Boost Systems for Helicopter Gas Turbines

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WING-COMMANDER R A C BRIE (*Vice-President*),
occupying the Chair

The CHAIRMAN, in introducing the Author, said that Dr Morley had been for 16 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 subsequently became the Supersonics Division Three years after that he was senior lecturer of aircraft propulsion at Cranfield In his present position as Forward Projects Engineer for the Napier Company he was engaged on technical investigations into developments in aeronautics

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The recent years have seen a tremendous increase in the importance of the helicopter both as a defence aircraft, for anti mine, anti submarine and assault purposes and as a civil transport between busy centres , and it has been overwhelmingly successful in a multitude of special duties from rescue work to crop spraying, some impossible with fixed wing aircraft The wider application of the helicopter in these many roles has directed increased attention towards the enhanced engine performance possible with the gas turbine, and to the more difficult problems of coupling the greater potential output of this form of engine with the inherent safety features of the aircraft

It is well known that the single engined helicopter requires a much bigger engine for take-off than is necessary for cruising flight In most cases a considerably greater payload could be carried if the engine power could be increased temporarily for take-off Again, in the twin-engined helicopter, which is required to fly safely on a single engine, unless the engines are oversize for take-off, more power is required to fly comfortably with one engine out of action than the remaining engine can stand In the great majority of cases extra power is required for a minute or two only , for example, to clear local high ground , to enable a manoeuvre from hovering flight into a comfortable cruising condition , or to make a safe take-off and landing

For such purposes it becomes important to develop ways of boosting the engine power for short periods If this can be done successfully the operator will then be able to accept bigger loads, guarantee satisfactory performance with one engine failure, and not be affected by the loss of engine power which occurs on a hot day Again from the designers point of view, use of emergency boost will permit a reduction in the size of the powerplant and thus offer major gains for no alteration in normal performance

Engine boosting is the natural way to meet an infrequent overload Such boosting has proved essential in earlier aircraft development , *e g* , the supercharging of the piston engine , water-methanol injection , reheating of the turbo jet It has, of course, its limitations due to the higher rate of fuel consumption, the extra stresses imposed on parts already well loaded, and the additional complication in the engine controls particularly if the boosting is to be absolutely automatic Nevertheless, there is little doubt that boosting for short periods will be attractive when applied to the helicopter engine

In this paper we shall discuss engine boosting from the engine aspect with the emphasis on the gas turbine type of power plant Basically the applications divide between the single engined helicopter and the twin engined helicopter In the former we are interested principally in improving performance at take-off and landing in order to carry a bigger payload In the latter we are interested principally in boosting the power of the remaining engine should one of the pair fail in flight

There are four methods of augmenting power which seem worthy of present interest , these are

(*a*) The Rocket-on-Rotor system which uses small rocket units at the rotor blade tips

(*b*) Where there is provision for a gas drive to the rotor tips, the boosting obtained by burning more fuel before the tip jet nozzles

(*c*) Where the rotor is mechanically driven, the power can be boosted by increasing the output of the main turbine for a short period

(*d*) Where an auxiliary gas turbine is brought into operation to meet conditions otherwise too severe for the main powerplant

Of these four, the first is already used on piston engined helicopters and its application to the turbine driven machine will follow the established technique The others concern the gas turbine helicopter, and here our discussion is somewhat of a tentative nature since this form of powerplant is only just coming into use

Rocket-on-Rotor System

A method of using a " cold " hydrogen peroxide rocket to augment rotor H P has been developed by the Reaction Motors Corporation in the United States and by Napier in this country The Napier system has been used successfully in the Saunders Roe Skeeter Mark 5 and Mark 6 and is also projected for use with the Skeeter Mark 12 and the Westland Whirlwind (Ref 1) Fig 1 shows the main features of the system applied to the Skeeter

Concentrated hydrogen peroxide is expelled as a mixture of superheated steam and oxygen from small chambers at the tips of the rotor blades The peroxide is carried in a tank mounted above the rotor hub and revolving

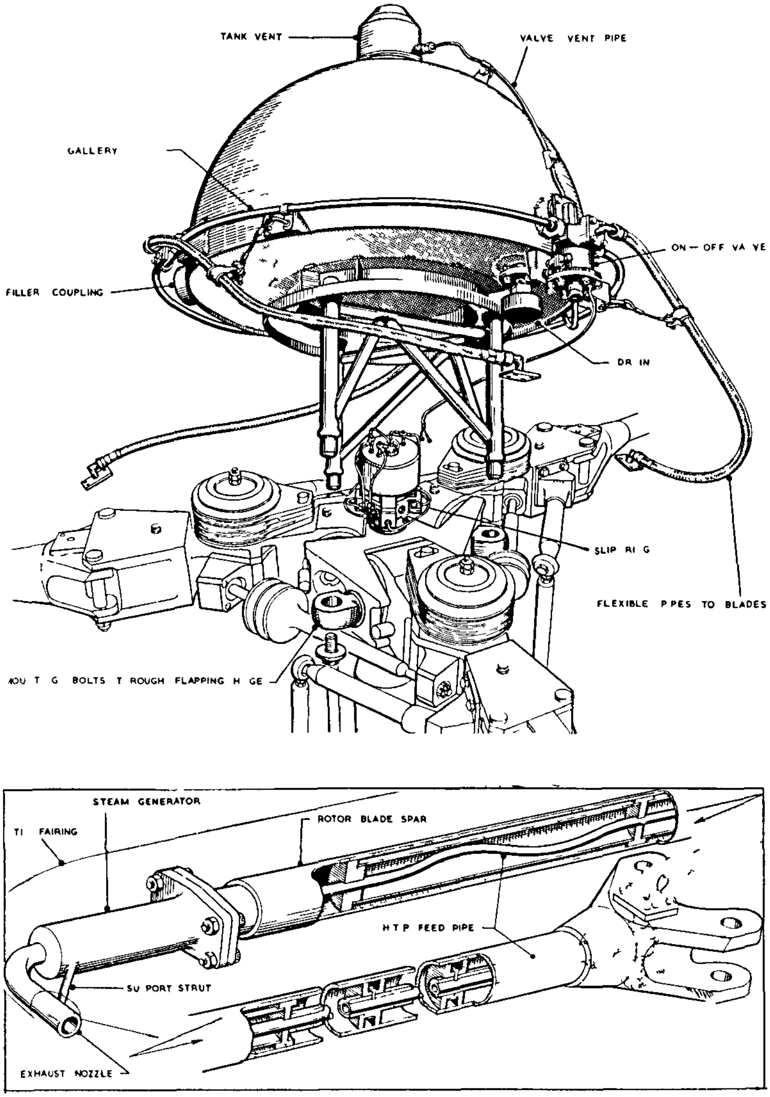


Fig 1 Rocket-on-rotor system, Saunders-Roe Skeeter

with it The liquid is taken along feed pipes inside each rotor blade via an on-off valve controlled by a solenoid or actuator worked off a switch By opening the switch, the pilot allows the peroxide to pass to the feed pipes, through restrictor units which cut down the high pressure generated by the centrifugal force, into small decomposition cells at the rotor tips where it is turned into gas at about 600°C The gas is expelled against the direction of rotation and so develops auxiliary thrust

As is well-known, high test peroxide was first exploited by the firm Walter of Kiel, who found many military applications for this versatile compound During 1939-1945 it was employed by the Germans for several projects but was not used for rotor drives since the helicopter had not reached a sufficiently advanced stage at the time The Rocket-on-Rotor system was first tried by the United States Forces in 1954 when a few small rocket helicopters were built following the rapid developments of rotating wing aircraft during the Korean War

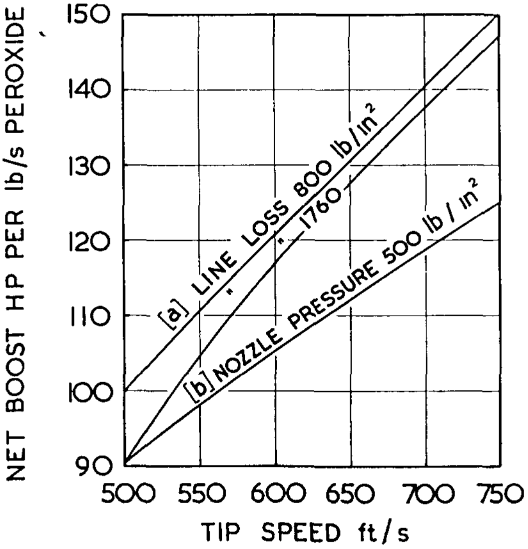
One of the main developments of hydrogen peroxide motors has been concerned with improvements in the catalytic decomposition of the liquid The Germans worked principally with chemical decomposers, *e g* , permanganate solution, and various forms of catalytic stones which would rapidly decompose peroxide over a long period of time at a steady rate Present day applications use metal gauze or granules which offer considerable improvements in technique This development has brought no small advantage to the use of the hydrogen peroxide rocket-on-rotor system

Chemically the process is a very simple one, thus,

H_2O_2 yields $H_2O + \frac{1}{2}O_2 + 13$ K Cals per gram mole

In this equation the heat liberated refers to the gaseous state of the products The temperature of the gases produced depends on the strength of the peroxide , for 80% concentration it is about 500°C , and for 90% concentration, about 730°C

Fig 2 Net rotor boost h p obtainable from a "cold" peroxide rocket-on-rotor system with (a) constant pressure losses and (b) constant nozzle pressure



The efficiency, and therefore the economy of this boost system depends upon the steam generator pressure The centrifugal pressure generated in a typical rotor is considerably higher than required for the decomposition and discharge process , thus if the rotor tip speed is $V_T$ft /sec and the density of the peroxide is ρ lb /ft ^{3}, the centrifugal pressure will be $\rho \frac{V_T^2}{2g}$

With the peroxide a typical density is 1 34 times that of water and pressures of the order of 3,000 to 4,000 lb /sq in and upwards would be reached by the centrifugal effect on the column of liquid in the blade A typical steam generator pressure is 500 to 600 lb /sq in and a restrictor in the feed pipe is thus necessary to reduce the pressure of the peroxide The restrictor may be fitted at the blade root where it will produce a column of low pressure vapour along part of the blade pipe, and thus limit the total pressure rise, or at the tip where it will reduce the pressure of the liquid before it enters the steam generator In a multi bladed rotor the pressures in the separate tip chambers can be made equal by trimming the restrictor units

Fig 2 gives the theoretical performance in terms of H P obtained per lb /sec of peroxide consumption if the chamber pressure is the centrifugal pressure minus a constant pressure loss in the feed line (obtained partly in the restrictor) and also for a constant pressure in the decomposer Some 10% of the potential power is used in rotor pumping As pointed out above, there is no lack of pressure from the centrifugal action of the rotor The theoretical specific impulse of the peroxide increases from about 121 secs at 500 lb /sq in to 128 3 secs at 1,000 lb /sq in and 134 4 at 2,000 lb /sq in With this trend of increase in specific impulse with pressure, the theoretical boost H P /lb /sec of peroxide would increase with tip speed from about 90 at 500 ft /sec tip speed to about 137 at 700 ft /sec tip speed

A typical specific weight for the Napier tip unit which includes the decomposer chamber and discharge nozzle, but not the rotor blade fairing, is 1/20th lb per lb of rated sea level thrust A typical gain in helicopter take-off weight under boost is about 10 lb per boost rotor H P The rocket motor for a helicopter of take-off weight 5,000—6,000 lb might consist of three units each of 30 lb rated thrust At a rotor tip speed of 550 ft /sec an additional rotor H P of 90 is obtained with the motor and will permit some 900 lb to be added to the useful take-off weight of the machine The initial filled weight of the rocket will be about 90 lb per minute of boost operation or about 190 lb for three minutes

A comparison of the performance of the Skeeter Mark 6 with and without rocket boost is given in Table I

TABLE I

COMPARISON OF PERFORMANCE BOOSTED SKEETER MARK 6

(Civil Version of Skeeter Mark 10)
Gipsy Major 201—200 B H P

For identical payloads and piston-engine fuel weights Design thrust per unit 22 lb Duration under full boost 2 minutes

	Normal Machine	*Rocket Boosted*
Aircraft Weight at Take-off, lb	2150	2272
Vertical Rate of Climb (Sea Level), ft /min	230	1470
Hover Ceiling (free air), ft	1100	8800
Maximum Rate of Climb (Sea Level), ft /min	1020	1850
Minimum Rate of Descent (piston engine off), ft /min	1350	650
Maximum Forward Speed, knots	88	100

The essence of the system is its simplicity which must not be impaired if the helicopter is to be a success However, it is possible with future development to envisage the use of the " hot " peroxide system, in which a fuel, *e g* , kerosene as employed in the main engine, is used to burn with the peroxide at the rotor tips If the hot system were employed in the helicopter, about twice the power output per lb of the cold peroxide would be obtained but the better consumption has to be paid for in part by weight increases of the chamber at the blade tips, for this must now include a burner head and a cooling system for keeping the chamber wall temperatures within practical limits The additional complexities of the hot system are unlikely to make its use worthwhile other than for large thrust tip units

The use of any type of engine employing hydrogen peroxide, particularly the higher concentrations in arctic climates, needs special care, since typical freezing points are —

80% concentration, —23°C

90% concentration, —11°C

This disadvantage does not present unsurmountable difficulties , the bulk temperature of the peroxide can be kept reasonably high during storage or ammonium nitrate and water can be added to lower its freezing point Peroxide with ammonium nitrate added, however, is not regarded as being as safe as the unmixed substance

A method of preventing freezing of the peroxide by controlled decomposition of the liquid in a catalytic heater inside the container vessel has been developed by the U S Army Ballistic Missile Agency, Alabama (Ref 2), for use by field units This method has been used successfully to heat peroxide in drums, but as far as is known no one has yet produced a version of catalytic heater to warm peroxide in flight Preventing freezing by catalytic heater appears to be simple and easily workable particularly if the flow of liquid through the heater can be maintained by natural convection The loss of peroxide can be small (say half of one per cent per hour) once the liquid is at the desired temperature and only the heat loss to the atmosphere has to be made good

Looking further ahead some alternative liquids have been suggested in place of peroxide for rocket-on-rotor use Thus a mixture of ethyl nitrate and propyl nitrate gives a theoretical specific impulse up to 50% greater than the peroxide This combination has been used with some success in monopropellant rockets At present, however, ignition is a problem, and further the combustion chamber size would be considerably greater than that for the simple decomposition of the peroxide

GAS DRIVE TO THE ROTOR TIPS

Rotor power boosting by afterburning at the rotor blade tips can be applied to four possible types of tip jet propulsive unit These are the tip mounted turbo jet, the ram jet, the pulse jet and the air or gas pressure jet

When the tip mounted turbo jet arrives, boosting by reheat will be straightforward The ram jet has already been used successfully for the main propulsion of small helicopters but depends entirely on the intake ram obtained by rotation of the rotor Since the rotor is limited to subsonic speeds the amount of ram that can be obtained is too small to permit efficient working Moreover, the thrust is influenced by the angle of attack of the rotor and is therefore liable to suffer unwanted variations as the pilot alters the rotor pitch controls Pulse jets have also been used successfully for small helicopters and so should be considered when reviewing the whole field of possible boost motors Here the thrust characteristic is such that the available power is reduced to practically zero when the high tip speeds are reached which unfortunately is opposite to ideal requirements We come, finally, to the pressure jet which has more possibilities as a boost system Here combustion chambers at the blade tips are supplied with compressed combustible gas from an engine mounted in the aircraft In one form an air bleed is taken from the engine compressor and in another, air is supplied from an auxiliary compressor clutched in when the pressure jet is required The latter system is used in the Fairey Rotodyne

In connection with the choice of unit for tip jet boosting it is of interest to quote some figures comparing ram jet, pulse jet and pressure jet, given by the Fairey Aviation Co from a study of possible main rotor tip propulsion for a Rotodyne aircraft (Ref 3)

TABLE II

COMPARISON OF BLADE TIP PROPULSION SYSTEMS

	Maximum Cross Section	*Disposable Load*	*Specific Fuel Cons*	*Maximum Endurance*
Ram Jet	9 2	1 5	3 6	0 48
Pulse Jet	5 2	1 48	2 5	0 77
Pressure Jet	1 0	1 0	1 0	1 0

In Table II the pressure jet is given the figure of merit 1 0 throughout and the stated characteristics of the other two units given as a ratio It is seen that the pressure jet is superior in three of the four counts and it is only its disposable load which suffers by comparison

With the pressure jet system the ability to boost depends upon the normal tip jet combustion temperature remaining well below the stoichiometric temperature Thus a typical maximum temperature for extended use would be about 1,300°K, whereas with the right proportions of fuel and air (a ratio of about 1—13½) it is theoretically possible to work to temperatures of the order of 2,200°K The rotor power obtainable for a given rate of air supply is roughly proportional to the combustion temperature over the running range so that a useful margin for boost is theoretically available

The tip jet is best supplied with air at a pressure of between 3 and 5 atmospheres depending upon the air compressor design, the rotor-duct capacity and the efficiency required in the combustion chamber For the best propulsive efficiency at the blade tips, with the speeds of rotation common today, we need a combustion pressure of the order of two atmospheres, the main consideration here being the Froude efficiency of the jet

In practice the air supply pressure is raised to cut down the size of the air duct from the compressor and the diameter of the passage in the rotor blade and hence improve the aerodynamic efficiency of the rotor A higher pressure also reduces the volume of the combustion chamber at the blade tips necessary to obtain the desirable standard of combustion efficiency The chamber must, of course, be small enough to be buried within the blade tip without any serious excrescence in order to cut down the rotor drag Another important feature of the combustion chamber is that it must permit a clean light-up and shut down and this is usually more easily obtainable with a high air pressure Against high pressure, however, is the need for increased combustion chamber shell strength and the disadvantage of increased noise from the jet which can be a real problem for any form of helicopter tip jet burning

A potential advantage of boosting by tip jet burning is that there is no sudden change in anti-torque reaction even if the boost is very rapidly applied, and no loss of effectiveness due to the need to supply power to an anti-torque propeller Since the boost system is likely to be called on quickly in an emergency this absence of any further upset to the forces acting on the helicopter will be most desirable

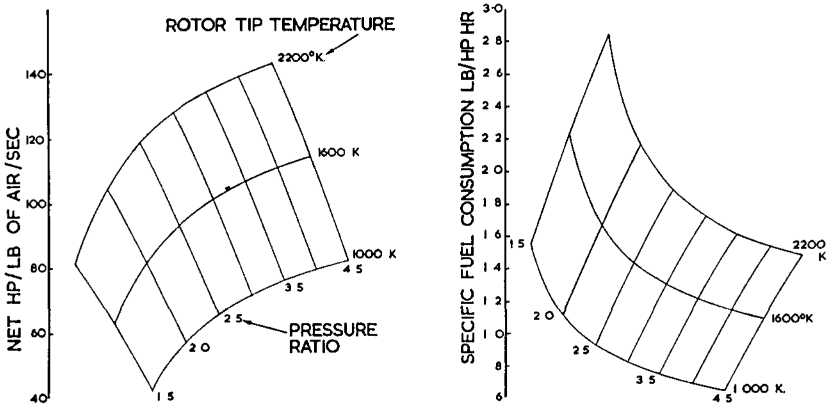


Fig 3 Pressure jet performance rotor tip speed 700 *ft /s*

The capabilities of the pressure jet system have been examined both in America and this country Fig 3 shows estimates of a low-loss boost system The losses can be kept small in a system such as that to be described in the next section of the paper where only part of the propulsive effort comes from the pressure jets

These plotted results which are for design cases only, give a useful assessment of the potentialities of helicopter power boosting by pressure jets

The most valuable experience on the practical possibilities of boosting rotor power by pressure jets comes from pioneering work by the Fairey Aviation Co with their Ultra Light, Gyrodyne and Rotodyne helicopters In the table below are recent results of actual tests by this company One task is that of obtaining good combustion under the effects of the very high gravitational field For the typical helicopter rotor speed of 240 r p m , we have to meet 20g centrifugal acceleration for each foot length of rotor radius Burning is now believed to be relatively easy up to 400g

There is also the noise problem which has always been severe in reheat applications and which cannot be solved to the complete satisfaction of all members of the public without imposing a costly handicap on the performance of tip jets To some extent the sound spectrum is amenable to treatment by arranging mixing with atmospheric air around the nozzle perimeter The Fairey Aviation Co have had noteworthy success in their attack on the jet noise problem of the Rotodyne and claim to have reduced it to about the same level as the other noise of the machine

TABLE III

	Fairey Gyrodyne	*Fairey Rotodyne*
Compression ratio $\frac{\text{Rotor supply pressure}}{\text{Atmospheric pressure}}$	2 72	4 13
Rotor tip speed f p s	690	700
Specific thrust $\frac{\text{lb thr net}}{\text{lb air/sec}}$	76 8	90 4
Rotor H P $\frac{\text{H P net}}{\text{lb air/sec}}$	96 4	115 1
Fuel consumption $\frac{\text{lb fuel/hr}}{\text{lb thr net}}$	2 56	2 06
lb /H P net/hr	2 04	1 62

Both in Fig 3 and Table III the fuel consumption is for the tip burners only and the consumption of the compressor plant must be added to obtain the total consumption These actual test results agree well with design predictions, particularly in the case of the more highly developed Rotodyne

The pressure jet considered as a method of emergency boosting and not for main propulsion requires a powerplant which can supply considerable air bleed at short notice It also requires special ignition equipment The air bleed to the rotor tips would either have to be permanently on or available immediately if there was any chance of the boost being required When the emergency arose the rotor fuel and igniters would have to be quickly switched on and it would be essential to obtain the extra rotor H P without delay It is obvious that such a system would have to be fully automatic The extra air capacity, fuel demand (and igniters) would have to be so linked with the main engine control that there would be no tendency for instability of the main engine, the auxiliary compressor or the combustor, however rapidly boost is demanded The same extreme flexibility, though most desirable, is not necessary if the boost is used solely for giving extra lift at take-off and we can expect a somewhat less complicated and more rugged control system will meet the requirements in this case

BOOSTING BY A MECHANICAL DRIVE TURBINE

With the type of gas turbine developed today for fixed wing aircraft the maximum power rating is used for take-off and initial climb and is permitted for five minutes With the twin engined helicopter the take-off is not necessarily the maximum power condition and other requirements relating to flight safety may make it desirable to seek new ratings for the gas turbine Thus a twin engined machine must be able to fly on one engine at the forward speed for minimum power, for a fair period of time For such a condition a rating has been introduced called " the one hour rating," which declares the normal maximum power required from the engine for periods up to 1 hour When a twin engined helicopter makes a take-off with full load it will normally require the maximum or one-hour power from each engine Since a helicopter engine is likely to use more of its life taking off and hovering than does the engine of a fixed wing machine in take-off and initial climb, the one hour rating may need to be set to a load slightly less than the corresponding take-off rating of the fixed wing type of engine

A severe power requirement of the twin-engined helicopter is to meet sudden engine failure under hovering conditions It appears to be impractical to make both engines of such a size that either would cope with the full hovering requirement of the aircraft, even though the normal maximum power of the engine, as we have just said leaves more margin for increased power than the maximum rating of the fixed wing engine To legislate for the case of one engine failure during hovering a new rating called the emergency rating has been adopted A typical limit period for this rating is 2½ minutes , it is in fact a boost rating and as such is an important development coming within the scope of this lecture

The boosting of the helicopter turbine engine by uprating inevitably requires an increased turbine inlet temperature The higher up the scale we go the shorter becomes the running time allowable It is of interest to quote some figures of turbine inlet temperature against the rating level of a typical engine , and although an absolute value cannot be given here to the temperature scale, because it depends so much on the manufacturers' design techniques, the relative turbine inlet temperatures will be something like those given in Table IV

In this table the temperatures are reckoned on the absolute or Kelvin scale It will be noticed that the fixed wing and helicopter engine ratings for maximum continuous engine operation have the same turbine inlet temperature, while the emergency rating of the helicopter engine and the typical cruise are respectively above and below the corresponding limitations of the fixed wing engine

Basing our discussion of the helicopter engine on the above figures we see that there is an 8% margin between the normal maximum turbine temperature and the emergency maximum This margin is, of course, tied in with the permissible increase in engine R P M and shaft horsepower

TABLE IV RELATIVE ENGINE RATINGS

Fixed Wing Engine	*Relative Turbine Inlet Temperature*	*Typical S H P Ratio*
Take-off 5 minutes	100%	1 1
Maximum continuous	94%	0 8
Typical cruise	89%	0 65
Helicopter Engine		
Emergency 2½ minutes	105%	1 25
One Hour	97%	1 0
Maximum continuous	94%	0 8
Typical cruise (twin engined helicopter)	83%	0 6

A typical power increment corresponding to the 8% rise in absolute turbine inlet temperature is about 25% With a twin engined helicopter, it is quite on the cards that emergency cases will arise which will demand more than an extra 25% on single engine power Obviously the aircraft and engine manufacturers have to decide together just how far they will meet all possible failures by overloading the engine For example a sudden engine failure when hovering might impose more load than is available from the remaining engine under full boost if the pilot must maintain the hovering condition, but a quick manipulation into forward flight will rapidly reduce the power required to maintain height and make flight on one engine possible

For the single engined helicopter there is obviously no need for an emergency rating to cope with engine failure and the need for boost depends on the demand for extra take-off power only

In the twin engine case the future of mechanical boosting by overloading the engine tends to be a complicated design issue Thus it involves questions of handling such as what is the best rotor R P M ? For the power required to hover is a minimum when rotor R P M are relatively low but many pilots prefer high rotor R P M to have more rotor inertia in hand for emergency landing It also enters into the important problem of best engine size Thus if the engine can accept a large percentage overload it can in effect be made smaller and yet meet the specified emergency requirement Then, with the normal cruise load, it will operate at a higher fraction of its rated power As is well-known the shaft drive engine improves in specific fuel consumption as the load point moves up the power curve Hence the engine designed for boosting will not only weigh less but also have a better cruising consumption

Perhaps it would be as well to illustrate this point by figures relating to a twin engined helicopter with Napier Gazelles Here the one hour rating is 1,300 S H P (Table V)

Now engines of a given family identical except for size can be scaled according to output power ratio Hence for a given emergency power we see, that if a Gazelle is scaled on the fixed wing maximum power rating ratio of 1 1, it would require to be 15% bigger than a Gazelle engine scaled on the emergency rating ratio of 1 27, that is, assuming size will be proportional to the maximum continuous power of the engine This extra size would involve about 300 lb in extra powerplant apart from the increase in the aircraft weight to support it Alongside this, since the larger engine will cruise at a power fraction given by 0 593/1 15 or 0 515 of the one hour rating, its specific fuel consumption will increase from 0 845 to 0 89 lb /S H P /hr which would add about 70 lb to the fuel consumption of the helicopter per hour of cruise Thus, by the introduction of the 2½ minute emergency rating we save at least 370 lb of total aircraft weight per hour of cruise flight One might argue that a 15% bigger engine would allow a substantial increase in take-off load but it must be remembered that with two engines each capable of supporting the helicopter in level flight on their own, there will already be as much power as is usable for take-off Further power might be necessary in certain rare cases, but would not normally be usable because of the structural limitations

We are interested here in the free turbine type of engine where the power turbine is not connected mechanically to the compressor turbine The boosting of such an engine by increasing the fuel supply and so raising the turbine inlet temperature above the normal maximum, requires an increase in the R P M of the compressor which presents yet another major design consideration In theory, it would be possible to boost the power turbine without overspeeding the compressor turbine by injecting the boost fuel into a separate combustion chamber located between the outlet of the compressor turbine and the inlet to the power turbine Unfortunately, this system is impractical because it would involve severe compromise in the free turbine to cope with the change in mass flow parameter Also the gas in this region is already deficient in oxygen and at less than the full combustion pressure, so that the chamber required to obtain uniform combustion would be quite large, and besides taking up space, would cause a most expensive pressure loss under normal running without boost

TABLE V OUTPUT POWER AND SPECIFIC FUEL CONSUMPTION

	Output Power Ratio	*Specific Fuel Consumption at Sea Level lb /Shaft H P /hr*
2½ minute rating	1 27	676
1 hour	1 0	720
Maximum continuous	808	769
Typical cruise	593	845

We are thus obliged to concentrate our efforts on increasing the fuel to the main combustion chamber and therefore must accept an increased compressor R P M and heat flow through the whole turbine

Various attempts have been made to overcome the problem of short-period turbine heat flow by the use of liquid coolant sprayed into the first stage, and as far back as 1950 the N G T E did tests on a Whittle type jet engine with water flows up to one quarter of the fuel flow of the engine, showing that the turbine blade metal temperature could be reduced by about 300°C It was predicted that by limiting the temperature gain to 200°C a 60% increase in engine output was obtainable In the case of the Whittle engine about 10% overspeed would be necessary to obtain the full power augmentation In reading across to a free power turbine engine a similar increase in power should be obtainable for roughly the same compressor overspeed However, the engine output R P M would not have to be increased to the same extent The N G T E also found that provided the engine is mechanically sound and able to stand the extra load corresponding to the augmented power, then the direct effect of the injected water on the operation of the engine was not serious One might venture to say that as an engine structure, the shaft drive gas turbine with the free turbine drive is eminently suitable for power boosting so long as the turbine can be cooled effectively There are no other severe problems limiting the engine Hence if a coolant spray can be made successful the way is opened for considerable gains in engine flexibility in the mechanical drive helicopter field There are problems of materials and one of the more tricky questions concerns the aerodynamic effects of the water spray on the flow through the multi-stage turbine and the compromise in turbine design which will be necessary

One possible disadvantage of direct boosting of the shaft H P of a single rotor helicopter is the need for a proportional increase in the anti torque power We must point out that with a twin engined helicopter, the boosting system is not envisaged as a method of increasing the normal maximum power to the rotor, but only the maximum power of the individual engine should one of the pair fail There is no intention of the overload going into the rotor head In fact, when the strength of the rotor is just sufficient for the requirements of the helicopter, the engine control must be so designed that it is absolutely impossible for the boost to come into action unless the other engine is giving less than its normal output by an amount exceeding the boost increment, for this would otherwise wreck the rotor drive

To avoid some of the complications connected with the overload of the mechanical rotor drive at the cost of introducing others, perhaps not so serious a combined system may be considered in which the normal power to the rotor is by mechanical drive while the boost power is by pressure jet to the rotor tips (Fig 4) This composite scheme is good in one respect because the air pressure jet is probably the best all round system performance wise for hovering and short endurance flight, which is the sort of operation in which an emergency system is most likely to be wanted while the direct drive is probably the best all round for cruising and extended flight The composite system would burn engine compressed air at the rotor tips in emergency and no more load would be imposed on the load turbine or rotor drive This air might be taken from the compressor flow at a convenient stage and its volume would be small enough for the duct through the blades to have no effect on the outer aerofoil form However, an examination of such a system for a Gazelle engine shows that the straightforward bleeding of the compressor to supply air for tip burning under overload conditions would not be of much use since the power augmentation would be less than could be obtained if the same turbine temperatures were used with normal mechanical drive and overspeed If the boost compressor were separate from the engine compressor the performance would be better, and such a system would be helpful where the mechanical drive from the turbine to the rotor could not take the extra power or where the anti torque to offset the boost torque is a problem

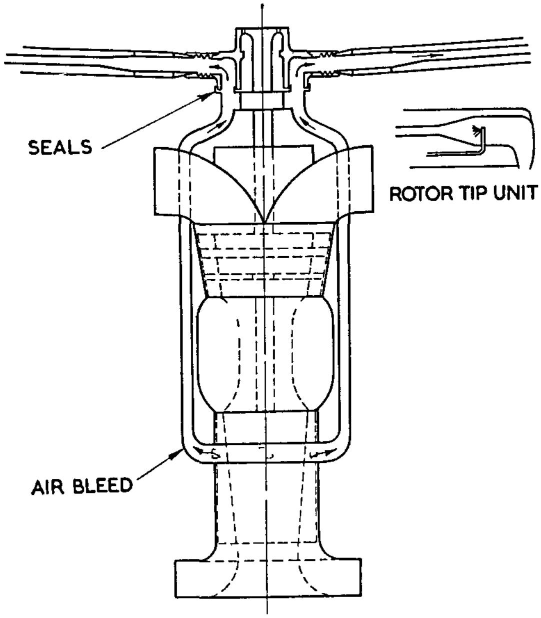


Fig 4 Diagram of engine combining free turbine drive and pressure jets at rotor blade tips

BOOSTING BY AN AUXILIARY GAS TURBINE

Finally, we should like to look briefly at another scheme for boosting which consists of an auxiliary gas turbine connected via a free wheel to the main rotor drive, in such a way that it augments the output from the main engines in an emergency Thus in a twin-engine helicopter, coupled to the common transmission, there would be two identical main turbine units and one auxiliary boost turbine unit Unlike the ram jet or other tip reaction motors considered above, we now have a boost unit of the same type as the main units with the same handling characteristics and good fuel economy Undesirable as will be the complication of a 3rd engine, this solution can appear attractive to the designer when an engine of proved design and suitable size for an auxiliary already exists, and where the main units cannot be boosted sufficient to permit the full use of the capabilities of the aircraft

To carry an idle 3rd engine solely as a flight safeguard does not seem practicable Even if regarded as a flight spare it would have to be run up at take-off for power checks and kept idling in case it should be needed soon after leaving the ground The only possible application therefore seems to be where the auxiliary is also used for take-off, but it remains to be seen whether the helicopter would then have sufficient margin should failure occur on any one of its three engines in flight

Reflection will show that the problem resolves itself into one of permissible engine ratings and of the power ratios required for level flight and hovering as compared with the take-off power Thus, if a main engine fails the auxiliary must obviously be above a certain power to support the aircraft whereas if the auxiliary engine fails it must be below a certain power in order that the remaining main units can still fly the aircraft We find that the cases of main engine failure and auxiliary engine failure can only be met if the minimum power required for flight is between a $\frac{1}{2}$ and $\frac{2}{3}$ of the take-off power of the helicopter (Fig 5) To meet a typical case where the minimum flight power is 625 of the take-off power the auxiliary would have to be at least $\frac{2}{3}$ of the power of the main engine Further, if the minimum flight power is greater than 667 of the take-off power no auxiliary whatever the size could meet the engine out requirement In fact the case is most nearly met when the main and auxiliary engines are all equal and we have in fact a three engined machine

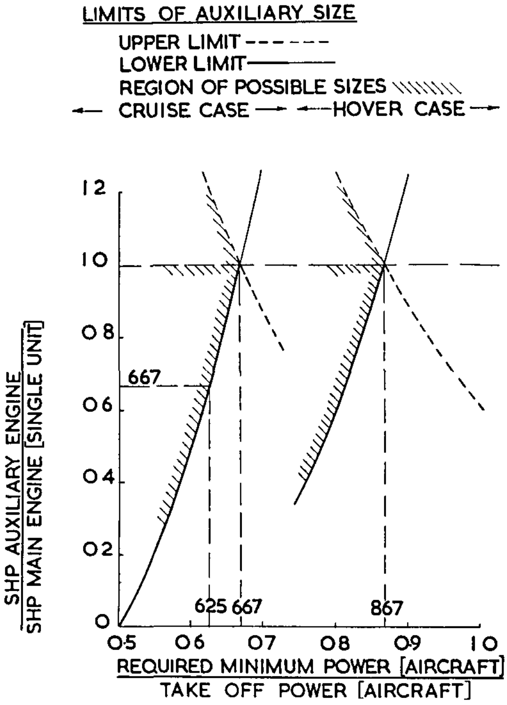


Fig 5 Limits of auxiliary size

The upper limit refers to failure of the auxiliary and the lower to failure of a main unit In the cruise case minimum power corresponds to the 1 hour rating and in the hover case to the emergency rating of the two remaining engines (1 hour power = take-off power emergency = 1 3 take-off power all engines in use for take-off)

A similar look at the hovering condition shows that whatever the size of auxiliary it is impossible to meet hovering requirements with one engine out unless this requirement calls for less than 86% of the take-off power for the aircraft, and again this needs an auxiliary as large as the main engine

If the auxiliary is not to be used for take-off it will be possible to extend the cruising range of the machine by shutting down one of the main turbines There are, however, a number of extremely difficult problems to be solved here, for example, the idle engine would have to be started up in readiness when flying over houses or near hilltops and would in fact be running round for a large proportion of the flight time The fuel consumption when idling would be a dead loss to the performance of the helicopter An independent method of starting would be necessary which could be relied on absolutely to give starts in flight Again from the supply point of view, the complication in the main powerplant and division in responsibility caused by the introduction of an auxiliary engine produced by another manufacturer would in most cases be extremely unwelcome There is, therefore a strong desire to avoid an auxiliary gas turbine as a boost unit Although some excellent small gas turbines are available we have not yet seen the emergence of a helicopter carrying such an auxiliary

CONCLUSION

Any conclusions as to the best system for boosting must be based on the degree of boost available, on the endurance required and the total weight for a given endurance One assessment of endurance which has been made is given in Table VI Reliability and flexibility must also be properly considered

The rocket-on-rotor system probably has the greatest power potential and calls for the minimum of modifications to the existing powerplant and airframe As far as total boost weight is concerned we must expect the rocket-on-rotor system to be heavier if more than a very short endurance is required This is, of course, due to the voracious appetite of the rocket engine For the same installed weight, including fuel, we may expect the endurance of the various turbine arrangements to be several times greater

The composite pressure jet-mechanical drive system using an auxiliary compressor clutched in to the remaining " live " engine has a high potential output without imposing any more load on the live engine In such an arrangement the ultimate amount of boost is obtained when all the power of the live engine is absorbed by the auxiliary compressor, and the compressed air is heated in the tip units to the highest possible temperature In theory the highest boosts are obtained at low pressure jet pressure ratios, *e g* , 1 5 to 2, but a limiting factor is the rotor ducting which requires a higher pressure By a compromise between the conflicting requirements of boost power per lb of air per second and duct area per lb of air per second a suitable pressure ratio may be found and substantial percentage boosts should be obtainable

Boosts of the order 40 to 50% take-off power should be available with the helicopter gas turbine engine using a mechanical drive by overspeeding combined with water injection With a twin-engined machine which suffers an engine failure, the final transmission is not overstressed by boosting

TABLE VI

Estimated endurance (mins) under boost for 1,000 lb of fuel, or fuel plus propellent or water, one engine failed Main engines are 2 × 1,300 h p (unboosted)

$\frac{\text{Power to maintain height}}{\text{Take-off power}}$	N B Boost is used for all take-offs			0 55	0 575	0 60	0 65	0 70	0 75
$\frac{\text{Required power boost}}{\text{Unboosted single engine t o power}}$				0 222	0 353	0 50	0 856	1 33	2 00
Minutes endurance under boost	Rocket-on-Rotor	550 ft /sec tip speed		5 2 mins	3 3 mins	2 5 mins	1 4 mins	0 9 mins	0 6 mins
		750 ft /sec tip speed		6 4 ,,		3 0 ,,		1 2 ,,	
	Boosted Gas Turbine	Overspeed — increased T_{max}		57 ,,	51 ,,				
		Overspeed + water cooling water/gas = 0 03				19 ,,			
	Auxiliary gas turbine with same s f c as main engine			52 ,,	47 ,,	42 ,,	34 ,,	27 ,,	20 ,,
	Composite gas turbine and pressure jet								
	Press Jet Press Ratio	Tip Temp °K	Tip Vel ft /sec						
	1 5	1,000	550	19 7 ,,	14 0 ,,				
	2 0	2,200	750	32 ,,	25 ,,	20 ,,	13 ,,	9 ,,	6 ,,

The engine and its gear box are overloaded but the weight penalty is small and there are no difficulties with the installation

If boost power is obtained by overspeeding the compressor turbine and water injection is not used one would expect to find a lower safety margin on the turbine blade stresses Nevertheless, it is simpler to avoid the use of water injection and, therefore, preferable to develop the engine to the necessary standard of reliability without it

Finally, it is not possible to classify the systems discussed above on a basis of endurance, since endurance and system weight go together and cannot be separated to make a just comparison Thus the rocket-on-rotor has a high rate of consumption and poor endurance but is the simplest system in many ways In the table endurances are compared for a comparatively heavy fixed weight of fuel, water or propellent and to some extent the differences in system weight are reduced because of the high proportion of consumed liquid in the total boost weight On this basis the straight uprated hot turbine, with its low specific consumption has a clear advantage The same engine using spray cooling of the turbine has less endurance due to the additional water consumption but the turbine itself will have an improved life due to its lower metal temperatures The use of an auxiliary gas turbine to boost main engine power shows a somewhat shorter endurance than the " hot " turbine engine because of the latter's better specific consumption

The composite gas turbine and pressure jet system is an interesting possibility According to these estimates its endurance time would be intermediate between the rocket-on-rotor and the straight up-rated mechanical drive turbine It would permit the power to the rotor to be increased without torque reaction and for no more load on the rotor mechanical drive In cases where such advantages are not sought the up-rating of the main gas turbine appears preferable

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