NACA

RESEARCH MEMORANDUM

for the

Air Materiel Command, U.S. Army Air Forces

WIND-TUNNEL INVESTIGATION OF THE LOW-SPEED CHARACTERISTICS OF A 1/8-SCALE MODEL OF THE REPUBLIC XP-91 AIRPLANE WITH A VEE AND A CONVENTIONAL TAIL

By James A. Weiberg and Warren E. Anderson

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

Dec. 15, 1947

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SUMMARY

Low-speed wind-tunnel tests of a 1/8-scale model of the Republic XP-91 airplane were made to determine its low-speed characteristics and the relative merits of a vee and a conventional tail on the model.

The results of the tests showed that for the same amount of longitudinal and directional stability the conventional tail gave less roll due to sideslip than did the vee tail. The directional stability of the model was considered inadequate for both the vee and conventional tails; however, increasing the area and aspect ratio of the conventional vertical tail provided adequate directional stability. It was possible with negative wing dihedral and open main landing-gear doors to reduce the excessive roll due to sideslip for the landing configuration (flaps and gear down) to a more reasonable value commensurate with the aileron power. The use of variable wing incidence to adjust the longitudinal balance was sufficiently effective to reduce the predicted up-elevator required for landing by approximately 5°.

INTRODUCTION

Preliminary tests of a 1/8-scale model of the Republic XP-91 airplane were made in the $7\frac{1}{2}$- by 10-foot Wright Brothers wind tunnel at the Massachusetts Institute of Technology.

These tests indicated that the airplane with the original vee tail would have insufficient directional stability and excessive roll due to sideslip. Consequently, a new tail with conventional horizontal and vertical surfaces was designed and built by the Republic Aviation Corporation for the 1/8-scale model. At the request of the Air Materiel Command, U. S. Army Air Forces, the tests reported herein were made with the model in the Ames 7- by 10-foot wind tunnel to compare the relative merits of the vee and the conventional tails. Modifications of the conventional tail were made and tested to improve the directional characteristics of the model. Means were also investigated for reducing the excessive roll due to sideslip that existed for both the vee and conventional tails. The tests were made during the period from August 12 to September 2, 1947. During the testing, the Republic Aviation Corporation was represented by Mr. Phillip L. Michel.

DESCRIPTION OF THE AIRPLANE AND THE MODEL

The Republic XP-91 airplane is a single-place interceptor having a swept-back wing with an inverse taper ratio and swept-back tail surfaces. The wing incidence can be varied in flight to adjust the longitudinal balance and to reduce the fuselage angle of attack in approaches and landings.

The power plant of the airplane comprises three units:

1. A J-47 (TG-190) turbo-jet engine supplied with air from an intake in the fuselage nose and exhausting from the rear of the fuselage.

2. Four 1000-pound-thrust rockets also exhausting from the rear of the fuselage and supplied with fuel from external droppable tanks slung under the wings.

3. Two 600-pound-thrust rockets.

The gross weight of the airplane varies from approximately 15,000 pounds empty to 29,000 pounds fully loaded.

The general arrangement of the airplane with the vee and the conventional tails is shown in figure 1, and the major airplane dimensions are given in table I. The two tail types, including the three sizes of vertical surfaces for the conventional tail, are shown in figure 2.

The model tested (fig. 3) represented the airplane to one-eighth scale with the following exceptions:

1. The air inlet in the fuselage nose was faired over, adding 1.67 feet (full scale) to the fuselage length.

2. The external wing tanks were omitted.

3. Only the vee tail and the right wing panel were constructed with movable control surfaces. However, the control surfaces were sealed and were not deflected during the tests.

The model was mounted in the wind tunnel on a single strut (fig. 4). Rolling and pitching moments were measured by resistance-type electrical strain gages within the model. All other forces and moments were measured by the wind-tunnel balance system.

SYMBOLS AND COEFFICIENTS

All data are presented as standard NACA coefficients corrected for support tares, tunnel-wall interference, and stream inclination. Corrections for tunnel-wall interference and stream inclination are given in the appendix. All force coefficients are referred to the wind axes. Yawing- and pitching-moment coefficients are given about the stability axes and rolling-moment coefficients about the body axes.[1] These systems of axes[2] are each composed of three mutually

[1] If rolling moments are transferred to the stability axes, they are reduced by approximately 2 percent at an angle of attack of 12° and 0 percent at an angle of attack of 0°.

[2] The longitudinal axis for the wind-axes system remains parallel to the relative wind; for the stability-axes system the longitudinal axis yaws with the model, remaining at an angle of attack of 0° as the model is pitched; for the body axes system, the longitudinal axis yaws and pitches with the model, remaining parallel to the body axis of the model. The directional axis remains in the plane of symmetry for all the systems of axes.

perpendicular axes with their origins at a center of gravity of the airplane located on the fuselage reference line and 18 percent of the M.A.C. aft of the leading edge of the M.A.C.

The angle of attack is referred to the wing reference plane which contains the fuselage reference line when the wing incidence is 0°. The angle of yaw is referred to the plane of symmetry.

Coefficients and symbols used throughout the report are defined in the appendix.

RESULTS AND DISCUSSION

The tests to determine the lateral characteristics were run at a Reynolds number of 1,600,000, while those to determine the longitudinal characteristics were run at a Reynolds number of 1,100,000. In order to ascertain the effects of Reynolds number, tests were made with a net installed in the wind tunnel ahead of the model for the purpose of increasing the stream turbulence and, thereby, the effective Reynolds number. With the net, a maximum effective Reynolds number of 3,500,000 was obtained (full-scale Reynolds number at 120 mph is 12,000,000). Within this test range (1.1 to 3.5×10^6) the effect of Reynolds number on the aerodynamic characteristics of the model was negligible.

Comparative Effectiveness of Vee and Conventional Tails

Lateral characteristics.- A comparison of the lateral characteristics of the model with vee tail and the three conventional tails is shown in figures 5 and 6 for the model with the flaps and gear retracted and extended, respectively. The lateral characteristics of the model with the tail removed are shown in figure 7. Data are presented for several angles of attack. These data were obtained with a dihedral and wing incidence of 0°, with the exception of the data for the medium vertical tail. The data for this vertical tail were obtained with a wing dihedral of $-5.5°$ and a wing incidence of 6°; however, the effect of dihedral and wing incidence on C_{n_ψ} and

C_{Y_ψ}[3] was found to be small and will be discussed later. The variations of the stability parameters, C_{n_ψ} and C_{l_ψ}[4] with lift coefficient have been evaluated from figures 5, 6, and 7 and are presented in figure 8. It is noted that the directional-stability parameter C_{n_ψ} was nearly constant with lift coefficient and that both the vee tail and the conventional tail, for the same effective vertical area,[5] gave nearly neutral directional stability. Increasing the area and aspect ratio of the conventional vertical tail increased the directional stability as shown in figure 8.

Comparison of the lateral-stability parameters C_{l_ψ} for the four tails (fig. 8) indicates that the vee tail gave slightly more roll due to sideslip than the conventional tail for the same effective vertical area.

Longitudinal characteristics.- A comparison of the longitudinal characteristics of the model with the vee and conventional tails (with the small vertical) is presented in figure 9 along with tail-off data. This figure shows that the static longitudinal stability (as measured by dC_m/dC_L) of the model was approximately the same for both the vee and the conventional tails.

Figure 9 shows a large change in balance ($\Delta C_{m_0} = 0.04$) between the vee and conventional tails. Since, from consideration of their relative geometric locations, the two tails appear to have been operating in similar downwash fields, a large part of the change in balance appears to have been due to a difference in tail incidence (intended to be zero for both tails). A difference in tail incidence of approximately 2° would account for the change in balance. The absolute

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[3] The rolling-moment data for the medium vertical tail were in error and hence are not presented.

[4] Values of C_{n_ψ} and C_{l_ψ} were measured between approximately ±2° of yaw.

[5] From reference 1, the effective vertical area of an unswept vee tail is equal to $\cos^2 \Gamma$ times the actual area.

magnitude of the tail incidence on the model was not readily measurable and hence no check of the tail incidence was made during the tests. The test data, however, have been checked and no errors in computation have been found.

The lift characteristics of the model were similar for both the vee and conventional tails (fig. 9).

Roll Due to Sideslip

With the flaps and gear down, the data of figure 8 indicate that maximum values of C_{l_ψ} of 0.0060 and 0.0053 will be attained at a lift coefficient of 0.73 for the airplane with the vee and small conventional tails, respectively. Reference 2 indicates that large increases in Reynolds number may tend to increase this value at higher lift coefficients so that for the full-scale airplane the maximum value of C_{l_ψ} may be even higher than that indicated by figure 8. Full-scale tests of the ailerons on the XP-91 airplane show that full aileron deflection is only sufficient to hold the wings level in a 10° sideslip with a value of C_{l_ψ} of 0.003. These data, therefore, indicate that means should be provided for reducing the maximum rolling moment due to sideslip.

Effect of negative dihedral.- Results of tests with the vee tail to determine the effect of -5.5° of wing dihedral[6] on the lateral characteristics of the model are shown in figure 10. The values of C_{l_ψ} obtained from figure 10 are presented in figure 11 and compared with those for a wing dihedral angle of 0°. These data show that -5.5° of wing dihedral contributed a C_{l_ψ} of approximately -0.001, which compares favorably with that predicted using references 3, 4, and 5.

Effect of landing-gear doors.- The main landing gear on the XP-91 airplane retracts outboard into the wing tips because of the greater depth available at the tips as a result of the inverse taper. When the wheels are lowered, large doors, which normally cover the wheel wells, are opened (fig. 12).

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[6] The model was tested with -5.5° of wing dihedral; however, -5° dihedral is the maximum that can be built into the airplane and still maintain ground clearance.

The doors have a total area of 24.5 square feet (full scale) or 7.7 percent of the wing area. The lateral characteristics of the model with these doors open are shown in figure 13 for two angles of door opening. The ability of the doors to reduce C_{l_ψ} is shown in figure 11 where it may be seen that the doors reduced the maximum value of C_{l_ψ} by as much as 0.002 for the 120° opening.

Thus, at the Reynolds number of these tests, the maximum value of C_{l_ψ} for the landing configuration was reduced nearly to the allowable 0.003 with -5° dihedral and the open landing-gear doors. At full-scale Reynolds numbers, however, this peak value may be somewhat higher.

Effect of Wing Incidence

The wing on the XP-91 airplane is equipped with a mechanism for adjusting the incidence in flight from 0° (high-speed level flight) to 6° (landing) for the purpose of adjusting the longitudinal balance and of reducing the fuselage angle of attack in approaches and landings. Changing the wing incidence with respect to the fuselage effects a change in the tail angle of attack and, consequently, in the balancing lift coefficient. This change in longitudinal balance for the landing configuration (flaps and gear down) can be seen by comparison of figure 14 with figure 9. Increasing the wing incidence 6° resulted in an increase of 0.04 in the pitching-moment coefficient corresponding to a given lift coefficient, with approximately no change in stability. This change in balance would reduce the up elevator required for landing by approximately 5°. A reduction of 0.1 in the lift coefficient for a constant wing angle of attack resulted from rotating the fuselage relative to the wing.

The static lateral characteristics for the landing configuration with 6° wing incidence are shown in figure 15[7]. Comparison of figure 15 with the data presented in figures 6 and 10 shows that the lateral characteristics of the model were relatively unaffected by the increase in wing incidence.

[7] The rolling-moment data obtained for this configuration were in error and hence are not presented.

The data for the conventional tail (fig. 15(b)) were obtained with -5.5° wing dihedral. This difference in dihedral (figs. 15(b) and 6) had a negligible effect on C_{n_ψ}, as may be seen by comparing figure 10 with figure 6.

Effect of Flap Type

The 1/8-scale model of the XP-91 airplane was originally equipped with 55-percent-span, 30-percent-chord split flaps with a maximum deflection of 60°. However, the flap design on the airplane was changed to 25-percent-chord plain flaps having a maximum deflection of 40°. To determine the effect of this change, the flaps on the model were revised to correspond to those on the airplane. A comparison of the geometry of the two flap types on the model can be seen from figures 16 and 3. The effect of the change in flap design on the longitudinal characteristics is shown in figure 17. The drag of the plain flaps was approximately 40 percent less and the lift increment slightly greater at low angles of attack ($\Delta C_L = 0.07$ at $\alpha = 0^\circ$) than those of the split flaps. The maximum lift ($C_{L_{max}} = 1.08$) of the model was approximately the same for both flaps. The plain flaps caused a slightly smaller change in balance with approximately the same static longitudinal stability (dC_m/dC_L) as that obtained with the split flaps.

The lateral characteristics with the plain flaps are presented in figure 18. Comparison of this figure with figure 10(b) for the split flaps shows that C_{l_ψ} was unaffected by flap type but C_{n_ψ} was more negative with plain flaps ($\Delta C_{n_\psi} = -0.001$).

CONCLUSIONS

From the foregoing discussion of the results of tests of a 1/8-scale model of the Republic XP-91 airplane, the following may be said in conclusion:

1. For the same directional stability, the conventional tail gave less roll due to sideslip. This is of particular importance for swept-wing designs, since they develop high roll due to sideslip at high lift where aileron control becomes critical.

2. By increasing the area and aspect ratio of the vertical surface adequate directional stability was obtained with the conventional tail.

3. The static longitudinal stability of the model was the same with both the vee and the conventional tail.

4. It was possible with negative wing dihedral and open main landing-gear doors to reduce the excessive roll due to sideslip for the landing configuration (flaps and gear down) to a more reasonable value commensurate with the aileron power.

5. The variable wing incidence gave sufficient balance change to reduce the predicted up-elevator required for landing by approximately 5°.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

APPENDIX

Symbols and Coefficients

Symbols and coefficients used throughout the report are defined below:

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

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

C_Y side-force coefficient $\left(\frac{\text{side force}}{qS_w}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{rolling moment}}{qS_w b_w}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{pitching moment}}{qS_w c_w}\right)$

C_n yawing-moment coefficient $\left(\frac{\text{yawing moment}}{qS_w b_w}\right)$

C_{n_ψ} rate of change of yawing moment with angle of yaw $\left(\frac{dC_n}{d\psi}\right)$, degrees

C_{l_ψ} rate of change of rolling moment with angle of yaw $\left(\frac{\partial C_l}{\partial \psi}\right)$, degrees

C_{m_o} C_m at $C_L = 0$

A aspect ratio

b span, feet

c chord, feet

$\bar{c}$ mean aerodynamic chord, feet

i incidence, degrees

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

S area, square feet

V velocity, feet per second

α_u geometric angle of attack of wing reference plane (uncorrected), degrees

α angle of attack of wing reference plane corrected for tunnel-wall interference and stream inclination, degrees

Γ dihedral, degrees

ρ mass density of air, slugs per cubic foot

ψ angle of yaw of fuselage plane of symmetry, degrees

Subscript

w wing

Corrections

Wind-tunnel-wall corrections were applied to the drag, pitching moment, and angle of attack. The corrections were those for unswept wings obtained from reference 6. Because of the small size of the model relative to the wind tunnel, the corrections were small and hence are considered sufficiently accurate to apply to the swept wing of this model. The corrections were additive and were computed as follows:

$$\Delta\alpha_T = \delta_w \frac{S}{C} C_L \, 57.3 = 0.48 \, C_L$$

$$\Delta C_{D_T} = \delta_w \frac{S}{C} C_L^2 = 0.0079 \, C_L^2$$

$$\Delta C_{m_T} = 0$$

where

$\delta_W = 0.113$

S = wing area, 5.0 square feet

C = cross-sectional area of test section, 70 square feet

The drag and angle of attack were also corrected for stream inclination. The corrections were additive and were computed as follows:

$$\Delta\alpha_\alpha = 0.32$$

$$\Delta C_{D_\alpha} = \frac{0.32}{57.3} C_L = 0.0056 \, C_L$$

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6. Swanson, Robert S., and Schuldenfrei, Marvin J.: Jet-Boundary Corrections to the Downwash Behind Powered Models in Rectangular Wind Tunnels with Numerical Values for 7- by 10-Foot Closed Wind Tunnels. NACA ARR, Aug. 1942.

TABLE I

BASIC DIMENSIONAL DATA OF THE REPUBLIC XP-91 AIRPLANE AND MODIFICATIONS TO THE TAIL

Item	Wing	Vee tail	Conventional Tail			
		Chord plane	Horizontal	Small vertical	Medium vertical	Large vertical
Area, sq ft	320	81.4	59.9	38.6	51.4	58.7
Span, ft	31.33	20.68	14.67	7.58	8.90	10.90
Aspect ratio	3.07	5.25	3.59	1.49	1.54	2.03
Taper ratio, $\left(\frac{\text{tip chord}}{\text{root chord}}\right)$	1.625	1.0	1.0	.362	.540	.437
M.A.C., ft	10.59	3.94	4.08	5.47	5.95	5.65
Dihedral	varied	38°	0	-	-	-
Incidence	variable	0°	0	-	-	-
Airfoil Section	Republic R-4,45-1$_5$10-.9	Republic R4,40-010	-	-	-	-
Percent thickness (normal to leading edge)	9.1	10	10	14.1	-	-
Sweep (leading edge)	34.3	33.5°	40°	44.8	36.7	36.7
Tail length[1], ft	-	16.7	16.3	14.2	14.2	14.6
Tail volume, ft^3	-	-	.288	.0547	.0727	.0854

[1] 0.25 M.A.C. wing to 0.25 M.A.C. tail.

FIGURE LEGENDS

Figure 1.- General arrangement of the Republic XP-91 airplane.

Figure 2.- Tails tested on the 1/8-scale model of the Republic XP-91 airplane.

Figure 3.- The 1/8-scale model of the Republic XP-91 airplane. (a) Complete model with vee tail, flaps up.

Figure 3.- Continued. (b) Complete model with vee tail, flaps and gear down.

Figure 3.- Continued. (c) Detail of conventional tail.

Figure 3.- Concluded. (d) Complete model with tail off, flaps and gear down.

Figure 4.- Detail of model support.

Figure 5.- Comparison of lateral characteristics of the vee and conventional tails, flaps up. (a) $\alpha_u = 0^o$.

Figure 5.- Continued. (b) $\alpha_u = 4^o$.

Figure 5.- Continued. (c) $\alpha_u = 8^o$.

Figure 5.- Concluded. (d) $\alpha_u = 12^o$.

Figure 6.- Comparison of lateral characteristics of the vee and conventional tails, flaps and gear down. (a) $\alpha_u = 0^o$.

Figure 6.- Continued. (b) $\alpha_u = 4^o$.

Figure 6.- Continued. (c) $\alpha_u = 8^o$.

Figure 6.- Concluded. (d) $\alpha_u = 12^o$.

Figure 7.- Tail-off lateral characteristics. (a) Flaps up.

Figure 7.- Concluded. (b) Flaps and gear down.

Figure 8.- Effect of tail type and size on the variation of the parameters C_{l_ψ} and C_{n_ψ} with lift coefficient.

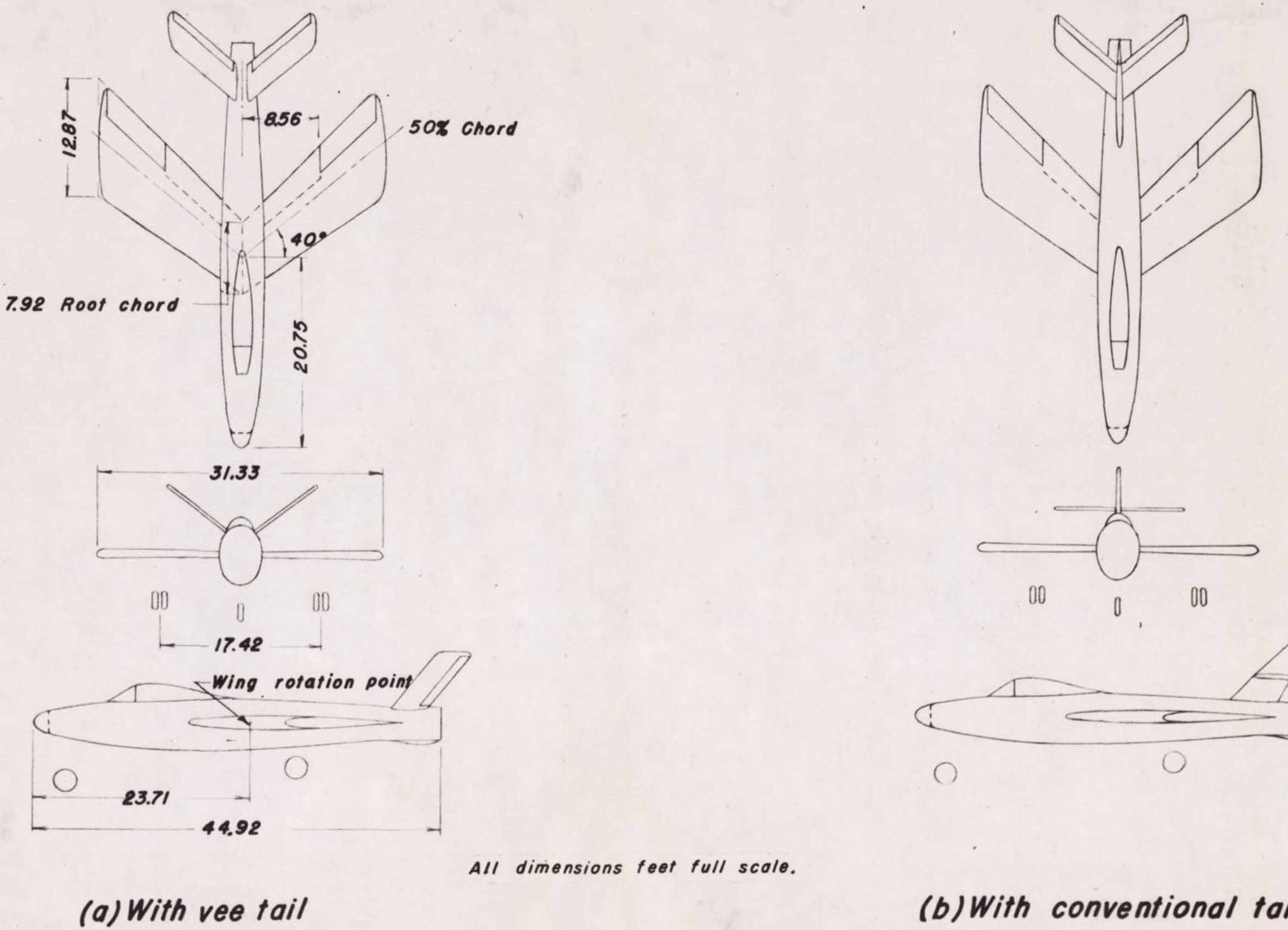

Figure 1.- General arrangement of the Republic XP-91 Airplane.

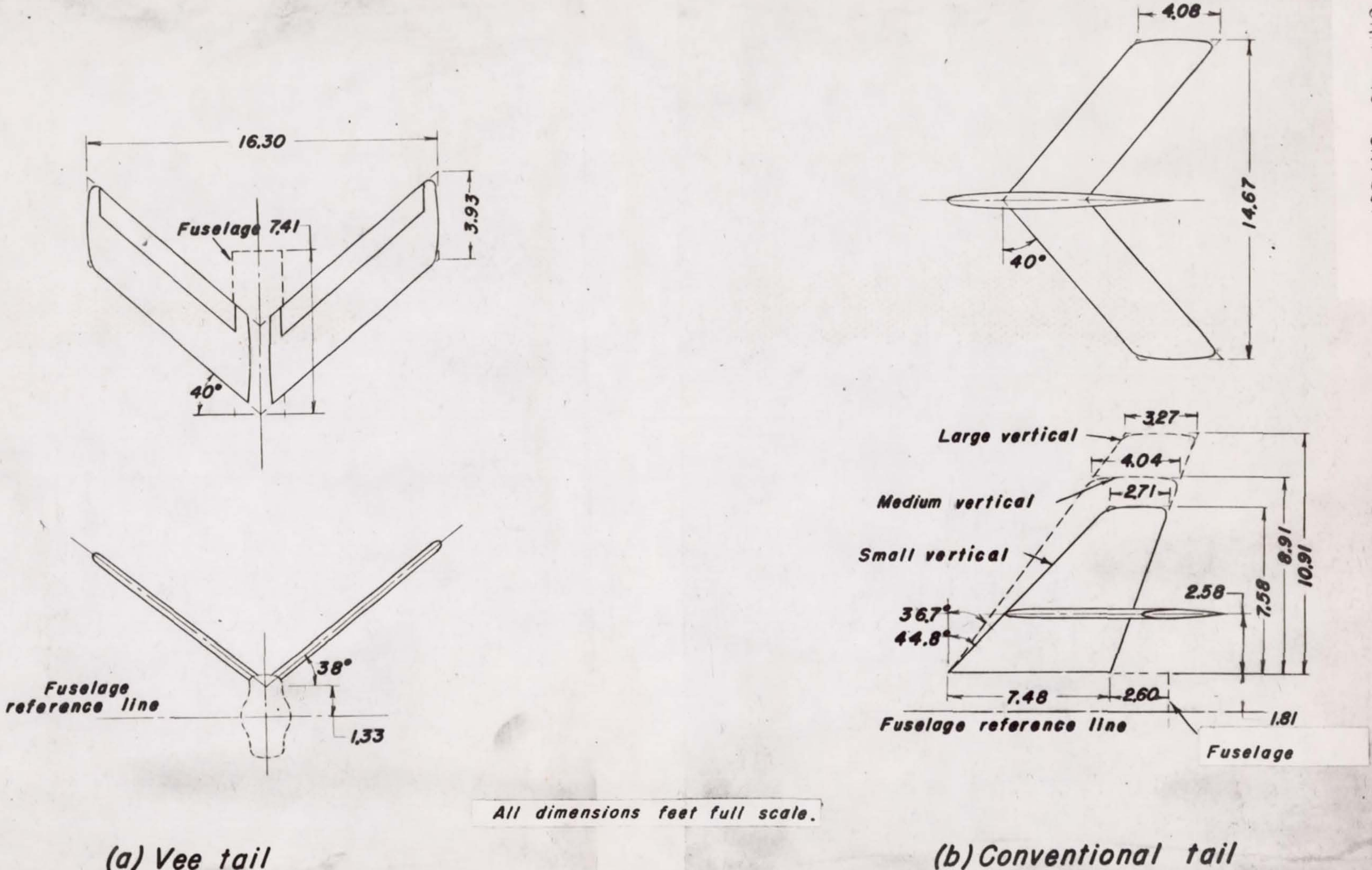

Figure 2.- Tails tested on the $\frac{1}{8}$-scale model of the Republic XP-91 Airplane.

Front view.

Rear view.

(a) Complete model with vee tail, flaps up.

Figure 3.- The 1/8-scale model of the Republic XP-91 Airplane.

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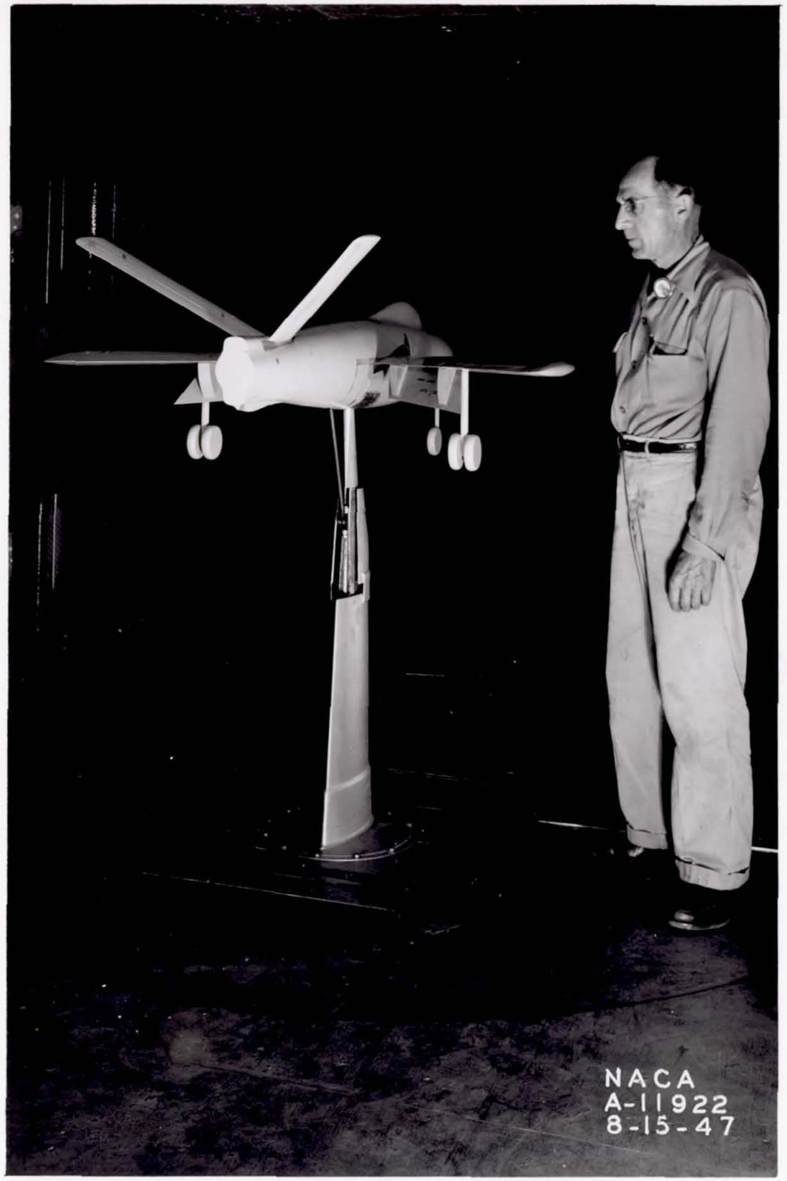
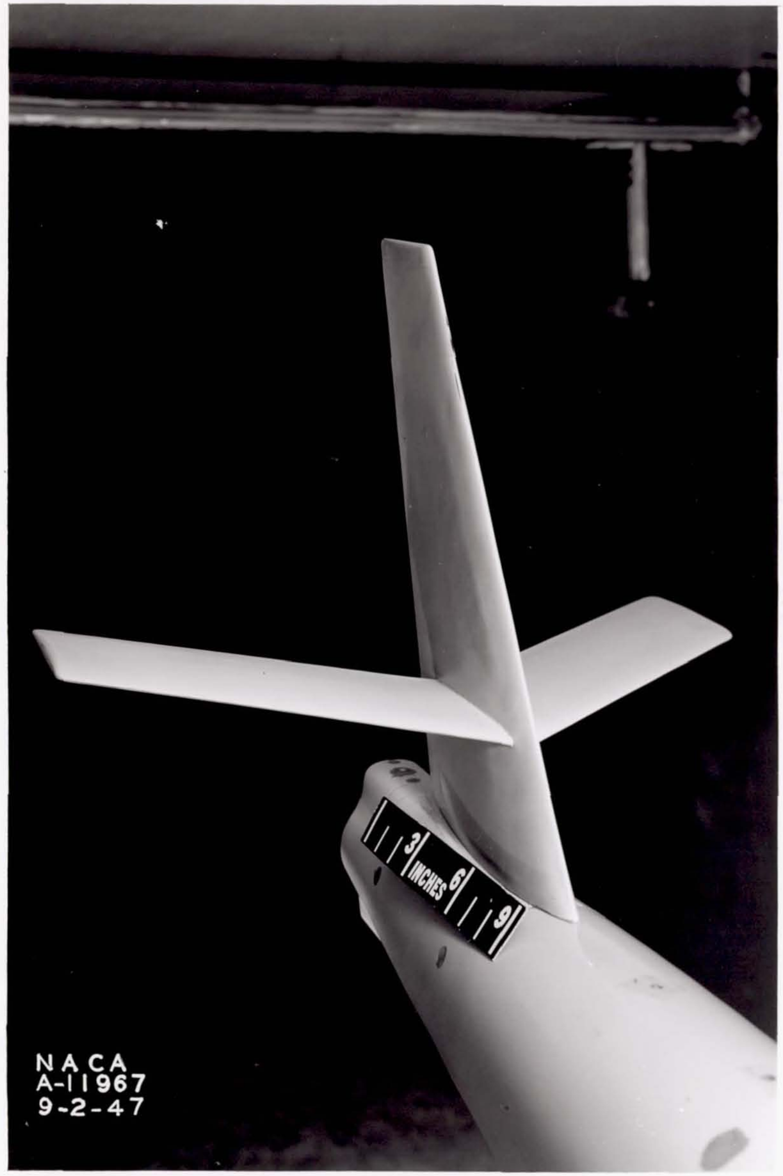


Rear view.

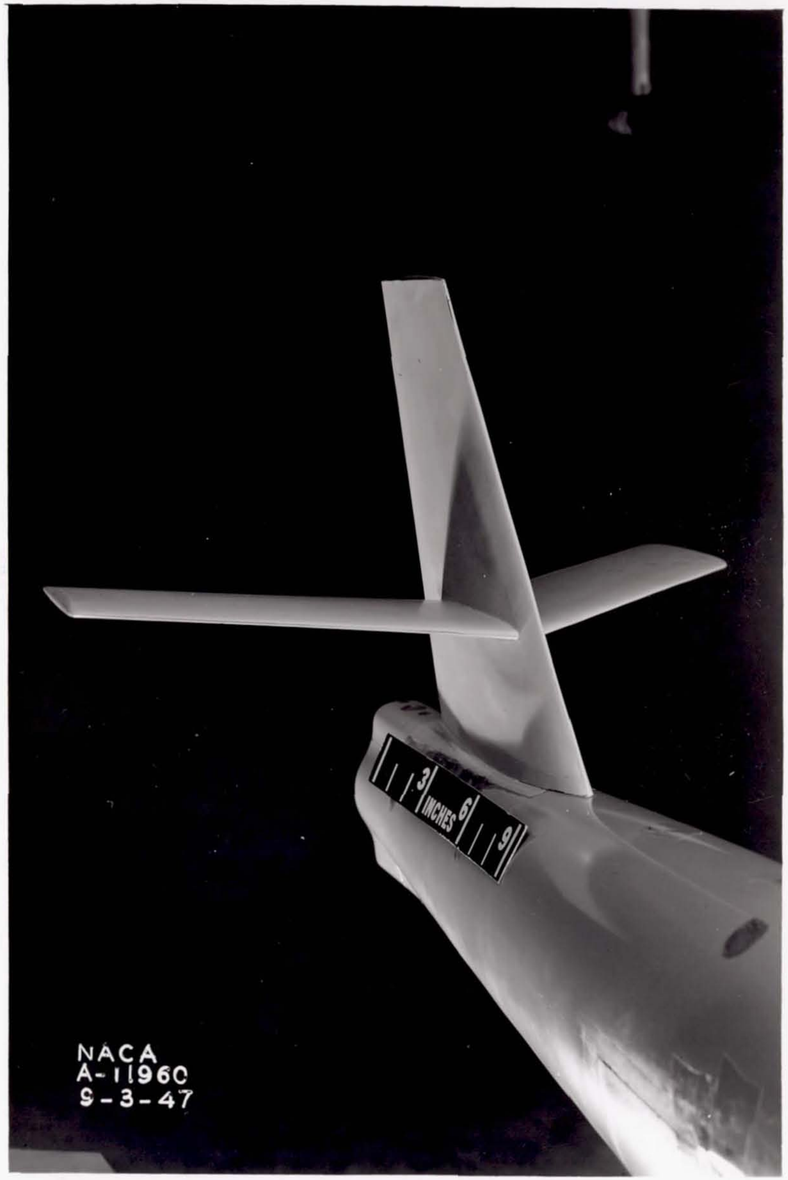
Front view.

(b) Complete model with vee tail, flaps and gear down.

Figure 3.- Continued.



With large vertical.



With medium vertical.

(c) Detail of conventional tail.

Figure 3.- Continued.

Front view.

Rear view.

(d) Complete model with tail off, flaps and gear down.

Figure 3.- Concluded.

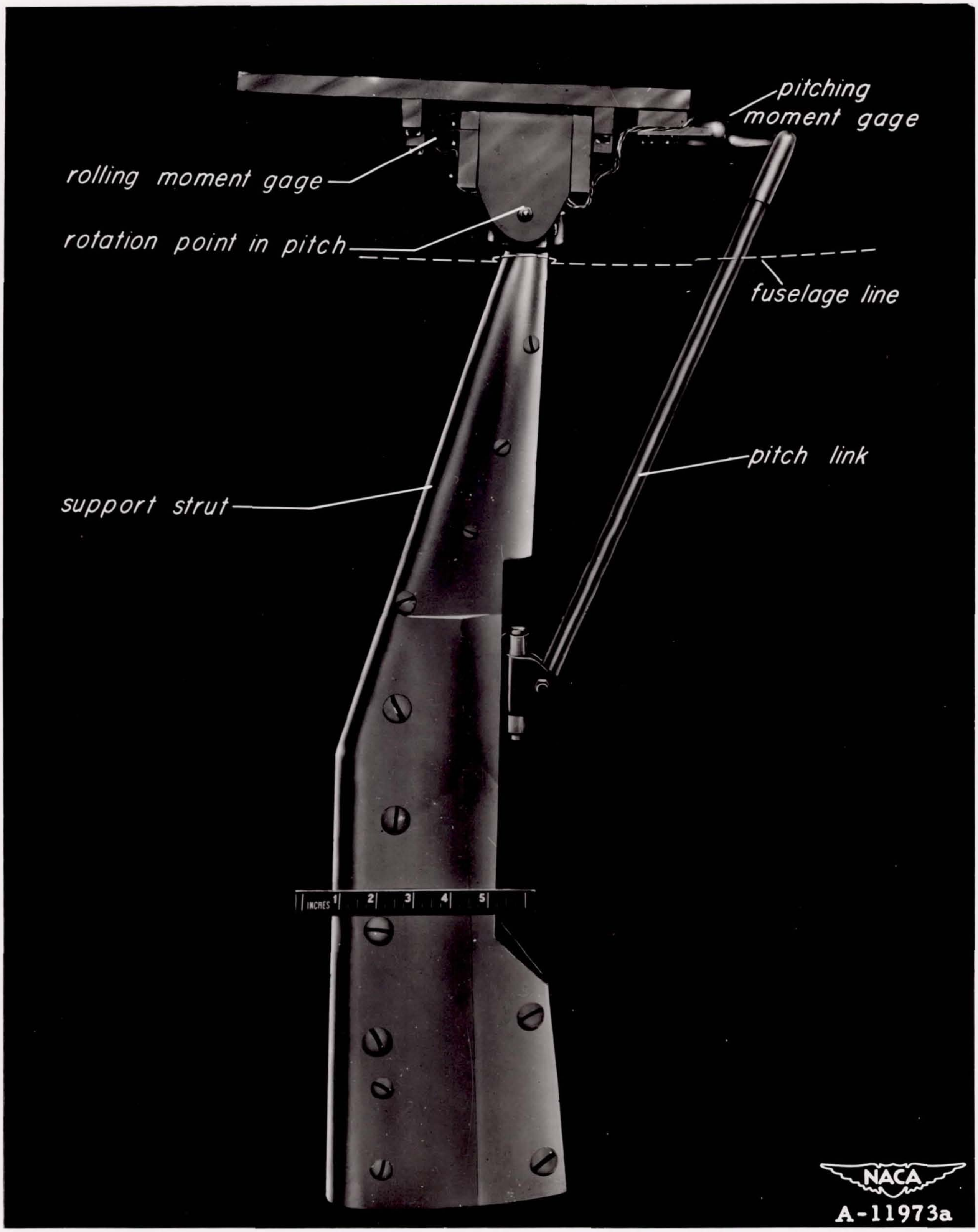


Figure 4.- Detail of model support.

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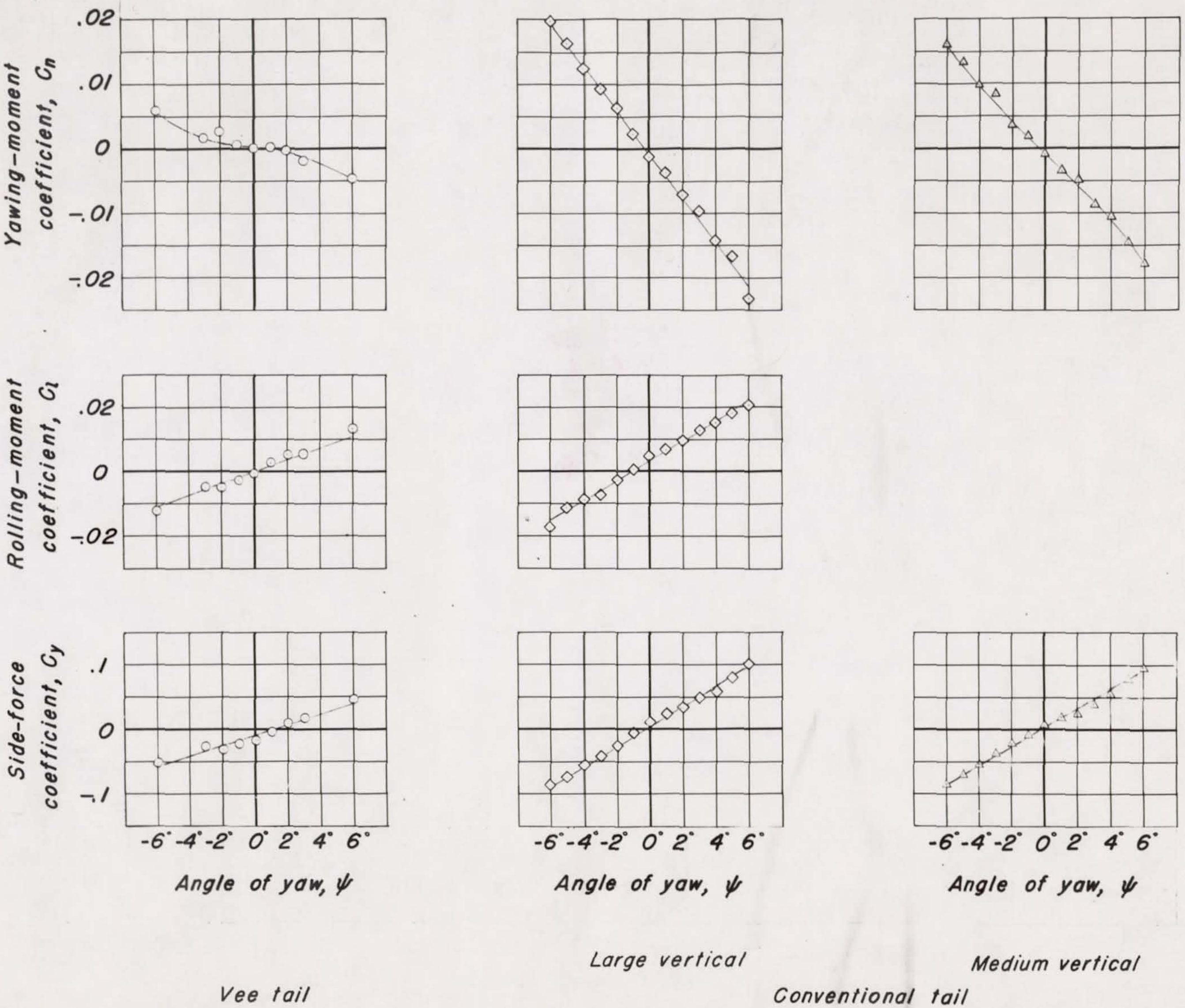
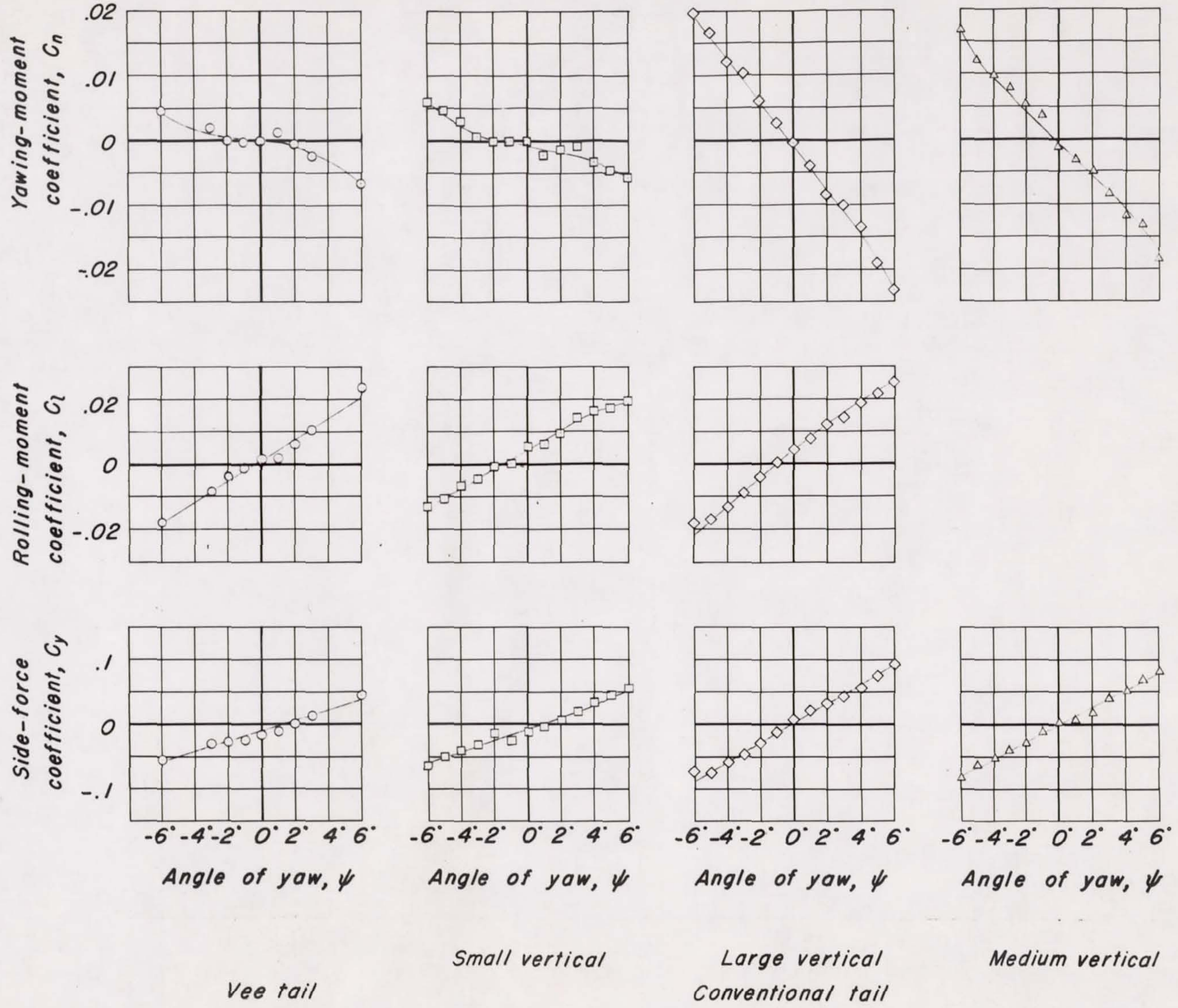
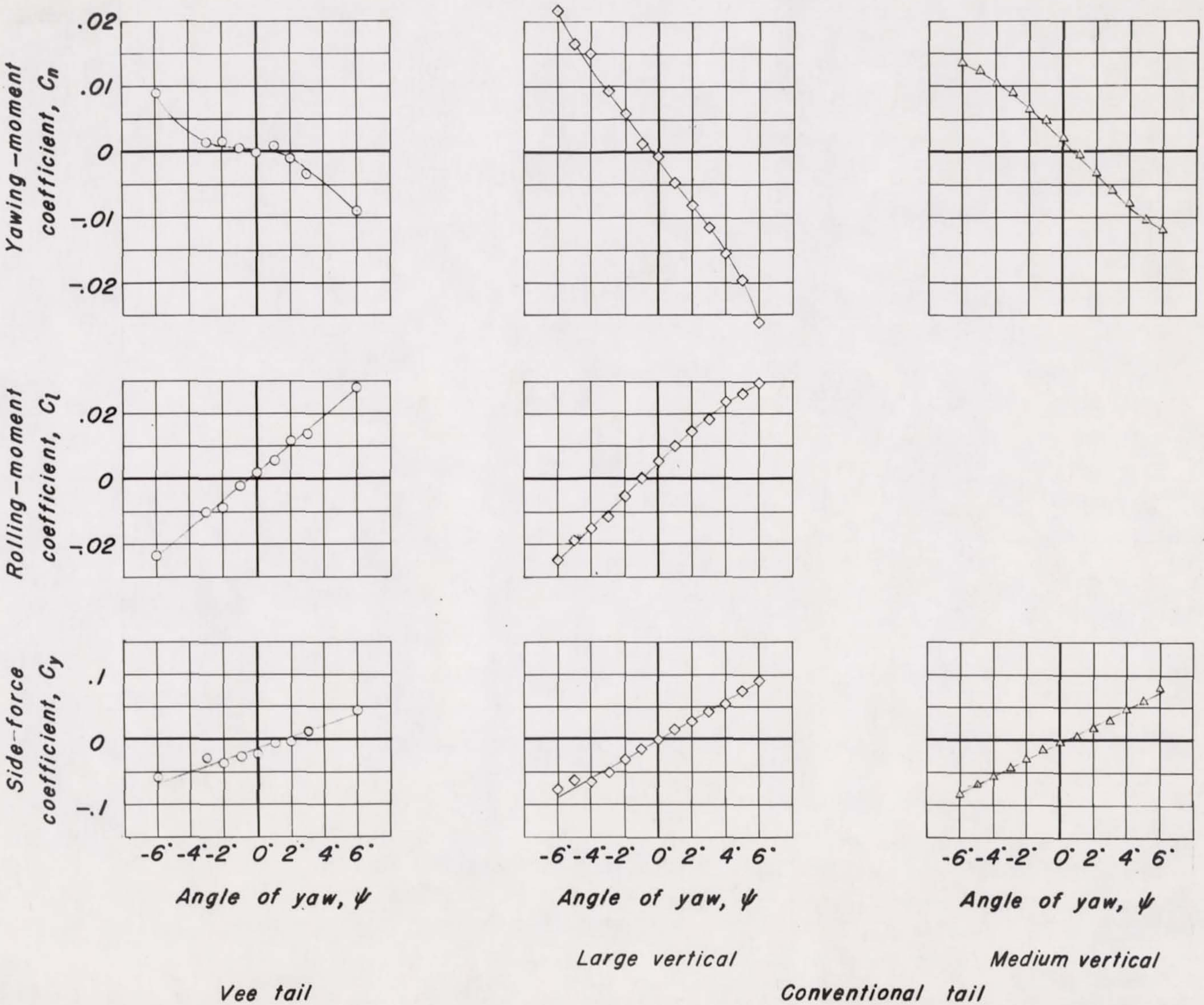


(a) $\alpha_u = 0°$

Figure 5.– Comparison of lateral characteristics of the vee and conventional tails, flaps up.

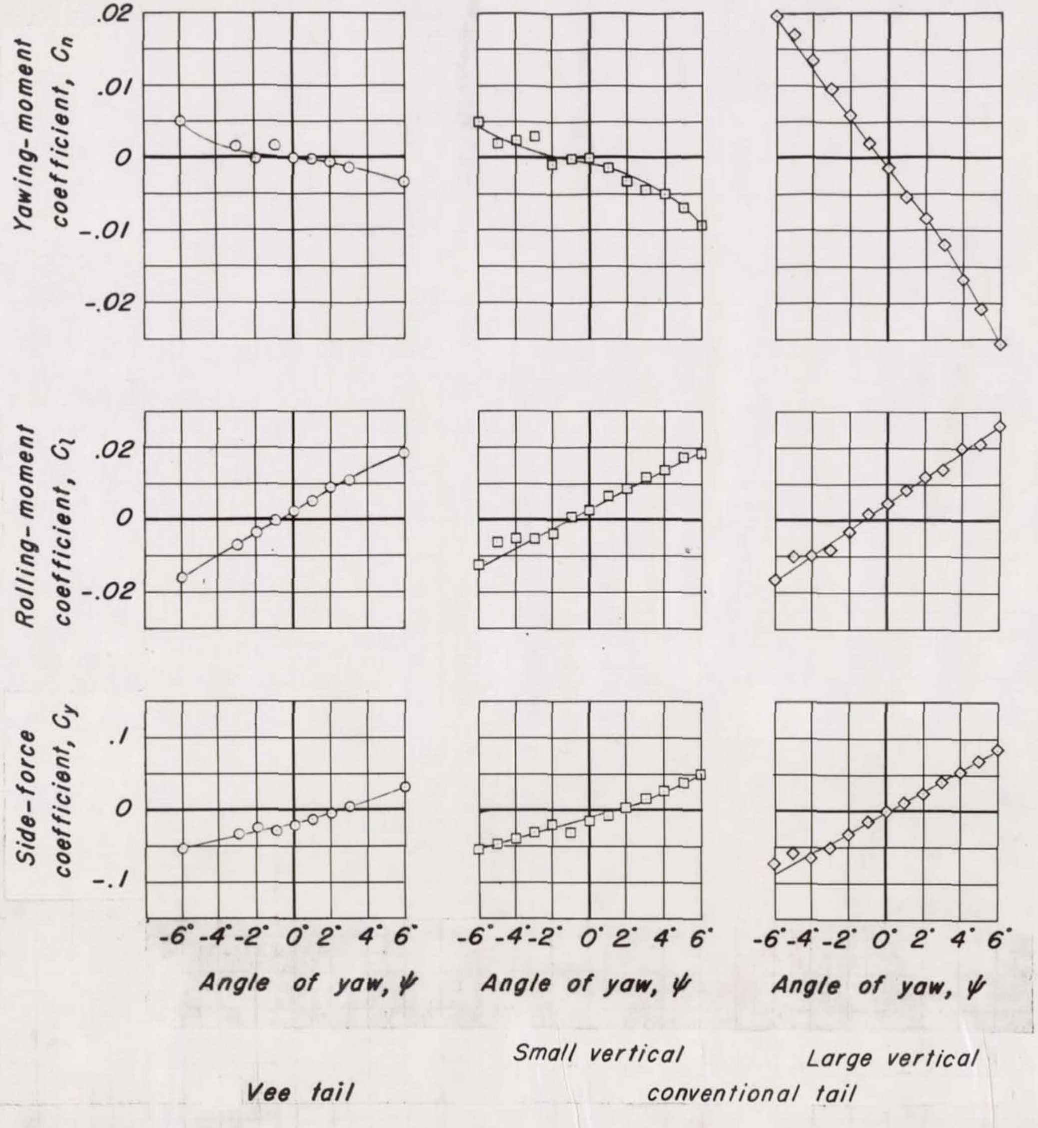


(b) $\alpha_u = 4°$
Figure 5.- Continued.



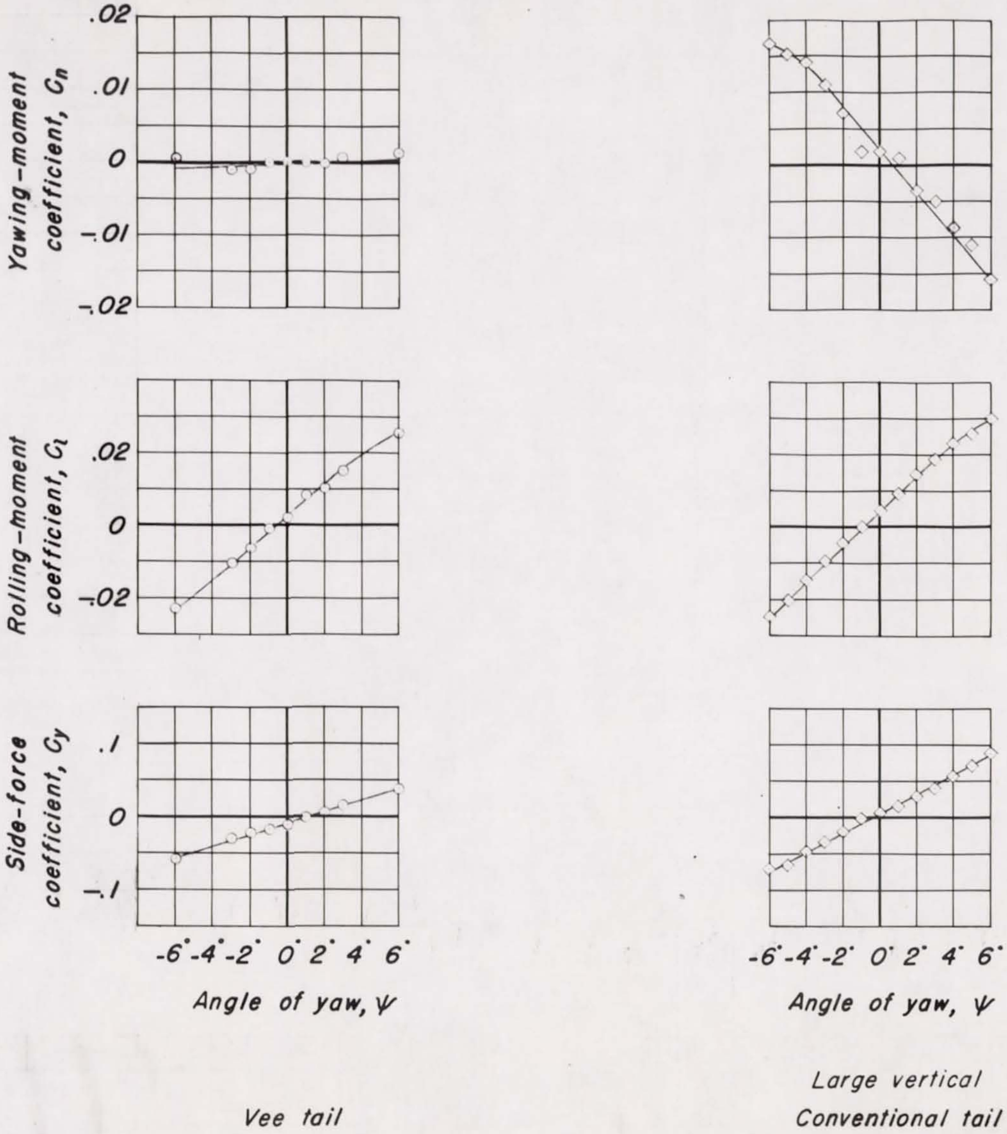
(c) $\alpha_u = 8°$

Figure 5.- Continued.



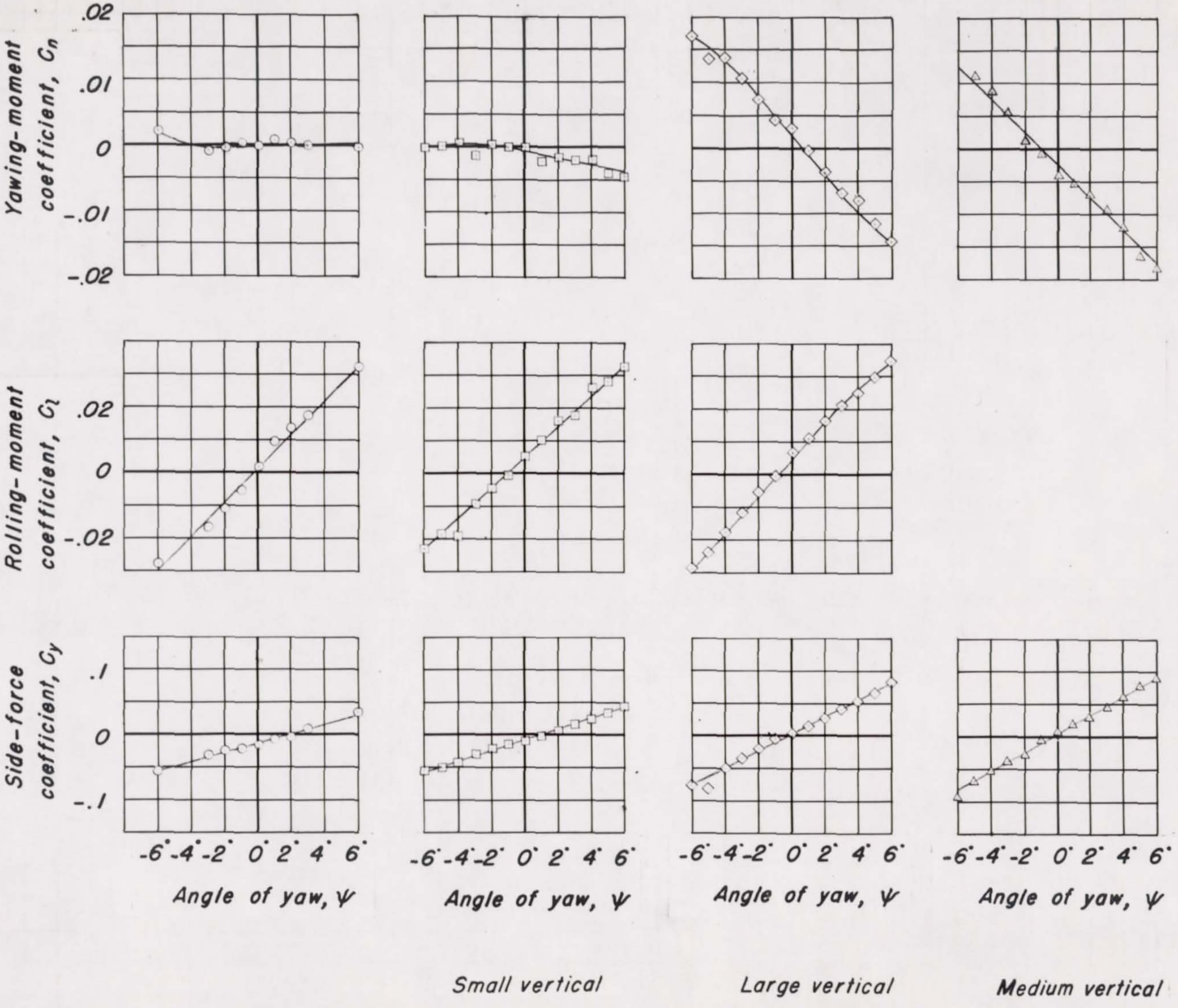
(d) $\alpha_u = 12°$

Figure 5.- Concluded.



(a) $\alpha_u = 0°$

Figure 6.- Comparison of lateral characteristics of the vee and conventional tails, flaps and gear down.



(b) $\alpha_u = 4°$

Figure 6.– Continued.

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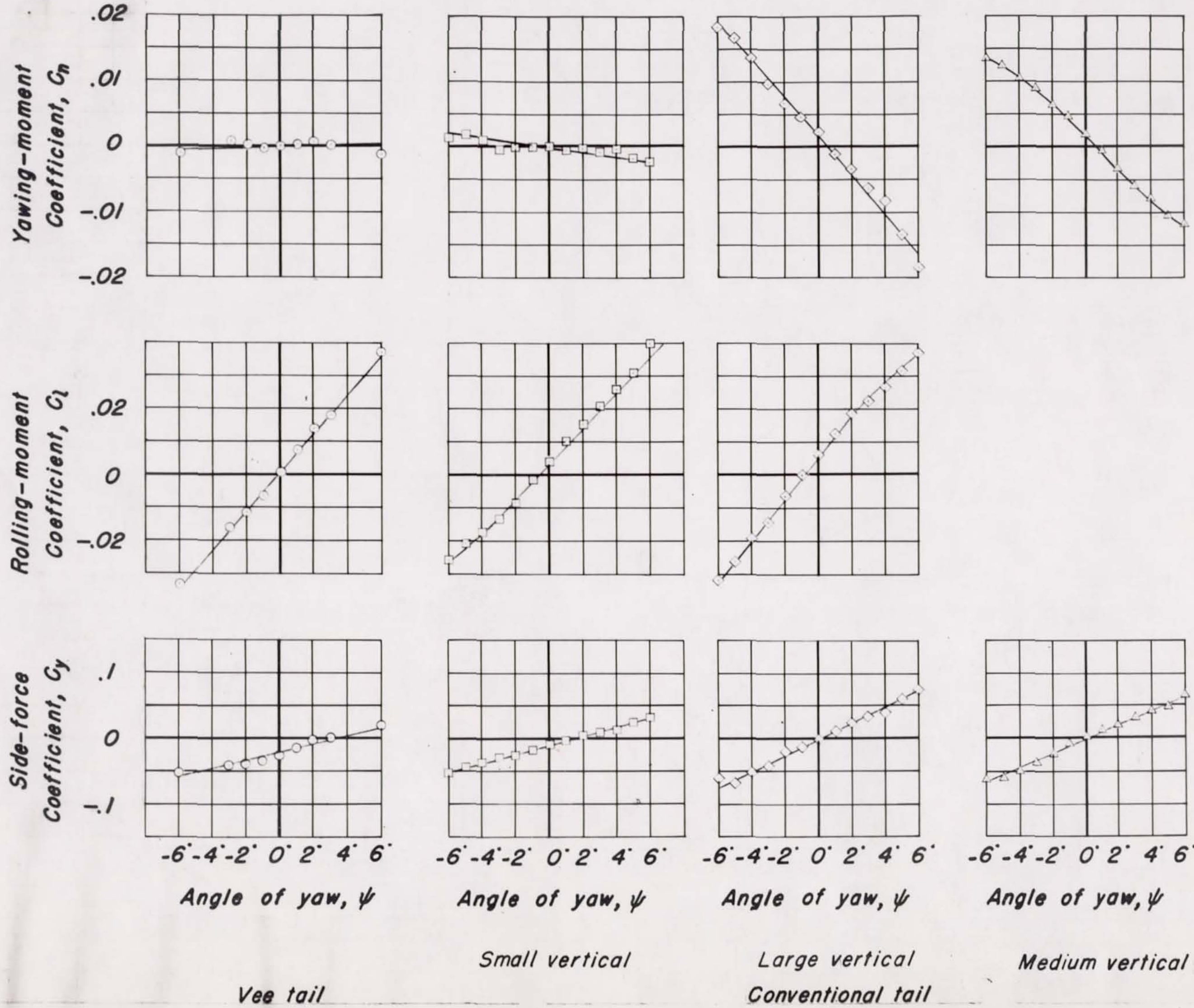
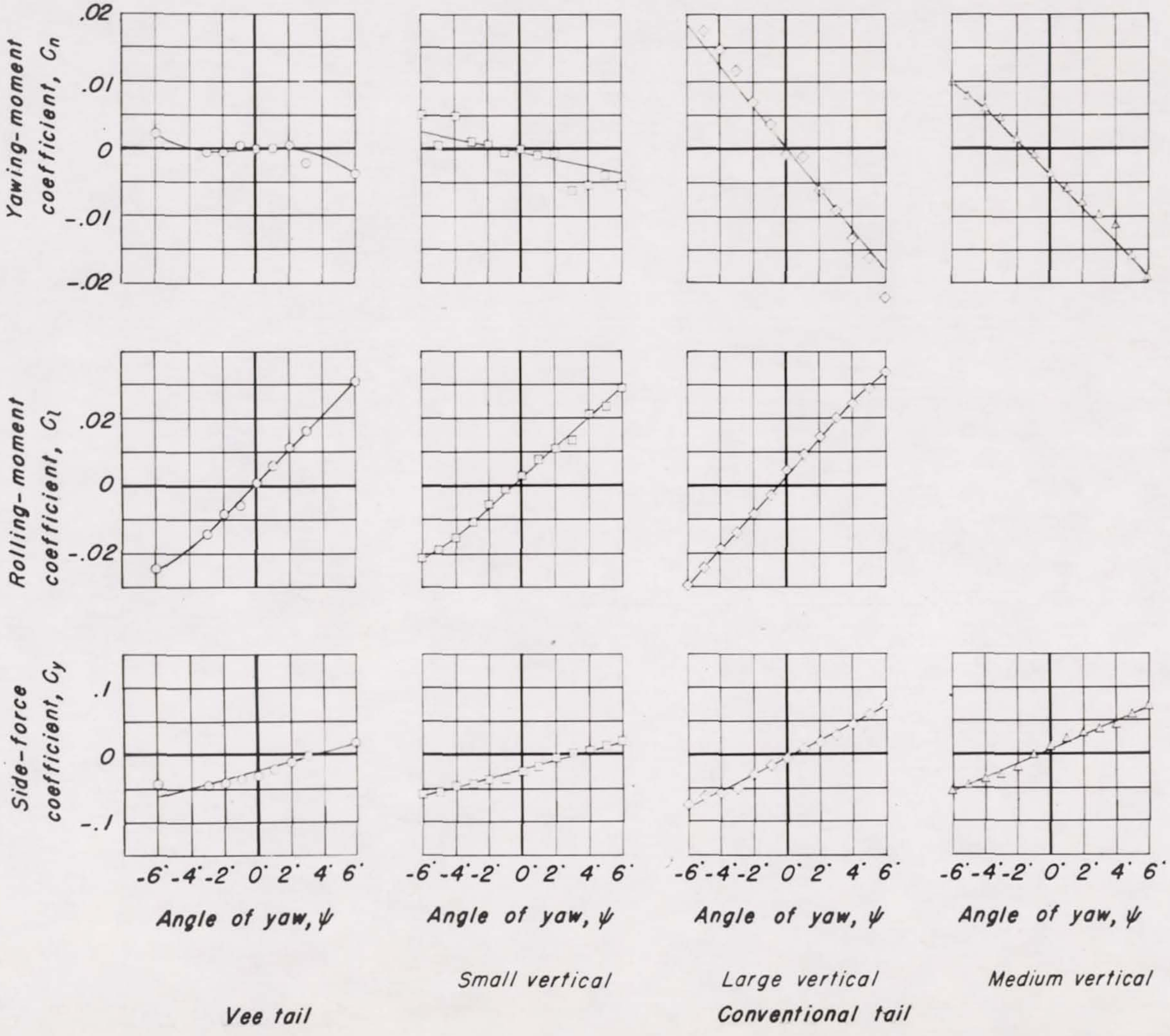


(c) $\alpha_u = 8°$

Figure 6.- Continued.



(d) $\alpha_u = 12°$

Figure 6. – Concluded.

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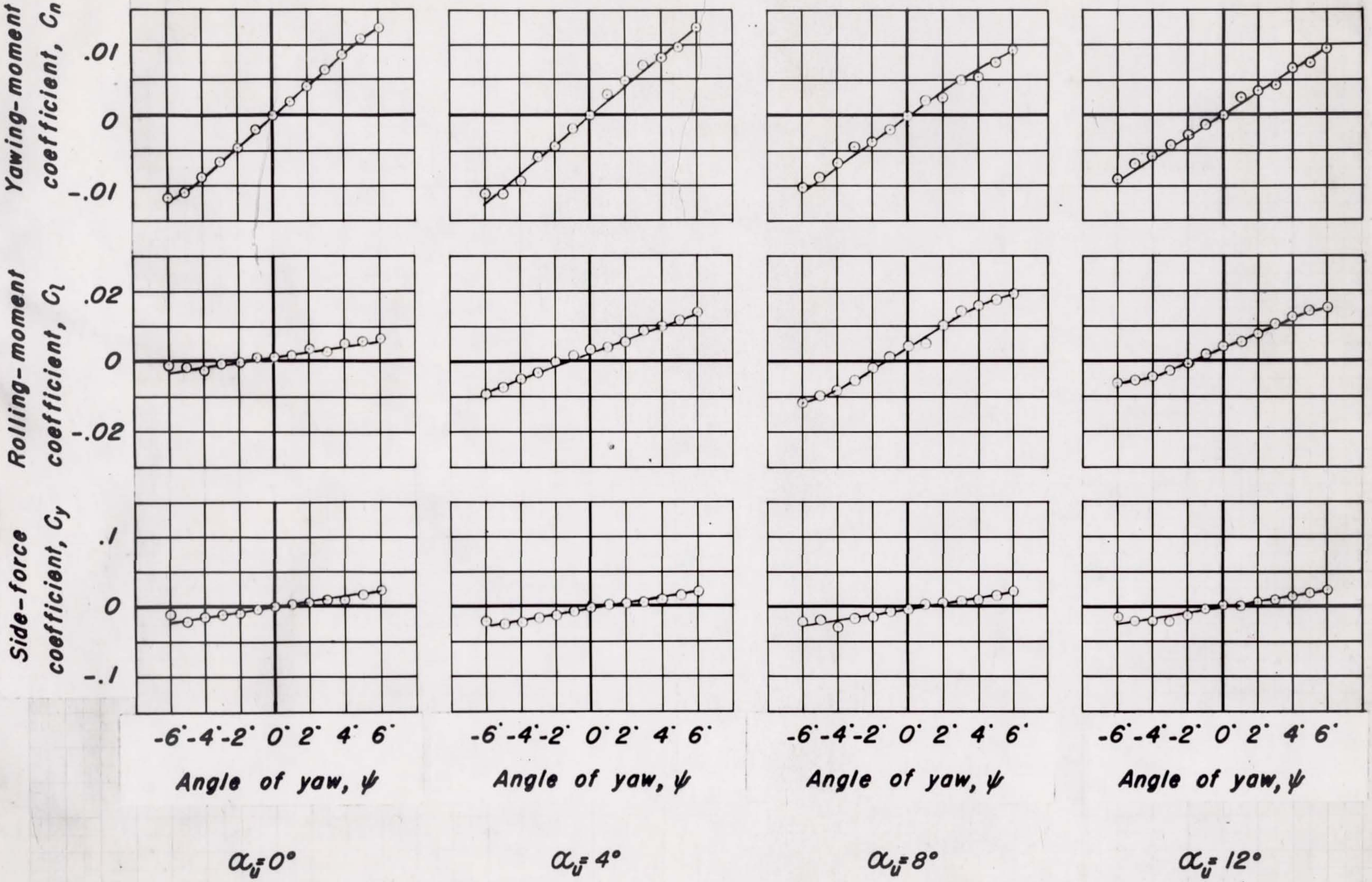
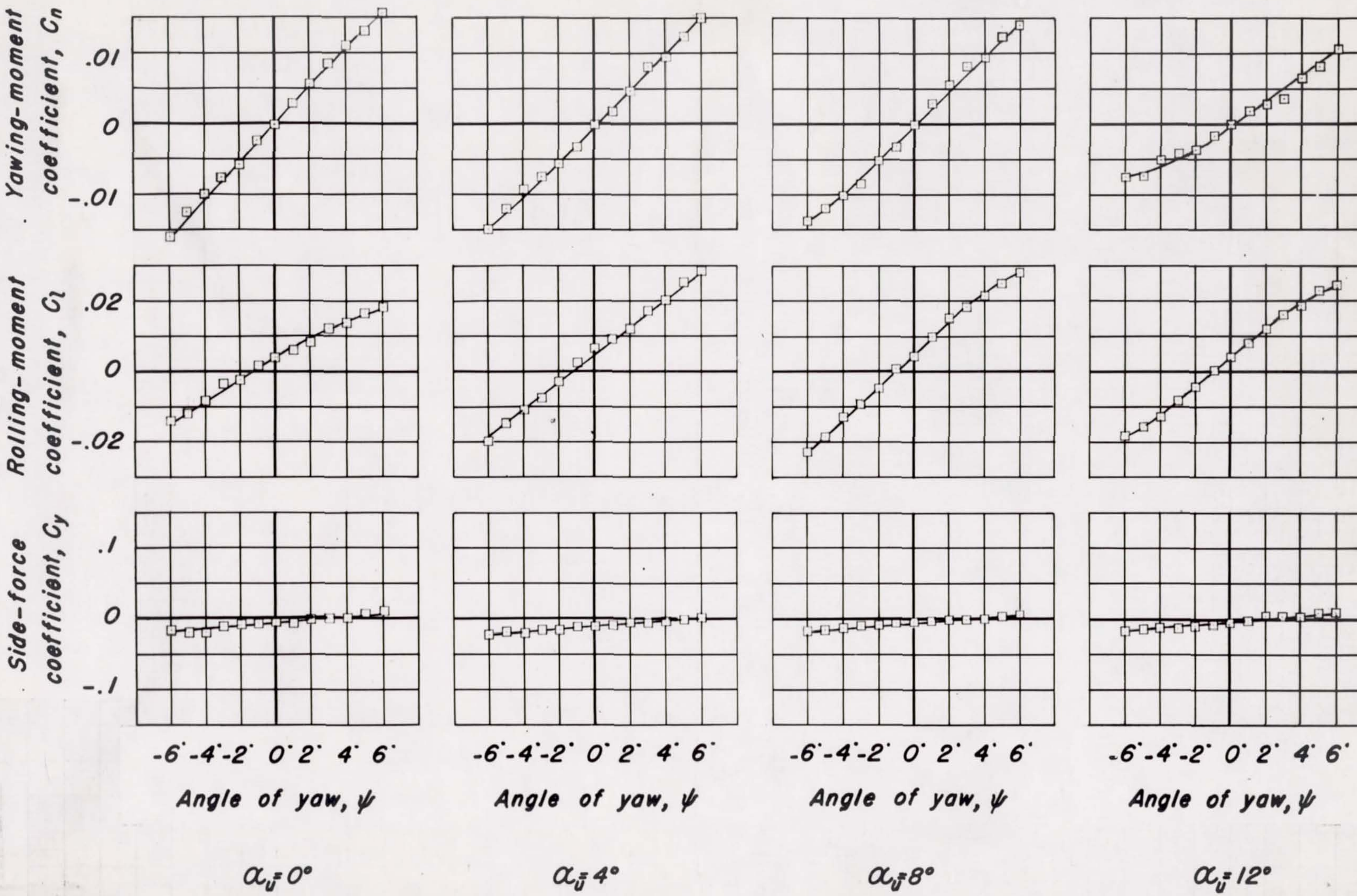


(a) Flaps up

Figure 7.– Tail-off lateral characteristics.



(b) Flaps and gear down

Figure 7.– Concluded.

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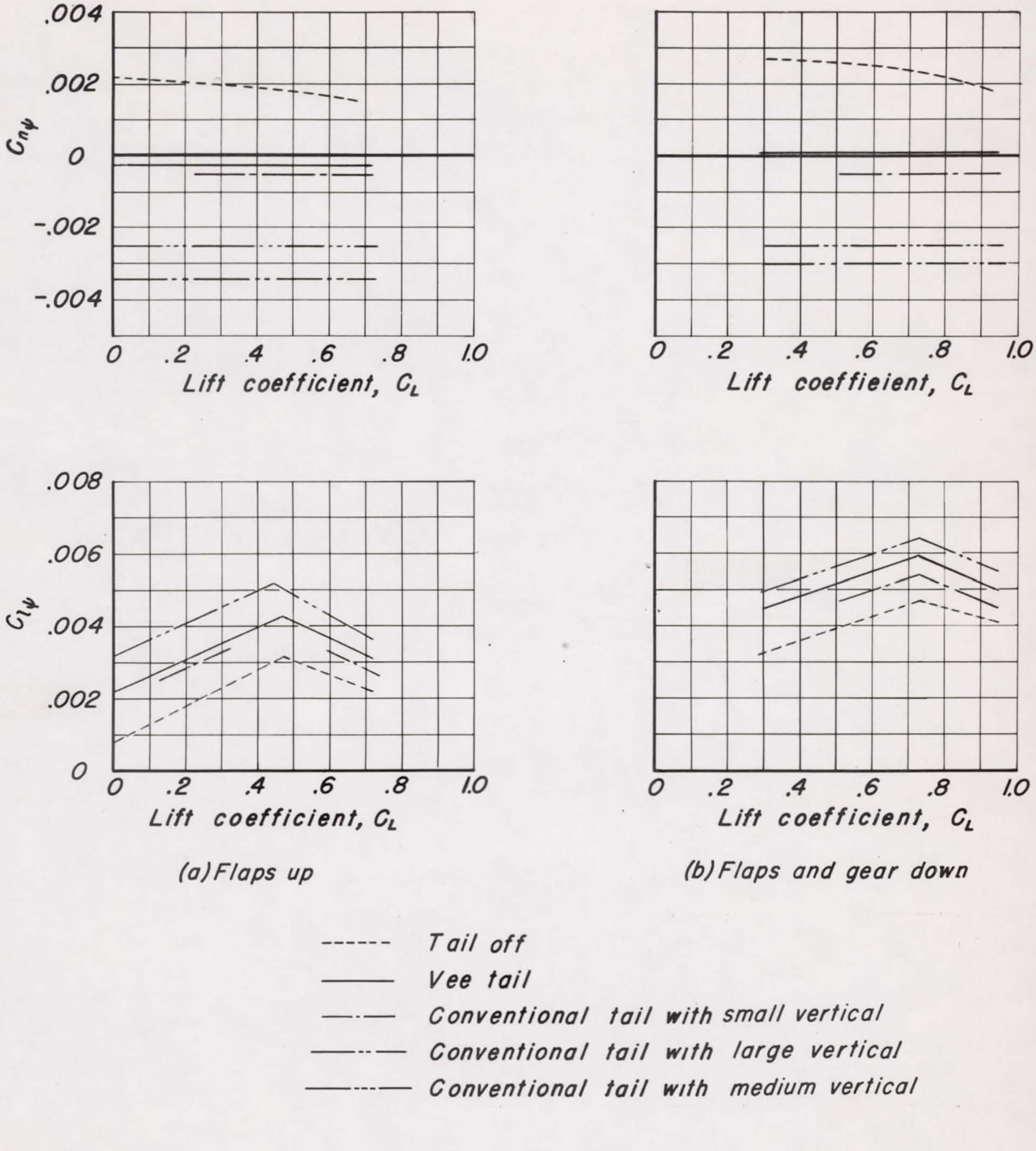


Figure 8.- Effect of tail type and size on the variation of the parameters C_{l_ψ} and C_{n_ψ} with lift coefficient.

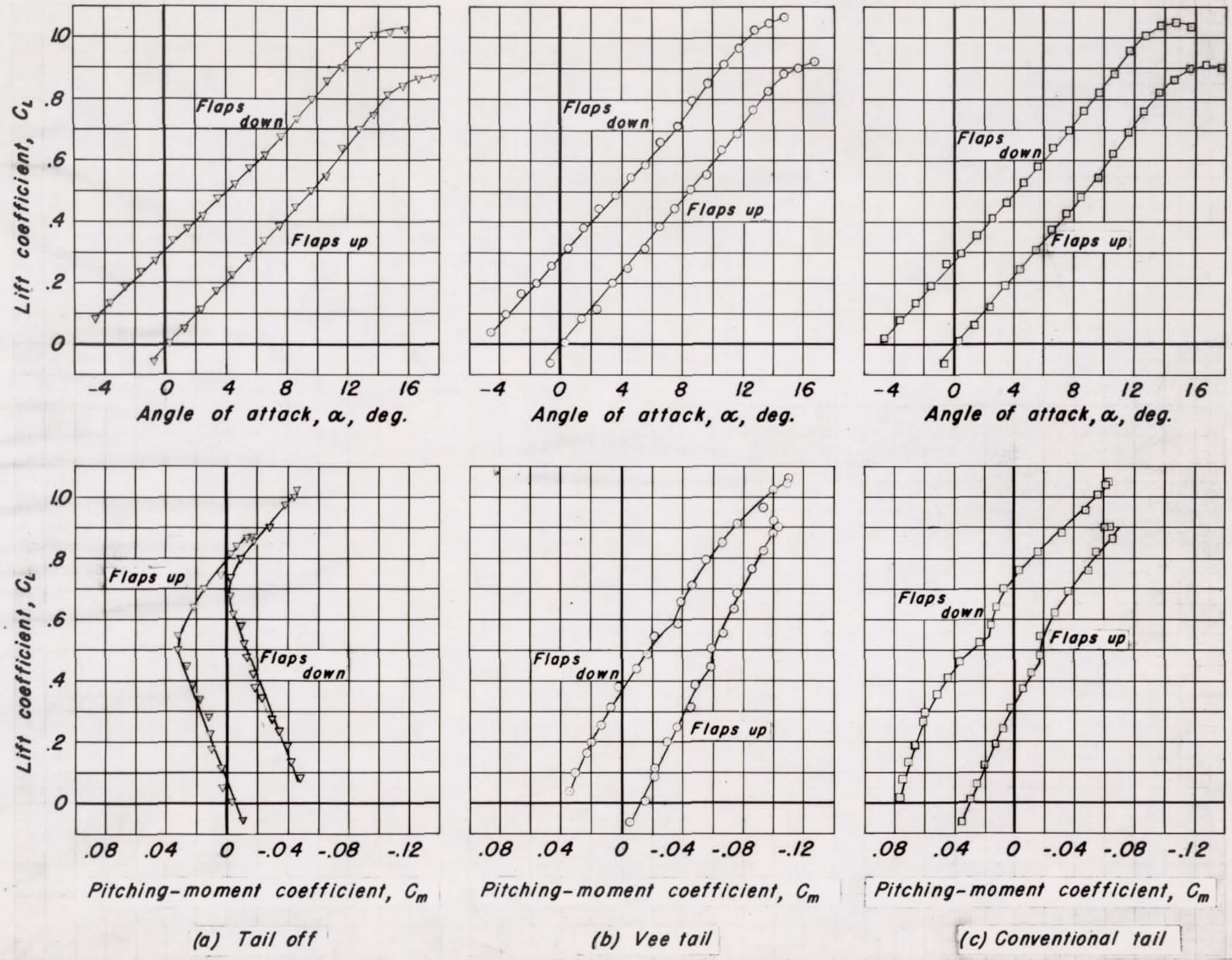
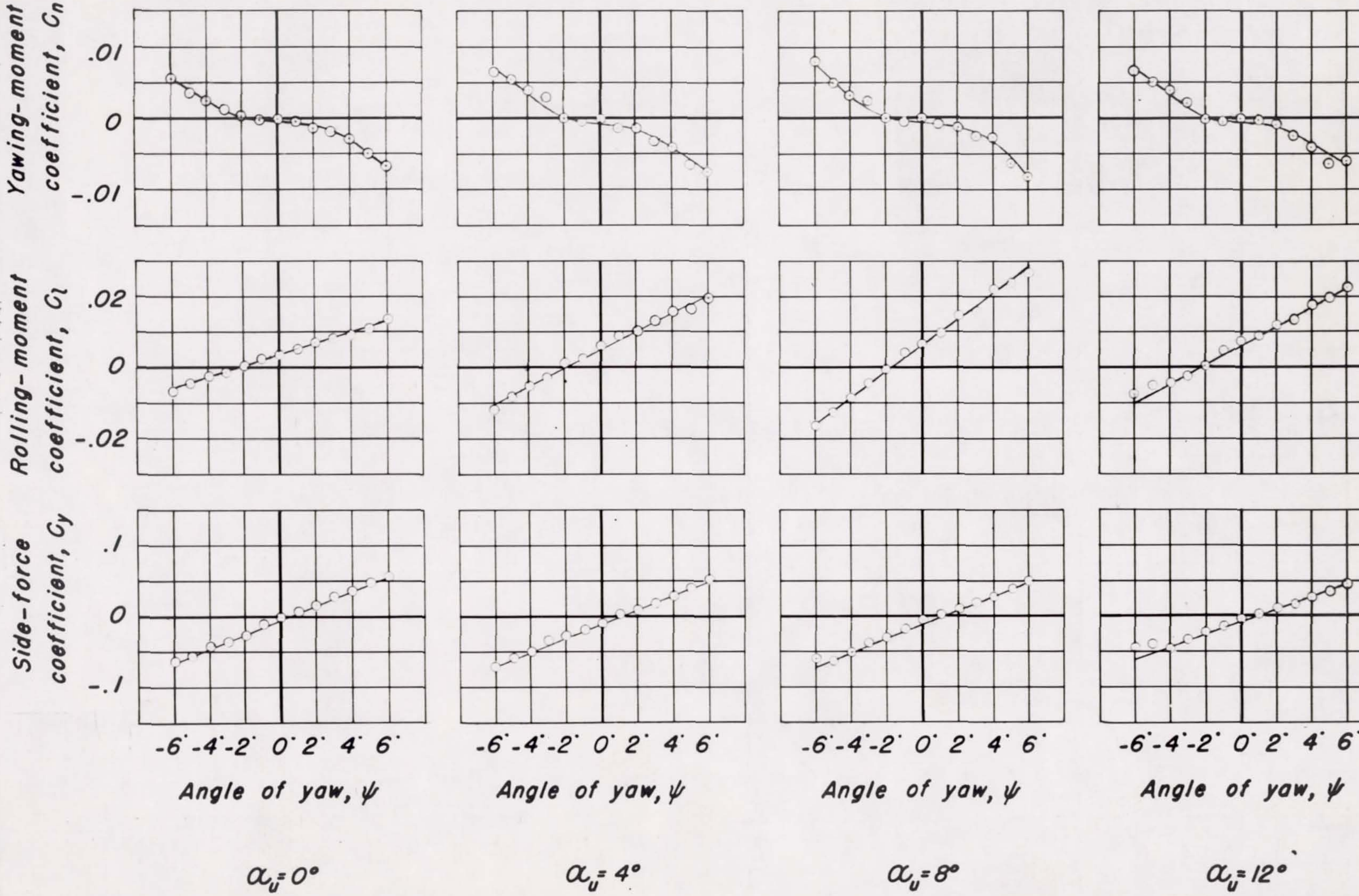
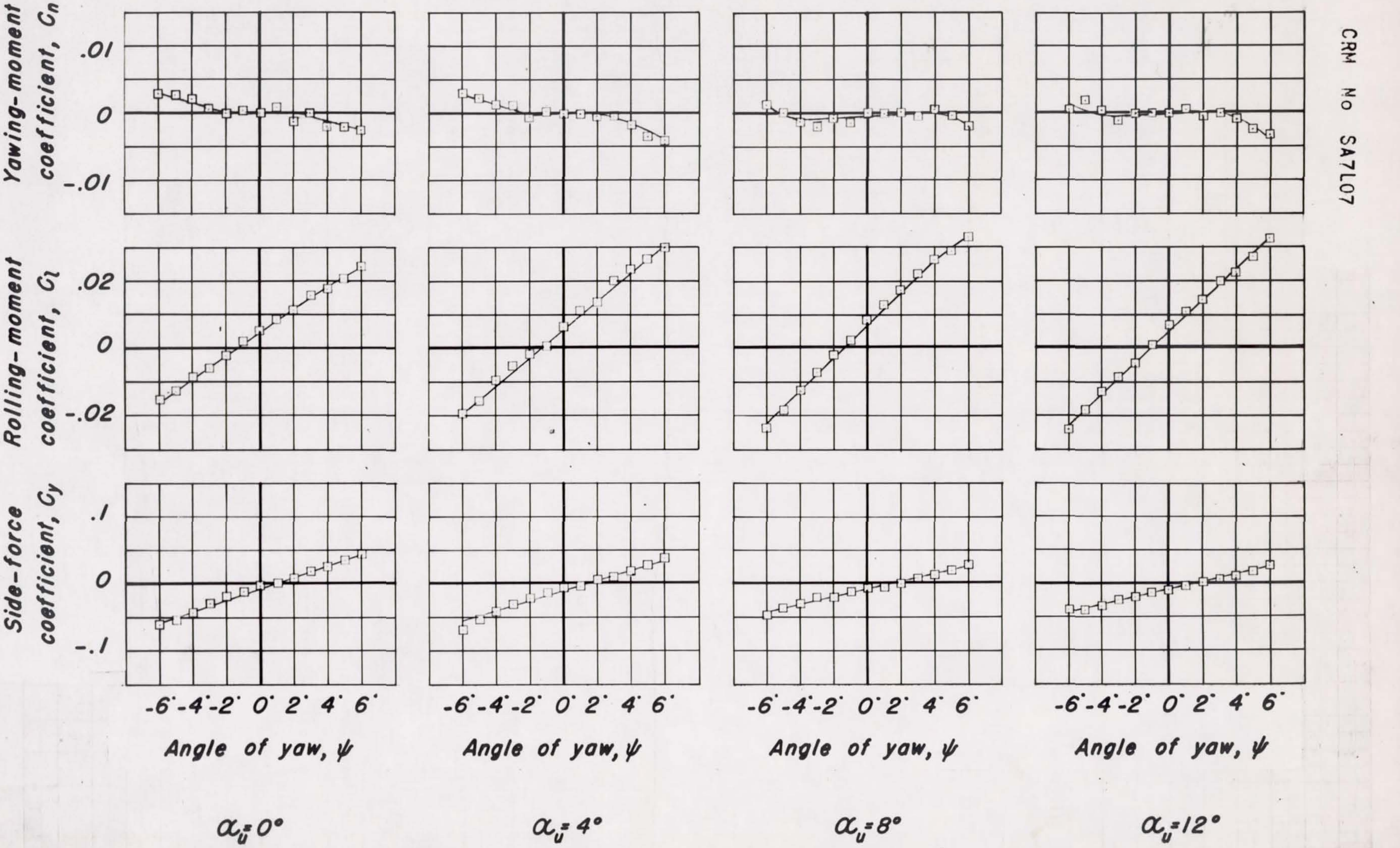


Figure 9. - Comparision of longitudinal characteristics of the model with the vee and conventional tails.



(a) Flaps up

Figure 10.– Lateral characteristics with -5.5° of dihedral, vee tail.



(b) Flaps and gear down

Figure 10.– Concluded.

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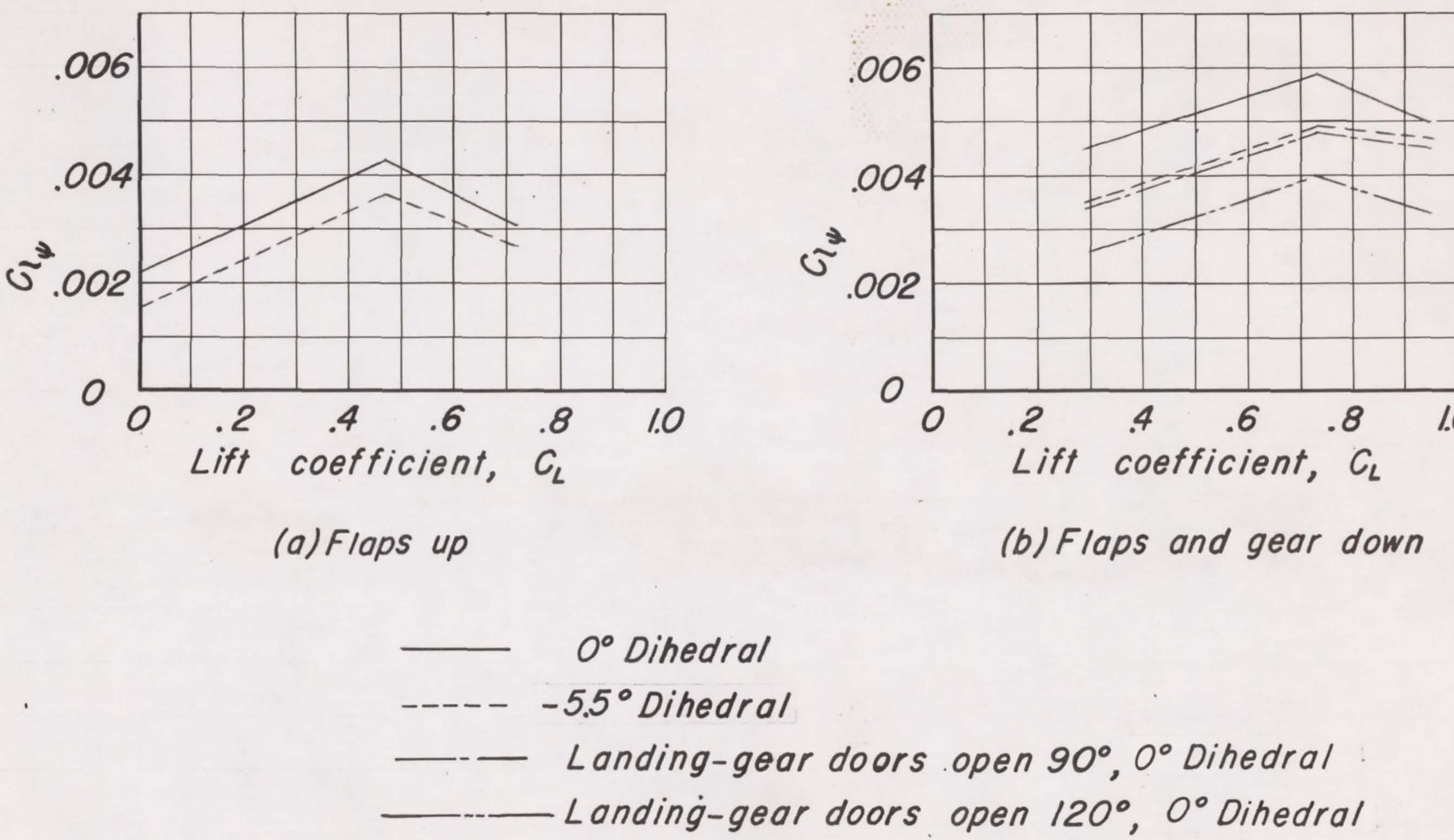
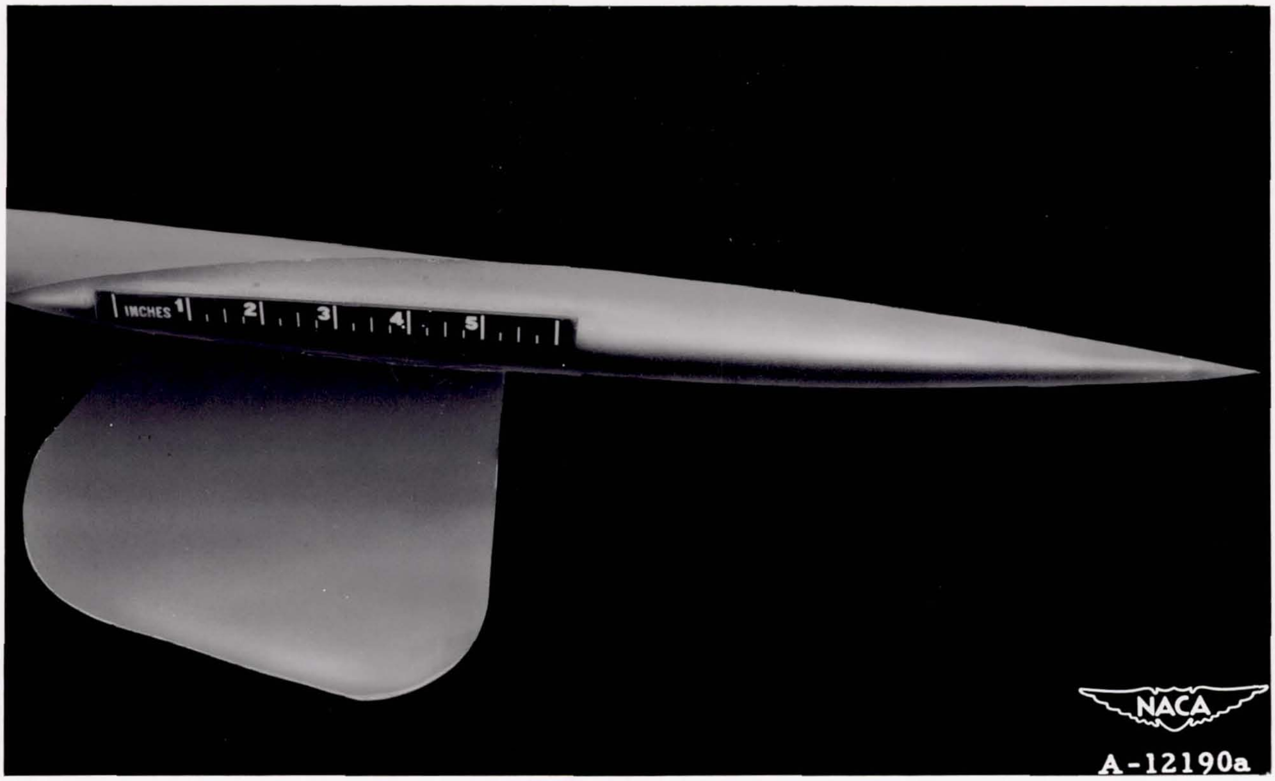
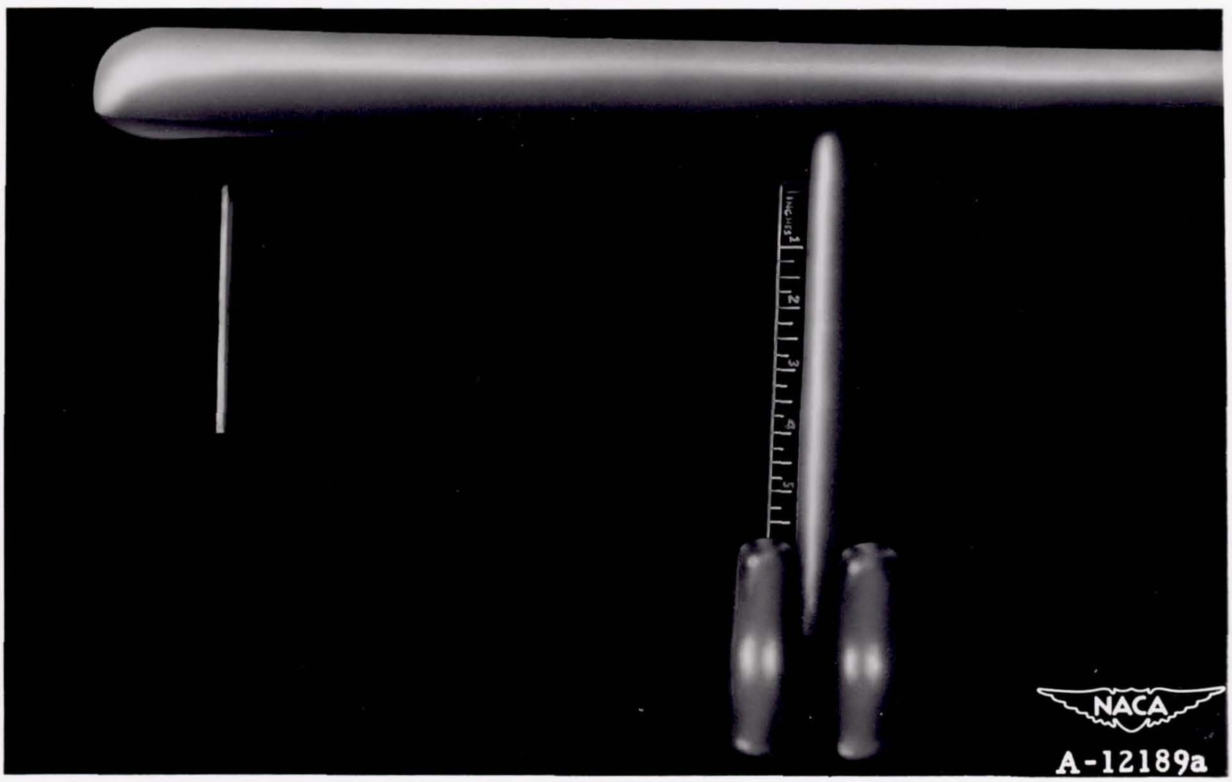


Figure 11.- Effect of -5.5° of dihedral and landing-gear doors on the variation of the parameter C_{l_ψ} with lift coefficient, vee tail.

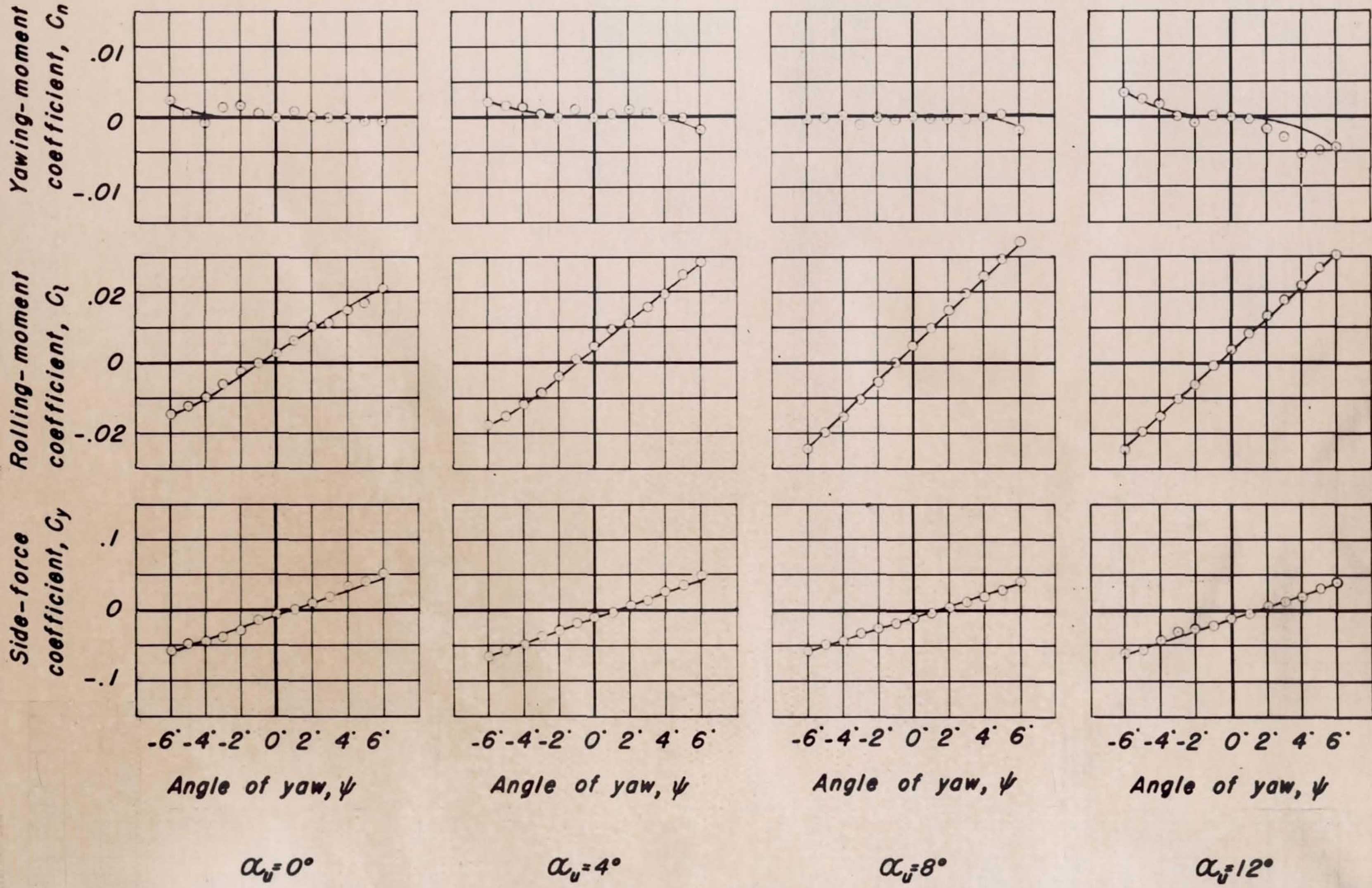


Side view.



Rear view.

Figure 12.- Detail of landing-gear door.



(a) Landing-gear doors open 90°

Figure 13.- Lateral characteristics with landing-gear doors open, vee tail, flaps and gear down.

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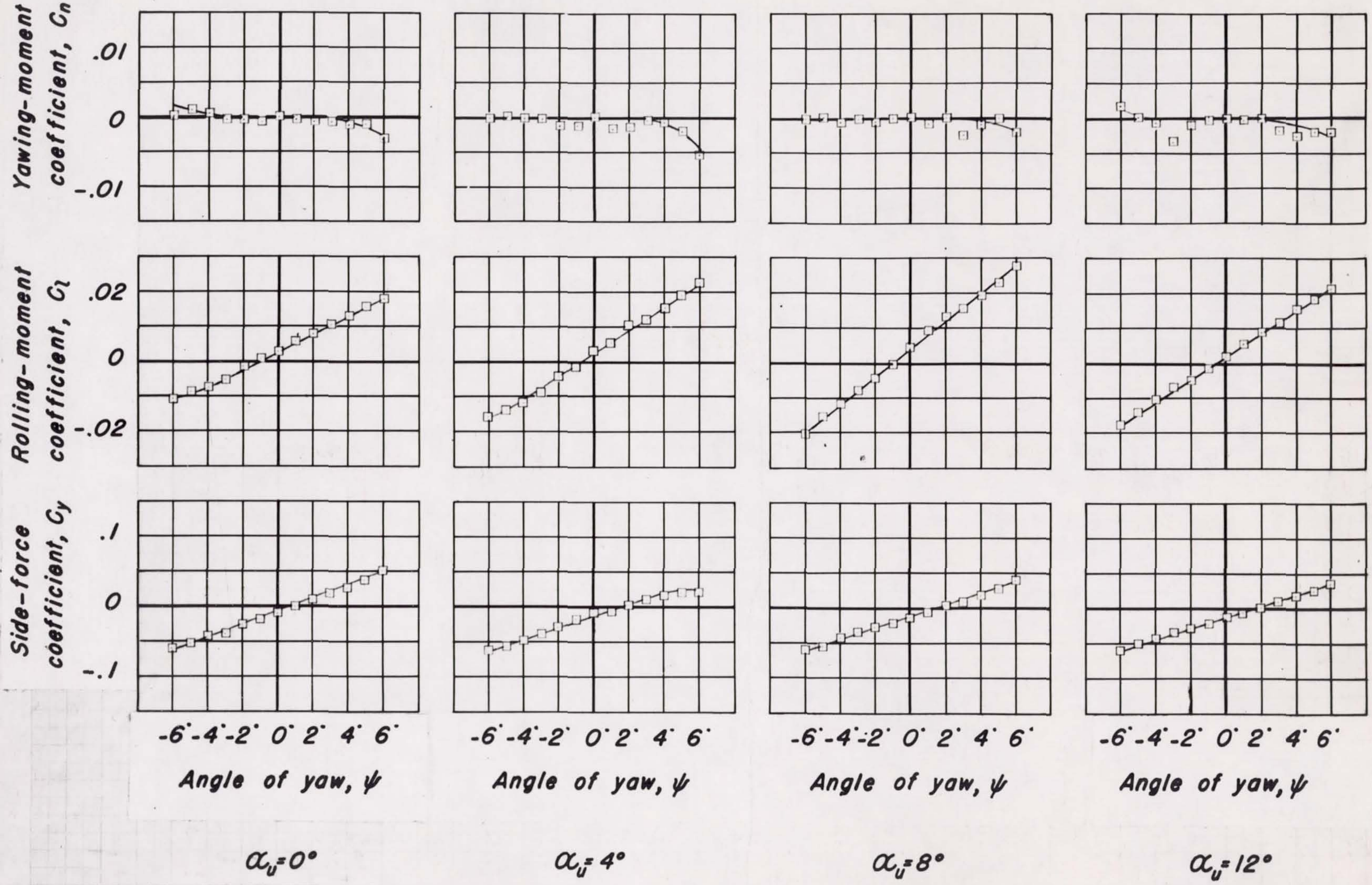
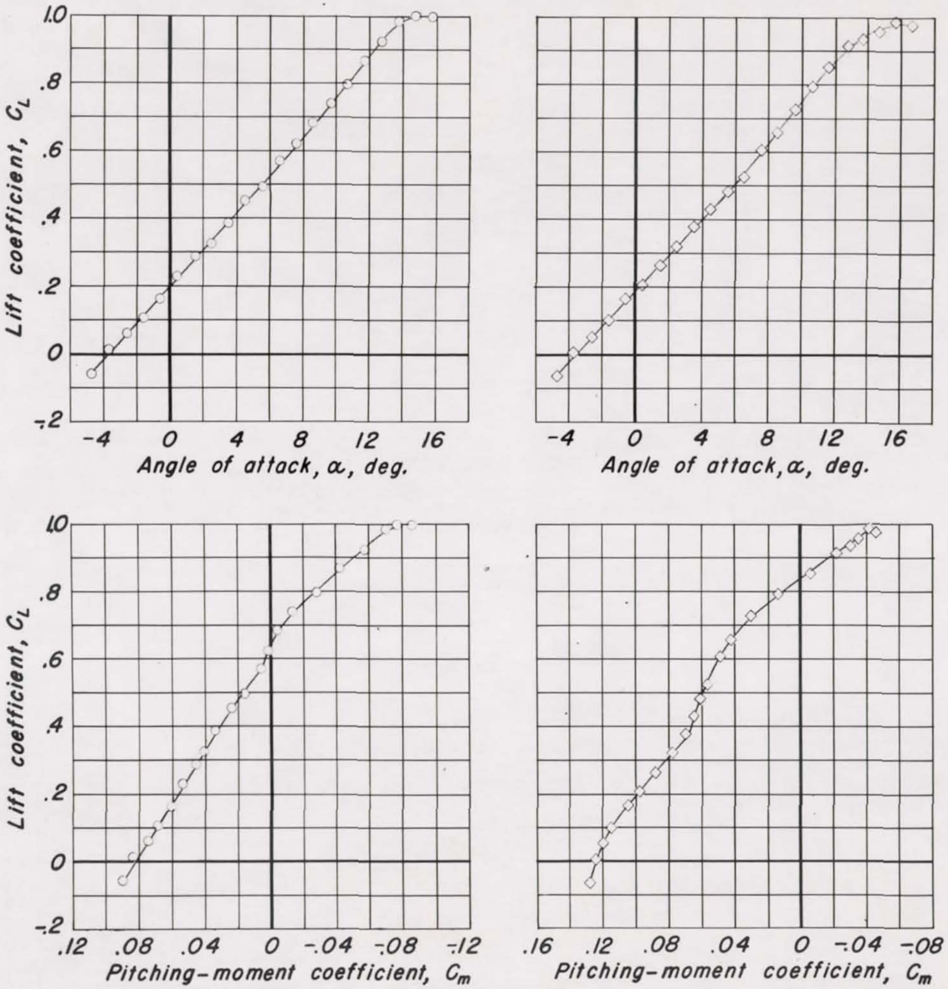


(b) Landing-gear doors open 120°

Figure 13.– Concluded.

AAG

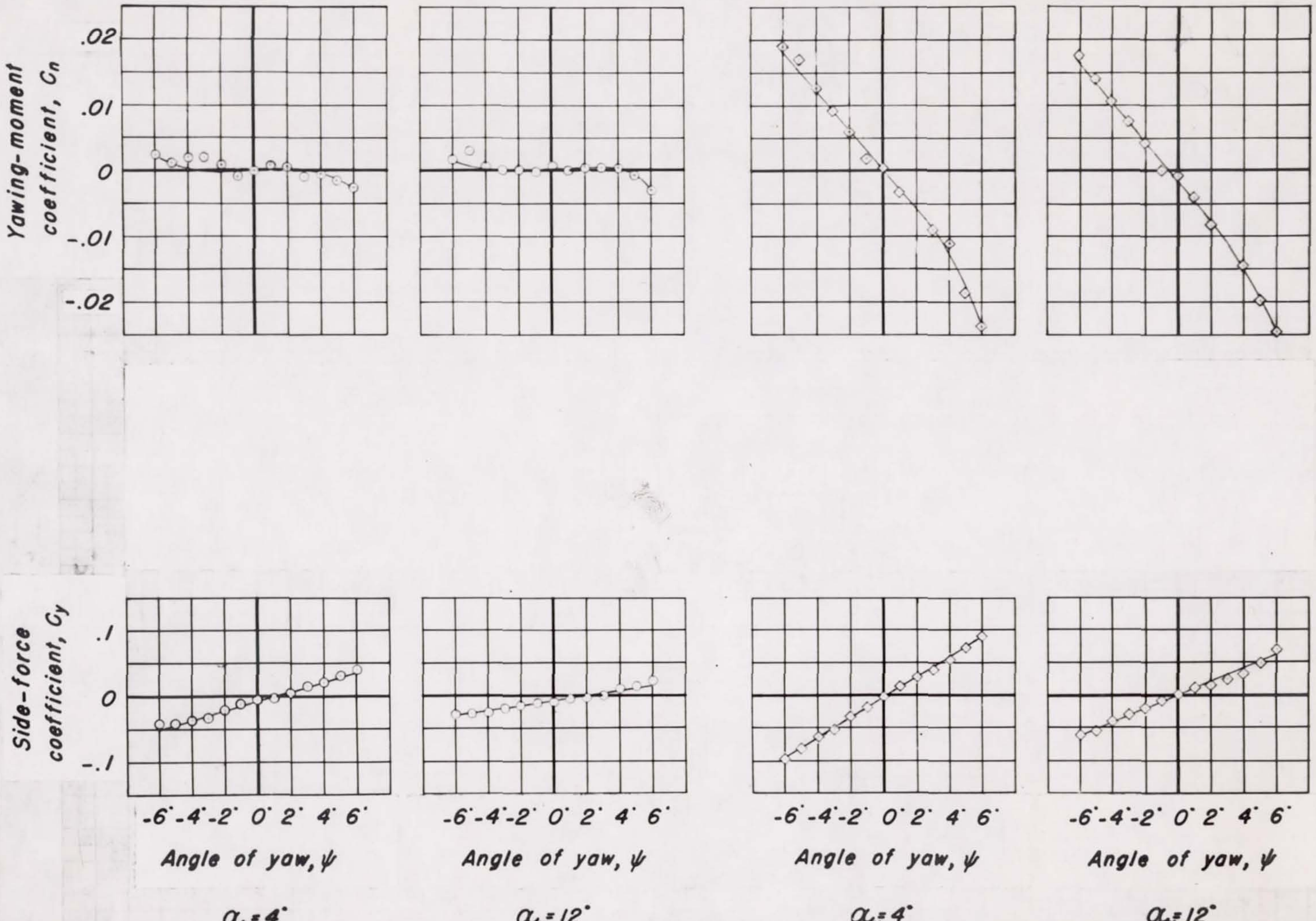


(a) Vee tail

(b) Conventional tail with large vertical, - 5.5° dihedral

Figure 14.- Longitudinal characteristics with 6° wing incidence, flaps and gear down.

CRM No SA7L07



(a) Vee tail

(b) Conventional tail with large vertical, -5.5° dihedral

Figure 15.– Lateral characteristics with 6° wing incidence, flaps and gear down.

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Figure 16.- Detail of plain flap.

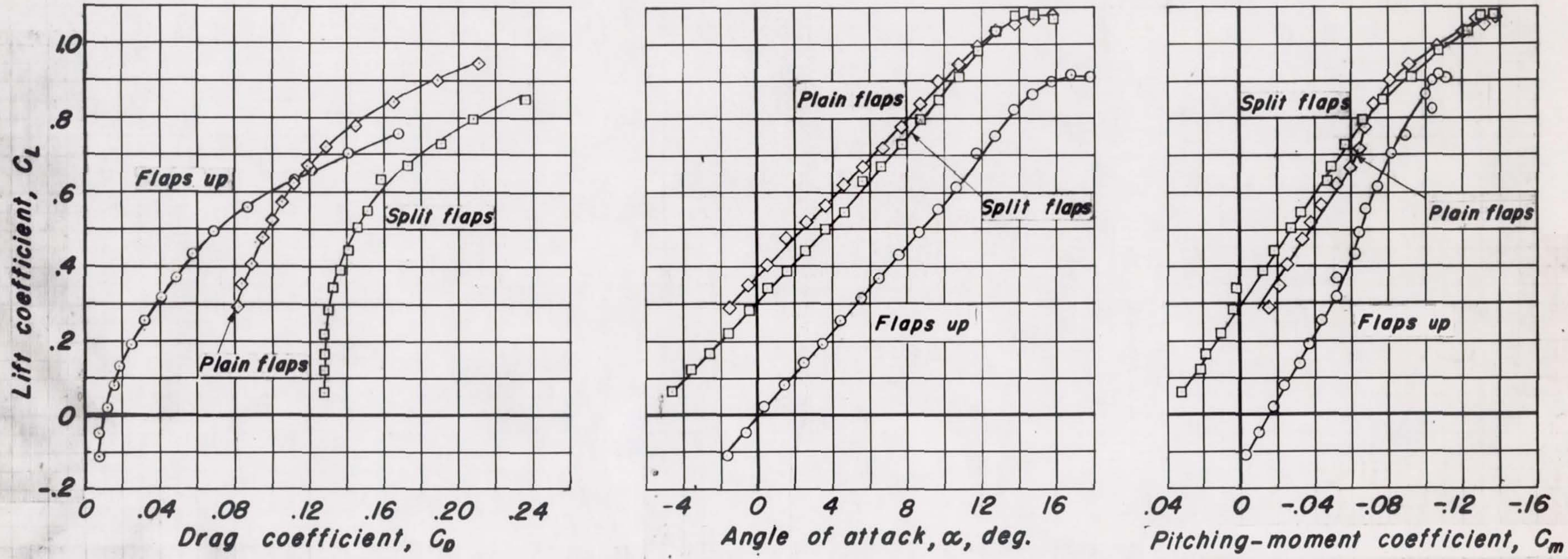

Figure 17.- Effect of flap type on longitudinal characteristics, -5.5° dihedral, vee tail.

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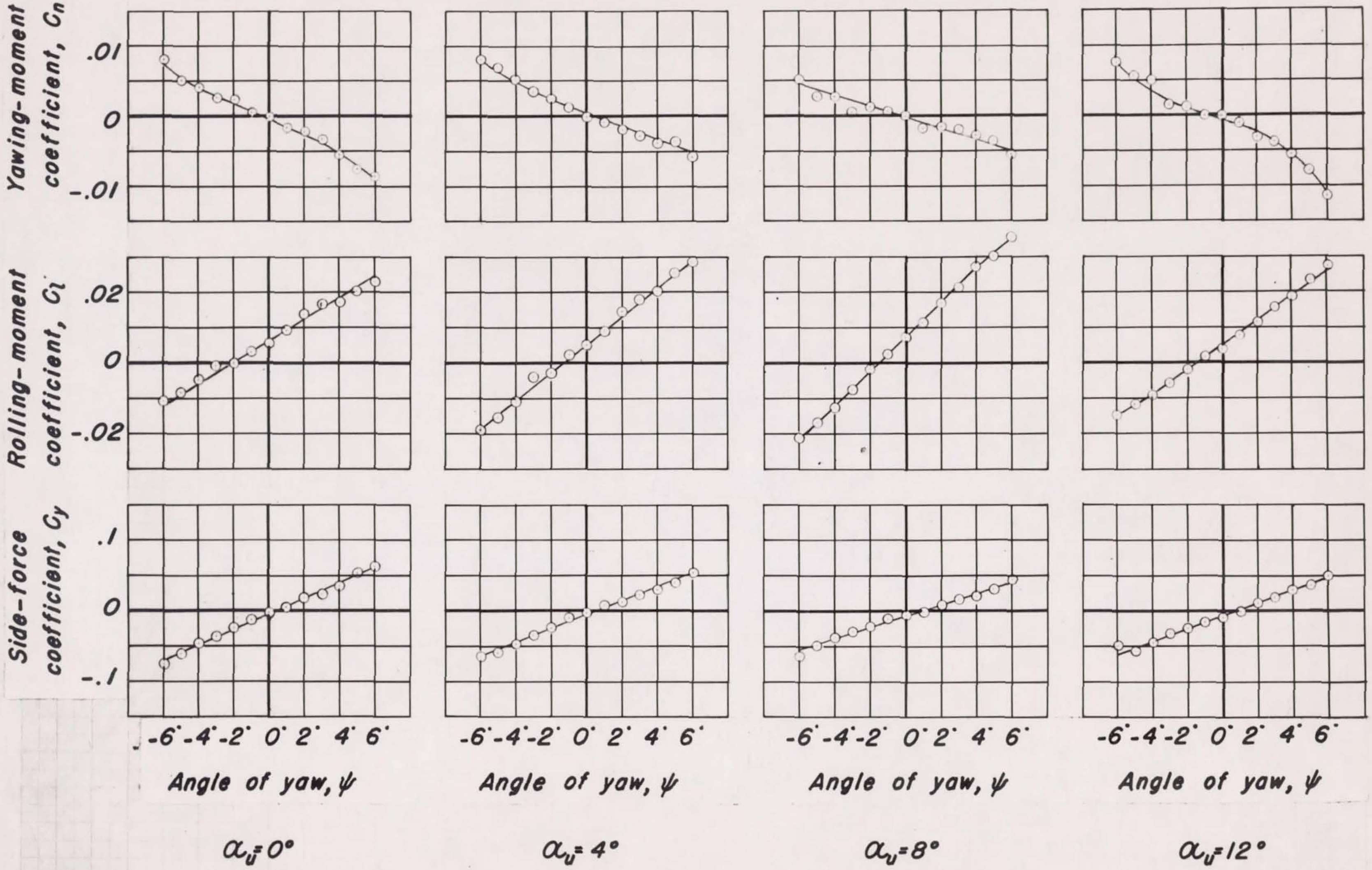

Figure 18.– Lateral characteristics with plain flaps, -5.5° dihedral, vee tail.