NOTE

Mr BROWN, in presenting his paper, explained that Figure 7 might need correction This scheme and the one with the tip burning had not been shown in their best perspective—in other words, the Mach number ought to have been increased from 1 to something like 2 or 25 , but having done all the calculations on 1, he had not gone to the trouble of doing them again

To stimulate discussion, he added at the end of his lecture that the chief reason for the variation in the engine weight figures (*i e*, 820 lb 1300 lb , 2340 lb , 1170 lb and 840 lb) was not only the specific power produced by the various schemes, but also the actual power required *i e*, the horse power calculated as being required to lift the 10,000 lb helicopter This was something which appeared to be difficult to calculate, and people did not seem able to agree on it It depended upon such things as the drag of blades which carried ducting and upon whether a blade which carried along it a series of ducts which had in them hot gas or air could be made to give drags as low as those of the conventional blade

Discussion

The **Chairman** said that they had listened to a very interesting discourse and he—in another capacity—was relieved that the ducted air scheme with tip burning had come out reasonably well ! Before making any detailed comments on the paper he would like to hear the views from the engine builders and others Accordingly he called upon Mr BELL, Chief Designer (Engines) to Blackburn & General Aircraft Ltd , to open the discussion

Mr F R Bell (*Chief Designer (Engines), Blackburn & General Aircraft, Ltd*), who opened the discussion, said that Mr Brown's paper was extremely useful because it gave a great deal of information which he had always wanted and also because Mr Brown had come to the conclusion which he wanted him to reach, having said the same things himself On most of the points he was in complete agreement

One of the difficulties with helicopters today was the question of safety over cities and the like For civil transport helicopters at any rate, twin engine reliability was needed The author had said that the free turbine was better for periods of over 30 minutes, but from the point of view of safety, even if one wanted to travel for only 30 minutes, one would need a greater margin Were he himself the A R B , he would say that he wanted longer than 30 minutes Therefore, even on Mr Brown's own conclusions, the free turbine type of engine with a mechanical drive would appear to be better

Taking into account the twin engine reliability, however, the picture leaned even more that way As the lecturer had shown, for all schemes other than the free turbine and the hot gas scheme burning at the rotor tip, the engine weight was much greater

It was a characteristic, apparently, of the helicopter that its cruise performance required somewhat more than half its maximum hovering power This meant that with a twin engine unit, and if the helicopter was capable of cruising on one engine —which was necessary for safety—there must be somewhat bigger engines than was demanded by the maximum power conditions The engine weight then became a rather greater percentage than Mr Brown had used In other words, all the calculations being made for a single engine, if one took into account the cruise conditons on one engine and on a twin engine unit, these figures would be emphasised somewhat because the engine weight was a bigger percentage

He admitted that his next remarks might not apply to small helicopters—privately-owned little things, running on one engine—but in order to use two engines with a ducted gas scheme a variable tip jet was necessary, because when one engine was closed down the nozzle areas must be closed down proportionately, otherwise the engine would get too hot and would melt It would be difficult to develop a reliable variable tip jet Under 700 G —at the rotor tip—a variable jet would be extremely difficult Without a variable jet, which would put more weight on to it, it was not possible to get the desired reliability

Commenting on the engines at the rotor tip, he thought that this also might be solved , but as an engine designer he would hate to have the problem of designing an engine to run at 700 G This was the sort of problem that would have to be faced when inter-planetary travel arrived and landings had to be made on Jupiter !

Mr Brown, *in reply*, explained that he had assumed two-engine reliability and that the weights he quoted were those for two engines for each scheme, without a variable tip jet

Mr Bell That has to be allowed for ?

Mr Brown Yes, that has to be allowed for

Mr J Tustanowski (*Member—Hunting Percival Aircraft, Ltd*), congratulating Mr Brown on an excellent lecture, said it was unique in that it gave a review of all the recognised ways of applying the gas turbine to the helicopter

The outstanding merit of the paper was in its thermodynamic considerations and the comparisons were all referred to a common basis of design for the main turbine units, with realistically chosen design points and part-load characteristics As a result, and for what he thought was the first time, the fuel consumptions given enabled a sound comparison of the merits of the several propulsion schemes to be made

Referring to the last sentence of the paper, he said that the features which were decisive as far as load carrying merit was concerned (*i e* , endurance limit, to use the criterion in the paper) were disposable load, fuel consumption and aerodynamic cleanliness The first two obviously involved the power plant directly, and fell naturally within the scope of the lecture The third, whilst admittedly a by-product of the type of propulsion, could not properly be left out of consideration

The final assessment of relative merit must be made on the balance of these three items, and any attempt to determine the break-even point imposed a heavy responsibility on the assessor

In making his illustration he did not propose to consider the ducted air scheme or its derivatives, but would concentrate on the comparison of the shaft-drive as applied to a single rotor helicopter of moderate disc loading—say, 3 5 lb per sq ft , and 100 m p h cruising speed

Mr Brown's fuel consumption data were as follows

Shaft drive scheme	0 73 lb /hr /s h p
Ducted gas scheme	1 23 lb /hr /r h p

at a rotor tip speed of 0 55 Mach No

Even neglecting the transmission losses for the shaft-drive scheme, it was readily seen that the difference in fuel load for the two schemes was 3 per cent of the all-up weight per hour, for a representative cruising power loading of 16 lb /r h p Thus it was necessary to determine the disposable load percentage within 3 per cent to determine the break-even endurance within one hour

This, he contended, was a goal incapable of achievement on paper, and as no developed turbine helicopters were flying the question of the endurance which determined whether the shaft-drive or the gas drive scheme was best, must remain controversial for the present

The disposable load of a turbine shaft-drive helicopter could clearly be more reliably estimated than could that for one with a ducted gas drive The advantage of fitting shaft-drive turbines to helicopters which had many years of development with piston engines behind them was clearly due in the main to the lighter power plant and to the elimination of the clutch and the cooling provisions The overall gain in these circumstances, he estimated, was a 6 or 7 per cent increase in disposable loads

The ducted gas scheme, despite its higher rotor system weight, promised to give 45 per cent disposable load Extension of the thermodynamic cycle could increase this figure to at least 55 per cent

He did not think he could be accused of unfairness in putting the target disposable load for a helicopter designed *ab initio* for shaft turbine drive at 40 per cent , comparable with the 45 per cent he had quoted for the gas scheme

On the fuel side, the specific fuel consumption ratio (gas drive to shaft drive) was about 1 55 1 It was reasonable to allow that the lower helicopter drag possible with a gas drive might be taken as alleviating this by 10 per cent, giving a net ratio of about 1 40 1 Even this ratio might suggest a doubtful case for the gas drive, but the actual difference in specific fuel consumption per r h p —estimated at 0 35—when interpreted through power loading, modified his earlier figure of 3 per cent to 2 2 per cent per hour In other words, the problem was even more difficult than he had suggested

Based on the foregoing figures, he would put the break-even endurance at two hours as opposed to the one hour quoted by the author, whose figure was, presumably, related to a higher disc loading It would appear from this choice of loading that Mr Brown had disregarded the auto-rotative characteristics after the failure of both power plants Although he was himself in favour of such a loading, he had assumed in his figures the currently accepted disc loading, which gave moderate rates of descent in auto-rotation

His main point was that exceptional difficulty attended any attempt to pin-point absolute endurance criteria, in which direction such precision as he had indicated was called for and real evidence was lacking

He had no doubt that on a payload/endurance basis both the gas drive and the shaft drive had their spheres of application, but the determination of these must await practical demonstration

Mr J Shapiro (*Founder Member—Consultant*), said that he thanked Mr Brown particularly as he had experienced for many years that gas turbines had become something of a religion, and it was often difficult to have a reasonable and sound discussion

Mr Tustanowski had made the essential point that they were dealing with margins which could be established only by practical tests At the present juncture it was entirely impossible to make valid predictions

The author, he thought, had succeeded in reducing the number of variables, but while this was helpful in giving the general picture and making the enquiry sweep over a wide range, Mr Brown might have missed a few points which deserved to be brought in

He did not think that the author s methods of assuming certain optima on the helicopter side—*i e*, the velocity of gas through the blade, and even the blade characteristics themselves—were really acceptable in a more general discussion, because such methods might mean overlooking of minima and maxima which perhaps should not be overlooked He would hesitate, therefore, to take the results of the lecture, even from the purely aero-thermodynamic point of view, as covering the whole field By resorting to unorthodox combinations there were possibilities which had not been brought out

In dealing with the turbine shaft drive, the author had thrown out rather lightly the so-called solid drive turbine as opposed to the free turbine In America, where quite a lot of work had been done in the practical sense, there were two schools of thought He could not quote detailed figures, but he would like to know whether, from the standpoint of efficiency, the solid turbine did not actually gain

By having a solid turbine with some form of hydraulic drive, could one not achieve all the benefits of the free turbine plus a better efficiency? He did not suggest that that was a very practical proposition, and the free turbine undoubtedly had very good operating and functional characteristics—*i e*, it governed itself Nevertheless, he had heard opinions that it was not the best from the efficiency point of view and that by governing by means of instruments a solid turbine, perhaps slightly oversize, it was possible to get a better combination He would like to have Mr Brown's views on this

Mr Shapiro said he would like to know what was the combustion chamber pressure loss and what method of assessing the blade duct losses was used in the author's calculations These things could be quite decisive

There was one point which he thought was obscure One of the curves showed that in the ducted air scheme, by increasing the pressure ratio, the specific power went down He would like to know the simple physical explanation of this, because it would seem that by increasing the pressure ratio more energy was put into the air and the specific power per lb of air per second should go up

An important point in considering all these schemes, especially when associating them with weights, was that when considering engine ratings one should consider the worst climatic conditions This applied particularly to the comparison of any turbine with piston engines All turbines responded badly to temperature, and since all helicopters must be rated to operate at least under temperate summer conditions and some altitude, this should be taken into account

In his own design experience he had known cases where the difference between temperate summer and standard conditions had completely reversed the picture All comparisons, especially for civil helicopters, should be done under the limiting conditions for the operation

The Chairman, emphasising the very telling point which Mr SHAPIRO had made, said that the question of high temperature operation was certainly a very important issue

Mr A McClements (*Founder Member—Ministry of Supply*), described the author as a man of considerable courage in coming to talk on a subject which contained so many unknowns Whilst undoubtedly Mr BROWN could discuss the engine aspect with authority, the final performance of the helicopter was not so easy to assess because it was dependent, not only on the engine, but on the rotor system This was particularly so in the gas systems which he described Fortunately we would be much better informed about the unknowns before very long so he felt that it would be very valuable to bring the paper up to date in say 18 months' time by amending the helicopter performance section of it as necessary in the light of practical results

Mr BELL referred to emergency power This was a subject of vital importance and one which should be a challenge to the engine manufacturers The crux of the matter was the difficulty of reconciling the shape of the power required curve with turbine engines having good cruising economy and an adequate ratio between say the one hour emergency en route power and the emergency take off power The result was that it seemed difficult to provide multi-engined reliability over the whole speed range without depreciating the economics of the machine

He felt that the helicopter would be penalised operationally unless provided with multi-engined reliability right down to the hovering condition and if this was to be possible with the minimum number of engines (2) stretch in ratings was necessary

Finally, it was encouraging to have a lecture from a member of the N G T E staff because it indicated that that Establishment was now working on helicopter propulsion problems This was important because the full realisation of the helicopter's future was very dependent on the development of optimum propulsion methods We wanted to know what these methods were and we all hoped that N G T E would continue with their work and make an important contribution towards this end

Mr N E Rowe (*Member—Director, Blackburn and General Aircraft, Ltd*), who said that Mr McCLEMENTS had made some important points, asked whether Mr BROWN could extend the data in his paper to cover other aspects

On the critical point of specific consumption, the author by his curves had shown a marked diminution of specific consumption with increased tip Mach number It would be helpful to see this effect examined at still higher Mach numbers, say up to 1 0 It might be that people were being over-cautious on the question of high tip speeds

The most notable feature was the big increase of specific fuel consumption between the ordinary mechanical drive and the tip drive This was mainly due, presumably, to the relative inefficiency of propulsion by jet at the tip The efficiency of propulsion, he supposed, would steadily improve with increasing tip speed, and it might improve better than linearly

He would also like to see the paper extended to ways and means of obtaining true multi-engine reliability from two engines in the hovering case Could the methods proposed in the paper, if developed to this end, still give reasonable properties in cruising flight ?

Although Mr Brown had done a first-rate job on the question of weight, he was disappointed that only engine weights were quoted in the paper In assessments of this kind it was necessary to have engine plus fuel weights The engine weight alone was quite valueless His own rough calculations led him to conclude that there were much bigger differences than had been quoted in the paper, and although he might be " sticking out his neck " he would give his calculations in the hope that it might lead the author to give more specific information

His calculations for engine weight plus fuel weight, as against the author's for engine weight only, were 2940 lb compared with 820 lb , 3700 lb compared with 1300 lb , and 4576 lb as against Mr Brown's 2340 lb These calculations were for a 200 miles stage, assuming that this would be equivalent to two hours, thus allowing something for reserves Further information in this direction would add tremendously to the value of the paper, and perhaps it could be included with some degree of realism when the paper was published

The author had given a clear exposition on an extremely difficult subject, with many variables, which if not dealt with firmly, could make a very confused picture He was particularly impressed by the author's parameter of the ' specific rotor horse power,' which was quite a basic notion in overall considerations of helicopter power requirements

Mr G T S Clarke (*Development Engineer, Alvis Limited*), who said that he would like to ask some questions on the shaft drive schemes, explained that his only experience was on the piston engine type of helicopter power unit What he was concerned with was that the tendency with the present-day helicopter was to confine the rotor speed to a more or less constant figure with a probable range of 20 or 40 r p m This meant that through a relatively small gear ratio the engine itself had an operating speed range of no more than 200 to 400 r p m , and it had to deliver changes of power of approximately 50 per cent without any change of r p m quickly to meet the case of emergency manoeuvre in the helicopter

Dealing with the application of the gas turbine, and especially the free turbine, to the helicopter, he asked whether they would be faced with the problem of a constant speed rotor—and, consequently, a constant speed turbine, or whether they were to have a variable speed rotor and a variable speed turbine In the latter case, would the variable speed turbine be able to meet the demands in power that would be made on it to enable the helicopter to be handled safely ?

Speaking of the question of twin engine reliability with turbine engines, he asked what would be the problem in regard to the ducted system when one engine stopped If there was one engine at one end and another at the other end, would the duct losses along the aircraft fuselage be so great as to take away the possibility of being able to use an engine rating on the one remaining engine which did not cause an emergency rating to be resorted to whereby the engine had to be removed immediately afterwards ?

The Chairman said that the question of the ready acceptance of the free turbine for the drive was largely based on pictures of the incompatibility of the rotor characteristics with those of a fixed shaft turbine which had been published, particularly in America Shortly afterwards, however, a small helicopter with a fixed shaft drive had been flown in America and it had worked well The answer was that it was a fairly powerful turbine for the helicopter in question This might be an interesting pointer that the turbine in such an application should be given plenty reserve of power so that the control and stability problem should not arise in its extremely acute form, as it would do if the turbine was being worked right up to the limit In other words, enough power margin should be available above the maximum power demand of the rotor, including an allowance for mishandling, gusts, etc , so as to provide " elbow room " for the governing system

As a corollary to that, he wondered how much detailed consideration had been given to the problem of the control of the free turbine when the latter was mechanically coupled to the rotor and rapid changes in power were being sought by a pilot Perhaps the propeller and engine manufacturers had enough experience to feed in to make the solution easy

He emphasised that the value of the paper would be greatly enhanced if Mr Brown were to extend the range of some of his parameters, in particular the tip Mach number going up to 0 8 If, in view of the amount of work involved, the additional notes were not available in time for publication in the Journal, they would be printed later as an extension to the paper

Mr P R Payne (*Member—Auster Aircraft, Ltd*), said that in making calculations on the basis of fuel plus engine weight he had reached the same results as Mr Rowe It seemed that the difference was much greater between the shaft drive engine and the alternative schemes if the fuel weight was allowed for and if two other small points were taken into account First, Mr BROWN had said that he had allowed for a transmission weight on the shaft drive helicopter, including tail rotor Presumably this meant that the figures referred to a single rotored helicopter—(Mr BROWN *indicated assent*)—and that a twin engine helicopter with shaft drive would come out with considerably lighter shaft weights Secondly, Mr Brown had mentioned the difference between the drag of the gas turbine with the ordinary rotor blade and the gas propelled rotor blade but had not specifically said whether allowance was made for this in his calculations His own impression was that the blade for a gas jet was of a thickness of 20 per cent , which, if true, was something like an aerodynamicist's nightmare, whereas the blade for a gas turbine helicopter was as thin as the designer required for maximum efficiency

TOTAL ENGINE + FUEL WEIGHT ON 70% MAX POWER

Engine	*Specific Fuel Cons at 70% Max Power*	*Engine Weight (2 engines)*	*Engine + Fuel Weight*	
			1 hour	*½ hour*
Gas turbine	0 88 lb /RHP /hr	§ 1600 lb	2216 lb	1910 lb
Ducted gas scheme	1 41 lb /RHP /hr	1300 lb	2288 lb	1794 lb
Ducted air scheme	1 90 lb /RHP /hr	2340 lb	3670 lb	3005 lb
Ducted air with tip burning (1,000°K)	1 9 lb /RHP /hr	1170 lb	2500 lb	1835 lb
Subsonic ram jet $M_T = 0\ 8$	4 44 lb /RHP /hr	150† lb	3260 lb	1705 lb
Supersonic ram jet, $M_T = 2\ 0$*	1 33 lb /RHP /hr	100 lb	1032 lb	566 lb

NOTES * Specific consumption of supersonic ram jet is weighted to allow for the reduction in efficiency of a supersonic rotor Weight includes items in the fuselage

§ Mr Brown's figure reduced by 120 lb

† The weight of a structurally efficient subsonic ram jet is given approximately by

$$\text{Weight (lb)} = \frac{[\sqrt{\text{frontal area (ft)}^2}]^{\frac{3}{2}}}{0\ 145}$$

For circular cross-sectioned ram jets such as the Hiller, the power is greater than 3/2 by an unknown amount

He was not certain of the precise definition of a gas turbine but imagined that any acceptable definition included ram jets mounted at the tip of the rotor blades , he could not think of any objection to including them in the definition If ram jets were included, the first conclusion that a gas jet was preferable to a shaft turbine for half hour duration was not then true

Most investigators agreed that a ram jet running at a Mach number of 8 was better than anything else running up to half-hour duration Secondly, with a supersonic ram jet running at a Mach number of about 2, one would get a rotor system which, on an engine weight plus fuel basis, was more efficient than any of the other schemes which the author had described, up to an endurance of about four hours

Mr Brown, replying to the discussion, said that many of the questions, as he had expected, were not directly concerned with the power plant as such but were concerned with helicopter performance He confessed straightaway that he knew nothing whatever about helicopter operation, he knew only about gas turbine performance

He apologised for not extending the investigation to rotor tip Mach numbers of 0 8, but pointed out that this study had been made in collaboration with the Royal Aircraft Establishment, who had limited the tip Mach number to 0 6 He confessed ignorance of the effect of rotor tip Mach number on helicopter performance, and so could not comment on the suitability of tip Mach numbers of 2 He did know that a ram jet would have a reasonable fuel consumption at $M = 2$ and the power plant, which, he thought, could be designed to bear the loads consequent on tip mounting, would be comparatively very light and cheap to produce

He had deliberately omitted ram jets and pulse jets from the scope of his paper , ram jets were omitted because the maximum rotor tip Mach number considered in the overall comparison was only 0 6 Pulse jets were not included because this form of power plant did not fall within the present scope of work at the National Gas Turbine Establishment, but work was now proceeding, in conjunction with the Royal Aircraft Establishment, to examine both ram and pulse jet applications in a general way, although that study was as yet incomplete

He had also deliberately avoided the question of engine-plus-fuel weight Having specified hover and cruise endurance, one would then have to estimate the actual power required for hovering and cruising He had said at the end of the lecture that the subject was controversial, and without specialised helicopter knowledge he had no idea of these actual powers, and had given generalised cruise curves down to 50 or 60 per cent of hovering power He had heard cruise estimates varying from 50 to 80 per cent hovering power, and he preferred others to make their own calculations of engine-plus-fuel weight from the graphs presented Even engine weight was, of course, a function of estimated hover power required, but might not vary as widely as the fuel consumption

Referring to the comparison between free and coupled turbines, he noted that two of the speakers had offered opposite views on the matter One had said that coupled turbines were possibly the better, whereas another had said that the coupled turbine surely could not be applied because it could not accommodate wide changes of rotor r p m

Once again, he must refer back to helicopter experts , if it were stated that the engine must accommodate a rapid, large fall in rotor r p m without loss in power, then the coupled turbine would not be suitable , the free turbine should, however, be capable of meeting these conditions This was the main reason for omitting the coupled turbine, which had not been lightly dismissed It gained little in thermodynamic efficiency over the free-power turbine, for the only difference would be a small loss in pressure between the two turbines of the latter, in order to put in supports That loss would be small, and the efficiency would not fall by more than 0 1% or so in the 19% efficiency of the gas turbine

Calculation of pressure drop along the tubes of ducted schemes had been done by assuming a certain number of tubes of fixed diameter ratios, which gave a hydraulic mean depth A friction coefficient of 0 005 had been taken, and an American paper used which showed how to take account of the centrifugal compression, the frictional pressure drop, and the momentum change along the blade Applying this method to a given total head pressure at the hub, a total pressure had been derived at the tip, and hence the expansion ratio

He had said that the combustion system loss at the tip was six dynamic heads This might seem rather low in comparison with the main engine combustion system, but six was a practical figure and it would not be possible to go much lower

It was true that higher tip speeds increased propulsive efficiency This efficiency, he thought, accounted in quite large measure for the difference between the shaft drive, which could be assumed to have an 80% efficiency (20% power loss in gearing) —and the jet drives, for which, with the rotor tip Mach numbers used in this paper, propulsive efficiency was only of the order of 50% or lower With increasing tip speed, then, the ducted gas and ducted air schemes might show to better advantage, but within the scope of the investigation, which was limited to a rotor tip Mach number of 0 6, he thought that his conclusions were true

He was not surprised that Mr TUSTANOWSKI had said that his cross-over point did not agree with that in the paper, for the conclusions reached there were based on Royal Aircraft Establishment cruise powers, and he knew that Mr Tustanowski believed these figures unduly pessimistic , hence the difference in cross-over point of the two schemes

Written Answers to other points raised during the discussion

Mr Bell It is certainly most important that there be a two-position nozzle for the ducted schemes If one engine should fail in the twin-engined ducted gas scheme, for instance, and there is no provision for an immediate closure of the final nozzles to half of their design area, then, if we assume that the other engine continues to work at the same r p m , the operating point would slide down the appropriate $\frac{N}{\sqrt{T}}$ line on the main compressor characteristic , turbine inlet temperature and power would fall, with the auxiliary compressor running at low pressure ratio and efficiency There would therefore be considerably less power available than that normally obtained from one engine, although the remaining good engine would not burn out

Mr Tustanowski It is agreed that, in order to give the final comparison between schemes as a conclusion to the lecture, a disc loading of 6 lb /sq ft was used by the R A E , in order to derive cruise and hover powers The effect of disc loading and blade drag coefficient has still to be investigated, and this may be pursued in the near future , presumably a range of " break-even " points will then be determined which should include among them the 2 hrs mentioned by this speaker

Mr Shapiro It does not seem to be a valid criticism to disagree with the use of an optimum gas velocity through the blades of ducted schemes, for these optima are not obtained thermodynamically—there would then be no optimum, but one would merely use a very low velocity in order to minimise the pressure drop These optima were obtained by consideration of several gas velocities and the appropriate specific rotor powers on the one hand, and the power required by the helicopter for hovering, using blade areas consistent with the chosen gas velocities, on the other hand An optimum was thus found for the ducted gas scheme, but it was admitted during the lecture that a simplifying assumption made thereafter for the ducted air schemes did not give optimum values for the calculations on them

It is admitted that possibilities of unorthodox combinations might show advantages over the schemes discussed , the title of the lecture, however, is " Some Applications, etc ", and does not pretend to be a comprehensive survey of all possible gas turbine schemes

With tip-mounted engines, gyroscopic forces are present, naturally, whether the engines are mounted radially or tangentially, and the centrifugal forces are the ones which determine loads on the bearings , in addition, however—which was my real point—with an engine mounted across the blade, the gyroscopic forces tend to bend compressor and turbine disc across a diameter such as to take up axial clearances , extremely heavy designs would have to be put forward to overcome this

The point raised that specific power, in the ducted air scheme, should rise continuously with increased pressure ratio shows, I regret, that the introductory remarks based on Fig 1 were not appreciated by the speaker The turbine takes out sufficient energy from its incoming gases to drive its own compressor and then, for a fixed turbine inlet temperature, main compressor pressure ratio and exhaust system, there remains a fixed quantity of energy for the auxiliary compressor to absorb The auxiliary compressor may, then, either pass a large mass of air at a low pressure, or a small mass of air at a high pressure, and it is shown that a higher specific rotor horse power arises for the lower pressure ratio Perhaps some actual figures may be appropriate at this point We can easily show that, for a main compressor pressure ratio of 7/1 with a turbine inlet temperature of 1050°K , and conventional exhaust system losses, then per lb of air mass flow there are 25 92 CHU/lb of work available for use by an auxiliary compressor The following figures apply

Auxiliary compressor pressure ratio	2	4
,, ,, temperature rise, °C	74.5	167.3
,, ,, work, per lb. of aux. air, CHU	17.89	40.35
x = aux. mass flow/main mass flow	1.449	0.642
Total pressure at entry to blades, p.s.i.	26.54	53.09
Flow Mach No. along the blade	0.1	0.1
Total pressure at entry to tip nozzle, p.s.i.	29.79	58.05
Air outlet velocity, f.p.s. (V)	1167	1815
Rotor tip speed, 0.5 Mach No., f.p.s. (u)	558	558
V — u	609	1257
Thrust/lb. air flow through nozzle	20.72*	39.05
Thrust/lb. air flow through main engine	30.06	25.12
Rotor Horsepower	30.50	25.43

* Includes a small pressure thrust.

Probably the speaker was thinking only of the thrust per lb. of air flowing through the nozzle, forgetting that the definition of rotor horse-power used in this paper is based on airflow through the main engine.

The point concerning the fall-off in power with increased ambient temperature is a very true one, but if all the schemes, for hover and cruise, had to be compared for a series of inlet temperatures and altitudes, then the work would be increased many times and the correspondingly large number of graphs would certainly confuse readers. There are a few remarks of general interest on this point, however. The shaft drive, it is estimated, loses 15% power for an ambient temperature rise of 30°C. Conventional methods of power boosting, such as water/methanol injection, would be unsuitable if hovering conditions were maintained, for, say, an hour, as the extra fuel consumption would be prohibitive; overspeeding is equally impossible since the turbine inlet temperature would be raised to an unacceptable value. Perhaps it would be possible to design a helicopter 10% overpowered at 288°K ambient temperature, and make up the extra 5% power required at 318°K by water/methanol injection, say; for, as fuel is used up, so less power is required for hovering, and the engine moves towards cruise rating as time goes by. The ducted gas scheme seems to have a distinct advantage here, for provision could be made for burning extra fuel in tip combustion chambers which would be inoperative at temperate conditions, and only a small quantity of extra fuel would need to be injected to restore full power under tropical conditions. Equally, of course, the simple ducted air scheme would be dismissed altogether, and burning at the tips would be employed in all cases—higher temperatures being necessary for those schemes already using burning at the rotor tips. As Mr. Shapiro says, these considerations might alter the picture, but they would involve doing the entire study again in order to find optima for the various schemes—and one would have to check that these optima did not change with either ambient temperature or inlet pressure. At present, such an undertaking is out of the question.

Mr. Rowe: A point not brought out in the lecture, but mentioned during the discussion, is that all the shaft drive figures are given as power at the turbine shaft, *i.e.*, there is no gearing loss, etc., included in these figures. Again, the reader is left to insert his own estimated value for the transmission efficiency, although the tip drives, by virtue of the definition of rotor horsepower, take into account their propulsive efficiencies. The gearing and tail rotor power losses were taken into account, however, when assessing the power required for the 10,000 lb. A.U.W. example, and hence the engine weight also takes account of this. This loss must be remembered when making one's own calculations using the specific fuel consumption curves, however.

With regard to the question whether any of these schemes can give reasonable performance in the event of one engine in a twin-engined system failing, bearing in mind Mr. Bell's vital point of change of final nozzle area for the ducted schemes, then the point can only be resolved when helicopter designers have sufficient practical knowledge to state exactly what percentage of full-load power is required for given cruise conditions. If this percentage is less than 50, then one engine will enable the helicopter to cruise; indeed, with ducted schemes, some 60% full power is developed on one engine, due to lower duct pressure losses; but if, say, 70% is re-

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quired, then we must start examining the power boosting arrangements already mentioned

Mr Payne The difference in drag between ordinary rotor blades and duct-carrying blades was taken into account in assessing power requirements and consequently engine weight, and the controversial nature of this difference was mentioned in the few remarks made at the end of the lecture

With reference to the possibility of using ram jets at the rotor tips, while agreeing that the power output and specific fuel consumption for M = 2 are such that, combined with the low power plant weight, 4 hours might sound a reasonable " cross-over " endurance time, nevertheless I have no knowledge at all of the actual power required by a supersonic rotor , my colleagues at the R A E believe this to be high, and so a comparison of this scheme with the others must await correct data on the most important factor of actual power required

Mr Clarke The curve of Fig 4 shows that the compressor-turbine has a relatively small change in r p m with large changes in power, but the free power turbine should be capable of accepting fairly substantial changes in speed without large falls in power

As already mentioned in reply to Mr Rowe, for the ducted gas scheme (on which an actual calculation has been made), the loss of one engine means less than a 50% drop in power If one assumes that the failed engine could be cut out by means of a valve, then apart from slight losses due to sudden expansions where the exhaust passes from ducts designed to take single flow to those designed to take double flow, all the pressure losses in ducts are considerably reduced (losses varying as the square of the velocity) and an expansion ratio at the final nozzle results which actually gives some 60% of the power with 2 engines, without any over-heating of the remaining " good " engine

Dr Hislop It is regretted that the calculations cannot yet be extended to higher rotor tip Mach numbers because of pressure of other work, but it might be possible to submit them, as a written contribution, to the Association at a later date, although no promise of actual date can be given It is felt, however, that if helicopter designers wish to use hovering tip Mach numbers of up to 0 8, they must specify lower cruise tip Mach numbers associated with a given forward speed , for, with a forward speed of 100 knots, say, and cruising tip Mach number of 0 8 relative to the helicopter, the advancing blade would have a tip Mach number in excess of 0 9 which seems rather high to one as inexperienced in helicopter flight calculations as I am

The Chairman, in closing the meeting, recalled the now famous paper presented some time ago by Mr Fitzwilliams on the giant helicopter, with a scheme for turbo jets at the tips Many had said " Sapphires at the tips ? Rotor of 200 ft diameter ? Too Jules Verne-ish ! " At Farnborough this year, however, there was a certain small turbo-jet engine which looked not unpromising for such an application and it would not be at all surprising if engine builders were being asked seriously to consider the possibility of designing light turbo-jets for use at the tips of the blades

In Britain there was justifiable pride in their work on the gas turbine and its application to aircraft but, in spite of that, it was remarkable that as far as helicopters were concerned the only applications of the gas turbines had been in France and America There was, therefore, a definite challenge to the U K to get busy and see what could be produced in the way of a good flying helicopter with turbine engines

Finally, the Chairman said they were all greatly indebted to Mr Brown for giving such an excellent discourse on a subject of great topical importance The response from the audience had shown that it was very much appreciated Some hard things might have been said about the scope of the parameters, but Mr Brown could quite reasonably plead a little ignorance

He hoped that by the time the next National Gas Turbine Establishment representatives came to give a lecture they would know all about the applications of turbines in helicopters from practical experience in British aircraft

The vote of thanks to Mr Brown was carried unanimously with acclamation, and the proceedings then terminated