Don't Write Off the Centrifugal Compressor

By
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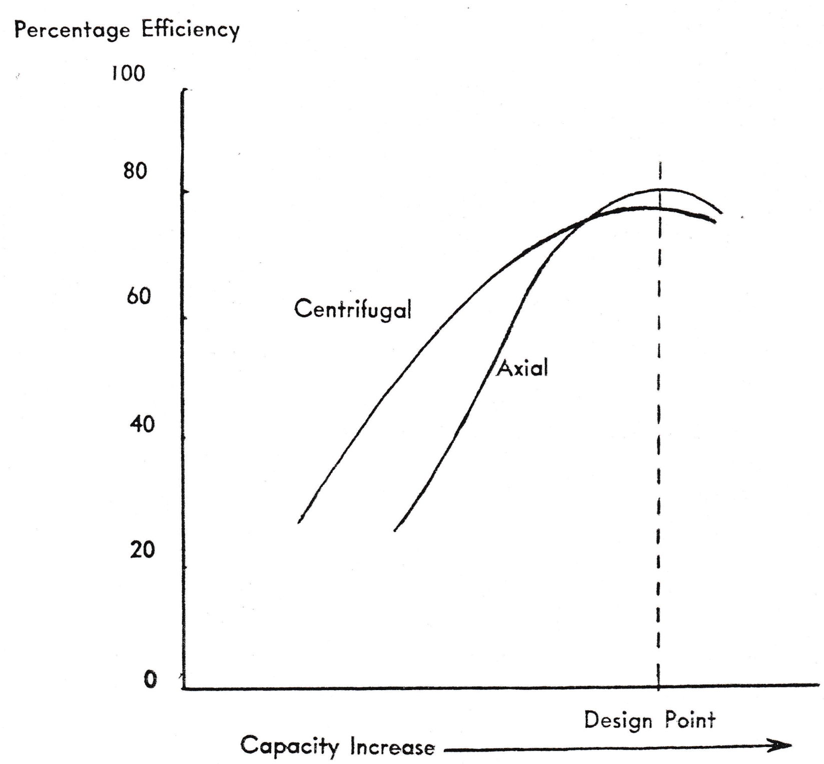


Curves showing the efficiences of typical compressors

In all branches of engineering, as in most fields of endeavor, there are alternative, even conflicting, schools of opinion which vary in popularity to the whims of the time.

Aeronautical engineering provides no exception. For years the advocates of the monoplane fought a losing fight against the popularity of the biplane, until the position was reversed by the demand for higher performances in general and the introduction of the thick cantilever wing in particular.

It was the same with engines. In a peace loving world, where war seemed to be an abandoned pastime and economy of operation—commercial operation, was of prime importance, the air cooled engine was supreme. Then conditions altered and other standards asserted themselves to govern the value of the engine.

War, with its confounded disregard for economy, demanded the superior performance of the Merlins and their imitations and left behind a renewed attachment for the liquid cooled engine. That fight, that conflict of opinion, is now over, for aircraft piston engines of either type have reached the zenith of their development and are rapidly being replaced by gas turbine systems that require no specific cooling devices other than the conversion of heat into useful work.

Nevertheless there is no lack of opinionative conflict. Gas turbines have already developed into distinctive types, each with its own peculiarities that provide food for argument as to their advantages and disadvantages. Naturally we find advocates of each type; ready to support their opinions with sound arguments but with convenient disregard for some of the considerations that could depreciate their theories.

Classifying Component

As far as aircraft are concerned, the gas turbine system is used as a turbojet, either with or without a propeller attachment, and, at the present time, the most distinctively classifying component is the compressor. This also is the component that causes the most argument; the advantages and disadvantages of the axial types as against those of the centrifugal types. The former is in favor at the moment.

The concensus of opinion seems to be that the axial compressor will soon oust altogether its rival and, certainly, design tendencies point towards such a happening. Having seen a lot of spade work done for them, the majority of designers now entering the turbojet field are concentrating on the axial type of unit because, under certain conditions, which are encountered in high-speed flight, it is the more efficient machine.

However, and well knowing the weight of contrary opinion, it is proposed here to discuss some of the considerations that favor the centrifugal compressor.

It is admitted that the axial compressor can operate with greater efficiency than its rival can, but what is frequently and conveniently overlooked is the fact that it does so only at or near peak operating conditions. The several stages of an axial compressor can easily be matched to give efficient operation provided only one set of operating conditions is involved. If the unit is required to operate under widely varying conditions many extra difficulties are encountered and much experimental work yet remains before the majority of these can be overcome.

When the conditions change from those under which an axial compressor operates with greatest efficiency, known as the design point, the incidence on some or all of the blades changes and causes a reduction in over-all efficiency. If the change continues, either by altering the mass flow at constant rotational speed or vice versa, the incidence on some of the blades will eventually reach stalling value and an undesirable condition known as surging will result.

Complete Breakdown

This is followed, unless the unit is returned to more suitable operating conditions, by complete breakdown of the airflow and failure of the engine to operate. There is only one rotational speed and only one mass airflow at that speed when all stages of an axial compressor are matched and capable of operating with a high degree of efficiency. On the other hand, while it also operates with greatest efficiency under certain defined conditions, the centrifugal type of compressor is now so drastically affected by any change in those conditions. There is no danger of stalling the blades at low speeds and consequently less trouble in maintaining the airflow or in starting the operating cycle.

The axial compressor is, in fact, very temperamental and fussy about its working conditions. At the design point it can, if well designed and maintained in good mechanical condition, operate with an over-all efficiency of about 85% as against somewhat less than 80% in the case of a comparable centrifugal type. A very desirable advantage of course, but, as mentioned before, any diversion from the design point will cause a greater reduction in overall efficiency of the former type than it will in the case of the latter. Typical efficiency curves are shown in the accompanying graph from which it will be seen that the axial unit maintains its advantages in efficiency only in the vicinity of the design point. Under other conditions the centrifugal type of unit is the more efficient.

This ability to maintain a high degree of efficiency under varying conditions, which we can call flexibility, is an asset of debatable value when applied to aircraft engines, but space does not permit a discussion of the matter here. We are concerned with compressors and for the moment it must be accepted that flexibility is a very desirable quality because of the varying demands placed upon an aero engine and the varying atmospheric conditions under which it must operate.

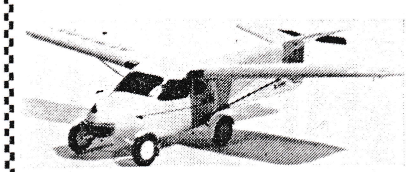
To be flexible a turbo-jet must incorporate a flexible compressor of course, but the flexibility of the latter is of importance for another reason. With the present day knowledge it is possible to design an axial compressor to give a pressure ratio of up to 6:1 while still maintaining good efficiency and reasonable flexibility but it seems unlikely that this ratio can be greatly increased without serious sacrifice of the other qualities. It will therefore be necessary, when higher pressures are required, to split the process of compression between two or more units and the matching of these units will be facilitated in the case of the centrifugal compressor by reason of its good flexibility characteristics.

High Pressure Ratio

The placing of a number of stages in series to give a higher pressure ratio, can be accomplished quite easily while still maintaining good efficiency and flexibility. The matching of axial compressor units, however, is a very much more complicated proceeding. The matching of anything up to 20 stages on a single shaft has already been done, but only at the expense of almost all flexibility. Furthermore the assembly required extremely accurate manufacture and maintenance and would have withstood very little abuse in service

A maladjustment of only one or two degrees in the incidence of one blade row would have resulted in very serious loss of performance. The unit would therefore have been totally unfit for aircraft use. The matching of two mechanically independent compressors is an easier process but would result in a very cumbersome engine. The general compactness of the centrifugal design, on the other hand, lends itself more readily to incorporation in a compound unit.

Now let us consider some of the other points on which the two types of compressor are compared. Over-



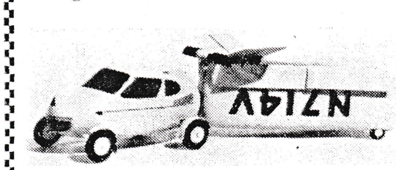
THE AEROCAR

One of the most elusive objectives of aviation has always been the roadable airplane. Above and below are photographs of a model of a machine which constitutes the latest attempt to make a combination auto-airplane.

Known as the Aerocar and made by Aerocar Inc., of Longview, Washington, this project has actually advanced far beyond the model stage. A short time ago Moulton B. Taylor, manager of Aerocar, told *Aircraft and Airport* . . .

"Words cannot convey the detail of such a development . . . we have spent four years doing it. The flight component is now under construction (should now be completed) and we anticipate flight tests in the summer. Our operation of the car to date indicates satisfactory auto application of the air-cooled aircraft engine. This is the most difficult but least spectacular part of the project. The drive line is direct from a Crossley automobile, but turned around to make the car a front wheel drive . . ."

The dimensions of the Aerocar as an airplane are approximately that of the average small lightplane. Power is by a Franklin 225 with a maximum output of 115 hp. The cruising speed has been estimated at over 100 mph. (in the air); designed road speeed is 60 mph. maximum. Changeover time from airplane to automobile is just one minute. Carrying two passengers, the aircraft has a flying range of over 300 miles; on the road its range is extended to 500 miles.



all diameter is a favorite one with the axial advocates because, unit for unit, the axial design is diametrically smaller than its rival. However, we must not be carried away by this advantage before assessing its true value. It is overall diameter of the engine that counts and this is not necessarily controlled by compressor diameter.

Present-day engines incorporating axial compressors are, admittedly, diametrically smaller—by only a few inches, be it emphasized—than those incorporating centrifugal compressors, but, as engines of higher powers are developed, combustion space and turbine diameter will be the controlling factors. The advantage gained from small compressor diameter will be nullified by virtue of the fact that it will be absorbed in the overall diameter of the engine.

And how much advantage is a few inches reduction in engine overall diameter anyway? To the designer still laboring under the Christmas tree complex it is likely to mean quite a lot. Any saving in frontal area, no matter how slight, can be considered a saving grace so long as engines are allowed to hang on the outside of the airframe like an afterthought and cancel out a goodly portion of their propulsive effort by dragging on the airstream.

An Enlightened Age

But what was good enough for the piston engine era is not necessarily good enough in a more enlightened age and there are indications that greater efforts are already being made to place the engines inside the airframe where they can do their work without, at the same time impeding the progress of the aircraft. The overall diameter of the engine consequently becomes of comparatively little importance, if only a few inches here or there are involved.

Certainly, it is of no more importance than the overall length, on which point the centrifugal compressor is at an advantage. In other words, the slight advantage in overall diameter enjoyed by the axial compressor engine is obtained at the expense of overall length and which of these dimensions is the more important depends on circumstances.

Reliability in service is something that usually improves as more experience is gained but it is doubtful whether the axial engine will ever surpass its rival in this respect. To begin with, the blades of an axial compressor must be manufactured and installed with extreme accuracy; minute errors in blade profile or setting cause very noticeable losses in efficiency. Therefore, the manufacturing costs are high and the temptation to reduce these, in spite of the consequent reduction in the quality of the finished product is ever present.

A Prime Example

This happened in the case of the German Heinkel-Hirth OII turbo-jet which was being tooled up for mass production toward the end of the war. This engine incorporated a three-stage axial compressor working in series with a diagonal stage and it was claimed that the arrangement had developed a maximum overall adiabatic efficiency of over 86%. Then changes in clearances to allow easier manufacture and increased reliability in service—compressor blade creep was one of the major causes of breakdown in the German engines, which were all axial types—resulted in reducing the efficiency to about 82%.

The Heinkel-Hirth OII also provided a sharp reminder of the high cost of manufacturing axial compressor blades. It was designed with the object of developing an engine suitable for mass production and 500-man-hours machining time for the entire engine less accessories was the goal. A goal that went the way of all Hitler's hopes. The position by V-E Day was that the fabrication of the axial compressor blades alone required 624 man-hours.

In service the axial compressor is intensely vulnerable to damage from ice and other foreign matter. The clearances between rotary and stationary blades must be small to maintain efficient operation and it can be readily appreciated that fouling of only one blade could very quickly result in stripping the entire assembly. This has happened on several occasions and the exclusion of ice from the airstream is one of the biggest problems encountered in the operation of axial turbojets at the present time. Even dust or sand can very quickly damage the delicately formed profile of the blades sufficiently to cause considerable reduction in operating efficiency.

How very much less vulnerable is the centrifugal compressor. In the many years that this type of compressor has been in use in the form of a supercharger for piston engines only isolated cases of complete failure from ice bombardment have been reported. Its robust construction coupled with its lack of dependence on difficultly formed blade profiles and small working clearances give it the ability to handle all but the most unexpected flotsam.

To sum up, therefore, the axial compressor is the more efficient machine under design point conditions but is less flexible than the centrifugal type and consequently the latter is able to hold a higher average efficiency under a wide range of operating conditions. Also because of its flexibility and its compact construction, the centrifugal type lends itself more readily to compounding and may, therefore, be the useful type of compressor when high pressure ratios are in demand.

Axial compressors are of smaller overall diameter than that of the centrifugals but this is not likely to remain an important asset. Centrifugal compressors do not depend on a large number of fastidiously formed blades and their manufacturing cost is comparatively low. This type is more reliable in service than the axial type because it is less vulnerable to ice, sand, and other air impurities.

A Fatal Mistake

The position now is not unlike that which faced Great Britain and Germany when these two nations, independently, pioneered the jet-propulsion idea. The higher peak efficiencies of the axial compressor is realized but the cost must not be overlooked. The Germans made the fatal mistake of entirely abandoning the centrifugal design and seriously retarded the development of their engines thereby. Great Britain, on the other hand, in a characteristically conservative manner, concentrated on this type while quietly assessing the qualities of the other and produced engines that were, and still are, the envy of the world. It is too early yet to abandon the centrifugal compressor.