The Fairey Rotodyne

By G S Hislop,
Ph D , B Sc (Eng), A R C S T , M I Mech E ,
F R Ae S
(*The Fairey Aviation Company Ltd*)

A Paper presented to The Helicopter Association of Great Britain and The Royal Aeronautical Society, at the Institution of Civil Engineers, Great George Street, London, S W 1, at 7 p m , on Friday, 7th November, 1958

Sir Arnold Hall, M A, F R S , F R Ae S , *President of the Royal Aeronautical Society,* occupying the Chair

The President of the Royal Aeronautical Society (Sir Arnold Hall) invited Professor J A J Bennett (Chairman, Lecture Committee, of the Helicopter Association of Great Britain) to introduce the Lecturer

Professor J A J Bennett said that this was a very important occasion, both for the Royal Aeronautical Society and for the Helicopter Association of Great Britain Tonight, they were to hear about the development of an aircraft which was certainly not an aeroplane, and it was certainly not a helicopter according to present-day definitions To accept the F A I nomenclature, it was in an intermediate class, the so-called " Convertiplane " category As, however, there was neither a Convertiplane Association of Great Britain nor yet a Convertiplane Section of the Royal Aeronautical Society, it was appropriate that the two societies should get together and discuss the project

Dr Hislop, who was to give the lecture, required no introduction He was a Vice-President and a former Chairman of the Helicopter Association, as well as a Simms Gold Medallist and Fellow of the Royal Aeronautical Society and a Member of the Institution of Mechanical Engineers After studying at the Royal Technical College, Glasgow, where he graduated B Sc , he had won the Sir James Caird Scholarship in aeronautics with which he went to Cambridge and obtained his Ph D He then spent six years at the A and A E E , Boscombe Down, before transferring to the R A E , Farnborough, for a further two years Afterwards, he worked for six years with B E A In 1953, Dr Hislop was appointed Chief Designer (Helicopters) at the Fairey Aviation Company, where he was now Chief Engineer (Aircraft)

The subject of his lecture this evening was " The Fairey Rotodyne "

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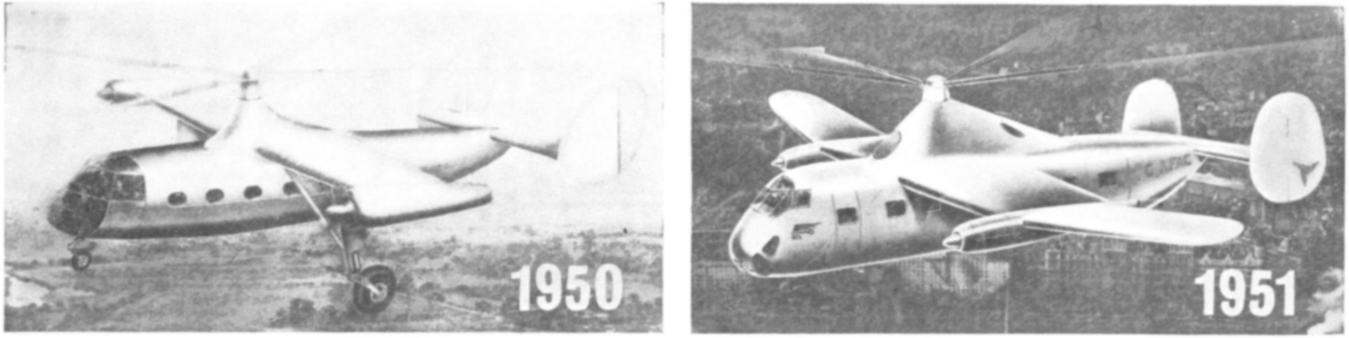
G S HISLOP
Ph D , B Sc (Eng), A R C S T , M I Mech E , F R Ae S
Chief Engineer (Aircraft), Fairey Aviation Company

SUMMARY

The paper outlines the design philosophy underlying the conception of the Rotodyne and reviews briefly its tremendous potential as an economic all-weather VTOL transport aircraft The aerodynamic, structural, tip propulsion, power plant control and piloting techniques are discussed A brief description is given of the major testing programmes including aerodynamic, fatigue, ground resonance, full scale rig, ancillary system development, and the design and development of the tip jet silencers

The paper concludes with a review of the progress achieved in the year since the first flight of the prototype and the likely future development possibilities of the configuration



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3 MAMBA ENGINES 28 SEATS

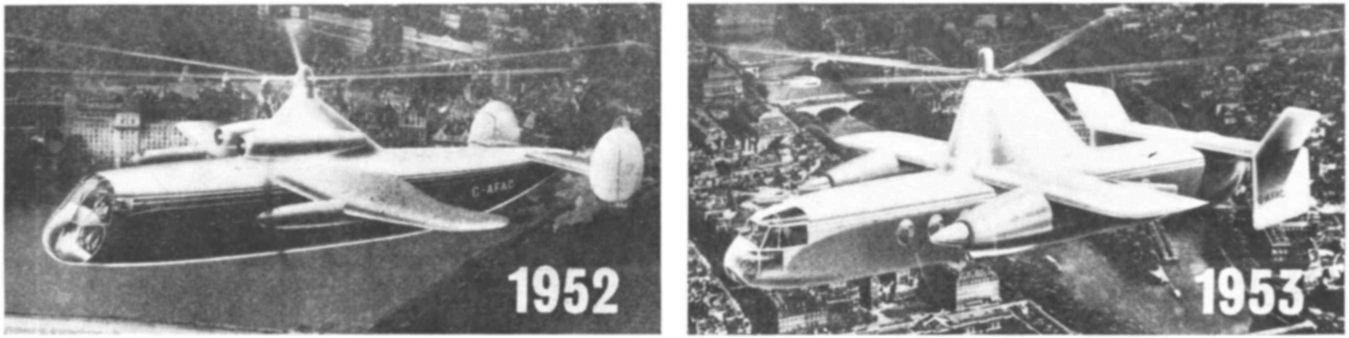

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Fig 1 Early Rotodyne design layouts

The Fairey Rotodyne

1 Introduction

1 1 The conception and main purpose of the Fairey Rotodyne is to overcome the serious drawbacks of current helicopters, especially for transport purposes, drawbacks which are just as obvious now as they were some twelve or more years ago when the Rotodyne conception first formed in the minds of the original patent[1] holders, Dr J A J Bennett and Capt A G Forsyth The main aims were then —

- (i) An increase in rotorcraft size
- (ii) Elimination of the tail rotor with its complexity in transmission and control
- (iii) The simplification of the power drive to the rotor

In addition to the foregoing, in time it became equally obvious that for a transport helicopter a very considerable increase in size and speed was needed to achieve an operating economy competitive with fixed wing aircraft over stage distances of around 200/250 miles Design studies stimulated by B E A in 1951 for a transport helicopter capable of carrying at least 30 passengers over 200 miles at speeds of at least 130 knots, showed this up forcibly

Evolution of the Rotodyne and its various power plants shows a growth in aircraft size during this early paper design stage, before the design settled on the present 40/48 seat aircraft with two Napier Eland engines This engine was finally chosen because it was in being, was of the appropriate power , and could easily drive an auxiliary compressor with little modification to the basic engine

I have mentioned the transport application because in either the civil or military roles, this problem of the transport of goods and people in fast, economic aircraft capable of vertical take-off and landing is of tremendous importance It is specially important where water crossings are involved since surface transport is so materially affected Whether it be for the movement of passengers and freight in undeveloped areas, the transport of a military hospital to a stricken area, or the scheduled transport of passengers from one city centre to another, the requirements are broadly similar, viz good performance, safety and reliability, low maintenance costs and competitive economy

Another very important application for a large rotorcraft is its occasional use as a crane for the lifting of heavy or awkward loads across short, difficult stretches of country or into otherwise near-inaccessible situations This additional role is easily dealt with by any rotating wing aircraft of adequate performance

1 2 This paper is aimed at dealing broadly with the technical features of the Rotodyne and is not intended to be an exposition of the economic case for the machine in relation to other rotorcraft, fixed wing aircraft or surface transport However, it seems appropriate in this introduction to draw attention once more to the tremendous potential of an economic transport vehicle capable of vertical take-off and landing

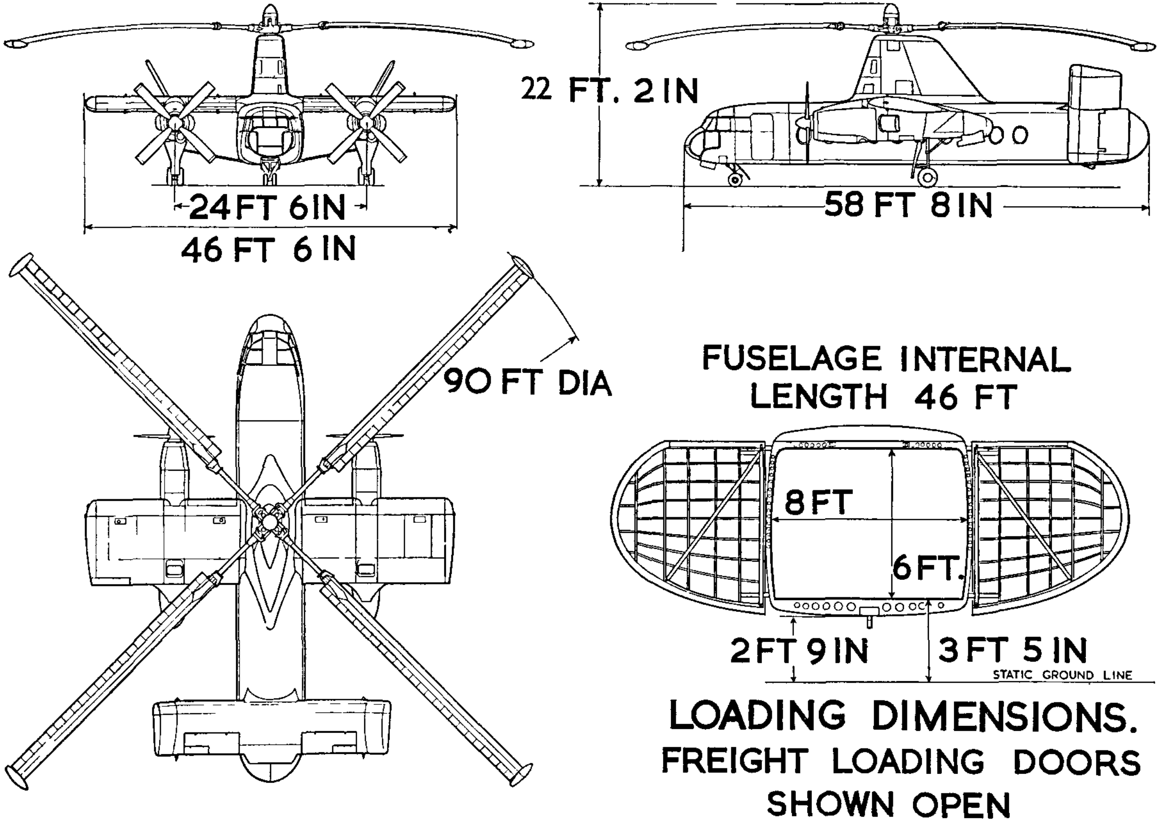


Fig 2

G A of present aircraft

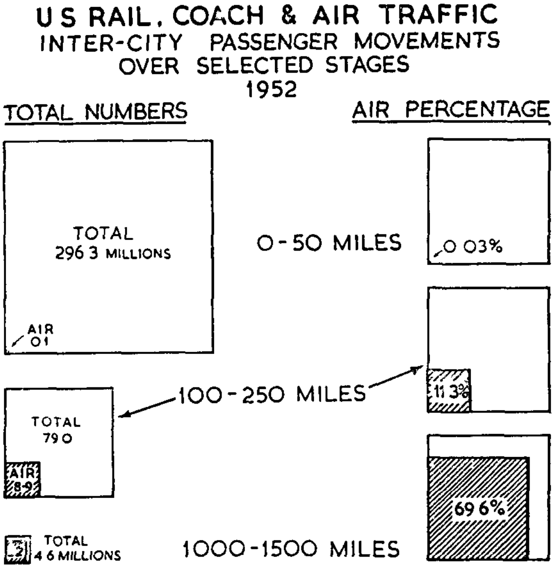
Fig 3 shows a typical traffic pattern It shows the variation and the proportion of air and surface travel with stage distance The obvious deduction is that air travel takes the lion's share of all long distance traffic but that its share of the rapidly increasing total falls steadily as the distance decreases In fact the air transport share at distances below 100 miles is quite insignificant whereas the total amount of traffic is enormous

One of the main reasons why the air share of short haul traffic is so small is obvious from Fig 4 in that the total journey time even with fast fixed wing aircraft is very high because of the time lost at each end of the journey The illustration shows clearly the potential time saving with a VTOL aircraft capable of reasonable cruising speeds, say around 160 knots Until this time saving is achieved with an economic aircraft, the air transport share of short haul traffic will scarcely increase, but let a solution be found, and here we think that the Rotodyne does offer the first real solution to the problems involved, then this air traffic will grow with leaps and bounds

Finally, for a simple geography lesson in Fig 5, which shows the distribution of population in North West Europe, and is related to a series of circles centred for convenience on Brussels It shows that most of the major cities of N W Europe lie about 200 miles from each other and hence a VTOL aircraft of economic performance over this range can operate in an area of tremendous traffic potential I may remark in passing that the total population within the 200 mile radius is about 78 millions For comparison, the number living within 200 miles of New York is 22 millions

1 3 Some other civil roles are of equal importance to the schedules transport role, and in fact may grow even larger because aircraft with this capability can be used for many, many tasks It is no longer necessary, for example, to open up undeveloped territory or conduct exploration work in inaccessible areas by laying down roads and railways, or even by laying

Fig 3 Comparison of air and surface traffic



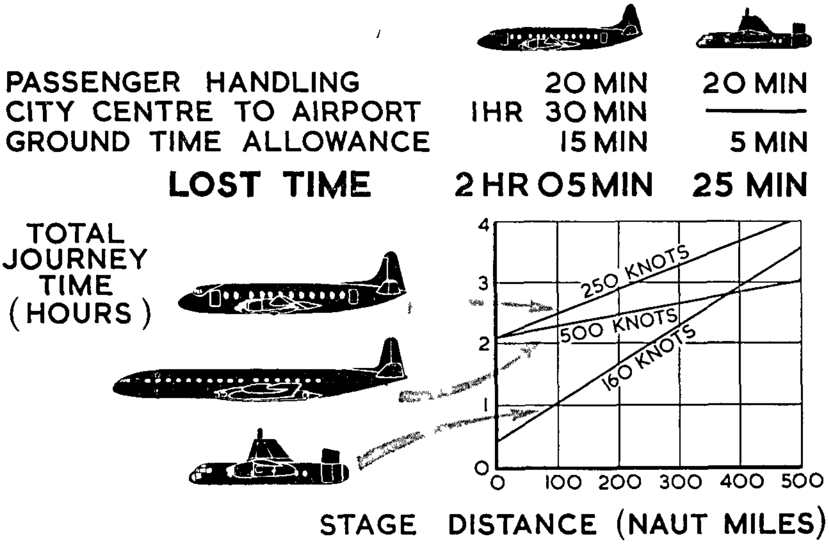


Fig 4 Stage time, helicopter versus fixed wing

major airstrips big enough to accept fixed wing aircraft Instead, a relatively small clearing will suffice, in the early stages of the development, until the latter reaches such a stage that the cost of roads or even railways can be justified The capital investment in the Rotodyne is then available for other tasks, either in the same area or elsewhere

2 *Basic configuration*

Much has already appeared in the technical[2] [3] [4] and lay press on the Rotodyne and I do not intend to take up time on a detailed description of the machine The leading particulars are given in Appendix 1 However, I will refer briefly in this part of the paper to the reasons for three of the main engineering features of the Rotodyne, viz the rotor propulsion system, the use of a lifting wing to offload the rotor, and the use of propellers for forward thrust

2 1 *Rotor propulsion system*

Tip propulsion has been a most attractive means of driving rotors, at least on paper, for a long time, but it is only in the last dozen or so years that practical means of such propulsion have become available The chief advantage is elimination of the heavy, complicated, and costly shaft transmission system , the chief drawbacks are higher fuel consumption and noise These and other related aspects have been fully discussed in various papers[5] [6] [7] and I don't propose to do more than touch on some of the issues as they affect the Rotodyne

A number of tip jet propulsion schemes exist, varying from the very simple, but exceedingly thirsty, rocket to the complex system of installing turbo-jet engines at rotor tips This latter is still in the very embryo idea stage and in undoubtedly bristling with formidable engineering difficulties, but has the great attraction of a low specific fuel consumption

A comparison of the various specific fuel consumptions is of interest

Relative Specific Fuel Consumptions		*lb fuel/rotor h p /hr*
Rocket		about 40
Ram jet		10
Pulse jet		6
Pressure jet	Burning	2 2
	" Cold " air	1 8
Tip turbo-jet		0 9
Mechanical drive		0 8

The ram jet system of propulsion has been proposed and flown, more or less successfully, on one or two small helicopters There are in use at least two such aircraft , one is the Hiller Hornet military observation aircraft, and the other is the Dutch " Kolibrie " agricultural machine The engine is light and simple but its specific fuel consumption is very high, though not so high as to be completely unacceptable for short durations

Fig 5 Population distribution in Europe

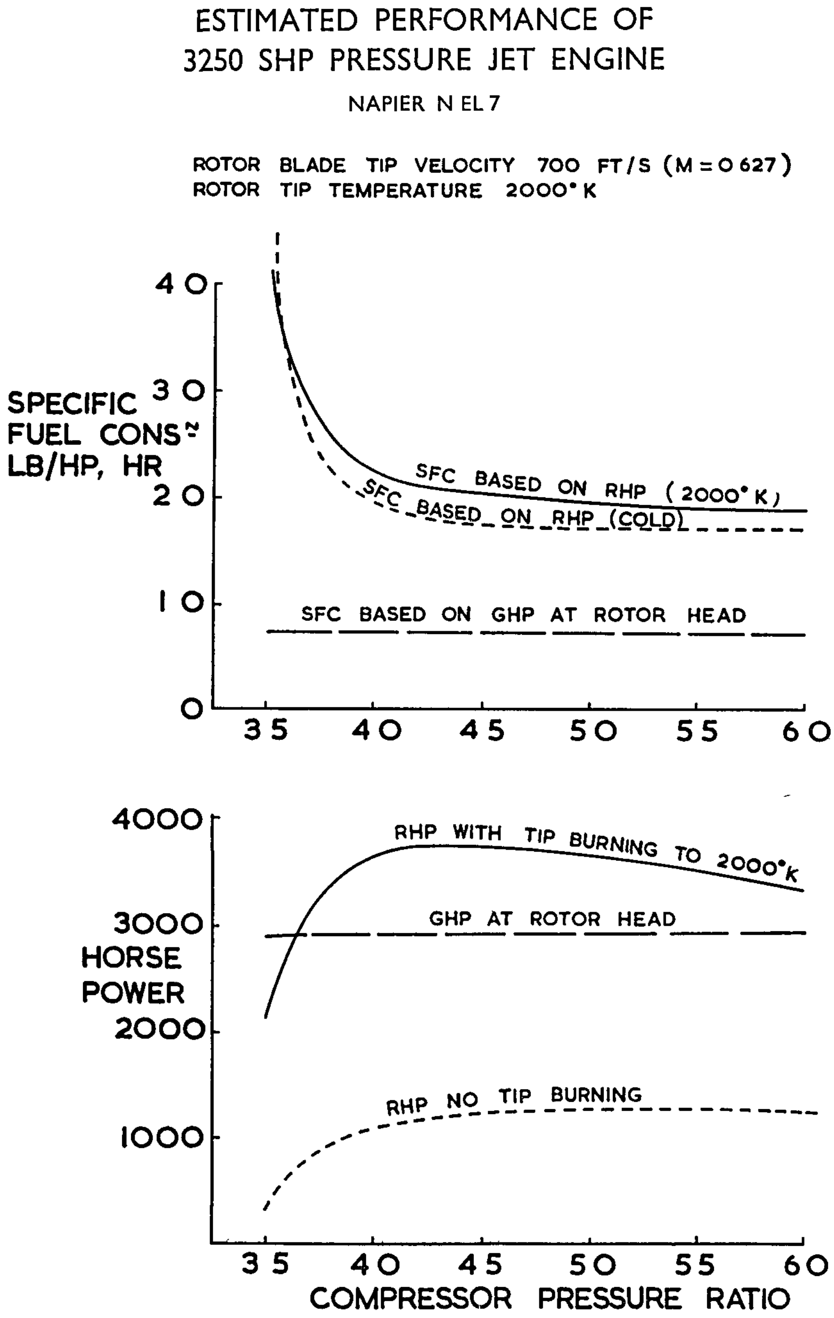


Fig 6 Power and specific fuel consumption of hot and cold pressure jets
(with acknowledgements to Morley and Cushing Ref 8)

The pulse jet offers an improved fuel consumption over the ram jet but no really successful pulse jet helicopter has been built The engineering problems associated with the power unit and its most objectionable noise characteristics have combined to kill this propulsion system

The pressure jet rotor offers a very considerable improvement in specific fuel consumption at the expense of some complication in ducting compressed air from the power plant in the airframe to jet units at the tips This is seen in two forms , the so-called cold pressure jet, as is exemplified by the Sud Aviation " Djinn," where the compressed air is ejected through a suitable nozzle at the tip, and the burning pressure jet, as in the Rotodyne, where fuel is added at the tip in order to produce a much greater thrust for a given amount of air with little additional increase in fuel[8]

An intermediate form of pressure jet was that employed in the Percival P 74 where the compressed air and exhaust gas from a Napier Oryx gas generator were ducted through the blades and ejected from a propulsion nozzle at the tips

Let us take the problem of rotor power transmission in large rotorcraft There may be 6,000 h p to be transmitted to the rotor, the tip speed of which is limited to a maximum of about 700 ft /sec Using a mechanical system of power transmission to the necessarily large rotor, a big reduction in speed between the power plant and the rotor is needed Thus the torque at the rotor shaft is very high, up to marine propulsion standards in fact It has been found from bitter experience that the complexity of such a mechanical transmission is great, the problems of proving its integrity very severe, and the overall costs of maintenance in service are very high[9] Further, the power plant and rotor must not only first be developed separately, but then the two must be developed together so as to ensure that neither adversely affects the other The use of multiple rotors and power plants only serves to aggravate these problems

Now these difficulties are reflected by the growing weight, first cost,

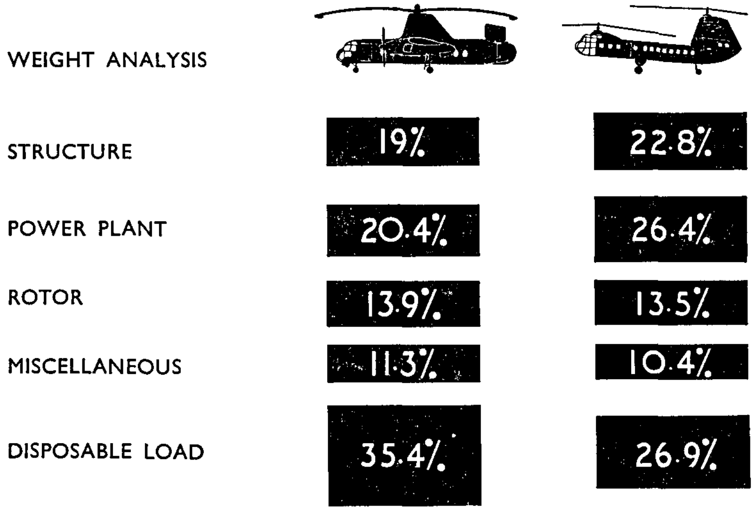


Fig 7 Weight breakdown, pressure jet versus mechanical drive

and overhaul cost of the rotor and transmission system as the size and h p increase until the economic penalty becomes so severe that an alternative must be sought

This is not to say that large mechanically-driven rotors cannot be made , they have been and may continue to be made, but at a very severe price The tip pressure jet system, however, overcomes all these objections In the absence of a rotating mechanism connecting the power plant(s) and rotor these can each be developed separately and brought to a highly developed state in the full confidence that there is virtually no inter-action one upon the other, at least in the sense liable to induce undesirable or severe vibration

2 2 *Aerodynamic considerations of wing-rotor-propeller combination*

The next major area of interest is that concerning the use of a lifting wing in conjunction with a rotor and propellers

First let us go back to the conventional helicopter In this a very real limit is set to the achievement of high forward speeds by the tip stall of the retreating rotor blade, which normally results in heavy vibration This limit is dictated by the ratio of forward speed to rotational speed It can be increased either by a reduction in blade mean lift coefficient (*i e* by an increase of blade area, or tip speed, or by a decrease in rotor lift), or alternatively by a reduction in total forward thrust

The advantages of an increase in tip speed are, in turn, limited by the onset of compressibility affecting the tip of the advancing blade and which like the tip stall, causes roughness and requires more power to drive the rotor

In the basic concept of the Rotodyne higher forward speed is achieved by employing the autogyro configuration, *i e* by deriving forward thrust

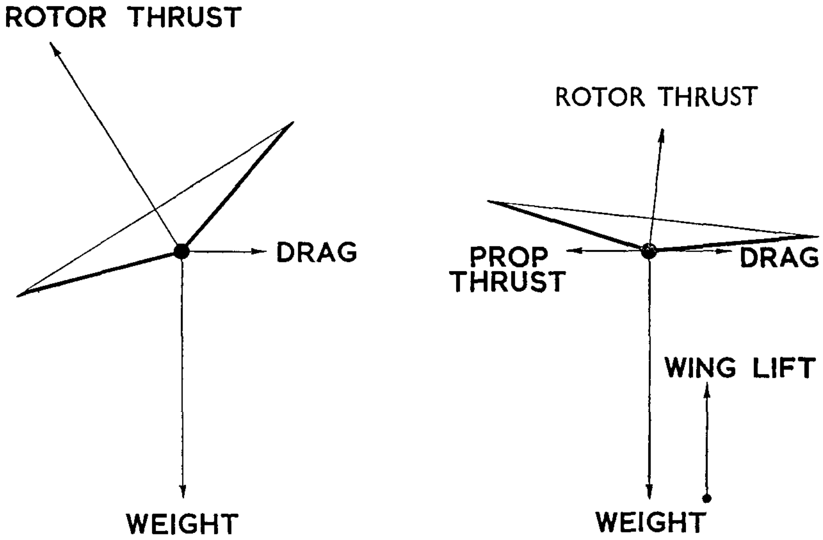


Fig 8 Rotor forces, helicopter versus Rotodyne

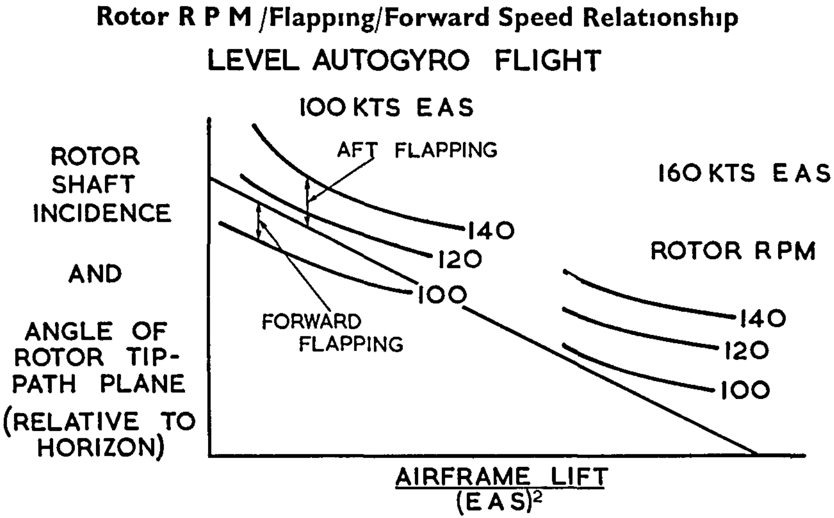


Fig 9 Relationship of flapping/attitude/rotor speed

from propellers instead of tilting the rotor disc, thus relieving the rotor of a major part of its task at high speed With the rearward tilted rotor of the autogyro regime, the effect of the forward speed is now to direct the rotor airflow *up* through the rotor, which brings about a more even distribution of blade lift coefficient, with the most irregular region now at the inner end of the retreating blade—a much less sensitive position than at the tip Secondly, by using a fixed wing to supply lift and hence further relieve the rotor, the rotor speed *and* the lift coefficient can be reduced, hence postponing the compressibility rise and lowering the rotor drag

This employment of a high proportion of wing lift, as well as the powered rotor for vertical flight, distinguishes the Rotodyne from the ordinary autogyro The facility for varying rotor lift makes feasible a design in which r p m and hence flapping is readily controlled and which can thus be kept to low values with low vibration and low oscillating stress values compatible with design for long fatigue life With the control of r p m it is also possible to choose the value most suitable for stability or performance and yet avoid rotor resonant speeds

For level flight at a chosen wing incidence and airspeed, the amount of rotor lift is substantially defined with only minor variations due to interference This rotor lift can be achieved over a range of rotor r p m values by altering the collective pitch Generally as the rotor r p m is increased, the rotor has to be tilted back further, mainly because of the increased blade profile drag This increased backward tilt is achieved by conventional cyclic pitch control Ultimately it means increased backward flapping, with a decrease in the clearance between the blades and the fins Any change in wing incidence, which is done mainly by elevator setting, requires a corresponding change in rotor lift Hence a wide range of r p m /collective pitch values are available from which to choose a combination which is most appropriate to the required aircraft flight conditions

Fortunately from a design point of view, the rotor backward tilt required at fixed rotor r p m generally increases with a decrease in rotor lift, and this is compatible with the increased wing incidence needed to provide a lift balance Equally, as forward speed is increased, the rotor tilt required for constant rotor lift tends to decrease and the wing incidence also needs to decrease

The primary design criterion of the wing, therefore, becomes one of matching its absolute lift curve slope to complement that of the rotor as far as possible, so as to provide minimum flapping over the desired range of r p m , forward speed, and collective pitch under all aircraft flight and loading conditions

In the low speed and hovering cases the Rotodyne is aerodynamically very similar in its characteristics to a conventional helicopter and there is no need to enlarge here on any slight effects brought about by the wing and tailplane, or propellers

(A discussion on some of these problems of the lifting wing has already been given in an earlier paper[10])

2 3 *Power plant functioning and control*

Having dealt with the rotor tip propulsion systems and the fundamental aerodynamics of the aircraft, it now seems appropriate to consider the power plant and its control The Rotodyne conception of an airarcft capable of vertical take-off as a helicopter and forward flight as an autogyro obviously poses several problems of control, primarily because the two aircraft states are not essentially compatible and the maximum control simplicity can only be achieved by maintaining some facets of the control systems exclusive to the particular aircraft state This results in two separate control regimes either of which can be selected on the ground or in the air These are designated by the method of control of propeller pitch, " manual " for helicopter and " automatic " for autogyro flight

Before describing the two regimes I will refresh your memory of the major elements of the propulsion system

The two basic power units are Napier Eland* turbo propeller engines, each fitted in a conventional manner with a Rotol* four-bladed propeller, but modified behind the turbine to provide an additional drive shaft via a hydraulic clutch to an auxiliary compressor capable, in this prototype, of absorbing about 80% of the engine power in delivering compressed air at a little more than 4 1 compression ratio The compressed air passes through thin stainless steel ducts in the wing leading edge and up the rotor pylon to the rotor head Here each duct divides to supply diametrically opposite tip jets via ducts in the rotor blades With fuel separately supplied to each pair of tip jets each half rotor is an individual, independent power unit In the event of failure of an auxiliary compressor or engine the rotor power can be maintained at half the maximum value

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* At this point I should like to say how much we in Faireys owe to the engineering staff of the Napier and Rotol companies, not only for the basic power plant " hardware " but for the skill and competence with which they co-operated in developing the power plant and its controls

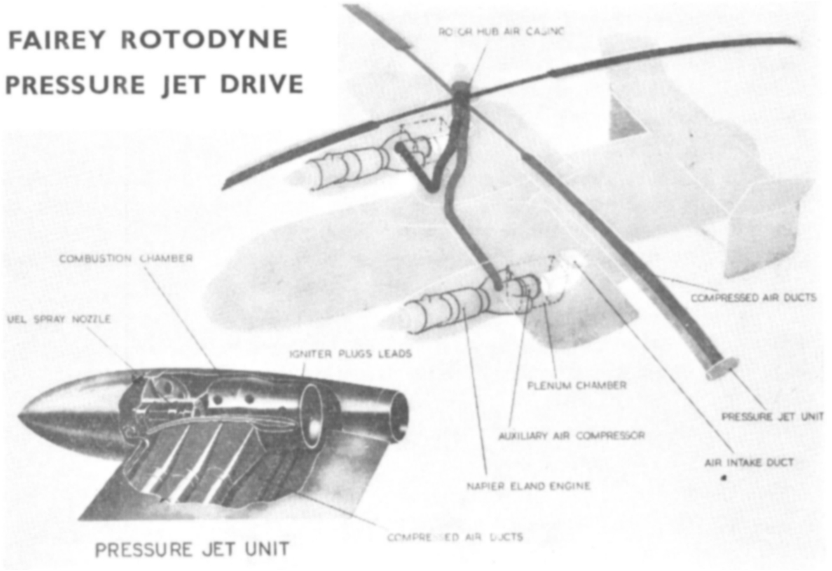


Fig 10 Diagram of air duct and tip jet system

Flying as an autogyro, the controls are essentially conventional Engine power is controlled by a throttle lever, propeller pitch is controlled by a straightforward propeller controller unit in conjunction with the normal safeguards such as torque sensitive pitch coarsening, overspeed fuel cut-off and oil pressure failure lock The engine h p cock and feather pump are operated in turn by the progressive backward movement of the throttle If desired, an engine speed greater than the automatic speed given by the interlinkage of P C U and fuel metering unit is obtained by means of a speed override lever Flying controls consist of cyclic stick, elevator trimmer and conventional rudders, the collective pitch being locked at a low value

In the helicopter condition the amount of air fed to the pressure jets and hence the rotor power is controlled by a valve (the so-called " umbrella " valve) at the inlet to the auxiliary compressor This valve is moved by the pilot's twist grip on the rotor collective pitch lever and is the primary power control during helicopter flight, thus following conventional helicopter practice A cam on the collective pitch lever limits the power range available to the pilot at a particular pitch setting and assists him in maintaining a steady rotor r p m

The conventional type of cyclic pitch stick provides pitching and rolling control Directional control is achieved through rudder pedals giving air rudder movement throughout the speed range, with differential propeller pitch at the low speeds where the air rudders are ineffective Indeed it is partly the yaw consideration which necessitates the direct or manual control

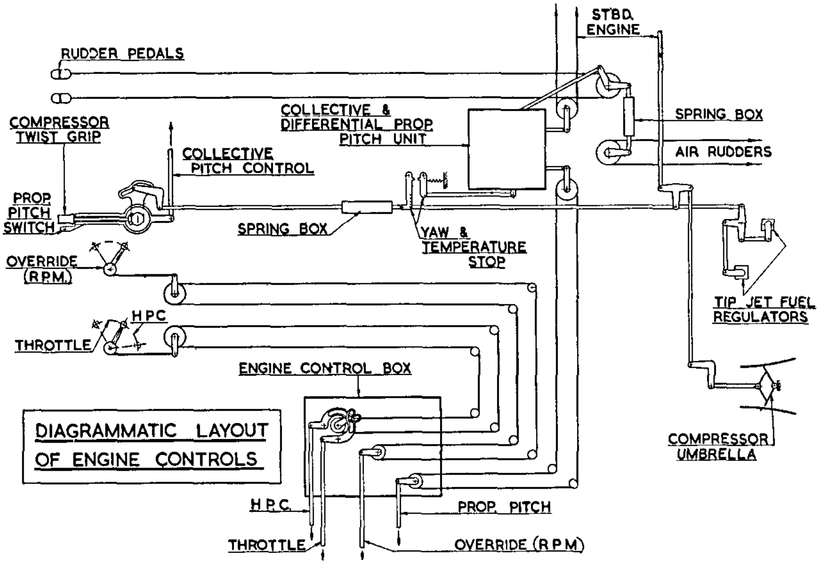


Fig 11 Power plant controls

of propeller pitch in helicopter flight, since dependence on throttle manipulation to give differential thrust around the zero thrust condition would have been impracticable and the single engine case could not have been met

The propeller collective pitch range in manual is from —10° to +35° with a yaw differential range of $\pm 4\frac{1}{4}^\circ$ at minimum collective propeller pitch setting falling to zero at about 12° of collective propeller pitch

For helicopter flight it was felt desirable to design so that the engine speed was constant and the propeller pitch varied solely by the pilot To meet the varying loads from the auxiliary compressor as well as the propeller necessitated a separate engine governor linked with the fuel metering unit to maintain this constant engine speed which is selected through the speed override lever This throttle governor is made operative automatically with manual pitch control and simultaneously the propeller controller unit is disarmed in such a way as to enable the P C U valve to be moved only by the pilot's collective propeller pitch control or differentially during yaw by the rudder pedals Two additional safeguards are necessary because it is possible in certain circumstances to overload the engine by the combined demands of propeller and auxiliary compressor In the yaw condition under high ambient temperatures overload is avoided by stops which prevent the umbrella valve from being opened too far when yaw is applied During helicopter forward flight it is possible that gross mishandling will give overload due to excessive propeller pitch In this case pitch is automatically reduced below the overload condition

3 Structural Design

3 1 When compared with the current trend in fixed wing transport aircraft the Rotodyne airframe can be of simple design, since the top speed is not high by such standards nor is a pressure cabin necessary because of the fairly low operating altitudes Hence the airframe is basically a very simple light alloy structure with an exceptionally low percentage A U W of just under 20% as compared with the more usual figure of around 28% for fixed wing aircraft

The wing consists of a two spar, two cell torsion box and is manufactured as a single unit, whilst the fuselage is a stiffened thin shell with four main longerons The pylon is a tubular steel structure surrounded by a simple light alloy fairing

The retractable undercarriage is of conventional design with the exception of specially designed lateral and fore and aft struts which have been introduced to eliminate ground instability (ground resonance) To the best of my knowledge this is the only rotary wing aircraft now flying with a retractable undercarriage

On the rotor head and controls it was decided early that the objective should be infinite life, since the overhead and maintenance costs of these items has been extremely heavy on conventional helicopters Even at the expense of a somewhat higher initial cost this seems well worthwhile The objective was made more realistic of attainment by the employment of high strength steel as the main structural material with its much superior fatigue properties and finite endurance limit

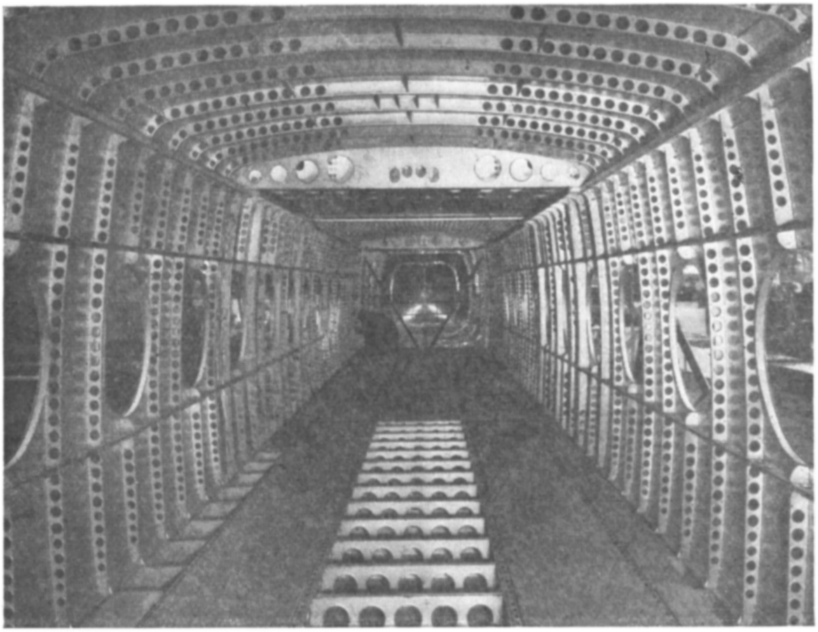


Fig 12 Fuselage construction

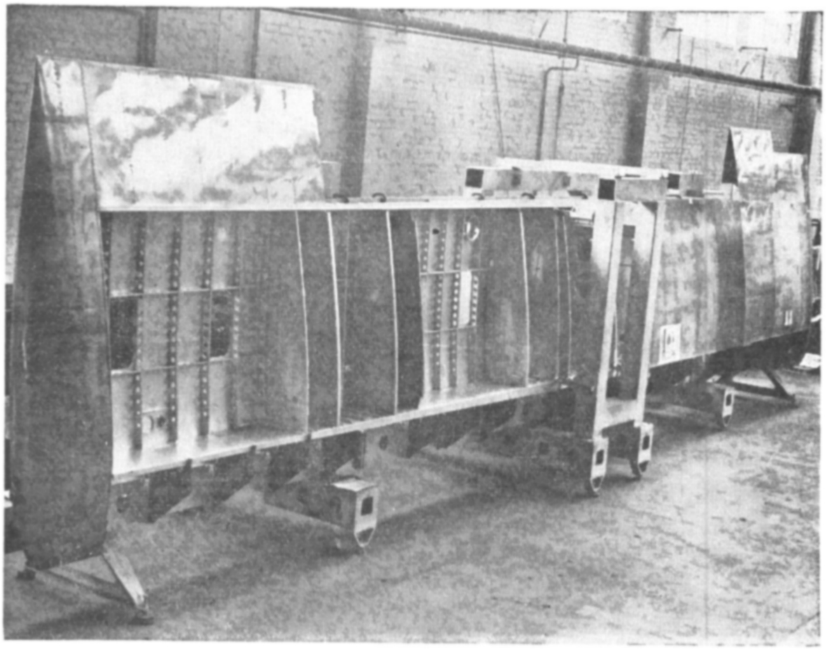


Fig 13 Wing construction

The rotor head is basically a “ cruciform ” box structure fabricated mostly from 80 t p s i steel forgings (S 99) with some steel sheet It consists of a central circular hub to which are attached four box beams, each beam terminating at a set of flapping hinge lugs

The blade consists of two main components, an inboard circular steel spar manufactured from 80 t p s i steel forging (S 99) embodying conventional flapping and feathering hinges at its root, and an outboard aerofoil section comprising a two-spar single cell steel torsion box No drag hinges are needed because in cruise the flapping angles are kept small The one piece leading edge front spar at 34 feet long is machined from the longest heat treated steel billet (D T D 730) so far made in this country The top and bottom skins and rear spar of the torsion box are manufactured from 65 t p s i stainless steel sheet (D T D 166B) and the trailing edge fairing consists of a number of floating light alloy segments Compressed air is ducted through three thin walled stainless steel tubes to the jet units

The rotor head control system is of a double swashplate type The lower non-rotating swashplate is positioned by four F A C tandem hydraulic jacks, the upper rotating swashplate controlling the blade feathering for cyclic pitch control by a simple bell crank lever mechanism Swashplate operation is by concentric torsion tubes passing up through the centre of the rotor head

3 2 The general stressing cases for both airframe and rotor consisted of a mixture of normal aircraft and rotorcraft requirements (B C A R Sections D and G), together with additional cases agreed with the R A E , Farn-

borough, since no one set adequately covers this particular aircraft configuration

The airframe was stressed by conventional means for all the design ultimate cases, and a statistical gust fatigue case was considered

The rotor was treated similarly except that calculated normal flight fatigue cases were also considered The rotor stressing loads were obtained by considering the whole aircraft as a dynamical system in order to obtain

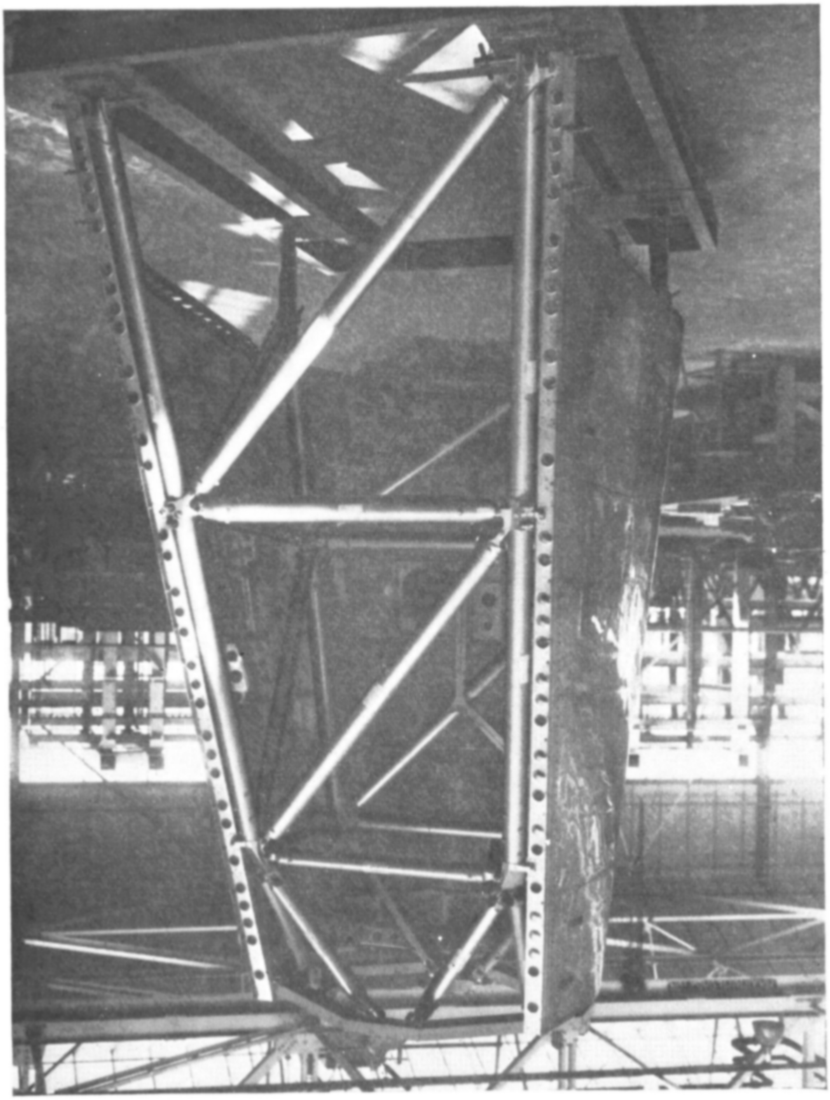


Fig 14 Pylon construction

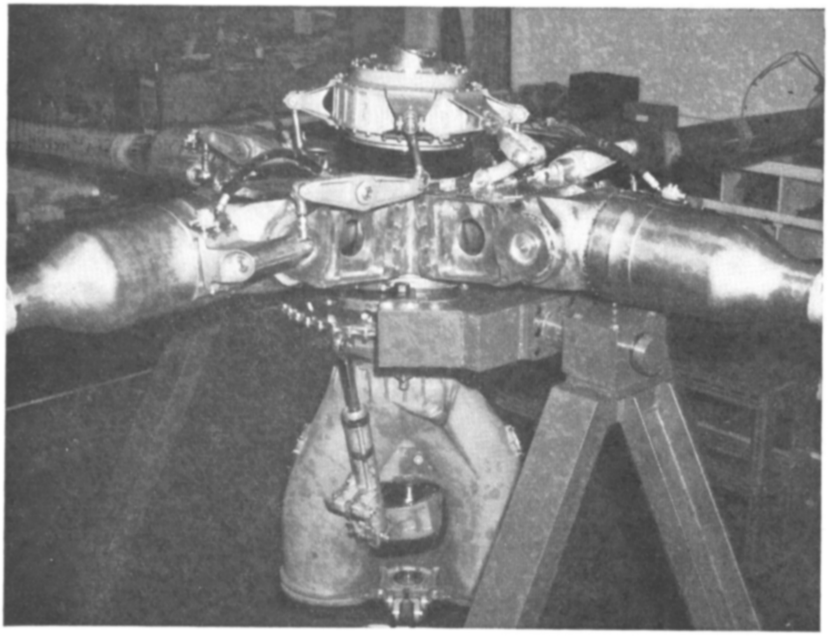


Fig 15 Head construction

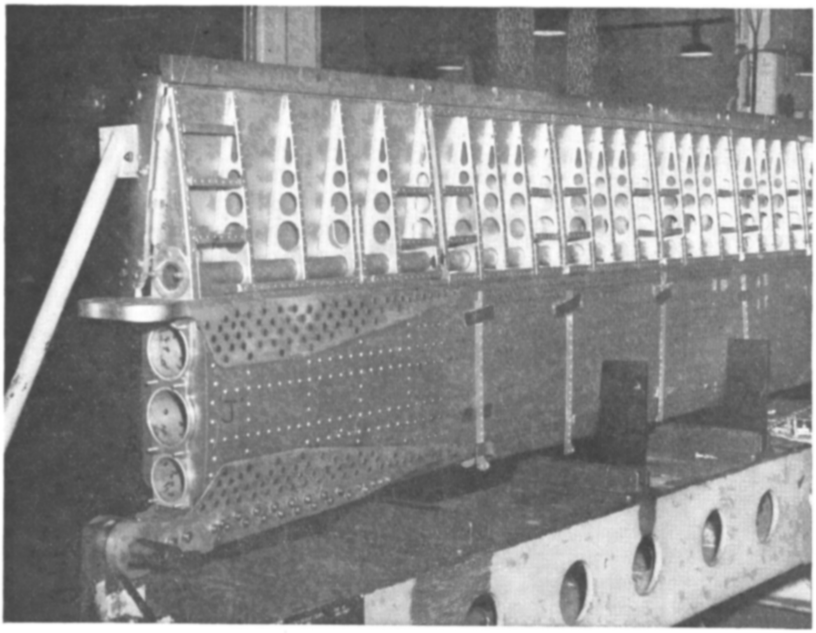


Fig 16 Rotor blade construction

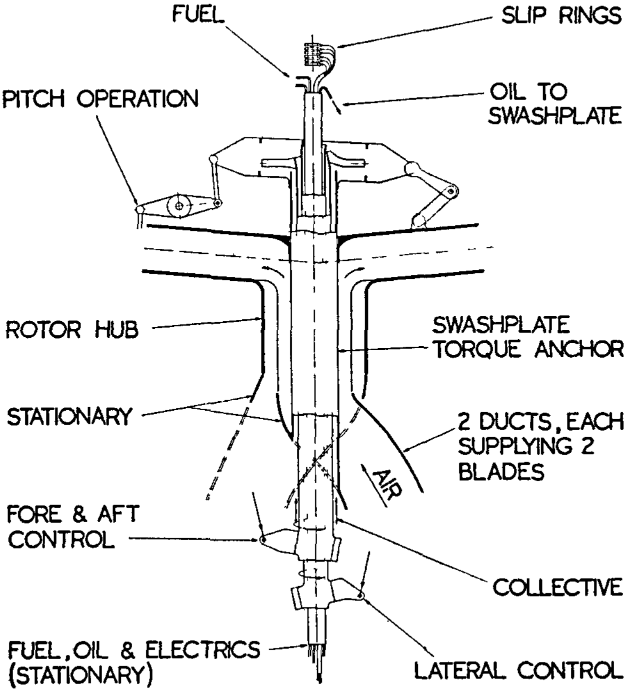
the correct response to the periodic forcing loads, and to assess the possibility of ground or airborne instability

The periodic aerodynamic forcing loads were obtained by the application of normal aerodynamic theories, but it was realised that the accuracy of the result obtained was very dependent upon the assumed induced velocity distribution, and although this was considered sufficiently accurate to enable the estimate of the magnitude of the lower order harmonics to be obtained, an empirical allowance was made to cover the effect of the higher harmonics

It was realised however that any rotor strength assessment could only be tentative, but such an approach would lead to a structure of consistent strength to which all flight test data could be related During the initial stages of design the fatigue strength of both airframe and rotor components was assessed by using basic material fatigue data coupled with estimated stress concentration factors These initial assessments were checked by tests on simple components and finally by tests on complete assemblies

Some of the rotor stressing methods and dynamical considerations have already been described in greater detail in a fairly recent paper[11] to the Helicopter Association

Fig 17 Rotor head layout—diagrammatic



ROTOR HEAD SERVICES

4 MAIN FLYING PROCEDURES

4 1 *General*

The general approach to Rotodyne handling and a natural consequence of its size, is to treat it as any large aircraft in all flight states, *i e* with somewhat slower response rates than those desirable for small helicopters

(*a*) *Helicopter flight*

In helicopter flight as used for the take-off and landing, the controls and their sense of operation are as for conventional helicopters, with the sole addition of collective propeller pitch selection for near-zero thrust and drag at any given airspeed There is a small time-lag in tip jet response to twist-grip movements, but since there is no torque reaction and rotor speed is less critical than on many other machines (16% of total rotor r p m range, excluding overspeed, is so far available) the power response is in good harmony with control response

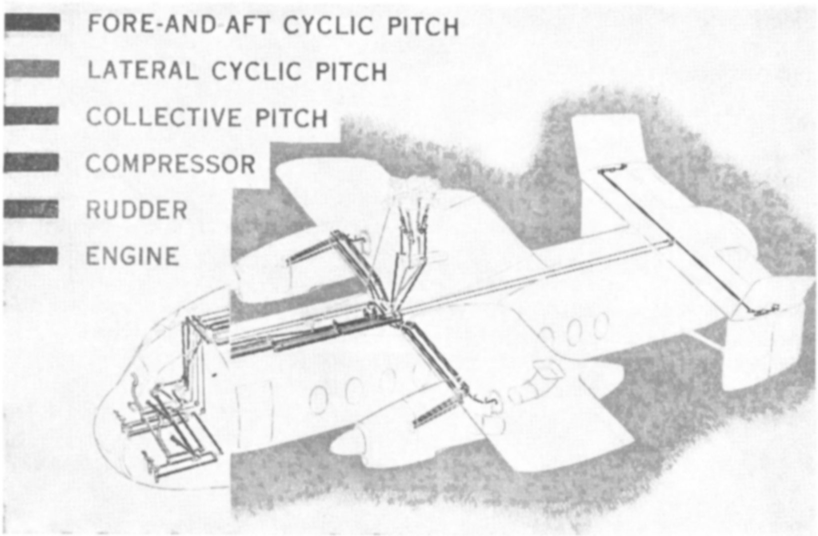


Fig 18 Head and flying controls

(*b*) *Autogyro flight*

In the autogyro flight regime as for cruise, the controls are as for a standard aeroplane, but the functions differ somewhat Major manoeuvre control in pitch and roll is by cyclic pitch action, but the elevator trim is an essential control for establishing the fuselage attitude in pitch and hence the amount of lift on the wing This trim control therefore decides the mean longitudinal cyclic control position and, consequently, the mean rotor speed

32% of the normal total rotor speed range (again excluding overspeed) is readily available for autogyro flight, and at any given airspeed the minimum rotor speed for minimum total drag is used In manoeuvres the rotor is allowed to accelerate and decelerate freely above and below this optimum and hence generally, rotor speed may be ignored once it has been set-up for cruise At the top end of the present forward speed range the available rotor speed range has narrowed by virtue of the increased flapping, but automatic rotor speed compensation in manoeuvre still occurs satisfactorily

4 2 *Transitional flying*

As apart from the Fairey " Gyrodyne " and the McDonnell XV-1, the transition regime lying between helicopter and autogyro flight is fairly new, and one which arouses most interest in outsiders, it seems worthwhile to describe the process in a little detail

A " stage-by-stage " transition technique has been evolved to give complete handling safety at any point in flight, to allow the procedure to be followed during any normal flight condition without change in flight path or noticeable change in attitude and to permit easy pilot training in the technique The total sequence is completed in about half a minute in either direction

(*a*) *Transition from helicopter to autogyro flight*

From the helicopter climbaway after take-off at 60-80 knots and 8° collective pitch, the aircraft is accelerated at the desired transition height (or in a gentle climb), by slowly increasing propeller pitch and at the same time slowly reducing rotor power, until at 110 knots and collective pitch 4° the tip jets are at idling power, and the propellers are providing practically all the forward thrust The aircraft attitude is then about 2° nose up

With two movements on a single lever on the pilot's console, fuel to the rotor is switched off and both auxiliary compressors are declutched The rotor speed begins to fall slowly towards a steady autogyro setting, which at this low airspeed is not at all critical The desired operating collective pitch of around 2½° to 3° is then selected and locked without reference to rotor speed A small aft cyclic movement to maintain level flight (or climb) is quite automatic to the pilot, and the transition proper is complete The fuselage attitude is now about 3° to 4° nose up and passengers have had no impression of a changing flight state throughout the whole sequence

As the auxiliary compressors spin down, the aircraft is accelerated to the cruising air speed, either through the manual propeller pitch selection or, as soon as convenient, engine speed control is transferred to the normal propeller constant speed governor as on any conventional propeller driven aircraft In his own time the pilot then adjusts thrust by the throttle lever and elevator trim settings for the desired cruising air and rotor speeds

(*b*) *Transition from autogyro to helicopter flight*

In drill sequence, the transition to helicopter flight is essentially the reverse of that to autogyro flight Firstly the engines are brought under constant speed throttle governor control in cruising flight, and the airspeed is reduced to about 110 knots

At minimum rotor power settings, clutches are selected IN, and are fully engaged in 4 secs with the air speed at about 100 knots It is usual in test flying to light the jets immediately after clutch engagement and then reduce propeller pitch to zero for the approach to land But tip jet relighting is now often delayed until 200-300 ft before touchdown with an airspeed of 80 knots or less Hence the total tips lit time at the end of a flight is therefore

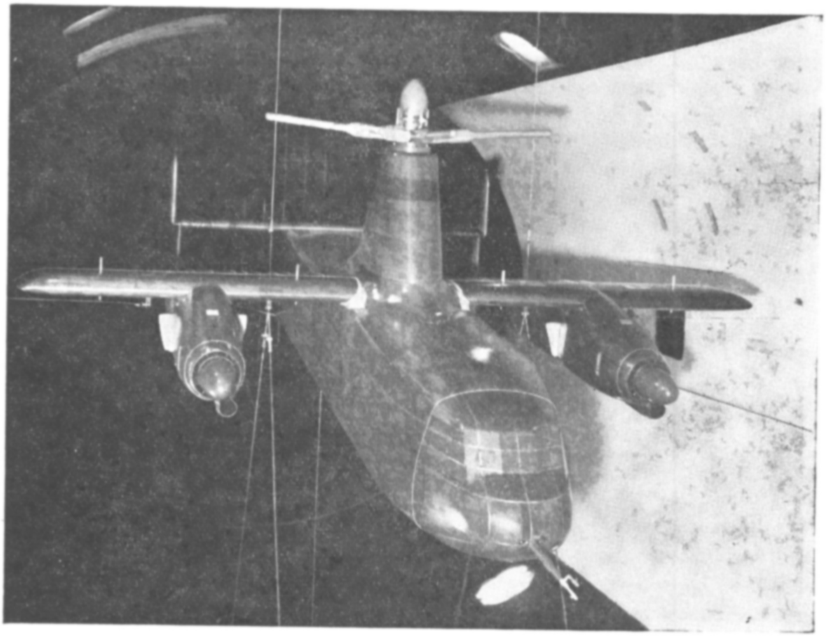


Fig 19 1/6th scale wind tunnel model

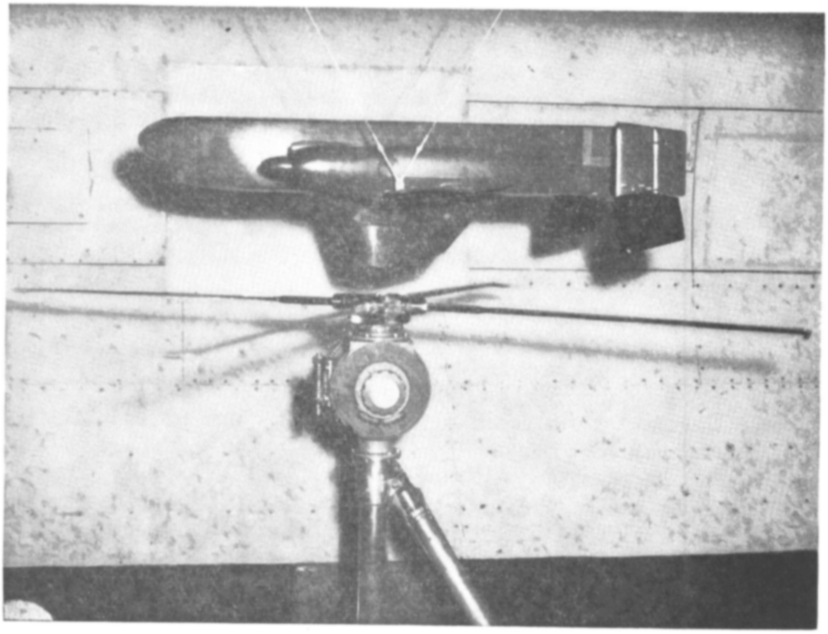


Fig 20 1/15th scale wind tunnel model

only about 1 minute as development stands at the moment On religh rotor r p m increases gradually by about 10 r p m

Finally collective pitch and power is applied for a normal helicopter type landing

(*c*) *General*

Transitional flying is already both easy and safe At any point in flight, immediate recover of the previous condition is possible if for any reason the pilot wishes to revert and, should any system mechanism fail during the sequences, a standby or emergency system is available for each stage As proof of the success of the method the Rotodyne has already made transitions to and from autogyro flight in instrument conditions at 300 feet above the ground

5 *Test and development approach*

In this section are outlined briefly the major areas in which we conducted test and development programmes and how these were planned and executed

5 1 *Aerodynamic testing*

(*a*) *Model work*

Very early in the design of the aircraft it was decided to build and test appropriate models in the large F A C Wind Tunnel at Hayes because it was felt that, though relatively little had been done hitherto in this country using such models of helicopters, there were a great many problems which could best be explored initially by this technique Further, in the event of serious problems arising in the later steps of aircraft development, the necessary tools would thus be available to conduct systematic investigations

Two basic types of models were decided upon, one of 1/6th scale less rotor for orthodox six component measurements of the airframe characteristics, and development thereof, and a 1/15th scale model with rotor, primarily to determine the interference effects of rotor on the airframe over a wide forward speed and tip speed ratio range[12]

The 1/15th scale model had a geometrically correct rotor in aerodynamic connection only with the airframe In this type of model representation it is impracticable to achieve complete dynamic similarity, and the criteria chosen were —

(i) Maximum model rotor tip speed equal to that of the aircraft, *i e* approx 700 ft /sec
(ii) Geometrically correct blade and flapping hinge position , correct rotor position relative to airframe
(iii) Full scale thrust coefficients , disc tilt range somewhat greater than full scale range
(iv) Ability to represent ground effect

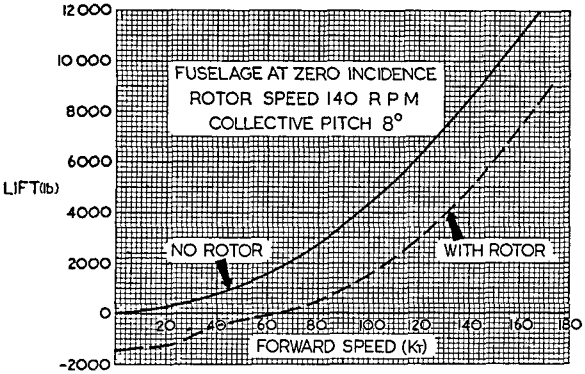
The rotor was shaft-driven from below the tunnel through an adjustable tripod on the floor of the tunnel which, in conjunction with the head arrangement below the rotor, provided the means of tilting the whole rotor relative to the wind axis The rotor hub, which had a limited axial freedom of movement, was linked by a wire passing through the airframe model to the tunnel balance in order to measure rotor thrust Rotor and airframe forces were thus measured separately

The primary measurements taken were —

(i) Forces and moments on the airframe, under varying conditions in the non-linear speed range, *i e* speeds below 50 knots

(ii) Interference in symmetric forces and moments on the airframe or rotor under aircraft balance conditions and, more important, under varying rotor and airframe conditions to determine the effect of interference on stability parameters

In practice the low speed tests were simple and the results showed no important interference in full scale aircraft terms Some early tests were carried out with varying amounts of tunnel walls removed near the rotor, which showed that the tunnel constraint was not significant Ground effect tests confirmed the calculated increase in apparent weight due to downwash of about 4-5%



Airframe Lift

Airframe Pitching Moment

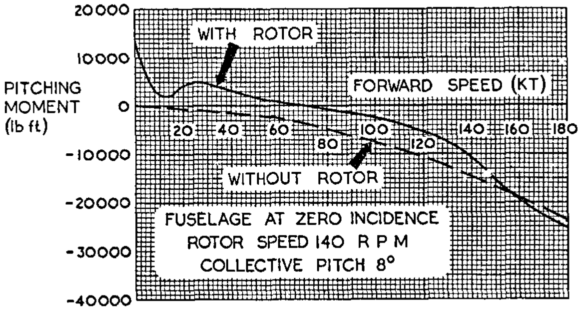


Fig 21 Typical wind tunnel results

The determination of the interference at higher forward speeds (up to tip speed ratio of 0 6) was much more difficult The values were much less than originally estimated, and in fact were generally (in angular equivalents) less than the deflections caused by some of the equipment Early rotor tests showed that a local flow variation of up to three degrees was caused by the bulky assembly of tilting head and hub and that additional errors were caused by the thrust wire gap at the pylon top and forces transmitted directly by the change in rotor thrust wire direction occurring on a pulley in the airframe model

Separate interference downwash measurements were made which showed that rotor interference downwash angles and therefore lift and moment were satisfactory, that drag interference results were unsatisfactory, but airframe interference effects on the rotor were so small that they lay in the normal scatter band

The 1/6th scale model was employed to give the largest possible airframe Reynolds Number Additional to the conventional investigations this was used for —

(i) Comprehensive slipstream measurements
(ii) Tackling the tricky problems of the directional stability with tight limit on fin height forced by the backward flapping rotor
(iii) Drag reduction development

Implicit in the design of the Rotodyne is the aim of keeping rotor flapping down to very much smaller values than in conventional helicopters or indeed much smaller than in previous autogyros Programmes of full scale balance had to be conducted over the whole operating range and these were compounded from the results of these 1/6th scale tunnel tests and the best available estimates of rotor contribution

(*b*) *Flight test*

In the flight test programme so far most of the aerodynamic measurements made have been devoted to confirming trim balance and flapping values to enable the maximum achievement of the speed potential of the aircraft compatible with allowable rotor stresses The first 97 flights were made with fixed undercarriage and aerodynamic recording was therefore mainly confined to the measurements mentioned over a wide range of collective pitch, rotor r p m and forward speed Stability and control assessments have so far been mainly made by the pilot Broadly speaking the flapping results have come out within one degree of the estimated values over most of the measured range

The general trim changes in helicopter flight confirmed the wind tunnel measurements, with the only major difference arising in the effective rotor lift curve slope, which from full scale collective pitch measurements was found to be very much higher either than that estimated or that measured in the tunnel Some of this can be explained by the comparatively high Reynolds Number arising from the large blade chord and high tip speed, but it is also possible that the tip jets (which were not effectively represented on the tunnel model) serve as end plates, hence reducing much of the tip loss normally experienced

5 2 *Structural and fatigue testing*

Our main attack so far has been concentrated on fatigue substantiation, under calculated loads, of the main joints of the rotor, the control system, and the airframe, though comprehensive static tests on certain parts of the airframe have been made

The main criterion for the final fatigue clearance of the rotor will be rig testing of major assemblies rather than full scale ground running owing to the difficulty of obtaining the correct load distribution on the blades by this method This policy requires the construction of fairly complicated

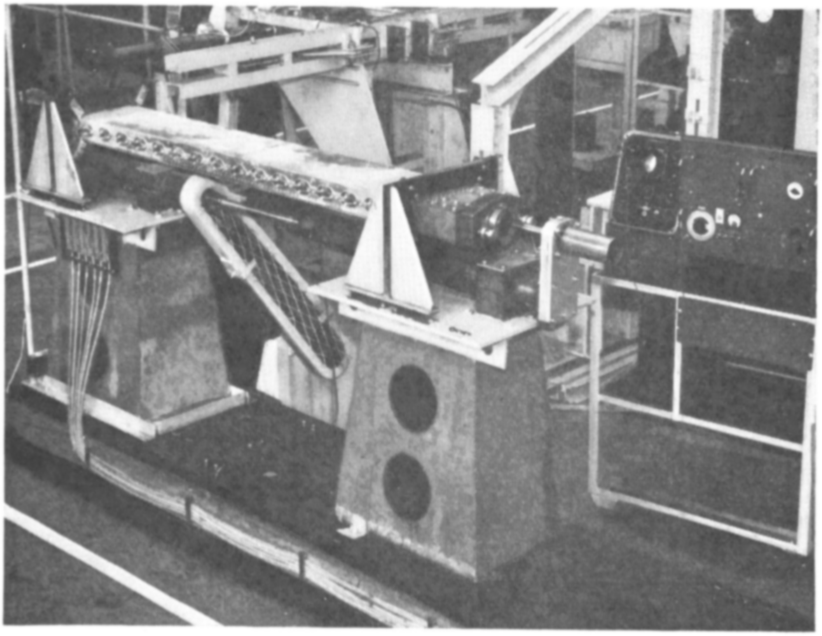


Fig 22 Blade on fatigue test

rigs but fatigue tests on blade sections, blade attachments, and flapping hinge assembly are already in progress A resonance method is employed where the centrifugal force is simulated by internal crippled struts The full scale rig referred to in para 5 5 has been of very great value however in providing background information for the test programme, particularly on the rotor head

All testing of assemblies is carried out under simulated flight loads, once representative values are available Rather than rely on the theory of cumulative damage in deciding upon testing cycles we have made all rigs so that programme loading can be applied One apparatus of this nature is a hydraulic type of fatigue machine specially made by Losenhausenwerk This is of particular value as, apart from testing in the machine itself, separate cylinders can be used for loading a component in any required phase or plane

Wherever possible, we have used non-destructive methods of test and development, and have found that three dimensional photoelastic methods, plastic models and brittle lacquers can often give useful guidance prior to full scale fatigue testing[12]

5 3 *Pressure jet development*

Tip jet unit chambers of the tangential circular type (as distinct from a flat radial type) were chosen because many design and performance features could be based on experience with the Jet Gyrodyne chamber, although some further development was necessary

A perfect blade profile right to the chamber body and a reduction of the ratio of frontal area per lb thrust, resulted in higher chamber entry speeds and an increase of cross sectional loading by 25% compared with those of the Gyrodyne chamber This high air speed with asymetric air entry, the high cross sectional loading, and the airborne re-light requirement at gas speeds corresponding to 50% of the maximum mass flow, were the most difficult development items

After passing through the head and blade ducts, the air from the auxiliary compressor reaches the chamber at roughly the same pressure as it leaves the compressor, the friction losses being compensated by a pressure gain

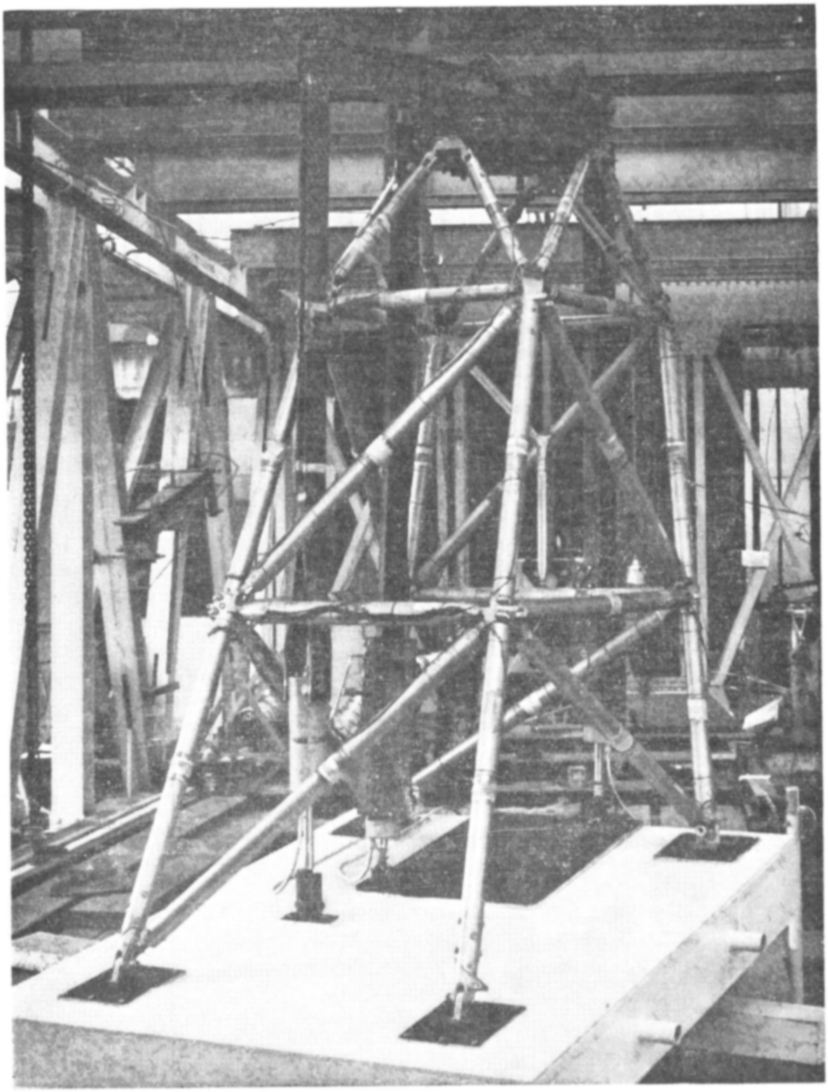


Fig 25 Pylon on fatigue test

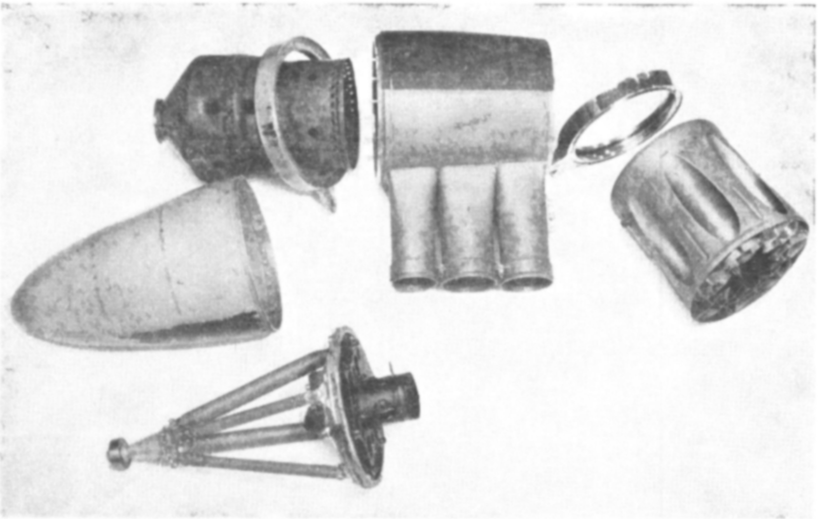


Fig 24 Jet unit construction

through the rotating blade An inner liner with deep plunged holes provides a vortex pattern which, although asymetric due to the side entry, still guarantees equal temperature distribution and satisfactory stability over a wide air fuel ratio range down to stoichiometric mixtures for the maximum rotor power requirement

A small fraction of the air is used to provide inner cooling for the end cone which has to stand flame temperatures above 1,700°C, and is mixed with the main jet just upstream of the exhaust nozzle Fuel is metered by a head pressure sensitive fuel regulator in the pylon, which adjusts the fuel-air ratio according to the power requirements, with the richest mixture at take-off power The C F of the rotating fuel column provides the pressure for the conical swirl type fuel sprayers inside the chambers Two high energy igniter plugs in each chamber supplied from entirely separate ignition systems, are operating during light up and re-light cycles only

The chamber is built up from machined forgings and sheet metal in Nimonic 80A , the liners are manufactured in Nimonic 75 The stressing of all chamber components was a particularly difficult task in view of the very high flame temperatures and centrifugal loads (roughly 350 g)

A new method of assessing the power output of the rotating chamber was specially developed Pressures and temperatures are taken on the rotating chamber and transmitted via blade capillary tubes, pressure transmitters and a slip ring arrangement to indicators inside the aircraft Thus, for practically the first time a reliable measure of rotor power was obtained

Each chamber is tested functionally and performancewise on the static rig and then on the rotating test stand at White Waltham , the whole rotor is then tested on the Boscombe Down spinning rig Some very useful liner development work was done employing models, notably half scale three dimensional perspex models run in the N G T E water tunnel

A very high performance range, reliable light up and re-light performance and good endurance of all components are the main characteristics of these chambers

Some typical figures from flight analysis and tethered testing are given in Appendix II

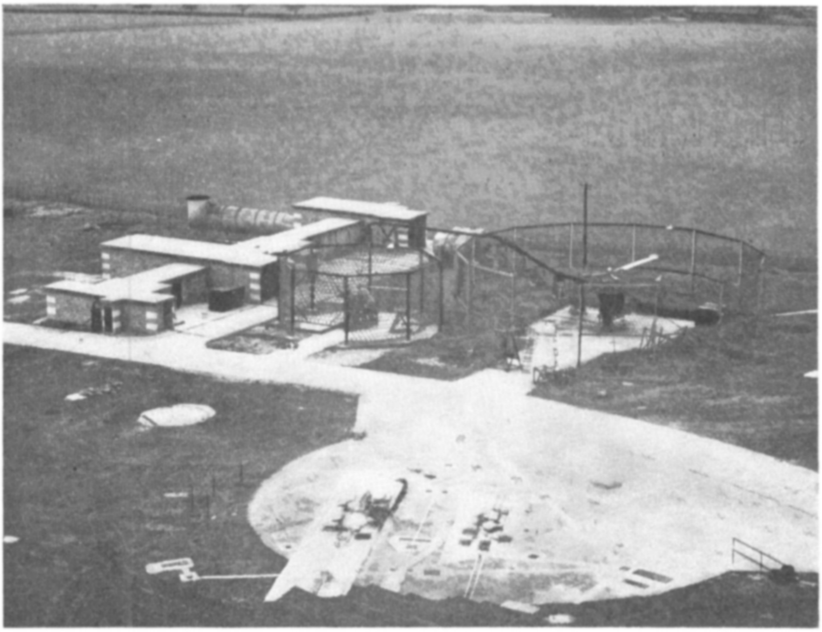


Fig 25 Tip jet development rigs

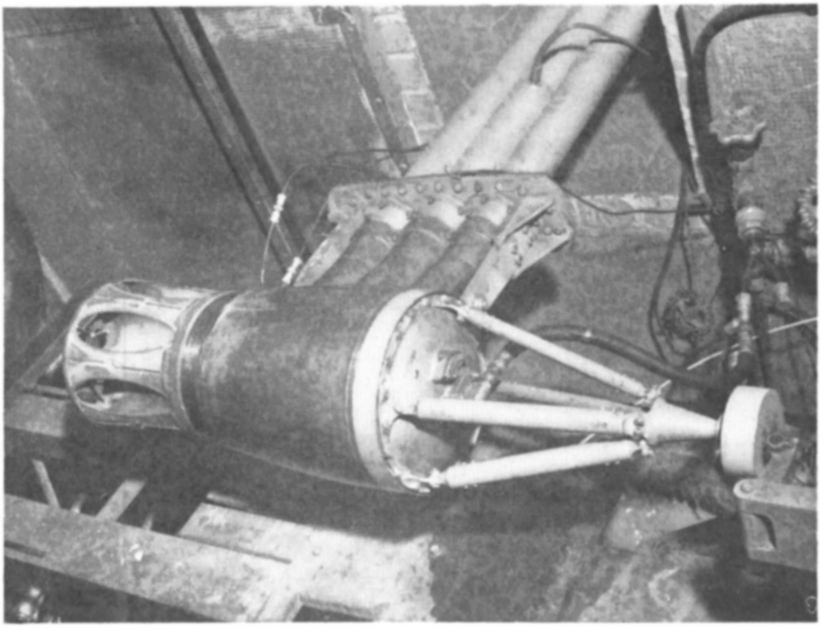


Fig 26 Tip jet on static test

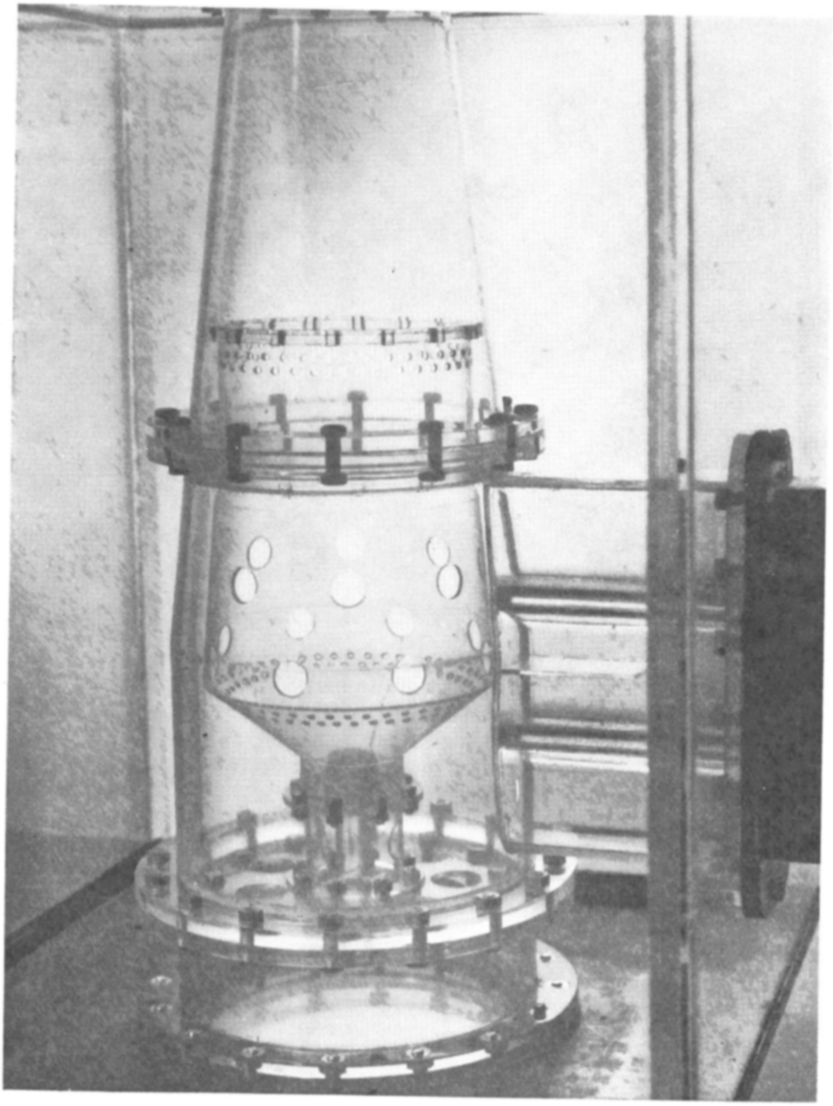


Fig 27 Model of tip jet for flow visualisation

5 4 *Development of tip-jet silencers*

One of the principle objections to pressure jet drive is the noise emission from the jets A really intensive study of the problem began in mid 1956 with extensive tests on the effect of nozzle configuration employing a static noise rig fed by air bled from the compressor of a Dart engine

Over 40 nozzles were tested covering two major classes, those composed of one or more slots and those of a miscellaneous class incorporating various ideas current inside and outside the Company

Fig 28 Range of experimental silencers

From these tests it became clear that suppression increased with a decrease in the minimum width in the discharge orifice and that by maintaining this minimum width in the form of a parallel sided slot, the attenuation achieved could be predicted at the design stage

In addition to this examination of nozzle configuration, a study was made of the effect on noise emission of pressure ratio, air fuel ratio and combustion noise It was found that pressure ratio and air fuel ratio influenced noise from the jet solely by their effect on jet velocity, noise emission being proportional to V^n where n is between 6 and 7 Combustion noise appears to have no influence on the overall noise emission probably because the noise from a smooth running combustion chamber is quite low

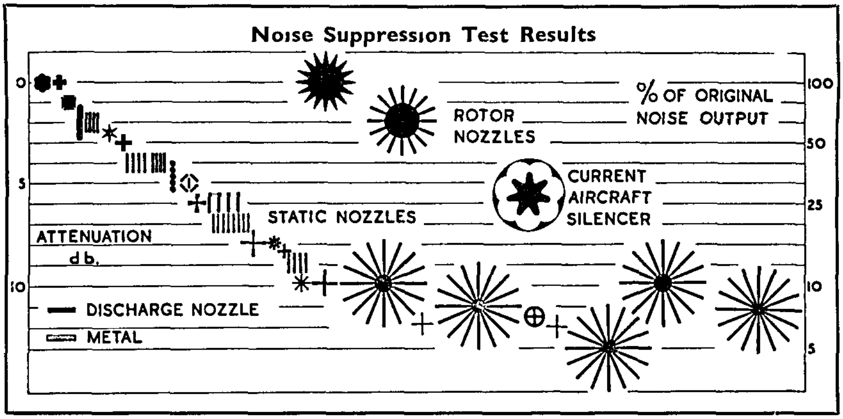


Fig 29 Attenuation with various silencers

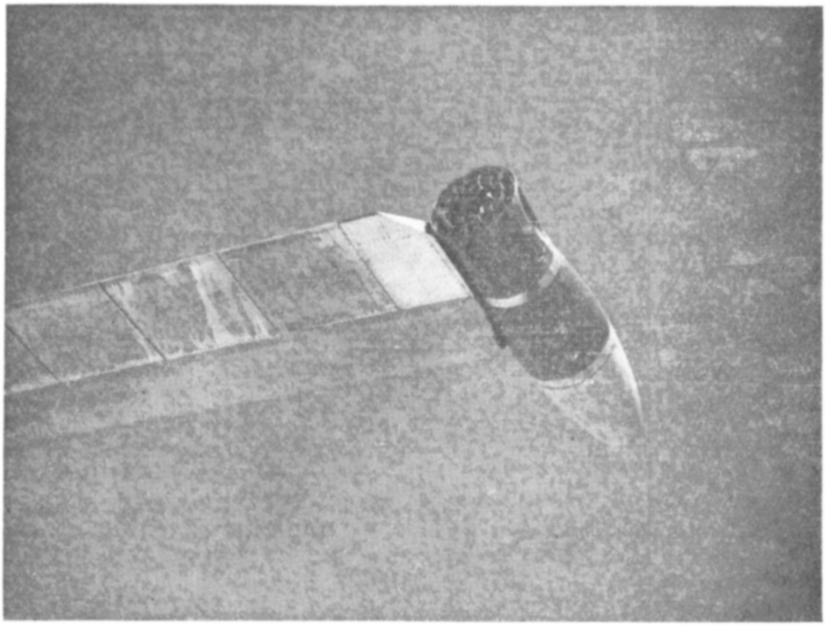


Fig 30   Current silencer

From this information, full scale silencers were constructed and tested both statically and at the tip of a rotating slave blade The noise level of the jet on the slave blade was lower by the amount expected from the change of relative velocity Silencers giving some 14 db attenuation were tested on the slave blade as the outcome of this chain of development There was no deterioration in attenuation with increasing tip speed

The pressure jet unit of the Rotodyne operates at near stoichiometric kerosene/air mixtures at 4 1 compression ratio with an imposed centrifugal force of 350 g Thus any silencer must be strong enough to stand up to this C F when dealing with jet gases at 1800°C and 45 p s i g In addition a severe weight restriction is imposed to reduce loads on the blade and to avoid blade flutter Because the vehicle employs pressure jets for only 5—10% of its flight time, the drag of the silenced unit in autogyro flight is of major importance Any final design must be a compromise between attenuation, drag, weight and strength

Since early flight experience of silencers was considered essential, it was decided that as a first step, there should be some sacrifice of attenuation to ensure a very reliable structure, well within the weight limitation and with an acceptable drag in autogyro flight

Three designs were built and developed in parallel, the best being flown early in August and retained for all subsequent flights This gives an overall attenuation of 4 d b with 5—6 d b suppression in the mid frequencies Immediate development of this design in the light of flight experience should result in 6 d b attenuation overall

Work continues to reduce the loss of attenuation imposed by the weight and drag limitation and it is anticipated that a 10 d b suppressor, whic cuts the mid frequencies by about 15 d b will be up to flight standard before long Detailed consideration is being given to further designs which offer further noise reductions and I am completely confident that this aspect of the Rotodyne will not be an obstacle to its use even in regular city centre operation

5 5 *Full scale power plant and rotor test rig*

The Rotodyne represents a new departure in the control of an aircraft power plant and rotor system, and it was obvious that a full scale rig representative of all the essential components involved would be needed in order to prove and develop the system By courtesy of the Ministry of Supply and the Officer Commanding A & A E E such a rig was built at Boscombe Down and this has proved truly invaluable, not least as a training ground for the technical staff and pilots before the first flight of the aircraft

The rig is a complete representation of the rotor, power plant, and controls of the aircraft and thus allows endurance testing, control development, and pilot familiarization to be carried out The instrumentation includes normal aircraft instruments, 12 channel strain gauge apparatus with automatic switching to permit measurements from a hundred strain gauges on the rotor, and instrumentation for the measurement of tip jet performance

Initial engine running was begun early in 1957 and as the complete power plant and rotor system gradually became available, development

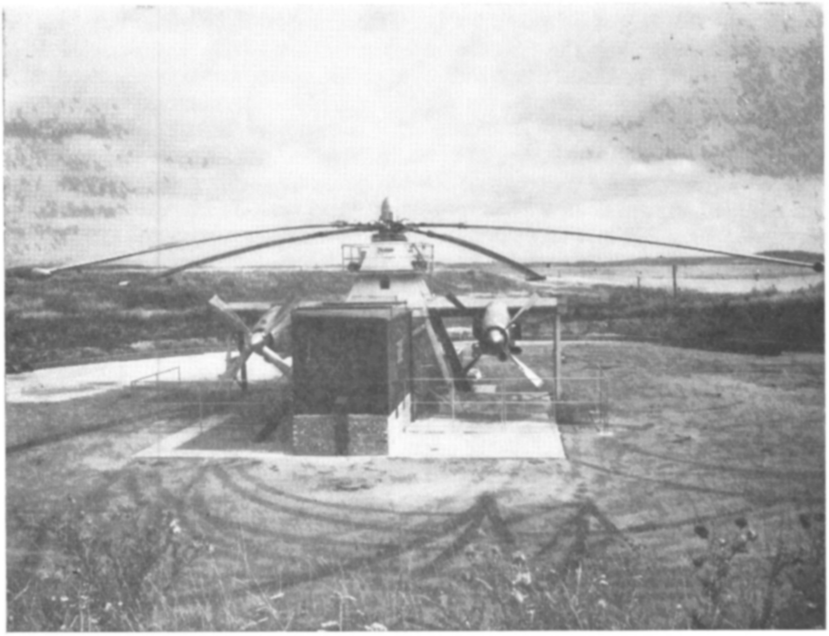


Fig 31 Full scale rotor and power plant test rig at Boscombe Down

Fig 32 Power Plant testing before first flight

progressed in stages until a complete twin engine four blade rotor system was run late in August, 1957 By the first flight of the aircraft some two months later about 50 hours rotor and 100 hours engine running had been completed on this rig without the need for any significant modification other than to the lubrication of the main head air seal Indeed, this has been the only major change made to the head and controls even up to the present time

In this preliminary period the rotor power was measured, the rotor, its controls and the propellers strain gauged, and the functioning of the head and propeller controls and the throttle governors assessed

The effort involved paid off handsomely, since on the actual aircraft only some 4 working days was spent on ground running prior to first flight This ground running included a complete power plant functioning check, engine and compressor performance determination, and the final full scale ground resonance checking We regard the completion of a comprehensive pre-flight programme of this nature in such short time as a major triumph, largely attributable to the lessons learnt on the rig

Since first flight, apart from endurance and development testing, we have been mainly concerned with development of silencers for the tip jets and with improvements to the throttle governors Some time has been given to research problems such as investigations into the effect of chordwise position of rotor blade centre of gravity on flutter characteristics

This rig is going to be invaluable in building up quickly the experience necessary to ensure adequate life of the components under conditions representative of the aircraft

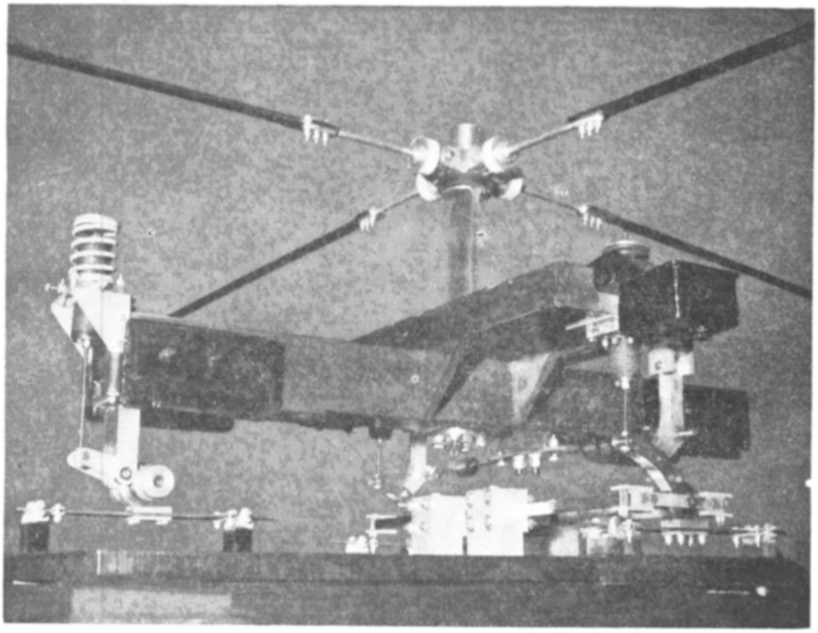


Fig 33 Dynamic model

5.6 *Investigation of ground resonance*

To achieve our aim of a light retracting undercarriage, we realised it would be necessary to supplement theoretical work on self-excited ground vibrations by testing of a dynamic model. Accordingly, a model was built

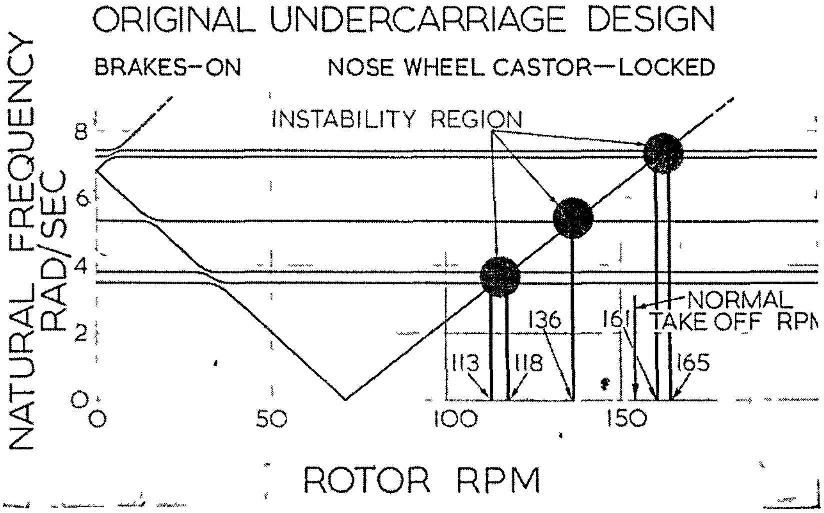


Fig 34 Analysis of ground resonance problem

representing all degrees of freedom of the aircraft on its undercarriage, and of the rotor, to the following scales —

Mass	1 450
Length	1 15
Stiffness	1 5 13
Speed and frequency	9 35 1

First model tests confirmed theoretical predictions of instability in one condition and, following experimental verification of the calculated imped-

Fig 35 New undercarriage

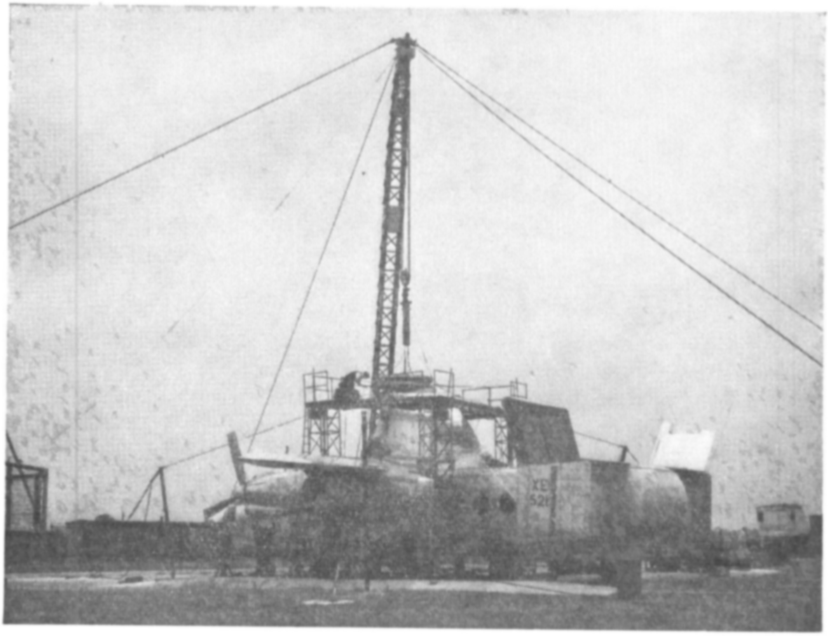


Fig 36 Full scale impedance test rig

ances of the airframe, it was decided to proceed with the initial flying with a fixed, stiffened undercarriage to allow of a thorough examination of the problem without delay to the rest of the test programme

Tests were made by shaking the airframe at the top of the pylon using hydraulic jacks to apply the required forces at various frequencies and measuring the displacements of the structure Partly airborne conditions were simulated by supporting the aircraft from a crane through a soft air spring

Model testing and calculations led to the present successful design of undercarriage in which springs give low natural frequencies in translational modes while rolling and pitching modes are high, resulting in a very weak instability at 105 r p m The model proved particularly valuable for this development as the effect of any parameter could be studied quickly and because the severity of instability was also indicated to a degree that, we found later, was comparable with the aircraft

A full scale test simulating the new design was made by running the rotor with the aircraft standing on platens, which were free to move in any direction, and restraining it by springs of appropriate stiffness coupled to earth These tests confirmed the model work

To protect the aircraft while running under conditions likely to lead to ground resonance, a restraining rig was clearly necessary even at the risk of complicating the interpretation of results

In the tethering gear the aircraft is restrained by three cables, at 120° to one another, running from the rotor head to the ground, and in fore and aft direction at the main wheels, where soft springs were used to react any thrust All these restraints were arranged so that only slight stiffness was added to the system but when desired the cables could be instantaneously tensioned hydraulically and clamped This system was tested first on model scale, and in use has been found satisfactory for damping violent instability without introducing any false stiffnesses

The most sensitive method of detecting instability is by observation of the dynamic stresses on the blades Testing is normally run under the control of an external observer who monitors these values, and with the opinion of the pilot and an observer close to the aircraft, assesses the degree of any instability which may develop

5 7 *Functional test rigs and ancillary systems*

To minimise development on the aircraft test rigs were built which were capable of simulating flight conditions for the various systems, mechanisms and components fitted to the Rotodyne By beginning such a test programme well before the aircraft was completed, it was possible to eliminate many of the faults which might otherwise have developed in the aircraft installation

The fuel system was designed to the simplest possible standards for reliability, safety and ease of maintenance, and was tested on a full scale rig simulating flight attitudes and conditions wherever possible

In addition, since it was necessary to feed fuel to the rotor blade tip jet units as well as the engines, certain specialised components, such as the

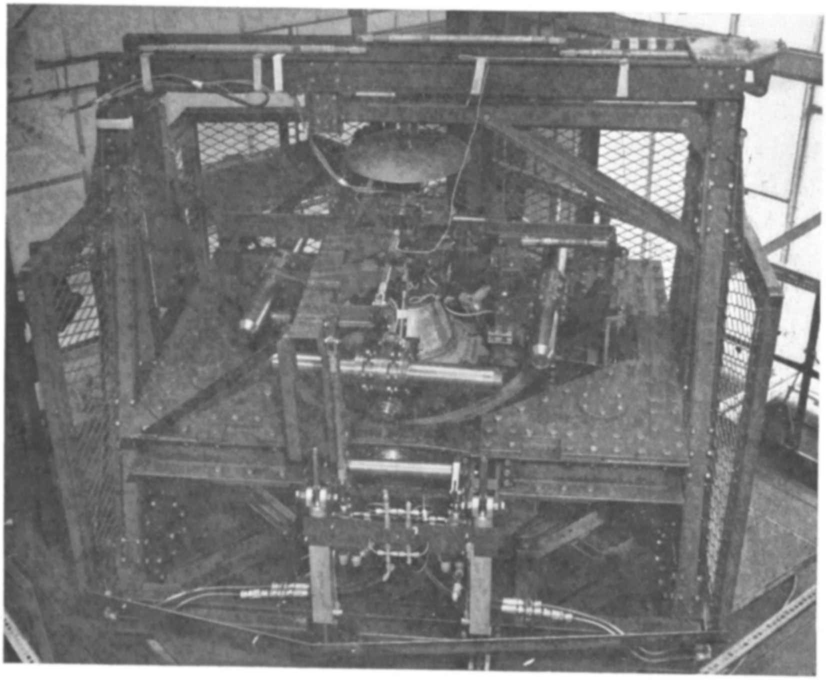


Fig 37 Rotor head and controls test rig

rotor driven gearbox (which drives the rotor fuel pump, No 2 hydraulic system pump, and the rotor tachometers), and the fuel/air regulator for tip jet units were developed and cleared for flight on rigs before installation on the aircraft

The blade pitch change mechanism in the rotor head consists of a swashplate assembly operated by four Fairey tandem hydrobooster power control jacks, two for the lateral cyclic control and two for both fore and aft cyclic and collective control The power control system is fully duplicated, being supplied from the main engine driven hydraulic system The second side of each jack is supplied from the rotor driven No 2 hydraulic system A rig was built incorporating all this mechanism, together with a means for applying factored flight loads to it during rotation and for any required change in plane of the swashplate An automatic input mechanism feeds a condensed flight programme into the control mechanism for both the cyclic and collective controls , continuous strain gauge readings and pressure recordings are taken at all salient points

On this rig, which is considered to be one of the most comprehensive of its type, the efficiency of the mechanism was determined statically and dynamically and developed to an acceptable standard before first flight Extended endurance running and fatigue tests have been undertaken and are continuing at a sufficient rate to keep the rig time well ahead of aircraft flying hours

The hydraulic system also provides power for the retractable undercarriage and fin folding, operation of the rudders, freight doors, wheel and rotor brakes These circuits were so straightforward that only flight clearance tests on the aircraft were necessary , this also applied to all the electrical services

5 8 *Balancing of rotating assembly*

Clearly this is of major importance, since the aim was to obtain completely interchangeable blades and jet units This has been achieved without the need to balance a complete rotor head and blade assembly at any time

All components of the rotor system are individually weighed and balanced, the results for each item being related to each other theoretically to establish the mass and position of the adjustable balance weights on the head and inner blade spars to bring the resultant centre of gravity of the whole to within 0 040″ of the axis of rotation

The centre of gravity of each blade is determined by means of a bifilar rig and adjusted to the required position of 23½% chord Similarly, the centre of gravity of each tip jet unit is established and corrected to this same position This procedure enables tip jet units or blades to be interchanged with the minimum adjustment to achieve balance

The rotor head including inner blade spar is balanced statically and the relative positions of the blade root attachments checked for geometric accuracy Overall rotor balance is achieved by adding any necessary weights near the outer extremities of the inner spars

5 9 *Aircraft Instrumentation*

From the very first step comprehensive instrumentation was installed to ensure adequate collection of all vital data connected with handling and performance characteristics, power plant and systems functioning, and structural integrity

Steady or near steady quantities are recorded by cine photography of instrument panels situated in the cabin , these are monitored by the flight crew Dynamic quantities for control and stability tests, measurements of blade feathering and flapping motion, and a record of undercarriage behaviour are obtained from multi-channel continuous trace recorders In this way about 140 quantities are recorded or monitored during flight All recording instruments can be controlled either by the second pilot or by the flight test observer

Approximately 250 strain gauges are fitted to the rotor head and blades and a similar number distributed over the airframe structure, in addition to accelerometers for vibration measurement Further multi-channel galvanometer trace recorders of appropriate response are used for the recording of this data

Interesting special pilot's instruments include aircraft incidence and sideslip, and an indicator showing the proximity of the rotor blades to the droop stop A jet alight indicator is also provided for each tip jet motor

The transmission of measurements relating to the tip jets, blades and head is effected by means of a 35 channel slip-ring installation with remotely controlled group selector switches situated in the rotor head

On a typical test flight lasting 40 minutes, 300 feet of 35 mm film is exposed in addition to an aggregate of 2,500 feet of continuous trace recording

In addition the pilot's V H F transmission of his test procedures is recorded on the ground, whilst the second pilot maintains an independent record on a pocket wire recorder

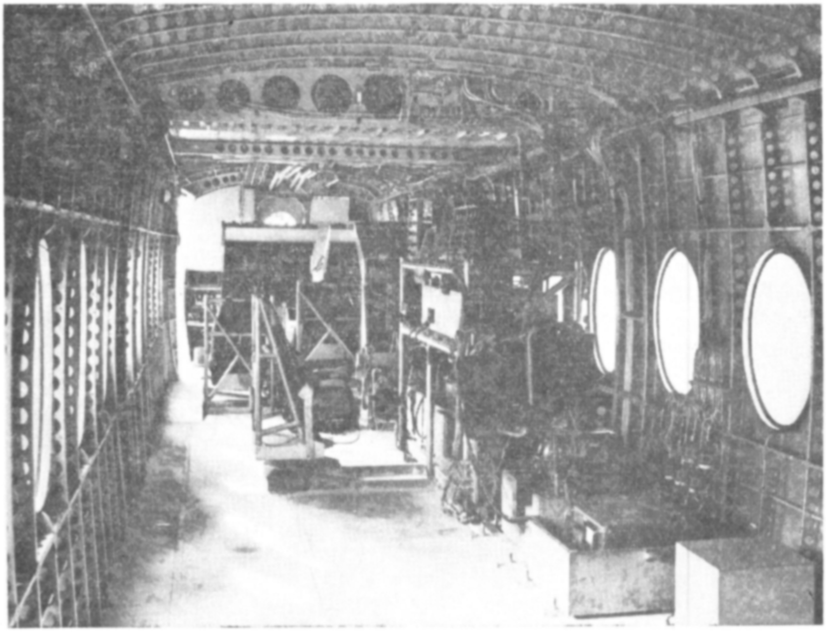


Fig 38 Aircraft instrumentation

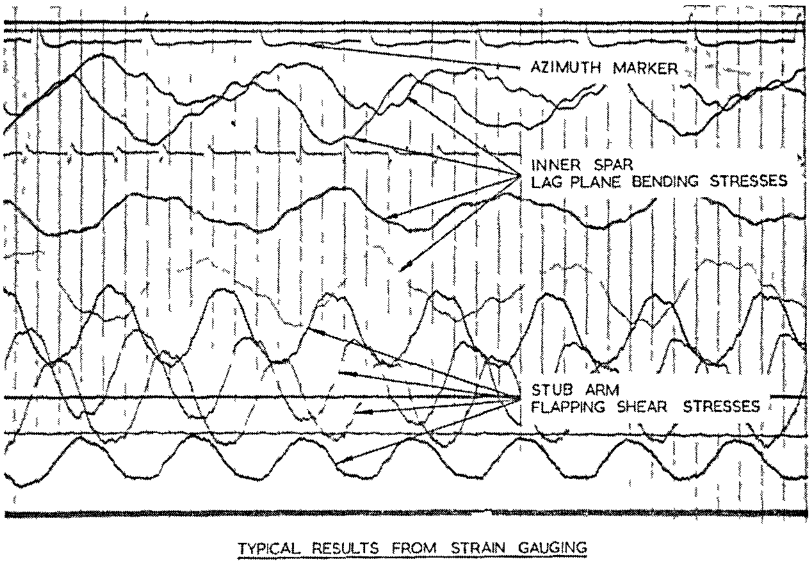


Fig 39 Typical strain gauge results

6 *Review of Flight Progress to date*

6 1 The first flight took place at 8 45 a m on November 6th, 1957, three flights, including a low speed circuit of White Waltham aerodrome, being completed by noon on that day

In the opening phase of the flight test programme the principal aims were —

To assess the quality of the pilot's flying controls in the hover and at low speed

To check the functioning of the power plant and its control system

To maintain a close check on the stress levels in the main parts of the rotor system

To extend gradually the speed/height envelope

All this initial flying was confined to the helicopter regime until an indicated speed of 136 knots and an altitude of 6,800 feet had been attained The flying controls proved eminently satisfactory, particularly those of the rotor, an adequate degree of directional control being achieved by the differential propeller pitch scheme

Aerodynamic investigation had shown that the optimum speed for transition, based on a combination of performance and control factors, was likely to be around 100 knots and thus sufficient speed margin above this was cleared for helicopter flight On the Boscombe Down rig development tests had proved, within the rig limits, that relighting of the tip jest in the air could be relied upon from either of the duplicated tip jet ignition systems

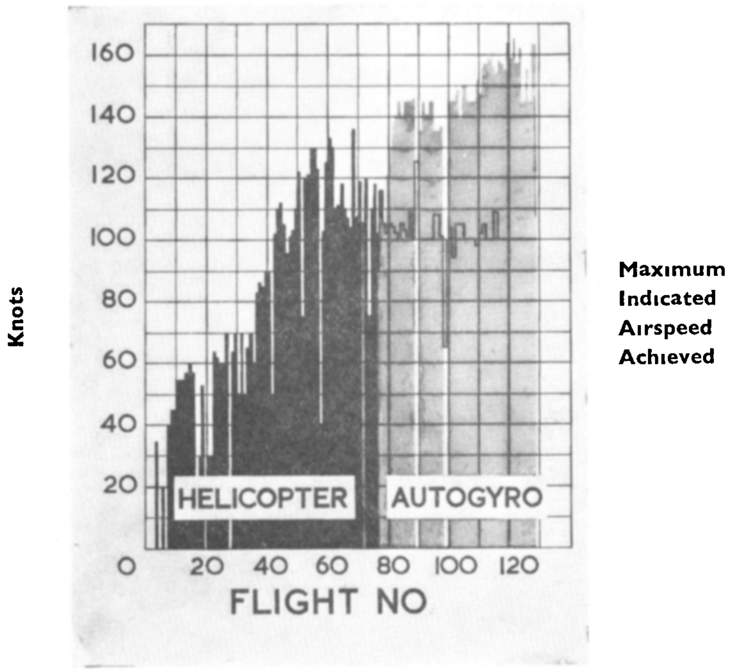


Fig 40 Forward speed growth as test flying proceeds

6 2 The stage was now set in which to begin the transition work We were fortunate in that several hundred transitions had already been accomplished on the Jet Gyrodyne and thus the principles of the power plant control during the process were well understood The lifting wing, however, introduced a very important new feature which was thoroughly studied by the aerodynamic staff using theory and model tests We decided to follow a gradual approach, reducing the maximum rotor power in discrete steps from the " all four jets lit " condition by extinguishing each pair of jets in turn, then declutching each half rotor in turn, until finally no tip power was transmitted to the rotor This phase threw up some further problems of relighting, and compressor air blow-off valves were introduced to facilitate the process at the higher altitudes where these initial transition tests were conducted These blow-off valves showed to advantage in allowing a more rapid rate of descent than had hitherto been possible This step by step approach allowed the pilots to assess the trim problems involved at each stage, until on the 71st flight on 10th April, 1958, after a total of 20 hours' flying, the first full transitions were completed

6 3 Once the autogyro regime had been reached, more and more time was spent in this condition, extending the speed and height range, assessing the aircraft's flying characteristics and control qualities, and always keeping a careful watch on hub and blade stresses as well as on the power plant and its control The transition technique has been steadily perfected and

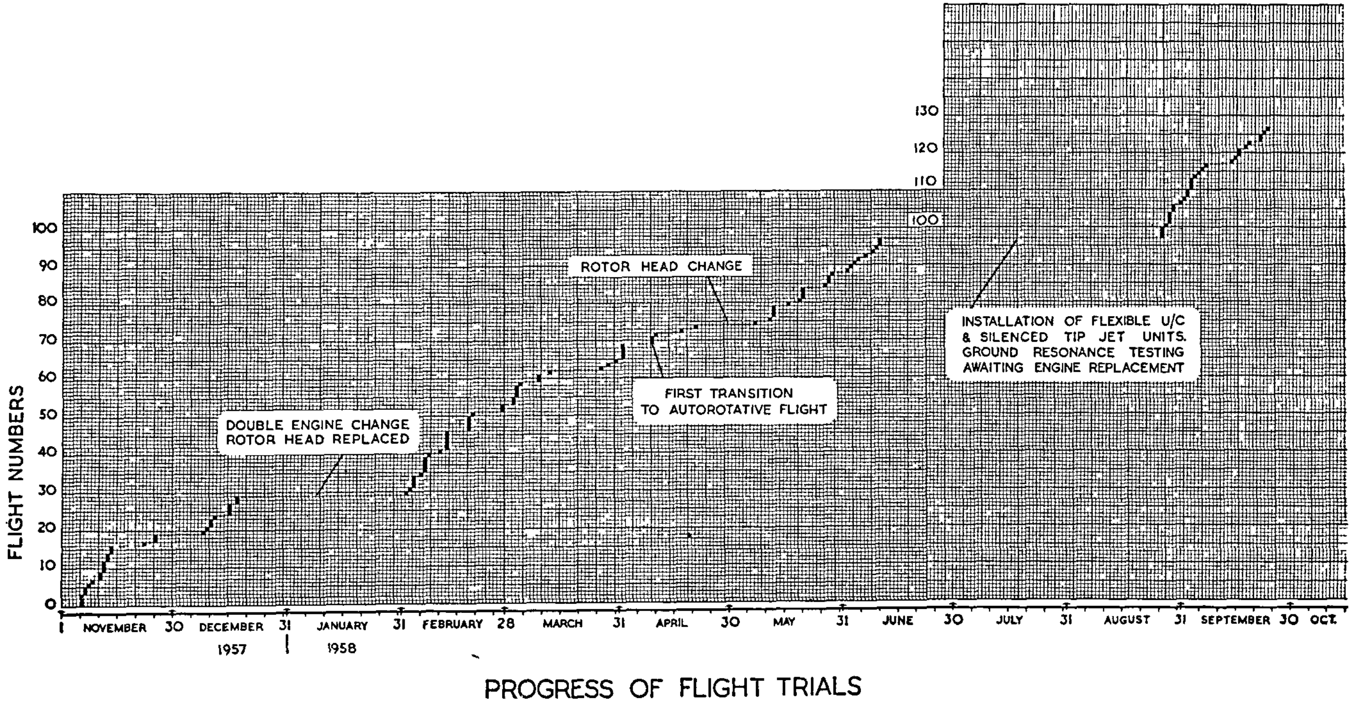
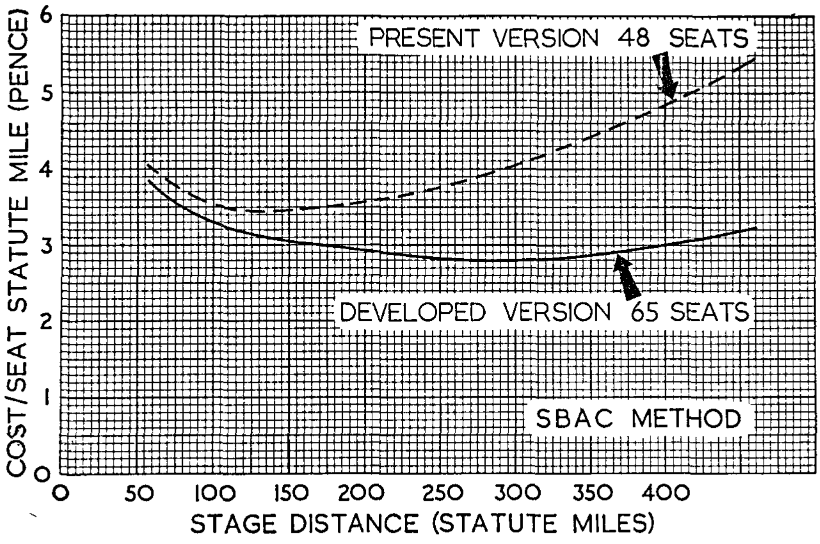


Fig 41 History of aircraft development flying



Direct Operating Costs

Fig 42 Operating costs of present and developed aircraft

now this is often conducted at very low altitudes and very shortly after take-off or before landing The cruise speed of 160 knots on which the economics have been based has been exceeded, even at this relatively early development stage, at a power inside the cruise power rating of the engine, thus demonstrating beyond all shadow of doubt the soundness of the basis approach The tip speed ratio so far reached in cruise is about 0 53, though ratios exceeding 0 6 have been attained The climb performance is phenomenal for such a large aircraft as vertical rates of climb of over 1,900 ft /min and forward rates of climb of over 2,400 ft /min have been measured at full gross weight appropriate to the present engine ratings I might emphasise here that virtually all flights have been done at the full design take-off weight appropriate to these engines,* or slightly above

It would be wrong of me to suggest that no problems have shown themselves, and in any case no one would believe me I can say though that few, if any, serious problems have asserted themselves within the speed range originally fixed when design began about five years ago The aircraft manoeuvreability is very impressive for such a large, heavy aircraft, turns of 60° bank having been done in the course of such handling tests as we have covered to date At the higher speeds which have been attained, there is evidence of a reduction in the rolling control and an increase in the sensitivity of the fore and aft control

The steps required to overcome these problems are clear to us and will be taken as soon as sufficient break in the flying programme offers itself In the meantime, the emphasis will be on performance and handling assessment, especially in the engine failed case which is of such vital importance to any civil air transport machine

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* The A U W was originally fixed as that at which 200 ft /min rate of climb on one engine at one-hour power rating could be maintained

7 *Further Development*

You may now ask what development possibilities there are with this configuration   Apart from increase in weight by a factor of 1½ which can be contemplated with equanimity, we are especially concerned with exploiting the speed potential as much as possible—one of the earlier slides showing why this is so attractive   We believe that cruising speeds of 220 knots are possible with this basic configuration by developments mainly aimed at maintaining good control for the pilot and reducing rotor drag

At the moment, I would not care to say that higher speeds than 220 knots cruise could be achieved, though experience is a great teacher   In any case, an economic VTOL aircraft, with adequate performance standards with an engine failed, *and* a cruising speed of 220 knots, with all weather capabilities is, I am certain, a vehicle which no operator, civil or military, scheduled or bush, can possibly afford to ignore

8 *Acknowledgments*

Now that I have reached the end of the paper comes the most difficult part of all   How is it possible to express the immense debt which is owed to all those in the Fairey Aviation Company, Napiers, and the other companies involved who by their faith and hard work have made it possible for me to be privileged to present this paper to you tonight? One cannot give a list of all those who have made a contribution, even major contributions, and I must content myself with a photograph of some representative members of the Fairey design, manufacturing and development teams   To this anony-

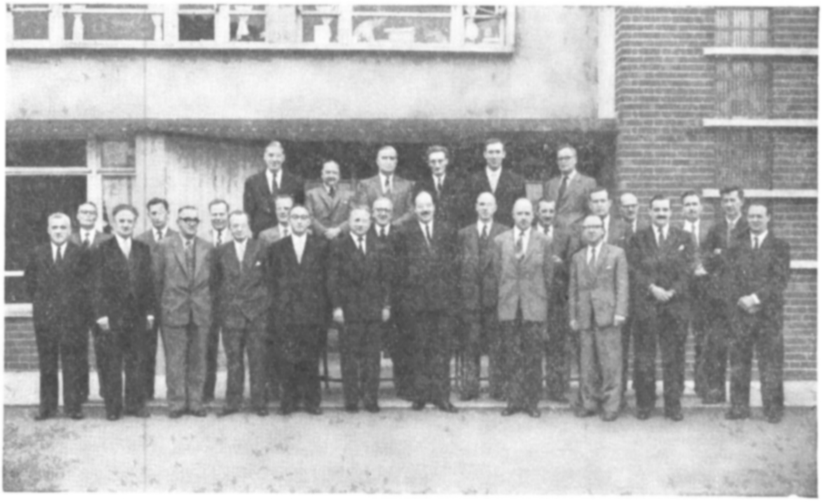

Fig 43   The Rotodyne team

Front row (left to right)   A E Bennett M S Hooper E K Whipp R E S Swinfield H H Tozer R C Maltby S Molyneaux, J L Flintoff Dr H Roberts F H Parker W E Cooper Dr G S Hislop Dr H F Winney C W Cowle H A Tozer A Stepan W Denyer A F Farr J C D Cotes, Dr D B Leason K T McKenzie D M Davies   back row, (left to right)   R W S Thorley F L Hodgess J J Hillard A H Smith, V A B Rogers, R D Trumper mity I would make one exception, however Without the professional skill and devotion of our two pilots, S/Ldr W R Gellatly, A F C, and L/Cdr J G P Morton, our technical efforts would have got nowhere and to them I would pay a special tribute

We are much indebted to the research and air branches of the Ministry of Supply for their technical and financial support of this venture, and we hope that this fruitful co-operation will continue I personally am indebted to the Chairman and Directors of the Fairey Company for permission to give this paper, to my immediate colleagues who have helped so much in its preparation, and in particular to my Technical Director, Mr R L Lickley, for his constant encouragement and advice throughout the design and development of the Fairey Rotodyne

THE ROTODYNE PILOTS

S/Ldr W R Gellatly and L/Cdr J G P Morton

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APPENDIX I

LEADING PARTICULARS OF ROTODYNE

Rotor Dia		90′
Rotor Blade Chord		27″
No of Blades		4
Nominal Rotor Solidity		0637
Rotor Aerofoil Section		N A C A 0015
Flapping Hinge Offset		2′
Rotor Blade Twist		0°
Gross Wing Area		475 sq ft
Wing Span		46′ 6″
Wing Chord		10′ 4″
Wing Aspect Ratio		4 5
Wing Section		N A C A 23015
Wing Incidence to Fuselage C/L		4° 40′
Tail Plane and Elevator Area (Gross)		163 sq ft
Tail Plane t/c		14%
Fin and Rudder Area (Total)	Fixed fin surface Retracting fin surface	106 sq ft 64 sq ft 170 sq ft
Fin and Rudder t/c ratio		10%
Tail Unit Aerofoil Sections		N A C A Symmetrical
Overall Length of Fuselage		58′ 8″
Overall Height		22′ 2″
Fuselage internal length		46′
Fuselage internal height		6′
Fuselage internal width		8′
Floor height off ground		3 ft 5″
Clamshell door size		8′ wide × 6′ deep
Forward door size		5′ 10″ high × 3′ wide
Window spacing		36″
Track of Undercarriage		24′ 6″
Fuselage C/L Angle to Ground (Static)		0°
Propellers		2 × 13′ dia , 4 Blade, Roto'
Gross Weight		39,000 lb
Disc Loading (Hovering)		6 14 lb /sq ft
Nominal Blade Loading (Hovering)		96 4 lb /sq ft
Tip Speed (Hovering at S L)		720 ft /sec

Power Plant	2 Napier Eland N E L 7 with Hydraulic Clutches and Auxiliary Compressors Four Fairey Pressure Jet Units
Engine Data	
Max Rating (S L)	3,250 S H P
1 Hour Rating (S L)	2,900 S H P
Auxiliary Compressor	
Mass Flow at 12,500 r p m	22 7 lb /sec
Compression ratio at 12,500 r p m	4 35 1
Direction of Rotation, Propeller	L H Traction
Propeller Reduction Gear Ratio	0 0912
Shaft Size	No 6 S B A C

Note Prototype Aircraft operates at a design weight of 33,000 lb and uses Eland N E L 3 engines of 2,800 S H P Max Rating

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APPENDIX II

TYPICAL TIP JET PERFORMANCE DATA—FROM FLIGHT ANALYSIS AND TETHERED TESTING

Conditions

1	Power	4,000 Rotor h p
2	Air/fuel ratio (R)	21
3	Specific fuel consumption	
	Main engine	823
	Rotor	1 65
	Total	2 473
		$\left.\right\} \frac{\text{lb fuel}}{\text{Rotor h p}}$
4	Duct Mach Number	0 3
5	$\frac{\text{Gas h p at combustion chamber entry}}{\text{Gas h p compressor delivery}}$	96
6	Air entry speed into combustion chamber	331 ft -/sec
7	Volumetric heat loading	$12\ 4 \times 10^6 \frac{\text{lb /C H U 's}}{\text{Hr Atm ft}^3}$
8	Cross sectional heat loading	$14\ 6 \times 10^6 \frac{\text{lb /C H U 's}}{\text{Hr Atm ft}^2}$
9	Combustion efficiency	88%
10	$\left\{\frac{\text{Pressure drop across chamber}}{\text{Total chamber entry pressure}}\right\} \times 100$	9 5
11	Jet outlet speed	2,520 ft /sec
12	Flame temperature in chamber	1,600°C at R = 21 1,800°C at R = 17