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NATIONAL ADVISORY COMMITTEE  
FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1073

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AXIAL SUPERCHARGERS

By A. Betz

Jahrbuch 1938 der Deutschen Luftfahrtforschung



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## AXIAL SUPERCHARGERS\*

By A. Betz

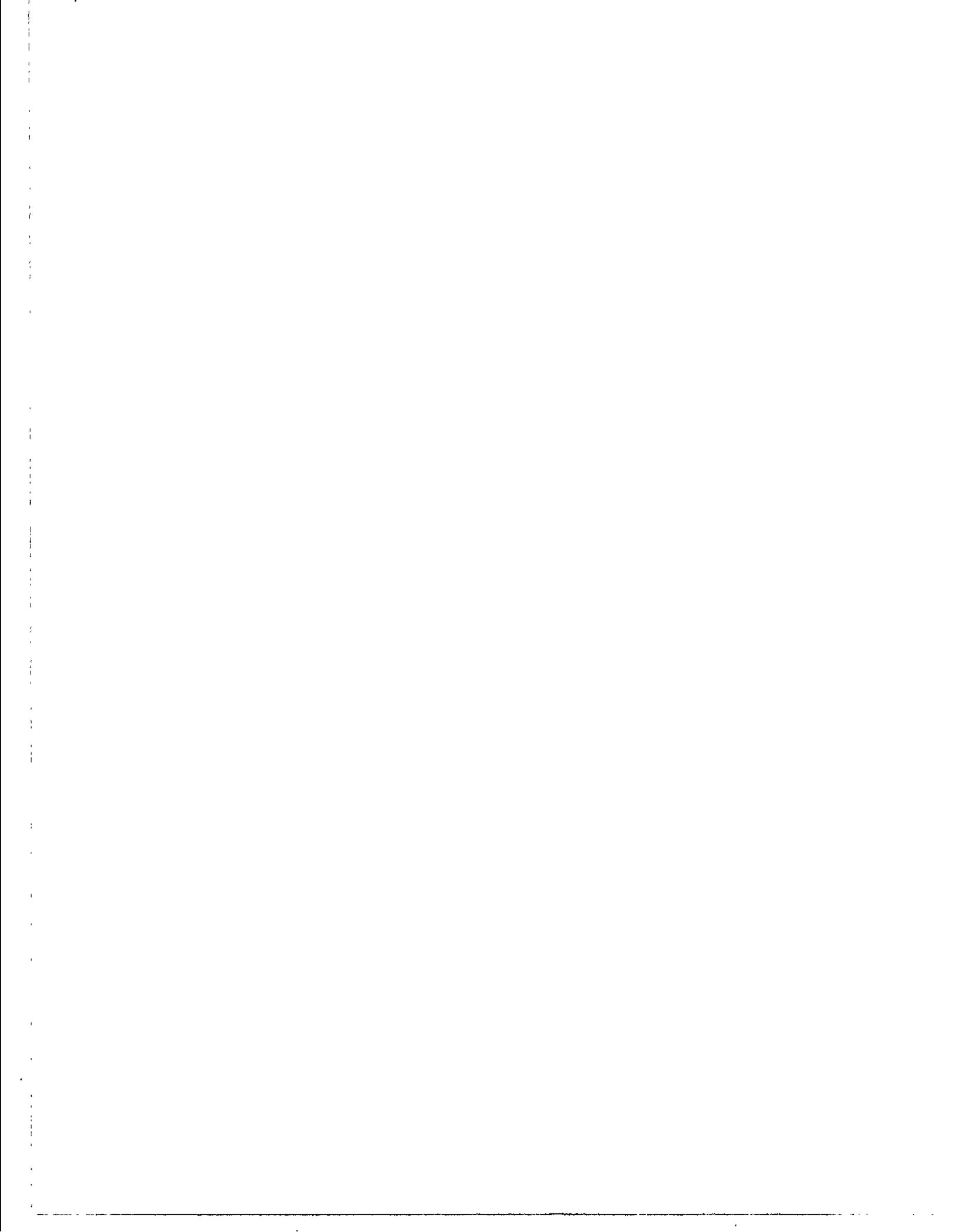
The axial supercharger has a better efficiency and a simpler design than the radial supercharger. The relatively narrow range in which it operates satisfactorily should not be a very disturbing factor for practical flight problems. The length of this type of supercharger may be reduced considerably if some impairment in the efficiency is permitted. Improvements, however, have been attained which permit a shortening of the structure without any impairment of the efficiency.

When, about 10 years ago, the author first attempted to apply the favorable results that had been obtained with axial blowers to the development of superchargers there were essentially two points of view that argued in favor of this type of design. One was the good efficiency possessed by the axial blower; the other was the smooth flow process which permitted a light, simple, and reliable design. In the meantime, however, the efficiency of the radial type blower had also considerably improved so that today the difference is not so great. Nevertheless this small difference can be of great significance when it is necessary to make use of the limited energy of the exhaust gases for supercharging. The second factor - namely, the smooth flow process, had in the meantime acquired still greater significance, since at the high altitudes, such as are at present under consideration, the cross section of the inlet opening must be very large in order to handle the required air volume and in the case of the radial supercharger the outside diameter of the impeller then becomes excessively large while for the axial supercharger the inlet diameter is not very much larger than the inlet opening.

Figure 1 shows the dimensions that are obtained for a compression ratio 1:8 corresponding to a critical altitude

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\*"Axiallader," Jahrbuch 1938 der deutschen Luftfahrtforschung, pp. II 183--II 186.



cylinder volume and the rotational speed of the engine. If the engine speed is constant the required air quantity delivered is practically constant and independent of the altitude, increasing only if the engine speed increases with the altitude. On the right of figure 2 are given the curves as a function of the compressed air quantity delivered  $Q_v$  and it may be seen that there is a considerable extension in the range of good efficiency.

The required compression that must be supplied by the supercharger increases with the altitude. A supercharger with constant speed will, at low altitudes, give either too high pressures or deliver too large air quantities. With regard to economy, therefore, it will be necessary to allow the speed to increase with the altitude. In the case of mechanical drive from the engine shaft this will naturally raise considerable difficulties. If the drive is by means of an exhaust turbine, however, which is also desirable for reasons of economy, then it is possible to vary the speed with the altitude since the pressure drop available in the exhaust gases increases with the altitude. It will then be possible to consider, independent of the question of method of drive, the rotational speeds employed at the various altitudes in order to utilize a given supercharger most efficiently.

For each altitude the air quantity delivered and the compression ratio is given. If these conditions are to be satisfied without artificial throttling, then there is obtained, for each altitude, a quite definite rotational speed and a quite definite condition of operation of the supercharger. In figure 3 these speeds  $n$  (or the peripheral speeds  $u$ ) and the efficiencies  $\eta$  are plotted against the compression ratio  $p/p_0$ , the two sets of curves being obtained on the assumptions of constant engine speed and engine speed decreasing to 70 percent toward the ground, respectively. The pressure ratio  $p/p_0$ , instead of the altitude, is used as abscissa since the results are then independent of the initial altitude. The corresponding critical altitudes starting from the ground are also plotted. It may be seen that good efficiency ( $\eta > 0.75$ ) at constant engine speed extends over a range of  $p/p_0$  from 1.43 to 2.13 corresponding to a critical altitude of 2.9 to 6 kilometers while for the decreasing engine speeds the corresponding lower limits of  $p/p_0$  and  $H$  are 1.3 and 2.1 kilometers, respectively. The ranges of good efficiency (indicated by the hatched lines) are extended considerably and efficiency begins to fall rapidly only at much lower altitudes. For

these low altitudes, however, the required supercharger performance is much lower so that the impaired efficiencies are no longer of any great importance.

### REDUCTION OF THE LENGTH OF THE AXIAL SUPERCHARGER

In order to combat the second disadvantage of the axial supercharger - namely, that of great structural length - a series of tests, under the direction of Encke, are being conducted on which a brief report is given without, however, presenting any definite conclusions since the work is still in its initial stages.

The following general remarks are made by the author: namely, that there is a possibility of making a considerable reduction in the length, provided a certain impairment in the efficiency is taken into account. It will have to be decided, in each case, how far this is permissible. In particular, for high compression ratios in the first stages it will be possible to permit lower efficiencies in order to gain a saving in structural length. Since, because of the low air density, these stages require very large space, the space saving is of greater importance than in the later stages and since it is only a portion of the total performance in question the efficiency impairment in these first stages will not have too great an effect on the over-all efficiency. The aim should, naturally, be a reduction in length without a sacrifice in efficiency.

There are two possibilities for reducing the structural length:

1. Constructional means in the design of the blower, applying the already familiar impeller and guide vanes.
2. Improvement in the impellers so that a greater pressure increase may be attained with one wheel

#### Constructional Means

The author first considers the constructional possibilities. Figure 4 shows, at the top, the usual design of an axial supercharger in the stage of development of the year 1930. Five stages are provided that permit a compression ratio of 2. As may be seen from the sketch the impeller wheels themselves, which actually perform the work,

contribute relatively little to the great length of the supercharger. The length is mainly determined by the guide vanes between the impellers and by the interspaces between the guide and impeller wheels. Now it is possible to reduce considerably the length of the guide vanes and also the lengths of the interspaces by increasing the number of guide vanes and correspondingly reducing their depth. Unfortunately difficulties are here encountered in the Reynolds number. The dimensions of the blower are already rather small and as a result the guide vanes are in a range of Reynolds number in which a further reduction in length already leads to a considerable increase in the resistance. In one test, in which the vanes were reduced 35 percent, a lowering of efficiency was obtained of about 3 percent. It will have to be decided, in each individual case, whether the reduction in length is worth the resulting sacrifice in efficiency.

Cases are conceivable in which the increase in resistance in the guide vanes does no harm because of other possible advantages gained. For example, one such case would, if it were possible, utilize the guide vanes to conduct away a considerable portion of the heat compression. The heat conduction would increase with increasing resistance and a saving would be obtained in the intercoolers still required. Whether this consideration will play any important part in view of the present small heat conducting capacity of the guide vanes is doubtful.

Another very effective constructive measure for reducing the structural length is the application of counter-rotating impellers in which case the guide vanes between the rotors drop out altogether and only an entrance and exit guide vane is required for the entire supercharger. Figure 4, at the bottom, shows such an arrangement for the same conditions as in the sketch above it (compression ratio 1:2 with five stages). The considerable space saving effected is evident. Such counter-rotating wheels have proven themselves to be aerodynamically favorable. Figure 5 shows test results with two counter-rotating wheels with various blade settings, the curves having been obtained, however, only at low speeds. Both the pressure increases obtained and the efficiencies are quite favorable. Difficulties are encountered only in the drive when the number of stages is more than two. If, for example, the wheels rotating in one direction are driven internally while the opposite rotating wheels are driven externally then the external drive leads to difficulties in regard to strength at high speeds. It

is possible to drive both sets of wheels from within in which case, however, an unfortunately complicated mechanism is required.

#### Increase in Performance of Each Impeller

The second possibility of reducing the length; namely, by increasing the performance of each impeller may be arrived at in various ways. It might be possible to increase the pressure by raising the rotational speed. When the relative velocities, however, are made to approach the speed of sound there is a strong drop in the efficiency curves and a restriction is thus imposed on this method.

In the case of the wheels, which have thus far been developed, there has generally been taken into account an efficiency loss of a few percent as a result of the approach to the speed of sound in order to attain as high a pressure increase per wheel as possible. A further increase in the speed, however, would lead to quite a disproportionate increase in the losses. Figure 6 shows results for various rotational speeds and the effect of the peripheral speed is clearly evident.

One possible path of development, therefore, is that by which higher pressures are sought by suitable design of the blades while maintaining the same peripheral speed. The other is that in which supersonic velocities are taken into account in which case, however, entirely new points of view are encountered for the design of the blades. By using the first method some degree of success has been attained. By the more accurate manufacture of the blades, using special machines, there was obtained a pressure increase of 12 percent in one case. Through further development of the blade shape together with improved manufacture the pressure was raised by about 20 percent above that of the wheels already considered. More recent tests even appear to give results exceeding this value. With a 20 percent pressure rise the compression ratio attainable with a single wheel increases from 1.17 to 1.21. With four wheels there is obtained a compression ratio of 2.14, whereas, previously the value 2.19 with five wheels had been obtained.

Progress along this path has, up to now, appeared rather difficult and laborious; the reason for the difficulties encountered appeared to be due, fundamentally, to the large rotational motion given the air and which results

in the setting up of disturbances by the rotational motion of the air relative to the blades and by centrifugal and Coriolis forces in the friction layer, disturbances over which there is, as yet, no control.

In the case of the second method; namely, operation within the supersonic range - this is still in the very first stages and it is impossible, as yet, to report on any success obtained. This method does not, however, appear to be entirely without promise. When it becomes possible to use this method at all successfully considerably greater pressure increases may be expected than those obtained in the subsonic range.

The author has attempted to give you a brief review of the characteristics of axial supercharger in its present state of development and the methods and possibilities of its improvement. The author believes that even today the axial supercharger, in spite of the defects from which it suffers, is suitable for many purposes and for some special objects, particularly for flight at very high altitudes it offers considerable advantages.

Translation by S. Reiss,  
National Advisory Committee  
for Aeronautics.

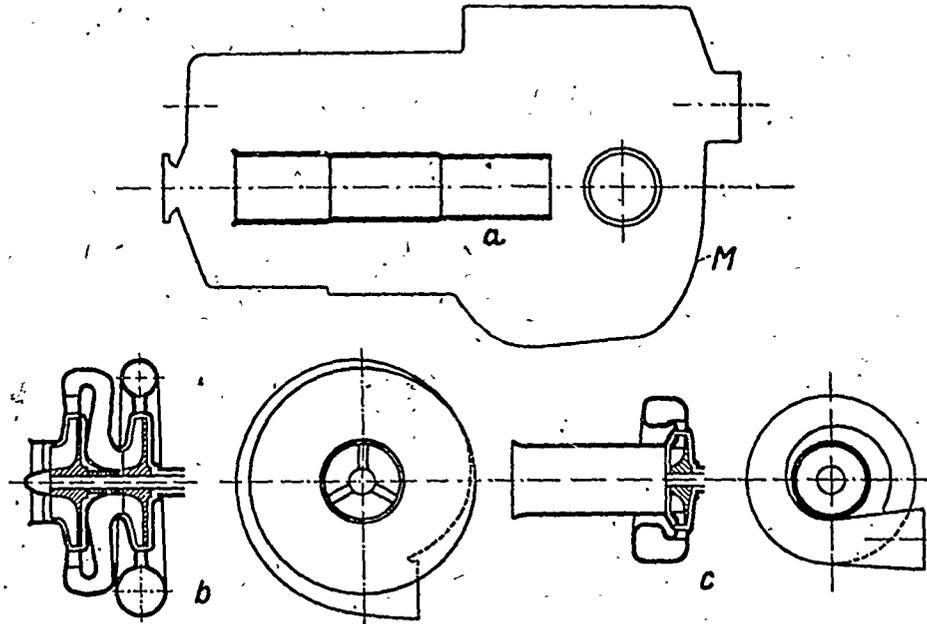


Figure 1.- Space requirements of various supercharger designs for compression ratio 1:8. M, engine; a, axial supercharger in all stages; b, radial supercharger in all stages; c, combination of axial and radial superchargers.

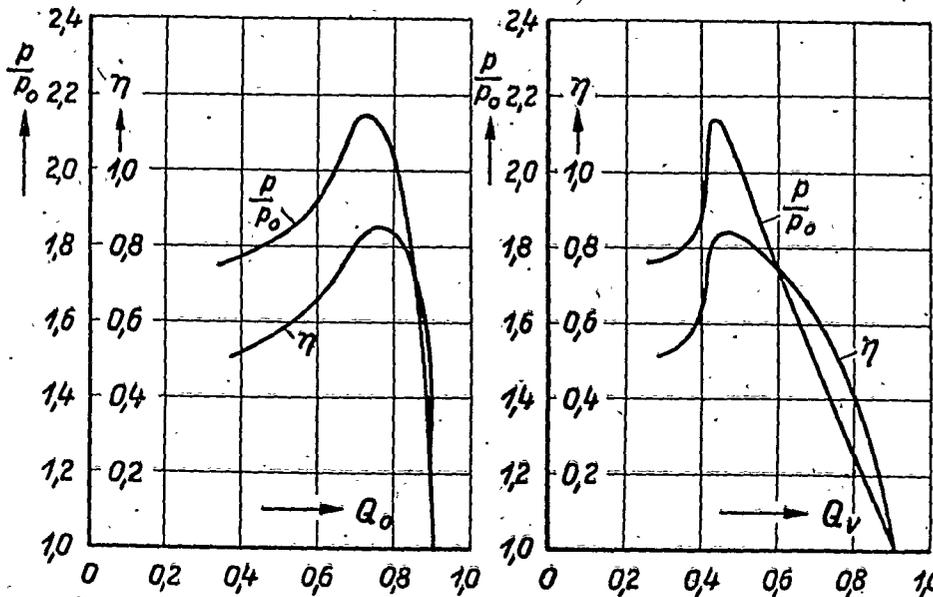


Figure 2.- Compression ratio and efficiency of an axial supercharger, as a function of the air quantity  $Q_0$  ( $m^3/s$ ) in the uncompressed state (left) and of the air quantity delivered  $Q_v$  ( $m^3/s$ ) in the compressed state (right).

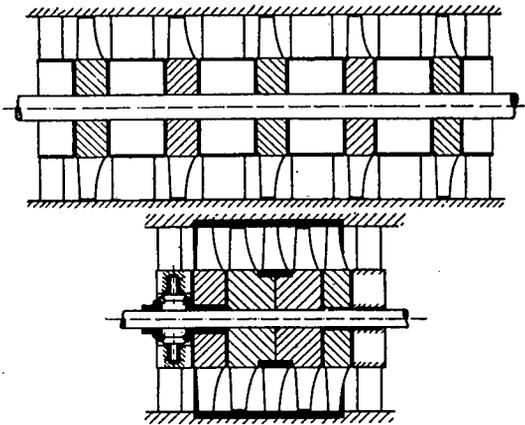
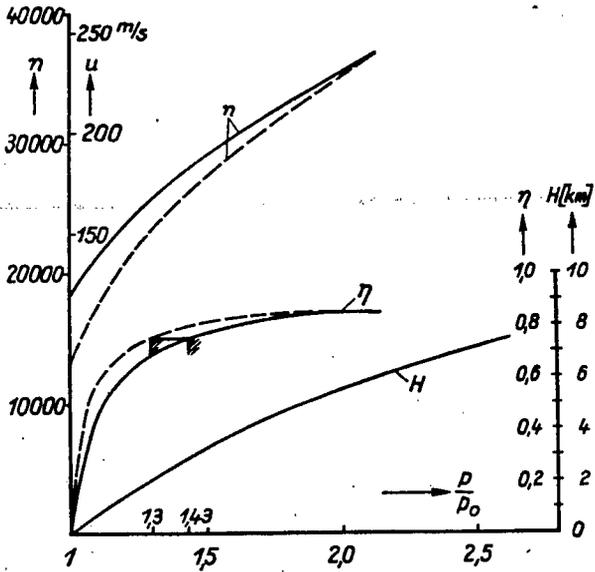


Figure 4.- Five-stage axial blower without and with counter-rotating wheels.

Figure 3.- Critical altitude  $H$  as a function of the compression ratio  $p/p_0$ . Continuous lines for constant assumed engine speed, dotted lines for engine speed decreasing toward ground to 70 percent.

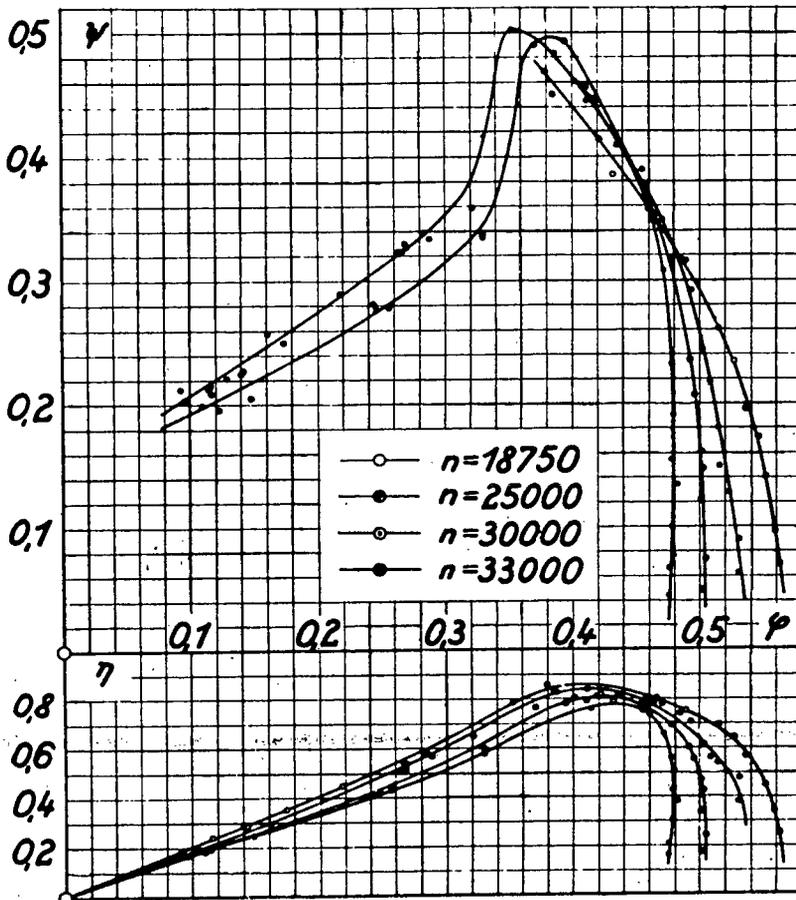


Figure 6.- Effect of approach to the speed of sound on the pressure coefficient and the efficiency (impeller diameter 150 mm).

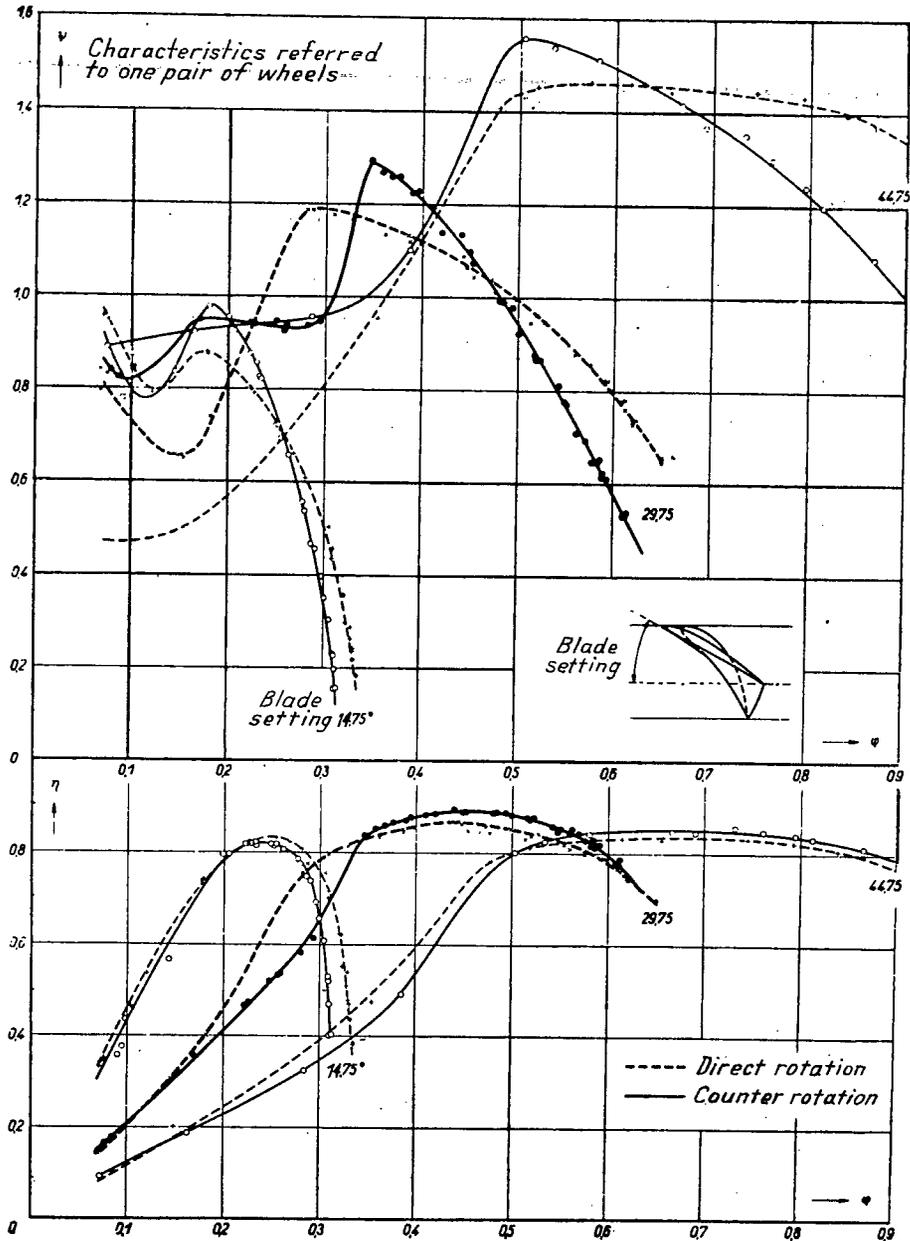


Figure 5.- Pressure characteristics and efficiencies of a two-stage blower with and without counter-rotating wheels for various blade settings.

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