The Turbine Helicopter

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B SC, F R Ae S

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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, June 6th, 1958, at 6 p m

PROFESSOR J A J BENNETT (*Chairman, Lecture Committee*)
occupying the Chair

The CHAIRMAN, in opening the meeting, said that the Author required no introduction As Technical Director of the Westland Aircraft Company since 1952, MR HOLLIS WILLIAMS had been responsible for a very successful family of helicopters, all based on well-established Sikorsky experience Previously, as Chief Engineer of the Fairey Aviation Company, he had been responsible for the development of naval aircraft, and prior to that, as Chief Engineer of General Aircraft at Hanworth, his developments had included the well-known troop-carrying gliders, the Hotspur and the Hamilcar He was a member of Council of this Association and a Fellow and Silver Medallist of the Royal Aeronautical Society He was also a helicopter pilot, having undertaken a conversion course under BASIL ARKELL in 1946, as a result of which he now held Royal Aero Club helicopter certificate No 13

The spectacular demonstration last year at the S B A C Show of the turbine-powered forerunner of the Wessex had given a glimpse of things to come from the Westland Company, and tonight Mr Hollis Williams had undertaken to discuss, on the basis of his recent experience, some of the characteristic features of "The Turbine Helicopter"

MR D L HOLLIS WILLIAMS

INTRODUCTION

The title for this lecture was chosen over a year ago, at a time when my Company was just commencing preliminary ground runs with its first turbine installation It was not clear at that time whether sufficient technical information would emerge based on the installation in hand to produce a worth while lecture, and the title therefore permitted a broad field to be surveyed which could have dealt with all forms of turbine produced power However, after a year's development work a number of interesting features have emerged and so I propose to restrict my lecture to subject matter which falls within this experience I shall be dealing with shaft turbines which are directly or almost directly connected to a single main, tail rotor configuration

In this country the development of the reciprocating engine has ceased for sizes above 1,000 B H P, although some development is going on in the smaller sizes Therefore between 500 and 1,000 B H P the designer can still exercise some choice, but above 1,000 B H P he has no option — it must be a turbine, and his choice is limited by availability

The indications are that turbine power is likely to cost more than equivalent piston power, and it is important therefore to be certain whether the added cost of turbine power brings definite advantages in its train, or whether the designer is a slave to circumstances and fashion

Westland Aircraft is in rather an exceptional position Over a period of ten years it has entered into four licence agreements with Sikorsky, and in each case has taken over a successful design with a considerable background of experience based on American piston engines, and by substitution of British engines has endeavoured to maintain or improve the performance characteristics of the type Thus in the case of the S 51 which in the States was powered by the 450 H P Wasp Jr, the Alvis Leonides, giving 500/525 H P, was fitted to the Westland Dragonfly, which has subsequently been converted to the Widgeon

In the case of the S 55 there was, at the start, no suitable British engine and so early production of the Whirlwind was based on reconditioned Pratt & Whitney 1340 engines When Sikorsky installed the Wright 1300, again at the time there was no British equivalent and Westland produced a number of Whirlwind helicopters with the 1300 It is only comparatively recently that the Alvis Leonides Major has entered into service This is a 900 H P engine de-rated to 750 H P

The S 58 was already a very successful helicopter with the Wright 1820 engine, but in its Wessex form the Gazelle turbine is used

The S 56 was powered by twin Pratt & Whitney 2800 engines, but in its Westminster form, this large helicopter is powered by two Napier Eland turbines

Thus we have always started from Sikorsky helicopter type or at least a Sikorsky rotor system with known characteristics, and the power plant and other changes we have introduced have never placed us in the position of combining an experimental helicopter with an undeveloped engine So far we have been successful with this formula, due to the excellence and variety of British engines But we must regard the future with anxiety, due to the reduction in official support for engine development, which may well lead to a reduction in the number and variety available

It is not my intention to give an engine lecture, which is not within my competence, nor is this actually a helicopter lecture I propose to confine myself to a fairly narrow field, the matching or marriage of a British Shaft Turbine to a helicopter wholly or partly of Sikorsky origin

COMPARISON BETWEEN RECIPROCATING ENGINE AND GAS TURBINE

Mechanically driven helicopter power plant installations are characterised by three features

(1) All cooling air supply for engine and accessories must be provided from power sources within the helicopter

(2) The engine is directly connected to the main lifting and controlling elements via the transmission

(3) The engine must be capable of operation at all altitudes when disconnected from the transmission

The piston engine requires cooling of cylinders, oil magnetos and accessories This is usually provided by a cooling fan with appropriate ducting and may absorb up to 8% of the available engine power The fan must be not only capable of adequate cooling air supply at the right pressure, but also free from high blade stress levels when in operation In fact, for these reasons cooling fan development can be a protracted exercise The problem of mounting the reciprocating engine and its associated transmission items, e g , clutch, and fan, involves considerable development of flexible mountings

A clutch is needed so that the engine can be deliberately disconnected from the transmission and this introduces further complication Thus the cooling fan, clutch, and the flexible mountings, together with the engine vibrations, constitute a complex dynamic problem and an additional development programme The necessity for off-load operation of the engine, as in auto rotative conditions, introduces a new element in control, which differs from fixed wing practice, and constitutes a further problem in certain cases The possibility of C O contamination must not be overlooked Engine noise is penetrating even with relatively low powered installations, and for civil operations near built up areas there has been a demand for silencers with attendant weight penalty and structural complications

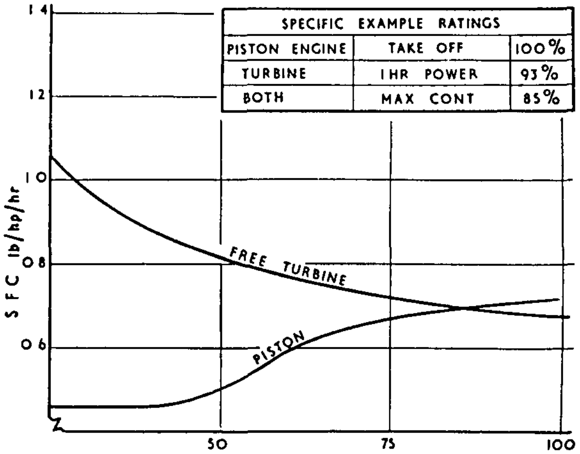


FIG I

COMPARATIVE SPECIFIC FUEL CONSUMPTION

The gas turbine, on the other hand, as far as the installation is concerned, poses no major cooling problem, and no complicated dynamic problem because of its low vibration levels and absence of fan and flexible mountings, there is little or no C O contamination Engine noise is less than with the piston engine

With the fixed turbine, as for the piston engine, a clutch is necessary, but with the turbine's low vibration level and with no flexible mountings, clutch development for the installation is relatively simple Turbines generally use cheaper and safer fuel, but at a higher consumption rate than the piston engine

A turbine power plant, and by this I mean the complete engine change unit, whether fixed or free, will be considerably lighter than the equivalent piston E C U , probably by at least 25% The weight saving of the turbine has to be offset by higher consumption, but even this statement has to be qualified because, as shown in Fig 1, turbine consumptions compare not unfavourably with supercharged piston engines under high power conditions If a mission involves the use of a large amount of hovering power, it will be found that there is practically no difference between the fuel consumption of a turbine and that of a piston engine The piston engine shows to advantage when it can operate in the weak mixture cruising condition This means that a helicopter (of conventional drag value) with a boosted piston engine, must fly at relatively low forward speeds so that it can be in the economic mixture range, whereas in the case of a turbine helicopter it pays to fly faster and get the benefit of the relatively low specific fuel consumption associated with high power Thus, a piston engine tends to be better on an endurance operation, it does not show up so well if a large proportion of high power is used The turbine tends to show to advantage on range if possible head winds are taken into account

For short range operation, the available pay load is greater with the gas turbine by virtue of its lower installed weight

THE FIXED VERSUS THE FREE TURBINE

For some years a favourite subject for discussion has been the relative merits of the fixed or the free turbine with opinion usually heavily weighted in favour of the free turbine for helicopter applications

As far as I know, only one Company, the Sikorsky Division of United Aircraft, has had experience of both fixed and free turbines Sikorsky started by converting the S 52 into the S 59 by substituting a Turbo Meca Artouste fixed turbine for the Franklin piston engine Sikorsky then followed this up with a twin General Electric T 58 free turbine installation in a S 58

Fig 2 Twin Turbine version of the Sikorsky S 58

Fig 3 The Sikorsky S 62

By now it has also had experience with a single T 58 free turbine in the S 62 The S 59 did not go into production, but using the same engine and governing system Sud Aviation made a success of the Alouette, which is now in service

We have tackled the problem in reverse by first obtaining development experience with a single free turbine and now are just starting development work with a twin fixed turbine installation

I propose first of all to review generalised turbine characteristics and then to deal with our own development experience

Engine manufacturers have approached us from time to time asking for advice as to whether their new turbine proposals should be of the fixed or the free type

I must repeat that whereas various authorities have expressed strong preferences for the free turbine for helicopter applications we have so far been unable to reach so definite a conclusion In our opinion, there are pros and cons on both sides and the final decision can only be arrived at after actual experience with both types of installation This I shall seek to show

The fixed or free turbine may have a compressor which is all axial, all centrifugal, or a mixture of the two The axial flow compressor is a remarkable piece of engineering requiring extreme precision in the smaller sizes Sometimes I wonder where the practical limit to reduction in size will occur I am fairly certain that with the postage stamp size of compressor blade, special precautions will have to be taken with the intake I imagine that the open type of forward facing intake will not stand the test of service use in such cases, and that some form of guarded plenum chamber will be necessary

The centrifugal compressor is probably the least sensitive to the ingress of foreign matter or to limits of size, and it may be there is some mixture of the two which will give the best ultimate solution

The fixed turbine engine is normally limited by turbine inlet temperature Thus if overloaded as by over pitching, engine R P M fall with rotor

R P M , fuel/air ratio is increased and up goes the temperature with consequent possible damage

The free turbine engine is limited by torque which may be either an engine or a transmission limitation These limitations are illustrated by the following figures

The axial compressor at least has a severe surge line limitation, which is particularly important at low powers For this reason, very careful control

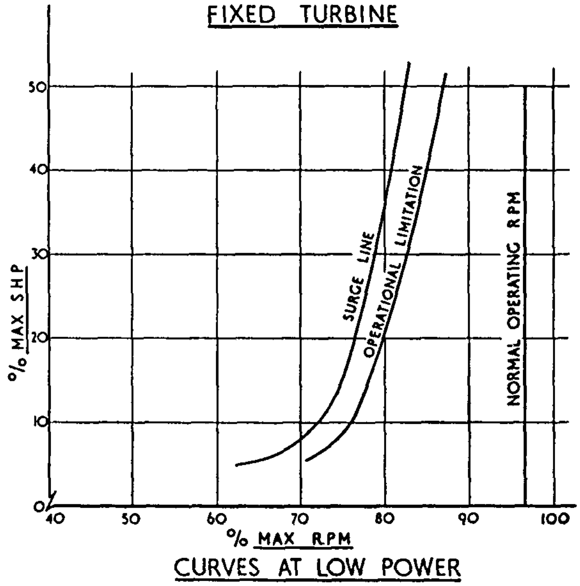


Fig 4

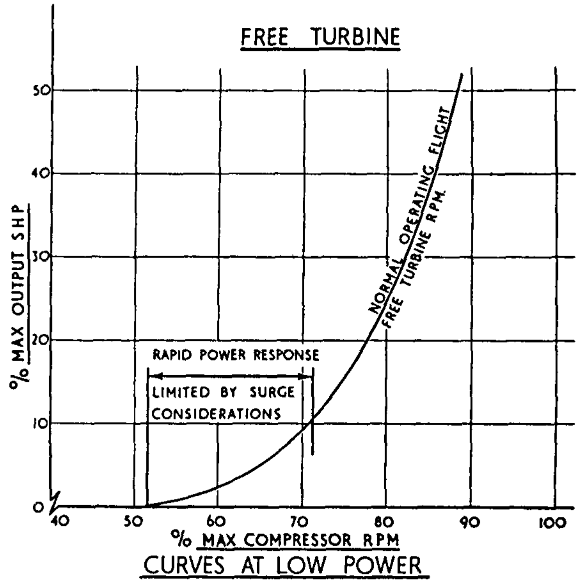


Fig 5

of fuel flow is required to avoid compressor stall in accelerating from ground idling to flight idling R P M On the Gazelle an automatic acceleration control unit is provided to avoid compressor stall in this condition This usual automatic starting cycle is required for the same reason

Figs 4 and 5 show the operating characteristics, in the low power range, of the fixed and free turbines It will be noticed that for the fixed

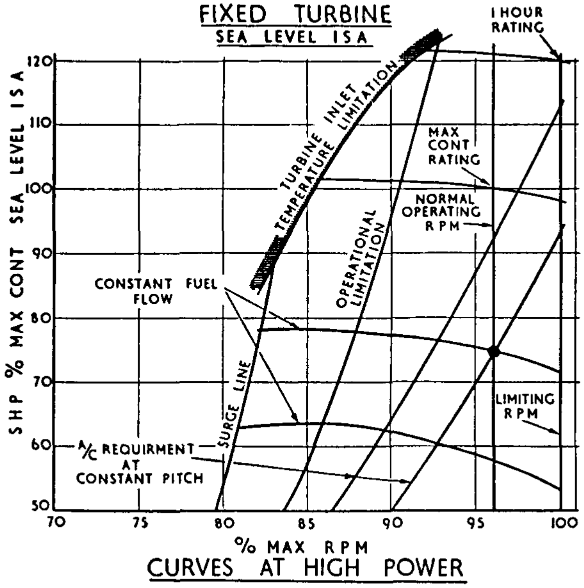


Fig 6

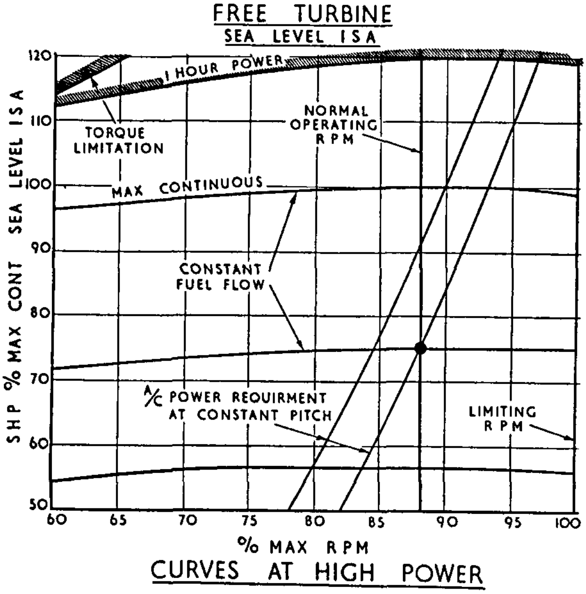
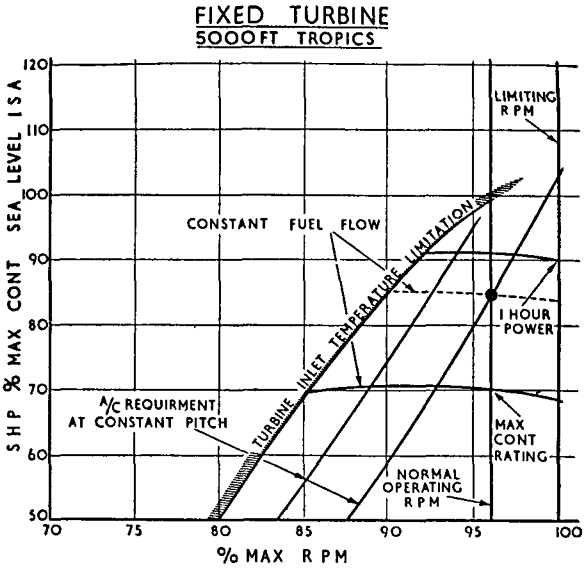


Fig 7

turbine, lower power operation at high normal output R P M is situated well away from the surge line, while with the free turbine, low power operation implies low compressor R P M and power response is affected by surge limitations The significance of this is shown later

Figs 6–9 show the high power, high R P M range, and two operating conditions are used to illustrate another important difference between the two turbines It is assumed, for the purpose of illustration, that the helicopter power requirement is 75% of the sea level maximum continuous rating It will be seen from Figs 6 and 7 that for both types of engine adequate reserve of power is available at sea level



CURVES AT HIGH POWER

Fig 8

A *selected* increase of power results in increased fuel flow to, and hence increased power from, the engine and both types of turbine will behave in a similar manner This state of affairs applies also when an increase in rotor power requirement occurs from an external source (e g , gust) The effect of altitude is illustrated in Figs 8 and 9, from which it will be seen that, in conditions of insufficient reserve power, there is a marked difference in the behaviour of the two types of turbine With the *free* turbine, there is less danger of exceeding engine limitations (in this case a torque limitation) when excess power is demanded by the rotor, although rotor R P M will drop This confirms the practice, in marginal power conditions, that pilots should operate at high rotor R P M so that loss of rotor R P M will not be a serious embarrassment With the *fixed* turbine, however, (whether governed or not) if excess rotor power is required, loss of R P M is accompanied by increase of turbine inlet temperature and in certain designs, the compressor may even surge In the former case a safety device prevents this temperature from exceeding the limit by reducing fuel

In general it is wise to install a turbine with ample capacity A fixed turbine needs plenty of margin to avoid over-loading by over-pitching and it also needs reserve capacity for altitude and high ambient temperature

The free turbine although not subject to overloading from the temperature point of view, should also have reserve capacity for altitude and high ambient temperature, and either visual or automatic torque limitation to avoid overloading of the transmission, particularly under very cold conditions

One important difference between fixed and free turbine is that with the fixed turbine a clutch is essential, whereas with the free turbine this can be avoided At first sight this is a definite advantage in the favour of the free turbine because the clutch is quite a weighty bit of mechanism and is an additional feature requiring maintenance If the operational requirement does not prescribe a need for stopping the main rotor with engines running, then this is a favourable application for the free turbine If, on the other hand, it is necessary to stop the rotors, then the fixed turbine with clutch appears to give the better answer The rotor brake is discussed later

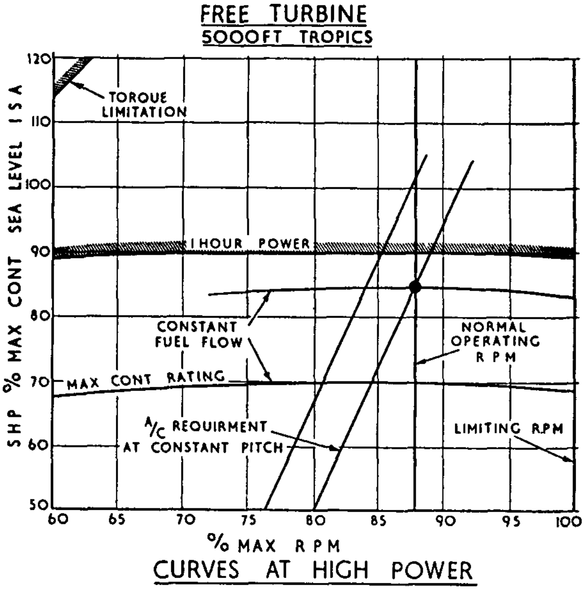


Fig 9

The Control Problem

In the case of a fixed turbine, it is all too easy for a pilot operating the turbine under manual control to exceed the engine temperature limitations, particularly if the turbine has no great reserve of power over and above its normal operating conditions

A convenient arrangement is to provide a constant speeding governor set with suitable margin, with full authority, and remove the throttle from the collective pitch stick In some cases warning is given to the pilot that he is making excessive power demands on the turbine by means of a warning light or other indicator, in other cases an automatic device is provided

The free turbine on the other hand can be operated manually over a wide range of power and R P M without running into critical conditions

A constant speeding governor is therefore rather a luxury except in certain role conditions, where it becomes a necessity

The provision of a governor may be more difficult due to the extra degree of freedom between compressor and power turbine, but it can be with advantage, a limited authority governor, leaving the pilot with over-riding control

The Wessex 'Gazelle' Installation

The development of the Wessex 'Gazelle' started in mid-1956 An American S 58 was purchased by Westland (later transferred to M of S) and some 76 hours of flight time was carried out with the Wright 1820 engine In November 1956 the helicopter was laid up, the piston engine removed and a Gazelle power plant installed The Gazelle had fortunately been designed to operate at any angle, so it was possible to mount it at the same inclined angle as the piston engine Ground running commenced in March, the first flight was made on May 18th 1957, and to date about 100 hours of flight time, plus a large amount of ground running time has been carried out In general the development was straight forward, and with one or two small exceptions, nothing has been designed into or out of the trial installation However, there are several points which may be of general interest

Fig 10 The Westland Wessex prototype

The Gazelle is a free turbine with rear drive, and as under development at the time had the wrong direction of rotation for our purpose The problem of reversing the direction of rotation of an engine is usually a considerable operation, but as a point in favour of the free turbine, Napier achieved this simply by providing mirror image nozzle vanes and blading for the power turbine No other changes were necessary, and engine performance was not penalised Because the Gazelle engine was considerably lighter than the piston engine which it replaced, it was necessary to carry a large amount of ballast on the engine mounting for the first trial installation For the production version it was necessary to achieve the same balance without ballast and this was effected by transferring equipment from the rear of the cabin to a new stowage immediately over the turbine

At the start of flight development, an open intake was used, this caused a certain amount of anxiety and in due course in the early running period some compressor damage was found, which from marks on the blades was thought to be part of a split pin A system of guards was therefore built up until a plenum chamber modelled on the production version was installed (Fig 10) and this formed a crude momentum separator, which so far seems to have been effective

After some initial development work in which three turbines were used alternately, we were able to settle down and do a clean run of 25 hours on one turbine and then a clean 50 hours run on the next turbine

With regard to noise, there is no doubt that the Wessex with the Gazelle is very much quieter than the S 58 with the Wright R 1820 engine The R 1820 is one sided with respect to its exhaust, but the exhaust of the Gazelle has been split so that an equal amount is discharged on both sides The net result is that the level of engine noise has been reduced to the point where other sounds start to emerge, particularly that of the tail rotor

It is of interest to note that when we were working with an open intake, an intense beam of compressor noise was projected forwards and downwards Since the intake has been buried in a plenum chamber, this noise has been muffled

The exhaust from the Gazelle is split into four outlets which are brought out to port and starboard and deflected downwards The exhaust nozzles are encased in ejector shrouds to ventilate the engine compartments Prior to the first start up, I imagined that the exhaust would present the most difficult development problem I felt it might be dangerous and would in any case prevent the ground crew from approaching the helicopter when the turbine was running To my amazement, a few minutes after the first start up with the gas generator at idling R P M , ground crew were walking within a few feet of the ejector nozzles, and the exhaust has since presented no problem In actual fact we have made no changes to the initial design

The problem of flame damping for night work seems to be non-existent and we do not expect trouble by reflection from the water during low level operations Moreover there has been no contamination of cockpit or cabin

The rotor brake has already been mentioned as one of the features which may need re-design with a free turbine The static torque with the gas generator at idling speed is high and although the Wessex has quite a powerful brake, we found that it was only just good enough to hold the rotor stationary

Efforts were made to stop the rotor with gas generator idling, but this produced a tremendous amount of heat in the brake with no particular effect on the rotor R P M We became worried about the strength of the transmission as attempts were made to increase brake capacity, and consequently had to abandon the operation of stopping the rotor with turbine running

A design study of the brake necessary to stop the rotor under these conditions in a time deemed satisfactory by the user resulted in an excessively large and heavy installation, and would have introduced appreciable design changes to the transmission

The prime engine control is the fuel metering lever and this is operated through a throttle harmonisation linkage in a manner similar to that for the reciprocating engine Some adjustment had to be made to the synchronising cam because of the change in the throttle lever/power characteristics of the turbine Despite the apparent simplicity of the control, some problems were expected to appear At the start, we ran into trouble with compressor R P M fluctuations, but found this due to ingress of hot air from the engine oil cooler outlet A small change to the outlet corrected this Particular safeguards introduced by the engine maker to prevent a runaway of the free turbine (in case of an output shaft fracture) could be inadvertently operated during certain throttle manipulations, this was quickly solved by the retiming of these units

A further problem was generally to obtain turbine power response of a similar nature to the piston engine During a "quick stop" manoeuvre of a

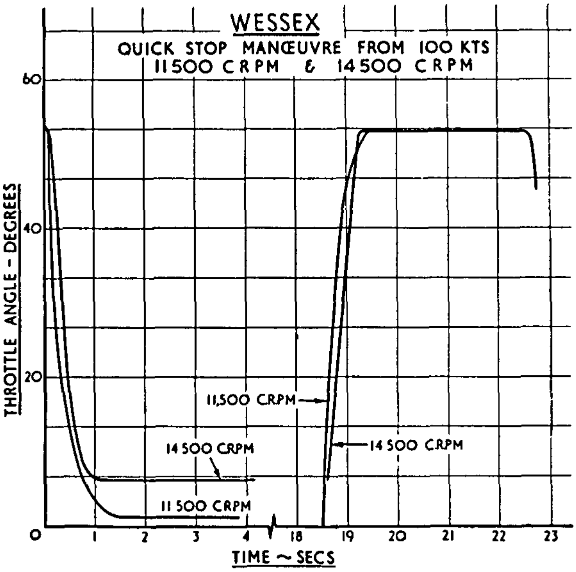


Fig 11

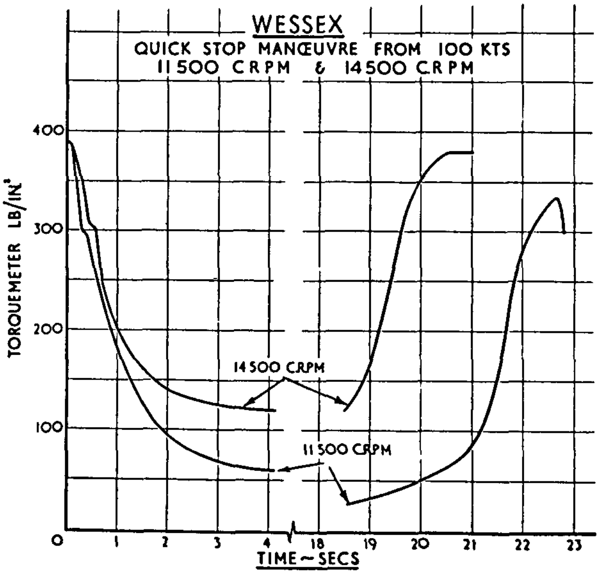


Fig 12

helicopter, engine power is required to be rapidly reduced to a very low value and then increased rapidly to a full hovering value It was found after shutting the throttle at the commencement of a "quick stop", that some seven or eight seconds elapsed before full power could be restored This was due to the accelerated control unit taking charge at low powers, to avoid compressor surges, and the solution was to provide a flight idle stop set sufficiently high to avoid this possibility Subsequently this flight manoeuvre was carried out with the necessary instrumentation to establish the position of this flight idle stop Figs 11, 12 and 13, show recordings of the throttle movement, the torque response, and the rotor R P M , against time It is significant to notice that, while there is no great increase in time for the manoeuvre between the nominal ground idle power (10,500 C R P M) to power corresponding to 14,500 C R P M , the drop in rotor R P M was much less with the higher value of the compressor R P M These tests were done with an adjustable flight stop which was finalised at the above mentioned higher C R P M

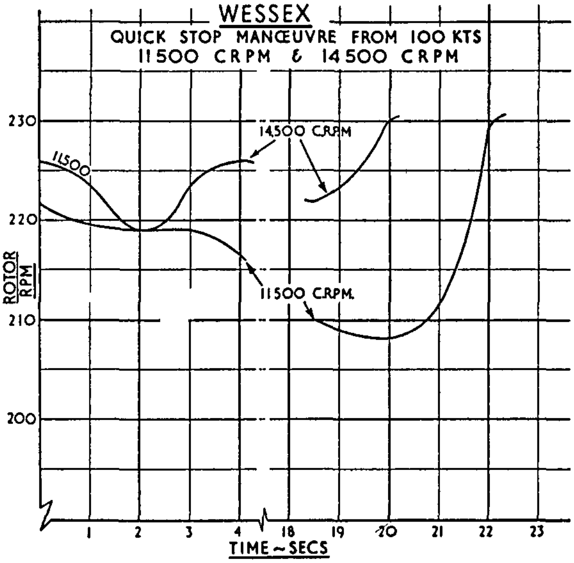


Fig 13

We imagined, prior to first runs, that the power turbine would always be leaning up against the free wheel, and that some form of ground test equipment might have to be introduced to make sure that the freewheel was functioning Tests proved this to be very nearly the case, as we have found under ground idling conditions that the freewheel needle can only just be split from the rotor needle

Due to the position of the engine under the pilot's floor, it was anticipated that a large amount of heat would be generated and would have to be dispersed This was certainly the case at the start, but it yielded to normal treatment by increasing the flow of ventilating air and by insulating where necessary In general, the whole development had been quite rapid and apart from other advantages, the turbine has justified itself on one outstanding point, that of the quick start

In the case of the piston engine, the warm-up period took a very considerable time, something over ten minutes from cold

In the case of the turbine, this time is under a minute, apart from cockpit checks In fact, with the pilot in his seat the helicopter has been demonstrated to become airborne in under 30 seconds from cold

It is so quick that the plane guard helicopter for an aircraft carrier could now be contemplated as sitting at readiness on an out-rigger platform, and not continually airborne during operations

By using an American built S 58 for the initial flight testing of the Gazelle, one year's development of the turbine installation has been carried out, and when the first Westland built Wessex arrives on the flight line, as it will do very shortly it will literally have a flying start, with the early experimental stage of the turbine left well in the background

The Westminster

Westland entered into a licence agreement with Sikorsky for the S 56 This is the largest helicopter so far in the Sikorsky range and was initiated as a Marine Assault Helicopter, but has also been used by the U S Army

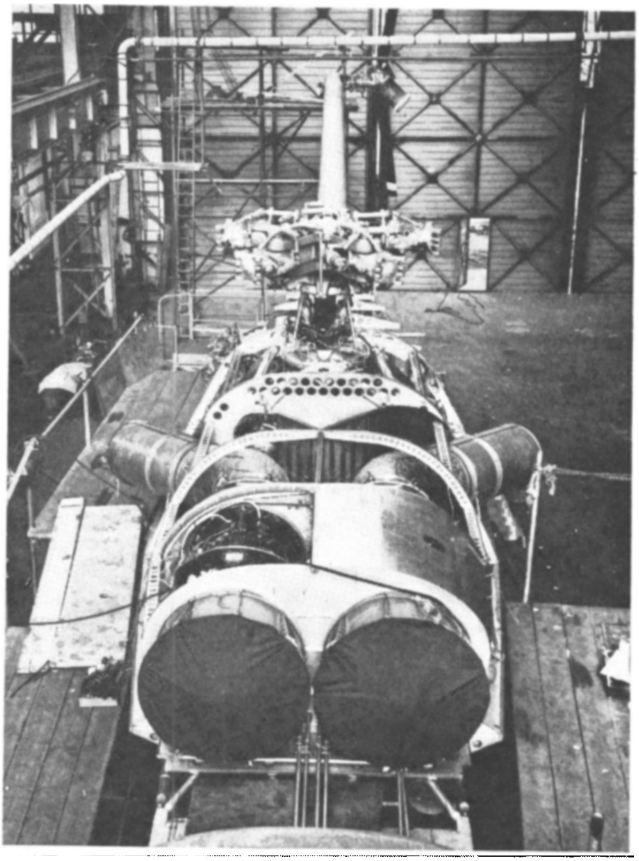


Fig 14 Installation of the Napier Eland Turbines in the Westminster

A considerable number of these large helicopters are now in Squadron service with the U S Forces

The S 56 is powered by two Pratt & Whitney 2800 engines which are mounted in pods on a stub wing set in the high wing position The helicopter is designed for internal loading with front clam shell doors and loading ramps

In the U K the only suitable engine that was available was the Napier Eland turbine Fortunately this turbine was already under development with a rear drive and it appeared to us that the best proposition would be to dispense with the stub wing and the engine nacelles and to mount the turbines on the cabin roof, forward of the main gearbox as shown in Fig 14 The Westminster project has developed as a combined private venture effort between Westland and Napier

Illustration by arrangement with World Helicopter

Fig 15 The Flying Crane version of the Westminster

The Napier Eland is a fixed shaft turbine with which we had had no actual experience, and again we were making the problem more difficult by using a pair of fixed turbines driving on to a common rotor shaft Fortunately Napier had under development a clutch which was also a fluid drive and we seized on this as a method of avoiding direct mechanical connection between the high energy rotating parts of the two turbines, and in a similar way avoiding direct mechanical connection between the rotor head and the turbines

The Westminster project, although based on an S 56 Licence Agreement, in actual fact only makes use of part of the S 56, but the parts used nevertheless comprise some of the most difficult components requiring the greatest amount of development work Thus, the main rotor hub, the main rotor blades with the rotor shaft, tail rotor assembly, duplicated power controls, and a number of other items are actual S 56 parts

They have behind them a large amount of accumulated flight experience, and in fact as a result of this experience numerous design changes have already been incorporated

At the start of the Westminster project there was no firm Operational

Requirement, and we realised that we could spend a vast amount of engineering time and money producing a helicopter which, when complete, was not exactly what was required We therefore, decided to prove the turbines in association with the new parts of the transmission, by building in the first instance a flying test rig, and our aim was to get our results in the cheapest and simplest possible manner However, there is no such thing as cheapness or simplicity with a flying prototype of any description Everything is relative and we eventually decided that our Flying Test Rig had most of the elements for a successful crane, and should be so developed as a forerunner to the Westminster transport This, therefore, is our immediate line of development Fig 15

We intend by means of this rig and by a second similar one which is now under construction, to build up flying hours and so accumulate the experience and background which will lead up to certification and good serviceability on the actual Westminster transport as shown in Fig 16

Fig 16 Artists impression of the Westminster passenger transport version

THE TURBINE CONTROL PROBLEM

The Napier Eland turbine has a full authority fuel governor and hence the main engine control is a speed selection lever

In the Westminster, each of the turbines is coupled into a single coupling gear box via a hydraulic clutch, a reduction gear box, and a freewheel The importance of accurate speed selection of the two engines in order to prevent large asymmetry of power distribution has been indicated by a simple analysis and subsequently confirmed by a more elaborate dynamic investigation carried out on a digital computer The slipping clutch (up to 2% slip at maximum torque) is an important feature in the control of this coupled installation

The engine control in the cockpit comprises two speed selection levers with appropriate R P M "gates", at the top of each lever is a trimming knob so that fine adjustments can be made to the engine speed selector Engine control has therefore been removed from the collective pitch lever, the pilot has only to select constant speeding R P M

In the event of failure of one turbine, the other turbine automatically develops full power without conscious action on the part of the pilot

INSTALLATION

The engine installation is in general orthodox, but the rear drive turbines have fairly long high speed drive shafts and the mounting of turbines and gearbox on a flexible airframe introduces problems associated with shaft mal-alignment The original toothed couplings on these shafts, have been replaced by specially designed ball couplings These are capable of standing a greater degree of mal-alignment and are based on a similar coupling, operating successfully in the Gazelle installation

The high speed shaft on each turbine connects to the clutch which is also the fluid drive, and then through the primary reduction gear, which incorporates the torquemeter, into the lower part of the main gearbox The fluid drive introduces a heat dissipation problem, and reacts on consumption, but the advantage of a non-mechanical link in the transmission, will, we are confident, outweigh the disadvantages

The lower part of the main gearbox, of Westland design, is connected to the upper part which is Sikorsky designed and manufactured This upper gearbox contains the final double epicyclic gear reduction and the total gear reduction is 12,500 turbine R P M down to 197 rotor R P M

As this paper goes to print development testing of our first twin turbine installation in the Westminster is about to start, and shortly we shall be in a position to assess the extent of the development programme

To sum up, based on experience to date with one trial installation of a single turbine, I would say without hesitation that development time and effort can be saved, compared with a piston engine installation of comparable power

The piston engine has been the mainstay of helicopter development up to this date, has given good service, and where first cost is an important consideration, will compete with the turbine for some years to come, particularly in the smaller sizes where engine development continues

The turbine is the more sensitive to altitude combined with high ambient temperature Where such conditions have to be met, as in a world wide Operational Requirement, an oversize turbine must be installed, probably run in a gated condition at sea level I S A This tends to increase first cost and the gating reacts unfavourably on consumption

However, taken all round I am sure that the many advantages of turbine power outweigh the few disadvantages, and that better helicopters will result from its use It will no doubt have been noticed that throughout the paper an open mind has been maintained on the best arrangement of helicopter turbine In my view the only characteristic which distinguishes the helicopter turbine is the ability to operate continuously at angles far outside fixed wing practice Given a basically sound turbine with this ability, then I think a satisfactory power plant for a helicopter can be provided with either fixed or free turbine, with front or rear drives

In conclusion I must thank my staff for compiling the material for this paper, my Company for providing the facilities, and the Sikorsky Division of United Aircraft Corporation for providing some of the photographs used for illustration

Discussion

The **Chairman** called upon Mr Boddington, of the Ministry of Supply, to open the discussion

Mr L Boddington (*Ministry of Supply*) recalled that in his introduction the Author had said that he would confine his talk to a subject matter which was fully