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RESEARCH MEMORANDUM

LOW-SPEED INVESTIGATION OF THE EFFECTS OF FREQUENCY AND AMPLITUDE OF OSCILLATION IN SIDESLIP ON THE LATERAL STABILITY DERIVATIVES OF A 60° DELTA WING, A 45° SWEPTBACK WING, AND AN UNSWEPT WING

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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LOW-SPEED INVESTIGATION OF THE EFFECTS OF FREQUENCY AND AMPLITUDE OF OSCILLATION IN SIDESLIP ON THE LATERAL STABILITY DERIVATIVES OF A 60° DELTA WING, A 45° SWEPTBACK WING, AND AN UNSWEPT WING

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SUMMARY

A low-speed investigation has been conducted in the Langley stability tunnel to study the effects of frequency and amplitude of sideslipping motion on the lateral stability derivatives of a 60° delta wing, a 45° sweptback wing, and an unswept wing. The investigation was made for values of the reduced-frequency parameter of 0.066 and 0.218 and for a range of amplitudes from ±2° to ±6°.

The results of the investigation indicated that increasing the frequency of the oscillation generally produced an appreciable change in magnitude of the lateral oscillatory stability derivatives in the higher angle-of-attack range. This effect was greatest for the 60° delta wing and smallest for the unswept wing and generally resulted in a more linear variation of these derivatives with angle of attack. For the relatively high frequency at which the amplitude was varied, there appeared to be little effect on the measured derivatives as a result of the change in amplitude of the oscillation.

INTRODUCTION

At the present time, there is considerable interest in stability derivatives measured by various oscillation techniques. The results of such tests are of interest mainly because of the very large effects of frequency and amplitude on the stability derivatives. There is considerable literature on oscillation-in-yaw tests; some typical results for wing-alone and complete-model configurations are given, for example, in references 1, 2, and 3. Results of some oscillation in pure yawing tests are presented in reference 4. Some preliminary free-damping oscillation-in-sideslip tests on wings alone are presented in reference 5, and forced-oscillation tests of a 60° delta complete model are presented in reference 6.

The purpose of this investigation was to obtain information about the effects of frequency and amplitude of pure sideslipping oscillations by the forced-oscillation technique on the stability derivatives of a 60° delta wing, a 45° swept wing, and an unswept wing. The frequencies of oscillation used in the tests were 1 and 3.31 cycles per second ($\omega b/2V$ of 0.066 and 0.218) and the amplitude of oscillation varied from ±2° to ±6°.

SYMBOLS

The data are presented in the form of coefficients of forces and moments which are referred to the stability system of axes with the origin at the projection on the plane of symmetry of the quarter-chord point of the mean aerodynamic chord. The positive direction of forces, moments, angular displacements, and velocities are shown in figure 1. The coefficients and symbols used are defined as follows:

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_m pitching-moment coefficient, $\frac{M_Y}{qS\bar{c}}$

C_l rolling-moment coefficient, $\frac{M_X}{qSb}$

C_n yawing-moment coefficient, $\frac{M_Z}{qSb}$

M_X rolling moment, ft-lb

M_Y pitching moment, ft-lb

M_Z yawing moment, ft-lb

q dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft

ρ mass density of air, slugs/cu ft

V free-stream velocity, ft/sec

S area of wing, sq ft

b span of wing, ft

$\bar{c}$ mean aerodynamic chord, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

c chord, ft

X,Y,Z stability-axis system

y distance along Y-axis, ft

α angle of attack with respect to wing-chord plane, deg

β angle of sideslip, degrees unless otherwise specified

$\dot{\beta} = \frac{\partial \beta}{\partial t}$, radians/sec

$\Lambda_{c/4}$ sweepback of quarter-chord line

ω angular velocity, $2\pi f$, radians/sec

f frequency, cps

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$, per radian

$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$, per radian

$$C_{n_{\dot{\beta}}} = \frac{\partial C_n}{\partial \frac{\dot{\beta} b}{2V}}$$

$$C_{l_{\dot{\beta}}} = \frac{\partial C_l}{\partial \frac{\dot{\beta} b}{2V}}$$

$\frac{\omega b}{2V}$ reduced-frequency parameter

Subscript:

ω mean oscillatory parameter

MODELS AND APPARATUS

The models used in this investigation were the same as those used in the tests of references 1, 4, and 5. A sketch of the models is shown in figure 2. These models consisted of an unswept wing $(\Lambda_{c/4} = 0)$ and a 45° sweptback wing $(\Lambda_{c/4} = 45^{\circ})$, both of aspect ratio 4 and taper ratio of 0.6, and a 60° delta wing of aspect ratio 2.31. Each of the wings was made from 3/4-inch-thick plywood with a circular leading edge and a beveled trailing edge; the airfoil section, therefore, was essentially a flat plate. The trailing edge of the wings was beveled to give a trailing-edge angle of 10°. Photographs of the three wings mounted in the tunnel are shown in figure 3.

The forced-oscillation-in-sideslip apparatus used for the present tests was the same as that used for the oscillation tests described in reference 6; and the data-reduction method and apparatus are described in reference 4. Since the apparatus is adequately described in the references mentioned, no further description of the apparatus will be made herein.

TESTS AND CORRECTIONS

Tests

The tests were conducted in the 6- by 6-foot test section of the Langley stability tunnel at a dynamic pressure of 24.9 pounds per square foot and a Mach number of 0.13. The Reynolds numbers, based upon the wing mean aerodynamic chords, were 0.7×10^{6} for the unswept and swept wings and 1.6×10^{6} for the delta wing.

The forced-oscillation-in-sideslip tests were made for each of the wings as shown in the following table:

Configuration	α range, deg	f, cps	$\frac{\omega b}{2V}$	β, deg
Unswept wing	0 to about 16	1.00 3.31	0.066 .218	±2 ±2, ±4, ±6
45° swept wing	0 to about 30	1.00 3.31	.066 .218	±2 ±2, ±4, ±6
60° delta wing	0 to about 33	1.00 3.31	.066 .218	±2 ±2, ±4, ±6

The values of $\frac{\omega b}{2V}$ used in the investigation are believed to be within the range of those which may be encountered by an airplane.

No static tests were made and the static longitudinal and lateral data were taken from reference 5.

Corrections

Jet boundary corrections to the angle of attack had already been applied to the static data of reference 5 and the same corrections to the angles of attack have been applied to the data described herein. The dynamic data have been corrected for a variation in angularity of the airstream as the model oscillated back and forth. No other corrections have been applied to the data because it is believed that, in general, the corrections are small; however, the support-strut interference may have some effect at the higher angles of attack.

RESULTS AND DISCUSSION

The static test data were taken from reference 5. The lift, drag, and pitching-moment coefficients for the three wings are presented herein for convenience in figure 4, and the static lateral stability data are presented in figures 5, 6, and 7 as the zero frequency data. The oscillation data are presented in figures 5, 6, and 7 for the 60° delta, the 45° swept wing, and the unswept wing, respectively. The static longitudinal data have been discussed in reference 5 and therefore no discussion will be made herein.

60° Delta Wing

Effect of frequency.- The effects of changes in the frequency of oscillation at a maximum amplitude of ±2° on the four stability derivatives $\left(C_{n_{\dot{\beta},\omega}},\ C_{n_{\beta,\omega}},\ C_{l_{\dot{\beta},\omega}},\ \text{and}\ C_{l_{\beta,\omega}}\right)$ are shown in figure 5(a). The effects of frequency manifest themselves by an appreciable change in magnitude of the derivative with changes in frequency at the high angles of attack and relatively little change in magnitude at the low angles of attack. Increasing the frequency of oscillation decreased the variations of the stability derivative with angle of attack. The results of these tests are similar to the results obtained in previous oscillation-in-sideslip tests (ref. 6) and oscillation-in-yaw tests (ref. 1).

Effect of amplitude.- At an oscillation frequency of 3.31 cycles per second $\left(\frac{\omega b}{2V} = 0.218\right)$, there appeared to be very little effect of varying the maximum amplitude of oscillation from ±2° to ±6° on any of the four stability derivatives (fig. 5(b)). This result is similar to that presented in reference 1 for oscillation-in-yaw tests where relatively minor effects also were found at the high frequencies, but considerable effects were found to exist at the low frequencies.

45° Swept Wing

Effect of frequency.- The effects of changes in frequency of the sideslip oscillation for the 45° swept wing are shown in figure 6(a). An increase in the frequency generally decreased the variations of the derivatives with angle of attack for all four derivatives, $C_{n_{\dot{\beta},\omega}}$, $C_{n_{\beta,\omega}}$, $C_{l_{\dot{\beta},\omega}}$, and $C_{l_{\beta,\omega}}$. The effects of frequency appeared more pronounced at the higher angles of attack; these effects are similar to those obtained for the 60° delta wing. This frequency effect is generally similar to that obtained previously for oscillation-in-yaw tests reported in reference 1.

Effect of amplitude.- The effect of amplitude of oscillation (fig. 6(b)) for a reduced frequency of $\frac{\omega b}{2V} = 0.218$ shows very little effect on any of the four stability derivatives.

Unswept Wing

Effect of frequency.- The oscillatory data show the effects of frequency at a maximum amplitude of sideslip of ±2° in figure 7(a). For the range of frequencies employed in these tests, there appeared to be a negligible effect of frequency on the yawing-moment acceleration derivative $\left(C_{n_{\dot{\beta},\omega}}\right)$ throughout the angle-of-attack range and on the directional stability $\left(C_{n_{\beta,\omega}}\right)$ up to $\alpha = 12^{\circ}$. Above $\alpha = 12^{\circ}$, the directional stability decreased as the frequency of oscillation increased. These results generally agree with those for the oscillation-in-yaw tests of reference 1.

The effects of frequency on the rolling-moment acceleration derivative $C_{l_{\dot{\beta},\omega}}$ were quite pronounced, with the low-frequency results exhibiting a very erratic variation at the higher angles of attack and the high-frequency results a much smoother variation. The erratic variation of $C_{l_{\dot{\beta},\omega}}$ at the low frequency probably results from the inherent stalling characteristics of an unswept wing. There appeared to be no consistent effect of frequency. The effect of frequency on the oscillatory dihedral parameter $C_{l_{\beta,\omega}}$ appeared to be appreciable at some angles of attack but no consistent variation with frequency was obtained over the angle-of-attack range.

Effect of amplitude.- The effect of amplitude at a value of $\frac{\omega b}{2V} = 0.218$ appeared to be rather small on both yawing-moment and rolling-moment derivatives. (See fig. 7(b).)

CONCLUSIONS

The results of some oscillation-in-sideslip tests performed on three flat-plate airfoil wings, a 60° delta wing, a 45° swept wing, and an unswept wing, indicate the following conclusions:

1. Increasing the frequency of the oscillation generally produced an appreciable change in magnitude of the oscillatory stability derivatives in the higher angle-of-attack range. This effect was greatest for the 60° delta wing and smallest for the unswept wing and generally resulted in a more linear variation of these derivatives with angle of attack.

2. For the relatively high frequency at which the amplitude was varied (reduced-frequency parameter equal to 0.218), there appeared to be little effect on the measured derivatives as a result of the change in amplitude of oscillation.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 12, 1958.

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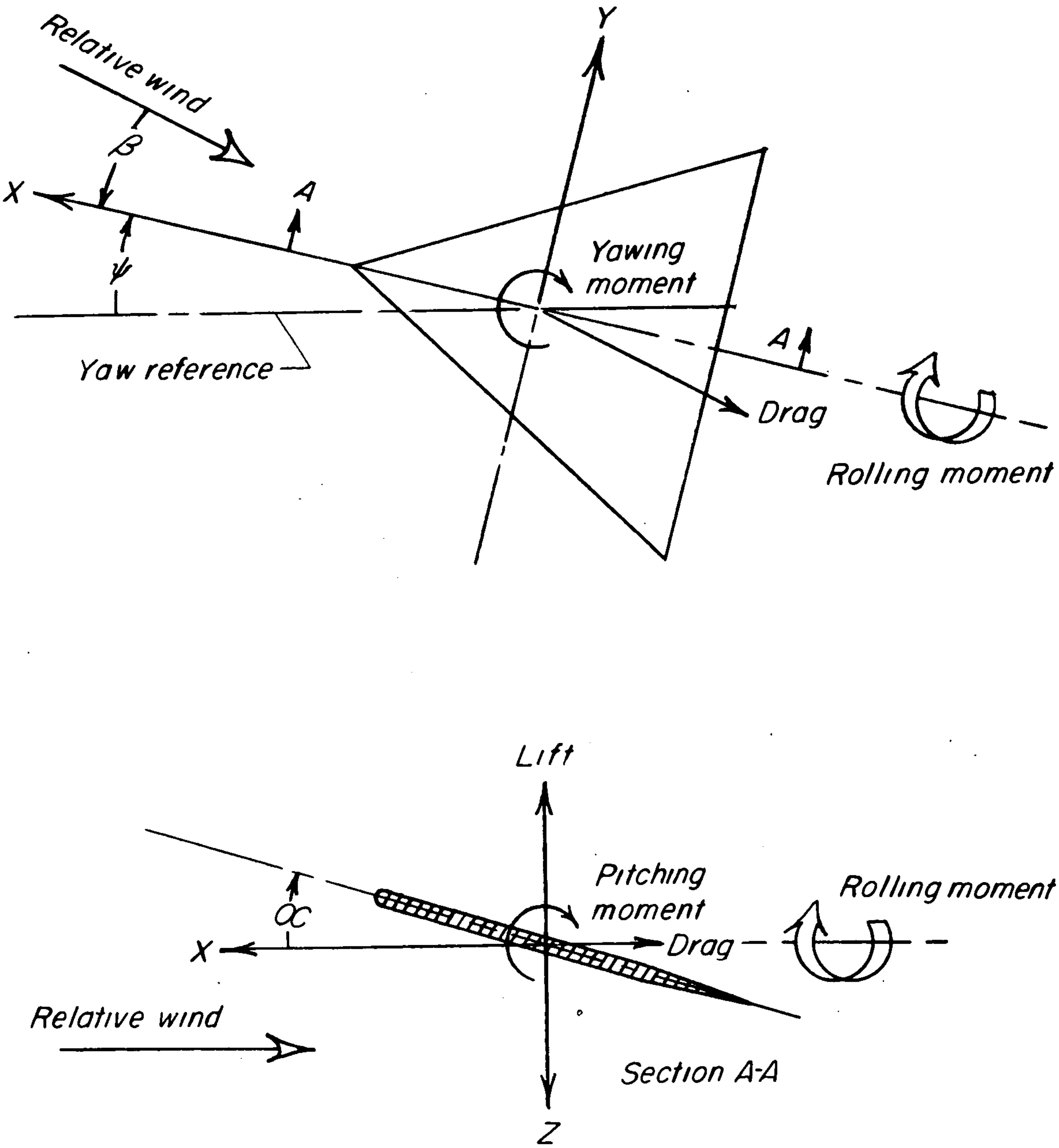
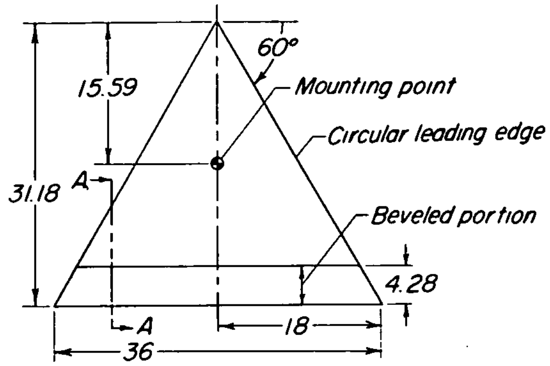
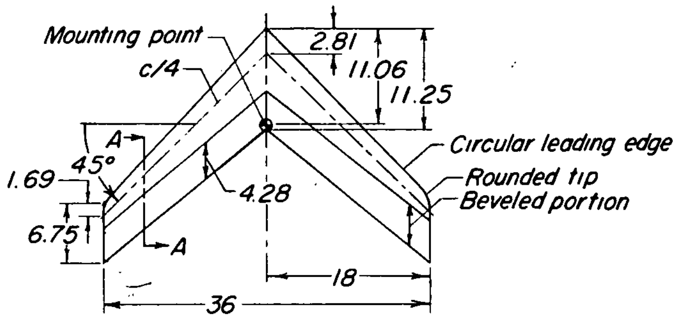


Figure 1.- System of stability axes. Arrows indicate positive forces, moments, and angular displacements. Yaw reference is generally chosen to coincide with initial relative wind.



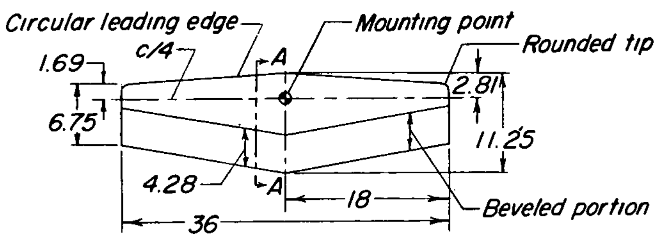
Delta wing

Aspect ratio	2.31
Leading-edge sweep angle, deg	60
Dihedral angle, deg	0
Twist, deg	0
Airfoil section	Flat plate
Area, sq. in.	561.20
Span, in.	36.00
Mean aerodynamic chord, in.	20.79



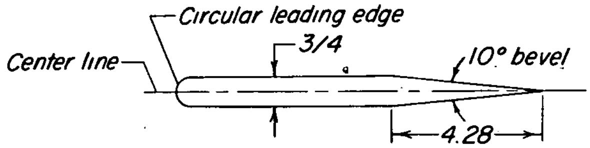
Swept wing

Aspect ratio	4.0
Taper ratio	0.6
Quarter-chord sweep angle, deg	45
Dihedral angle, deg	0
Twist, deg	0
Airfoil section	Flat plate
Area, sq. in.	324
Span, in.	36
Mean aerodynamic chord, in.	9.19



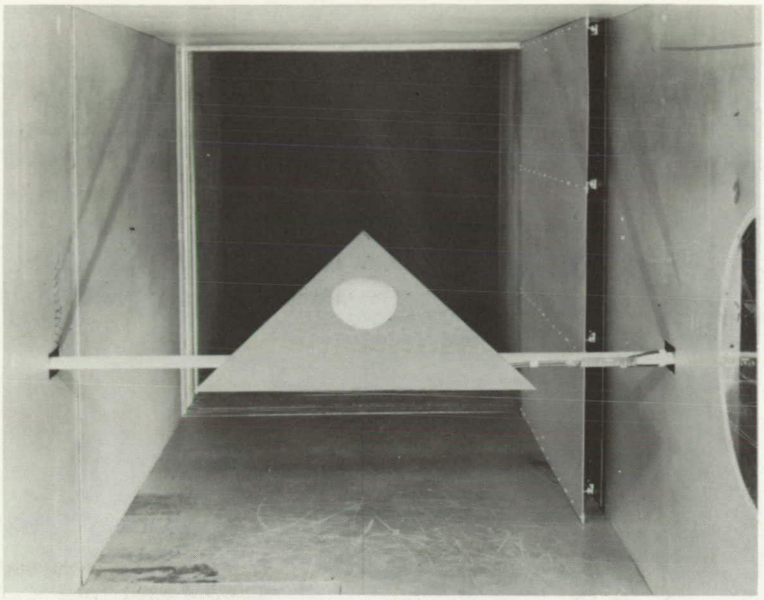
Unswept wing

Aspect ratio	4.0
Taper ratio	0.6
Quarter-chord sweep angle, deg	0
Dihedral angle, deg	0
Twist, deg	0
Airfoil section	Flat plate
Area, sq. in.	324
Span, in.	36
Mean aerodynamic chord, in.	9.19

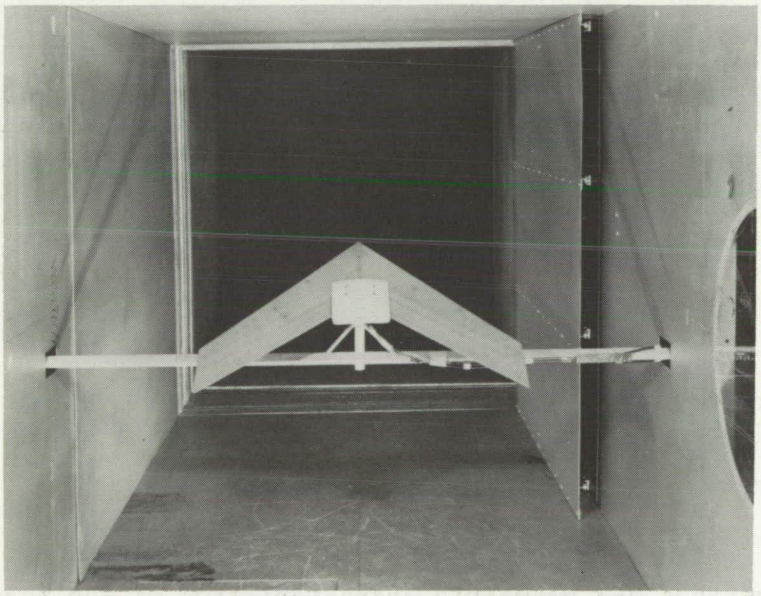


Section A-A

Figure 2.- Sketches and geometric characteristics of the three wing models investigated. All dimensions are in inches.

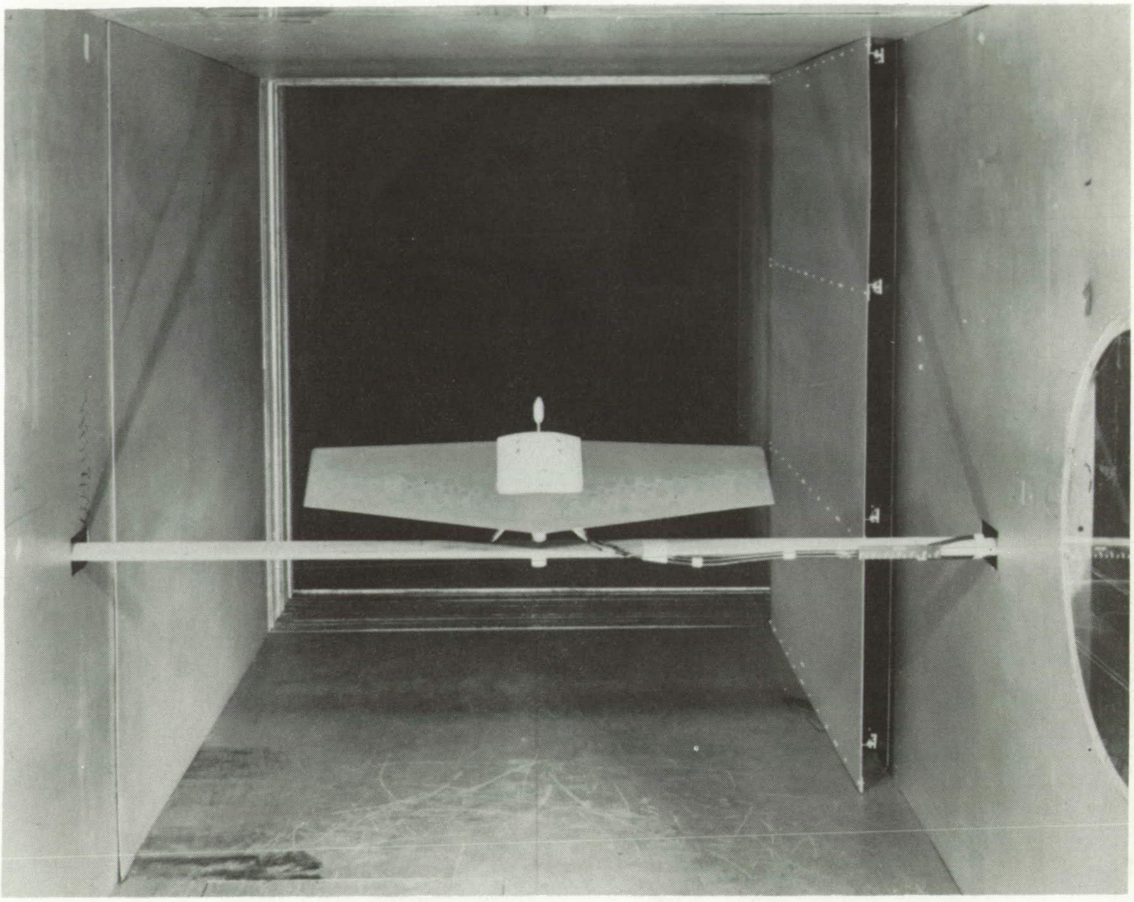


(a) 60° delta wing. L-85320



(b) 45° swept wing. L-85321

Figure 3.- Photographs of the three wing models mounted on the oscillation test rig in the 6- by 6-foot test section of the Langley stability tunnel.



(c) Unswept wing. L-85322

Figure 3.- Concluded.

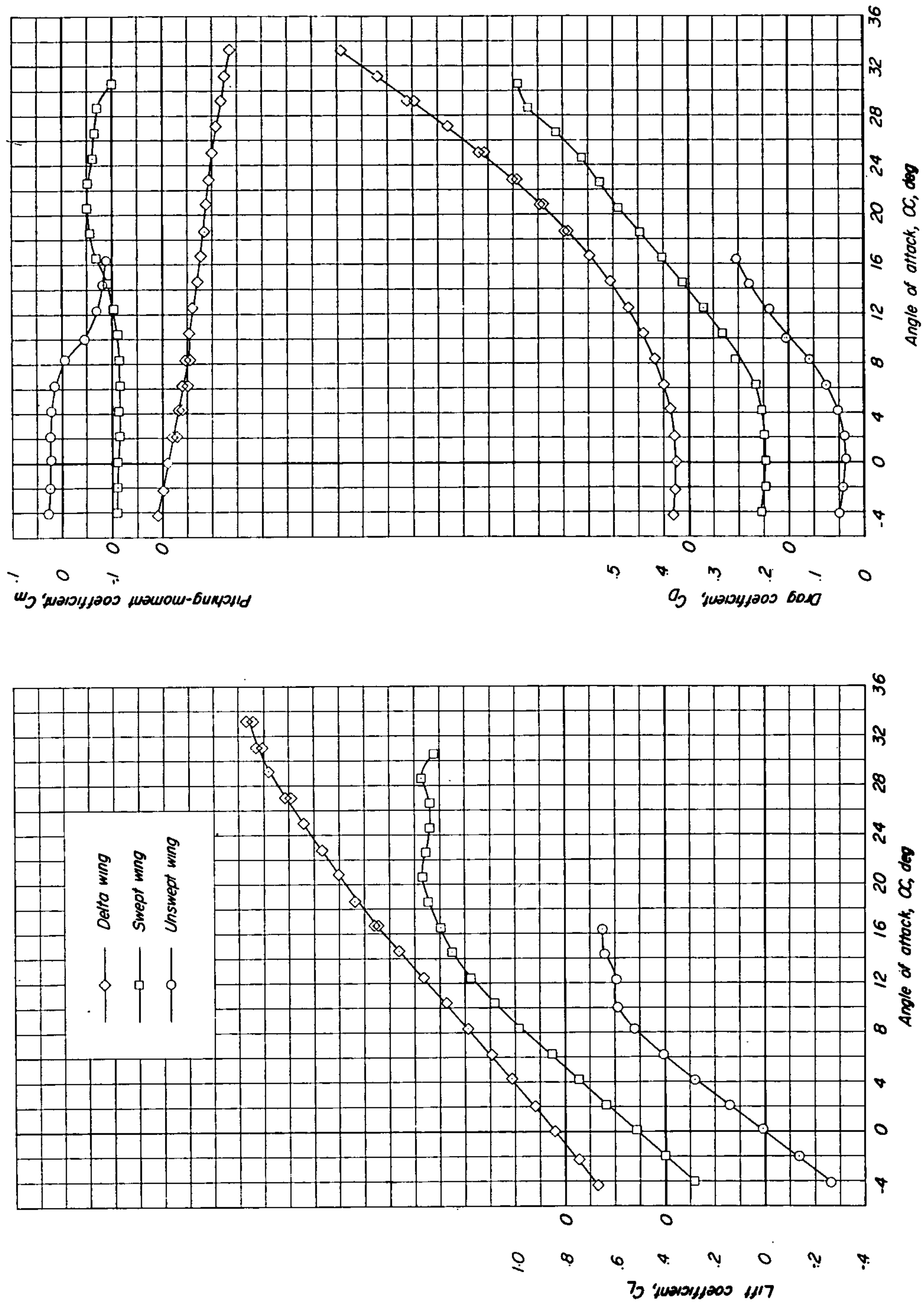
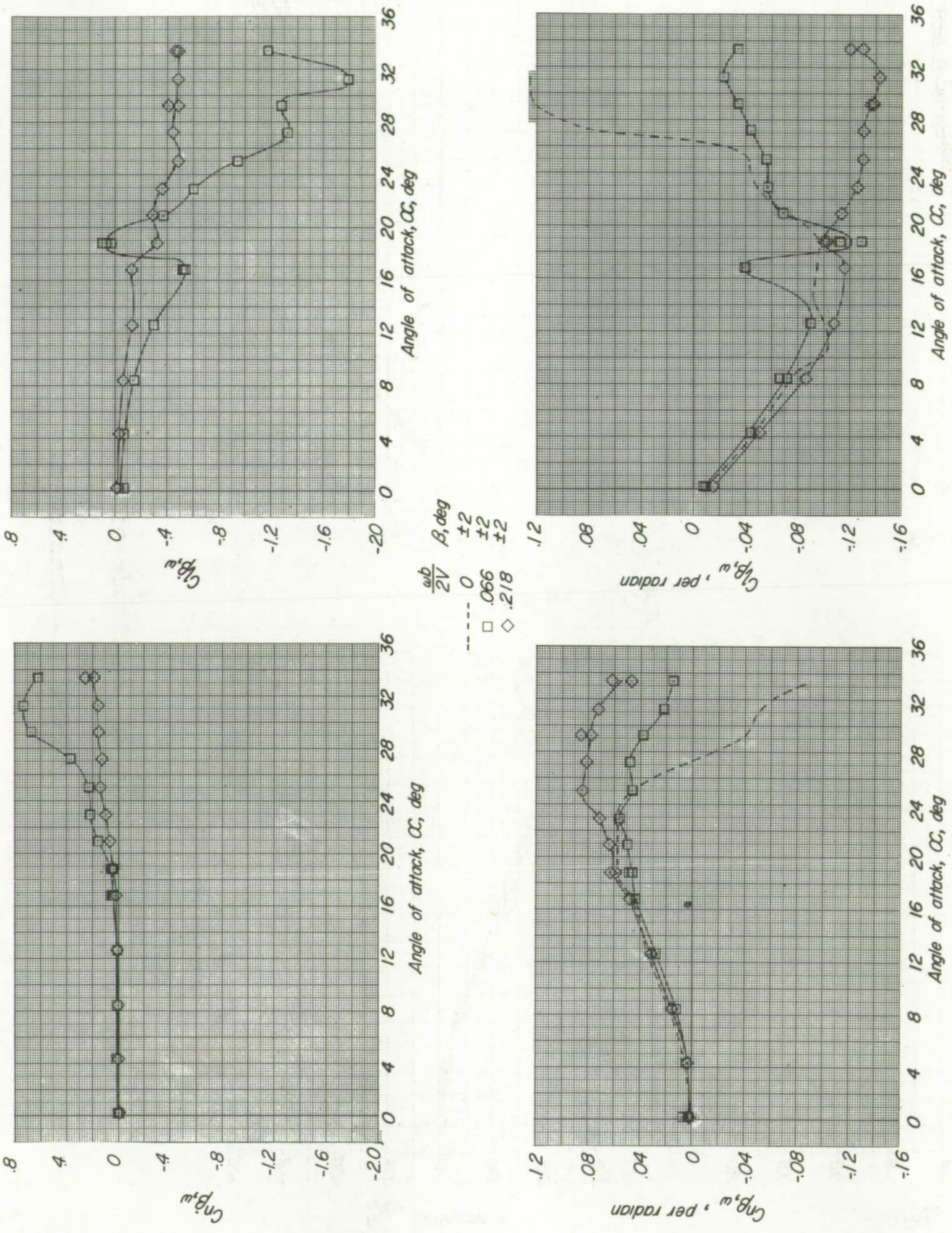
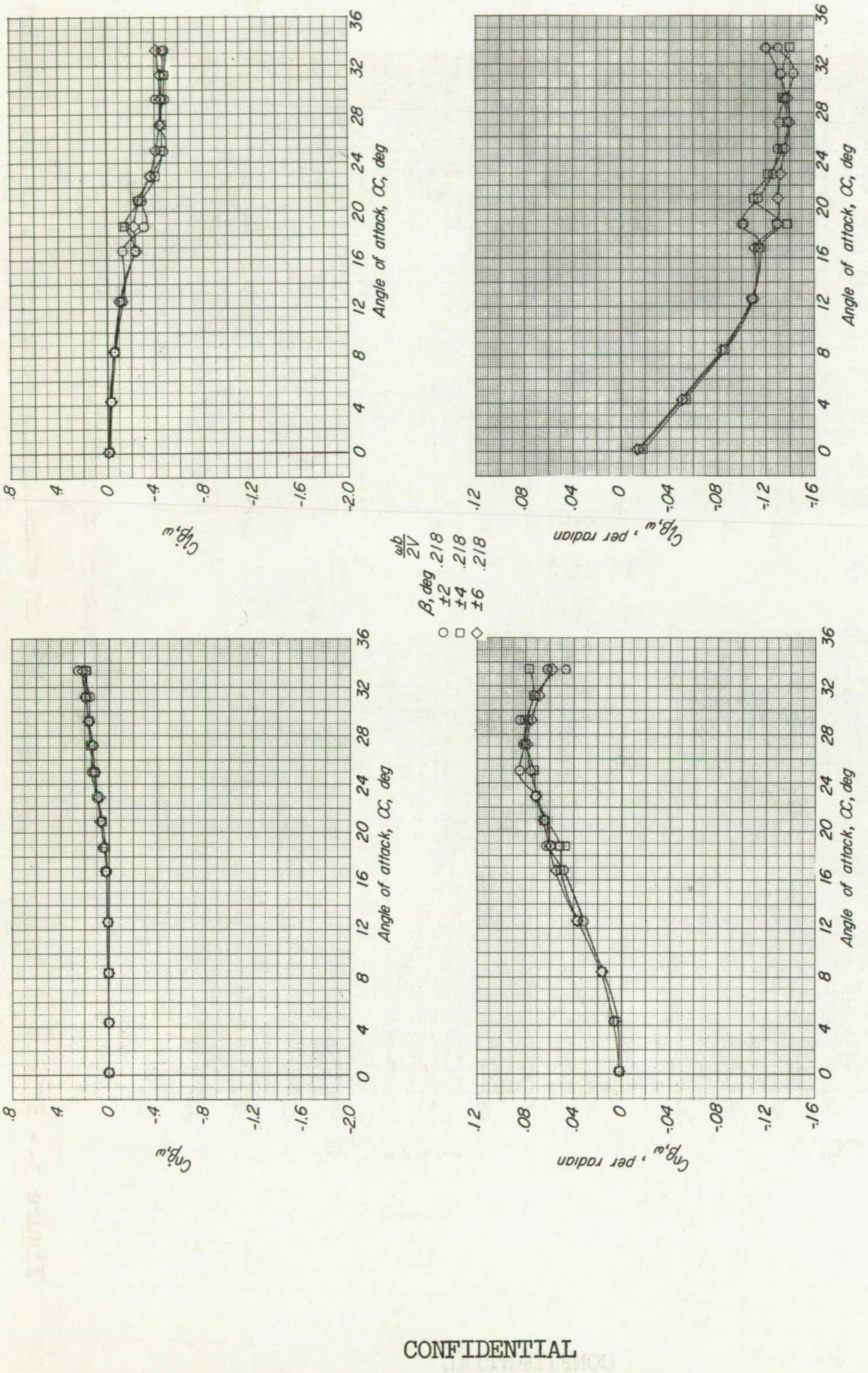


Figure 4.- Lift, drag, and pitching-moment characteristics as a function of angle of attack for the unswept, the 45° swept, and the 60° delta wings.



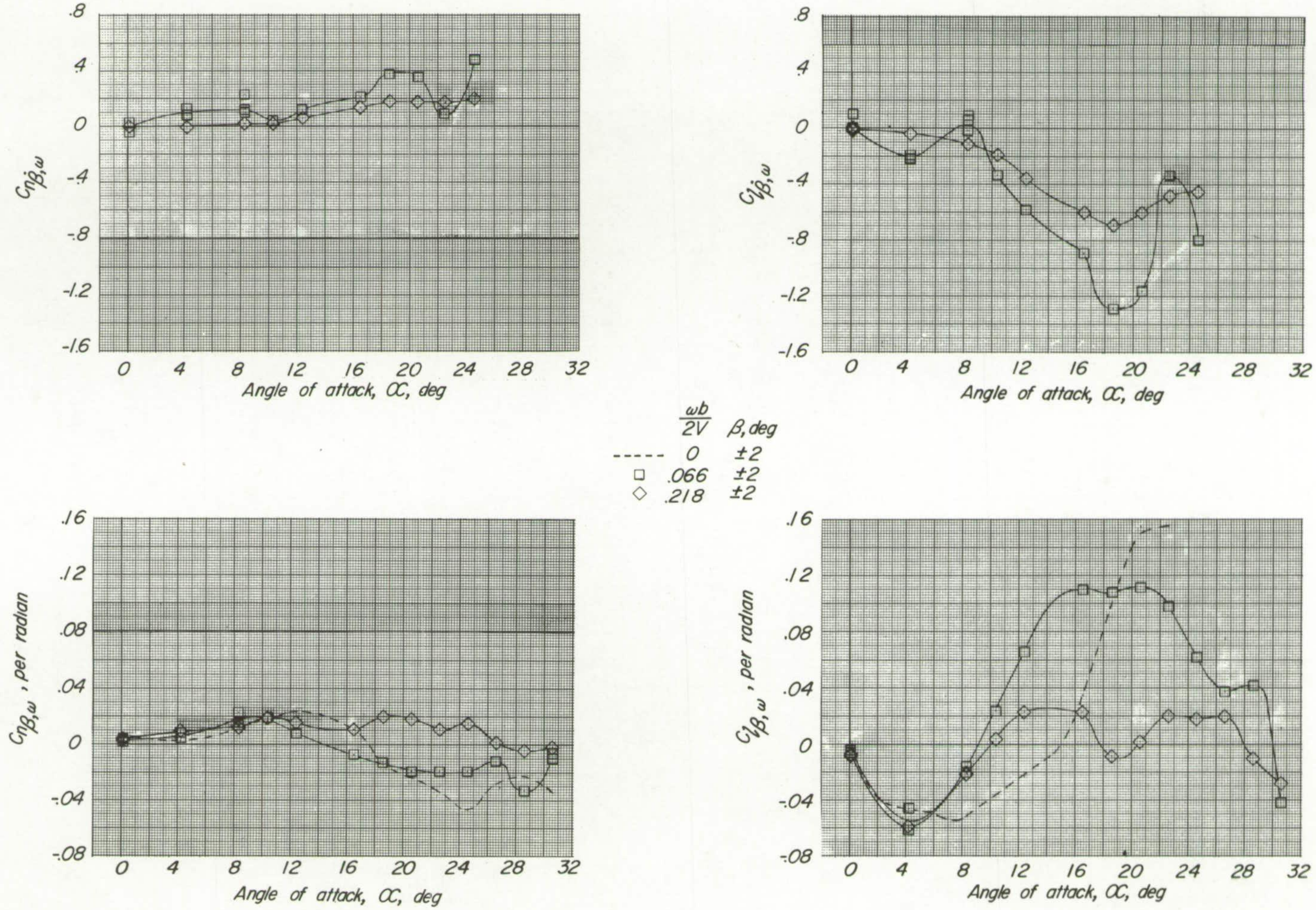
(a) Effect of frequency of oscillation.

Figure 5.- Effect of frequency and amplitude of sideslipping oscillation on the oscillatory yawing- and rolling-moment derivatives for the 60° delta wing.



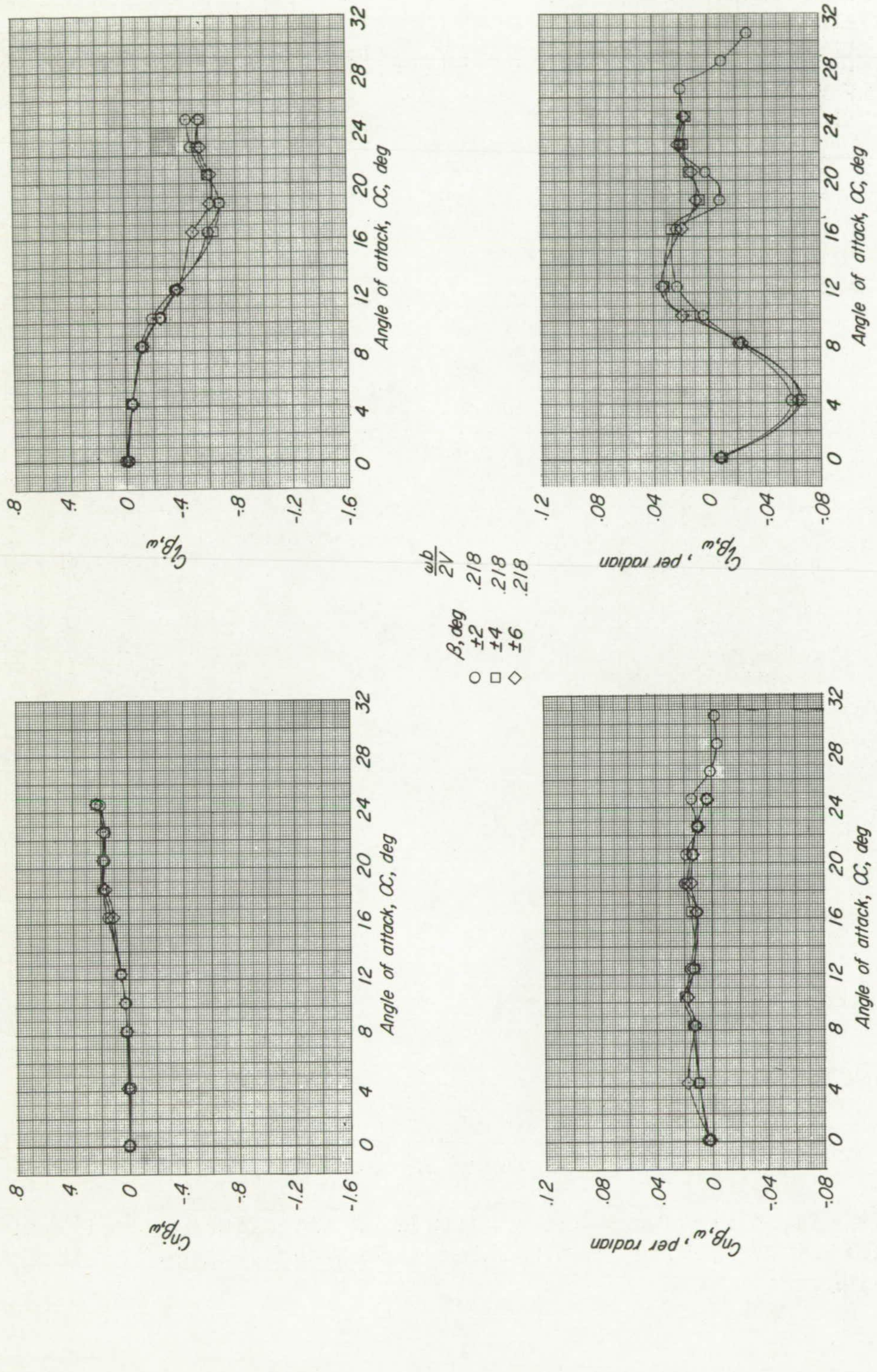
(b) Effect of amplitude of oscillation.

Figure 5.- Concluded.



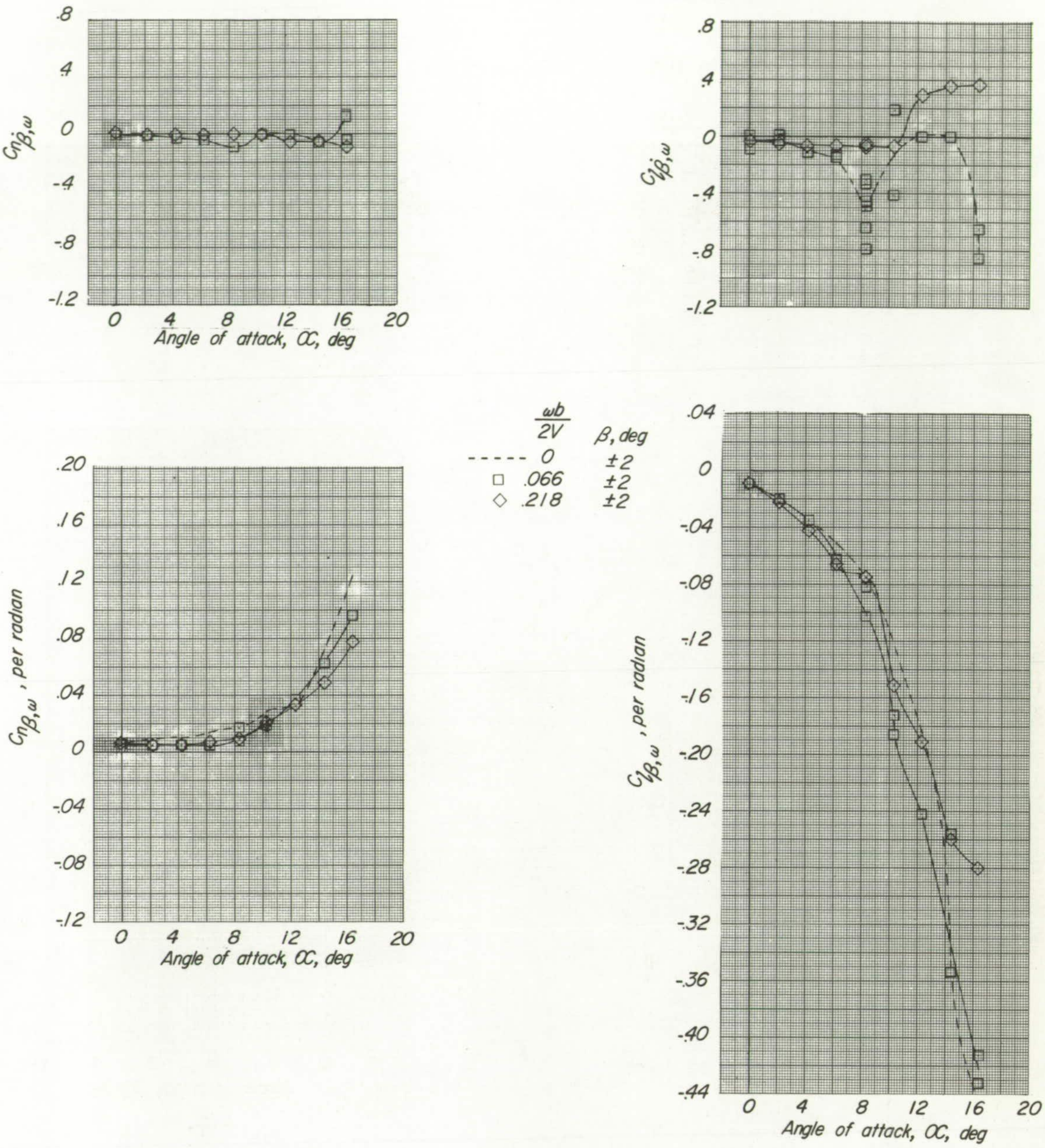
(a) Effect of frequency of oscillation.

Figure 6.- Effect of frequency and amplitude of sideslipping oscillation on the oscillatory yawing- and rolling-moment derivatives for the 45° sweptback wing.



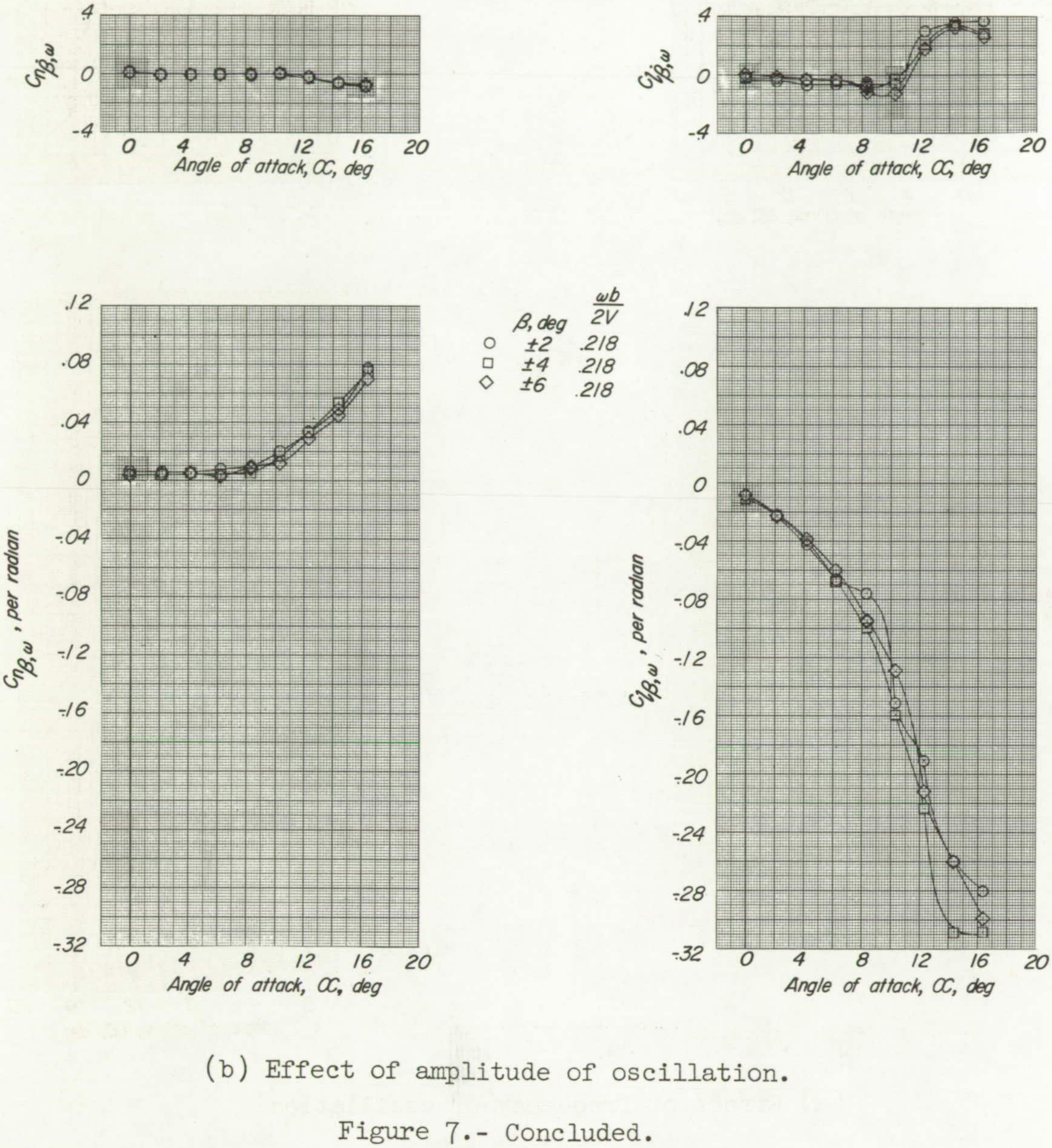
(b) Effect of amplitude of oscillation.

Figure 6.- Concluded.



(a) Effect of frequency of oscillation.

Figure 7.- Effect of frequency and amplitude of sideslipping oscillation on the oscillatory yawing- and rolling-moment derivatives for the unswept wing.



(b) Effect of amplitude of oscillation.

Figure 7.- Concluded.

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