Some Helicopter Turbine Installations

By A W MORLEY

Ph D , M Sc , A C G I , A F R Ae S *

A Paper presented to The Helicopter Association of Great Britain in the Library of The Royal Aeronautical Society, 4 Hamilton Place, London, W 1, on Friday, 9th December, 1955

DR G S HISLOP (*Chairman of the Executive Council*) *in the Chair*

INTRODUCTION BY THE CHAIRMAN

The CHAIRMAN, in introducing the Author, said that Dr MORLEY, who was Forward Projects Engineer, D Napier & Son Ltd , had been sixteen years on the scientific staff of the Engine Department of the Royal Aircraft Establishment, and at the end of the war was deputy head of the Gas Dynamics Division, which ultimately became the Supersonics Division For three years thereafter, he had lectured on aircraft propulsion at the College of Aeronautics, Cranfield In his present position as Forward Projects Engineer with D Napier & Son Ltd , he was engaged principally on technical investigations into developments in aeronautics

DR A W MORLEY

Summary

This paper is concerned with the application of the gas turbine to helicopters from the point of view of the engine designer There are three aircraft of special interest nearing the flight stage which are examples of (*a*) a mechanical rotor drive, (*b*) gas drive and (*c*) combined gas drive with normal propeller The basic principles of the three gas turbine installations are briefly described

The gas turbine has a number of known advantages to offer helicopter designers It poses, in its turn, some novel problems in flexibility and control which are far reaching The method of overcoming these in the three cases is indicated The rotor system behaviour in cases (*b*) and (*c*) is closely integrated with engine control relationships The use of two engines can be justified since the engine system can cope quickly and adequately with emergency requirements following single engine power failure

The paper does not attempt to draw an overall comparison between the three forms of turbine rotorcraft and concludes that much has still to be done before the most suitable form for any given purpose can be decided

---

*The opinions expressed are those of the author and do not necessarily indicate the policy of D Napier & Son Ltd

(1) INTRODUCTION

Special attributes of the gas turbine engine which make it attractive for helicopter propulsion are its low weight per horse-power, freedom from vibration, simplicity of installation, low frontal area and bulk, the freedom of choice in rotor speed, and its ability to make use of a range of liquid fuels carrying less fire risk than petrol

The major limitations of the gas turbine which determine its scope in helicopters are its relatively heavy fuel consumption and high first cost Also it presents the designer with a number of new engineering problems The object of this paper is to describe the application of the gas turbine in helicopters known to the author which show how the attractive features of certain Napier engines are exploited A number of valuable papers giving other aspects of helicopter gas turbines have appeared previously (see Refs)

The future of the helicopter in the Military and Civil fields is tied to the future of the gas turbine engine Both the aircraft and engine have a wide variety of possible forms and a long period of development ahead

(2) TYPES OF INSTALLATION WITH TURBINE ENGINES

The gas turbine can be used in the helicopter to power the rotor in two distinct ways (*a*) direct mechanical drive and (*b*) tip jet reaction

In the former there is direct application of the output torque of the turbine, through a shaft and reduction gear to the rotor heads We refer to this system as a mechanical drive It is typical of all piston engined helicopters in service and some prominent gas turbine installations It is eminently suitable for a multi rotor machine in which the rotors are mechanically coupled A notable example is a development of the Bristol 173 twin rotor helicopter powered by two Napier Gazelle units

In the second class we have the reaction drive of the rotor by means of tip jets These jets are produced from gas delivered by the engine The engine power output can be wholly in the form of compressed air which is discharged at the rotor tips or, to increase the rotor power, extra fuel may be burnt at the discharge nozzles, as in the reheat system of a turbo jet engine Again by using a slightly different thermodynamic cycle, the rotor discharge can include all the gas in the engine efflux including the turbine exhaust There is no mechanical output, except to auxiliary drives, and the rotor receives all its propulsive energy in the form of gas horse-power

As an example of the latter class we have the Napier Oryx engine which is under development for the Percival P 74 and P 105 helicopters It appears to be specially suited for the single rotor helicopter since fundamentally there is no rotor torque reaction to be counteracted when manoeuvring the aircraft

A further example of the second class of turbine installation in development, is a combination of jet rotor drive by tip jets and a normal aircraft turbo propeller drive In this system the engine is used to drive the rotor by compressed air, with or without tip jet burning, and the propellers by shaft drive through a reduction gear As engine power is transferred from the rotor jets to the propellers so the aircraft changes from being supported by the rotor to an approximately equal division of load between the wings and autorotating rotor Thus it can take off and land with little or zero horizontal distance covered and yet cruise almost as a fixed wing aircraft This system is used in the Fairey Rotodyne, the engine being a close derivative of the Napier Eland known as the N El 3

It will be seen that of the above helicopter turbine systems only the first bears any resemblance to the mechanical drive of the orthodox piston engine technique Even in this case, there may be no direct mechanical coupling between the main engine rotor and the helicopter rotor because a free power turbine is usually employed in order to get the necessary flexibility in the ratio of rotor R P M to engine main compressor speed The other two techniques are essentially pure gas rotor drives and are advances made desirable by the advent of the gas turbine engine

(3) General Features of a Gas Turbine Helicopter Installation

One question of high importance at the inception of a helicopter design is the choice of the best number of engines This is clearly related to the aircraft performance demanded with an engine out and therefore depends on the type of civil or service operation for which the machine is intended and which in turn will dictate by experience the flight condition and loading it must be able to hold under the emergency It is also closely related to engine performance, and in particular to the question of what overload ratings the gas turbine engine can safely stand, for a given output on a short term rating As both helicopter requirements and gas turbine ratings are in the formative stage and depend upon engineering developments along a number of lines there can as yet be no firm answer to this question (Fig 1)

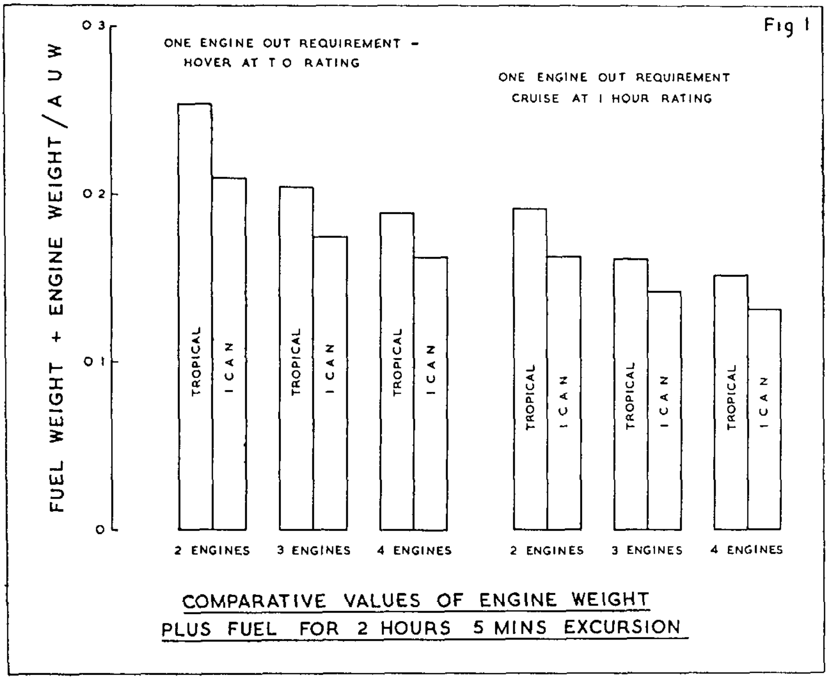


Fig 1 Comparative values of fuel weight plus engine weight as a proportion of helicopter all-up-weight assuming 10 lb of lift per S H P There is sufficient engine power installed in all cases to satisfy flight with one engine inoperative under the stated conditions The fuel load is that necessary for the 2 hrs 5 mins excursion with all engines in use

The total engine plus fuel weight for a given duty may be reduced by increasing the number of engines, under certain assumed conditions

Some of the problems facing the engine designer in the application of a gas turbine to a helicopter are concerned with the following

(i) The necessity for a comprehensive engine control

(ii) Emergency power requirements and the determination of satisfactory engine ratings

(iii) Dirt accumulation on the compressor blades

(iv) The novel situation of the engine

(i) The relative inflexibility of the manually operated turbine compared with the piston type engine, as measured by the narrowness of its stable range of mass flow at a given speed, means that changes in operating conditions can only be made smoothly and rapidly if the engine variables are linked and limited by automatic control Flexibility depends upon the success of the designer in making full use of the operating field of the compressor and getting the better performance available when operating near the surge line without running into surge When an engine cuts out through a failure and full power is required from the remaining engines, the quick changes that must be made can only be effectively carried out by an automatic control These problems call for a very careful appreciation of compressor and turbine behaviour With a satisfactory control system a gas turbine engine has ample flexibility

The starting of the small gas turbines likely to be used in helicopters over the next few years can be accomplished in a few seconds, and their acceleration and deceleration under automatic controls can be as good as the best piston engine

(ii) Engine Ratings including Emergency Power Requirements Helicopter engine ratings have been framed in the past on the background of engine experience with the fixed wing This was inevitable so long as there was insufficient experience to dictate the endurance and load carrying requirements and the failure cases of the helicopter engine particularly if of the gas turbine type Eventually the great majority of helicopters will be multi-engined machines with ample reserve to meet the case of engine failure At present, with turbines of sufficient power for take off, top speed, and cruise, and a twin or three-engined machine, a difficult design case can arise if it is necessary to clear the helicopter for climb at zero forward speed with one engine out For example, if a fully-loaded twin-engined helicopter with mechanical drive, climbing at zero forward speed, suffers an engine failure it is likely to be left with insufficient power to sustain height unless the remaining engine can give 30% or more above its normal maximum take-off power However the power necessary to sustain height in forward flight is much less than when hovering and so the remaining engine has only to provide overload for a short period until a moderate forward speed is reached

If no time is lost in carrying out the engine running changes the overload will last but a few seconds There will be sufficient power for level cruise from the operative power unit and it may only need to take a partial overload again just before landing Thus the required endurance under the emergency overload will depend on the rapidity and smoothness of the engine change which in turn are decided by the efficiency of the engine control system

Should the engine be incapable of meeting the overload peak for the required time interval some additional emergency propulsion equipment must be carried, which will involve extra weight and complication, and tend to defeat the main object of a gas turbine drive   It is, therefore, most desirable for the engine manufacturer to guarantee the required emergency power from the lightest possible engine, offsetting the greater percentage overload by reducing the peak load period to a minimum with good automatic controls

With a twin-engined mechanical-drive helicopter, like the Bristol 173 developments, the full emergency power must be potentially available as a safe engine rating   This rating sets the maximum requirements of the installation although it may never have to be used in flying operations   If required at all it will be to maintain height at near zero forward speed on one engine while the pilot trims the helicopter into forward flight, and perhaps for a short period later as he comes in to land   The overload time will be short and be required at comparatively rare intervals, which will sum up to a much shorter total than the maximum power periods needed every take-off on a fixed wing machine   Thus it will be expected that the helicopter engine will be uprated for the emergency requirement above the comparable fixed wing take-off power

In a jet reaction rotor drive by compressed gas the emergency power cases can be met by the use of rotor tip burning

With the Rotodyne the engine failure case has to allow for yaw control The normal ratings of the Eland plus the use of the tip jet burners and manual control of propeller pitch can cope satisfactorily

Other methods of overcoming the overload difficulty, such as the use of an auxiliary gas turbine to be brought into use only on engine failure, and tip ram jets or rockets have been suggested for a similar purpose

(iii) The problem of dirt accumulation on the compressor blades the helicopter in civil application spends most of its flight time within a few thousand feet of the ground and in the vicinity of large centres of population Here the air is often badly polluted with fine particles of solid matter, which, with moisture present, are capable of sticking to the stationary and rotating compressor blades with serious aerodynamic effect on the precise properties of the aerofoils   A noticeable loss of engine performance can occur in a few hours under severe conditions and means must be found to prevent it This may take the form of an injection of turbo-cleansing concentrate at regular intervals or whenever the ground check shows that the gas temperature is exceeding its stipulated value

(iv) The novel situation of the engine   the rotor axis is vertical, and so in a mechanical drive, to avoid high powered bevel gearing the easiest way to fit the engine is with its axis vertical, and the power take-off at the top   In this case unless an extension shaft to the power turbine is run right through from back to front, it is convenient to put the rotor drive at what is normally considered to be the rear end of the engine   The inlet to the compressor is then at the bottom which may not be good for compressor inflow or compressor protection unless special arrangements are made   And, of course, the engine must be designed so that it will run and can be allowed to " stay put " indefinitely in the vertical plane   Finally there is no ram air in the hover condition to boost performance or cool the engine oil

(4) THE NAPIER GAZELLE ENGINE

The Gazelle is a free turbine engine intended for a mechanical drive direct to the rotor head In its present form it is designed for a normal maximum rating of 1,250 shaft horse-power With the free turbine, the full horse-power can be developed with the rotor R P M as low as 85% the maximum, as is required for take-off in some cases

The engine is not yet released for publication and so only brief mention may be made concerning it

The axial compressor combustion chambers and turbine aerodynamic form will follow well established Napier practice

The final speed of the engine shaft is likely to be of such an order that another reduction gear stage is needed at the rotor head This second gear box will be the responsibility of the aircraft constructor Because rotors of both directions of rotation may have to be catered for it is obviously necessary to supply the engine for both right and left hand rotation

Although a vertical position is unusual for the aero-gas turbine the effect of gravity is only small in comparison with the end loads normally existing due to unbalanced air gas pressures in the engine Thus the near vertical position normally needed with a mechanical drive produces no forces of serious consequence In fact due to the absence of rapid manoeuvres the engine loads will be easily contained

Items needing special care are a comprehensive, single lever control for the fuel metering unit, compressor inlet guide vanes, and turbine inlet temperature control (*e g* , the Napier mercury vapour boiler), and a fan for the supply of cooling air to the oil cooler and other cooled accessories

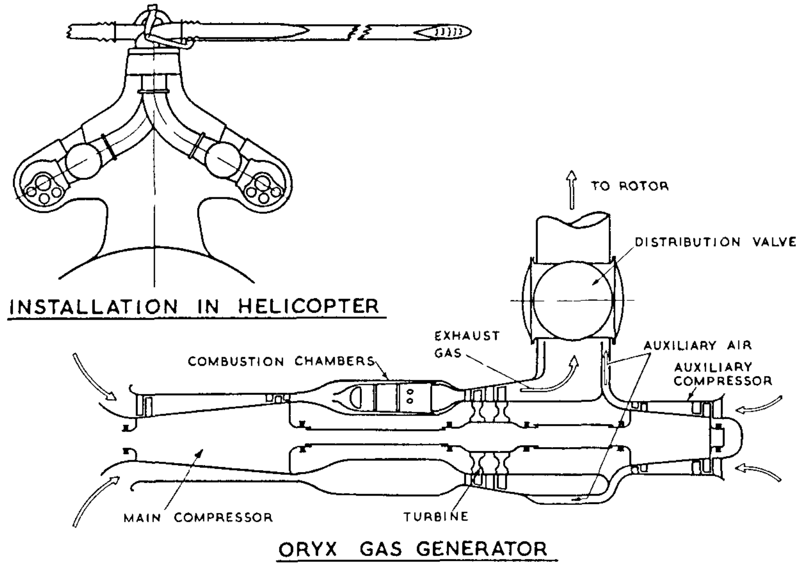
The Gazelle is designed from the start for helicopter use This applies in particular to its control system, its power ratings, including a short period emergency which should suit the general trend of engine requirements for this class of aircraft, and its installation design which is to fit in with known requirements It is believed that the basic design data such as pressure ratio, gas temperature, and mass flow, are about optimum for its duty In a typical helicopter installation 1 S H P to the rotor is roughly equivalent to 10 lb of lift and therefore it is advantageous to design the engine to give maximum S H P at the expense of jet thrust, since the latter is of less importance for low speed aircraft The exhaust system has been carefully studied so as to reduce the leaving velocity to a minimum in an efficient manner These requirements have been arrived at from a continuous study of the needs of rotorcraft over the last few years

(5) THE ORYX AND THE PERCIVAL HELICOPTERS

The author would like to preface this section of the paper with a word of praise for the work of the Hunting Percival Co , who pioneered the form of helicopter which uses the Napier Oryx engine The earliest suggestions for a turbine gas generator drive emanated from the Percival Company in early 1950 and these eventually bore fruit after prolonged study by the two firms (Figs 2 and 3)

The design of engine for a helicopter rotor gas drive eventually chosen by the Napier Company as appearing to be the most practical of all the possible cycles, showed good promise of success after a broad investigation

Fig 2

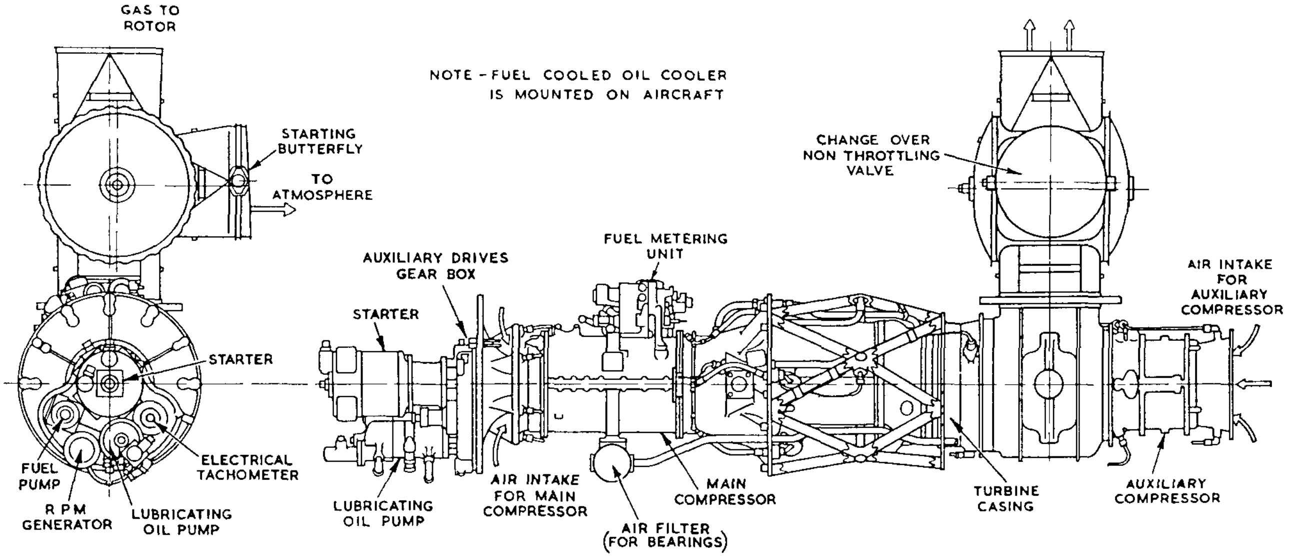


and is now known as the Oryx The design of the Oryx was crystallised in May, 1952, and the first engine ran successfully in November, 1953 This engine build had been preceded by rig tests of prototype compressor and turbine units at the Napier Research Station, and the aerodynamic designs were accepted from these tests as capable of giving design performance in the engine

Oryx units have since completed many hours of test running and the engine has reached the stage for testing in the complete helicopter previous to initial flight trials A helicopter test tower has been built in which the installation of the complete power unit can be investigated and the control system of the engine thoroughly checked This work will continue in parallel with rotor development at Percivals Much of it is of a novel nature

The Oryx gas turbine cycle will be familiar to most engineers as the by-pass engine cycle in which the power left over from the turbine, after is has compressed its own air, is used to compress more air which does not enter the turbine but instead passes directly into the turbine exhaust to augment the flow and dilute its temperature When this basic cycle is optimised for the helicopter it is found that the by-pass should be somewhat over 50% of the main compressor flow A satisfactory pressure ratio is 6 to 1 which permits a 2-stage turbine and produces exhaust gas at suitable temperature and pressure for feeding the rotor In the present application the absolute delivery pressure is about 1 6 atmospheres at sea level and the temperature about 400°C The whole design implies a delicate choice by

Fig 3



NOTE - FUEL COOLED OIL COOLER IS MOUNTED ON AIRCRAFT

NAPIER ORYX ENGINE FOR PERCIVAL HELICOPTER both engine and aircraft designers so that all its qualities—not only efficient delivery of gas at suitable temperature and pressure, but also flexibility, light weight, good fuel consumption, simplicity to facilitate low running costs , are all taken into careful consideration

Since the drive to the rotor head is by aerodynamic means great care must be taken in the ducting arrangements Many experiments have been made at the Napier Research Station to obtain the best ducting

In its present form the auxiliary compressor of the Oryx is placed behind the turbine with its inlet facing the opposite direction from the main compressor inlet, so that the turbine exhaust and auxiliary compressor delivery flow in opposite directions to meet in a carefully cascaded collector box about the auxiliary compressor coupling shaft The gas is mixed at the outlet from this chamber and then proceeds to the rotor

The main properties of this form of gas turbine engine from the thermodynamic point of view follow from the solution of its three basic operating equations which decide the matching points of the various components, *viz*

(i) The turbine H P is the sum of the main compressor power and auxiliary compressor power
(ii) The two compressors and the turbine run at the same speed
(iii) The delivery pressure from the auxiliary compressor equals the pressure at the turbine exhaust

When the engine is running steadily it solves these three conditions simultaneously They settle the correct run of pressures and temperatures throughout the engine The delivery flow must in turn satisfy the flow capacity of the rotor duct, *i e* , the mass flow rate, temperature and pressure must be those appropriate to the rotor revolutions and its tip nozzle area Rotor work is done by the propelling jets issuing tangentially from the ends of the blades The rotor gas passage is in effect the jet pipe of the engine By having the jet pipe inside an aerofoil-section duct, which is set in spanwise rotation by the propelling nozzle, the engine is able to generate lift, even at zero forward speed

Power ratings of the Oryx engine are quoted in Gas Horse-Power (G H P) This is the most convenient quantity although it is a hypothetical horse power On the test bed the engine power is measured by observing the thrust equivalent, *i e* , the thrust obtained when all the compressed gas produced by the engine is delivered into a short rigid jet pipe fitted with a propelling nozzle of the appropriate area A direct thrust determination of this sort is open to some objection since the simple jet pipe does not simulate the rotor blade , it is, however, in keeping with the way the engine is used to power the helicopter and is a simple measurement to make

The formula for gas horse-power is

$$\mathrm{G\,H\,P} = \frac{J\,C_P}{550}\,Q\;T_D\left\{1 - \left(\frac{P_a}{P_D}\right)^{\frac{\gamma-1}{\gamma}}\right\}$$

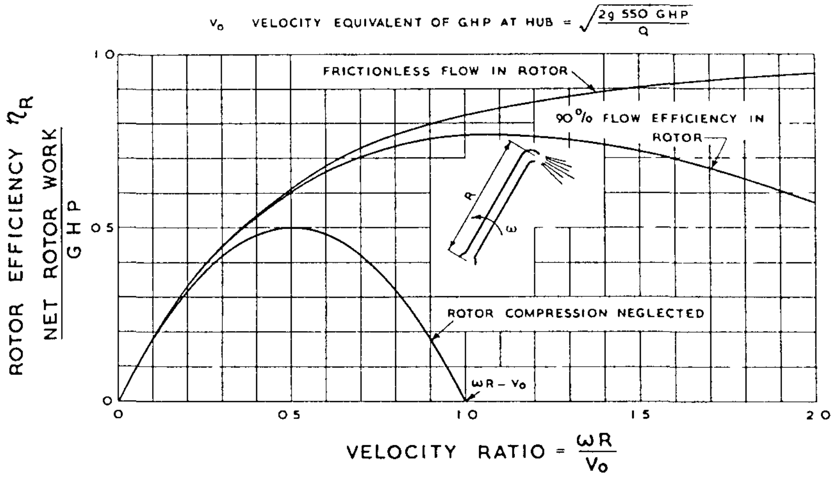
where Q is the total mass flow in lb /sec , T_D and P_D the delivery temperature and pressure °K and lb /sq in respectively, P_a the atmospheric pressure lb /sq in J Joules equivalent 1,400 ft lb /C H U , C_p the mean specific heat at constant pressure over the expansion from delivery pressure to atmospheric pressure and γ the corresponding ratio of specific heats

One criticism of this simple formula is its failure to show the true value of the delivery temperature, which is limited by the rotor design On the engine side a careful study has to be made of the way the delivery temperature and delivery pressure are inter-related For example, it is possible to show the correct G H P when the temperature is up on standard while the pressure is below standard A minor improvement in auxiliary pressure ratio can restore the delivery pressure (at the same G H P rating), but would increase the delivery temperature still further and reduce the mass flow Both these effects are likely to be detrimental to the rotor power Thus the G H P rating must be used with caution, particularly when comparing weight and specific fuel consumption

The rotor receives the pressurised gas and does more work on it, compressing it by centrifugal action, and so increasing the velocity of the jet issuing at the blade tip as the rotor speed increases Theoretically, with no losses, the tip jet velocity would continue to increase to the limit of tip speed, so also would the rotor net horse-power available for lift, despite the increasing amount of work done within the rotor to compress the gas At infinite tip speed, with an ideal system, all the G H P would be converted into net rotor work (Fig 4) To suit such a system the engine, of a given G H P , should deliver at the highest possible temperature and pressure and therefore the lowest possible mass flow

With present day rotor tip speeds limited to subsonic values, and with the inevitable duct losses, the net rotor horse-power available for lift cannot approach the full gas horse-power Let us imagine all the G H P is turned into kinetic energy by the gas expanding isentropically from engine delivery

Fig 4



VARIATION OF ROTOR EFFICIENCY WITH ROTOR TIP SPEED FOR TIP JET SYSTEM conditions P_D T_D to the atmosphere Let the hypothetic jet velocity thus attained be V_O then the gas horse-power is proportional to $Q\ V_O^2$ In the rotor, due to the internal compression, the factor of conversion of G H P to net rotor horse-power improves as the ratio of the rotor tip speed ΩR to V_O increases , that is to say, $\Omega R/V_O$ is the important criterion, and the rotor internal efficiency in the working range is roughly proportional to it In this case therefore the net rotor horse-power depends upon $Q\ V_O^2$ $x\Omega R/V_O$ or we may say, on $Q\ V_O$ when the tip speed ΩR is determined from other considerations Since the net rotor horse-power is then proportional to $Q\ V_O$ while the gas horse-power of the engine is proportional to $Q\ V_O^2$ we see that any improvement in V_O is only worth half as much as a percentage power addition to the rotor as it appears to be worth to the engine Any improvement in mass flow Q augments the rotor or the engine horse-power equally From the rotor point of view therefore one per cent improvement in mass flow is worth two per cent in absolute temperature and nearly one per cent in pressure

It is seen that competent decisions relating to the relative merits of more mass flow, delivery temperature or pressure can only be taken by the engine and rotor designers working in close collaboration In the case of the Percival helicopters the attainable levels were mutually agreed at an early stage, not only for the prototype but also for targets beyond the prototype as these latter once agreed lay down the lines along which development must proceed

Since the tip nozzle area is the controlling nozzle area, its inter-relation with engine speed and rotor speed is continuous and must be so designed as to get the best out of the helicopter It is found in the case of the Oryx for the Percival P 74 helicopter, where the two engines share common rotor ducts, that the simplest solution of the final nozzle control problem is a 2-position control, full open for operation on both engines and part closed for the single engine case With careful choice of the areas for the two positions the matching can be very satisfactory apart from near the extremes of the running range where a rotor gas blow-off must be arranged The blow-off valve can be controlled according to rotor speed only

With regard to the engine installation the compactness of the engine and its gas drive give more choice of position than the mechanical drive Ideally the engine delivery ducts must be close coupled to the rotor head with no pressure loss In a twin engined aircraft the rotor head encompasses a common trouser piece astride the aircraft, one leg being fed from each engine The Oryx N Or 1 has its delivery at right angles to its axis and is intended to be mounted horizontally, with sufficient length of straight duct for the gas to make a clean approach into the rotor head

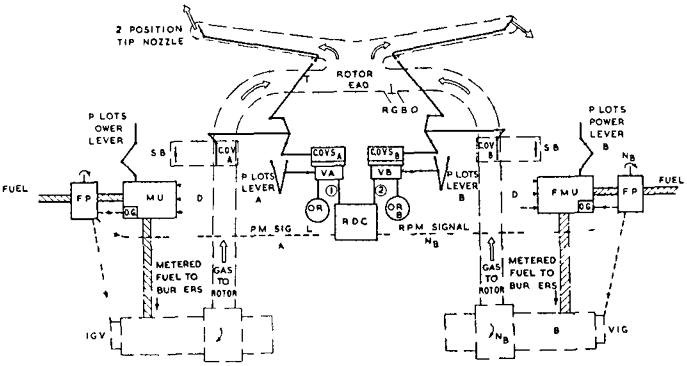
For starting purposes, particularly in a multi engine single rotor system, it is necessary to isolate each engine from the rotor while it is being brought up to speed and delivery pressure, and then to bring it in fairly smartly yet smoothly, so that there is no tendency for the engine to surge in the process The Oryx is therefore fitted with a 2-way change-over non-throttling valve leading either to atmosphere, or to the rotor

The lead to the atmosphere contains a butterfly valve with two settings " start " and " run " The " start " is fully open and the " run " is given a flow area equivalent to that of the rotor ducts Thus when the 2nd engine has been brought up to the same speed as the engine already delivering to the rotor it will also have the same delivery pressure and can therefore be diverted to the rotor without affecting the running conditions of either engine The change-over valve is thus operated to open to the rotor when the gas delivery pressure is balanced by the rotor pressure

Similarly in flight if one unit suddenly loses speed and is no longer discharging to the rotor, its change over valve automatically closes to prevent useful rotor gas disappearing into the failed engine The control, on single engine failure, senses the discrepancy in engine speed and moves the 2-way valve of the failed engine to isolate it from the rotor and allow discharge of any remaining output overboard At the same time the final nozzle at the rotor tip is brought into the part closed position With one engine only in operation the rotor head pressure will be unchanged, and due to the somewhat lower duct losses the rotor power is more than half that for 2 engines To free the pilot from having to manipulate engine controls during the process they must be fully automatic The changes may have to be made so rapidly that it is doubtful if any manual operator however well drilled could carry out the operations successfully (Fig 5)

In later developments (the Percival P 105) an alternative rotor duct system will be used in which each engine delivers to separate ducts right up to the rotor tips, thereby eliminating the need for automatic control of the change over valve on engine failure

Fig 5



F M U	FUEL METER G U IT
P	FUEL PUMP
O G	OVERSPEED GOVER OR
A B	TW ORYX ENGINES
GV	VAR BLE LET GUIDE VANE CONTROL
D	D T FED I MB ENT P ESSURE AMB E T TEMPERATURE AND TURBINE INLET TEMPERATURE
C O	C GE OVER VALVE
C O S	SERVO TO OPER TE C O V
①	O L PRESSURE ADMITTED O S UTTLE VALVE VA IF (N_B N_A) IS IN EXCESS
②	OIL PRESSURE ADMITTED TO S UTTLE AL E VB IF ($_B$) IS EXCESS

OR OR$_B$	OIL PRESSURE ACCUMULATORS FOR C.O V SERVOS ENGINES A A D B
VA VB	SHUTTLES CONTROLLI G C O SERVOS AND OVERRIDING PILOTS LEVERS
R D C	R P M DIFFERENCE CONT OL
S B	STARTING BUTTERFLY D ATMOSPHER C DISCHARGE
T	TR P RELEASE TO C USE T NOZZLES TO P RT CLOSE WHEN EITHE C O V OPENS TO ATMOSPHERE
R G B O	ROTOR GAS BLOW OFF CO TROLLED BY ROTOR S EED

DIAGRAM OF ORYX CONTROL SYSTEM

(PERCIVAL P 74 HELICOPTER)

Fig 5 This control system safeguards against the failure of one engine of a pair feeding a common rotor duct If the R P M of one engine falls more than a certain margin below the other, the change-over-valve servo of the defective engine overrides the manual lever, switches the change-over-valve smartly from rotor to atmosphere and part closes the rotor tip nozzles The remaining engine can thus maintain normal operation The engine fuel metering unit is fundamentally similar to a jet engine control

A valuable feature of the Oryx scheme is that the rotor gas ducts can be allowed to transfer sufficient heat to cope with rotor icing

One remaining feature is noteworthy There is virtually no oil cooling to be done because there is no reduction gear, which in a mechanical drive unavoidably converts one to two per cent of the engine power into heat A simple oil cooler, using the fuel as the coolant is sufficient

(6) STARTING

Related to the provisions for engine failure is the question of starting in flight Since there is no slip stream and in the case of the Oryx no mechanical rotor drive, means of starting in flight are limited to some form of starter motor as used in ordinary ground starting The development of light silver-zinc alkali batteries with greatly increased capacity for short periods marks a big step forward in electric starting Alternatively, forms of turbine type starters have been advocated, a propyl nitrate starter is a typical example

Methods available for starting the Oryx engine in the Percival helicopter are not vastly different from those employed in other helicopters It is convenient here to mention a few of the factors involved

Firstly a normal ground start with present day electrics takes between 20 and 30 seconds which is satisfactory because starting time on the ground is not of vital importance However, if full advantage is to be taken of a multi engine installation it may well become the practice to shut down an engine for cruise in order to improve fuel economy Conditions can then be envisaged where a long starting time in flight might be of considerable inconvenience For example, a twin-engined helicopter may be on single engine cruise at 1,500 feet say, when the engine in use fades If it is going to take 30 seconds to start the idle unit and there is a possibility of having to begin again after several seconds have been wasted on a false start, the only thing to do is to land in auto rotation On the other hand, if the idle engine could have been up to power in say 3 to 4 seconds the flight could have been continued The starter effectiveness is thus an important factor in deciding minimum altitude for single engine cruise

When cruising a twin engine helicopter one engine can generally be shut down without losing height In this case generation of current continues A long-period starting system would be quite satisfactory here , but would not cope with a restart when there is a total power failure

Secondly the helicopter starter must be capable of a number of starts on the ground when there are no station services available The versatility of the helicopter depends on this A further condition is that successive starts must be possible without a long period of recuperation in between

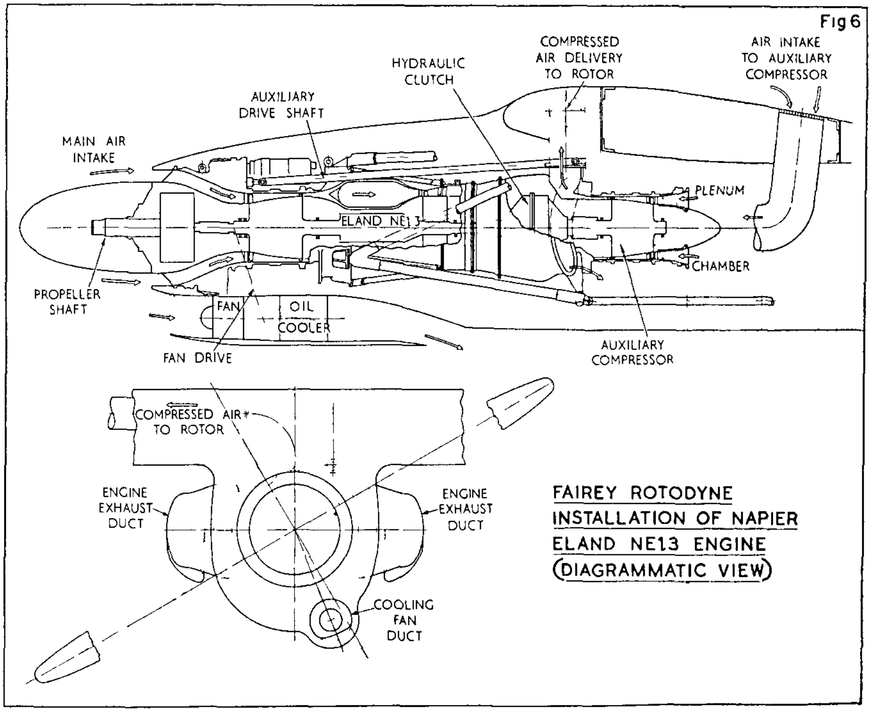
Thirdly it must be fully automatic and of the push button type , so that the whole operation from commencement to turn, to rotor on load, needs a minimum of attention from the pilot

(7) THE ELAND INSTALLATION IN THE ROTODYNE

In the Fairey Rotodyne the two power units have the dual purpose of providing a gas drive for the rotor and propeller thrust for forward flight For take off and landing practically all the engine power goes to the rotor, and the balance to the propellers for yaw control if required In forward flight all the power goes into the propellers and with the gas drive shut off the rotor revolves freely in autorotation and this supplies about half the total lift of the aircraft

The engine in this aircraft is virtually a standard Eland as far back as the rear flange of the turbine casing It provides in fact about 100 S H P more than the standard Eland by virtue of a somewhat greater expansion ratio in the turbine since there is no requirement here for jet thrust From the turbine rearwards the engine is designed to suit the rotor requirements A direct 1 to 1 drive is taken from the rear of the power turbine to one side of a hydraulic clutch The other side of the clutch is directly connected to a fairly large axial compressor which absorbs the bulk of the total engine power at maximum R P M The compressor draws air in from the atmosphere and delivers it to the internal duct system of the rotor Tip burning is incorporated so that the maximum advantage is taken of the compressed air supplied The pressure ratio of the compressor is 4 to 1 this being about the optimum when tip burning is used (Fig 6)

Fig 6



FAIREY ROTODYNE
INSTALLATION OF NAPIER
ELAND NE13 ENGINE
(DIAGRAMMATIC VIEW)

The clutch between the power turbine and the auxiliary compressor is of the Sinclair Fluid Coupling type and is operated by engine oil It is so arranged that the engine power may be taken off the propellers and put on to the rotor or vice-versa at the will of the pilot

Rotol propellers are used in conjunction with a specially designed control

From the engine makers viewpoint the auxiliary compressor, its clutch, and the associated control system form the novel item of the installation

The auxiliary compressor sits between the bifurcated exhaust pipe It follows standard axial practice fairly closely There is no inlet ram so nothing is lost by the rear facing inlet In cruising flight the compressor inlet will probably be throttled to avoid too much pumping loss which may otherwise occur due to the windmilling of the rotor It is desirable to allow some rotation of the compressor in order to reduce the clutch idling load Any power generated in the latter is a dead loss because it is converted into heat in the circulating oil and must be dissipated in the oil cooler at the expense of further drag

Fig 7 The Napier Rotor Test Rig (see page 447 of Discussion)

The clutch idling power depends on the difference between the power turbine speed (or propeller r p m) and the auxiliary compressor speed in the windmilling condition The compressor actually reaches about 1/3 of the engine speed in the latter condition, so that the windmilling helps substantially to reduce the idling loss This loss is not very significant as a power loss, but must be continuously dissipated by surface heat transfer within the body of the clutch

When tip burning is not used, then, as in the Oryx driven rotor, the rotor horse-power is a maximum when the product Q V_O^2 and $\Omega R/V_O$ is a maximum For best rotor efficiency the velocity V_O, which, it will be remembered, is the free discharge jet velocity of the compressed air or gas, must be as low as possible This condition would require a low rotor pressure However, in the compressed air system, the tip burning forms an essential part of the installation, and to burn with reasonable efficiency the air pressure is increased A number of other factors enter into the choice of the best pressure such as the best overall dimensions for the auxiliary compressor, the rotor duct design, including the rotor head flow path and running seals, and finally rotor tip Mach number The same fuel, aviation kerosene, is used for the main units and the tip burners The rotor fuel is provided by a high pressure booster pump

For installation in the Rotodyne the power plant is supported by a single tubular structure built on to the auxiliary compressor casing with triangulated links forward to the engine support ring at the main compressor outlet station The air outlet to the rotor is at the top of the compressor delivery volute which collects the compressed air from the last stage and turns it through a right angle This air outlet is disposed symmetrically between the two turbine exit flanges With the tubular framework, access to the exterior of the engine is relatively easy The engine auxiliaries, generator and cooling fan are driven from the accessory gear box near the front end of the main compressor

In this form of installation the control design problem is governed by the sudden failure of one of the engines on the climb when developing full rotor lift and full engine power Failure of one engine then halves the quantity of air flowing through the rotor , but does not upset the remaining engine since each feeds its own rotor ducts

The control system has to be such that during the change to single engine operation the aircraft remains directionally stable with sufficient lift to maintain height or to descend at an acceptable rate

The engine designers' contribution to this general handling problem is to see that the flexibility of the one power unit is not in any way effected by the failure of the other and that the changes in engine settings can be made quickly and smoothly

(8) CONCLUSION

In limiting our paper to a fairly general discussion of three known helicopter turbines it is hoped that sufficient has been said to satisfy some curiosity concerning engineering problems of future helicopter installations It is apparent that the gas turbine is making considerable progress in its application to rotorcraft We have shown that direct drive applications can be very satisfactory and that gas drives—hot or cold—have been successfully introduced using gas turbines These engines are special to the form of helicopter and are already well advanced in development

In the opinion of the author the novel problems are those of engine control and these are far reaching They are formidable enough to make it obvious that only a proved unit with unrestricted flexibility can be really successful in a turbine helicopter The same problems have important repercussions in the design of the airframe on such major issues as the best number of engines for a rotorcraft

So far as one can be convinced on present achievements, the improvements promised by the more rational advocates of the gas turbine in regard to better payload, less noise and vibration, and better life, will be achieved A great deal has yet to be done and ultimate success will depend on the closest collaboration between the helicopter and engine manufacturers

The author's thanks are due to the Managing Director of D Napier & Son Ltd , and also the Ministry of Supply for permission to give this paper

He would like to express his appreciation of the assistance received from Mr Greenly, Mr Bayne and Mr Cushing, of D Napier & Son Ltd, and from the late Mr Tustanowski, of Hunting Percival Ltd, and several others whose work and advice has been of great value

The opinions expressed are those of the author and do not necessarily indicate the policy of D Napier & Son Ltd

REFERENCES

1 R HAFNER "The Domain of the Helicopter' Royal Aeronautical Society Lecture, 10th March, 1954

2 O L L FITZWILLIAMS "The Giant Helicopter" Lecture to The Helicopter Association of Great Britain 23rd November, 1951

3 A GRAHAM FORSYTH "Power Plants for Rotary Wing Aircraft" Lecture to Fourth Anglo-American Aeronautical Conference 16th September, 1951

4 R H MILLER "Some Factors Affecting Helicopter Design and Future Operations" Lecture to Fourth Anglo-American Aeronautical Conference 16th September, 1951

5 "Rotary Wing Power" *Flight* 12th March, 1954 pp 318—322

6 J BROWN "Some applications of Gas Turbine to Helicopter Propulsion Lecture to The Helicopter Association of Great Britain 15th October, 1954

7 D N MEYERS AND Z M CIOLKOSZ "Matching the Characteristics of Helicopters and Shaft-Turbines" *S A E Trans* Vol 62, 1954, p 437

Discussion

The **Chairman** invited Mr CHALLIER, as representing another well known firm of engine builders from Derby, to open the discussion

Mr W O W Challier (*Chief Aircraft Project Engineer, Rolls-Royce, Derby*), commented that Dr MORLEY had given a very good survey of some of the control and installation problems associated with turbine engines in helicopters and had shown how certain engines had been designed and, up to a point, developed to meet various requirements

He fully agreed with the Author that the future of the helicopter was tied to the future of the gas turbine engine, mainly for the reason that only with the gas turbine could there be power units light enough to make the helicopter really safe in flight Everyone knew that at present, with some of the engines available, there was no such thing as a completely safe twin-engined helicopter, and it would never be really safe as long as piston engines were used because of their prohibitive weight

More emphasis should, perhaps, be put upon the mechanical drive system He was not attempting to decry the merits of the pressure jet system, for its advantages were well known There were, however, certain disadvantages One of these was the time scale It might take longer to develop the pressure jet system to a point at which it was both as safe and as efficient—which was important—as the mechanical drive system, and it was essential that large transport helicopters should make their appearance in the not too distant future

The other disadvantage was operational—the noise problem, which was a very serious one There were great difficulties in introducing jet transport aircraft unless means were found to reduce the noise associated with take-off and initial climb The Comet, for instance, was not allowed to land at Idlewild The problem was already serious but would become more serious as the size and speed of aircraft increased When thinking of the operation of the future large transport helicopter from city centres, he was not so sure that it would be easy, or even possible, to bring the noise with this method of propulsion down to a level which would be acceptable

He was a little surprised that in the section of the Paper dealing with mechanical drive, the relative merits of fixed shaft and free power turbines were not discussed in greater detail There was no doubt that the free power turbine was better both in performance and control-wise, but it had not yet been established exactly how much better it really was or must be

Some interesting conclusions had been reached in a recent American paper following an investigation into shaft gas turbines for helicopters The first of these