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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

PROGRESS REPORT ON COWLINGS FOR AIR-COOLED ENGINES INVESTIGATED IN THE NACA 19-FOOT PRESSURE WIND TUNNEL

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INTRODUCTION

At the present time there is considerable demand for improvement in the aerodynamic characteristics of cowlings for radial air-cooled aircraft engines. During the past year, numerous cowling arrangements have been investigated in various departments of the NACA laboratory. Although a few full-scale investigations have been carried out, most of the studies have been preliminary in nature and have been confined to the investigation of model arrangements in wind tunnels. Because of the existing national emergency it appears advisable to release immediately to the aircraft industry the information available on the more promising of the arrangements that have been studied.

An investigation having as its aim the improvement in performance and flying qualities of single-engine air-cooled military pursuit airplanes is being conducted in the NACA 19-foot pressure wind tunnel. As a part of that investigation, studies have been made of the relative merits of a conventional NACA open-nose cowling arrangement and of a less conventional but better streamline NACA high-speed cowling arrangement in which the cooling air enters the cowling through an opening ahead of the propeller, passes internally through an element of the cowling which rotates with the propeller, and thence past the engine cylinders to the exit at the rear of the engine.

These investigations indicate that at airplane speeds of around 400 miles per hour there is not a great deal to be gained in high-speed performance through the application of the latter cowling arrangement, but at speeds in excess of about 450 miles per hour a very appreciable gain is indicated. Present indications are that improved engine cooling can be obtained throughout the speed range as well as ground cooling through the use of the high-speed cowling.

This paper summarizes the results obtained from wind-tunnel tests of models of the two cowling arrangements.

MODELS AND TESTS

The 0.4-scale airplane model used in this investigation was of 16-foot span, of 42.83 square feet wing area and, except for being equipped with a wing of the NACA 6-series low-drag section, was representative of a conventional single-engine military pursuit airplane equipped with the 1830 air-cooled radial engine.

The model was of wood construction. All exposed surfaces were sprayed with lacquer, and an "aerodynamically smooth" finish was obtained by rubbing the lacquered surfaces with no. 400 water cloth in a direction parallel to the wing chord.

Two engine-cowling arrangements were investigated. Both were designed to introduce all the cooling air required for the engine and its accessories at the cowling entrance.

The NACA open-nose cowling arrangement (fig. 1) was of nose shape similar to nose C of reference 1. A diagram of the arrangement tested is shown in figure 2.

The other cowling arrangement (fig. 3) was of nose shape approximating the geometric proportions of nose B of reference 2. The nose shape as defined by the ordinates given on figure 4 applies only to the particular airplane design represented by the model tested. As shown in the diagram of figure 4, the cooling air enters at the nose of the forward element of the cowling, which rotates with the propeller. The rotating element is fitted with internal blades disposed to serve as fairings for the propeller-blade shanks, and so oriented that, at the high-speed condition, they operated at or near zero lift. Thus, the forward portion of the cowling forms a propeller-hub spinner, and present indications are that it could be designed to act as a cooling-air blower at low-speed flight conditions. The cowling exit arrangement was unconventional in that the engine cooling air was exhausted through two ducts, one on either side of the fuselage, instead of being exhausted through the more conventional annular exit at the cowling skirt.

The resistance offered by the engine to air flow through the cowling was simulated by a perforated plate to which dummy cylinders were attached. The arrangement was such that its conductance could be varied, and for these tests the conductance was adjusted to approximate that of the full-scale engine installation.

Neither of the model cowling arrangements tested made definite provision for ducting the auxiliary cooling air. However, the shape of both cowlings was such as to provide the approximate clearances required for an internal-duct arrangement to pass sufficient air to cool the auxiliary equipment of an 1830 engine. The duct arrangement considered in laying out the cowling lines was such that the air passing through it entered the duct at the inside of the cowling forward of the engine and discharged at the bottom of the fuselage (fig. 5) in the vicinity of the wing trailing edge. Figure 6 shows a possible practical engine installation for both cowling arrangements.

The 3-blade 4-foot-diameter propeller used in the investigation was fitted with blades of Clark Y section. They are similar to the blades of the full-scale Hamilton Standard propeller No. 6101. For these tests the blades were set at 40°, 45°, 50°, and 55° at 0.75 of the tip radius. For all propeller tests with the high-speed cowling arrangement, the intersection of the propeller blades with the outer surface of the spinner was as shown in figure 7.

The propeller was driven by a variable-speed alternating-current induction motor capable of developing 60 horsepower at 5000 rpm.

With the model set at an angle of attack of 0° (C_L = 0.1), the aerodynamic characteristics of the propeller were measured, with each cowling arrangement, for several values of propeller blade-angle setting.

The volume of cooling air flowing through the cowling was determined from measurements of air velocity at the cowling exit.

The drag, with propeller removed, of each cowling arrangement was measured through an angle-of-attack range. For use in computing propeller characteristics, similar measurements of drag were made, with the angle of attack fixed at 0°, through an air-speed range from 50 to 150 miles per hour.

All the tests were made in the NACA 19-foot pressure wind tunnel with the air in the tunnel at atmospheric pressure. The value of Reynolds number (based on average wing chord) at which the tests were conducted was approximately 3,000,000.

RESULTS

All data are reduced to nondimensional coefficients corrected for tares and for jet-boundary interference effects. The symbols and the coefficients involved are as follows:

η propulsive efficiency, $\frac{(R + D)V}{P}$

C_D drag coefficient, $\frac{D}{qS}$

C_L lift coefficient, $\frac{L}{qS}$

K conductance of cowling, $\frac{Q}{FV\sqrt{\frac{\Delta P}{q}}}$

V/nD advance diameter ratio of propeller

q dynamic pressure of the air stream $(\frac{1}{2}\rho V^2)$

ρ_o mass density of the air at standard sea-level conditions

ρ mass density of the air at test condition

V velocity of air stream

Q quantity of cooling-air flow

F engine cross-sectional area

ΔP pressure difference between cowling entrance and cowling exit

P power input to propeller

D drag of airplane model (propeller removed)

R resultant force along wind axis (propeller operating)

Drag and critical speed.- The variation of C_D with C_L obtained from tests of the airplane model when fitted with the conventional and high-speed cowlings is compared in figure 8. It is noted that at the speeds at which these tests were conducted, the drag of both arrangements is nearly equal. However, there is good reason to believe that at speeds in excess of 400 miles per hour, due to its much higher critical Mach number, the drag of the high-speed cowling will be considerably less than that of the open-nose cowling.

Measurements in the NACA 8-foot high-speed tunnel indicate that the critical speed of an open-nose cowling with the C nose shape (reference 1) occurs at a value of Mach number of 0.65 (approximately 460 miles per hour at 20,000 feet altitude).

Measurements made during this investigation of the pressure distribution over the high-speed cowling arrangement showed that the pressures over the nose were nearly equal to the free-stream static pressure. No measurements have been made of the pressure distribution over the fixed portion of the particular cowling under discussion. Such measurements have been obtained on a similar cowling of more sensitive shape and they indicate the location of the peak negative pressure to be on the blister at the bottom of the fixed cowling. On the basis of those measurements, it may be stated that the critical speed for the after portion of this cowling is well over 510 miles per hour.

Cooling-air flow.- Both cowlings were adjusted to pass approximately equal quantities of air at their high-speed operating condition. Measurements of the characteristics of both model cowling arrangements yielded the following results:

Open-nose cowling

$\Delta P/q = 0.23$; conductance, $K = 0.12$

NACA high-speed type cowling

$\Delta P/q = 0.15$; conductance, $K = 0.14$

Ground cooling characteristics at zero air speed with propeller removed

blower speed = 758 rpm; pressure rise through cowling,

ΔP = 0.5 inch alcohol; horsepower delivered to blower

$= 0.059; \frac{\rho}{\rho_o} = 2.32$

At the ground condition, geometrically similar cowling arrangements operate at equal values of pressure and power coefficient; the power and the pressure drop attainable for a Pratt & Whitney 1830 engine equipped with the high-speed cowling, and turning at 1430 rpm, are as follows:

Pressure rise through cowling

$$\Delta P = 0.5 \times \left(\frac{1430}{758}\right)^2 \times \left(\frac{1.0}{0.4}\right)^2 \times \left(\frac{1}{2.32}\right) = 4.8 \text{ inches alcohol}$$

Power absorbed by full-scale blower

$$P = 0.059 \left(\frac{1430}{758}\right)^3 \left(\frac{1.0}{0.4}\right)^5 \left(\frac{1}{2.32}\right) = 16.8 \text{ horsepower}$$

Other measurements of the power absorbed by the model high-speed cowling arrangement indicate that at the high-speed flight condition the blower absorbs about 2 percent of the engine power.

Propulsive efficiency.- All values of propulsive efficiency herein presented are based on the drag of the airplane model when fitted with the high-speed cowling arrangement. Thus, the values of efficiency obtained with the open-nose cowling arrangement are directly comparable with those obtained with the high-speed cowling arrangement.

Figure 9 compares the envelope propulsive-efficiency curve obtained from tests of the open-nose cowling with a similar curve obtained from tests of the high-speed cowling arrangement. It is of interest to note that, although the high-speed cowling increased η_{max} by only about 2 percent in the vicinity of $V/nD = 2.0$, the high-speed cowling increased η_{max} by approximately 10 percent in the vicinity of $V/nD = 3.0$.

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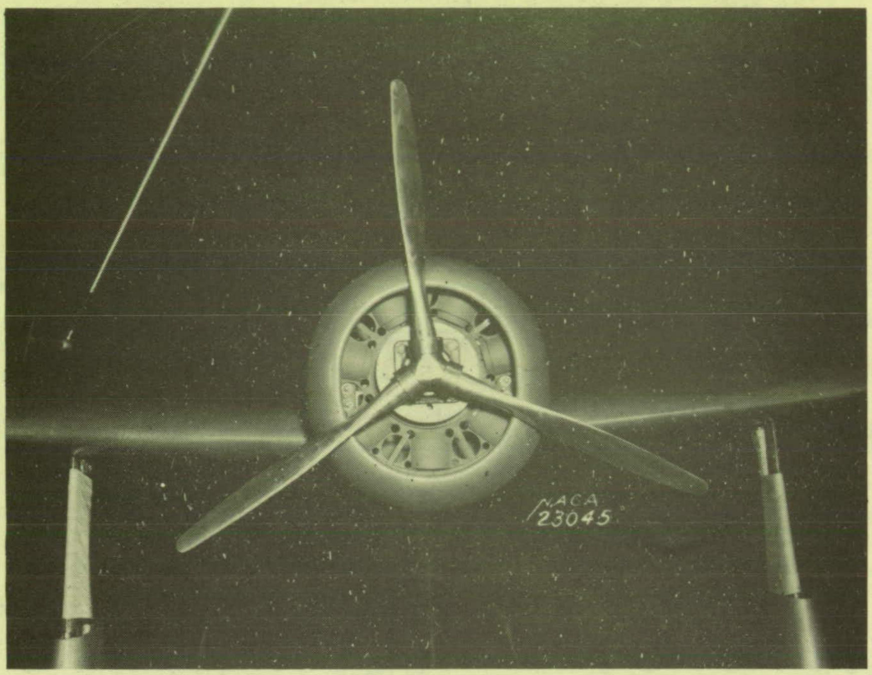
2. Becker, John V.: Wind-Tunnel Tests of Air Inlet and Outlet Openings on a Streamline Body. NACA confidential report, 1940.



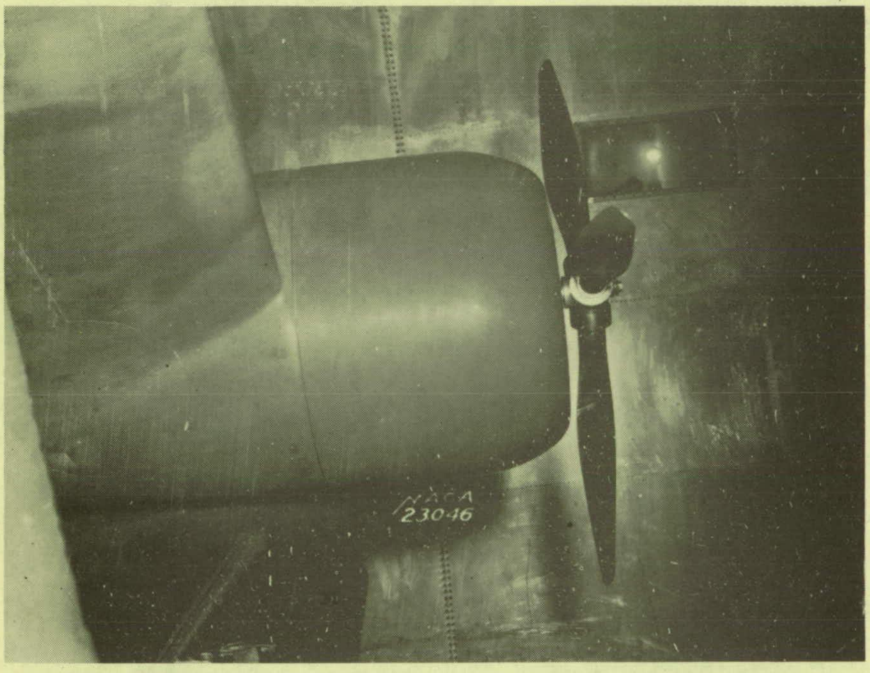
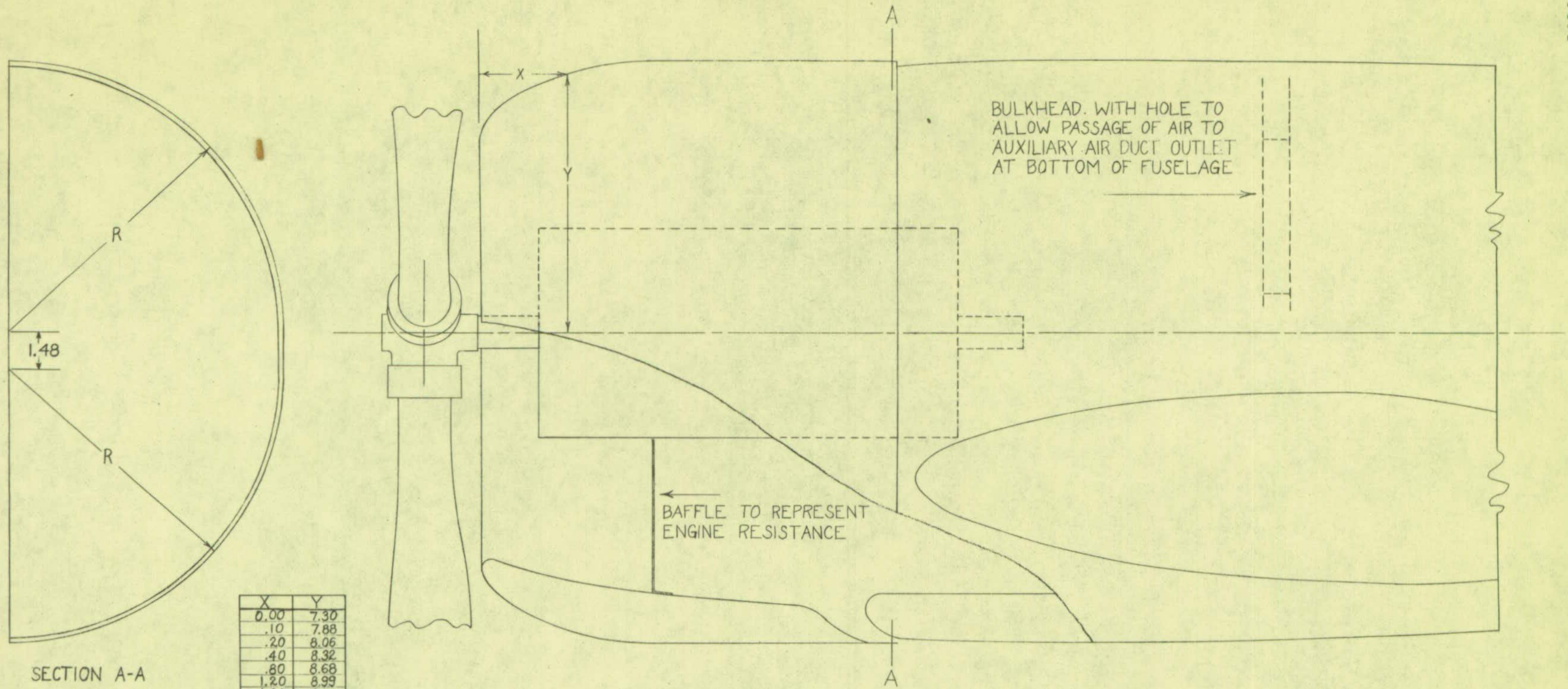


Figure 1.- The NACA open-nose cowling arrangement on the 0.4 - scale pursuit airplane model.



X	Y
0.00	7.30
.10	7.88
.20	8.06
.40	8.32
.80	8.68
1.20	8.99
1.60	9.21
2.01	9.43
2.41	9.59
2.81	9.75
3.21	9.89
4.01	10.13
4.81	10.29
5.62	10.39
6.42	10.43
7.8-----	10.43

FIG. 2.-TEST ARRANGEMENT FOR NACA OPEN-NOSE COWLING.

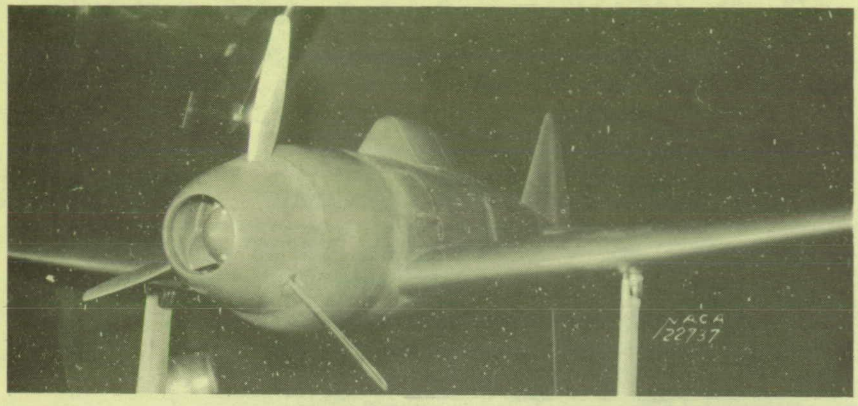


Figure 3.- The NACA high-speed cowling arrangement on the 0.4-scale pursuit airplane model.

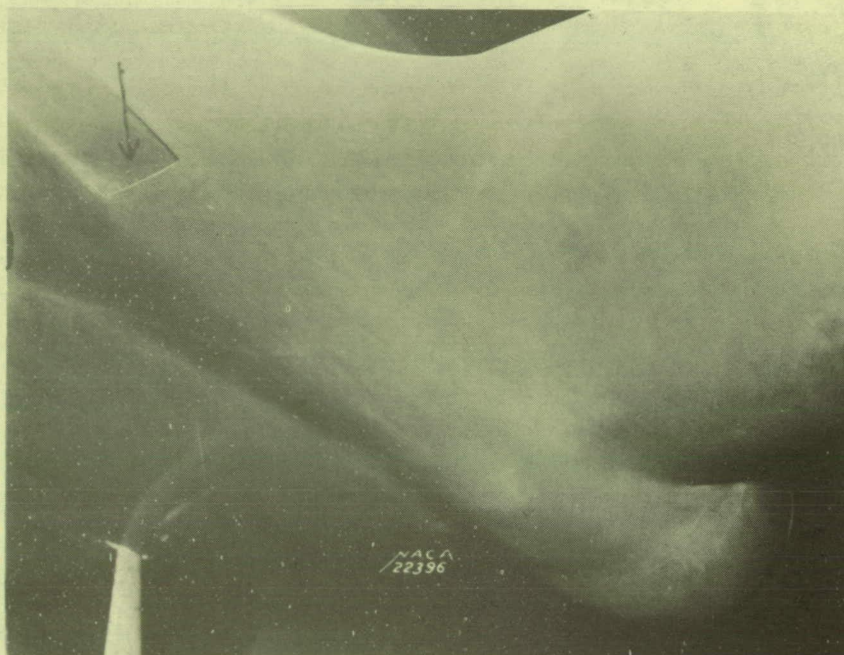


Figure 5.- Auxiliary cooling-air duct exit on the 0.4-scale pursuit airplane model.

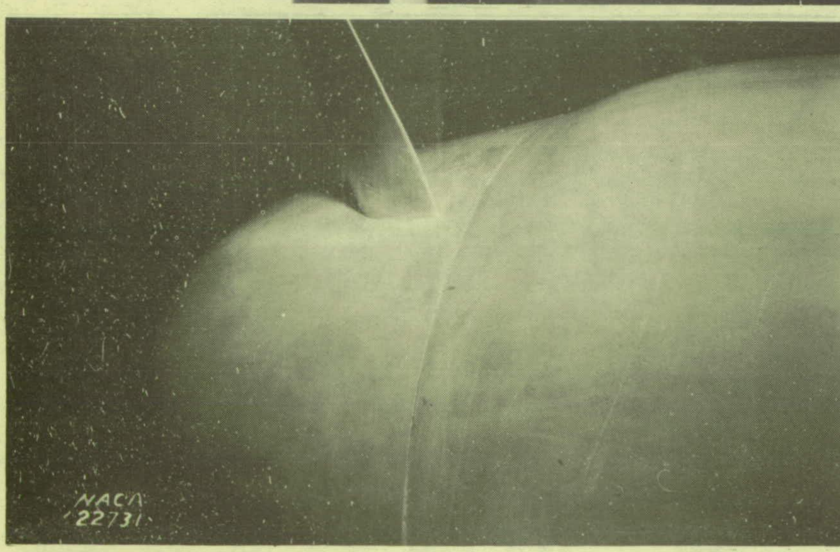
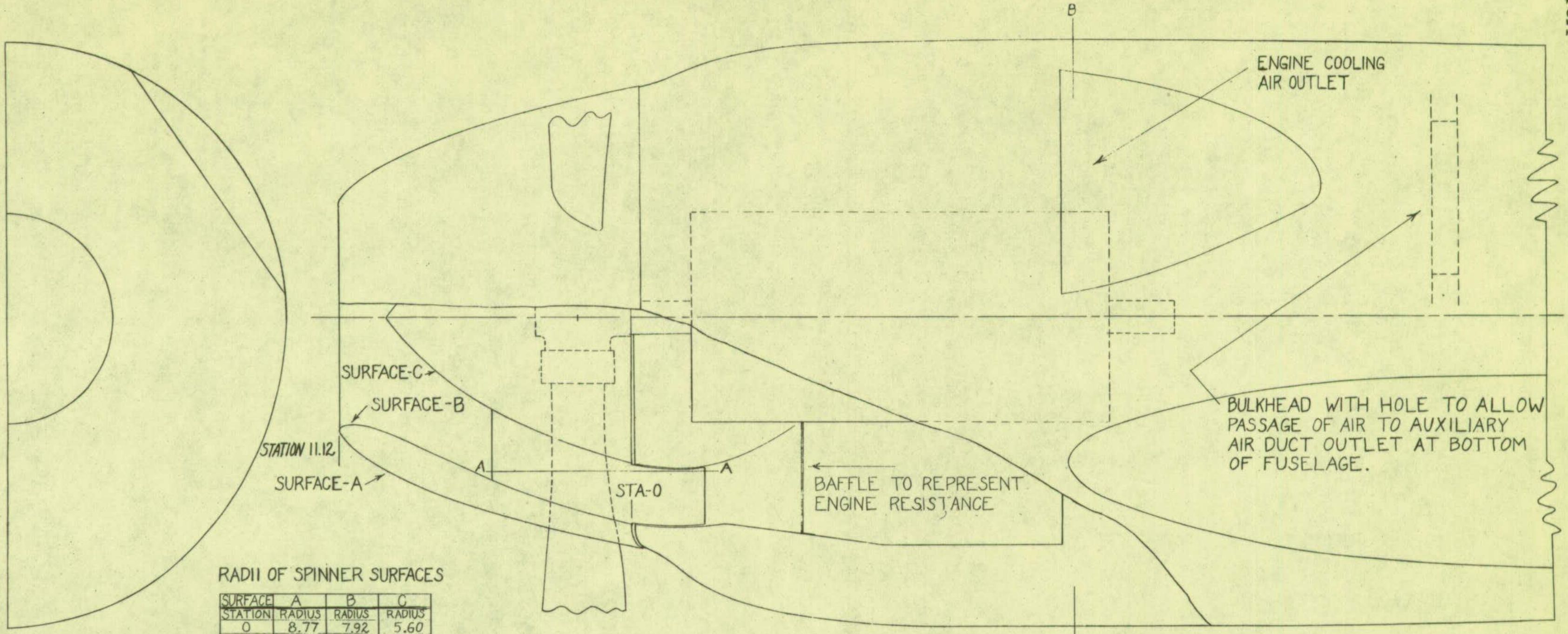


Figure 7.- Propeller blade intersection with surface of NACA high-speed cowling ; 0.4 - scale pursuit airplane model.



SECTION B-B

RADII OF SPINNER SURFACES

SURFACE	A	B	C
STATION	RADIUS	RADIUS	RADIUS
0	8.77	7.92	5.60
.8	8.60	7.72	5.34
1.6	8.42	7.50	5.06
2.0	8.32	7.38	4.94
2.4	8.22	7.26	4.80
3.2	8.03	6.99	4.50
4.0	7.82	6.72	4.15
4.8	7.60	6.42	3.77
5.6	7.36	6.08	3.33
6.4	7.10	5.72	2.82
7.2	6.81	5.40	2.22
8.0	6.48	5.03	1.52
8.8	6.12	4.66	.66
9.2	——	——	.16
9.32	——	——	0
9.6	5.70	4.30	——
10.4	5.19	4.10	——
10.8	4.84	4.10	——
11.0	4.61	4.14	——
11.12	4.32	4.32	——
	TIP RADIUS=0.17		

SECTION A-A

FIG. 4.-TEST ARRANGEMENT FOR NACA HIGH-SPEED COWLING.

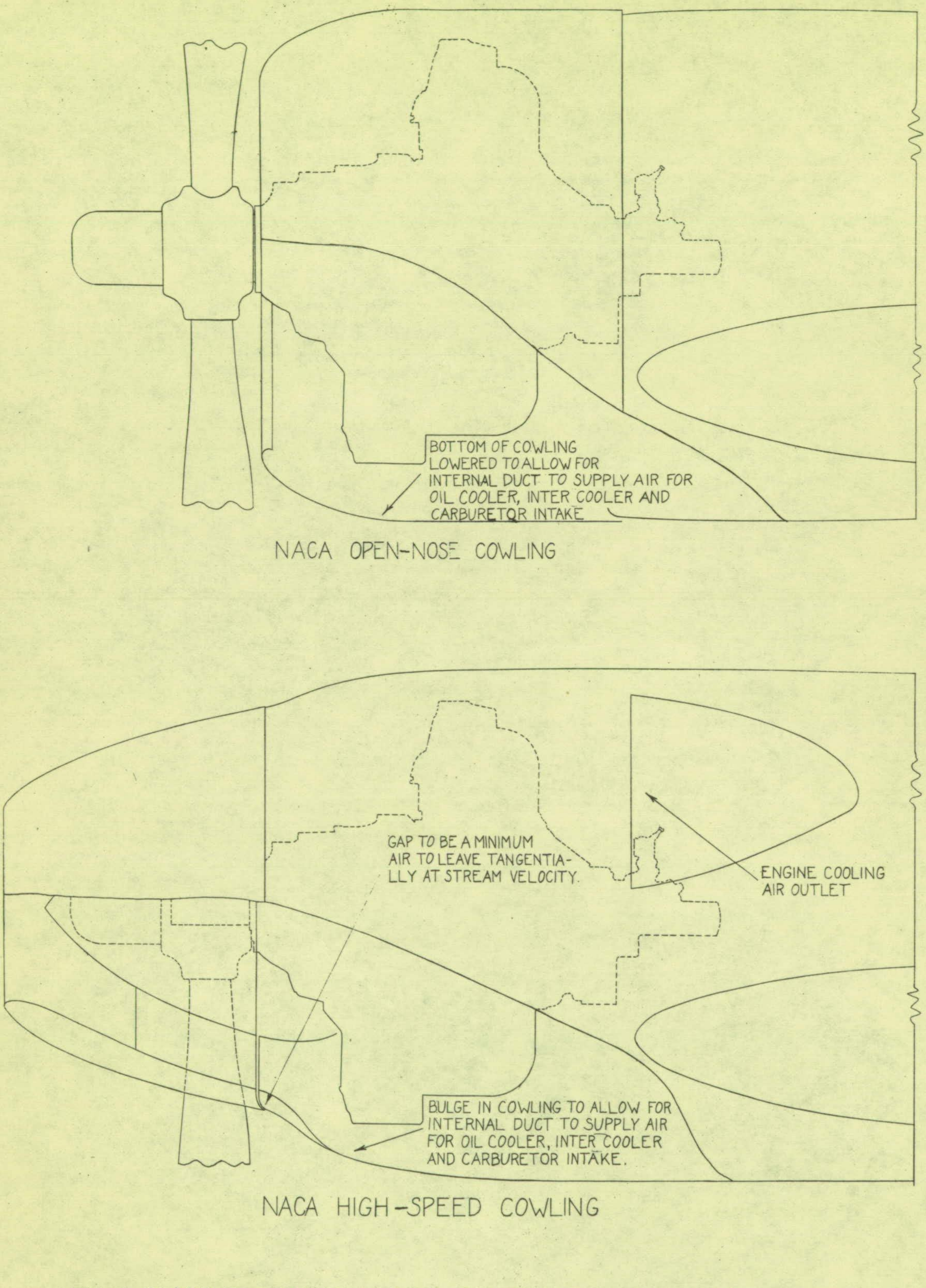


FIG. 6.- POSSIBLE ARRANGEMENTS FOR ENGINE INSTALLATION.

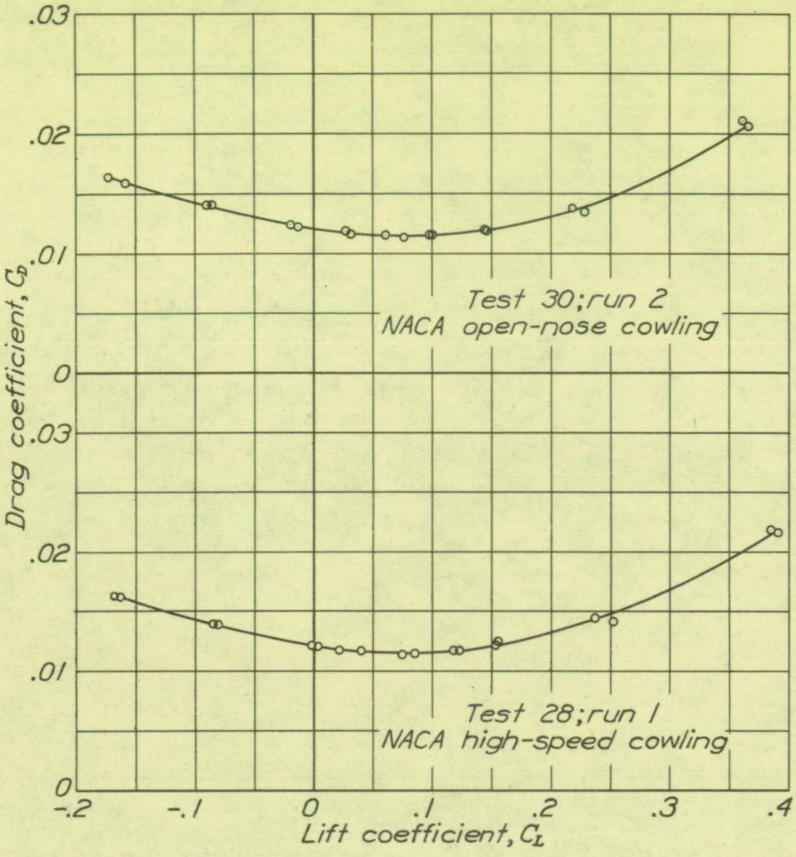


Figure 8.- Comparison of drag coefficients of 0.4-scale pursuit airplane model when fitted with open-nose and with NACA high-speed cowling arrangements.

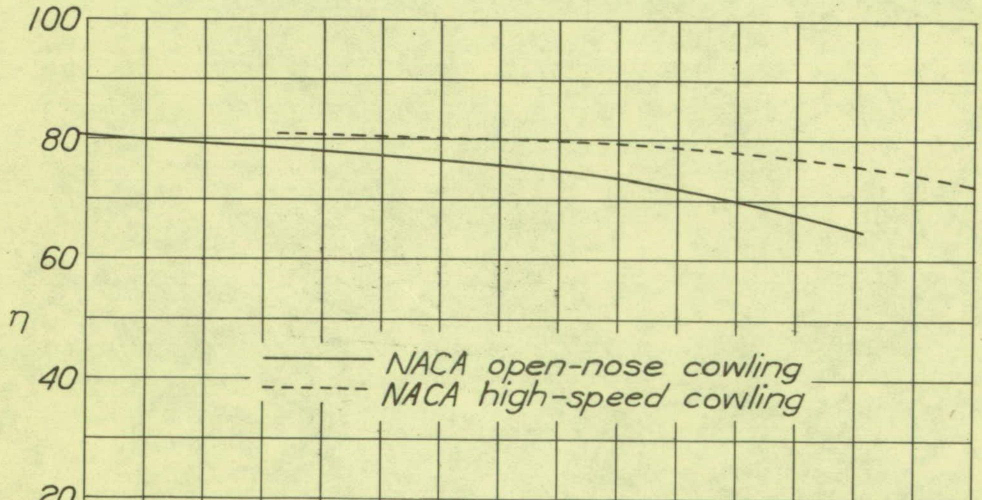


Figure 9.- Comparison of envelope efficiency curves; 0.4-scale pursuit airplane model: 3-blade, 4-foot-diameter propeller.