NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 327

THE EFFECT OF SUPERCHARGER CAPACITY ON ENGINE AND AIRPLANE PERFORMANCE

By O. W. SCHEY and W. D. GOVE

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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 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.

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55322—29 U. S. GOVERNMENT PRINTING OFFICE: 1929

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

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SUMMARY

Supercharging has already demonstrated its value as a means of improving the performance of an airplane at moderate and high altitudes. In order to obtain a maximum increase in the performance of an airplane designed to meet definite service requirements, it is necessary that a supercharger of the proper capacity be selected.

The effect of different supercharger capacities on the performance of an airplane and its engine was investigated by the staff of the National Advisory Committee for Aeronautics at Langley Field, Va. The tests were conducted on a DH4–M2 airplane powered with a Liberty 12 engine. In this investigation four supercharger capacities, obtained by driving a Roots type supercharger at 1.615, 1.957, 2.4, and 3 times engine speed, were used to maintain sea level pressure at the carburetor to altitudes of 7,000, 11,500, 17,000, and 22,000 feet, respectively.

The performance of the airplane in climb and in level flight was determined for each of the four supercharger drive ratios and for the unsupercharged condition. The engine power was measured during these tests by means of a calibrated propeller.

Although the results of this investigation are not conducive to general conclusions as to the proper capacity or type of supercharger for use with all types of airplanes, the information collected on the variation with altitude and supercharger capacity of such factors as carburetor air temperatures, power required to drive the supercharger, and the net engine power is of value as a guide in the selection of the most suitable supercharger capacity for airplanes having different performance characteristics than those of the one tested.

Several interesting conclusions pertaining to the effect of the capacity of a Roots type supercharger on the performance of this particular airplane have been drawn from the results of these tests.

It was found that very little sacrifice in sea-level performance was experienced with the larger supercharger drive ratios as compared with performance obtained when using the smaller drive ratios.

The results indicate that further increase in supercharger capacity over that obtained when using the 3 : 1 drive ratio would give a slight increase in ceiling and in high altitude performance, but would considerably impair the performance for an appreciable distance below the critical altitude.

As the supercharger capacity was increased, the height at which sea-level high speeds could be equaled or improved became a larger percentage of the maximum height of operation of the airplane.

INTRODUCTION

Supercharging has, in the past few years, established its value as a means of improving the performance of airplanes and, as a result, superchargers are now being used on a number of military and on a few commercial airplanes. Supplying the engine with sufficient air to maintain sea-level carburetor pressure at altitude, and thus increasing the weight of the charge, results in a large increase in power of the supercharged engine over that of the unsupercharged engine. This increase in engine power gives improved climb and level flight performance and an increase in the maximum altitude at which the airplane may be operated.

In the selection of a supercharger for use on an airplane designed to meet definite performance requirements, the question arises as to whether it is advisable to choose a supercharger of sufficient capacity to maintain sea-level pressure to the maximum useful altitude or to choose one of smaller capacity requiring less power. The selection of the best supercharger capacity depends largely upon the manner in which the type of supercharger in question affects the engine power and on the percentage of the engine power that is used in driving the supercharger.

A small amount of information on this subject is found in reports on experimental investigations conducted by the National Advisory Committee for Aeronautics and on a theoretical investigation made by the Matériel Division, Air Corps, United States Army. During the preliminary investigation made to determine the suitability of the Roots type supercharger for airplane service, the performance of an airplane was determined with two supercharger capacities. (Reference 1.) Further information was obtained during an investigation of the supercharging of an air-cooled engine. (Reference 2.) Chenoweth gives theoretical curves of engine power versus altitude when using gear-driven centrifugal superchargers of three different capacities. (Reference 3.)

This investigation was undertaken by the staff of the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory to determine experimentally the effect of the capacity of a Roots type supercharger on the performance of an airplane and its engine. Flight tests were conducted on a DH4–M2 airplane powered with a Liberty 12 engine. The performance of the airplane in climb and in level flight was determined without supercharging and with four supercharger capacities which gave critical altitudes of 7,000, 11,500, 17,000, and 22,000 feet.

DESCRIPTION OF AIRPLANE AND EQUIPMENT

The airplane used in this investigation was designated as a DH4–M2. The fuselage, which was of welded steel tube construction, was so arranged that the space normally used for the rear cockpit was entirely inclosed and available for the instrument installation. The weight of the airplane with all equipment and fully serviced at the start of each flight was 4,300 pounds.

The Liberty 12 engine used on all these tests was equipped with two inverted Stromberg NA–L5A carburetors having 1⅝-inch diameter chokes and No. 42 drill size metering jets.

A Roots type supercharger, N. A. C. A. Model II, of 0.382 cubic foot displacement per revolution, was mounted at the rear of the engine and driven through a flexible coupling from the engine crank shaft. Descriptions and performance characteristics of Roots type superchargers are given in references 4 and 5. Four supercharger capacities, obtained by driving the supercharger at 1.615, 1.957, 2.4, and 3 times engine speed, enabled the maintenance of sea-level pressure at the carburetor to altitudes of 7,000, 11,500, 17,000, and 22,000 feet, respectively. The inlet passages to the supercharger were extended slightly beyond the fuselage on both sides to form air scoops. The duct from the supercharger to the carburetors was built from a flexible metal tube. A general view of this installation is shown in Figure 1.

A Martin bomber supercharger propeller, Air Service part No. 065323, diameter 10.67 feet, pitch 6.33 feet, was used on all flights. This propeller had previously been calibrated on the same airplane, by means of a hub dynamometer, and a curve of the variation in its torque coefficient with $\frac{V}{nD}$ obtained.

The cooling system was augmented by a booster radiator, having a 9-inch core with a frontal area of 2.25 square feet, connected in series with the nose radiator as shown in Figure 1. This booster radiator was made sufficiently large so that ample cooling would be obtained during full supercharged continuous climbs in the hottest summer weather. A pressure relief valve set at 3 pounds per square inch was used to increase the boiling point of the water at high altitudes.

All readings taken during this investigation were recorded automatically. The readings of the indicating instrument were recorded by an "automatic observer," which consisted essentially of a light-tight box and a motor-driven motion-picture camera focused on the dials of the instruments. These indicating instruments were: A sealed altimeter for the measurement of carburetor inlet air pressure; four electric resistance thermometers for measurement of (1) atmospheric temperature at a point under the lower wing, (2) air temperature at the inlet of the supercharger, (3) air temperature at the outlet of the supercharger, and (4) air temperature at the inlet of the carburetor; a chronometric tachometer for measurement of engine speeds; an experimental Venturi type fuel flow meter; and a distance type vapor pressure thermometer for the measurement of fuel temperatures at the flow meter. In addition to the instruments in the automatic observer an N. A. C. A. type recording altimeter air-speed meter unit and a recording pressure instrument were used. The altimeter recorded atmospheric pressure. The air-speed meter was connected to a swivel type Pitot head mounted on a strut. The recording pressure instrument measured the pressure difference between the carburetor inlet and the point of attachment of the priming lines on the inlet manifold. All records were synchronized during flight by an electric motor-driven N. A. C. A. chronometric timer which made regular timing dots on the film records.

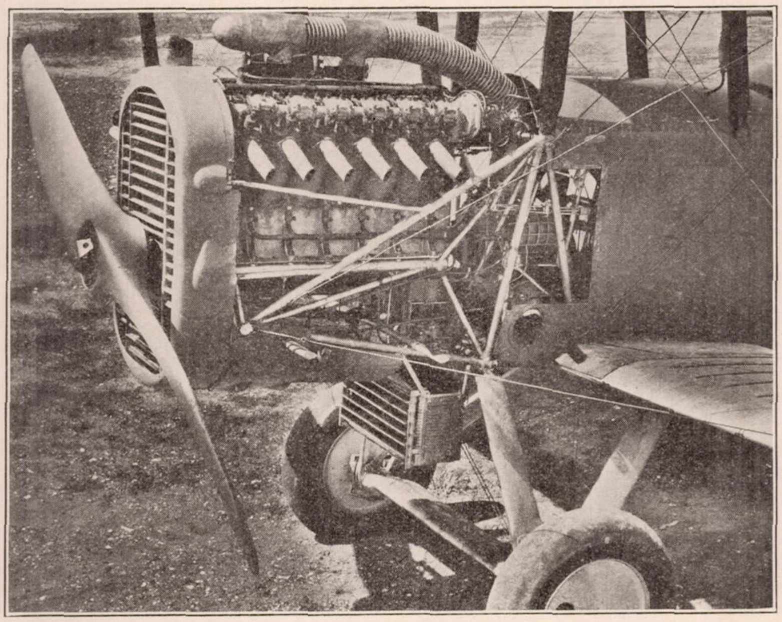

FIGURE 1.—DH4-M2 airplane showing installation of supercharger and booster radiator

METHODS

For an investigation of this nature, the best criteria of comparative performance are rate of climb and speed in level flight. In order that a comparison of climb performance could be obtained, it was necessary to determine the best rate of climb without supercharging and for each of the four supercharging conditions. The rate of climb with full engine power being dependent on air speed, the air speeds for the best rate of climb for each condition of supercharging and without supercharging were determined as follows: A continuous climb was first made at the air speeds estimated to give the best rate of climb, a second climb was made at air speeds 5 M. P. H. higher than in the first flight and a third climb made at air speeds 5 M. P. H. lower than in the first flight. From these three climbs, the air speeds for the best rate of climb were determined, and a final continuous climb was made at the selected air speeds. On all supercharged climbs the pilot first attained full throttle conditions and then, by regulation of the supercharger by-pass valve, maintained as nearly as possible a pressure of 29.92 inches of mercury at the carburetor inlet. These pressures, which were indicated by a sealed altimeter in the cockpit, were maintained constant until the by-pass valve was completely closed. The desired air speed was obtained by varying the attitude of the airplane.

To obtain high-speed performance, level runs of approximately six minutes duration were made at increments of 5,000 feet altitude for each supercharging condition.

During all of these tests the following readings were taken: Atmospheric pressure, atmospheric temperature, supercharger inlet air temperature, supercharger outlet air temperature, carburetor inlet air temperature, carburetor inlet air pressure, pressure drop from the carburetor inlet to the inlet manifolds, volume rate of fuel flow, fuel temperature at the flow meter, air speed, engine speed, and time.

The climb performance of the airplane was reduced to the conditions of operation in standard atmosphere by the method described in N. A. C. A. Technical Report No. 216. (Reference 6.) The rates of climb were determined graphically by drawing tangents to the time-altitude curves plotted on a large scale.

In order that engine power could be measured during this investigation, the propeller used was first calibrated on this airplane by means of a hub dynamometer. To calibrate the propeller, a series of runs was made at various angles of attack covering the useful range of $\frac{V}{nD}$ for the propeller. The values of a nondimensional torque coefficient were computed from measurements of engine torque, air speed, and density. This torque coefficient, commonly used in propeller work, is $C_Q=\frac{Q}{\rho V^2 D^3}$, where Q is torque, ρ is mass density of the air, V is velocity of the airplane, and D is propeller diameter. The values of the coefficient $\frac{V}{nD}$ were computed from air speeds, engine speeds, and propeller diameter. A curve of $\frac{V}{nD}$ versus C_Q was thus obtained for the propeller. This coefficient being nondimensional, is applicable at any altitude provided that there is no blade deflection or twist. For this propeller, no change in coefficient for the same value of $\frac{V}{nD}$ was obtained at 5,000 and at 14,000 feet altitude. The power delivered to the propeller was determined for the flight tests by computing $\frac{V}{nD}$ and then obtaining C_Q from the propeller calibration curve. All quantities in the equation for torque coefficient are known except the torque Q which can then be calculated.

To obtain an accurate comparison between flights, some of which were made in winter and some in summer, the brake horsepower measurements were corrected to standard atmospheric conditions. In applying this correction it was first necessary to establish, from the experimental information available, the variation in carburetor air temperature and pressure with altitude for each supercharging condition. The critical altitude or maximum altitude to which sea-level pressure was maintained was first determined from the experimental data. This critical altitude for each supercharger capacity was corrected for the effect of seasonal temperature changes so as to obtain the critical altitude for standard atmospheric conditions. Below the critical altitudes, the carburetor air pressure was assumed to be 29.92 inches of mercury. Above the critical altitudes the experimental data indicate that there was a gradual increase in the ratio of atmospheric to carburetor air pressure. Using these same rates of increase, the carburetor air pressures were computed from standard atmospheric pressures and the experimental pressure ratios. The temperatures of the supercharger outlet air were determined from the standard atmospheric temperatures and pressures and the established standard carburetor air pressures using the thermodynamic relation for polytropic changes of state $\left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}}=\frac{T_1}{T_2}$. Mean values of n, determined experimentally for each drive ratio, were used in this equation. The temperature drop from the supercharger outlet to carburetor inlet was found from experimental data to have a direct relation to the temperature difference between the inside and outside of the duct at the supercharger outlet. This relation was used to obtain the carburetor air temperatures from the supercharger outlet temperatures for standard conditions.

The observed values of brake horsepower, for the best flight of each supercharged condition and for the best flight of the unsupercharged condition, were corrected to the established standard carburetor air temperatures and pressures. Brake horsepower was corrected by direct ratio for the pressure change and by the inverse square-root relation for the temperature change. These changes in pressure and temperature from observed to standard conditions were so small that the error in correcting the brake horsepower rather than the indicated horsepower was negligible. (Reference 7.)

The power required to drive the supercharger at altitude for each capacity was calculated from the relation

$$\text{HP.} = \frac{dn\,(P_2 - P_1)}{33{,}000} + \text{power losses}$$

where d is supercharger displacement, n is supercharger speed, and $(P_2 - P_1)$ is the pressure difference at the supercharger outlet and inlet. The power losses for each speed and pressure difference were obtained from the curve of horsepower versus supercharger power losses given in reference 5.

RESULTS

Data from the flight tests are shown in Tables I to XV, inclusive. Calibrations have been applied to all quantities used in computation and designated in tables as "observed." Tables I, IV, VII, X, and XIII give data from the flights considered to be representative of optimum

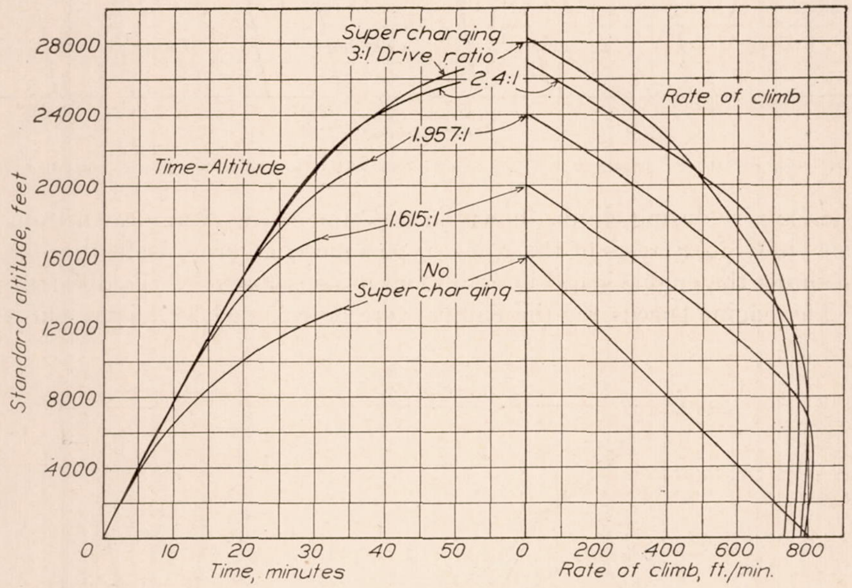

FIGURE 2.—Climb performance of DH4-M2 airplane with no supercharging and with four supercharging capacities

performance without supercharging and with supercharging using the 1.615:1, 1.957:1, 2.4:1, and 3:1 drive ratios, respectively.

Figure 2 shows the time to climb and the rate of climb for the five supercharging conditions plotted against standard altitude. These curves conform closely to the data from the optimum climbs given in the tables but have been faired slightly to form a family of curves. It is of interest to note that there is very little difference in the time to climb to 10,000 feet with the different supercharging conditions.

The air speeds in climb and in level flight for the five conditions are shown in Figure 3. The curves for the climbing conditions show the air speeds giving the best rates of climb as determined from cross plotting of all the data obtained with each supercharging condition. The curves for level flight were drawn from actual test data, but were faired to give a consistent family.

The curves in Figure 4 show the power delivered by the engine to the propeller during climb. These power values were obtained from the optimum climb data by using the propeller calibration and have been corrected to standard atmosphere. Data at the low altitudes were somewhat scattered and the curves have been faired in this range. The curves of power to

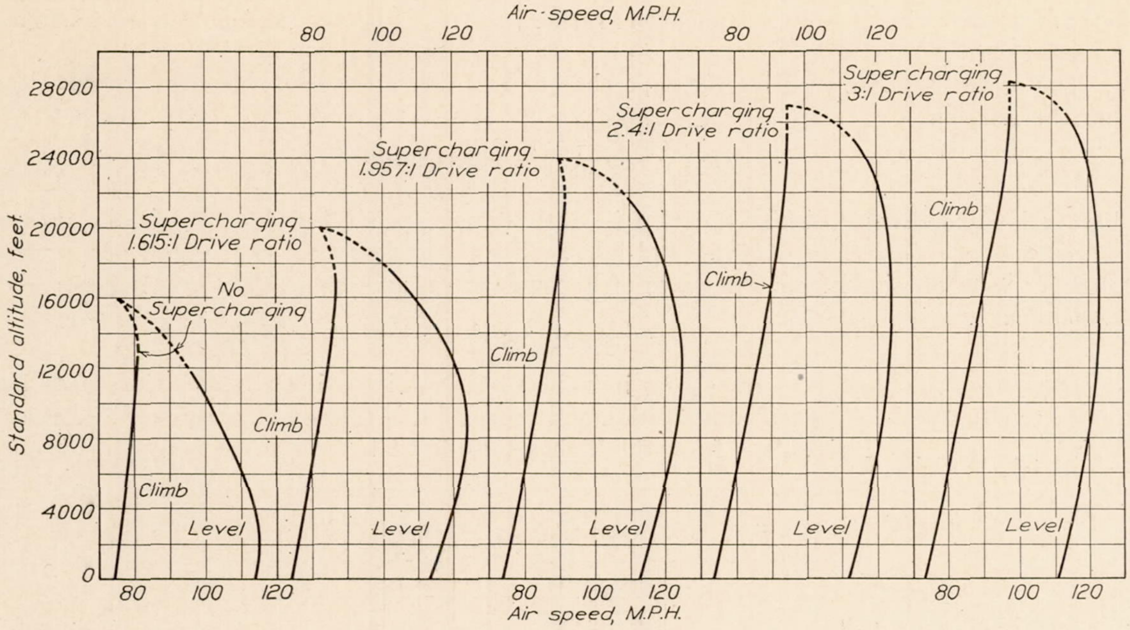

FIGURE 3.—Air speeds of DH4-M2 airplane in climb and in level flight with no supercharging and with four supercharging capacities

drive the supercharger during climb, shown on the same sheet, were drawn from data obtained during previous laboratory tests of the Roots type supercharger. (Reference 5.)

Figure 5 shows the engine speed in climb and in level flight for the different supercharging conditions. The engine speeds for the climbs were determined by fairing curves from all the

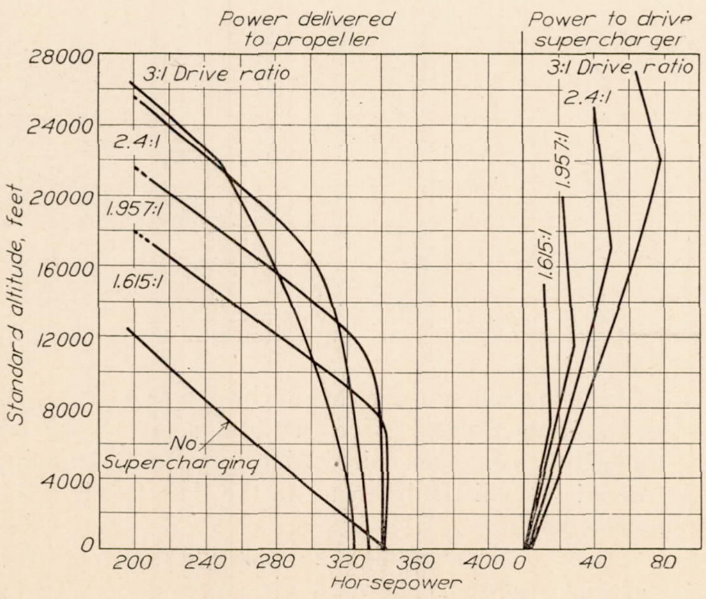

FIGURE 4.—Power delivered by the engine to the propeller and power required to drive the supercharger during climb

test data in a manner similar to that used for determining the air speeds in climb. The engine speed curves for level flight were drawn from actual test data.

Temperatures of the atmospheric air, supercharger outlet air, and curburetor inlet air for the four supercharged climbs are shown in Figure 6. These data were taken from the optimum

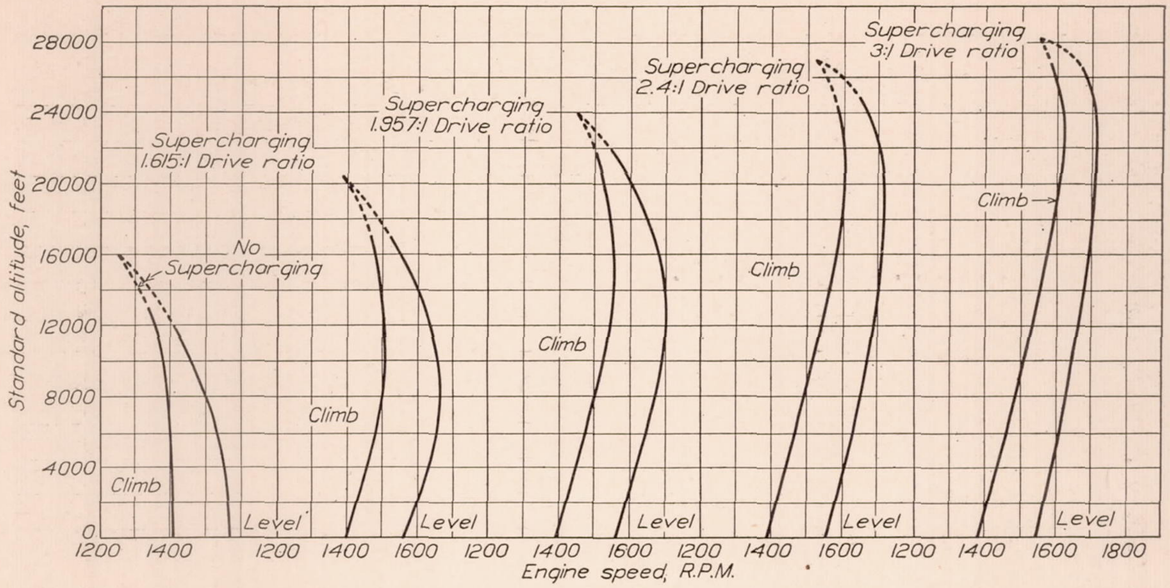

FIGURE 5.—Engine speeds of DH4-M2 airplane in climb and in level flight with no supercharging and with four supercharging capacities

climbs given in Tables IV, VII, X, and XIII. The atmospheric and carburetor air pressures for the same conditions are shown in Figure 7. The abrupt decrease in pressure shown by the carburetor pressure curves indicates that the by-pass valve had been completely closed and that the engine used all of the air delivered by the supercharger at higher altitudes.

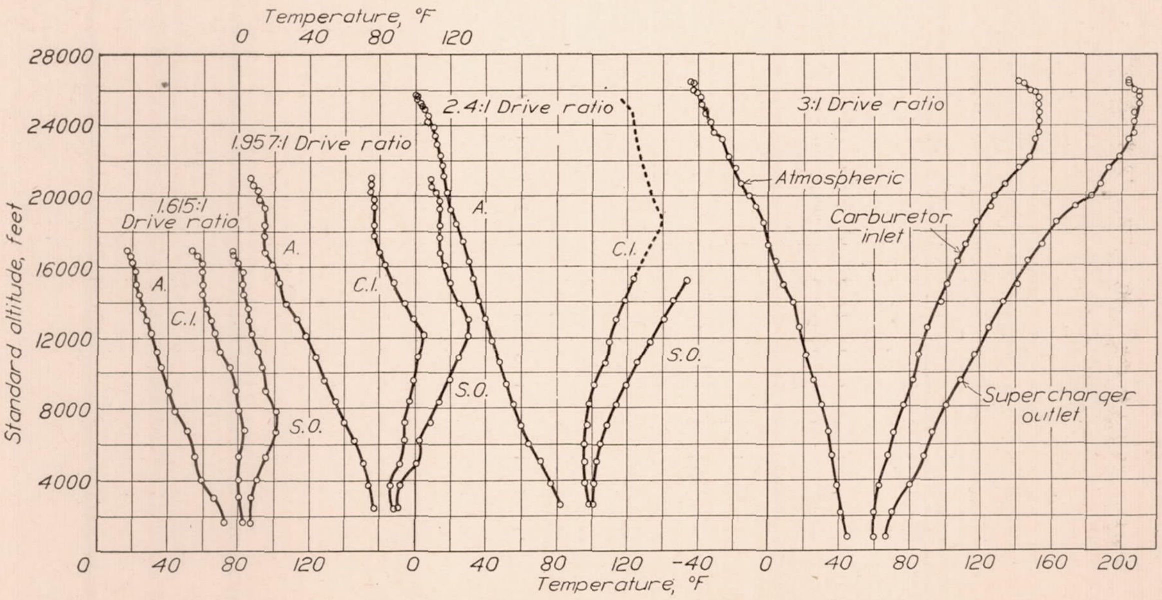

FIGURE 6.—Atmospheric, supercharger outlet and carburetor inlet air temperatures during climb for the four supercharging conditions. Data given in Tables IV, VII, X, and XIII

Figure 8 shows the atmospheric and carburetor air temperatures and pressures for the five test conditions in climb on the basis of operation in standard atmosphere. These curves show a rapid increase in maximum discharge temperature with an increase in supercharger capacity.

The pressure drop from the carburetor inlet to the inlet manifold is shown in the third group of curves of this figure.

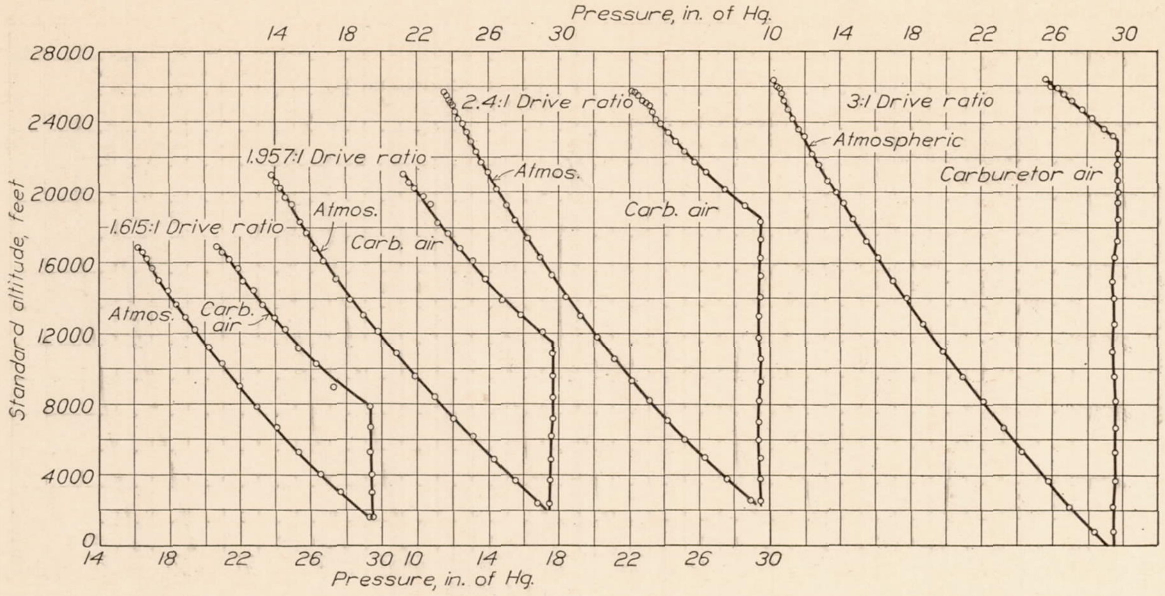

FIGURE 7.—Atmospheric and carburetor air pressures during climb for the four supercharged conditions. Data given in Tables IV, VII, X, and XIII

The slip speed, which is the speed necessary to maintain a definite pressure difference with no delivery, was determined by laboratory tests. The slip speed curve for the supercharger used is shown in Figure 9.

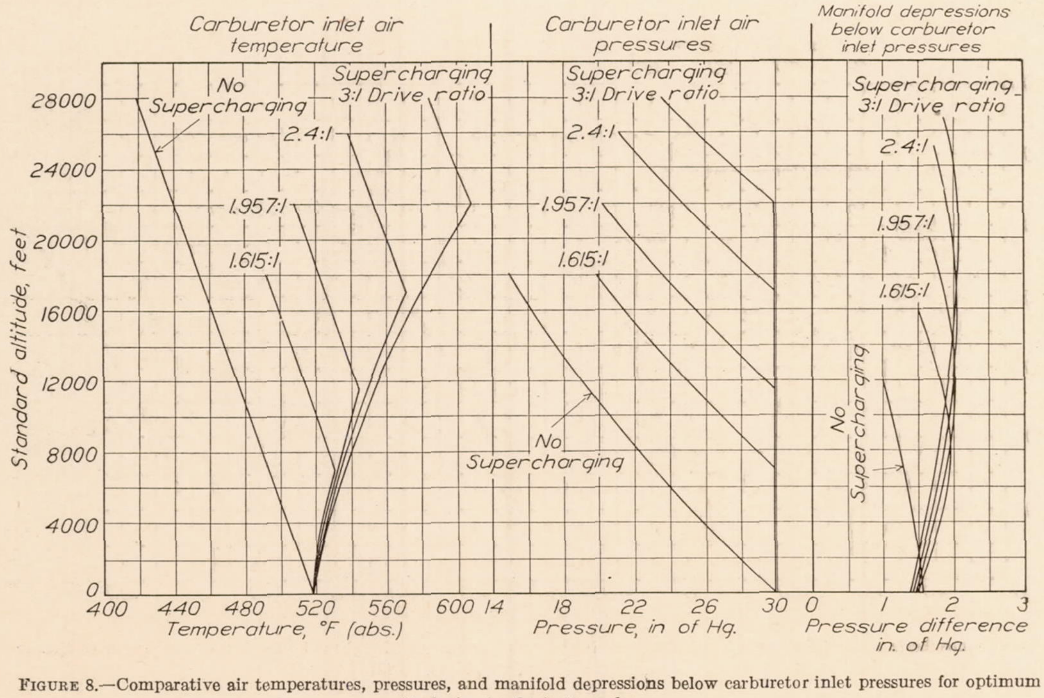

FIGURE 8.—Comparative air temperatures, pressures, and manifold depressions below carburetor inlet pressures for optimum climbs in standard atmosphere

The propeller calibration curve from which engine power was determined is shown in Figure 10.

DISCUSSION OF RESULTS

The airplane performance curves shown in Figures 2 and 3 indicate that there would be very little increase in ceiling and in high altitude performance if the drive ratio were increased beyond 3:1. The trend of the rate of climb curves shows that further increase in supercharger capacity would considerably impair the airplane performance near the critical altitude.

A loss in performance at sea level was expected with the larger capacities, due to the increased power required to drive the supercharger of larger capacity over that required for one

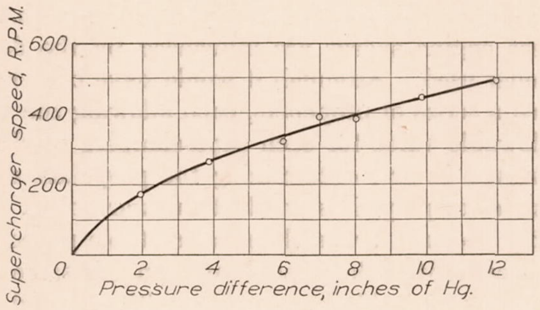

FIGURE 9.—Slip speeds of supercharger used during flight tests

of smaller capacity. This loss in sea-level performance, however, was actually found to be very small, as the curves in Figure 2 indicate. This difference in performance, while hardly noticeable from the time to climb curves, is easily seen from the rate of climb curves.

It is interesting to note, in Figure 3, that as the gear ratio was increased, the height to which sea-level high speed was maintained or bettered became a larger percentage of the maximum height of operation of the airplane. The air-speed curves indicate that up to the critical altitudes the maximum speeds in level flight were very nearly the same for each supercharger capacity.

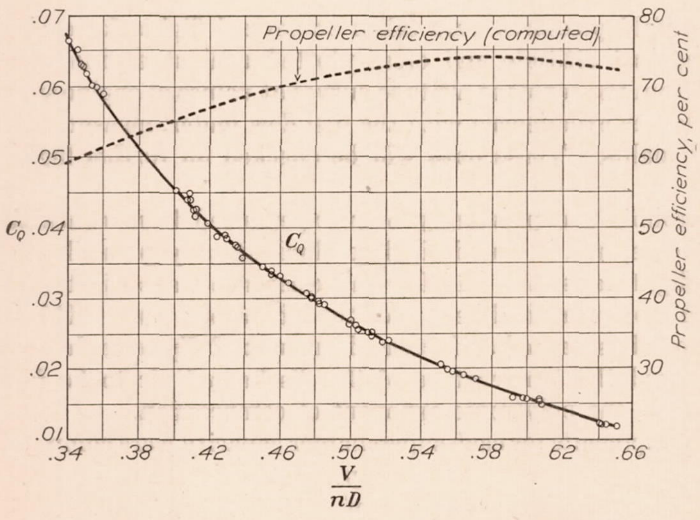

FIGURE 10.—Calibration curves for propeller used during flight tests

A considerable falling off in power below the critical altitude was experienced with the two higher supercharger capacities, as shown in Figure 4. This loss in power is partially accounted for by the increased power required to drive the supercharger, as the second group of curves in Figure 4 indicates. At the critical altitude with the 3 : 1 drive ratio the sum of net engine power and supercharger power is the same as the engine power at sea level. In all other cases the total engine power at the critical altitudes is slightly higher than at sea level. The net engine power curves represent actual flight conditions for a fixed pitch propeller and are considered to be of greater value for use in making analyses than power curves at constant engine speed. These power curves substantiate the conclusion made in connection with the airplane performance curves, that the supercharger drive ratio should not be increased beyond 3 : 1. A striking similarity is found between these power curves and the rate of climb curves of Figure 2.

The supercharger power curves show that, for the higher gear ratios, the power required to drive the supercharger increases very rapidly with altitude and that, for the highest gear ratio, the supercharger power is 24 per cent of the engine power at the critical altitude.

The engine speeds (fig. 5) are of interest only in connection with the manner in which they affect engine power. These engine speeds are influenced by the density of the air and the characteristics of the propeller used. Although it would have been better from the standpoint of performance to have used a series of propellers, each allowing the engine speed in level flight to reach the maximum allowable value for each supercharging condition, it was thought that the experimental work involved in first determining the propellers suitable for each condition and then calibrating the series of propellers would be unwarranted. On these tests a wooden propeller was used primarily because it was the most suitable propeller available for use with supercharged engines and because it could be calibrated on this same airplane. For calibrating the propeller, a hub dynamometer suitable for use at low altitudes and only applicable to wooden propellers was available at this time. The propeller efficiency curve (fig. 10) shows that at the values of $\frac{V}{nD}$ given in the tables the propeller used was operating near its maximum efficiency during climbs. In comparing the performance with the different capacities it should be borne in mind that the performance with the smaller capacities would have been improved somewhat had more suitable propellers been used.

The temperature curves of Figure 6 show the large temperature rise caused by the compression of the air in the supercharger at the higher altitudes. A measure of the cooling that took place while the air flowed from the supercharger to the carburetor is also shown on these curves.

Readings of manifold pressures were taken on several flights for each drive ratio. These data were plotted against altitude and cross plotted against engine speed. The curves in Figure 8 were taken from the constant altitude curves at values of engine speed given in Figure 5.

Although trouble was experienced with the fuel flow meter, measurements of fuel flow were obtained for several flights. These data will be checked on further flight tests and reported upon later.

Because some trouble had previously been experienced from contacting of the impellers with the end of the case, and it was desired to eliminate any possibility of repetition of this trouble during the flight tests, the impeller end clearance was adjusted to 0.015 inch, which was about 0.005 inch more than had been used for laboratory tests. This increase in clearance at the ends of the impellers caused an increased amount of slip over that obtained with smaller clearances. This caused the temperature of the discharged air to be further increased and, therefore, an increase in the polytropic exponent of compression.

The compression exponents for each supercharger capacity were computed from the measurements of temperatures and pressures of the supercharger inlet and outlet. The computations showed that average compression exponents of 1.740, 1.776, 1.838, and 1.915 were obtained for the 1.615 : 1, 1.957 : 1, 2.4 : 1, and 3 : 1 drive ratios, respectively. Previous laboratory tests with smaller impeller end clearances gave an average value for the compression exponent of 1.48 for this model supercharger. (Reference 5.) Although it was realized that increasing the impeller clearances would lower the volumetric efficiency, it was not expected that the additional heat added to the air slipping back through the clearance spaces would result in such a marked increase in the compression exponent.

Precision type ball bearings were installed in the supercharger for these tests and their successful maintenance of constant impeller end clearance indicates that no mechanical troubles would be expected with clearance reduced to that used in laboratory tests. No mechanical troubles of any kind were experienced during these tests, which extended over 50 hours of full-power flying.

Considerable cooling of the air delivered to the engine by the supercharger was obtained with the long air duct used on these tests. (See figs. 1 and 6.) The influence of this cooling on the comparative performance of the airplane is of interest. If no cooling were obtained, the carburetor air temperatures would be higher, the engine would use less weight of air, the critical altitude would be raised, and the engine would deliver less power below the critical altitude. If an air intercooler had been used the reverse condition would be true. Above the critical altitude the use of an intercooler is a detriment to performance, for the reason that the engine uses all of the air that the supercharger will deliver regardless of the temperature, while the intercooler creates additional drag. It is evident that the use of an intercooler would improve performance below the critical altitude with the higher supercharger capacities. It is also believed that less cooling of the inlet air would be experienced in most service installations than was obtained in this experimental case unless an intercooler were used. An improvement of the adiabatic efficiency of a supercharger would obviously be of greater value than the use of an intercooler and there would be no increase in drag. For this particular supercharger the efficiency could be considerably improved by reducing the impeller end clearances.

The temperatures recorded by the thermometer at the supercharger inlet were from 10° to 20° F. higher than the atmospheric temperature as measured under the lower wing. It is believed that heat was conducted from the supercharger case to this thermometer, so that in calculating the temperature rise in the supercharger the atmospheric temperature values were used instead of those given by the thermometer in the inlet passage.

CONCLUSIONS

From the results of these tests several interesting conclusions pertaining to the effect of the capacity of a Roots supercharger on the performance of this particular airplane are drawn.

It was found that an increase in supercharger drive ratio resulted in only a very small reduction in sea-level performance from that obtained with the lower gear ratios.

These results indicate that a further increase in supercharger capacity over that when using the 3 : 1 drive ratio would result in but slight increase in ceiling and in high altitude performance. This further increase in capacity would considerably impair the performance for the range of altitudes immediately below the critical altitude.

As the supercharger capacity was increased, the height to which sea level high speed could be equaled or improved became a larger percentage of the maximum height of operation of the airplane.

Although the results of this investigation are not conducive to drawing general conclusions as to the proper capacity or type of supercharger for use with all types of airplanes, the information collected on the variation with altitude and supercharger capacity of such factors as carburetor air temperatures, power required to drive the supercharger, and the net engine power is of considerable value as a guide in the selection of the proper supercharger capacity for airplanes of different performance characteristics than those of the one tested.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *March 13, 1929.*

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TABLE I.—OPTIMUM, FULL THROTTLE CLIMB WITH NO SUPERCHARGING

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.	Brake horsepower corrected to standard pressure and temperature
1	1.85	71	29.35	0.0733	1,500	1,415	74.0	0.432	319	82	539	29.50	314
2	2.11	64	28.15	.0713	2,400	1,405	75.5	.441	318	78	534	28.20	317
3	4.68	60	26.90	.0687	3,600	1,400	76.5	.451	298	75	531	27.20	295
4	6.06	55	26.10	.0673	4,300	1,395	77.0	.456	287	71	526	26.30	285
5	7.60	50	25.10	.0654	5,300	1,395	77.5	.459	279	65	520	25.40	276
6	9.11	46	24.40	.0640	6,000	1,395	78.0	.462	271	63	515	24.50	269
7	10.77	44	23.60	.0622	6,900	1,385	78.0	.465	259	60	512	23.85	256
8	12.80	44	23.00	.0606	7,750	1,385	79.0	.471	250	60	511	23.20	247
9	15.46	46	22.50	.0590	8,600	1,385	80.5	.480	242	60	512	22.70	237
10	17.35	46	22.00	.0577	9,300	1,375	81.0	.486	230	60	512	22.15	226
11	19.13	45	21.70	.0571	9,700	1,375	81.0	.486	227	60	512	21.80	223
12	20.88	44	21.25	.0560	10,300	1,375	82.0	.492	221	60	512	21.50	215
13	22.18	41	20.90	.0553	10,650	1,375	81.0	.486	220	60	511	21.10	215
14	23.99	40	20.55	.0545	11,150	1,375	81.0	.486	217	60	509	20.80	211
15	25.88	40	20.35	.0539	11,450	1,375	80.5	.483	216	60	508	20.50	211
16	27.53	38	20.05	.0533	11,850	1,365	80.5	.487	208	60	508	20.20	203
17	29.11	37	19.70	.0526	12,300	1,365	80.0	.484	206	59	508	19.90	201
18	29.92	36	19.55	.0523	12,400	1,365	80.0	.484	204	59	508	19.75	200
19	31.13	34	19.35	.0520	12,600	1,365	79.5	.478	204	58	506	19.50	202
20	32.33	33	19.15	.0517	12,800	1,365	79.0	.478	203	55	506	19.40	200

TABLE II.—FULL THROTTLE CLIMB WITH NO SUPERCHARGING

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.
1	1.96	66	28.95	0.0730	1,600	1,425	80.0	0.463	330	77	534	29.25
2	3.43	59	27.55	.0704	2,800	1,415	81.0	.472	311	74	528	28.00
3	5.00	55	26.70	.0688	3,600	1,415	81.0	.472	304	68	523	27.10
4	6.26	50	25.80	.0673	4,300	1,415	81.5	.475	295	66	517	26.15
5	7.85	46	25.00	.0657	5,100	1,395	81.5	.482	275	63	515	25.30
6	9.53	42	24.35	.0644	5,800	1,395	82.0	.485	269	58	509	24.60
7	11.05	39	23.75	.0632	6,400	1,395	82.5	.488	263	55	506	24.05
8	12.79	38	23.15	.0618	7,100	1,395	83.5	.494	256	---	---	23.55
9	14.98	37	22.70	.0606	7,750	1,395	83.5	.494	251	---	---	23.10
10	16.41	35	22.35	.0599	8,100	1,395	84.0	.497	246	---	---	22.70
11	18.57	34	21.95	.0589	8,650	1,395	85.0	.503	239	---	---	22.30
12	19.56	31	21.60	.0584	8,900	1,395	86.0	.509	235	---	---	21.95
13	21.16	30	21.30	.0578	9,250	1,395	86.5	.512	232	---	---	21.70
14	23.34	30	21.05	.0571	9,650	1,395	87.0	.515	229	---	---	21.40
15	25.49	30	20.80	.0564	10,050	1,395	87.0	.515	226	---	---	21.10
16	28.48	31	20.60	.0556	10,500	1,395	87.0	.515	223	---	---	20.85
17	30.32	30	20.35	.0550	10,850	1,395	86.0	.509	221	---	---	20.65
18	32.13	30	20.10	.0544	11,200	1,385	86.5	.510	220	---	---	20.50
19	33.85	30	19.95	.0540	11,400	1,385	86.5	.510	218	---	---	20.35

TABLE III.—FULL THROTTLE CLIMB WITH NO SUPERCHARGING

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.
1	3.39	75	28.90	0.0717	2,200	1,395	74.0	0.438	311	91	546	29.10
2	4.93	71	27.85	.0696	3,200	1,395	74.5	.441	300	89	543	28.10
3	6.35	67	26.85	.0677	4,100	1,395	75.0	.450	291	85	539	27.20
4	7.80	63	26.00	.0661	4,900	1,395	76.0	.450	284	82	535	26.20
5	9.52	60	25.05	.0640	6,000	1,395	77.0	.455	274	78	531	25.35
6	10.98	57	24.55	.0630	6,500	1,395	78.0	.461	269	74	527	24.70
7	12.40	55	23.90	.0617	7,150	1,395	78.5	.464	263	71	524	24.10
8	14.02	52	23.30	.0604	7,850	1,395	79.5	.470	255	70	523	23.60
9	15.97	51	22.95	.0595	8,350	1,395	80.0	.473	251	68	520	23.20
10	16.87	49	22.65	.0591	8,550	1,385	80.0	.477	242	67	517	22.85
11	18.42	48	22.35	.0584	8,900	1,375	78.5	.471	236	66	516	22.60
12	20.62	48	22.20	.0580	9,150	1,370	77.0	.464	233	63	515	22.40
13	22.15	47	21.90	.0574	9,500	1,370	76.0	.458	232	60	515	22.15
14	23.89	47	21.60	.0566	9,900	1,370	77.0	.464	228	----------	513	21.85
15	25.41	45	21.35	.0562	10,200	1,365	76.5	.463	223	----------	512	21.65
16	26.26	44	21.20	.0559	10,300	1,365	76.5	.463	222	----------	512	21.40
17	28.16	43	21.00	.0554	10,600	1,365	77.0	.466	220	----------	512	21.25
18	29.84	42	20.85	.0551	10,800	1,355	76.0	.463	214	----------	512	21.05
19	31.10	41	20.65	.0547	11,000	1,345	75.0	.460	209	----------	510	20.85
20	33.28	41	20.45	.0541	11,350	1,345	75.5	.463	206	----------	510	20.60
21	35.34	41	20.30	.0537	11,600	1,345	76.0	.466	204	----------	510	20.50
22	35.95	40	20.20	.0536	11,650	1,345	76.0	.466	204	----------	510	20.35
23	38.13	40	19.95	.0529	12,100	1,345	76.5	.469	201	----------	512	20.20
24	38.54	38	19.80	.0528	12,150	1,345	76.5	.469	201	----------	512	20.10
25	40.92	38	19.75	.0526	12,250	1,340	76.5	.471	197	----------	510	20.00
26	42.71	38	19.55	.0521	12,550	1,335	77.0	.476	192	----------	509	19.85
27	43.89	37	19.50	.0520	12,600	1,335	76.5	.473	193	----------	----------	19.80
28	45.05	37	19.45	.0519	12,650	1,335	76.5	.473	192	----------	----------	19.75
29	46.21	37	19.40	.0519	12,700	1,335	76.5	.473	192	----------	----------	19.70

TABLE IV.—OPTIMUM, SUPERCHARGED CLIMB USING THE 1.615:1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.	Brake horsepower corrected to standard pressure and temperature
1	2.07	72	29.25	0.0730	1,600	1,425	75.0	0.434	339	87	542	29.50	352
2	3.59	66	27.70	.0699	3,000	1,435	75.5	.434	330	87	539	29.50	341
3	5.01	59	26.55	.0679	4,000	1,445	75.5	.431	330	90	539	29.50	340
4	6.66	55	25.30	.0654	5,300	1,455	76.0	.431	324	95	539	29.40	334
5	8.42	51	24.05	.0625	6,750	1,475	76.5	.428	324	101	542	29.40	334
6	9.87	44	22.95	.0604	7,850	1,485	77.5	.431	316	101	539	28.40	326
7	11.48	40	21.95	.0582	9,000	1,495	79.0	.436	310	95	537	27.30	320
8	13.23	36	20.95	.0560	10,300	1,495	80.5	.444	298	93	534	26.30	306
9	14.80	33	20.20	.0543	11,200	1,495	80.5	.444	290	90	528	25.30	298
10	16.49	30	19.45	.0527	12,200	1,495	82.0	.453	279	87	525	24.60	284
11	18.06	27	18.90	.0516	12,900	1,495	83.0	.458	272	85	523	24.00	276
12	19.59	25	18.35	.0503	13,600	1,495	84.0	.464	263	85	520	23.30	268
13	21.59	23	17.85	.0491	14,450	1,495	83.5	.461	257	82	518	22.80	259
14	22.99	21	17.40	.0481	15,000	1,485	83.0	.461	248	82	518	22.20	252
15	24.95	21	17,00	.0470	15,700	1,475	82.5	.462	235	82	518	21.90	237
16	26.79	19	16.70	.0463	16,200	1,455	82.0	.465	223	79	518	21.40	225
17	28.53	18	16.45	.0457	16,600	1,445	82.5	.471	215	76	515	21.00	218
18	29.81	16	16.20	.0452	16,900	1,435	83.0	.477	207	76	512	20.70	210

TABLE V.—SUPERCHARGED CLIMB USING THE 1.615:1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.
1	3.66	74	28.30	0.0704	2,800	1,445	80.0	0.457	332	85	537	29.50
2	5.36	72	27.10	.0677	4,100	1,475	81.0	.453	342	95	548	29.50
3	6.87	67	25.90	.0654	5,300	1,485	82.0	.456	336	101	550	29.40
4	8.33	61	24.70	.0630	6,500	1,495	82.0	.453	332	103	550	29.40
5	9.54	53	23.65	.0613	7,400	1,515	82.0	.450	332	106	550	29.40
6	11.15	49	22.55	.0588	8,700	1,505	84.0	.461	315	106	548	28.25
7	12.72	45	21.55	.0566	9,900	1,515	85.5	.466	308	101	542	27.20
8	14.08	40	20.80	.0552	10,700	1,515	86.5	.471	300	95	537	26.35
9	15.79	37	20.15	.0537	11,600	1,515	88.0	.479	288	92	534	25.60
10	17.00	33	19.60	.0528	12,150	1,505	87.0	.477	278	90	528	24.85
11	18.31	29	19.10	.0519	12,700	1,505	88.0	.483	271	87	526	24.35
12	19.63	27	18.70	.0511	13,150	1,505	89.0	.487	269	82	523	23.80
13	21.50	26	18.30	.0501	13,800	1,495	90.0	.497	253	82	523	23.40
14	23.43	26	17.95	.0491	14,400	1,495	90.5	.500	246	82	523	23.10
15	25.20	25	17.70	.0485	14,800	1,495	92.0	.508	241	82	520	22.75
16	26.30	22	17.40	.0480	15,100	1,495	90.0	.497	243	79	518	22.50
17	28.28	22	17.05	.0470	15,800	1,485	90.0	.500	232	79	518	22.10
18	29.68	20	16.75	.0463	16,200	1,475	89.0	.498	225	79	515	21.80
19	31.25	19	16.55	.0459	16,500	1,455	87.0	.493	215	76	515	21.50
20	32.63	19	16.40	.0455	16,700	1,445	85.0	.485	211	76	515	21.25

TABLE VI.—SUPERCHARGED CLIMB USING THE 1.615:1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet ° F.	Temperature at carburetor inlet ° F. (abs.)	Pressure at carburetor inlet in. Hg.
1	1.88	75	29.40	0.0729	1,500	1,415	81.0	0.473	320	87	542	29.60
2	3.39	67	28.05	.0707	2,700	1,435	82.0	.472	325	87	539	29.60
3	5.06	63	26.70	.0678	4,100	1,455	83.0	.471	324	87	539	29.50
4	6.86	62	25.65	.0653	5,300	1,475	84.5	.473	325	92	542	29.50
5	8.50	58	24.55	.0629	6,500	1,495	86.0	.475	324	98	545	29.50
6	10.24	55	23.30	.0601	8,000	1,515	88.0	.480	323	103	550	29.30
7	11.96	51	22.25	.0578	9,300	1,525	90.0	.487	315	106	550	28.40
8	13.54	48	21.40	.0560	10,300	1,535	91.5	.492	306	103	547	27.40
9	15.19	44	20.65	.0543	11,250	1,525	93.0	.504	285	101	542	26.55
10	16.65	41	19.95	.0529	12,100	1,525	93.0	.504	277	98	539	25.60
11	18.23	38	19.25	.0514	13,000	1,525	94.0	.509	270	95	535	24.80
12	20.07	36	18.60	.0498	14,000	1,515	94.5	.515	255	92	531	24.15
13	21.47	33	18.10	.0488	14,600	1,515	94.0	.512	251	90	528	23.50
14	22.84	30	17.60	.0478	15,200	1,505	95.0	.521	239	87	527	22.95
15	24.18	27	17.35	.0473	15,500	1,495	95.5	.528	229	87	526	22.45
16	25.62	26	17.00	.0464	16,000	1,495	96.5	.533	224	85	524	22.10
17	27.79	26	16.75	.0458	16,500	1,495	96.0	.530	222	83	523	21.85
18	29.10	26	16.65	.0455	16,700	1,495	96.0	.530	220	82	520	21.65

TABLE VII.—OPTIMUM, SUPERCHARGED CLIMB USING THE 1.957:1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet, ° F. (abs.)	Pressure at carburetor inlet, in. Hg.	Brake horsepower corrected to standard pressure and temperature
1	3.16	77	28.85	0.0713	2,400	1,415	79.5	0.464	316	90	547	29.50	329
2	4.87	74	27.60	.0686	3,700	1,445	80.0	.456	327	92	545	29.60	338
3	6.44	71	26.40	.0661	4,900	1,475	81.5	.456	334	101	550	29.60	345
4	8.09	66	25.20	.0636	6,200	1,495	82.0	.453	336	103	553	29.60	347
5	9.43	60	24.10	.0616	7,200	1,505	83.5	.458	330	109	553	29.70	340
6	11.05	55	23.05	.0594	8,400	1,525	84.0	.455	332	114	556	29.70	341
7	12.48	49	21.90	.0572	9,600	1,535	84.0	.451	328	120	558	29.70	337
8	14.11	44	20.85	.0549	10,900	1,545	86.0	.454	325	125	561	29.70	333
9	15.63	38	19.85	.0529	12,100	1,555	87.0	.461	305	130	564	29.20	312
10	17.21	33	19.00	.0513	13,000	1,555	87.0	.461	304	130	558	27.90	314
11	18.63	27	18.25	.0499	13,900	1,555	88.0	.466	294	125	553	26.90	304
12	20.35	23	17.45	.0480	15,100	1,555	89.0	.472	281	120	547	25.90	289
13	21.93	19	16.75	.0464	16,100	1,545	90.0	.480	265	117	542	25.20	270
14	23.44	15	16.25	.0454	16,800	1,545	90.0	.480	260	114	539	24.50	265
15	25.33	15	15.75	.0440	17,700	1,535	91.0	.489	243	114	536	23.80	246
16	27.08	15	15.40	.0431	18,300	1,535	91.0	.489	239	114	536	23.20	244
17	29.29	15	14.95	.0417	19,300	1,535	92.0	.495	229	114	536	22.80	229
18	30.55	12	14.60	.0411	19,750	1,535	93.0	.505	217	114	536	22.40	218
19	32.15	11	14.30	.0404	20,250	1,525	94.0	.509	212	112	534	21.90	214
20	33.47	8	14.05	.0399	20,600	1,525	94.0	.509	210	109	534	21.60	211
21	35.34	7	13.85	.0394	21,000	1,525	95.0	.514	206	109	534	21.30	208

TABLE VIII.—SUPERCHARGED CLIMB USING THE 1.957 : 1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature ° F.	Observed atmospheric pressure, in. Hg.	-Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed R. P. M.	Air speed M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetorinlet, ° F. (abs.)	Pressure at carburetorinlet, in. Hg.
1	0. 25	47	29. 10	0. 0760	200	1, 415	75. 0	0. 437	346	66	515	29. 60
2	2. 00	43	27. 65	. 0730	1, 600	1, 425	76. 0	. 440	338	68	515	29. 40
3	3. 76	38	26. 30	. 0701	2, 950	1, 445	76. 0	. 434	340	71	515	29. 50
4	6. 01	39	25. 00	. 0666	4, 650	1, 475	77. 0	. 430	344	82	523	29. 50
5	8. 06	38	23. 80	. 0635	6, 200	1, 495	79. 0	. 436	340	87	528	29. 40
6	9. 81	31	22. 60	. 0611	7, 500	1, 495	80. 0	. 441	328	95	528	29. 40
7	11. 35	26	21. 35	. 0584	8, 900	1, 525	82. 0	. 444	330	101	534	29. 40
8	13. 26	21	20. 25	. 0558	10, 400	1, 535	83. 0	. 446	321	109	537	29. 40
9	14. 91	16	19. 20	. 0536	11, 700	1, 535	82. 0	. 440	312	112	537	28. 40
10	17. 09	18	18. 35	. 0511	13, 150	1, 535	83. 0	. 446	295	112	539	27. 30
11	18. 97	15	17. 60	. 0492	14, 300	1, 545	85. 0	. 454	286	112	537	26. 40
12	20. 72	11	16. 85	. 0475	15, 400	1, 535	86. 5	. 465	269	109	531	25. 50
13	22. 26	7	16. 40	. 0466	16, 000	1, 535	86. 0	. 462	264	103	528	24. 90
14	23. 76	4	15. 95	. 0457	16, 600	1, 535	85. 5	. 460	258	98	526	24. 20
15	25. 86	3	15. 50	. 0444	17, 450	1, 535	85. 0	. 457	252	95	523	23. 70
16	27. 36	1	15. 25	. 0439	17, 800	1, 525	86. 0	. 465	245	95	520	23. 40
17	24. 13	0	14. 95	. 0432	18, 300	1, 525	86. 5	. 468	240	95	517	23. 10
18	29. 97	−3	14. 70	. 0428	18, 500	1, 525	88. 5	. 479	235	95	515	22. 80
19	32. 05	−4	14. 45	. 0421	19, 000	1, 525	89. 0	. 481	232	92	515	22. 50
20	33. 12	−7	14. 30	. 0420	19, 150	1, 505	86. 5	. 474	222	92	515	22. 20
21	35. 16	−8	14. 20	. 0417	19, 350	1, 495	82. 5	. 455	220	90	512	21. 90
22	37. 18	−8	14. 00	. 0411	19, 750	1, 495	81. 5	. 450	218	90	512	21. 70
23	38. 18	−10	13. 80	. 0408	19, 950	1, 495	82. 0	. 452	216	87	509	21. 40

TABLE IX.—SUPERCHARGED CLIMB USING THE 1.957 : 1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature, ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Airspeed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet, ° F. (abs.)	Pressure at carburetor inlet, in. Hg.
1	1. 02	54	29. 05	0. 0750	700	1, 415	79. 0	0. 460	334	68	526	29. 50
2	2. 62	50	27. 80	. 0725	1, 800	1, 435	81. 0	. 465	336	71	523	29. 50
3	4. 31	45	26. 70	. 0702	2, 900	1, 465	82. 5	. 465	346	74	523	29. 60
4	6. 07	40	25. 30	. 0672	4, 400	1, 495	84. 0	. 463	353	82	528	29. 70
5	7. 70	34	23. 95	. 0644	5, 800	1, 525	86. 0	. 465	357	92	534	29. 80
6	9. 40	30	22. 80	. 0618	7, 100	1, 555	87. 0	. 461	366	98	537	29. 70
7	11. 14	25	21. 55	. 0590	8, 600	1, 565	89. 0	. 469	352	106	542	29. 60
8	13. 08	22	20. 35	. 0560	10, 300	1, 575	91. 0	. 476	340	114	545	28. 75
9	14. 78	18	19. 35	. 0537	11, 600	1, 565	92. 0	. 484	317	111	542	27. 30
10	16. 51	15	18. 55	. 0519	12, 700	1, 555	94. 0	. 498	296	109	537	26. 25
11	18. 22	12	17. 80	. 0501	13, 750	1, 555	94. 0	. 498	287	106	534	25. 40
12	19. 86	9	17. 15	. 0486	14, 700	1, 555	94. 0	. 498	278	106	531	24. 35
13	21. 52	7	16. 60	. 0473	15, 500	1, 535	94. 0	. 505	254	103	528	23. 80
14	23. 43	5	16. 25	. 0464	16, 100	1, 525	95. 0	. 514	242	98	526	23. 30
15	25. 19	4	16. 00	. 0458	16, 500	1, 515	96. 0	. 523	232	98	523	23. 00
16	26. 89	3	15. 75	. 0452	16, 900	1, 515	96. 5	. 525	231	95	523	22. 80
17	28. 60	1	15. 50	. 0446	17, 300	1, 515	97. 0	. 528	226	95	520	22. 50
18	30. 18	0	15. 30	. 0442	17, 600	1, 505	96. 0	. 526	221	93	518	22. 15
19	32. 28	0	15. 10	. 0436	18, 000	1, 505	97. 0	. 531	215	93	518	21. 95
20	34. 34	0	14. 95	. 0432	18, 300	1, 525	98. 5	. 532	223	93	518	21. 80
21	36. 09	−1	14. 60	. 0423	18, 900	1, 535	98. 0	. 526	224	95	520	21. 65
22	37. 43	−4	14. 30	. 0417	19, 300	1, 545	99. 0	. 529	224	95	518	21. 20
23	38. 91	−7	14. 00	. 0411	19, 750	1, 545	94. 0	. 502	226	93	515	20. 80
24	40. 99	−8	13. 65	. 0401	20, 500	1, 535	94. 0	. 504	216	93	512	20. 45
25	42. 13	−11	13. 40	. 0397	20, 800	1, 535	96. 0	. 516	213	93	512	20. 10
26	43. 07	−13	13. 20	. 0393	21, 050	1, 535	98. 0	. 526	208	90	512	19. 80
27	45. 25	−14	13. 05	. 0389	21, 400	1, 535	101. 0	. 543	199	87	512	19. 50

TABLE X.—OPTIMUM SUPERCHARGED CLIMB USING THE 2.4 : 1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature, ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Airspeed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet, ° F. (abs.)	Pressure at carburetor inlet, in. Hg.	Brake horsepower corrected to standard pressure and temperature
1	3. 40	82	28. 95	0. 0708	2, 600	1, 405	74. 5	0. 437	316	101	558	29. 50	332
2	4. 83	77	27. 60	. 0683	3, 800	1, 425	74. 5	. 431	315	101	555	29. 50	329
3	6. 30	71	26. 35	. 0659	5, 000	1, 435	74. 0	. 425	314	103	555	29. 50	326
4	7. 60	64	25. 20	. 0639	6, 000	1, 455	75. 0	. 425	317	105	555	29. 40	330
5	9. 12	60	24. 20	. 0619	7, 050	1, 465	75. 5	. 425	314	109	557	29. 40	326
6	10. 79	56	23. 20	. 0597	8, 250	1, 475	77. 0	. 430	309	114	558	29. 40	320
7	12. 27	52	22. 20	. 0576	9, 350	1, 495	78. 0	. 430	312	120	561	29. 50	322
8	13. 89	48	21. 20	. 0554	10, 600	1, 515	79. 0	. 430	310	126	567	29. 50	320
9	15. 48	44	20. 25	. 0533	11, 800	1, 525	80. 0	. 433	304	133	569	29. 40	315
10	17. 00	40	19. 30	. 0513	13, 000	1, 545	81. 5	. 435	303	141	573	29. 40	314
11	18. 62	36	18. 50	. 0496	14, 100	1, 565	82. 5	. 435	302	146	578	29. 50	312
12	20. 32	33	17. 70	. 0477	15, 300	1, 575	84. 0	. 440	298	154	583	29. 50	307
13	21. 90	30	17. 00	. 0461	16, 300	1, 585	84. 5	. 440	294	----------	586	29. 50	303
14	23. 58	27	16. 30	. 0445	17, 400	1, 595	86. 0	. 445	289	----------	----------	29. 50	295
15	25. 05	23	15. 60	. 0430	18, 400	1, 605	87. 5	. 450	288	----------	----------	29. 50	285
16	26. 65	20	15. 10	. 0418	19, 250	1, 605	89. 0	. 457	272	----------	----------	28. 60	269
17	28. 32	18	14. 55	. 0405	20, 200	1, 615	89. 5	. 457	269	----------	----------	27. 45	267
18	30. 08	16	14. 05	. 0392	21, 150	1, 615	91. 0	. 465	258	----------	----------	26. 45	257
19	31. 65	15	13. 70	. 0384	21, 750	1, 615	92. 0	. 470	252	----------	----------	25. 80	251
20	33. 29	14	13. 40	. 0376	22, 300	1, 605	92. 5	. 475	242	----------	----------	25. 20	242
21	35. 05	12	13. 10	. 0369	22, 900	1, 605	93. 0	. 478	236	----------	----------	24. 70	235
22	36. 77	11	12. 85	. 0362	23, 400	1, 595	93. 5	. 483	227	----------	----------	24. 25	226
23	38. 47	10	12. 60	. 0356	23, 900	1, 595	94. 5	. 489	222	----------	----------	23. 85	221
24	39. 51	7	12. 40	. 0353	24, 150	1, 595	95. 0	. 491	219	----------	----------	23. 60	217
25	41. 16	7	12. 20	. 0348	24, 550	1, 595	95. 5	. 494	214	----------	----------	23. 40	212
26	43. 06	5	12. 05	. 0344	24, 900	1, 595	95. 0	. 491	213	----------	----------	23. 20	210
27	44. 28	4	11. 95	. 0342	25, 050	1, 595	95. 0	. 491	213	----------	----------	23. 00	210
28	45. 50	3	11. 85	. 0340	25, 200	1, 595	95. 5	. 494	210	----------	----------	22. 80	208
29	47. 10	1	11. 70	. 0337	25, 500	1, 595	96. 0	. 496	206	----------	----------	22. 55	203
30	49. 46	1	11. 65	. 0335	25, 650	1, 585	96. 0	. 494	207	----------	----------	22. 40	204
31	50. 64	0	11. 60	. 0334	25, 725	1, 585	96. 0	. 494	207	----------	----------	22. 25	205

TABLE XI.—SUPERCHARGED CLIMB USING THE 2.4 : 1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature, °F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, °F.	Temperature at carburetor inlet, °F. (abs.)	Pressure at carburetor inlet, in. Hg.
1	0. 95	47	28. 65	0. 0749	700	1, 390	77. 0	0. 457	317	64	517	29. 40
2	2. 43	41	27. 45	. 0728	1, 700	1, 420	78. 5	. 456	329	67	517	29. 50
3	4. 42	39	26. 20	. 0697	3, 150	1, 450	80. 0	. 455	335	70	519	29. 70
4	6. 26	36	24. 95	. 0668	4, 550	1, 480	81. 0	. 451	343	75	524	29. 50
5	8. 37	36	23. 80	. 0638	6, 100	1, 500	83. 0	. 456	340	85	527	29. 50
6	10. 37	35	22. 75	. 0610	7, 500	1, 510	84. 5	. 462	328	95	535	29. 50
7	12. 31	34	21. 65	. 0582	9, 000	1, 530	86. 4	. 464	326	106	544	29. 50
8	14. 14	30	20. 60	. 0558	10, 400	1, 550	88. 0	. 469	324	115	552	29. 60
9	15. 85	26	19. 60	. 0535	11, 700	1, 560	90. 0	. 476	314	120	554	29. 60
10	17. 51	23	18. 65	. 0514	12, 950	1, 580	91. 5	. 478	312	130	560	29. 60
11	19. 44	21	17. 80	. 0492	14, 300	1, 600	92. 5	. 477	313	141	566	29. 50
12	20. 88	15	17. 15	. 0480	15, 100	1, 600	93. 0	. 480	303	147	571	29. 60
13	22. 62	12	16. 50	. 0464	16, 100	1, 600	94. 0	. 485	292	152	574	29. 50
14	24. 09	8	15. 90	. 0452	16, 900	1, 610	95. 0	. 487	290	160	579	29. 10
15	25. 85	5	15. 35	. 0438	17, 800	1, 620	97. 0	. 494	284	160	579	28. 35
16	27. 24	1	14. 90	. 0430	18, 400	1, 630	98. 0	. 496	283	160	576	27. 55
17	28. 67	−2	14. 65	. 0425	18, 750	1, 620	97. 5	. 497	270	155	571	27. 05
18	30. 54	−3	14. 30	. 0416	19, 400	1, 610	97. 0	. 497	264	152	568	26. 50
19	32. 12	−5	14. 05	. 0410	19, 800	1, 600	96. 0	. 495	255	149	566	26. 05
20	33. 88	−6	13. 80	. 0404	20, 250	1, 590	96. 5	. 500	246	149	563	25. 70
21	35. 64	−8	13. 50	. 0397	20, 800	1, 590	98. 0	. 509	238	147	563	25. 20
22	36. 90	−10	13. 35	. 0394	21, 000	1, 590	99. 0	. 514	234	144	563	25. 00
23	38. 32	−11	13. 25	. 0392	21, 150	1, 590	100. 5	. 522	231	144	560	24. 80
24	39. 95	−12	13. 05	. 0387	21, 500	1, 590	100. 5	. 522	228	144	560	24. 45

TABLE XII.—SUPERCHARGED CLIMB USING THE 2.4 : 1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature, °F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, °F.	Temperature at carburetor inlet, °F. (abs.)	Pressure at carburetor inlet, in. Hg.
1	1.88	64	29.10	0.0737	1,300	1,420	78.5	0.456	334	75	533	29.40
2	3.47	59	27.85	.0713	2,400	1,430	79.0	.456	329	80	533	29.50
3	5.67	59	26.55	.0679	4,050	1,450	80.0	.455	327	85	536	29.60
4	7.70	59	25.45	.0651	5,400	1,480	81.0	.452	333	96	541	29.60
5	9.22	52	24.35	.0631	6,450	1,490	82.5	.457	328	101	544	29.60
6	10.97	48	23.25	.0607	7,700	1,500	83.5	.460	321	104	546	29.60
7	12.65	43	22.10	.0583	9,000	1,520	84.0	.456	323	107	549	29.40
8	14.45	39	21.00	.0558	10,400	1,530	86.0	.464	313	114	552	29.40
9	16.06	34	19.90	.0535	11,700	1,540	87.0	.466	306	122	557	29.50
10	18.23	36	18.80	.0504	13,550	1,550	88.5	.471	294	136	566	29.50
11	20.43	37	17.85	.0477	15,250	1,570	89.5	.470	290	149	576	29.60
12	22.29	35	17.00	.0457	16,600	1,580	89.5	.468	281	157	584	29.60
13	24.03	32	16.30	.0440	17,700	1,590	89.0	.462	278	169	590	29.50
14	25.87	30	15.60	.0423	18,900	1,590	91.0	.472	265	169	587	28.70
15	27.09	22	15.00	.0413	19,600	1,590	91.5	.475	255	163	582	27.75
16	28.22	17	14.55	.0406	20,100	1,580	91.0	.475	249	163	577	26.90
17	29.82	14	14.30	.0401	20,500	1,580	91.0	.475	246	155	571	26.05
18	32.04	15	13.90	.0389	21,400	1,570	92.0	.484	232	152	568	25.50
19	34.22	17	13.55	.0378	22,200	1,570	93.0	.490	220	152	568	25.00
20	36.07	17	13.30	.0371	22,700	1,560	92.0	.487	216	152	568	24.30
21	38.19	17	13.00	.0362	23,400	1,550	92.0	.490	206	152	566	23.70

TABLE XIII.—OPTIMUM SUPERCHARGED CLIMB USING THE 3:1 DRIVE RATIO

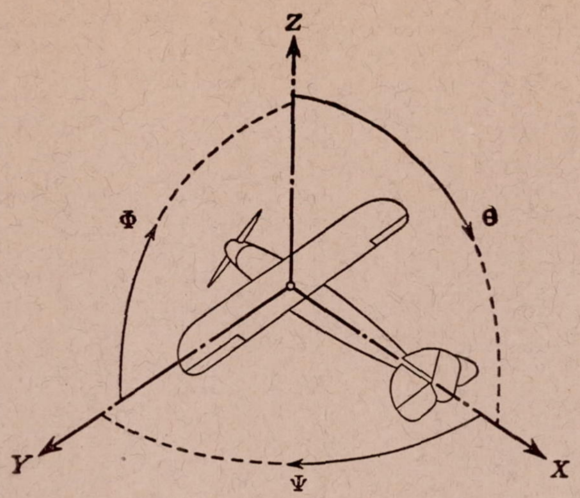
Reading No.	Corrected time, minutes	Observed atmospheric temperature, °F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Airspeed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, °F.	Temperature at carburetor inlet, °F. (abs.)	Pressure at carburetor inlet. in Hg.	Brake horsepower corrected to standard pressure and temperature
1	1.22	45	28.40	0.0748	800	1,400	79.5	0.469	319	67	519	29.50	323
2	3.04	41	27.00	.0716	2,200	1,430	81.0	.467	326	70	519	29.50	329
3	5.23	39	25.80	.0687	3,700	1,440	81.5	.467	320	80	522	29.60	322
4	7.12	36	24.35	.0652	5,350	1,450	83.5	.475	317	88	527	29.60	319
5	9.19	34	23.30	.0626	6,700	1,470	83.5	.469	309	93	530	29.60	310
6	11.11	30	22.10	.0598	8,200	1,500	84.0	.462	314	101	536	29.60	316
7	12.90	26	20.95	.0572	9,600	1,500	85.0	.468	301	109	541	29.50	304
8	14.67	21	19.80	.0547	11,050	1,520	85.5	.464	301	117	544	29.40	304
9	16.50	17	18.70	.0521	12,550	1,530	87.5	.472	290	125	549	29.50	292
10	18.45	14	17.75	.0497	14,000	1,550	88.0	.469	288	133	557	29.50	290
11	20.08	9	17.00	.0482	15,000	1,560	89.0	.471	285	141	560	29.40	287
12	21.90	4	16.15	.0461	16,300	1,570	91.0	.478	276	147	566	29.50	278
13	23.57	0	15.50	.0447	17,250	1,580	92.0	.481	272	155	571	29.70	272
14	25.41	−3	14.75	.0429	18,500	1,600	94.5	.488	268	163	577	29.70	267
15	27.16	−7	14.20	.0416	19,400	1,600	94.5	.488	260	174	585	29.70	260
16	28.54	−11	13.75	.0407	20,000	1,600	94.5	.488	254	183	587	29.70	254
17	30.11	−16	13.30	.0398	20,700	1,610	95.5	.490	253	188	593	29.70	254
18	31.89	−19	12.80	.0386	21,600	1,620	96.5	.491	251	193	601	29.70	252
19	33.33	−23	12.40	.0378	22,200	1,620	96.0	.489	244	199	607	29.70	244
20	35.41	−26	11.95	.0365	23,200	1,620	96.0	.489	236	204	610	29.40	230
21	36.63	−31	11.65	.0360	23,600	1,620	96.0	.489	233	207	612	28.90	228
22	38.17	−33	11.30	.0352	24,200	1,610	97.0	.497	223	207	612	28.20	219
23	40.93	−36	11.05	.0346	24,700	1,610	97.0	.497	219	207	612	27.65	215
24	42.66	−38	10.80	.0340	25,200	1,610	97.0	.497	215	210	612	27.05	213
25	44.92	−39	10.65	.0335	25,600	1,600	98.0	.505	204	210	612	26.60	202
26	45.60	−41	10.50	.0332	25,900	1,600	98.5	.508	203	210	610	26.25	201
27	46.43	−43	10.40	.0331	26,000	1,590	93.5	.485	204	207	607	25.90	204
28	48.63	−43	10.25	.0326	26,400	1,570	93.0	.489	192	204	604	25.60	190

TABLE XIV.—SUPERCHARGED CLIMB USING THE 3:1 DRIVE RATIO

Reading No.	Corrected time, minutes	Observed atmospheric temperature, °F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, °F.	Temperature at carburetor inlet, °F. (abs.)	Pressure at carburetor inlet, in. Hg.
1	2.21	52	28.10	0.0729	1,650	1,420	75.0	0.436	329	75	527	29.70
2	4.12	49	26.70	.0697	3,150	1,440	76.0	.436	330	85	533	29.70
3	5.84	44	25.40	.0670	4,450	1,460	76.0	.429	334	96	538	29.70
4	7.80	40	24.10	.0640	6,000	1,480	77.5	.432	332	104	544	29.70
5	9.91	40	22.95	.0610	7,550	1,500	80.5	.443	326	117	549	29.70
6	11.56	34	21.95	.0589	8,650	1,510	82.0	.488	321	125	555	29.80
7	13.16	30	21.00	.0570	8,700	1,510	81.5	.446	308	133	560	29.80
8	14.95	25	20.10	.0550	10,850	1,520	80.0	.434	305	141	566	29.90
9	16.89	23	19.30	.0530	12,000	1,530	80.0	.431	304	149	574	29.90
10	18.49	19	18.35	.0512	13,100	1,540	80.5	.431	300	160	579	30.00
11	20.55	17	17.55	.0489	14,500	1,540	82.0	.439	286	169	587	30.15
12	22.09	13	17.00	.0478	15,200	1,540	83.5	.447	278	180	596	30.15
13	23.91	8	16.35	.0463	16,200	1,540	83.5.	.447	269	188	601	30.30
14	25.37	5	15.80	.0452	16,900	1,550	84.5	.450	268	191	610	30.30
15	27.60	4	15.40	.0440	17,700	1,560	85.0	.449	264	201	612	30.30
16	28.90	0	14.90	.0431	18,300	1,560	85.5	.452	259	207	618	30.30
17	30.73	−3	14.55	.0423	18,900	1,560	85.5	.452	253	212	621	30.30

TABLE XV.—SUPERCHARGED CLIMB USING THE 3:1 DRIVE RATIO

Reading, No.	Corrected time, minutes	Observed atmospheric temperature, ° F.	Observed atmospheric pressure, in. Hg.	Atmospheric density, lb. per cu. ft.	Standard altitude, feet	Observed engine speed, R. P. M.	Air speed, M. P. H.	$\frac{V}{nD}$	Brake horsepower	Temperature at supercharger outlet, ° F.	Temperature at carburetor inlet, ° F. (abs.)	Pressure at carburetor inlet, in. Hg.
1	0.74	48	28.90	0.0756	400	1,410	78.0	0.456	333	62	511	29.60
2	2.76	45	27.50	.0724	1,900	1,440	79.0	.453	342	70	522	29.50
3	4.59	41	26.20	.0695	3,250	1,460	81.5	.460	340	78	524	29.50
4	6.33	36	24.80	.0665	4,700	1,480	82.0	.457	339	83	527	29.50
5	8.21	31	23.75	.0642	5,900	1,490	83.0	.460	332	88	530	29.40
6	9.90	26	22.55	.0616	7,200	1,510	84.0	.459	334	93	533	29.50
7	11.58	20	21.30	.0590	8,600	1,520	85.0	.461	326	101	533	29.50
8	13.38	14	20.15	.0564	10,050	1,530	86.5	.467	314	109	536	29.50
9	15.21	10	19.25	.0543	11,250	1,560	87.5	.463	322	114	541	29.50
10	17.18	10	18.30	.0519	12,700	1,570	90.0	.473	311	125	546	29.50
11	19.29	9	17.30	.0491	14,400	1,580	93.5	.488	296	139	560	29.50
12	21.07	5	16.50	.0472	15,600	1,600	95.0	.490	295	144	566	29.50
13	22.76	0	15.75	.0455	16,700	1,610	95.5	.490	290	155	571	29.60
14	24.58	−4	15.20	.0442	17,600	1,620	96.0	.489	287	166	576	29.60
15	26.07	−8	14.55	.0428	18,500	1,630	97.0	.491	283	174	582	29.70
16	27.93	−12	14.10	.0418	19,300	1,630	97.0	.491	277	182	587	29.70
17	29.29	−16	13.65	.0409	19,900	1,640	97.0	.488	276	188	593	29.70
18	31.28	−18	13.25	.0398	20,700	1,640	98.5	.495	276	196	598	29.70
19	32.78	−21	12.80	.0388	21,400	1,640	99.5	.500	258	201	607	29.70
20	34.44	−24	12.40	.0379	22,100	1,640	99.5	.500	252	209	612	29.50
21	36.03	−29	12.05	.0371	22,700	1,640	101.0	.504	248	209	612	28.80
22	37.76	−32	11.70	.0363	23,350	1,630	101.0	.511	234	201	604	27.40
23	39.90	−32	11.45	.0355	24,000	1,630	101.5	.512	229	196	598	27.00
24	41.51	−33	11.25	.0350	24,400	1,625	102.0	.514	224	193	596	26.50
25	42.77	−36	11.00	.0345	24,800	1,625	103.5	.523	218	193	593	26.10
26	44.85	−36	10.85	.0340	25,200	1,620	106.0	.540	207	193	593	25.90
27	46.77	−37	10.75	.0337	25,450	1,610	106.5	.546	199	193	590	25.60
28	48.30	−37	10.70	.0336	25,550	1,610	105.0	.538	200	190	587	25.40
29	50.56	−37	10.55	.0331	26,000	1,610	106.5	.546	195	190	587	25.20
30	52.80	−37	10.50	.0329	26,150	1,610	106.0	.543	195	190	587	25.00



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L = \frac{L}{qbS} \quad C_M = \frac{M}{qcS} \quad C_N = \frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.