The Development of the Skeeter Helicopter

by

T D NISBET, A F R Ae S

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W /Cmdr R A C BRIE (*Vice-President*) *in the Chair*

INTRODUCTION BY THE CHAIRMAN

The CHAIRMAN, in introducing the Author, expressed pleasure in welcoming Mr NISBET who was a Founder Member of the Association and an Associate Fellow of The Royal Aeronautical Society

Mr Nisbet was educated at Glasgow Academy and the Royal Technical College, Glasgow He joined G & J Weir, at Cathcart, in 1936, as an apprentice and was engaged in the early development work on Autogiros and the first helicopters in this country He was for a short period Assistant Ground Engineer at Scottish Aviation, and for a further short period he was engaged as a junior draughtsman with Mr Hafner in the AR III Construction Company

In 1941 Mr Nisbet rejoined G & J Weir as Assistant to the Chief Engineer of the Aircraft Department, again being engaged on helicopters When this department was transferred to the Cierva Autogiro Company in 1943, Mr Nisbet became a Junior Technical Officer and in 1946 was made Assistant Chief Mechanical Engineer In 1950, he was appointed Engineer in charge of mechanical tests

When the Cierva Autogyro Company was disbanded in 1951, Mr Nisbet joined the Helicopter Division of Saunders-Roe Ltd , as Development Engineer and has subsequently been promoted Chief Development Engineer He was responsible for the co-ordination and application of Design Department requirements in connection with research and development of helicopters He was also responsible for tests and flight trials of helicopters

INTRODUCTION

The paper describes some of the highlights of the practical development work carried out by the Saunders-Roe Helicopter Division Team, mainly on our " Skeeter " Marks 5 and 6 helicopters This work has succeeded in developing the aircraft into a practical and safe working piece of machinery Inevitably, this has taken some considerable time, as the basic principles and engineering of any helicopter are more complex than those of a fixed-wing aircraft

The paper is concerned mainly with the " Skeeter " Mark 6 which represents the results of progress to date, and hence this machine will be briefly described

Military versions of the Mark 6 are now being supplied to both the British Army and Air Force, and may also equip the armed forces of Western Germany Civil potentialities include crop spraying and dusting, surveying, airborne inspection of power and pipelines, police, Customs and Post Office work, club flying, training and use as a personal transport machine

The Saunders-Roe " Skeeter " Mark 6 is a single-engined, single rotor, two seat helicopter with a tail rotor for torque compensation and yaw control

The crew of two are seated side-by-side in the cabin Their field of vision is excellent A full set of dual controls is available, allowing the helicopter to be flown from either seat, or to be used as a trainer The " Skeeter " is equipped with all essential instruments, including those necessary for night and instrument flying The radio is fitted on the floor between the crew

The aircraft is powered by a de Havilland " Gipsy Major " 201 helicopter engine (200 B H P Maximum One Hour Rating) It is of the 4 cylinder, inverted, in-line type and is fitted with a direct fuel injection system The engine is installed transversely, the drive for the main rotor being taken from the rear end of the crankshaft on the starboard side of the aircraft Fan cooling is provided through a starboard intake

Transmission is via a primary gearbox installed at the starboard end of the engine crankshaft, an intermediate shaft, and a secondary gearbox mounted centrally above the engine and attached to the fuselage centre section The secondary gearbox supports the main rotor shaft A centrifugal clutch is incorporated in the primary gearbox and this can be overridden by a manual control to enable the engine to be run up independently of the rotor The tail rotor is driven from the secondary gearbox through shafting and two subsidiary gearboxes

Each of the main rotor blades consists of a wooden secondary structure bonded to a steel tubular spar, the whole being covered with fabric The leading edge is plywood covered The blades are twisted and untapered The two-bladed tail rotor is of ' improved wood ' construction

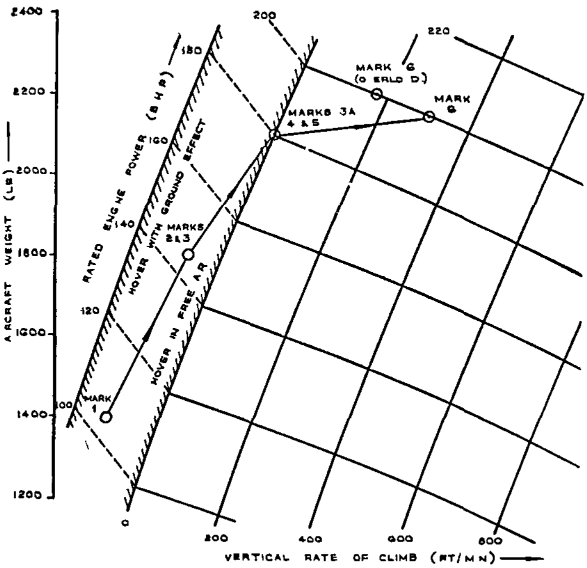
Full dual control is fitted so that the aircraft may be flown from either seat The azimuth and pitch controls are of the conventional type, utilising a ' spider ' in the rotor system in place of the usual ' swashplate ' The aircraft type rudder pedals change the pitch of the tail rotor, giving yawing control Electrically-operated control trimmers are provided There is a special interlinkage of the throttle and the collective pitch lever

The aircraft is of all metal construction with the exception of the rotor blades The forward fuselage is a conventional light-alloy structure incorporating a crashproof tank situated behind the pilot's seat The centre section, which also constitutes the engine mounting, is fabricated from steel tubes to facilitate engine and transmission maintenance The rear fuselage is of light-alloy monocoque construction, enclosing the shafting and gearboxes which drive the tail rotor The main undercarriage, which is of the hydraulic shock absorber type, is attached to the fuselage centre section The nose wheel undercarriage is mounted under the forward fuselage

The present Saunders-Roe " Skeeter " Mark 6 (military designation Mark 10 & 11) helicopter is derived directly from the Mark 2 machine which first flew in October, 1949, being powered with a 145 B H P de Havilland " Gipsy Major " engine   This Mark 2 was in fact a completely re-engineered derivative of the original " Skeeter " Mark 1 helicopter, which was essentially an experimental flying test bed

The Marks 3 and 4, which followed were intended for military use, and were fitted with the 180 B H P Blackburn " Bombardier " 702 engine These machines incorporated considerable redesign (in addition to being re-engined) The Mark 5 civil machine again used the " Bombardier " 702 engine, but incorporated many design improvements resulting from the accumulation of experience on the previous aircraft and, of course, was designed to carry different equipment with improved accommodation for the occupants

VERTICAL CLIMB PERFORMANCE



SEA LEVEL INTERNATIONAL STANDARD ATMOSPHERE (+15 C)

Fig 1   Vertical Climb Performance Carpet

The effect of this continuous overall development of the aircraft on its performance is demonstrated in the Performance Carpet shown   This covers the major parameters of aircraft operating all-up-weight, engine power output, and vertical rate of climb achieved (if any !)   As may be seen, the improvement from Mark 1 to the Mark 5 was very limited, this was explained by the fact that beneficial effects of the power-increase were largely negatived by the increased tare weights necessitated by stressing and mechanical consideration   It is only from the Mark 5 to the Mark 6 that the power increase has really paid off   The introduction of the Rocket Boost System has made a dramatic difference to the picture for short-period operations

A " family tree " which orientates the major relationships between some of the development problems which occurred is shown, and is self explanatory

Before discussing several of these subjects individually, it will be convenient to list the major facilities which are available at Saunders-Roe for such development work

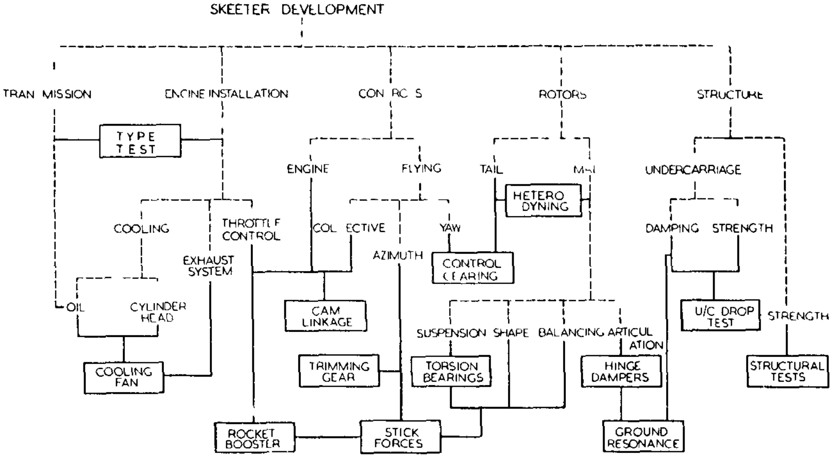


Fig 2 Development " Family Tree "

MAJOR TEST FACILITIES

(*a*) *Rotor Test Tower*

This tower has been a valuable aid in the development of the Skeeter rotor system and particularly in the diagnosis of troubles associated with blades and their suspension systems Although relatively simple, it is capable of being " flown " since a complete control circuit is incorporated within it Lift and torque balance mechanisms are fitted, so that the performance of rotor blades can be established

(*b*) *Rotor Test Pit*

This facility has been used for pulse-jet running, and has been designed to reduce noise levels Although not used as yet for the " Skeeter " it will figure in future programmes

(*c*) *Helicopter Instrumentation Gear*

At a recent paper to the Association (Ref 2), this equipment was described in detail It has proved to be a most valuable practical and accurate tool

(*d*) *Structural Testing Equipment*

A subsonic wind tunnel and an analogue computor are also available and have been used

GROUND RESONANCE

It is fair to say that the major obstacle in the development of our " Skeeter " helicopter has been the problem of ground resonance (Ref 3)

This phenomenon is, of course, common to all helicopters with articulated rotor systems, and was, in fact, a source of trouble even with the early Autogyros The " Skeeter " suffered from a particularly violent form however, and was quite unacceptable as a working machine until this danger was eliminated Naturally, ground resonance did not occur regularly, but a suitable set of conditions were occasionally present which were conducive to resonance This condition could be initiated by any suitable disturbance, such as those due to a run-on landing or an uneven surface or a rough engine, or a prolonged landing with partial load on the wheels

" Ground resonance " is a divergent oscillation of the helicopter on its undercarriage It is not associated with the rotor system in itself, but depends on a combination of fuselage, transmission, and undercarriage characteristics, in addition to those of the rotor The main parameters to be considered (*i e*, those which may be varied on a given machine) are rotor blade damping, undercarriage leg damping and tyre stiffnesses It will be noted that the two associated with the undercarriage may vary with the amount of aircraft weight on wheels

It was decided to attack this problem from two standpoints, theoretically and by practical full-scale test on an aircraft

For the theoretical approach it was essential to provide technicians with accurate data on the natural frequencies and dynamic stiffnesses of the fuselage/undercarriage system, together with the effect of lift on these frequencies

Earlier, a number of shake tests using vibrating masses actually attached to the rotor hub drive shaft had been carried out by the Cierva Autogyro Company However, the degree of excitation given by this means proved insufficient, as it was found that the relatively small amplitudes obtained could give misleading results The method of controlling the frequency of this out-of-balance was also troublesome inasmuch as the driving motor had to be remote from the aircraft, being connected through universally jointed drive shafts

It was therefore decided that for further tests on the " Skeeter " an externally excited spring system should be used The impedance test rig used is driven by a variable speed electric motor, which is geared down through Vee belts to a large flywheel From this flywheel there are two connecting rods, one to the balance torsion bar and the other to the main torsion bar, the phase relationship of these bars being 90° which was found to effect the best balance The output end of the main torsion bar being connected to the aircraft through a lever and a light push-pull rod A lift mechanism in the form of a Chinese balance hung from the hangar roof was used to vary the weight on the wheels of the aircraft By adjusting the lengths of the input and output levers around the main torsion bar, the effect of spring rate could be varied It will therefore be seen that the frequency of oscillations, the spring output and the lift could be altered to give their effects for the theoretical investigation

A motor-car type brake and drum were fitted around the torsion bar output so that the aircraft could be damped should the motions become too violent, or alternatively, the aircraft could be violently shaken with a known frequency

With this rig it was essential that the instrumentation should give ready answers and that all resonance could be accurately picked up Accurate speed control of the motor was also required, the order obtained being within one r p m in approximately 300 r p m

The instrumentation consisted of two methods of recording resonance , by means of photographed lissajou figures and by measurement of frequencies on a Hughes Pen Recorder, these records being obtained simultaneously An oscillograph was used to display Lissajou figures, the supplies to this oscillograph were from displacement pick-up units through integrator, attenuator and amplifier systems to the x and y plates of the oscillograph It was found by experiment that Lissajou figures gave an excellent method of detecting these resonances The input or the output pick-up could be isolated so that calibrated displacements could be measured on the oscilloscope tube, it is known when a Lissajou figure is displayed whose axes are 45° that resonance of a natural frequency has been found, and by slowly varying the speed of oscillation the Lissajou figure would topple in a clockwise or anti-clockwise direction By taking a series of photographs when recording, it was possible to accurately detect resonant frequencies The Hughes Pen Recorder received a signal from a small magnet indicator mounted on the driving flywheel, this signal appearing as a blip on the Hughes Pen Recorder trace Mains frequency was used on a separate pen as a frequency datum and a cross trace was made on a third pen to show the exact instant of oscillograph camera operation

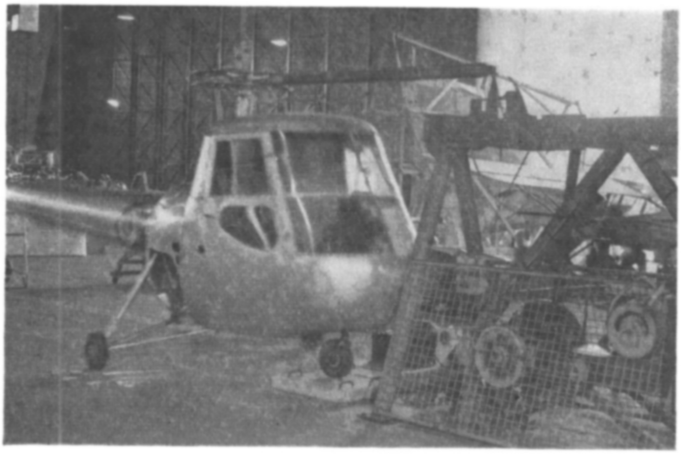


Fig 3 Impedance Test Rig in operation

This instrumentation proved itself to be most useful in cutting down the amount of time required for a complete survey of the aircraft, in fact, a full scale check of the " Skeeter " was carried out within two weeks

As mentioned earlier, the undercarriage damping, together with relative tyre stiffness and damping of the blades around the drag hinge are the three easily controllable forms of damping available in a helicopter These components were also tested separately and are discussed later

In parallel with the impedance tests the full scale ground resonance tests were carried out In these tests undercarriages with five different damping rates were used in combination with five different damper settings

The aircraft was restrained at a central point beneath the rotor, and snubber cables were attached to the top of the pylon The tail of the aircraft was ground picketed by means of a simple spring loaded snubber Yaw of the aircraft was controlled by lashing the tail to two further ground pickets on either side of the aircraft and a lashing was used also to restrict the nose movement of the aircraft If aircraft oscillations became too violent, external restraint in the form of hand cam-operated cables could be used to snub the aircraft

It is important to note that the snubbing arrangements was such that the helicopter had complete freedom of oscillations, with large amplitudes Only when snubbing was applied, in actual cases of ground resonance was this freedom restricted

The instrumentation for these tests consisted of two potentiometers driving two pens of a Hughes Pen Recorder, one potentiometer being used to measure the lateral motion of the aircraft and the other to measure pilots for and aft azimuth control stick movement At first, it was not known precisely how to excite the " Skeeter " to produce resonance at will The first attempts at excitation were made by jerking the machine laterally, and subsequently attempting to excite the natural frequency of the machine Neither of these methods proved successful

By experiment, it was found that if the pilot rotated his azimuth control column in the direction of rotation of the rotor, suitable frequencies could be induced causing the aircraft to oscillate By close collaboration of the test pilot and a ground observer a satisfactory method was soon developed The observer in charge of instrumentation became sufficiently familiar with the equipment to be able to " lead " the pilot's stick stirring This approach was made possible by the use of a pen recorder trace which produced immediate records

Complete ranges of rotor r p m and collective pitch settings corresponding to rotor thrusts of up to the order of 85% of the aircraft all-up were covered in these tests Cine camera recordings were taken throughout

The effect of drag hinge damping on the helicopter roll oscillations is shown in Fig 4, which covers the range undercarriage and blade damping values examined Incidentally, during these tests, on one occasion ground resonance was not completely suppressed with the snubbing gear The trailing edges of the blades were damaged and the interblade snubbers failed in compression This gives an indication of the violence of the resonance of this aircraft

With undercarriage damping rates appreciably higher than those originally used, a condition of near ground resonance could still be achieved, even when using the " safe " figure of blade hinge damping previously obtained

However, as a result of these tests, completely safe combinations of drag hinge and undercarriage dampings were evolved It was found that a damping rate equivalent to a minimum of 8 lb pull-off force at the tip of the blades and a damping rate of the undercarriage of 1,500 lb in sec would make the aircraft free from instability These figures have been subsequently factored to allow user margins

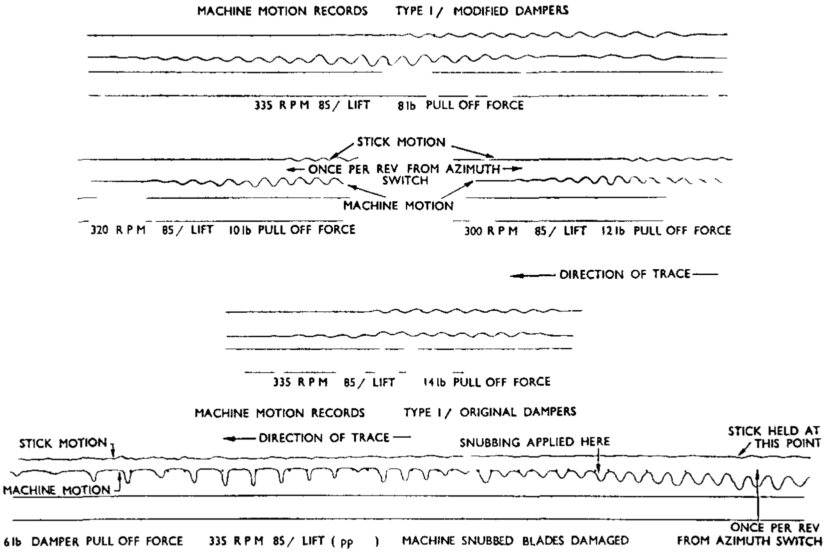


Fig 4 Pen Recordings showing Aircraft motion and effects of Undercarriage and Blade Damping

Following these tests, an aircraft was subjected to a severe programme of flight testing (both by ourselves and A A E E) using these recommended values This included operation from a variety of ground surfaces, protracted vertical take-offs and landings with aircraft hovering for appreciable periods with the wheels just in contact with the ground These tests confirmed that the aircraft is now free from ground resonance

Ground resonance of the helicopter is still a major problem in their design and development although much has been learned from both our theoretical work and the practical full-scale tests It is certainly fair to say that we are now in a very much better position to be able to solve this difficulty should it arise again on any of our future aircraft designs

UNDERCARRIAGE DAMPING

In the design stages of the " Skeeter," it was decided that suitable proprietary oleo legs were both too heavy and expensive, consequently, it was decided that we should design our own legs These legs have undergone a number of changes from those originally fitted to the Mark 1 " Skeeter," but they are still both simple and light

The undercarriage leg is essentially a simple piston submerged in oil and the cylinder is a thin steel tube ground internally A taxi or buffer spring is used towards the end of the piston stroke, this provides undercarriage suspension while the aircraft is on the ground

There are three essential features in our present piston design

(*a*) An annular orifice between the inside of the cylinder tube and the outside of the piston forms the main source of damping

(*b*) A blow-off relief valve which is preset to ensure that limited loads are transferred to the fuselage structure

(*c*) A simple Neoprene faced spring loaded clack valve to allow the oil to be transferred from the bottom to the top of the piston on the return stroke to prevent leg pumping

The damping rate of the undercarriage leg was found experimentally by timing the leg closure accurately with various end loads and by cross plotting to give damping in lb /ft sec Control of the damping rate of the leg is thus possible

Temperature effects on the hydraulic oil in the leg, were found to be quite marked and for comparative purposes test figures were reduced to 15°C (I C A N) The damping of the legs has been increased to 2,000 lb /ft sec , this figure being determined finally not from ground resonance requirements but from test work on the undercarriage drop test rig, and being well above the damping required to prevent ground resonance

Originally standard aircraft balloon-type tyres were fitted to the " Skeeter " From the results of static tests on the complete aircraft and of rig tests on these wheels, it was found that the tyre stiffnesses obtained were far too low Satisfactory values have been achieved by changing to a twin-contact tyre of the same size with considerably increased tyre pressure

Blade Drag Hinger Dampers

The " Skeeter " is now fitted with " stepped " friction dampers These are so designed that friction is increased with blade drag amplitude in such

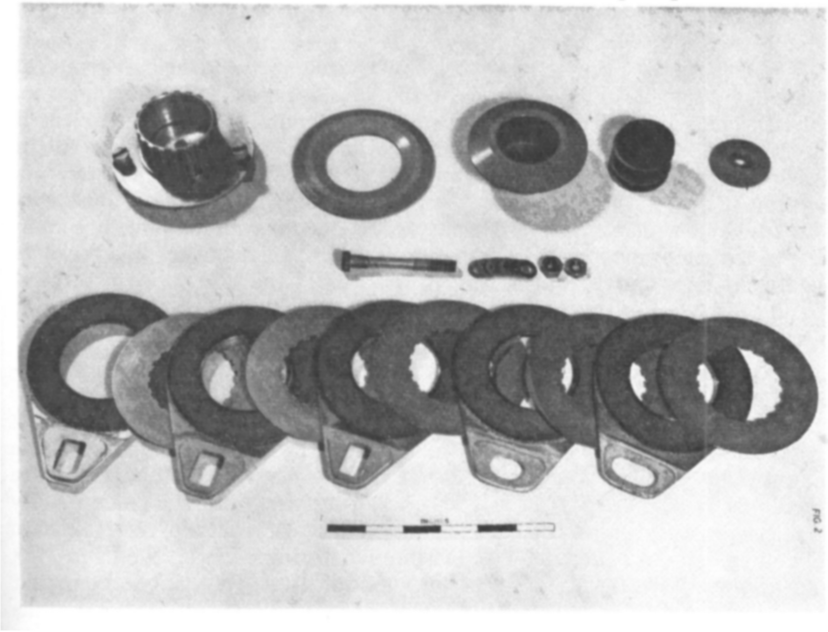


Fig 5 Blade Hinge Damper Assembly

a manner that a viscous damping conditions is almost obtained This is desirable in the prevention of ground resonance

Apart from the increased damping requirements, development work on the dampers has been associated with the need for relative freedom from wear and adjustment so that they may be left untouched for reasonably long periods of flying To obtain this, certain design features have been incorporated, one of which is the bonding of the Ferodo disc to either side of the hub attachment plates thus using the inner diameter of the bonded pack as a bearing surface

To facilitate this development a damper test rig has been designed which incidentally used the same driving motor as the impedance test rig, but incorporates a linkage to vary the amplitude of oscillation of the damper under test

A strain gauged bar is used to record the damper load and a simple potentiometer to measure amplitude, mains frequency is used to provide the frequency datum scale This damper test rig has been used to test varying forms of friction damper and can also obtain the characteristics of hydraulic dampers

It is not intended to discuss the respective merits of friction and hydraulic type dampers, but it is felt that if either are sufficiently well developed for an aircraft, satisfactory damping can be obtained

CONTROL DEVELOPMENT

Control forces from blade pitch change mechanisms or residual forces from rotor blades have been a cause of trouble for years In a number of cases with small helicopters this problem has been solved by " brute force " through fitting power controls This was the case with the Cierva W 9 with its tilting hub

A considerable amount of work is required in the development of an azimuth control which is acceptable to pilots As far as blades are concerned it has been known from Autogyro work since about 1935 that each element of the blade must approximately provide its own dynamic balance and in addition the aerofoil characteristics must be suitable, that is there must be no violent aero-dynamic pitching moment change with change of incidence Careful control of balance and blade shape during manufacture (especially that of the trailing edge) can eliminate the main sources of trouble from the blades arising from manufacturing tolerances The chordwise centres of gravity of blades of the size used in the " Skeeter," must be situated within a few thousandths of an inch between any one of a set

With the " Skeeter," during early test flights our pilots reported undesirable forces feeding back into the azimuth control stick As a result of this work, satisfactory characteristics have now been obtained In the first instance, strain gauges were used to measure the bending of the azimuth column, but results were misleading as it was possible to introduce false signals by the pilots grip feeding a bending moment into the column By modifying the spring of a standard 2-axis stick force desynn transmitter to give its maximum deflection with ten pounds load applied on the hand-grip, and also by changing the desynns to potentiometers, the stick force output could be recorded in the standard Hussenot galvanometer camera Results from this stick force measuring system proved consistent and accurate to within $\frac{1}{8}$ of a pound Control positions of both azimuth and pitch controls were also recorded Stable stick displacement versus aircraft speed curves have been obtained from the " Skeeter " Much of the undesirable forces in the azimuth control can be explained as follows It is known that their frictional torque, with small movements of the bearing assembly can be large, but when the movements become relatively greater, the frictional torque from the bearing assembly can become less and is then only prominent when the motion of the assembly reaches its reversal point This characteristic can be explained by considering the efficiency of the lubrication When the bearing is moved only a small amount the ends of the rollers cannot replenish their oil or grease supply, but when the motion becomes larger lubricant can be drawn between the working surfaces due to the motion of the balls or rollers When the torsion bearings are no longer moving, *i e*, at each end of the excursion, there is a period of dwell during which time a small amount of oil is squeezed away from the roller faces, so producing higher friction A rig has been made to oscillate the bearings under these conditions

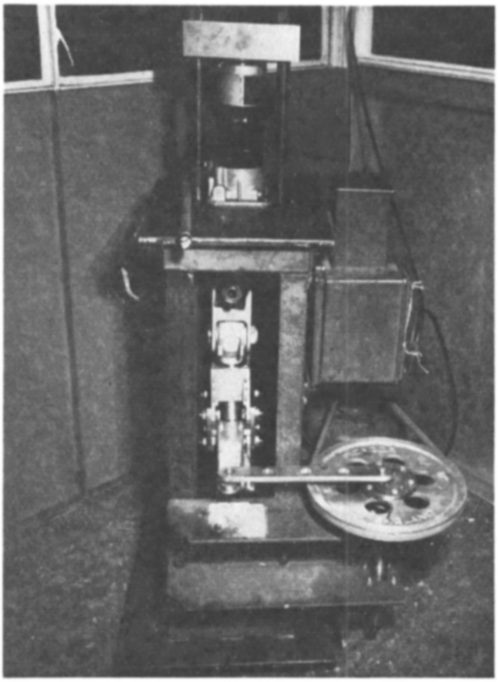


Fig 6 Blade Torsion Bearing Test Rig

The centrifugal loading of the bearing is simulated by a commercial hydraulic jack and the torsional excitation by means of a simple crank and electric motor In parallel with this running test, a number of static tests with bearings mounted back to back have been carried out to measure their frictional torque The frictional torque loads of some bearings are relatively high and it is only with specially developed and hand selected bearings that the lightness of control required in small helicopters may be achieved with this form of blade suspension It was found during the course of these tests that an extreme pressure lubricating oil was superior to any of the greases at present in use in helicopter controls, both regarding frictional torque and life

In spite of considerable development work, the blade torsion bearings still suffer from limited life, and there are strong arguments in favour of a torsion bar blade suspension system Such a system is now under active development and prototypes have been rig tested and flown.

The early Mark 5 aircraft had its collective pitch control interconnected with the lateral tilt of the rotor in such a way that when the pilot applied pitch to the rotor, he also applied approximately the correct amount of lateral tilt. This was quite satisfactory for normal power flight conditions, but during autorotation and especially engine-off flare-outs, it was found that an abnormal amount of lateral displacement of the azimuth control was required. It was, therefore, decided that this interconnection should be eliminated and the aircraft is now fitted with non-interconnected controls. Some stiffening of the control circuit was also carried out.

The throttle control has also undergone a major change. The original pitch/throttle combination was such that approximately half the throttle opening was controlled by the movement of the pitch lever, while the throttle twist-grip controlled the remainder, apart from acting as a fine adjustment. We have now been able to develop a suitable cam-linkage for the throttle/pitch movement so that once a given rotor r.p.m. has been established the collective pitch lever settings can be changed without further throttle movements. This cam-mechanism can be overridden by means of the throttle twist-grip. For training roles, a simple linkage has been fitted allowing the instructor to disconnect the pupil's throttle from his collective pitch control for practice engine-off landings. The dual collective pitch controls have been separated from their original mutual central location to provide a left hand pitch control for both pilot and co-pilot. The azimuth control bias gear which was originally operated by means of hand wheels, mounted between the pilots, has now been superseded by electrically actuated trimmers with the actuation switch mounted on top of the pilot's control column.

TAIL ROTOR AND CONTROL

In the early stages of development of the "Skeeter," a wooden three-blade tail rotor was fitted, but subsequently an all-metal tail rotor was introduced.

This metal three-bladed tail rotor was given extensive ground running and flight testing. It proved to require careful development and at one stage the blade root had to be strengthened in the skin area by means of Redux doublers.

It also suffered from heterodyning torsional vibrations between the tail and the main rotors, the resulting noise was disturbing to the test pilot. This heterodyning did not cause any serious mechanical problems.

During the development of the Mark 6 in which a more powerful engine was installed, it became necessary to increase the torque balance thrust from the tail rotor and also to give the pilot more yaw control. The opportunity was also taken to cure the heterodyning, by introducing a two-bladed teetering-hub rotor. The hub controls of this rotor were also stiffened. It was found necessary to sheath the blade tips with stainless steel sheet to avoid erosion. The rotor has now proved to be very satisfactory in service.

During the development of the tail rotor, various control gear ratio characteristics were tried, including a differential control giving an increase of sensitivity with pedal movement.

ENGINE INSTALLATION AND ASSOCIATED DEVELOPMENTS

Apart from the routine installation problems involved in the changes of engine type, and the development of the throttle/collective pitch cam-linkage previously discussed, the main problem from the helicopter standpoint has been that of engine cooling

The cooling fan design is derived from that fitted originally in the Cierva W 9 helicopter It is a small single stage axial blower which provides sufficient air to enable the conventional engine cooling system to be used In the W 9 the fan was driven through bevel gears and a quill drive shaft It was found that engine accelerations could shear the drive and that a slipping clutch was required with this arrangement

From this experience it was decided to use conventional Double Vee belts in the " Skeeter " These belts are running well beyond their normal rating both as regards pulley size and speed A number of belts manufactured by various firms were tried, and satisfactory running was not obtained until nylon cord Vee belts were used

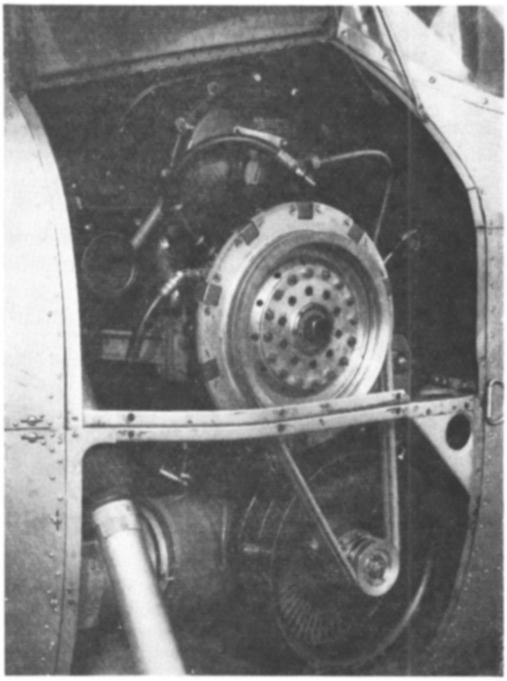


Fig 7 Port Side of Engine Installation

The cooling for the Mark 2 and 3 " Skeeters " (fitted with a 145 b h p D H " Gipsy Major " engine) was found to be quite satisfactory as designed but on fitting the 180 b h p Blackburn " Bombardier " to the Mark 4, it was found that although the mass flow was still adequate, a separate oil cooler receiving air from the fan had to be fitted Nevertheless the cooling of this Mark 4 gave some trouble It was found that an external ear type scoop fitted to the fan inlet was an advantage, but by flight testing with thermocouples mounted in the fan inlet it was found that the fan was drawing warm gas up to 35/40°C from the engine exhaust

Tests to determine the amount of cooling air supplied by the fan were carried out to provide data for cooling the 200 b h p D H " Gipsy Major " engine in the present Mark 6

The exhaust manifold system installed in the Mark 4 was such that each cylinder had a separate stub pipe, one pair of stubs being led to each side of the aircraft In consultation with De Havillands the exhaust system was redesigned, two of each of the four exhausts being led into a common pipe Both of these pipes exhaust on the port side of the aircraft away from the cooling fan

It was also found necessary to modify the outlet from the oil cooler This was made to exhaust outside the engine bay through the side of the cowlings and thus to increase the pressure drop through the oil cooler The previous internal fan exhaust had proved inefficient due to pressure build-ups existing within the cowlings

One further development problem involving the cooling fan has been that of its mounting The fan assembly was rigidly mounted on four bolts which provided the adjustment for the Vee Belts These bolts failed in fatigue within the mounting flange of the primary gearbox Fan frequencies were measured and as a result a suitable rubber mounting was designed which now insulated the fan assembly from vibration

TRANSMISSION

The two main problems in the development of a transmission system are the prevention of vibration and the provision of adequate life We have not had any serious troubles with vibration, this is no doubt due in part to careful design of engine and gearbox mountings, and of shaft supports

The life involves both wear and fatigue aspects On the fatigue side, confirmation of the design stressing assumptions has been obtained on both the Mark 5 and the Mark 6 aircraft, using our specially developed helicopter instrumentation equipment

This equipment was so successfully developed that on the Mark 6 “ Skeeter ” we were able to complete the whole of the flight strain gauge programme and partially analyse the results within eight days of the aircraft being made available for this work This equipment will also form the basis of future work with metal rotor blades on the Rotor Test Tower

The problem of fatigue is one which will always hinder the swift development of a helicopter It is true that as more knowledge of fatigue stressing is obtained the chances of fatigue failure will become remoter Nevertheless, it appears that it will always be essential to confirm the safe life of a component, either by running it on a completed aircraft or on a suitable rig The rig must impart exactly the same type of loading as that which would be experienced in operating conditions

Prior to the establishment of the Helicopter Type Test the Ministry of Supply decided that the complete machine should be ground run for 200 hours in conditions which were to simulate as closely as possible those found in a normal flight

The first test, on the Mark 5 aircraft, gave valuable information on the wear of transmission components

The Mark 6 machine has just completed test work on a Type Test to the latest Helicopter Requirements These tests were, in fact, more severe than the previous 200 hour ground running test, both in itself, and because of the increased engine power involved The test consisted of approximately

50 hours ground running followed by an additional 50 hours flying using engine power similar to those used in a normal Engine Type Test A close control of engine oil and cylinder head temperatures was necessary to meet the requirements and as a result of a series of exploratory tests, it was found that this could be achieved by installing adjustable shutters at the engine cooling fan entry and also at the oil cooler outlet These were controlled by the observer from the cockpit

We were able to complete these tests in a very short period of time This could be attributed to the aircraft maintaining a high degree of serviceability, and also to the fact that the complete series of tests had been previously programmed in great detail Log sheet layouts were carefully planned so that the test requirements, pilot's notes and observer's records were already in " report " form In the flight tests, up to 8 hours flying per day was achieved (with only one pilot available)

STRUCTURAL TESTING

Naturally, all ' Class 1 ' forgings and castings required structural test In addition, various major structural components have been tested to confirm stress analyses The problems involved did not differ essentially from those encountered in any structural testing work, and it is not proposed to deal with them in any detail

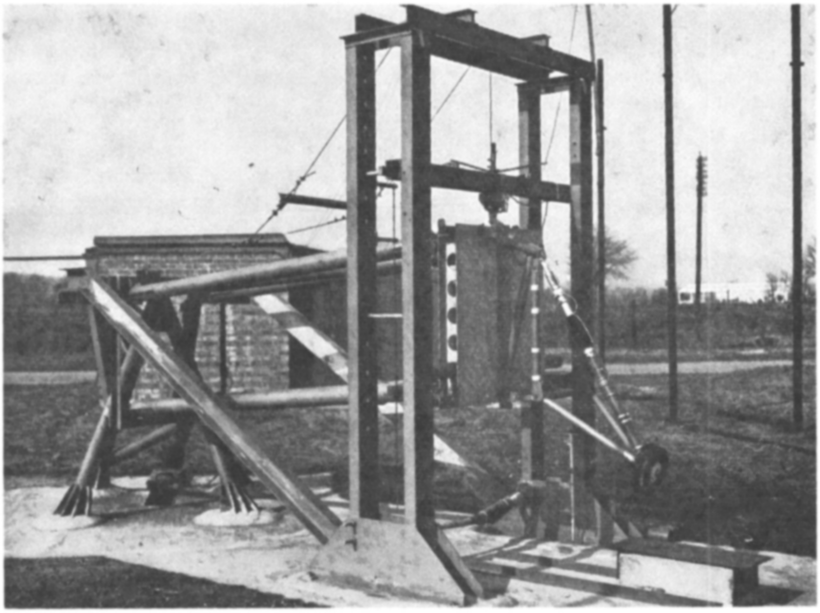


Fig 8 Undercarriage Drop Test Rig

A case of some exceptional interest is that of the undercarriage

Undercarriage Drop Tests have been carried out to meet requirements and to find the undercarriage reaction loads A rig with a small equivalent mass (200 lbs) had to be constructed since a rig of this nature was not available The design chosen was of the parallel linkage type using light-alloy tubing and a light -alloy loading platten on which an undercarriage can be attached   Care was taken to allow the rig to be easily adjusted in height, to allow rapid change of weights, and to provide a simple means of lifting the assembly prior to drop   A standard electrically actuated bomb release has been used as the dropping trigger

The rig is fully instrumentated around a Hughes Pen Recorder giving the history of rig travel, leg closure and the leg loads both at the attachment and within the leg   Mains frequency is used as a time base   The rig travel and leg motion are measured using wire potentiometers while loads are measured by strain-gauges

The equivalent ‘ mass ’ of the rig was found by oscillating it on a calibrated spring   The velocity at impact was checked by timing the free fall to find possible effects of the operating radius of the rig and of friction   From these experiments the ‘ effective airborne mass ’ and the drop height for various cases were determined

Contact surfaces can be varied and the extremes chosen have been from rough concrete and to a greased polished steel plate   Photographs show that the surface has little effect on tyre scrubbing

The “ Skeeter ” Rocket Booster System

A recent important and rather exciting development of our “ Skeeter ” series of helicopters has been the introduction of a rocket boost system (Ref 4)   The “ Skeeter ” is the first machine in this country to be equipped with this device   A boosted aircraft made its first public appearance at the S B A C Show at Farnborough in September, where its exceptional performance was demonstrated

Fig 9   Rocket Booster “ Skeeter ” in flight

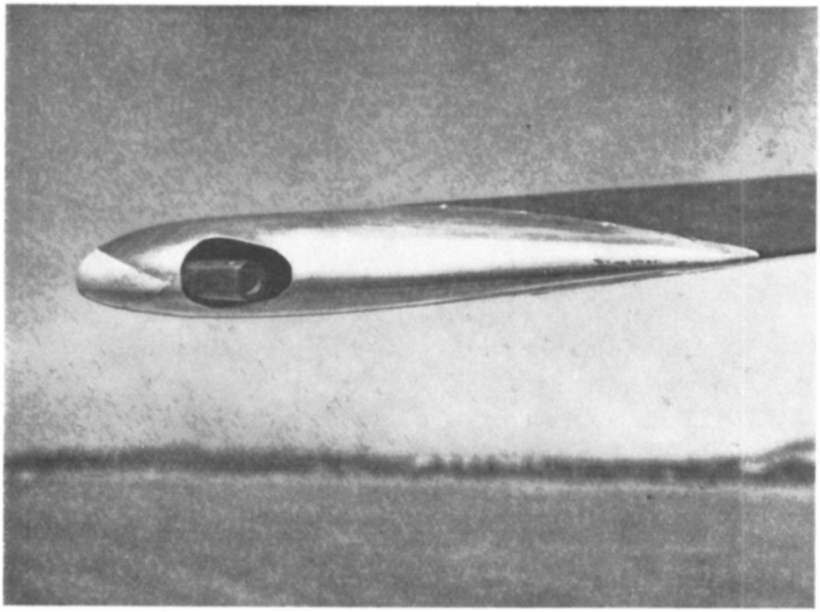


Fig 10 Rocket Motor at Blade Tip

For many operational duties, there are strong arguments in favour of the use of 'mixed power' systems in helicopters That is, where the primary power unit, which gives adequate power in forward flight, is supplemented by a booster system during take-off and landing when substantially more power is required for short periods

The rocket booster system for the Saunders-Roe " Skeeter " helicopter has been developed in collaboration with the engine manufacturers, D Napier & Son Ltd It gives the machine greatly enhanced vertical flight and climb performances together with a greatly decreased gliding angle in the event of piston engine failure

The system is simple and can be fitted to the standard " Skeeter " helicopter, only minor modifications being required to the basic aircraft

The liquid mono-propellant used in the Napier Rocket Motors is H T P (Hydrogen Peroxide diluted with not more than 20% by weight of water)

The H T P fuel is stored in a removable dome-shaped tank mounted above the rotor hub and is pumped to the rocket motors at the blade tips by the centrifugal action of the rotating rotor The blade feed pipes are connected to the tank through flexible hoses from a common gallery pipe

These feed pipes are situated inside the main spar tubes of the rotor blades, being supported at intervals by plastic spacers which locate the pipes centrally in the spar tubes

On entering the motors, the H T P is decomposed into superheated steam and oxygen The generated gases then pass to a nozzle which causes them to be ejected at high velocity to provide thrust reaction

The rocket motors are attached to the ends of the blade spar tubes by bolts through flanged fittings on both the motors and the tubes

Rocket motor control is effected by a solenoid operated On/Off valve In parallel is a vent pipe which admits air to displace the Hydrogen Peroxide in the pipelines to the motors when the main supply is shut-off

The valve is operated by the pilot via a firing switch which is connected to the solenoid through slip rings at the rotor hub

The firing trigger is mounted on the pilot's cyclic pitch stick A control panel is situated on the cockpit dashboard sill and includes a master switch (car type, key-operated), together with a ' firing-ON ' warning lamp, the timer giving fuel gone/available, and a tell-tale safety meter which indicates the condition of the firing circuitry

Three completely separate problems were involved in this development

(*a*) That of the temporary storage and handling of H T P

(*b*) The effect of the rocket assistance on the pilot's controls

(*c*) To meet the project design requirements

All three of these problems were tackled successfully and this aircraft was demonstrated at the S B A C Show

H T P must be stored in a passive tank which is made from a suitable material No dirt, foreign matter or grease should be allowed to contaminate the fuel

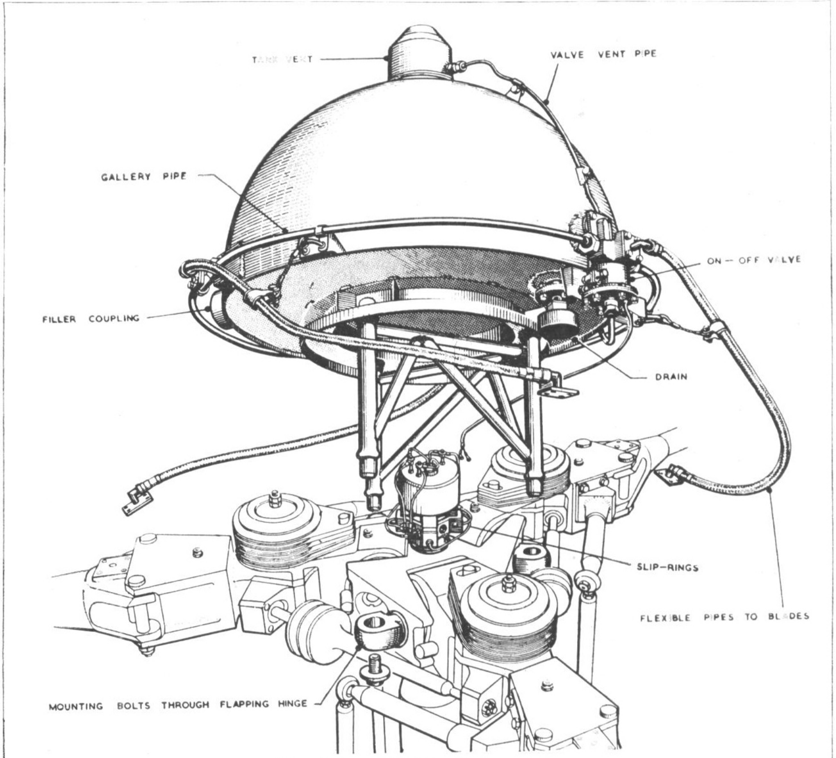


Fig 11 Hub Tank Assembly

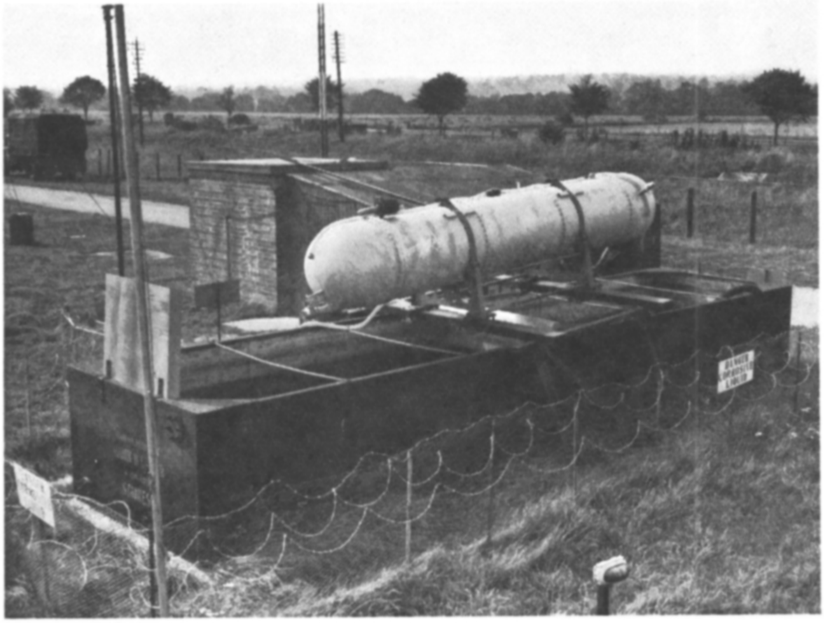


Fig 12 H T P Storage Tank

Fig 12 shows the temporary storage installation, it consisted of a storage tank supported on a simple structure and positioned above two large tanks containing water, the principle being that should the H T P leak from the storage tank it will leak into a relatively large volume of water which will immediately dilute it Either of the tanks contains sufficient water to allow the H T P to be jettisoned into the water should the fuel become contaminated

This method of storage proved itself quite adequate for the short time that we required to complete the tests

Messrs Napiers were responsible for supervising the fuelling of the aircraft and the design of many H T P components

A recommended refuelling technique which is similar to that used is one in which the pipe line from a storage tank is connected up to the aircraft tank through a self-sealing coupling and H T P is then pumped until an automatic cut-off valve operated

The refuelling trolley unit employed consisted of two h t p tanks (connected by a transfer pipe) with a hand pump mounted above them A water tank with hose and pump, together with a fire extinguisher, are included for safety

The fatigue life of the flexible pipes was covered by running them on our Rotor Test Tower They were run empty and filled with fluid

Functional tests of the system were first carried out using distilled water in place of H T P fuel Ground running and flight tests in this condition proved that the fluid flow was controllable, that there were no out-of-balance forces from the rotor, and that aircraft handling characteristics were unaffected

Similar ' live ' tests were then made, first with the aircraft tethered on the ground, and then in flight These tests were entirely successful, and no real difficulties were encountered During this development period, some runs were made with one or more units running at less than full thrust Apart from the resultant loss of power, no undue vibration levels were experienced, and the aircraft remained completely controllable

This work had proved the practicability of the " Skeeter " Rocket Booster system, and performance test results have substantiated predicted figures As a result, the operating potential of the " Skeeter " helicopters has been considerably enlarged, and the success of the scheme represents a step of major significance in the development of the type

CONCLUSIONS

Although it has not been possible to give a complete review of the entire development of our " Skeeter " helicopter, it is hoped that the paper has achieved the desired object of presenting some of the problems encountered and their methods of solution

The detail design problems, theoretical investigations, testing techniques and manufacturing processes essential to the development of the helicopter have, of course, involved more work than has been described In fact, a design team of about 40 has been involved for some five years, which perhaps gives a better indication of the amount of real work entailed

In helicopter development work, it is felt that rig testing will play an increasingly predominant part, and will be required at much earlier stages, than is usually the case at present It must be emphasised that such tests are only of value if exact simulation of true working conditions is obtained This is becoming possible with conventional types of helicopters, as much information on these conditions has now been amassed An example of this state of affairs occurred with our Rocket Booster Programme, where the development period proved to be short and design predictions were completely confirmed

The cockpit layout has proved to be one of our most distracting problems, and has called for an entirely disproportionate amount of effort in its various solutions This emphasises the need for standardisation in this field

It will be appreciated that the success of the development of the " Skeeter " helicopter has only been made possible by excellent team-work The complete collaboration of the Design Staff, Test Pilots, and Experimental Shops is, of course, essential to success

In conclusion, I wish to thank Saunders-Roe Ltd for permission to publish this paper However, any opinions expressed are not necessarily those of my firm I also wish to thank my colleagues for their help in its preparations

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