# The Giant Helicopter

*By* O L L FITZWILLIAMS, B A

*A lecture presented to The Helicopter Association of Great Britain on Friday, 23rd November, 1951, in the Library of The Royal Aeronautical Society, 4 Hamilton Place, London, W 1*

NORMAN HILL, A M I MECH E, A R AE S
*in the Chair*

## INTRODUCTION BY THE CHAIRMAN

THE CHAIRMAN, introducing the author, spoke of the great work which is being done at Yeovil by Westland Aircraft Limited on helicopters, and of the close association of Mr FITZWILLIAMS with this work He felt sure that Mr Fitzwilliams would agree with the opinion that his paper would give us a peep into the future Papers of this kind were fully in accord with the general activities of the Helicopter Association—not over-optimistic but nevertheless having a firm eye on the future

Mr FITZWILLIAMS gained his B A at Cambridge, and later spent many years with the Autogiro department of Messrs G & J Weir In the year 1940 he joined the Ministry of Supply and was engaged for some time on military projects being concerned with the development of gliders and rotary wing parachutes with Dr BENNETT and Mr HAFNER at the Airborne Forces Experimental Establishment He joined Westland Aircraft Limited in 1947, and ever since that time has been in charge of the helicopter division and we all know of the work which that company has done in the helicopter field during the past few years

LORD TEDDER, when addressing the Institution of Civil Engineers at a recent meeting, posed the following question to those present

" How technical should the technician be "

and with other advice he went on to say

> " Talk about the ideas which inspire you , stop pretending that you are simply materialists, concerned only with bread and butter matters The engineer should be the mediator between the philosopher and the working mechanic "

With those words in mind I invite our member philosopher to present to us his paper entitled " The Giant Helicopter "

## MR O L L FITZWILLIAMS

In view of the controversial nature of some of the statements in this paper I must, at the outset, make it clear that I speak as an individual and that my opinions do not necessarily represent the views of the Westland Company or of the Helicopter Association

## INTRODUCTION

The Americans have acquired from their operations in Korea a great sense of urgency as regards the use of helicopters for military transport and have made considerable resources available for the development of large helicopters, of which the giant Hughes is the best known example My paper is presented in the hope that it may do something to quicken interest in the possibility of parallel British developments

The paper describes a hypothetical family of Giant Helicopters, in which certain design and operational trends are taken to what seem to me their logical conclusions and I believe that it indicates, even if only in broad outline, the sort and order of achievement which may be within our reach in the reasonably near future

To begin with, I have assumed that turbo jet engines can be operated at the tips of the rotor blades Whatever its engineering merits or demerits, this assumption represents essentially a solution of the three main problems facing the designer of the large helicopter, namely the control of transmission weight, the control of blade weight, and the achievement of an acceptable fuel consumption No other type of power plant seems to offer so effective a solution to these problems, but there are alternatives which depart from this optimum only by relatively small margins, and the validity of the picture which I have painted does not, absolutely, depend upon the correctness of this main assumption Nevertheless, toward the end of my paper I hope to persuade you not only that the blade tip installation of turbo-jet engines is desirable, but also that it is a practical engineering possibility

Many investigators[1] have shown that as the size of the conventional shaft driven helicopter is increased, the proportionate weight of the blades and transmission increases rapidly so as to set an upper limit of size beyond which it may be impossible to achieve a reasonable proportion of useful load This upper limit is not clearly defined and it may be that the various published estimates are no more valid than the similar limits which were at one time foreseen during the early development of the aeroplane Nevertheless it is widely accepted that some form of jet rotor propulsion may be expected to be a feature of large helicopters, since by this means the weight of the mechanical transmission can be eliminated

Accepting the principle of jet drive, the designer is still faced by the excessive blade weight which is generally required to ensure a reasonable coning angle in large rotors To minimise this weight the designer will naturally wish to concentrate as much of it as possible at the blade tip, where it has the maximum effect as a means of controlling the coning angle, but for large rotors of sufficiently high disc loading it can be shown that the non-structural weights concentrated at the blade tips may be of the same order of magnitude as the weight of the entire power plant of the helicopter

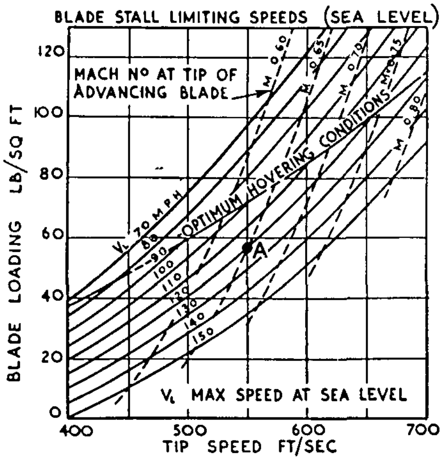
Thus the problem of blade weight in large rotors, which arises from their slow rotation, also suggests its own solution since the centrifugal acceleration at the blade tips may no longer be so formidable as to prevent the mounting of turbo-jet engines in place of the blade tip weights

The turbo-jet engine also offers a direct solution to the problem of acceptable fuel consumption because, at least for sub-sonic speeds, it is undoubtedly the most efficient form of jet drive That statement would have to be qualified if it were found that unduly high disc loadings (and therefore excessive power) had to be employed in order to provide the necessary blade strength and rigidity, but I believe this proviso does not have the effect which might be supposed, at any rate for very large rotors in which the desired amount of non-structural weight concentrated at the tips, and therefore the strength and stiffness requirements of the blade, do not seem to be much affected by whether or not the tip weight is in the form of a jet engine

## METHOD

I have not attempted a generalised theoretical presentation such as would be necessary to demonstrate the maximum performance obtainable with turbo-jet engines, but the somewhat arbitrary examples which follow are based on data applicable to any single rotor helicopter, and I have obtained what seems to me a realistic picture, in the following rather simple manner

For instance, when the forward speed and rotor tip speed have been decided it is convenient as the next step to determine the maximum blade loading consistent with freedom from stalling of the retreating blade and reasonable Mach number of the advancing blade tip Fig 1 shows the relationship between these variables It is based on the work of GUSTAFSON[2 3] and consists simply of Mach number indications superimposed on a plot of the equation,



By courtesy of *Flight*

*Fig 1 Blade Stall and Mach No Limits*

$$V_L = \tfrac{3}{4}\, V_T - 31\ 3\sqrt{\text{Blade Loading}}\ \text{ft /sec} \qquad (1)$$

The Figure also shows a relation, suggested by SISSINGH, between blade loading and tip speed corresponding to optimum hovering conditions This line, which is sometimes useful for estimating purposes, is derived from the equation

$$V_{T_{\text{opt}}} = 65\ 0\sqrt{\text{Blade Loading}}\ \text{ft /sec} \qquad (2)$$

For my examples I have assumed a maximum forward speed of 120 m.p.h. at sea level in ICAN conditions at normal load, and a rotor tip speed of 550 ft. per sec. in all conditions of flight. From Fig. 1 the corresponding maximum blade loading is 57 lb./sq. ft. to ensure freedom from blade stalling, giving a low Mach number of 0·65 at the tip of the advancing blade. These conditions are identified by point A in Fig. 1, and the location of this point in relation to the " optimum hovering " line is an indication that my examples do not necessarily represent the best possible performance.

Having found the blade loading it is convenient to consider next the blade aspect ratio. For my examples I have attempted only a crude estimate of the highest aspect ratio likely to give adequate strength and stiffness. For this purpose Fig. 2 offers a rough guide since it shows a family of blades of constant total area but varying aspect ratio, each carrying an appropriately sized pair of jet engines housed side-by-side in a common nacelle at the blade tip.

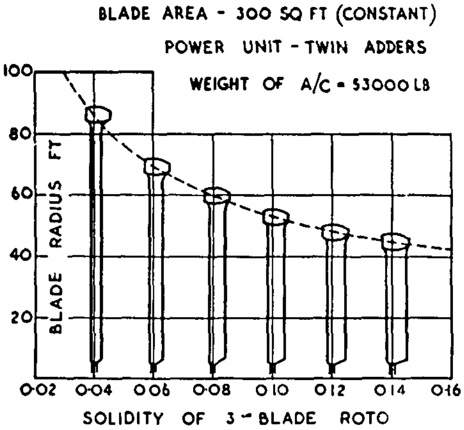


*Fig. 2. Blade Aspect Ratio Variation*

*By courtesy of "Flight"*

The Figure indicates that even a rough estimate will probably not be very misleading. The profile drag power is not affected by blade length in this case since the blade area and tip speed are constant. The induced power, which is the major part of the power required for hovering, varies inversely with blade length, but for high solidities this variation is not very sensitive to changes in aspect ratio. Therefore, if a solidity is chosen from the right-hand side of Fig. 2, subsequent more pessimistic correction would be unlikely to affect the results to a serious extent. For my examples I have assumed a solidity of 0·114 and later checks indicate that this is about right from the structural point of view. Combined with the 57 lb./ft.$^2$ blade loading, this corresponds to a disc loading of 6½ lb./sq. ft. and because the disc loading is constant for the entire family the variation of gross weight can conveniently be plotted for the family as a function of rotor radius.

I have assumed that all helicopters of the family are fitted with jet engines having a sea-level static thrust given by the equation :—

$$\text{Static Thrust} = \frac{1{\cdot}625W}{550}\sqrt{\frac{\text{Disc Loading}}{2\rho_0}}\ \text{lb.} \qquad (3)$$

This variation of static thrust gives a reasonable level of performance and is convenient since it expresses power requirements in terms of gross weight, and hence also in terms of rotor radius

In estimating the weight of the rotor blades I have assumed that they are freely hinged at the rotor centre line  Fig 3 shows the forces and moments acting on such a blade, and using the notation of this Figure it can be shown that the ratio of blade weight to aircraft gross weight is,

$$^{b}/_{W} = \frac{k_3 - \frac{NW_J}{W}\left(1 + \frac{\beta V_T{}^2}{Rg}\right)}{k_1\left(1 + \frac{k_2\beta V_T{}^2}{Rg}\right)} \qquad (4)$$

where $W_J$ is the weight of the jet engines attached to the tip of each blade

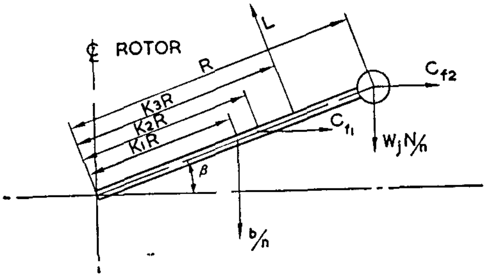


*Fig 3  Blade Coning Equilibrium*

*By courtesy of  Flight*

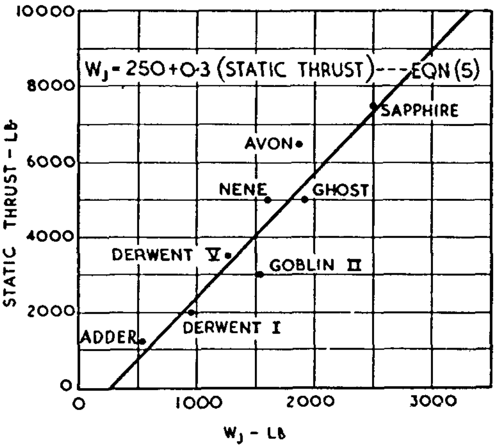


*Fig 4  Engine Static Thrust vs Weight*

*By courtesy of  Flight*

I have also assumed that the modifications needed to render a normal jet engine suitable for operation at the tip of the rotor blade, would not add materially to the weight of the engine  Quite large errors in this assumption would have little effect on the analysis, and the ability to relate the power requirements of particular helicopters to the characteristics of actual engines, greatly helps appreciation of the examples Fig 4 shows a plot of the relationship between the static thrust and the weight of various existing jet engines and indicates that a suitable assumption is represented by the equation —

$$W_J = 250 + 0\ 3\ (\text{Static Thrust})\ \text{lb} \qquad (5)$$

Since the static engine thrust is taken to be a function of gross weight and therefore of rotor radius so, by means of the above equation, the engine weight can also be determined as a function of rotor radius The engine weights can then be substituted in the blade weight equation (4), from which it is possible to plot the blade weight/gross weight ratio as in Figs 5, 6 and 7, which show the variation of this ratio with rotor radius for constant coning angles of 4°, 6° and 8°

These Figures show the large reduction in total blade weight which can be achieved by the addition of tip jet engines, as compared with blades of conventional weight distribution They also indicate how the blade weight/ gross weight ratio may be controlled by small increases in coning angle with increasing size, so as to remain even for very large helicopters within the limits to which we are now accustomed on small helicopters Moreover these graphs refer to a family of rotors of constant tip speed and disc loading, whereas in the larger sizes the rotational speeds are so low and the ground effect so powerful that both tip speed and disc loading would probably be increased in a practical case, thus providing additional means of blade weight control effective well beyond the range of foreseeable size requirements

Whereas there appears to be no significant upper limit to the size of this family of rotors, Figs 5, 6 and 7 do suggest that there is a lower size limit below which this type of rotor ceases to be attractive This is shown by the dotted and chain dotted lines superimposed upon the main curves These lines give a rough indication of the weight of blade material which is likely in any case to be necessary to provide sufficient strength and stiffness They actually show an amount of duralumin blade material 50% greater in weight than the amount necessary to resist the centrifugal pull of the jet engines at a stress of 10 tons/sq in (the dotted line), and a similar estimate (chain dotted) indicating the weight of blade material required to resist the static bending loads when the blades are stationary Such arbitrary standards would be of little value if it were not obvious from Fig 5 (refer to point B ) that even gross errors in the estimates would hardly alter the indicated radius of about 50 ft below which the advantages of a tip-mounted turbo-jet installation begin to be lost

In my examples the blade weight is assumed to be 5% of the gross weight for values of the rotor radius from 50 ft up to approximately 90 ft , indicating a gradual increase in coning angle with size Beyond 90 ft radius I have assumed that the ratio of blade weight to gross weight increases as indicated by the lower line of Fig 7, since a coning angle of 8° corresponds roughly with the upper limit of present experience

Having accounted for the weight of blades and engines, it is necessary to assume certain percentages of the gross weight as representing the fuselage structure, undercarriage, etc , and the percentages chosen correspond to the average achieved in present conventional helicopters (Fig 8) On this basis the fuselage of a jet driven helicopter might reasonably be expected

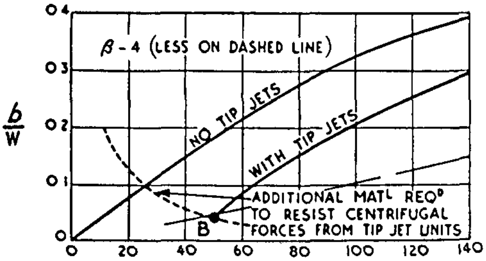


Fig 5

By courtesy of Flight

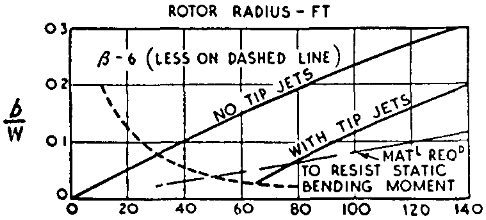


Fig 6

By courtesy of "Flight

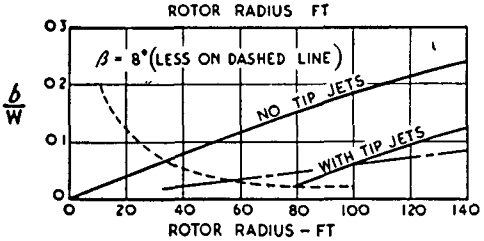


Fig 7

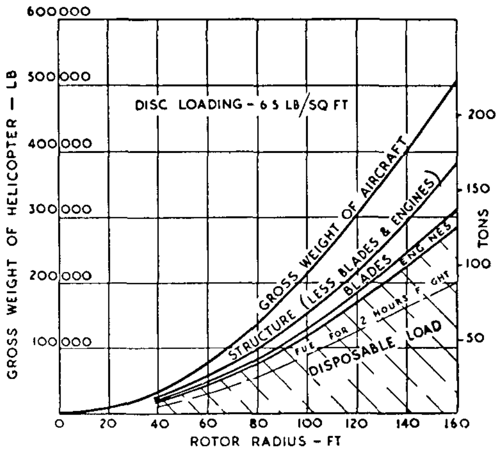
By courtesy of "Flight

to be lighter than assumed here since it would be proportionately much shorter and also free from the large tail rotor thrust moments of the conventional type The percentages assumed are as follows

| Structure Weight Breakdown | |
|---|---|
| Rotor Head | 3 80% |
| Tail Rotors | 0 40% |
| Fuselage | 13 00% |
| Landing Gear | 4 00% |
| Flight Controls | 1 50% |
| Fuel System | 2 00% |
| Transmission (Tail Rotors) | 0 20% |
| Hydraulics | 0 40% |
| Electrics | 1 20% |
| Miscellaneous<br>(Radio, Instruments, etc ) | 1 50% |
| **Total Structure**<br>(*Less Blades and Power Units*) | 28 00% |

Fig 8

Because the gross weight, blade weight and engine weight are known as functions of rotor radius, while the structure weight is a simple percentage of the gross weight, therefore a fairly comprehensive weight anaylsis for the entire family can be plotted as shown in Fig 9, which is arranged so that the space below the lowest full curve represents the disposable load for each size of rotor The magnitude of these loads may be appreciated by reference to the right-hand scale, graduated in tons When it is realised that, in round figures, ten troops with normal equipment are equivalent to one ton, the scale on which such helicopters could be used for the transport of troops and equipment would seem to introduce new possibilities in the concept of the air transportable army, and even in the task of evacuating civil populations in large-scale emergencies



By courtesy of *Flight*

*Fig 9 Generalized Size Range/Weight Analysis*

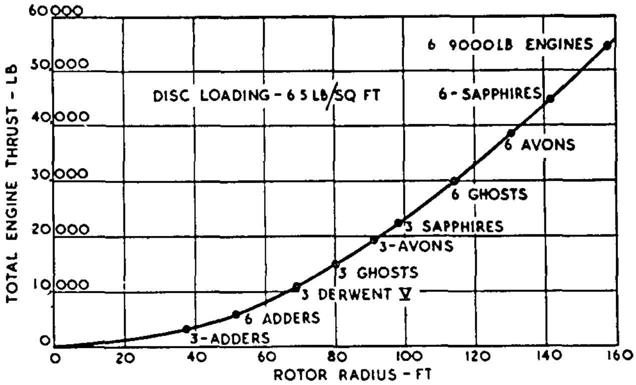
The disposable loads indicated in Fig 9 refer to the normal operational weights, but the extremely powerful ground effect associated with the larger helicopters would permit large increases in the already impressive normal lifting capacities Practical measurements with our helicopters have shown that the beneficial effect of the ground cushion extends to a height considerably greater than one rotor diameter and we have had consistent indications that this effect is still noticeable as high as two rotor diameters from the ground Even accepting the usual single rotor diameter standard, it will be realised that the ground effect assumes a new significance when it remains powerful at wheel clearances of over 100 ft

Relating the power requirements of this range of helicopters to the characteristics of existing turbo-jet units, the generalised size range of Fig 9 may be reduced to the specific examples illustrated in the top half of Fig 10 although the advantages of this type of rotor drive may not be fully effective for the smallest example quoted, in which the rotor radius is considerably less than 50 ft It is even doubtful whether the smallest example properly comes within the scope of this paper although it might be well suited to Airline operation It is, after all, only a very Little Giant Its size is less than that of one rotor of the new Piasecki and its lifting capacity hardly extends beyond 50 passengers !

From the table in the lower half of the Figure it will be seen that the centrifugal acceleration and yawing velocity to which the largest engines would be subjected are (at 60g and 3 5 rads /sec ) of an order very different from the conditions which would have to be considered in the application of tip engines to a small rotor These figures may be compared with the approximately 6g and 3 rads /sec for which turbo-jet engines are normally designed

Proceeding downwards in the scale of size, the rotor diameter is reduced from 316 ft to 160 ft before the severity of engine operating conditions is doubled as compared with the largest size A factor of three on the least severe case would cover the range of true Giants

The most optimistic presentation will not disguise the severity of the conditions indicated by this Table, but the gloomy impressions to which it may give rise at first sight do not seem to be justified even in respect of ordinary turbo-jet engines, as I hope to demonstrate in the concluding section of the paper



| WEIGHT OF A/C | ROTOR DIA | ROTOR R P M | ENGINE | ENGINE THRUST | No USED | Θ | g |
|---|---|---|---|---|---|---|---|
| 504 000 LB | 316FT | 33 | — | 9 000 LB | SIX PAIRED | 3 5 | 60 |
| 410 000 LB | 284FT | 37 | SAPPHIRE | 7 500 LB | SIX PAIRED | 3 9 | 66 |
| 355 000 LB | 262FT | 40 | AVON | 6 500 LB | SIX PAIRED | 4 2 | 72 |
| 276 000 LB | 228FT | 46 | GHOST | 5 000 LB | SIX PAIRED | 4 8 | 82 |
| 206 000 LB | 196FT | 53 5 | SAPPHIRE | 7 500 LB | THREE | 5 6 | 96 |
| 180 000 LB | 182FT | 58 | AVON | 6 500 LB | THREE | 6 0 | 103 |
| 137 000 LB | 160FT | 65 5 | GHOST | 5 000 LB | THREE | 6 9 | 118 |
| 100 000 LB | 136FT | 77 | DERWENT V | 3 500 LB | THREE | 8 1 | 138 |
| 53 000 LB | 104FT | 101 | ADDER | 1 000 LB | SIX PAIRED | 10 6 | 181 |
| 29 000 LB | 76FT | 138 | ADDER | 1 000 LB | THREE | 14 5 | 248 |

Θ RADIANS/SEC ANGULAR VELOCITY IN YAW OF TIP JET ENGINES AT A CONSTANT SPEED OF 550 FT/SEC

g CENTRIFUGAL INERTIA ON TIP JET ENGINE

*By courtesy of Flight*

*Fig 10 Helicopters with Particular Engines*

## FIRST EXAMPLE

In order to visualize the problems involved in the development of the helicopters, it is convenient to elaborate the second of the examples shown in Fig 10 This helicopter is assumed to be powered by six suitably modified Armstrong Siddeley " Adder " jet engines and in common with the others it has a three-blade rotor of solidity 114, a disc loading of 6½ lb /sq ft , and a top speed of 120 m p h at normal load The rotor diameter would be 102 ft The " Adder " engines exert a combined static thrust of 6,300 lb , corresponding to a combined operating thrust of 5,360 lb , at the 550 ft per second tip speed Owing to the characteristics of the " Adder " engine this thrust is substantially constant over the range of relative air speeds experienced by the advancing and retreating blade tips in forward flight, as shewn in Fig 11

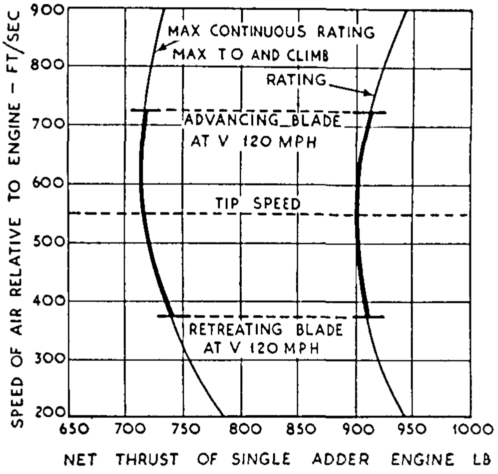


*Fig 11 Thrust vs Speed for Adder Engine*

*By courtesy of Flight*

From the given rotor size and disc loading it follows that the normal gross weight of the helicopter is 53,000 lb , and, applying the assumptions previously detailed, we have the following weight analysis —

JET TRANSPORT HELICOPTER
*6 Armstrong-Siddeley "Adder" Engines*
WEIGHT BREAKDOWN

| | |
|---|---|
| Rotor Head | 2,020 lb |
| Tail Rotors | 200 lb |
| Fuselage | 6,660 lb |
| Landing Gear | 2,120 lb |
| Flight Controls | 750 lb |
| Fuel System | 1,050 lb |
| Transmission (Tail Rotors) | 100 lb |
| Hydraulics | 200 lb |
| Electrics | 600 lb |
| Miscellaneous | 750 lb |
| **Total Structure** (*Less Blades*) | **14,450 lb** |
| Rotor Blades | 2,650 lb |
| Engines and Mountings | 3,600 lb |
| **Empty Weight** | 20,700 lb |

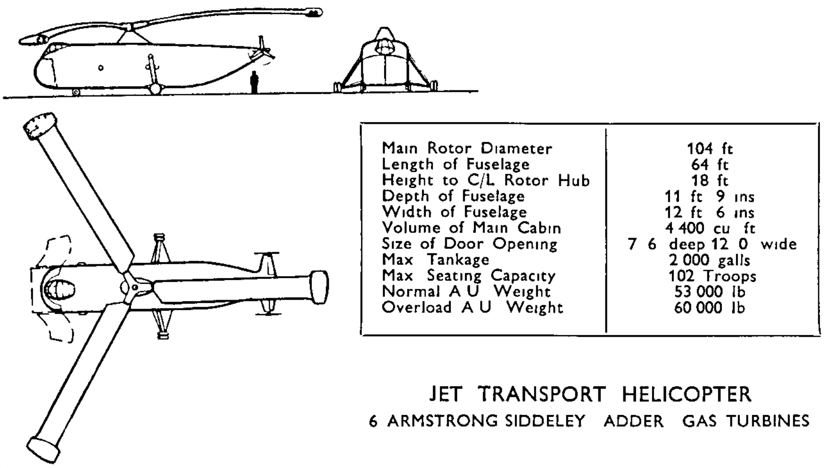
*Fig 12*

It wıll be seen that the normal dısposable load may amount to as much as 61% of the gross weıght of the helıcopter—32,300 lb or approxımately 14½ tons The arrangement of the helıcopter ıs shown ın Fıg 13 In general ıt ıs a sımple three-bladed sıngle rotor desıgn wıth the cabın suspended dırectly underneath the rotor Yawıng control ıs provıded by two taıl rotors mounted at the tıps of a horızontal stabılıser at the aft end of the fuselage The four-wheeled undercarrıage has castorıng nose wheels

Large doors and a ramp ın the nose of the fuselage enable wheeled vehıcles to be drıven ınto the cabın Passengers enter by a door under the stern of the fuselage

Fuel ıs carrıed under the cabın floor ın tanks havıng a total capacıty of 2,000 gallons

The crew of three comprıses a pılot, co-pılot-navıgator, and flight-engıneer, placed ın the nose of the fuselage where they command a good all-round vıew



| | |
|---|---|
| Maın Rotor Dıameter | 104 ft |
| Length of Fuselage | 64 ft |
| Heıght to C/L Rotor Hub | 18 ft |
| Depth of Fuselage | 11 ft 9 ıns |
| Wıdth of Fuselage | 12 ft 6 ıns |
| Volume of Maın Cabın | 4 400 cu ft |
| Sıze of Door Openıng | 7 6 deep 12 0 wıde |
| Max Tankage | 2 000 galls |
| Max Seatıng Capacıty | 102 Troops |
| Normal A U Weıght | 53 000 lb |
| Overload A U Weıght | 60 000 lb |

JET TRANSPORT HELICOPTER

6 ARMSTRONG SIDDELEY ADDER GAS TURBINES

*By courtesy of Flıght*

*Fıg 13 Fırst Example—General Arrangement*

The tail rotors have a ground clearance of some 7 ft, ensurıng safety for passengers and ground personnel

The mechanıcal sımplıcıty of the helıcopter ıs apparent ın the sketch sınce the only transmıssıon ıs the lıghtly loaded drıve to the taıl rotors

Detaıls of the rotor artıculatıon and controls are not shown, but apart from dıfferences ın the relatıve sıze of the varıous components, these aspects of rotor desıgn would ınvolve lıttle novelty To provıde an adequate c g range, offset flappıng hınges would be employed, probably wıth the centrıfugally controlled droop stops and flappıng restraıners whıch have already become normal practıce on small helıcopters Cyclıc and collectıve pıtch control are also expected to be ın accordance wıth conventıonal practıce, the control lınkage beıng operated by a duplıcated hydraulıc servo system

Some novelty ıs expected ın the means of controllıng rotor vıbratıons, and ıt may be assumed that the blade chordwıse balance and trım tab adjustments can be effected ın flıght vıa actuators mounted ın the blades and controlled by the flight-engineer from the cockpit Additionally the flight-engineer can adjust the angular settings of the individual blades These functions correspond with what we now know as the "tracking" and "matching" procedures and the various means for occasional adjustment in flight would also be very desirable in small helicopters if they were not generally prevented by space and weight limitations

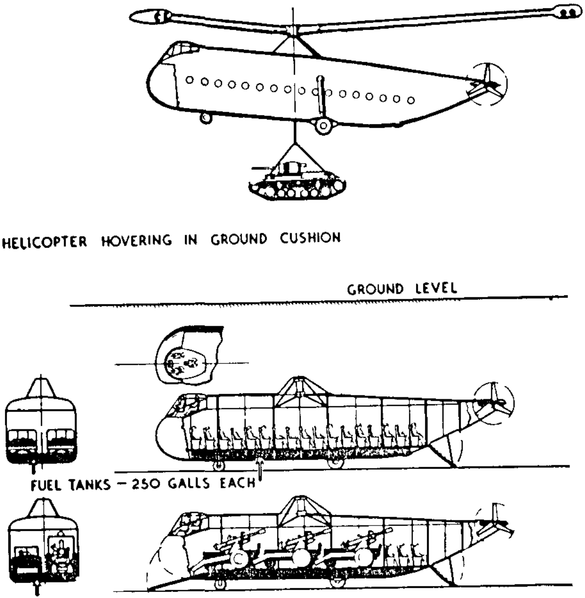
In these large helicopters, where individual engines may be shut down either voluntarily or as the result of power failure, it will be necessary to provide special means for counteracting such a primary unbalance of the rotor To some extent the out-of-balance forces could be counteracted by adjustment of the tracking of the rotor but an extremely powerful method of balancing is possible by means of a hydraulic system in which a small tank of balance fluid is carried near the tip of each blade, each tank having a pump so that the fluid can be shifted for balancing purposes from one blade to another By this means it should be possible to balance out the loss of thrust from both engines on a single blade, employing a total weight of hydraulic fluid equivalent to not more than one passenger Even a simultaneous failure of both engines on one blade would not induce vibration of the machine so severe as to prevent the flight-engineer from rapidly re-establishing a satisfactory state of balance The need to cater for conditions in which there may be a major loss of thrust from the power units on one blade seems to me sufficient indication that the normal blade drag articulation will be retained even for very large rotors of this type

Gyroscopic couples arising from the yawing velocity of the engines in the plane of the rotor and from cyclic pitching oscillations imposed by the controls could be entirely isolated from the blades by oppositely handing each pair of engines and gearing or synchronizing them together to run at the same speed, but such elaborate precautions are not necessary in view of the robust construction of the blades The gyroscopic couples due to yawing of the engines actually cause only a small steady increase or decrease of collective pitch, while the cyclic pitching due to control action gives rise to gyroscopic couples which act in the plane of the blade and which should therefore easily be resisted

I have made some estimates as to the likely rigidity of the blades in relation to the gyroscopic couples which would be imposed upon them if both the jet engines at the tip of each blade rotate in the same direction, *i e*, assuming that no steps are taken to counteract gyroscopic couples The results indicate that there would be a steady twist of the blade to the extent of not more than about 2° The gyroscopic couples arising from the cyclic pitch control motions should have a negligible effect on the controls

Although the weight of the blades is only a small percentage of the gross weight, it nevertheless represents an allowance of approximately 900 lb each, without tip engines This mass of material, suitably applied to the large cross-sectional area of the proportionately rather short blade, permits a structure of great strength and stiffness, which accounts for the small gyroscopic twist and the moderate static droop indicated in the Figure

The helicopter would be able to climb vertically outside the ground cushion while carrying its normal disposable load of $14\frac{1}{2}$ tons and could hover in the ground cushion at a wheel clearance height of 40 ft with a disposable load of $17\frac{1}{2}$ tons In spite of its large lifting capacity it would be very compact, with a total fuselage volume little larger than the minimum



*By courtesy of Flight*

JET TRANSPORT HELICOPTER

6 ARMSTRONG SIDDELEY ADDER GAS TURBINES

*Fig 14 First Example—Typical Loads*

TANK OR SELF PROPELLED GUN TRANSPORT

| | |
|---|---|
| Weight Unloaded | 20 700 lb |
| Crew | 600 lb |
| (Pilot | |
| Co Pilot/Navigator | |
| Flight Engineer) | |
| 15 Ton Tank | 33 600 lb |
| Fuel (630 galls ) | 5 100 lb |
| Overload A U Weight | 60 000 lb |

TROOP TRANSPORT

| | |
|---|---|
| Weight Unloaded | 21 860 lb |
| Crew | 600 lb |
| (Pilot | |
| Co Pilot/Navigator | |
| Flight Engineer) | |
| 102 Troops (180 lb each) | 18 400 lb |
| Fuel (1 500 galls ) | 12 140 lb |
| Normal A U Weight | 53 000 lb |

ARTILLERY TRANSPORT

| | |
|---|---|
| Weight Unloaded | 20 700 lb |
| Crew | 600 lb |
| (Pilot | |
| Co Pilot/Navigator | |
| Flight Engineer) | |
| 3 Jeeps | 7 050 lb |
| 3 25 lb Guns | 12 100 lb |
| 150 Rounds Ammo | 5 250 lb |
| 18 Gun Crew | 3 240 lb |
| Fuel (500 galls ) | 4 060 lb |
| Normal A U Weight | 53 000 lb |
| Additional Fuel 860 g | 7 000 lb |
| Overload A U Weight | 60 000 lb |

required to accommodate the loads envisaged  Three typical loads are illustrated in Fig 14, which shows the helicopter lifting a 15 ton tank while carrying fuel for approximately one hour's flight, and achieving with this load a clearance of approximately 20 ft between the tank undercarriage and the ground  In such a case the cable carrying the weight of the tank would project through the fuselage and be attached direct to the rotor mounting  The Figure also shows the accommodation which could be provided for 102 lightly armed troops at 180 lb each, in which case the helicopter, at its normal operating weight, carries sufficient fuel for a range of 240 miles with suitable fuel reserve  For civil operation the troop transport role illustrated would be applicable to passengers at the normal Airline weight  The Figure also shows a typical loading comprising three 25-pounder guns, accompanied by three gun crews of six men each, and three towing jeeps each containing a small allowance of fuel and 50 rounds of ammunition per gun  With this load the aircraft carries fuel for two hours' flight at a gross weight of 60,000 lb

Making allowance for reduction in weight during long flights the ferrying range at Maximum Continuous Power would be 960 miles at the normal gross weight, or 1,100 miles at a take-off weight of 60,000 lb , indicating the ease with which such helicopters could be transferred from one theatre of operations to another

The range/payload characteristics of the helicopter are indicated in Fig 15, which makes no allowance for reduction of weight in flight The Figure shows that the helicopter could transport a military load of 10 tons over a distance of 300 miles in 3 hours, or 15 tons over a distance of 100 miles in 1 hour

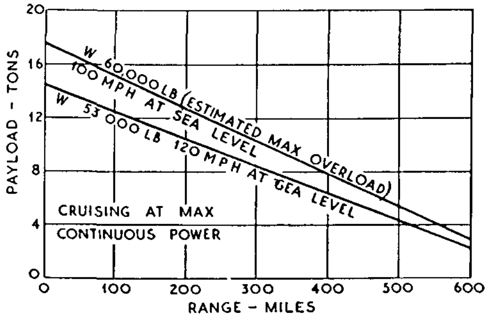


*Fig 15 First Example—Payload/Range Characteristics*

*By courtesy of Flight*

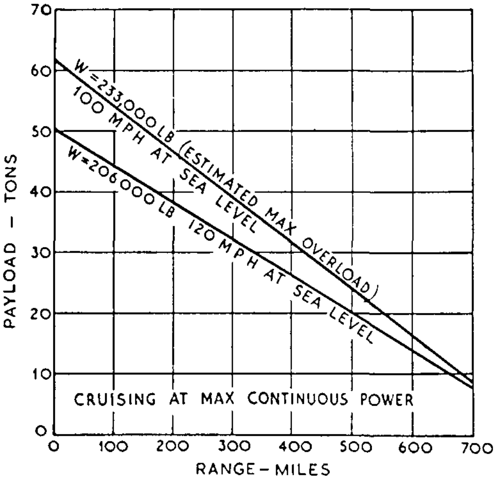


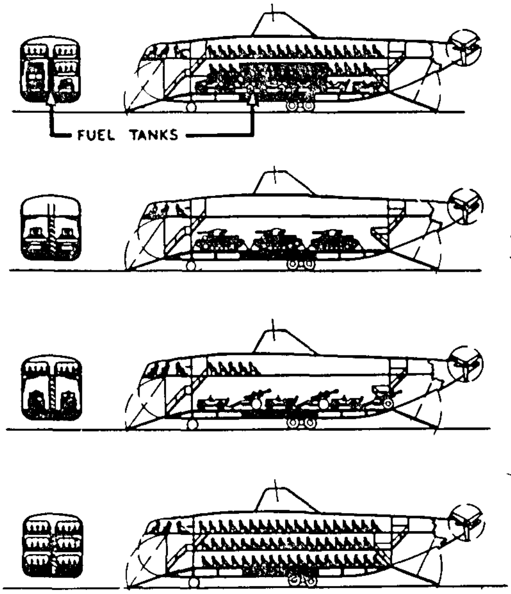
*Fig 16 Second Example—Payload/Range Characteristics*

*By courtesy of Flight*

## SECOND EXAMPLE

Fig 15 refers to the smallest of the true giants in this family, and in Fig 16 are shown the range/payload characteristics of what may be termed a Medium Giant, having a rotor approximately 200 ft in diameter powered by single Sapphire jet engines at the tip of each of the three blades This machine would transport a military load of 24 tons over a distance of 500 miles in 5 hours, or 39 tons over a distance of 300 miles in 3 hours, or 54 tons over a distance of 100 miles in 1 hour  Its ferrying range at Maximum Continuous Power would be 1,100 miles at a take-off weight of 233,000 lb

Fig 17 indicates the operating range of the helicopter for various typical loadings which might, for instance, consist of 450 troops, or three 15-ton tanks, or six 25-pounder guns, each with its 6-man crew, towing jeep and ammunition  The Figure also illustrates the sort of mixed load which in real operations is always likely to be required at short notice  For example, such a mixed load might consist of 220 troops, with 6 jeeps and for good measure an 8-ton trailer with a tractor weighing 4 tons  It seems to me more satisfactory to carry a standard trailer in this way than to accept the distortion of aeroplane and helicopter fuselages which seems to be inseparable from the use of pods as in the Fairchild Packplane and the new Piasecki  For medium journeys the helicopter could accommodate four of



*By courtesy of Flight*

JET TRANSPORT HELICOPTER
3 ARMSTRONG SIDDELEY SAPPHIRE GAS TURBINES

| GENERAL UTILITY TRANSPORT | |
|---|---|
| Weight Unloaded | 92 000 lb |
| Crew—Four | 800 lb |
| Fuel (4 000 galls ) | 32 100 lb |
| 6 Jeeps | 14 100 lb |
| 220 Troops (180 lb ea ) | 39 600 lb |
| 1 Truck or Tractor | 9 480 lb |
| 8 Ton Container | 17 920 lb |
| Normal A U W | 206 000 lb |
| Still Air Range—230 miles | |

| TANK TRANSPORT | |
|---|---|
| Weight Unloaded | 90 000 lb |
| Crew—Four | 800 lb |
| Fuel (2 500 galls ) | 20 000 lb |
| 1 45 or 3 15 Ton Tanks | 110 800 lbs |
| Overload A U W | 221 600 lb |
| *Still Air Range—140 miles* | |

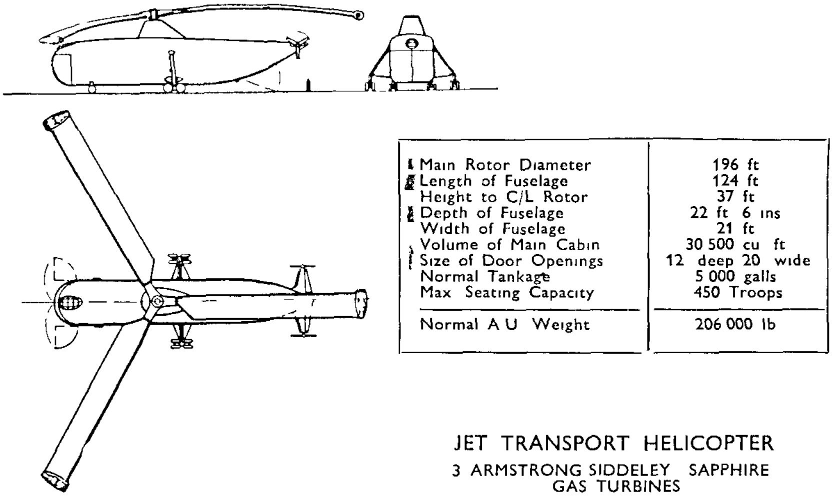
| ARTILLERY TRANSPORT | |
|---|---|
| Weight Unloaded | 90 000 lb |
| Crew—Four | 800 lb |
| Fuel (4 930 galls ) | 39 42g lb |
| 6 Jeeps | 14 100 lb |
| 6 25 lb Guns | 24 200 lb |
| 600 Rounds Ammo | 21 000 lb |
| 36 Gun Crew | 6 480 lb |
| Normal A U W | 206 000 lb |
| Still Air Range—280 miles | |

| TROOP TRANSPORT | |
|---|---|
| Weight Unloaded | 94 500 lb |
| Crew—Four | 800 lb |
| Fuel (3 720 galls ) | 29 700 lb |
| 450 Troops (180 lb ea ) | 81 000 lb |
| Normal A U W | 206 000 lb |
| Still Air Range—210 miles | |

*Fig 17  Second Example—Typical Loads*

these trailers and still leave room for upwards of 100 troops, which are many more than would be required to manhandle the trailers in and out in the absence of tractors

The wide fuselage provides two clear parallel gangways with entry ramp at either end, along which wheeled vehicles may be driven without disturbing the central troop stairways Either or both halves of the middle seating deck can be folded against the fuselage sides to give clearance for especially tall stores or vehicles When in use the two halves of this deck are supported by the central stairway structure, which would only be removed on the rare occasions when it might be desirable to carry the maximum concentrated load internally Such a load, represented typically by a 50-ton Centurion tank, would normally be suspended beneath the helicopter With this load and fuel for a flight of 100 miles with reasonable reserves, the helicopter could, while hovering in the ground cushion, achieve a clearance of approximately 100 ft between the tank undercarriage and the ground



| | |
|---|---|
| Main Rotor Diameter | 196 ft |
| Length of Fuselage | 124 ft |
| Height to C/L Rotor | 37 ft |
| Depth of Fuselage | 22 ft 6 ins |
| Width of Fuselage | 21 ft |
| Volume of Main Cabin | 30 500 cu ft |
| Size of Door Openings | 12 deep 20 wide |
| Normal Tankage | 5 000 galls |
| Max Seating Capacity | 450 Troops |
| Normal A U Weight | 206 000 lb |

JET TRANSPORT HELICOPTER
3 ARMSTRONG SIDDELEY SAPPHIRE GAS TURBINES

*By courtesy of Flight*

*Fig 18 Second Example—General Arrangement*

The arrangement and general appearance of this helicopter are illustrated in Fig 18, which shows that in all essentials it is simply a scaled up version of its smaller brother

I hope that these examples, however incomplete in engineering detail, give at least an understandable picture of the sort of job with which we may be faced in meeting the transport requirements of future armies The magnitude of the job should not, however, be exaggerated In point of pure size, for instance, a circle circumscribing the rotors of the already existing and very complicated Air Horse would actually be larger than the much simpler single rotor of the 100-seat helicopter shown in an earlier Figure Similarly the overall height and length of the helicopter now shown are not much different from the overall height and length of the new Piasecki already under construction

Even the largest members of this family—helicopters more than half as big again as the Medium Giant illustrated here—do not seem to me to present any fundamentally serious constructional difficulties The type of engineering required differs from that which is necessary for such large long-range aeroplanes as the Brabazon, for which success or failure in commercial operation depends upon the highest degree of structural refinement The great lifting capacity of the giant helicopter should, on the contrary, discount excessive refinement and encourage simple and even crude constructional methods

## POWER PLANTS

The crux of the problem is obviously the power plant In my examples I have assumed turbo-jet engines at the blade tips, partly because this permits me to speak in simple and familiar terms about these rather strange machines, but mainly because I believe that this type of power plant offers the best promise of a really versatile and useful solution

In existing circumstances the choice of an efficient jet system for large helicopters may be narrowed to the tip-mounted turbo-jet on the one hand, and on the other hand the two well-known systems in which the blades are used as gas or air ducts

### *Ducted Systems*

Both the ducted systems have the power plant in the fuselage, so that if substituted directly in my examples, the disposable load of the helicopter would have to be reduced by an amount equal to the weight of the power plant—*i e*, by about 6% of the gross weight, or 10% of the disposable load, and both would entail a further reduction in useful load for a given range, to cater for increased fuel consumption—in all, a reduction in useful load varying from about 20% for a flight of one hour to as much as 60% for a flight of 3 hours, assuming an overall specific fuel consumption of 1 4 lb /lb thrust/hr , for the ducted systems In a direct substitution both systems would also considerably complicate the rotor head and blades by the introduction of large ducts for the passage of air or gas at elevated pressures and temperatures

These considerations indicate that a helicopter layout suited to the ducted systems would differ considerably from that shewn in my examples Essentially, a larger rotor is required for the same useful load at a given range, and in practice this would undoubtedly lead to the adoption of a two-blade rotor

The two-blade rotor is well suited to the ducted systems From the structural point of view it gives a larger rotor for the same blade aspect ratio and proportionately much larger gas or air ducts, which improve the propulsive efficiency Both ducted systems also share an interesting characteristic, which is favourable for large jet driven two-blade rotors, in that a failure of jet thrust at one blade tip is accompanied by a loss of compression throughout the jet system, and therefore by an equal, or nearly equal, failure of thrust at the other blade tip, so that no provision need be made for a major unbalance such as would result from the failure of one of the turbo-jet engines in my examples

This type of rotor, as exemplified in the big Hughes helicopter, has I believe a somewhat deceptive simplicity For short range lifting capacity it can probably equal and perhaps exceed the performance of my examples but I feel that vibration and high fuel consumption will penalize it in respect of cruising speed and range, particularly in respect of ferrying range Its rotor articulation must also give it a somewhat restricted c g travel, and these various factors seem to indicate that helicopters of the Hughes type may tend to be confined to specialised application as aerial cranes For all normal duties, including crane duties, I believe that the type illustrated in my examples will prove to be a better investment

### *Turbo-jet Installations*

The problems involved in adapting the turbo-jet engine for operation at the tip of a rotor blade boil down primarily to the fatigue life of the blading and the provision of adequate bearings The first of these problems is, I believe, much less serious than it appears at first sight According to my estimates, the vibratory stresses in the blading due to gyroscopic action are unlikely to exceed some 5% of the already existing centrifugal stresses at least for the range of true Giants, and I see no reason why an acceptable service life should not be achieved

The turbine bearings present a more serious problem and I am now persuaded that there may be no solution for turbines mounted exactly as shewn in my examples I am therefore indebted to Dr MORLEY, of the Napier Company, who suggested that a solution to the bearing problem might be found for turbines mounted parallel with instead of across the blade, partly because the centrifugal loads would then be spread evenly over the thrust bearings, and partly because the nett thrust on the turbine shaft might considerably relieve the centrifugal loads

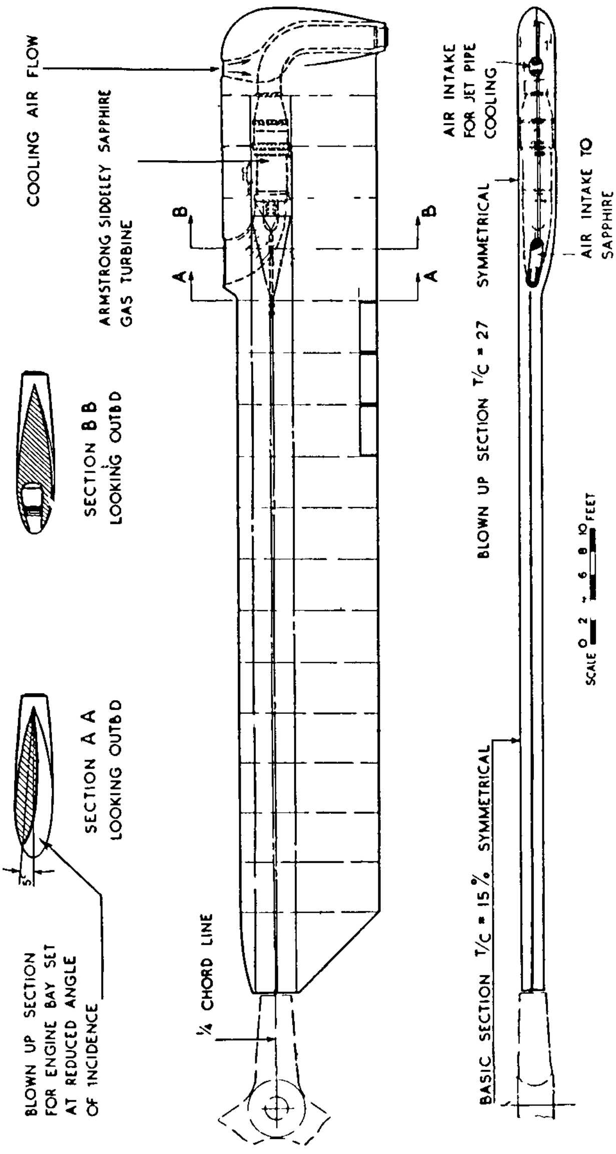
I am not able to judge the significance of the second point but the prospect of taking the centrifugal loads on thrust rather than on journal bearings was sufficiently attractive to overcome a certain resistance on my part to the idea of pushing a jet engine sideways through the air at the tip of a rotor blade My objections on this score were soon overcome because if there is one simple lesson to be learned from the previous examples, it is that big helicopters have big broad blades allowing liberties which might not be permissible with the slender blades to which we are accustomed on small helicopters

On sketching out a spanwise installation for the Sapphire the virtues of this arrangement soon become apparent In particular the heavily loaded thrust bearings need no longer be confined to the cramped and hot interior of the engine Instead, they can be concentrated at the nose of the engine where they can conveniently be up to a foot in diameter, and where they are favourably located in the cooling stream of air intake, as shewn in Fig 19

Tentatively, I visualise a thrust bearing assembly with relatively small diameter ball or roller bearings, capable of taking the centrifugal loads when the engine is shut down in flight but acting in conjunction with, and unloaded by, a pair of Michel bearings of comparatively large diameter which come into operation as the turbine is started up

As indicated in the Figure, the spanwise loads acting on the bearing assembly can conveniently be transferred, by means of a tie rod, to the blade structure inboard of the engine installation The loads arising in the turbine casing can be taken by the surrounding blade structure which, with the members joining the turbine casing to the bearing housing, completes the triangulation in this area

I think the bearing assembly would normally be part of the engine, but it might also be considered, with its associated structure, as a kind of mounting



By courtesy of Flight

Fig 19 Jet Transport Helicopter
Spanwise Installation of "Sapphire" Gas Turbine in Rotor Blade Tip

to which an otherwise ordinary jet engine could be attached in such a way that its casing and turbine rotor are independently supported so that, at least by comparison with first impressions, little more seems necessary to ensure its successful operation at the tip of a rotor blade.

The spanwise installation is also attractive in that the turbine is not affected by the cyclic pitching oscillation of the rotor blades, and the steady gyroscopic couple arising from the yawing of the engine can be made to act as a relief of rotor blade bending stresses in the flapping plane. The arrangement permits easy cooling of the engine and of the jet pipe bend, from which some heat energy may be recoverable as a small thrust to reduce cooling losses. Even the long jet pipe might ultimately be turned to advantage in a re-heat version of the Giant Helicopter!

The thickness of the aerofoil section enclosing the engine seems at first sight to be a serious obstacle to good efficiency, but on looking further I was surprised to find that the .012 mean blade profile drag coefficient, already assumed in my examples, would make sufficient allowance for the tip aerofoil, which has a thickness/chord ratio of 27%. In a twin-Sapphire installation the corresponding blade chord would be 40% greater for the same depth and the aerofoil enclosing the engines would have a thickness/chord ratio of only 19%.

The weight of the extra blade structure plus the long jet pipe, plus the additional bearing assembly and other modifications, might be assumed to increase the power plant weight by perhaps 20 to 30%, but I think it is not improbable that the static thrust of the Sapphire could in due course be increased by a similar percentage, in which case the relation which I have assumed between static thrust and engine weight would remain true for the modified power plant. In consequence, if my examples were revised, a helicopter powered by three Sapphires might turn out to be somewhat larger, and might be expected, for instance, to carry 70 tons instead of 54 tons for a distance of 100 miles.

The curvatures of the air intake and jet pipe would cause some loss of efficiency but this could probably be reduced to a quite small percentage if sufficient attention were paid to the design of the jet pipe bend. On the whole I think the effect on the range figures would not be significant since the figures do not refer to the speed for best range. At a guess, I imagine the nett result might be to drop the cruising speed to about 90 miles per hour at the start of a long flight.

## CONCLUSION

In conclusion, it is my impression that the manufacturing cost of a Medium Giant helicopter, including engines, is likely to run out at about one fifth the cost of the large number of the best type of existing helicopters which would be required to carry the same total loads for the same distances. For many duties the Giant would not replace the smaller types, but in its proper sphere I believe it would be a good investment, economically as well as from a military point of view.

Finally, I offer my apologies to Messrs. ARMSTRONG SIDDELEY MOTORS Ltd. for what they may consider to be a misuse of information concerning their engines! I have also to thank the WESTLAND COMPANY for their generous help in preparing the lecture, and particularly for the assistance

I have received from Mr JOHN SPEECHLEY, on whom I have leaned very heavily for estimates and illustrations

In offering this paper it was my original intention merely to point out that if suitable engines were available, the construction of these large helicopters seems to be quite practicable from the helicopter designer's point of view and I was anxious to know, firstly, whether such aircraft would be attractive to potential operators, and secondly, whether the engine manufacturers could offer a suitable power plant, so that I have to thank Dr MORLEY for the suggestion which has made possible at least a preliminary answer to the second question I am very conscious of the incompleteness of the paper but I hope it will at least serve as a useful basis for discussion

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## LIST OF SYMBOLS

| | |
|---|---|
| Blade radial length<br>Radial position of C G of tip engine(s) | R ft |
| Total blade weight per rotor | b lb |
| Gross weight of helicopter | W lb |
| Weight of tip jet engine | $W_j$ lb |
| No of engines per rotor | N |
| No of blades per rotor | n |
| Mean coning angle | $\beta$ rads |
| Tip speed | $V_T$ ft /sec |
| Max level speed at sea level | $V_L$ m p h |
| Angular velocity of rotor | $\omega$ rads /sec |
| Radial position of blade C G | $k_1$ R ft = 0 45 R ft |
| Radial position of blade centre of percussion | $k_2$ R ft = 0 60 R ft |
| Radial position of blade centre of lift | $k_3$ R ft = 0 72 R ft |
| Blade lift per unit length | $l$ |
| Blade weight per unit length | w |
| Lift on one blade | L |
| Lift moment above flapping hinge | $M_L$ |
| Blade weight moment about flapping hinge | Mq |
| Centrifugal force of blade weight | $C_{f_1}$ |
| Moment due to centrifugal force of blade weight | $M_{cf_1}$ |
| Centrifugal force of tip engine | $C_{f_2}$ |
| Moment due to centrifugal force of tip engine | $M_{cf}$ |