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AN INVESTIGATION OF THE USE OF DISCHARGE VALVES AND AN INTAKE CONTROL FOR IMPROVING THE PERFORMANCE OF N. A. C. A. ROOTS TYPE SUPERCHARGER

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SUMMARY

This report presents the results of an analytical investigation on the practicability of using mechanically operated discharge valves in conjunction with a manually operated intake control for improving the performance of N. A. C. A. Roots type superchargers. The investigation was conducted by the staff of the National Advisory Committee for Aeronautics at Langley Field, Va.

These valves, which may be either of the oscillating or rotating type, are placed in the discharge opening of the supercharger and are so shaped and synchronized with the supercharger impellers that they do not open until the air has been compressed to the delivery pressure. The intake control limits the quantity of air compressed to engine requirements by permitting the excess air to escape from the compression chamber before compression begins.

The percentage power saving and the actual horsepower saved were computed for altitudes from 0 to 20,000 feet. These computations are based on the pressure-volume cards for the conventional and the modified Roots type superchargers and on the results of laboratory tests of the conventional type.

The use of discharge valves shows a power saving of approximately 26 per cent at a critical altitude of 20,000 feet. In addition, these valves reduce the amplitude of the discharge pulsations and increase the volumetric efficiency. With slow-speed Roots blowers operating at high-pressure differences even better results would be expected. For aircraft engine superchargers operating at high speeds these discharge valves increase the performance as above, but have the disadvantages of increasing the weight and of adding a high-speed mechanism to a simple machine.

INTRODUCTION

The practicability of supercharging aircraft engines as a means of improving their performance at altitude has led to an increasing demand for superchargers of high efficiency, low weight, and low power requirements.

Most of the aircraft engine superchargers in use at the present time are modifications of conventional types of air compressors. The N. A. C. A. Roots type supercharger, which is a modification of the commercial Roots blower, has given very satisfactory results for the supercharging of aircraft engines. (References 1 and 2.) This supercharger is fully described in Report No. 230 of the National Advisory Committee for Aeronautics. (Reference 3.) The reciprocating compressor, which is the most efficient from a theoretical point of view, has met with little success as an aircraft engine supercharger, because of the strict weight limitations imposed by all aircraft service.

A comparison of the pressure-volume cards for the reciprocating and the Roots compressors shows that a considerable saving in power could be effected if the Roots supercharger were modified so that its card, which is rectangular, would approach that of the reciprocating compressor which has an adiabatic compression line. The practicability of using discharge valves and an intake control in obtaining this power saving was investigated by the staff of the National Advisory Committee for Aeronautics at Langley Field, Va.

Pressure-volume cards for conventional and modified Roots superchargers designed for 20,000 feet critical altitude were computed. The percentage saving in power and the actual horsepower saved were calculated for altitudes from 0 to 20,000 feet for a supercharger using rotating discharge valves with and without an intake control.

As far as is known, no experimental work of this nature has been attempted, with the exception of a few preliminary tests on flap valves that were conducted several years ago at this laboratory.

DESCRIPTION AND METHODS

The method herein described to improve the performance of a Roots type supercharger involves the use of mechanically operated discharge valves in conjunction with a manually operated intake control. The discharge valves reduce the impeller area subjected to the delivery pressure, prevent the back flow of air that has been compressed in the delivery duct by blocking the discharge passage, and prevent the flow of air from one side of the supercharger case to the other side. The intake control limits the volume of air compressed at any altitude below the critical altitude to the amount required by the engine instead of inducting and compressing more air than required and then by-passing the excess air as is done in the conventional type supercharger.

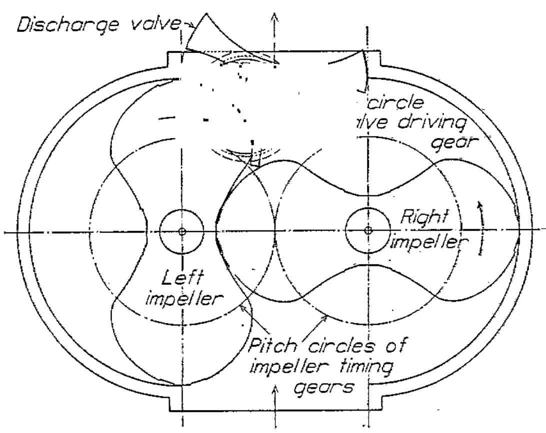

FIG. 1.—Diagrammatic cross section of a Roots type compressor with an oscillating discharge valve

These discharge valves are synchronized with the impellers and do not open until the intake air has been compressed to the desired pressure, usually 14.7 pounds per square inch. To obtain this condition with a simple driving mechanism, it is necessary that the discharge valves always open at the same time and that the compression pressure be controlled by the amount of air in the compression chamber when compression begins. The amount of air compressed is limited to engine requirements by permitting the excess air to escape from the compression chamber through manually controlled intake ports before compression begins.

If an intake control is not used in conjunction with the discharge valves, a by-pass valve of normal construction should be added to the upper part of the supercharger case to permit by-passing of the excess compressed air so that the pressures within the modified supercharger will not be greater than those for a normal supercharger.

The principal of operation of the oscillating discharge valve is shown in Figure 1. This valve is located in the center of the discharge opening and is mechanically operated, so that the tongue of the valve, which extends into the case between the impellers, contacts first with one impeller and then with the other. The back flow of air is prevented by the cross member of the valve which closes the discharge passage as soon as the compressed air has been delivered. The tongue prevents the flow of air from one side of the case to the other side and reduces the impeller area subjected to the delivery pressure. As the impeller rotates from the vertical position to the horizontal position, the point of contact between the discharge valve and impeller moves nearer the tip of the impeller. At this point the cross member of the discharge valve contacts with the other side of the impeller lobe. As soon as the impeller has reached the horizontal position the cycle is repeated on the other impeller. For each revolution of the impeller the discharge valve oscillates twice.

The principle of operation of the rotating discharge valves is shown in Figure 2. These valves are synchronized with the impellers by gears which are driven from the impeller timing gears. The discharge valves are so shaped that they contact with the implleer lobe in the vertical position on the high-pressure side, and as the impeller rotates this point of contact moves to the opposite side of the same impeller lobe. This contact for the rotating valve is maintained until the valve is opened, which, for a 20,000 foot supercharger using 9½-inch diameter impellers, corresponds to 80° rotation from the vertical. The air is discharged through the ends of the case with this valve arrangement. A flange is placed on the end of each discharge valve outside of the plane of impeller rotation to prevent the back flow of air. These valves rotate at twice the speed of the impellers.

The intake control shown diagrammatically in conjunction with the rotating discharge valves in Figure 2 is a simple method for limiting the volume of the air compressed. This control is manually operated and replaces the by-pass valve used on other installations where the conventional type supercharger is used. In order that this intake control may best serve its purpose, it must be so constructed that compression does not begin until all the air not required by the engine has escaped from the compression chamber. This control could also be used on a supercharger equipped with an oscillating discharge valve. The intake control would not be necessary on a supercharger that is always operating at approximately the same altitude and delivering air at a constant rate.

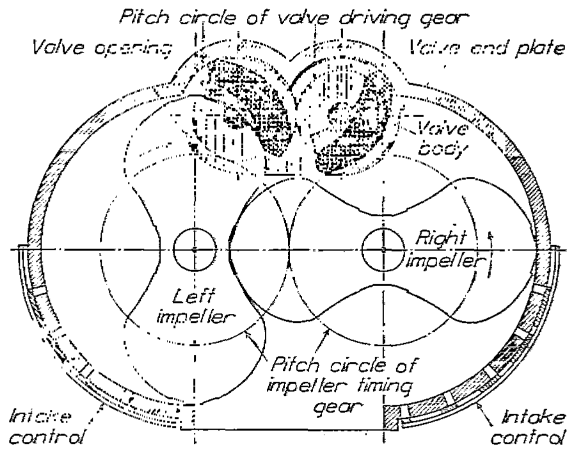

FIG. 2.—Diagrammatic cross section of a Roots type compressor with two rotating discharge valves

In computing the percentage power saving obtained by the use of discharge valves with and without an intake control it was necessary to assume some definite critical altitude which for this investigation was taken as 20,000 feet. Pressure-volume cards and torque curves corresponding to this critical altitude were prepared for the conventional and the modified Roots type superchargers. The volume and pressure of the air within the compression chamber for each 10° position of the impellers were determined for both the conventional and the modified Roots type superchargers. From the pressures thus obtained torque curves were computed for both superchargers, assuming an impeller length of 1 inch. The torque curves for the conventional and the modified supercharger were compared to obtain the percentage power saving at a critical altitude of 20,000 feet.

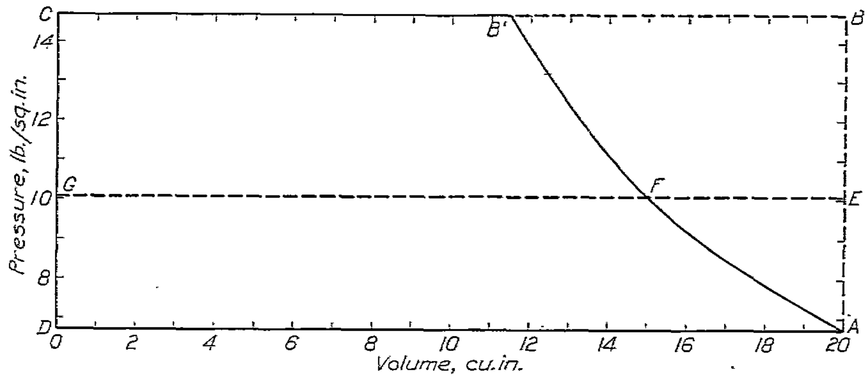

FIG. 3.—Pressure volume cards for the conventional and modified N. A. C. A. Roots type supercharger

The area of the pressure-volume cards ABCD and AB′CD (Fig. 3) for the conventional and the modified Roots superchargers, respectively, were also compared to obtain the per cent saving in power at a critical altitude of 20,000 feet. In a similar manner, the percentage saving in power for all altitudes below 20,000 feet was obtained. For instance, at 10,000 feet the ratio of the areas EBCG and FB′CG gives the ratio of the work in compressing air from intake pressure to discharge pressures and delivering at discharge pressures for the conventional and the modified superchargers, respectively. The actual horsepower saving was calculated from the percentage power saving determined from the pressure-volume cards and the results of power measurements obtained in laboratory tests on the conventional type of supercharger. (Reference 4.)

RESULTS

The results of this investigation are presented in the form of pressure-volume cards and curves. The pressure-volume card ABCD, shown in Figure 3, represents the work done in compressing the air by the conventional supercharger which operates against the delivery pressure throughout the complete cycle, and the pressure-volume card AB′CD, also shown in Figure 3, represents the work done by the modified supercharger which compresses the intake air adiabatically to the discharge pressure. The line AB′ represents the compression line at a

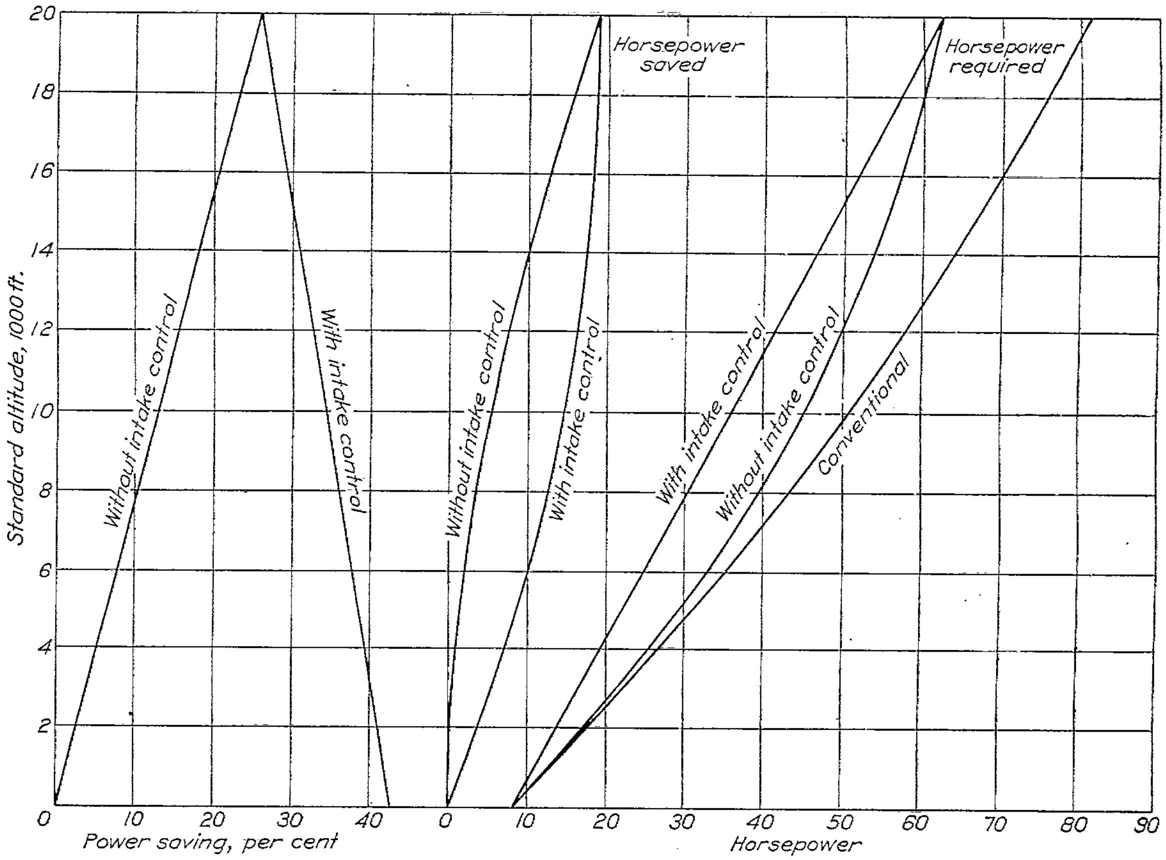

FIG. 4.—The percentage power saving and the power saved for the modified Roots supercharger with and without an intake control and the power required by the modified compared with the conventional

critical altitude of 20,000 feet for a modified Roots supercharger with or without an intake control. For lower altitudes the position where the excess air has escaped from the compression chamber and compression begins moves along the line AB′ to a pressure corresponding to the altitude at which the supercharger is operating.

The percentage power saving computed for altitudes up to 20,000 feet, with and without an intake control, is shown by the curves in Figure 4. For the modified type, without an intake control, the percentage power saving increased from zero per cent at sea level to approximately 26 per cent at 20,000 feet. For the same discharge valves with an intake control the percentage power saving varied from approximately 42 per cent at sea level to 26 per cent at 20,000 feet. The torque curves (fig. 5) show a percentage power saving of 24 per cent at 20,000 feet.

The actual horsepower saved by the use of rotating discharge valves, with and without an intake control, is shown in Figure 4. It will be noted that at the critical altitude the percentage power saved and the actual horsepower saved are the same for operation with or without an intake control.

Figure 4 also shows the power required to drive a conventional supercharger of 0.382 cubic feet displacement per revolution at 5,280 revolutions per minute for altitudes from 0 to 20,000 feet. These power measurements were obtained from laboratory tests. (Reference 4.) Similar curves representing the power required to drive the modified supercharger with and without an intake control and for altitudes from 0 to 20,000 feet are shown for comparison with the conventional supercharger.

DISCUSSION OF RESULTS

The pressure-volume cards shown in Figure 3 and the curves shown in Figures 4 and 5 give interesting information on the possibilities of using discharge valves in Roots type superchargers, the service for which they may be used, and their limitations.

The pressure-volume cards show that as the critical altitude is increased the percentage power saving will be increased, the line AB′ being transferred to the left, the point B′ moving toward C, and the point A moving down to the lower pressure which corresponds to the higher critical altitude. This, however, does not indicate that it would be better to use a 30,000-foot critical altitude supercharger for service in which only a 20,000-foot supercharger is needed because the increased impeller speed of the supercharger for the higher critical altitude would require considerably more power than the increased saving that could be effected on the pressure-volume card. It does, however, indicate that there may be critical altitudes so low that very little if any power saving can be effected.

An examination of the compression chambers of the conventional and the modified Roots superchargers showed that the volume of the compression chamber of the modified supercharger is about 5 per cent greater because of the space around the discharge valves. The difference in the volume caused by this space around the discharge valves has no effect on the results for this method of computing because the energy received during compression by the air trapped around these valves is equal to that given up during expansion on the following cycle. The results presented are based on the volume of a compression chamber of the conventional type supercharger.

A comparison of the results obtained with and without an intake control indicates that very little saving in power can be effected below 10,000 feet without the intake control. The saving of 5½ horsepower at 10,000 feet without the control corresponds to the power saving at 3,000 feet with the control. The intake control is a satisfactory method of limiting the quantity of air compressed because it shows a large saving in power, is simple to operate, and does not weight more than the by-pass valve which it replaces.

The curves shown in Figure 3 representing the power required to drive the modified superchargers are based on laboratory tests of a conventional supercharger operated at a speed of 5,280 revolutions per minute and on the percentage power saving as determined from the pressure-volume cards. In making these computations the friction and charging losses determined experimentally for a conventional supercharger were used for the modified supercharger so that the only losses that have not been considered in these computations are similar losses in the discharge valves. Inasmuch as the diameter of these valves is small compared to the diameter of the rotors, it is believed that the air friction losses would be small.

Figure 5 shows a graphical comparison between the torques determined for a critical altitude of 20,000 feet for a conventional and a modified supercharger. For the conventional supercharger the mean torque is 102-inch pounds as compared with 78-inch pounds for the modified supercharger. This gives a power saving of 24 per cent. It will be noted that the power saving at a critical altitude of 20,000 feet determined from the torque curves checks within 2 per cent of the power saving determined from the pressure-volume cards. The irregularities in the torque curve for the modified supercharger are caused by the expansion of the air trapped around the discharge valves and the change of the point of contact between the valve and the impeller from one side of the impeller to the other side. As soon as the discharge valves have opened, which is at about 80° for one and 170° for the other, the torque curves for the modified and conventional superchargers are the same for the next 10° of impeller rotation.

Several discharge valve arrangements and different driving mechanisms were considered, but nearly all methods tried required a driving mechanism giving a cyclic variation in speed which usually introduced high inertia stresses. From the various discharge valves considered in a general analysis, the rotating valves were selected as the most desirable for the high impeller speeds necessary in aircraft service and the oscillating valve as a desirable substitute for slower speed machines. Though the best discharge valve location and shape has not been definitely determined, a sufficient number of positions were studied to indicate that the location and shape shown in Figure 2 can not be greatly improved. The valves shown restrict the discharge opening, but this is not a serious objection because at sea level the volume inducted is reduced by the amount ordinarily by-passed and at higher altitudes the volume is reduced by compression.

A supercharger equipped with discharge valves should show an appreciable increase in volumetric efficiency when operating at low speeds and a slight increase in volumetric efficiency at high speeds, because the amount of air that slips back between the case and the impellers is reduced. The amount of air that slips back for each revolution of the impellers is a function of the time that the impellers are subjected to the delivery pressure. This time depends on both the speed at which the impellers are rotating and the number of degrees of impeller rotation that the discharge valves prevent the high-pressure air from acting on the impellers. Because the amount of air that slips back between the impellers and case is greater in a slow-speed supercharger than in a high-speed supercharger it is evident that the use of discharge valves will prevent a greater amount of air from slipping back in the slow-speed machine. The volumetric efficiency of the slow-speed supercharger will therefore be increased more than that of the high-speed supercharger.

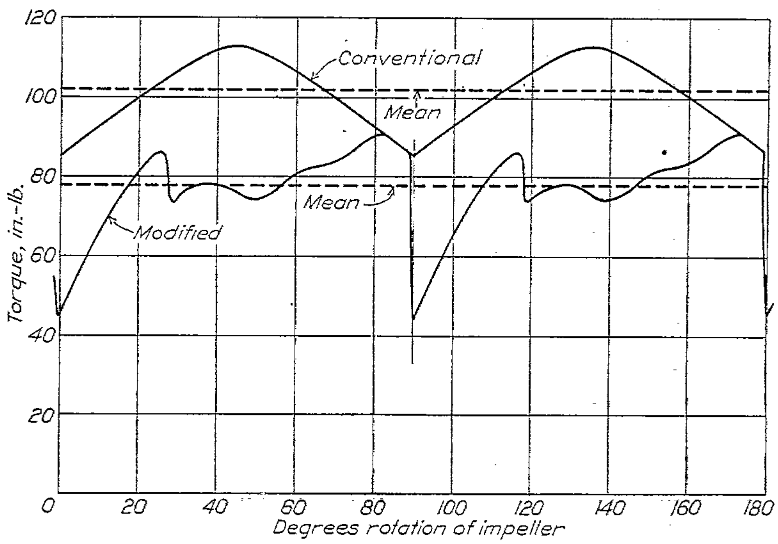

FIG. 5.—Torque curves for conventional and modified N. A. C. A. Roots type supercharger

An estimate was made of the increase in supercharger weight necessary in the application of the rotating discharge valves to the supercharger on which the power computations were based. In this estimate the weight of the discharge valves, counterbalance weights on the valves, increase in the length of the supercharger case, increase in length of the impeller shaft, valve gears, and bearings were considered. The increase in weight was estimated to be 17 pounds. Thus, a saving of approximately 20 horsepower may be obtained at a critical altitude of 20,000 feet by adding discharge valves which increase the weight of the supercharger approximately 17 pounds.

CONCLUSION

The results of this investigation show that the power saving varies from approximately 42 per cent at sea level to 26 per cent at 20,000 feet altitude by the use of discharge valves and an intake control in a conventional Roots type supercharger. Without the intake control the power saving will vary from 0 per cent at sea level to 26 per cent at 20,000 feet. These valves will reduce the discharge pulsations, because there is only a slight back flow of air, and will increase the volumetric efficiency by reducing the amount of air that slips back between the impellers and case.

For slow-speed Roots compressors operating at high-pressure differences the discharge valves will effect a saving in power greater than 26 per cent and also show a larger increase in volumetric efficiency than that obtained for high-speed compressors.

The application of these discharge valves to aircraft engine superchargers requires a consideration of the disadvantages of increasing the weight and of adding a mechanism operating at high speed to a simple machine.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *June 29, 1928.*

BIBLIOGRAPHY

Reference 1. Gardiner, Arthur W., and Reid, Elliott G.: Preliminary Flight Tests of the N. A. C. A. Roots Type Aircraft Engine Supercharger. N. A. C. A. Technical Report No. 263 (1927).

Reference 2. Ware, Marsden, and Schey, Oscar W.: A Preliminary Investigation of Supercharging an Air-Cooled Engine in Flight. N. A. C. A. Technical Report No. 283 (1928).

Reference 3. Ware, Marsden: Description and Laboratory Tests of a Roots Type Aircraft Engine Supercharger. N. A. C. A. Technical Report No. 230 (1926).

Reference 4. Ware, Marsden, and Wilson, Ernest E.: The Comparative Performance of Roots Type Aircraft Engine Superchargers as Affected by Changes in Impeller Speed and Displacement. N. A. C. A. Technical Report No. 284 (1928).