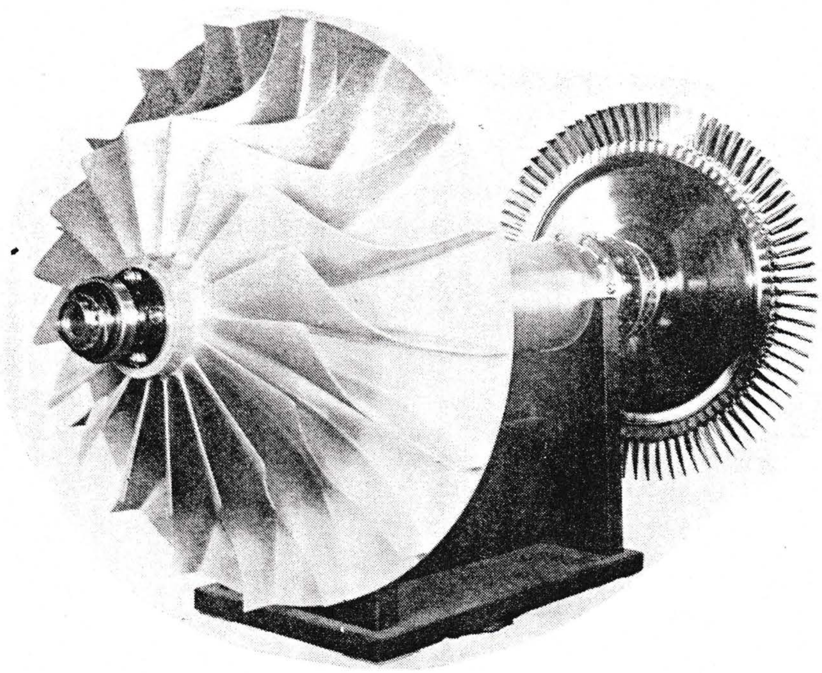

Centrifugal

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A single stage centrifugal compressor and turbine assembly.

With the age of jet propulsion now having secured a solid foothold in the world of aviation, more and more often we hear the use of such expressions as turbine, prop-jet, pounds of thrust, and so on. Just about as often as any of those terms are apt to be heard the words "Axial" and "Centrifugal." Between these two categories there is a sharp division, and in each division are the champions of one of the two types of compressors for gas turbines.

It is true that the designers of jet engines may know the differences between the two types of compressors, and the relative advantages and disadvantages of each, but how many other people in aviation do actually know what an Axial engine is? or what a Centrifugal engine is?

In the following paragraphs, which were supplied to *Aircraft and Airport* by Avro Canada, it is believed that the reader will be able to find the basic advantages and disadvantages of each type of compressor. Although the material has been written by Armstrong Siddeley Motors Ltd., of England, a company which has long been an exponent of the Axial flow turbine, it will be found that an honest comparison is made.

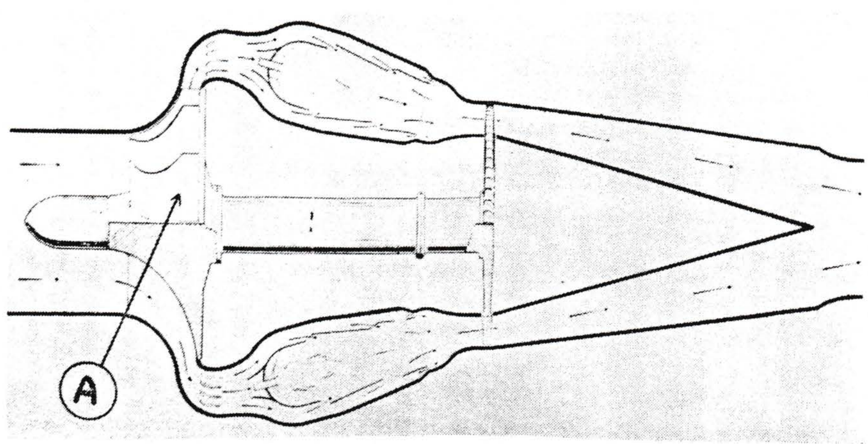
The relative merits of the Axial and Centrifugal compressors have been the subject of much argument during recent years. At one time some of the leading figures of the British engine industry came out strongly against the Axial type, but now there is a decided swing towards it, and with one exception British firms are developing gas turbines with Axial compressors. The Avro Chinook, Canada's contribution to jet design is incidentally an Axial type.

In order to present as complete a picture as possible, the engine should be considered as a whole. Any turbo-jet or propeller turbine engine can be considered to have the following broad characteristics:

(1) **Diameter**
(2) **Performance,** i.e., thrust and fuel consumption
(3) **Weight**
(4) **Reliability in Service** (including ease of de-icing)
(5) **Ease of Production**

Considerations

(1) Diameter—For a given thrust an Axial engine will always have a diameter, and consequently a frontal area, appreciably less than that of a Centrifugal. The corresponding reduction in drag is becoming more and more important as speeds increase. In fact, for the high speed bombers and fighters now being designed, the reduced frontal area of Axial engines is absolutely essential in order to obtain the desired performance.



This a rough cross sectional view of a typical centrifugal type engine. The arrow lettered A points to the compressor. The small arrows give some idea of the airflow through this type of engine. Compare proportions of this engine with that on opposite page.

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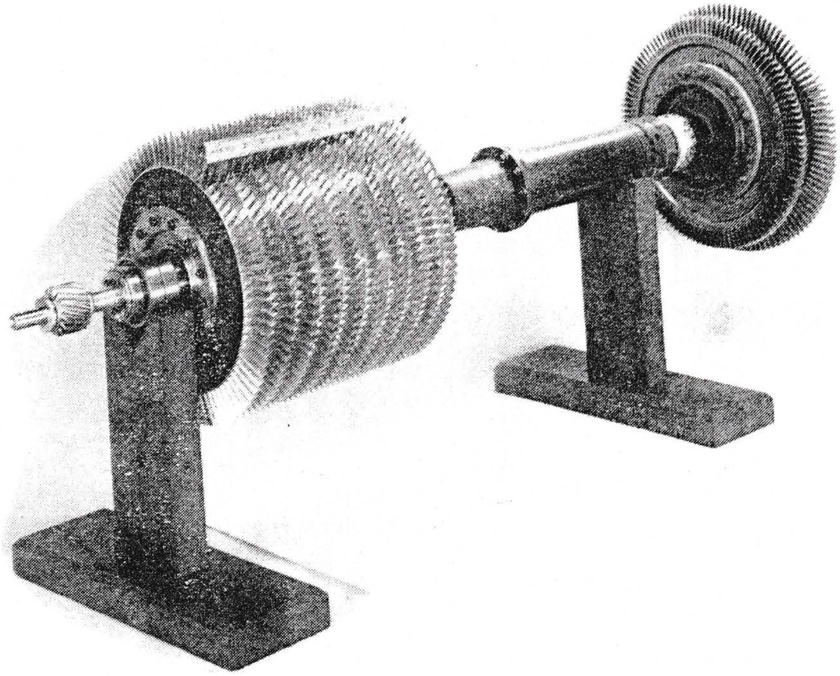
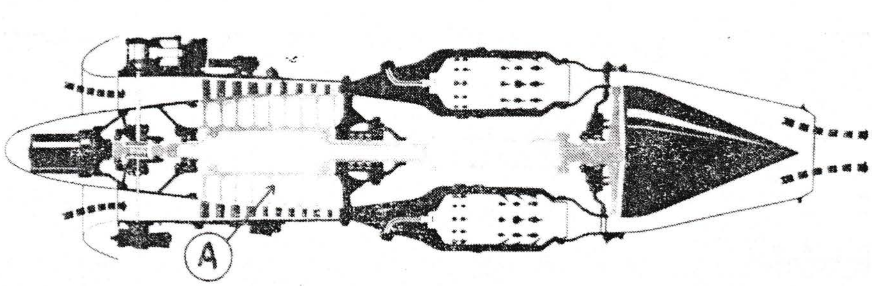


A ten-stage axial flow compressor and turbine assembly.

(2) **Performance** — Although not strictly true at the present time, the claim is that the Axial engines will have a lower specific fuel consumption than Centrifugals. As an example, the Metrovic Beryl I is about the same as the best of the Centrifugals, such as the Rolls Royce Derwent V or the Nene. However, several more year's development work has been put into Centrifugals than into Axials, and it is only now that the Axial is really beginning to come into its own. Details of engines at present under development cannot yet be released, but the improvements in performance obtainable with Axials will become apparent during the next two years or so.

The main reason for the reduction in fuel consumption possible with Axials is that their efficiency is appreciably higher—about 6%—than Centrifugal compressors. In order to improve the fuel consumption, it is necessary to develop compressors with a higher compression ratio. To do this with Centrifugals necessitates having them in two (or more) stages—i.e., in series one behind the other. This is inconvenient in practice, making the engine bulky and clumsy, besides leading to a reduction in over-all compressor efficiency thus offsetting the possible improvement in fuel consumption.

(3) **Weight**—In the past, Axials have been heavier than Centrifugals, but present-day Axials are no heavier, and in some cases lighter. An interesting comparison can be drawn between the Rolls Royce Dart and the Armstrong Siddeley Mamba. Both these propeller turbines were designed to produce 1,000 hp. for take-off, the Dart having a two-stage Centrifugal and the Mamba an Axial compressor. The Mamba has turned out to be lighter than the Dart and has only 50% of its frontal area.



This is the cross section of an axial flow engine with a nine stage compressor. The arrow lettered A points to the compressor assembly; the actual compressor blades are the black squares at the outer edges of the assembly. Note the diameter/length ratio.

The general trend of both Centrifugal and Axial engines is to get heavier, being unfortunately an unavoidable penalty to be paid for improvement in fuel consumption.

Concerning fuel consumption, the difference between established and "up and coming" Centrifugals is not very great, but the difference between corresponding Axials will be much more impressive, justifying the claims made earlier in this article.

Concerning diameter, the Beryl develops 50% more thrust per square foot of front area than the best established Centrifugals. The "next generation" Axials will develop two or three times the thrust per unit of frontal area of present Centrifugals, and will therefore have roughly that much less drag.

(4) **Reliability in Service**—With regard to the ordinary overhaul maintenance period, there is no reason why there should be any difference between Axials and Centrifugals. There is, however, no doubt that an Axial is more vulnerable to damage from ice or debris entering the compressor. If a foreign body enters a Centrifugal compressor it will probably only damage a small part of it, with little effect on the whole compressor. In the case of the Axial, a blade failure near the entry might remove all the blades be-

hind it, causing a complete engine failure.

The answer is of course to prevent debris or ice from entering an Axial compressor. It is no more difficult to stop stones, etc., reaching an Axial than a Centrifugal, and it is quite untrue to say that an Axial compressor cannot be protected from ice.

The consequences of debris entering an Axial compressor are by no means as serious as has often been predicted, and in this connection three observations can be made.

(a) If a foreign body persists in its course through the engine, it may well do serious damage irrespective of the type of compressor.

(b) Although the opinion has been widely felt that a blade failure in the early stages of an Axial compressor is almost certain to cause total failure, experience has shown that this is by no means true. In fact in many cases the individual blade failure causes very little further damage. This has happened several times during Mamba testing, and on occasions the mishap was not detected till the engine was stripped for inspection.

(c) Even if a blade failure in an Axial causes the sudden removal of all remaining blades this will not cause the engine to explode or in any way endanger the structure of the aircraft.

Some time ago a Python on test suffered a similar mishap, all the compressor blades being sheared off from the roots. The engine came to a stop but no one knew what had happened until it was stripped.

Icing

Because of the dangers resulting from ice being allowed to form inside an engine, whether the engine be a Centrifugal or an Axial gas turbine, (or for that matter a piston engine), requirements have been laid down that complete anti-icing protection must be provided. De-icing, incidentally, means removing ice which has already formed inside the engine; anti-icing means never allowing any ice to build up. This is perfectly possible and anti-icing rig-tests have been done on the Mamba with promising results. There are no grounds for saying that Axials cannot be protected from ice, and the development work now in hand will ensure that the protecting arrangements are efficient.

The method of doing this will almost certainly be to bleed off some hot gases from the exhaust system, lead them round to the front of the engine and mix them with the incoming air, thus raising its temperature above freezing point. The amount of hot gases can be varied according to the severity of the icing conditions. It will be possible to prevent ice forming in an Axial engine even if the incoming air is 40° below Centigrade.

This is a very extreme case, and will be encountered very rarely in actual practice, but the requirement is laid down to meet world-wide operating conditions. The consequent loss of thrust when this extreme anti-icing is being done will be appreciable, perhaps around 15%, but under any normal icing conditions when the outside air is only a few degrees, perhaps up to 10 or 15 below zero, the loss will be very much less.

One can't have something for nothing and if it is necessary to meet these conditions a price must be paid for it. The penalty would be the same for a Centrifugal as for an Axial. If it is decided not to use gases from the engine for de-icing in order to avoid loss of engine power, some comprehensive alternative source of heat would have to be carried in the aircraft.

Present-day Axials are made with light alloy blades because they are light, easy to manufacture and able to withstand the temperature rise in the compressor. Future developments will be the use of stronger materials—phosphor bronze or more probably steel blades for reasons of performance and strength at high temperatures. This will automatically appreciably reduce the vulnerability of the compressor.

An interesting point is that the reverse-flow layout of the Python makes the de-icing of by far the greater part of the intake (and the compressor) automatic, because of the heat from the combustion chambers. The only part which will need external heat for de-icing is the leading edge of the annular intake (and of course the propeller).

Because the temperature rises with the increasing pressure along the length of an Axial compressor, once the temperature of the incoming air is raised above 0°C., the rest of the compressor is automatically freed from icing conditions.

Other Trouble Sources

Axial compressors are more liable to deteriorate in performance because of dirt or sand entering the compressor, but although the effect is noticeable with the Mamba or the Python on the test bed, there has been no trouble in flight tests, and it is not anticipated that in actual operational use dirt will cause any appreciable nuisance. It is only long runs at ground level in a dirty atmosphere which cause the trouble; during flight in the upper air it does not occur. Built-in compressor cleaning jets will almost certainly be a permanent feature of Axial engines.

As yet no experience has been had with large quantities of sand entering the compressor of an Axial compressor but preparations for such tests are being made. It is considered that the compressor blades should be capable of standing up to the passage of an appreciable amount of sand through the compressor. In fact, such conditions may well help to clear off dirt clinging to the blades. Should the blades nevertheless prove incapable of withstanding the erosion, steps will have to be taken either to increase the surface hardness of the blades, or to replace them entirely with steel blades.

In this connection, it is perhaps of interest to point out that even with full tropicalization equipment and air filters, the overhaul period of the piston engines used in military aircraft in the Middle East during World War II was reduced to only about 10% of the normal time.

(5) Production and Costs—Hitherto Axial compressors have been more expensive to make than Centrifugals, but much less experience has been obtained on the production technique of Axial than on Centrifugal compressors. With improved production methods, the difference will be greatly reduced. No Axial engine has yet been put into production on any large scale at all—in fact every Axial engine yet has been hand built. Such cost figures that are available do not therefore provide a fair basis of comparison at all.