form a forward-facing intake. The rear of the bay is covered, forming, in effect, a plenum chamber from which the four engines are supplied. This rear cover carries a series of inward-opening, spring-loaded doors, which are opened by the small differences in pressure which exist between the inside of the bay and outside when the engines are running.

During the course of the intake development, the lift engines were fitted with 6 inch-deep scuttles around the front 180° of each exit nozzle. These scuttles helped to create a low pressure zone downstream of the turbine and to ensure that the engines "windmilled" in the correct direction. With the present intake and the latest engines, these scuttles are not necessary.

2.3 Air distribution system

The arrangement of the air distribution system is shown in diagrammatic form in Fig.6 while the location of some of the main components can be seen in Fig.3.

The four lift engines supply compressed air, via their mounting trunnions, to a ring main which feeds the control nozzles (described in the next section) and also a central distributor which feeds air to auxiliary turbines driving the main electric generator, the hydraulic pump and the fuel pumps. In conventional flight, when the lift engines are not running, the air for these turbines is supplied to the distributor by the propulsion engine, the change-over being achieved by non-return valves as will be seen from Fig.6.

About 10% of the mass flow of the lift engines is fed to the control nozzles. The auxiliary turbines take 1% of the lift engines or 4% of the propulsion engine mass flow.

2.4 Control system and autostabilizer

The S.C.1 has two types of controls; aerodynamic surfaces for use at normal flight speeds and air-jet nozzles for use at low speed and in hovering when the aerodynamic surfaces are ineffective. The aerodynamic surfaces are conventional, with ailerons and elevators on the wing trailing edge and a normal rudder.

The air-jet controls comprise roll control nozzles inboard of the wing tips and combined pitch and yaw nozzles below the nose and tail. These nozzles are of the single-eyelid pressure-balanced type, and are normally 50% open. Pitch and roll moments are produced by differential movements of the "eyelids" while maintaining constant total exit area. The nose and tail-mounted nozzles also rotate differentially about fore-and-aft axes to produce yawing moments which are largely independent of the pitching moment being applied. With the full ±30° rotation of the nozzles, however, the pitching moment is, of course, reduced to 87% of its normal value. Since the pitch nozzles contribute approximately 6% of the total vertical thrust, this rotation also reduces the total thrust by just under 1%.

In yaw the air-jet and aerodynamic controls are permanently linked mechanically to the rudder bar and there is no autostabilization. In pitch and roll, the two types of controls are not necessarily linked; different modes of operation are available in which the aerodynamic surfaces or the nozzles are actuated by direct mechanical connexion with the stick or by the electro-hydraulic servo-motor forming part of an electrically signalled control system. These modes of operation are described in the next section.

The electrically signalled control system, which was adopted to facilitate the provision of various degrees of synthetic stability, together with the equipment known as the "Autostabilizer" which generates the stabilizing signals, is described in section 2.4.2.

2.4.1 Modes of operation of control system

The mechanical outputs from the stick and from the electro-hydraulic servo-motor may be utilized in the following alternative ways which are illustrated in Fig.7:-

(a) The aerodynamic surfaces and the nozzles may both be operated by the servo-motor, with the pilot's demands and the stabilizing signals fed in electrically. This condition is known as "Fully-stabilized".*

(b) The nozzles may be operated by the servo-motor in response to electrical signals as in (a) while the aerodynamic surfaces are directly linked to the stick. This condition is known as "Nozzle-stabilized".*

(c) The nozzles and the aerodynamic surfaces may both be directly linked to the stick in the so-called "Manual",* (more accurately, "Direct") condition.

Changeover between the first two conditions is made on the ground, but the pilot has always the facility of reversion to the third condition, "Manual", in the air by an emergency lever.

Since the elevator hinge moments in certain phases of flight might be beyond the capacity of the servo-motor, the elevator is normally operated through a conventional power control unit. This unit can revert to true "manual" in the event of a hydraulic failure, but this is an emergency, not a test, condition.

2.4.2 Electrically signalled control system and autostabilizer

A simplified diagrammatic representation of this system is given in Fig.7. The control surfaces or nozzles are positioned by an electro-hydraulic servo-motor in response to the sum of stabilizing signals derived from a rate gyro in the autostabilizer and a signal proportional to the pilot's stick position. These signals, together with servo position and servo rate feedback signals are added in a magnetic amplifier whose output operates an electro-mechanical transducer ("Law's relay") which moves the valve spool of the hydraulic servo-motor. The position of this valve spool, which determines the rate at which the servo-motor moves, is measured by an AC pick-off to provide the servo rate feedback signal, required for stabilization of the servo system itself. The main feedback signal, the servo position signal, is obtained from a potentiometer coupled to the output shaft of the servo-motor.

To provide against the possibility of faults, the electrically signalled control system, including the autostabilizer, is triplex. That is, it comprises three independent lanes, each complete in itself and terminating in a servo-motor. The three servo-motors are mechanically coupled to a common shaft and are so designed that if a fault should occur and one of them attempt to move the

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* These terms have come into common use with the S.C.1, but they are far from ideal, and their use here is not to be construed as a recommendation for their general adoption.

control to an incorrect position, the other two would then be able to overpower it and move the control correctly. Thus one lane of the control system or the autostabilizer may fail without any great deterioration in the overall performance. The failure of a second lane could however leave the pilot without effective control through the electrically signalled control system and it would be necessary to change to "Manual" (mode (c) in section 2.4.1). For this reason a fault detection system has been provided to indicate to the pilot when a fault has occurred. This is achieved by comparing the three signals from a second set of AC pick-offs measuring the positions of the three valve spools. When one of these signals differs by more than a set amount from the other two, fault indicating lights are illuminated in the cockpit. The pilot will then normally land the aircraft as soon as possible. However, since a transient difference can exist between the three valve positions while a rapid manoeuvre is being performed, the pilot would generally cancel an indication appearing in such circumstances and take no further action unless the indication reappeared.

This emphasis on safety was dictated in the first place by the fundamental decision to use an autostabilizer in which the stabilizing signals are capable of making a demand greater (in fact 40% greater) than the maximum demand from the stick, so that even when the pilot demands maximum response, the autostabilizer is not saturated and can still maintain the required response despite external disturbances. If a single lane system had been used with an autostabilizer having this degree of authority, then in the event of a failure which resulted in a stabilizing signal reaching its maximum possible value, the pilot would have been unable to control the aircraft. The triplex arrangement overcomes this difficulty and also ensures that no undue hazard is introduced by the use of the electrically signalled control system, enabling the pilot to be given, as nearly as possible, infallible indication of any foreseeable faults as soon as it occurs. In addition, all power supplies, hydraulic piping etc are so arranged that no single fault can affect the functioning of the control system or autostabilizer and that any fault which is significant is immediately signalled to the pilot.

The autostabilizer can provide two forms of stabilization. Either the outputs of the rate gyros can be used unmodified to give angular velocity damping, or the rate gyro signals can be approximately integrated in a resistance/capacitor network to give quasi-position signals, providing a type of control which resembles pure position control in its initial response. A more detailed account of the operation of the autostabilizer is given in Ref.2.

3 SPECIAL OPERATIONAL EQUIPMENT

In the early stages of its development, the S.C.1 was operated in a special gantry (Fig.8) which allowed a limited amount of freedom at the hover, up to 15 ft vertically and 10 ft off-centre in any direction. Outside these limits, progressive restraints were applied. The system also limited the vertical velocity to less than 10 ft/sec. The aircraft took-off and landed on an open-work grid platform, 6 ft above ground level, to eliminate ground effect.

This facility was used for ab initio training of the first 8 of the 14 pilots who have flown the aircraft.

It was known from model tests[3] that operation from a plane surface would involve a serious loss in lift due to ground suction, and furthermore it was appreciated[4] that there might be trouble due to the recirculation of hot exhaust gases into the lift engine intake. A considerable amount of work was done by Short Brothers and Harland, Ltd.[5] to develop a suitable take-off platform to eliminate these effects. Based on the model tests of Ref.3, the earliest version of this platform embodied a series of channels designed to restrict the free spread of the exhaust gases to a narrow zone, and hence to reduce the mixing that was mainly responsible for the induced flow which caused the lift loss. However, when an open grid was placed on top of these channels, to support the aircraft wheels, there was a marked tendency for the exhaust gases to be forced up through the grid and thence into the intake, causing a loss in engine thrust. The effect was, in fact, aggravated by the presence of the channels, and the only effective cure was to cover the grid with metal sheeting, except for a hole under the lift engines. In this condition, the channels served no useful purpose and were removed.

The present platform (Fig.9) stands 18 inches high and measures 37 ft by 42 ft. It consists of a number of portable sections, forming a solid upper surface except for a central 9 ft diameter hole which admits the lift engine efflux to the open space below. The upwind edges of the platform can be sealed off by movable screens so that the efflux escapes mainly downwind. Sloping ramps allow the aircraft to be towed, backwards, up on to the platform. Most of the normal flying was done from this type of platform. It successfully reduces these ground effects to insignificant proportions, but the aircraft must remain over the hole during the first few feet of the lift-off, if lift and trim changes are to be avoided. It also introduces the hazard of landing, in emergency, with one wheel on or off the platform.

A more recent development has been the adaptation of a ground engine-running facility as a take-off base. This consisted, originally, of a 4 ft square section, U-shaped steel-lined duct over one end of which the aircraft could be tethered for engine-running, while exhaust gases escaped vertically from the other branch, 25 ft away. One end of this duct was subsequently opened out to a 10 ft square grid over which the aircraft could be positioned for take-off (Fig.10). Being set in a level expanse of concrete, this new take-off base was much more suitable for both training and normal operations. In fact, it has been used as a base for the first flights of the latest 6 pilots to fly the aircraft, and has eliminated the need to use the gantry for this purpose.

A much larger (50 ft by 100 ft) flush-fitting platform is now being built at RAE Bedford (Fig.11). This will, it is hoped, simplify operations considerably by removing the necessity for the pilot to maintain accurate plan position control during take-off. With present facilities, the aircraft is subject to significant and disturbing lift and trim changes if it drifts off the hole while at low height.

No special facilities are needed for landing on normal concrete, tarmac or good quality grass surfaces, but any loose surface rubble is liable to be violently disturbed.

4 TESTS COVERED BY THE PRESENT NOTE

The main research programme outlined in the Introduction has been under way for a year or more, and the first of a series of reports on the results of specific handling tests is in Ref.2. However, considerable experience, some of an ad hoc nature, has accumulated on items not specifically listed in the programme. These are of interest in relation to the general problems of operating a direct-jet-lift VTOL aircraft. These items include:-

(a) Rolling take-offs.) including studies of:-

(b) Take-offs from plain surfaces.)

(c) Structural heating, ground erosion and recirculation.

(d) Engines and autostabilizer maintenance and serviceability.

5 INSTRUMENTATION

The design of the aircraft provided for the installation of a comprehensive recording system intended to cover a research programme which was not, at that stage, defined in detail. Serious limitations of weight and space existed, so that, inevitably, not all the quantities that eventually proved necessary could be recorded by the original system. This system is, in fact, still in use, but refinements are in hand.

At the time of the tests to be described below, the recording system had not reached operational status, so that quantitative results are meagre. In particular, structural and intake temperature measurements were of low accuracy. The problem is accentuated by the transient nature of the hot gas flow during take-off and landing. Electrical recording of temperature was rather unsatisfactory, and reliance had to be placed on the use of temperature-indicating paints in many cases.

6 SPECIFIC OPERATIONAL TESTS AND OBSERVATIONS

6.1 Rolling take-offs

6.1.1 Description of tests

As a preliminary step in the study of the problem of operating from semi- or unprepared surfaces, a series of rolling take-offs was made from a normal concrete runway. It was expected that recirculation and erosion problems would be eased by the forward speed effect, and that the wing lift contributions at take-off could increase the allowable take-off weight.

For these initial tests, the engine starting phase was not covered. The engines were started with the aircraft on the platform (section 3) and it then took off and landed on the runway, taxying forward to the place appointed for the start of the test.

Temperature recording elements had been fitted in the lift engine intake, and thermal paints applied at strategic points on the structure. Patches of

French chalk had been laid in strips on the runway, along the take-off path, to give some indication of the recirculating flow pattern.

The ground run was made with all engines idling, with the lift engines tilted to provide an accelerating component of thrust - which was quite high (30-40% full thrust) even at idling speed.

6.1.2 Results

Preliminary tests showed that, during the initial stages of a ground roll performed with maximum accelerating tilt on the lift engines, the intake temperature was some 15°C above normal. An abrupt return of the intake temperature to normal was recorded as the airspeed exceeded 25 knots. At this speed and above, the French chalk showed the recirculating flow pattern to be contained under the wings. With the thrust line nearer the vertical, the same effect occurred at a somewhat higher forward speed.

Once this condition had been achieved during the ground roll, full lift-engine power could be applied and the aircraft rotated nose-up to increase the vertical component of the thrust and complete the take-off. This 15 degrees nose-up rotation, and full power, increased the tendency for hot gases to move forward, but at speeds above 40 knots, no recirculation was detected when the thrust line was 6° or more aft of the vertical (accelerate sense). Had more thrust been available, no rotation would have been necessary and a lower unstick speed could have been used.

No handling problems arose during the ground roll or during the application of the 15° nose-up rotation that was used. The low forward acceleration (0.1 to 0.2 g) resulting from the use of idling thrust only, gave the pilot ample time to execute the rotation, but resulted in unspectacular performance. It is estimated that full thrust on the propulsion engine, alone, would have reduced the ground run (up to 40 knots) to under 350 ft. Later tests have confirmed this estimate.

Thermal paints showed evidence of local temperatures up to 190°C on the tyres, with a "hot spot" at 220°C on the axle between the twin main wheels. Skin temperatures under the aircraft were all below 90°C - under 60°C in most places - except for the undercarriage fairings, which were generally below 120°C, although they, too, reached 190°C, just above the wheels. All internal temperatures remained normal.

Lift and thrust losses during the ground roll are difficult to estimate with any certainty, but rough calculation suggests that, at 40 knots, they may have totalled as much as 1000 lb. Too much weight should not be attached to the actual figures, but the total loss appears to be significantly higher than that measured during a true vertical take-off from a plain surface (see Section 6.2.1, below). This tentative conclusion is, however, in line with the results of model tests reported in Ref.6. These tests indicate the existence of a further loss in lift due to interference between the jet exit flow and the flow around the wing. This loss is additional to that due to ground effect, which may, in itself, be affected by forward speed. Further tests are planned, in which the effects of ground proximity and forward speed will be studied separately and together.

6.2 Vertical take-offs from plain surfaces

6.2.1 Description of tests

The above tests avoided the problems associated with the starting of the lift engines, before take-off, and the blast and high temperature effects during a true vertical take-off.

The latter problem was first examined by making a normal vertical landing on the concrete runway and then, after a few seconds idling, applying full thrust for a vertical take-off.

Some flaking of the top surface of the concrete occurred on occasions, but the weight of material removed was small, and could not be considered a serious hazard. Fig.12 shows the results of take-offs from two different areas of concrete, one of which shows only the slightest damage.

Before attempting the full starting and lift-off cycle, some rig tests were made by Rolls Royce, using a single RB108 engine and a dummy undercarriage leg and wheel. Thermal paints were applied to this dummy. To simulate the effect of having 4 engines, some runs were done with the engine only half the normal distance above the ground, though this procedure is not now thought to give a true simulation of a multi-engine system.

Temperatures on this undercarriage, during a 10-second run at 14,500 r.p.m. (full power is at 17,500 r.p.m.) were all below 100°C. The estimated local gas temperature was 125°C. It was deduced that a full power take-off on the S.C.1 would not result in excessive undercarriage temperatures.

The first test on the S.C.1 involved starting and holding the lift engines at 12,500 r.p.m. for 30 seconds, and then stopping. Thermal paints indicated that the nose and main wheel tyres had reached 165°C and 160°C respectively. Elsewhere, temperatures were all reasonably low, and around the lift engine intake, in particular, were below 40°C (the lowest temperature that could be measured).

The aircraft was then re-started, at the same position as before (the concrete having been only slightly flaked), lifted off as rapidly as possible, and landed again a short distance away. The engines had taken 30 seconds to reach idling r.p.m. and the aircraft left the ground 15 seconds later.

The maximum surface temperatures recorded were 190°C and 170°C on the nose and main wheel tyres, respectively. Elsewhere, surface temperatures were as before, though there was one place on the leading edge where the temperature had exceeded 40°C. Neither test resulted in any damage to the aircraft.

The estimated loss in net vertical thrust based on the maximum take-off weight, was 800 lb., i.e. less than that derived from the rolling take-off tests.

6.2.2. Discussion of temperature measurements

It is of interest to compare these measured surface temperatures with the estimated local gas temperature. For a single round jet normal to, and within about 10 diameters of the ground, the local gas temperature, at more than about 2 diameters from the jet axis, is roughly inversely proportional to the radial distance from the jet axis and directly proportional to the jet exit temperature, i.e.

$$\frac{T_g - T_o}{T_j - T_o} = \frac{k}{x/d}$$

where T_g, T_o and T_j are the local gas, ambient and jet exit temperatures, respectively, x/d is the radial distance/jet diameter ratio and k is a constant (about 1.1, from model tests).

When 4 nozzles are used, this simple circular distribution is distorted, temperatures being highest along the axes of symmetry. Using model results (unpublished) the estimated local temperature distribution close to the ground can be superimposed on the plan view of the S.C.1, as in Fig.13. The temperatures to which the wheels and undercarriage were subjected can then be compared with the measured surface temperatures. As would be expected, surface temperatures are less than the gas temperature, by an amount which depends on the duration of the exposure and the surface material (i.e. rubber or metal).

The results are collected in Fig.14A, which relates the temperature ratio $(T_s - T_o)/(T_g - T_o)$ to the exposure time, T_s being the surface temperature. These results are very approximate, as the exposure time makes no allowance for starting and stopping the test, during which, generally, the gas temperature varied also.

However, Fig.14A does illustrate a logical trend, in that non-metallic (poorly conducting) surfaces get hotter than metallic surfaces, and temperatures approach the local gas temperature in time.

6.3 Ground heating studies

Some tests have been made to find the temperature rise in and below a steel deck during a vertical take-off[7]. Temperature sensors were embedded ½ inch into 1 inch deck plating mounted on typical ship structure. The aircraft hovered for 30 seconds over the take-off spot, following the normal starting cycle.

The highest recorded temperature in the deck plating was only 125°C, and this was achieved 3 minutes after take-off. Beyond an 8 ft radius circle, the deck temperatures were not significantly affected. The temperature ratio averaged only 0.15 (after 3 minutes). Clearly, this type of structure is a very effective heat sink.

Other tests[8], using a single RB108 engine, have yielded the surface temperature distribution on concrete after a 10 seconds take-off cycle, with the results shown in Fig.14B. The estimated local gas temperature is also shown, together with an estimated surface temperature distribution based on a constant temperature ratio. The value of this ratio (0.45) is also indicated on Fig.14A, for comparison with the aircraft heating data. It is lower than any value measured on the aircraft, possibly because the flow is largely parallel to the concrete, whereas the "hot spots" on the aircraft were more nearly normal to the flow.

All these tests were done with little or no wind. The rolling take-off tests (Section 6.1) resulted in the temperatures on the main undercarriage reaching 220°C in one place - appreciably hotter than during the static tests. It appears that the axi-symmetrical temperature distribution of Fig.13 may become distorted downstream, due to forward speed, which would increase the local gas temperature around the main undercarriage.

6.4 Discussion of thrust and lift loss measurements during vertical and rolling take-offs

These tests were designed for demonstration purposes, rather than for accurate measurement of lift losses. Further, the instrumentation was not entirely suitable. The main problem is uncertainty regarding actual intake temperatures, which probably vary with location and time. Thus, a single temperature element (as was used during the rolling take-offs) could give misleading results. From bench tests, a 10°C intake temperature rise, at constant throttle setting, reduces the total thrust by nearly 150 lb. However, during these tests, the full throttle settings were not precisely fixed, and, in addition, normal acceleration was not accurately known.

Therefore, the numerical results quoted must be treated with reserve, but, assuming that the normal accelerations were not much different from 1g in the two cases, there is an indication that the lift loss during a rolling take-off is greater than that during a vertical take-off. Furthermore, there is a suggestion that losses during a vertical take-off may be greater than in a landing (the measured loss for a landing is reported in Ref.2); this may possibly be due to the recirculation having had a longer time in which to establish itself during the engine starting procedure.

Clearly further tests are required, with refined instrumentation for the measurement of effective intake temperature, in particular.

6.5 Other experience of operation from plain surfaces

Normal runway concrete appears to be entirely adequate for vertical take-off and landing of the S.C.1. In addition, many landings have been made on asphalt and grass surfaces, with no problems when these surfaces are in good condition. Old, cracked asphalt or tarmac will "peel" off at a spectacular rate, and loose material in recently-filled trenches, etc can result in something of a hazard for personnel on the ground, although no damage to the aircraft has ever been reported.

The recirculating flow pattern near the ground was dramatically illustrated on one occasion while hovering over a freshly-mown grass surface. Cut grass accumulated on the lift engine intake cover, blocking the intake to the extent that the aircraft could not maintain height. No damage was done to the engines, in spite of the excessive jet pipe temperatures which occurred.

7 MAINTENANCE AND SERVICEABILITY RECORD

7.1 Relevance of current experience

The maintenance and serviceability experience on the S.C.1 must be viewed in the light of the fact that it is a prototype aircraft of small size in which the engines, and much of the equipment are at an early stage of development. Its role as a variable stability research aircraft has resulted in some complications, while accessibility of components and ease of maintenance were not primary design requirements. The triplex autostabilizer, in particular, was of a new type, with no background of operational experience.

On the other hand, like all experimental aircraft, the S.C.1 is always operated under favourable conditions. Every care is taken to avoid the risk of damage. It is flown by highly skilled pilots and serviced by above-average engineers.

With these qualifications, a factual account follows of actual operating experience on the aircraft.

7.2 Engine maintenance

During a typical 12-month period, the aircraft made 200 VTOL flights averaging 5 minutes hovering flight time each - though an operational aircraft would only use its lift engines for 1 or 2 minutes per flight. In addition, 20 ground runs of about 7 minutes each were required for normal maintenance and inspection checks.

In this period, which includes two series of intensive public demonstrations (Paris and Farnborough), the engines themselves required no maintenance whatever. Some effort was expanded, however, on associated systems (fuel, etc) which accounts for the above ground running time.

This maintenance effort is difficult to state fairly, because, initially, the ground crew were not familiar with the aircraft. By far the biggest single job was the replacement of a fuel proportioner unit, buried deep in the crowded rear fuselage. It is estimated that the total effort on power plant maintenance alone was 20-25 man-hours.

It is interesting - and probably valid - to compare this effort with that for another small experimental aircraft, having a single, well developed engine of the same total thrust as the S.C.1.

Over the same 12-months period this aircraft accumulated almost exactly the same flight time as the S.C.1 and the engine maintenance effort expended was 22 man-hours. Two-thirds of this total were accounted for by jet pipe or re-heat unit replacement - items which do not apply to the S.C.1.

From this admittedly very limited comparison it appears that the S.C.1's multiple lift engines do not, in themselves, raise any more maintenance problems than a typical single engine of the same total thrust.

To summarise S.C.1 experience, engine maintenance amounts to 1 man-hour per flight hour, and ground running accounts for 10-12% of the total engine usage.

7.3 Autostabilizer maintenance and serviceability

7.3.1 Routine inspection

Special-to-type equipment is used to compare input and output signals on each individual "lane" of the two channels (pitch and roll). The difference is adjusted to within the limits accepted by the fault detection network. Then, with all 3 lanes engaged, a transient disturbance is applied to each complete gyro unit (by rocking it on its anti-vibration mounting), to confirm that no faults are indicated. This final check is therefore to a higher standard than can be achieved on a single-lane system, since not only must the 3 lanes each function correctly, separately, but they must all be in step during a transient input also.

Inspection personnel state that they prefer the triplex system, in principle, to any other in their wide experience. The system is self-checking, and if a defect is present, they can generally locate not only the faulty lane, but also the faulty section of that lane, without removing the equipment from the aircraft.

7.3.2 Serviceability and reliability

Faults indicated in flight are of two types. The most common are transient in nature, arising during rapid manoeuvres and particularly during flat turns*. Unless the indication persistently reappears after cancellation by the pilot, they do not call for remedial action and no record has been kept of their occurrence.

Real faults - those which do persist - have all been of a passive (as opposed to "runway") nature, and have averaged one per 50 flights of about 8 minutes each. This leads to a mean time between faults (not failures) of $6\frac{1}{2}$ flight hours, but about twice this in terms of total running time.

The distinction between faults and failures is important. No auto-stabilizer fault that has ever occurred has endangered the aircraft, or even affected control or response in any way. Except for the fault indicating system, the pilot could not have detected that a fault had occurred. The principle of the triplex system is considered to have been fully justified; equally, a reliable fault indicating system is essential.

Fault rectification and maintenance problems are amplified by the small size and complex internal layout of the aircraft. The maintenance effort is greatly extended by the need to remove other units which restrict access to the autostabilizer components.

7.4 General causes of unserviceability

To put the engine and autostabilizer problem in perspective, it is interesting to break down the total period of unserviceability into separate causes. The following table applies to a continuous 20-month period of operations:-

---

* In each channel, the 3 rate gyros are mounted with their spin axes at 120° to each other. During a flat turn in a non-level attitude, slight differences in pitch/yaw and roll/yaw cross-coupling exist between the 3 lanes, which result in fault indications.

Percentage of total unserviceability time due to:-	
Engines (including routine engine changes)	14%
Autostabilizer	19%
Replacement of "time-expired" components	27%
Hydraulics	10%
Fuel system	2%
Electrics	4%
Routine inspection and modification	16%
Research installation work	8%

When the aircraft is serviceable, it averages 12 flights per week and has made 7 experimental VTOL sorties in a day on occasions. The overall average, however, is 2.6 flights per week.

8 CONCLUDING REMARKS

In the course of the research programme for which it was designed, the S.C.1 has also yielded valuable information on some of the problems of operating and maintaining a jet-lift VTOL aircraft.

Vertical and rolling take-offs from plain surfaces have confirmed the existence of a significant loss in effective lift force, but have shown that, purely from the handling and the structural heating aspects, there need be no serious problems. There are, however, indications that the loss in total vertical lift force during take-off may be larger than expected from the results of hovering tests near the ground, and that this loss is not, apparently, recovered by wing lift at forward speeds up to at least 40 knots.

Analysis of these tests has emphasised the difficulty and importance of measuring actual engine thrust under these conditions. Further tests are planned, using improved intake and engine instrumentation.

The engineering problem of servicing and maintaining the S.C.1 has been examined. The engines, on the whole, have given much less trouble than might be expected from their number, while the triplex autostabilizer, also, has an important point in its favour from the inspection aspect, in that fault-location is relatively easy, and the system is self-checking. When the aircraft is serviceable, quite long periods of intensive operations are possible.

Concerning the main research programme, it is expected that the S.C.1 can serve as an effective research vehicle within the limits imposed by its small size and restricted load-carrying capacity, but that experiments involving instrument flight and the assessment of guidance equipment for low-visibility operations, for which a "safety" pilot is essential, will need a larger, multi-seat research aircraft.

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TABLE 1

S.C.1 aircraft - principal data

Wing - span	23.5	ft
Area	211.5	ft^2
Standard mean chord	9.0	ft
Sweepback - leading edge	54°	
- trailing edge	3°	
Overall length (excluding nose boom)	25.5	ft
Pitch and yaw nozzle arm	11.33	ft
Roll nozzle arm	8.76	ft
Mean height of wing undersurface above ground - static	4.5	ft
- oleos extended	5.6	ft
Weight of aircraft, less fuel	6260	lb
Max. conventional take-off weight	8050	lb
Total lift engine thrust; including control thrust, but excluding installation losses	8600	lb
Propulsive engine thrust, excluding installation losses	2200	lb
Estimated moments of inertia at 6900 lb:		
Pitch	5480	slug-ft^2
Roll	1865	"
Yaw	7000	"

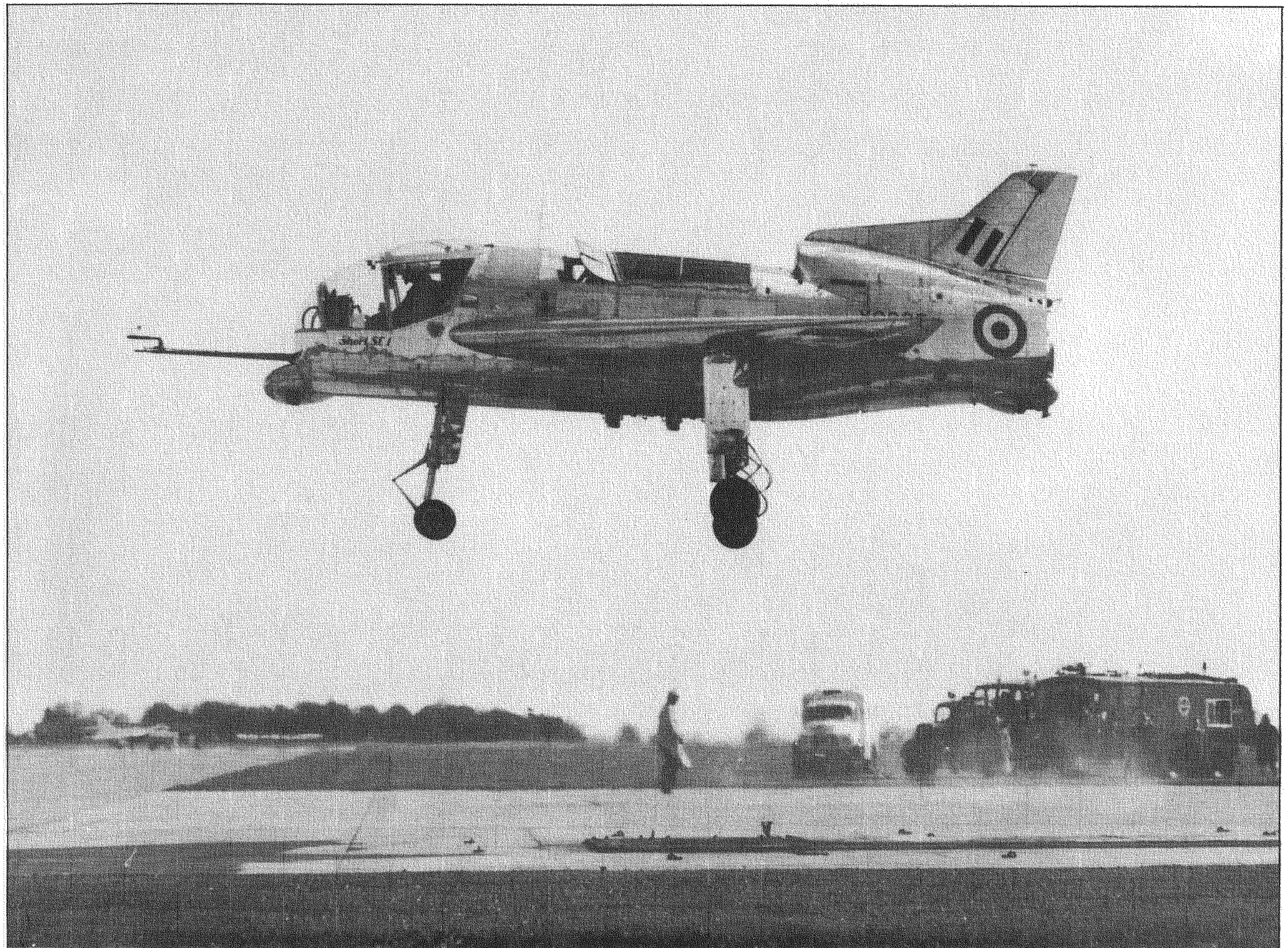
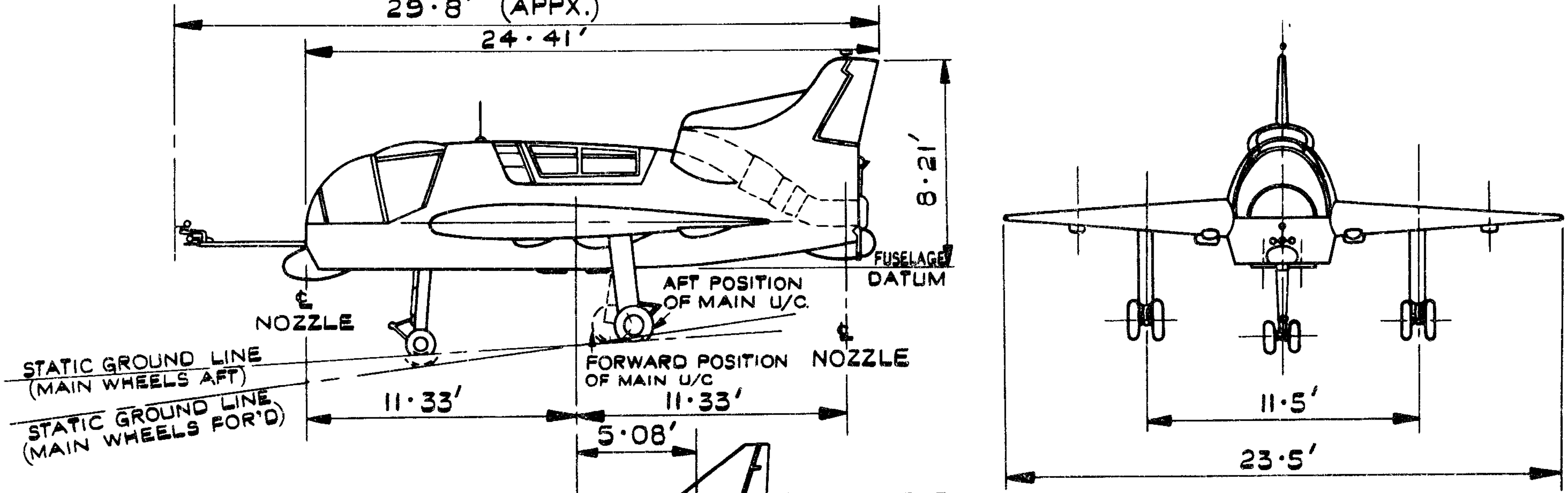
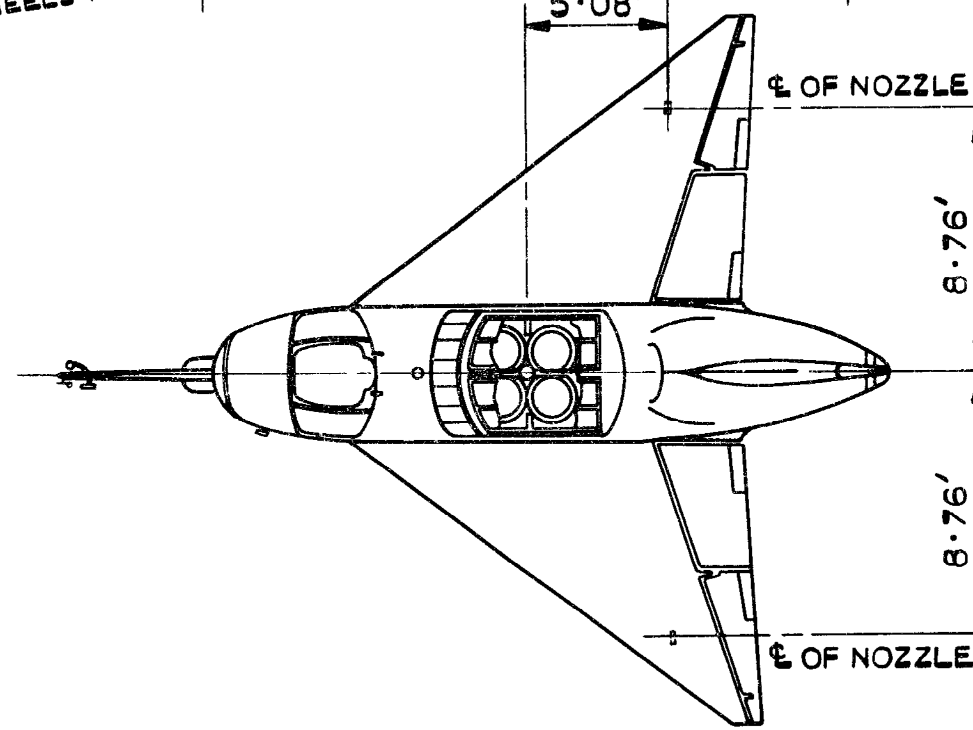


FIG.1. THE SHORT S.C.1. JET-LIFT RESEARCH AIRCRAFT





MAIN PLANE		
AEROFOIL SECTION	N.A.C.A. 0010	
DIHEDRAL	0°	
SETTING TO FUSELAGE DATUM	0°	
AREAS -		
GROSS (APEXED)	211·5	SQ. FT.
NETT	141·9	SQ. FT.
ELEVATORS AFT OF HINGE LINE (TOTAL)	14·76	SQ. FT.
AILERONS AFT OF HINGE LINE (TOTAL)	8·55	SQ. FT.
ELEVATOR TRIM TAB (ST'BD.)	0·569	SQ. FT.
ELEVATOR BALANCE TAB (PORT)	0·569	SQ. FT.
AILERON BALANCE TABS. (EACH)	0·569	SQ. FT.
FIN & RUDDER		
AEROFOIL SECTION	N.A.C.A. 0010	
AREAS -		
GROSS	28·64	SQ. FT.
NETT	11·63	SQ. FT.
RUDDER AFT OF HINGE LINE	4·44	SQ. FT.

FIG. 2. GENERAL ARRANGEMENT - SHORT S.C.I.

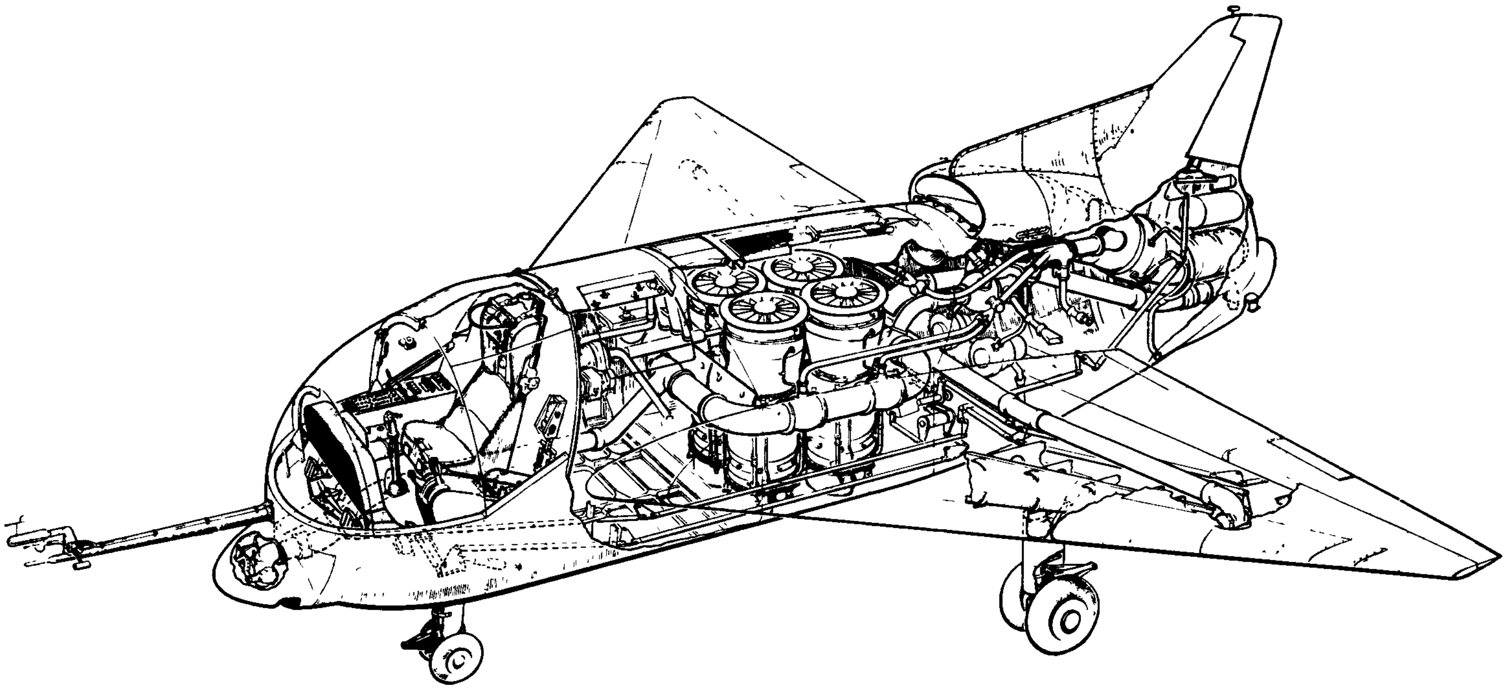


FIG.3. SECTIONAL VIEW OF THE AIRCRAFT

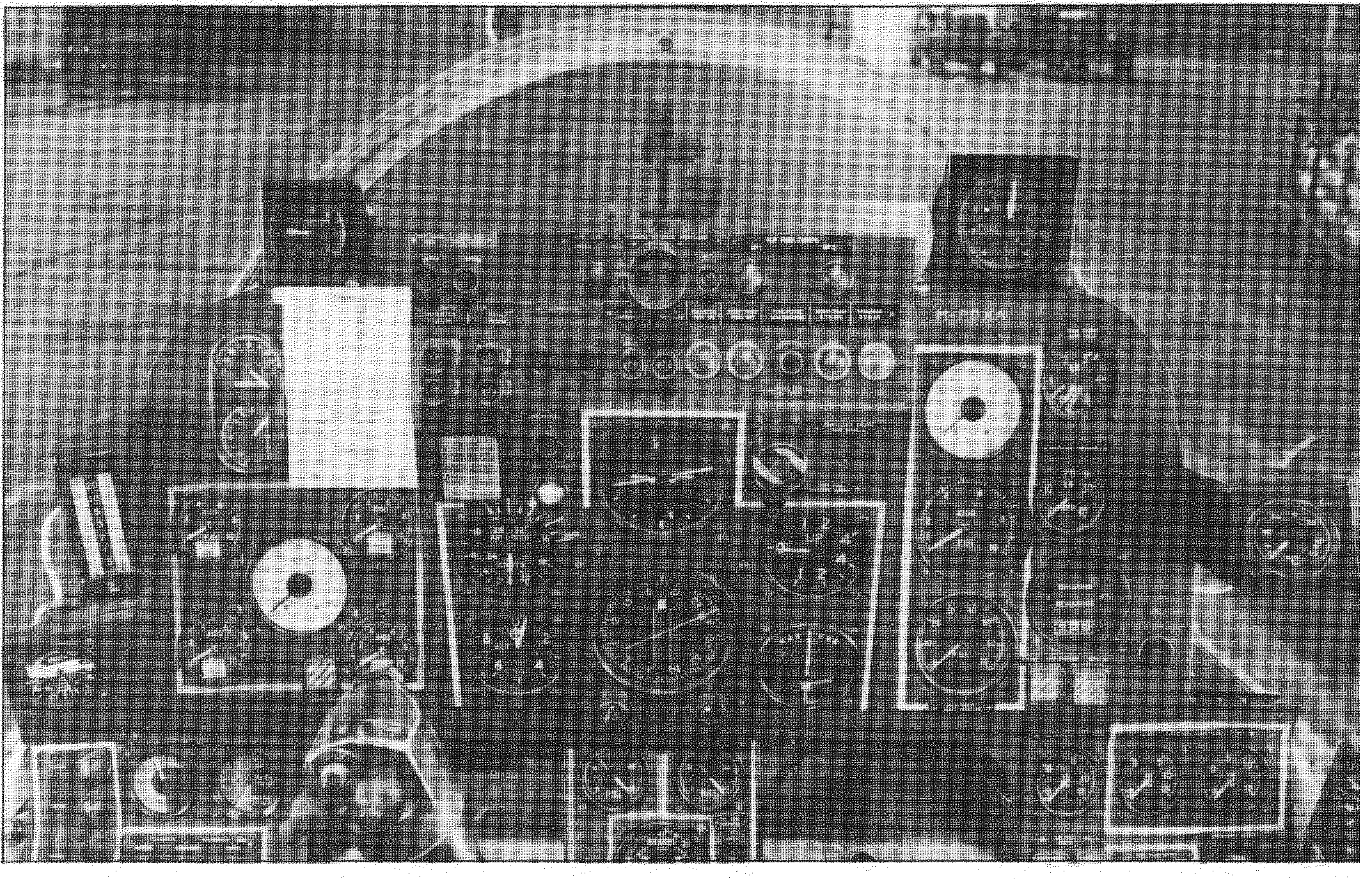


FIG.4a. THE INSTRUMENT PANEL

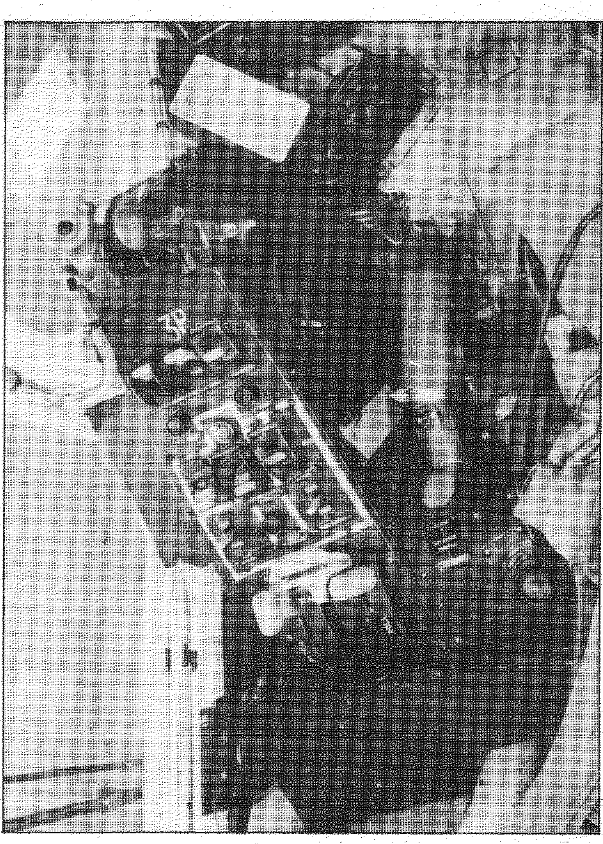


FIG.4b. LEFT HAND CONSOLE WITH ENGINE CONTROLS

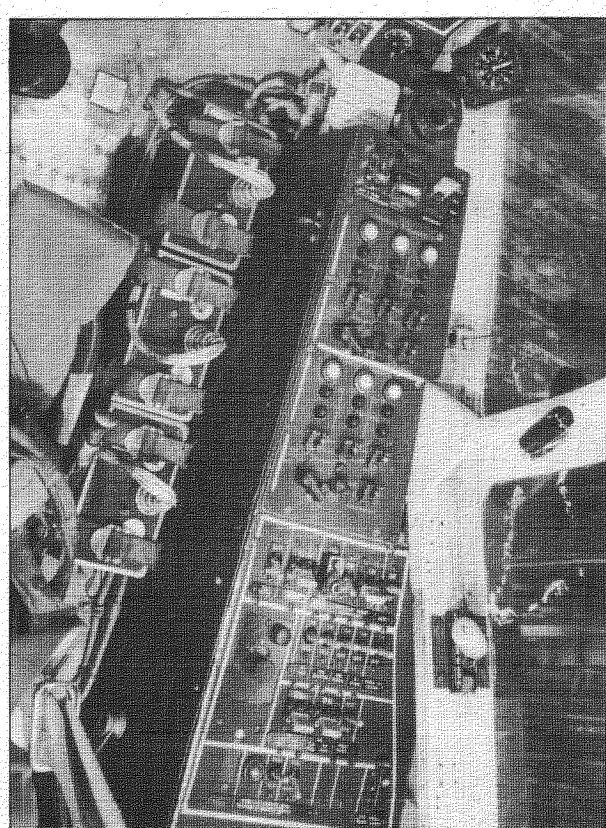


FIG.4c. RIGHT HAND CONSOLE WITH ELECTRICAL & AUTOSTABILIZER PANELS

FIG.4. THE COCKPIT OF THE S.C.I.

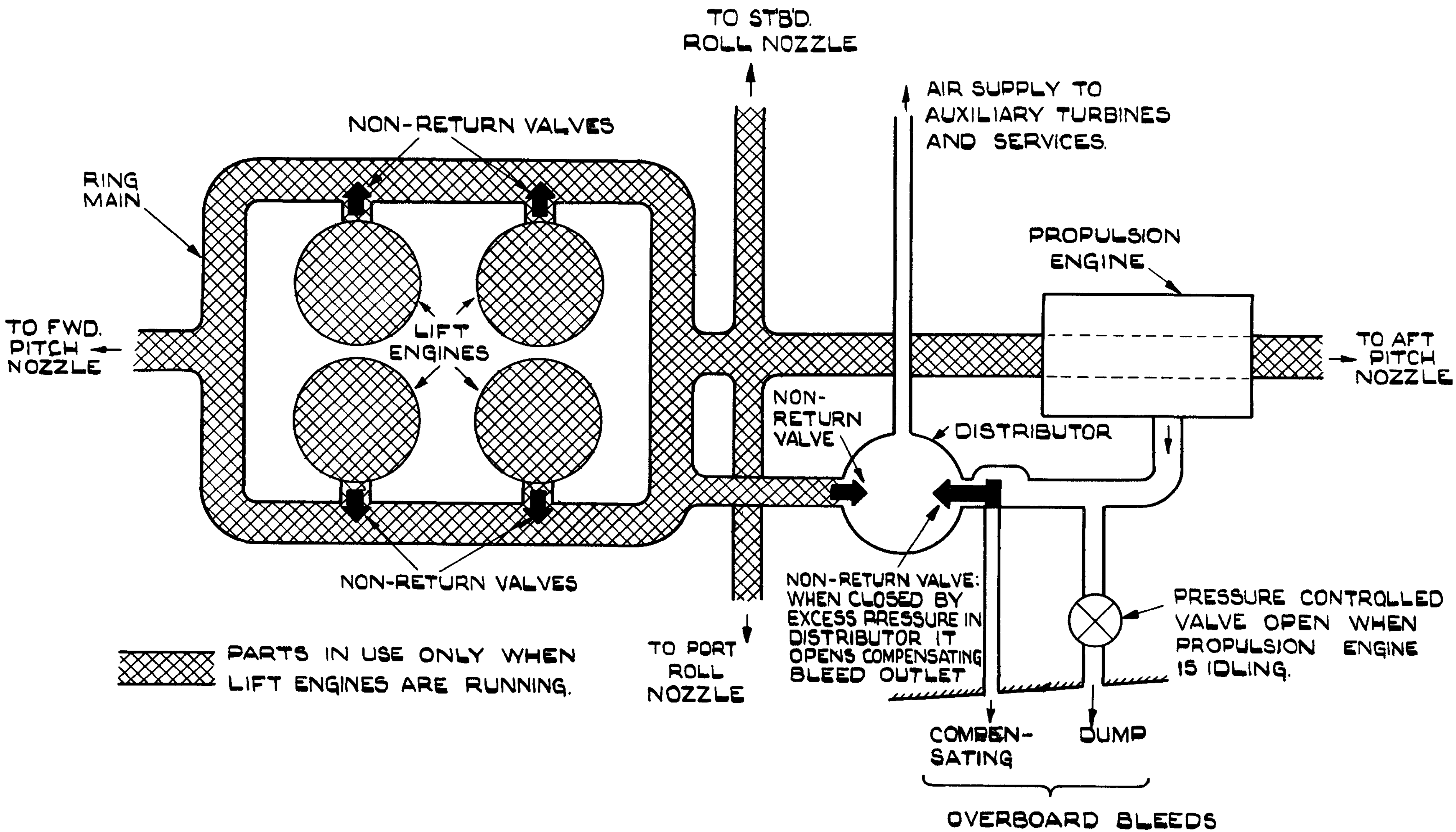
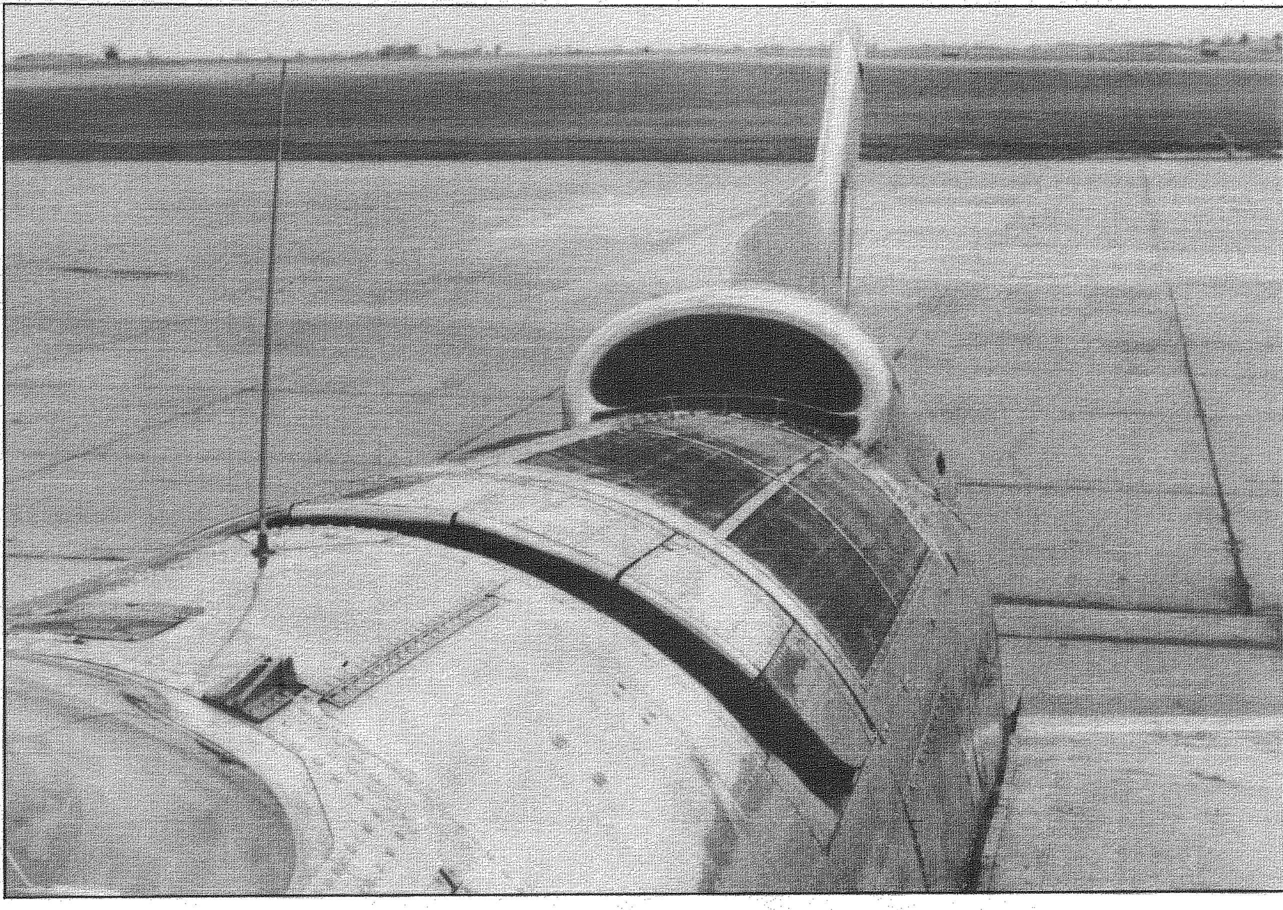
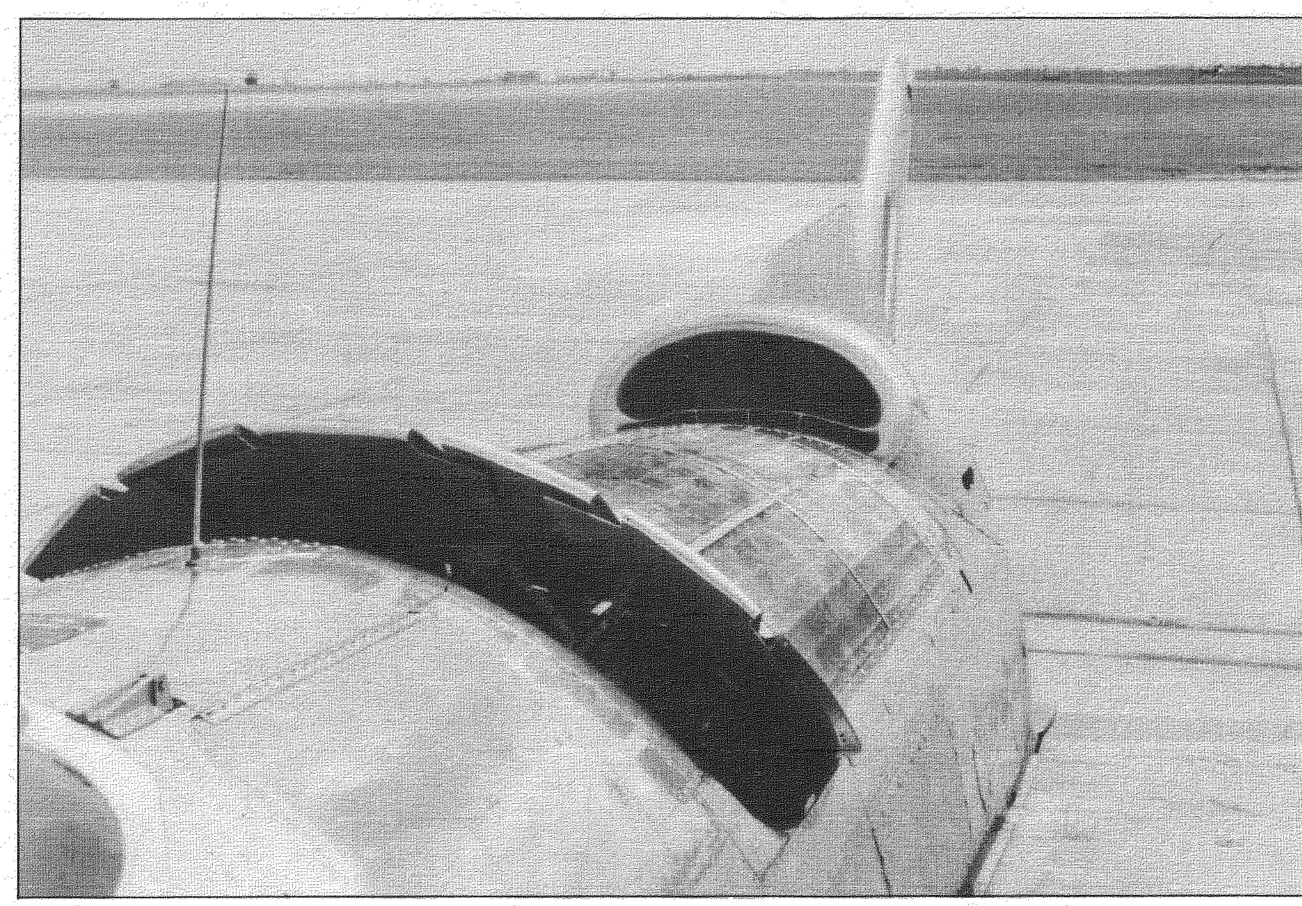


FIG. 6. AIR DISTRIBUTION SYSTEM DIAGRAM



LIFT ENGINE INTAKE GILLS CLOSED



LIFT ENGINE INTAKE GILLS OPEN

FIG.5. ENGINE INTAKES

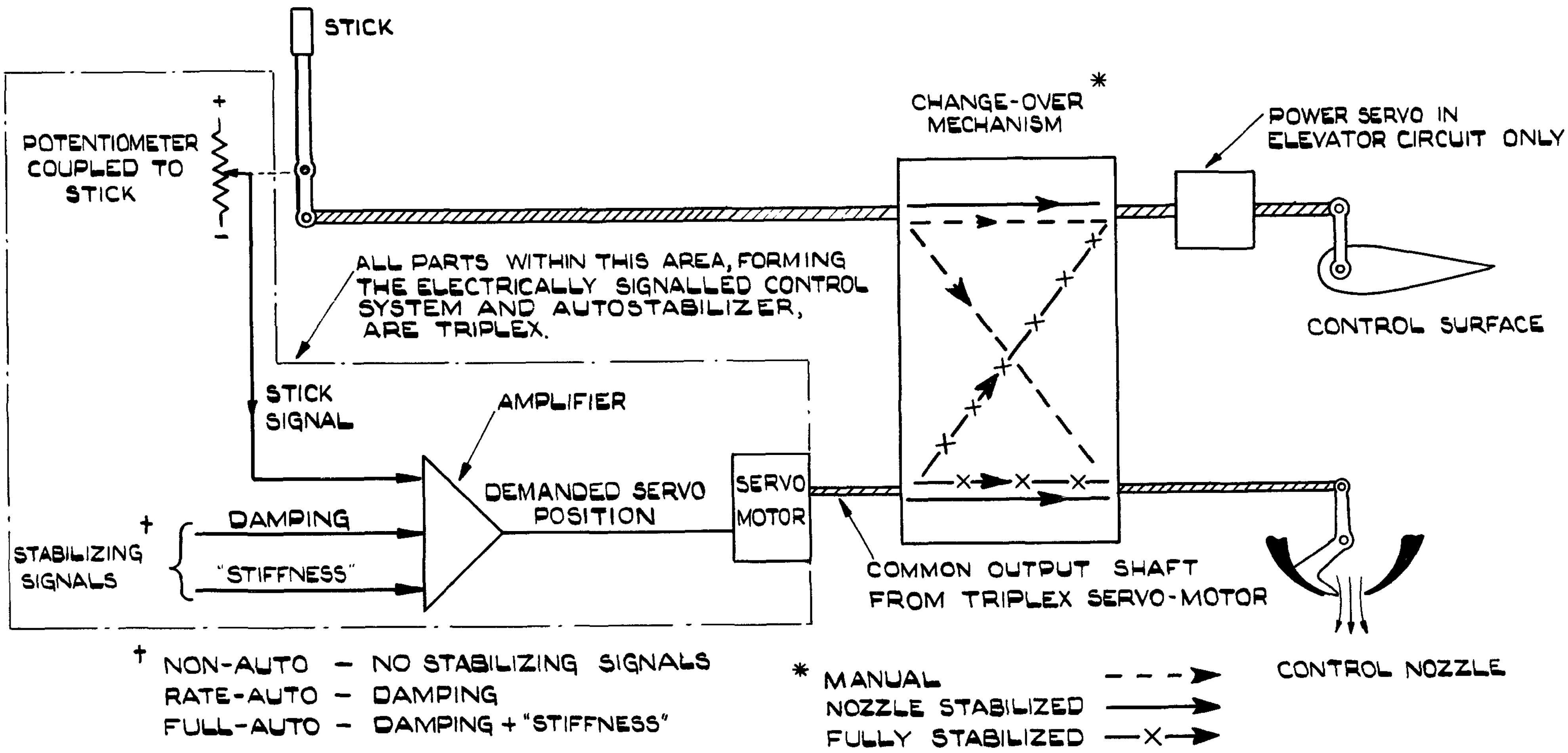


FIG. 7. DIAGRAMMATIC REPRESENTATION OF CONTROL AND AUTOSTABILIZER SYSTEM

FIG.8. GANTRY USED FOR TETHERED HOVERING AT SHORT BROS. AND HARLAND LTD., BELFAST

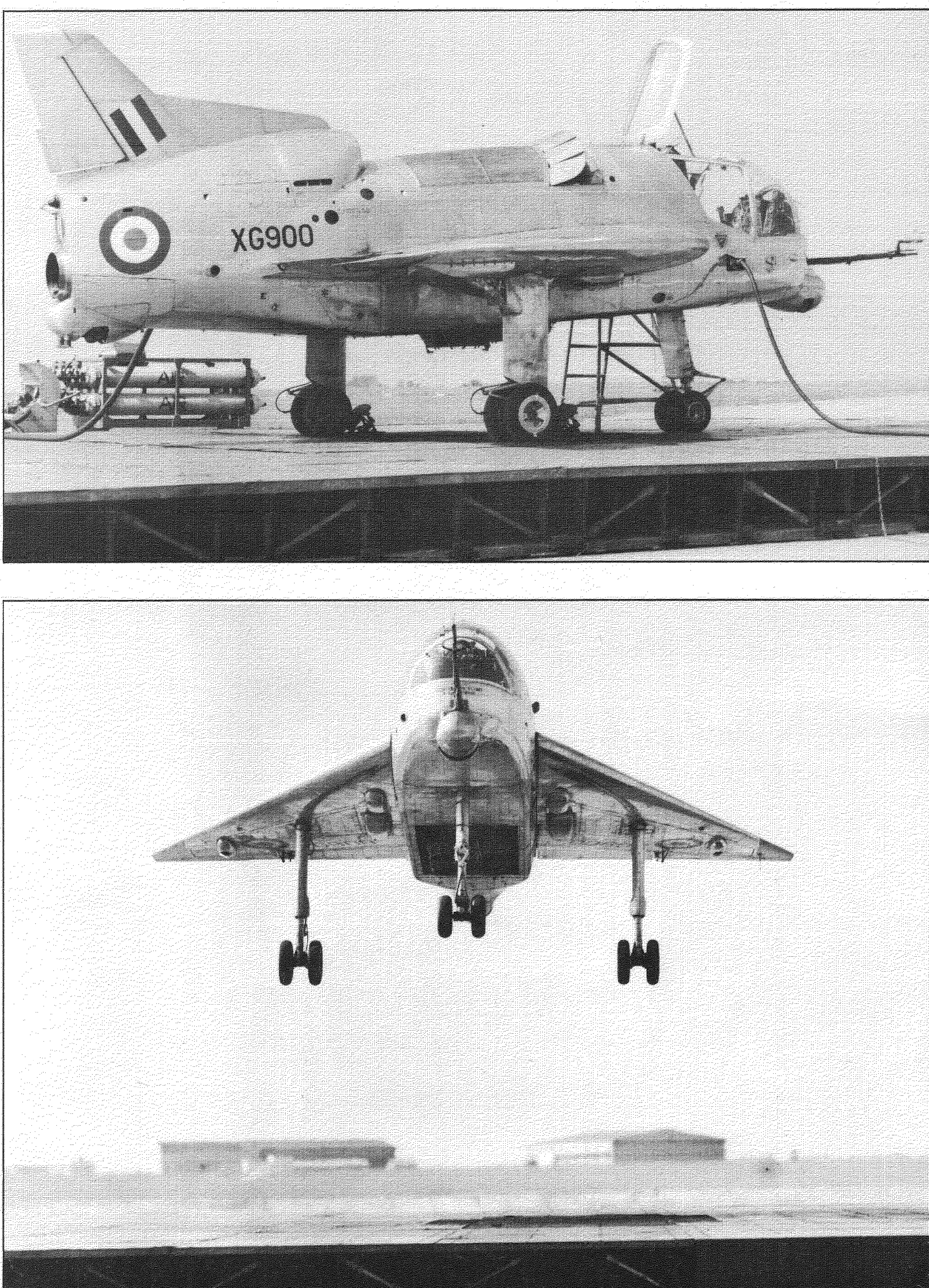


FIG.9. THE PLATFORM FOR VERTICAL TAKE-OFF

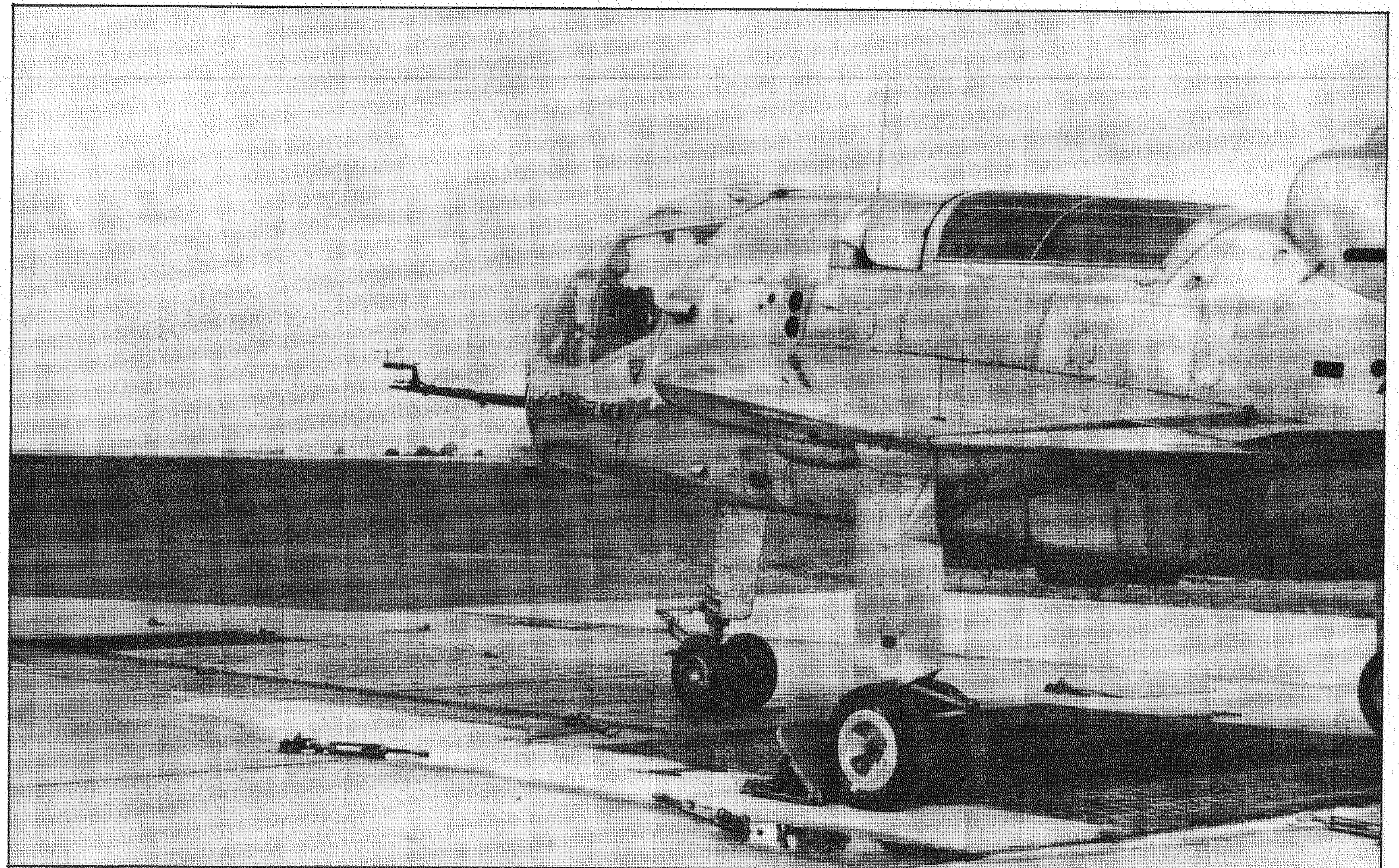


FIG.10. ENGINE RUNNING PIT MODIFIED FOR USE AS A TAKE-OFF BASE

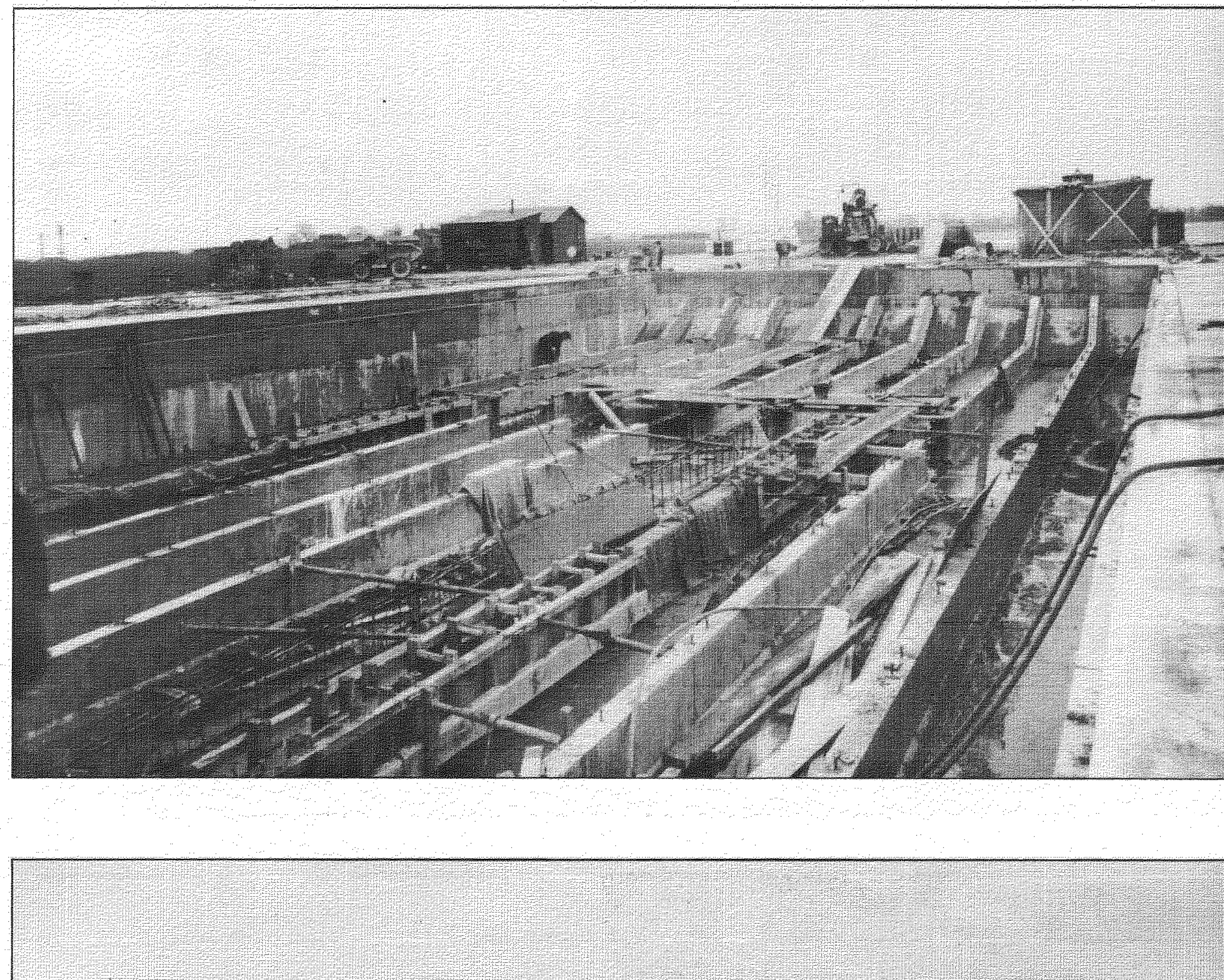


FIG.11. NEW TAKE-OFF BASE UNDER CONSTRUCTION AT BEDFORD

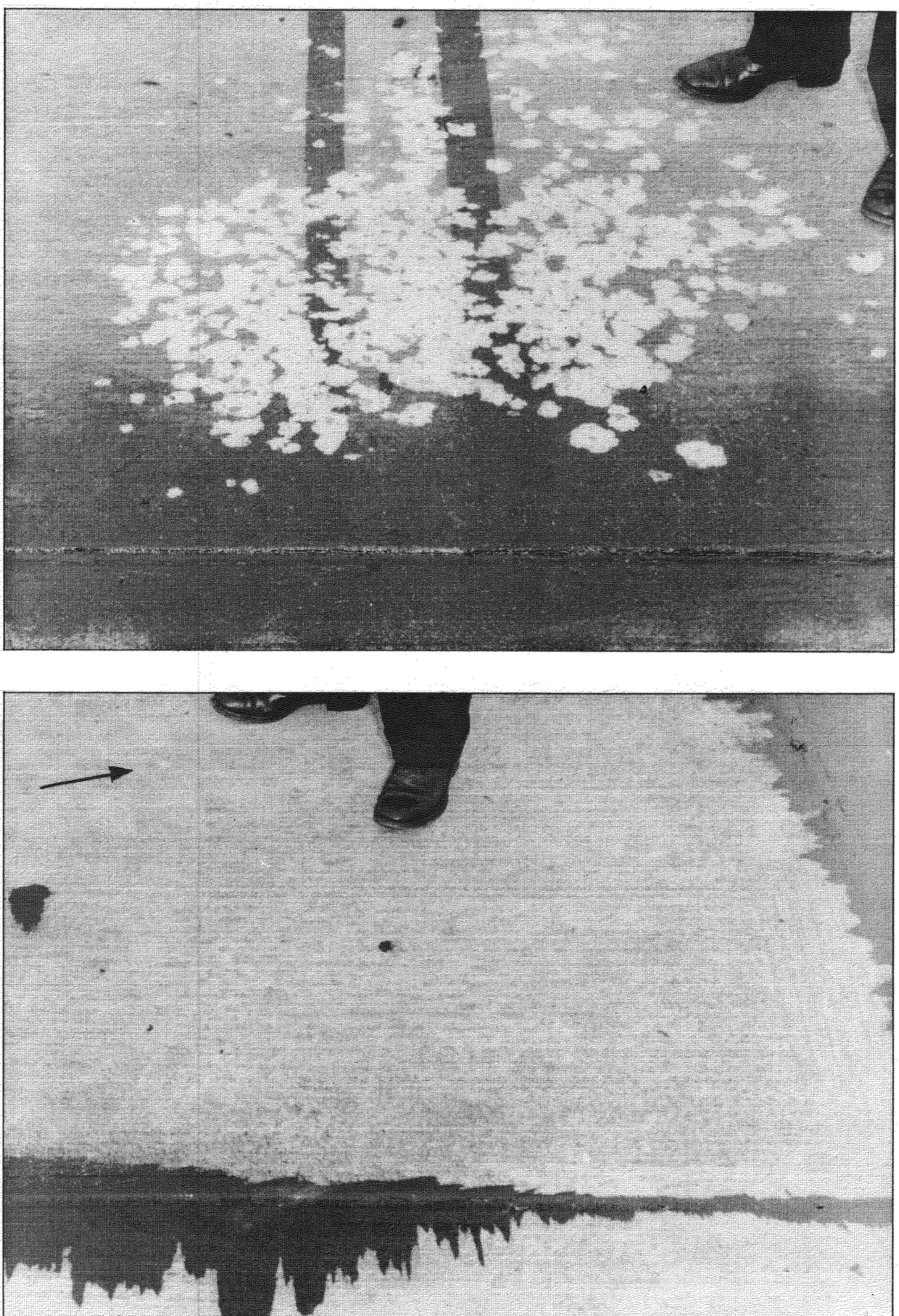


FIG.12. EXAMPLES OF DAMAGE TO CONCRETE SURFACE AFTER VERTICAL TAKE-OFFS

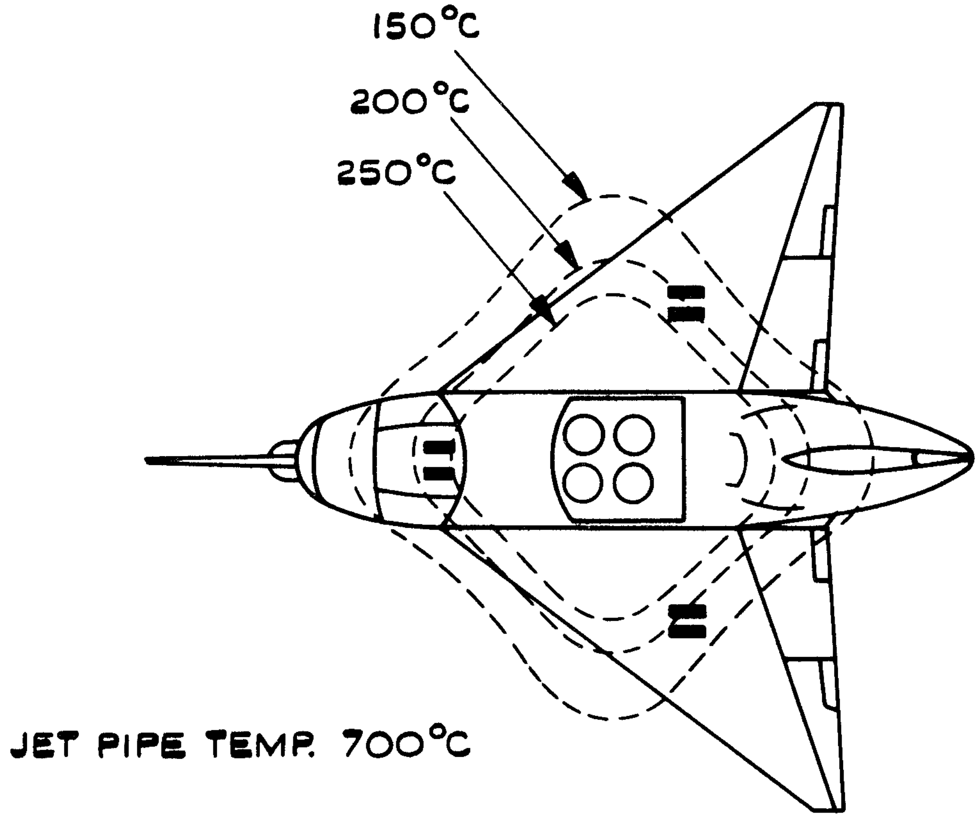


FIG. 13. ESTIMATED DISTRIBUTION OF GAS TEMPERATURE AROUND UNDERCARRIAGE.

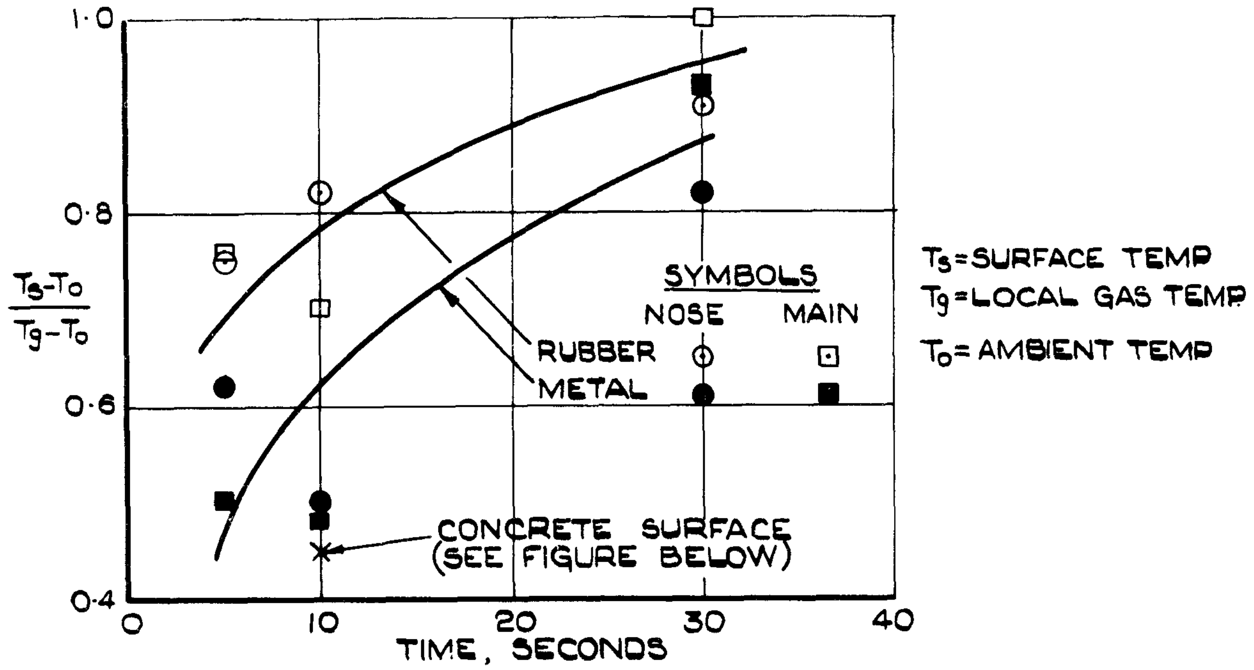


FIG.14 (a) S.C.I UNDERCARRIAGE HEATING RATES

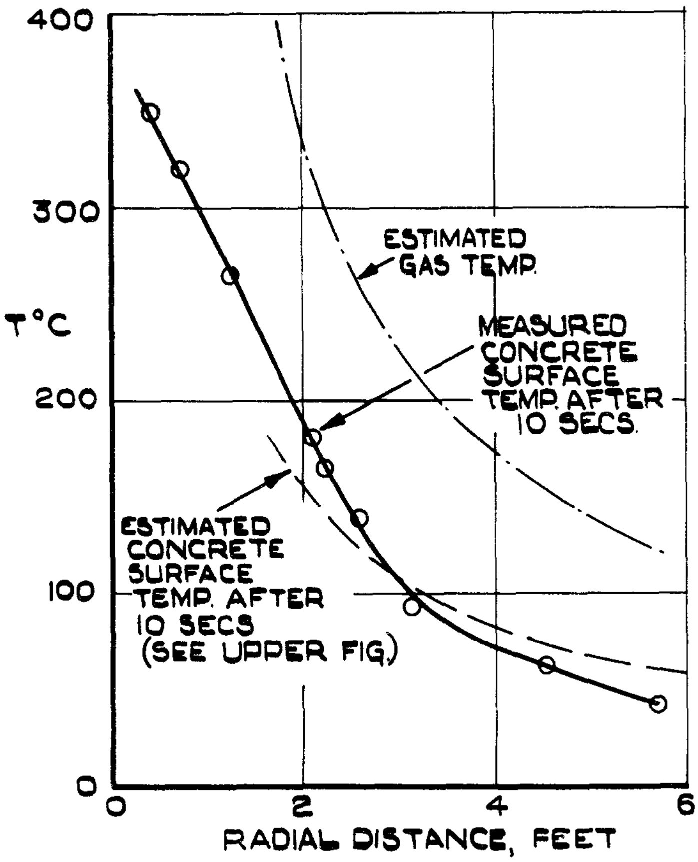


FIG. 14 (b) CONCRETE SURFACE HEATING RATE

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In the course of the research investigations on the S.C.1, considerable experience has been obtained on the general operating characteristics of VTOL aircraft. The aircraft has been operated from normal runway surfaces as well as from a special platform, and the associated ground suction, erosion, re-circulation and other effects are discussed. A detailed description of the aircraft and its equipment is included, and the serviceability and maintenance record of the aircraft is reviewed, with better results than might have been expected for an aircraft of the complexity of the S.C.1.

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