NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 263

PRELIMINARY FLIGHT TESTS OF THE N. A. C. A. ROOTS TYPE AIRCRAFT ENGINE SUPERCHARGER

By ARTHUR W. GARDINER and ELLIOTT G. REID

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		{km/hr		mi./hr	M. P. H.
		{m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

REPORT No. 263

PRELIMINARY FLIGHT TESTS OF THE N. A. C. A. ROOTS TYPE AIRCRAFT ENGINE SUPERCHARGER

By ARTHUR W. GARDINER and ELLIOTT G. REID
Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

3341 NAVY BUILDING, WASHINGTON, D. C.

[An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. It consists of twelve members who are appointed by the President, all of whom serve as such without compensation]

REPORT No. 263

PRELIMINARY FLIGHT TESTS OF THE N. A. C. A. ROOTS TYPE AIRCRAFT ENGINE SUPERCHARGER

By Arthur W. Gardiner and Elliott G. Reid

SUMMARY

An investigation of the suitability of the N. A. C. A. Roots type aircraft engine supercharger to flight-operating conditions, as determined by the effects of the use of the supercharger upon engine operation and airplane performance, is described in this report.

The supercharger has been previously described in N. A. C. A. Technical Report No. 230; the results of laboratory tests are also given there. The compressor has a displacement of 0.51 cubic foot per revolution and weighs 88 pounds.

The selection of a suitable propeller and the provision of satisfactory intake ducts and adequate engine cooling were preliminary problems. The supercharger was first tested in a modified DH–4 airplane with a 5.4 compression ratio Liberty–12 engine. Two sets of drive gears which enabled the maintenance of sea-level pressure at the carburetor intake up to 12,000 and 20,000 feet were provided. The higher gear ratio supercharger was next tested in a DT–2 landplane which was later converted to a twin-float seaplane; the DT–2 also had a Liberty engine. Loads up to 2,000 pounds were carried in the seaplane with normal and supercharged engines.

Attention was concentrated on the operation of the engine-supercharger unit and on the improvement of climbing ability; some information concerning high speeds at altitude was obtained.

The supercharger was found to be satisfactory under flight-operating conditions. Although two failures occurred during the tests, the causes of both were minor and have been eliminated. Careful examination of the engines revealed no detrimental effects which could be attributed to supercharging.

Marked improvements in climbing ability and high speeds at altitude were effected. It was also found that the load which could be carried to a given moderate or high altitude in a fixed time was considerably augmented. A slight sacrifice of low-altitude performance was necessitated, however, by the use of a fixed-pitch propeller.

From a consideration of the very satisfactory flight performance of the Roots supercharger and of its inherent advantages, it is concluded that this type is particularly attractive for use in certain classes of commercial airplanes and in a number of military types.

INTRODUCTION

The function of an aircraft engine supercharger is to prevent or reduce the diminution of power output which is experienced with engines of the conventional type as altitude is gained and the air pressure and density are correspondingly reduced. This is effected by compressing the air charge before it enters the engine cylinders.

It is known that the performance of an airplane at altitude may be improved by the addition of a supercharger to the power plant. Improvements in climbing ability and in maximum speed at altitude have the greatest practical importance. However, these practical advantages have not become generally appreciated. The mere attainment of extreme altitudes

40270—27——1

is of little importance except under special and unusual circumstances. Moreover, the maximum altitude to which an airplane can climb is not a measure of its performance at lower altitudes. In fact, the provision of supercharger and propeller equipment suitable for flight at very high altitudes occasions a reduction of the performance at lower altitudes.

The potentialities of a special Roots type blower as an aircraft engine supercharger have been dealt with in Reference 1. The laboratory tests described therein led to the conclusion that this type of blower could be advantageously used to effect improvements in the important characteristics mentioned above because its outstanding features are high efficiency, durability, mechanical simplicity, and small power requirements at low altitudes.

This report deals with the first flight tests of the Roots type supercharger in conjunction with standard Liberty engines of 5.4 compression ratio. The purpose of the investigation was to ascertain the suitability of the supercharger to flight-operating conditions, to observe the effect of supercharging on engine operation, and to determine, in a preliminary way, what improvements in airplane performance may be effected by this means.

INSTALLATION AND PRELIMINARY TRIALS

The principal features of the experimental installation of the Roots type supercharger in conjunction with a Liberty engine are illustrated by Figure 1; the airplane is a DT–2 landplane. The supercharger is mounted on the engine bearers and is driven by the crank shaft through a flexible coupling. Below the supercharger are the intake ducts which open outside the engine cowling; directly above it is the cylindrical receiver which, though used in these tests, has been subsequently found unnecessary. There are two outlets from this receiver. One is the short open-end pipe which will be seen on the top of the receiver; a butterfly valve in this pipe is the supercharger control. The other is the duct which extends along the top of the engine and communicates with the intake passages of the carburetors (inverted Stromberg, Model NAL–5A). The pressure in this duct depends on the amount of air which is allowed to escape into the atmosphere through the by-pass valve. Attached to the underside of the duct, just behind the rear carburetor, is the auxiliary air-intake valve. This is a large spring-loaded, poppet valve which was used in the experimental work to insure continuous engine operation in the event of supercharger failure with the by-pass valve closed.

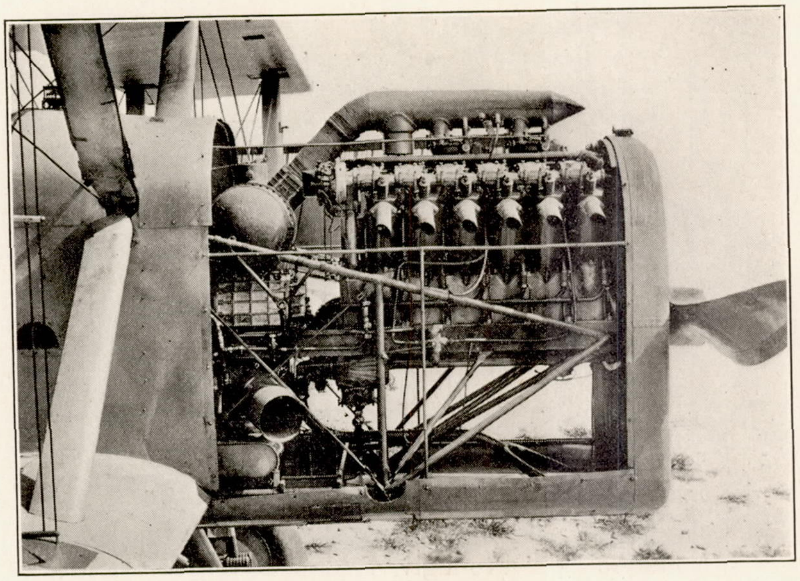

FIG. 1

The fuel system is necessarily somewhat different from that used on unsupercharged engines. Wind-driven fuel pumps were used on both the DH–4 and DT–2 airplanes. The ordinary spring-loaded fuel pressure relief valve is replaced by a spring-loaded Sylphon valve (fig. 3.); the pressure on the fuel supplied to the carburetors is made to exceed that of the air entering the carburetors by the amount of the spring load, regardless of atmospheric pressure, by providing an air line which connects the Sylphon to the carburetor duct. The usual mixture-control mechanism, which, in the Stromberg carburetor, is a valve through which atmospheric air is admitted to the float chamber, is replaced by a valve in a short air line of relatively large diameter which leads from the carburetor duct to the float chamber. Free flow through this line is necessary for the instantaneous balancing of pressures.

An ordinary Bourdon tube gage is used to indicate the differential fuel pressure. The Bourdon tube is connected to the fuel supply line and an air line is led from the carburetor duct to the gage case which is carefully sealed. The carburetor air pressure, or amount of supercharging, is indicated by an altimeter of the aneroid type; its ordinary atmospheric vent is connected by a tube to the carburetor duct and its case is also sealed to prevent leakage into the atmosphere. To maintain sea-level pressure at the carburetors, the pilot has but to regulate the by-pass valve until the sealed altimeter indicates zero.

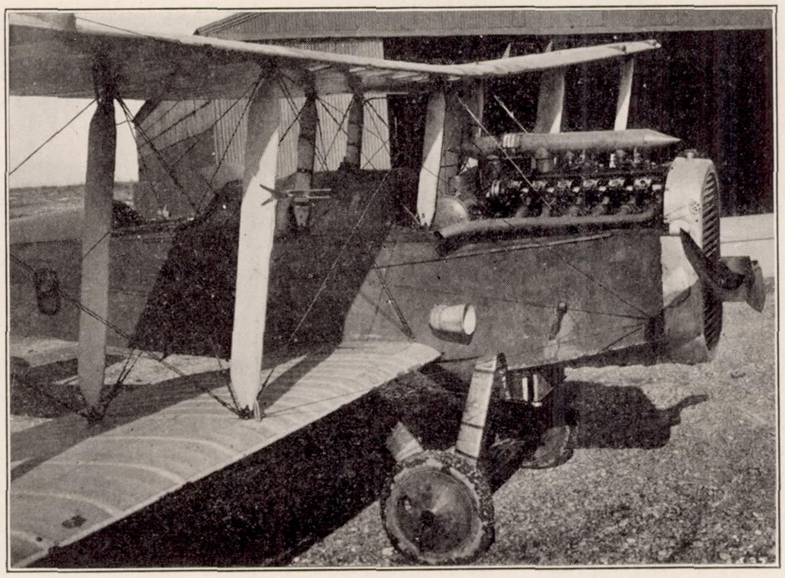

FIG. 2

A threaded rod, which could be pulled or screwed through a fitting which was anchored in the pilot's instrument board, was provided for the regulation of the supercharger by-pass valve. A hand lubricator was used to provide the necessary oil. These features are, of course, characteristic of experimental installations only, as a combined engine throttle and by-pass control and lubrication by the engine oiling system would be incorporated in a service installation.

A complete description of the supercharger is given in Reference 1; its displacement was 0.51 cubic foot per revolution and the rotor speed was 1.5 times crank-shaft speed. The supercharger was first installed in a modified DH–4 airplane. Air was taken directly into the compressor from the engine section; no supercharger intake header was used. This arrangement was found to be unsatisfactory as the "critical altitude" (maximum altitude at which sea-level pressure can be maintained at the carburetors) obtained in flight was much less than that predicted from the results of laboratory tests. Removal of the bottom cowling of the engine section produced very little improvement. Satisfactory operation was first obtained with the forward opening scoops shown in Figure 2. The ducts were later modified to the form which may be seen in Figure 1, which was also satisfactory.

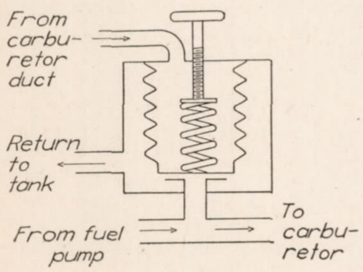

FIG. 3

The selection of a suitable propeller was the next problem encountered. Propellers designed for use on normal Liberty engines would not limit the speed of the supercharged engine to the arbitrary "maximum allowable R. P. M." with the airplane in level flight at any considerable altitude. Propellers for higher-powered engines which might have been suitable for this work were not available. A propeller designed for use on the supercharged Liberty engines of Martin bombers was obtained and found to meet the requirements reasonably well. Its pitch and diameter are 6.35 feet and 10.67 feet, respectively.

It had been anticipated that the radiator provided for the normal engine would be insufficient for the supercharged engine at high altitudes. Such was found to be the case and a booster radiator was connected in series with the nose radiator. (See fig. 2.) When, in later tests, the supercharger was fitted with a drive of higher gear ratio, thus increasing the critical altitude, the radiation was further augmented by the substitution of a pressure-type nose radiator having a slightly deeper core than that of the normal one.

TESTS

The preparatory work on the DH-4 was followed by tests of the supercharger with two drive gear ratios, 1.5 and 1.94, in that airplane. Comparative tests were then made with a DT-2 landplane equipped with normal and supercharged engines; a 1.94 drive gear ratio supercharger was used. The work was concluded by making a series of similar comparative tests on the DT-2 seaplane with nominal useful loads up to 2,000 pounds. The 1.94 drive ratio was used for these tests, but the performance characteristics of the seaplane were such that the critical altitude of the supercharger-engine unit was attained only in the flight with no load.

The principal characteristics of the DH-4 and DT-2 airplanes are given in Appendix I. Incidental information including weights, propellers used, etc., is also given.

Attention was concentrated on the climbing characteristics of the airplanes throughout this work. Determinations of maximum speed were made only in the case of the DH-4 with the 1.5 ratio supercharger. In all landplane tests, the climbs were carried above the critical altitude of the supercharger but only a few were extended far toward the absolute ceilings of the airplanes because of the small importance of this particular characteristic.

Continuous climbs were made rather than resorting to the "saw-tooth" method, which is frequently used in determining the climbing characteristics of an airplane. The former method was adopted in order that the results might be representative of service operating conditions, rather than ideal ones which can not be duplicated in service, and to demonstrate the adequacy of the engine-cooling system under the most severe conditions to be met in service. This demonstration is not conclusive if the saw-tooth method is used because the duration of engine operation at maximum output is very short and there is a considerable lag between the variations of engine output and cooling-water temperature.

Considerable information relating to the conditions of engine operation and the data required for the reduction of the performance to standard atmospheric conditions were obtained.

RESULTS

The supercharger was found to be mechanically satisfactory under flight operating conditions. Smooth engine operation was obtained with all degrees of supercharging.

No indication was found that the use of this type of supercharger is more injurious to the engine than is full throttle, unsupercharged operation near sea level. Valves, spark plugs, and pistons were in as good condition as would be expected after an equal period of full throttle operation of the normal engine at low altitude.

The results of the flight tests are presented in graphical form in Figures 4 to 9. Lesley's method (Reference 2) was used for the reduction of the flight data to the conditions of the standard atmosphere.

DISCUSSION

The curves of Figures 4, 5, and 7, picture the conditions under which the supercharged engine operates. A few general comments relative to the curves themselves are inserted to preface the discussion of this information.

It may be noted that the curve of carburetor air pressure in Figure 4 has fewer irregularities than those of Figures 5 and 7; this difference is the result of less frequent observations having been made in first tests than in the later ones during which recording instruments were carried in place of an observer. The curve of carburetor air temperature is omitted from Figure 4 because it was discovered, some time after completion of the tests, that the thermometer readings were erroneous. Erratic behavior of the strut thermometer at low temperatures gave rise to the double curves of Figure 5. It was found that the readings of this thermometer were unreliable below $-22°$ F. The continuous curve of atmospheric temperature passes through the observed points; the broken curve is extended, from the last reliable point, parallel to the curve of temperature versus altitude for the standard atmosphere. The other curves of this figure have been correspondingly modified and are shown as broken lines.

Upon inspection of the carburetor air-pressure curves of Figures 4, 5, and 7, it may be seen that sea-level pressure is approximately maintained up to considerable altitudes and that

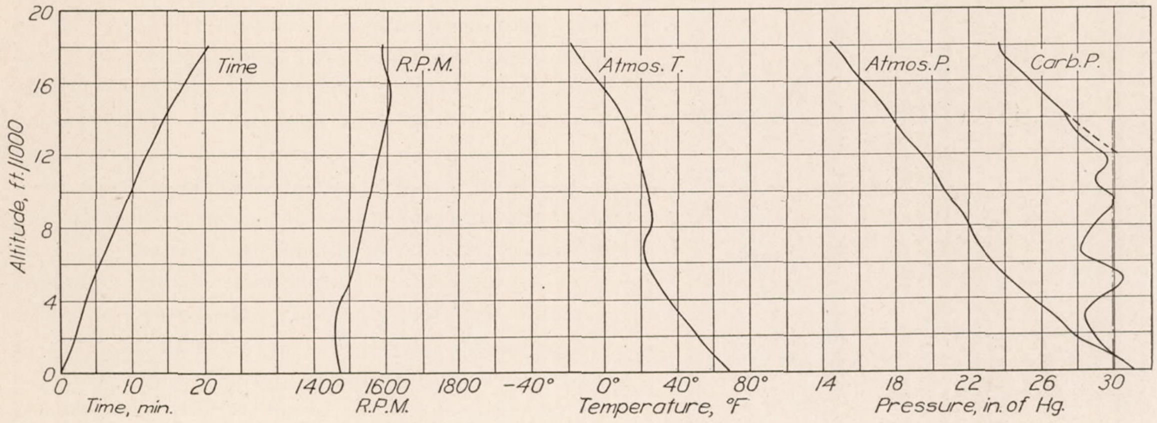

FIG. 4. —DH-4 with 1.5 gear ratio supercharger

beyond the point at which this is possible the pressure at the carburetor stays well above atmospheric pressure. The intersection of the sloping upper branch of the curve, which represents operation with the supercharger by-pass valve completely closed, with the sea-level pressure line defines the critical altitude of the engine-supercharger unit. The effect of changing the drive gear ratio of the supercharger is evident in the difference between the critical altitudes shown in Figures 4 and 5.

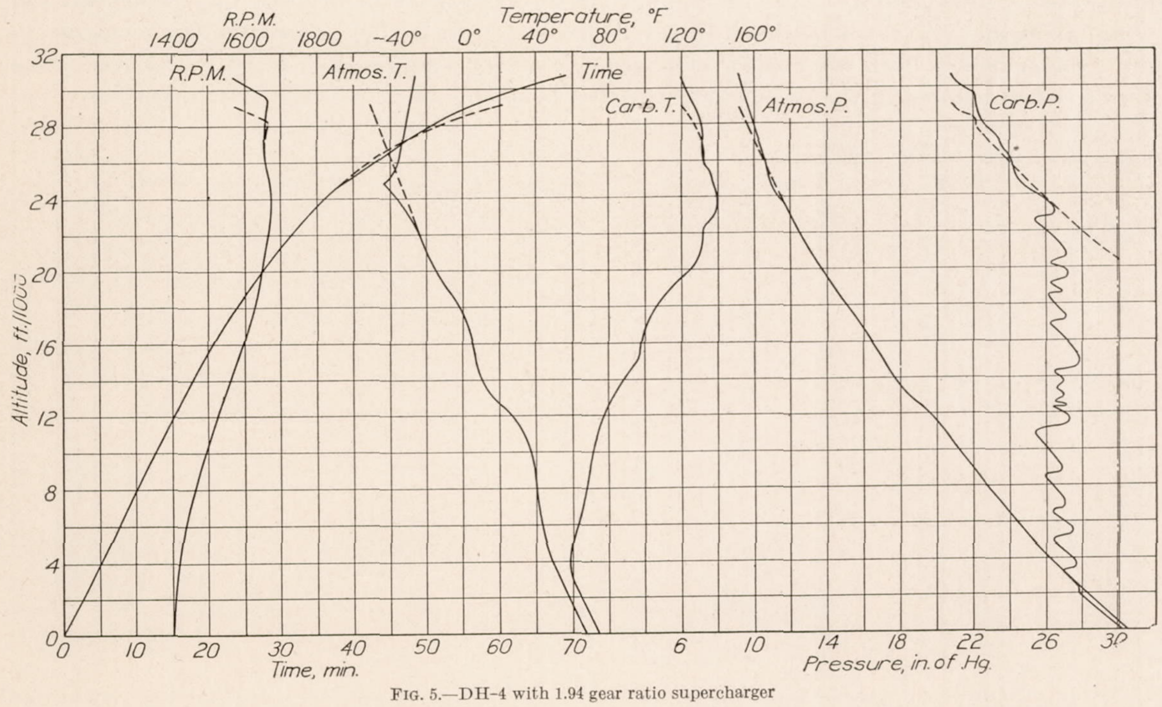

FIG. 5.—DH-4 with 1.94 gear ratio supercharger

The carburetor air temperatures (figs. 5 and 7) are of particular interest from the stand point of engine operation. These temperatures differ very little from the atmospheric temperatures at low altitudes. This condition is a result of using the by-pass method of control as, at the low altitudes, there is very little compression of the air passing through the supercharger.

At higher altitudes the carburetor air temperatures increase with the amount of compression and reach a maximum near the critical altitude, but do not reach excessive values because of the low atmospheric temperatures. Knowledge of this fact prompted the very desirable omission of the usual air intercooler from the experimental installations, thus saving considerable weight and parasite resistance. However, the temperatures at the carburetors are abnormal at high altitudes and, to combat the increased tendency for detonation under this condition, a 30–70 benzol-gasoline blend was used as fuel during the tests made with the DH–4. Plain domestic aviation gasoline was used in the DT–2 tests, but no unusual detonation was encountered. It has been found in subsequent laboratory tests that the normal Liberty engine suffers a loss of power which is caused by detonation even at ordinary inlet temperatures when straight gasoline is used as fuel. However, as inlet temperatures increase, the ratio of the power obtained with gasoline to that obtained with the 30–70 benzol-gasoline blend remains practically constant. From these results, it appears that the Roots supercharger with a critical altitude of at least 20,000 feet may be satisfactorily used without an air intercooler and without resorting to the use of special fuels.

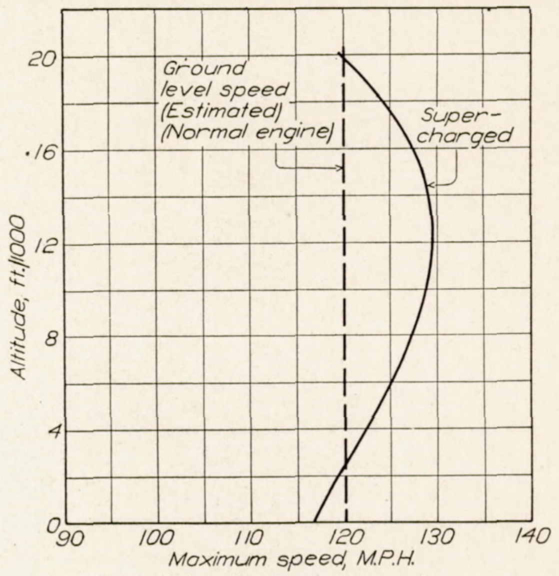

FIG. 6.—DH–4 with 1.5 gear ratio supercharger

It had been anticipated that this type of supercharger would be unusually free from mechanical troubles in flight. However, as an extra precaution, the clearances between rotors, and between rotors and case, were enlarged from the average value of 0.006 inch which existed during laboratory tests to 0.009 inch before flight tests were begun. Two failures occurred in flight; the causes of both were easily elimated. The first failure was caused by seizure of the rotors against one end of the case which resulted from the use of a brass part in the assembly

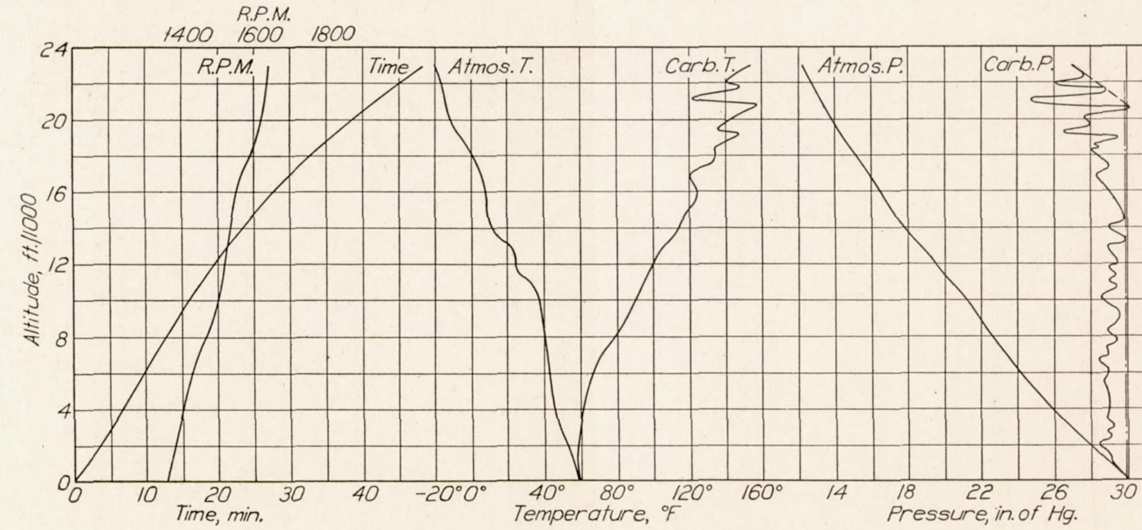

FIG. 7.—DT–2 landplane with 1.94 gear ratio supercharger

used for maintaining endwise location of the rotors. This part has been replaced by a similar one of hardened steel. The second failure was brought about by improper operation; the engine was partially throttled while the supercharger by-pass valve was closed. This gave rise to very high pressures and excessive heating in the system and consequent damage to the supercharger. A combined engine throttle and by-pass valve control which makes it impossible to throttle the engine while supercharging has been found satisfactory. This system of control would be suitable for service operation.

With the incorporation of this form of control and the maintenance of proper compression chamber clearances, the Roots type supercharger should have greater durability than that of any existing aircraft engine, because the only wearing parts are moderately loaded gears and ball bearings.

Some representative examples of the improvements of airplane performance which are made possible by the use of the supercharger are illustrated by Figures 6, 8, and 9.

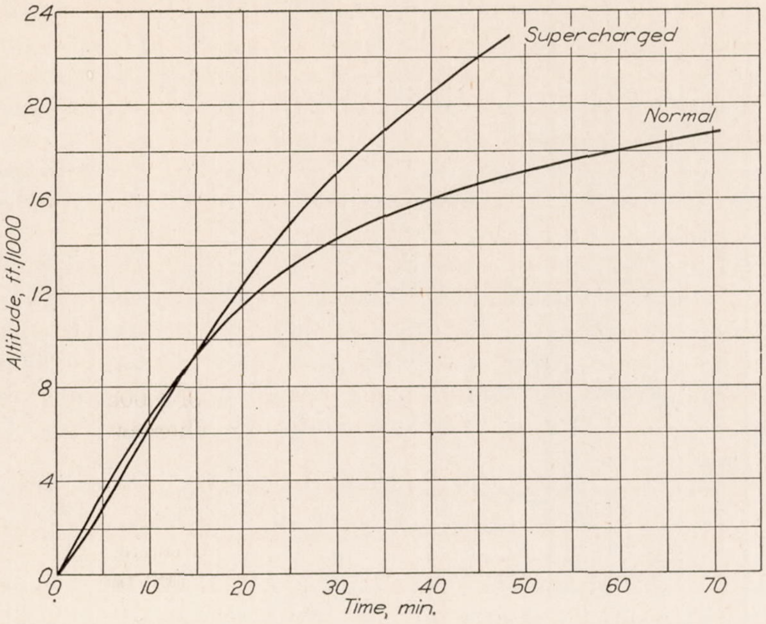

FIG. 8.—DT-2 landplane—normal and supercharged (1.94 gear ratio) engines

Let us consider the time required to reach given altitudes and the rates of climb at various heights. In the case of the DT–2 landplane without useful load (fig. 8), the use of the supercharger results in reducing the time required to reach altitudes in excess of 9,000 feet, but for lower altitudes the time required with the supercharged engine is slightly greater.

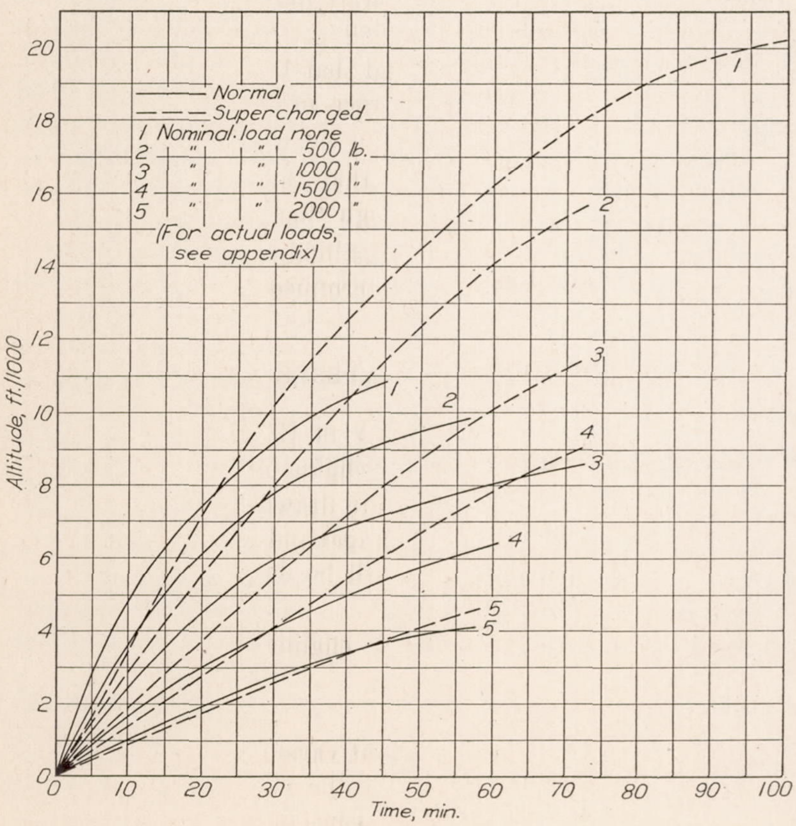

FIG. 9.—DT-2 seaplane—normal and supercharged (1.94 gear ratio) engines

At this point attention is called to the fact that the initial inferiority of the supercharged engine is also evident, although to a smaller degree, in both rates of climb and maximum horizontal speeds. (See fig. 6.) This is the result of having to fit the supercharged engine with a propeller which will limit the engine speed in level flight at high altitudes to the arbitary "maximum allowable R. P. M." stipulated for the unsupercharged engine. Consequently, at low altitudes, the engine speed and power output are limited to relatively low values by the heavy propeller load. (Note the maximum values of R. P. M. in Figures 4, 5, and 7.)

Returning to the consideration of the D T–2 time-altitude curves, it is interesting to see that the initial inferiority of the supercharged engine disappears at about 3,500 feet altitude. That is to say, as the curves are parallel at that height, the rates of climb are the same with both types of engine. Above that altitude, the advantage of supercharging increases. As a rather extreme example, the normal DT–2 climbs to 18,000 feet in 59.5 minutes while with the supercharged engine it reaches the same altitude in 32.5 minutes; the time is reduced by 45 per cent. For the climb from 5,000 to 15,000 feet, the reduction is from 26.5 to 17.1 minutes, or 35 per cent. Corresponding figures for 10,000 to 18,000 feet are 43.1 and 16.7 minutes, a reduction of 61 per cent.

It has been mentioned above that in the case of the DT–2 landplane with no useful load, improved rates of climb are obtained above 3,500 feet altitude by using the supercharged engine. By comparing the slopes of the curves of Figure 8, it is found that equal rates of climb are obtained at 5,000 and 10,000 feet with normal and supercharged engines, respectvely. Extending the comparison to higher altitudes, it will be seen that supercharging makes it possible for the DT–2 to climb as rapidly at 23,000 feet as it can at 13,000 feet with the normal engine.

The consideration of the time required to reach given altitudes is also of particular interest in the case of an airplane carrying a considerable useful load. The curves of Figure 9 are illustrative of the advantages of supercharging in this case. Let us compare the time-altitude curves corresponding to a nominal useful load of 1,000 pounds. With the normal engine, one hour is required for the climb to 8,000 feet, whereas only 45 minutes are required when the engine is supercharged. With the normal engine, a rate of climb of 100 feet per minute can not be maintained above 6,300 feet altitude, while the corresponding limit with the supercharged engine was 11,500 feet. Attention is also called to the fact that the time-altitude curves corresponding to nominal useful loads of 500 and 1,000 pounds with the normal and supercharged engines, respectively, intersect at about 10,000 feet altitude.

One of the most important assets of the airplane having a supercharged power plant is its ability to maintain, at high altitudes, speeds in excess of the maximum attainable at ground level without the supercharger. This characteristic is illustrated by Figure 6, which refers to the DH–4 landplane fitted with the 1.5 gear ratio supercharger. The highest speed is attained at 12,000 feet, which is approximately the critical altitude. Accurate determinations of maximum horizontal speed were not made while this airplane was fitted with the supercharger of larger capacity but, from the few observations made, it is believed that 140 M. P. H. could be attained at the critical altitude of the 1.94 gear ratio supercharger, or approximately 20,000 feet. The estimated sea level maximum speed shown in Figure 6 for the unsupercharged DH–4 is believed to be slightly optimistic as it is considerably higher than the best value obtained with the airplane used in these tests; it should be mentioned though that a somewhat unsuitable propeller, the Liberty "club," was used for this test. The estimated speed was selected as a compromise between the speed actually obtained and that determined with a DH–4 Corps observation airplane at McCook Field.

ADVANTAGES AND LIMITATIONS OF ROOTS TYPE SUPERCHARGER

The preceding discussion has been limited to the suitability of the Roots type supercharger to flight-operating conditions and the effects of its use on engine operation and on the performance of representative airplanes. It seems advisable before drawing any general conclusions relative to the merits of the type, to set forth the advantages and limitations inherent in its application. The following questions are pertinent and will be discussed in the order stated below:

How will the reliability and durability of a normal airplane engine be affected by the addition of a supercharger of this type?

How much weight will be added?

How much power will be required to drive the supercharger at various altitudes?

Can the engine be operated with or without supercharging at the will of the pilot and, if so, to what extent is the normal operation complicated by the presence of the supercharger?

Is it necessary to build entirely different superchargers to meet different operating conditions or for engines of different displacements operating under like conditions?

How complicated is the control of the supercharged engine?

To what extent must the aerodynamic characteristics of the airplane be modified to accommodate the supercharger?

How is airplane performance improved or impaired by the use of the supercharger?

RELIABILITY AND DURABILITY

A positive drive through a system of amply proportioned parts is provided for the supercharger. A simple fabric coupling gives satisfactory protection against possible damage by angular accelerations. As the only wearing parts are moderately loaded gears and ball bearings, pure mechanical failure within a life equal to that of an airplane engine is improbable in a Roots type supercharger having adequate compression chamber clearances. Maltreatment of the supercharger can be prevented and possible failure averted by the use of the combined throttle and by-pass control. It appears that the reliability and durability of a present-day airplane engine when equipped with a properly designed Roots type supercharger will be in no way inferior to those of the same engine under the conditions of unsupercharged, full load operation.

WEIGHT

The compressor unit which was used in the present tests weighed 88 pounds. The total weight chargeable to the supercharger installation in the DH–4, exclusive of the weight of the added radiator, was 185 pounds. This figure includes the weights of the supercharger complete with intake pipes, receiver, ducts, and drive coupling, and of all attachment fixtures. In the case of the DT–2, the total weight of the supercharger installation was reduced to 166 pounds; no additional radiator had to be provided, as removal of the top engine cowling gave sufficient cooling. (The figures given in Appendix I indicate a difference of 191 pounds between the normal and supercharged engine weights. This apparent discrepancy was brought about by the substitution of instruments for an observer and the addition of oxygen equipment.) It must be considered that these weights represent the weights added in experimental adaptations to normal power plants. It is conservatively estimated that a 400-horsepower V-type engine can be fitted with a Roots type supercharger giving a critical altitude of at least 20,000 feet without adding more than 110 pounds plus the weight of the addition to the engine cooling system that may be required. Further reductions could be obtained in a power plant designed to incorporate the supercharger as an integral part. While the value 110 pounds, or 0.275 pound per horsepower, may seem somewhat excessive, the values of weight per horsepower with and without supercharging, at 20,000 feet altitude illustrate the advantage of the supercharged engine. Consider a 400-horsepower engine which weighs 600 pounds dry. At 20,000 feet it will develop not more than 200-horsepower; the weight per horsepower is 3 pounds. When supercharged, the engine will develop its full 400-horsepower at 20,000 feet, and the weight per horsepower becomes 1.775 pounds. For larger V-type engines, the value 0.275 pound per horsepower can be improved, while for radial engines the supercharger installation will weigh less than that for a V-type of the same power.

POWER REQUIRED

The power required to drive either the 1.5 or the 1.94 gear ratio supercharger at sea level is less than 5 horsepower; at the critical altitudes of 12,000 and 20,000 feet, the requirements are 33 and 60 horsepower. Between these points, the power required varies linearly with the pressure difference across the supercharger. Above the critical altitude the supercharger will operate at an approximately constant pressure ratio. The pressure difference across the supercharger will therefore decrease as altitude increases and the power required will decrease with the pressure difference.

FLEXIBILITY

The supercharger can be made inoperative as such and its power requirement reduced to practically that of friction alone at any time in flight; the engine will continue to operate as it would without a supercharger. No complicated manipulation of controls is involved; the supercharger bypass valve has merely to be opened.

ADAPTABILITY

A single Roots type supercharger may be adapted to various conditions of operation, i. e., to supercharge a given engine to various critical altitudes or to supercharge engines of various displacements to the same critical altitude, by merely changing the drive gear ratio.

CONTROL

The supercharger has but one control—a by-pass valve on the delivery side. The combined form of control which has been designed for service installations is a linkage by which the forward movement of a lever successively opens the carburetor throttle and closes the supercharger by-pass valve. In operating the control, to which the engine responds instantly, the pilot refers to a sealed altimeter which indicates the altitude corresponding to the pressure of the air entering the carburetor. This altimeter serves principally as a danger signal; any throttle setting which does not give rise to a subsea level pressure is permissible.

AERODYNAMICS

As a suitable supercharger delivery duct can be inclosed, in most cases, within the normal engine cowling, the use of a supercharger involves only two questions of aerodynamics. The first and least important one is that of engine cooling. It is necessary to provide more cooling capacity for the supercharged water-cooled engine than is necessary for the normal one. The amount of this excess varies with the critical altitude of the engine-supercharger unit, but is rather small in any case. If the critical altitude is 20,000 feet, it will be necessary to augment the cooling capacity by approximately 10 per cent. This is not a serious item when the drag of the entire airplane is considered. The use of a retractable radiator for at least part of the cooling is suggested.

The most serious limitation of the usefulness of the supercharged power plant is imposed by the use of a propeller suitable for high altitude level flight. A small sacrifice of performance at low altitudes is unavoidable so long as propellers of fixed pitch must be used, unless it is permissible to overspeed the engine in level flight at high altitudes, i. e., to increase the engine speed above the "maximum allowable R. P. M." fixed for normal operation.

AIRPLANE PERFORMANCE

It has been demonstrated in the tests which are described above that the use of the Roots type supercharger materially improves the rates of climb of an airplane with a given engine and brings about marked reductions of the time required to reach high altitudes. It enables the attainment of higher speeds, throughout a considerable range of altitudes, than are possible with the unsupercharged power plant at any altitude and also augments the useful load which may be carried to a given altitude in a fixed time.

The price of these advantages is a small sacrifice of low-altitude performance, but this is far outweighed by the gains realized. It must be added that if an airplane is so heavily loaded that its ceiling is relatively low even when the engine is supercharged, the relative advantage of supercharging decreases. The effect of supercharging the engine of a given airplane upon the radius of action at altitude has not been investigated as yet but it is expected that the over-dimensioned engines with supercompression will find their greatest usefulness and probably be somewhat superior to supercharged engines at moderate altitudes because of their characteristic economy.

CONCLUSIONS

The N. A. C. A. Roots type supercharger for aircraft engines is satisfactory under flight operating conditions and its use enables the realization of greatly improved climbing performance and the attainment of speeds in excess of the normal sea level maximum throughout a considerable range of altitudes. A slight sacrifice of low-altitude performance results from the use of a fixed pitch propeller suitable for high-altitude flight.

This supercharging equipment, as compared with other types, is efficient, simple, and durable; it is readily adaptable to diversified operating conditions, and may be successfully used without an air intercooler and, for moderate amounts of supercharging, without resorting to special fuels; it effects its purpose with a minimum of harm to the engine.

The advantages of this type of supercharger make it particularly attractive for use in certain classes of commercial airplanes and in a number of military types.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD VA., *December 29, 1926.*

APPENDIX I

DH-4 AIRPLANE

This airplane has been termed the DH–4 throughout the report because it is not a standard DH–4B Corps Observation airplane although it resembles the latter more than it does the original DH–4. The wing cellule, tail surfaces, and landing gear are those of the DH–4B except in the detail of wheels and tires; these were of the small size used on the DH–4. The fuselage is externally that of a DH–4B except that the pilot and observer are seated in a single long cockpit; the inside arrangement is slightly different because the engine compartment had to be lengthened to accommodate the supercharger. However, the resulting position of the center of gravity was such that satisfactory longitudinal balance was obtained by small changes of rigging and adjustment of the horizontal stabilizer.

The principal characteristics of the airplane are:

Span (both wings)	42.46 feet
Chord (both wings)	5.5 feet
Gap	5.5 feet
Stagger	1 foot
Dihedral (both wings)	3 degrees
Total wing area	440 square feet
Engine, Liberty–12, 420 horsepower at	1,700 R. P. M.
Flying weight with supercharger	3,960 pounds.
Propeller	Martin Bomber (Supercharger).
Air Service Part No. 065323.	
Diameter	10.67 feet
Pitch	6.35 feet

DT-2 LANDPLANE

This is a service type airplane. The only changes which had to be made were lengthening of the engine compartment and extending the engine bearers. The principal characteristics are:

Span (both wings)	50.0 feet.
Chord (both wings)	7.5 feet.
Gap (at center)	8.5 feet.
Stagger	None.
Dihedral (lower only)	2 degrees.
Total wing area	707 square feet.
Engine, Liberty–12, 420 horsepower at	1,700 R. P. M.
Flying weight—normal	5,020 pounds.
Flying weight—supercharged	5,211 pounds.
Propeller—normal—DT–2:	
Navy Drawing No. X–4987.	
Diameter	10 feet.
Pitch	5.13 feet.
Propeller—supercharged. Same as for DH–4.	

DT-2 SEAPLANE

Same airplane as above with landing gear replaced by twin floats. The total flying weights and the useful loads carried were:

Nominal useful load	Actual disposal load carried[1]		Gross weight	
	Normal	Super-charged	Normal	Super-charged
	Pounds	*Pounds*	*Pounds*	*Pounds*
None	234	203	6,021	6,159
500 pounds	609	601	6,396	6,557
1,000 pounds	1,109	1,101	6,896	7,057
1,500 pounds	1,609	1,601	7,396	7,557
2,000 pounds	2,109	2,101	7,896	8,057

[1] Disposal load is obtained by subtracting the weight of the airplane with fuel, oil, water, and pilot (and supercharging equipment when used) from the gross weight.

For these tests the long-distance cruising type fuel tank, which is similar to a torpedo in shape and size, was slung in the torpedo tunnel in the underside of the fuselage. Water loads were carried in this tank.

The standard DT-2 propeller (X-4987) was used for all flights with the normal engine. The supercharged engine was equipped with a Martin bomber supercharger propeller (065323) which had been cut down to 10.33 feet diameter for the flight with zero nominal useful load. A plain Martin bomber propeller (Air Service part No. 047815, diameter 10.33 feet, pitch 5.74 feet) was used in the other load tests.

BIBLIOGRAPHY

REFERENCE 1. WARE, MARSDEN. Description and Laboratory Tests of a Roots Type Aircraft Engine Supercharger. N. A. C. A. Technical Report No. 230, 1925.

REFERENCE 2. DIEHL, WALTER S., and LESLEY, E. P. The Reduction of Airplane Flight Test Data to Standard Atmosphere Conditions. N. A. C. A. Technical Report No. 216, 1925.

GARDINER, ARTHUR W. A Roots Type Aircraft Engine Supercharger. Journal of the Society of Automotive Engineers, September, 1926.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
10 CENTS PER COPY
▽