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TECHNICAL NOTE

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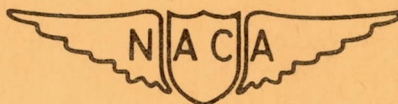
EXPERIMENTAL DETERMINATION OF THE DAMPING IN ROLL
AND AILERON ROLLING EFFECTIVENESS OF THREE
WINGS HAVING 2° , 42° , AND 62° SWEEPBACK

By Charles V. Bennett and Joseph L. Johnson

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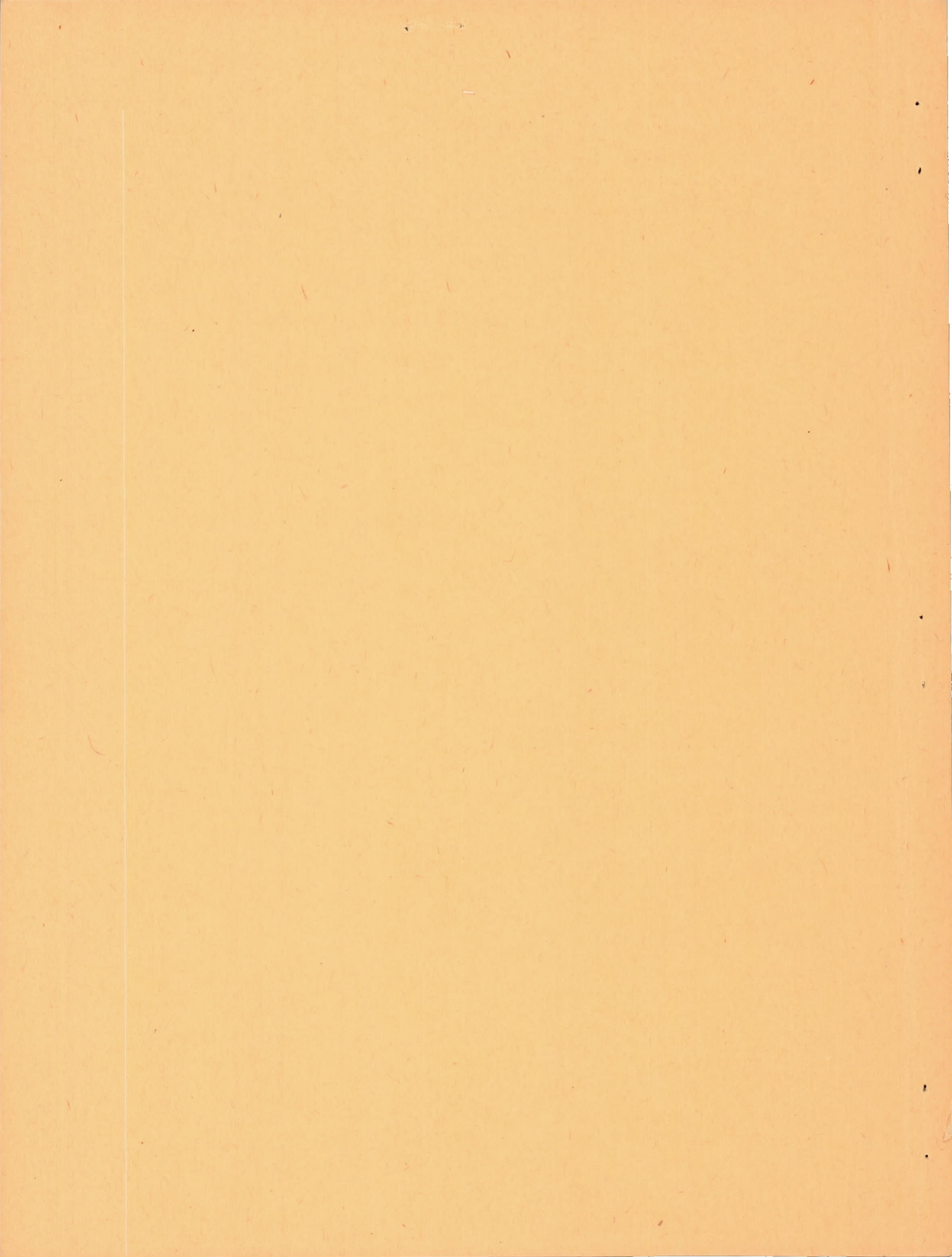
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EXPERIMENTAL DETERMINATION OF THE DAMPING IN ROLL
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WINGS HAVING 2° , 42° , AND 62° SWEEPBACK

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SUMMARY

Tests have been made to determine the damping in roll and the aileron rolling effectiveness of three wings having 2° , 42° , and 62° sweepback. The wing with 2° sweepback had an aspect ratio of 10 and the wings with 42° and 62° sweepback, which were obtained by rotating the panels of the wing with 2° sweepback about the 0.50-root-chord point while the length of the 0.50-chord line was held constant, had aspect ratios of 5.9 and 2.5, respectively. All wings had taper ratios of 0.5.

The results of the investigation showed that the values of damping in roll decreased with increasing sweepback. An approximate estimate of this reduction over the linear range of lift coefficient can be obtained by multiplying the straight-wing value of damping in roll by the cosine of the sweepback angle. The damping in roll for all three wings decreased with increasing lift coefficient. Increasing the amount of sweepback reduced the tendency toward instability in rolling as the maximum lift was approached. Increasing the amount of sweepback increased the aileron deflection required to produce a given value of the helix angle generated by the wing tip.

INTRODUCTION

Experimental and theoretical work has shown that the critical speed of aircraft can be increased considerably by employing large amounts of wing sweep. At the present time little experimental or theoretical data on the rotary damping derivatives of highly swept wing plan forms exist. Because these derivatives are essential in the theoretical determination of the dynamic stability and control characteristics of aircraft, an experimental investigation to determine these derivatives for swept wings is being conducted in

the Langley 15-foot free-spinning tunnel. In the first part of this investigation, measurements are being made of the damping-in-roll derivative.

Presented in this paper are the results of the experimental investigation made to determine the values of damping in roll for three wings having 2° , 42° , and 62° sweepback. Also presented are the results of tests made to determine the rolling effectiveness of ailerons on these wings.

SYMBOLS

S	wing area, square feet
V	airspeed, feet per second
b	wing span measured perpendicular to plane of symmetry, feet
c	wing chord parallel to plane of symmetry, feet
$\bar{c}$	mean aerodynamic chord parallel to plane of symmetry, feet
Λ	angle of sweepback of the quarter-chord line of the wing, degrees
λ	taper ratio (c_t/c_r)
α	angle of attack, degrees
δ_a	total aileron deflection, degrees (sum of deflections of right and left ailerons, equal up and down)
q	dynamic pressure, pounds per square foot
y	perpendicular distance from plane of symmetry to center-of-load distribution on one semispan, feet
A	aspect ratio (b^2/S)
C_L	lift coefficient $\left(\frac{\text{Lift}}{qS} \right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS} \right)$

- C_m pitching-moment coefficient measured about $\bar{c}/4$

$$\left(\frac{\text{Pitching moment}}{qS\bar{c}} \right)$$
- C_l rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb} \right)$
- $pb/2V$ helix angle generated by wing tip, radians
- C_{l_p} damping-in-roll parameter $\left(\frac{\partial C_l}{\partial \frac{pb}{2V}} \right)$; rate of change
 of rolling-moment coefficient with helix angle
 generated by wing tip
- C_{L_α} slope of lift curve, per degree
- $\Delta\alpha$ change in angle of attack at center-of-load distribution
 on one semispan resulting from rolling, degrees
- ΔC_L incremental lift coefficient resulting from rolling
- $C_{l_{\delta_a}}$ rolling-moment coefficient per degree deflection of one
 aileron $\left(\frac{\partial C_l}{\partial \delta_a} \right)$
- Subscripts:
- r root
- t tip
- Λ sweepback angle, degrees

APPARATUS AND TEST CONDITIONS

The damping tests and aileron-rolling-effectiveness tests were made in the Langley 15-foot free-spinning tunnel (reference 1) on a special stand which was free in roll about the wind axis. A photograph of the stand as set up for rotation tests is shown as figure 1 and figure 2 is a sketch of the stand as set up to measure rolling moments with a calibrated torque rod. These tests were made at a dynamic pressure of 2.8 pounds per square foot which corresponds to test Reynolds numbers of 163,000 for the wing with 2° sweepback and 326,000 for the wing with 62° sweepback, based on their respective mean aerodynamic chords.

Values of the damping-in-roll parameter C_{lp} were obtained for each wing through a range of angles of attack which covered a lift-coefficient range from small positive lift coefficients to maximum lift coefficient. For each wing, aileron-rolling-effectiveness tests were also made to determine the aileron deflection required to produce rates of rotation corresponding to values of $pb/2V$ of 0.05 and 0.10 through ranges of lift coefficients from 0.23 to 1.14, 0.04 to 0.95, and 0 to 0.76 for the wings with 2° , 42° , and 62° sweepback, respectively. In addition, static aileron rolling moments, covering these lift-coefficient ranges, were determined for each wing.

Force tests to determine the lift, drag, and pitching-moment characteristics of the wings were made on the Langley free-flight-tunnel balance (reference 2) at a dynamic pressure of 3.0 pounds per square foot.

The three straight-taper wing models ($\lambda = 0.5$) used in the tests had 2° , 42° , and 62° sweepback of the quarter chord and aspect ratios of 10, 5.9, and 2.5, respectively. The wings with 42° and 62° sweepback were obtained by rotating the panels of the wing with 2° sweepback about the 0.50-root-chord point while the length of the 0.50-chord line was held constant and cutting the wing tips off parallel to the wind stream. Thus all the wings had approximately the same area (2.5 sq ft). Each wing was equipped with 0.30-chord plain ailerons. Geometric characteristics of the wings, including the spanwise location of the ailerons, are given in figure 3.

METHOD

The damping in roll of the wings was obtained from steady-rotation tests on the roll stand and static rolling-moment tests. The stand and wing rotation was obtained by deflecting the vane (① in fig. 2). In steady rotation, the forcing moment was assumed to be equal to the damping moment and of opposite sign. By recording the rate of rotation for vane settings of 20° , 30° , -20° , and -30° , the damping in roll of the stand and wing combination and of the stand alone were determined. The vane settings used gave values of $pb/2V$ from approximately 0.04 to 0.07 for the wing with 2° sweepback and from approximately 0.07 to 0.24 for the wings with 42° and 62° sweepback. In order to determine the damping of the wing alone, the damping of the stand was subtracted from the damping of the stand and wing combination for any given rate of rotation.

For determining the aileron rolling effectiveness, the ailerons were adjusted to obtain values of $pb/2V$ of 0.05 and 0.10 for each wing. The total aileron settings for positive and negative rotation were averaged to give the total effective aileron deflection required for the desired rate of rotation. At each rate of rotation the damping moment of the stand was neutralized by setting the fin to produce an equal and opposite moment.

RESULTS AND DISCUSSION

The results of all tests are presented in figures 4 to 7. In figure 8 the data are summarized and compared with values calculated by the simplified theory for swept-back wings, which was verified experimentally in reference 4. Since the sweepback in the present investigation was obtained by pivoting the semispan of a given wing about an axis in the plane of symmetry, the theory may be used in the basic form without the aspect-ratio corrections required for the experimental data of reference 4.

The results of the tests to determine the lift, drag, and pitching moment of the wings are shown in figure 4. These data indicate that the lift-curve slope decreases with increasing sweepback angle. The simplified theoretical treatment of reference 4 showed that $C_{L\alpha}$ varied with sweepback as $\cos \Lambda$.

The experimental and calculated values of $C_{L\alpha}$ for the wings tested are presented in figure 8(a) and show good agreement.

The results of the damping-in-roll tests are shown in figure 5. The data indicate that sweeping the wing back reduced the damping in roll and that the damping in roll for a given wing decreased gradually over the linear portion of the lift curve (up to $C_L = 1.0$ for the wing with 2° sweepback and up to $C_L = 0.6$ for the wings with 42° and 62° sweepback). Beyond the linear portion of the lift curves, as the maximum lift was approached, the wing with 2° sweepback showed a rapid reduction in damping in roll and above the maximum lift coefficient, a marked instability in damping in roll (positive C_{l_p}). The wings with 42° and 62° sweepback showed an irregular decrease in C_{l_p} beyond the linear portion of the lift curve and retained a small amount of damping up to an angle of attack of 36° .

A reduction in C_{l_p} with sweepback for wings having the same basic wing panels would be expected from a simplified treatment of the theory of swept-back wings. The damping rolling moment produced during rolling results from the asymmetric lift distribution along the span, such that, for any wing

$$C_{l_p} = \frac{\partial C_l}{\partial \left(\frac{pb}{2V}\right)} = \frac{\partial \left(\Delta C_L \frac{y}{b}\right)}{\partial \left(\frac{pb}{2V}\right)} = \frac{\partial \left(\Delta \alpha C_{L_\alpha} \frac{y}{b}\right)}{\partial \left(\frac{pb}{2V}\right)} \quad (1)$$

For the swept-back wings, reference 4 and the experimental data of figure 8(a) show that C_{L_α} varies as $\cos \Lambda$; by geometry b can be shown to vary as $\cos \Lambda$ and y is assumed to vary approximately as $\cos \Lambda$ so that the ratio y/b remains approximately constant. The effective incremental angle of attack resulting from rolling $\Delta \alpha$, in degrees, can be expressed by the equation

$$\Delta \alpha = 57.3 \frac{2y}{b} \frac{pb}{2V} \quad (2)$$

Since the ratio y/b is assumed to be constant, if $pb/2V$ is held constant with sweepback, then

$$\Delta \alpha_\Lambda = (\Delta \alpha)_{\Lambda=0} \quad (3)$$

If these relationships are substituted in equation (1), the damping in roll for the swept-back wing $C_{l_{p\Lambda}}$ can be expressed in terms of the damping in roll of the straight wing $(C_{l_p})_{\Lambda=0}$ as

$$C_{l_{p\Lambda}} = (C_{l_p})_{\Lambda=0} \cos \Lambda \quad (4)$$

Figure 8(b) presents a comparison of the calculated and experimental values of C_{l_p} at a representative lift coefficient (0.3) in the linear portion of the lift curve. Although the calculated values for the swept-back wings predict slightly more damping than was obtained experimentally, it appears that equation (4) may be used as an approximate estimate of the damping of swept-back wings when sweep is obtained by rotating the wing panels about an axis in the plane of symmetry perpendicular to the chord line. The experimental value of C_{l_p} obtained for the wing with 2° sweepback is in good agreement with the theoretical value of C_{l_p} obtained from reference 5.

The measured static aileron rolling moments for the wings tested are presented in figure 6. These data indicate that with increasing sweepback greater aileron deflections are required to produce a given rolling moment. The aileron deflection required, for any sweepback, remains essentially constant over the linear portion of the lift curve. Reference 4 indicated that the aileron effectiveness of a swept-back wing was reduced as $\cos^2 \Lambda$. Figure 8(c) shows that this relationship holds reasonably well for wings with 2° and 42° sweepback. The data for the wing with 62° sweepback are also presented in figure 8(c) but since the location of the ailerons on this wing is not the same as the location of the ailerons on the wings with 2° and 42° sweepback the data are not directly comparable. (See fig. 3.)

The results of tests to determine the aileron deflections required to produce values of $pb/2V$ of 0.05 and 0.10 are presented in figure 7 with calculated values of the aileron deflections required. The calculated aileron rolling effectiveness was obtained from the damping-in-roll data of figure 5 and the static aileron-rolling-moment data of figure 6. The data of figure 7 show that as the sweepback was increased greater aileron deflections were required to produce a given value of $pb/2V$.

The data of figure 7 show that for the wing with 2° sweepback the experimental aileron rolling effectiveness remained nearly constant throughout the lift range investigated. The calculated data are in fair agreement with the experimental data. Figures 5 and 6 show that for the wing with 2° sweepback the aileron rolling effectiveness remains constant because the aileron rolling moment $C_{l_{\delta_a}}$ decreased in about the same ratio as the damping roll C_{l_p} up to maximum lift coefficient. For the wing with 42° sweepback, the experimental data of figure 7 show that aileron rolling

effectiveness remained constant up to a lift coefficient of 0.7 and that from a lift coefficient of 0.7 to 0.95 the aileron deflection required for a given value of $pb/2V$ decreased. The calculated data verify this reduction since the damping in roll C_{l_p} decreased more rapidly than the aileron rolling moments $C_{l_{\delta_a}}$. (See figs. 5 and 6.) No apparent systematic variation of aileron required for a given value of $pb/2V$ is noted for the wing with 62° sweepback. The calculated and experimental values, however, are in qualitative agreement.

Figure 7 shows that the ailerons could not produce a value of $pb/2V$ of 0.05 near maximum lift coefficient for the wings with 42° and 62° sweepback because the aileron rolling moments approach zero as maximum lift coefficients are reached while the wings retain a small amount of damping. (See figs. 5 and 6.)

In figure 8(d) the measured and calculated aileron deflections required to produce $pb/2V$ of 0.05 are plotted against sweepback angle. The calculations were based on the following relationship:

$$\delta_{a\Lambda} = \frac{pb}{2V} \frac{C_{l_p}}{C_{l_{\delta_a}}} = \frac{pb}{2V} \frac{(C_{l_p})_{\Lambda=0} \cos \Lambda}{(C_{l_{\delta_a}})_{\Lambda=0} \cos^2 \Lambda}$$

or

$$\delta_{a\Lambda} = (\delta_a)_{\Lambda=0} \frac{1}{\cos \Lambda} \quad (5)$$

The experimental data of figure 8(d) are in good agreement with the calculated values for the wings with 2° and 42° sweepback. Data for the wing with 62° sweepback are presented in figure 8(d), but the data on this wing are not directly comparable with data for the wings with 2° and 42° sweepback because the ailerons have different locations.

CONCLUSIONS

The results of tests of three wings having 2° , 42° , and 62° sweepback, with the 42° and 62° sweep obtained by rotating the

wing panels of the unswept wing about an axis in the plane of symmetry perpendicular to the chord line while the length of the 0.50-chord line was held constant, may be summarized as follows:

1. Increasing sweepback reduced the damping in roll. An approximate estimate of the damping in roll of the swept-back wings over the linear range of lift coefficient was obtained by multiplying the straight-wing value of damping in roll by the cosine of the sweepback angle.

2. The damping in roll for all three wings decreased with increasing lift coefficient.

3. Increasing the amount of sweepback reduced the tendency for instability in rolling as maximum lift was approached.

4. Increasing the amount of sweepback caused an increase in the aileron deflection required to produce a given value of helix angle $pb/2V$.

5. The aileron rolling effectiveness for the wing with 2° sweepback remained approximately constant up to the maximum lift coefficient because the aileron rolling moments decreased approximately in the same ratio as the damping in roll. For the wing with 42° sweepback the aileron rolling effectiveness remained constant up to a lift coefficient of 0.7, but from a lift coefficient of 0.7 to 0.95 the aileron deflection required to produce a given value of $pb/2V$ decreased because the damping in roll decreased faster than the aileron rolling moments. No apparent systematic variation with lift coefficient of the aileron required for a given value of $pb/2V$ was noted for the wing with 62° sweepback.

6. The rolling effectiveness of the aileron of the swept-back wings was predicted with fair accuracy from static aileron-rolling-moment tests and wing-damping tests.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., May 31, 1946

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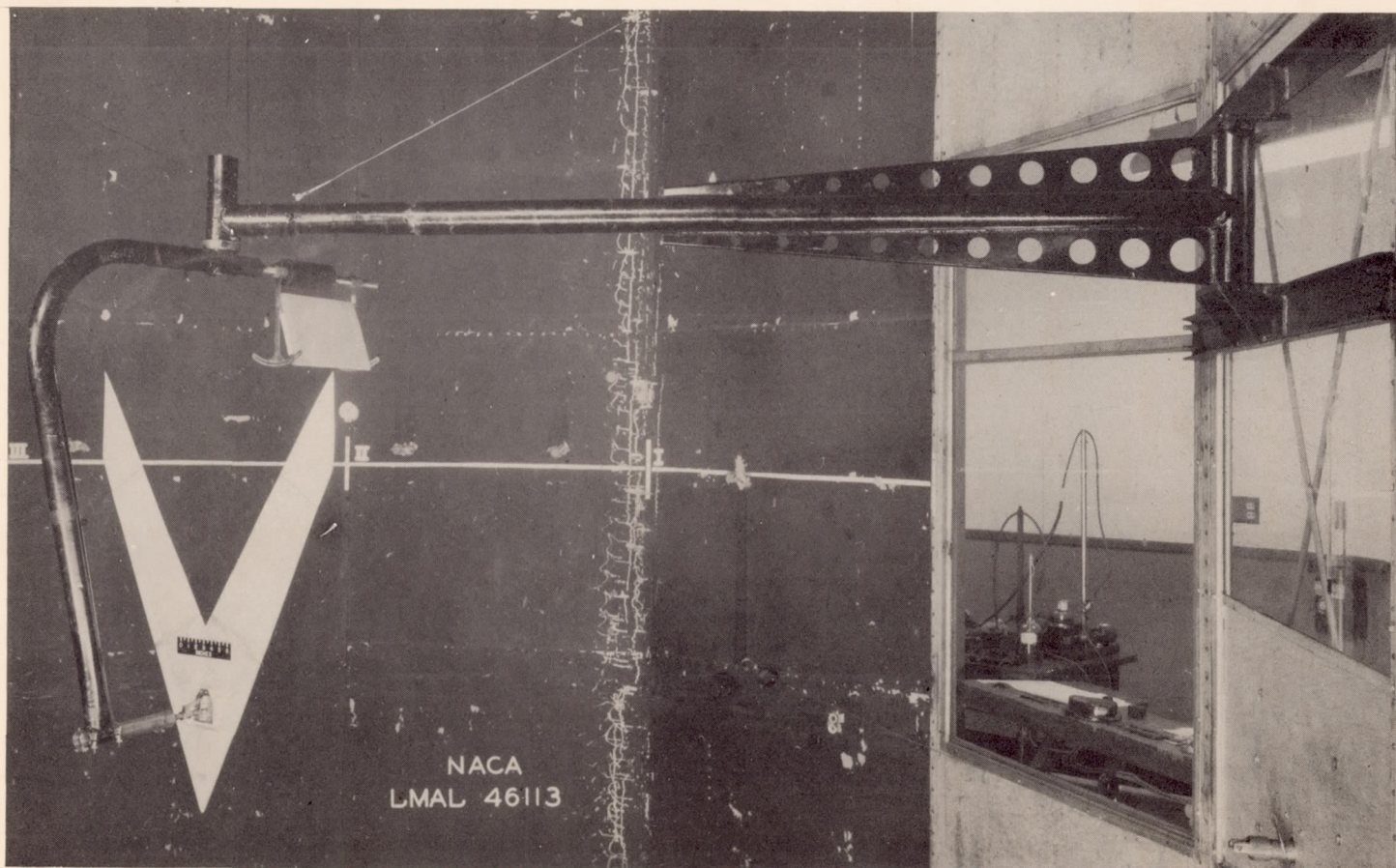
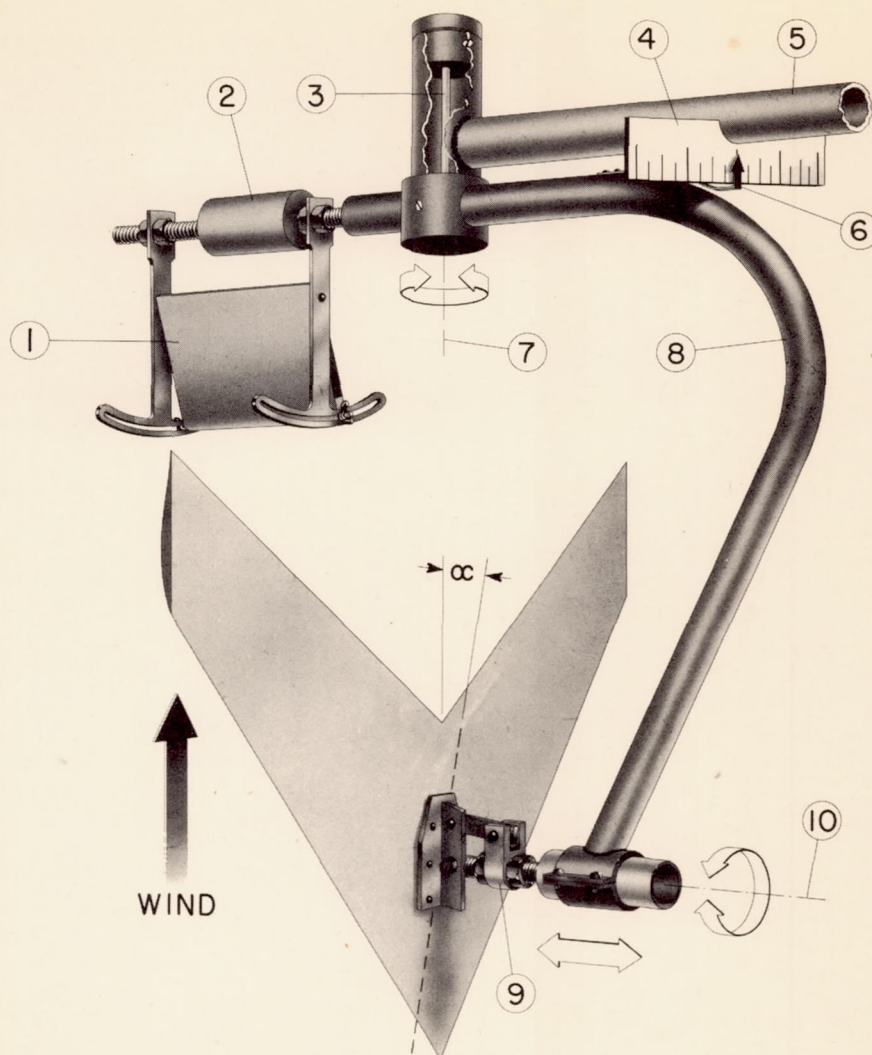


Figure 1.- Roll stand with model of wing with 62° sweepback attached, mounted in Langley 15-foot free-spinning tunnel.



- 1 Vane (to produce rolling moment)
- 2 Counterweight
- 3 Torque rod (can be mounted in this head to measure rolling moment)
- 4 Scale (for reading torque-rod deflection in static tests)
- 5 Supporting arm (mounted to tunnel wall)

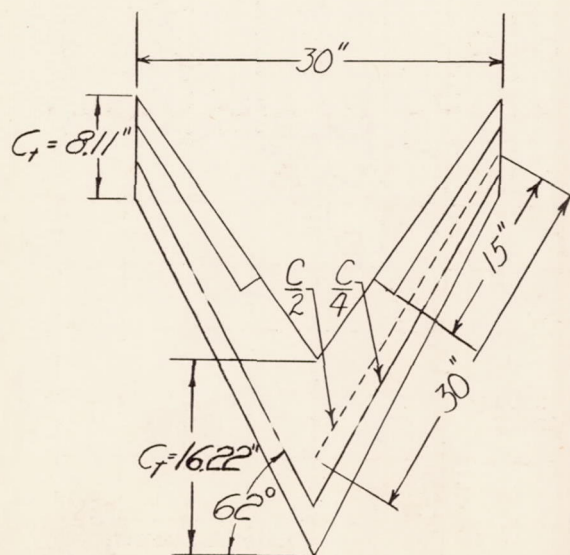
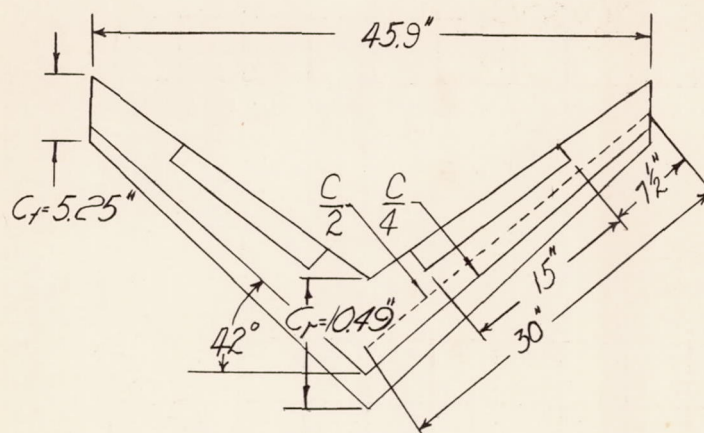
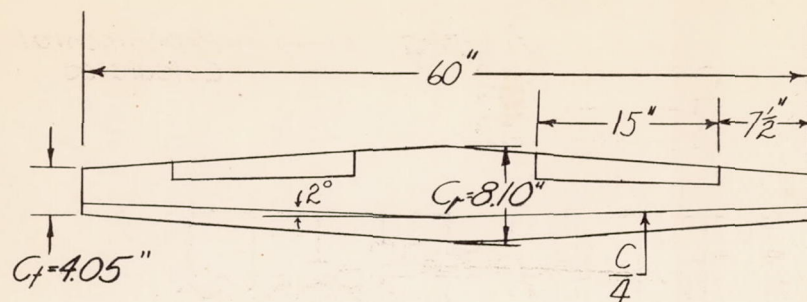
- 6 Pointer (to indicate torque-rod deflection in static tests)
- 7 Roll axis
- 8 Model support (can be free in roll or restrained by torque rod)
- 9 Mounting head (adjustable to desired angle of attack)
- 10 Yaw axis

Figure 2.- Roll bracket used to determine damping in roll and rolling moments.



It is to be understood that the present invention is not limited to the specific details herein shown, but is intended to cover all modifications and equivalents within the scope of the appended claims.

IN WITNESS WHEREOF, I have hereunto set my hand and seal this 1st day of January, 1901.



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Figure 3.- Sketch of wing plan forms used for swept-back-wing damping investigation. Ailerons, 0.30C; airfoil section on all wings, Rhode St. Genese 33, perpendicular to 0.50 chord line. (For Rhode St. Genese 33 airfoil, see reference 3.)

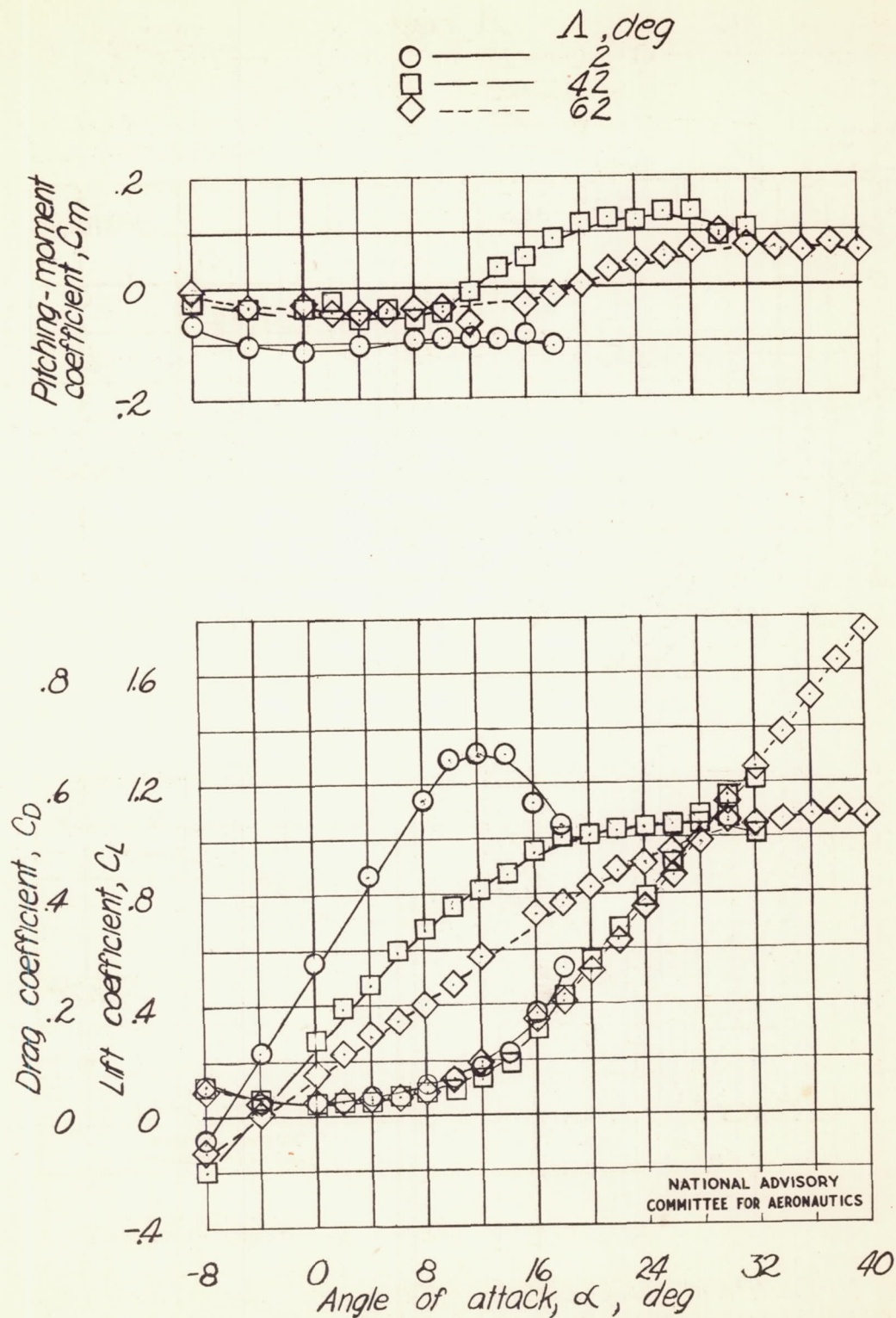


Figure 4.—Variation of lift, drag, and pitching characteristics with angle of attack of three swept-back wings as obtained from tests in Langley free-flight tunnel. $q=30$.

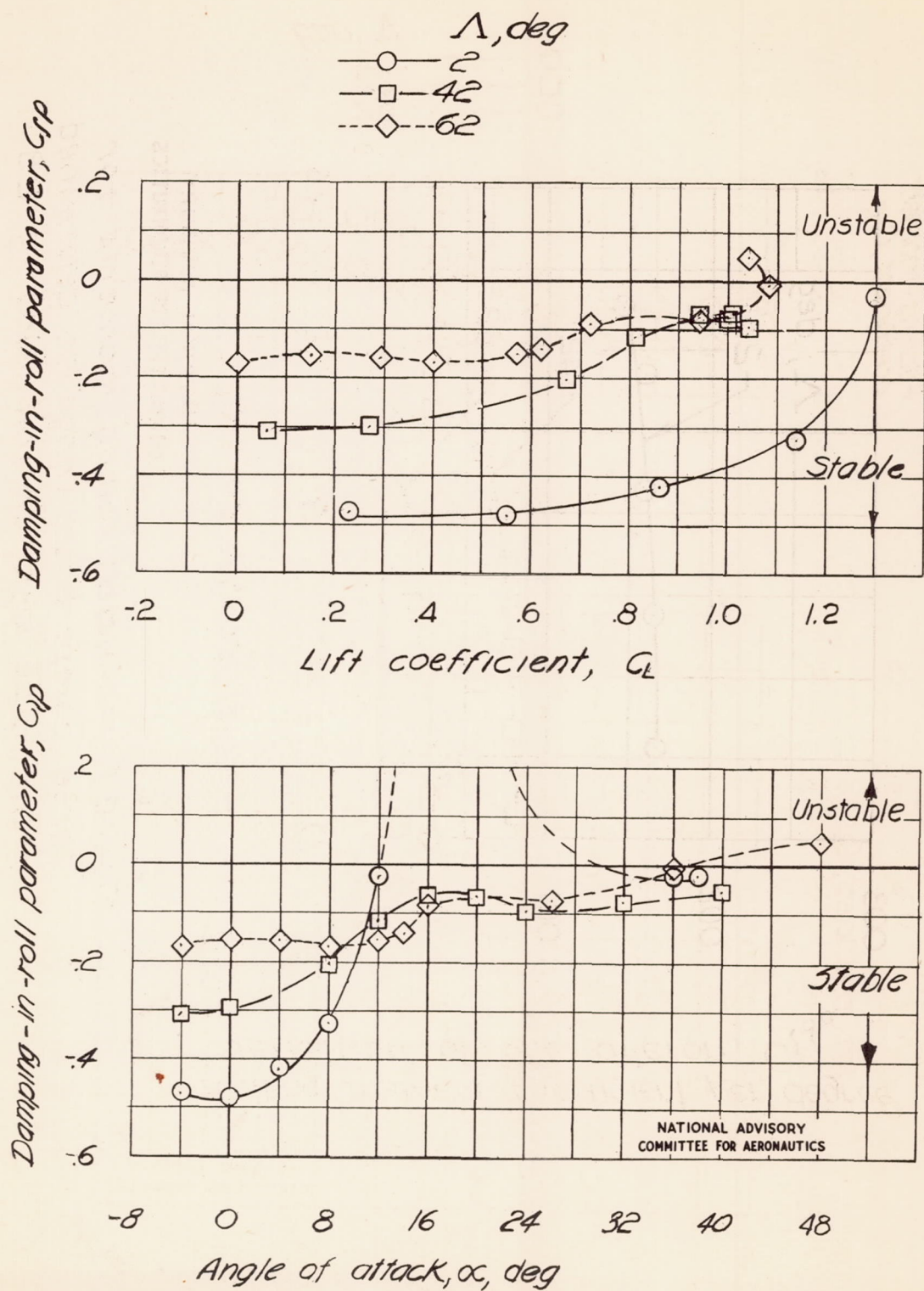
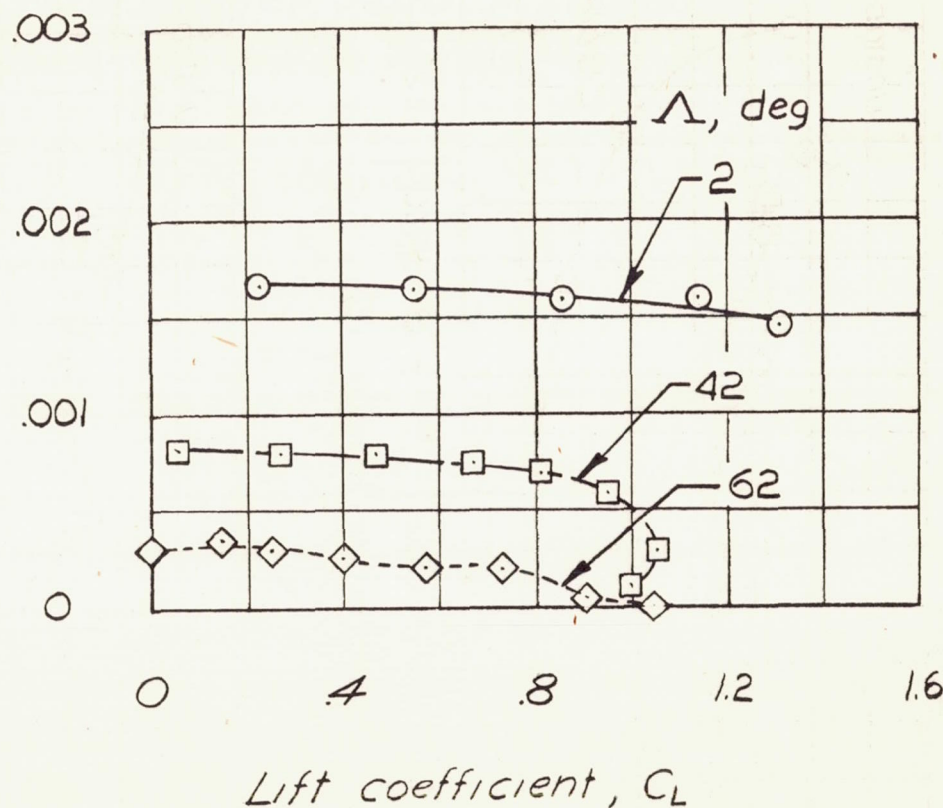


Figure 5.-Variation of the damping-in-roll parameter C_{rp} with angle of attack and lift coefficient as obtained from tests of wings having sweep back angles of 2° , 42° , and 62° ; $q=2.8$.

Rolling-moment coefficient per degree
deflection of one aileron, $C_{l_{\delta a}}$



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Figure 6. - Aileron rolling moments for three swept-back wings as determined from force tests on roll stand. $q=2.8$.

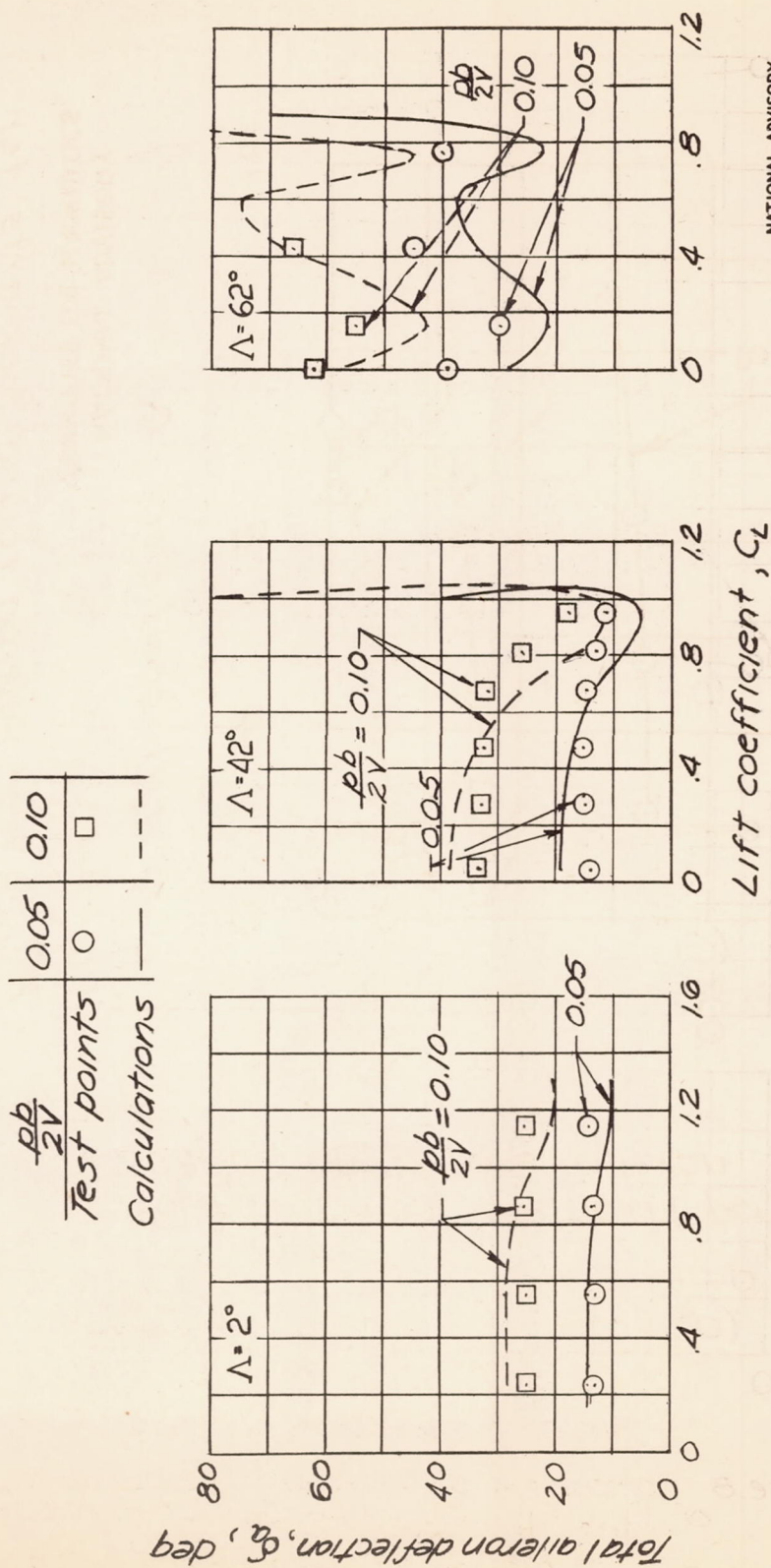


Figure 7.- Comparison of experimental and calculated aileron deflection required to produce a helix angle $\frac{pb}{2V}$ equal to 0.05 and 0.10.

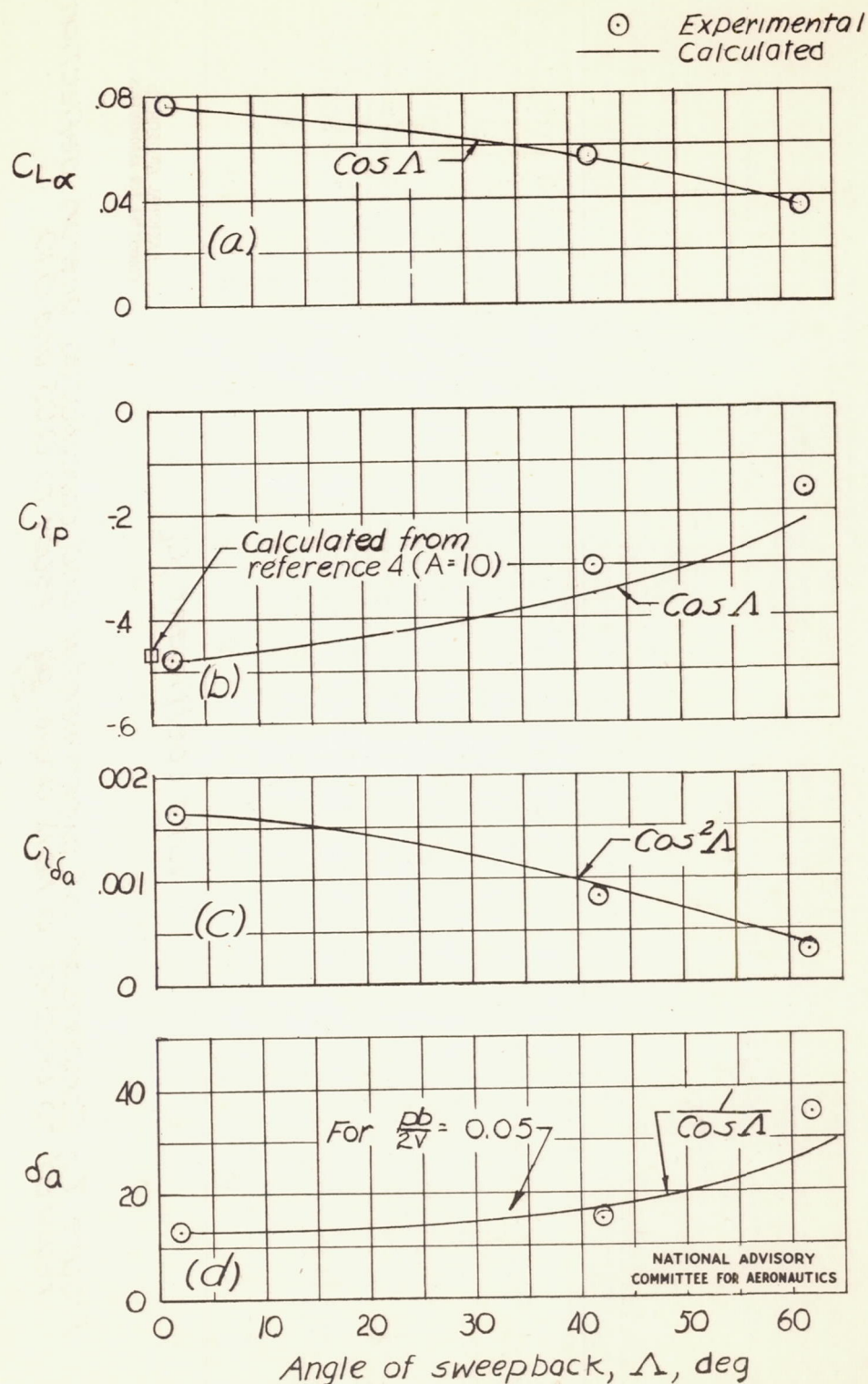


Figure 8 - Comparison of calculated and experimental values of $C_{L\alpha}$, C_{lp} , $C_{l\delta a}$, and δa for three wings with 2° , 42° , and 62° sweepback. $C_L = 0.3$.