UNCLASSIFIED

~~RESTRICTED~~

Copy No. 6

RM No. L8E21

NACA RM No. L8E21

1 NOV 1948

CLASSIFICATION CHANGED

To UNCLASSIFIED

NACA

By authority of J. W. Crowley Date 6-29-53
per NACA Release form #1546 By HJR 7-17-53

RESEARCH MEMORANDUM

THE EFFECT OF BOUNDARY-LAYER CONTROL BY SUCTION AND OF SEVERAL HIGH-LIFT DEVICES ON THE AERODYNAMIC CHARACTERISTICS IN YAW OF A 47.5° SWEPTBACK WING-FUSELAGE COMBINATION

By

Jerome Pasamanick

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

October 28, 1948

~~RESTRICTED~~

UNCLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

THE EFFECT OF BOUNDARY-LAYER CONTROL BY SUCTION AND OF SEVERAL HIGH-LIFT DEVICES ON THE AERODYNAMIC CHARACTERISTICS IN YAW OF A 47.5° SWEPTBACK WING-FUSELAGE COMBINATION

By Jerome Pasamanick

SUMMARY

The effect of boundary-layer control by suction on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with high-lift devices and on the effectiveness of a split-flap-type aileron has been investigated in the Langley full-scale tunnel. The wing section normal to the quarter-chord line was NACA 64_1-A112, the aspect ratio was 3.5, and the taper ratio was 0.5. The configurations tested included the plain wing and the wing with semispan split and extensible leading-edge flaps. The investigation was made at a Reynolds number of 4.2×10^6 corresponding to a Mach number of approximately 0.07.

The maximum effective dihedral of the plain wing with and without boundary-layer control was about 0.0031 at approximately 84 percent of the maximum lift coefficient. The installation of the semispan split flaps increased the maximum effective dihedral to 0.0037 as a result of the increase in lift but did not change the characteristic curve as obtained for the plain wing. Boundary-layer control increased the maximum effective dihedral to 0.0042. The extensible leading-edge flaps alone or in combination with the split flaps resulted in a linear variation of effective dihedral with lift coefficient and a rapid increase in the dihedral effect near maximum lift. Boundary-layer control produced an additional increase in effective dihedral and resulted in a maximum effective dihedral of 0.0063 near the maximum lift.

The wing-fuselage model had a small amount of directional instability and small lateral-force parameters for all flap configurations; however, there was a tendency for increasing directional stability with increasing lift coefficient. Boundary-layer control had no significant effect on the directional stability or lateral-force characteristics of the model.

Unsweeping the wing by yaw increased the effectiveness of the split-flap-type aileron for all conditions. Further improvement in the aileron effectiveness was obtained with boundary-layer suction of flow coefficient of 0.024 and 0.037.

INTRODUCTION

The design of airplanes with large amounts of sweepback as a means for delaying the adverse compressibility effects on wings in high-speed flight presents many problems of stability and control in low-speed flight. The characteristics inherent of sweptback wings including low maximum lift, high effective dihedral, reduced longitudinal stability, and lateral-control deficiency have been determined in investigations on both small-scale and large-scale models (references 1 and 2). Some improvements in the low-speed characteristics of sweptback wings have been shown with the use of various leading-edge and trailing-edge high-lift devices. In an effort to improve further the low-speed characteristics of sweptback wings an investigation has been initiated in the Langley full-scale tunnel on a 47.5° sweptback wing equipped for boundary-layer control by suction and with both leading-edge and trailing-edge flaps. The wing aspect ratio was 3.5, the taper ratio was 0.5, and the airfoil sections normal to the quarter-chord line were NACA 64_1-A112. The wing was mounted in a low mid-wing position on a fuselage.

The effect of boundary-layer control by suction on the lift, drag, and longitudinal stability characteristics of the model at zero yaw are reported in reference 3. The results of tests made to determine the effect of boundary-layer control by suction on the lateral stability characteristics of the model and on the effectiveness of a split-flap-type aileron at a Reynolds number of 4.2×10^6 are presented herein. The effect of boundary-layer suction through slots located at the 0.20-, 0.40-, and 0.70-chord positions was determined for suction-flow coefficients of 0.024 and 0.037. Forces and moments were measured with and without suction for the basic wing and the wing with semispan split and partial-span extensible leading-edge flaps used alone and in combination. The data are presented for a range of angle of attack over a range of yaw angle between -10° and 6°.

SYMBOLS AND COEFFICIENTS

The data are presented with respect to the stability axes. These axes are an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. Moments are referred to the quarter-chord point of the mean aerodynamic chord.

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

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

C_l rolling-moment coefficient $\left(\frac{L'}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{N}{qSb}\right)$

C_Y lateral-force coefficient $\left(\frac{Y}{qS}\right)$

L lift, pounds

M pitching moment about Y-axis, positive when nose is raised, foot-pounds

L' rolling moment about X-axis, positive when right wing is depressed, foot-pounds

N yawing moment about Z-axis, positive when right wing is retarded, foot-pounds

Y lateral force along Y-axis, positive when force is to the right, pounds

S total wing area, square feet

S' wing area covered by suction slots, square feet

b wing span, feet

c wing chord, measured in plane perpendicular to quarter-chord line, feet

c' wing chord, measured in plane parallel to plane of symmetry, feet

$\bar{c}$ wing mean aerodynamic chord, measured in plane parallel to plane of symmetry, feet $\left(\frac{2}{S}\int_0^{b/2} c^2\, db\right)$

q free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

ρ mass density of air, slugs per cubic foot

V free-stream velocity, feet per second

Q total quantity flow through suction slots, cubic feet per second

C_Q suction-flow coefficient $\left(\frac{Q}{S'V}\right)$

α angle of attack of wing chord line, measured in plane of symmetry, degrees

ψ angle of yaw, degrees

C_{l_ψ} effective-dihedral parameter, rate of change of rolling-moment coefficient with angle of yaw, per degree $\left(\frac{\partial C_l}{\partial \psi}\right)$

C_{n_ψ} directional-stability parameter, rate of change of yawing-moment coefficient with angle of yaw, per degree $\left(\frac{\partial C_n}{\partial \psi}\right)$

C_{Y_ψ} lateral-force parameter, rate of change of lateral-force coefficient with angle of yaw, per degree $\left(\frac{\partial C_Y}{\partial \psi}\right)$

δ_{a_R} right aileron deflection, positive when trailing edge is deflected downward, degrees

$C_{l_{\delta_{a_R}}}$ aileron effectiveness, rate of change of rolling-moment coefficient with right aileron deflection, per degree

δ_f split-flap deflection, degrees

δ_{LE} extensible leading-edge-flap deflection, degrees

DESCRIPTION OF MODEL

A three-view drawing showing the general dimensions of the model and a photograph of the model mounted in the Langley full-scale tunnel are given in figures 1 and 2, respectively. The wing has a leading-edge sweepback of 47.5°, an aspect ratio of 3.5, a taper ratio of 0.5, and has NACA 64_1-A112 airfoil sections normal to the quarter-chord line. The wing was constructed with no geometric dihedral, zero incidence, and no twist and was mounted in a low midwing position on a circular fuselage.

Boundary-layer suction was applied through slots located on the upper surface of each wing panel at the 20-, 40-, and 70-percent chordwise stations. The suction slots extended from the $0.50\frac{b}{2}$-span to the $0.92\frac{b}{2}$-span locations. The wing area affected by the slots was 83.8 square feet. Details of the slot installations are given in figure 3(a), 3(b), and 3(d). The suction flow was directed through the slots into a wing box beam which ducted the air directly to an axial-flow blower, and the air was then ejected through the fuselage tailpipe.

The high-lift devices tested in conjunction with boundary-layer control consisted of semispan split flaps and extensible leading-edge flaps. The dimensions and deflection angles of the split and extensible leading-edge flaps are given in figure 3(a), 3(b), and 3(c).

The model was not equipped with controls and, therefore, in order to obtain an approximate evaluation of the effectiveness of a lateral-control device, a 0.20-chord split-flap-type aileron was installed between the $0.55\frac{b}{2}$-span and the $0.88\frac{b}{2}$-span stations. The simulated aileron was attached to the right wing panel only and provided a deflection range of about 11° down from the lower wing surface and 15° up from the upper wing surface.

TESTS

The tests to determine the effect of boundary-layer control by suction on the lateral characteristics of the model were made on the standard yaw support and six-component balance system of the Langley full-scale tunnel. The data were obtained for an angle-of-attack range from small negative angles to the angle for maximum lift for yaw angles ranging from -10° to 6°. For each model configuration tests were made without suction (slots sealed) and with suction at flow coefficients of 0.024 and 0.037.

Aileron data were obtained at approximately 0°, $\pm 4^{\circ}$, and -10° yaw angles for a range of angle of attack between -0.8° and 17.9°. The aileron-deflection angles ranged between -15° and 11° in approximately 5° increments.

All tests were made at a Reynolds number of 4.2×10^{6} corresponding to a Mach number of approximately 0.07.

RESULTS AND DISCUSSION

The results of tests of the plain wing and of the wing with leading- and trailing-edge-flap configurations, without suction and with suction at a C_Q of 0.024, are presented in figures 4 to 7. The basic data for C_Q of 0.037 are not presented because of the similarity to the curves for the lower suction-flow coefficient. Stall-progression diagrams are presented in figure 8 for the various flap configurations at a yaw angle of -6° and for suction-flow coefficients of 0 and 0.037. The effects of boundary-layer control at suction-flow coefficients of 0, 0.024, and 0.037 on the stability derivatives are shown in the summary curves of figures 9 to 12. The basic data of the aileron tests are presented in figure 13, and the summary curve showing the effectiveness of the split-flap-type aileron is given in figure 14 for suction-flow coefficients of 0, 0.024, and 0.037. The stability parameters were determined by measuring the slopes of the respective data curves through ±4° yaw angles for several values of lift coefficient below the stall. The effectiveness curve $C_{l_{\delta_{aR}}}$ was determined by measuring the slopes of the rolling-moment curve between δ_{a_R} of ±5° for each angle of attack.

These data have been corrected for jet-boundary effects, blocking effects, and stream alinement. The thrust tare of the air-jet exhaust was negligible and therefore was not considered.

Characteristics of the Plain Wing

The effective-dihedral parameter C_{l_ψ} for the plain wing without boundary-layer control increased with increasing lift coefficient to a maximum value of 0.0032 at a C_L of approximately 0.81 and then decreased rapidly with further increase in lift coefficient (fig. 9). The maximum lift coefficient of the model at zero yaw is 0.96 (reference 3) and at that lift coefficient the effective-dihedral parameter is reduced to approximately 0.0006. Tuft observations showed that the tip of the leading wing panel stalled first as is shown in figure 8(a). The increase in positive effective dihedral in the low and moderate C_L range is attributed to the increase in lift of the leading wing panel possibly due to an increase in effective velocity and effective section angle of attack as it becomes unswept. Conversely, the retarded wing panel becomes more highly swept and thus retards the rate of lift increase. At a higher angle of attack the leading wing stalls first, thereby reducing lift and producing a reversal in the rolling tendency at that lift coefficient. These characteristics have also been observed in tests of similar swept-back wings having thin airfoil sections (references 2 and 4). Boundary-layer control at suction-flow coefficients of 0.024 and 0.037 had very little effect on the variation of the maximum value of the effective dihedral with lift coefficient. The C_{l_ψ} values were decreased slightly by boundary-layer suction up to a C_L of 0.85 but due to the increased lift-coefficient range the maximum value of 0.0030 was obtained at a C_L of 0.95. A rapid reduction in dihedral effect occurred at higher lift coefficients in a manner similar to the condition without boundary-layer control.

The wing-fuselage combination produced a small directional instability which was slightly alleviated at higher lift coefficients. Boundary-layer control at flow coefficients of 0.024 and 0.037 had very little effect on the directional characteristics of the model.

The lateral-force parameter was not appreciably affected by boundary-layer control and has a value of less than 0.005 over the lift-coefficient range.

Characteristics of the Wing with High-Lift Devices

Semispan split flaps.- The addition of semispan split flaps to the wing increased $C_{l_{\psi_{max}}}$ from 0.0032 to 0.0037 for the slot-sealed condition and to 0.0042 for suction-flow coefficients of 0.024 and 0.037 (fig. 10). The variations of C_{l_ψ} with C_L are very similar to those for the plain wing, and for all flow conditions the maximum value of C_{l_ψ} occurs at approximately $0.84C_{L_{max}}$. Tuft diagrams, figure 8(b), show that the stall progressions for the wing with split flaps are very similar to those for the plain wing (fig. 8(a)). The split flaps do not aid in eliminating the tip stall at high lift coefficients; therefore, the sudden drop of C_{l_ψ} still occurs near maximum lift. Boundary-layer control at a suction-flow coefficient of 0.024, up to a C_L of 0.6, had no effect on C_{l_ψ}; however, beyond this lift coefficient there was a more rapid rise in C_{l_ψ} until the maximum value ($\approx$ 0.0042) was reached. This increase in effective dihedral is attributed to the delay in stall over the wing region affected by the suction slots. Although boundary-layer suction at a C_Q of 0.024 did clean up the flow throughout the low and moderate lift-coefficient range, the forward wing panel reached the stall angle before the trailing wing panel giving the reduction in C_{l_ψ} at high lift coefficients. Increasing C_Q to 0.037 increased C_{l_ψ} somewhat over the lift-coefficient range from 0.26 to 0.8, after which the C_{l_ψ} curve was similar to that for the lower flow coefficient of 0.024.

Split-flap deflection with and without boundary-layer control had no appreciable effect on the directional-stability or lateral-force parameters of the model.

$0.50\frac{b}{2}$-span extensible leading-edge flaps.- With the installation of extensible leading-edge flaps the effective-dihedral parameter increased linearly throughout the lift range (fig. 11). The flow diagrams of figures 8(a) and 8(c) show that the leading-edge flaps were effective in delaying leading-edge separation and tip stall on the forward wing panel until high angles of attack thus permitting a uniform stall on both wing panels. The dihedral effect was greater with suction than without suction because the control of the boundary layer further delayed the stall over the outboard portion of the wing with the effect being more pronounced for the leading wing panel. The values of C_{l_ψ} at a C_L of 1.03 were about 0.0040 for all suction-flow conditions tested.

For this flap configuration, the model is also slightly unstable directionally $\left(C_{n_\psi} \approx 0.001\right)$ for all suction conditions up to a C_L of about 0.7. Above this lift coefficient, suction produces a stabilizing effect which results in a small degree of stability at the highest lift coefficient.

The $0.50\frac{b}{2}$-span leading-edge flap had very little effect on the lateral-force characteristics of the model with or without boundary-layer control.

<u>Semispan split flaps and $0.50\frac{b}{2}$-span extensible leading-edge flaps.</u>- The combination of the semispan split flaps and the $0.50\frac{b}{2}$-span extensible leading-edge flaps resulted in the largest dihedral effect at maximum lift for all the flap and suction configurations investigated (fig. 12). The variation of C_{l_ψ} with C_L is nearly linear up to high lift coefficients and near $C_{L_{max}}$ the dihedral effect is rapidly increased. The maximum value of C_{l_ψ} for the sealed condition was 0.0055; and for the conditions with boundary-layer control, 0.0063. The extensible leading-edge flaps were effective in delaying the stall at the wing tip as shown by a comparison of figures 8(a) and 8(d).

The combination of flaps had no appreciable effect on the directional-stability and lateral-force parameters over the other flap arrangements except at $C_{L_{max}}$ there is a destabilizing tendency directionally which may be associated with the rapid increase in dihedral effect.

Aileron Effectiveness

The use of extensible leading-edge flaps in order to delay tip stalling has been shown to produce high dihedral effect on the sweptback wing which in turn introduces difficult problems of lateral control. Inasmuch as the model was not originally provided with an aileron, lateral control was obtained by a simulated aileron consisting of a split flap attached to the outboard portion of the existing semispan split flap on the right wing panel. The effectiveness of the simulated aileron is given in figure 14 for conditions with and without boundary-layer control. The aileron power for this split-flap-type control is low with the maximum increment in rolling-moment coefficient being of the order of 0.025. It is evident from the summary curves that sweep has a marked effect upon the aileron effectiveness. When the model was yawed to the left by approximately 10°, or, in effect, the sweep of the right wing decreased, the aileron effectiveness for the sealed condition increased by approximately 20 percent at low lift coefficients and approximately 70 percent at moderate lift coefficients. The increase was approximately 30 percent for the highest suction-flow coefficient up to a lift coefficient of 0.9. In the higher C_L range the effectiveness of the split-flap aileron is largely reduced. The increase in effectiveness in the low and moderate lift-coefficient range is explained by the fact that the $0.33\frac{b}{2}$-span aileron extended outward only to the $0.88\frac{b}{2}$-span station; therefore, a large part of the aileron was unaffected by early tip stall. At high lift coefficients when the wing tip stalled and the disturbed flow spread to the region covered by the aileron, the effectiveness was greatly reduced. For all yaw attitudes boundary-layer control provided some improvement in the effectiveness of the simulated aileron and in all instances the effect was more pronounced for the larger flow coefficient in the higher C_L range.

In the tests of reference 3 the extensible leading-edge flaps produced the most satisfactory longitudinal stability characteristics, and although this configuration was not tested, it is possible that the effectiveness of the split-flap-type aileron would have been improved somewhat by the installation of the extensible leading-edge flaps.

SUMMARY OF RESULTS

The results of the effect of boundary-layer control by suction on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with high-lift devices and on the effectiveness of a split-flap-type aileron are summarized as follows:

1. The maximum effective dihedral of the plain wing with and without boundary-layer control was 0.0030 and 0.0032, respectively, at lift coefficients of approximately $0.84C_{L_{max}}$. The dihedral effect is considerably reduced at higher lift coefficients.

2. Installation of semispan split flaps increased the maximum effective dihedral to 0.0037 as a result of the increase in lift but did not change the characteristic curve as obtained for the plain wing. Boundary-layer suction increased C_{l_ψ} to about 0.0042 at approximately $0.84C_{L_{max}}$.

3. The addition of the extensible leading-edge flaps alone and in combination with the split flaps produced a linear variation of C_{l_ψ} with C_L and a rapid increase in the dihedral effect near $C_{L_{max}}$. Boundary-layer control produced an additional increase in effective dihedral and resulted in a maximum value of C_{l_ψ} of 0.0063 near maximum lift.

4. Without boundary-layer control the model was directionally unstable for all flap configurations with a tendency for increasing directional stability as the lift coefficient increased. Boundary-layer control produced no significant effect on the directional stability of the model.

5. The model has small lateral-force parameters for all configurations. Boundary-layer control had no material effect on the lateral-force characteristics.

6. Unsweeping the wing by yaw increased the effectiveness of the split-flap-type aileron for all conditions. Boundary-layer suction improved the aileron effectiveness with the improvement being more pronounced for the higher flow coefficient.

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

REFERENCES

1. Letko, William, and Goodman, Alex: Preliminary Wind-Tunnel Investigation at Low Speed of Stability and Control Characteristics of Swept-Back Wings. NACA TN No. 1046, 1946.

2. McCormack, Gerald M., and Stevens, Victor I., Jr.: An Investigation of the Low-Speed Stability and Control Characteristics of Swept-Forward and Swept-Back Wings in the Ames 40- by 80-Foot Wind Tunnel. NACA RM No. A6K15, 1947.

3. Pasamanick, Jerome, and Proterra, Anthony J.: The Effect of Boundary-Layer Control by Suction and Several High-Lift Devices on the Longitudinal Aerodynamic Characteristics of a 47.5° Sweptback Wing-Fuselage Combination. NACA RM No. L8E18, 1948.

4. Salmi, Reino J., Conner, D. William, and Graham, Robert R.: Effects of a Fuselage on the Aerodynamic Characteristics of a 42° Sweptback Wing at Reynolds Numbers to 8,000,000. NACA RM No. L7E13, 1947.

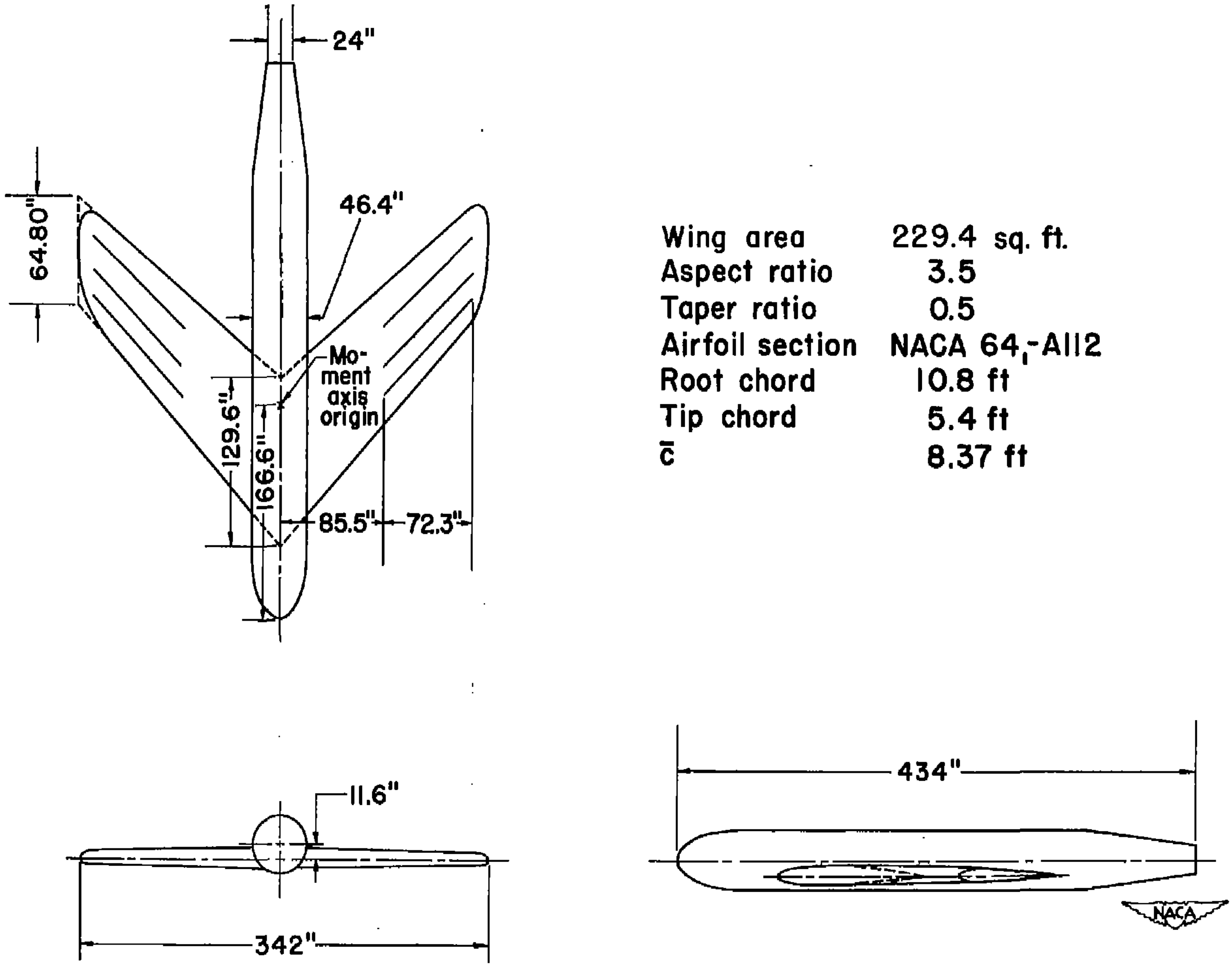


Figure 1.- Three-view drawing of a 47.5° sweptback wing-fuselage combination with boundary-layer control.

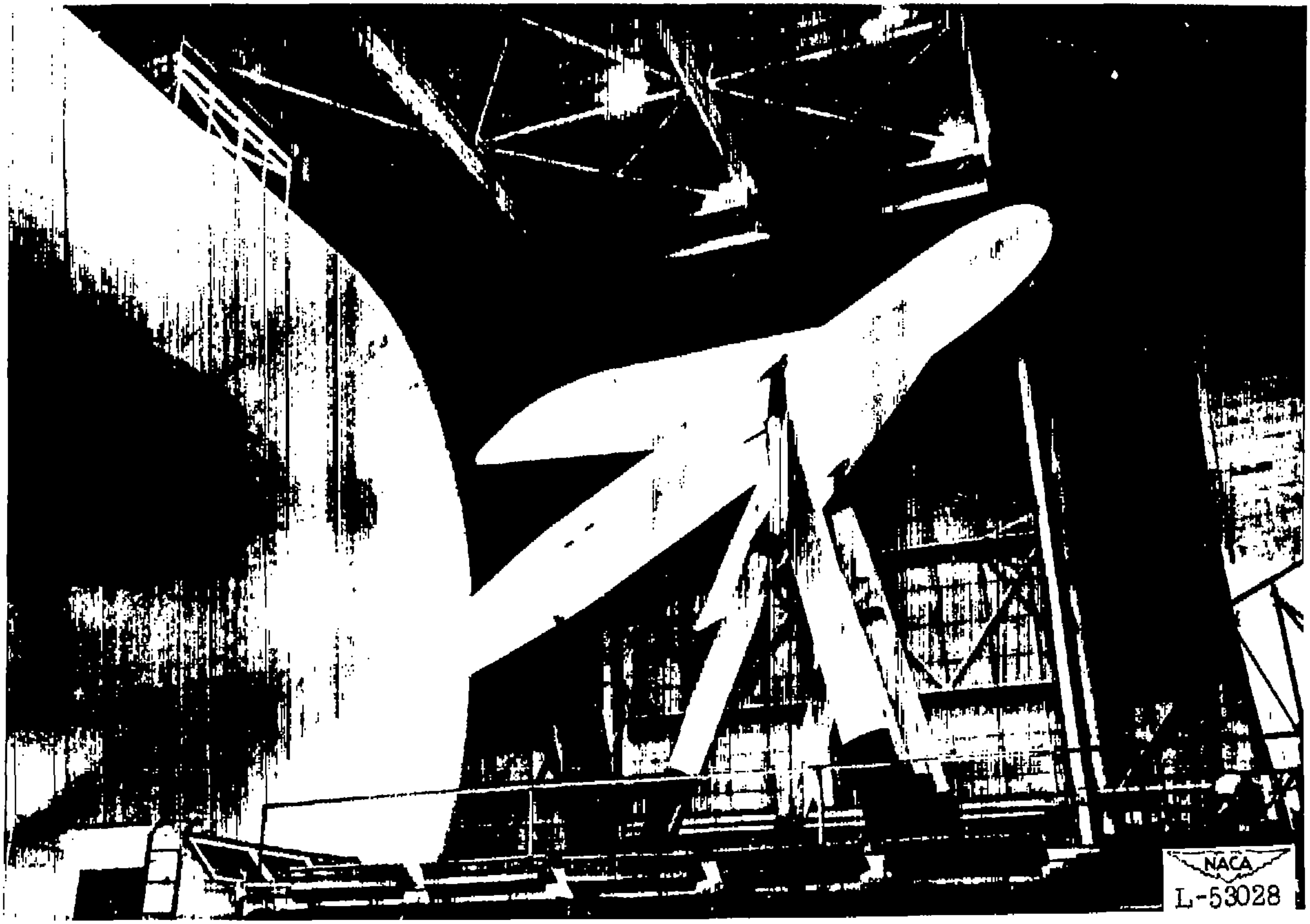


Figure 2.- Three-quarter front view of a 47.5° sweptback wing-fuselage combination with boundary-layer control.

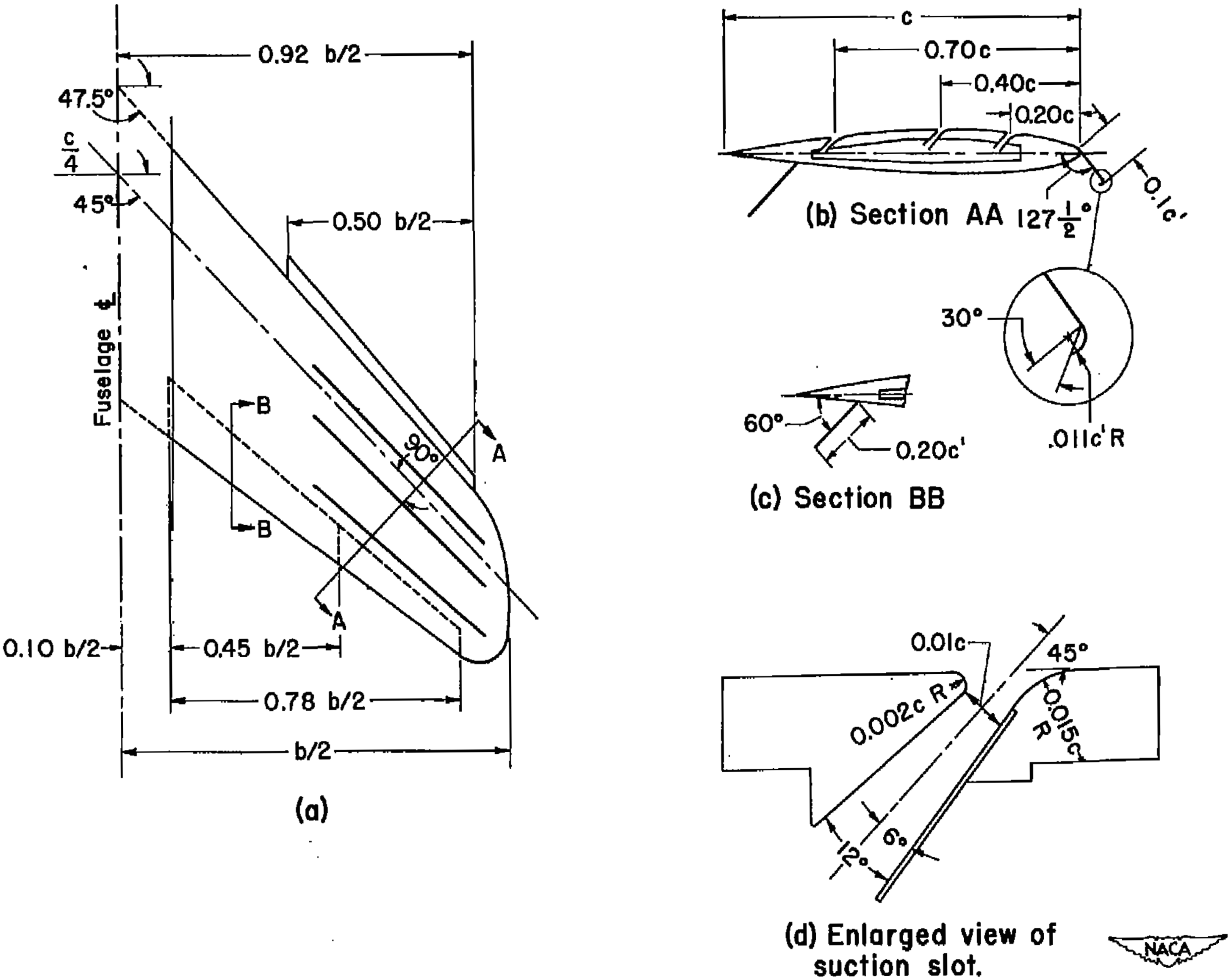
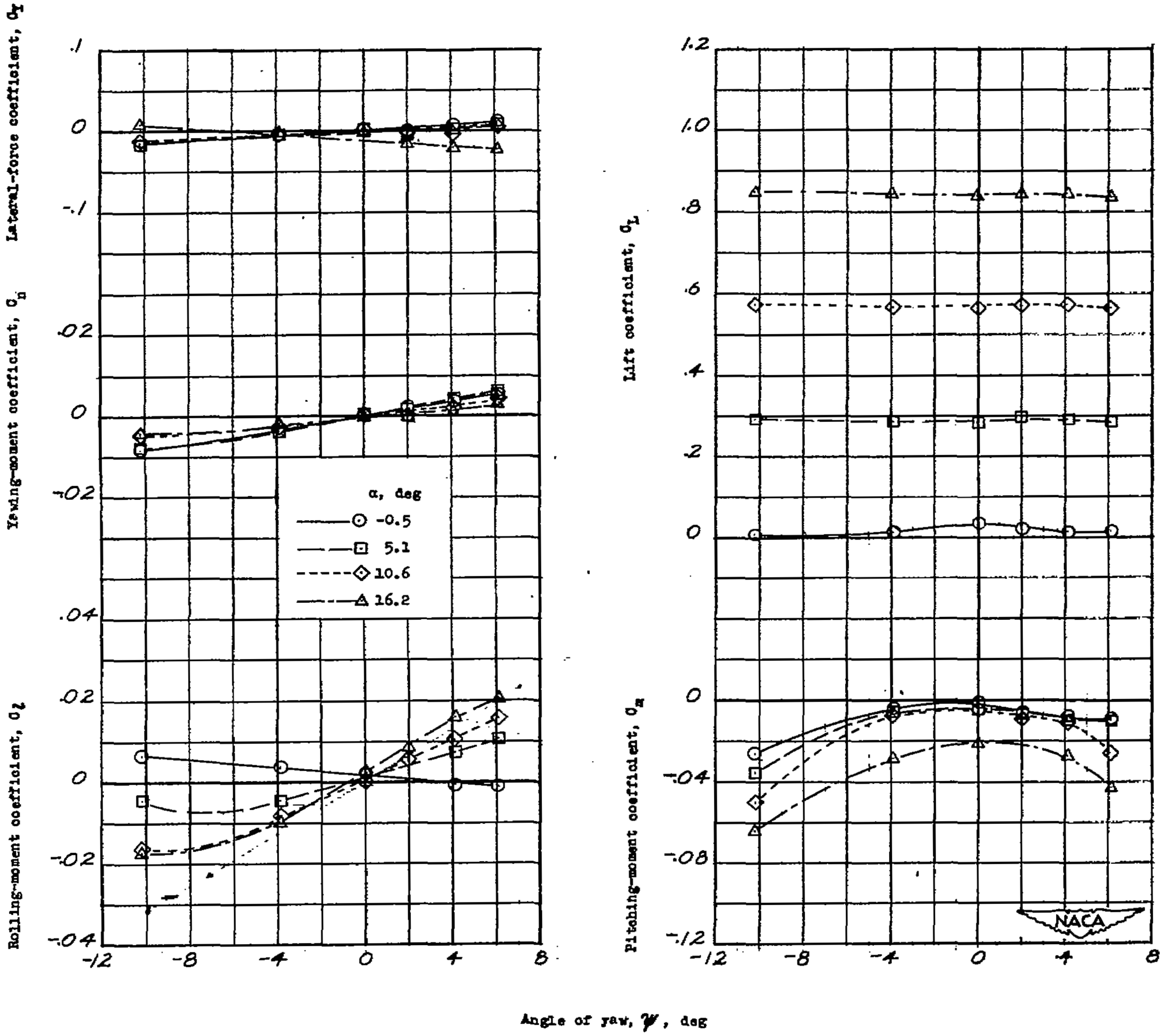
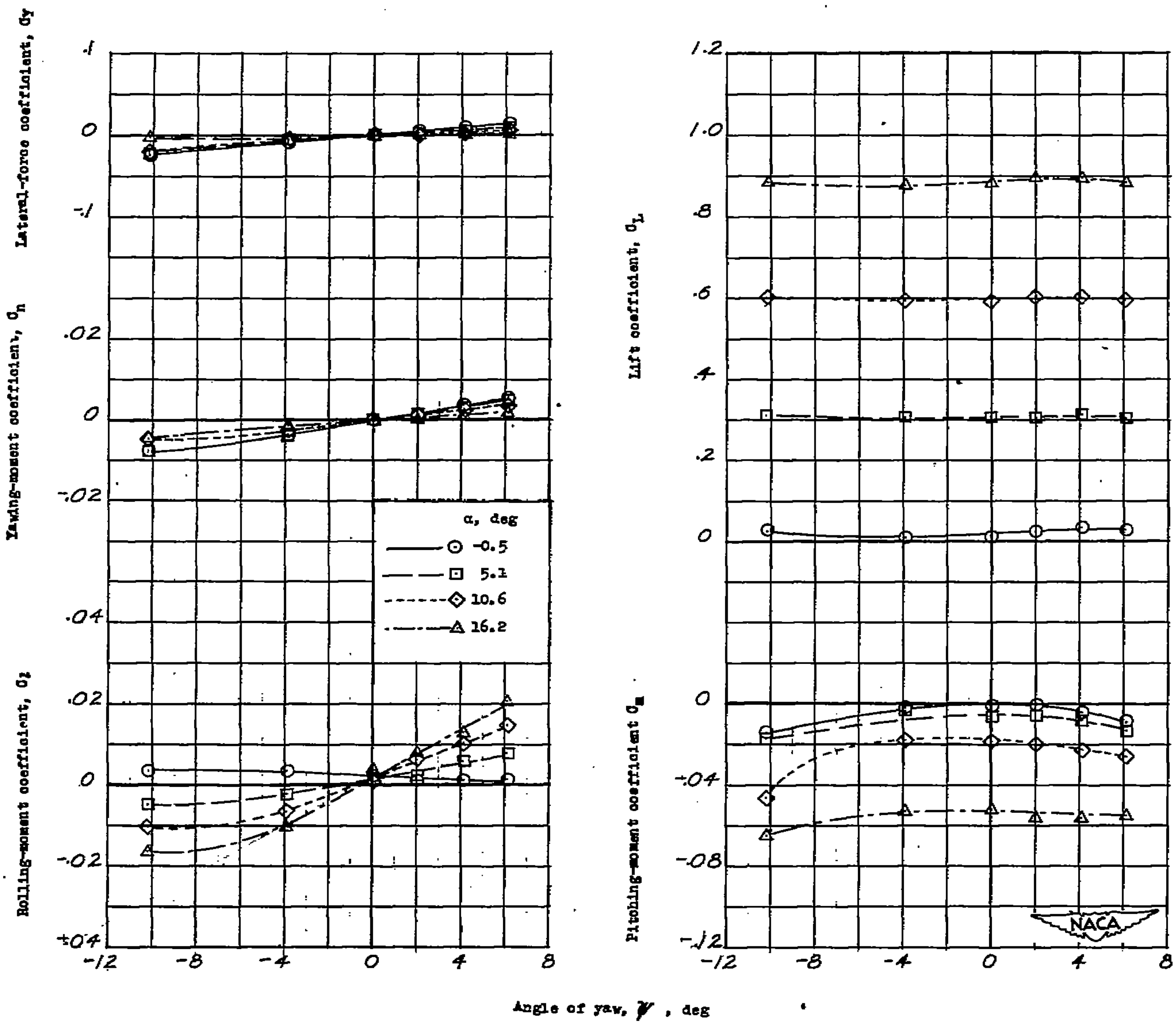


Figure 3.- The location and detail dimensions of high-lift devices, boundary-layer suction slots, and split-flap-type aileron on a 47.5° sweptback wing-fuselage combination.



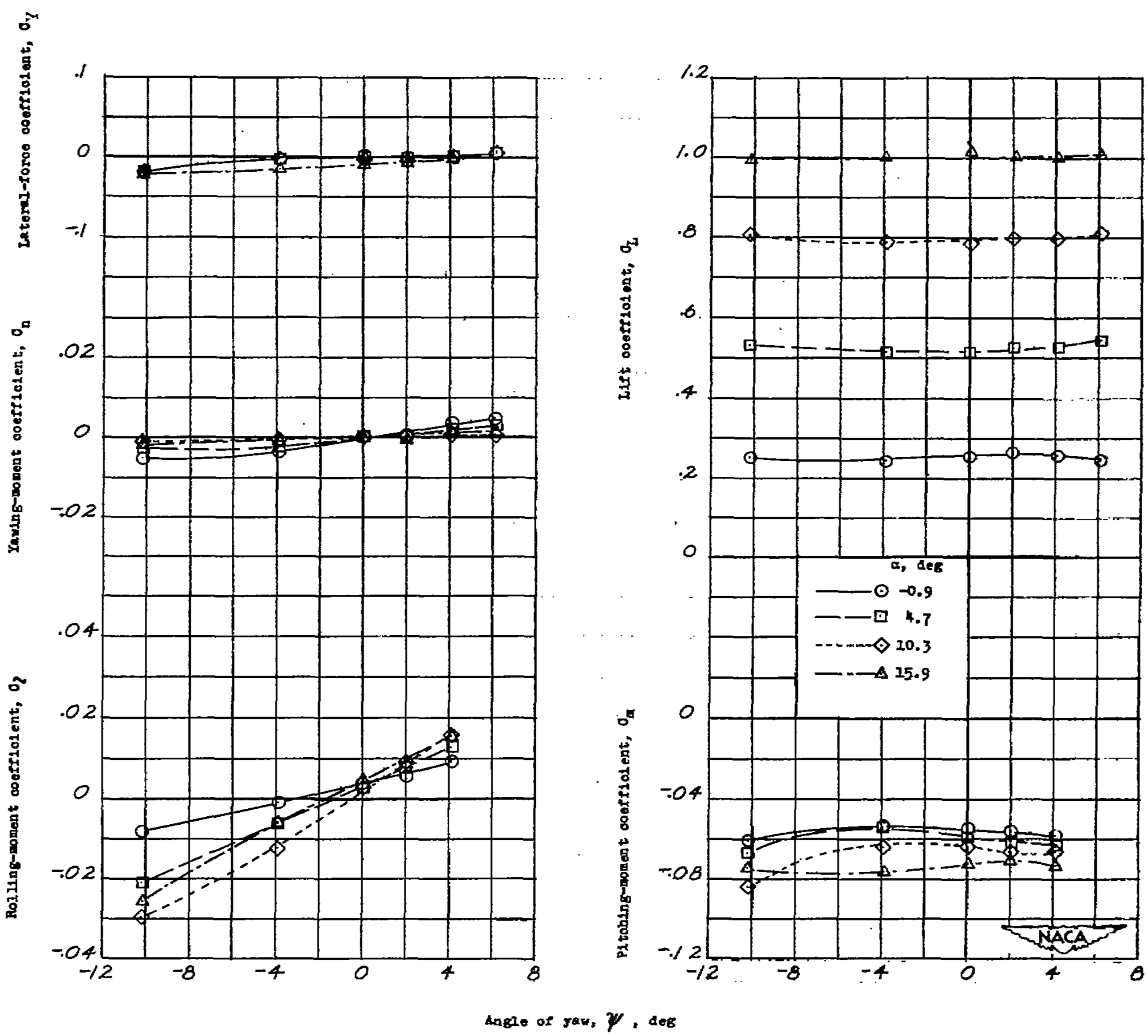
(a) $C_Q = 0$.

Figure 4.- Aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction.



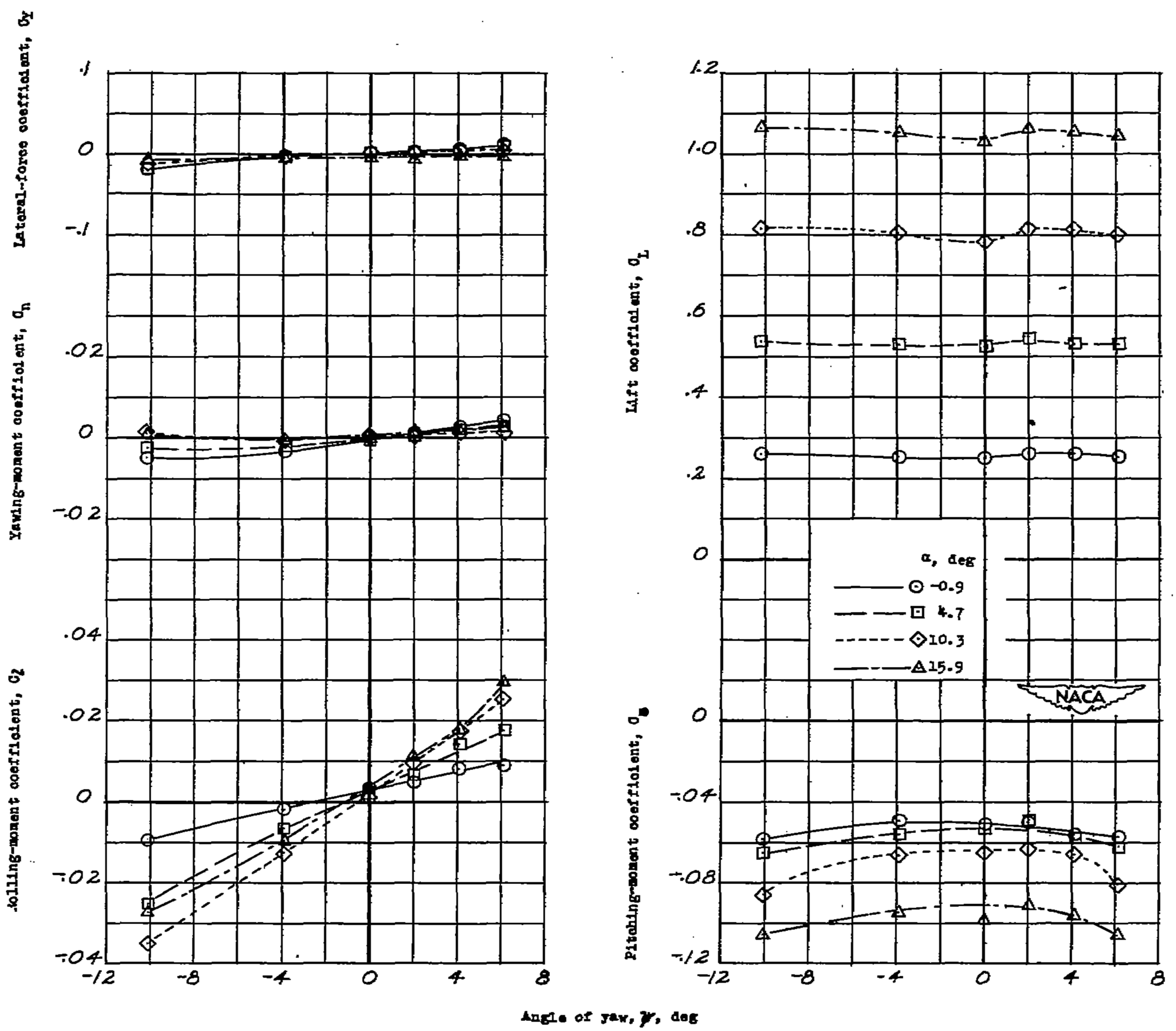
(b) $C_Q = 0.024$.

Figure 4.- Concluded.



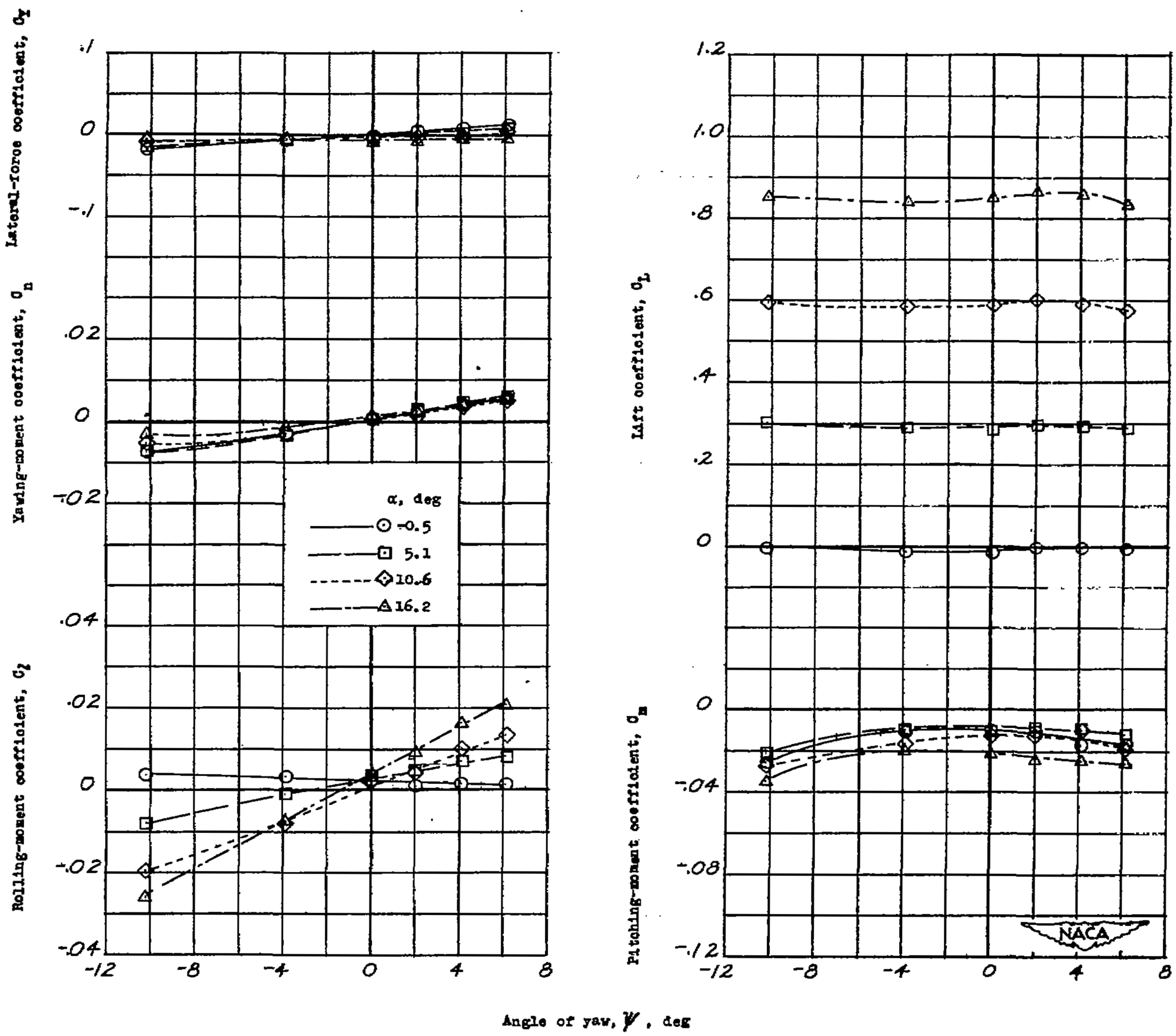
(a) $C_Q = 0$.

Figure 5.- Effect of semispan split flaps on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction. $\delta_f = 60°$.



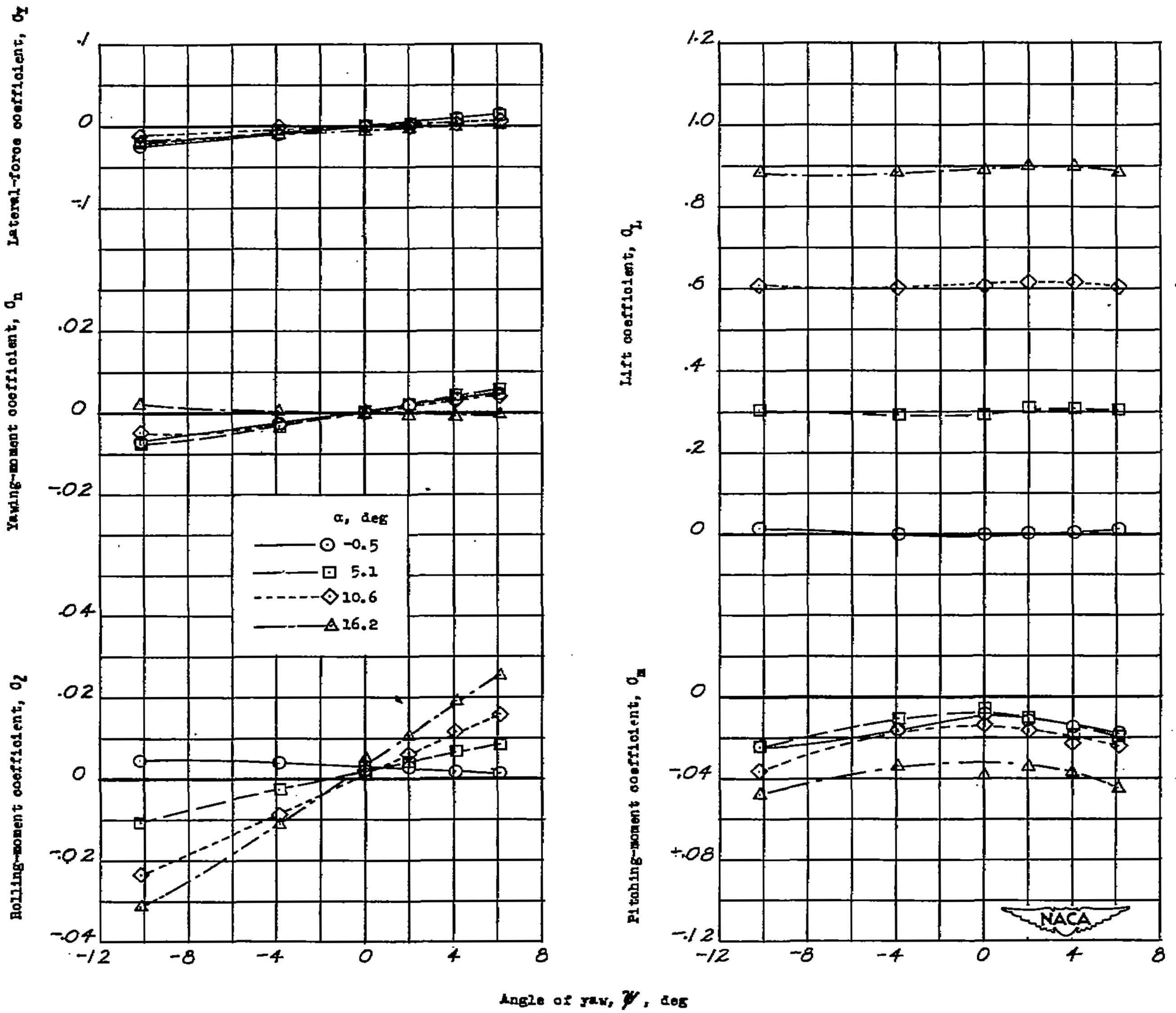
(b) $C_Q = 0.024$.

Figure 5.- Concluded.



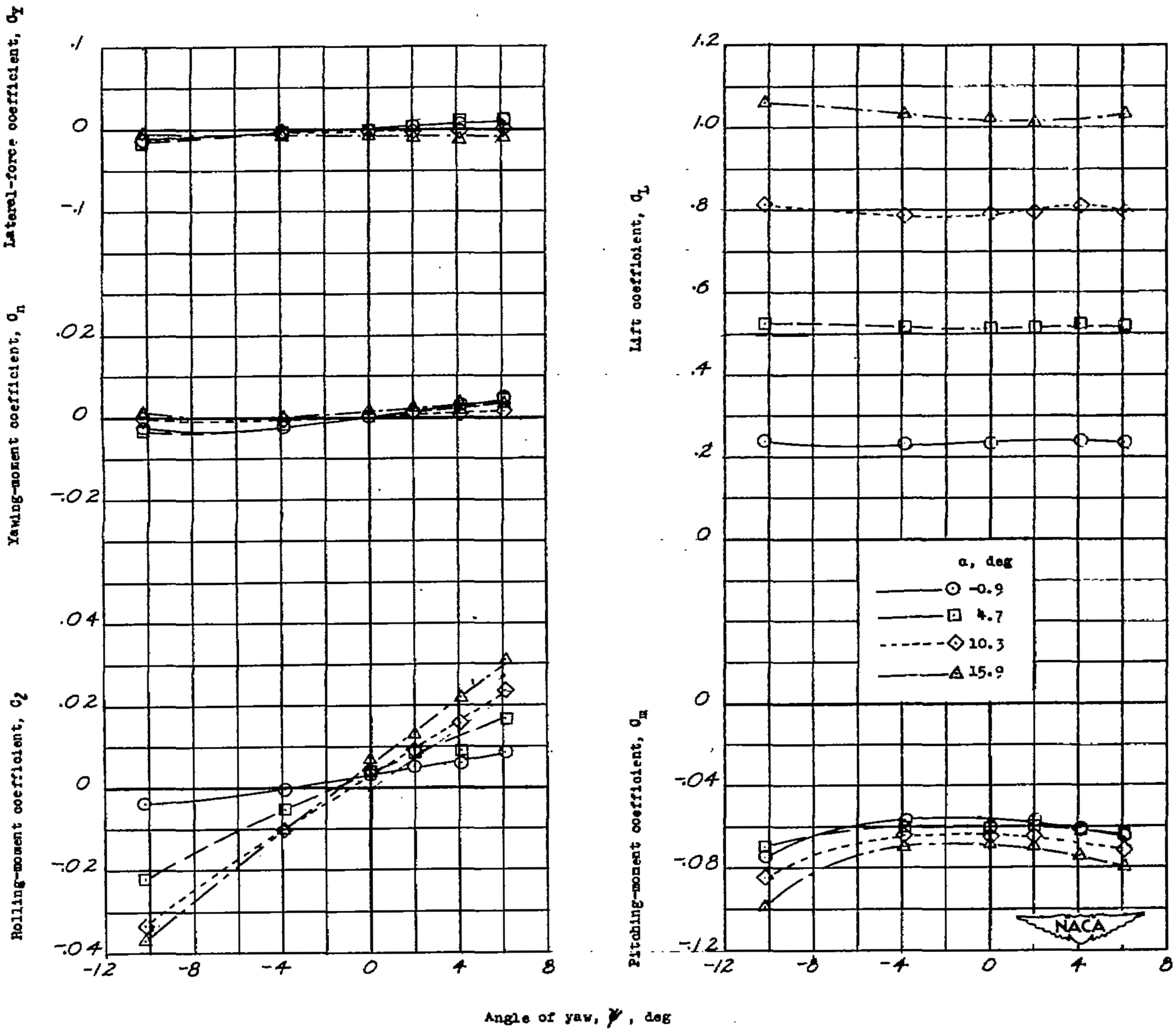
(a) $C_Q = 0$.

Figure 6.- Effect of $0.50\frac{b}{2}$-span extensible leading-edge flaps on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction. $\delta_{LE} = 127.5°$.



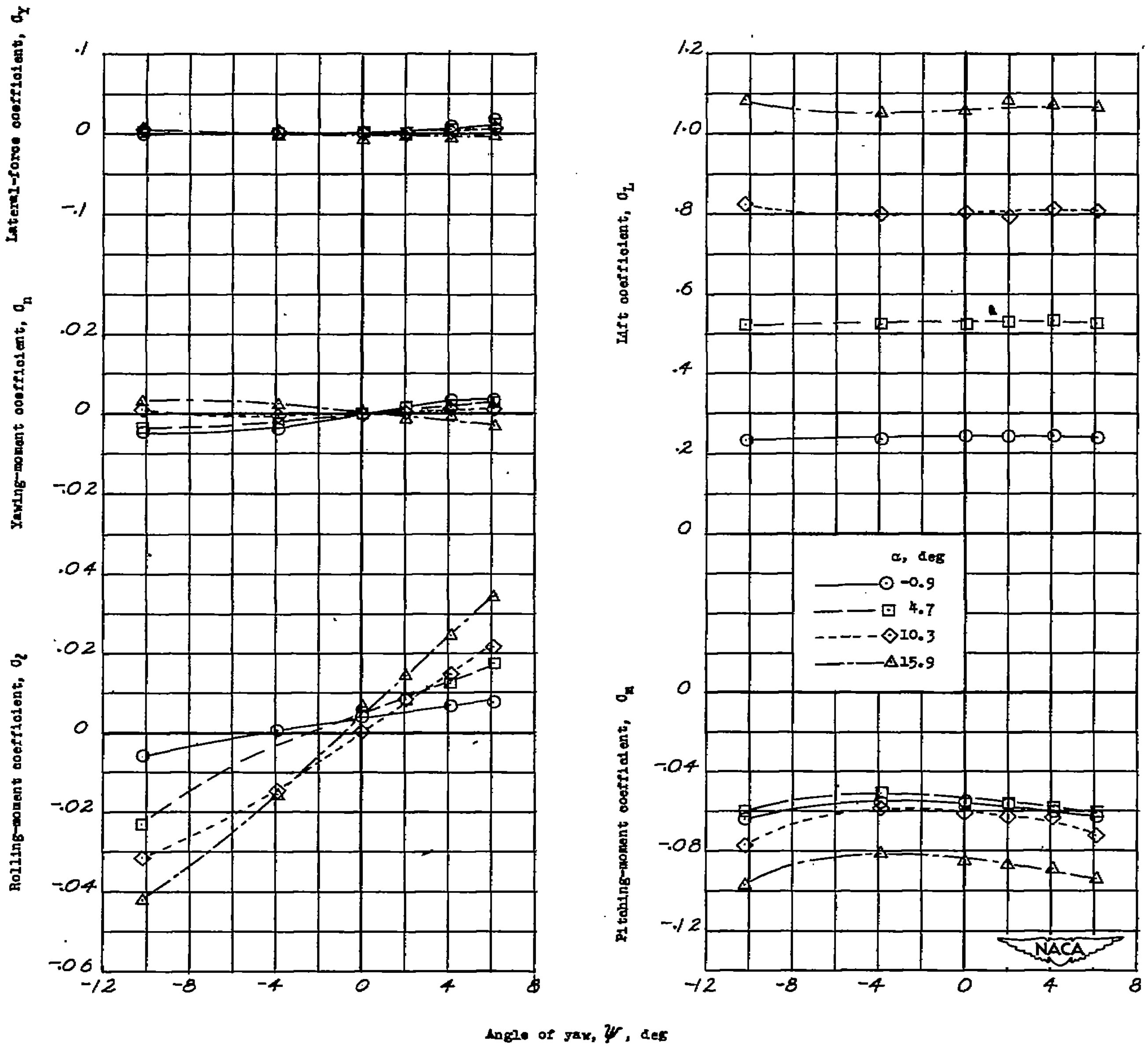
(b) $C_Q = 0.024$.

Figure 6.- Concluded.



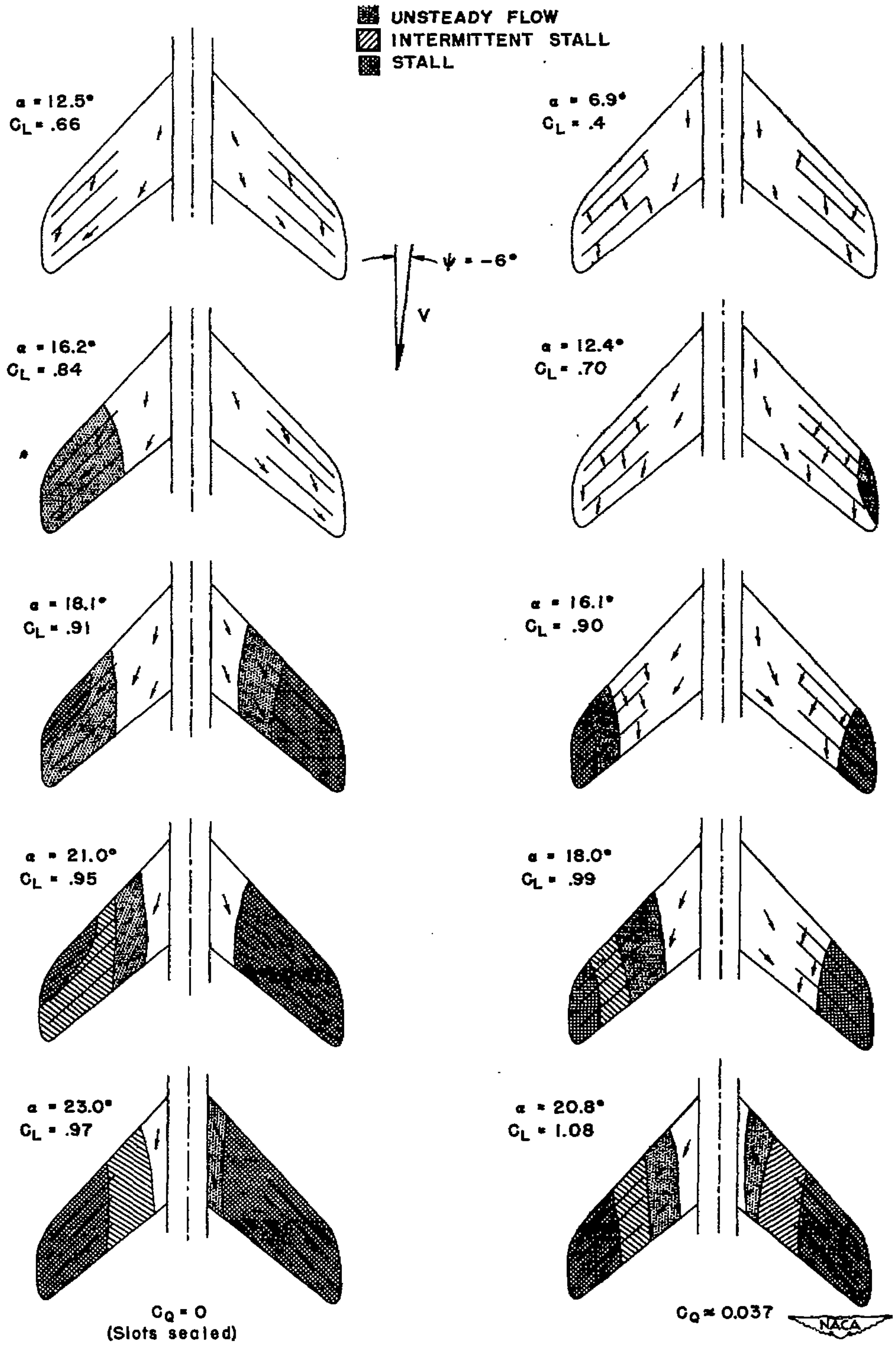
(a) $C_Q = 0$.

Figure 7.- Effect of semispan split and $0.50 \frac{b}{2}$-span extensible leading-edge flaps on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction. $\delta_f = 60^\circ$, $\delta_{LE} = 127.5^\circ$.



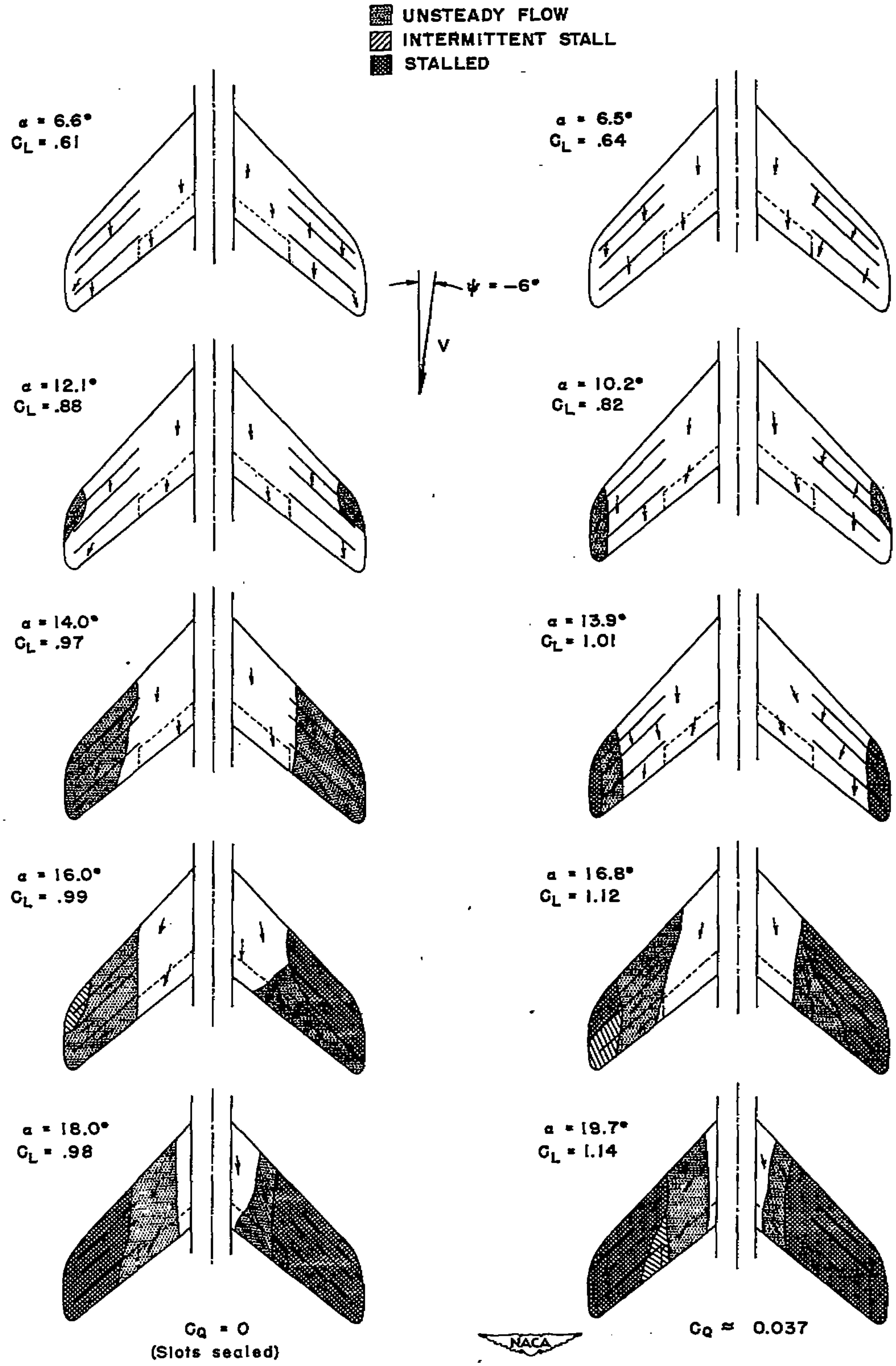
(b) $C_Q = 0.024$.

Figure 7.- Concluded.



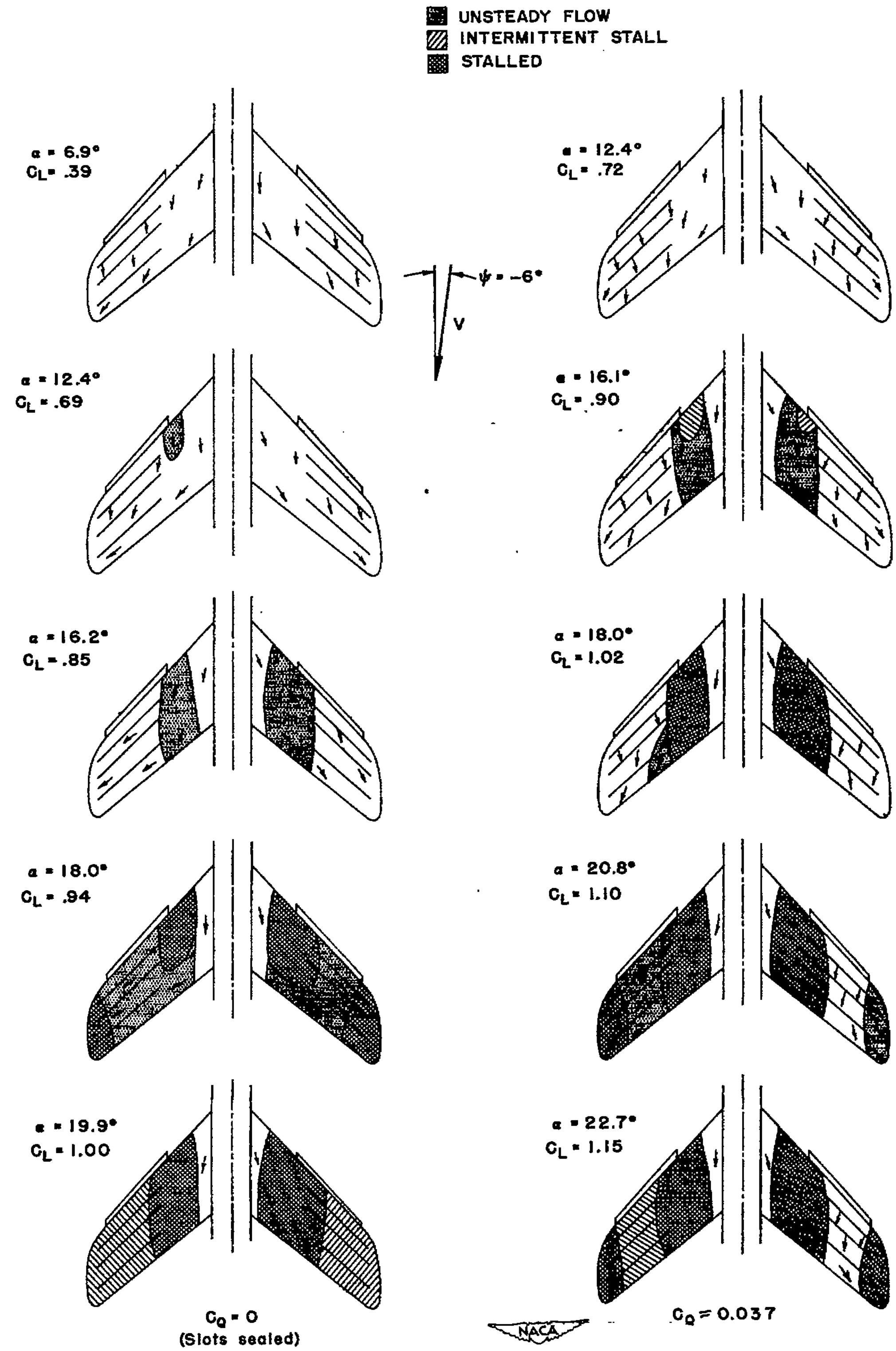
(a) Plain wing.

Figure 8.- Effect of boundary-layer control by suction on the stalling characteristics of a 47.5° sweptback wing-fuselage combination. $\psi = -6°$.



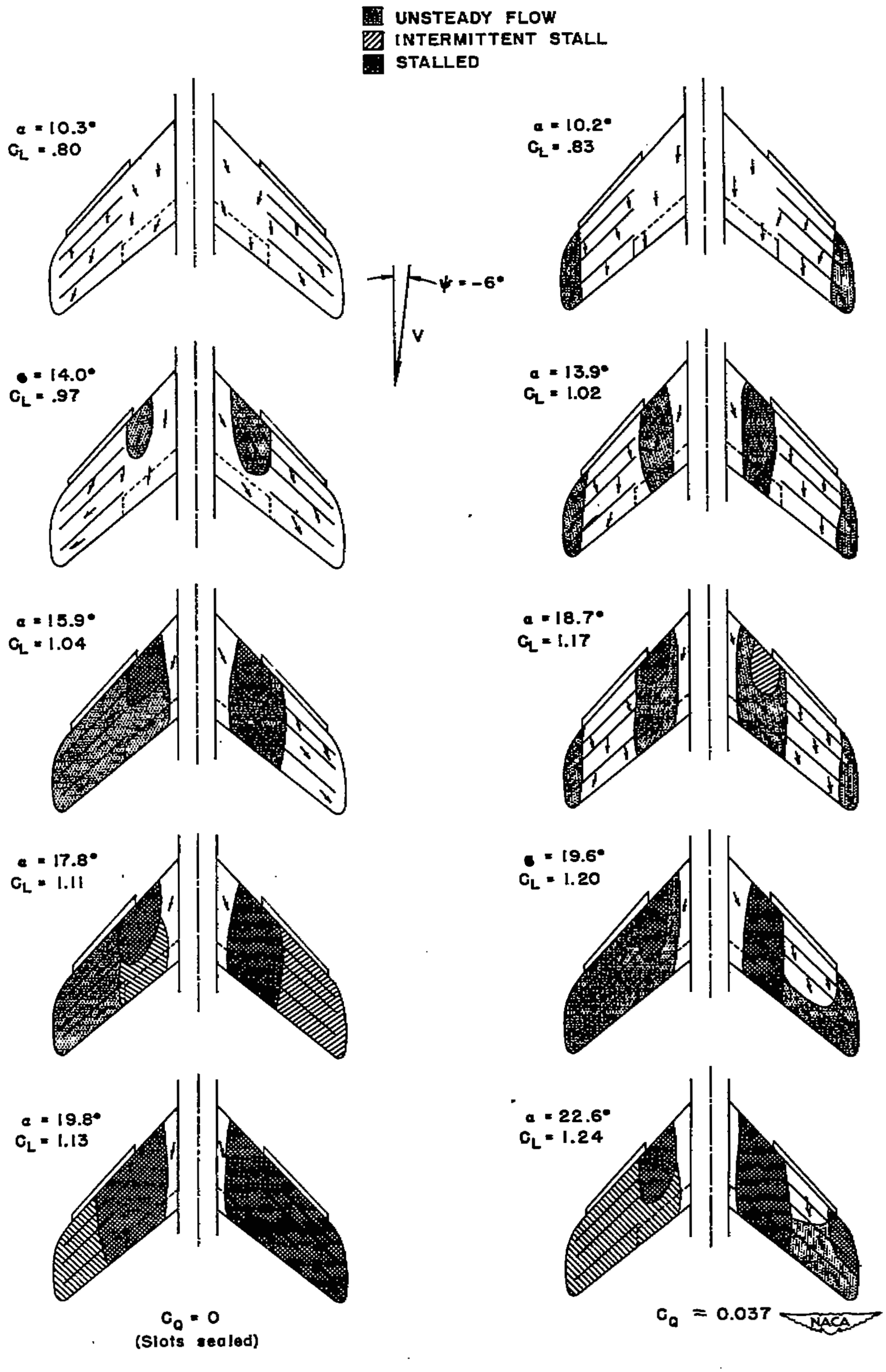
(b) Semispan split flaps; $\delta_f = 60^{\circ}$.

Figure 8.- Continued.



(c) $0.50\frac{b}{2}$-span extensible leading-edge flaps; $\delta_{LE} = 127.5^{\circ}$.

Figure 8.- Continued.



(d) Semispan split and $0.50\frac{b}{2}$-span extensible leading-edge flaps; $\delta_f = 60^\circ$; $\delta_{LE} = 127.5^\circ$.

Figure 8.- Concluded.

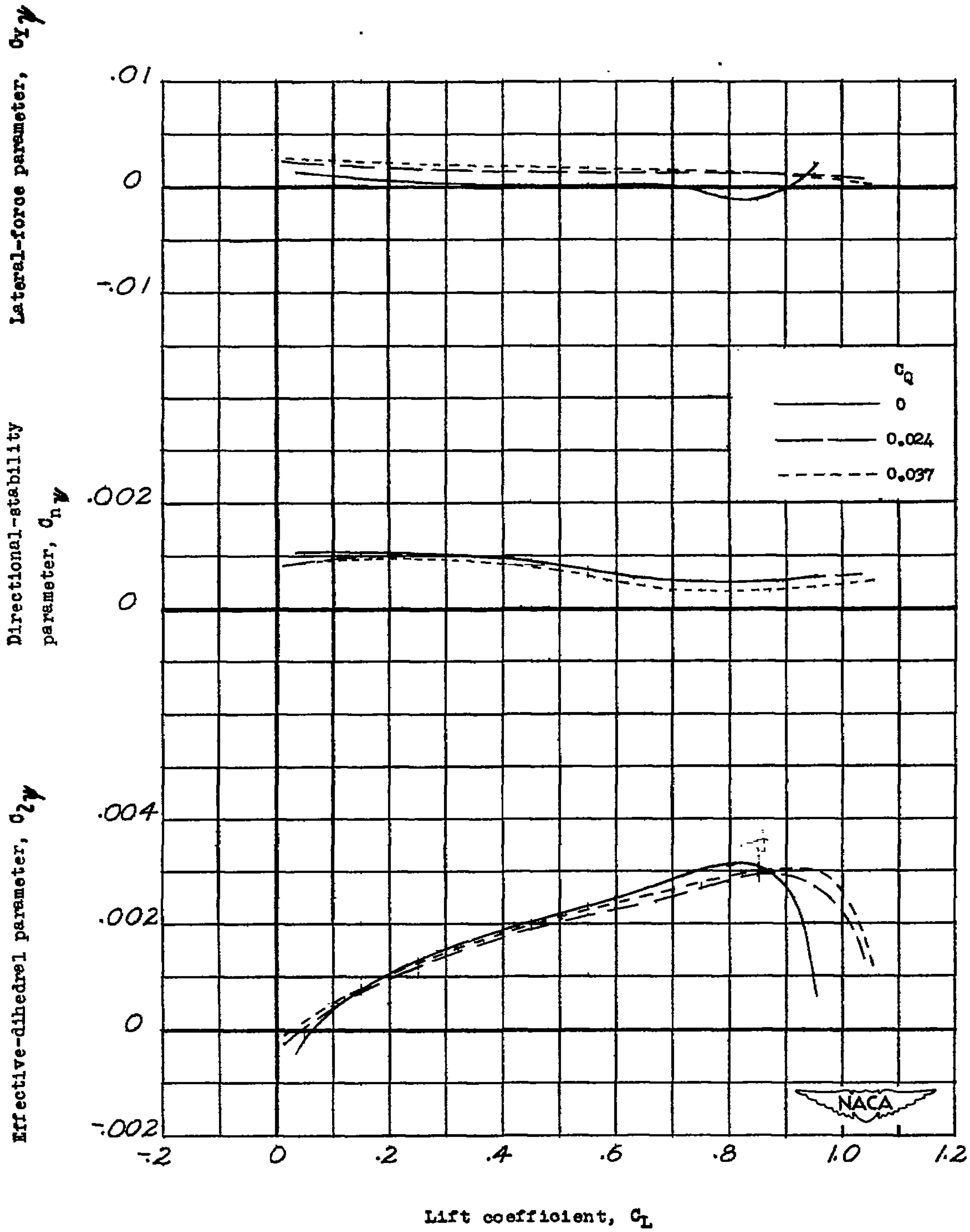


Figure 9.- Effect of boundary-layer control by suction on the lateral-stability parameters of a 47.5° sweptback wing-fuselage combination.

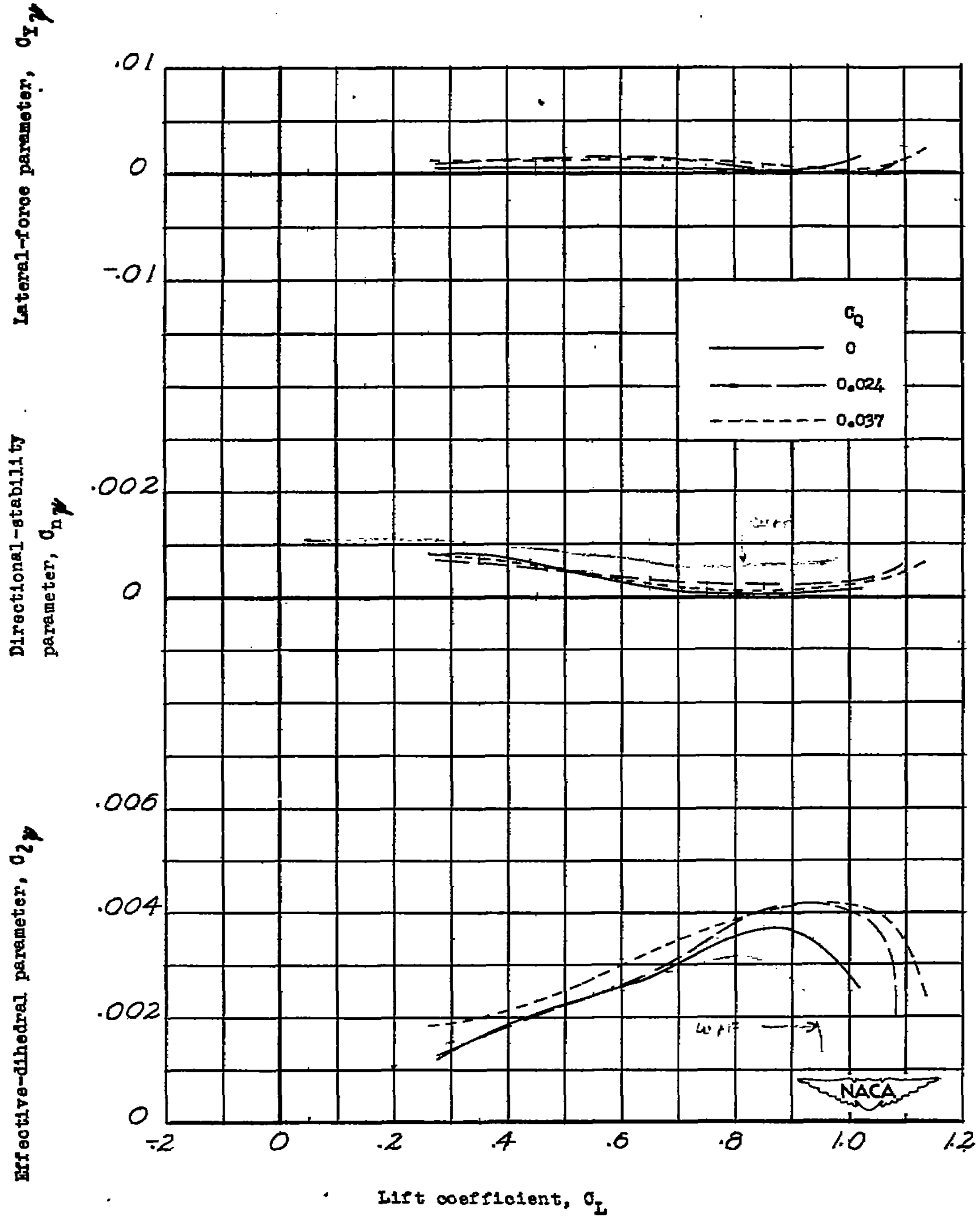


Figure 10.- Effect of boundary-layer control by suction on the lateral-stability parameters of a 47.5° sweptback wing-fuselage combination with semispan split flaps. $\delta_f = 60^\circ$.

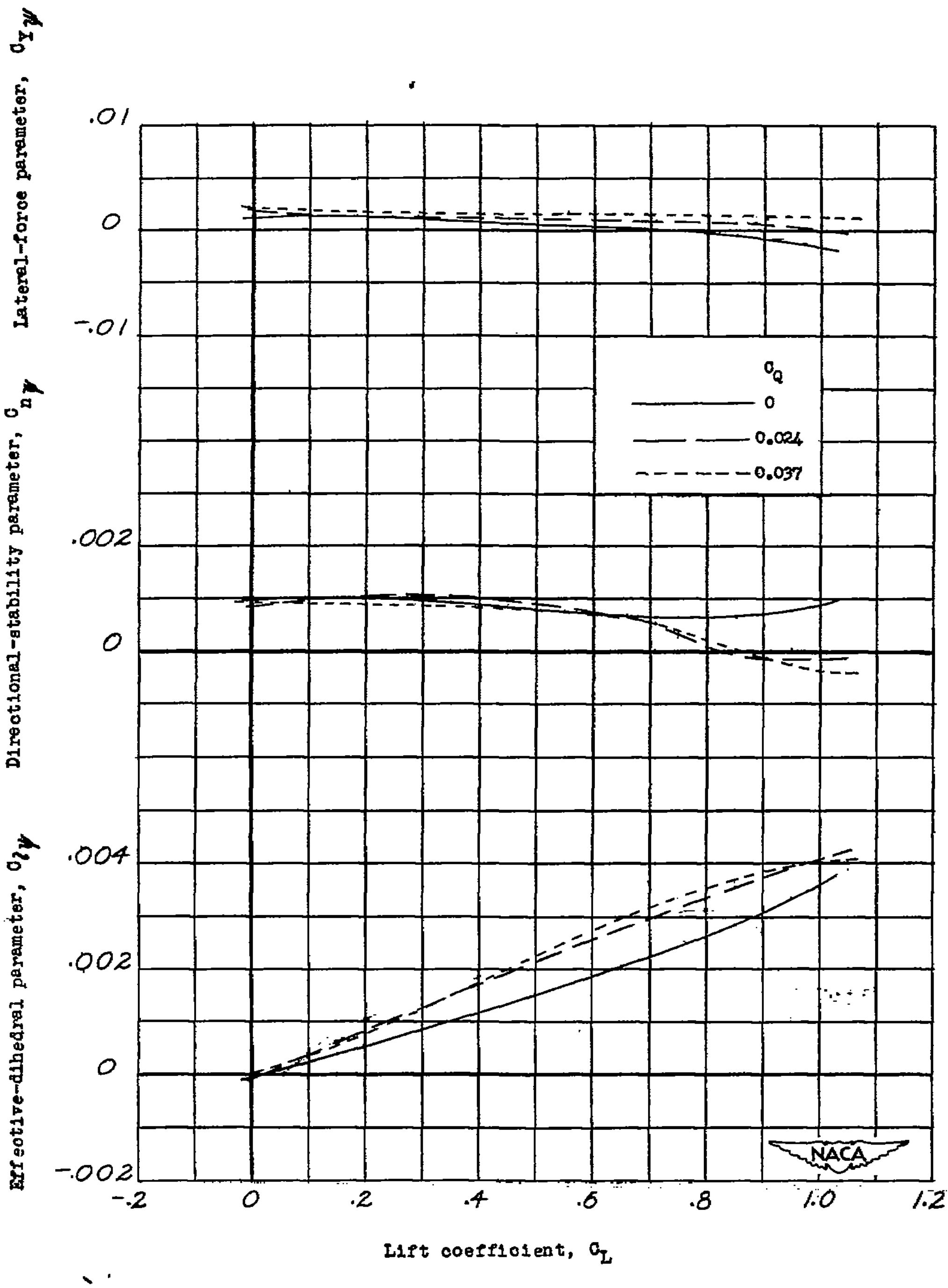


Figure 11.- Effect of boundary-layer control by suction on the lateral-stability parameters of a 47.5° sweptback wing-fuselage combination with $0.50 \frac{b}{2}$ -span extensible leading-edge flaps. $\delta_{LE} = 127.5°$.

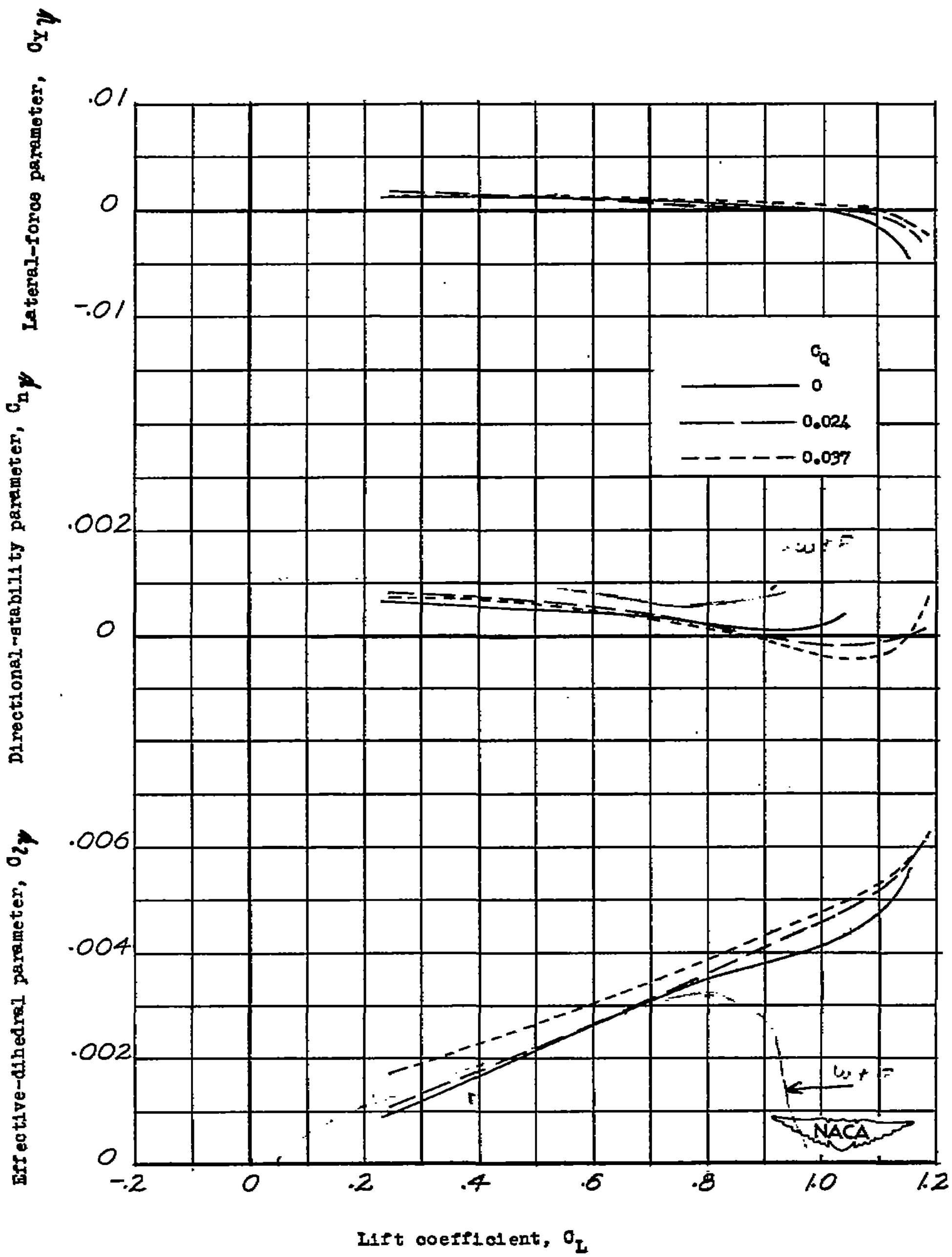
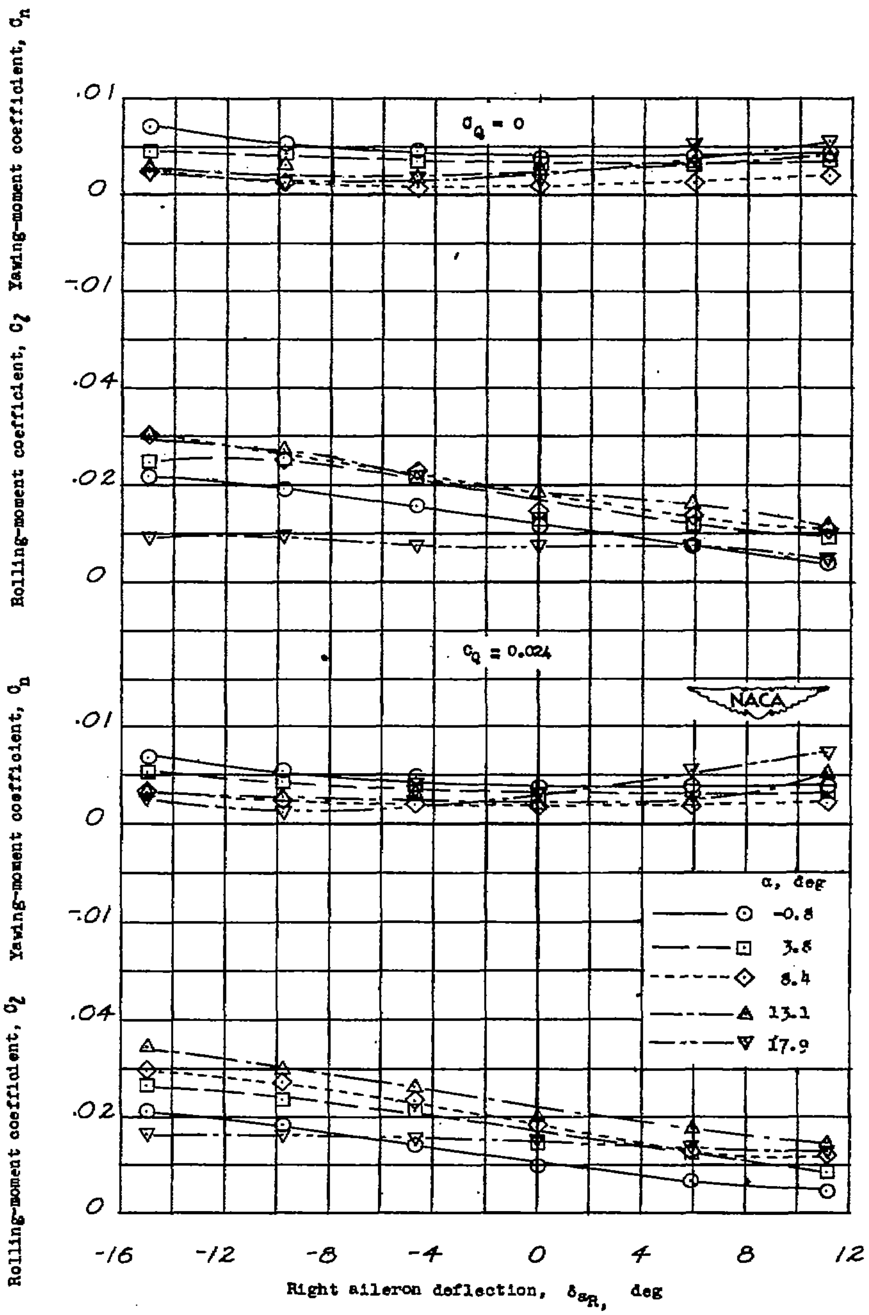


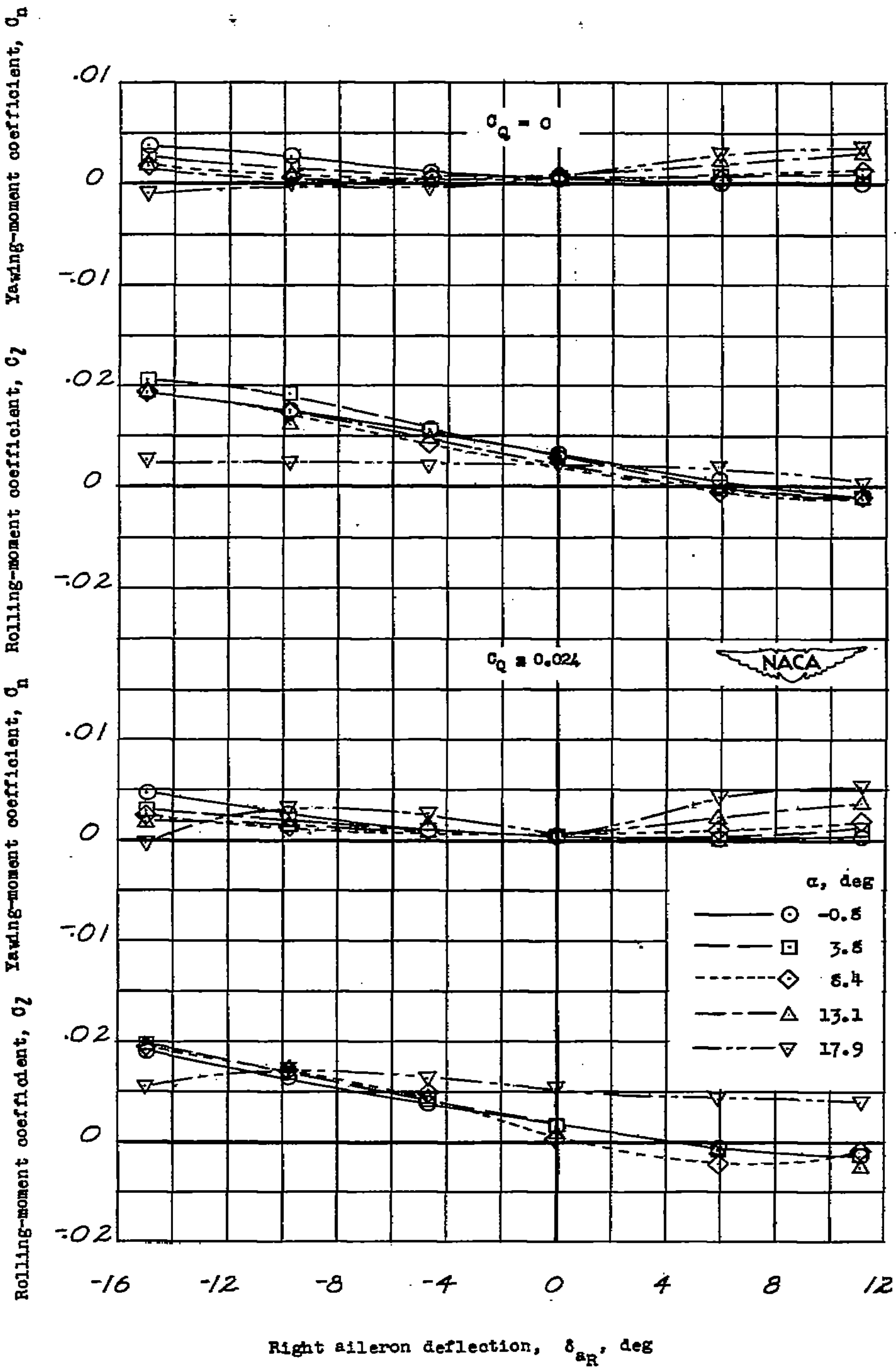
Figure 12.- Effect of boundary-layer control by suction on the lateral-stability parameters of a 47.5° sweptback wing-fuselage combination with semispan split and $0.50\frac{b}{2}$-span extensible leading-edge flaps. $\delta_f = 60°$, $\delta_{LE} = 127.5°$.

what span?



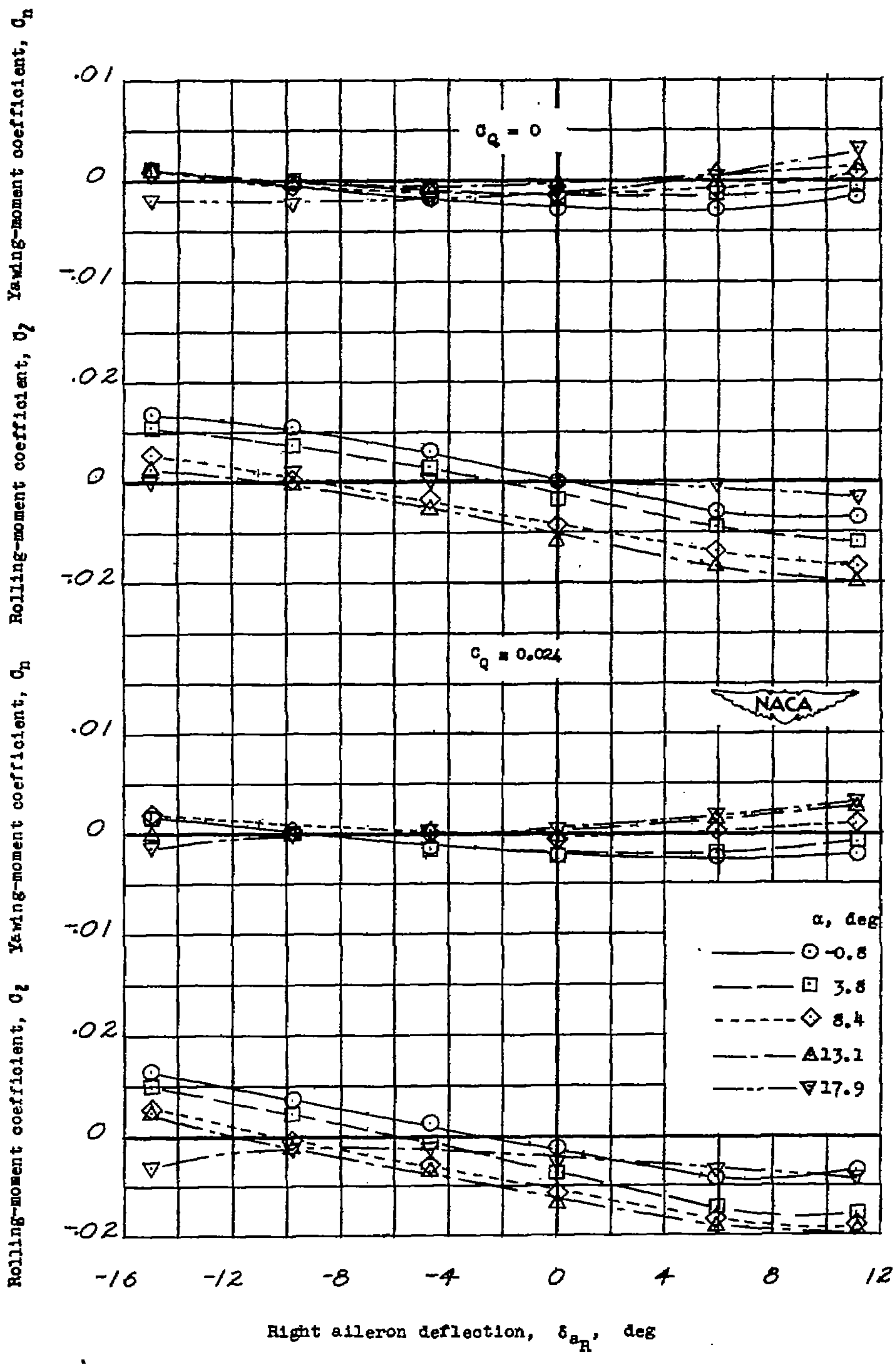
(a) $\psi = 4^{\circ}$.

Figure 13.- Effect of aileron deflection on the aerodynamic characteristics in yaw of a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction. Semispan split flaps, $\delta_f = 60^{\circ}$.



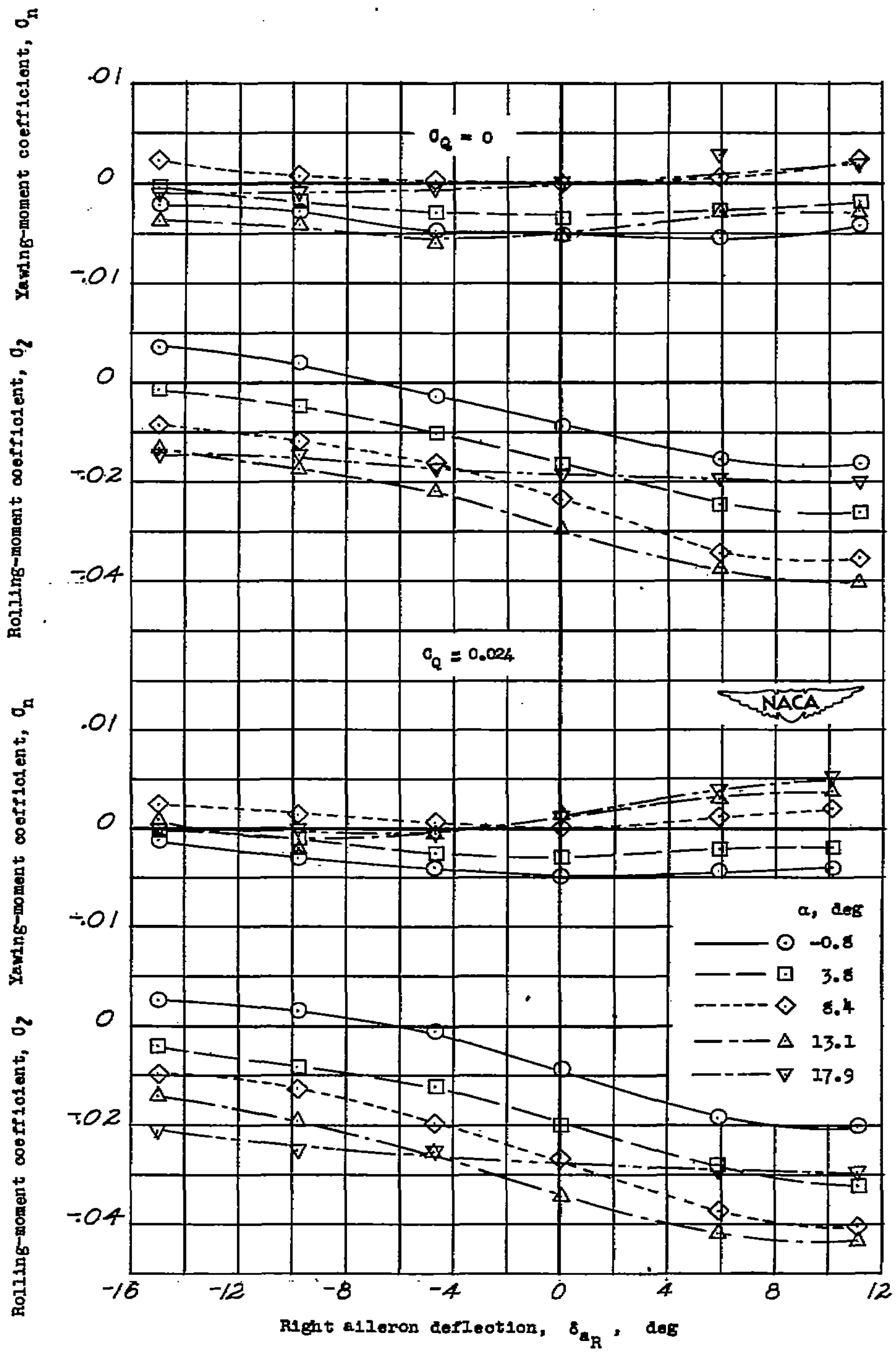
(b) $\psi = 0^{\circ}$.

Figure 13.- Continued.



(c) $\psi = -3.9^{\circ}$.

Figure 13.- Continued.



(d) $\psi = -10.2^{\circ}$.

Figure 13.- Concluded.

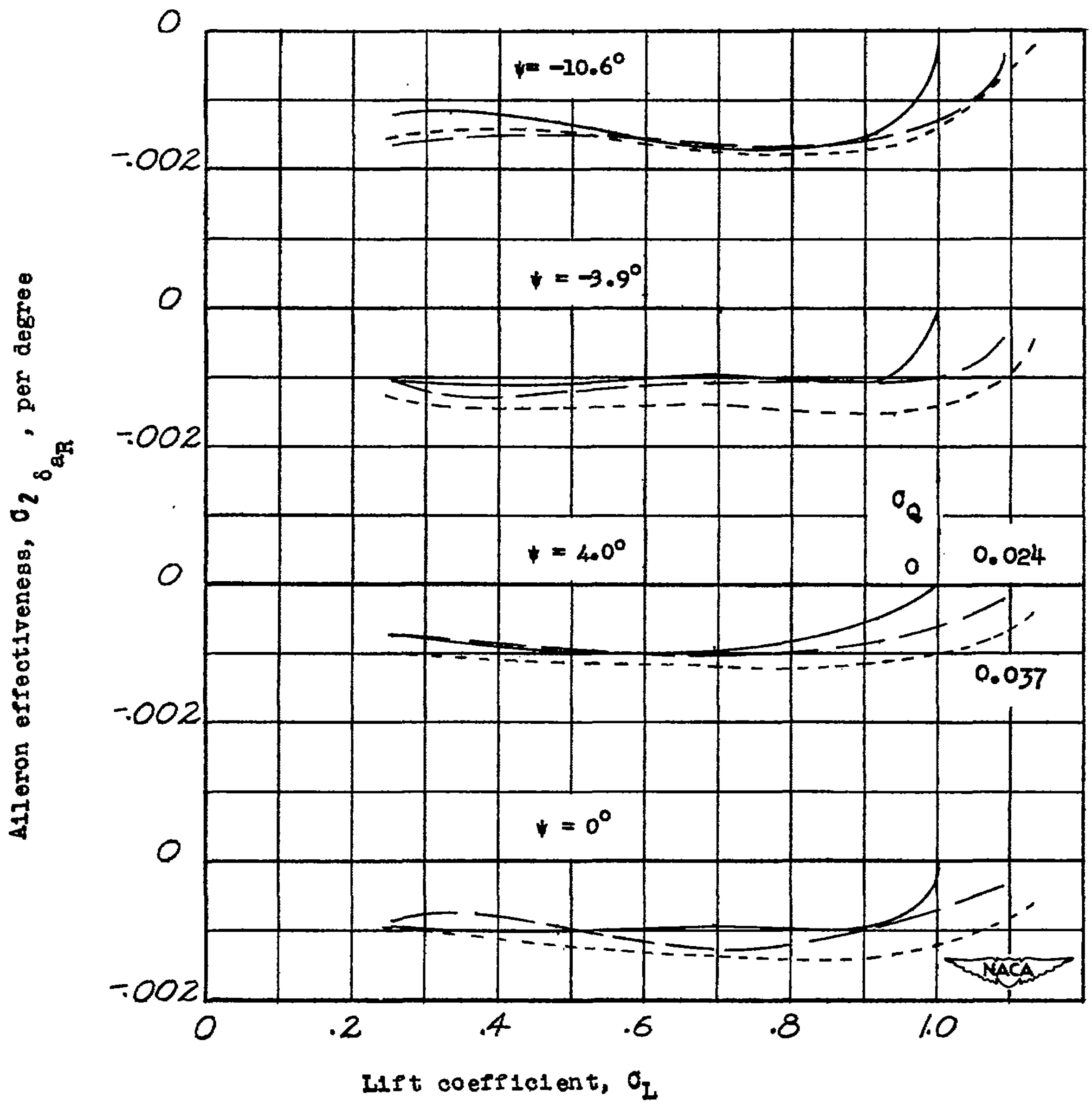


Figure 14.- Effectiveness of a split-flap aileron on a 47.5° sweptback wing-fuselage combination with and without boundary-layer control by suction. Semispan split flaps installed, $\delta_f = 60^\circ$.