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DEVELOPMENT OF COWLING FOR LONG-NOSE AIR-COOLED

ENGINE IN THE NACA FULL-SCALE WIND TUNNEL

By Abe Silverstein and Eugene R. Guryansky

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

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INTRODUCTION

An investigation of cowlings for long-nose radial engines has been made on the Curtiss XP-42 airplane in the NACA full-scale wind tunnel. The XP-42 airplane is provided with a Pratt & Whitney R-1830-31 engine, which has a propeller shaft and bearing housing that is 20 inches longer than the standard short-nose engine of the same series. This forward extension of the propeller enables the use of fuselage nose shapes of higher fineness ratio than are possible with the blunter short-nose engine. In the original Curtiss Company design of the XP-42 airplane the pointed fuselage nose was used (fig. 1) and sharp-edge scoops were added at the bottom and top of the cowling for the engine-cooling and the carburetor-air inlets. Flight tests showed the high speed of the airplane to be comparable with, but not superior to, that of the P-36, which is a similar airplane with a short-nose engine and a conventional NACA cowling installation. Inspection of the cowling scoops disclosed sources of drag, the existence of which were substantiated by preliminary NACA flight measurements. These tests showed that the engine cooling air entered the lower scoop at about half the airplane flight velocity and that the kinetic energy of this flow was dissipated by the sharp change in the air-flow direction at the rear of the scoop and by the expansion from the small scoop area to large area ahead of the engine. (See fig. 2.)

The existence of a large internal energy loss due to the cooling-air flow was established and experience led to the belief that a further substantial external drag would be added by the flow over the sharp scoop edges. The full-scale tunnel investigation was then instigated for the purpose of improving the original scoop cowling or developing an efficient cowl of another type.

The wind-tunnel program included an initial investigation of the original P-42 cowling, which was followed

by tests of several modified arrangements with improved
scoops. The general unsatisfactory aerodynamic charac-
teristics of all the cowlings with scoop inlets led to
the development of the annular high-velocity inlet cowl-
ing. Since it was the purpose of the wind-tunnel investi-
gation to develop an optimum cowling that could be later
constructed for flight tests, the various cowling param-
eters, such as inlet velocity ratio, exit area, etc.,
were studied in considerable detail. This cowling has
been constructed and is currently undergoing flight tests
on the P-42 airplane. The results of the flight investi-
gation will be reported at a later date.

METHOD AND APPARATUS

The NACA full-scale wind-tunnel balance equipment
used for the force measurements is described in reference
1. The method of mounting the airplane on the balance is
shown in figure 1. The special technique and apparatus
used for the momentum measurements are described in ref-
erence 2. Static-pressure measurements were obtained
either by the use of static orifices or 1/16-inch diam-
eter static-pressure tubes mounted near the airplane sur-
faces. The air flow through the engine cowling was meas-
ured by total-pressure and static-pressure tubes placed
in the diffusers ahead of the engine baffles, and in the
cowl outlets.

RESULTS AND DISCUSSIONS

Original XP-42 cowling.- A photograph of the instal-
lation of the original scoop cowling on the XP-42 airplane
is shown in figure 1; a sketch with a more detailed view
of the engine air scoop is shown in figure 2. The cool-
ing air is turned with a short radius through 90° and dis-
charged into the compartment ahead of the engine cylinders.
As a result of the energy losses occurring in the turn and
the expansion, the total pressure at the front of the
engine baffles was found to be only about 0.4 the free-
stream total pressure. This large inlet loss was chiefly
responsible for the high drag of the cowling installation
and the drag coefficient for the airplane equipped with
the original cooling-air scoop was 0.0040 higher than for

the smooth airplane with the scoop removed and the cowling
sealed. Although the internal losses largely accounted
for the drag of the original cowl, a substantial incre-
ment was also added by the sharp scoop edges. The drag
coefficient for the airplane in the smooth condition (fig.
3) served as a base value for determining the drags of
all the modifications tested.

Original cowling with multiple scoops.- In order to
avoid the large internal cowl losses, the single original
sharp-edge scoop was replaced with four smaller rounded
inlet scoops (fig. 4). The use of multiple scoops rather
than a single scoop was advantageous both in obtaining
better diffuser passages and in avoiding the sharp bend
required in the single-scoop arrangement. A sketch show-
ing the detailed dimensions of the ducts is contained in
figure 5(a). The results obtained with this arrangement,
which was designated cowl 1, are shown in table I.

The results were unsatisfactory since it was found
that the flow was separating from the inner wall of the
duct passages and owing to the negative pressures over
the top of the cowl in the climb condition, the flow
through the upper scoop was reversed. As a result of the
flow breakdown in the ducts, the pressure in front of the
engine averaged only about 0.6 the free-stream pressure
(fig. 6). The air-flow quantities measured for three
exit areas of 67, 84, and 98 square inches were 6,970,
8,810, and 10,280 cubic feet per minute, respectively.
The drag coefficient corresponding to the 67-square-inch
outlet area was 0.0023. The drag of the airplane with
the scoop outlets sealed and with the inlets unsealed was
increased 0.0017 above the drag of the smooth airplane.

As a result of the difficulties encountered with the
four-scoop arrangement, the top scoop was removed and the
scoop inlets were extended forward along the cowl about
11 inches (see fig. 7); with these changes the duct inlet
area was considerably reduced. (See fig. 5(b).) The
modifications served to locate the inlet more nearly
normal to the local flow direction and to lengthen the
diffusing passage. The results were somewhat more satis-
factory and the total pressures in front of the engine
were higher than for the former arrangement. (See fig.
6.)

The diffuser passage, however, was still inefficient, since flow breakaway occurred on its inner wall and a further modification was made in which the duct passages were straightened. (See fig. 5(c).) For this improved arrangement, with an outlet area of 91 square inches, a drag coefficient increment of 0.0024 was measured with an air-flow quantity of 12,700 cubic feet per minute. With the scoop inlets and outlets sealed, the airplane drag coefficient was increased 0.0006, which is a measure of the effect of the protruding scoops on the external drag of the airplane.

Annular inlet cowl.- Since the drag of all the scoop arrangements tested was high, the investigation was directed toward developing a cowl in which the cooling air was introduced through a narrow annular inlet at the nose of the airplane, with a spinner fairing for the propeller hub and the blade shanks (figs. 8 and 9). This cowl, which is designated cowl 2 (table I), was designed so that the velocity at the cooling-air inlet was about one-fourth of the free-stream velocity. It was tested first with the exit sealed and the airplane drag was increased 0.0012, owing to the cowl form drag and the circulation of air in the cowl opening. With the inlet also sealed, the airplane drag was increased by only 0.0003. For different outlet areas, the airplane drag coefficient was increased 0.0022 with an air flow of 12,050 cubic feet per minute and was increased 0.0027 with an air flow of 17,000 cubic feet per minute.

These drag increments caused by air flow were too large and since drag reductions that should have been expected owing to improved internal flow (see fig. 6) were not fully realized, it was suspected that the cowl outlet was unsatisfactory. Tuft investigation of the flow from the original cowl outlet on the XP-42 airplane (fig. 10) showed that air was being discharged over and around the exhaust collector and flap gear in such a manner that the flow over the fuselage was disturbed. The outlet was modified, as shown in figure 10, by removing the conventional flap gear and exhaust collector from behind the engine and installing a smooth unrestricted outlet. With this modification, the drag coefficient was reduced 0.0007 and the cowl drag coefficient of 0.0015 was measured with a flow of 12,040 cubic feet per minute. The investigation was continued by sealing the conventional radial cowling outlet and providing a bottom outlet on the cowl. (See fig. 11(a).) This bottom outlet was too small because

the measured air flow was lower than required and a larger
bottom outlet was constructed (fig. 11(b)). The cowl drag
coefficient for this arrangement was 0.0011 with air flow
of 12,800 cubic feet per minute. This drag is 0.0004
lower than for the cowling with the smooth radial outlet
and is 0.0011 lower than the conventional flap outlet.

The large drag reductions effected with the improved
outlets emphasize the importance of providing a smooth
outlet on production airplanes. Although the single bot-
tom outlet will probably be insufficient to provide uni-
form cooling for all the engine cylinders, the result ob-
tained with this arrangement is of particular interest as
a reference for evaluating the drag of the outlets.

From pressure measurements in the diffuser of the
annular cowl 2 (fig. 6), it was noted that the total pres-
sure was less than 0.9 the free-stream dynamic pressure.
Since it was expected that this value would be close to
stream pressure, the flow over the spinner was investi-
gated with tufts. It was found that flow reversal was
occurring on the upper part of the spinner at the inlet.
This phenomenon was further investigated by measurements
of pressures along the spinner, which are shown in fig-
ures 12 and 13. In these figures the magnitude of the
pressure is indicated as the length of the vector normal
to the spinner surface. It will be noted that a large
adverse pressure gradient exists in the direction of air
flow, the value of which is indicated by the slope of the
pressure plots. For the climb condition the slope is
high forward on the spinner and shows a jagged peak ahead
of the cowl inlet. For the high-speed lift coefficient
($C_L = 0.150$) the adverse pressure gradient is high toward
the forward part of the spinner and decreases several
inches ahead of the nose of the inlet. In agreement with
usual boundary-layer phenomena, the extent of tuft rever-
sal could be coordinated with the slope of the pressure
gradient along the spinner. Further modification was then
made to cowl 2 (fig. 14) to reduce the pressure gradient
along the spinner. The inlet area for the cowling was re-
duced by increasing the spinner size (spinner B, fig. 9)
so that the inlet-velocity ratio (V_i/V) was increased
above 0.5. With the higher inlet velocities, the diffuser
pressures were increased to approximately $0.97q_o$. The
pressures on the spinner corresponding to the two outlet
conditions tested are shown in figures 15 and 16.

L-241

indicates that the critical compressibility speed will occur above 500 miles per hour at 20,000 feet altitude. The uniform recovery pressure on the inside of the duct is demonstrated in figures 19 and 21.

CONCLUSIONS

1. The long-nose engine enables the design of an efficient annular inlet cowling owing to the length available for a diffusing passage.

2. The ratio of the cooling-air velocity at the cowling inlet to the stream velocity is one of the most important design variables for the annular inlet cowling and this ratio should not be less than about 0.5.

3. The critical compressibility speed for the long-nose engine cowling can be extended to above 500 miles per hour at 20,000 feet altitude.

4. Important drag losses occur due to the flow of cooling air out of conventional cowling outlets with flap gear and exhaust collectors to disturb the flow.

Langley Memorial Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va.

REFERENCES

1. DeFrance, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. Rep. No. 459, NACA, 1933.

2. Goett, Harry J.: Experimental Investigation of the Momentum Method for Determining Profile Drag. Rep. No. 660, NACA, 1939.

TABLE I. – SUMMARY OF RESULTS

| Cowl | Sketch | Cooling system | | Exit area (sq in.) | Drag coefficient (at 100 mph) | | | Air quantity (cu ft per min at 350 mph) | Inlet velocity ratio $\frac{v_i}{V}$ |
		Width outlet opening (in.)	Test conditions		$c_{D_{min}}$	c_D at $c_L=0.15$	Δc_D at $c_L=0.15$ (b)		
Smooth without original scoop		Sealed			0.0192	0.0203			
Smooth with original scoop		1.49	Standard	167	0.0232	0.0243	0.0040	16,100	0.69
Cowl 1		Sealed			0.0209	0.0220	0.0017		
		5/8		67	.0212	.0226	.0023	6,970	0.15
		3/4		84				8,810	.19
		7/8		98				10,280	.23
		Sealed	Oil cooler open		.0210	.0224	.0021		
Cowl 1 modified		Sealed	Scoops sealed		0.0194	0.0209	0.0006		
		5/8	" "		.0196	.0209	.0006		
		5/8	Scoops open	63	.0206	.0221	.0018	7,330	0.23
		3/4	" "		.0208	.0224	.0021		
		7/8	" "	98	.0210	.0225	.0022	10,900	.34
		5/8	Duct straightened, expansion reduced.	65	.0211	.0224	.0021	9,160	.28
		7/8	Same as 5/8	91	.0210	.0227	.0024	12,700	.39
Cowl 2 Spinner A		Sealed			0.0200	0.0215	0.0012		
		5/8		70	.0213	.0225	.0022	12,050	0.32
		3/4		78				13,750	.36
		7/8		98	.0216	.0230	.0027	17,000	.44
		Sealed	Oil cooler open		.0209	.0222	.0019		
		5/8	(a)	63	.0204	.0218	.0015	12,040	.31
		Sealed	Nose sealed [a]		.0192	.0206	.0003		
		"	Bottom exit open [a]	72	.0198	.0214	.0011	9,940	.26
		"	Modified bottom exit [a]	91	.0199	.0214	.0011	12,800	.33
		"	Modified bottom exit [a], upper inlet sealed.	91	.0199	.0212	.0009	13,550	.35
		Partial 5/8	Modified bottom exit [a]	136	.0202	.0216	.0013		
		" 5/8	Bottom sealed [a]	45				8,150	.21
		" 7/8	" " [a]	63				12,100	.32
		" 1-1/4	" " [a]	90	.0209	.0224	.0021	18,600	.49
Cowl 2 modified Spinner B		Sealed	Modified bottom [a]	91	0.0199	0.0209	0.0006	13,870	0.55
		Partial 5/8	" " [a]	131	.0204	.0215	.0012	21,140	.83
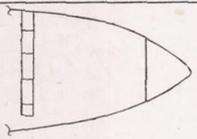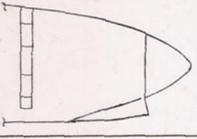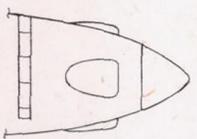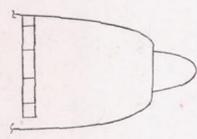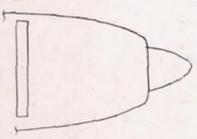
[a] Cowl flap gear removed and smooth exit installed.

[b] Based on smooth condition with original scoop off; landing gear fairing removed; control surfaces unsealed; and antenna on.
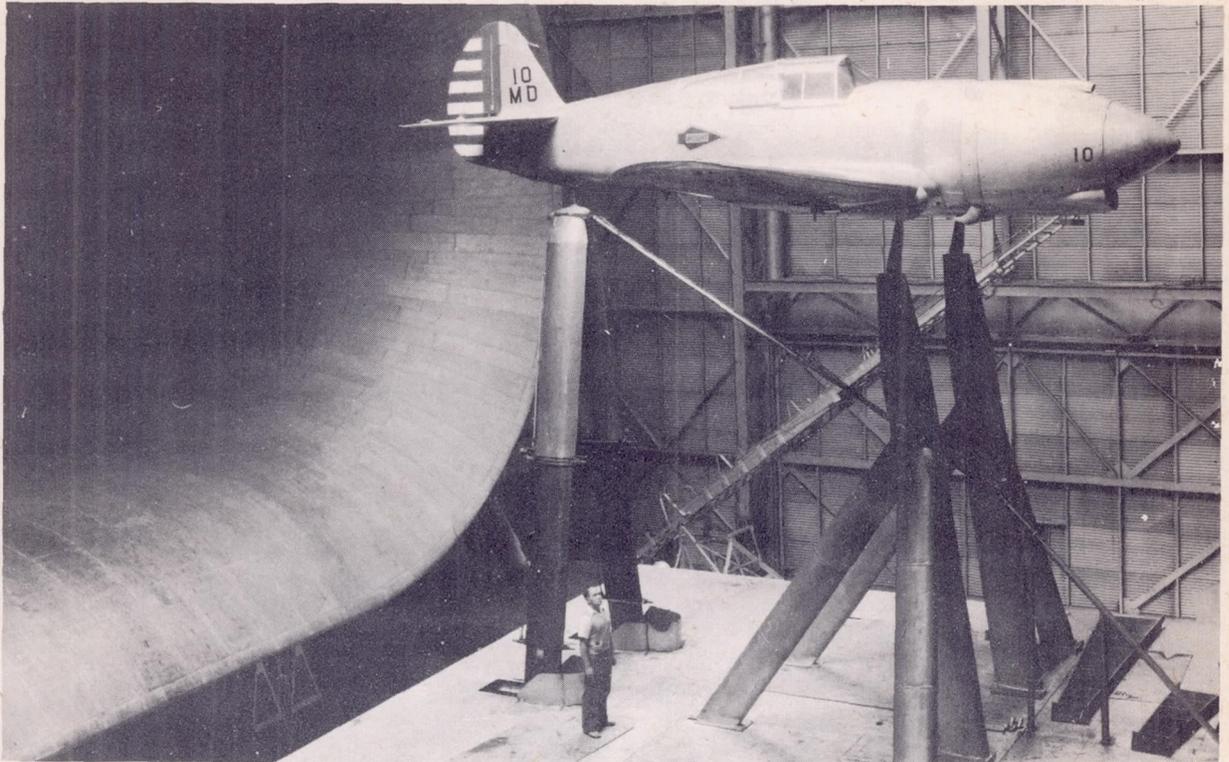
Figure 1.- The XP-42 airplane in the standard condition.
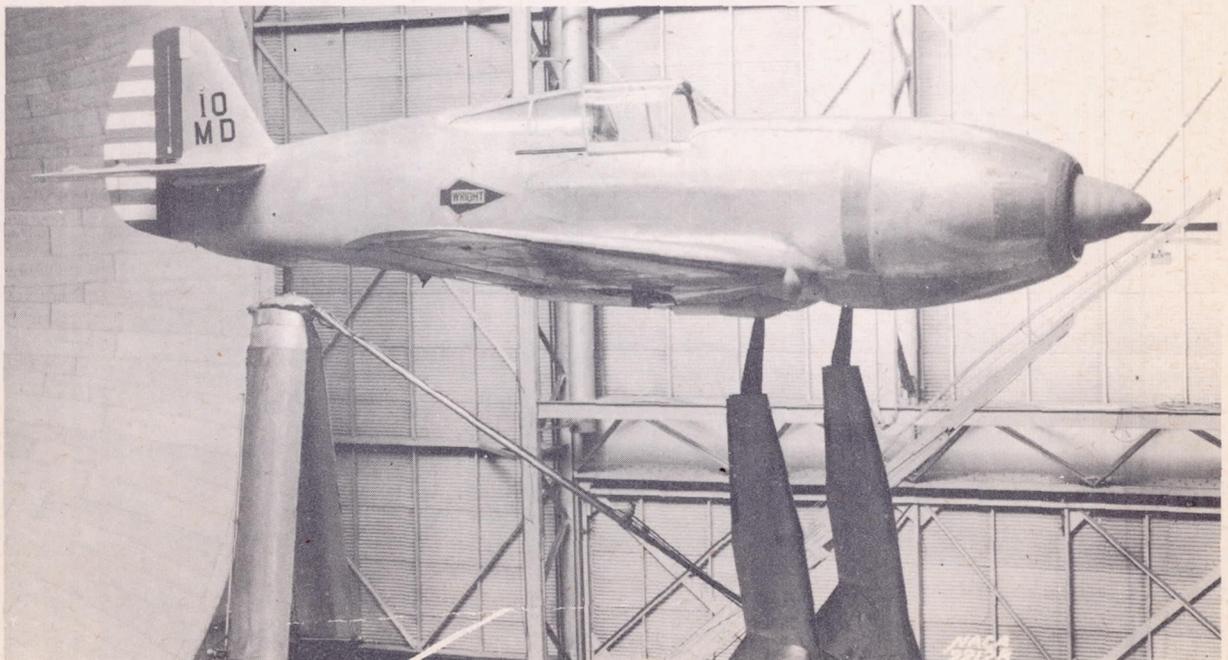
Figure 14.- The XP-42 airplane in the smooth condition with
cowl 2 modified and smooth cowl flaps.

L-721

COLLECTOR
RING

FLAP GEAR

SECTION AT
ORIGINAL OUTLET

SECTION AT
SMOOTH OUTLET

Figure 10.- Cowling outlets.

Figure 2.- Sketch of original XP-42 cowling.

CARBURETOR
SCOOP

℄ FRONT CYLINDER

BASIC COWL LINE

SCOOP

L-241
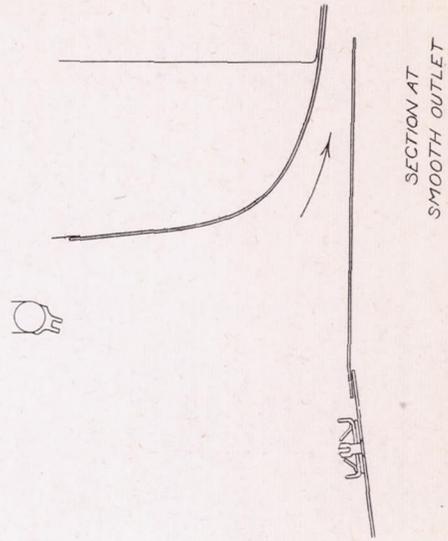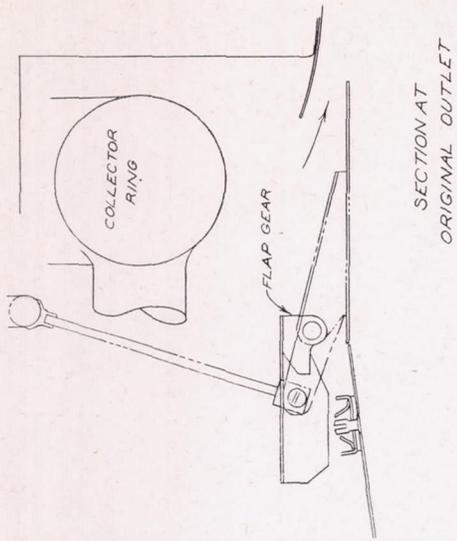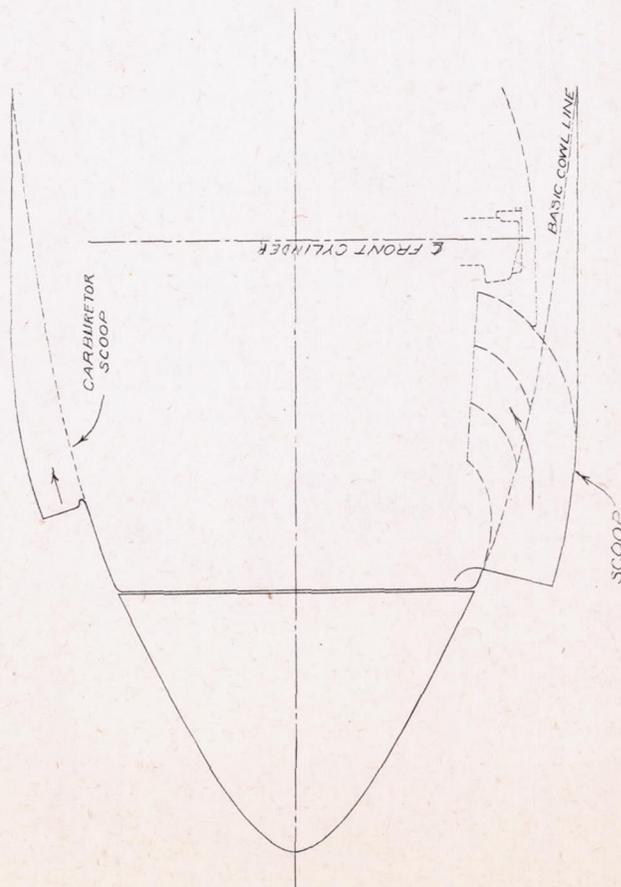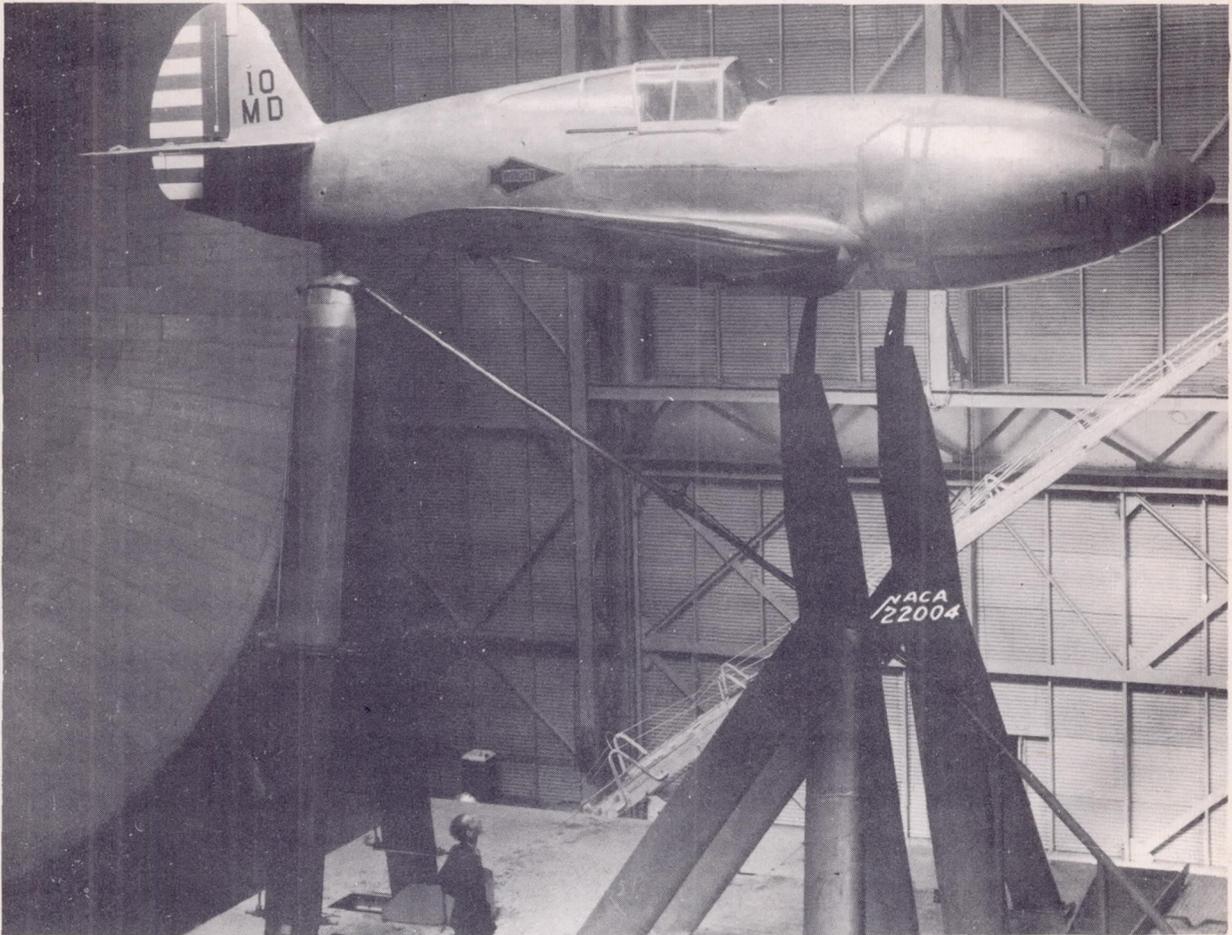
Figure 3.- The XP-42 airplane in the completely smooth condition mounted in the full-scale tunnel.
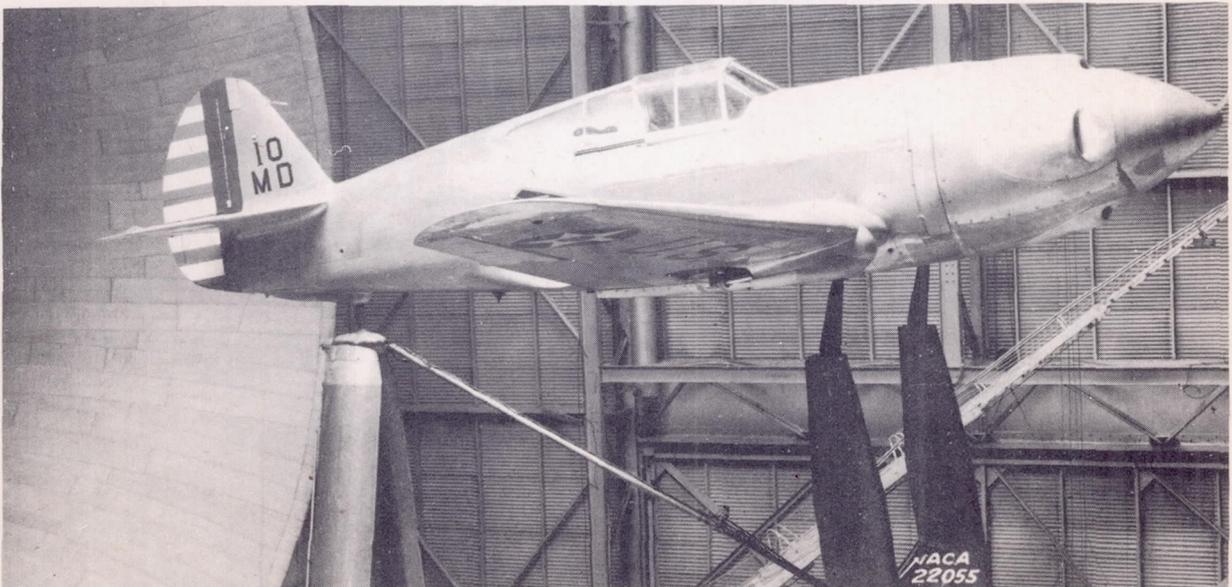
Figure 4.- The XP-42 airplane in the smooth condition with cowl 1 and original cowl flaps.

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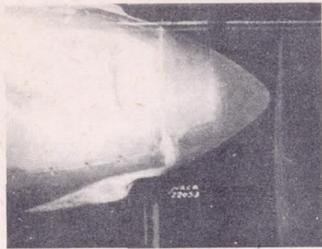
(a)
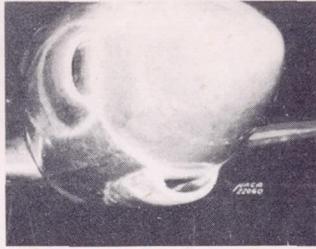
(b)
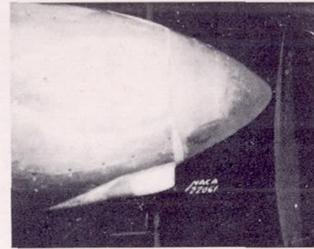
(c)

Section Area, sq in.		Dimension, in.
84.25	A	5.50
	B	8.25
39.00	C	4.00
	D	1.30
	E	5.95
27.75	F	3.13
	G	0.80
	H	5.15
71.80	J	4.69
	K	8.25

Fig. 5. - Cowl 1 and its modifications.
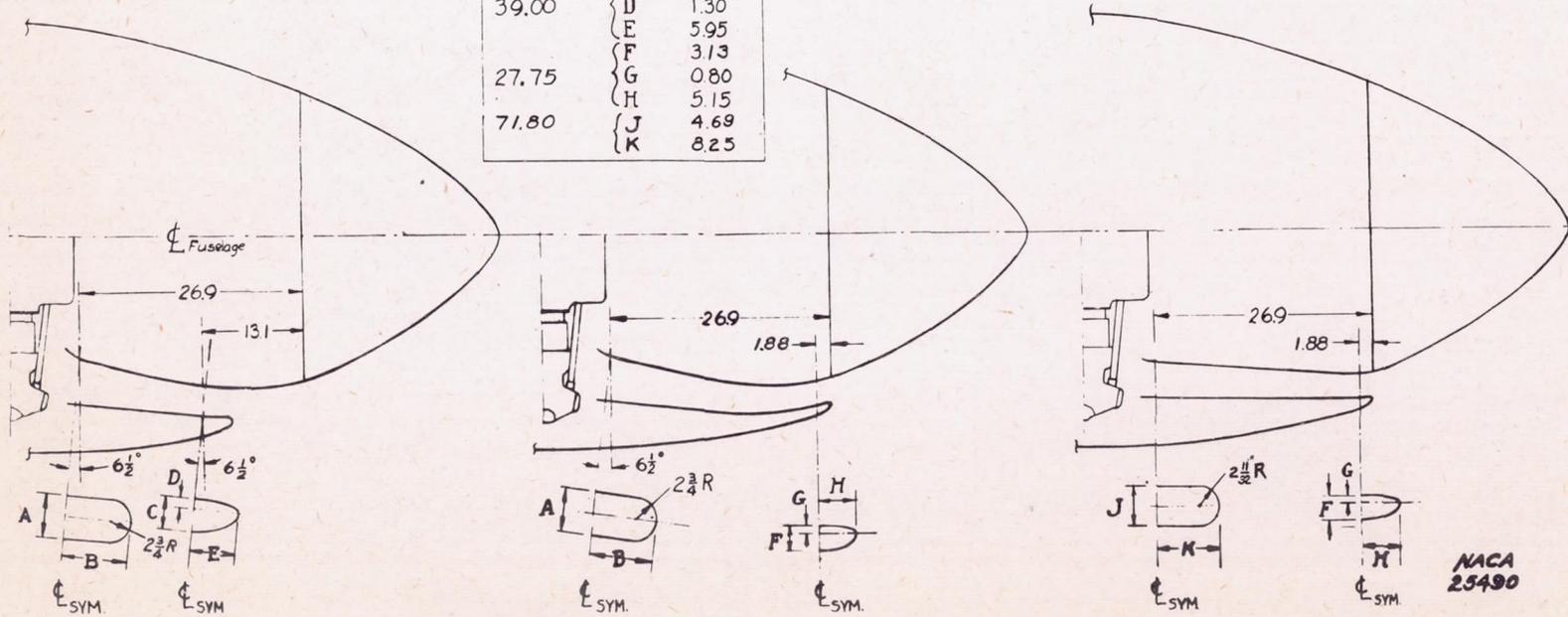
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Fig. 5
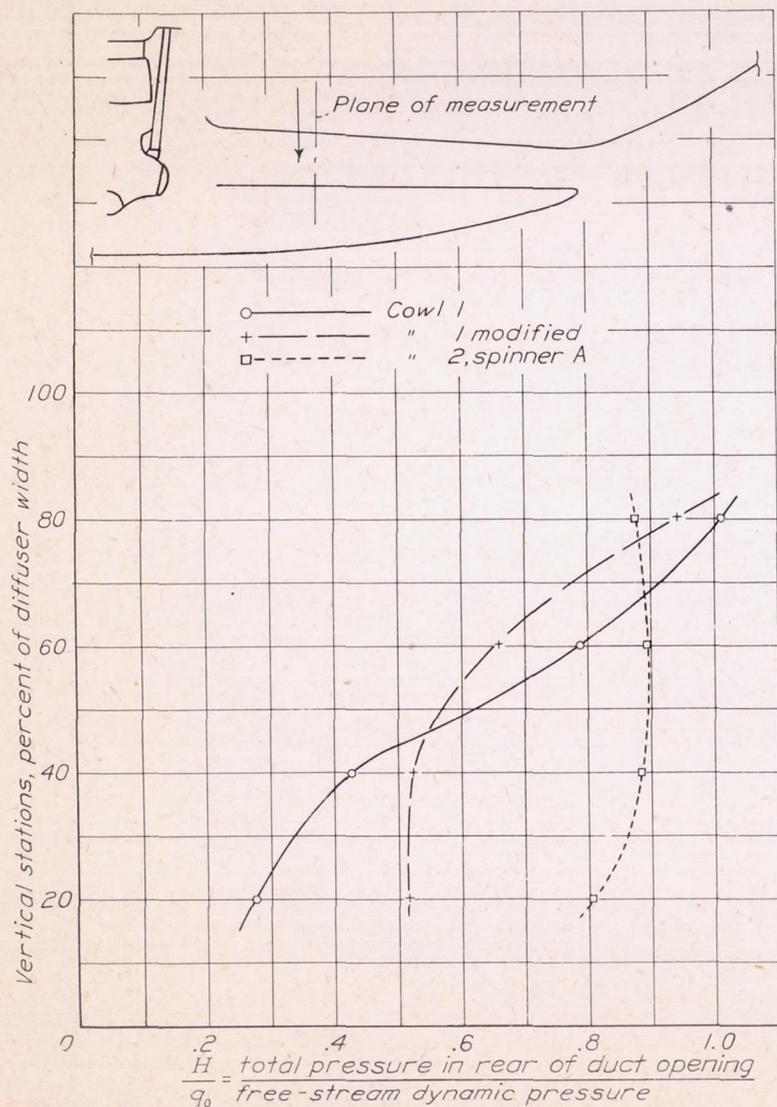
Figure 6.- Pressure in inlet diffuser.
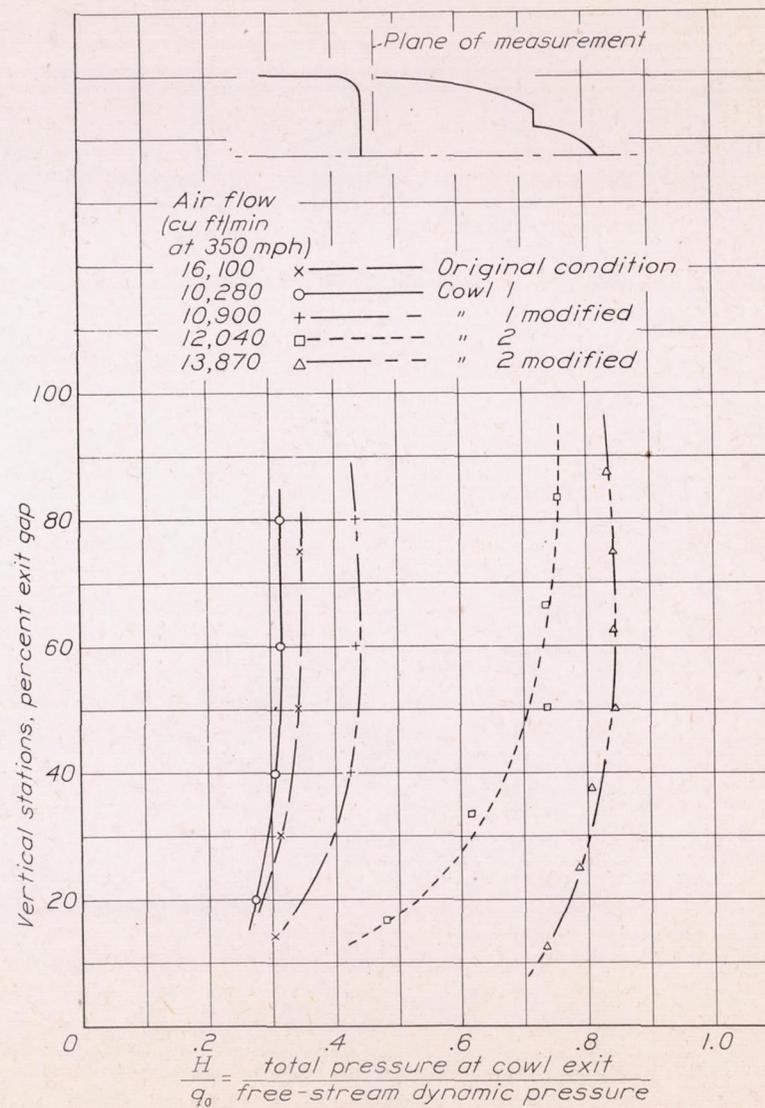
Figure 17.- Cowling outlet pressures.
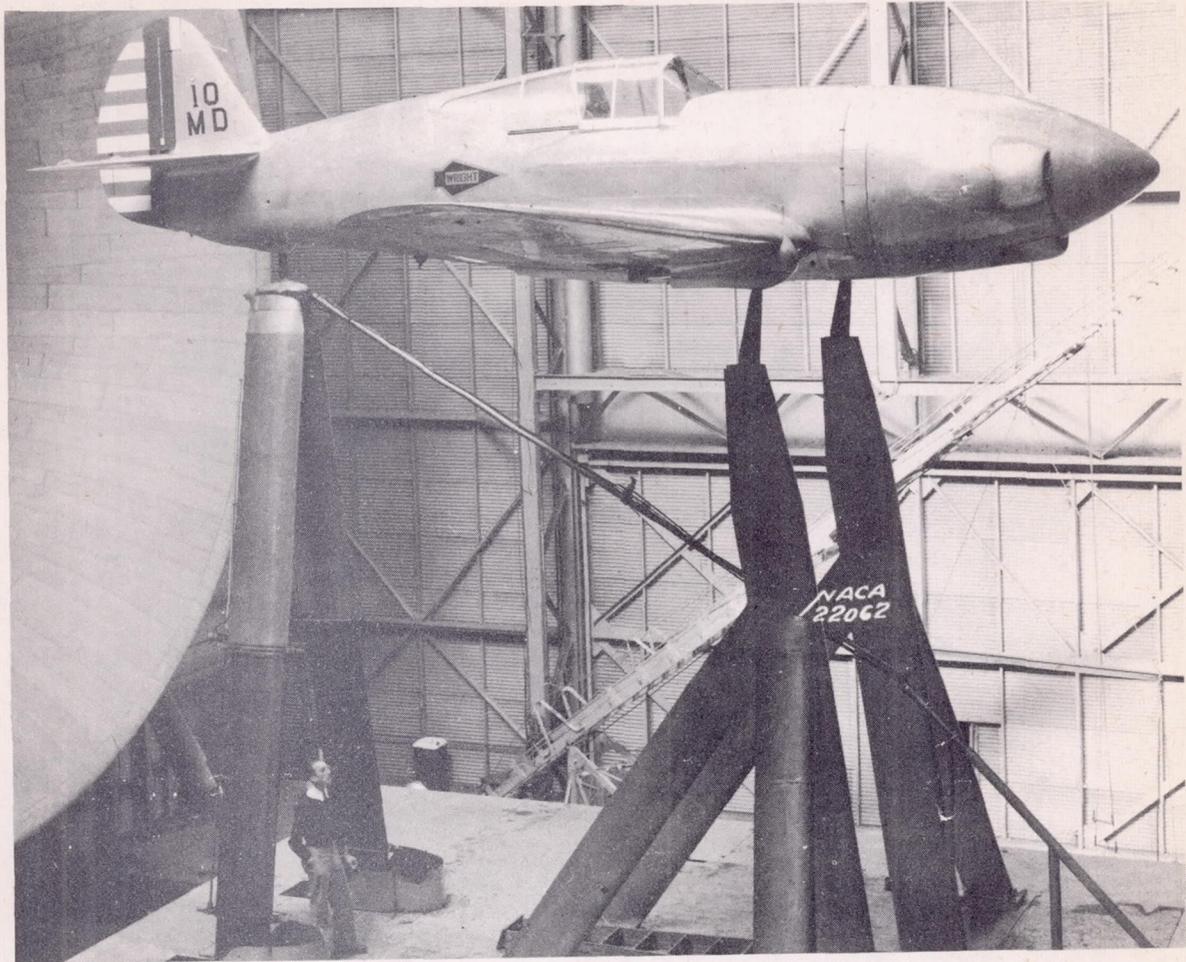
Figure 7.- The XP-42 airplane in the smooth condition with cowl 1 modified and original cowl flaps.
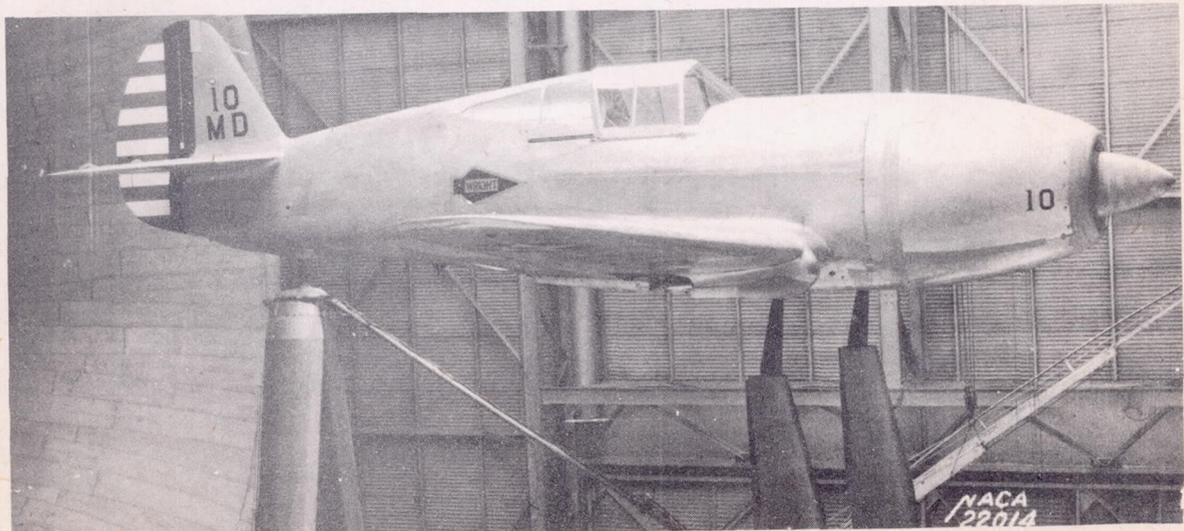
Figure 8.- The XP-42 airplane in the smooth condition with cowl 2, spinner A, and original cowl flaps.

Spinners

x	y	y'
0	0	0
5	1.20	1.45
1	1.72	2.00
2	2.49	2.95
4	3.85	4.50
6	4.93	5.73
8	5.80	6.70
12	7.21	8.20
16	8.33	9.38
20	9.20	10.28
24	9.80	10.92
28	10.22	11.42
48	11.97	13.57

Spinner A
Spinner B

3.11
4.96
5.5
2.27
3.5
10.2
12.45
x
y'
y
13.4
$\frac{15}{16}$
x
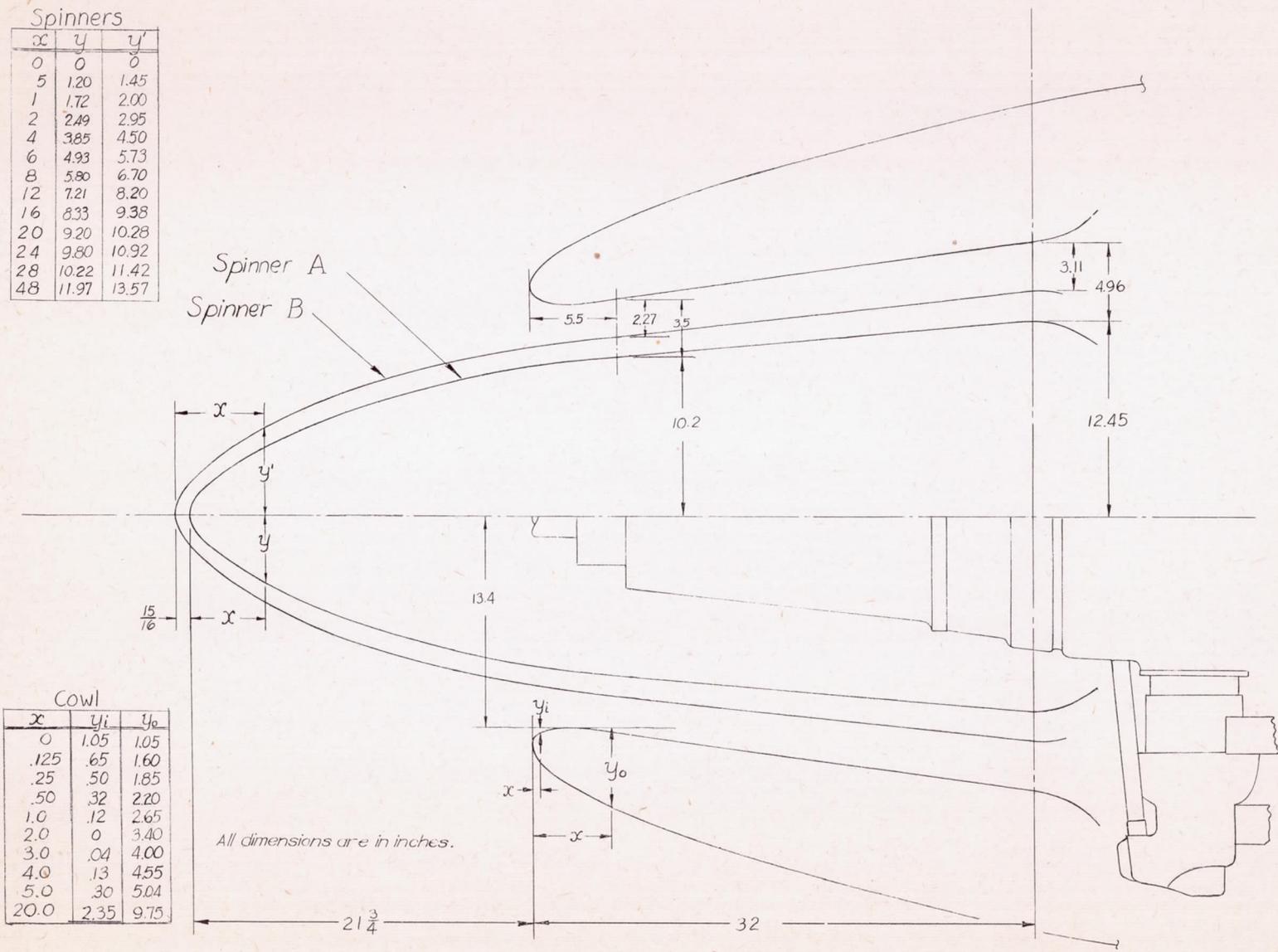
Cowl

x	y_i	y_o
0	1.05	1.05
.125	.65	1.60
.25	.50	1.85
.50	.32	2.20
1.0	.12	2.65
2.0	0	3.40
3.0	.04	4.00
4.0	.13	4.55
5.0	.30	5.04
20.0	2.35	9.75

All dimensions are in inches.

y_i
y_o
x
x

$21\frac{3}{4}$
32

Figure 9.- Annular inlet cowling number 2 with spinners A and B.

Fig. 9
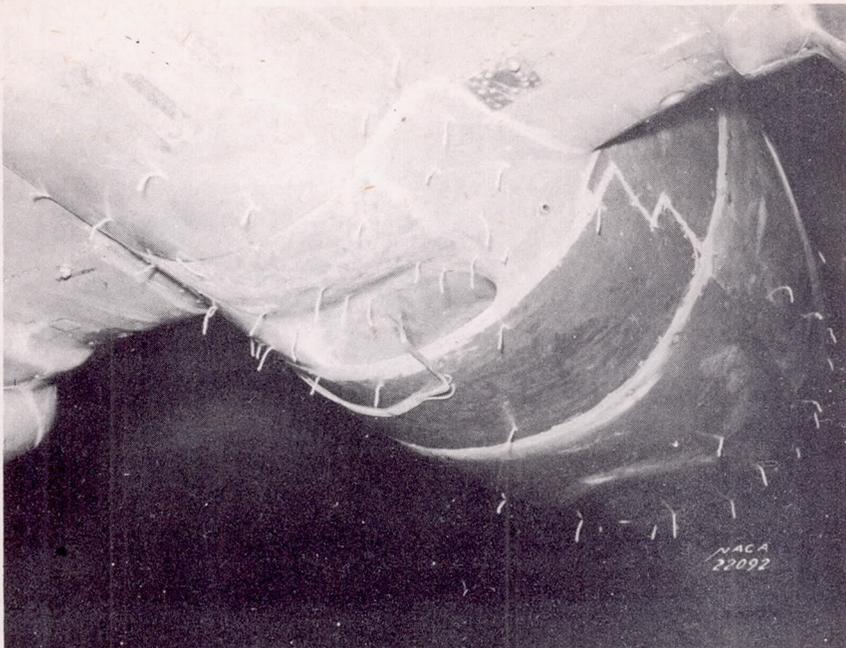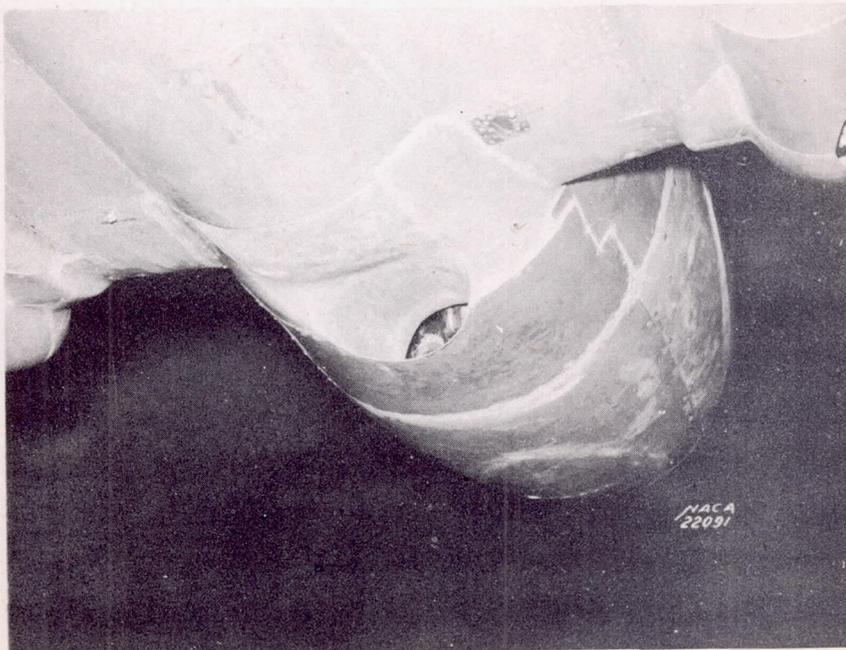
(a) Bottom outlet

(b) Modified bottom outlet

Figure 11.- Cowl outlet on XP-42 airplane.
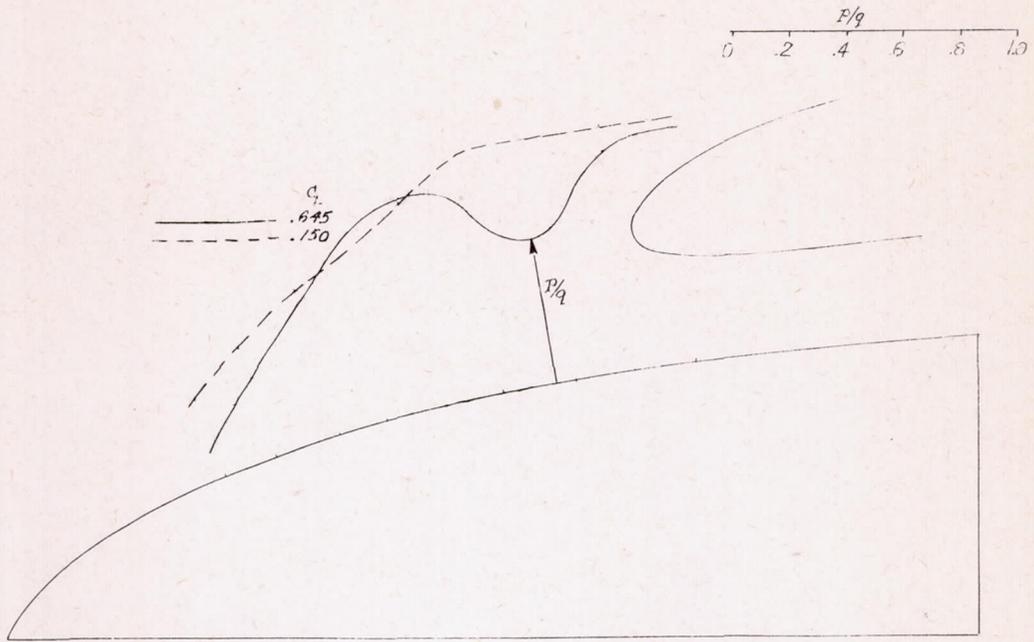
Figure 12.- Pressure distribution over top of spinner A with inlet velocity ratio $\frac{v_i}{V}$ 0.32.
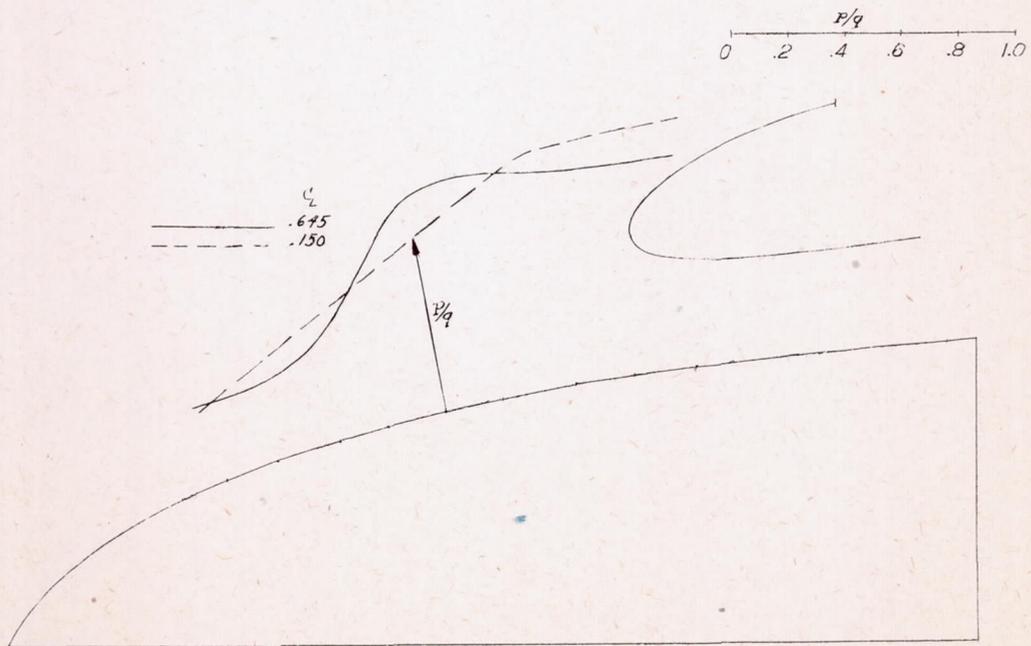
Figure 13.- Pressure distribution over top of spinner A with inlet velocity ratio $\frac{v_i}{V}$ 0.49.

P/q

0 .2 .4 .6 .8 1.0

C_L
——— .645
----- .150

P/q
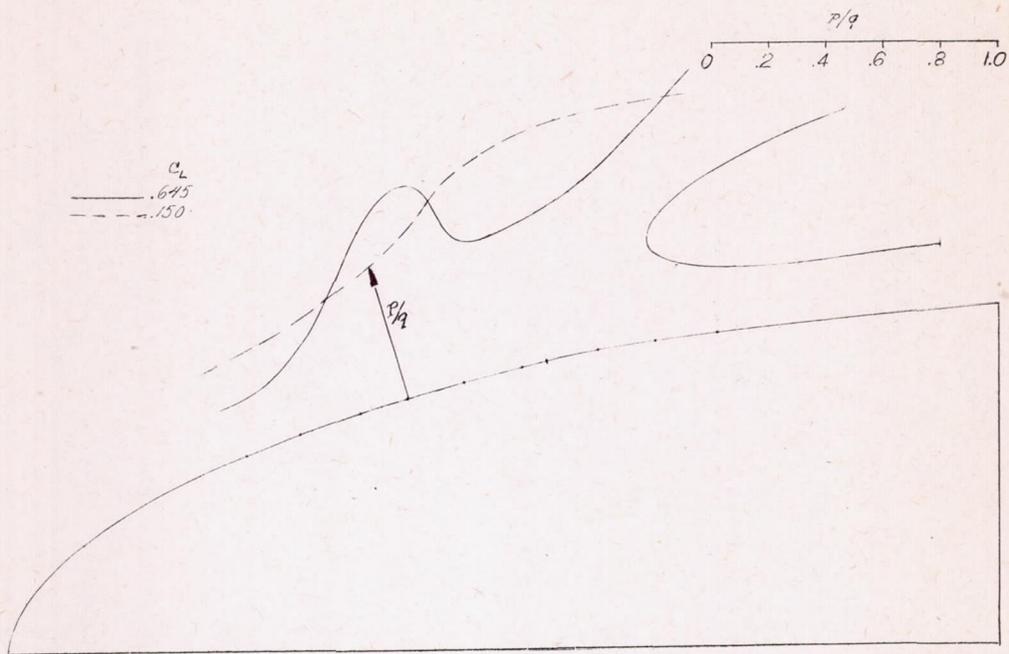
Figure 15.- Pressure distribution over top of spinner B with inlet velocity ratio V_i/V=0.55.

P/q

0 .2 .4 .6 .8 1.0

C_L
——— .645
----- .150

P/q
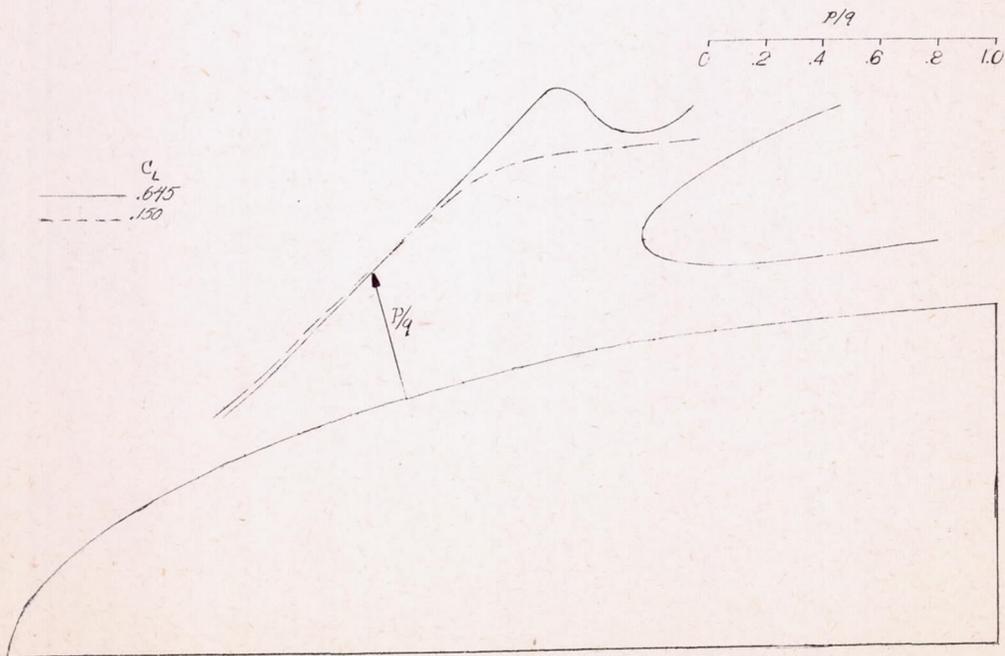
Figure 16.-Pressure distribution over top of spinner B with inlet velocity ratio V_i/V=0.83.
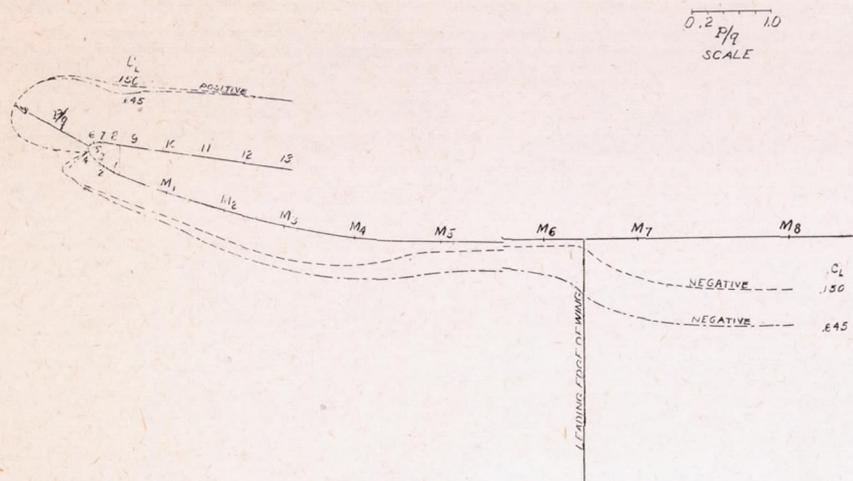
Figure 18.- Pressure distribution over side of cowl 2 with inlet
velocity ratio $V_i/V = 0.32$.
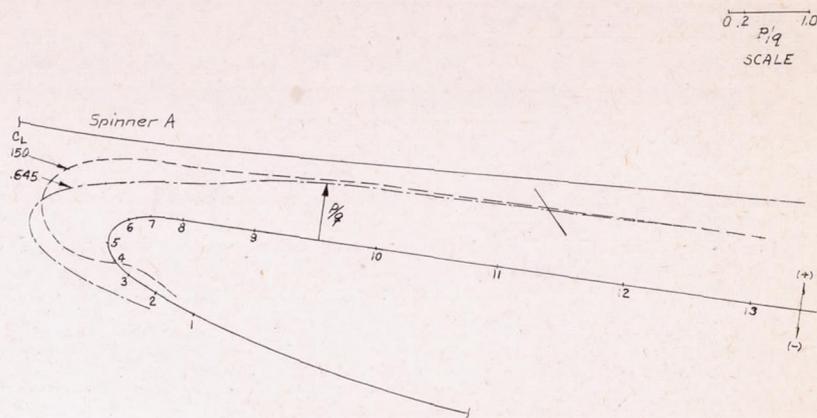
Figure 19.- Pressure distribution over bottom of cowl 2 with inlet
velocity ratio $V_i/V = 0.32$.
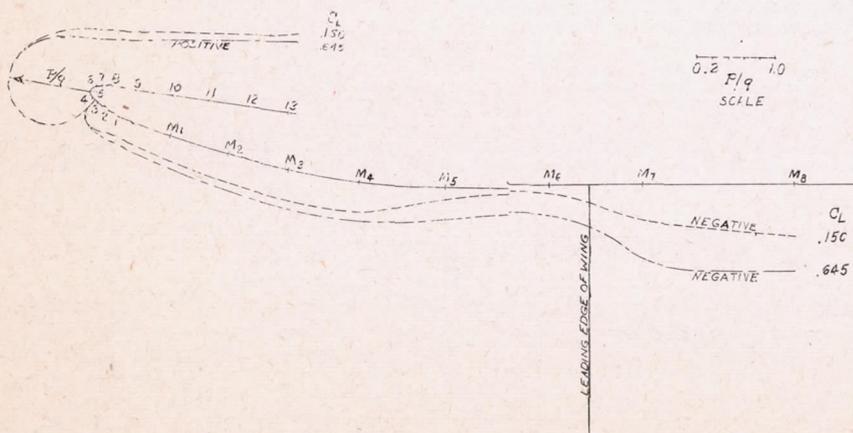
Figure 20.- Pressure distribution over side of cowl 2 with inlet
velocity ratio $V_i/V = 0.44$.
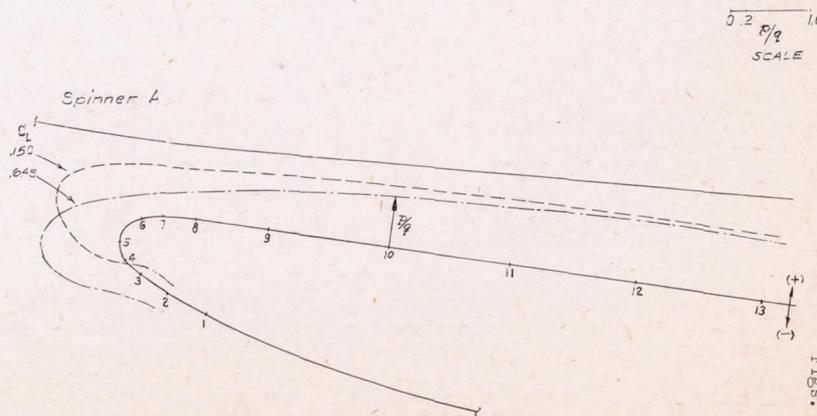
Figure 21.- Pressure distribution over bottom of cowl 2 with inlet
velocity ratio $V_i/V = 0.44$.