# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## REPORT No. 595

# FULL-SCALE TESTS OF A NEW TYPE N. A. C. A. NOSE-SLOT COWLING

By THEODORE THEODORSEN, M. J. BREVOORT
GEORGE W. STICKLE, and M. N. GOUGH

1937

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# AERONAUTIC SYMBOLS

## 1. FUNDAMENTAL AND DERIVED UNITS

|  | Symbol | Metric |  | English |  |
|---|---|---|---|---|---|
|  |  | Unit | Abbreviation | Unit | Abbreviation |
| Length | $l$ | meter | m | foot (or mile) | ft. (or mi.) |
| Time | $t$ | second | s | second (or hour) | sec. (or hr.) |
| Force | $F$ | weight of 1 kilogram | kg | weight of 1 pound | lb. |
| Power | $P$ | horsepower (metric) | ---------- | horsepower | hp. |
| Speed | $V$ | kilometers per hour<br>meters per second | k.p.h.<br>m.p.s. | miles per hour<br>feet per second | m.p.h.<br>f.p.s. |

## 2. GENERAL SYMBOLS

|  |  |
|---|---|
| $W$, | Weight $= mg$ |
| $g$, | Standard acceleration of gravity $= 9.80665$ m/s$^2$ or 32.1740 ft./sec.$^2$ |
| $m$, | Mass $= \frac{W}{g}$ |
| $I$, | Moment of inertia $= mk^2$. (Indicate axis of radius of gyration $k$ by proper subscript.) |
| $\mu$, | Coefficient of viscosity |
| $\nu$, | Kinematic viscosity |
| $\rho$, | Density (mass per unit volume) |
|  | Standard density of dry air, 0.12497 kg-m$^{-4}$-s$^2$ at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.$^2$ |
|  | Specific weight of "standard" air, 1.2255 kg/m$^3$ or 0.07651 lb./cu.ft. |

## 3. AERODYNAMIC SYMBOLS

|  |  |
|---|---|
| $S$, | Area |
| $S_w$, | Area of wing |
| $G$, | Gap |
| $b$, | Span |
| $c$, | Chord |
| $\frac{b^2}{S}$, | Aspect ratio |
| $V$, | True air speed |
| $q$, | Dynamic pressure $= \frac{1}{2}\rho V^2$ |
| $L$, | Lift, absolute coefficient $C_L = \frac{L}{qS}$ |
| $D$, | Drag, absolute coefficient $C_D = \frac{D}{qS}$ |
| $D_o$, | Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$ |
| $D_i$, | Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$ |
| $D_p$, | Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$ |
| $C$, | Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$ |
| $R$, | Resultant force |
| $i_w$, | Angle of setting of wings (relative to thrust line) |
| $i_t$, | Angle of stabilizer setting (relative to thrust line) |
| $Q$, | Resultant moment |
| $\Omega$, | Resultant angular velocity |
| $\rho\frac{Vl}{\mu}$, | Reynolds Number, where $l$ is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000) |
| $C_p$, | Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length) |
| $\alpha$, | Angle of attack |
| $\epsilon$, | Angle of downwash |
| $\alpha_o$, | Angle of attack, infinite aspect ratio |
| $\alpha_i$, | Angle of attack, induced |
| $\alpha_a$, | Angle of attack, absolute (measured from zero-lift position) |
| $\gamma$, | Flight-path angle |

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## SUMMARY

*An extended experimental study has been made in regard to the various refinements in the design of engine cowlings as related to the propeller-nacelle unit as a whole, under conditions corresponding to take-off, climb, and normal flight. The tests were all conducted at full scale in the 20-foot wind tunnel. This report presents the results of a novel type of engine cowling, characterized by the fact that the exit opening discharging the cooling air is not, as usual, located behind the engine but at the foremost extremity or nose of the cowling. This type of cowling is inherently capable of producing two to three times the pressure head obtainable with the normal type of cowling because the exit opening is located in a field of considerable negative pressure. Thus identical conditions of cooling can be obtained at correspondingly lower air speeds. In general, the efficiency is found to be high, owing to the fact that higher velocities may be used in the exit opening.*

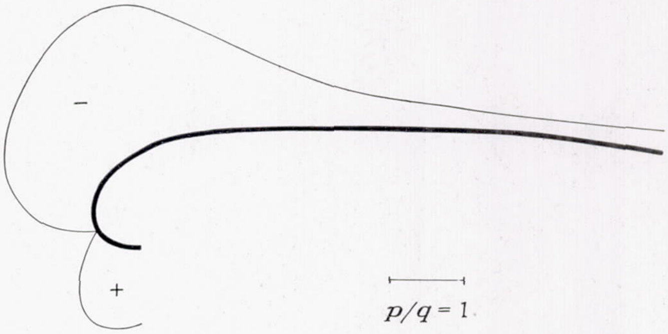

Figure 1.—Typical pressure distribution on cowlings. Test arrangement 7-2-0-3-0.

*Flight tests of a temporary installation showed promising results.*

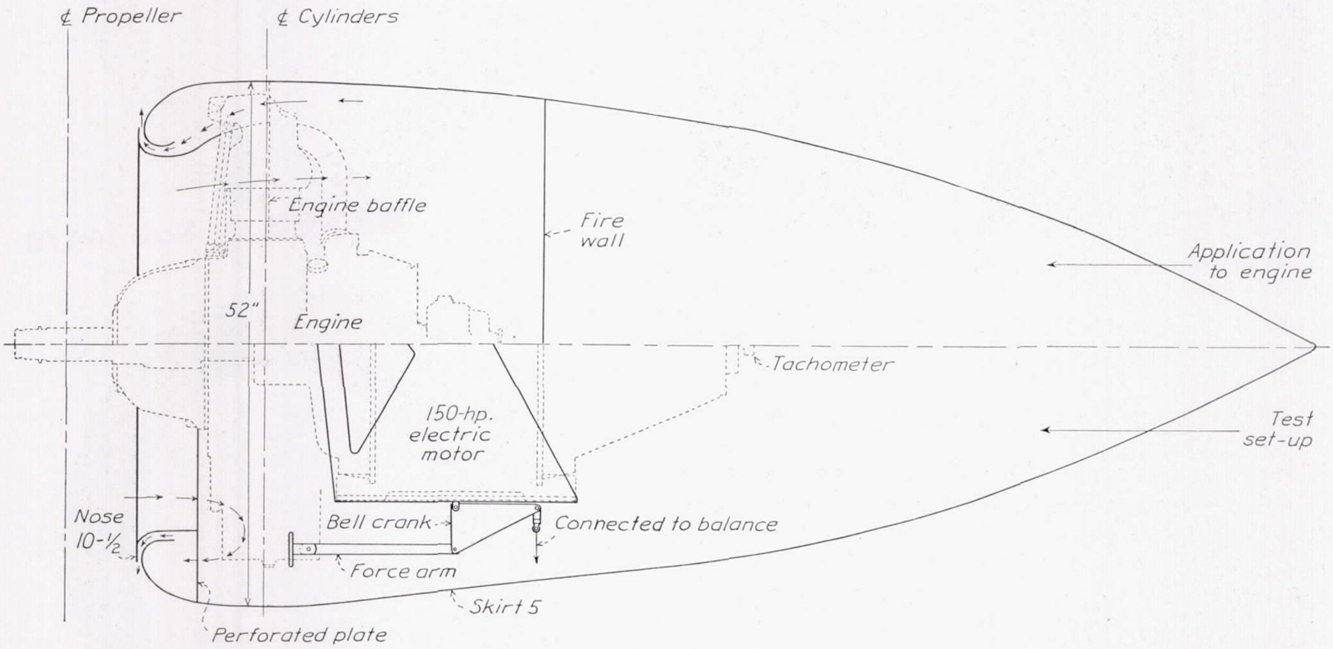

Figure 2.—Drawing showing the principle of operation of the nose-slot cowling. The upper half of the drawing shows the practical application; the lower half shows the arrangement of the test installation with nose 10-½.

## INTRODUCTION

It has been shown in the report on conventional cowlings (reference 1) that the available pressure head across the engine is very nearly equal to 1 $q$ and that only in very extreme cases, as by the use of skirt flaps, may this value be exceeded by about 20 percent. The pressure-distribution tests reported in the same reference show that a negative pressure of several times the velocity head is available near the nose of the cowling. (See fig. 1.) Since cases may be expected to occur in which a large pressure drop is desired, a special type of cowling was designed to have the exit opening at or very near the front portion of the cowling in order to make use of this available pressure drop. At first thought, this arrangement might be expected to be inefficient as a fairly large disturbance in the entire boundary layer is normally expected. Peculiarly enough the contrary seemed to be the case, the very first design showing a very high efficiency. The air enters the cowling in the central front opening in the usual manner, passes through the engine baffles, and is then returned across the top of the cylinders, guided into the nose ring, and discharged through the slot.

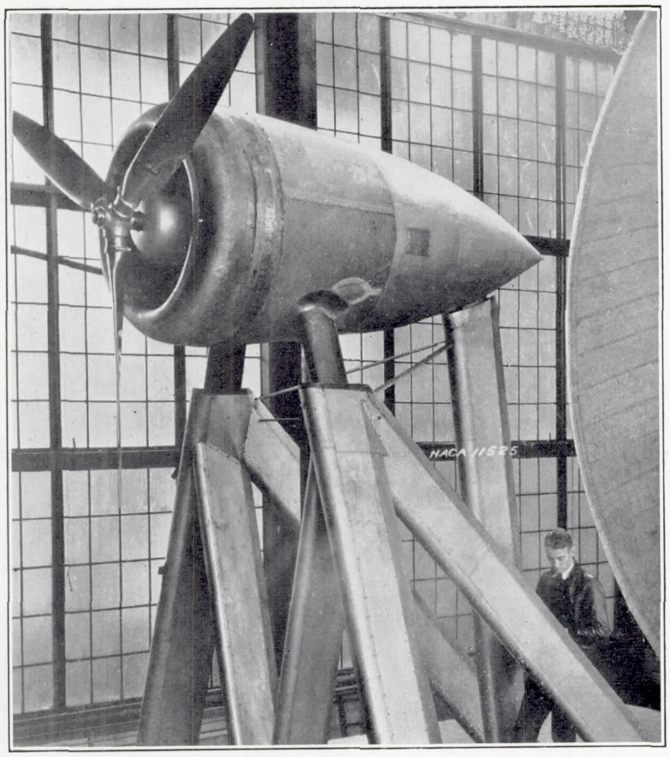

FIGURE 3.—The test installation in the 20-foot wind tunnel.

### DESCRIPTION OF TEST ARRANGEMENT

Figure 2 gives a general idea of the test arrangement; the engine resistance was replaced by a perforated plate just behind the nose ring, as shown in the lower half of the figure. This plate contained several hundred 1-inch holes, any number of which could be closed as desired, thus representing engines of a wide variety of conductivities. Figure 3 is a photograph of the installation with the original nose, which is designated 10–½, the first numeral giving the number of the nose and the second numeral giving the exit opening in inches, as some of these noses were tested with two sizes of exit opening. Figure 4 (a) is a photograph of nose 10–½; figures 4 (b) and 4 (c) show two more designs, 11–1 and 12–1, tested successively. A total of nine cowlings of

(a) Nose 10–½. **(b) Nose 11-1**

(b) Nose 11–1. **(a) Nose 10-1/2**

(c) Nose 12–1.

FIGURE 4.—Photographs of noses tested.

this type were tested, all of which are shown with the proper designations in the scale drawing (fig. 5). All the cowling nose rings were given the same major dimensions; all were fitted to the same perforated disk comprising the test resistance. The conductivity of this perforated disk could be changed at will between the limits of 0 to 0.09, thus simulating the complete range of actual installations. No heat-transmission tests were conducted in connection with these tests as the requisite information was available from reference 1.

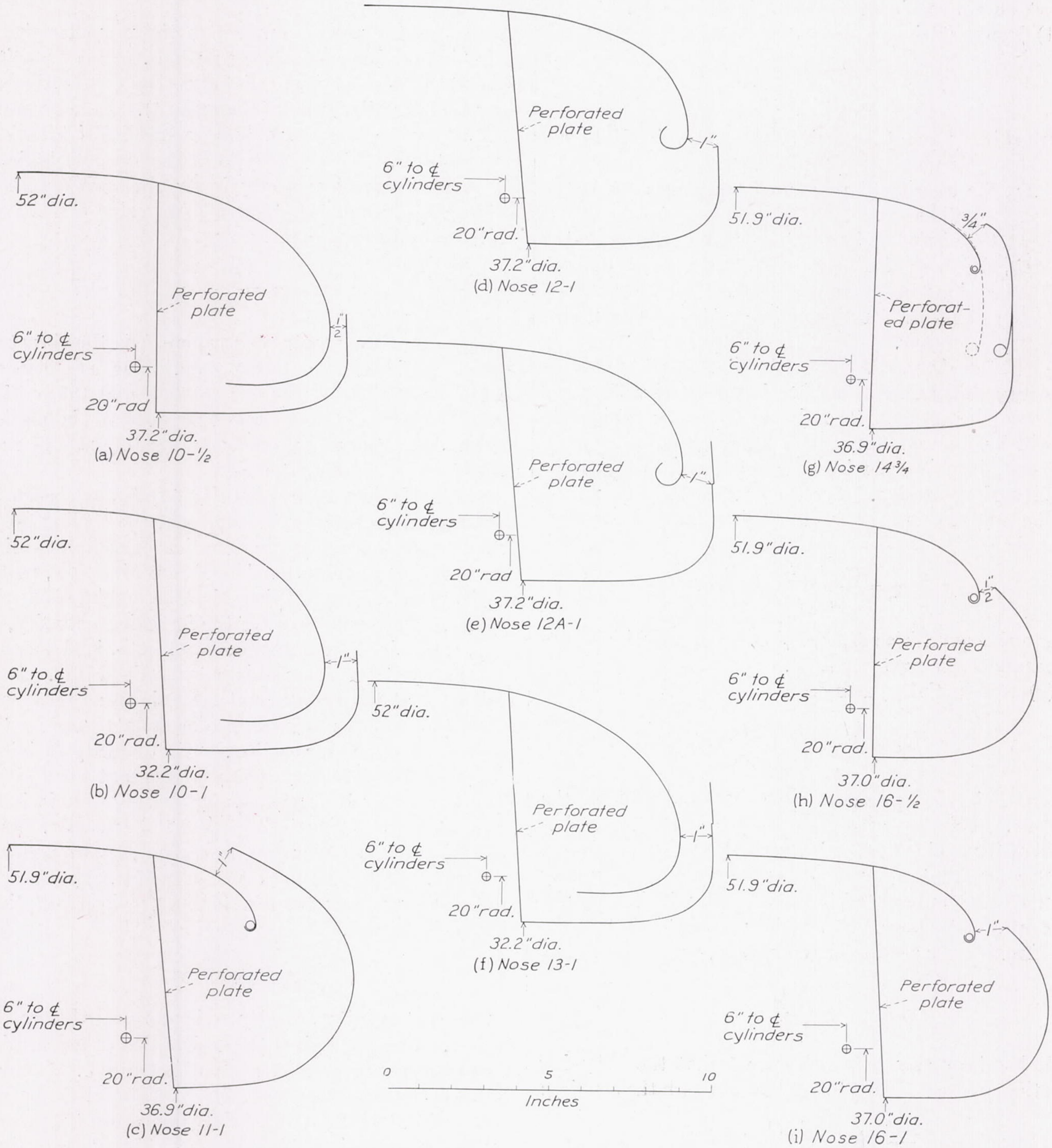

FIGURE 5.—Drawings of the nine nose cowlings tested.

The tests were performed at both high and low air speeds, the low speeds for the purpose of obtaining the cooling from the propeller slipstream alone. The tests were conducted as usual, with the propeller both on and off for the sake of completeness.

## DEFINITION OF PARAMETERS USED

The various terms used in the paper will be defined and briefly discussed. These terms are taken from the report on conventional cowlings (reference 1).

(1) Pump efficiency, defined as

$$\eta_p=\frac{Q\Delta p}{(D-D_0)V}$$

where $Q$ is the quantity of air per second which is forced through the resistance.

$\Delta p$, the associated pressure drop across the same resistance.

$D$, the observed drag of the cowling-nacelle unit.

$D_0$, the drag of a body of identical major dimensions but with the cooling channels closed and the outline faired into a streamline contour.

$V$, the air speed.

It may thus be seen that $Q\Delta p$ is the useful work done per second and that $(D-D_0)V$ is the work expended. It will be realized from the following that the pump efficiency is a very precise measure of the aerodynamic quality of the design. For the case of the power run, or the propeller on, the pump efficiency is given by the formula

$$\eta_p=\frac{(\Delta p/q)^{3/2}}{\eta_0-\eta}\quad\frac{P_cS}{KF}$$

where the quantities $K$, $F$, $P_c$, $S$, $\eta_0$, and $\eta$ will be defined under the next headings.

(2) Conductivity, defined as

$$K=\frac{A/F}{\sqrt{\Delta p/q}}=\frac{Q}{\sqrt{\Delta p/q}FV}$$

where $F$ is the maximum cross-sectional area of the nacelle. This quantity gives the inverse of the resistance of the engine to the air flow and is nondimensional.

The apparent conductivity of the exit opening may similarly be represented by a value $K_2$ which is simply the ratio of the area of the exit opening to that of the maximum cross section of the nacelle, or

$$K_2=\frac{A_2}{F}$$

It has been shown in reference 1 that the following relation exists in regard to the flow through the cowling:

$$\frac{\Delta P}{q}=\left(\frac{Q}{FV}\right)^2\left[\frac{1}{K^2}+\frac{1}{K_2^2}\right]$$

where $\Delta P$ is equal to the total head of the air entering the cowling minus the static pressure in the region of the exit opening. The former pressure is always found to be very nearly equal to the total head of the air stream. This equation will be referred to as "the equation of flow regulation."

(3) Propeller load factor or disk-loading coefficient, defined as

$$P_c=\frac{P}{qSV}$$

where $P$ is the power supplied to the propeller shaft, and $S$ is the disk area of the propeller. This quantity is in the first order proportional to the contraction of the propeller slipstream (reference 1). Equal values of $P_c$ thus essentially represent geometrically identical flow pictures. In the analysis of the results obtained for various propellers a certain simplicity is achieved in comparing such results at a fixed value of $P_c$.

(4) Net efficiency, defined as

$$\eta_n=\frac{RV}{P}$$

in the case of the power runs, where $R$ is the thrust of the unit as given by the thrust scale. The net efficiency obtained with the cooling air shut off and the outline faired into a carefully streamline contour is needed to determine the pump efficiency for the case of propeller on and is designated $\eta_0$.

(5) In reference 2 the quantity $\Delta p/n^2$ was chosen as a characteristic function to represent the cooling properties of any particular combination of engine cowling and propeller at the condition of zero air speed, representing the case of cooling airplane engines on the ground. The square root of the foregoing quantity, or $\sqrt{\Delta p}/n$, obtained from experimental data, is given as a function of the advance-diameter ratio $V/nD$. It is realized that the propeller at zero air speed acts very much the same as any other blower in regard to the pressure produced for cooling. The quantity $\Delta p/n^2$ or $\sqrt{\Delta p}/n$ is therefore very nearly a constant for a given propeller at a given blade-angle setting and is independent of the revolution speed of the propeller. It is referred to in the following discussion as the "pressure constant." The speed of the propeller may be considered known from the results of a previous investigation (reference 3).

## TEST RESULTS

The test results are shown in condensed form in table I. Column 1 gives the designation of the cowling nose corresponding to those given in figure 5. Column 2 shows the propeller used, the zero standing for propeller off and the $B_x$ and C, for the purpose of the present paper, representing two normal 10-foot propellers (reference 3). The main difference between $B_x$ and C is that $B_x$ has a well-shaped airfoil section extending down close to the hub, whereas C has a round shank. Column 3 shows the apparent conductivity of the exit opening. Column 4 is the conductivity of the test resistance or "engine." Columns 5, 6, and 7 show the pressures (in terms of $q$) with respect to the test resistance. Column 5 gives values of $p_f$, the pressures in front of, and column 6 gives values of $p_r$, the pressures in the rear of the resistance; column 7 gives values of $\Delta p$, the pressure difference across the resistance. Column 8 gives the drag in usual coefficient form $C_D$. Column 9 is given, for convenience, to illustrate the approximate forces involved by giving the drag at 100 miles per hour or, more exactly, at a $q$ of 25.6 pounds per square foot for the drag run; i. e., the forward net thrust at the same tunnel speed and at a fixed disk loading for the propeller runs. Column 10 gives the net efficiency $\eta_n$ for the propeller runs, and column 11 the pump efficiency $\eta_p$ as defined in the preceding section.

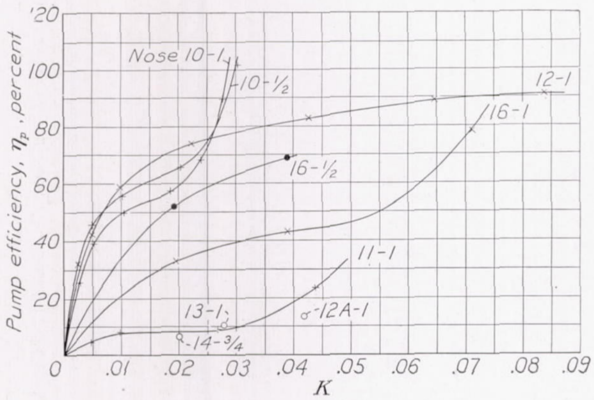

FIGURE 6.—Dependency of pump efficiency on conductivity.

In figure 6 the pump efficiency has been plotted against the conductivity for various noses. It was the very successful result on the original nose 10–½ that prompted the study of several other designs, which were later tested. Noses 10, 12, and 16 all tend to reach a 100-percent efficiency at conductivities beyond 0.07 and 0.08. Nose 10 actually exceeds 100-percent pump efficiency even at the low conductivity 0.03.

The reason for the relatively large efficiences obtained with this type of cowling lies in the fact that the velocities in the exit opening more nearly equal those of the external air stream. The beneficial effect of large exit velocities on the pump efficiency has been conclusively demonstrated in reference 1. The reason for the larger exit velocities is due to the fact that a much larger pressure difference is available and that part of this difference may be used in the exit opening, leaving at least the usual pressure drop for cooling.

The noses showing a very low efficiency in figure 6 were designed primarily with the intention of obtaining a large available pressure drop at zero air speed. On the whole, the design was found to be critical, a minor change in the external contour sufficing to drop the efficiency from near 100 percent to a small quantity. It was found that a projecting edge at the slot, such as embodied in cowlings 12, 13, or 14 in figure 5, was very detrimental to the efficiency. It was also noted that the highest efficiency was obtained by locating the outlet in a converging-flow field, as for nose 10, in contrast to the low efficiency obtaining by locating the outlet back of the maximum velocity, as for nose 11.

As is evident from the introduction, the main reason for designing and testing the new nose-slot cowling is the large pressure available for cooling. Figure 7 is a plot of the results in table I giving the available pressure against the engine conductivity, $K$. It is seen that the available pressure difference created by this type of cowling lies in the region of 2 $q$ and in a few cases even exceeds 2.5 $q$. The decrease in available pressure with increased conductivity is caused by the fairly small size of the apparent exit conductivities. It may be observed from the equation of flow regulation previously given that a small value of $K_2$ means that a large part of the pressure difference created by the cowling is used to produce velocity head in the exit opening and the remaining pressure $\Delta p$ available for cooling is correspondingly reduced. If the pressure available for cooling $\Delta p$ is added to the velocity head in the slot, it is found that the total, which is $\Delta P$, is of a nearly constant magnitude for any given cowling.

The values $K_2$ have been inserted for the various noses shown in figure 7. It has been shown in reference 1 that $K=0.05$ may be considered as the normal value of the conductivity of a well-baffled single-row radial engine. The average available pressure of the nose cowling at this conductivity is seen to approximate 1 $q$ and to reach a maximum of about 1¼ $q$ with nose 16–1. A comparison of the available pressure drops and efficiencies at any desired conductivity with those obtained on the regular cowlings (reference 1) shows that the nose-slot cowlings for most conditions are superior; hence, at an available pressure drop across the engine of about 1 $q$, the efficiencies on some of the nose-slot cowlings approach 100 percent, while in the normal type they were of the order of 60 to 80 percent.

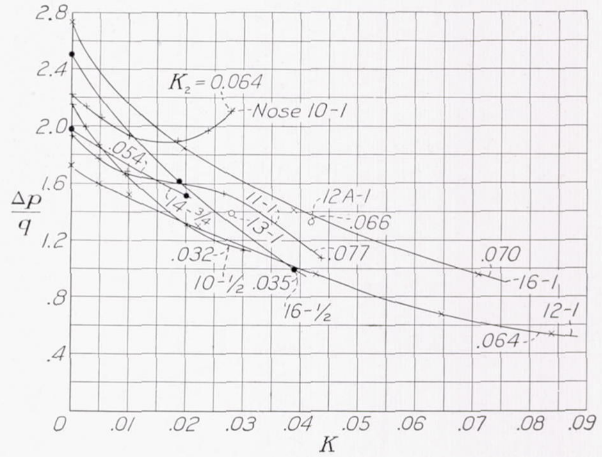

FIGURE 7.—Available pressure differences across the engine plotted against conductivity.

No attempt was made during the present investigation to test nose-slot cowlings with large exit conductivities. Such cowlings should provide a larger pres-

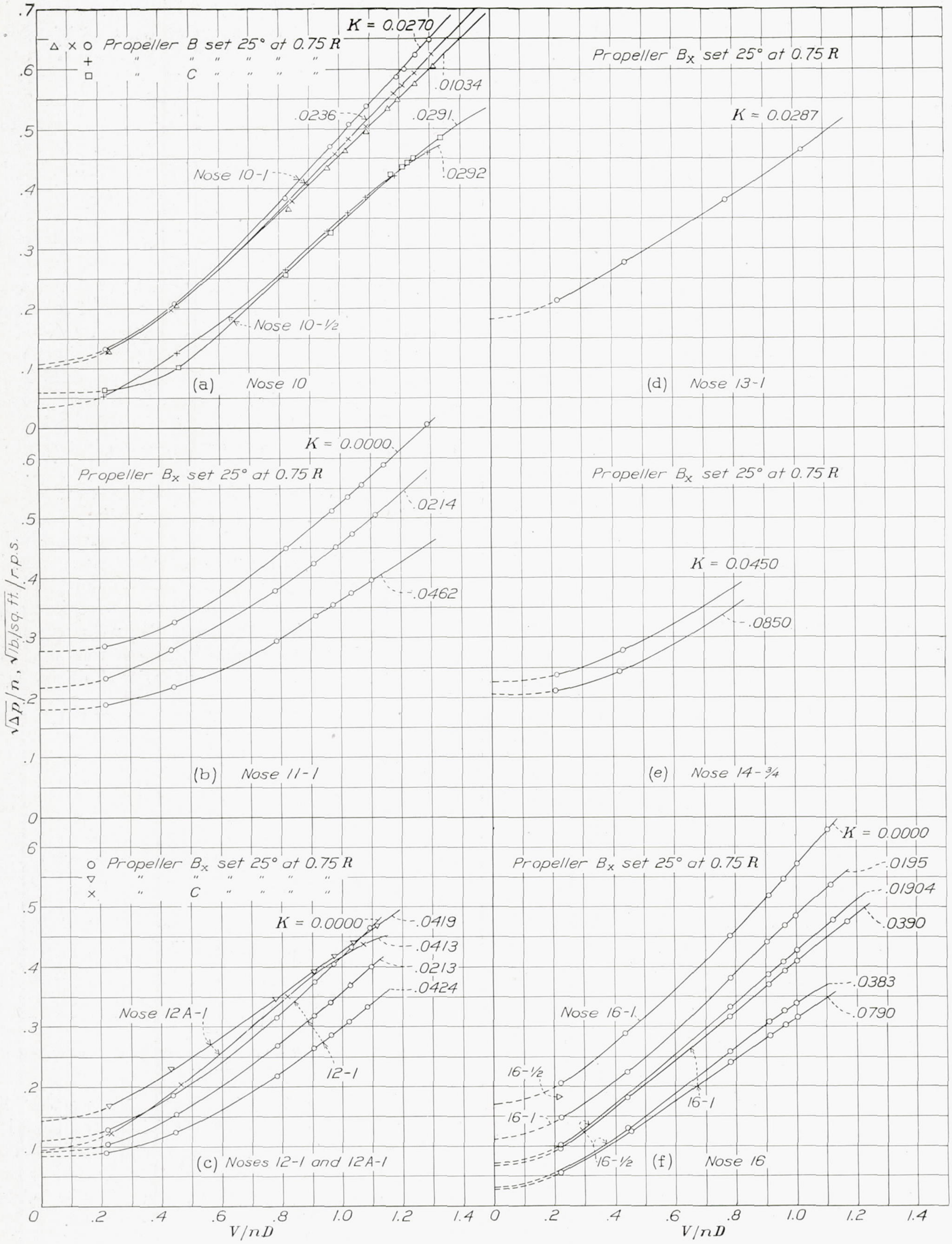

FIGURE 8.—Pressure constants $\sqrt{\Delta p}/n$ against $V/nD$ for the several noses tested.

sure drop for cooling, probably at some expense of pump efficiency. Since the largest pressure drop is needed only at low speed, the matter of some efficiency loss is not important. It is perfectly possible to provide means for changing the exit opening during flights.

FIGURE 9.—Original cowling installation on the Curtiss BFC-1 airplane.

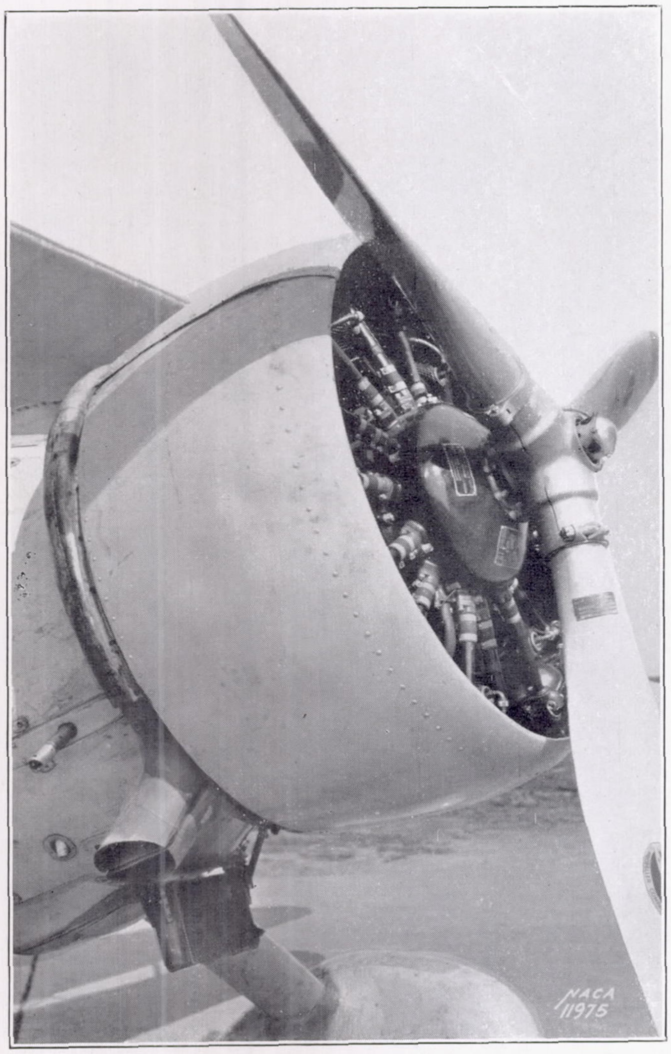

FIGURE 10.—Close-up of the original cowling on the Curtiss BFC-1 airplane

The experimental results in regard to the pressure drop available for cooling with the propeller slipstream at zero air speed are given in figure 8 for noses 10, 11, 12, 13, 14, and 16. These results will be more fully understood by a study of reference 2, which shows the pressure constant at zero air speed for various normal and special arrangements. Noses 10, 12, and 16 are seen to give very low pressure constants at the ground point. Nose 11 compares favorably with the best results previously obtained on normal cowlings. Noses 13 and 14 also give large available pressures on the ground. It is noticed, in general, that the noses giving high available pressures on the ground are not efficient in the flight condition, and vice versa.

## PRELIMINARY FLIGHT TESTS OF THE NEW TYPE N. A. C. A. COWLING ON BFC-1 AIRPLANE

In order that the practical value of the information on the new type of cowling might be demonstrated, the following flight tests were made with a preliminary cowling installation on the Curtiss BFC-1 airplane.

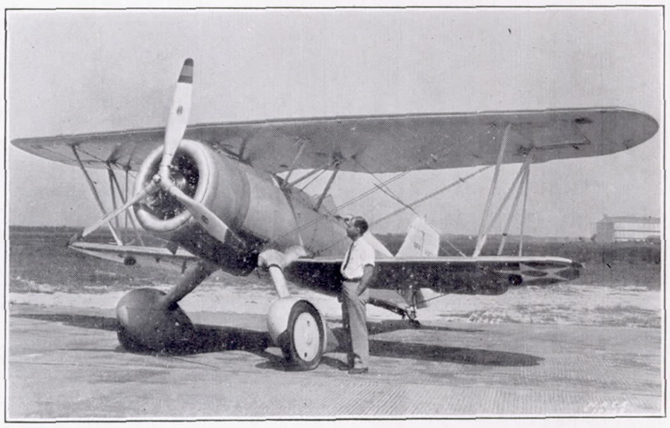

FIGURE 11.—The Curtiss BFC-1 airplane equipped with the nose-slot cowling.

The Curtiss BFC-1 airplane (fig. 9) has a Wright SGR-1510 twin-row, 14-cylinder, geared engine, completely equipped with pressure baffles and a wide-chord ring cowling (fig. 10). A selective thermocouple installation allowed the determination of temperature for 28 positions on the heads and bases of the 14 cylinders. In this condition a level flight was made for reference purposes at maximum allowable continuous power for a sufficient length of time to allow all temperatures to stabilize. Complete data identifying the flight were recorded.

The new N. A. C. A. nose-slot cowling was then installed as shown in figure 11. This photograph does not show the external oil cooler, as in figure 1, as it had been removed just before the picture was taken. The installation used nose 16-1 (fig. 5) and was arranged as shown in the upper part of figure 2, except for the fact that the internal dividing wall was located between the heads and the cylinder barrel and below the spark plugs. The wall extended back to the second row. The flow is approximately as indicated by arrows in the upper part of figure 2. Close-up photographs of the design are shown in figure 12.

Another change consisted in reversing the pressure baffles on the cylinder heads to suit the reversed flow direction; the baffles on the barrel were redesigned to fit the new installation. Three thermocouples on front cylinders were moved from the rear to the front spark-plug bosses. It should be noted that the location of the exhaust manifold (see fig. 10) could not be changed for these tests and that therefore it was entirely enclosed within the new cowling.

The operation on the ground of the engine with the new nose-slot cowling indicated the absence of excessive heating, which would have prevented flight tests. There was some evidence of unusual local heating, mainly of the rubber connections on the intake manifold. It is appreciated that the completely new arrangement might cause some change in local heating of parts not designed for the type of air flow provided by this cowling. No evidence of overheating appeared. After a cautious take-off and climb, a level flight reproducing the conditions of the one with the original cowling was made. From this flight the following comparison was obtained.

At the same density altitude and with the same power but with a free-air temperature lower by 13° C., the indicated air speed was, within the accuracy of measurement, the same. The oil, both in and out, was 6° C. cooler; the cylinder bases consistently averaged 30° C. cooler; the heads, 35° C. hotter, there being little difference between the front and rear plugs; and the magneto, 30° C. cooler. No difficulties were experienced. The handling characteristics of the airplane, the visibility, the local cockpit heating, and the engine-operating conditions appeared unchanged. Another flight verified the results.

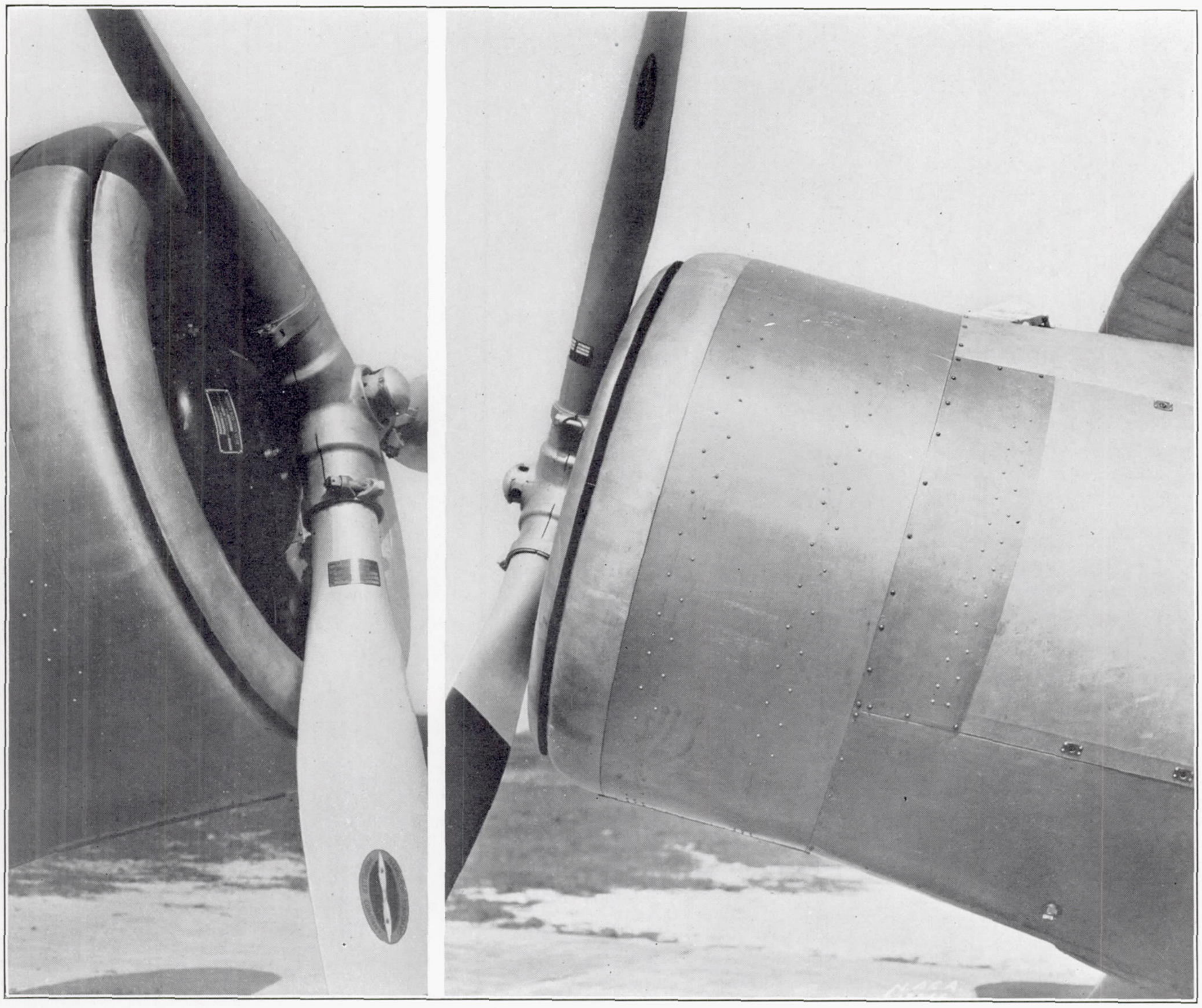

FIGURE 12.—Close-ups of the nose-slot cowling installed on a Curtiss BFC-1 airplane.

An inspection immediately after the engine was stopped on the ground revealed nothing amiss; the engine accessory or auxiliary compartment and the cowling aft of the cylinders was exceptionally cool. It was interesting to observe that, as expected, the nose of the cowling was the hottest point.

In view of the fact that the air used to cool the heads contains also the accumulated heat obtained from the exhaust manifold, the results obtained indicate very promising possibilities for considerably improved cooling when the baffling and manifold locations are designed specifically for this type cowling. Possible speed gains are also indicated when the external cowling lines may be incorporated in a new design rather than adapted to an already existing afterbody shape.

## GENERAL CONCLUSIONS

1. It has been found that the new type nose-slot cowling produces pressure differences of 2 to 2.5 times the velocity head of the air stream, as compared with 1 velocity head for the normal cowling. This fact is important as regards cooling in climb and at low air speeds.
2. A well-designed nose-slot cowling shows pump efficiencies close to 100 percent, owing to the fact that a smaller fraction of the total available pressure head is needed in the resistance, thus leaving a larger velocity head in the exit opening and reducing the impact or mixing losses that take place as the low-energy cooling air re-enters the main air stream.
3. Nose-slot cowlings designed for high efficiency at normal speed were found to be slightly inferior to normal cowlings in regard to cooling in the propeller slipstream. A specially designed nose-slot cowling for improving the cooling on the ground was found to be inefficient at normal-flight speeds in comparison with normal cowlings. A two-slot design, in which one slot may be closed at will, may therefore be recommended for cases in which good cooling from the propeller slipstream is particularly important.
4. The nose-slot cowling is critical in regard to design. It has been found that the exit opening should be located so as to permit the low-energy air to join the main air stream in a convergent-flow field, that is, ahead of the point of maximum velocity. High efficiency is obtained only by exercising great care in the detail design.
5. Preliminary flight tests gave promising results.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *June 5, 1936.*

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TABLE I.—CONDENSED TEST RESULTS

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| Nose | Propeller | $K_2$ | $K$ | $\frac{p_f}{q}$ | $\frac{p_r}{q}$ | $\frac{\Delta p}{q}$ | $C_D$ | Drag in pounds at $q=25.6$ pounds/square foot, or thrust at $1/\sqrt[3]{P_c}=1.8$ and $q=25.6$ pounds/square foot | $\eta_n$ | $\eta_p$ |
| 10–½ | 0 | 0.032 | 0.0000 | 0.922 | −1.250 | 2.170 | 0.1287 | 48.6 | ------ | 0.000 |
| 10–½ | 0 | | .00248 | .904 | −1.083 | 1.986 | .1330 | 50.2 | ------ | .318 |
| 10–½ | 0 | | .00497 | .904 | −.955 | 1.860 | .1388 | 52.4 | ------ | .457 |
| 10–½ | 0 | | .00981 | .929 | −.756 | 1.683 | .1499 | 56.6 | ------ | .552 |
| 10–½ | 0 | | .0200 | .926 | −.388 | 1.313 | .1573 | 59.4 | ------ | .652 |
| 10–½ | 0 | | .0304 | .918 | −.216 | 1.135 | .1475 | 55.7 | ------ | 1.013 |
| 10–½ | B | | .0292 | .881 | −.153 | 1.034 | ------ | 250 | 0.716 | 1.278 |
| 10–½ | C | | .0291 | .854 | −.190 | 1.043 | ------ | 247 | .708 | .998 |
| 10–1 | 0 | .064 | .0000 | .911 | −1.313 | 2.223 | .1372 | 51.8 | ------ | .000 |
| 10–1 | 0 | | .00267 | .930 | −1.209 | 2.140 | .1433 | 54.1 | ------ | .260 |
| 10–1 | 0 | | .00527 | .923 | −1.117 | 2.040 | .1510 | 57.0 | ------ | .386 |
| 10–1 | 0 | | .01034 | .927 | −1.010 | 1.938 | .1671 | 63.1 | ------ | .500 |
| 10–1 | 0 | | .01862 | .926 | −.966 | 1.894 | .1965 | 74.2 | ------ | .568 |
| 10–1 | 0 | | .0238 | .925 | −1.058 | 1.983 | .209 | 78.9 | ------ | .680 |
| 10–1 | 0 | | .0278 | .928 | −1.166 | 2.095 | .205 | 77.6 | ------ | .899 |
| 10–1 | B | | .0270 | .891 | −1.101 | 1.992 | ------ | 236.0 | .676 | 1.243 |
| 10–1 | B | | .0236 | .887 | −.955 | 1.840 | ------ | 239.0 | .685 | 1.117 |
| 10–1 | B | | .01034 | .901 | −.907 | 1.808 | ------ | 242.0 | .693 | .555 |
| 11–1 | 0 | .077 | .0000 | .925 | −1.009 | 1.935 | .299 | 113.0 | ------ | .000 |
| 11–1 | $B_x$ | | .0000 | .913 | −1.306 | 2.220 | ------ | 200.0 | .573 | .000 |
| 11–1 | 0 | | .00484 | .918 | −.849 | 1.768 | .342 | 129.0 | ------ | .0493 |
| 11–1 | 0 | | .00979 | .934 | −.731 | 1.665 | .381 | 144.0 | ------ | .0780 |
| 11–1 | 0 | | .0267 | .943 | −.593 | 1.536 | .416 | 157.0 | ------ | .0865 |
| 11–1 | $B_x$ | | .0214 | .923 | −.800 | 1.723 | ------ | 166.0 | .476 | .197 |
| 11–1 | $B_x$ | | .0462 | .918 | −.172 | 1.090 | ------ | 180.0 | .516 | .252 |
| 11–1 | 0 | | .0438 | .950 | −.114 | 1.064 | .318 | 120.0 | ------ | .233 |
| 12–1 | 0 | .064 | .0000 | .933 | −.794 | 1.725 | .1245 | 47.0 | ------ | .000 |
| 12–1 | $B_x$ | | .0000 | .920 | −.561 | 1.482 | ------ | 244.0 | .698 | .000 |
| 12–1 | 0 | | .00493 | .914 | −.681 | 1.594 | .1345 | 50.8 | ------ | .426 |
| 12–1 | 0 | | .00998 | .910 | −.595 | 1.504 | .1427 | 53.9 | ------ | .584 |
| 12–1 | 0 | | .0222 | .914 | −.386 | 1.301 | .1557 | 58.8 | ------ | .739 |
| 12–1 | $B_x$ | | .0213 | .920 | −.175 | 1.095 | ------ | 243.0 | .696 | .574 |
| 12–1 | 0 | | .0427 | .932 | −.017 | .948 | .1589 | 60.0 | ------ | .827 |
| 12–1 | 0 | | .0647 | .939 | .261 | .679 | .1520 | 57.4 | ------ | .890 |
| 12–1 | $B_x$ | | .0424 | .915 | .137 | .779 | ------ | 242.0 | .693 | .645 |
| 12–1 | 0 | | .0839 | .933 | .397 | .536 | .1475 | 55.7 | ------ | .908 |
| 12A–1 | $B_x$ | .066 | .0419 | .920 | −.613 | 1.531 | ------ | 150.5 | .431 | .276 |
| 12A–1 | 0 | | .0419 | .957 | −.373 | 1.330 | .580 | 219.0 | ------ | .137 |
| 12A–1 | C | | .0413 | .863 | −.569 | 1.433 | ------ | 147.0 | .42 | .240 |
| 13–1 | 0 | .066 | .0281 | .938 | −.446 | 1.384 | .575 | 217.0 | ------ | .099 |
| 13–1 | $B_x$ | | .0287 | .913 | −.767 | 1.679 | ------ | 143.0 | .41 | .203 |
| 14–¾ | 0 | .054 | .0000 | .948 | −1.038 | 1.983 | .527 | 199.0 | ------ | .000 |
| 14–¾ | $B_x$ | | .0000 | ------ | ------ | ------ | ------ | ------ | .44 | .000 |
| 14–¾ | $B_x$ | | ------ | ------ | ------ | ------ | ------ | 112.0 | .32 | ------ |
| 14–¾ | 0 | | .0201 | .955 | −.563 | 1.519 | .651 | 246.0 | ------ | .070 |
| 14–¾ | 0 | | ------ | ------ | ------ | ------ | .625 | 236.0 | ------ | ------ |
| 14–¾ | $B_x$ | | ------ | ------ | ------ | ------ | ------ | 105.0 | .30 | ------ |
| 16–1 | 0 | .070 | .0000 | .921 | −1.809 | 2.730 | .1324 | 50.0 | ------ | .000 |
| 16–1 | $B_x$ | | .0000 | .897 | −1.750 | 2.645 | ------ | 244.0 | .700 | .000 |
| 16–1 | $B_x$ | | .01950 | .894 | −1.030 | 1.923 | ------ | 219.0 | .627 | .490 |
| 16–1 | 0 | | .01965 | .903 | −.946 | 1.848 | .263 | 99.5 | ------ | .325 |
| 16–1 | 0 | | .0388 | .918 | −.488 | 1.408 | .263 | 99.5 | ------ | .427 |
| 16–1 | $B_x$ | | .0390 | .893 | −.499 | 1.391 | ------ | 216.0 | .620 | .568 |
| 16–1 | $B_x$ | | .0790 | .888 | .061 | .826 | ------ | 226.0 | .648 | .683 |
| 16–1 | 0 | | .0711 | .908 | −.049 | .958 | .1967 | 74.3 | ------ | .782 |
| 16–½ | 0 | .035 | .0000 | .890 | −1.621 | 2.513 | .1290 | 48.7 | ------ | .000 |
| 16–½ | $B_x$ | | .01904 | .878 | −.668 | 1.547 | ------ | 234.0 | .671 | .557 |
| 16–½ | 0 | | .01920 | .903 | −.712 | 1.614 | .1872 | 70.7 | ------ | .518 |
| 16–½ | 0 | | .0390 | .907 | .095 | 1.000 | .1679 | 63.4 | ------ | .688 |
| 16–½ | $B_x$ | | .0383 | .875 | −.082 | .955 | ------ | 235.0 | .673 | .561 |

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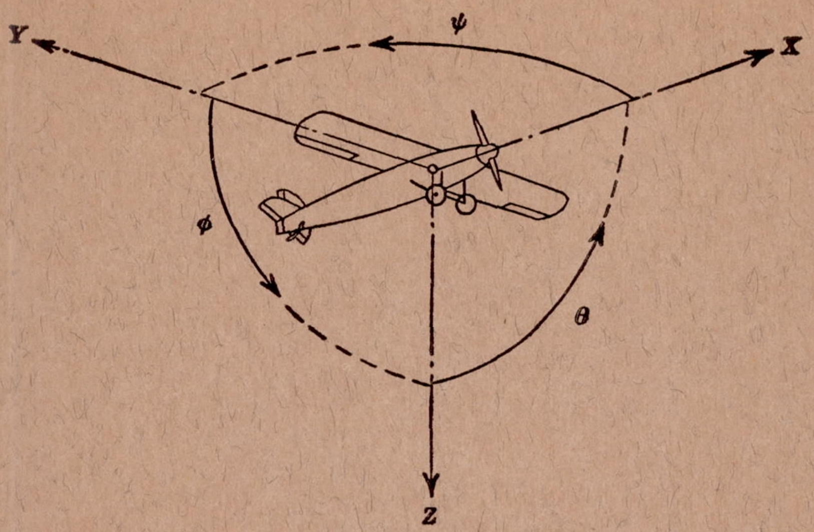

Positive directions of axes and angles (forces and moments) are shown by arrows

| 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 | $\phi$ | $u$ | $p$ |
| Lateral | $Y$ | $Y$ | Pitching | $M$ | $Z \longrightarrow X$ | Pitch | $\theta$ | $v$ | $q$ |
| Normal | $Z$ | $Z$ | Yawing | $N$ | $X \longrightarrow Y$ | Yaw | $\psi$ | $w$ | $r$ |

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

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

### 4. PROPELLER SYMBOLS

$D$, Diameter

$p$, Geometric pitch

$p/D$, Pitch ratio

$V'$, Inflow velocity

$V_s$, Slipstream velocity

$T$, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$

$Q$, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$

$P$, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$

$C_s$, Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$

$\eta$, Efficiency

$n$, Revolutions per second, r.p.s.

$\Phi$, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

### 5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.

1 metric horsepower = 1.0132 hp.

1 m.p.h. = 0.4470 m.p.s.

1 m.p.s. = 2.2369 m.p.h.

1 lb. = 0.4536 kg

1 kg = 2.2046 lb.

1 mi. = 1,609.35 m = 5,280 ft.

1 m = 3.2808 ft.