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RESEARCH MEMORANDUM

EFFECTS OF BOUNDARY-LAYER CONTROL ON THE LONGITUDINAL CHARACTERISTICS OF A 45° SWEPT-FORWARD WING-FUSELAGE COMBINATION

By Gerald M. McCormack and Woodrow L. Cook

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Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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EFFECTS OF BOUNDARY-LAYER CONTROL ON THE LONGITUDINAL CHARACTERISTICS OF A 45° SWEPT-FORWARD WING-FUSELAGE COMBINATION

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SUMMARY

An investigation has been conducted to determine the benefits obtainable by applying boundary-layer control to a 45° swept-forward wing-fuselage combination. Force and pressure-distribution data were obtained with and without boundary-layer control with various combinations of leading-edge and trailing-edge flaps.

The results showed that with suction applied, for a flow coefficient of 0.012, the occurrence of separation was postponed from a lift coefficient between 30 and 50 percent of the maximum to a lift coefficient between 78 and 93 percent of the maximum. As a result, improvements were effected in the longitudinal characteristics in the high-lift-coefficient range. Aerodynamic-center travel was reduced to an insignificant amount until just prior to maximum lift (in contrast to a rearward movement followed by a forward movement when suction was not applied). Drag coefficients were reduced in the high-lift-coefficient range by as much as 56 to 62 percent (dependent upon the configuration) when suction was applied.

The most effectual location of the suction slots was found to be at the wing-fuselage juncture over the forward part of the upper surface of the wing: Thus, for the plain wing, the forward edge of the slot coincided with the leading edge of the wing; and, for the wing with a leading-edge flap deflected, the forward edge of the slot was located opposite the hinge line of the flap.

INTRODUCTION

Previous investigations of highly swept wings at moderate and high lift coefficients have shown that undesirable characteristics are caused by separation occurring relatively early over the outboard area of swept-back wings or the inboard area of swept-forward wings. Since this separation pattern is, to a large extent, the result of the spanwise flow of the boundary layer, it suggested that the application of boundary-layer control might yield substantial improvements in the characteristics of highly swept wings. Accordingly, research was undertaken to determine the improvements obtainable by applying boundary-layer control to a 45° swept-forward wing.

Fundamental flow studies were first made to determine the underlying causes of the faulty characteristics of the 45° swept-forward wing and provide a groundwork for applying boundary-layer control. The results of these studies were reported in reference 1. It was shown that at a moderate lift coefficient ($C_L \cong 0.55$) the aerodynamic center shifted rearward (from $0.26\bar{c}$ to $0.43\bar{c}$), the drag increased at a rapid rate, but no lift was lost. These changes were attributed to turbulent separation over the trailing edge of the inboard sections of the wing. Within a short lift-coefficient range ($C_L = 0.75$) the aerodynamic center shifted rapidly forward (from $0.43\bar{c}$ to $-0.05\bar{c}$), the drag increased at an even faster rate, and the lift-curve slope began to decrease. These changes were the result of separation from the leading edge. Thus, although a form of turbulent separation occurred first, the primary cause of section stall and of the more serious of the undesirable wing characteristics was a relatively abrupt separation from the leading edge.

Since it is possible to control leading-edge separation to a considerable extent by modifying the contour of the leading edge, an investigation was next made to determine the extent to which leading-edge separation could be delayed by means of various modifications. The results of this investigation were reported in reference 2. It was found that a plain, full-span, leading-edge flap delayed the occurrence of both leading-edge and turbulent separation.

Separation still occurred, however, at a moderate lift coefficient. Therefore, in order to improve further the characteristics of the swept-forward wing, boundary-layer control by suction was applied through slots variously located in the wing and fuselage of the 45° swept-forward wing which was mounted on a fuselage of fineness ratio 10. The results of this investigation conducted in the Ames 40- by 80-foot wind tunnel with the same large-scale wing previously used are presented herein.

COEFFICIENTS AND SYMBOLS

The data are presented in the form of standard NACA coefficients and symbols, which are defined in the following tabulation:

a mean-line designation

a.c. aerodynamic center measured in percent chord aft of leading edge of the mean aerodynamic chord b wing span, feet

c local chord, feet

$\bar{c}$ mean aerodynamic chord $\left(\frac{\int_0^{b/2} c^2\,dy}{\int_0^{b/2} c\,dy}\right)$, feet

c_l section lift coefficient $\left(\frac{1}{c}\int_0^c P\,dx \cos\alpha - \frac{1}{c}\int_0^t P\,dz \sin\alpha\right)$

C_D drag coefficient $\left(\frac{\text{drag}}{qS}\right)$

C_L lift coefficient $\left(\frac{\text{lift}}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{pitching moment}}{qS\bar{c}}\right)$

C_Q flow coefficient $\left(\frac{Q}{VS}\right)$

p free-stream static pressure, pounds per square foot

p_l local static pressure, pounds per square foot

P pressure coefficient $\left(\frac{p_l - p}{q}\right)$

q free-stream dynamic pressure, pounds per square foot

Q quantity of flow at free-stream conditions, cubic feet per second

R Reynolds number $\left(\frac{V\bar{c}}{\nu}\right)$

S wing area, square feet

t maximum thickness of local section, feet

V free-stream velocity, feet per second

x chordwise coordinate parallel to the plane of symmetry, feet

y spanwise coordinate perpendicular to the plane of symmetry, feet z vertical coordinate to airfoil contour perpendicular to chord line, feet

α angle of attack of chord plane of basic wing, degrees

δ_f angle of deflection of split flap, positive downward, degrees

δ_n angle of deflection of leading-edge flap, positive downward, degrees

ν kinematic viscosity of air, square feet per second

MODEL

The geometric characteristics of the 45° swept-forward wing-fuselage combination are shown in figure 1. The quarter-chord line was swept forward 45°, the aspect ratio was 3.55, and the taper ratio was 0.5. There was no twist, incidence or dihedral. The wing sections were constant across the span and were NACA 64_1A112, a = 0.8 (modified) sections perpendicular to the quarter-chord line.

The blower used for supplying suction was housed in the fuselage. For some of the tests, an extension was added to the exhaust-pipe diffuser in order to decrease the exit losses and, hence, to enable higher flow quantities to be obtained. A photograph of the wing-fuselage combination mounted in the wind tunnel is shown in figure 2.

The flap arrangements used on the model are shown in figure 3. The wing was equipped with a full-span leading-edge flap and a partial-span trailing-edge flap. The leading-edge flap was hinged about the 12.5-percent-chord line (of sections perpendicular to the quarter-chord line) on the lower surface of the wing. The transition surface between the upper surface of the flap and the wing when the flap was deflected had a radius of curvature equal to the radius about the hinge line. The trailing-edge split flap was a 0.588-span flap hinged about the 82.2-percent-chord line (of sections perpendicular to the quarter-chord line) on the lower surface of the wing.

The principal slots used for boundary-layer control in these tests were cut in the side of the fuselage at the juncture of the fuselage and upper surface of the wing. The various configurations of these slots are shown in figure 4. Other boundary-layer control slots and devices that were tested are shown in figure 5.

Pressure orifices were positioned over the upper and lower surfaces of four streamwise sections. They were located at 20.9 percent, 28.1 percent, 57.4 percent, and 85.0 percent of the semispan. The chordwise positions are tabulated in table I for the two leading-edge configurations.

TESTS

Force tests, pressure-distribution measurements, and tuft studies were made through the angle-of-attack range at zero sideslip. The data were obtained mainly at an airspeed of 63 miles per hour, corresponding to a Reynolds number of 6.1×10^6, although some tests were made at an airspeed of 110 miles per hour ($R = 10.6 \times 10^6$). The tests were made at a relatively low speed in order to obtain higher flow coefficients for the boundary-layer-control investigation.

Standard tunnel-wall corrections for a straight wing of the same area and span as the swept-forward wing have been applied to angle-of-attack and drag-coefficient data. This procedure was followed since a brief analysis indicated that tunnel-wall corrections were approximately the same for straight and swept wings of the size under consideration. The corrections are as follows:

$$\Delta\alpha = 0.74\ C_L$$

$$\Delta C_D = 0.013\ {C_L}^2$$

The data were corrected for drag tares. The drag data for the tests with suction applied were, in addition, adjusted so as to give the same minimum drag for those data as for the base data. This was done since data necessary for computing the net thrust of the blower were not obtained. Table II gives the increments of drag for each drag-coefficient curve.

Pitching-moment tares were not applied since they were not known with sufficient accuracy to warrant application. Indications are that they are not of sufficient magnitude to affect materially the results of this report. The pitching-moment curves on all the force tests were adjusted to have approximately neutral stability at the lower lift coefficients to enable better comparison between the data. Table II shows the point about which the moments were taken to give neutral stability in the linear portion of the pitching-moment curve for each of the curves.

RESULTS AND DISCUSSION

The form of boundary-layer control primarily used was that suggested by the results of reference 1. It was shown that the outboard sections of the swept-forward wing attained considerably higher maximum lift coefficients than the inboard sections. This was the result of spanwise flow in the boundary layer by which boundary-layer air was drained off the outboard area, but accumulated over the inboard area; in effect, a natural system of boundary-layer control existed for the outboard sections. It was deduced that, if this natural system of boundary-layer control could be extended so as to affect the entire wing instead of only the outboard sections, the maximum benefits might be obtained for the least expenditure of power. Accordingly, suction slots were incorporated in the region of the wing-fuselage juncture in order to prevent the accumulation of boundary layer over the inboard area.

In the following discussion, the effects of suction applied at the wing-fuselage juncture will be discussed in regard to the force data (showing the over-all results) and the pressure-distribution data (showing the flow conditions over the wing). The effects of various other locations of boundary-layer-control slots will then be briefly described. Lastly, an evaluation, in terms of flight performance, of the benefits that can be obtained by applying boundary-layer control in such a manner will be made.

Force Data

Basic characteristics.- The characteristics of certain basic configurations were determined before boundary-layer control was applied. These included the wing alone (from reference 1) to provide a base for evaluating the effect of a fuselage; the wing-fuselage combination; the wing with a full-span leading-edge flap deflected 30° down, which was shown in reference 2 to offer substantial delays in the occurrence of leading-edge separation; the wing with 0.588-span split flaps; and various combinations of the foregoing. A summary of the results follows:

Configuration	$C_{L_{sep}}$[1]	$C_{L_{max}}$	Refer to figure number
A	0.49	1.04	6
B	.35	1.12	6
C	.76	1.26	7
D	.39	1.29	7
E	.50	1.24	8
F	.72	1.40	9

[1]$C_{L_{sep}}$ is defined as the lift coefficient at which either form of separation, turbulent or leading-edge, first occurred.

Note:

A. Wing alone
B. Wing-fuselage combination
C. Wing alone with full-span leading-edge flap deflected 30° down
D. Wing-fuselage combination with the full-span leading-edge flap deflected 30° down

E. Wing-fuselage combination with the half-span split flap deflected 60° down

F. Wing-fuselage combination with the full-span leading-edge flap deflected 30° down and the half-span split flap deflected 60° down

The effect of the fuselage on the plain wing was to lower the first occurrence of separation from a lift coefficient of 0.49 to a lift coefficient of 0.35. Moreover, with the fuselage on, deflecting the leading-edge flap caused no significant delay in the occurrence of separation as it did on the wing alone. Deflecting the leading-edge flap, however, increased the maximum lift coefficient from 1.12 to 1.29. With the split flaps deflected, a higher value of lift coefficient was reached before separation occurred ($C_{L_{sep}}$ was increased from 0.35 to 0.50 without leading-edge flaps and from 0.39 to 0.72 with leading-edge flaps), and also a higher maximum lift coefficient was attained.

Effect of suction through the most effective slots.- The effect of suction slots located over various regions of the wing and fuselage (figs. 4 and 5) showed that by far the most effective region to apply suction was at the wing-fuselage juncture over the forward part of the wing. (The detailed results of these exploratory tests will be described later.) For the wing with no deflection of the leading-edge flap, the most effective slot, either with or without split flaps, was an opening 15 inches long by 10.75 inches high with the forward edge coincident with the leading edge of the wing (fig. 4). With the leading-edge flap deflected, the most effective slot was an opening 24.5 inches long by 4.5 inches high with the forward edge at the beginning of the transition between the leading-edge flap and the body of the wing (fig. 4). A summary of the results with these two slots follows:

Configuration	C_Q	$C_{L_{sep}}$	$\Delta C_{L_{sep}}$	$C_{L_{max}}$	$\Delta C_{L_{max}}$	Refer to figure number
B	0.0121	0.92	0.57	1.18	0.06	10
D	.0125	1.23	.84	1.40	≅.11	11
E	.0118	1.14	.64	1.28	.04	12
F	.0121	1.39	.67	1.50	≅.10	13

Note:

B. Wing-fuselage combination, 15-inch by 10.75-inch slot

D. Wing-fuselage combination with the full-span leading-edge flap deflected 30° down, 24.5-inch by 4.5-inch slot

E. Wing-fuselage combination with the half-span split flap deflected 60° down, 15-inch by 10.75-inch slot

F. Wing-fuselage combination with the full-span leading-edge flap deflected 30° down and the half-span split flap deflected 60° down, 24.5-inch by 4.5-inch slot

The primary effect of applying suction to any of the configurations was to delay the occurrence of separation from a lift coefficient which was between 30 percent and 50 percent of the maximum to a lift coefficient which was between 78 and 93 percent of the maximum. The maximum lift coefficient was increased only a small amount. (For these tests the maximum power input to the blower was approximately 300 hp.)

As a consequence of delaying separation, substantial reductions were effected in drag coefficients and aerodynamic-center travel (figs. 10, 11, 12, and 13). The maximum reductions in drag coefficient were between 56 and 62 percent, dependent upon the configuration. For all configurations with flaps deflected and suction applied, aerodynamic-center travel was insignificant until just prior to the attainment of maximum lift coefficient; this was in contrast to the excessive rearward and forward shifts without suction. Thus, it is evident that considerable improvement can be obtained by applying suction at the wing-fuselage juncture.

Effects of slot location.- Tests were made to determine the effects of the slot location on the wing with the full-span leading-edge flap deflected 30°. Owing to the characteristics of the blower equipment used, the slot area and, hence, the slot length for a given width could not be decreased below a certain minimum.

Starting with a 1.5-inch-wide slot extending from the leading edge to 82.5 percent of the local chord (fig. 14 (a)), it was found that no detrimental effects resulted from closing part of the slot forward of the junction between the leading-edge flap and the main part of the wing. Likewise (fig. 14(b)), no detrimental effects resulted from closing the rear part of the slot from a length of 114 inches down to the minimum length of 32 inches.

When the slot width was increased to 3 inches (fig. 15), there was an improvement in the wing characteristics, compared to those with the 1.5-inch slot, due to the increased flow quantity. No significant effects, however, resulted from closing the aft part of the slot from a length of 42 inches down to the minimum of 24.5 inches.

When the slot width was increased to 4.5 inches (fig. 16), there was again, due to the increased flow quantity, an improvement in the wing characteristics. A slight detrimental effect resulted when the slot length was decreased from 24.5 inches down to the minimum length of 18 inches.

From the foregoing it is clear that the effective part of the slot is a relatively small region over the hinge line of the leading-edge flap. It was in this region that, without suction, separation first occurred. It can, therefore, be inferred that for other configurations the slot should be located over the region at which the leading-edge type of separation would first occur. Thus, for the tests in which suction was applied to the wing without the leading-edge flap, the forward edge of the slot was located at the leading edge of the wing.

Pressure Distributions

The results of the tuft studies (fig. 17), which were shown in reference 1 to be closely related to the pressure distributions, give a general picture of the effect of suction on flow conditions over the wing. In contrast to the slow progression of separation which started at a low angle of attack ($\alpha < 6.38$) without suction, when suction was applied there was no evidence of separation until an angle of attack greater than 20.9° was reached.

Pressure distributions for various configurations of the swept-forward wing with and without suction are shown in figures 18, 19, 20, and 21. A comparison is made in figure 22 of the pressure distributions with and without suction for a typical section, the streamwise section at 20.9-percent semispan. Without suction, at an angle of attack of 16.7° the pressures were not recovering normally to the trailing edge, and the negative pressure peak at the hinge line of the leading-edge flap was beginning to decrease. With suction applied, complete pressure recovery was obtained up to angles of attack of about 18.8°. At about 18.8°, the suction peak over the upper surface opposite the hinge line of the leading-edge flap began to decrease, indicating that local separation was occurring over this area but apparently was followed by reattached flow. At angles of attack above 20.9°, the suction peak at the leading edge began to decrease and the section began to lose lift.

The influence of both the natural spanwise boundary-layer drain and the boundary-layer control exerted through the slot at the wing-fuselage juncture can be seen in the section-lift characteristics (fig. 23) which were obtained by integrating the pressure distributions. Without suction, the maximum section-lift coefficients varied from 0.96 at 20.9-percent semispan to 1.75 at 57.4-percent semispan. This, as discussed in reference 1, indicated that boundary layer was drained off the outboard sections and enabled these sections to attain considerably higher lift coefficients than could be obtained by the same section in two-dimensional flow. The inboard sections, however, owing to the accumulation of boundary layer, had maximum lift coefficients that were much lower.

With suction applied, the stall of the section at 20.9-percent semispan, however, was delayed from an angle of attack of about 14.5° to an angle of attack of about 20°. This corresponded to an increase in maximum section lift coefficient from 0.96 to 1.56. Thus, the application of suction enabled this inboard section to attain about 62 percent more lift. The stalling angles and maximum lift coefficients of the outboard sections were not greatly changed.

From the foregoing it is evident that if suction is applied at the wing-fuselage juncture in such a manner as to prevent the accumulation of boundary layer over the inboard area, separation over the inboard sections will be delayed and a postponement of separation over the entire wing will result.

Other Systems of Boundary-Layer Control

Tests were made with various slots distributed along the span of the wing and in the fuselage. Figures 24, 25, and 26 show the results of applying suction through the single slot that gave the best results and through a combination of all slots of the same series. Shown also in figure 26 are the effects of boundary-layer skimmer plates which were intended to prevent any possible deleterious effects which might result from a combining of the fuselage boundary layer with the wing boundary layer. It is apparent that these systems of boundary-layer control are ineffective.

Effects of Boundary-Layer Control on Airplane Performance

An analysis has been made to determine the improvements in flight performance (as contrasted to the improvements in longitudinal stability previously discussed) that are obtainable by applying suction at the wing-fuselage juncture of an airplane having a 45° swept-forward wing. The longitudinal characteristics of the airplane, with and without suction, were taken to be the same as those obtained for the test model. The airplane was assumed to be powered by two turbojet engines having static thrust ratings of 4000 pounds each;[1] wing loadings were assumed to be 75 pounds per square foot for take-off and 45 pounds per square foot for landing.

The suction required for the boundary-layer control was assumed to be supplied by the compressors of the turbojet engines. This would require that a portion of the intake air for the turbojets be drawn from the high-velocity region over the upper surface of the wing. There is a question whether or not drawing off intake air in such a manner would lower the performance of the turbojet engine since losses in ram pressure would likely result. Judging from these tests, however, the losses would appear to be quite small. With the crude ducting used in these tests, a pumping pressure ratio of 1.07 was required; furthermore, the air flow required for boundary-layer control (approximately 30 lb/sec) would constitute only a portion of the total inlet air for the turbojet engines (approximately 140 lb/sec). In the following analysis, therefore, turbojet-engine performance was assumed to be the same either with or without boundary-layer control.

The performance items affected by applying the kind of boundary-layer control discussed herein are those at high lift coefficients: take-off and climb to 50 feet, and landing approach and landing. Other performance

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[1]Net thrust was computed by using the procedure and charts given in reference 3. Pressure losses in the ducting system were assumed to be 0.15 of the inlet velocity head.

items – rate of climb, ceiling, range, maximum speed – are unaffected since they occur at relatively low lift coefficients before significant amounts of separation occur over the wing.

Based on the presupposition that no significant amount of separation over the wing can be tolerated during flight,[2] the low-speed performance of the airplane with and without boundary-layer control can be compared:

Flight condition	No suction	Suction applied
Take-off[1]		
Take-off speed, miles per hour	302	170
Ground-run distance, feet	14,390	4,020
Distance to climb to 50 feet, feet	1,710	960
Total distance, feet	16,100	4,980
Landing[2]		
Approach speed, miles per hour	265	149
Sinking speed, feet per second	34	23
Contact speed, miles per hour	169	122

[1]The leading-edge flaps are deflected for take-off. Take-off is assumed to be made at a speed 10 percent greater than the minimum. Ground-run distance was calculated by the method of reference 4; distance to climb to 50 feet by the method of reference 5.

[2]The leading-edge flaps are deflected for the approach; both leading-edge and split flaps are deflected for landing. Following the findings of reference 6, approach speed is assumed to be 25 percent greater than the minimum speed; ground contact is assumed to be made at a lift coefficient which is 85 percent of the maximum. Note that the maximum permissible sinking speed, according to reference 6, is 25 feet per second.

It is evident that large improvements can be obtained in low-speed performance by applying boundary-layer control. These, of course, are in addition to the improvements in longitudinal stability.

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[2]If separation were tolerated over the wing, all items of low-speed performance could be considerably improved due to higher lift coefficients available and, consequently, lower flight speeds. This involves considerations, however, such as longitudinal stability and control which are not within the scope of this discussion. Hence, comparisons are limited only to flight conditions for which there would be no significant amount of separation over the wing. Accordingly, the maximum usable lift coefficient is taken to be the lift coefficient at which separation begins to cause appreciable change in force characteristics.

CONCLUDING REMARKS

The results of a wind-tunnel investigation conducted to determine the benefits obtainable by applying boundary-layer control to a 45° swept-forward wing-fuselage combination are summarized as follows:

The occurrence of separation over the wing was delayed substantially by applying boundary-layer control. With no boundary-layer control, separation occurred at a lift coefficient that was between 30 and 50 percent of the maximum, dependent upon the configuration. In contrast, with boundary-layer control, separation did not occur until a lift coefficient between 78 and 93 percent of the maximum was reached.

Corresponding improvements in the longitudinal characteristics were obtained. Aerodynamic-center travel was reduced to an insignificant amount until just prior to the attainment of maximum lift, in contrast to the rearward followed by large forward movements of aerodynamic center without boundary-layer control. Drag coefficients were reduced by as much as 56 to 62 percent, dependent upon the configuration. The maximum lift coefficients were not greatly increased.

The most effectual location for suction slots for boundary-layer control on the 45° swept-forward wing was found to be at the wing-fuselage juncture over the forward part of the wing: Thus, with no leading-edge flap, the forward edge of the slot coincided with the leading edge of the wing; and, with the leading-edge flap deflected, the forward edge of the slot was located at the beginning of the transition between the flap and the wing.

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REFERENCES

1. McCormack, Gerald M., and Cook, Woodrow L.: A Study of Stall Phenomena on a 45° Swept-Forward Wing. NACA TN 1797, 1949.

2. McCormack, Gerald M., and Cook, Woodrow L.: Effects of Several Leading-Edge Modifications on the Stalling Characteristics of a 45° Swept-Forward Wing. NACA RM A9D29, 1949

3. Anon.: Performance and Installation Manual Aircraft Gas Turbine for Jet Propulsion Type TG-180. General Electric Company Rep. GEI-19474, Oct 1, 1944.

4. Hartman, Edwin P.: Considerations of the Take-Off Problem. NACA TN 557, 1936.

5. Wetmore, J. W.: Calculated Effect of Various Types of Flap on Take-Off Over Obstacles. NACA TN 568, 1936.

6. Gustafson, F. B., and O'Sullivan, William J.: The Effect of High Wing Loading on Landing Technique and Distance with Experimental Data for the B-26 Airplane. NACA ARR L4K07, 1945.

TABLE I

LOCATIONS OF PRESSURE ORIFICES

Orifice number	Plain wing		Leading-edge flap deflected 30° down	
	Upper surface percent chord	Lower surface percent chord	Upper surface percent chord	Lower surface percent chord
1	0	--	0	--
2	.25	0.25	.06	0.38
3	.5	.5	.23	.67
4	1.0	1.0	.58	1.22
5	1.5	1.5	1.0	1.75
6	2.5	2.5	1.82	2.79
7	3.5	3.5	2.66	3.8
8	5.0	5.0	3.95	5.29
9	7.5	7.5	6.14	7.74
10	20.0	20.0	8.36	10.17
11	30.0	30.0	10.75	15.0
12	40.0	40.0	13.25	20.0
13	50.0	50.0	15.0	30.0
14	60.0	60.0	15.88	40.0
15	70.0	70.0	20.0	50.0
16	80.0	80.0	30.0	60.0
17	90.0	90.0	40.0	70.0
18	97.5	97.5	50.0	80.0
19	--	--	60.0	90.0
20	--	--	70.0	97.5
21	--	--	80.0	--
22	--	--	90.0	--
23	--	--	97.5	--

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TABLE II

DRAG INCREMENTS AND MOMENT CENTERS USED
IN FORCE DATA

Figure number and symbol	Flow coefficient	Increment of drag coefficient added to each curve	Moment center location (percent $\bar{c}$)
6	0	0	14.1
7	0	0	12.3
8	0	0	14.0
8	0	0	20.4
9	0	0	12.3
9	0	0	22.1
9	0	0	22.1
9	0	0	22.1
10	.0121	.0113	12.8
11	0	0	15.2
11	.0093	.0008	15.9
11	.0125	.0085	15.0
12	.0118	.0109	19.8
13	0	0	21.5
13	.0121	.0132	20.4
13	.0092	.0020	20.4
14(a)	.0125	.0089	15.4
14(a)	.0124	.0055	15.4
14(a)	.0123	.0052	14.2
14(b)	.0069	−.0021	14.2
14(b)	.0060	−.0036	15.9
15	.0092	.0121	14.8
15	.0079	.0002	14.8
15	.0103	.0021	14.8
16	.0076	−.0021	15.8
24	.0040	.0032	14.0
24	.0045	.0039	14.6
24	.0053	.0064	15.0
25	.0045	.0038	15.6
25	.0055	.0070	14.7
26	0	0	15.2
26	.0082	.0215	15.0
26	.0100	.0356	14.6
26	.0113	.0469	14.7
26	0	0	15.0

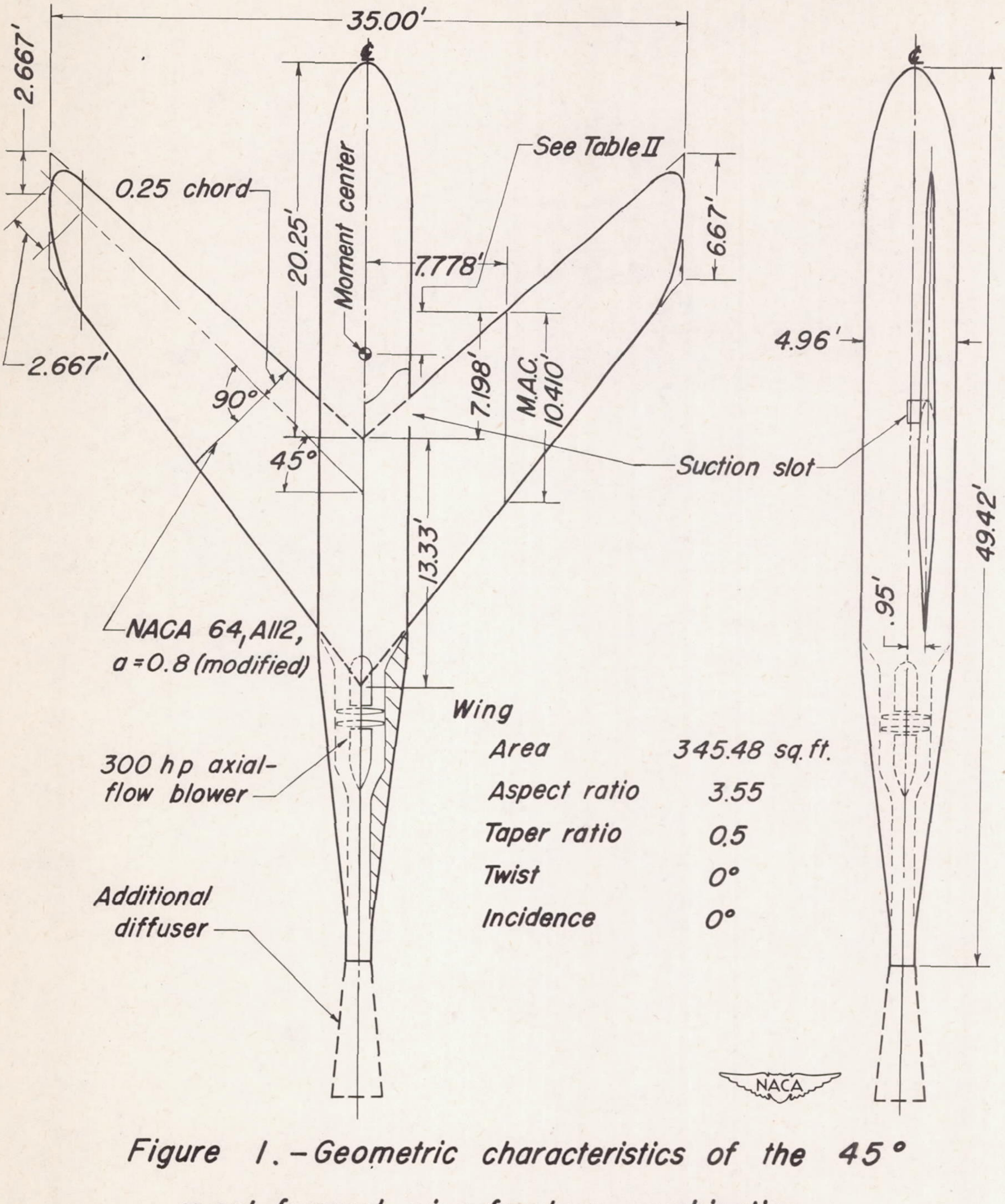


Figure 1.- Geometric characteristics of the 45° swept-forward wing-fuselage combination.

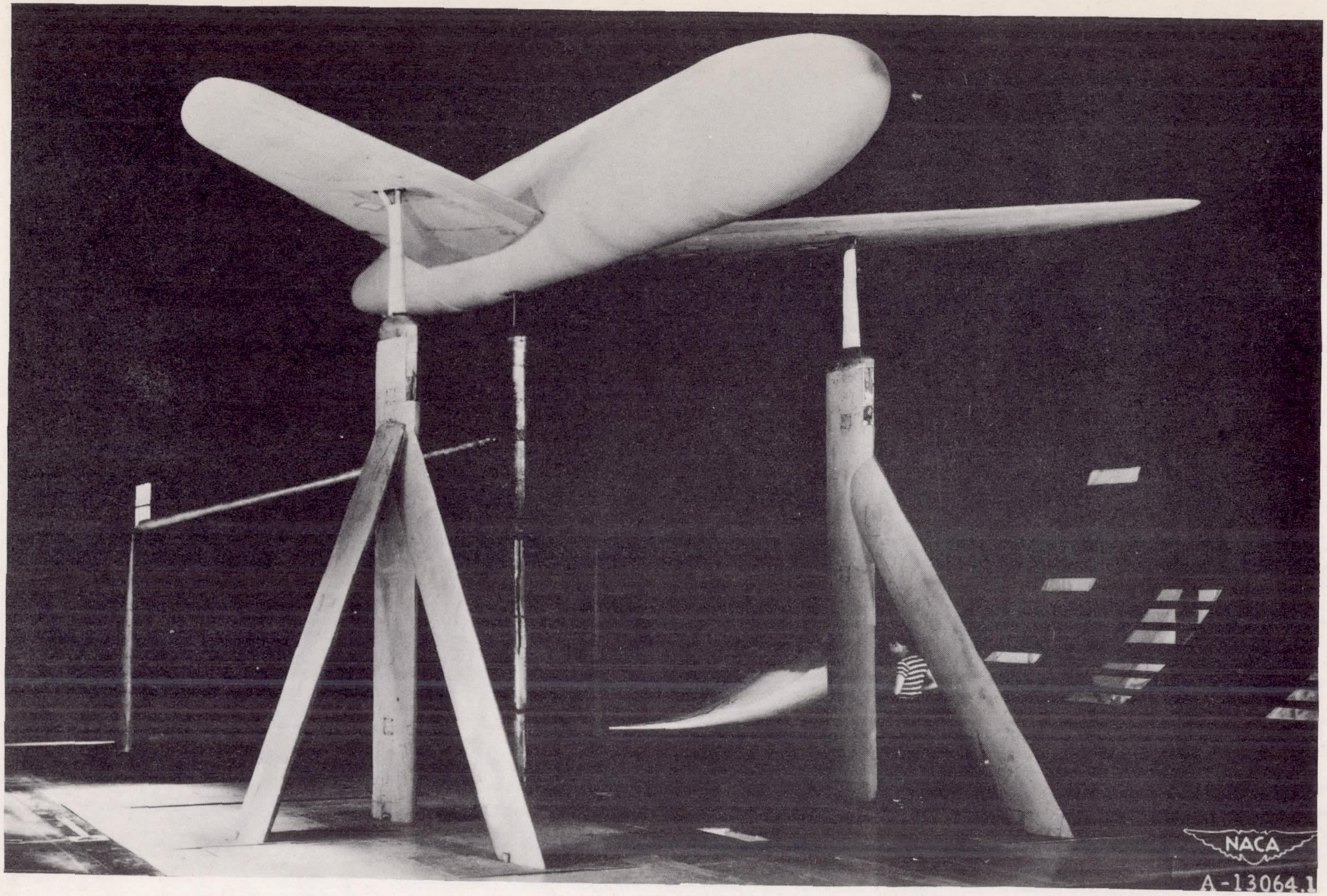


Figure 2.- The 45° swept-forward wing-fuselage combination in the Ames 40- by 80-foot wind tunnel.

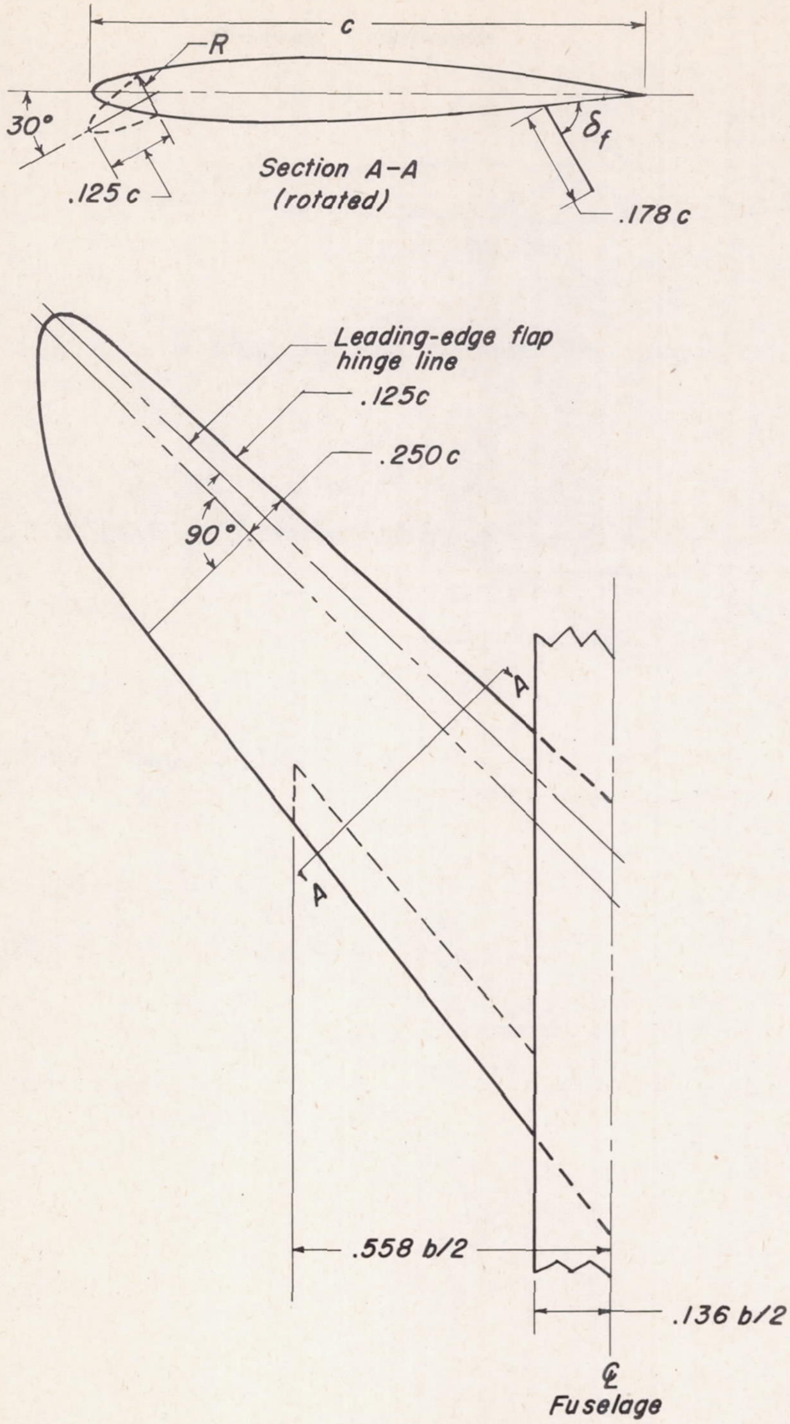
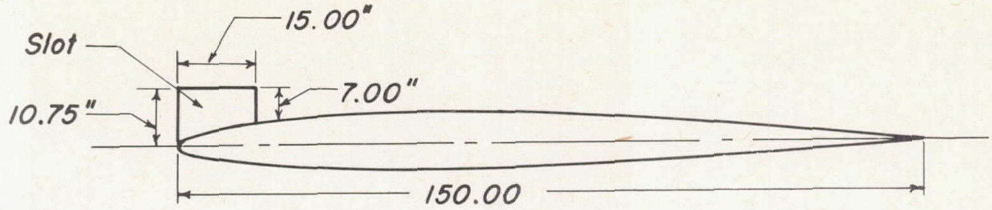
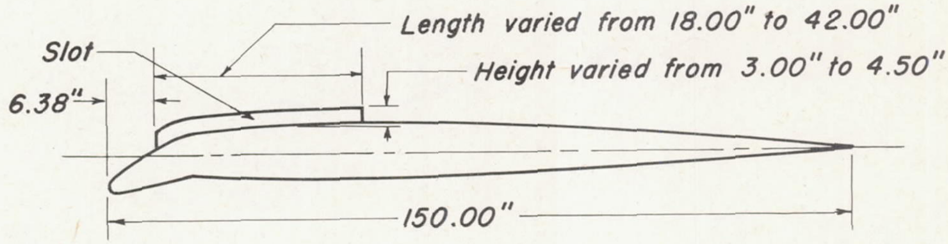


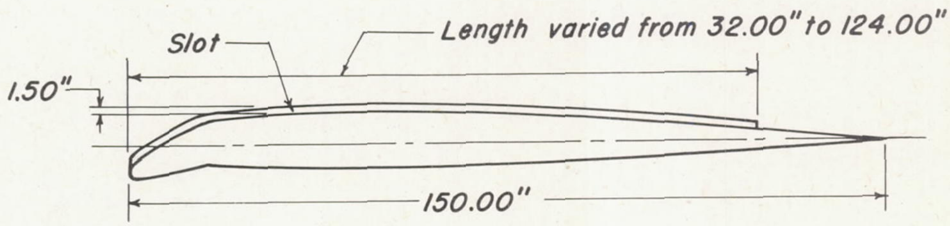
Figure 3.- Flap arrangements used on the 45° swept-forward wing-fuselage combination.



10.75-by 15-inch suction slot for plain wing section



3-and 4.5-inch suction slots for wing with leading-edge flap



1.5-inch suction slots for wing with leading-edge flap

Figure 4.– Suction slots at the wing-fuselage juncture used for boundary-layer control on the 45° swept-forward wing-fuselage combination.

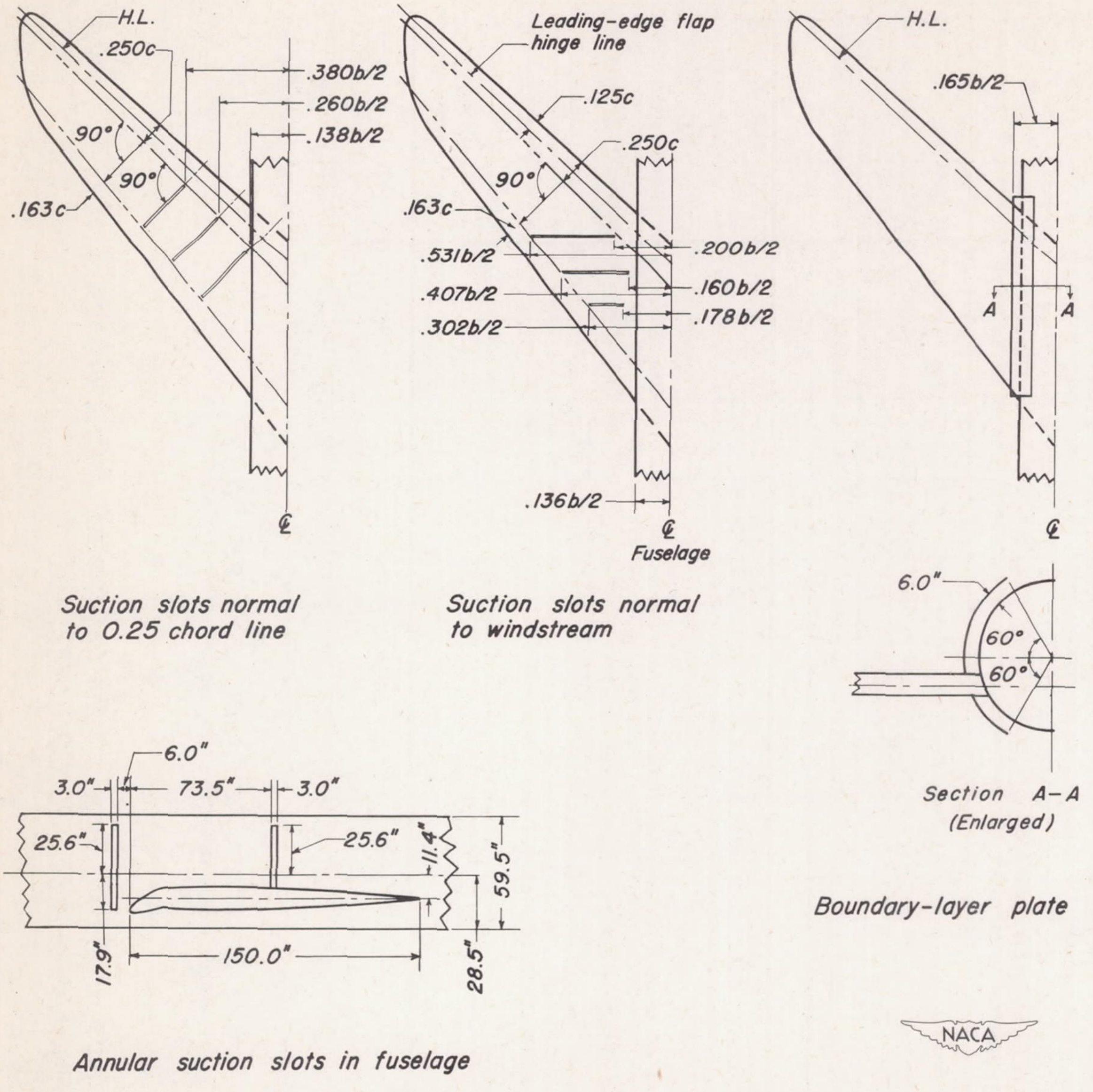


Figure 5. - Miscellaneous types of boundary-layer control devices used on the 45° swept-forward wing-fuselage combination.

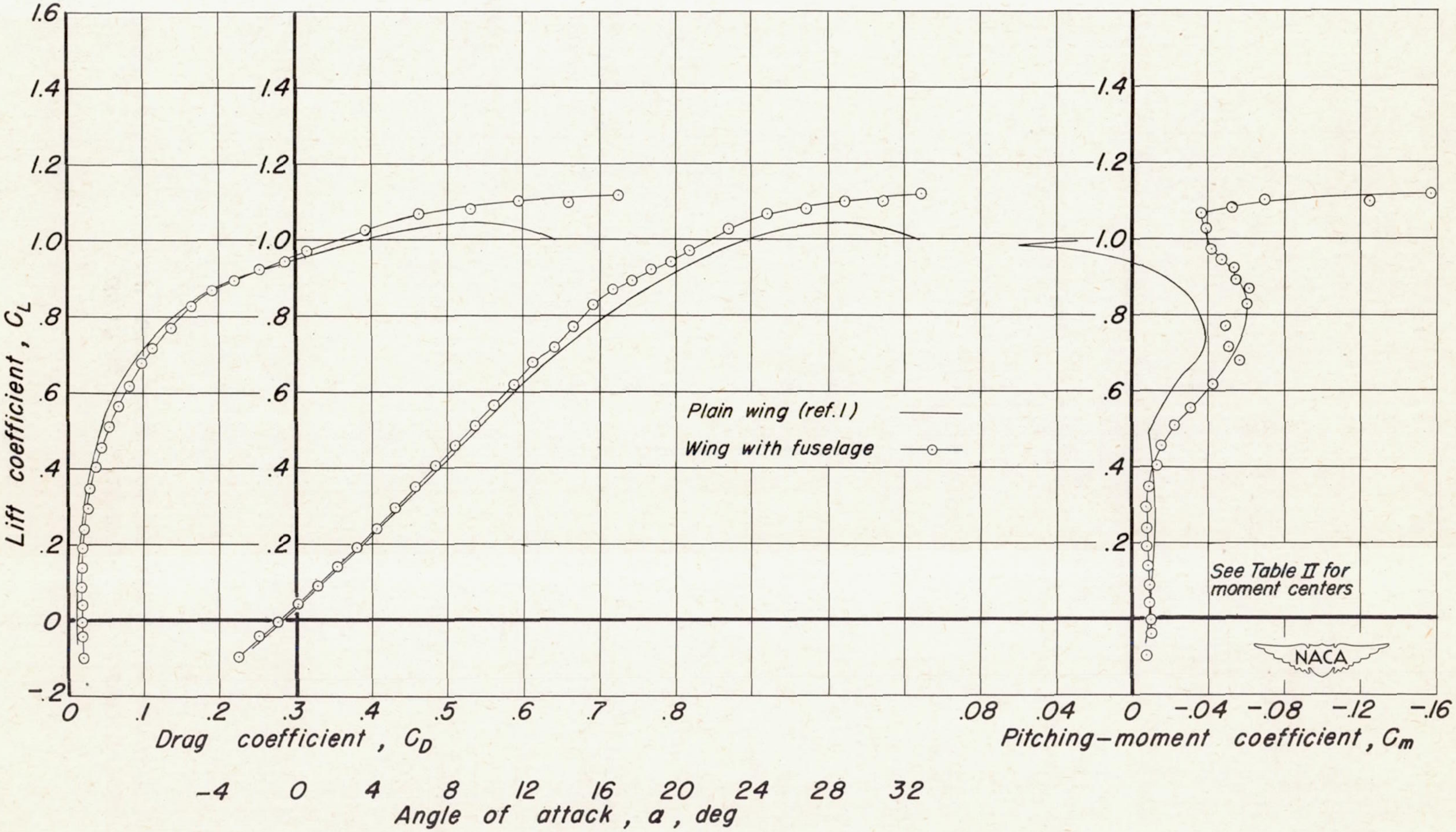


Figure 6.– The effects of the fuselage on the longitudinal characteristics of the 45° swept-forward wing. Reynolds number, 10,600,000.

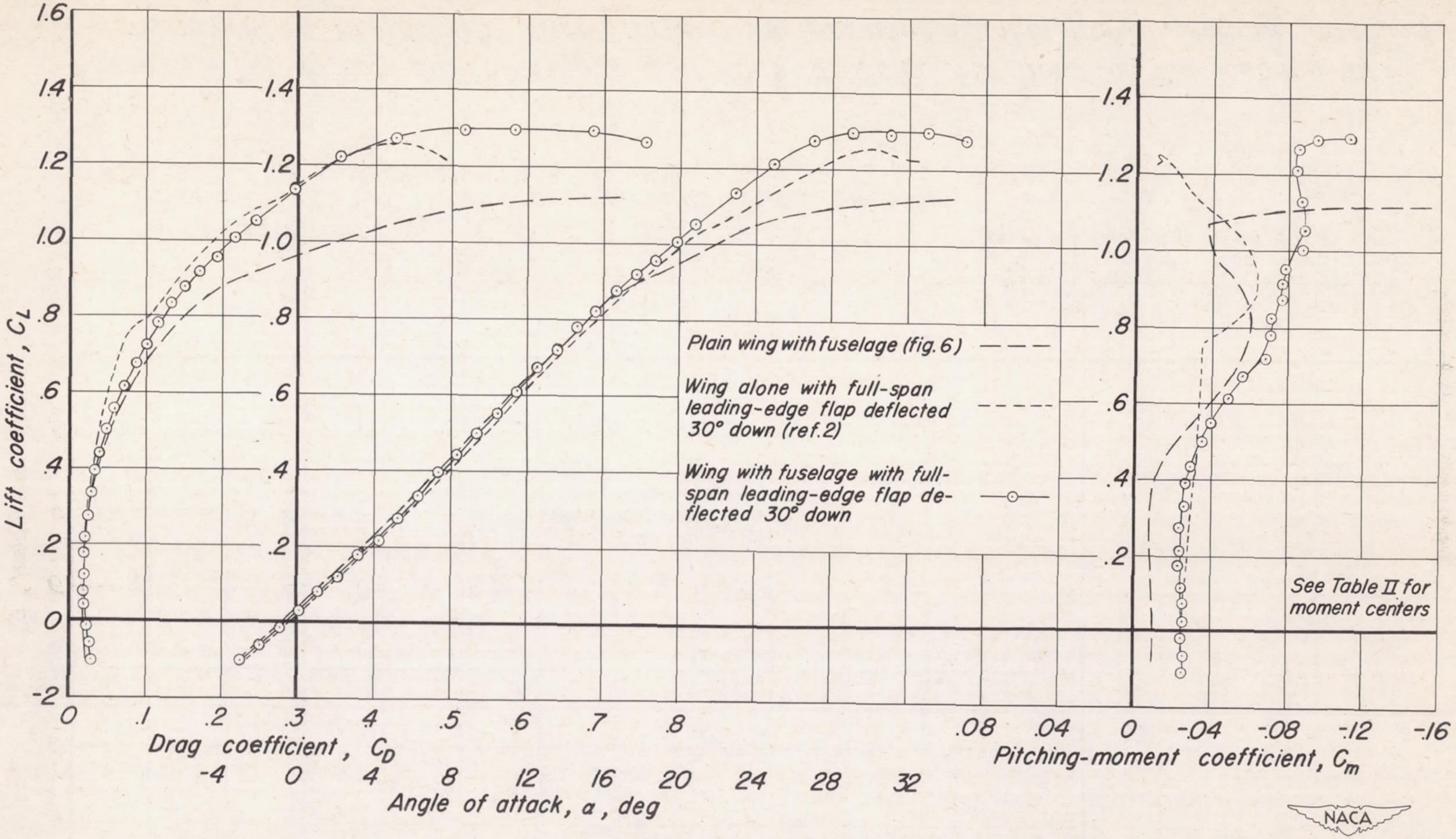


Figure 7.–The effects of a full-span leading-edge flap deflected 30° down on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination. Reynolds number, 10,600,000.

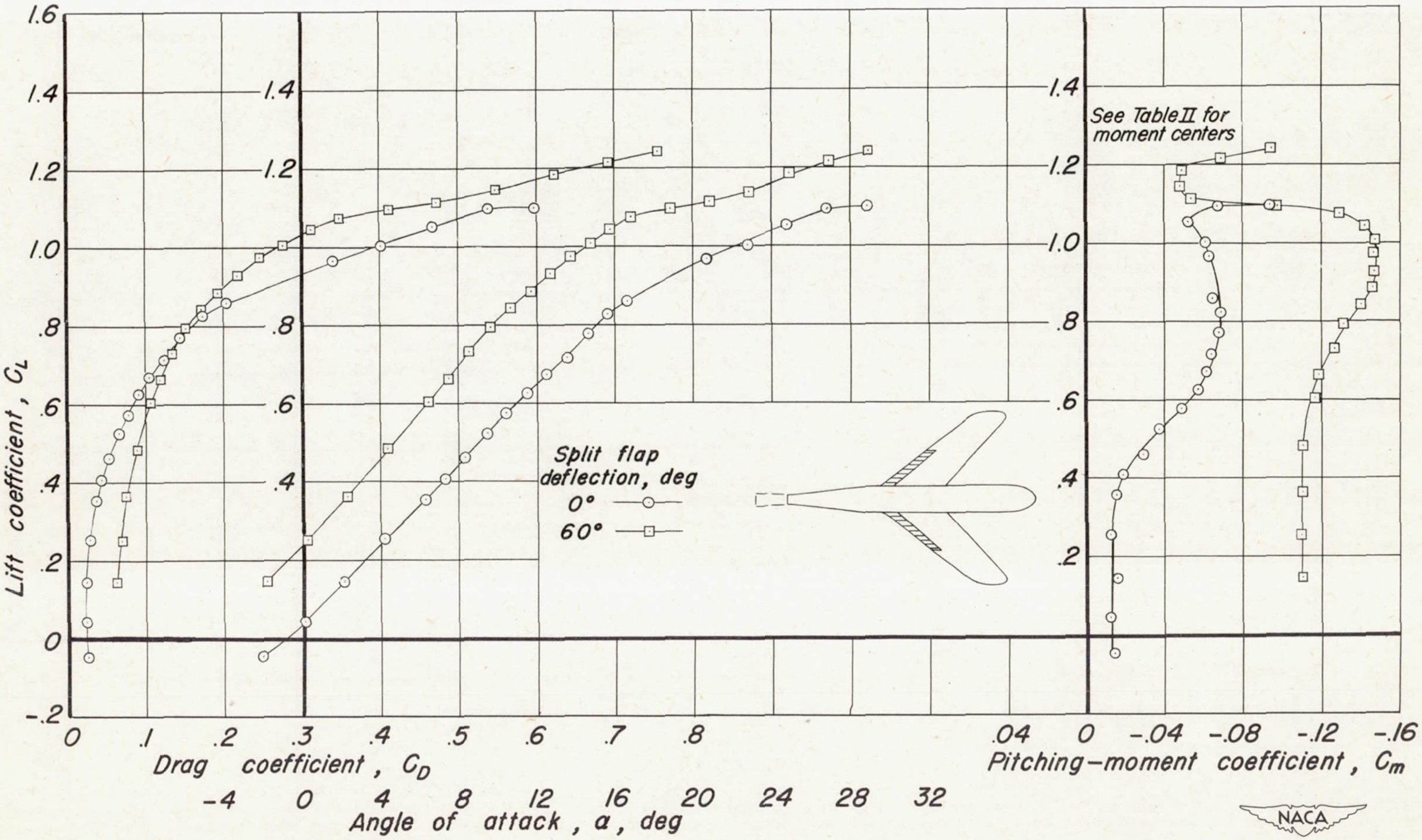


Figure 8.–The effects of 0.558-span split flaps deflected 60° down on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination. Diffuser attached. Reynolds number, 6,100,000.

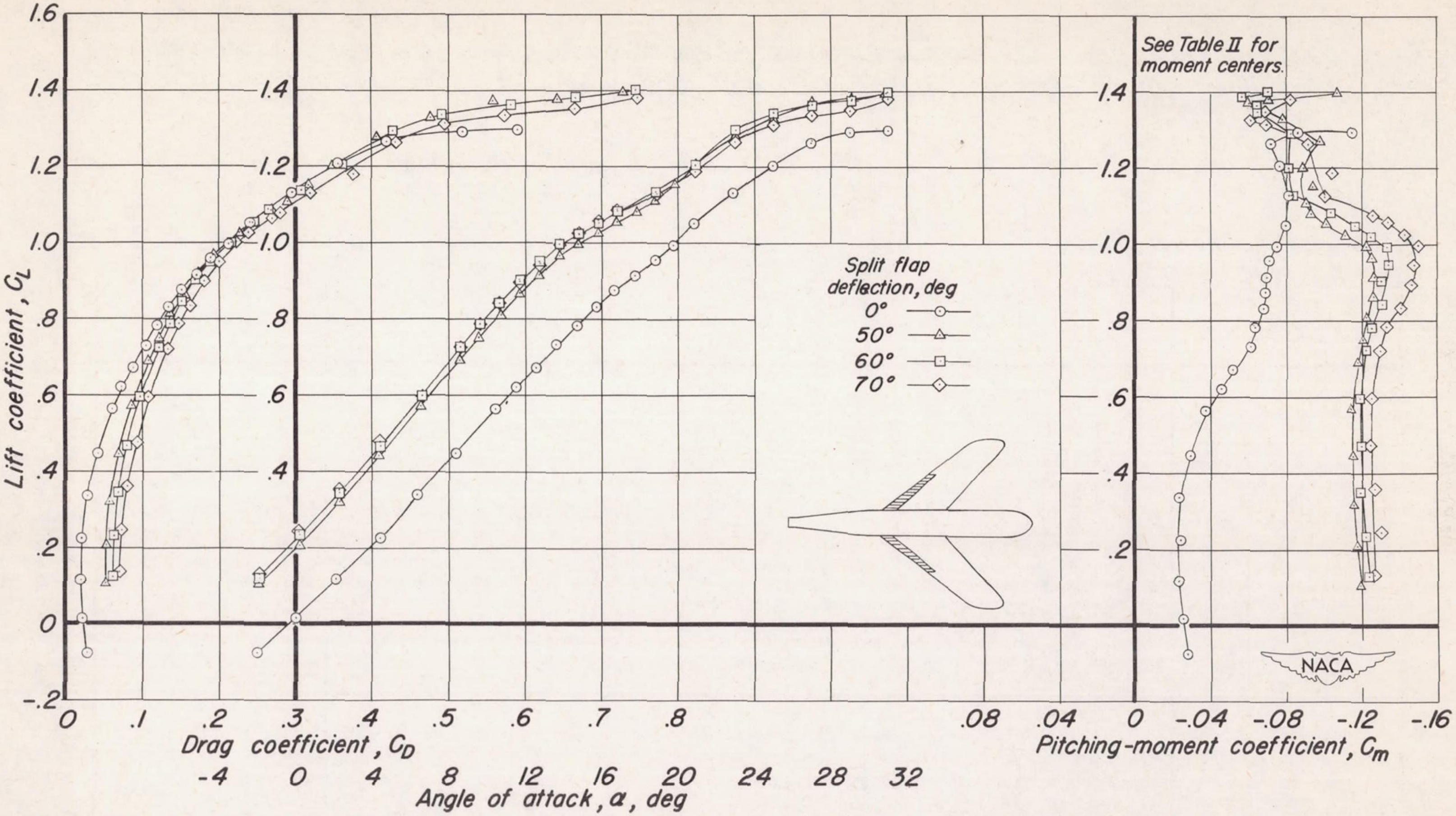


Figure 9.-The effects of various split flap deflections on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Reynolds number, 10,600,000.

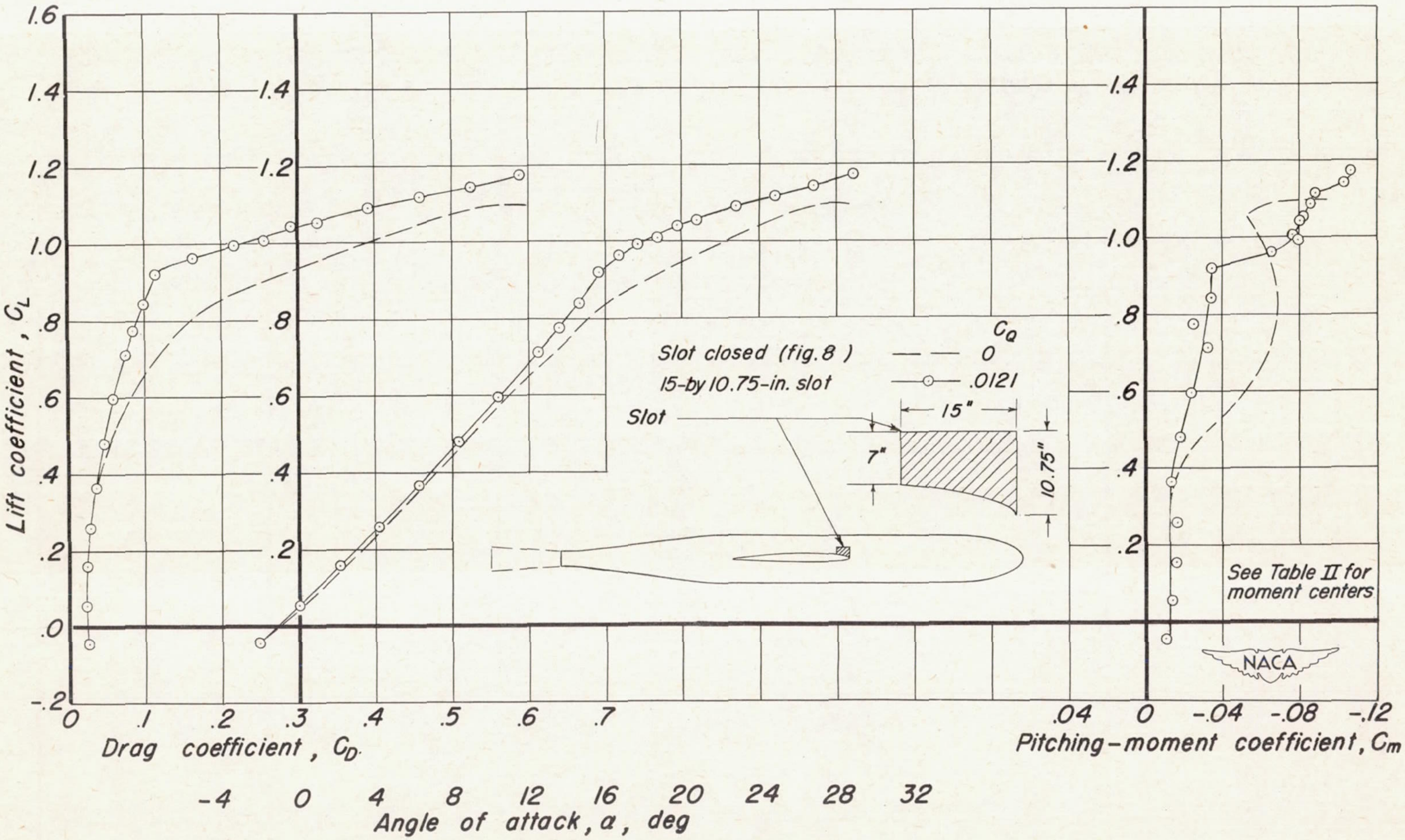


Figure 10.—The effects of suction through the 15-by 10.75-inch slot on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination. Diffuser attached. Reynolds number, 6,100,000.

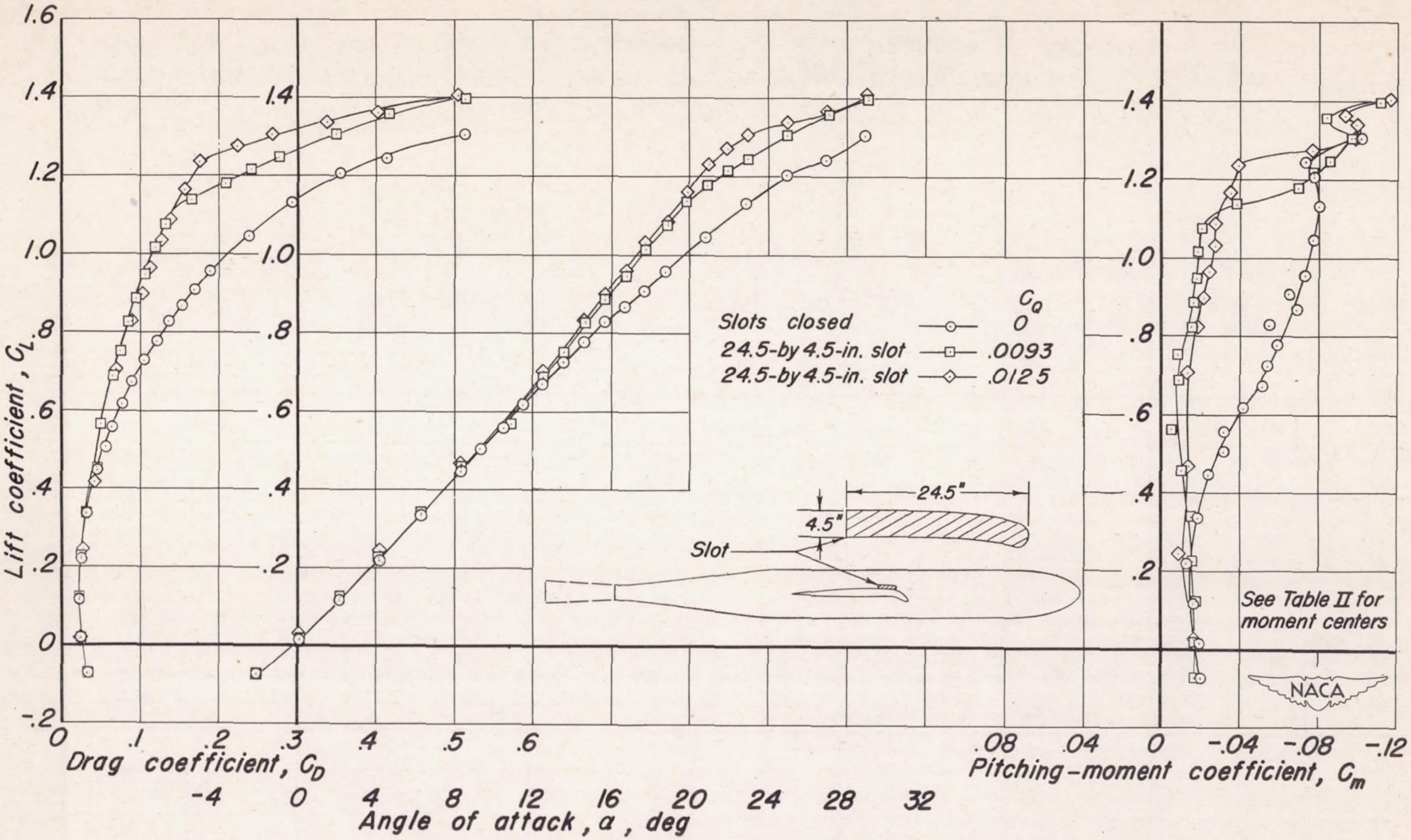


Figure 11.-The effects of suction through the 24.5-by 4.5-inch slot on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Diffuser attached. Reynolds number, 6,100,000.

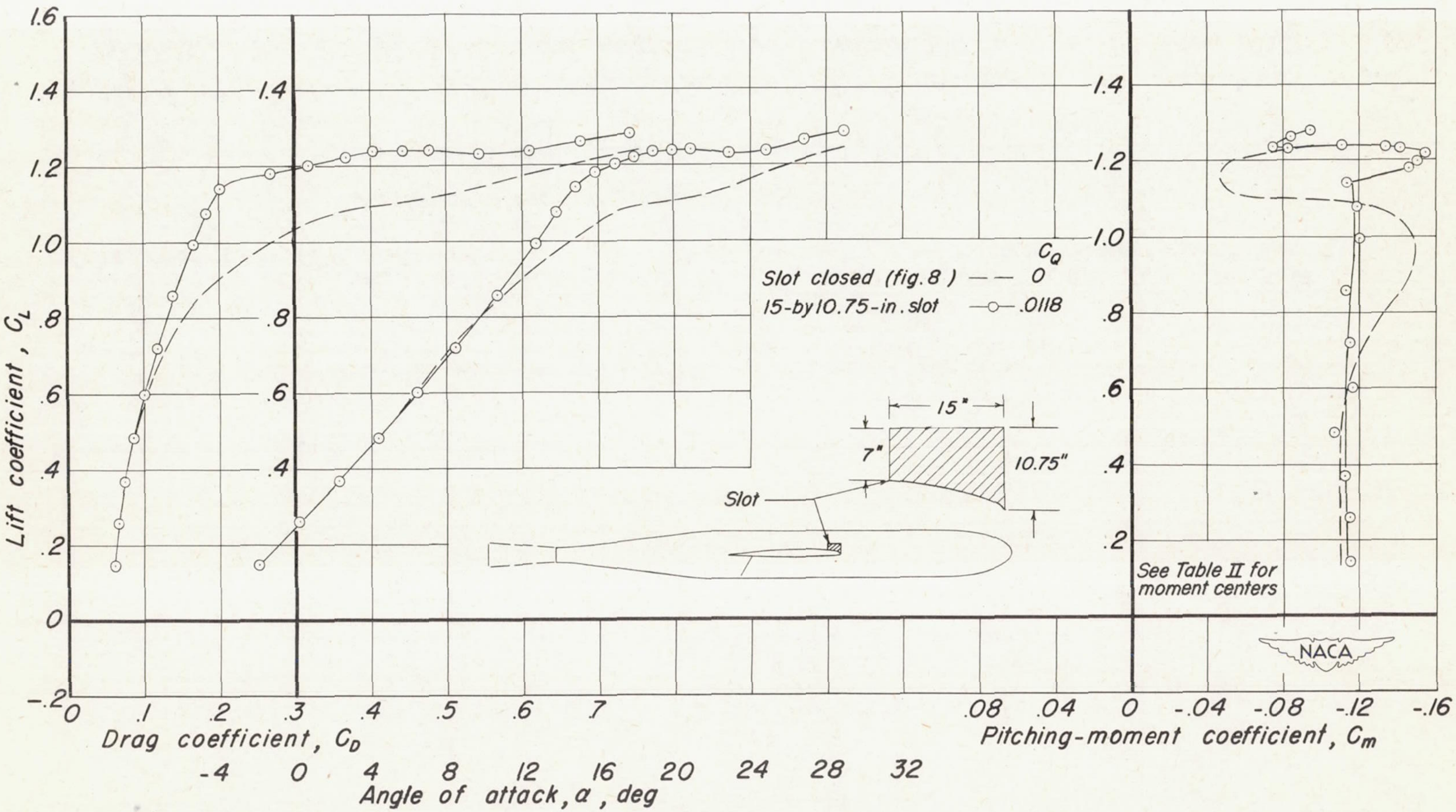


Figure 12.- The effects of suction through the 15-by 10.75-inch slot on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with 0.558-span split flaps deflected 60° down. Diffuser attached. Reynolds number, 6,100,000.

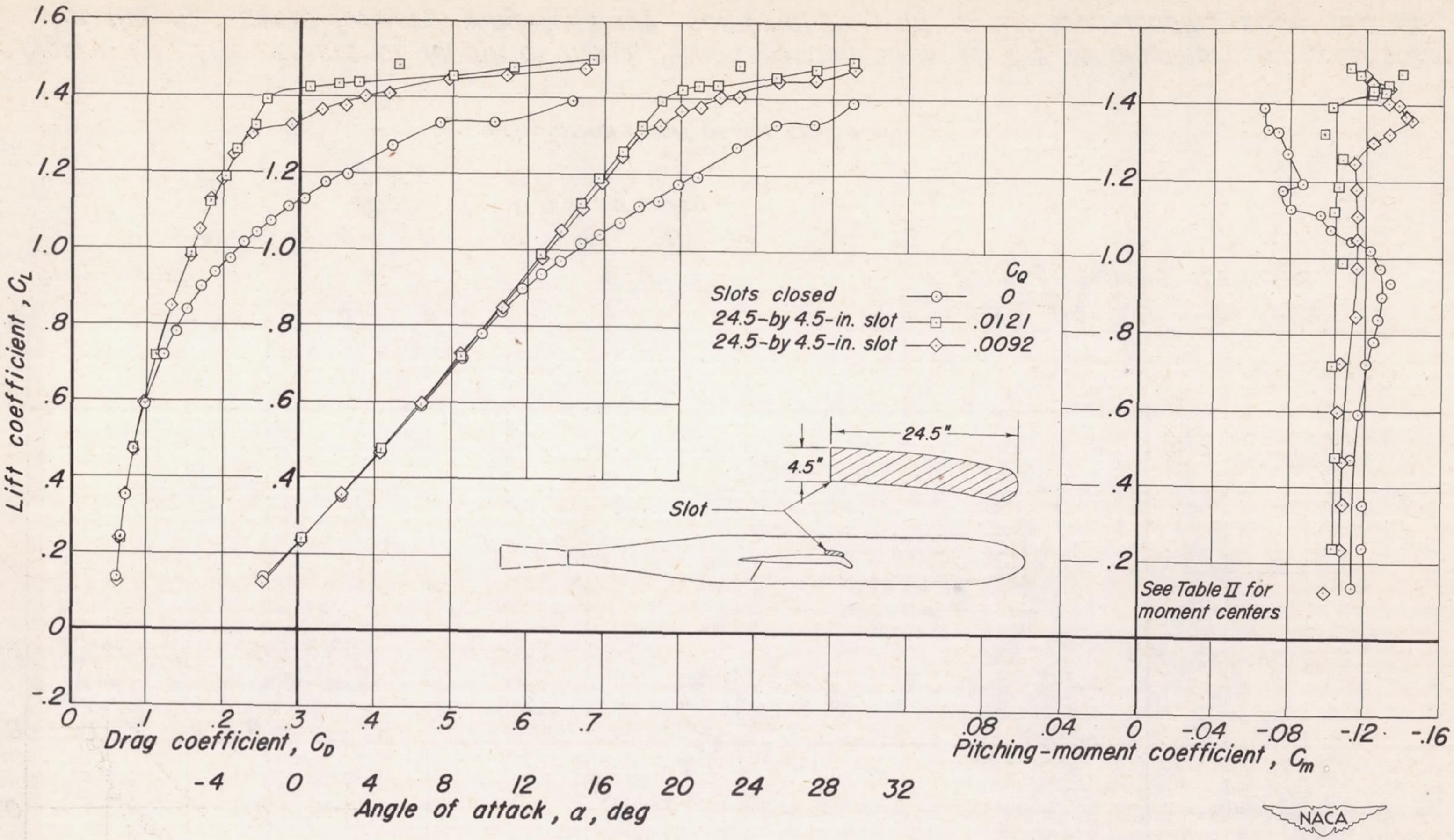
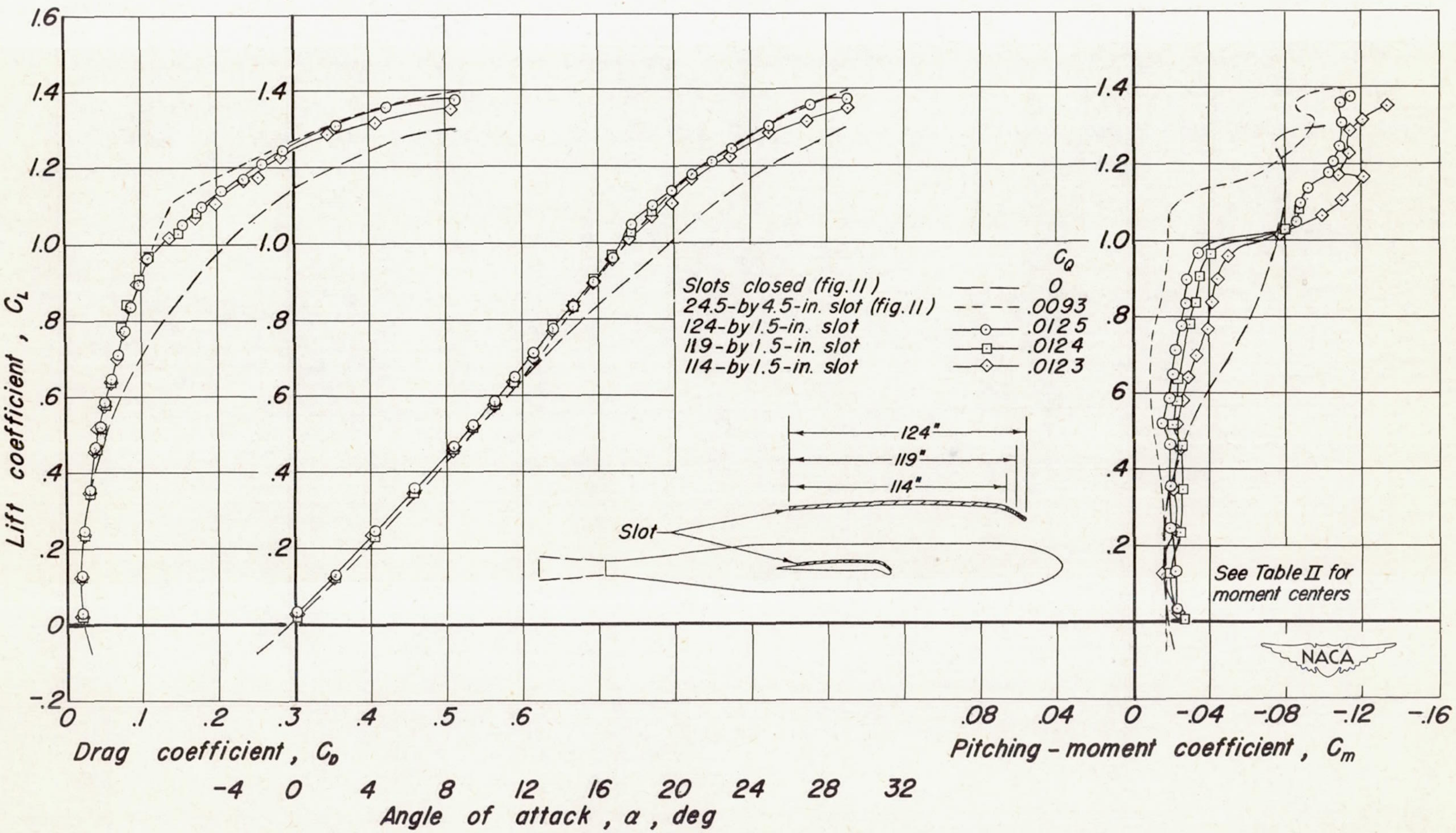
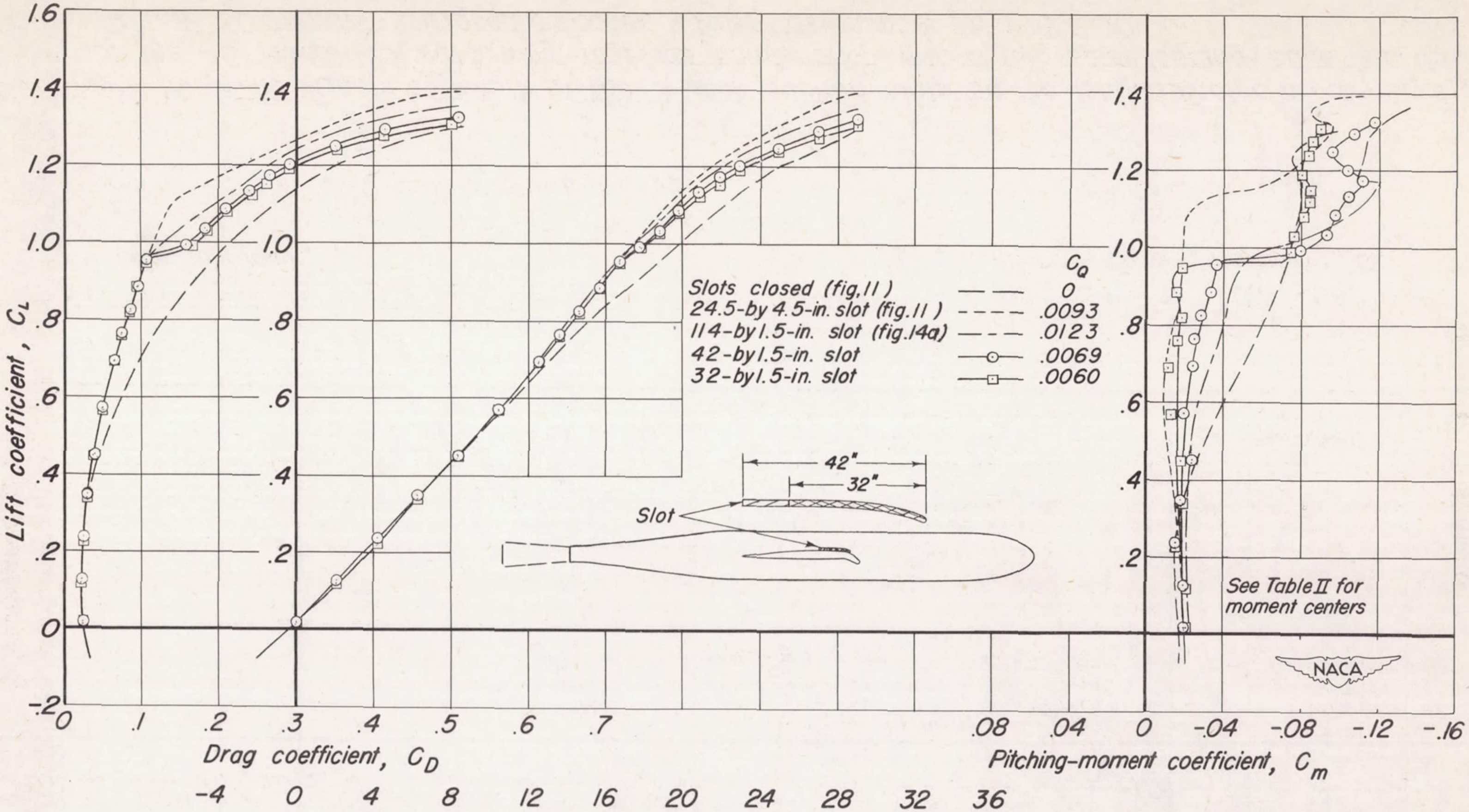


Figure 13.–The effects of suction through the 24.5-by 4.5-inch slot on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down and 0.558-span split flaps deflected 60° down. Diffuser attached. Reynolds number, 6,100,000.



(a) Forward part of slot closed off.

Figure 14.-The effects of length of the 1.5-inch suction slots on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Diffuser attached. Reynolds number, 6,100,000.



(b) Rear part of slot closed off.

Figure 14.– Concluded.

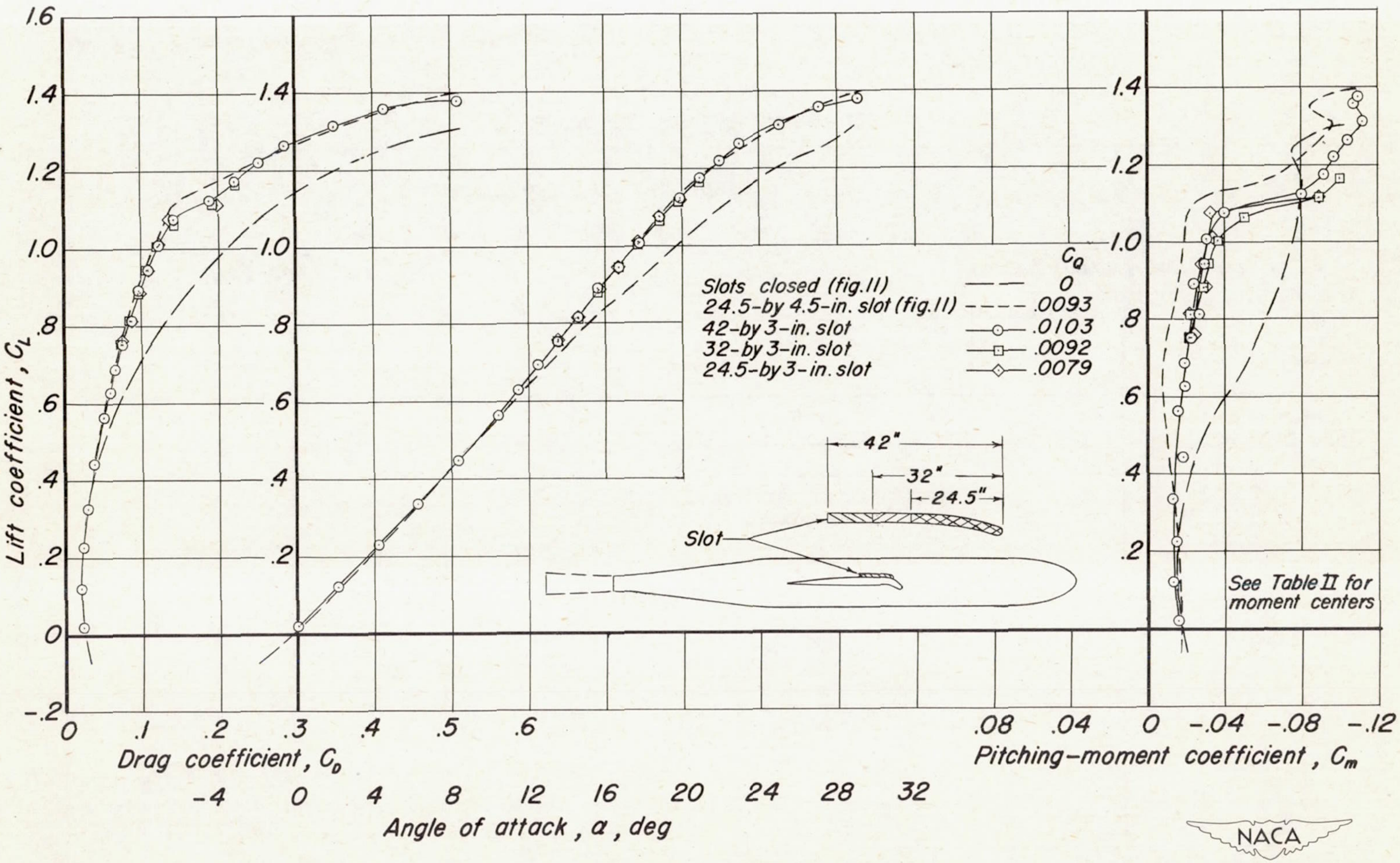


Figure 15.—The effects of length of the 3-inch suction slots on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Diffuser attached. Reynolds number, 6,100,000.

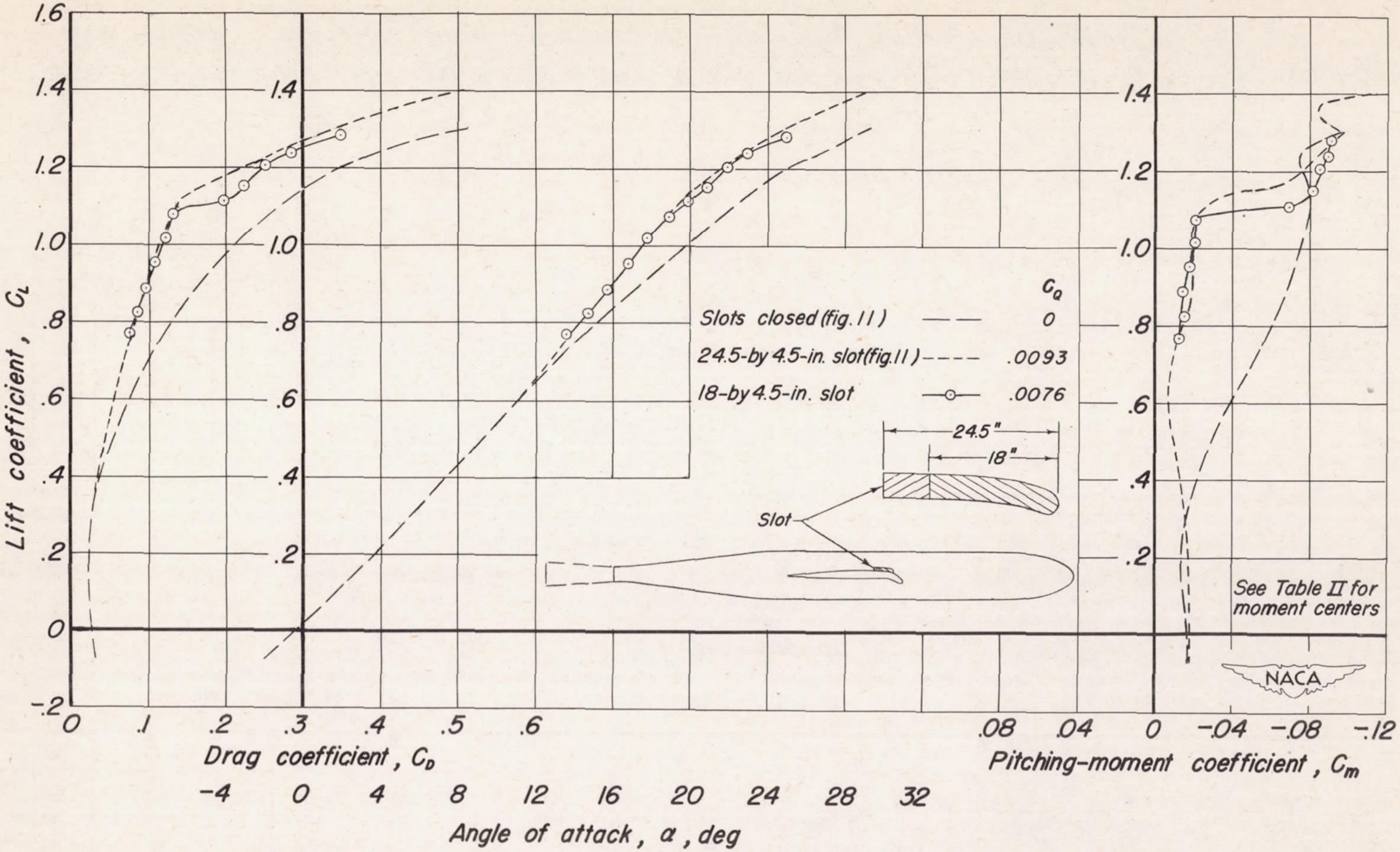
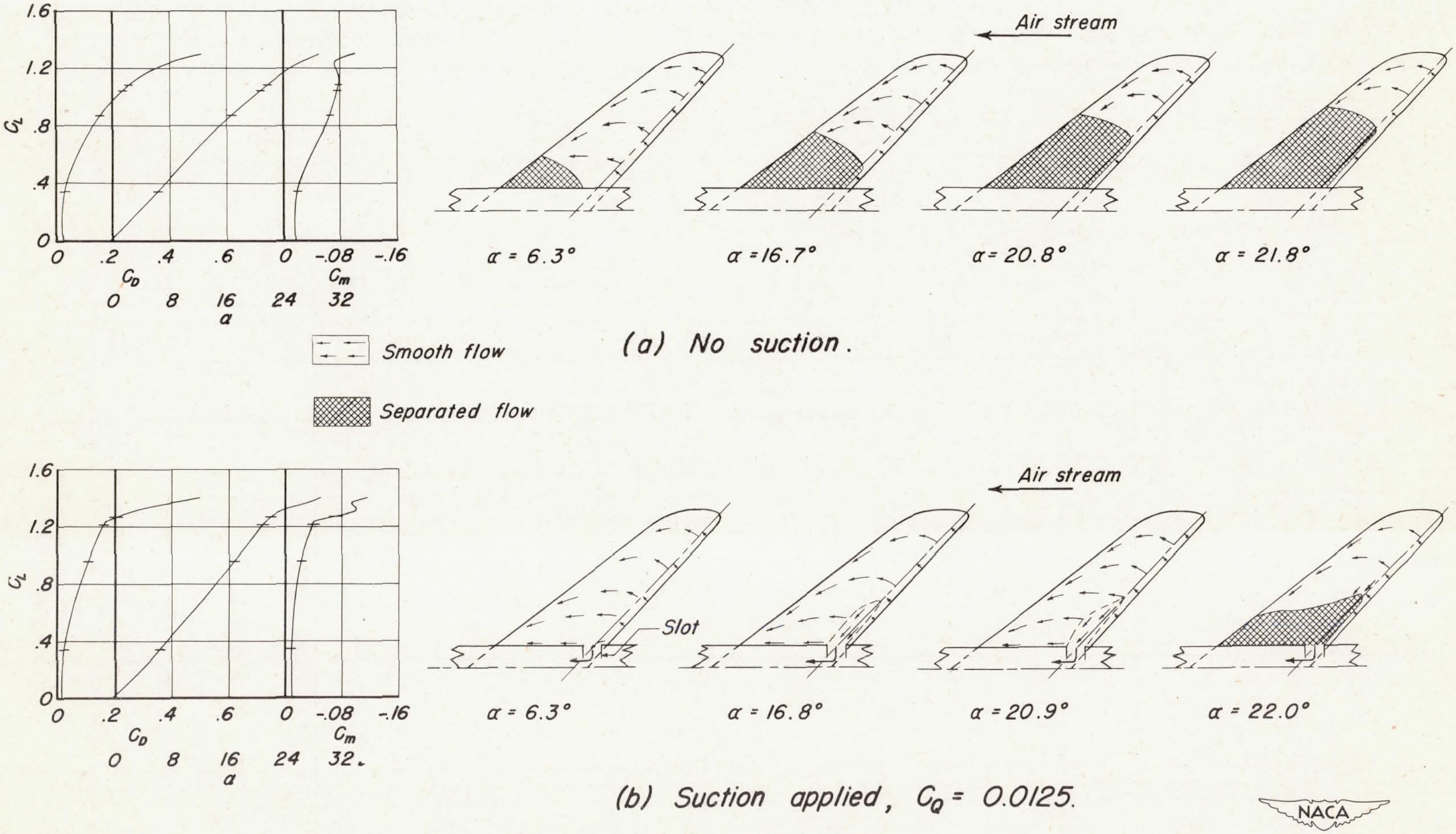


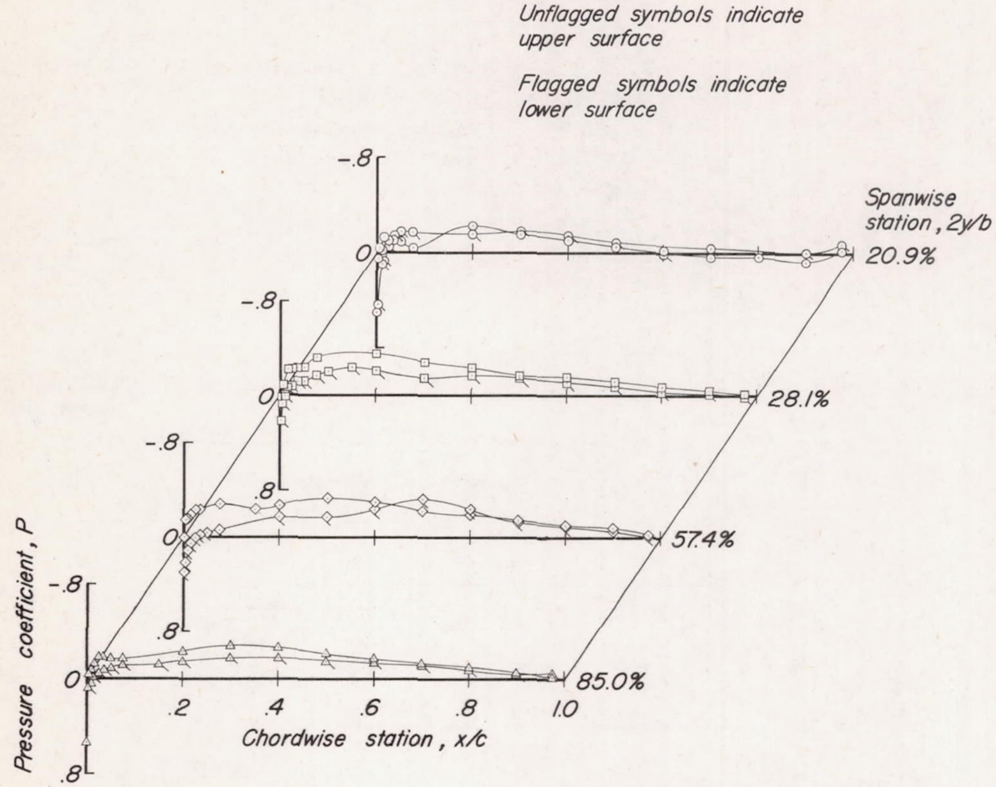
Figure 16.— The effects of length of the 4.5-inch suction slots on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Diffuser attached. Reynolds number, 6,100,000.



(a) No suction.

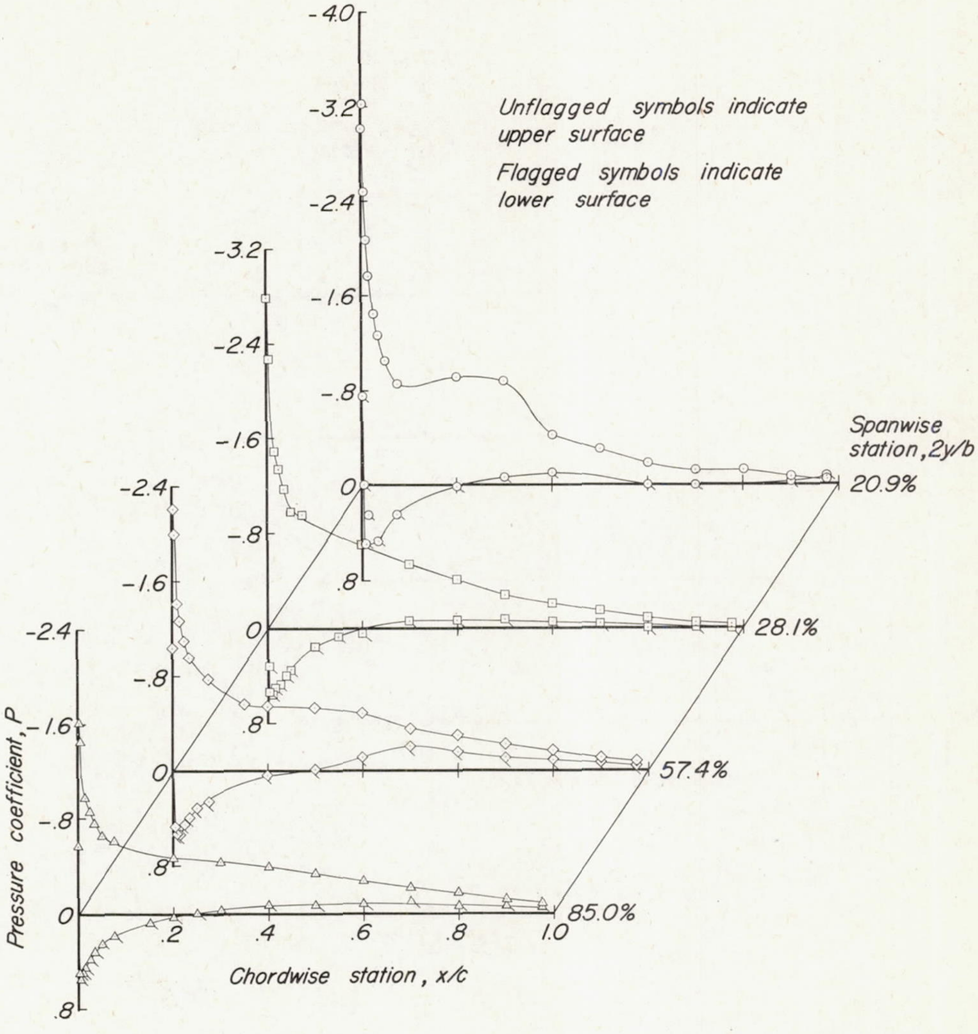
(b) Suction applied, C_Q = 0.0125.

Figure 17.– Tuft studies with and without suction through the 24.5-by 4.5-inch slot on the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down.



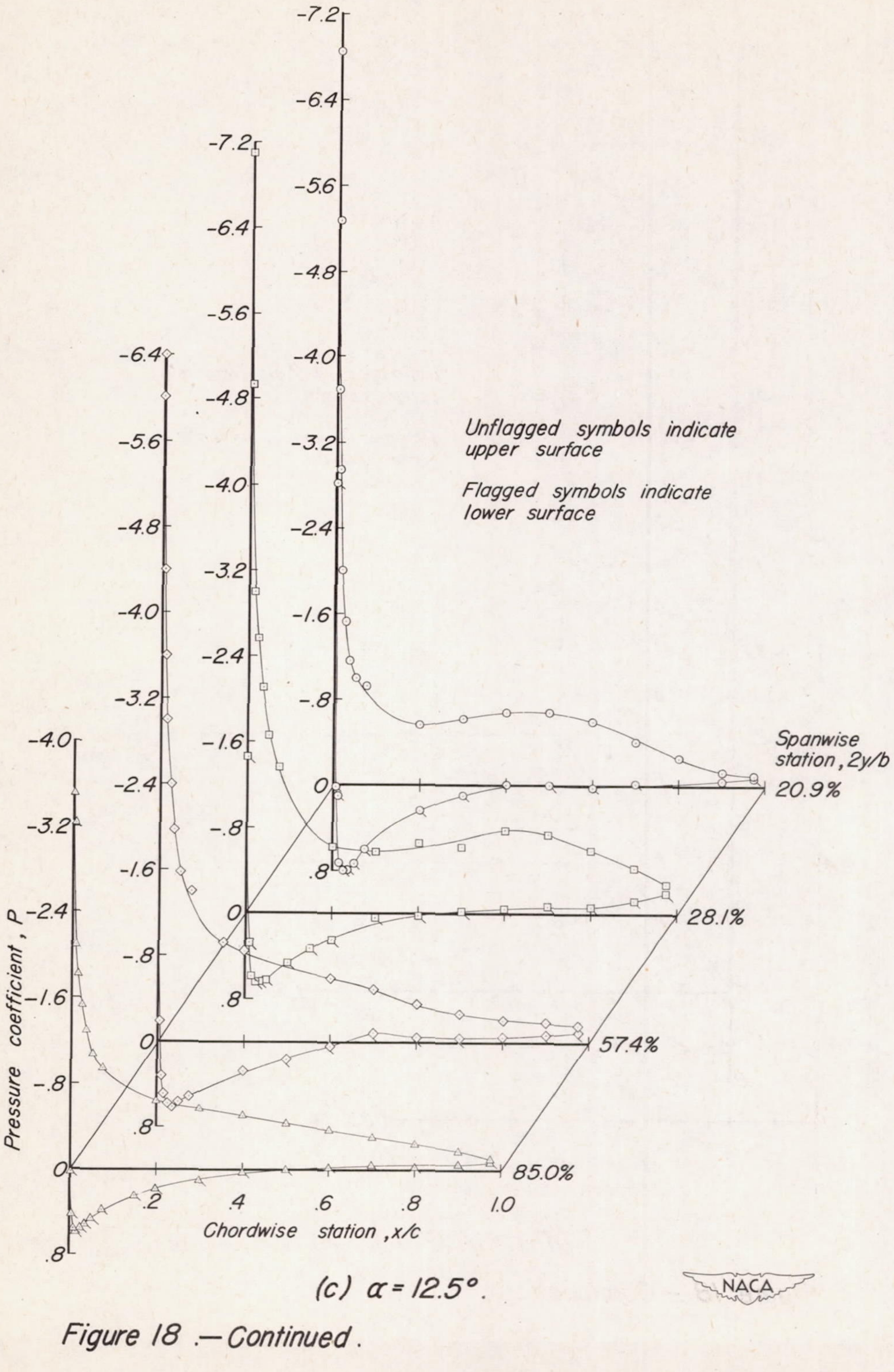
(a) $\alpha = 0.1°$.

Figure 18.—Chordwise pressure distributions for the 45° swept-forward wing-fuselage combination. Reynolds number, 10,600,000.



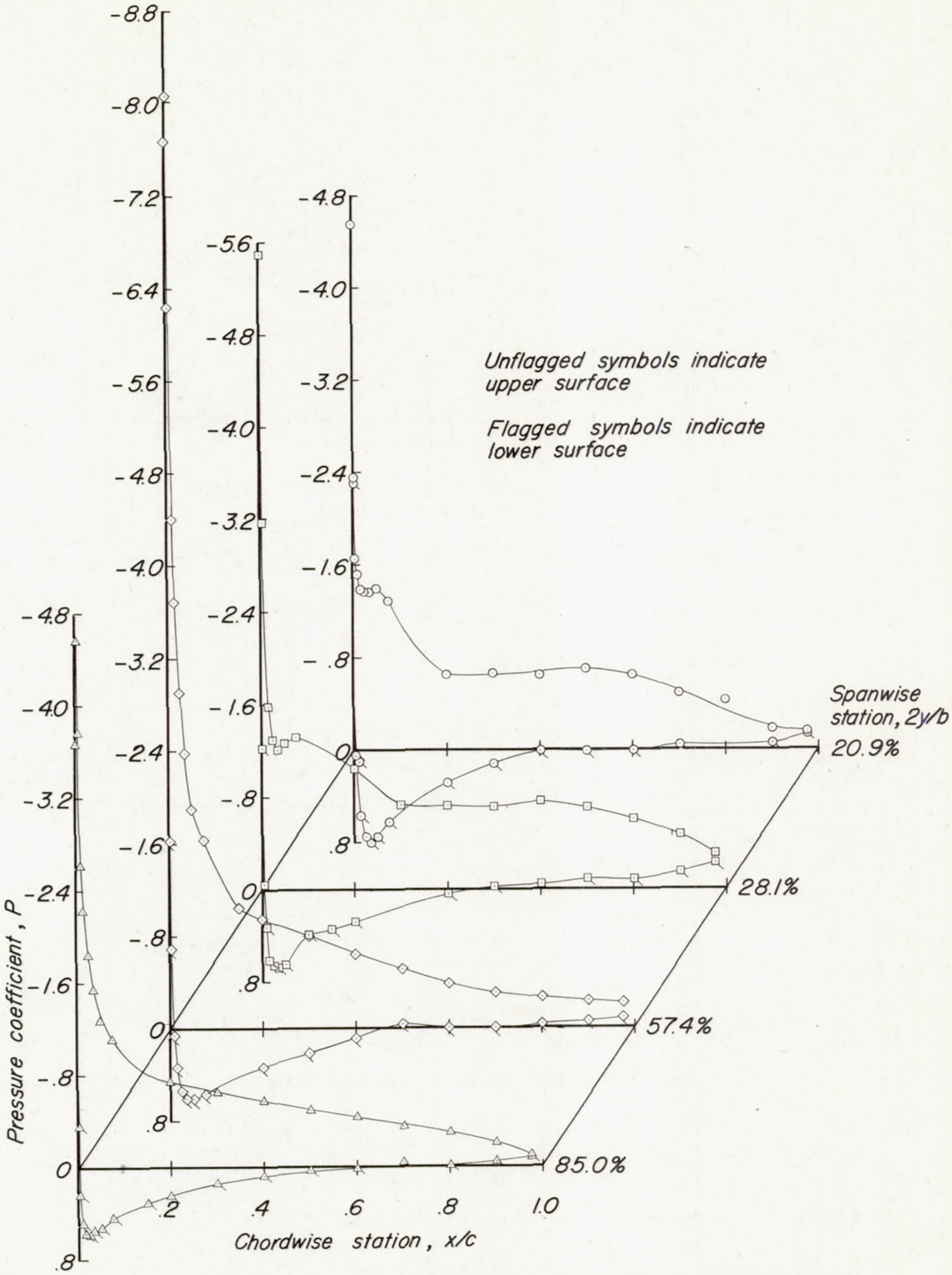
(b) $\alpha = 6.3^\circ$.

Figure 18.— Continued.



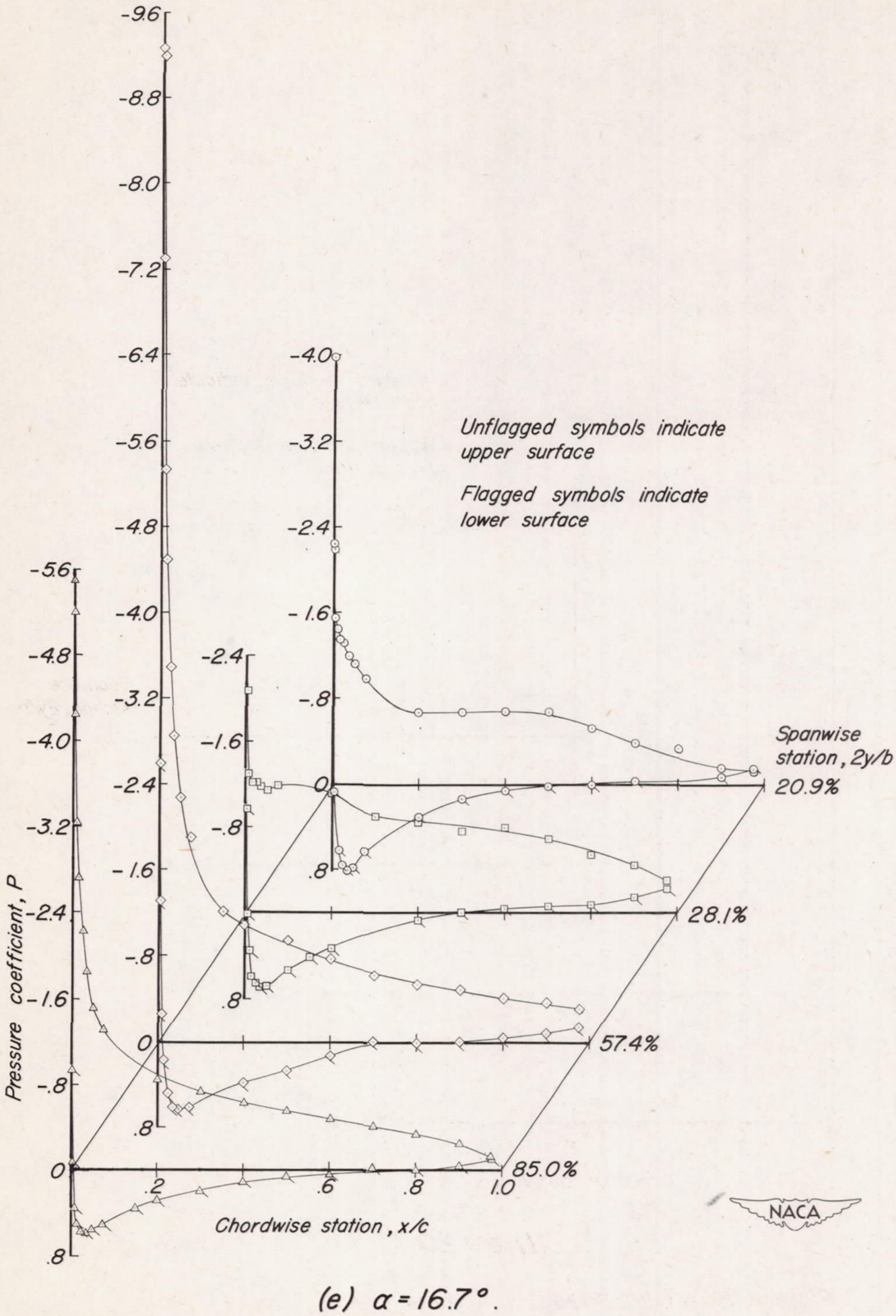
(c) α = 12.5°.

Figure 18.—Continued.



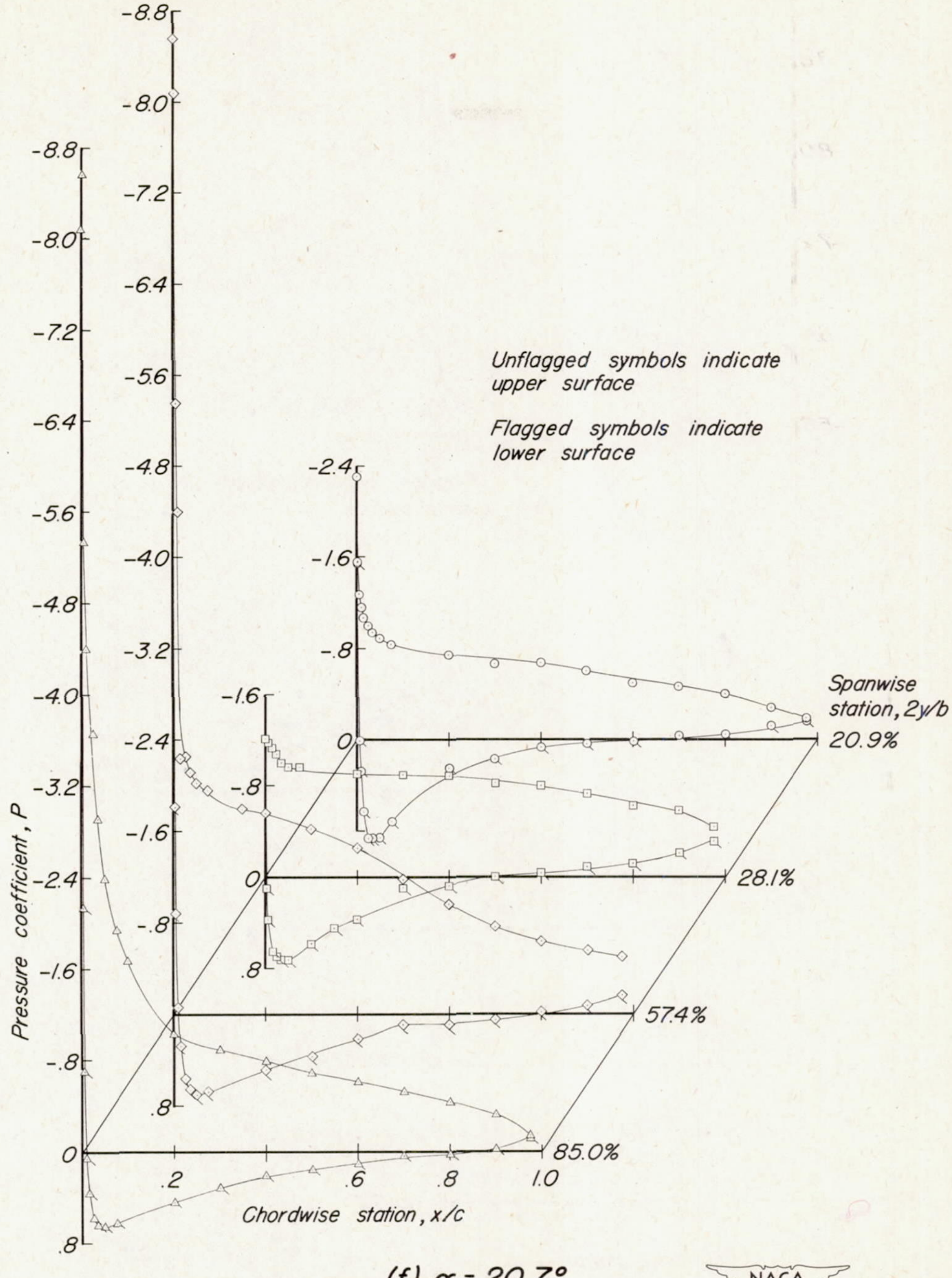
(d) $\alpha = 14.6°$.

Figure 18.—Continued.



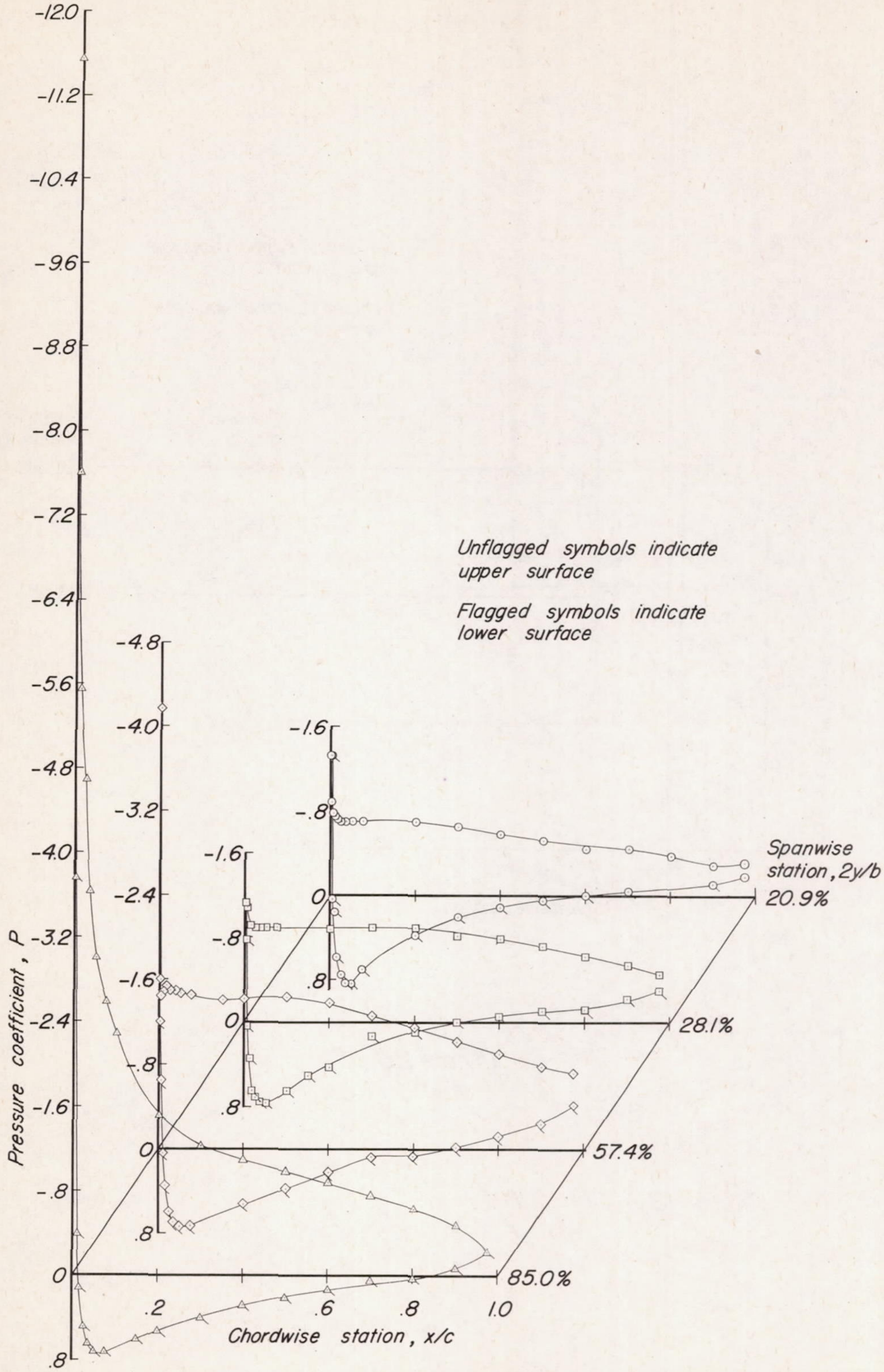
(e) α = 16.7°.

Figure 18 .—Continued.



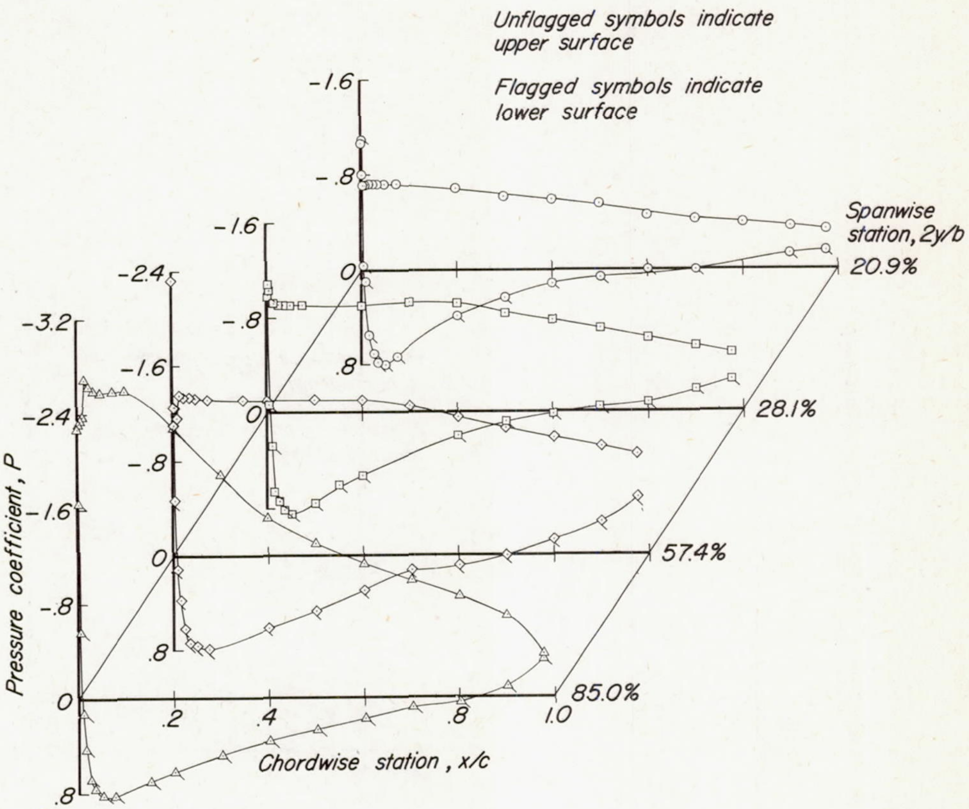
(f) $\alpha = 20.7°$.

Figure 18 .– Continued.



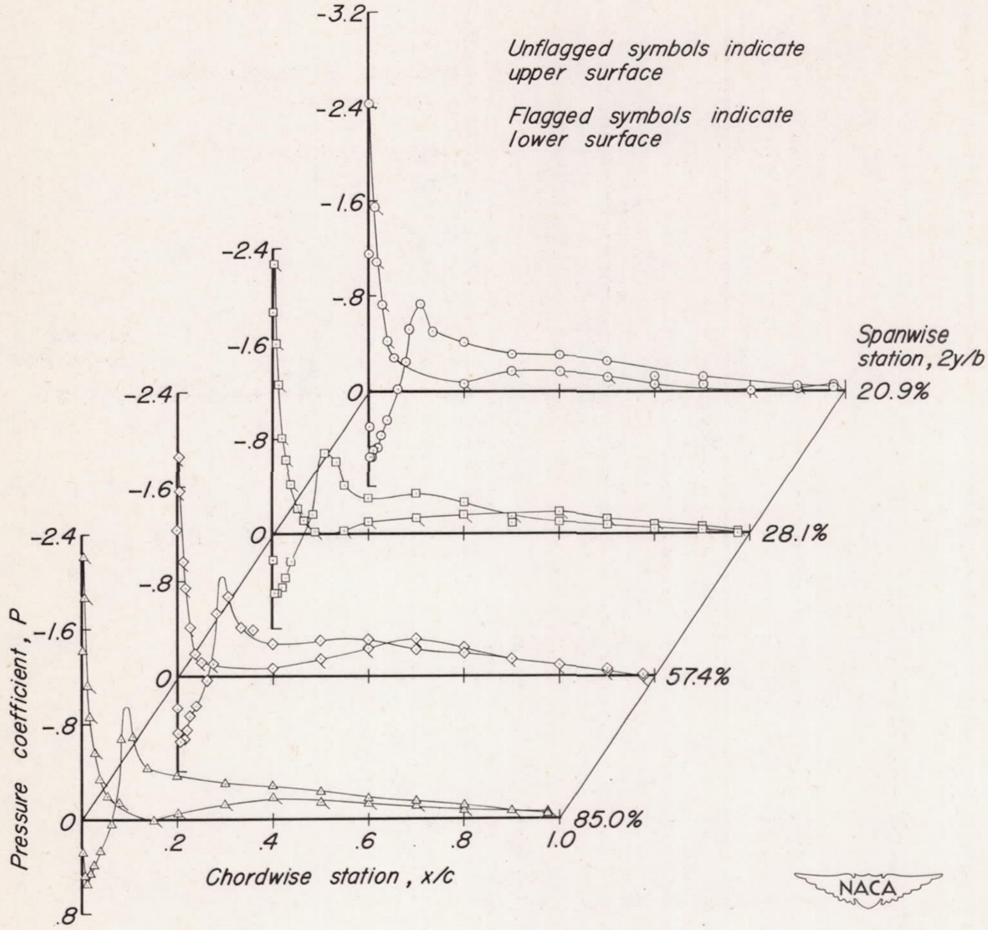
(g) $\alpha = 24.8^{\circ}$.

Figure 18.— Continued.



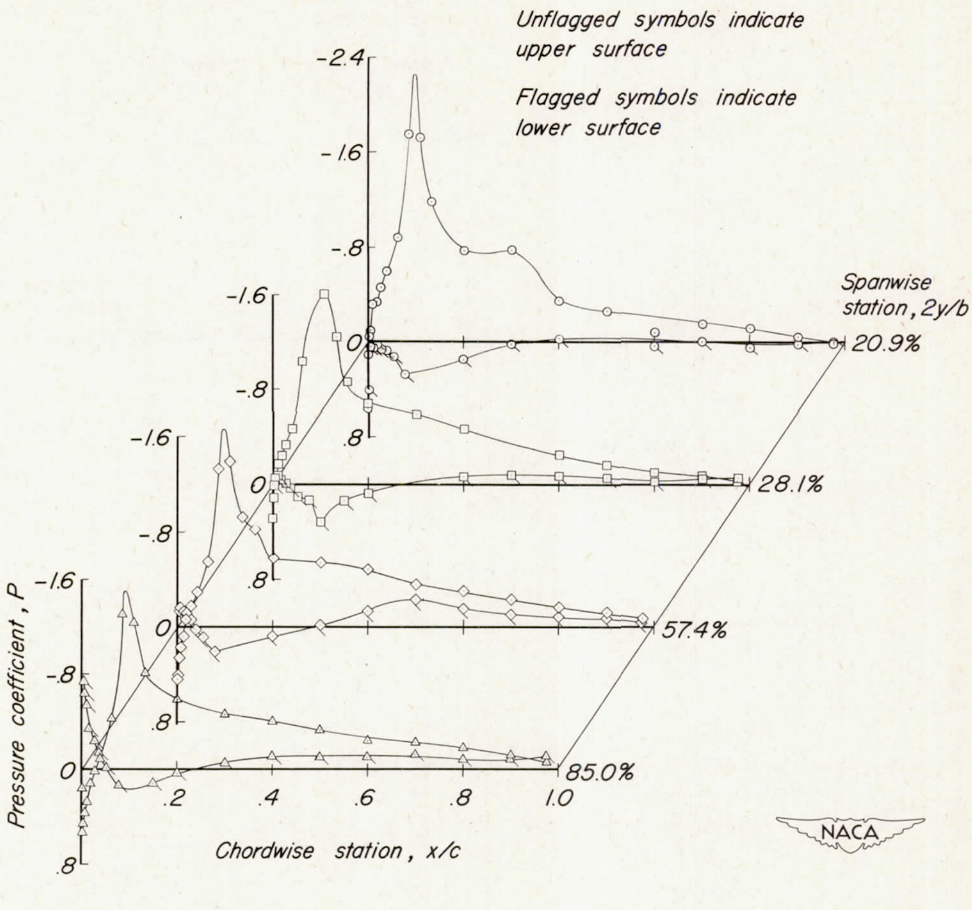
(h) $\alpha = 28.8°$.

Figure 18.– Concluded.



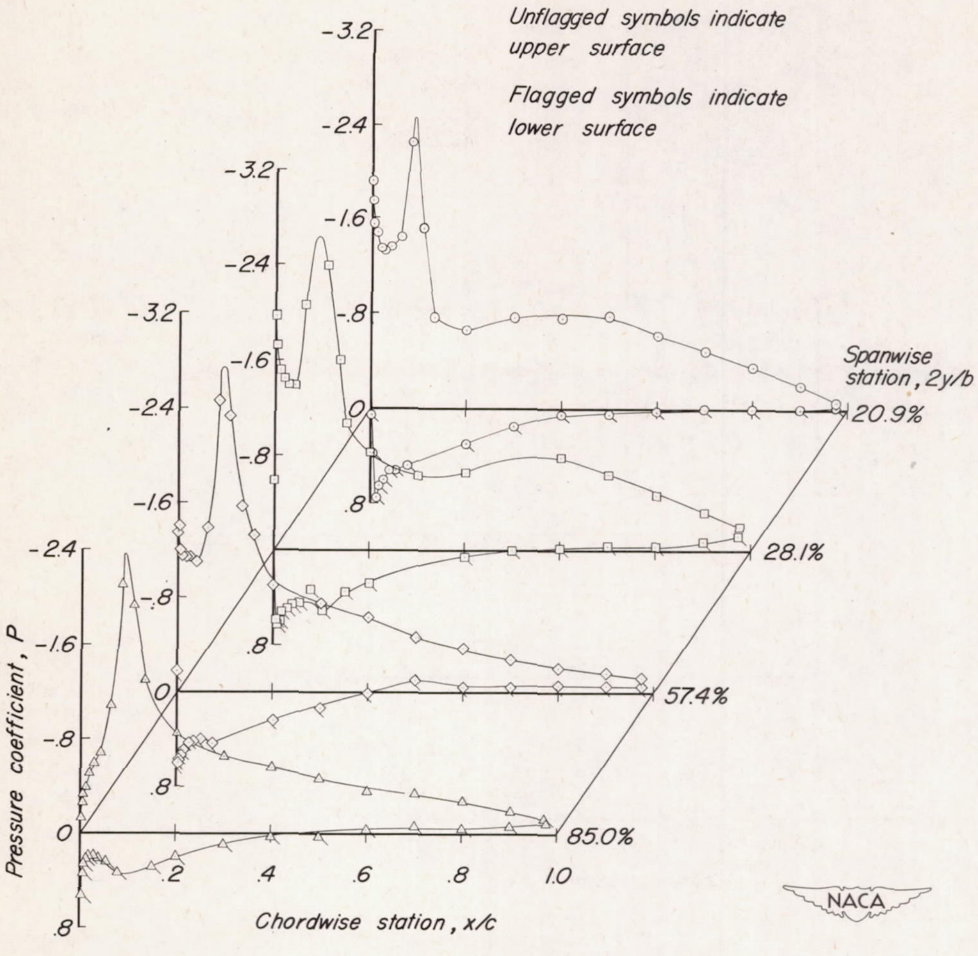
(a) $\alpha = 0.1°$.

Figure 19.— Chordwise pressure distributions for the 45° swept-forward wing-fuselage combination with a full-span leading edge flap deflected 30° down. Reynolds number, 10,600,000.



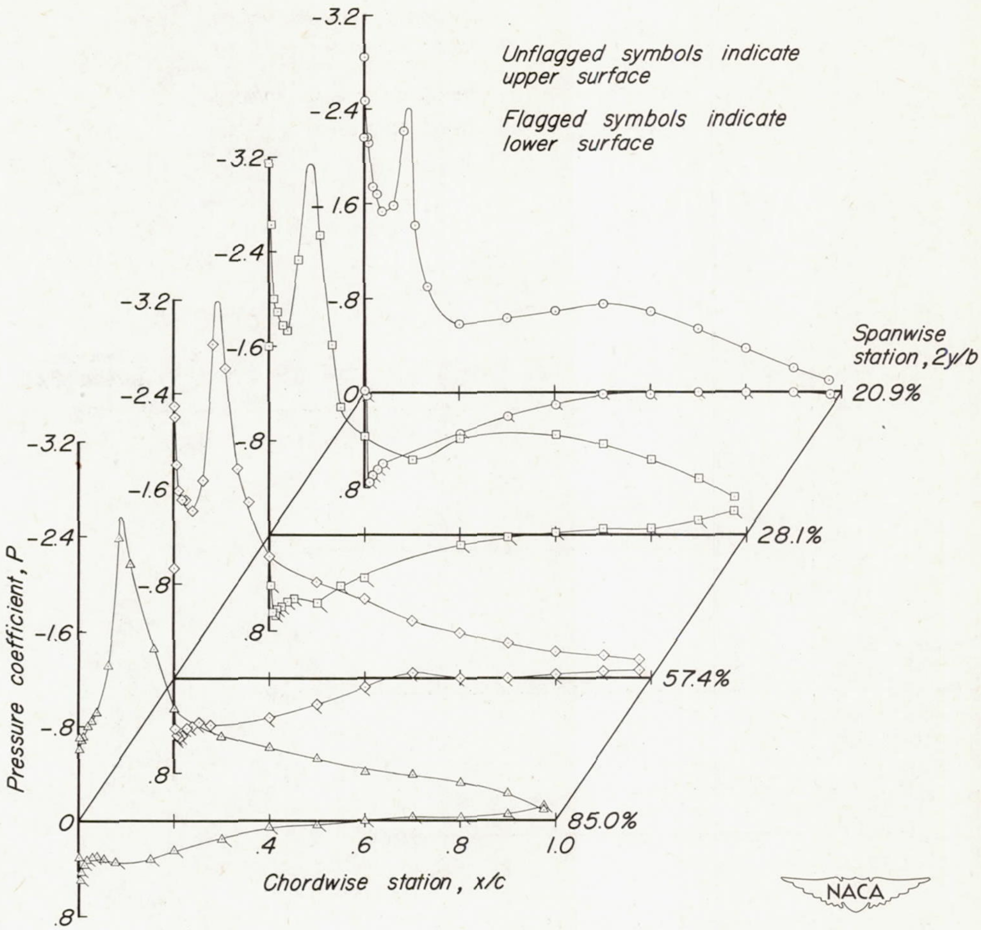
(b) $\alpha = 6.3°$.

Figure 19.— Continued



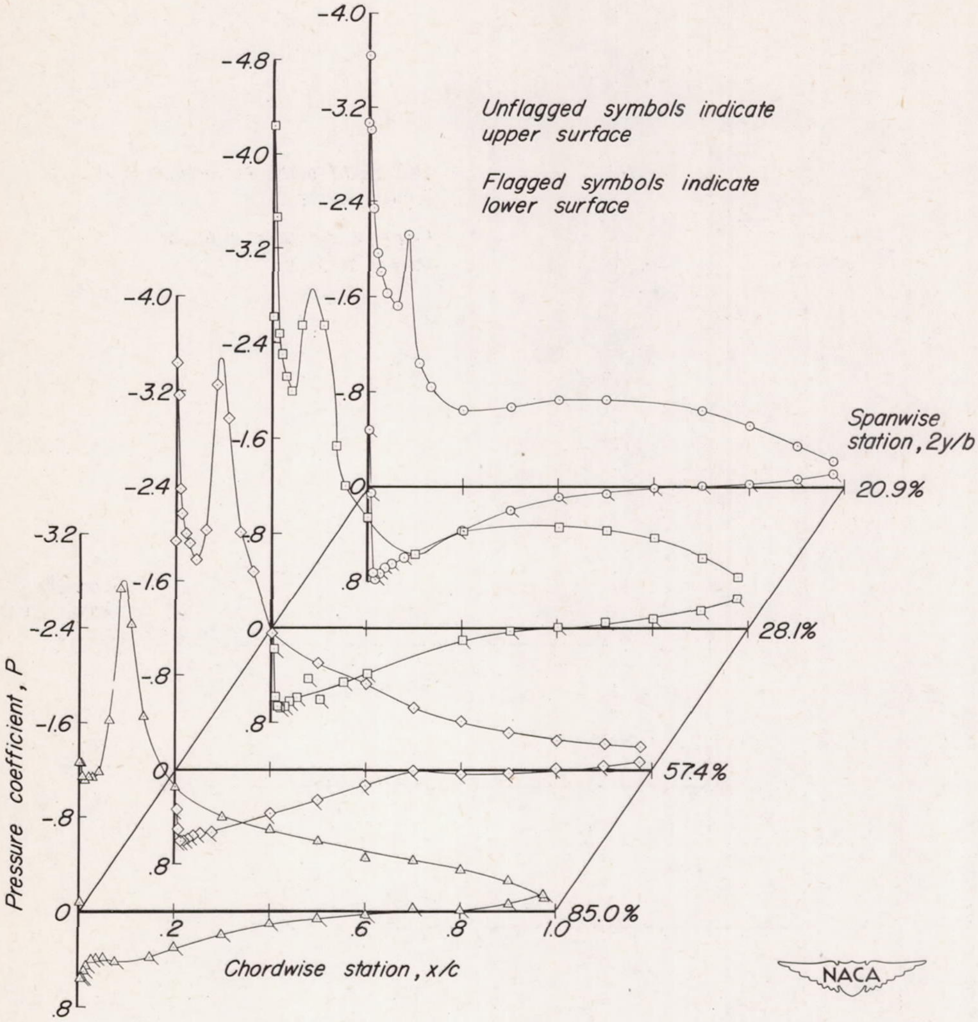
(c) $\alpha = 12.5°$.

Figure 19.— Continued.



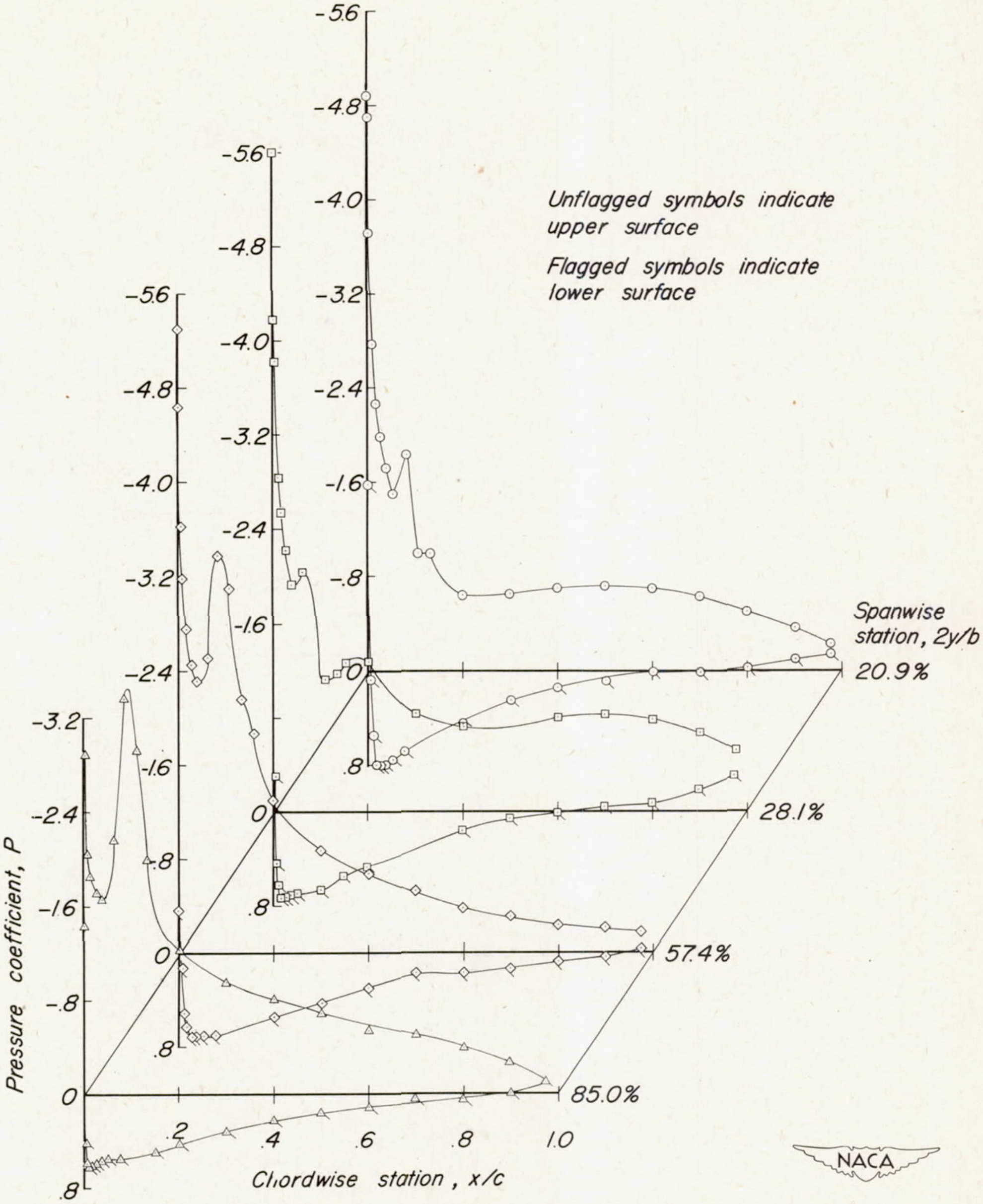
(d) $\alpha = 14.6°$.

Figure 19.– Continued.



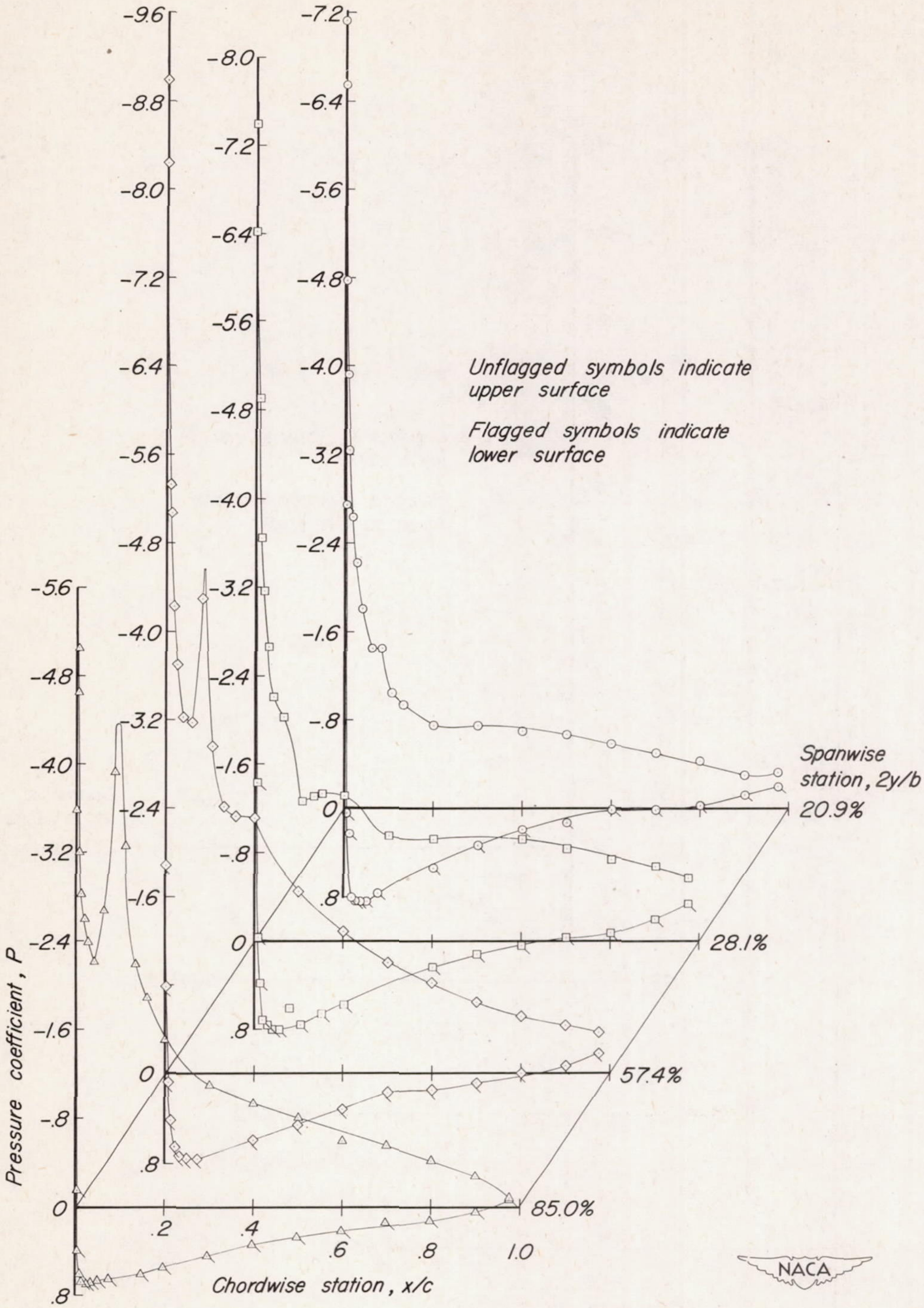
(e) $\alpha = 16.7°$.

Figure 19 .— Continued.



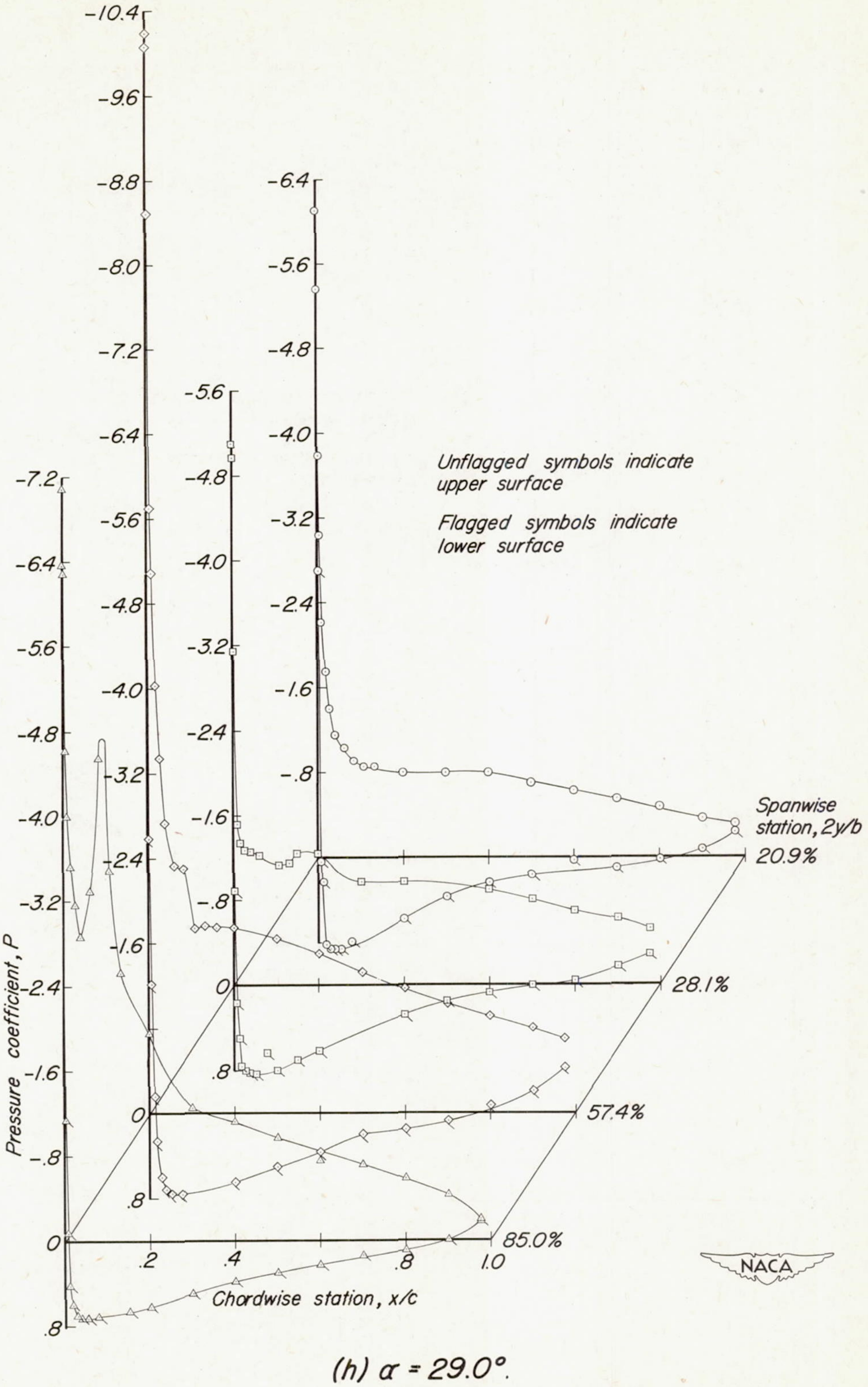
(f) $\alpha = 20.8°$.

Figure 19.— Continued.



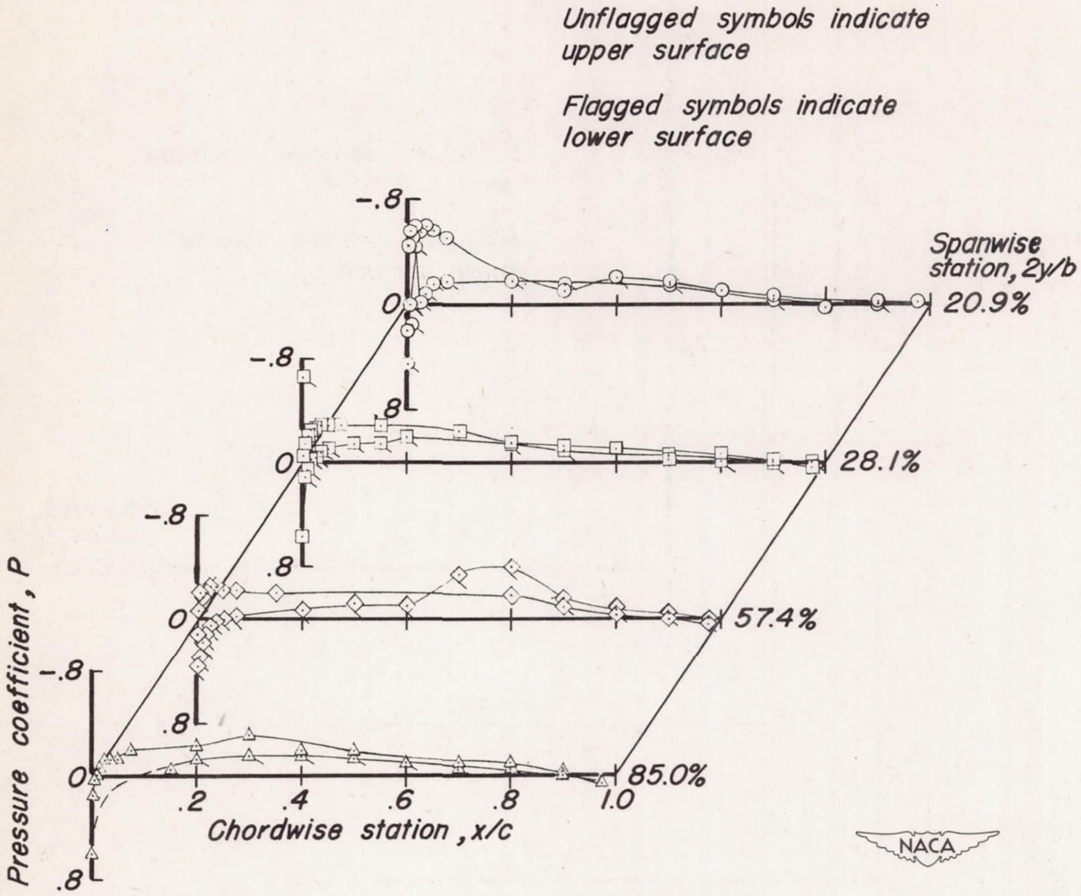
(g) $\alpha = 24.9°$.

Figure 19 .— Continued.



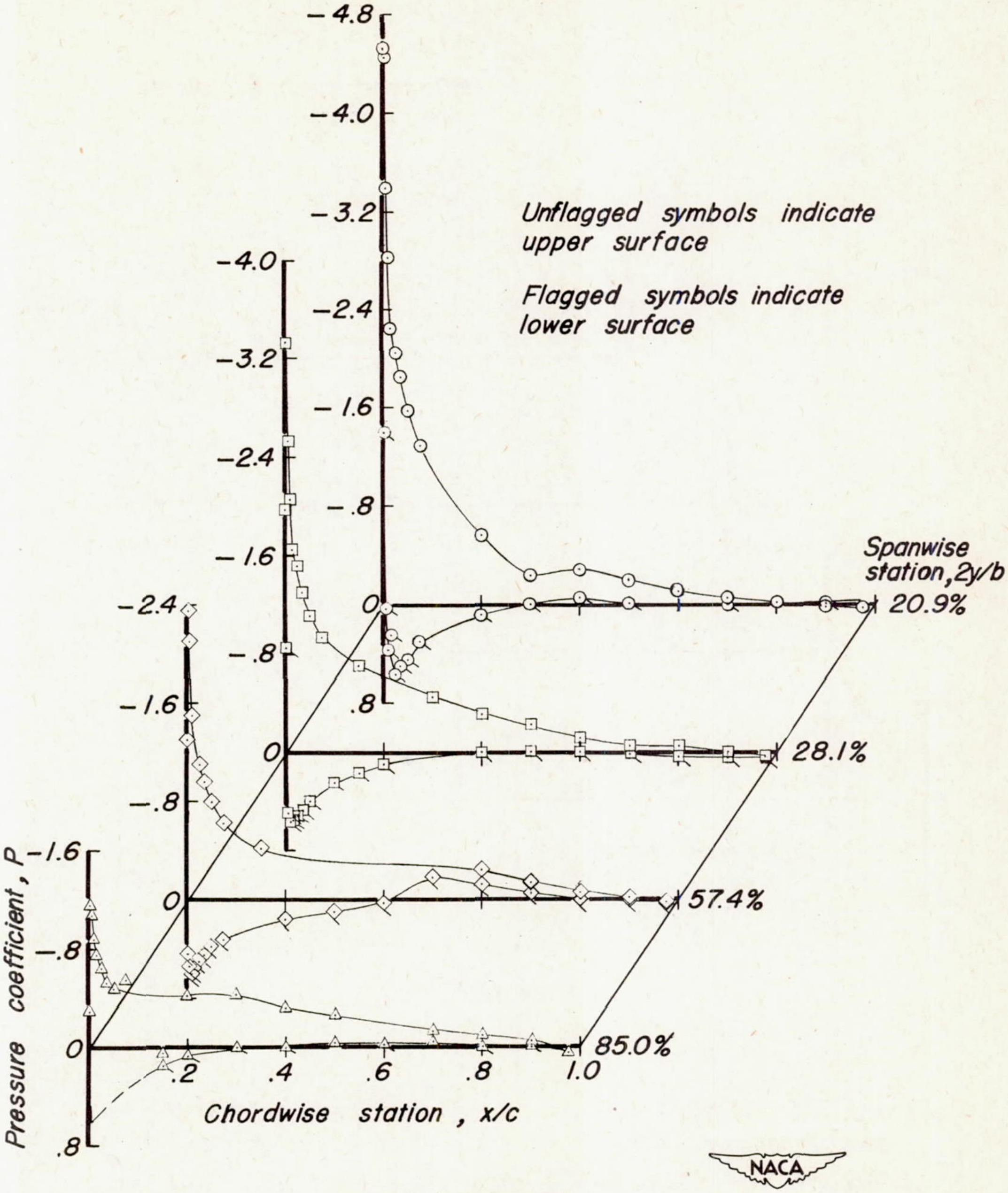
(h) α = 29.0°.

Figure 19.– Concluded.



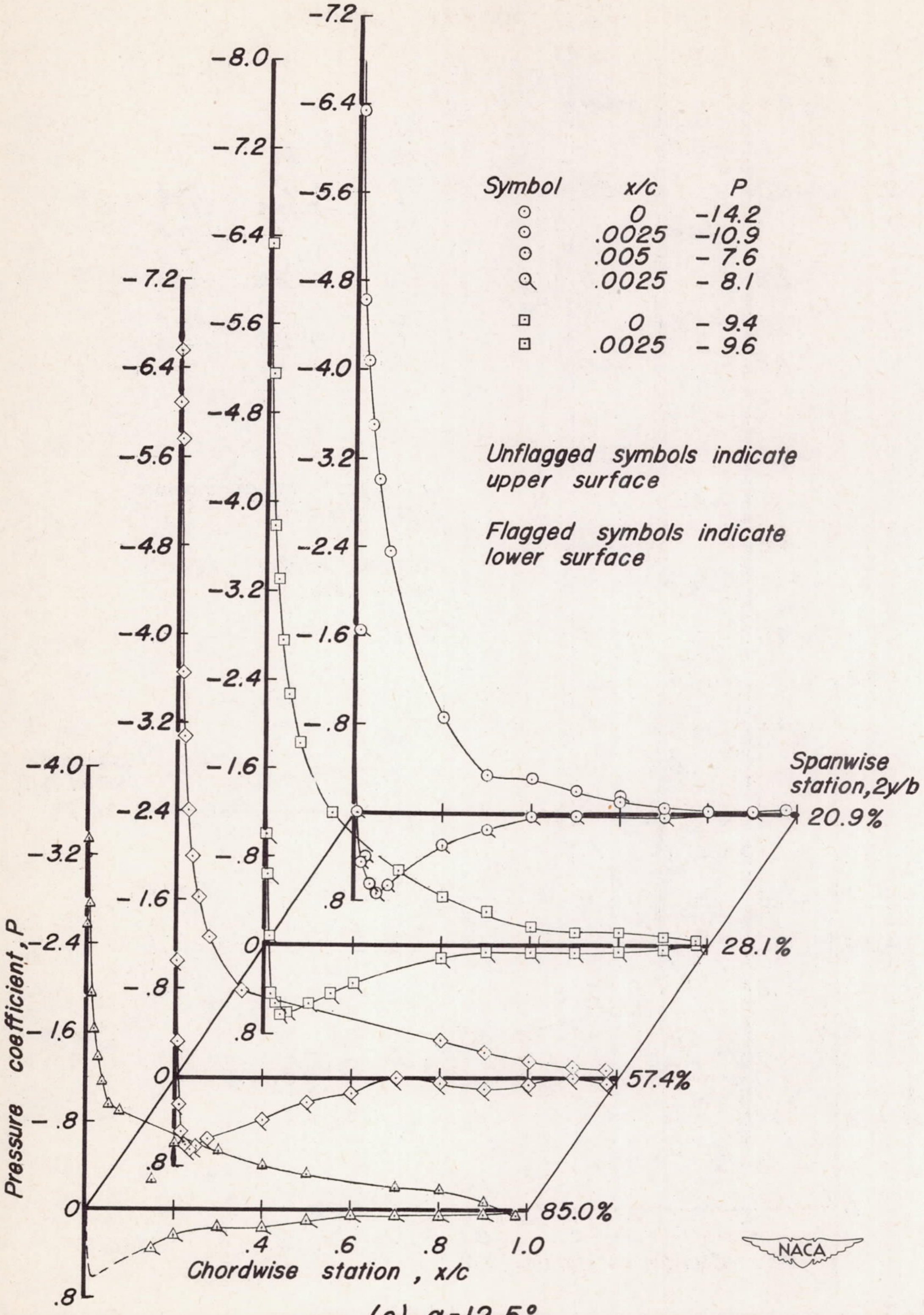
(a) α = 0.1°.

Figure 20.– Chordwise pressure distributions for the 45° swept-forward wing-fuselage combination with suction through the 15-by 10.75-inch slot. Reynolds number, 6,100,000.



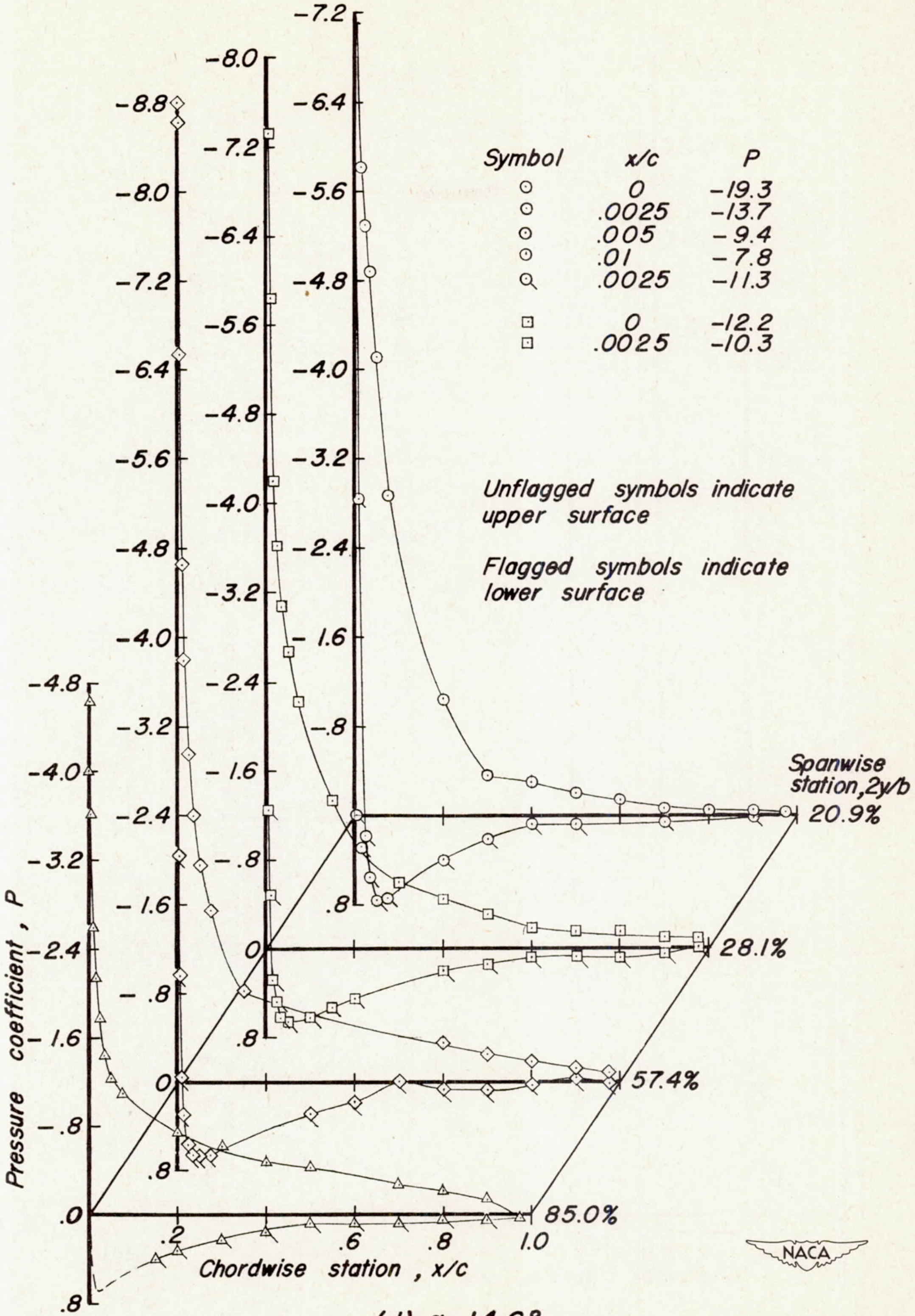
(b) α=6.3°.

Figure 20.— Continued.



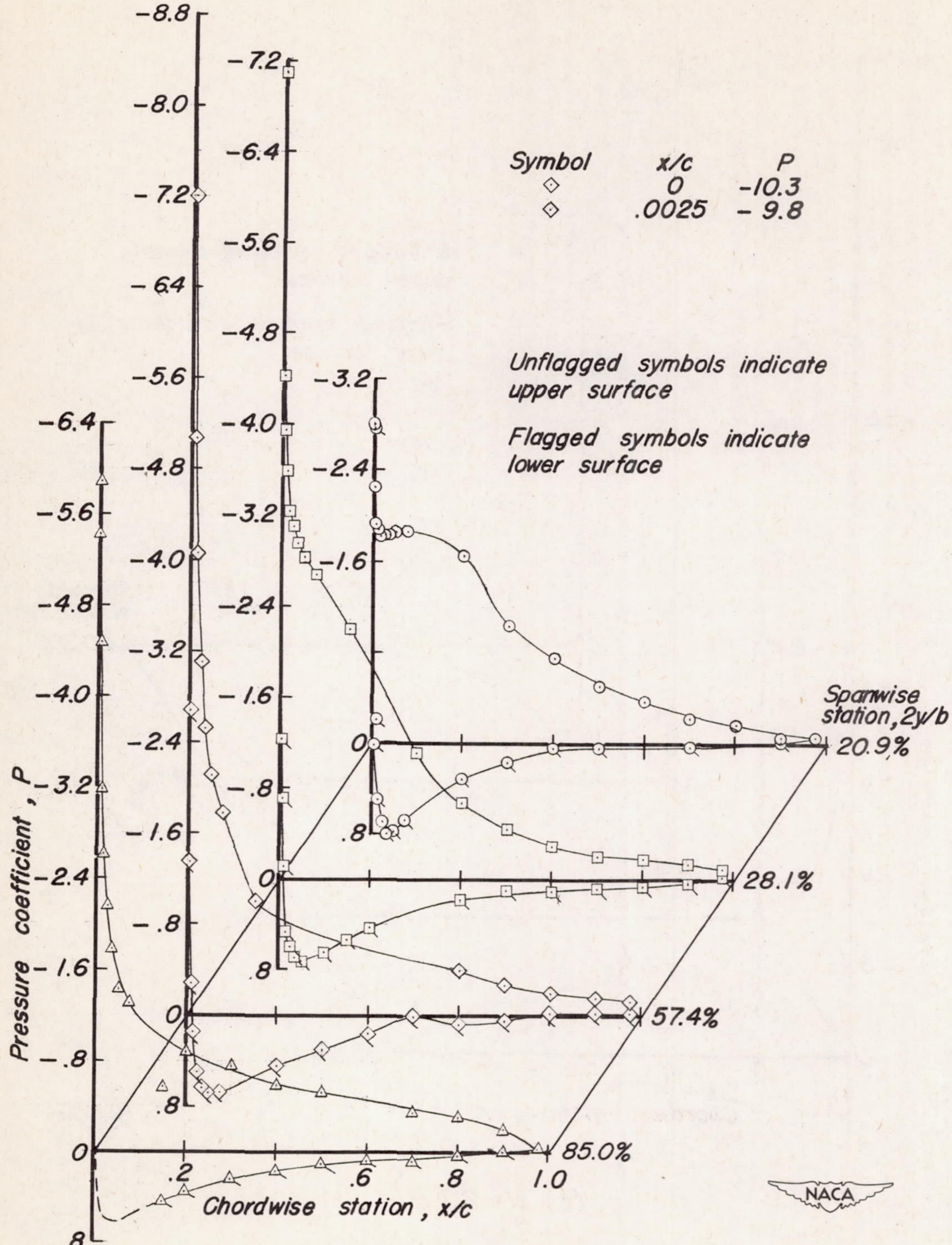
(c) α=12.5°.

Figure 20.— Continued .



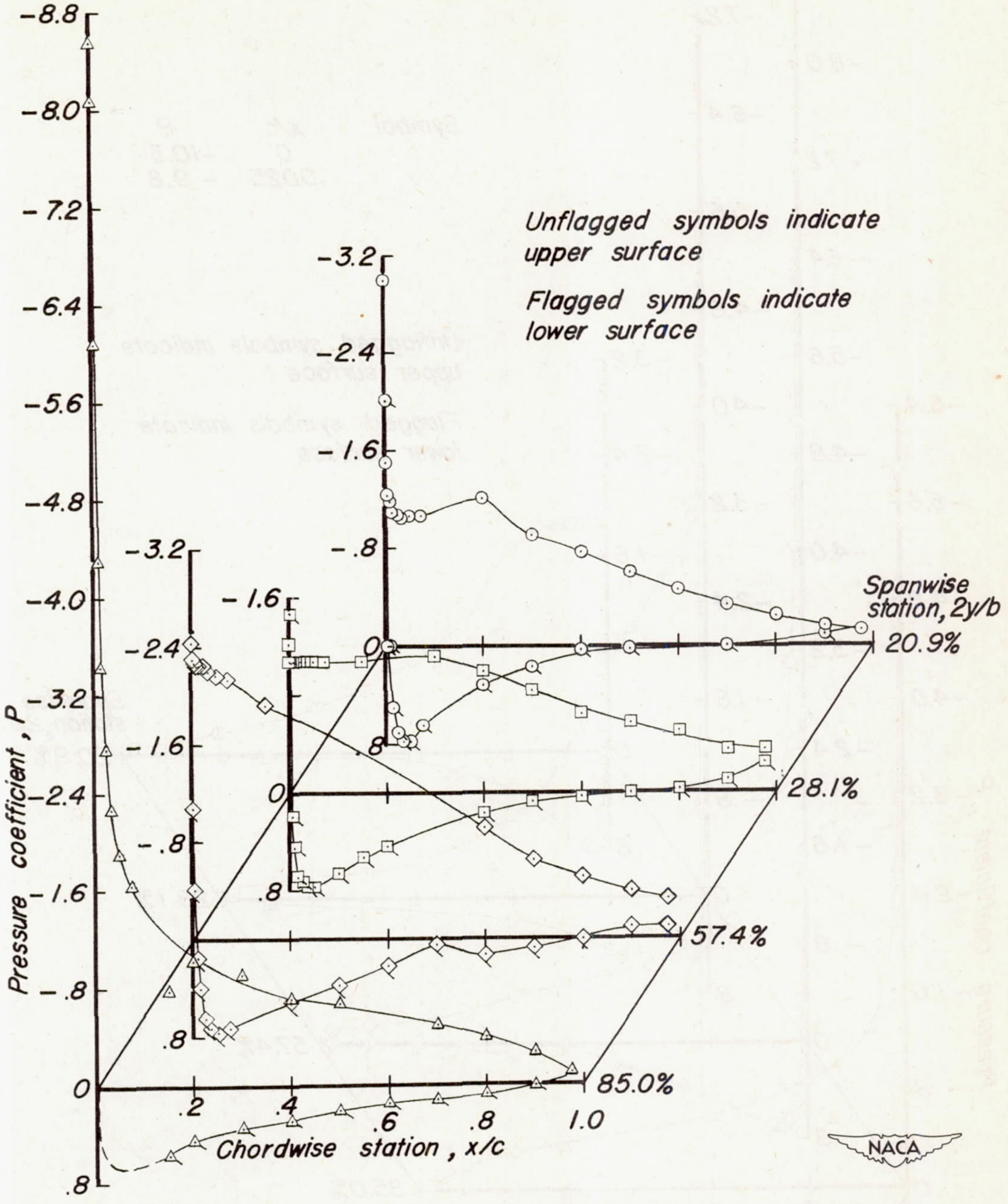
(d) α = 14.6°.

Figure 20.— Continued.



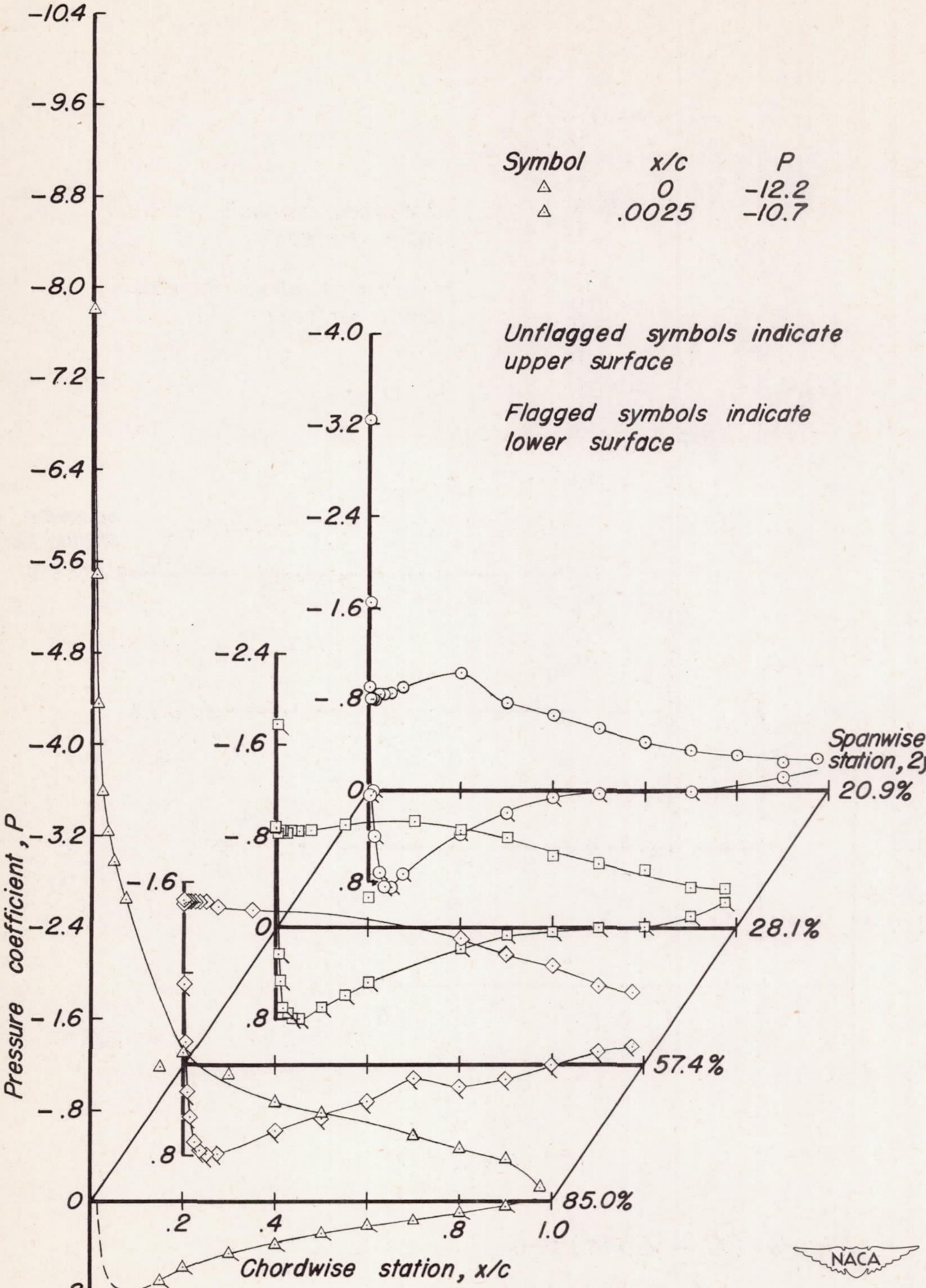
(e) α = 16.7°.

Figure 20.– Continued.



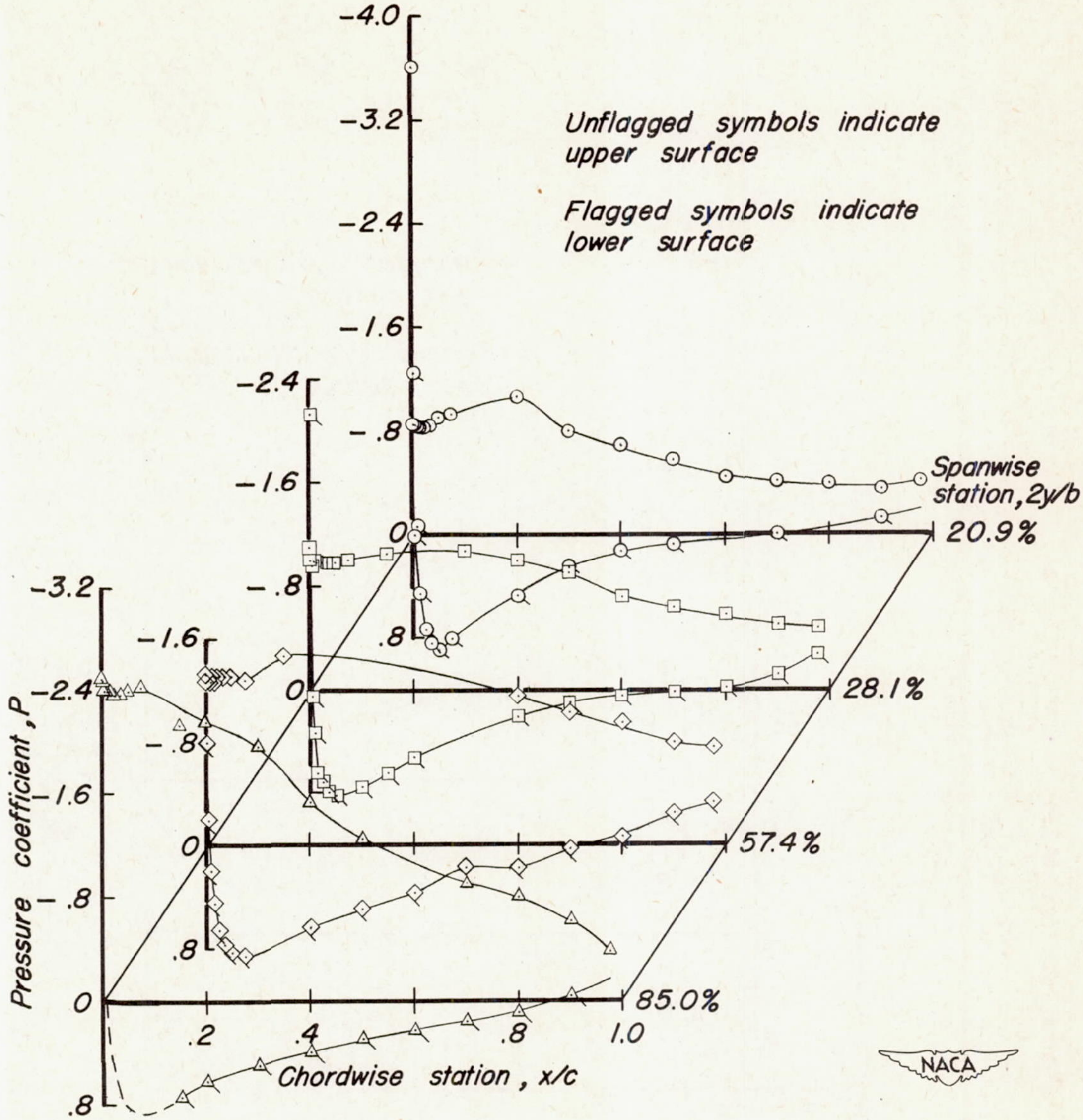
(f) α = 20.8°.

Figure 20.— Continued.



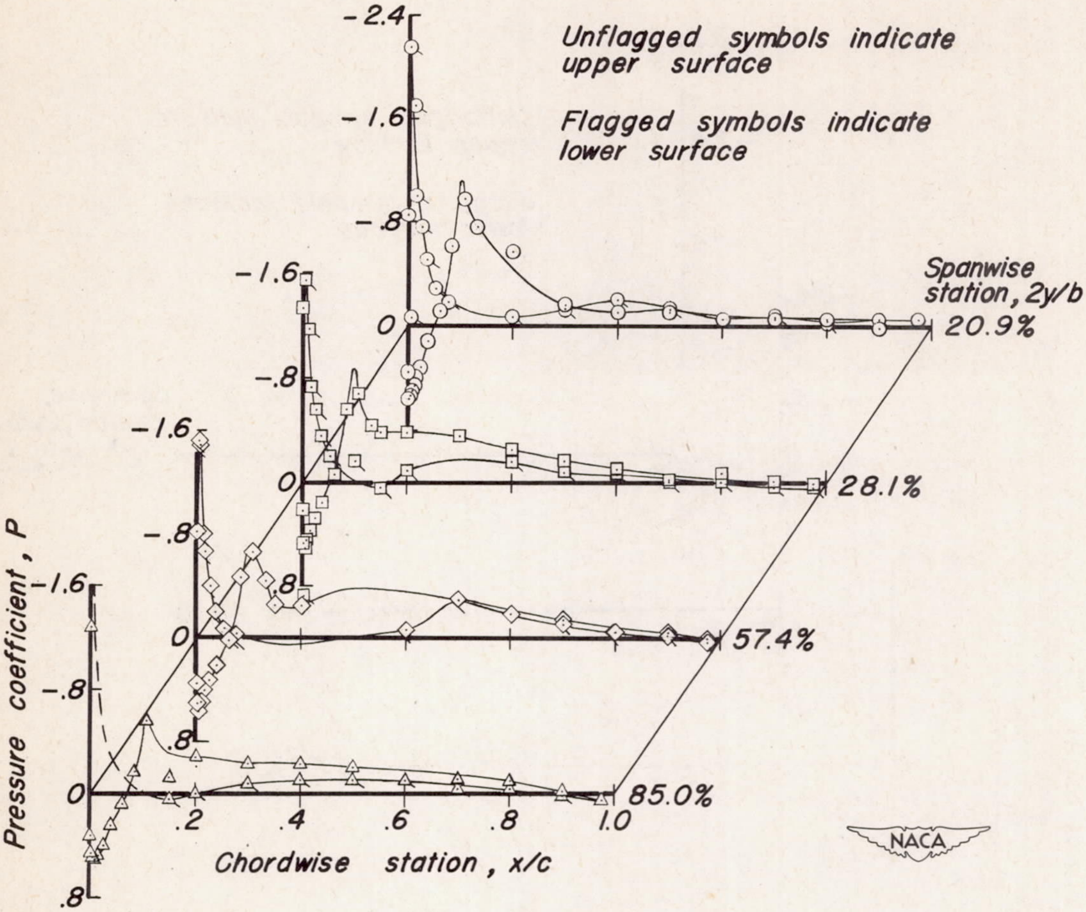
(g) α = 24.8°.

Figure 20.— Continued.



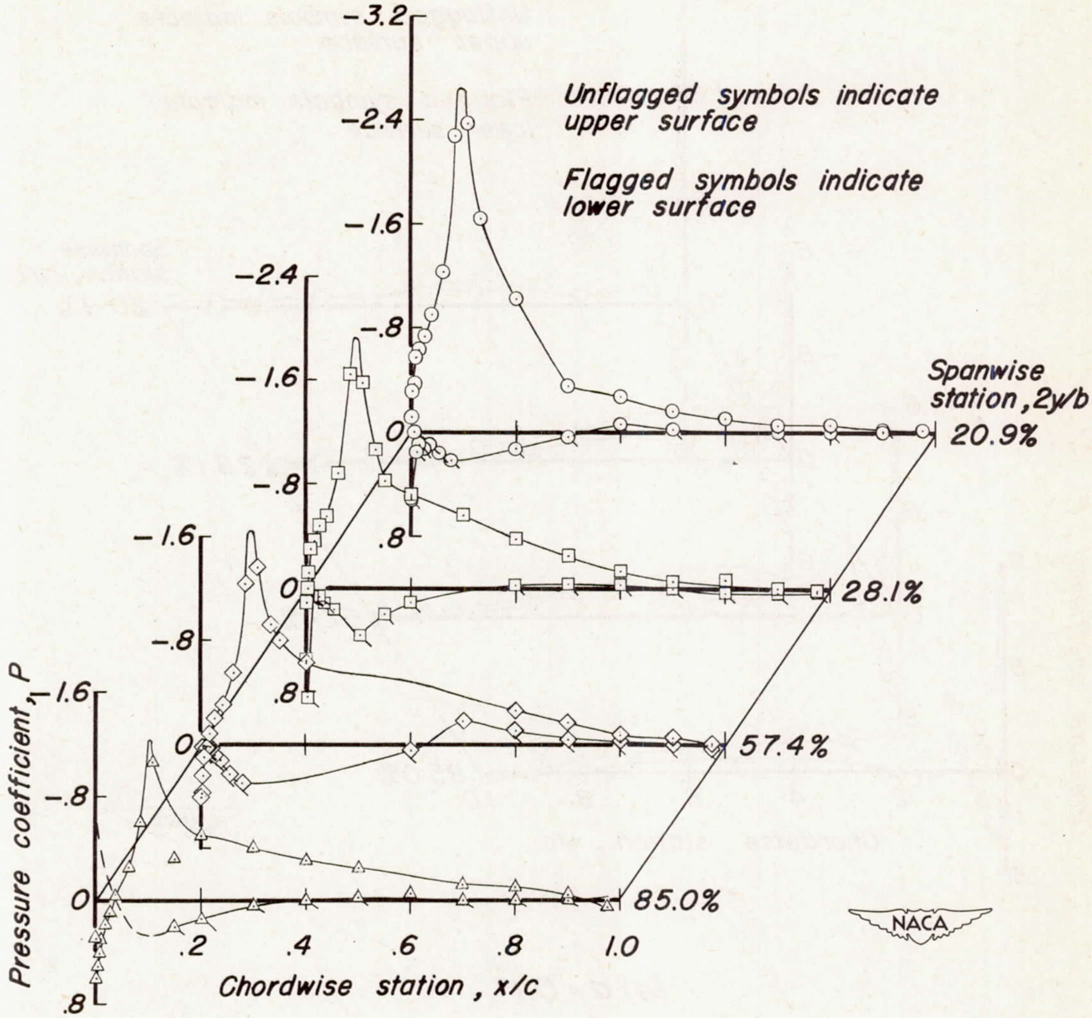
(h) $\alpha = 28.9°$.

Figure 20.— Concluded.



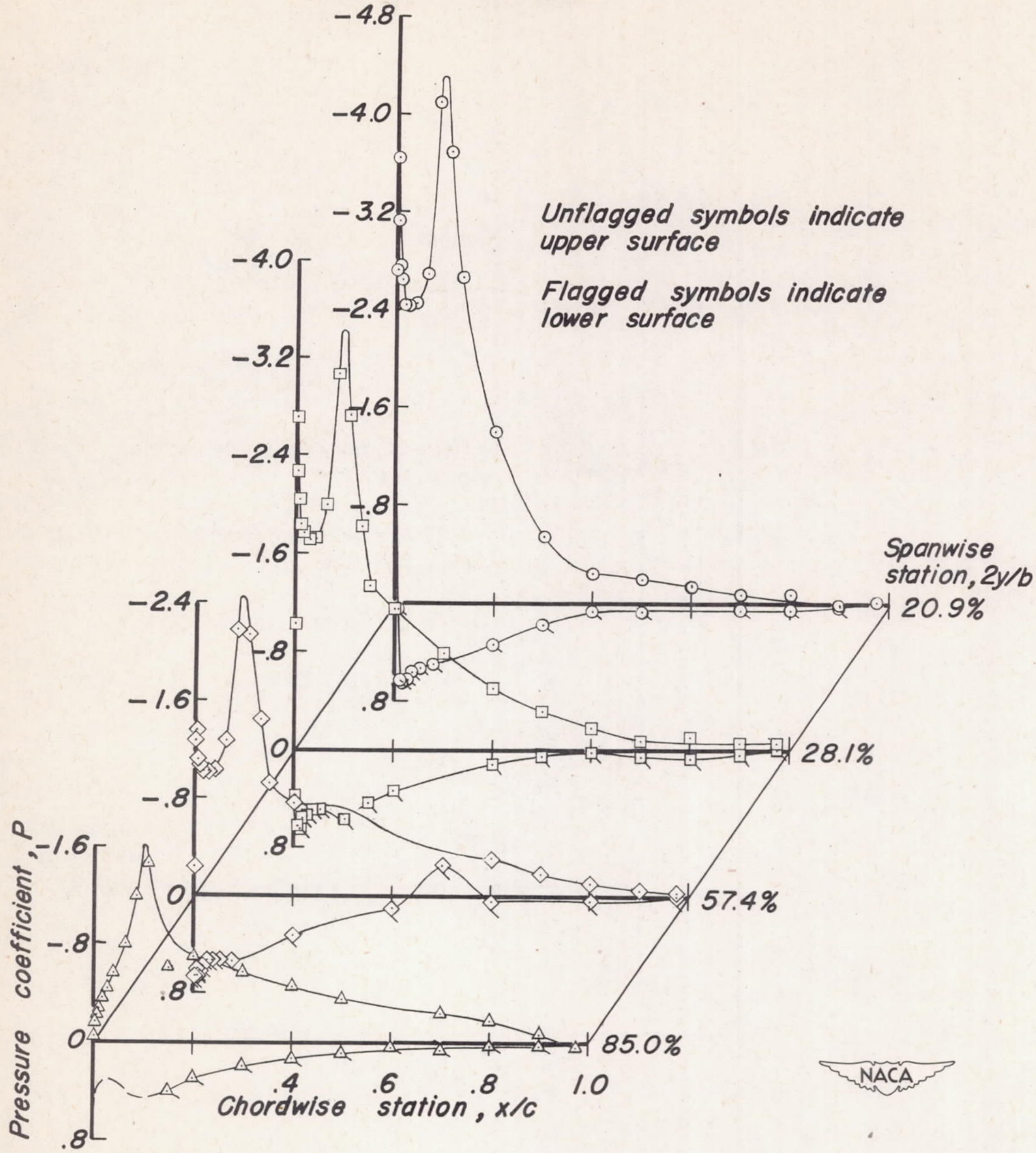
(a) $\alpha = 0.1°$.

Figure 21.–Chordwise pressure distributions for the 45° swept-forward wing-fuselage combination with a full span leading-edge flap deflected 30° down and suction through the 24.5-by 4.5-inch slot. Reynolds number, 6,100,000.



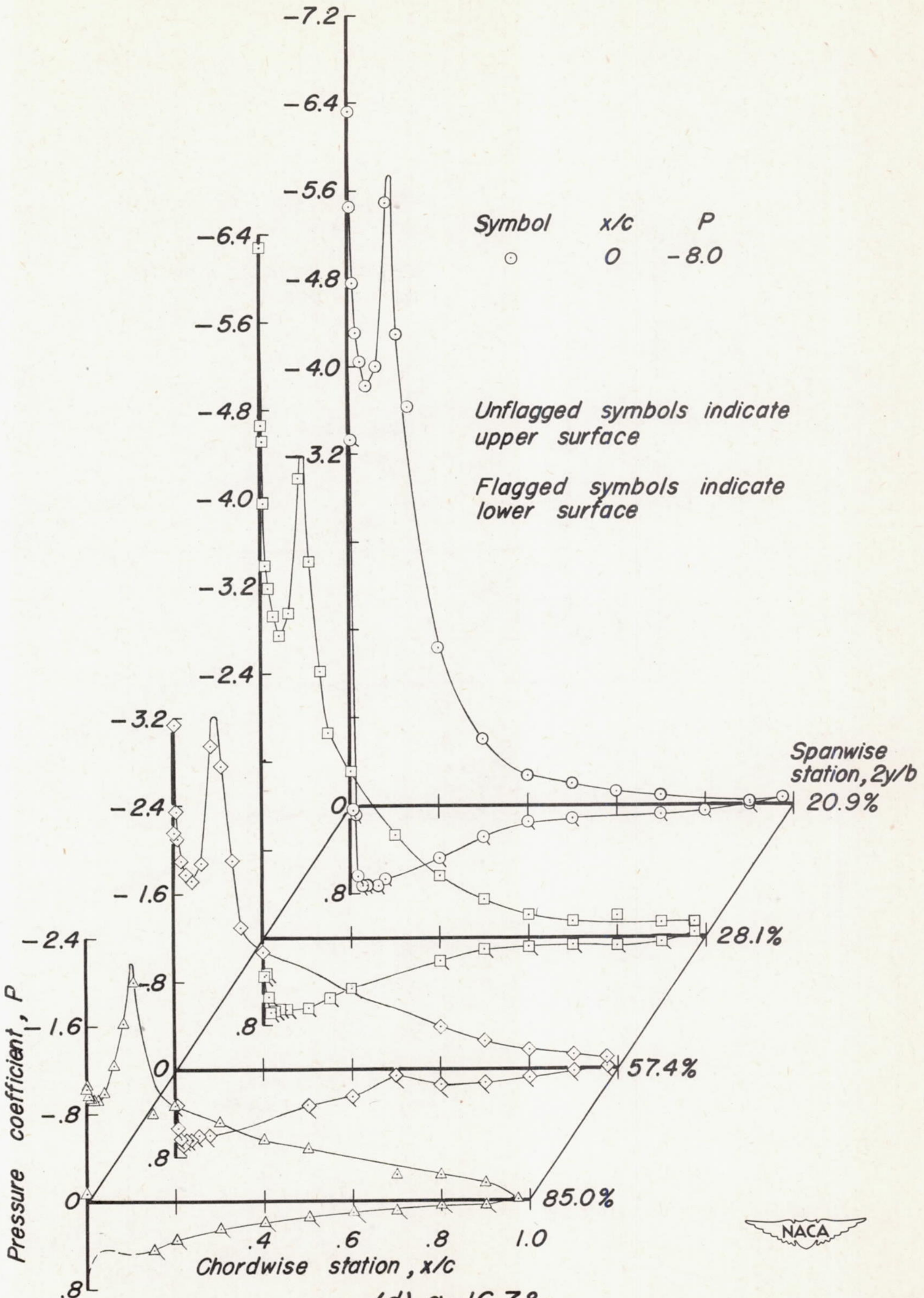
(b) $\alpha = 6.3°$.

Figure 21.— Continued .



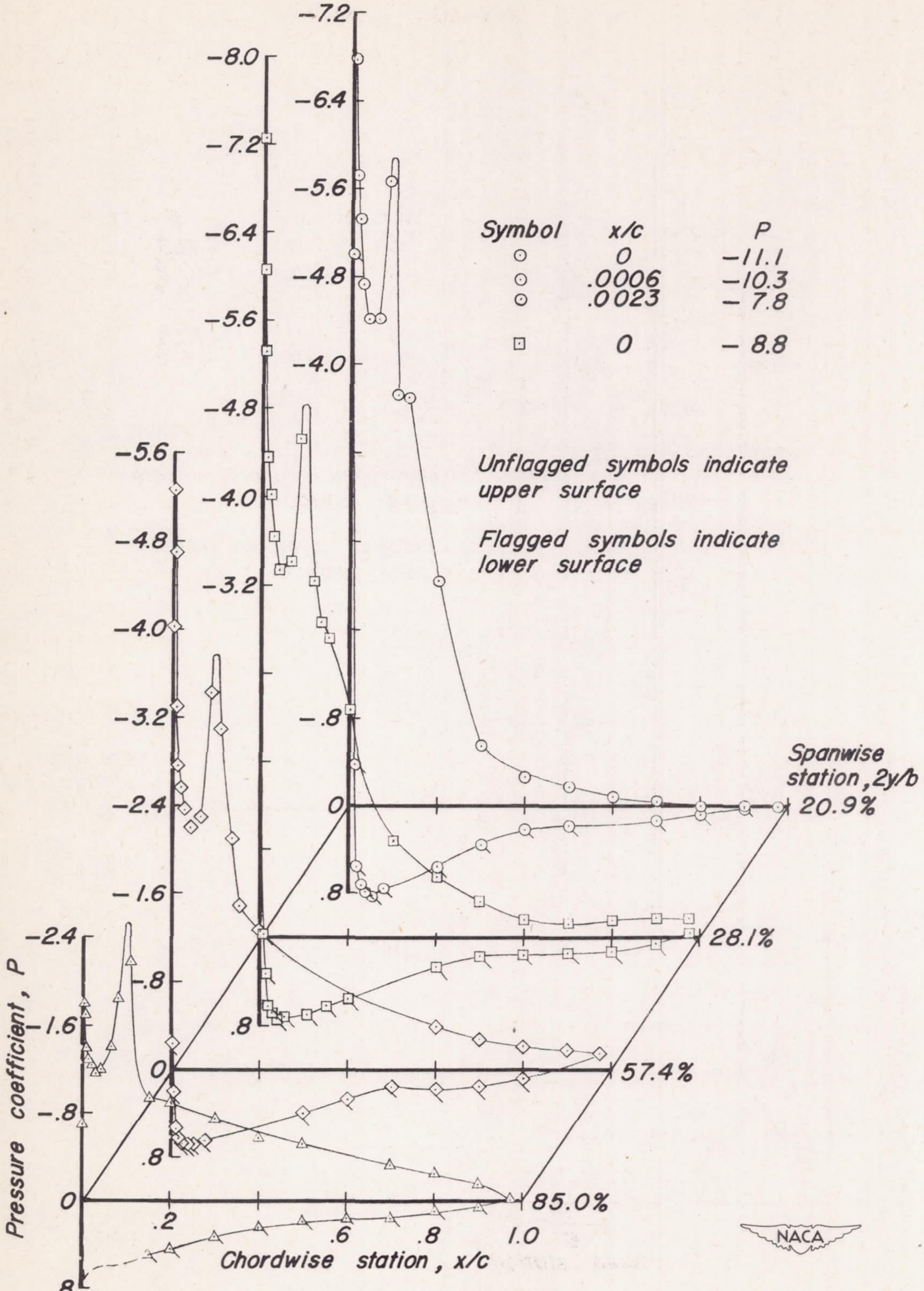
(c) α=12.5°.

Figure 21.– Continued.



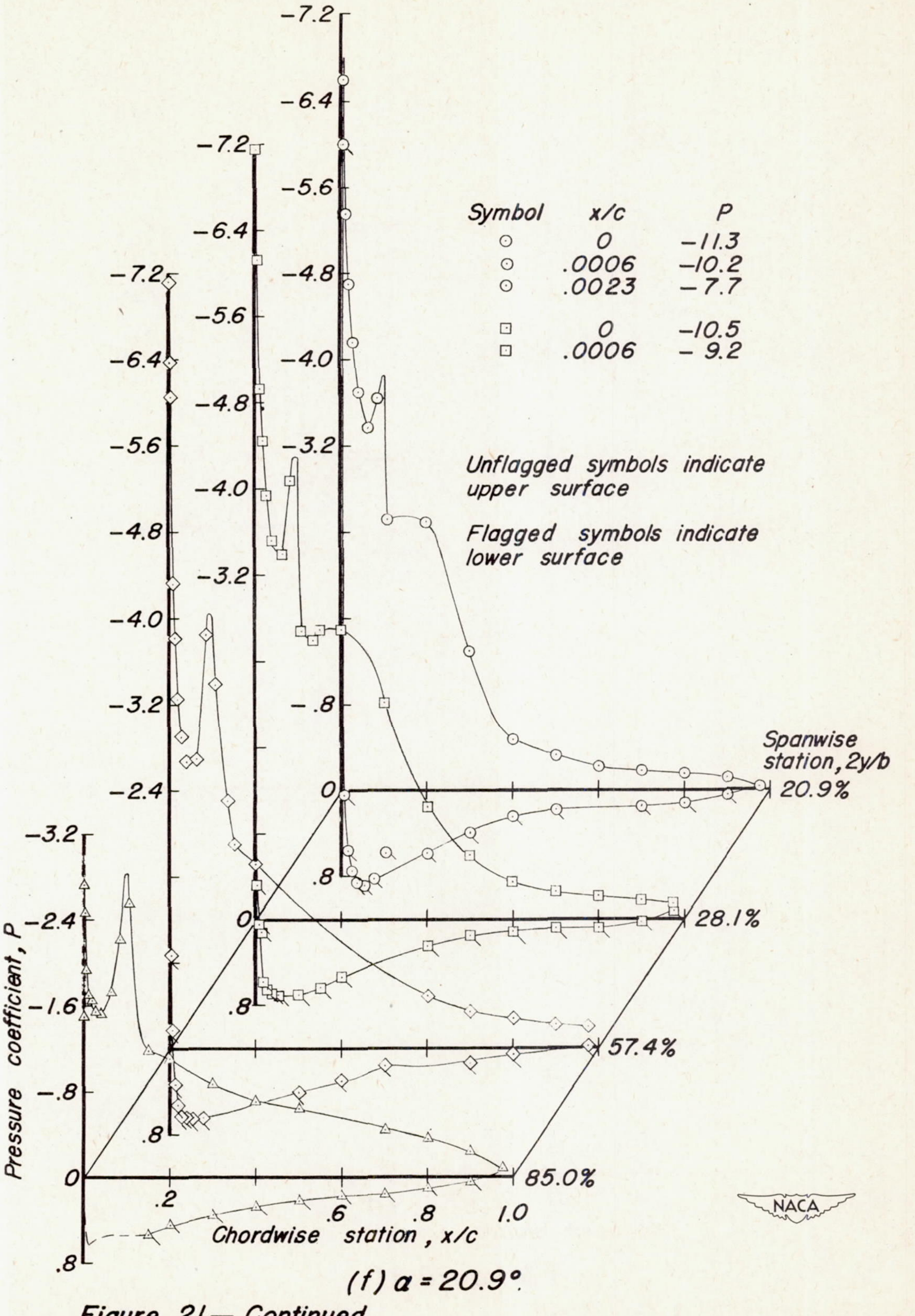
(d) α = 16.7°.

Figure 21.— Continued.



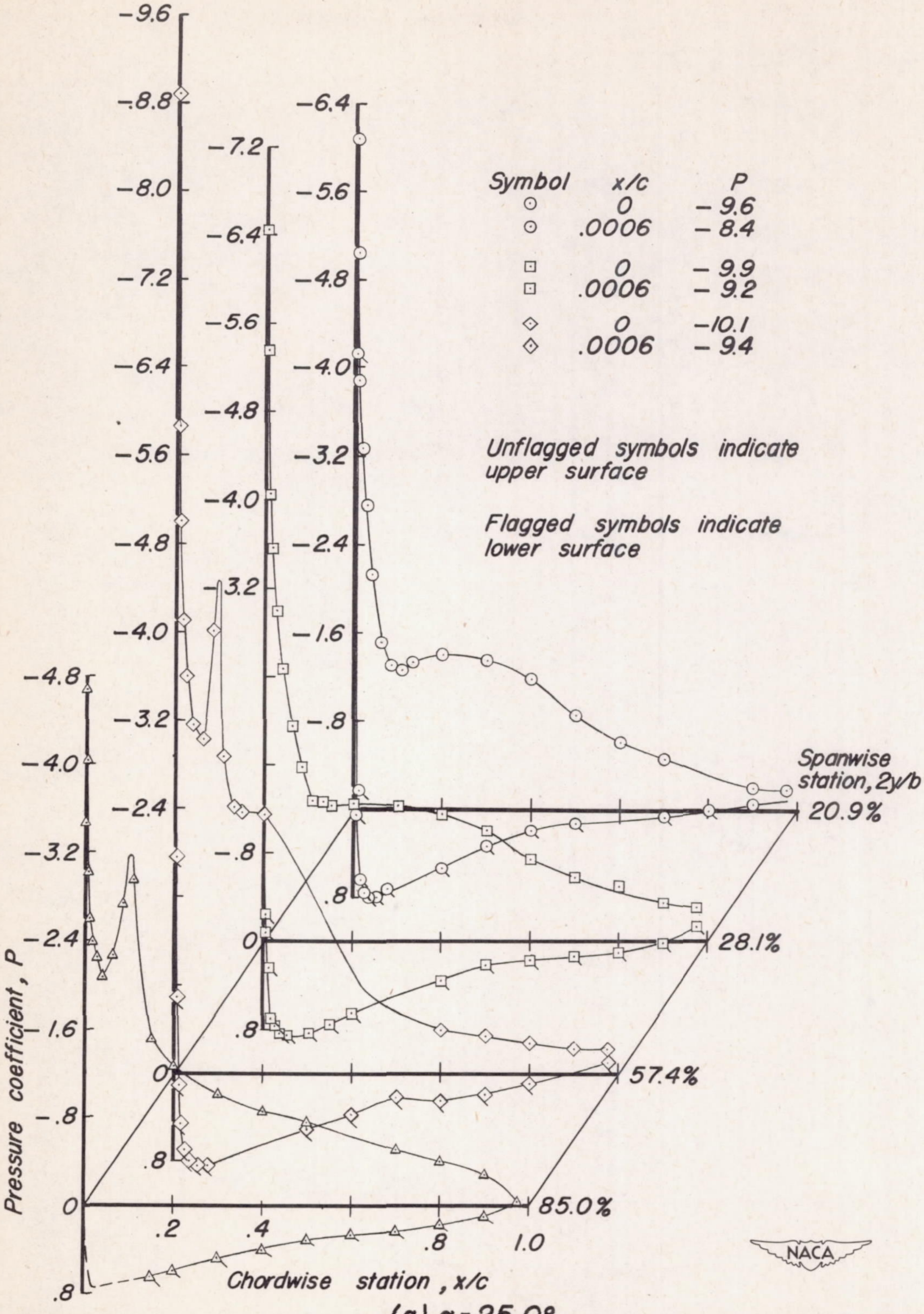
(e) $\alpha = 18.8°$.

Figure 21.— Continued.



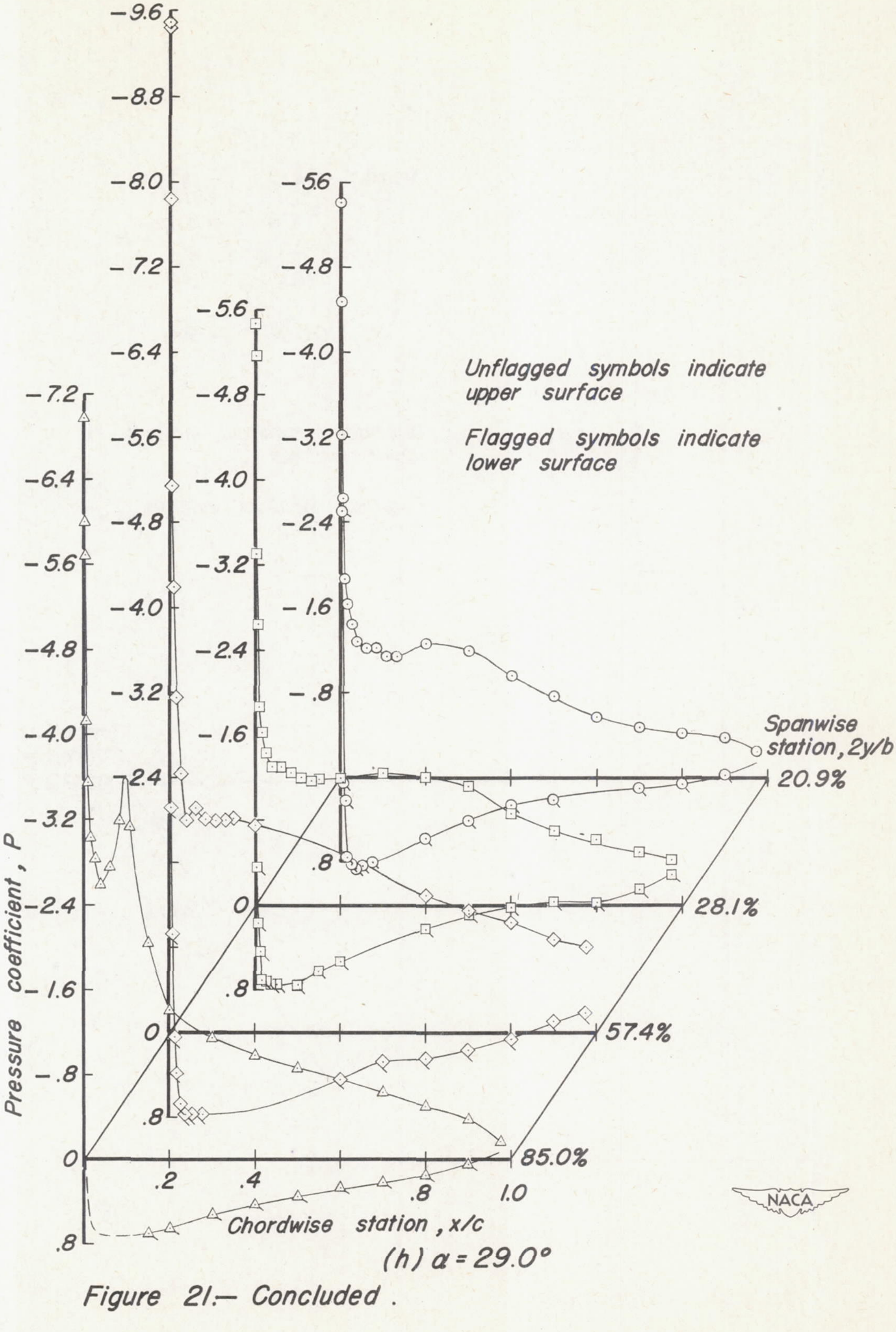
(f) $\alpha = 20.9°$.

Figure 21.— Continued.



(g) $\alpha = 25.0°$.

Figure 21.— Continued.



(h) α = 29.0°

Figure 21.— Concluded.

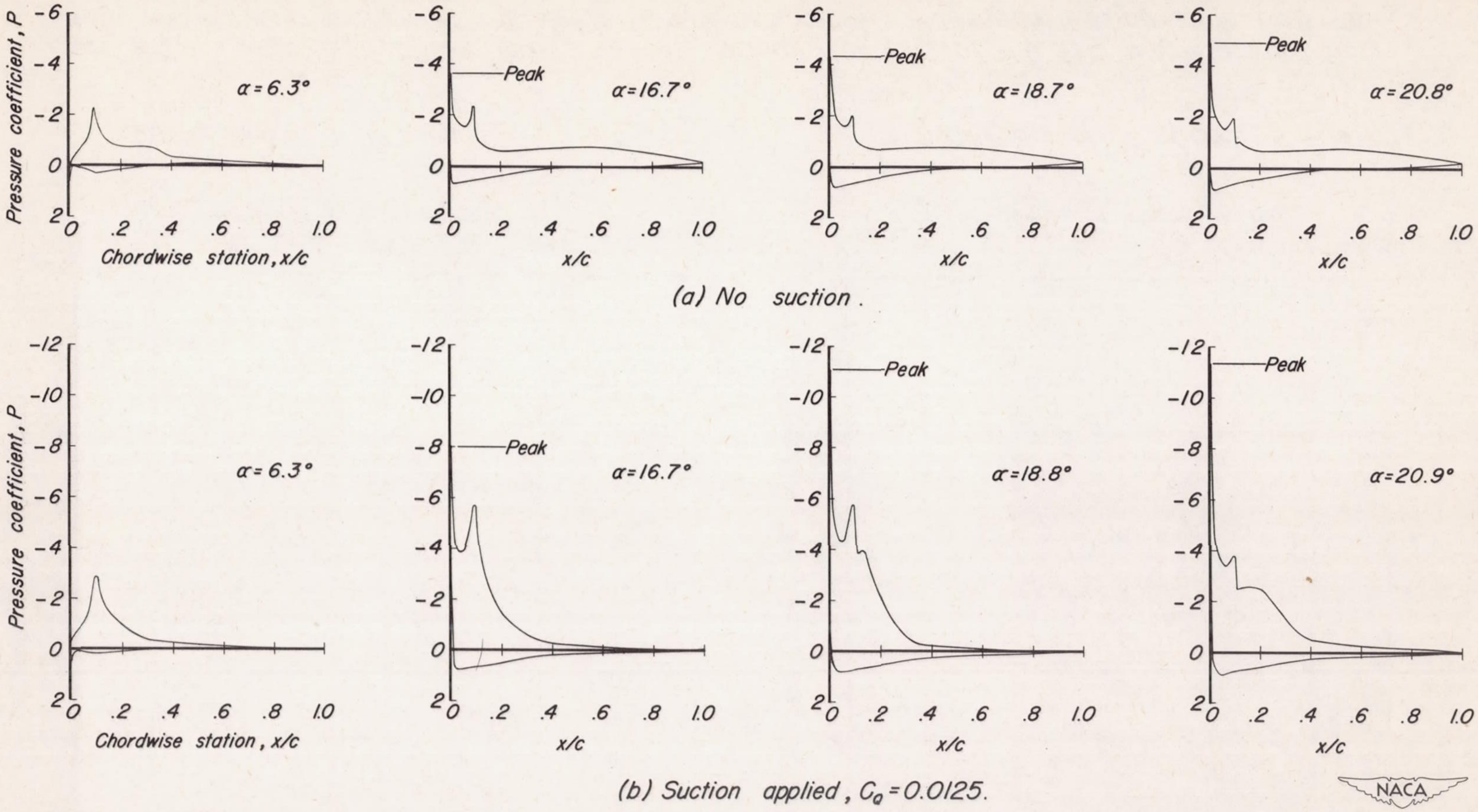
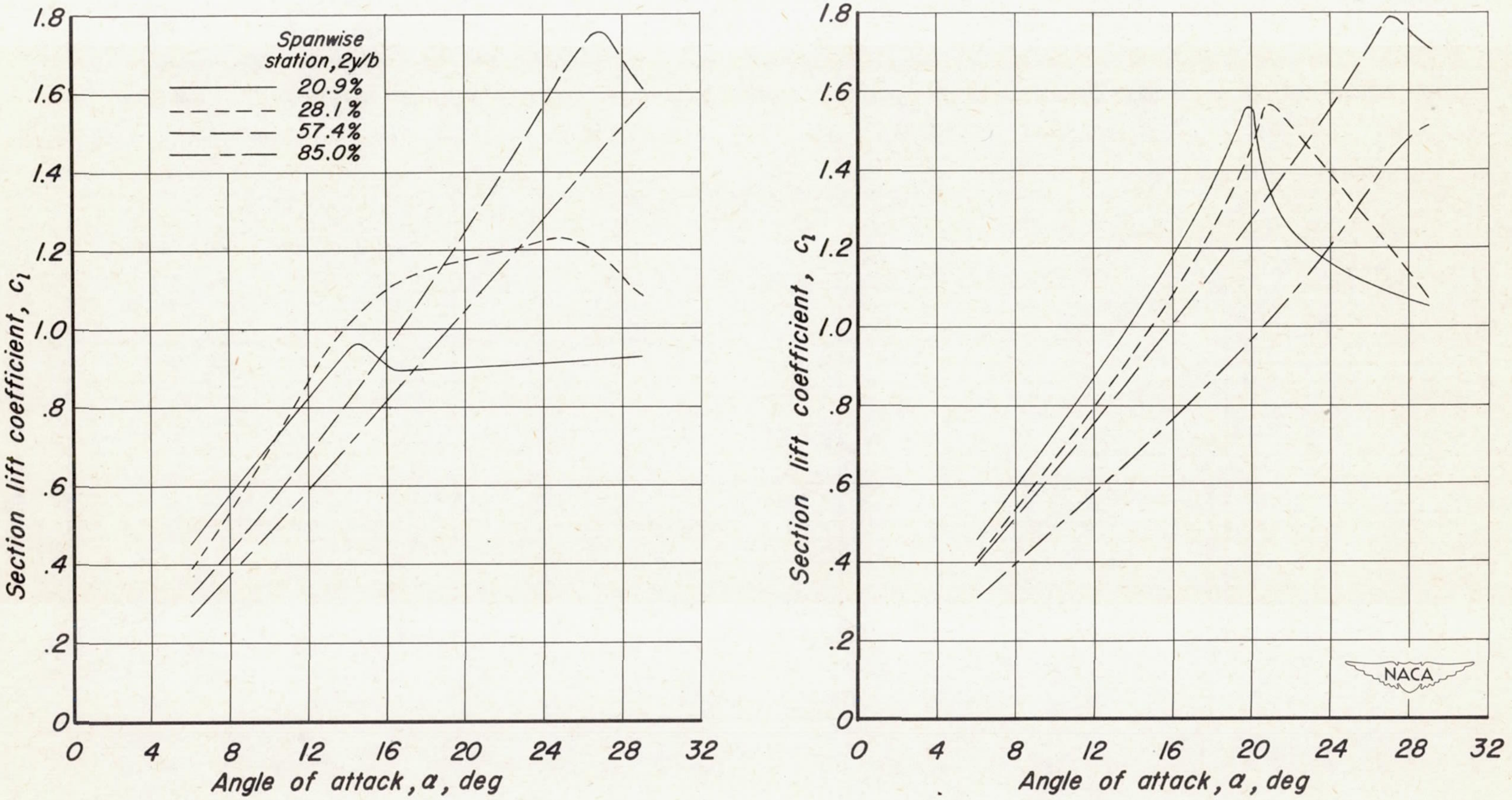


Figure 22.– Comparison of the pressure distributions over the chordwise section at 20.9-percent semispan with and without suction at the 24.5-by 4.5-inch slot. Full-span leading-edge flap deflected 30° down. Reynolds number, 6,100,000.



(a) No suction. $R = 10.6 \times 10^6$.

(b) Suction applied. $C_Q = 0.0125$, $R = 6.1 \times 10^6$.

Figure 23.— Comparison of the lift curves of various sections of the 45° swept-forward wing with and without suction at the 24.5-by 4.5-inch slot. Full-span leading-edge flap deflected 30° down.

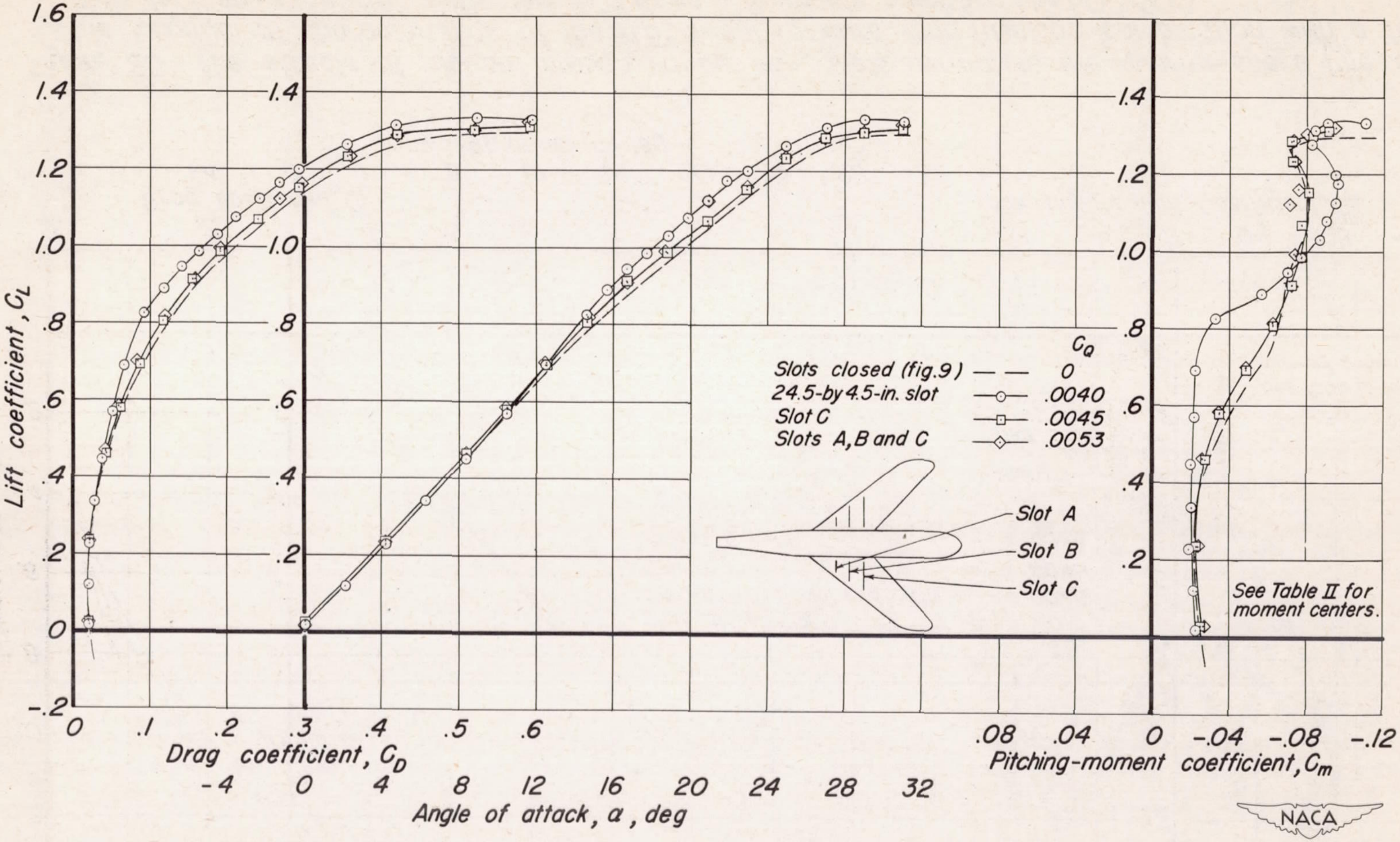


Figure 24.– The effects of suction through various wing slots normal to the free stream on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Reynolds number, 10,600,000.

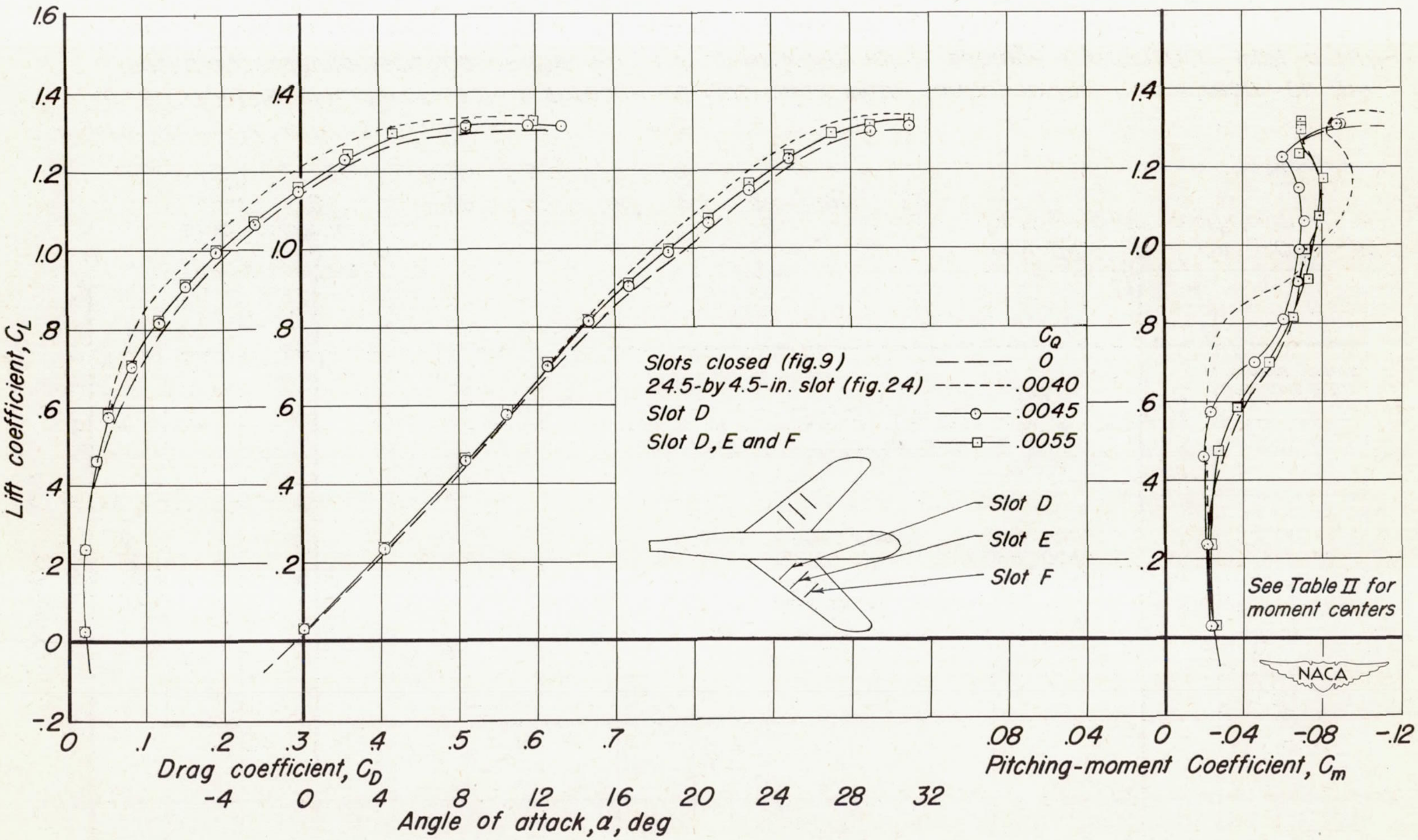


Figure 25.–The effects of suction through various wing slots normal to the quarter-chord line on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Reynolds number, 10,600,000.

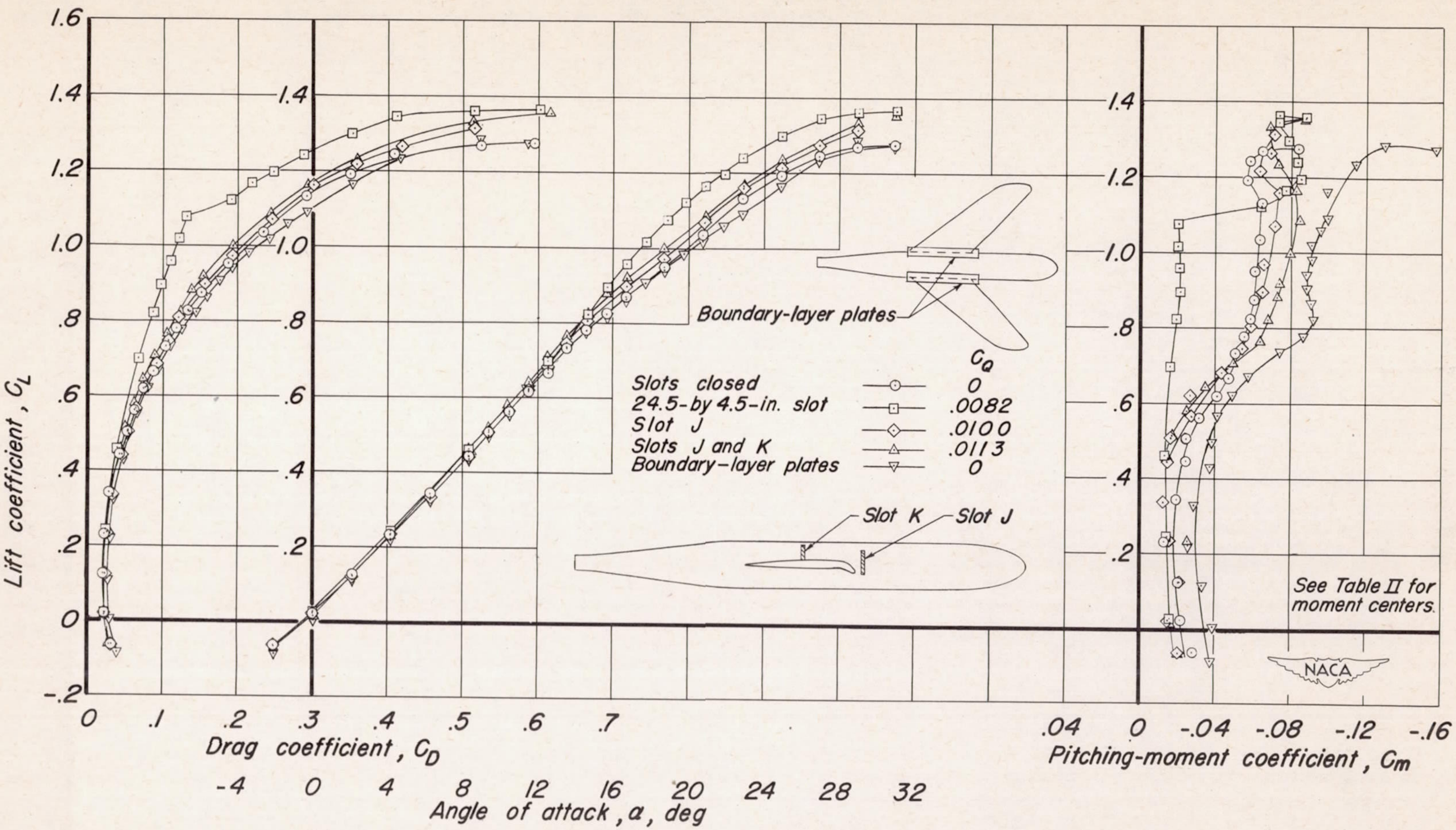


Figure 26.—The effects of boundary-layer plates and suction through annular slots in the fuselage on the longitudinal characteristics of the 45° swept-forward wing-fuselage combination with a full-span leading-edge flap deflected 30° down. Reynolds number, 6,100,000.

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