Copy No. 193

2

RM No. L8H18

RESTRICTED

CLASSIFICATION CANCELED

NACA RM No. L8H18

CLASSIFICATION CANCELLED

403

Authority NACA DRYDEN Date JUL 3 1951

Change 640

By ET MAHER/TW See

AUG 2 1951

CASE FILE COPY

RESEARCH MEMORANDUM

EFFECT OF TAPER RATIO ON THE LOW-SPEED ROLLING STABILITY DERIVATIVES OF SWEPT AND UNSWEPT WINGS OF ASPECT RATIO 2.61

By

Jack D. Brewer and Lewis R. Fisher

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

November 9, 1948

RESTRICTED

CLASSIFICATION CANCELED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF TAPER RATIO ON THE LOW-SPEED ROLLING STABILITY DERIVATIVES OF SWEPT AND UNSWEPT WINGS OF ASPECT RATIO 2.61

By Jack D. Brewer and Lewis R. Fisher

SUMMARY

An investigation has been conducted on a series of tapered swept wings in the 6-foot circular test section of the Langley stability tunnel under conditions simulating rolling flight.

The results of the tests showed that a decrease in taper ratio (ratio of tip chord to root chord) of a swept wing caused a small decrease in damping in roll at low and moderate lift coefficients; at high lift coefficients, decreasing the taper ratio caused a large reduction in the damping in roll, greatly reducing the increase obtained for the untapered wing prior to maximum lift. For an unswept wing, a decrease in taper ratio caused a moderate decrease in the damping in roll throughout the lift-coefficient range. The rate of change with lift coefficient of the yawing moment due to roll and of the lateral force due to roll were slightly decreased by a decrease in taper ratio.

Available theory generally predicts the effect of change in taper ratio on the rate of change of the yawing moment due to roll with lift coefficient and on the damping in roll at zero lift more accurately than it does the effect of sweep. Tip-suction effects, not accounted for by the theory, may cause large errors in the theoretical values of the yawing moment due to roll and the lateral force due to roll. For a swept wing the yawing moment due to roll can be estimated by applying a correction to the available theory utilizing the experimental value of the lateral force for an unswept wing of the same aspect ratio and taper ratio (the tip-suction force) and the geometric characteristics of the wing.

INTRODUCTION

An extensive investigation is being carried out at the Langley stability tunnel to determine the effect of various geometric variables on rotary and static stability characteristics. The values of the stability derivatives are required for the determination of the dynamic flight characteristics of an airplane. The static stability derivatives are readily determined by conventional wind-tunnel tests, and the rotary stability derivatives, heretofore generally estimated from theory, can now also be quickly determined by the utilization of the stability-wind-tunnel curved- and rolling-flow test equipment (references 1 and 2).

In this paper results are presented of tests made in straight and rolling flow to determine the effect of taper ratio on the rolling characteristics of a 45° sweptback wing and an unswept wing (both having an aspect ratio of 2.61). The effects of changes in taper ratio on the yawing characteristics of the swept wings are presented in reference 3.

SYMBOLS

The data are presented in the form of standard NACA coefficients of forces and moments which are referred, in all cases, to the stability axes, with the origin at the quarter-chord point of the mean aerodynamic chord of the models tested. The positive directions of the forces, moments, and angular displacements are shown in figure 1. The coefficients and symbols used herein are defined as follows:

C_L	lift coefficient (L/qS)
C_X	longitudinal-force coefficient (X/qS)
C_D	drag coefficient $(-C_X$ for $\psi = 0^\circ)$
C_Y	lateral-force coefficient (Y/qS)
C_l	rolling-moment coefficient (L'/qSb)
C_m	pitching-moment coefficient $(M/qS\bar{c})$
C_n	yawing-moment coefficient (N/qSb)
L	lift
X	longitudinal force
Y	lateral force
L'	rolling moment about X-axis
M	pitching moment about Y-axis
N	yawing moment about Z-axis
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

ρ	mass density of air
V	free-stream velocity
S	wing area
b	span of wing measured perpendicular to plane of symmetry
c	chord of wing, measured parallel to plane of symmetry
$\bar{c}$	mean aerodynamic chord $\left(\frac{2}{S}\int_0^{b/2} c^2\,dy\right)$
y	distance measured perpendicular to the plane of symmetry
x	distance of quarter-chord point of any chordwise section from the leading edge of the root section
$\bar{x}$	distance from the leading edge of the root chord to the quarter chord of the mean aerodynamic chord $\left(\frac{2}{S}\int_0^{b/2} cx\,dy\right)$
A	aspect ratio (b^2/S)
λ	taper ratio $\left(\frac{\text{Tip chord (extended)}}{\text{Root chord}}\right)$
α	angle of attack measured in plane of symmetry
Λ	sweep of quarter-chord line
$\frac{pb}{2V}$	wing-tip helix angle, radians
p	rolling angular velocity, radians per second

$$C_{Y_p} = \frac{\partial C_Y}{\partial \frac{pb}{2V}}$$

$$C_{n_p} = \frac{\partial C_n}{\partial \frac{pb}{2V}}$$

$$C_{l_p} = \frac{\partial C_l}{\partial \frac{pb}{2V}}$$

$$C_{Y_{p_{C_L}}} = \frac{\partial C_{Y_p}}{\partial C_L}$$

$$C_{n_{p_{C_L}}} = \frac{\partial C_{n_p}}{\partial C_L}$$

$$C_{Y_\psi} = \frac{\partial C_Y}{\partial \psi}$$

$$C_{n_\psi} = \frac{\partial C_n}{\partial \psi}$$

$$C_{l_\psi} = \frac{\partial C_l}{\partial \psi}$$

APPARATUS AND TESTS

The tests of the present investigation were conducted in the 6-foot circular test section of the Langley stability tunnel. In this test section, it is possible to rotate the air stream about a rigidly mounted model in such a way as to simulate rolling flight. (See reference 2.)

The models tested consisted of five mahogany wings having the NACA 0012 contour in sections normal to the quarter-chord line. The aspect ratio of each model was 2.61. Three wings having taper ratios of 1.0, 0.5, and 0.25 were swept back 45° at the quarter-chord line; two wings having taper ratios of 1.0 and 0.5 had zero sweep at the quarter-chord line. Plan forms of the five models are shown in figure 2.

The models were rigidly mounted at the quarter-chord point of the mean aerodynamic chord on a six-component strain-gage-balance strut (reference 4). Lift, longitudinal force, and pitching moment were measured in straight flow through an angle-of-attack range from about -4° to an angle beyond the stall; lateral force, rolling moment, and yawing moment were measured through the same angle-of-attack range in rolling flow for tip helix angles $pb/2V$ of ±0.021 and ±0.062. All the tests were made at a dynamic pressure of 39.7 pounds per square foot which corresponds to a Mach number of 0.17. The corresponding Reynolds number, based on the mean aerodynamic chord, was 1.40×10^6 for the untapered wings, 1.45×10^6 for the wings with taper ratios of 0.50, and 1.56×10^6 for the wing with a taper ratio of 0.25. A photograph of one of the models mounted in the tunnel is presented as figure 3.

CORRECTIONS

Corrections for the effects of jet boundaries, based on unswept-wing theory, have been applied to the angle of attack, the longitudinal-force coefficient, and the rolling-moment coefficient.

No corrections for the effects of blocking, turbulence, or for the effects of static-pressure gradient on the boundary-layer flow have been applied.

RESULTS AND DISCUSSION

The lift, longitudinal-force, and pitching-moment characteristics for the three swept wings tested are presented in figure 4 (for a dynamic pressure of 39.7 pounds per square foot). These results agree well with the results previously obtained for the same wings and presented in figure 4 of reference 3 (for a dynamic pressure of 24.9 pounds per square foot). The rearward movement of the aerodynamic center with a decrease in taper ratio is apparent from the pitching-moment results; the effect of taper ratio on the lift and longitudinal-force characteristics is small at low and moderate lift coefficients. At high lift coefficients, larger longitudinal-force coefficients were obtained with the more highly tapered wings. At a lift coefficient of about 0.6, an increase occurred in the lift-curve slope; this increase became smaller as the taper ratio decreased.

It can be seen from figure 5 that reducing the taper ratio of the unswept wing from 1.00 to 0.50 caused a small increase in the lift-curve slope. As was true in the case of the swept wing, taper ratio had a negligible effect on the maximum value of lift coefficient. The angle of attack at which the maximum value occurred decreased with a decrease in taper ratio, a result opposite to that obtained for the swept wings. The pitching-moment results for the unswept wings indicate almost no shift of the aerodynamic center with a change in taper ratio. Changing the taper ratio had a negligible effect on the longitudinal-force results for the unswept wings.

The effect of sweep on the lift characteristics of a tapered wing can be determined from the data presented in figure 5. Sweep caused a decrease in the lift-curve slope, an increase in the maximum value of lift coefficient, and an increase in the angle of attack at which it occurred. The shift rearward of the aerodynamic center with sweep is apparent from the pitching-moment results; there is little change in the value of the longitudinal-force coefficient.

In reference 3, it was shown that, for the swept wings, there was a large change in the slopes of the lateral-stability-derivative curves and of the yawing-derivative curves at a lift coefficient of about 0.6, the lift coefficient at which the quantity $C_D - \frac{{C_L}^2}{\pi A}$ began to increase rapidly. For the same wings the rolling parameters C_{l_p}, C_{n_p}, and C_{Y_p} plotted against lift coefficient in figure 6 of the present paper also show large changes in slope at a lift coefficient of about 0.6.

In figure 6 it can be seen that a decrease in taper ratio caused a small decrease in damping in roll at low and moderate lift coefficients; at high lift coefficients, decreasing the taper ratio caused a large reduction in the damping in roll, greatly reducing the increase obtained for the untapered wing prior to maximum lift. The rate of change of C_{n_p} and C_{Y_p} with lift coefficient was slightly decreased with a decrease in taper ratio at low lift coefficients; at high lift coefficients there was no consistent variation with taper ratio.

For the unswept wings (fig. 7) a decrease in taper ratio caused a small decrease in the damping in roll throughout the lift-coefficient range. The rate of change of C_{n_p} and C_{Y_p} with lift coefficient was slightly decreased by a decrease in taper ratio.

The variation with taper ratio of $C_{n_{p_{C_L}}}$ and $C_{Y_{p_{C_L}}}$ for the low lift-coefficient range, and of C_{l_p} at zero lift are presented in figure 8. Experimental values of C_{l_p} at zero lift are compared with values indicated by the theories of references 5 and 6. Theoretical values of $C_{n_{p_{C_L}}}$ and $C_{Y_{p_{C_L}}}$ were obtained by the method of reference 5 which is based on a lifting-line-theory concept and does not consider the effect of unbalanced tip suction under asymmetric conditions. The experimental values of C_{Y_p} $\left(\text{and } C_{Y_{p_{C_L}}}\right)$ for the wings with zero sweep show that such unbalanced suction does exist. If it is assumed that the suction forces are independent of sweep, it is possible to obtain a correction to the theoretical value of $C_{n_{p_{C_L}}}$ for a swept wing. For example, assuming that the value of $C_{Y_{p_{C_L}}}$ due to tip suction for the unswept wing with 0.5 taper ratio (0.28 from fig. 8) is the same for the 45° swept wing of 0.5 taper ratio, a correction to $C_{n_{p_{C_L}}}$ can be determined. By multiplying this value of $C_{Y_{p_{C_L}}}$ by -1.01, the longitudinal distance between the mounting point (quarter chord of the mean aerodynamic chord) and the 50-percent point of the tip chord (where the suction force is assumed to act), and dividing by the span 3.04, a value of $C_{n_{p_{C_L}}}$ due to tip suction is determined; in this case the addition to $C_{n_{p_{C_L}}}$ is -0.093. The final value of $C_{n_{p_{C_L}}}$ is then the sum of the theoretical value (-0.065) and the tip-suction increment (-0.093). This value (-0.158) is in close agreement with the actual experimental value of -0.160. Theory predicts the effect of a change in taper ratio on $\left(C_{l_p}\right)_{C_L=0}$ and $C_{n_{p_{C_L}}}$ more accurately than it does the effect of sweep. The apparent close agreement between the theoretical and experimental values of $C_{Y_{p_{C_L}}}$ for the swept wings is actually due to the overprediction of the theory which, in this case, compensates for the unaccounted-for tip-suction effect. As the aspect ratio of the wing increases, the value of C_Y due to the tip suction would be expected to become smaller. The errors associated with the neglect of the tip suction in the theoretical analysis should then be quite small for wings of high aspect ratio. The theoretical values of C_{l_p} at zero lift as obtained by the method of reference 6 show the same effect of a change in taper ratio as did the theory of reference 5.

CONCLUSIONS

Results of tests made in the 6-foot circular test section of the Langley stability tunnel in straight and rolling flow on a series of tapered swept wings indicate the following conclusions:

1. A decrease in taper ratio on a swept wing caused a small decrease in damping in roll at low and moderate lift coefficients; at high lift coefficients, decreasing the taper ratio caused a large reduction in the damping in roll, greatly reducing the increase obtained for the untapered wing prior to maximum lift. For an unswept wing, a decrease in taper ratio caused a moderate decrease in the damping in roll throughout the lift-coefficient range.

2. At low lift coefficients, a decrease in taper ratio caused a small decrease in the rate of change of the yawing moment due to roll and the lateral force due to roll with lift coefficient.

3. Available theory predicts the effect of change in taper ratio on the rate of change of the yawing moment due to roll with lift coefficient and on the damping in roll at zero lift more accurately than it does the effect of sweep.

4. Tip suction may cause large errors in the available theoretical values of the yawing moment due to roll and the lateral force due to roll; the yawing moment due to roll of a swept wing can be estimated quite accurately by applying a simple correction to the available theory utilizing the experimental value of the lateral force for an unswept wing of the same aspect ratio and taper ratio (the tip-suction force) and the geometric characteristics of the wing.

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

REFERENCES

1. Bird, John D., Jaquet, Byron M., and Cowan, John W.: Effect of Fuselage and Tail Surfaces on Low-Speed Yawing Characteristics of a Swept-Wing Model as Determined in Curved-Flow Test Section of Langley Stability Tunnel. NACA RM No. L8G13, 1948.

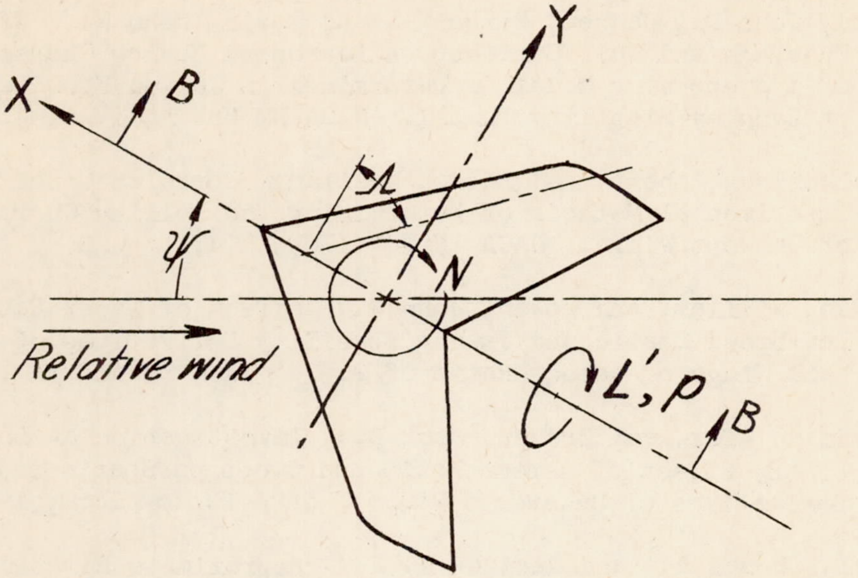
2. MacLachlan, Robert, and Letko, William: Correlation of Two Experimental Methods of Determining the Rolling Characteristics of Unswept Wings. NACA TN No. 1309, 1947.

3. Letko, William, and Cowan, John W.: Effect of Taper Ratio on Low-Speed Static and Yawing Stability Derivatives of 45° Sweptback Wings of Aspect Ratio of 2.61. NACA TN No. 1671, 1948.

4. Goodman, Alex, and Brewer, Jack D.: Investigation at Low Speeds of the Effect of Aspect Ratio and Sweep on Static and Yawing Stability Derivatives of Untapered Wings. NACA TN No. 1669, 1948.

5. Toll, Thomas A., and Queijo, M. J.: Approximate Relations and Charts for Low-Speed Stability Derivatives of Swept Wings. NACA TN No. 1581, 1948.

6. Weissinger, J.: The Lift Distribution of Swept-Back Wings. NACA TM No. 1120, 1947.



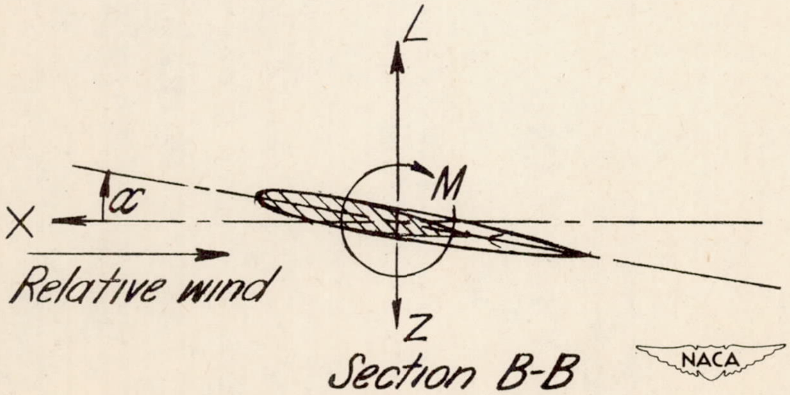
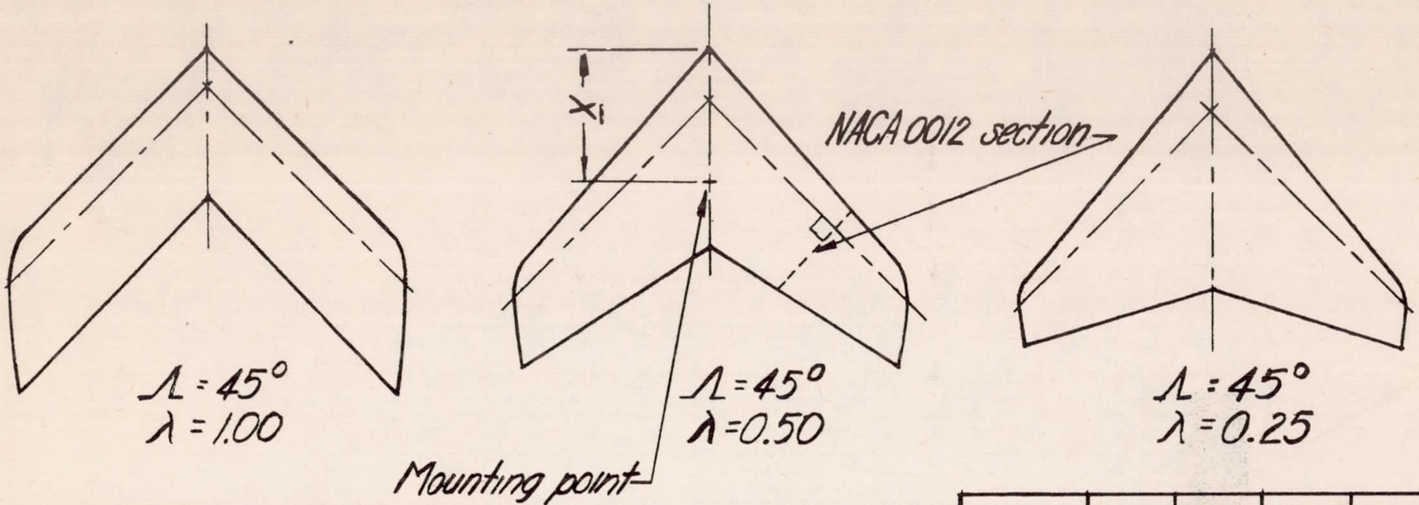
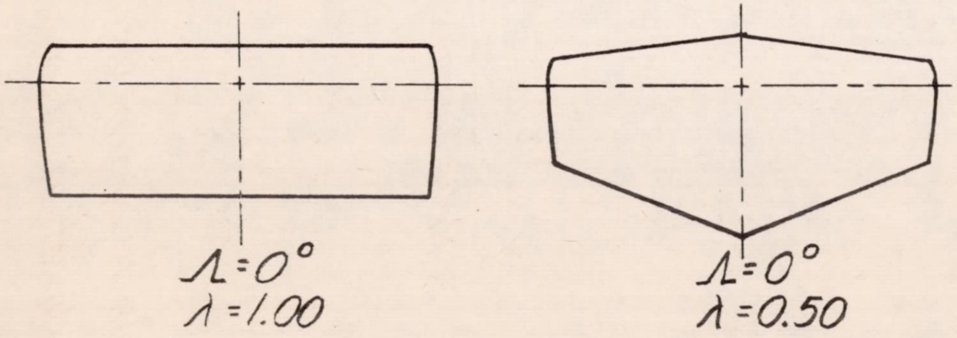


Figure 1. System of axes used. Arrows indicate positive direction of angles, forces, and moments.





Λ (deg)	λ	b (ft)	S (sq ft)	$\bar{c}$ (ft)	$\bar{x}$ (ft)
45	1.00	3.05	3.56	1.17	1.05
	.50	3.04	3.55	1.22	1.06
	.25	3.04	3.55	1.31	1.07
0	1.00	3.08	3.60	1.18	.30
	.50	3.04	3.55	1.22	.39

Figure 2.- Planforms of wings tested. NACA 0012 profile (perpendicular to quarter-chord line); $A = 2.61$.

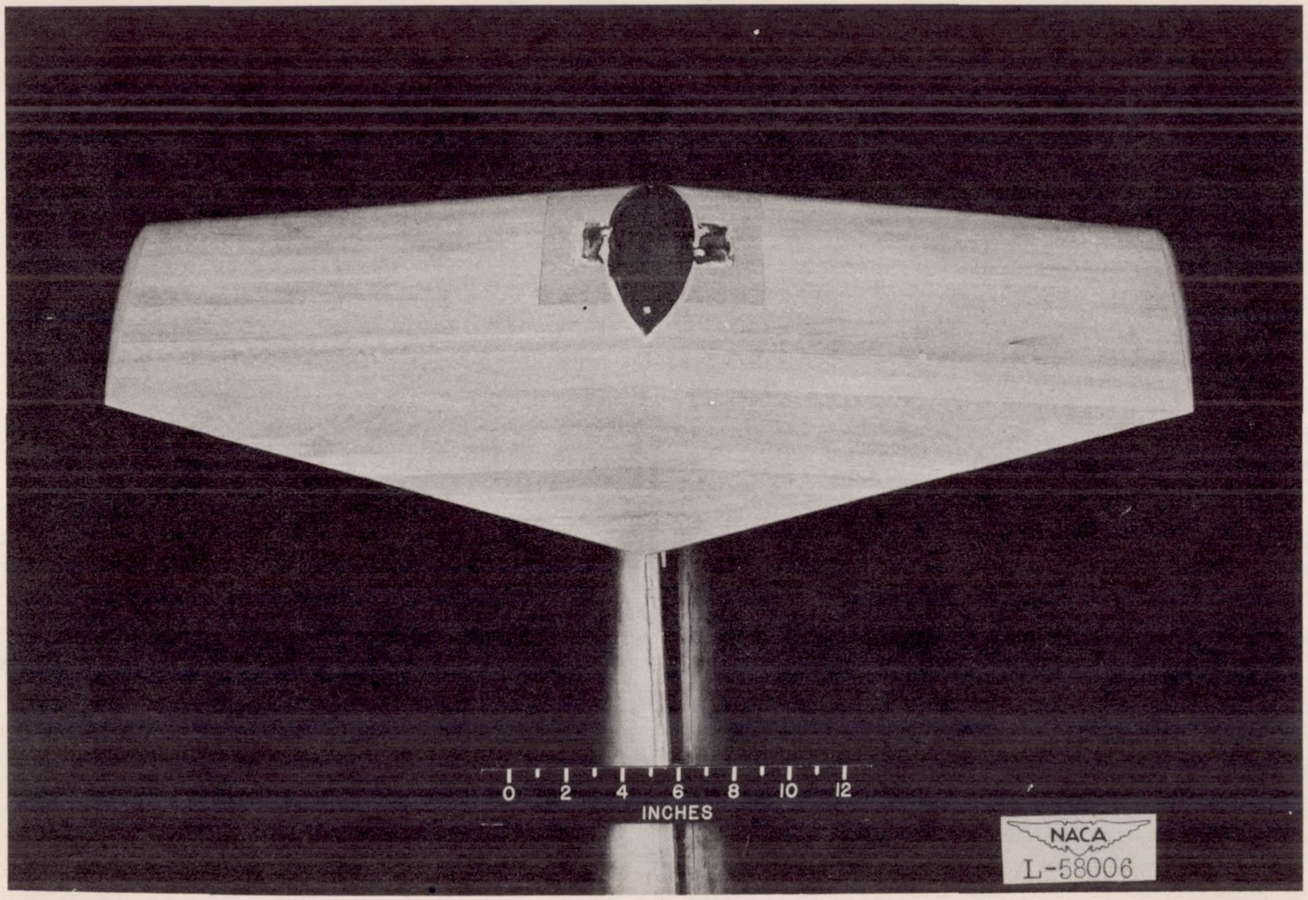


Figure 3.- View of the unswept model mounted in the 6-foot circular test section of the Langley stability tunnel. Taper ratio, 0.50.

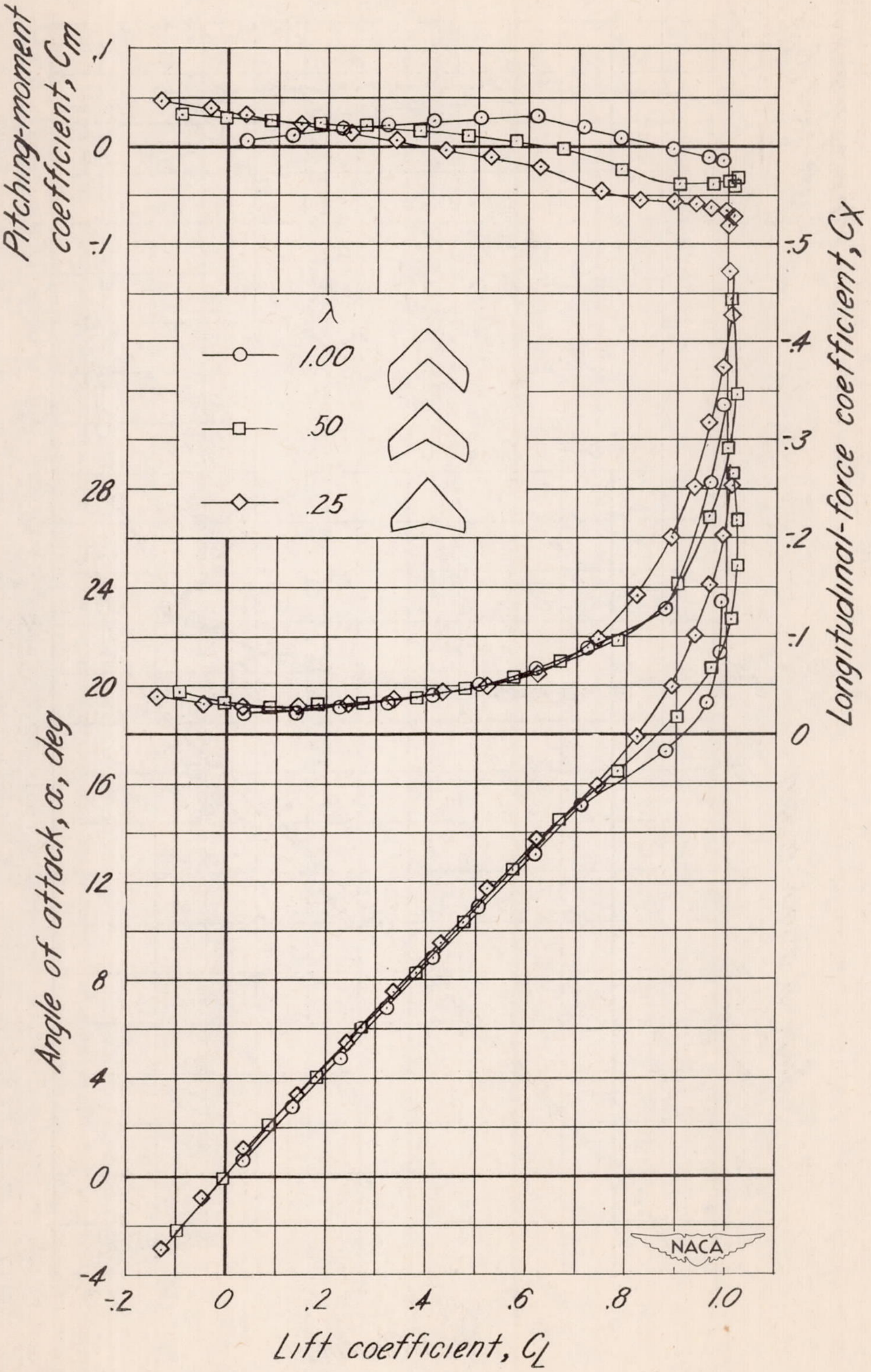


Figure 4.- Effect of taper on the aerodynamic characteristics of a swept wing. $\Lambda = 45°$; $A = 2.61$.

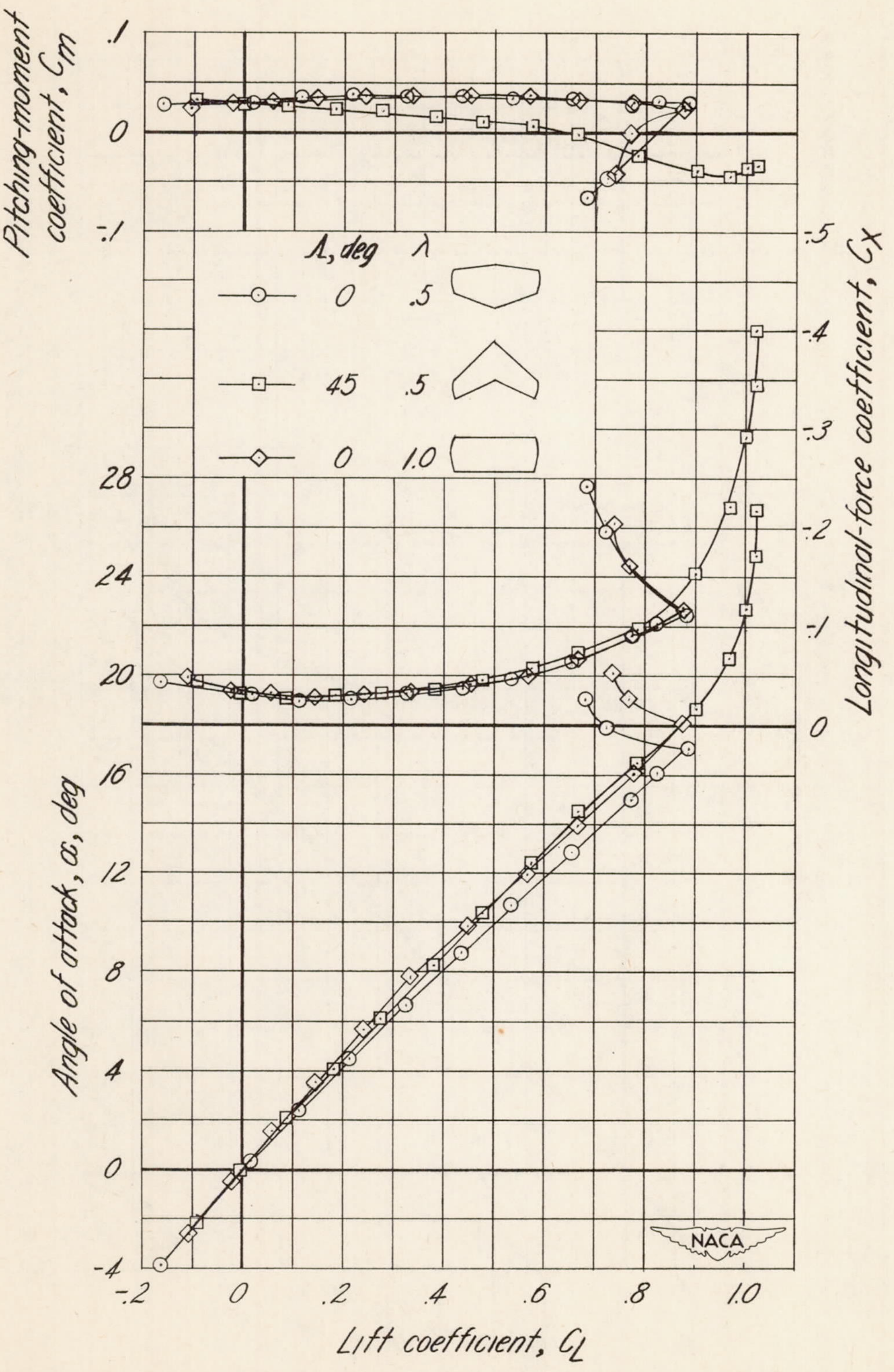


Figure 5.- Effect of taper and sweep on the aerodynamic characteristics of a wing. $A = 2.61$.

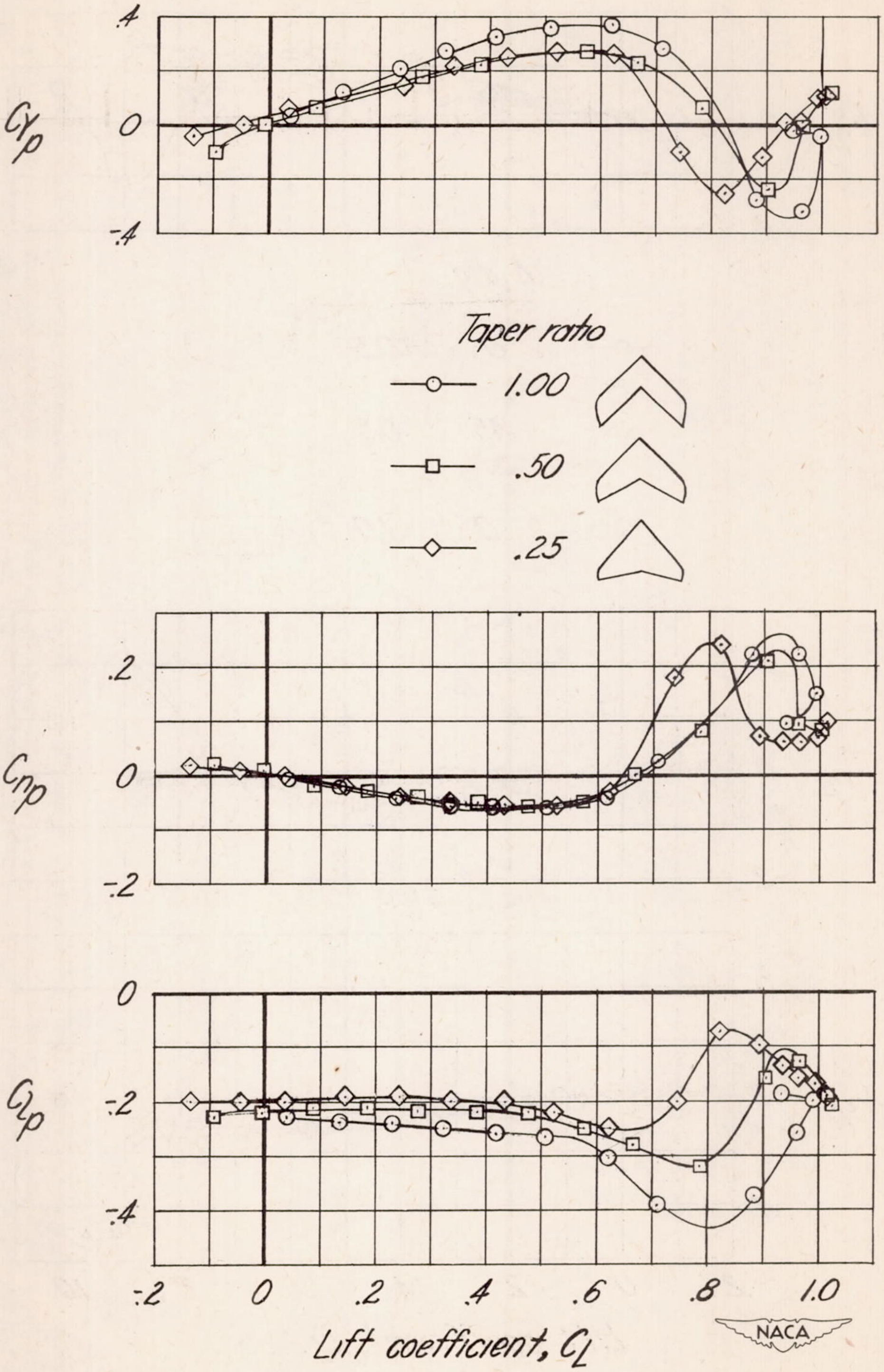


Figure 6.-Effect of taper on the rolling parameters of a swept wing. $\Lambda = 45°$; $A = 2.61$.

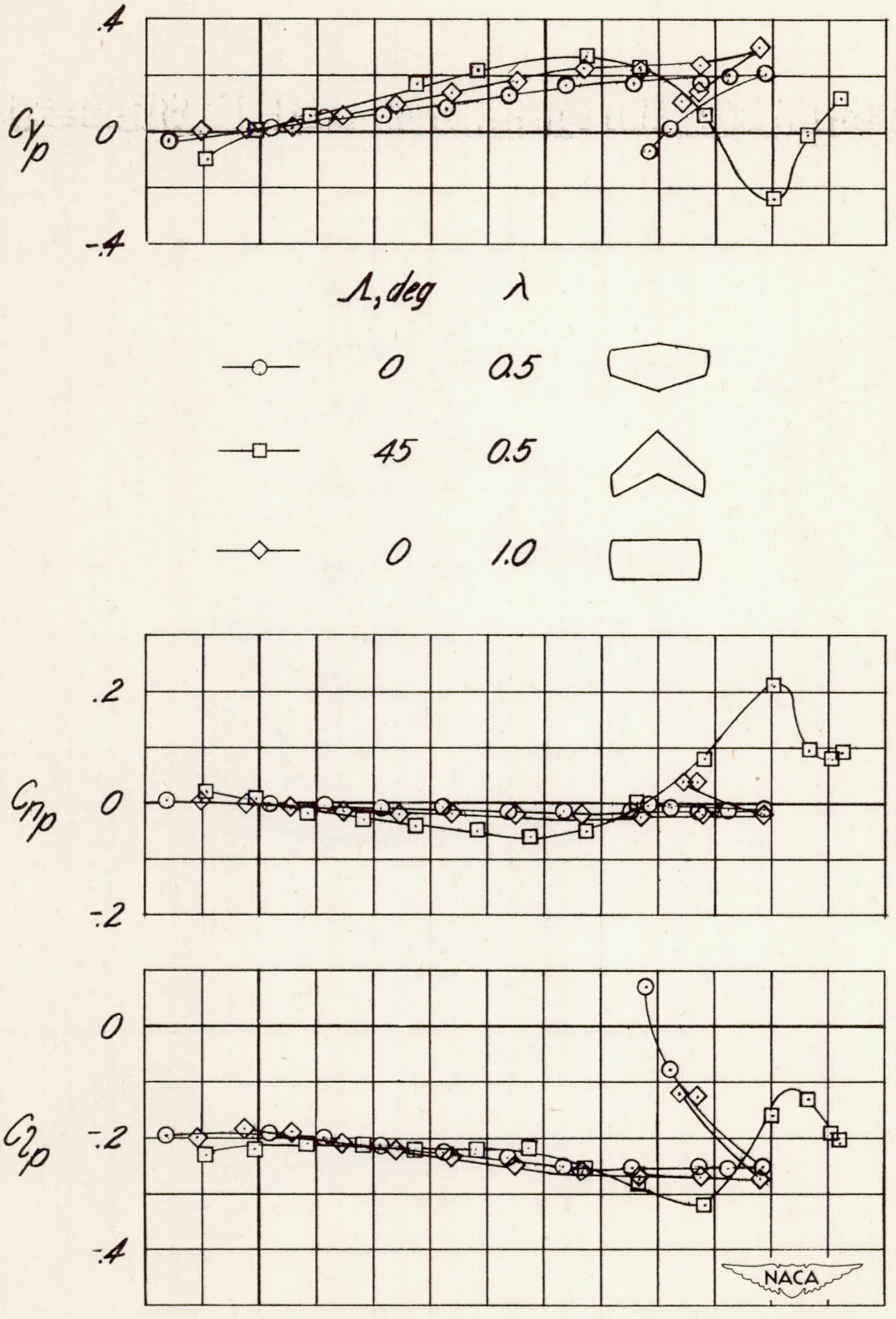
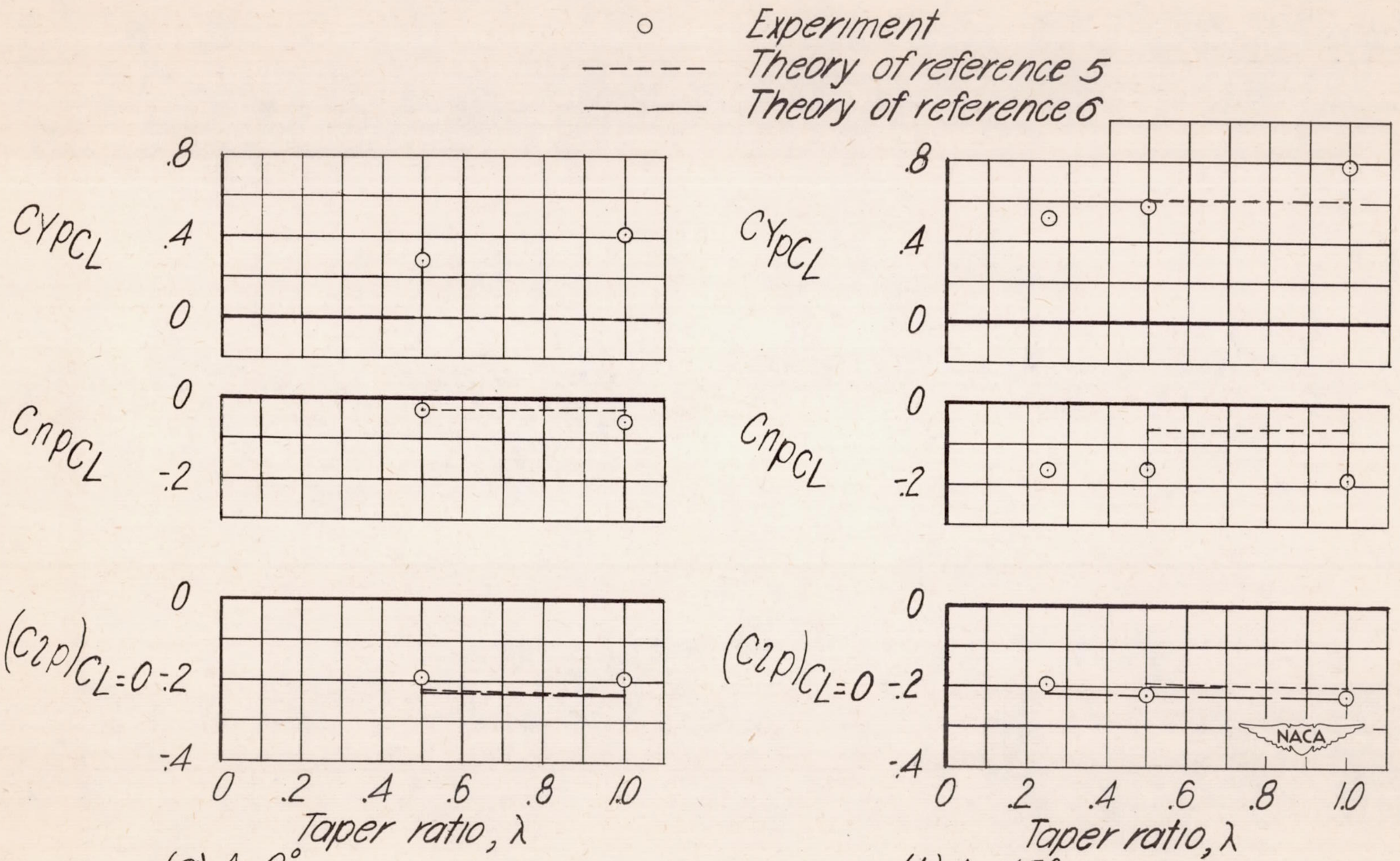


Figure 7.- Effect of taper and sweep on the rolling parameters of a wing. A=2.61.



(a) $\Lambda = 0°$.

(b) $\Lambda = 45°$.

Figure 8.- Variation of $C_{Y_{p_{C_L}}}$, $C_{n_{p_{C_L}}}$, and $(C_{l_p})_{C_L=0}$ with taper ratio.