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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 313

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DRAG AND COOLING WITH VARIOUS FORMS OF COWLING FOR A "WHIRLWIND" RADIAL AIR-COOLED ENGINE—I

By FRED E. WEICK



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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length-----	<i>l</i>	meter-----	m	foot (or mile)-----	ft. (or mi.)
Time-----	<i>t</i>	second-----	sec	second (or hour)-----	sec. (or hr.)
Force-----	<i>F</i>	weight of one kilogram-----	kg	weight of one pound-----	lb.
Power-----	<i>P</i>	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/m³ = 0.07651 lb./ft.³

mk^2 , Moment of inertia (indicate axis of the
radius of gyration, *k*, by proper sub-
script).

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 coeffi-
cients are twice as large as the old co-
efficients *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.

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

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

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

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

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

α , Angle of attack.

ϵ , Angle of downwash.

REPORT No. 313

**DRAG AND COOLING WITH
VARIOUS FORMS OF COWLING FOR A "WHIRLWIND"
RADIAL AIR-COOLED ENGINE—I**

By FRED E. WEICK
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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TECHNICAL REPORT No. 313

DRAG AND COOLING WITH VARIOUS FORMS OF COWLING FOR A "WHIRLWIND" RADIAL AIR COOLED ENGINE—I¹

By Fred E. Weick

SUMMARY

The National Advisory Committee for Aeronautics has undertaken an investigation in the 20-foot Propeller Research Tunnel at Langley Field on the cowling of radial air-cooled engines. A portion of the investigation has been completed, in which several forms and degrees of cowling were tested on a Wright "Whirlwind" J-5 engine mounted in the nose of a cabin fuselage. The cowlings varied from the one extreme of an entirely exposed engine to the other in which the engine was entirely inclosed. Cooling tests were made and each cowling modified, if necessary, until the engine cooled approximately as satisfactorily as when it was entirely exposed. Drag tests were then made with each form of cowling, and the effect of the cowling on the propulsive efficiency determined with a metal propeller.

The propulsive efficiency was found to be practically the same with all forms of cowling. The drag of the cabin fuselage with uncowed engine was found to be more than three times as great as the drag of the fuselage with the engine removed and nose rounded. The conventional forms of cowling, in which at least the tops of the cylinder heads and valve gear are exposed, reduce the drag somewhat, but the cowling entirely covering the engine reduces it 2.6 times as much as the best conventional one. The decrease in drag due to the use of spinners proved to be almost negligible.

The use of the cowling completely covering the engine seems entirely practical as regards both cooling and maintenance under service conditions. It must be carefully designed, however, to cool properly. With cabin fuselages its use should result in a substantial increase in high speed over that obtained with present forms of cowling on engines similar in contour to the J-5.

INTRODUCTION

The problem of cowling radial air-cooled engines has puzzled aircraft designers since the adoption of the static radial engine. The cowling has an important effect on both the cooling of the engine and the drag of the airplane, and no reliable data on either have been available.

At the conference of aircraft manufacturers held at Langley Field on May 24, 1927, several requests were made that an investigation of the cowling and cooling problem in regard to radial air-cooled engines be undertaken in the new full-scale Propeller Research Tunnel which was then just being completed. A program for a series of tests was drawn up and submitted to the manufacturers for criticisms and suggestions, several of which were adopted.

The program as finally arranged includes 10 main forms of cowling to be tested on a J-5 engine in connection with 2 fuselages, 3 on an open cockpit fuselage and 7 on a closed cabin type. The seven forms of cowling on the cabin fuselage range from the one extreme of an engine entirely exposed except for the rear crank case, to the other extreme of a totally inclosed engine. One of the cowlings with the open cockpit fuselage includes individual fairings behind each cylinder. Three forms of cowling, two of which are on the cabin fuselage, afford direct comparisons with and without a propeller spinner. The program involves the measurement of the engine cylinder temperatures, each cowling being modified, if necessary, until the cooling is satisfactory. The cowling is then tested for its effect on drag and propulsive efficiency.

¹ This report was originally published as N. A. C. A. Technical Note No. 301.

The portion of the investigation involving the cabin fuselage is covered in this report, and the rest of the investigation will be given in another report called part 2 (reference 2).

Although the tests are being made in the Propeller Research Tunnel, a great deal of help has been received from other sections of the laboratory, especially the Flight Operations Section, which made a beautiful job of the cowling and also contributed many helpful suggestions, and the Power Plants Division, which conducted the measurement of the cylinder temperatures.

METHODS AND APPARATUS

The Propeller Research Tunnel is of the open throat type with an air stream 20 feet in diameter, in which velocities up to 110 M. P. H. can be obtained. A complete description of the tunnel, balances, and other measuring devices is given in Reference 1.

A standard Wright "Whirlwind" J-5 engine delivering 200 HP. at 1,800 R. P. M. was used for these tests. It was mounted on a dynamometer inclosed within the fuselage so that the engine torque could be measured directly. The torque as measured included the torque on the engine cylinders due to the twist of the slip stream. In order to correct for this effect a special test was made in which three J-5 cylinders complete with valve housings were mounted under the front portion of a water-cooled Wright E-2 engine on a VE-7 fuselage in the Propeller Research Tunnel (Fig. 11). The cylinders were in the same position relative to the propeller as on a J-5 engine. The middle cylinder only was supported in such a manner that its torque about the engine axis could be measured, and the same propeller used in the cowling tests was driven by the E-2 engine. The torque on the middle cylinder was then found for various engine and air speeds with different amounts of cowling, and the results have been used to apply a correction, amounting to as much as 3 per cent in some cases, to the engine torque and power.

The cabin fuselage was designed to have a shape and size approximating the average of the fuselages of several commercial "Whirlwind" engined cabin monoplanes. The fuselage was of rectangular cross section from the maximum section to the tail, and the forward portion was gradually faired to a circular section at the engine. This whole forward portion was rebuilt for the various cowlings.

In order to make certain that the tests would be directly applicable to the present-day high-wing cabin monoplanes, a stub wing and pilot's extension cabin and windshield were mounted on the fuselage and tested with three different cowlings. The wing, which was constructed of flat sheet aluminum over a wooden frame, had the Göttingen 398 section, with a 7-foot chord and 16-foot span.

The open cockpit fuselage is similar in shape to that of a Vought UO-1 airplane, and a UO-1 type landing gear is being used with both the open and cabin fuselages in this investigation in order to keep the landing gear factor constant.

The cylinder temperatures of the J-5 engine were measured at 69 different points, 47 being on the top (Number 1) cylinder and the rest distributed at two or three representative points on each of the other cylinders. A mass of other engine data such as the manifold depression, fuel consumption, and carburetor air temperature, were also obtained. Only a small portion of the engine data is necessary to the present investigation, and most of it, along with a complete description of the thermocouples, pyrometers, and other instruments, will be published in a separate report by the Power Plants Division of the laboratory.

The entire program includes ten main sets of cowling. Numbers 1, 2, and 3 are to be used with the open cockpit fuselage and have not yet been tested. The cowlings tested on the cabin fuselage may be outlined as follows:

Number 4. No cowling over cylinders or crank case. Tested with and without wing. (Fig. 1.)

Number 5. Cowling covering slightly less than one-half of each cylinder and over crank case. Tested with and without wing. (Fig. 2.)

Number 6. Same as Number 5, but with spinner. Tested with and without wing. (Fig. 3.)

Number 7. Cowling over nearly all of each cylinder and over crank case. (Fig. 4.)

Number 8. Same as Number 7, but with spinner. (Fig. 5.)

Number 9. Single cowling completely covering cylinders, but no cowling over crank case. (Fig. 6.)

Number 10. Same as Number 9, but with internal cowling similar to Number 5 over lower portion of cylinders and crank case. (Fig. 7.)

All of the cowlings were constructed in a practical manner with fire walls and louvers.

The first test made with each cowling was on the cooling properties, the cylinder temperatures with the uncowed engine (Number 4) being used as a criterion. In the first few series of cooling tests the engine was run at full throttle at air speeds of 60, 80, and 100 M. P. H. At each speed the run was maintained until the temperature conditions had become constant. It was found that in each case the engine ran slightly warmer at 80 M. P. H. than at either 60 or 100, so the remainder of the tests were run at 80 M. P. H. as representing the worst flight conditions for cooling. The conditions were therefore similar to those in an extended full throttle climb in flight. If the cooling with any cowling was not as satisfactory as that with the uncowed engine, the cowling was modified until satisfactory.

Drag tests were run with the various cowlings, both as they were originally constructed and as they were finally modified to cool properly.

After a cowling cooled properly, propeller tests were made to determine the effect of the cowling on the propulsive efficiency. The propeller, which had adjustable aluminum alloy blades (Fig. 31), was tested at both a low and a high pitch setting with each cowling. The hub to which the blades were fitted was of steel, and in order to save weight, had been made 1 inch shorter than the hub for which the blades had been designed, so that while the drawing shows a 9-foot propeller, the diameter in these tests was actually 8 feet 11 inches. The propulsive efficiency found from these propeller tests includes the increase in drag of all parts of the body affected by the slip stream and also the effect of the body interference on the propeller thrust and power.

COOLING TESTS

The cylinder temperatures obtained with cowling Number 4 (engine uncowed, Figs. 1, 12, and 13) at full throttle and 80 M. P. H. were used as a criterion by which to judge the cooling with the other forms of cowling. The particular temperatures used for comparison are tabulated in Table I. The hottest part of each cylinder was the rear spark-plug boss, and it was at first thought that the average of the rear spark-plug boss temperatures for all nine cylinders would be used as a measure for comparison. In some runs, however, one or two cylinders had very low temperatures, probably because they were not developing full power, so the average of the five hottest cylinders has been taken as a better criterion of the cooling. The highest temperature recorded on any cylinder was also used as a criterion, and also three representative points on cylinder Number 1 (top cylinder). One of these was at the rear spark-plug boss, one at the rear central portion of the barrel, and the third at the rear lower portion of the barrel. The rear points were chosen because they represented the highest temperatures around the cylinders. In addition to the above cylinder temperatures, the lubricating oil temperature and the temperature of the air in the tunnel were considered.

The temperature conditions under which these tests were made in the wind tunnel were more severe than the conditions found in flight in a temperate climate, and probably correspond to those of a sustained full throttle climb in a tropical climate. The cylinder temperatures recorded were therefore in the neighborhood of 100° higher than have been found in flight tests.

The cooling with cowling Number 5 (Figs. 2 and 14), in which the cowling covered the crank case and nearly half of each cylinder, was better than with no cowling whatever over the engine. The hottest five cylinder head temperatures averaged nearly 70° F. lower than with cowling Number 4, while the cylinder barrel and oil temperatures were the same. With cowling Number 6 (Figs. 3 and 15), which was the same as Number 5 excepting for the spinner, the cooling effect would be obviously about the same as with Number 5, so no cooling tests were considered necessary. (Since the full throttle running seemed unusually severe, and since it was necessary to run the engine with thermocouples attached for over 100 hours in all no full throttle running was done which was not necessary.)

Number 7 cowling (Figs. 4 and 16) as originally constructed inclosed the whole engine except for the tops of the cylinder heads and the valve gear. At the front of the cylinder the cowling came just under the spark plug, and at the rear it came just over the cylinder head proper, inclosing the rear spark plug. The cooling with this cowling was not satisfactory, for the oil and cylinder barrel temperatures were excessive, although the head temperatures, even those of the inclosed rear spark-plug boss, were considerably lower than with no cowling over the engine.

Apparently with cowling Numbers 5, 6, 7, and 8, the air flows past the cylinder heads at greater speed than with no cowling over the engine. In order to improve the oil and cylinder barrel cooling with cowling Number 7, four slots were cut in the nose as shown in Figure 17. These were effective in reducing the oil and barrel temperatures somewhat, but the temperatures were still too high, and on this run the piston in cylinder Number 9 failed, due apparently to excessive temperature. The high piston temperature was probably due to the fact that with the high oil and cylinder wall temperatures with cowling Number 7, the heat was not conducted away from the piston skirt rapidly enough. The engine was repaired, and six larger slots were put in the nose cowling over the crank case as shown in Figure 18. Enough louvers were already in the cowling behind the engine to permit the escape of the air passing through the nose slots. With this arrangement the cooling was considered satisfactory as compared with that of the uncowled engine (Number 4). The cylinder head temperatures were a little lower than for the uncowled engine, the oil temperature was practically the same, and the barrel temperatures were a little higher.

Incidentally, a series of tests with different sized carburetor jets was run with cowling Number 7. It was found that the cylinder temperatures could be reduced materially by increasing the jet size.

Cowling Number 8, which was the same as Number 7 except that it had a spinner, is shown as originally constructed in Figures 5, 19, and 20. On account of the large spinner, nose slots similar to those in cowling Number 7 could not be used. Instead, the cowling was cut away immediately in front of each cylinder, as shown in Figure 21, to make the engine cool properly.

Cowling Number 9 completely covered the engine (Figs. 6 and 22). The air was taken in at the nose and allowed to flow past the engine, which was entirely uncowled inside of the outer hood, and out of an annular slot similar in section to some wing slots which have been tested. This type of nose and slot were designed to offer as little disturbance to the flow of air over the fuselage as possible, separating the air for cooling the engine from the general flow and then feeding it back smoothly through the slot. No information was available when this cowling was designed regarding the necessary size of the hole in the nose or the slot. In the cooling test with the original Number 9 cowling the cylinder head temperatures became excessive in a very short time.

Number 10 cowling was the same as Number 9 except that it had Number 5 cowling inside also (Figs. 7 and 23), so that the air was directed more particularly at the cylinder heads, and at the same time had a smoother path past the engine. This improved the cooling of the cylinder heads slightly, but they still ran much too hot. During the test the head of Number 3 cylinder developed a small hole about one-eighth inch in diameter, apparently caused by a defective spot in the aluminum alloy becoming too hot to withstand the cylinder pressures. This cylinder was therefore replaced. It is interesting to note that the two cylinders which gave trouble due to cooling—Numbers 3 and 9—were deprived of their full share of cooling air by the magnetos, which on the J-5 engine are placed in front of the cylinders.

The outlet area at the slot had originally been made smaller than the inlet area, and the cowling was then modified by cutting 3 inches off of the skirt of the hood or nose piece, which increased the area of the slot to that of the opening at the nose. With this modification the cooling was fairly satisfactory except for the cylinders located behind the magnetos (Numbers 2, 3, 8, and 9). The magnetos effectively blocked most of the air from those cylinders.

Next, deflectors, as shown in Figure 9, were installed between the cylinders to direct the air to the hottest portions at the rear. These also reduced the temperatures slightly and were retained. The next modification was to enlarge the hole in the nose from 24 inches to 28 inches

in diameter. It was thought that this would not only allow more air to flow past the engine, but also enable some air to pass over the magnetos. With the 28-inch opening the cooling was much better, but the cylinders behind the magnetos, especially Number 9, still ran too hot.

Next a cut-out was made in the nose piece over each magneto. This improved the conditions somewhat, but not sufficiently, so the cut-outs over the magnetos were enlarged, the cowling as it then appeared being as shown in Figures 8, 24, and 25. With this arrangement, the cooling was fairly satisfactory, but the temperatures were still a little higher than for the uncowled engine, especially at the lower portion of the cylinder barrels.

In the original design the slot had been placed as far forward as possible in the hope that it would help remove the boundary layer near the region of rather sharp curvature at the nose, and thereby help reduce the drag. This necessitated a sharp rise in the internal cowling immediately behind the cylinders, which hindered the flow of the cooling air. In an effort to reduce mainly the barrel, but also the head temperatures, still further, the rise behind the cylinders was made gradual and the slot moved farther back as shown in Figures 8 and 26. The inside deflectors were retained as before. With this arrangement the cooling was very nearly as good as with the uncowled engine, and for the first time with the cowling completely covering the engine, the test was continued until the temperature conditions became constant (about 10 minutes). The five highest head temperatures averaged about 30° F. higher than for the uncowled engine, the barrel temperatures averaged about 60° F. higher, and the oil temperature was only 5° F. higher. The oil temperature could, of course, be reduced by reducing the cowling covering the crank case. One thermocouple had consistently recorded the highest temperatures with Number 10 cowling, and this one was still somewhat high.

A run was made next without the deflectors which directed the air around the cylinders. All of the cylinder temperatures became rather high in a short time, and the run was stopped.

Since the above deflectors were evidently very helpful in cooling the engine, another run was made with improved ones. The original deflectors directed the air around both sides of the cylinders, but the second set turned the air in one direction only, as shown in Figures 10 and 27. They were larger than the first ones, and directed about two-thirds of the air between each two cylinders around the exhaust valve and rear spark plug. The cooling with this arrangement was considered approximately as satisfactory as with the uncowled engine. The cylinder head temperatures were about the same, and the cylinder barrel temperatures, which still averaged about 60° F. higher, were considered permissible.

In order to determine whether inclosing the propeller hub in a spinner would help the air flow, and consequently the cooling and drag, the above cowling was tested with Number 6 nose inside as shown in Figure 28. After a few minutes of running it was apparent that the cooling and drag were about the same as without the spinner, so the run was discontinued.

RESULTS OF DRAG TESTS

The observed drag-test data are given in Table II and the results are plotted in Figure 30. The drag of the bare fuselage (without supports or landing gear) with the various cowlings is given for an air speed of 100 M. P. H. in the following table:

Cowling	Fuselage and engine drag, pounds at 100 M. P. H.	Reduction from uncowled engine, pounds at 100 M. P. H.
Number 4. Engine uncowled.....	125	0
Number 5. No spinner; original.....	119	6
Number 6. Spinner; original.....	116	9
Number 7. No spinner; original.....	103	22
Number 7. Modified to cool.....	111	14
Number 8. Spinner; original.....	100	25
Number 8. Modified to cool.....	106	19
Number 10. Combination of 9 and 5; original.....	64	61
Number 10. Modified to cool.....	75	50
Number 10. Modified to cool; with spinner.....	75	50
Number 4. Engine removed, nose rounded.....	40	85

The last item listed, Number 4 cowling with the engine removed and the nose rounded as shown in Figure 29, has been included as an ideal with which to compare the effect of the various cowlings. Using this as a basis, the uncowed engine is responsible for an increase in drag of 85 pounds at 100 M. P. H.

The outstanding feature of the drag tests is the large reduction in drag obtained with the cowling which completely covers the engine. Considering only the cowlings which cool properly the reduction of drag with Number 10 cowling is about 60 per cent of the total possible reduction, and is 2.6 times as great as with the next best, Number 8.

The drag of the bare fuselage without engine is only 40 pounds at 100 M. P. H. When the uncowed engine is placed on the nose the drag is increased to 125 pounds, or 3.13 times that of the bare fuselage without engine. With the best conventional cowling (Number 8) the drag is 106 pounds, or 2.65 times that of the fuselage alone, and with the cowling totally inclosing the engine (Number 10) the drag is 75 pounds, or 1.87 times that of the fuselage without engine.

The forms of cowling most used in service are similar to Numbers 5 and 6, and these have a very slight effect on the drag, and consequently an almost insignificant effect on the performance of an airplane. The reduction of drag is small even when practically the whole of the cylinders are cowed in, as in Number 8. Apparently, if even a small portion of the engine is exposed, it is sufficient to disturb the smooth flow over the body, and the turbulent flow is associated with high drag. When the entire engine is covered and the cooling air is separated from and returned to the outside air smoothly, as with cowling Number 10, the smoother flow is evidently accompanied by a substantial decrease in drag.

It is interesting to note that with cowling Numbers 7, 8, and 10, it cost, respectively, 8, 6, and 11 pounds in drag at 100 M. P. H. to make the original designs cool properly. Apparently, the method used with Number 8, which was to cut away the cowling immediately in front of the cylinders, costs slightly less in drag than the slots of Number 7.

The value of spinners in reducing the drag, when used in front of radial air-cooled engines, is shown by a comparison of cowling Numbers 5, 6, 7, and 8 as originally designed. In each case the drag with spinner was 3 pounds less at 100 M. P. H. than the drag without spinner. This would represent a difference in speed of a small fraction (about one-third) of a mile per hour on an average airplane with a J-5 engine.

It is interesting that the stub wing with windshield increased the drag only 57 pounds at 100 M. P. H. with cowling Number 4 and 50 pounds with Numbers 5 and 6 (Number 4 had slightly more pilot's windshield exposed), although the drag of the wing alone would be about 75 pounds as computed from model tests.

RESULTS OF PROPELLER TESTS

A large mass of propeller test data has been obtained during these cowling tests, only a small portion of which is necessary to show the effect of the various cowlings on propulsive efficiency. The rest will be used in another report dealing with body interference. The propulsive efficiencies obtained with the various cowlings are shown in Figure 32 for a propeller blade angle of 15° at the 42-inch radius, and in Figure 33 for 23° at the 42-inch radius. (These angle settings correspond to pitch-diameter ratios of 0.66 and 1.02, the pitch being taken at 75 per cent of the radius. The pitch of this propeller is approximately uniform for all working sections when the pitch-diameter ratio is about 0.5.) The curves of propulsive efficiency are very nearly the same for all cowlings, although for both pitch settings the efficiencies with cowling Number 10 are the highest. The power and thrust coefficients were also practically the same for all cowlings.

DISCUSSION

Effect on Airplane Performance.

It is interesting to compare the various forms of cowling with regard to their effect on the performance of a typical "Whirlwind" engined cabin monoplane. Suppose such an airplane with an uncowed engine similar to Number 4 required 200 HP. to fly horizontally at 125 M. P. H. If the airplane were equipped with the usual amount of cowling, similar to Numbers

5 and 6, the power required would be reduced to 196 or 194 HP., respectively, at 125 M. P. H. If a cowling similar to Number 8, which is the best of the conventional forms, were used, the airplane would require only 187 HP., and with a cowling covering the entire engine similar to Number 10, 167 HP. The airplane with the latter cowling could therefore fly at 125 M. P. H. with the engine throttled more than 100 R. P. M. from the revolution speed required with the uncowed engine. If the full 200 HP. were to be used, a cowling similar to Number 6 (with spinner) would increase the speed less than 1 M. P. H., one similar to Number 8, about 3 M. P. H., and one similar to Number 10, about 8 M. P. H.

Considering all types of cabin airplanes having the same engine, the higher the speed attained with ordinary forms of cowling, the greater will be the improvement possible. This is, of course, due to the fact that in the faster airplanes the fuselage-engine drag is a larger portion of the total.

Practicability.

All of the forms of cowling tested have been used on airplanes in service excepting the one entirely covering the engine. The forms inclosing a large portion of the engine have been found rather poor from a maintenance standpoint because of the large number of small parts which must be removed when it is necessary to work on the engine. This difficulty is accentuated where metal spinners are used, but, fortunately, as these tests have shown, spinners have an almost negligible effect on the performance of airplanes.

The Number 10 cowling is similar to Number 5 in construction, except for the nose piece. When this is removed, most parts of the engine requiring frequent attention are accessible. As made for the tests, the nose piece for Number 10 cowling was a 1-piece ring which was easily constructed and easily handled, its shape being such that it was stiff and strong without bracing. It had the disadvantage, however, that in order to remove it, it was first necessary to take off the propeller. To avoid this in practice it would probably be desirable to make the nose piece in two or three quick-detachable sections.

With the J-5 engine it was necessary to have a rather sharp curvature at the nose of the Number 10 cowling. A better shape, and therefore still better performance, could be obtained with an engine having (1) a greater distance between the cylinders and the propeller, (2) smaller over-all diameter, (3) the valve gear at the rear of the cylinders instead of projecting in front, and (4) magnetos at the rear of the cylinders.

CONCLUSIONS

1. The drag of an average sized cabin fuselage with the engine removed and the nose rounded is tripled by placing an uncowed J-5 engine on the nose.

2. With the conventional forms of cowling, in which a portion of the cylinders and valve gear is exposed, the drag becomes less as the cowling is increased, but even in the most extreme case the reduction amounts to only about 23 per cent of the increase in drag due to an uncowed engine.

3. A spinner, if used in front of a radial engine, decreases the drag but a very small amount and has an almost negligible effect on the performance of an airplane.

4. With a cowling similar to Number 10, which covers the entire engine and separates the cooling air from the general flow about the body, the reduction in drag is about 60 per cent of the increase due to an uncowed engine. This is about 2.6 times as great as with the best conventional form of cowling.

5. The use of cowling similar to Number 10 seems entirely practical as regards both cooling and maintenance under service conditions. It must be carefully designed, however, to cool properly.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., October 5, 1928.

REFERENCE

1. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300. (1928.)
2. Weick, Fred E.: Drag and Cooling with Various Forms of Cowling for a "Whirlwind" Radial Air-Cooled Engine, II. N. A. C. A. Technical Report No. 314. (1929.)

TABLE I.—COOLING TEST DATA

Cowling	Average temperature 5 hottest cylinder heads, rear plug boss	Highest temperature on any cylinder	Cylinder Number 1, rear plug boss	Cylinder Number 1 barrel, middle rear	Cylinder Number 1 barrel, bottom rear	Oil temperature	Air temperature
	° F.	° F.	° F.	° F.	° F.	° F.	° F.
Number 4.....	673	728	583	353	378	140	84
Number 5.....	605	666	585	361	379	138	86
Number 7.....	626	681	618	476	557	167	88
Number 7, 4 holes in nose ¹	638	702	612	397	458	144	88
Number 7, 6 large holes.....	664	750	653	432	447	146	82
Number 9 ¹	731	800+	673	377	438	127	93
Number 10 ¹	755	800+	682	403	430	133	97
Number 10, larger slot ¹	740	800+	654	335	355	126	91
Number 10, 28-inch hole in nose, cylinder deflection ¹	695	768	635	428	467	133	75
Number 10, cut-outs over magnetos ¹	705	760	658	452	477	132	77
Number 10, larger cut-outs ¹	697	778	670	460	498	140	82
Number 10, slot moved back.....	701	772	668	396	428	145	86
Number 10, cylinder deflectors removed ¹	704	778	670	460	498	145	86
Number 10, single cylinder deflectors.....	683	753	662	430	432	149	86

¹ Run stopped because of high temperatures before constant conditions were reached.

TABLE II.—OBSERVED GROSS DRAG DATA, INCLUDING LANDING GEAR AND SUPPORTS

Number 4 (without wing)		Number 5 (without wing)		Number 6 (without wing)		Number 7-O (without wing)		Number 4 (with wing)		Number 5 (with wing)		Number 6 (with wing)		Number 4 (with wing, without engine)	
q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.
18.25	169	16.50	149	17.99	161	16.92	143	17.78	202	16.31	182	17.07	186	18.40	147
18.32	169	16.50	149	18.01	161	16.97	143	17.78	202	16.49	182	16.94	185	18.39	147
20.95	193	17.92	161	18.90	169	19.06	160	25.05	279	18.14	198	18.21	199	20.43	161
20.73	191	17.92	162	18.96	169	19.08	160	25.05	281	18.02	198	18.21	199	20.62	161
25.40	231	20.00	179	20.18	181	20.30	169	25.85	290	19.42	212	20.35	221	25.40	202
25.05	230	20.00	179	19.11	170	20.15	170	26.26	295	19.35	212	20.23	220	25.70	202
25.96	235	24.82	221	25.00	220	26.18	215	20.06	228	22.70	247	24.48	265	16.72	135
25.76	236	24.58	219	24.95	220	26.28	217	20.60	232	22.61	247	24.82	265	16.72	134
16.82	156	14.76	135	14.88	134	13.92	118	18.15	207	15.13	168	14.98	164	15.25	124
16.87	157	14.83	135	15.14	137	13.58	116	18.38	208	15.13	168	15.03	166	15.05	124
15.32	143	13.29	123	12.59	115	11.25	98	15.03	172	14.04	155	13.35	147	13.30	109
15.20	143	13.08	119	13.18	121	11.28	97	14.95	172	13.89	155	13.39	150	13.30	110
15.39	129	11.59	108	10.58	97	9.43	81	13.03	150	11.42	130	10.22	118	11.58	96
13.50	128	11.50	106	10.89	99	9.88	85	13.12	153	11.42	129	10.17	114	11.24	94
11.98	114	9.05	85	8.34	78			11.00	128	10.01	114	8.64	95	9.40	79
11.53	110	8.97	84	8.85	81			11.14	129	10.12	115	8.86	100	9.41	79
9.27	90							9.08	107	8.95	102			8.24	69
9.95	96							8.72	102	8.80	100			8.37	72
7.94	79							7.84	93						
8.04	78							7.84	93						

NOTE.—O denotes original.

TABLE II.—OBSERVED GROSS DRAG DATA, INCLUDING LANDING GEAR AND SUPPORTS—Continued

No. 8-O (without wing)		No. 7-M (without wing)		No. 8-M (without wing)		No. 10-O (without wing)		No. 10-M (without wing)		No. 10-M (with spinner, without wing)		Landing gear and supports only	
q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.	q lb. per sq. ft.	Drag lb.
16.71	140	16.63	146	16.42	141	16.58	115	15.96	117	16.60	122	16.44	72
16.70	140	16.58	145	16.46	141	16.56	115	15.96	117	16.62	122	16.56	72
19.09	157	18.70	163	18.33	156	18.34	127	17.32	127	18.10	131	17.05	74
18.86	157	18.70	163	18.60	156	18.42	127	17.38	127	18.09	131	17.07	75
20.25	168	20.00	174	19.95	169	20.43	140	18.12	131	19.29	139	17.01	74
20.35	167	20.00	174	19.91	169	20.08	138	18.00	131	19.30	140	18.71	80
24.95	203	25.48	219	24.45	206	24.60	167	19.30	142	20.42	148	18.60	80
24.95	205	25.38	218	24.90	209	24.67	167	19.30	140	20.44	149	19.76	85
15.45	130	17.07	150	14.40	123	14.98	106	19.35	141	24.50	175	19.66	85
15.14	127	17.13	150	14.92	129	15.18	106	14.52	109	24.95	179	20.91	89
14.04	117	14.64	130	13.01	113	13.43	94	14.45	107	14.88	110	25.82	110
14.14	119	14.64	130	13.02	113	13.37	94	12.70	92	14.68	108	15.40	68
12.98	111	12.30	110	11.24	97	11.83	84	12.60	94	13.41	100	15.30	67
12.69	107	12.52	111	11.15	98	11.90	85	20.50	148	13.10	97	13.95	62
11.84	101	11.00	99	9.66	84	9.60	68	20.55	149	11.82	89	14.14	62
11.92	101	11.25	101	9.69	85	9.48	69	25.00	180	11.96	90	12.63	56
9.92	85	8.65	79	9.07	80	8.67	61	24.35	174	10.31	77	12.60	57
10.19	87	8.84	79	9.00	80	8.65	61	24.95	180	10.42	78	10.94	50
9.00	77							10.97	83	9.79	73	10.94	50
8.41	73							11.11	84			9.86	45
								10.00	73			9.81	45
								10.09	77			8.24	39
												8.24	38

NOTE.—O denotes original. M denotes modified to cool.

APPENDIX

FLIGHT TESTS OF NUMBER 10 COWLING

By THOMAS CARROLL

In order that the practical value of the information in the foregoing report might be demonstrated, simple flight tests have been made of the Number 10 cowling.

Through the courtesy of the Army Air Corps at Langley Field, Va., a Curtiss AT-5A airplane was obtained on which an adaptation of the Number 10 cowling was installed as shown in Figures 34 and 35. A series of flights was made by the three pilots of the laboratory.

The maximum speed of this type airplane as in use at Langley Field had been reported at 118 miles per hour. This was checked by making a series of level runs with a Curtiss AT-5A airplane at low altitude over the water at full power. The maximum speed was found to be 118 miles per hour at 1,900 R. P. M., both air speed and R. P. M. being measured on calibrated instruments. Similar high speed runs made with the modified AT-5A showed a performance of 137 miles per hour at 1,900 R. P. M., an increase of 19 miles per hour. The original speed of 118 miles per hour was attained at 1,720 R. P. M. on the modified airplane.

While the type of cowling as normally installed on an AT-5 is not particularly adaptable to speed, the increase is considered remarkable. Furthermore, the improvement of flying qualities in smoothness of operation was also very favorably commented upon by all pilots who have flown it. The air flow over the fuselage and over the tail surfaces is very obviously improved.

The cooling of the engine was found to be normal in these tests. The oil temperature reached 58° and was fairly constant, and there was no other indication of overheating. Likewise, there was no interference to the pilot's vision in any useful field.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *October 13, 1928.*

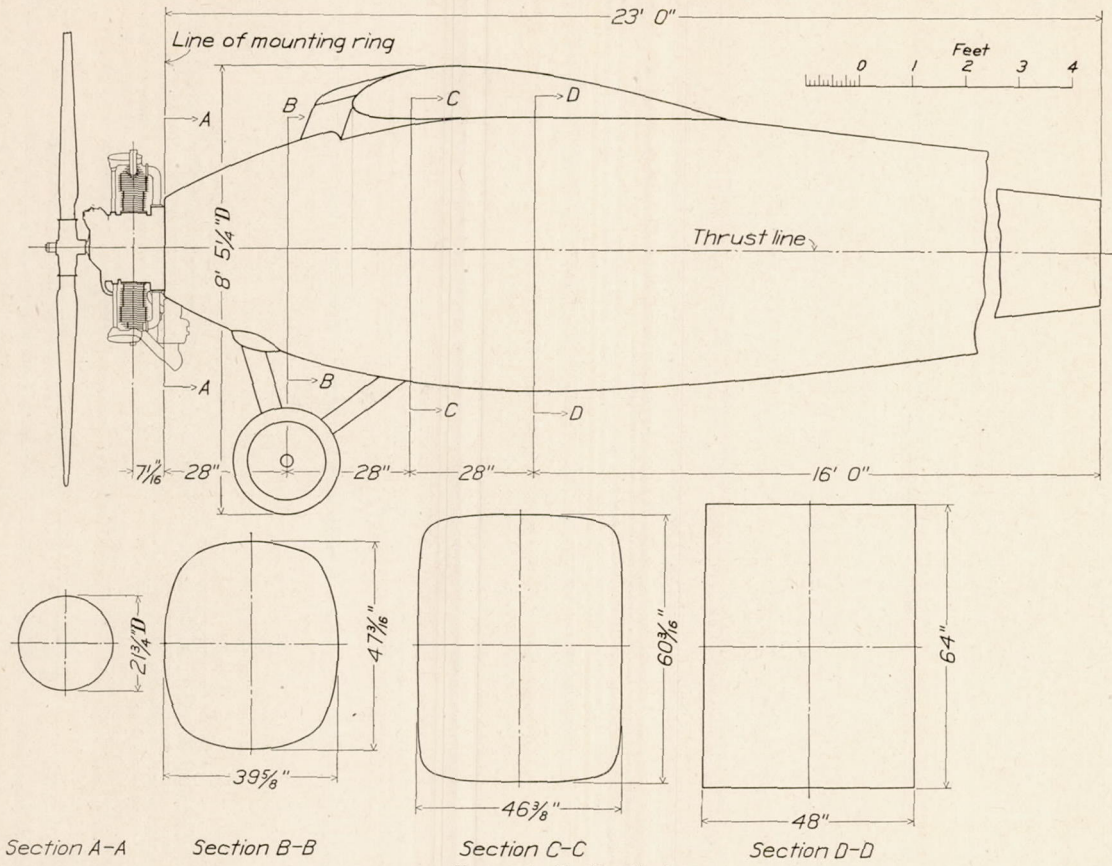


FIGURE 1.—Cowling No. 4

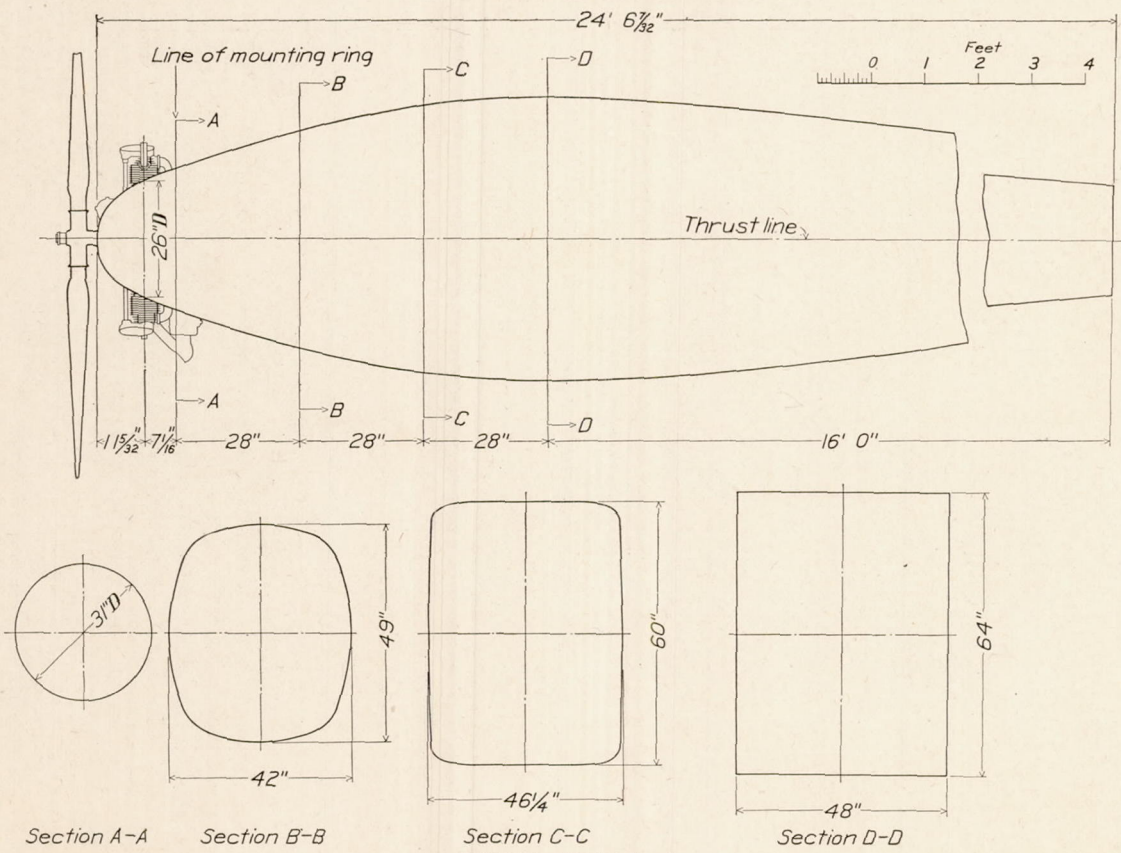


FIGURE 2.—Cowling No. 5

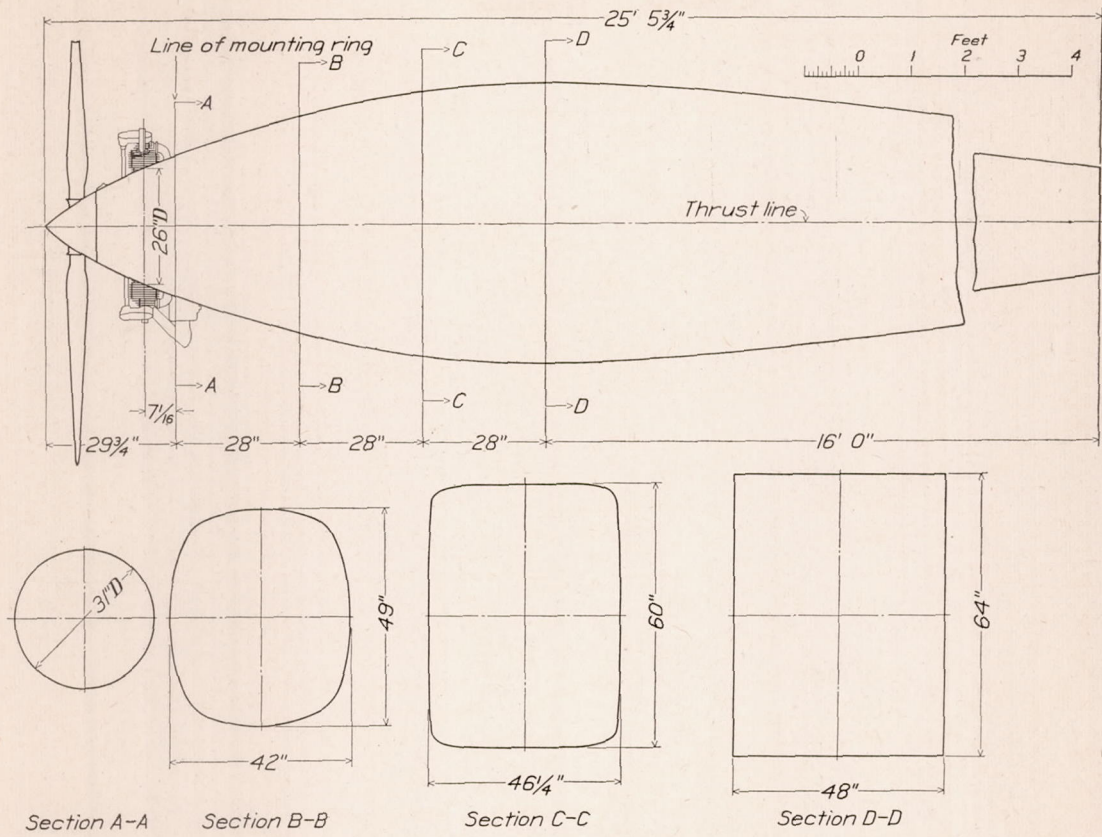


FIGURE 3.—Cowling No. 6

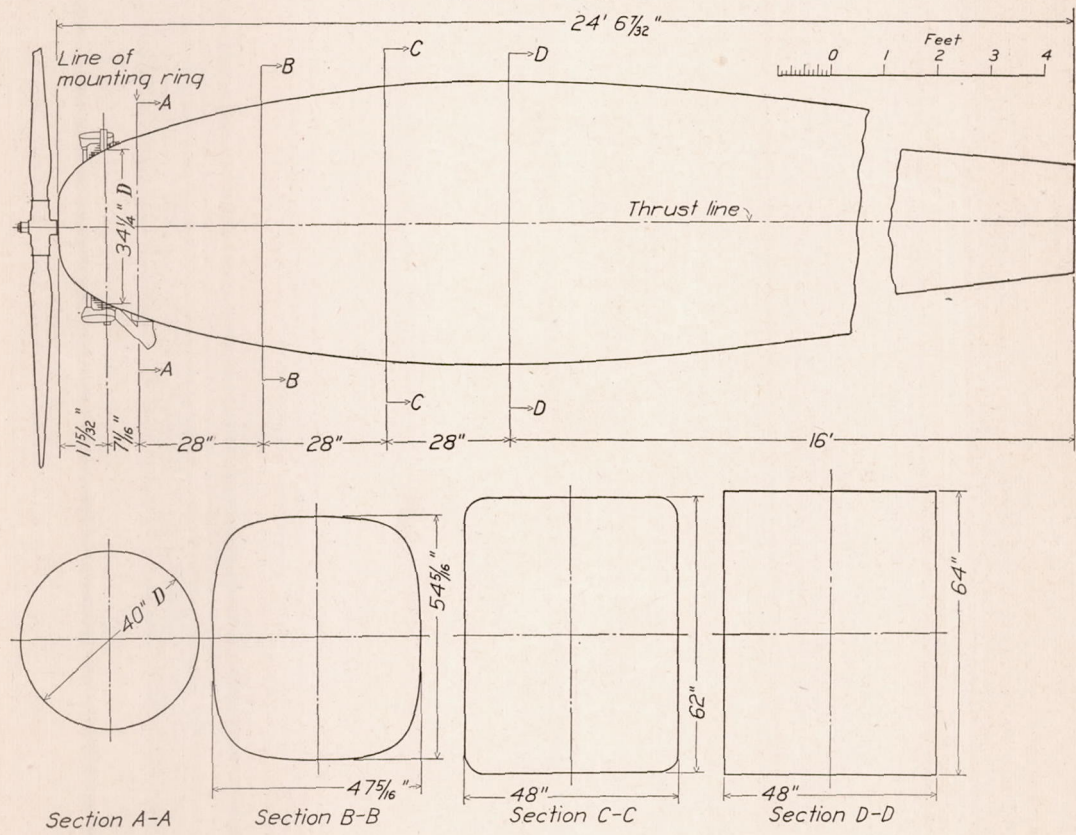


FIGURE 4.—Cowling No. 7

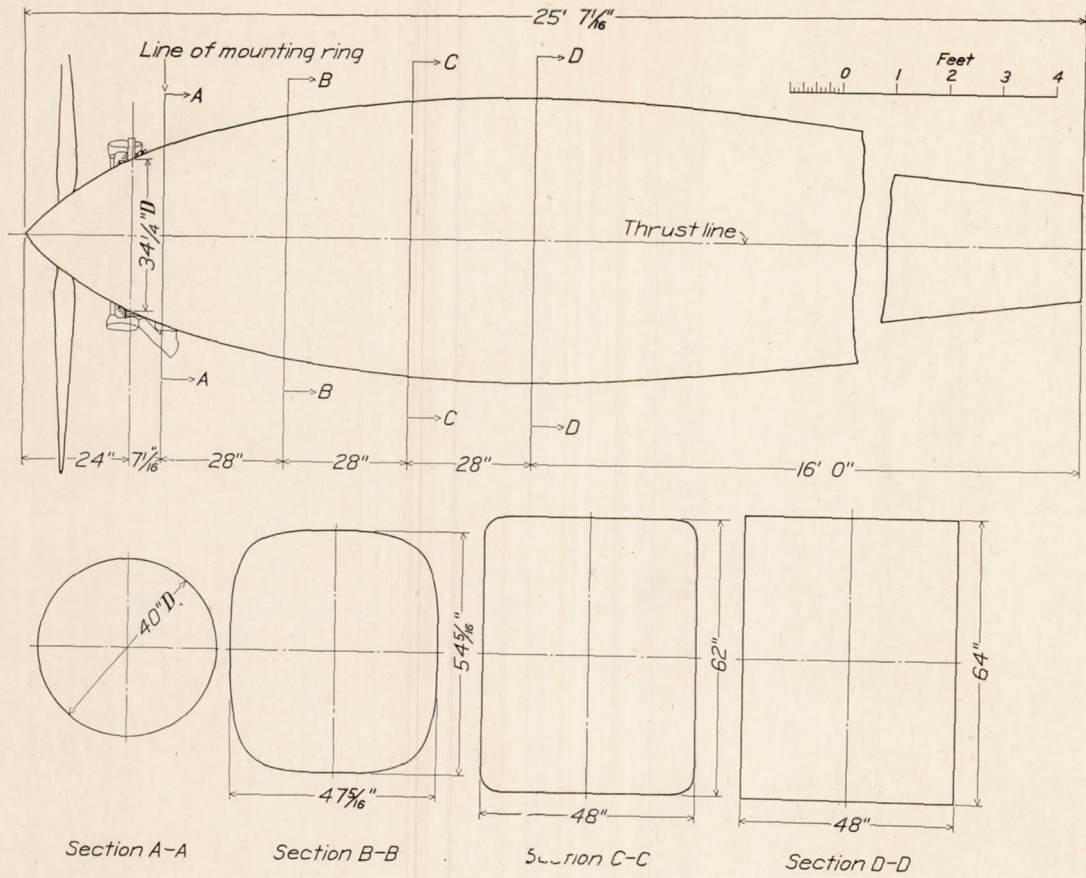


FIGURE 5.—Cowling No. 8

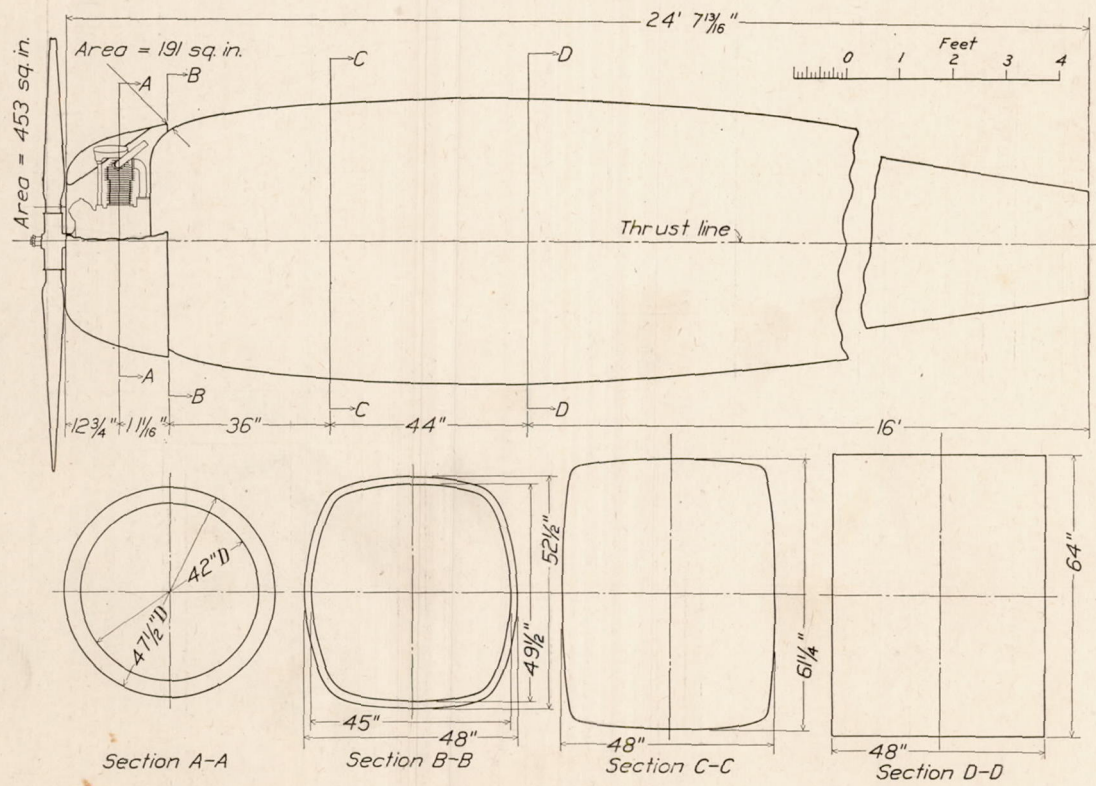


FIGURE 6.—Cowling No. 9

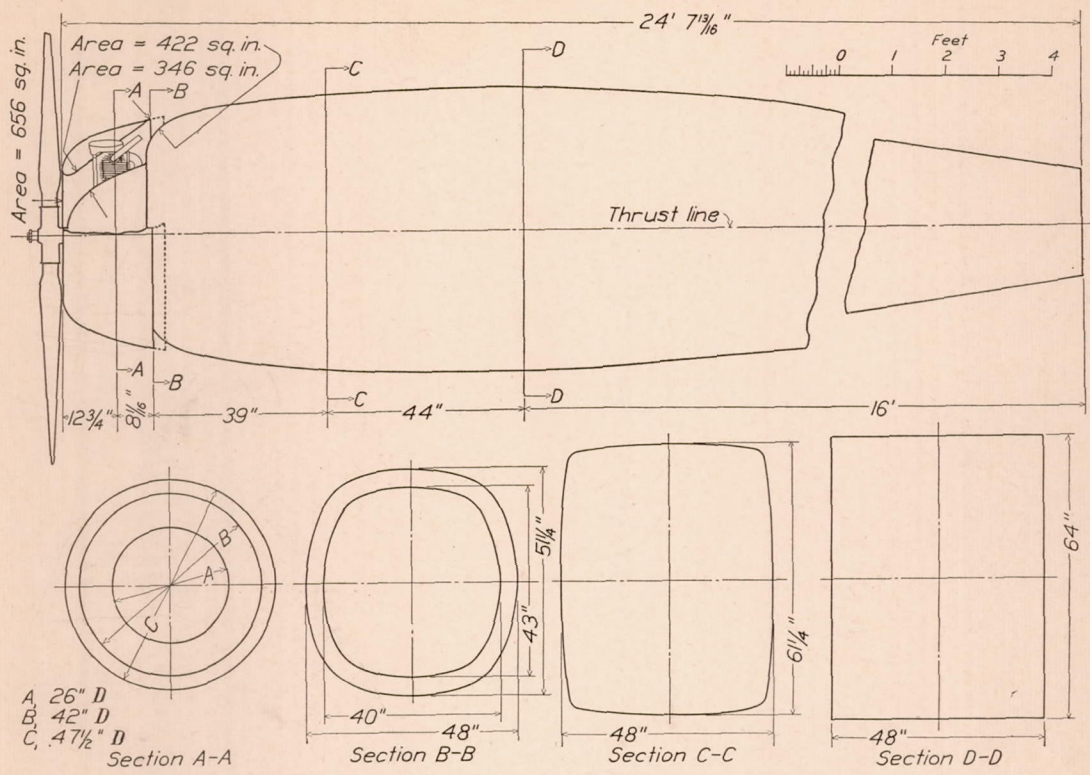


FIGURE 7.—Cowling No. 10 modified

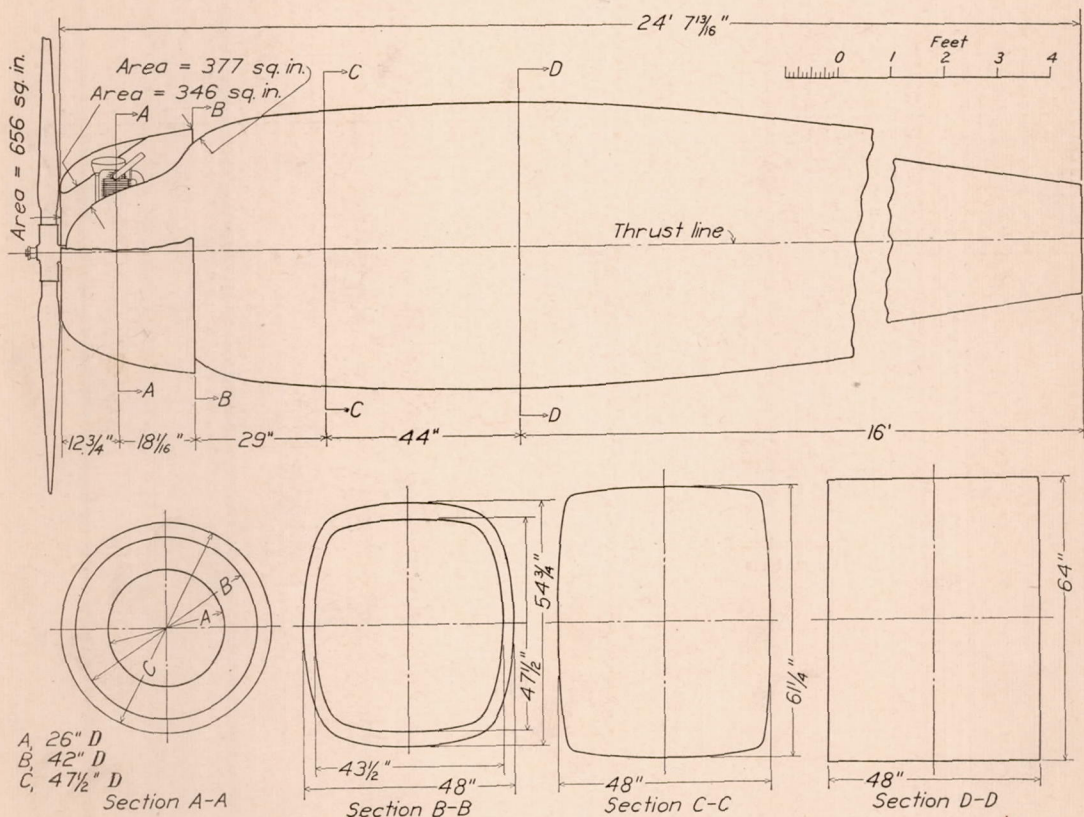


FIGURE 8.—Cowling No. 10 modified. Slot in nose moved back

122 404 00

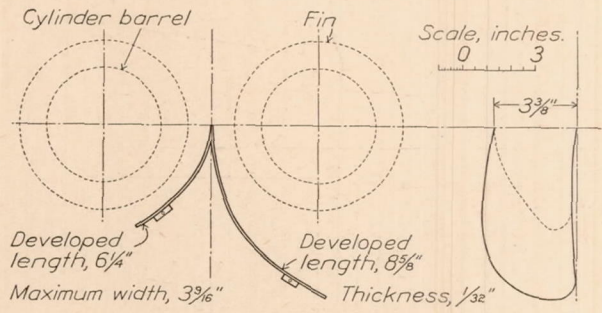


FIGURE 9.—Double deflectors

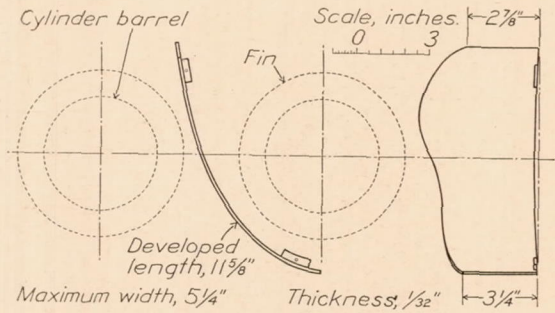


FIGURE 10.—Single deflector

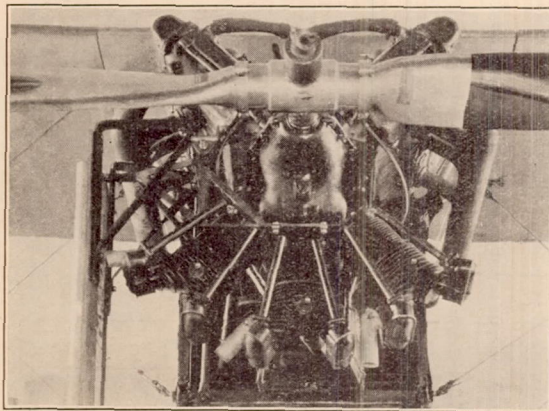


FIGURE 11.—J-5 cylinders mounted on E-2 engine for slip-stream torque tests

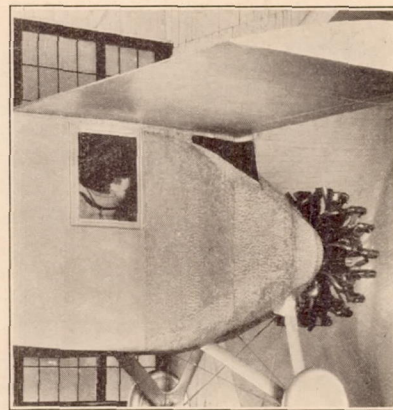


FIGURE 12.—Cowling No. 4, engine exposed

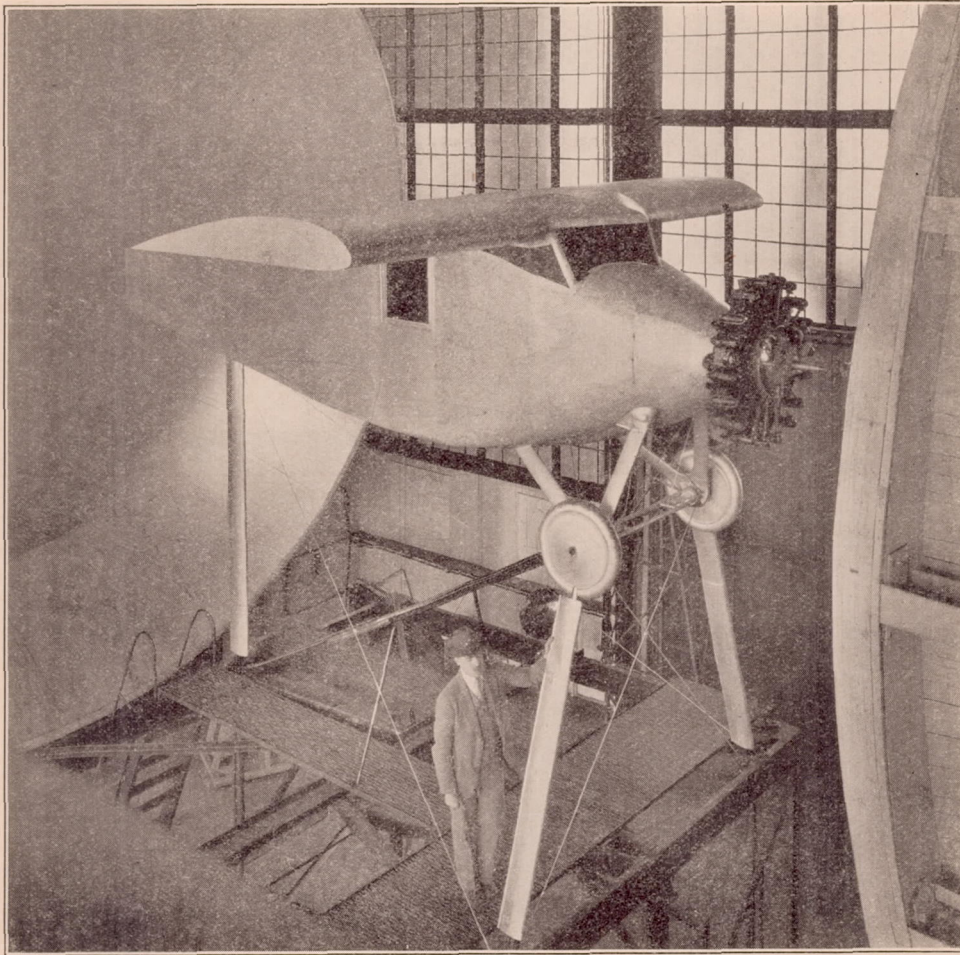


FIGURE 13.—Cowling No. 4 on fuselage with stub wing and landing gear mounted in the propeller research tunnel

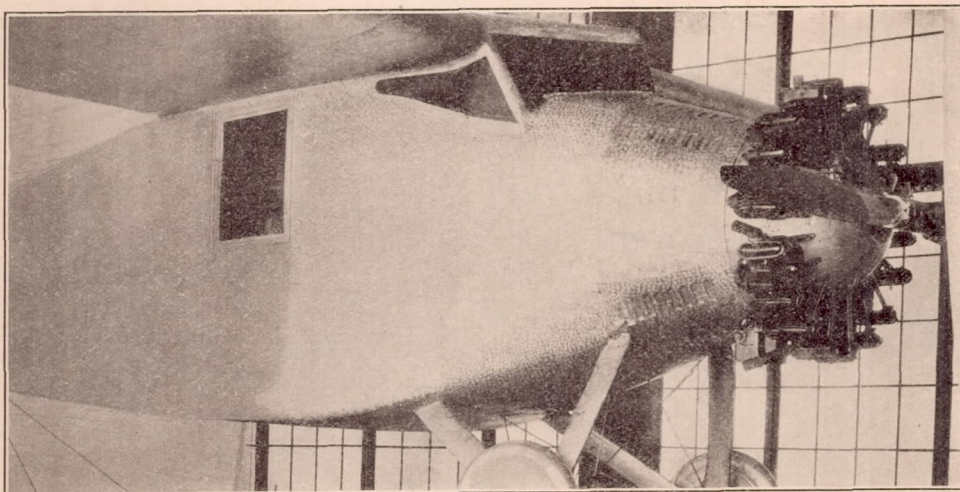


FIGURE 14.—Cowling No. 5

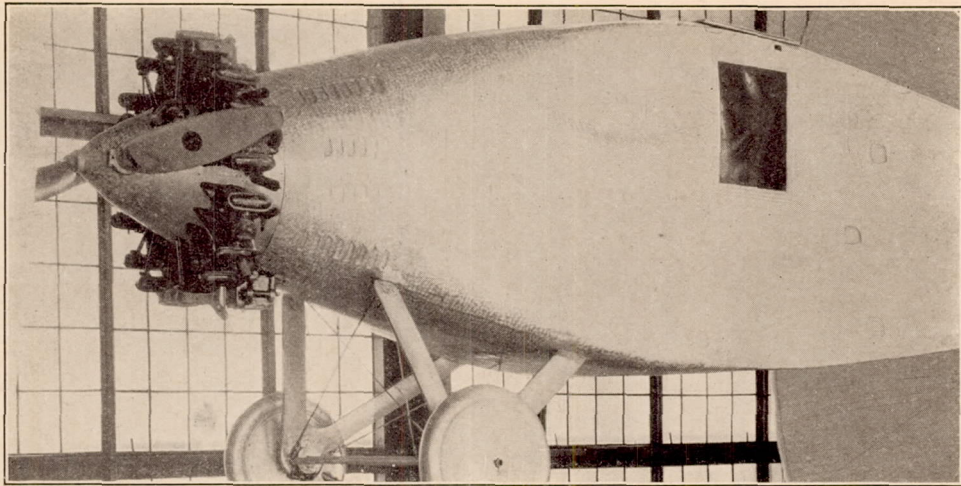


FIGURE 15.—Cowling No. 6

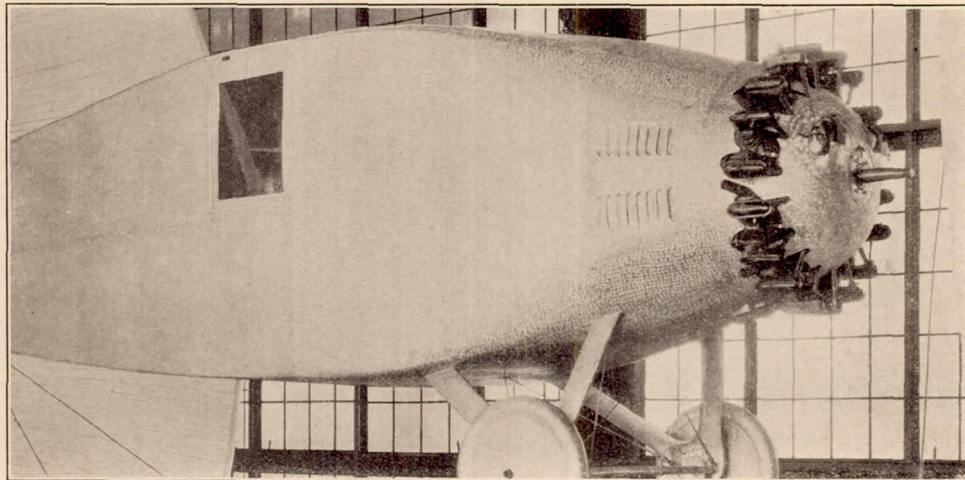


FIGURE 16.—Cowling No. 7, original

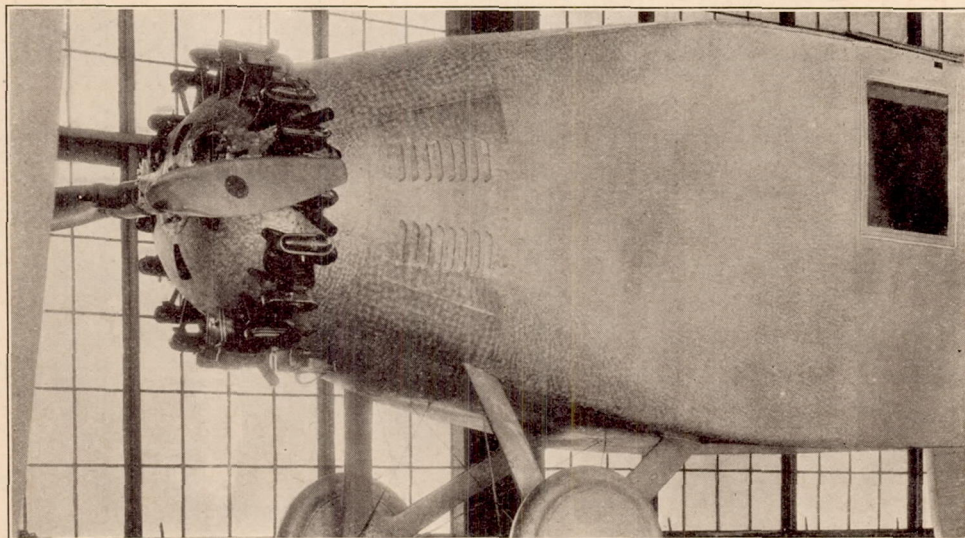


FIGURE 17.—Cowling No. 7, four slots

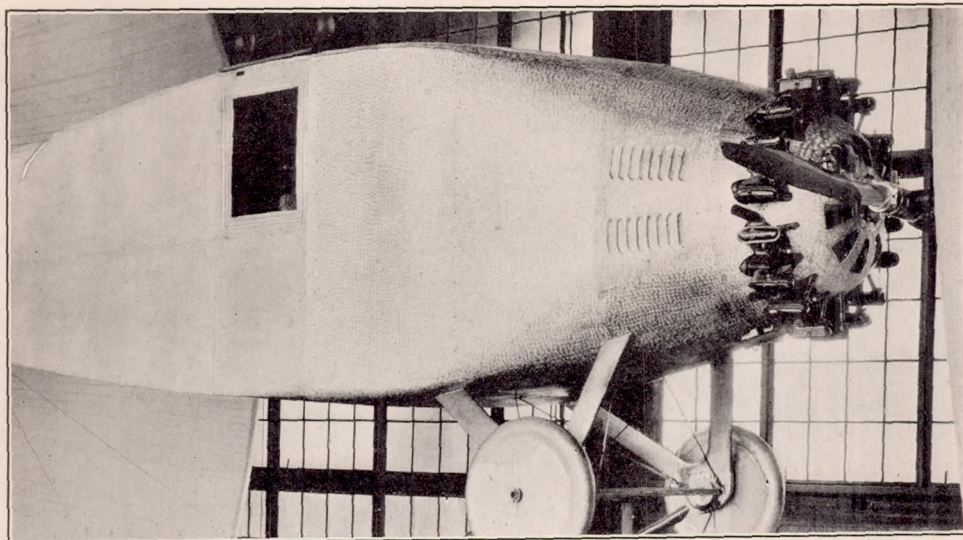


FIGURE 18—Cowling No. 7, six large slots

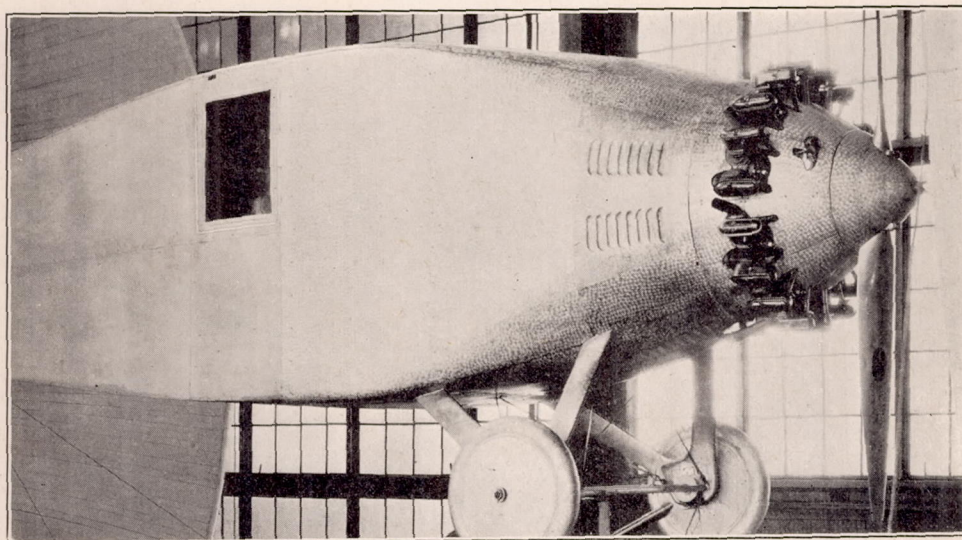


FIGURE 19.—Cowling No. 8, original

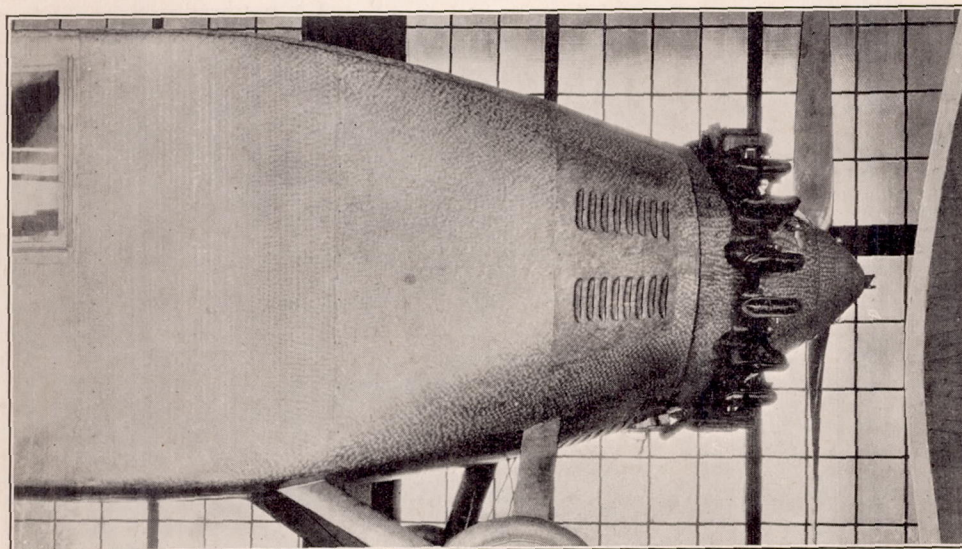


FIGURE 20—Cowling No. 8, original

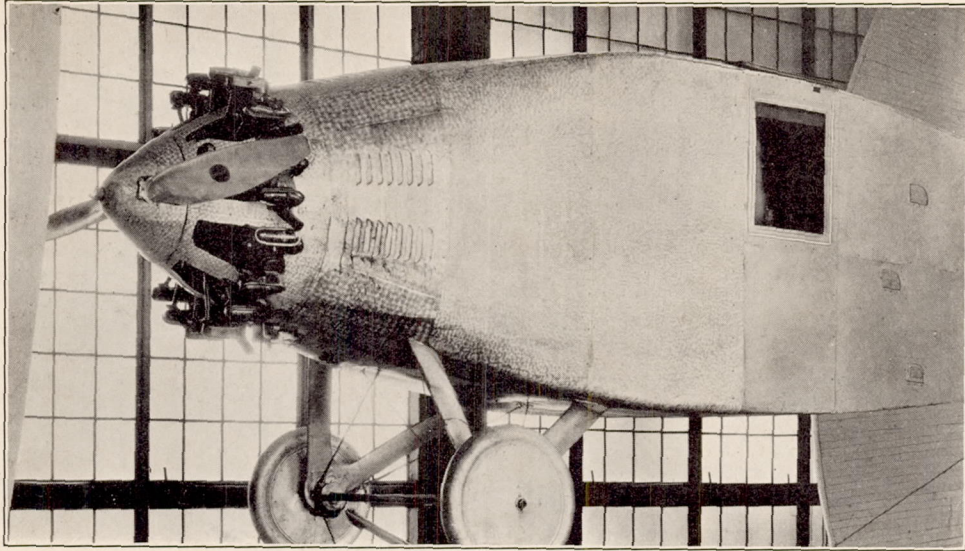


FIGURE 21.—Cowling No. 8, with cut-outs

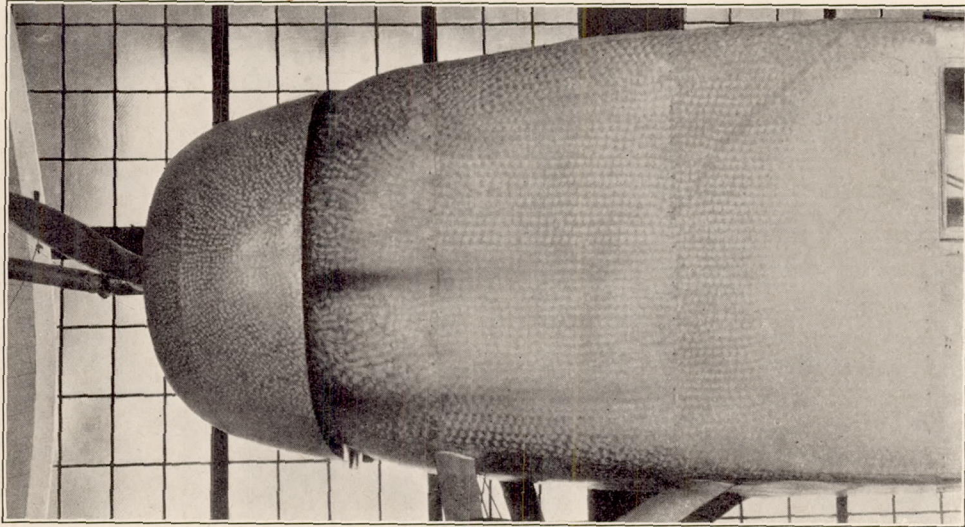


FIGURE 22.—Cowling No. 9

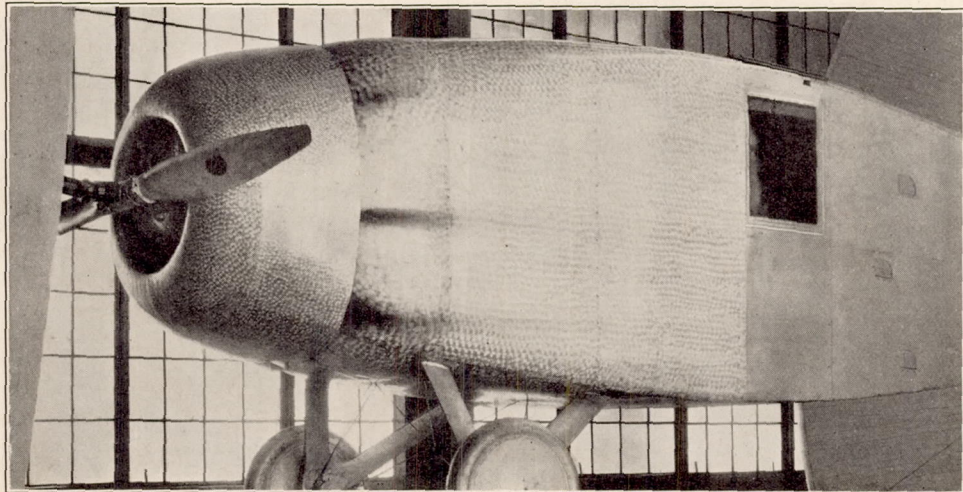


FIGURE 23.—Cowling No. 10

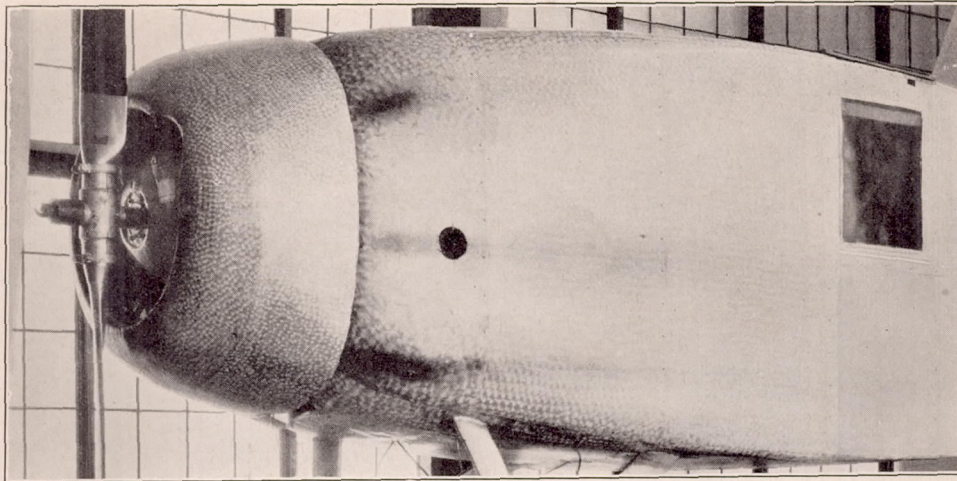


FIGURE 24.—Cowling No. 10, enlarged slot and nose hole and cut-outs over magnetos

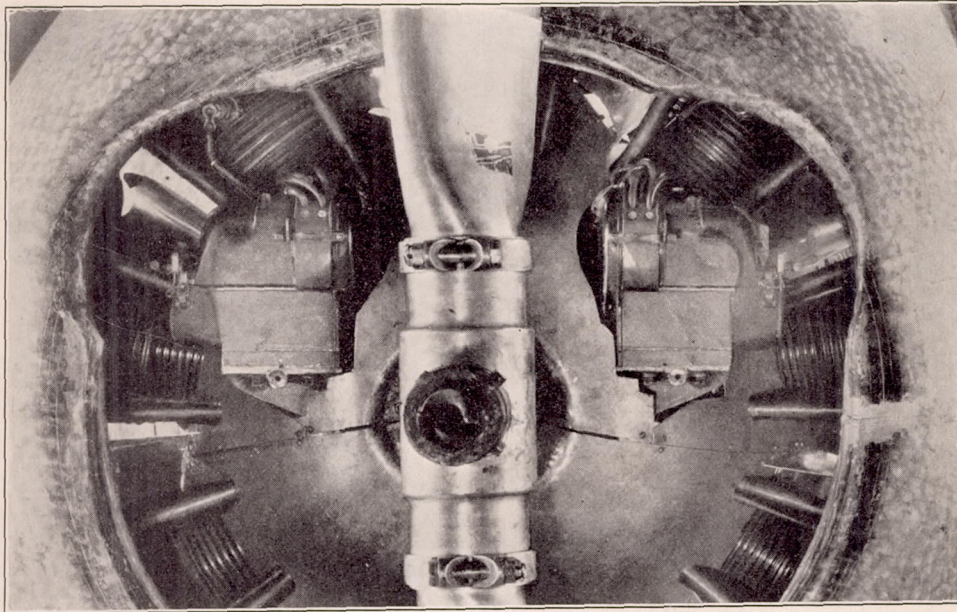


FIGURE 25.—Detail view of cut-outs over magnetos

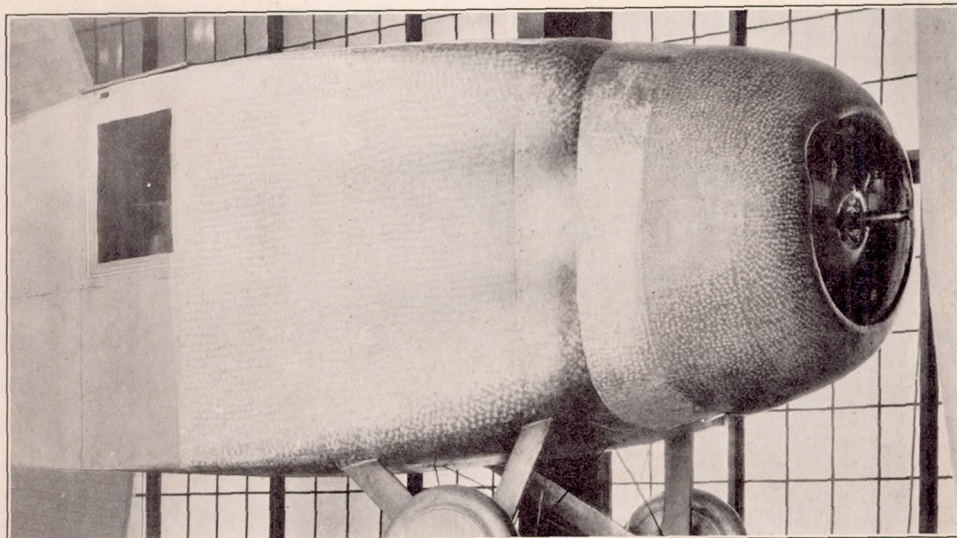


FIGURE 26.—Cowling No. 10 with slot moved back

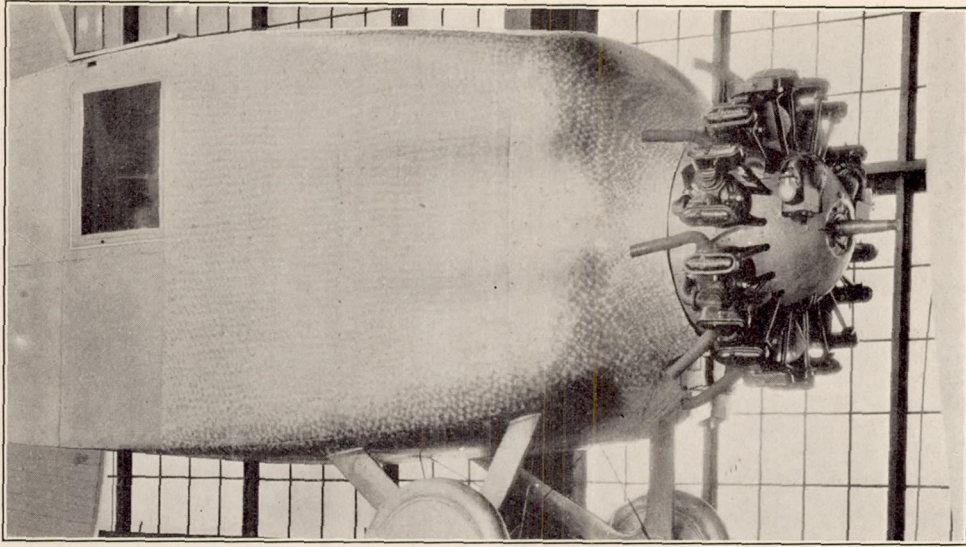


FIGURE 27.—Modified cowling No. 10 with nose piece removed showing deflector between cylinders

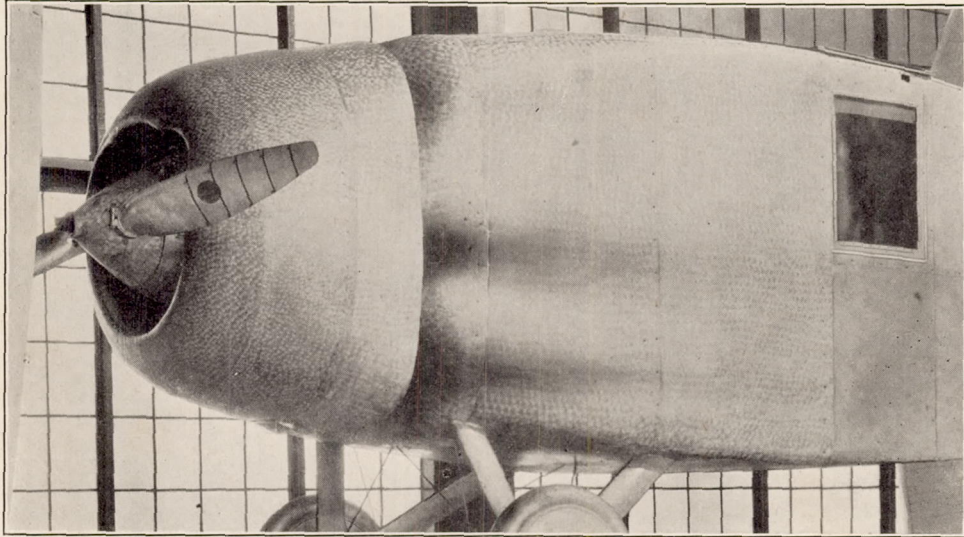


FIGURE 28.—Cowling No. 10 with No. 6 nose with spinner

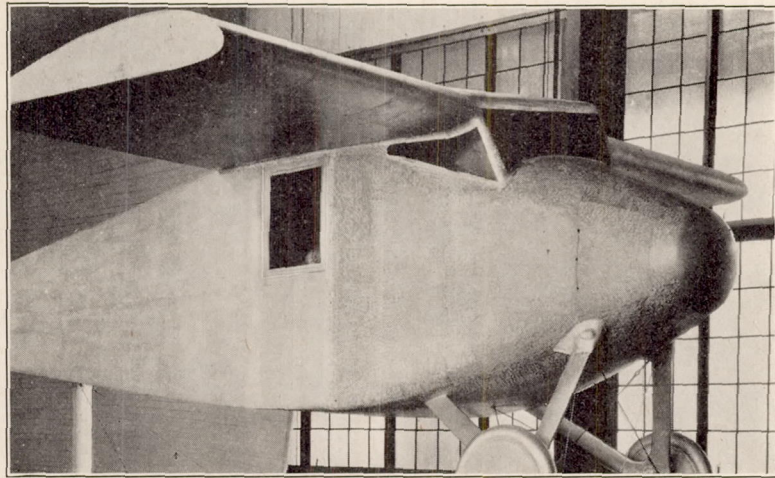


FIGURE 29.—No. 4 with engine removed and nose rounded

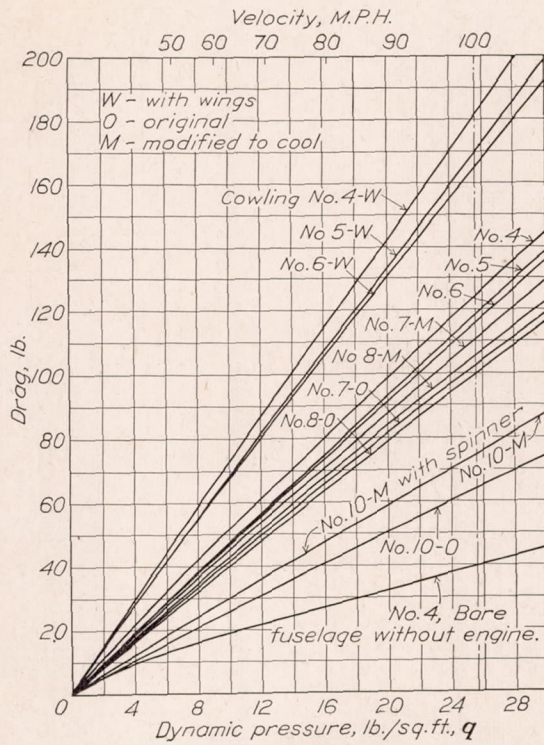


FIGURE 30.—Drag of fuselage and engine with various cowlings

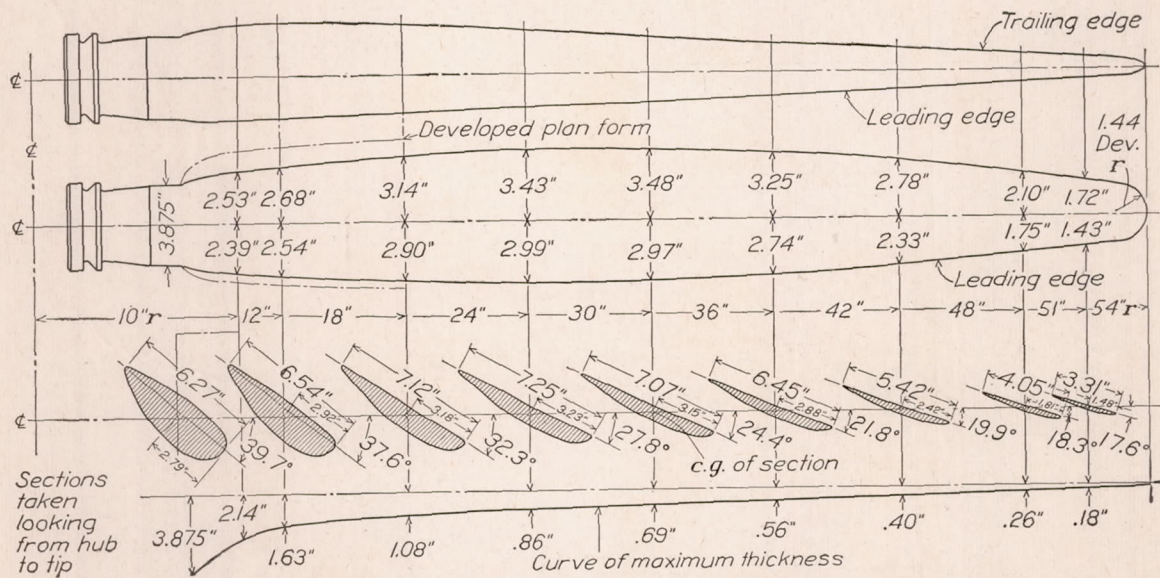


FIGURE 31.—Metal propeller blade, 9 feet diameter, right hand. Navy Department, Bureau of Aeronautics

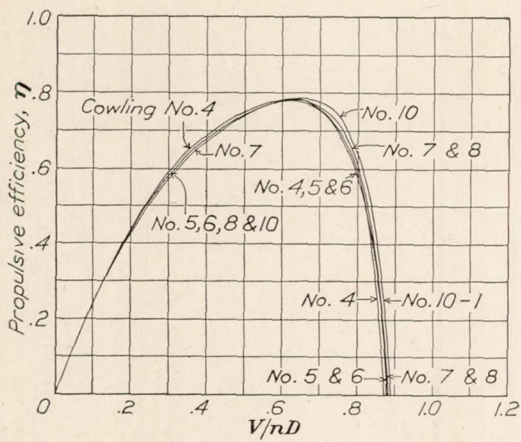


FIGURE 32.—Propeller No. 4412 (15° at 42 inches) on various cowlings without wing and with J-5 engine

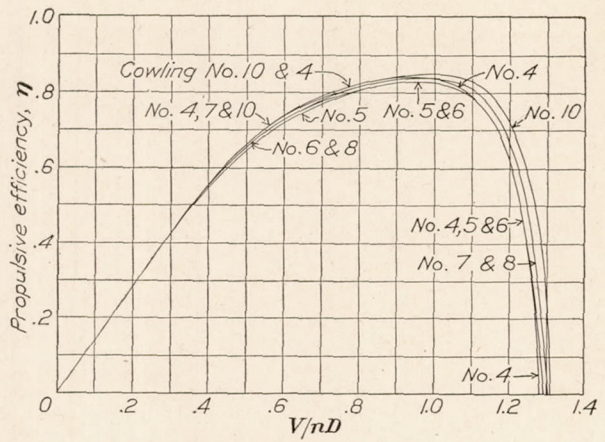
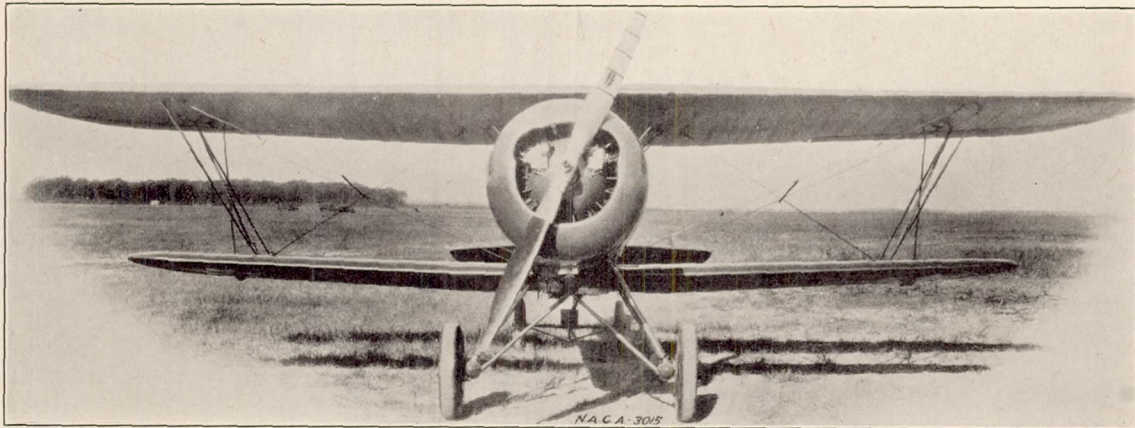


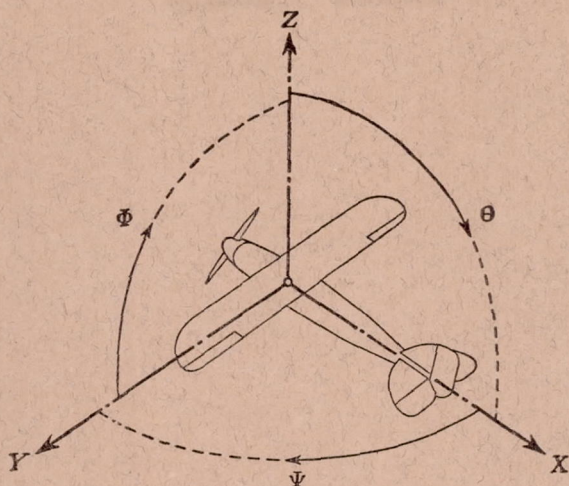
FIGURE 33.—Propeller No. 4412 (23° at 42 inches) on various cowlings without wings and with J-5 engine



FIGURES 34, 35.—Curtiss A T-5 airplane with No. 10 cowling

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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	Sym- bol		Designa- tion	Sym- bol	Positive direction	Designa- tion	Sym- bol	Linear (compo- nent along axis)	Angular
Longitudinal	X	X	rolling	L	Y → Z	roll	Φ	u	p
Lateral	Y	Y	pitching	M	Z → X	pitch	Θ	v	q
Normal	Z	Z	yawing	N	X → 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 = $\tan^{-1} \left(\frac{V}{2\pi r n} \right)$

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.

