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

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

REFERENCES

1 R HAFNER " The Domain of the Helicopter ' Royal Aeronautical Society Lecture, 10th March, 1954
2 O L L FITZWILLIAMS " The Giant Helicopter " Lecture to The Helicopter Association of Great Britain 23rd November, 1951
3 A GRAHAM FORSYTH " Power Plants for Rotary Wing Aircraft " Lecture to Fourth Anglo-American Aeronautical Conference 16th September, 1951
4 R H MILLER " Some Factors Affecting Helicopter Design and Future Operations " Lecture to Fourth Anglo-American Aeronautical Conference 16th September, 1951
5 " Rotary Wing Power " *Flight* 12th March, 1954 pp 318—322
6 J BROWN " Some applications of Gas Turbine to Helicopter Propulsion Lecture to The Helicopter Association of Great Britain 15th October, 1954
7 D N MEYERS AND Z M CIOLKOSZ " Matching the Characteristics of Helicopters and Shaft-Turbines " *S A E Trans* Vol 62, 1954, p 437

Discussion

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

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

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

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

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

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

Some interesting conclusions had been reached in a recent American paper following an investigation into shaft gas turbines for helicopters The first of these was that the loss in maximum available horse power with reduced rotor speed might not be so drastic with fixed shaft engines as to rule out their use In fact, this need not necessarily happen if one assumed that when the revolutions per minute were reduced, the turbine inlet temperature could rise He thought that was a perfectly logical proposition, and in such a case the slope of the power curve might not be so vastly different between fixed and free turbine engines

It had also been suggested that the thrust response would be better in a fixed shaft engine if the engine were operated as a " constant speed engine " He was not, however, convinced that this was the right thing to do The Americans had also found that over-speed and over-heating problems are more severe for free turbine engines and that at least an over-speed governor on the free turbine engine was required

Although the characteristics of free power turbine engines were better, there was no need for instability with fixed shaft engines The Americans had investigated several axial types, and his own company had done the investigation for the Dart engine The result was the same there was really no instability Perhaps the Author would say a few words on these problems

Referring to the all-important aspect of flight safety, he thought it should not be difficult to provide safety in all flight conditions in the event of a single engine failure in a three-engined helicopter It was, of course, a little difficult to provide full safety in the case of a twin-engined helicopter, but here again a lot could be done to achieve, perhaps not the ideal, but a very considerable measure of success He was not fully convinced that a standby power unit was required

In the first place, for example, it would be possible to have a slightly over-size engine While it was not the best engine for cruise conditions, it should be remembered that the same problem arose with fixed wing aircraft As a rule, the over-size engine was needed not for cruising, but for take-off and initial climb

On the other hand, the life of the engine depended very largely on the ratio of cruise power/take-off power, and in twin-engined aircraft the ratio of cruising power to take-off power was less than in three- or four-engined aircraft , so that the engine life was, if anything, influenced favourably by this kind of factor The same thing would apply with helicopters Alternatively, there could be a temporary power boost of the engine by liquid injection or some other means

The water-methanol injection yielded handsome dividends on the centrifugal type engine On the Dart engine, an enormous power boost could be achieved by injecting a reasonable quantity of water-methanol It did not give quite the same effect on axial engines

Mr CHALLIER said that he did not favour the idea of mounting engines in a vertical position for the reasons given by the Author , and what he was about to say was more in the nature of a thought than established fact In examining the performance of helicopters with turbine engines, it was found that the optimum range speed was very high, probably higher than the maximum speed permissible due to retreating blade stall It was desirable to increase the speed of the helicopter for other considerations, and the best thing might well be to have an engine giving the maximum possible shaft power for no-speed conditions—*i e* , hovering and vertical rise—and to have a variable nozzle, or something of that nature, and get some jet thrust out for forward flight This might result in a better maximum speed and better range for the helicopter He felt that the speed of the helicopter was at present too low and must be increased if it was to be used for transport purposes

Analysis made on the Oryx and the Percival helicopters showed very clearly that duct losses must be reduced to the minimum, otherwise the system could not be efficient With a large duct, however, there could not be a very thin blade The solution adopted by Percivals of using a laminar aerofoil section was satisfactory up to a point but it meant that the surface finish must be of a high order and that during operation there must be reliance on laminar flow being maintained Pollution caused by dirt affected engines, as well as rotor blades Unless the methods of cleaning were very refined, the result might be a possible reduction in performance of the helicopter during operation

He understood that on the French S O 1221 Djinn helicopter the use of tip burning had been discontinued because of the difficulty of achieving an even flow of fuel at the rotor blade tips , had there been similar experience with the Fairey installation and was it possible to overcome this without affecting performanc ?

He agreed with the Author that only an approved unit with unrestricted flexibility could be successful in a helicopter It was, however, important that this unit was reliable in the first place As yet, the helicopter had not proved itself It was at least as important to have a reliable engine, backed by considerable operational experience, as to make the aircraft itself safe Such a unit should differ as little as possible from its application to fixed wing aircraft, so that the reliability obtained in the operation of fixed wing aircraft could be extended to use in helicopters

The unit might be an axial turbine engine or it might be a centrifugal type engine It might not be the best engine to start with, but it was more important to have an engine which was reliable than one which, while giving the best performance on paper, presented the operators with poorer overhaul life or delays in operation

The Author had shown how thoroughly he and his company had tackled the problem, but Mr CHALLIER hoped he could be permitted to say that such an engine already existed It had proved itself in aircraft It had very good surge characteristics, was less susceptible to dirt effects and responded extremely well to water-methanol boost It could be operated as a fixed shaft engine, and perhaps this was the way to introduce it initially and to develop a free turbine version later, since it was known that the free power turbine engine was better He felt that this might be the best way to introduce turbine engines into helicopter operation

The **Author** (in reply), said it might be neither within his power nor possible in the time available to answer every problem, but he would deal with one or two

His company were trying their best to exploit the three systems of mechanical drive, gas drive and air drive They were trying to be impartial and they hoped to be on the winner when it arrived Opinion at this stage was that each type had its own particular advantages, and it was too early for anyone to say that the ideal helicopter system had been found There were certainly problems, some of them peculiar to individual types, but in aviation solutions had often presented themselves when problems were tackled vigorously This was the way in which it was still necessary to face up to the work

As with all aircraft, the question of noise was a difficult one The gas drive might have certain advantages in this direction The fact that the velocity of the tip jet had to be moderate in order to get a good efficiency might represent a particular virtue of this type

He agreed with the claims made for the Dart engine by Mr CHALLIER, who had put a good case for the well-proved helicopter engine But when a programme such as a helicopter programme was undertaken, quite a lot depended upon making a good choice of size If at the outset one was obliged to start with an engine which did not, for example, fit in with the demands of the aircraft, in the long run the result would be an aircraft which was a misfit There was a certain amount of foresight in trying to develop new engines which would fit better into the expected helicopter market

The Author proceeded to show additional slides to illustrate the Napier rotor-test rig, which to some extent answered Mr Challier's point about the laminar flow section of the rotor blades (Fig 7)

The next slide was of the Gazelle unit being built in the shop prior to test, although it had since run

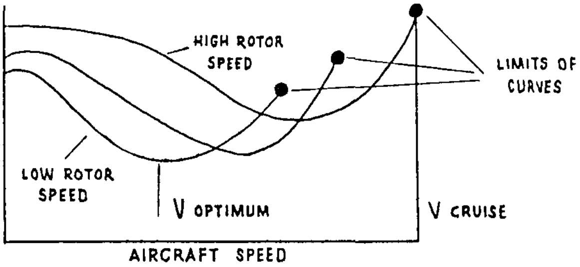
Admittedly, there was still an unresolved controversy as to the best form of turbine—whether it should be fixed or free—but he thought that the advantages came down rather heavily in favour of the free turbine After all, the maximum possible flexibility was needed between the rotor drive and the engine , and since the free turbine was fairly easy to design—it was, so to speak, a gift from Nature—and gave an infinitely variable gear between the main shaft and the turbine shaft It would thus appear to be the better form for the helicopter gas turbine

The **Chairman** suggested that the question of fixed *versus* free shaft could stand quite a lot of examination When the free turbine conception first came on the scene, there was a tendency by the free turbine protagonists to put the operating characteristics of the fixed turbine, as applied to rotors, in the worst possible light Yet, in spite of that, one of the first applications of the gas turbine to a helicopter was a fixed shaft turbine in the S 59 Even the largest helicopter now flying, the Piasecki H 16, was equipped with fixed shaft Allison turbines

In inviting the views of the aircraft designers, the Chairman called upon Mr HAFNER to contribute to the discussion

Mr R Hafner (*Bristol Aircraft Ltd —Member*) said that of all the gas turbine installations shown by the Lecturer, the one that interested him the most was that for shaft driven helicopters. Moreover, he would confine his observations to the multi-engined helicopter.

There was at first the question of whether a free or a fixed shaft turbine was wanted. The following graph showed the power required by a helicopter *versus* speed.



The power required increased generally with rotor speed, but was also a function of aircraft speed. During hovering and at high forward speed, the power required was high and the minimum was at V optimum. There were also certain limitations to the power curves which were imposed by the stalling of the retreating blade and other factors. At a very low rotor speed it was not possible to fly fast and as the rotor r.p.m. was increased, so also the forward speed could be increased.

In looking ahead to helicopters which could fly fast, a rotor condition was envisaged which involved a fairly high rotor speed and this constituted normal cruising condition.

Another condition arose after an en-route engine failure. Here it was necessary to look for the minimum power required. This could be seen from the graph to be at minimum rotor speed and at V optimum.

A third critical condition arose after an engine failure during take-off or hovering. Here also minimum power was desired and achieved at minimum rotor speed. During cruising all engines would normally be used, so that the power required from any one engine was probably low and the corresponding engine speed was low also. However, after an engine failure it would be necessary to obtain the maximum available power from the remaining working engine(s) and this could only be achieved by running fast.

There was thus on the one hand the cruising condition characterised by *high* rotor speed and *low* engine speed and on the other the emergency conditions with *low* rotor speed and *high* engine speed. A variable gear ratio between rotor and engine was, therefore, needed and the free gas turbine with its built in torque convertor offered the best solution.

Mr. Hafner then considered the question of engine rating. He defined four significant ratings:—

(*a*) The "cruising" rating. Here low fuel consumption was important.

(*b*) The "maximum continuous" rating. This represented the highest power that was required with all engines operative. It was mainly used during vertical climb.

(*c*) The "one hour" rating. This applied to en-route flight with one engine inoperative. The power level should be such that moderate rate of climb was possible at V optimum. This power should be available for one hour or so in order to enable the pilot to reach his destination or alternatively select another suitable landing place.

(*d*) The "2½ minute" rating. This applied to hovering or vertical flight with one engine inoperative. The need for this power would arise in the event of an engine failure at take-off or prior to landing, in order to cushion the landing or alternatively to accelerate to reach V optimum (if diversion is desired). For these purposes only brief bursts of power were needed, which would certainly not exceed a duration of 2½ minutes. For this rating it was important that the power was available at low rotor speed. It was, therefore, necessary to provide sufficient blade area in the power turbine so that it would not stall at this extreme combination of high torque and low speed.

His next comments were on the control of the engine As distinct from fixed wing aircraft, helicopter engines were controlled by a linkage which was connected to the flying control Thus the engine was continually worried by changes in power demand, and in particular during the landing manoeuvre there were violent changes in power It was essential that the engines responded promptly and reliably to these demands

A second point on control for multi-engined helicopters was associated with the emergency after an engine failure during take-off or landing in a restricted area In such an event every second was precious and it was important that the emergency power on the remaining engine(s) came into operation immediately The reaction of the pilot in this case may be too slow and an automatic device was therefore required

As regards general design, the helicopter designers requirement was a *compact* power plant The helicopter differed here somewhat from the fixed wing aircraft In the latter it was generally convenient to arrange for the cooling of the oil by means of an oil cooler, situated external to the engine, so that ram air could be used with advantage for cooling purposes That was not the case with the helicopter which required independent means of cooling It could best be done by the engine itself

The gas turbine—as distinct from the piston engine—did not consume much oil, thus there was—especially for short range aircraft—no need for an oil tank The oil circulation could best be carried in the engine sump

The most simple heat exchanger for oil cooling of helicopter engines was probably one that used an air bleed off the first stage of the compressor

Mr Hafner's final plea was for a simple installation As a helicopter designer he did not want to know anything about the domestic engine problem of the cooling of its oil All he wanted to know was the location of the filler cap for the engine oil and perhaps an oil level and temperature gauge If this had not yet been done, what was the reason ?

The **Author** (in reply) said they must thank Mr Hafner for his very able explanation of why the ordinary turbine engine simply would not suffice in a helicopter ! He had also made the great point that the engine must be fully controllable This was one of the points on which he himself felt very strongly His company was in fact working on the three forms of turbine to try to get the whole thing thoroughly sorted out

On a twin rotor helicopter, when switching of the engine had to be done almost instantaneously, there would probably be need of an electrical control worked back from the torque meter of the engine This gave an indication of the lines along which his company was thinking

Mr Hafner's point that oil cooling was a problem in the mechanical drive helicopter allowed the Author to score a point for the Percival Oryx system In the gas drive, there was no oil cooling problem , there was no gear and, therefore, no cooling The cooling of any part of the power plant in a helicopter engine, as one knew from experience with piston engines, was still quite a problem

The Author said he thought proper provision had been made for compactness in the case of the Gazelle It would be fitted into a cowling or jacket forming an air skin and the oil cooling and ventilating system had to be well thought out One of the major accessories of the engine would, in fact, be the cooling fan, and this was driven off the engine auxiliary shaft

The **Chairman** said that in all fairness Mr Challier should have the opportunity to reply to Mr Hafner

In reply to the point raised by Mr Challier about the tip burning, the Chairman said that without committing himself too far, he could say " Fairey's are getting on very well, thank you We intend sticking to tip burning "

Mr Challier said he had perhaps not made his opening remarks sufficiently clear If a fixed shaft engine was operated as a constant speed engine, then the thrust response was much better than a free power turbine could be, because there was no question of accelerating when the load on the engine was changed

He did not disagree with the qualitative conclusions arrived at by Mr Hafner , it was the quantitative gains possible by reducing the rotor r p m in hovering that required accurate assessment The Americans had concluded that the gains were not overwhelming with a free power turbine as compared with a constant speed fixed shaft engine He believed the margin would be even smaller if turbine inlet temparatures were permitted to go up with decreasing r p m

Mr R M Cracknell (*B E A Engineering Base*), said he would like to hear more of the Author's opinion on engine overhaul life, taking into account experience with piston engines Secondly, what his views were concerning operating problems with a gas turbine engine operating for most of its life at relatively low altitude , and thirdly, did he feel that there were any peculiar problems associated with the design of fuel systems for helicopters , the Author had discussed the gas turbine power plant but operational experience had shown that there were quite a lot of problems associated with gas turbine fuel systems It would be interesting to hear the Author's views about this on helicopters

Mr Cracknell said that he agreed wholeheartedly with Mr HAFNER'S comments on oil system design In fact, he would not confine his remarks to the helicopter in saying that he would like to see oil systems always contained completely within the engine It was already partly done in this way on some piston engine installations An operator would always prefer to keep the oil system as a complete part of the power unit—rather than have it draped round the aeroplane He would, however, like to go a stage further and always have it confined to the engine

His last question to the Author concerned engine cooling It would seem that on a helicopter installation there must be a far greater problem in keeping the engines cool than was the case with fixed wing aircraft

The **Author** (in reply), said that when the question of overhaul life was considered, he thought most of the engine firms would now agree that there was nothing to beat the gas turbine In service, the gas turbines had all achieved running periods far greater than piston engines of comparable development It was, in fact, quite common to look forward to 1,000 hours of life

In the helicopter there was, perhaps, the special difficulty that the power plants had to be very compact In certain installations there might be difficulty in servicing, and the units themselves would probably have to come out of the machine in ways which today were not conventional He felt, however, that odd difficulties of this nature would be overcome as they were encountered He could see no great difficulty in getting a good overhaul life In fact, this went with the name of the gas turbine

The Author said he did not understand the reason for Mr CRACKNELL'S query on the behaviour of the gas turbine at low altitude He knew, of course, that the thermodynamics of the engine required a nice high pressure ratio, and to some extent with the more usual form of gas turbine—the jet engine—this was augmented at altitude Although there would not be this advantage, the gas turbine in other forms than for aircraft was, or could be, highly successful under low altitude operation Although he did not know what Mr Cracknell had in mind, he did not think there was any special point in regard to operation at low altitude

While he could not give the full answer on fuel systems, he saw no reason why the problem should not be easier There was no forward speed or violent manoeuvre to worry about, and there was only a fairly low altitude band to be considered The fuel systems should not pose any special problems that had not been, or could not be, well foreseen

One could well imagine that in the early days the oil consumption changed from type test to type test, but usually, he would agree, one of the advantages of the gas turbine was its very low oil consumption The fact that consumption was so low compared with the piston engine enabled use to be made of the expensive synthetic oils Some arrangement had to be made whereby the oil was not wasted at every engine change if engine changes were rather frequent in the initial stages, but this should present no great difficulty

Similarly with the engine cooling With the helicopter engine all cooling would cost more, because there was not the ram to do it Any system of cooling would mean more waste of power, which in turn meant the equivalent of drag, or more power

In the case of the Gazelle, for a mechanical drive the cooling was a pressing need, but it was fully catered for The engine bay had to be ventilated, and the oil cooler had to be given the necessary air flow This called for quite a bit of power but it was one of the things that were designed for in the engine It may be in some case that the requirements would become excessive or awkward later on or in service, but this might be said to be a fault of the design in the early stages

He did not think there was any great difficulty in the engine cooling provided the manufacturers faced up to the requirements at the beginning

Mr J S Shapiro (*Consulting Engineer*) (*Founder Member*), recalled an experience which made him feel that one should sometimes be a little old-fashioned When the company with which he was working—the Cierva Autogiro Company—was investigating the Air Horse successor with twin engines, he was rather struck by the fact that the air cooler requirements of the " Dart," as it then was, demanded a fan of almost exactly the same performance as that used to cool the radiator of the " Merlin " engine That experience had gone as far as comparing the requirements of an oil cooler as given by Rolls-Royce with the actually designed and operated radiator fan on a " Merlin " installation

The cooling in a helicopter was more difficult mechanically but almost all ram cooling was wasteful, not because it must be so, but because it was difficult and expensive in weight to design it for efficient operation

That was why the near-laboratory problem of cooling the " Merlin "—of designing a radiator and a fan which were exactly right—produced the very efficient cooling installation compared with the turbine oil cooler intended for ram cooling Although the actual cooling performance was vastly different, the same fan performance was demanded

Having said that, he added that the piston engine must not be abandoned too lightly or too easily There was always a tendency to compare an existing installation with something which one imagined would come in the future As the future was approached, the problems could be seen

The lecture given by Mr Russell, of the Bristol Aircraft Company, made an important point in considering the future of the propeller turbine as against the turbo-jet aircraft As techniques advanced, the main gain which it was hoped to achieve was that of increasing blade temperature because of better materials In fixed wing aircraft, an increase in blade temperature would favour the turbo-prop aircraft Therefore, as time went on, until completely new methods were discovered, the comparison between turbo-prop and turbo-jet would shift, certainly economically, in favour of the turbo-prop

Mr Shapiro wondered whether a similar investigation leading to a similarly simple conclusion had been made with helicopters The same conclusion would not necessarily apply, for in helicopters the whole difference between power plants was far more marginal

The **Author** expressed his agreement with Mr Shapiro that in the fixed wing aircraft, cooling by the use of slipstream would appear, to an engine designer like himself, relatively simple to arrange , but from an aerodynamic point of view it was usually very difficult to make it efficient If one tackled the problem of applying the cooling in the best way when there was no slipstream, it might be possible to make a better job of it

Various ways had been considered in which the Gazelle engine could be cooled with no ram available Various systems of fans and ejectors were explored, and it had been decided to use a cooling fan which was driven as one of the main engine accessories and carefully arranged so that the pressure losses were as small as possible This arrangement was considered to have a reasonable chance of being completely successful

The three turbine engine schemes dealt with in the paper comprised, in effect, two power turbine drives—the Rotodyne and the Gazelle—and the Oryx, which was a by-pass jet type He would not expect the two power turbine drives to have quite the same law of response to increased temperature as the by-pass jet , but definitely, for the Eland and the Gazelle, the increases in allowable blade temperature which would permit the designer to use a higher gas temperature would give great benefit, both in increased power and in improved fuel consumption With the Oryx, which used a by-pass cycle, he would expect also an improvement in both power and consumption, although not quite as marked as in the case of the pure turbine drives

In the Oryx system, because it was a gas drive, there was virtually no oil cooling Consequently, it had this rather important advantage

Mr Cracknell, recalling the remarks concerning the oil cooler for the " Dart " engine, said that B E A had experienced the opposite, and had even considered the advisability of fitting a cooler shutter to raise the oil temperature He was interested to hear that this was not considered to be important for helicopter installations

Although there might be a little more difficulty with helicopters, the problem regarding oil cooling on turbine engines was not so much a problem during flight but rather the ground running case, which, it seemed, would not differ greatly for helicopter installations

Among the fundamental advantages that everybody spoke about with the turbine engine were the small requirements for maintenance and the elimination of running-up checks before putting an aircraft into the air What one did not want to do, on any turbine engine installation, was to spend a long time waiting for oil temperatures and so on to creep up From what he had seen, he thought there was a tendency to over-cool turbine engines rather than to under-cool them

Mr Cracknell said he realised that the engine designer must study not simply one operator, but quite a range of operators and climatic conditions , however, he would still not have thought that the problem was one of high temperature

Mr Shapiro suggested that the two sets of remarks related to two aspects of the same problem Cooling by ram was not the ideal cooling condition Therefore, the cooler was over-size, and under certain conditions there would be over-cooling He had been speaking of a cooler designed for ram cooling under, presumably, the worst conditions—tropical atmosphere, climbing, and so on—as against a fan cooler designed for ideal, almost laboratory, conditions There was this paradox of a fan, which could remove something like ten times the amount of heat, which was just good enough to produce the amount of cooling which, according to the specification as it then was—it might have changed considerably meanwhile—was required for the oil cooler This meant that it was possible to get it just right, whereas when tied to ram cooling one was bound to a set of conditions which were not of one s choosing, and, therefore, there would be an over-size cooler

Mr Challier said he thought Mr CRACKNELL would agree that on the Dart unit, the complete oil system, including the cooler and the tank, was integral with the engine and was not spread over the aircraft

Mr Cracknell said he hoped he did not give that impression

Mr Challier said he was still not clear what point Mr SHAPIRO was making Obviously, with piston or turbine engine, it was possible to make either a ram or a fan cooler installation efficient One could have a fan for a piston or for a turbine engine

What was aimed at with the Dart was simplicity of installation A simple duct was made big enough for all atmospheric conditions and for aircraft speeds ranging from, say, 80 to 400 miles an hour There were losses in some flight conditions but they were not large enough to warrant a more efficient and more complicated cooling system

Mr D J Moore (*Hunting Percival Aircraft Ltd*) (*Member*), said he wished to take up one or two points on the Percival system which the Author and others had raised In the early stages of the design there were two main problems in connection with the ducting One was to design an efficient ducting, and the other was to design a ducting which could be manufactured The first problem led to the combined ducting with the two engines coupled together and the gases passing through a common ducting in the rotor system Later designs, on which work was at present being carried out, have shown that it is possible to separate the ducts from the two engines right through to the tip of the blades This not only did away with the Author s control gear on the engines, but it also did away with the necessity to have a tip nozzle control varying from the single to the twin-engined case

On the manufacturing aspect, Mr Moore said that due to the difficulty of manufacturing blades and ducting, they had initially used a simple duct shape This led to the laminar flow blade section, to which Mr CHALLIER had referred It was realised that there were limitations to that section for use on a helicopter at low altitudes over cities On the later design, due to modified ducting shapes and changes in ducting design and configuration, they had got away from the laminar flow blade section to a more normal section

Referring to noise, he said a rotor had been running for a considerable time on the test rig but it had not been possible to do absolute noise measurements This was largely because the noise could not be heard above the noise of Mr Challier's Derwent engine In general, however, it appeared to confirm the calculations that the tip jet noise was of about the same order as the aerodynamic noise of the rotor Therefore, there was not much point in trying to reduce it further

The **Author** (in reply) said Mr Moore had pointed out the difficulty of the common ducting system which needed the control gear used on the Oryx-P74 installation Its solution was likely to prove quite a good step forward in gas drive development

Mr Moore had pointed out that in the present system the two engines fed into the common duct, and, therefore, special provision was needed to guard against engine failure , whereas if the ducting system were in two parallel parts, one fed by each engine, those arrangements would not be needed if one engine failed

It must, however, be pointed out that the time would come when a twin-engine machine was not necessarily the best one from the performance point of view It would become a trifle more difficult to fit, say, three engines with separate ducts, which would mean a three-duct rotor, and more so when it was desired to have an even larger number of engines later on

There was, therefore, a good case for the development of a control for the single duct system, which was the one on which his company was at present going ahead

Mr R J Jupe (*Bristol Aircraft Limited*) (*Member*) said he would like to make two points in favour of the free turbine One was that the free turbine had within it a gas clutch This enabled the normal clutch to be done away with, and it emphasised still further the fact that the turbine was much lighter than the piston engine It should also be lighter than the fixed shaft turbine His second point was that a free turbine would be rather different for a helicopter than for a fixed wing aircraft

To meet the height of the cruise point shown on Mr Hafner's diagram, the engine would be designed to give the minimum fuel consumption Fuel could be thrown away at the hovering point on the curve, and with the engine running more slowly there would be a somewhat larger gas generator for the helicopter It would give much wider range of r p m than would normally be obtained from a free turbine

He was not sure whether the comparisons made by the Americans were for a free turbine designed specifically for a helicopter or for a fixed wing aircraft

Mr A W J Smith (*Air Registration Board*), suggested that there seemed to be two directly opposing views on the turbine engine between Mr Challier and the Author A possible compromise might be the two-spool engine, which had been shown to have very good acceleration characteristics, and the low pressure turbine stage could well be connected to the rotor system

One point which had not so far been mentioned was that under certain circumstances there could possibly be over-speeding, or running away of the free power turbine This had occurred in the past and it was understood that slots had been observed in the turbine shroudings of certain turbine engines ! If the fuel system was driven from the L P compressor and the H P compressor was allowed to be merely a further portion of the compressor system, there was a semi-automatic safeguard against violent over-speeding

Recalling the Author's suggestion that the overhaul life might rapidly be brought up to about 1,000 hours, Mr Smith pointed out that at least one turbine operator was already operating at 1,400 hours overhaul life On the other hand, the helicopter engine was likely to spend a lot of its time running under rather high powered conditions, which might well affect the overhaul life In addition, if it was mounted vertically, he had a suspicion that bearing problems might arise In the past, the development of the deep groove ball bearing had not always been straightforward The Americans, he understood, had already experienced some of these troubles with their vertical take-off fighters

Obviously, it was necessary to dispose the air intakes and the exhaust outlets at various positions around the engine Was there any great difficulty in arranging them so that as the helicopter entered or left the ground effect zone or changed its conditions of flight—different pitch angles, and so on—the hot gases did not recirculate into the intake, which, obviously, could seriously affect the power of the engine ?

These comments were made entirely as a private individual

The **Author** (in reply), agreed that the two-spool engine could be made a more efficient engine when the compressors were running correctly matched and delivering a high pressure ratio The whole question of two-spool *versus* single spool, which ran very much through the fixed wing aircraft field, was quite deep, and in the time available it was not possible to consider it at all thoroughly

The space requirement in the helicopter was important It was therefore most important that the engine should be as compact as possible, and it had not been found that the two-spooling was worth while

It was at one time thought that the vibration problem of the gas turbine driven system—*i e*, its rotor and its engine—might be partly solved by the use of the moment of inertia that it was possible to get from the two-spool, but generally the extra complication and bulk of the two-spool engine would rule out its use for helicopter application The weight was also another limiting factor

Referring to the difficulty of maintaining a good overhaul life, he said that an important point regarding the vertical position was that although there were extra axial loads on the engine due to its weight, the axial loads were very small in comparison with the air forces normally encountered, although the loadings were affected by G in a different manner The loadings in the axial sense were not greatly different from those of a horizontal turbine engine

It was true that the engine might have to stay put for a long time on its end, and the old trouble of the " Brinelling " of the bearings might have a certain significance, but he did not think that with the knowledge now available on bearings it would constitute a problem

He agreed that if the hot air from the exhaust got into the air intake in any appreciable proportion, it might upset the stability of the engine The engine could not be allowed to gulp in exhaust gases at a temperature of, say, 200 or 300° C above atmospheric temperature, for there would be trouble with the compressor Some special arrangement must therefore be made to ensure that the engine did not recirculate its own air This could only be done finally, he imagined, when the helicopter was about ready to fly It would be possible to form an idea of where not to put the intakes once it was appreciated that there must not be recirculation

Mr E A Voss (*Bristol Aircraft Ltd*) (*Member*), said he wished to take to task the earlier speaker who suggested that helicopters were not safe The majority of accidents with helicopters had been caused by the power plants Five out of ten were the result of power losses, three out of ten were caused through over-pitching, by pilot-error, and the remaining two out of ten were attributable to what he called " pure helicopter " reasons—*i e*, mal-assembly or malfunctioning He would say that if comparisons were made the helicopter would be found to be just as reliable as the single engine fixed wing aircraft

If there was a turbine in the helicopter, he pleaded, " let us have it dependable "

Mr C Faulkner (*Saunders-Roe Ltd*) (*Associate Member*), said that there were three points which he wished to discuss

The first concerned the vertical mounting of gas turbines in transmission-drive helicopters He realised that bevel gearing was not desirable in itself, but there were nevertheless, stong arguments in favour of horizontal engine mounting arrangements, particularly for large multi-engined machines He favoured layouts involving the segregation of the power plants and the fuselage By mounting the engines in external nacelles or " pods " adjacent to the main rotor gearbox(es), intake and exhaust design was simplified and cooling and fire protection problems were eased Routine maintenance was facilitated and rapid engine changes (both maintenance and design-wise) were possible

He was surprised that the Author should so easily reject the twin-spool arrangement The Rolls-Royce R B 109 (" Tyne ") was probably the most outstanding contemporary engine from the viewpoints of specific weight and fuel consumption These were two things that mattered

Conventional gas turbines lost a lot of power in the tropics, much more than the piston engines which were already severely limiting helicopter performance in adverse climatic/altitude conditions Was there not a case for derating gas turbines in the Bristol B E 25 sense of the word, where I C A N power was maintained in tropical conditions ? i e , The turbine is designed thermodynamically to deliver full power in the tropics, but is limited structurally/mechanically to this same power in more favourable climates

The **Author** (in reply), said Mr FAULKNER had raised two very good points, to which it was not easy to give a complete answer With vertical mounting, the overriding consideration was the bevelled gearing He would not like to put up a bevelled gearing of such high power as, say, 1,500-1,600 h p at the speeds and weight limitations to be met in aircraft He did not think anyone had got anywhere near that stage The nearest, he thought, was the Double Vee Allison engine which appeared at the time of the last war, with a great, long shaft which tapped off four propellers through bevelled gears, but it never got into aircraft use No designer was likely to want to put up a bevelled gear to take the full engine power

The drop in performance in the tropics was aided or abetted to some extent by the fact that the helicopter itself needed almost the same power in the tropics, whereas it was known that the engine would lose 15 per cent or more of its power This could to some extent be overcome by the use of power boosting, like water methanol injection, and by avoiding carrying the heaviest load on the worst day

Mr J Wotton (*Hunting Percival Aircraft Ltd*) (*Member*), who referred to starting and engine acceleration, said that on reading the Paper he gained the impression that it was claimed that the turbine engine could be started from rest and be brought to full power in three to four seconds If this was true, there must be something quite new "just round the corner," for he had been under the impression that the best starting system in use at the moment was the Propyl-Nitrate starter, which would bring an engine from rest to self-sustaining speed in three to four seconds, but that a further 10 or 11 seconds was required to bring the engine to full power

In view of the fact that turbines needed an enormous amount of power put into the compressor by the main unit to overcome the inertia of the moving parts, it seemed unlikely that acceleration could be obtained in a very short time, and certainly not comparable with the piston engine as it was now known

The piston engine, for instance, when geared to the rotor, could be running at its cruising r p m on very small throttle, and it could be brought to full power almost instantaneously, simply because the power of the engine did not depend on rotational speed The turbine, however, did depend on its rotational speed for power The fact that this was so meant that a new technique must be accepted in handling such a machine

Why, for instance, should the operating conditions under which the pilot handled his machine near the ground not be adapted to the characteristics of the turbine, as were the vital actions of a pilot handling a fixed wing machine ? A few years ago it was thought that the handling of a jet engined aircraft was something only for the very experienced pilot The past few months had shown that this was not the case, and pilots were going straight on to jet aircraft without handling a piston engine type They were handling jet engines although the technique was quite different Just as serious consequences might arise if the pilot did not follow the correct procedure, but this was now accepted Pilots were passing out in at least as good time as with piston engines The helicopter pilot would have to learn his job anew to some extent when turbo engines arrived

Mr Wotton said that he was horrified at the prospect of automaticity and the suggestion that turbines in the future, if used in helicopters, must essentially be accompanied by all kinds of gadgets to work in split-second time, or else all would be lost This was a dangerous trend, because automatic devices were safe only when protected by further automatic devices and when the requirements were analysed they were always covered with an overriding manual system

As an analogy, he cited a clock which not only told the time but showed the phases of the moon and the days of the month It was more satisfactory and economic to look at one s watch, to look out of the window, or to glance at a calendar

The **Author** (in reply), said that the acceleration of a helicopter gas turbine was one of the final products of the designer, who struggled hard to get his engine to the starting point and then continued to struggle to get it to accelerate correctly Taking it generally, with not too much complication or nursing, from start to full power should occupy something like 15 seconds Probably it could be quite a bit less with more refinement in the control of the starting cycle A great deal could be done by development of the control of the engine

It was not correct to use the word "gadgets" The control devices must be considered as part of the gas turbine The very fact that, as Mr HAFNER had pointed out, the helicopter pilot may need to call on his engine so very quickly to save the day, made rapid changes rather vital and the only was to achieve this was by an automatic arrangement

It was because of the way that the power gas turbine had developed with its torque meter, and the sensing that the torque meter could give when the power was not what it ought to be on the engine, that automatic power controls had become possible, and it was one of the probable lines of development of the future

The **Chairman** said that one of the alleged drawbacks of the fixed shaft turbine which had been little mentioned was the question of its alleged instability because of the ill-matching of its characteristics with that of the rotor when considered against a variation of r p m To enlarge, if because of a demand for power from the pilot the rotor, and hence the turbine, slowed down with the turbine operating near its designed optimum, the rotor would demand more power than the turbine could give Unless instant correcting action was taken the turbine might stall This was a strong theoretical objection to the fixed shaft turbine, yet as he had mentioned earlier the S 59 and the H 16 had apparently been successful with such turbines Some further thought should be given to this control problem

The practical ground had been covered very well, and in addition to presenting his excellent Paper, the Author had done a very good service in meeting the questions in the way he had done

The more futuristic applications, however, had not been ventilated Had Mr FITZWILLIAMS been able to attend, he might again have put forward the point about fitting tip jet units at the tips of the blades This was a gas turbine installation problem *par excellence !*

The vote of thanks to Dr MORLEY was carried with acclamation

WRITTEN CONTRIBUTION

Received from Capt A G Forsyth (*Fairey Aviation Co Ltd*) (*Member*)

The Author has given us a splendid description of the Oryx and Eland installations, and also his views covering the change over from piston engines to turbines

The piston engine has virtues which we have not been able to take full advantage of , in fact the progress of helicopters in this country has been held up to a great extent by the lack of suitable engines Even today we have only two engines which can claim to be specially designed for helicopter use

It is unfortunate that at this stage we have to consider changing over to gas turbines before we have fully explored installations using ground boosted engines fitted with two-stage superchargers in conjunction with single or two speed reduction gears in the rotor system, as by using suitable combinations to suit the aircraft requirements, the " take off, ' rate of climb and performance at altitude would be vastly improved

Dr Morley has described three engines which have been specially designed to suit specific systems

i e , The Oryx for Percival ,
The modified Eland for Fairey Rotodyne ,
The Gazelle for Bristol 173 ,

and cannot be regarded as potential universal engines What we must have is a fully type tested engine, so arranged that any form of reduction gear, compressor, etc , can be added to it to suit any installation, as this is the only way we will be able to keep the price down

As the gas turbine has come to stay and as it is most unlikely that we can afford to develop the piston engine further we must take into consideration what could have been done with it, and ensure that the new gas turbine goes one better

In the past is has been difficult to get the engine firms interested in helicopter engines due to the limited field As there is now a good outlet for helicopters the time is opportune to put forward proposals to cover the building of turbines suitable for helicopter installations covering various roles, standardised to suit any type of machine by interchanging assemblies

What we must avoid is to produce special engines, as these with their limited application are most expensive to develop and type test, etc

I should like to suggest that the ideal engine should be designed suitable for installation in a streamlined nacelle The standard assembly to consist of

(*a*) Compressor , (*b*) Combustion Chamber , (*c*) Turbine , (*d*) A free turbine mounted on a shaft running through the unit, to enable a drive to be picked up at either end , and (*e*) Ancillaries to be mounted round the compressor casing driven from the compressor shaft

This arrangement would allow the reduction gear, compressors, etc , to be mounted at either end of the standard unit to suit any system

The Eland as converted to suit the Rotodyne is an example of how it is possible to modify a standard turbo propeller engine to drive an auxiliary compressor from the rear end by bifurcating the jet pipes to allow the turbine shaft to be extended to drive the compressor by means of a fluid coupling The Blackburn variations of the Turbomeca engines show what can be done by producing a standard compressor, turbine combination and coupling the various requirements by adding suitable units to the standard power pack

Further points to consider are

(*A*) Reduce fuel comsumption
(*B*) Reduce first cost of unit
(*C*) Noise level of jet
(*D*) Dealing with high jet temperature in an enclosed space

(*E*) Eliminating the fire risk when lighted fuel is ejected from the jet pipe (*C*), (*D*), (*E*) indicate that where possible the turbines should be kept outside the fuselage, unless elaborate precautions are taken to install them inside a sound and fire proof casing

(*A*) and (*B*) will be reduced by development and increased production The Gazelle engine being mounted vertically eliminates the need for a right-angle drive, and reduces drag owing to being installed in the fuselage It is thought that difficulty may be experienced in overcoming (*C*), (*D*), (*E*) due to the jet pipes, gearboxes and head controls being adjacent to each other in a confined space This engine must be considered as a special one and a very good one at that for installation in a twin rotor aircraft with both engines carried inside the fuselage, and could be conceivably used in a single engine, single rotor machine As most new aircraft will have twin engines it is thought it will have a wider application mounted horizontally with a modified air inlet eliminating the need for a plenum chamber

Handed engines should be avoided as in service thay are a continual source of trouble You always have available the one you don't want In the case of the Gazelle an additional gearbox has to be fitted above the engine to complete the reduction between the turbine and the rotor The reversal should be made in this box, as the addition of one extra gear and two bearings in one of the boxes will avoid the manufacture of reversed rotors, stators, etc , and will eliminate an extra type test

These boxes should be made and tested with the engine

The orthodox engine appears to lend itself for most installations It can be mounted below the head as shown for Percival, for either mechanical or jet driven rotors, mounted on the top of twin rotor machines or for the single rotor, underneath and outside the fuselage with a sloping shaft going up to the head, provided a drive is available at each end of the engine Mention is made of turning the corner on gearing There is no need for this as by using high speed ground bevels the corner can be turned at an early stage of reduction The turbine eases the clutching in of the rotor provided the engine is fitted with a suitable control system on the lines described by the author In the piston engine installation the clutch is generally of the single plate type, centrifugally or manually operated running at engine speed, whereas due to the high speed of the turbine any stage in the reduction gear can be chosen to install the clutch, thereby enabling a light clutch to be used without any increase in gear weight The high speed of the clutch makes it possible to consider fluid, or torque convertors, as alternatives to the plate clutch

The free turbine appears to have advantages over any type of clutch and provided it can be controlled to suit the rotor variations in speed and power, should become universal

As an interim measure pending the development of the free turbine and its controls, the fluid clutch warrants serious consideration

I trust Dr Morley will forgive my remarks concerning the congestion at the top end of the Gazelle They are intended to be constructive and refer to installations where the roof is approximately 6 ft 6 in high with the forward head kept as low as possible on top of the fuselage If on the other hand there is room to introduce a short shaft between the Napier box and the aircraft final stage of reduction, there will be no congestion

Dr Morley's written reply to Captain Forsyth's comments

The author thanks Capt Forsyth for his comments which, coming from one so experienced in helicopter problems, are particularly valuable

Capt Forsyth rightly states that the piston engine helicopter installation has had a comparatively short history which leads to the possible conclusion that the full potential of the piston engine-helicopter combination has not been realised Possible developments mentioned by Capt Forsyth are two stage supercharging and rotor systems with variable gear ratio The provision of a two speed gear in the rotor drive would certainly improve the performance of a piston-engined helicopter but the complication involved must be weighed against the simpler layout of the free turbine engined version having the same flexibility in rotor speed

The author would point out that the Gazelle has been designed especially to suit varied installational requirements and as such does have considerable potential application The engine can be mounted in any position from the horizontal to the vertical Contrary to Capt Forsyth's suggestion the major speed reduction should take place in the engine gear box, leaving the helicopter designers to undertake the design of the low speed train In this way the engine is actually made more adaptable , since the design of a high speed gear train, whether plain or including a bevel drive, to suit each installation, would be impractical It would seem that handed engines are desirable and that this provision can be made for little extra cost

The nacelle mounted engine has some attractive features but in most cases the drive layout is more complicated Concerning the noise problem, it is thought that the fuselage mounted engine will be quieter since the exhaust jet will discharge at the top of the cabin, whereas the exhaust jets of nacelle mounted engines will be nearer the passenger level and may therefore be noisier

The suggestion of a shaft running through the engine for power take-off at either end is impractical in an engine of small to medium power class, due to a disproportionate weight penalty

In conclusion, it is agreed that the free turbine is most suitable for universal application, eliminating as it does the need for a clutch or variable gear ratio