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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
October 1941 as
Advance Restricted Report

DEVELOPMENT OF COWLING FOR LONG-NOSE AIR-COOLED ENGINE IN THE NACA FULL-SCALE WIND TUNNEL

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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

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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 increment 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 showing 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 satisfactory and the total pressures in front of the engine were higher than for the former arrangement. (See fig. 6.)

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 bottom outlet will probably be insufficient to provide uniform cooling for all the engine cylinders, the result obtained 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 pressure 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 investigated 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 figures 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 reversal 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 reduced 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 $0.97q_0$. The pressures on the spinner corresponding to the two outlet conditions tested are shown in figures 15 and 16.

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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.

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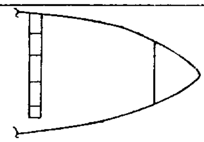
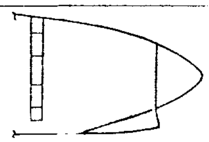
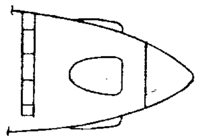
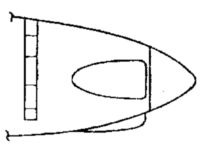
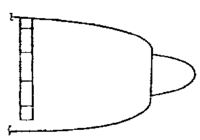
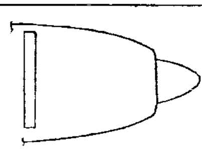
REFERENCES

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: Width outlet opening (in.)	Cooling system: Test conditions	Exit area (sq in.)	Drag coefficient (at 100 mph): $C_{D_{min}}$	Drag coefficient (at 100 mph): C_D at C_L=0.15	Drag coefficient (at 100 mph): ΔC_D at C_L=0.15 (b)	Air quantity (cu ft per min at 350 mph)	Inlet velocity ratio $\frac{V_i}{V}$
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 botton 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.

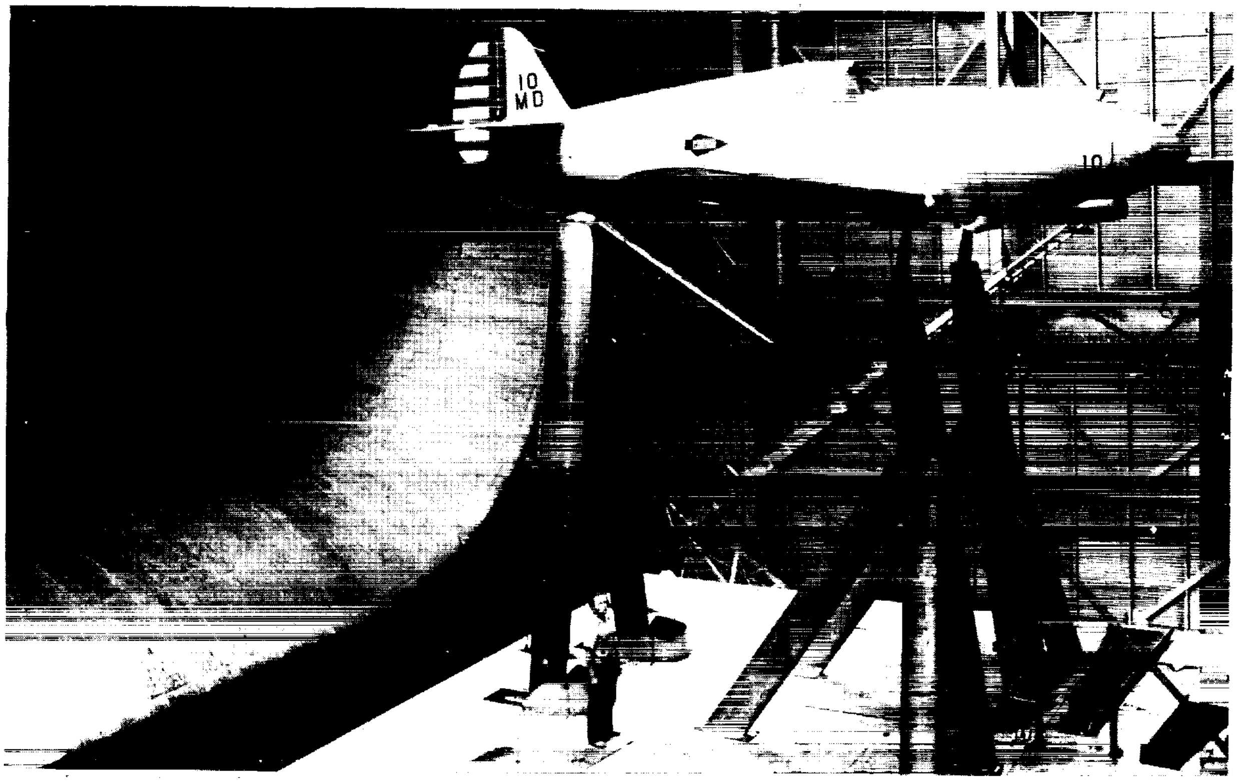


Figure 1.- The XP-42 airplane in the standard condition.

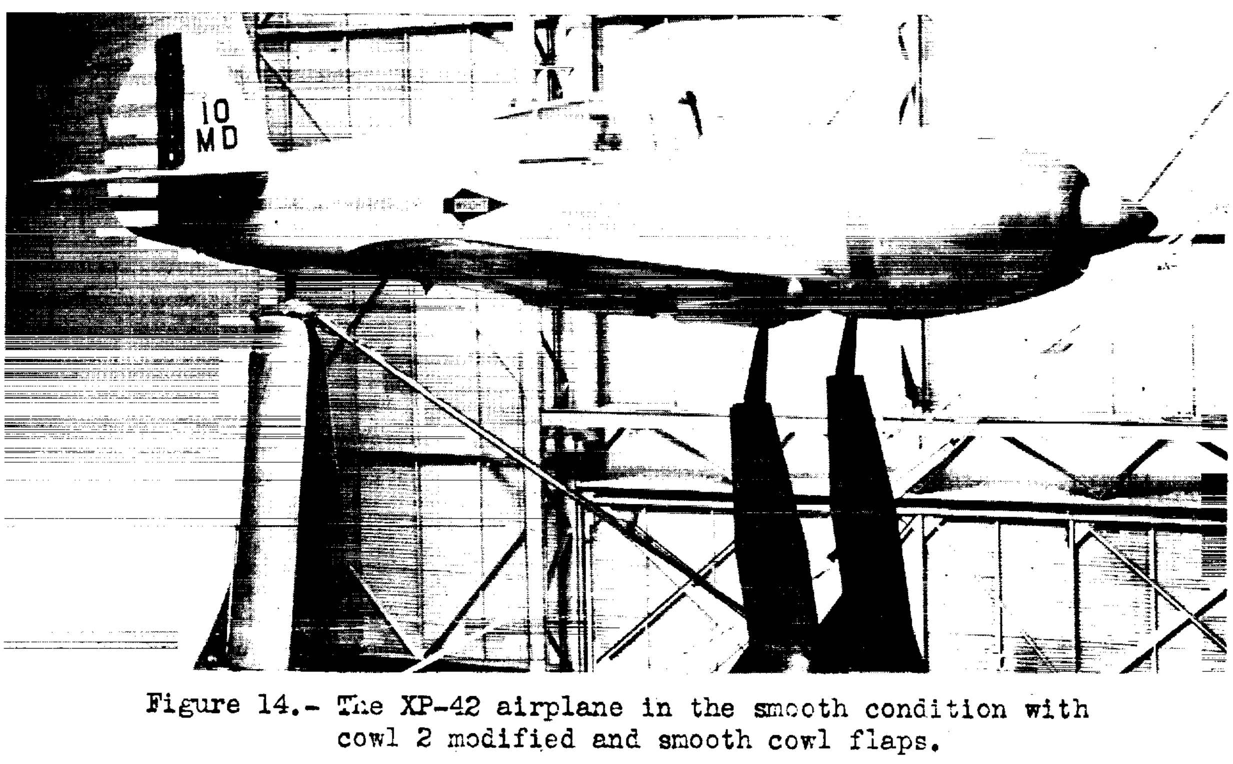


Figure 14.- The XP-42 airplane in the smooth condition with cowl 2 modified and smooth cowl flaps.

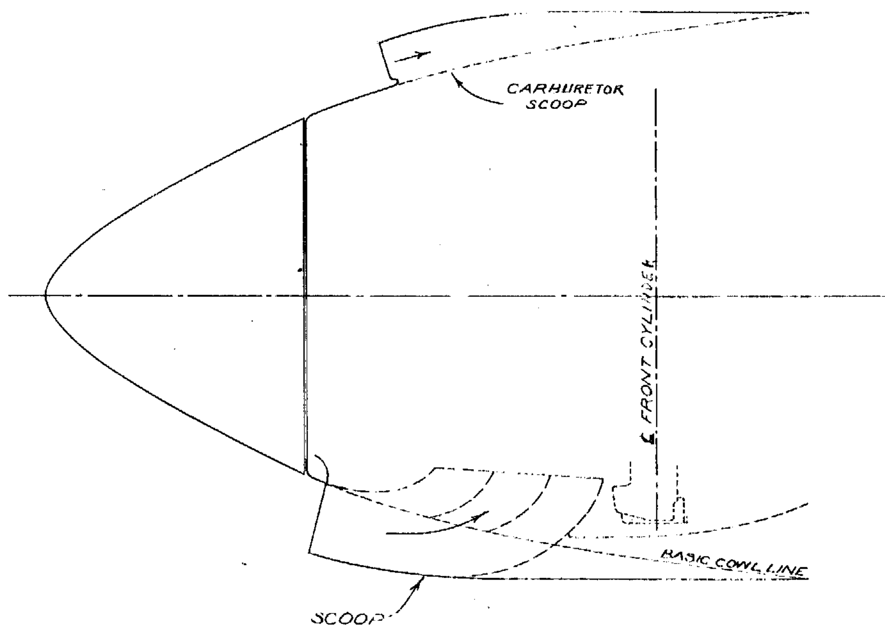


Figure 2.- Sketch of original XP-42 cowling.

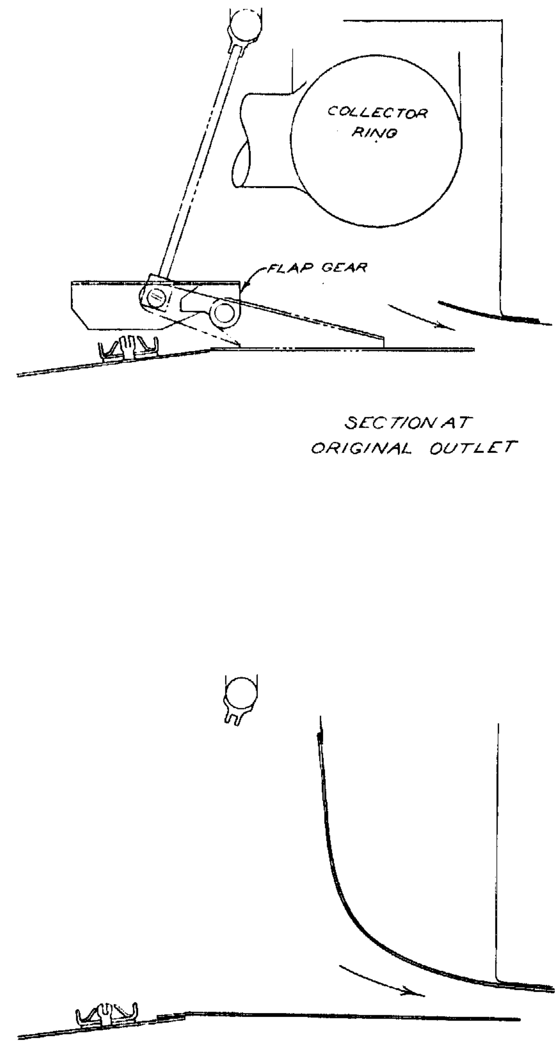


Figure 10.- Cowling outlets.

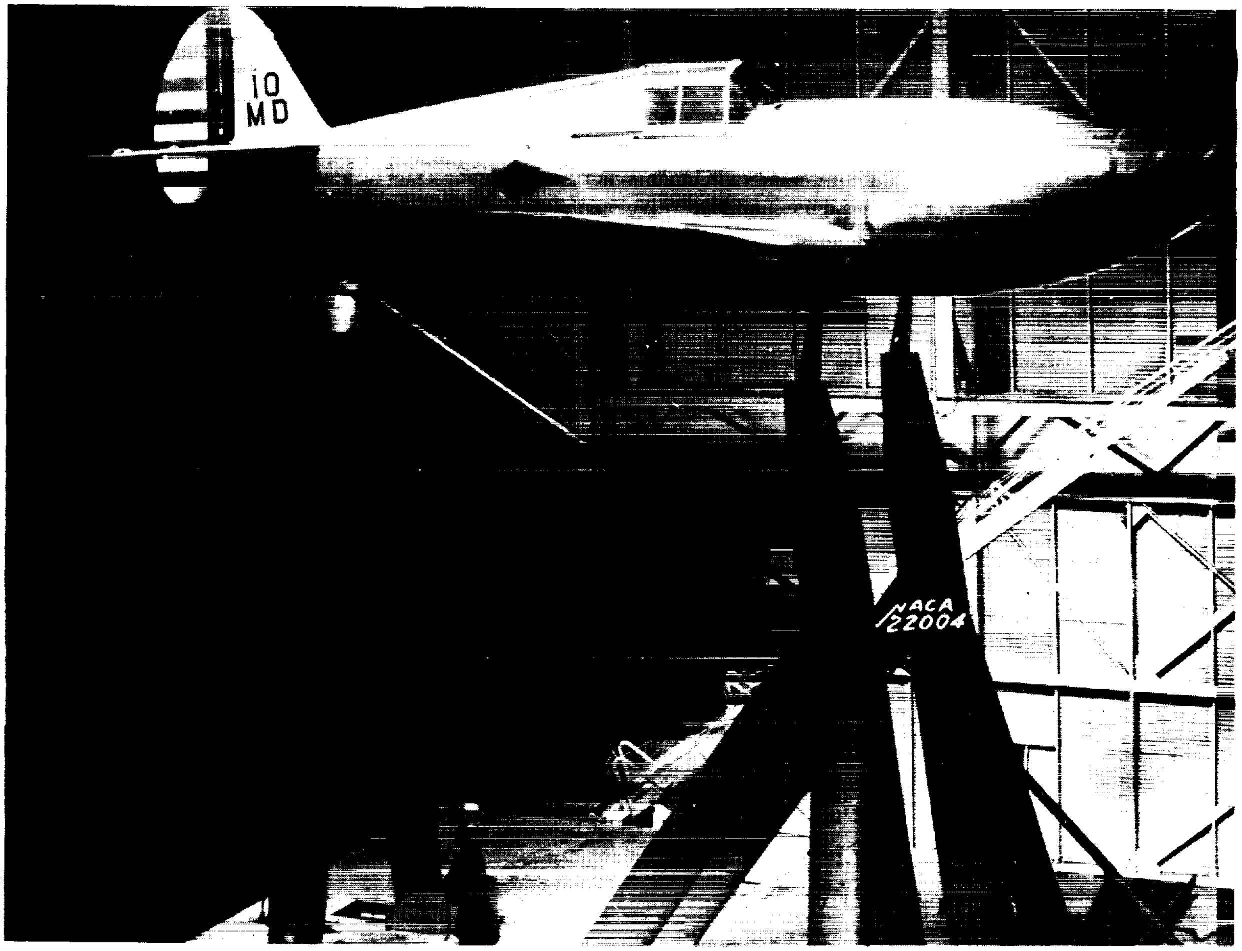


Figure 3.- The XP-42 airplane in the completely smooth condition mounted in the full-scale tunnel.

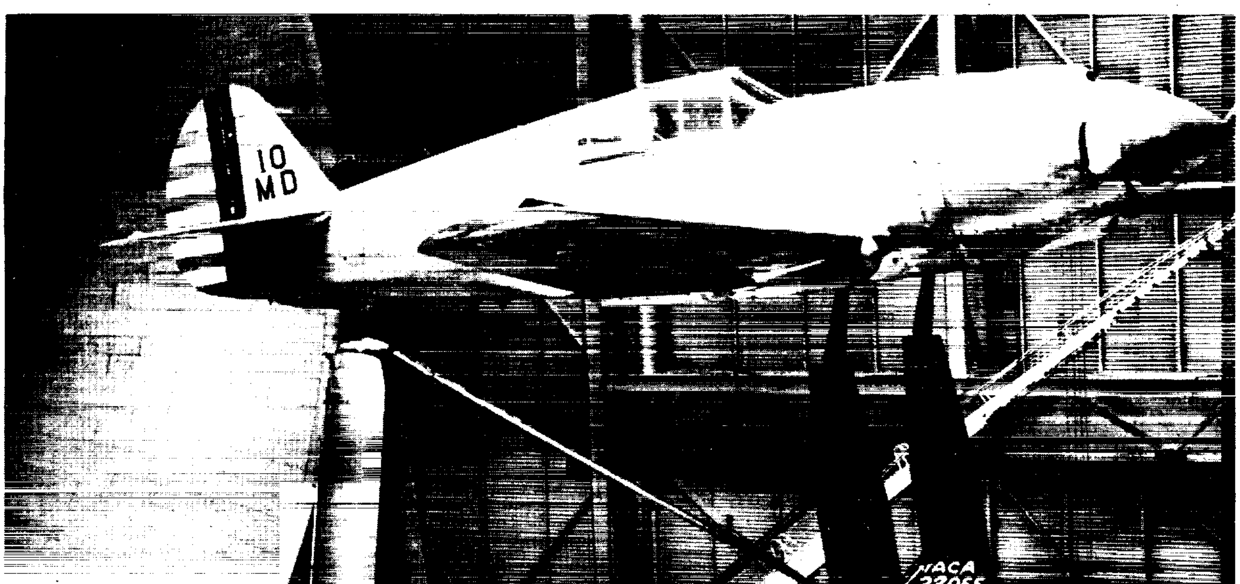


Figure 4.- The XP-42 airplane in the smooth condition with cowl 1 and original cowl flaps.

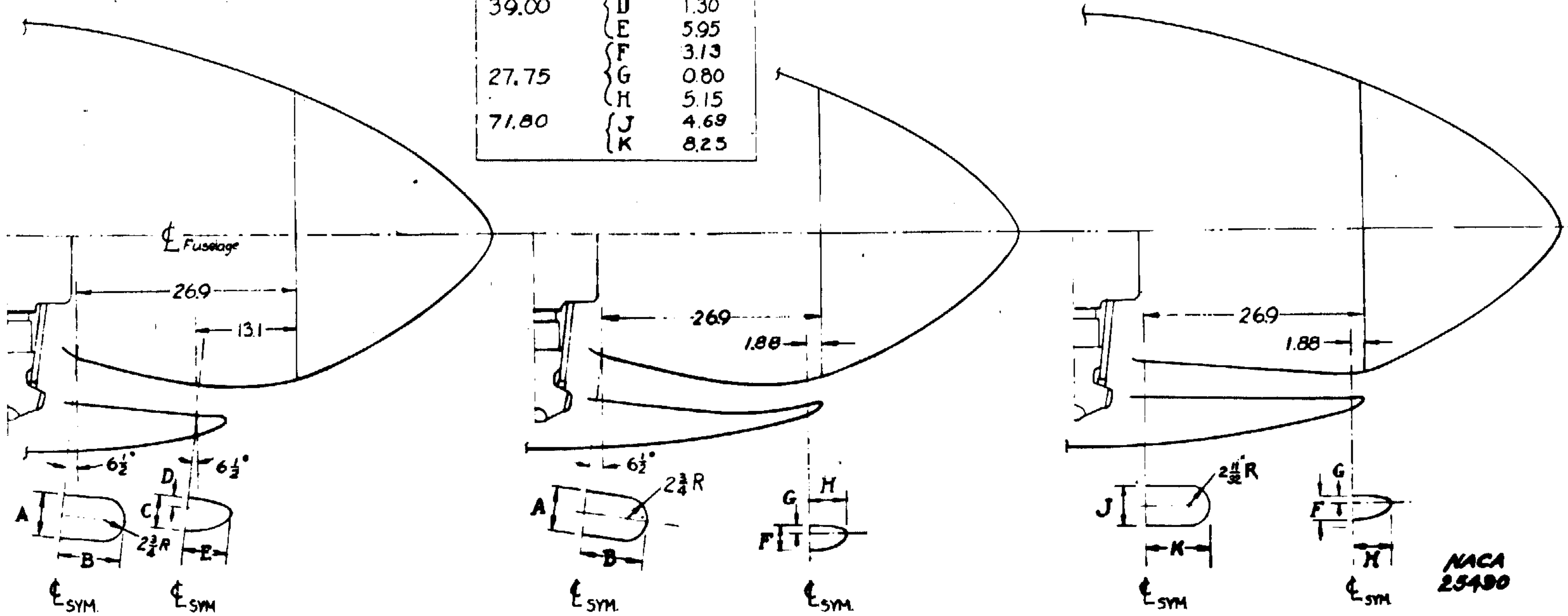
(a)

(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 I and its modifications.



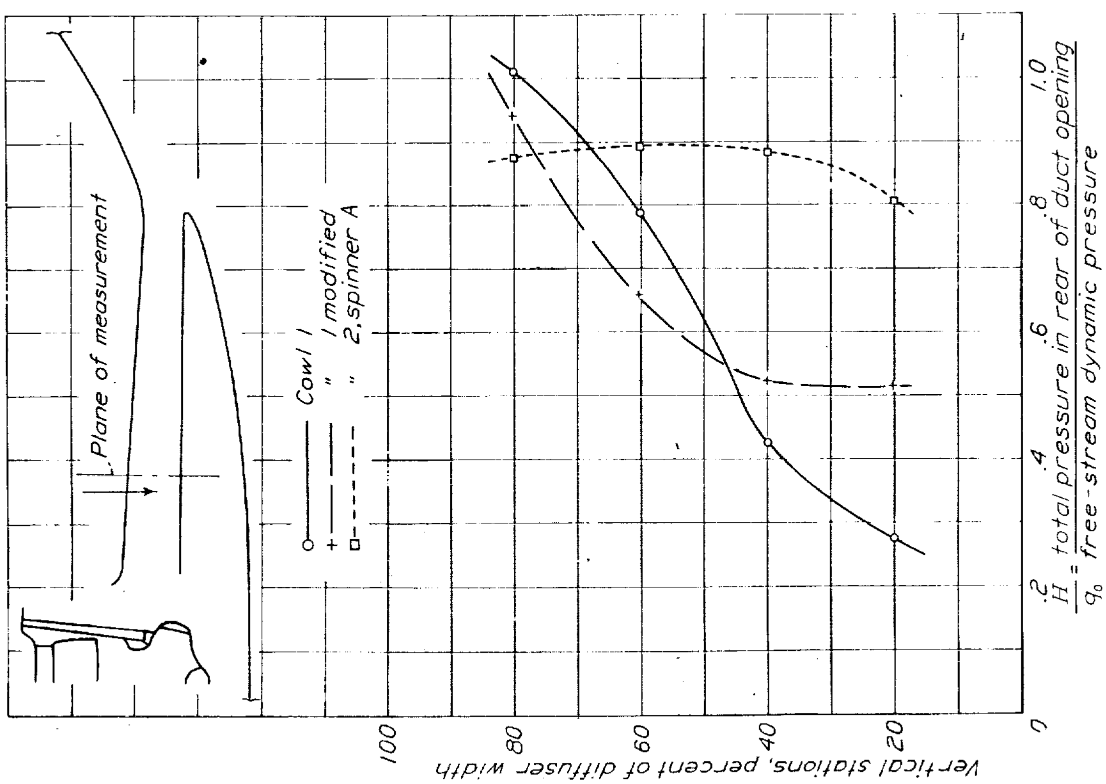


Figure 6.- Pressure in inlet diffuser.

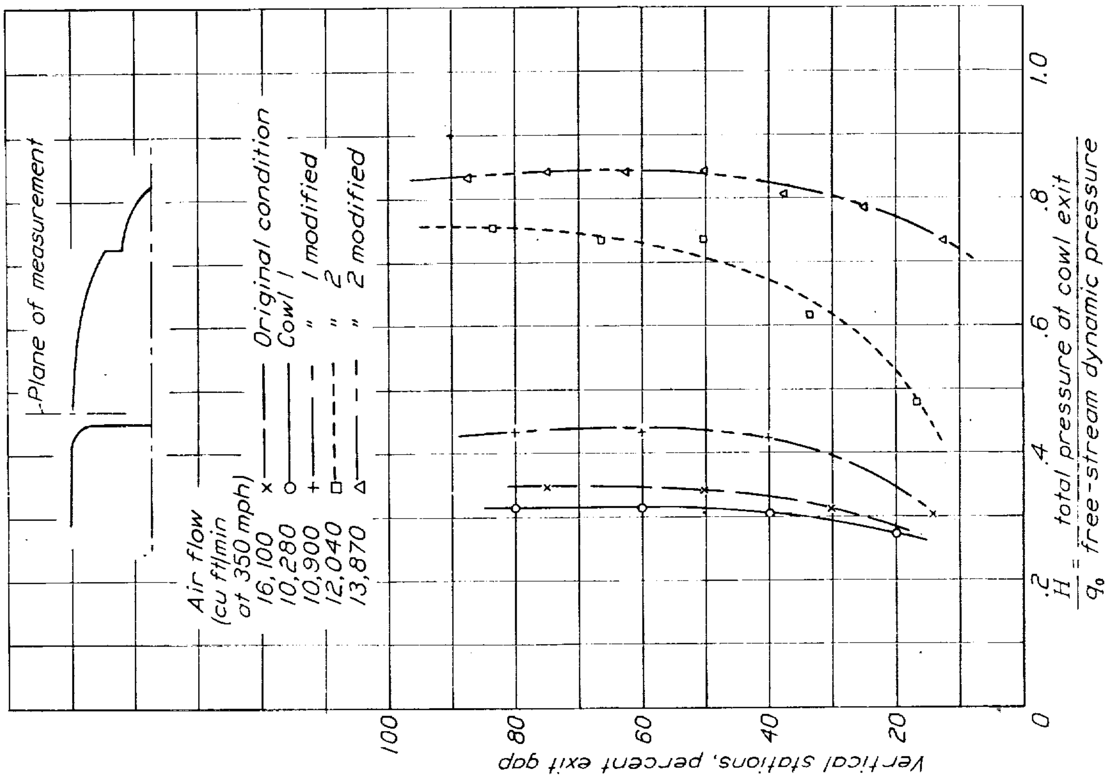


Figure 17.- Cowling outlet pressures.

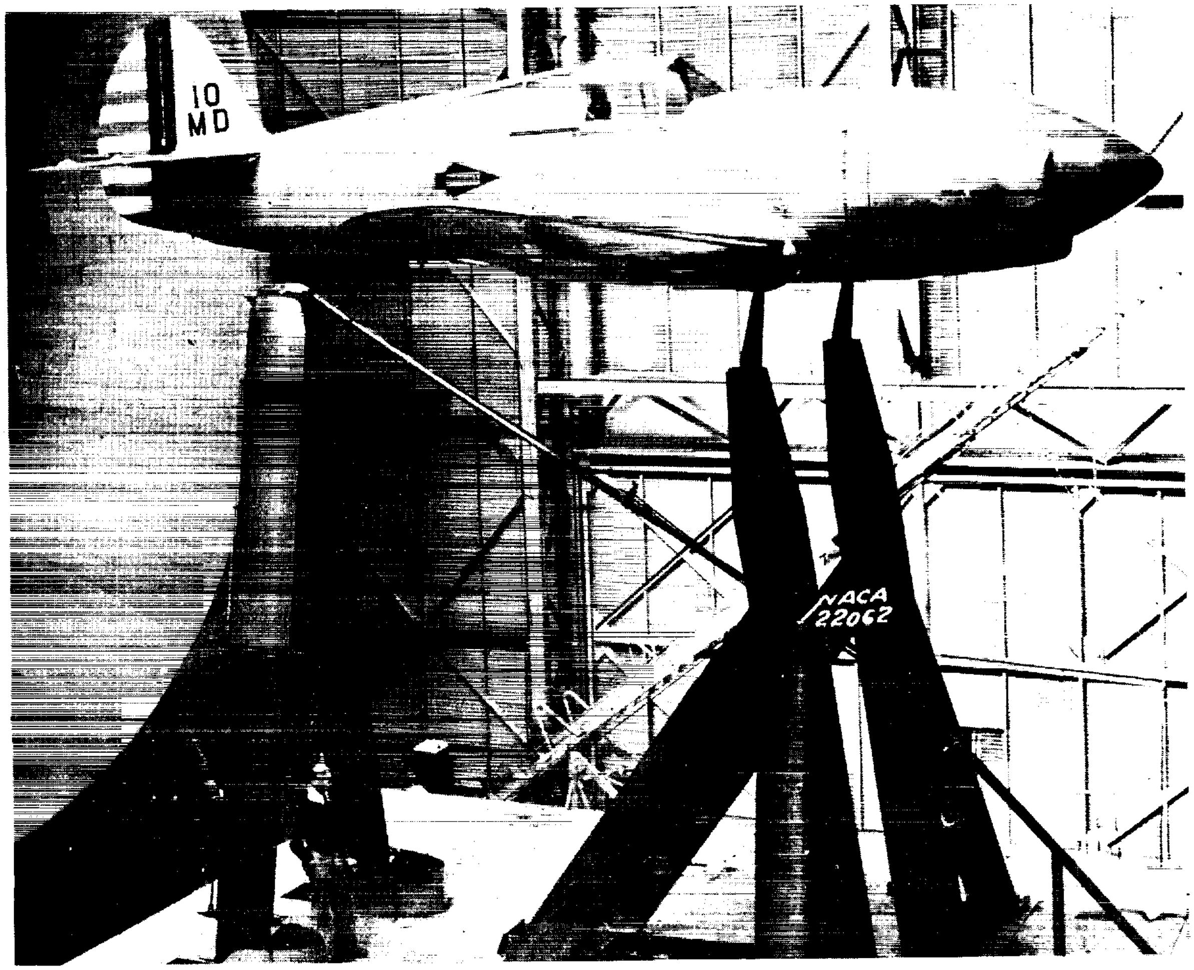


Figure 7.- The XP-42 airplane in the smooth condition with cowl 1 modified and original cowl flaps.

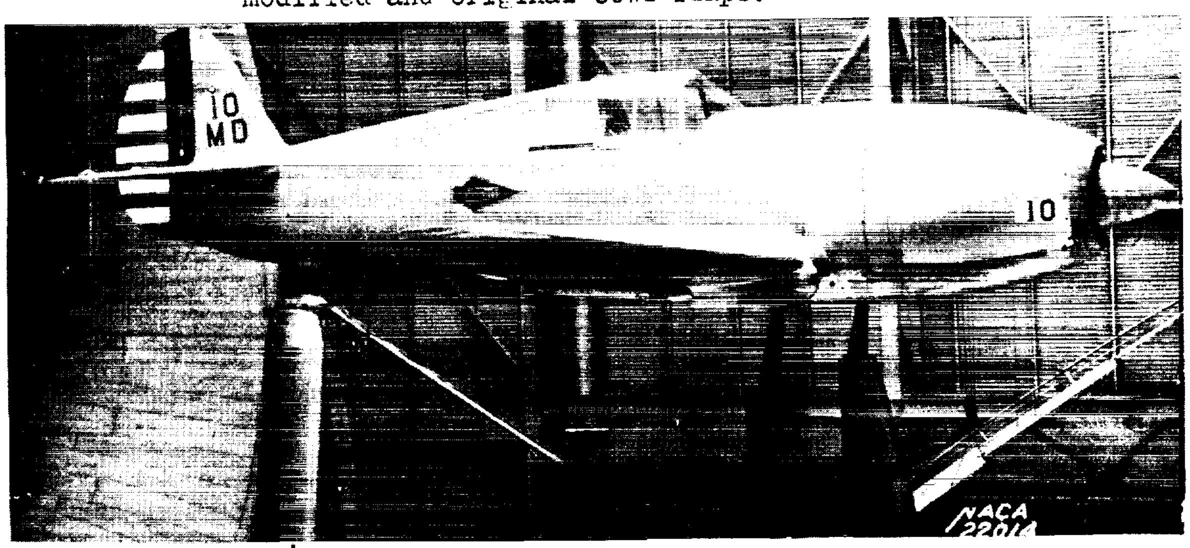
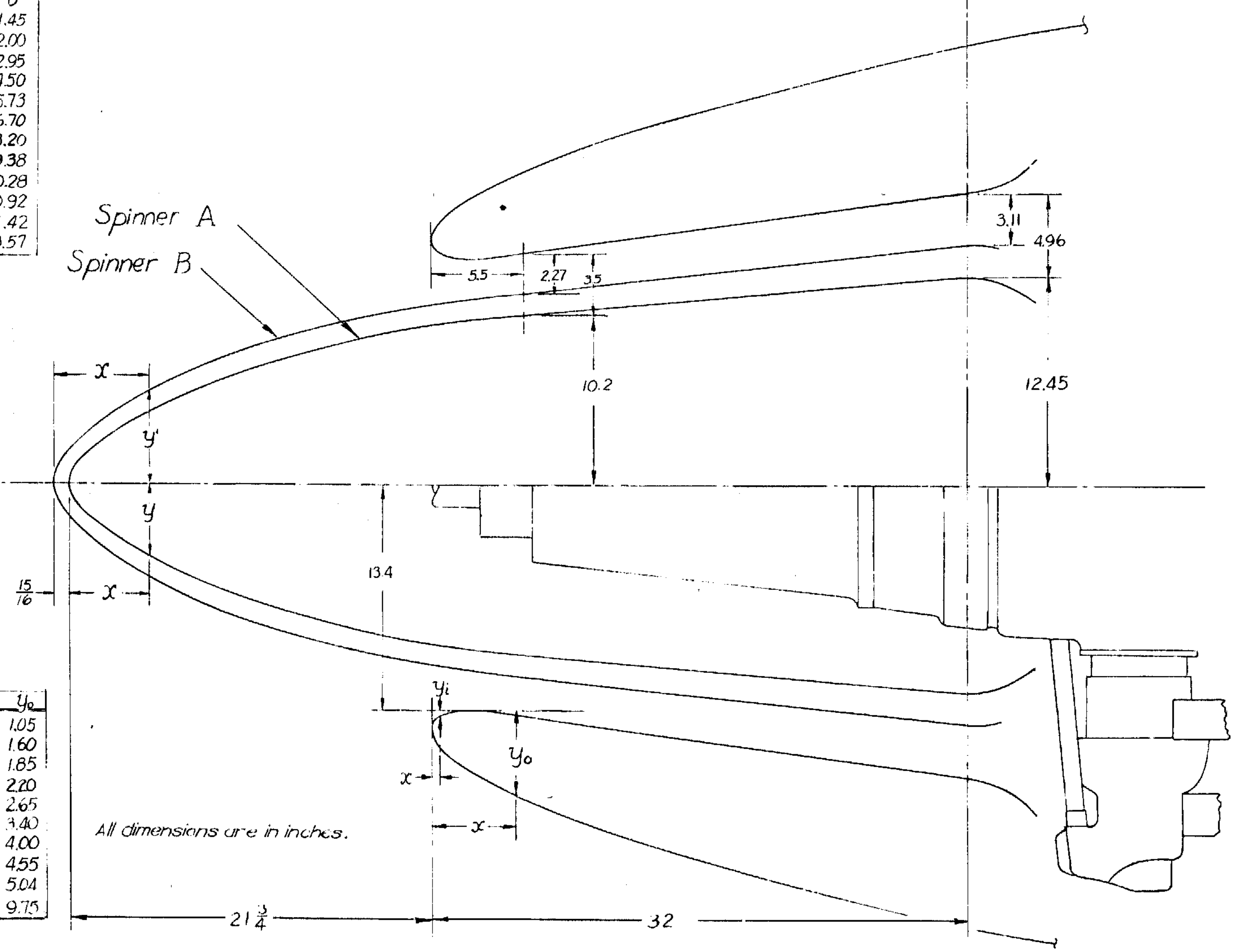


Figure 8.- The XP-42 airplane in the smooth condition with cowl 2, spinner A, and original cowl flaps.

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

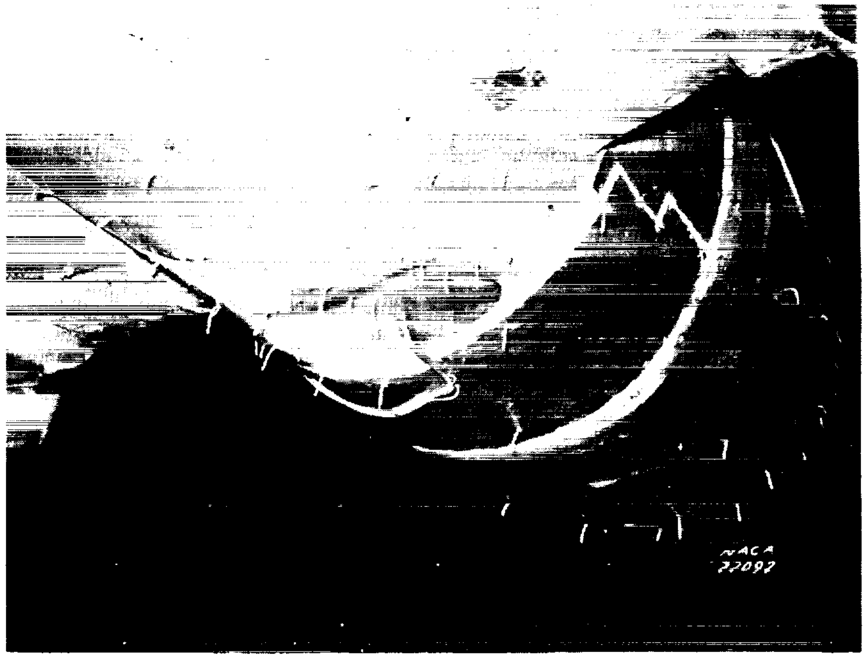


Cowl

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.

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



(a) Bottom outlet

(b) Modified bottom outlet

Figure 11.- Cowl outlet on XP-42 airplane.

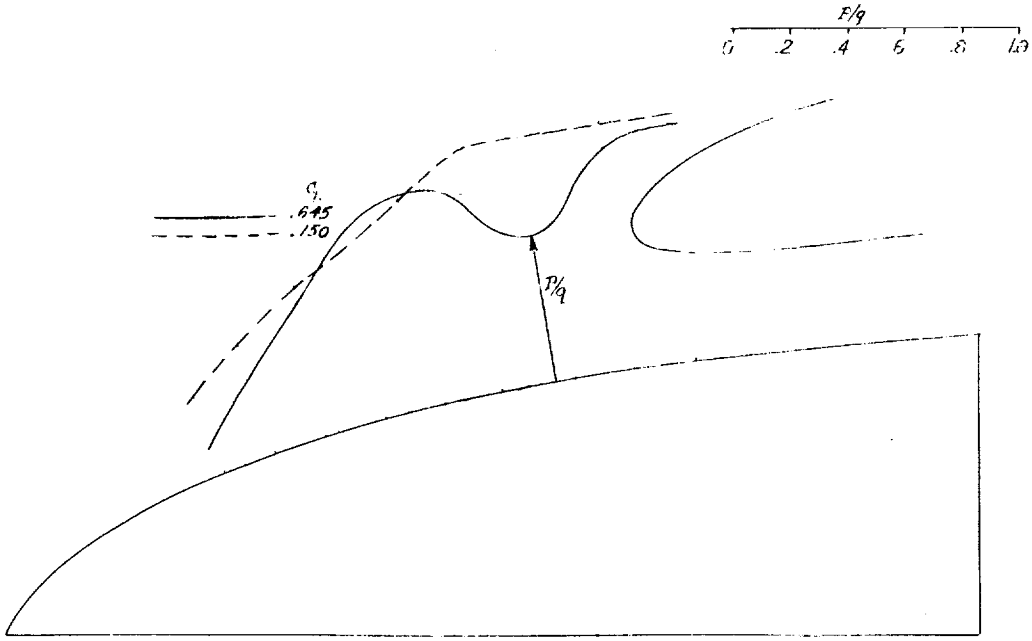


Figure 12.- Pressure distribution over top of spinner A with inlet velocity ratio V_i/V 0.32.

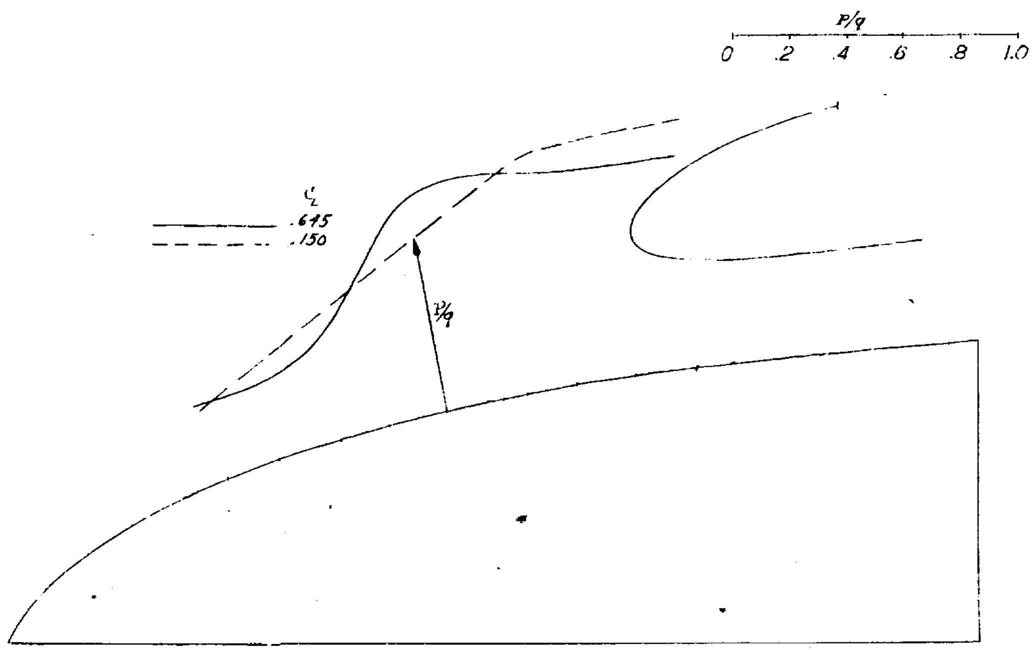


Figure 13.- Pressure distribution over top of spinner A with inlet velocity ratio V_i/V 0.49.

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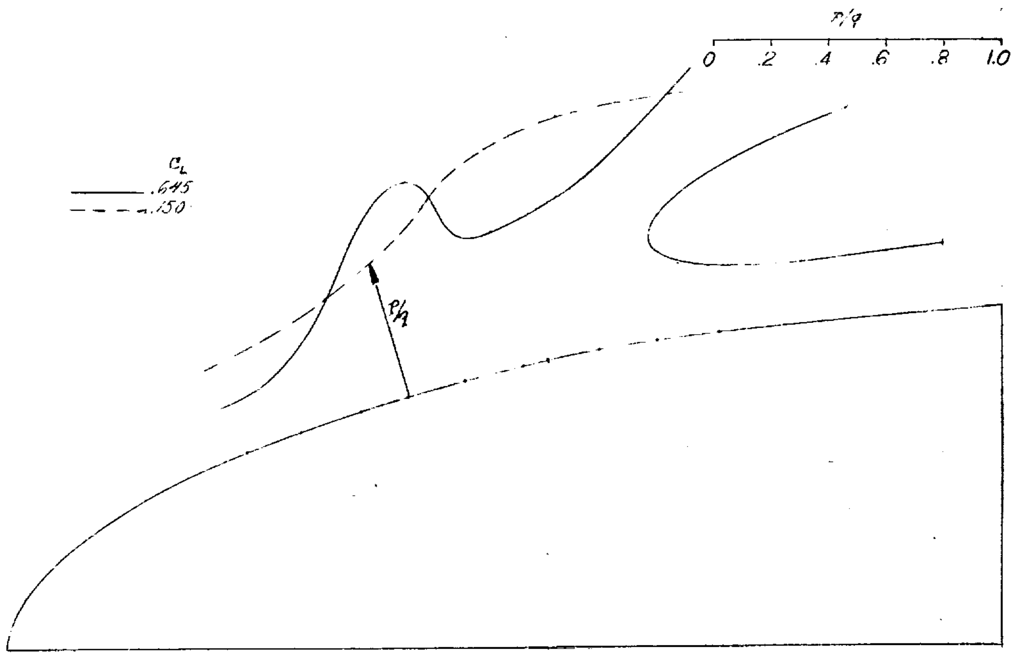

Figure 15.- Pressure distribution over top of spinner B with inlet velocity ratio $V_i/V = 0.55$.

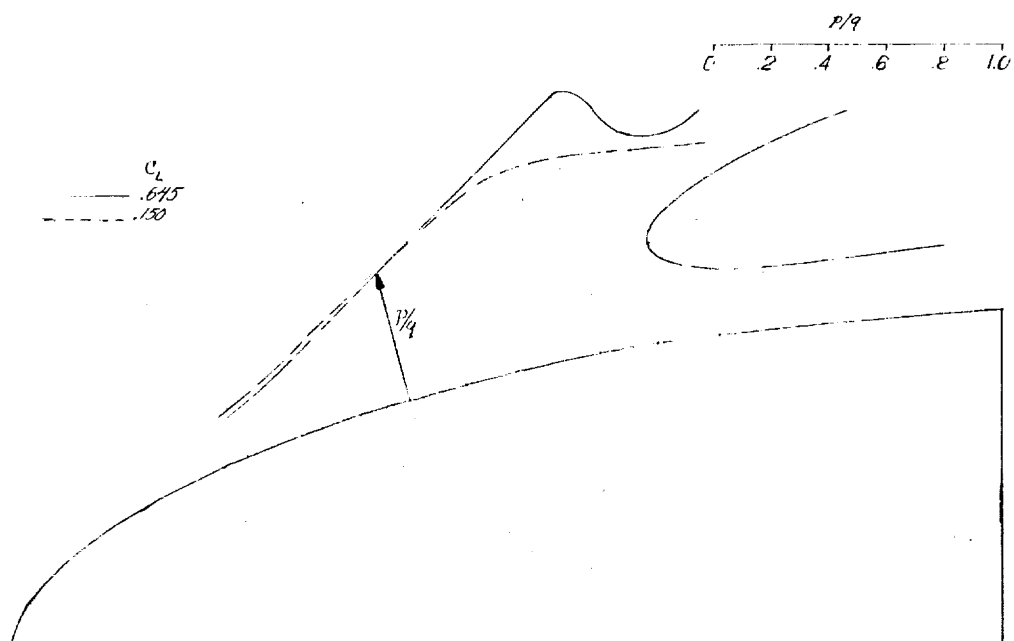

Figure 16.- Pressure distribution over top of spinner B with inlet velocity ratio $V_i/V = 0.83$.

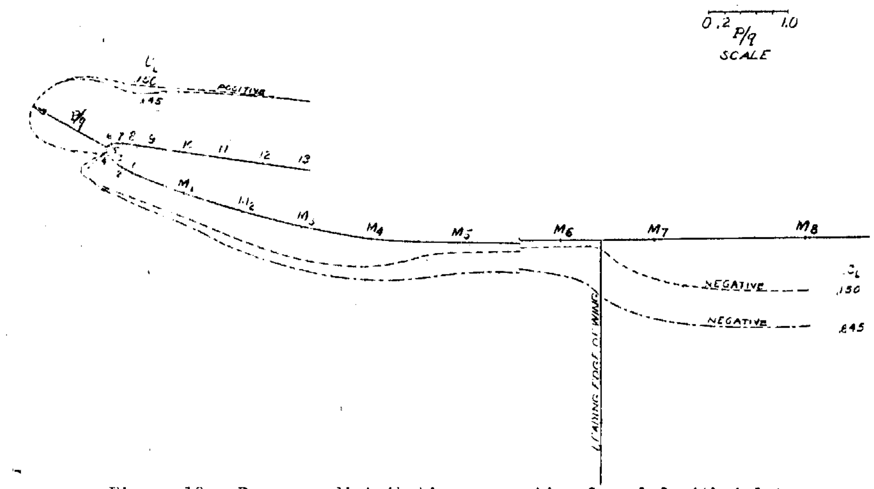

Figure 18.- Pressure distribution over side of cowl 2 with inlet velocity ratio $V_i/V = 0.32$.

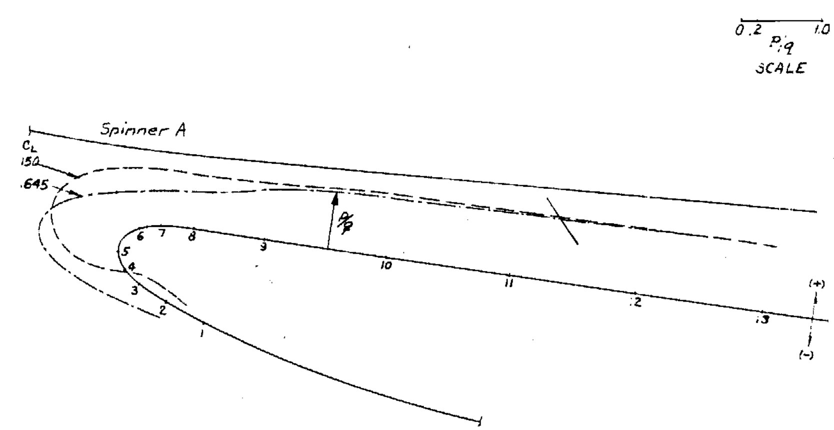

Figure 19.- Pressure distribution over bottom of cowl 2 with inlet velocity ratio $V_i/V = 0.32$.

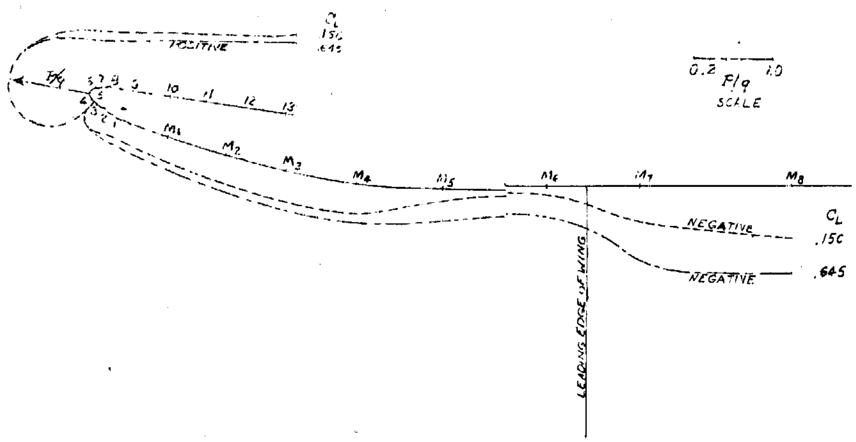

Figure 20.- Pressure distribution over side of cowl 2 with inlet velocity ratio $V_i/V = 0.44$.

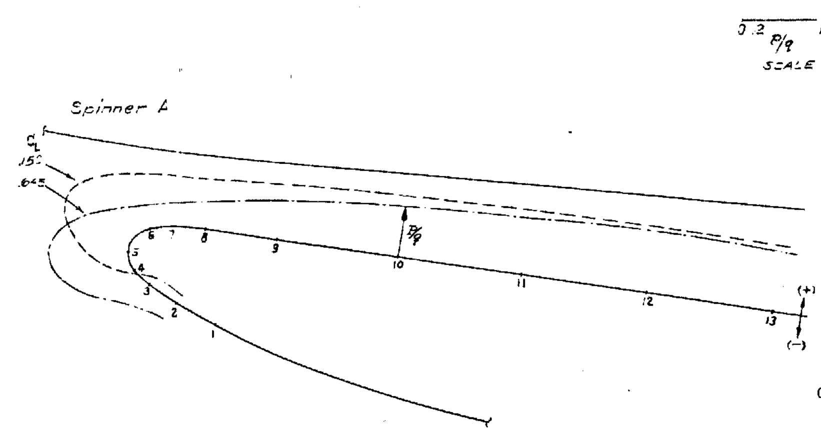

Figure 21.- Pressure distribution over bottom of cowl 2 with inlet velocity ratio $V_i/V = 0.44$.