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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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A COMPARISON OF FLIGHT-TEST RESULTS ON A SCOUT-BOMBER AIRPLANE WITH 4.7° AND WITH 10° GEOMETRIC DIHEDRAL IN THE WING OUTER PANELS

By Charles M. Forsyth and William E. Gray, Jr.

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A flight investigation of a scout-bomber airplane with 4.7° and 10° geometric dihedral in the wing outer panels has been conducted in order to obtain flight-test results pertaining to the upper limit of the wing-dihedral angle for satisfactory handling qualities. Navy specifications, which define the upper limit of dihedral, state that the rolling moment due to sideslip shall never be so great that a reversal of rolling velocity due to aileron yaw occurs during rudder-fixed aileron rolls and that the control-free lateral oscillations shall damp to 1/2 amplitude in 2 cycles. The upper limit of geometric dihedral for this airplane appears to be set by the condition at which the rolling velocity approaches zero in rudder-fixed aileron rolls at low speeds and small aileron deflections rather than by any undesirable control-free lateral oscillatory characteristics. Inasmuch as the combination of either of the two wing-dihedral configurations with the directional stability of the airplane as tested did not lead to any undesirable lateral control characteristics, a 10° dihedral angle does not appear to be excessive for this airplane; however, with dihedral angles slightly greater than 10°, the requirement that the rolling velocity should not reverse in a rudder-fixed roll would probably not be met.

The airplane with both 4.7° and 10° geometric dihedral possessed positive stick-fixed effective dihedral in all conditions tested. The increase in measured effective dihedral with the change in theoretical effective dihedral showed fair agreement with wind-tunnel test results of a $\frac{1}{5}$-scale model of the airplane.

INTRODUCTION

In order to obtain data related to the upper limit of geometric dihedral for satisfactory handling qualities of airplanes of the scout-bomber type, a flight investigation has been made at the Langley Memorial Aeronautical Laboratory of a scout bomber having 10° dihedral in the wing outer panels. Results of tests of the same airplane with 4.7° dihedral and with various tail modifications are presented in reference 1. The lateral stability characteristics of the airplane with 10° dihedral and with tail configuration 3 are compared with those obtained with 4.7° dihedral and with tail configuration 3. (See reference 1.)

SYMBOLS

V_c calibrated airspeed $\left(f_0\sqrt{\frac{2q_c}{\rho_0}}\right)$

f_0 compressibility correction at sea level

q dynamic pressure

q_c impact pressure corrected for position error

ρ mass density of air at flight conditions

ρ_0 mass density of ambient air at sea level

S wing area

δ_a total aileron deflection, degrees

β sideslip angle, degrees

g acceleration in gravitational units

p rolling velocity, radians per second

m mass

b wing span

V true airspeed, feet per second

N	yawing moment
L	rolling moment
C_n	yawing-moment coefficient $\left(\frac{N}{qSb}\right)$
C_l	rolling-moment coefficient $\left(\frac{L}{qSb}\right)$
Γ	dihedral angle of isolated unswept wing
Γ_{geom}	wing geometric-dihedral angle, degrees measured at wing leading edge
Γ_{eff}	wing effective-dihedral angle, degrees
C_{l_β}	rate of change of rolling-moment coefficient with sideslip angle, per radian $\left(\frac{dC_l}{d\beta}\right)$
C_{l_p}	rate of change of rolling-moment coefficient with helix angle, per radian $\left(\frac{dC_l}{d\frac{pb}{2V}}\right)$
μ	airplane relative density factor $\left(\frac{m}{\rho Sb}\right)$

APPARATUS

The airplane tested is a two-place, midwing, single-engine scout bomber. A three-view layout of the airplane is presented in figure 1. Pertinent details of the airplane are given in reference 2. The tail configuration used is described in reference 1. This tail configuration was used for tests with both the 4.7° and 10° dihedral configurations. A thrust-axis-level photograph of the airplane with 10° dihedral is shown in figure 2.

Standard NACA photographically recording instruments synchronized by means of a timer were used to measure the necessary quantities. Calibrated airspeed as used herein is the reading that would be given by a standard Army-Navy airspeed meter connected to a pitot-static system corrected for position error.

TESTS, RESULTS, AND DISCUSSION

The data for the configuration with 4.7° geometric dihedral in the wing outer panels were taken from reference 1 and previously unpublished data.

Comparable test results for both dihedral configurations are presented of data taken from steady sideslips, rudder-fixed aileron rolls, rudder kicks, control-free lateral oscillations, and rapid 180° turns.

Steady sideslip characteristics obtained with the airplane in the clean condition with power on at airspeeds of approximately 90 and 190 miles per hour and in the landing condition at an airspeed of about 85 miles per hour are presented in figures 3 to 5. For these conditions a measure of the dihedral effect for the two dihedral configurations can be obtained from the variation of aileron angle with sideslip angle. The following table gives a comparison of the values of $d\delta_a/d\beta$ at zero sideslip for the various flight conditions and the two dihedral configurations of the airplane:

Flight condition	$d\delta_a/d\beta$ (per deg)	
	$\Gamma_{geom} = 4.7°$	$\Gamma_{geom} = 10°$
Landing condition; $V_c \approx 85$ mph	0.27	0.83
Power for level flight; clean condition; $V_c \approx 90$ mph	.33	.89
Power for level flight; clean condition; $V_c \approx 190$ mph	.53	1.03

Time histories of rudder-fixed aileron rolls at low speeds are shown in figures 6 to 8. For the same airspeed and aileron deflection the maximum value of rolling velocity was slightly less for the airplane with 10° geometric dihedral than with 4.7° geometric dihedral. Further, the rolling velocity decreased more rapidly for the airplane with 10° geometric dihedral than with 4.7° geometric dihedral as is seen from the data presented in figure 6 (aileron deflection, approximately 2/3 full). Figure 7 shows that, with a small aileron deflection, the rolling velocity essentially maintained its peak value for the airplane with 4.7° geometric dihedral. Figure 8, however, shows that, with 10° geometric dihedral, the rolling velocity approached zero but did not reverse in low-speed rolls with rudder fixed at small aileron deflections. The Navy handling-qualities specification F-2.2 (reference 3), which states that the rolling moment due to sideslip in rudder-fixed aileron rolls shall never be so great that a reversal of rolling velocity occurs due to aileron yaw, has been met with both dihedral configurations. With a slightly greater amount of dihedral than 10°, however, it is probable that this requirement would not have been met in low-speed rolls.

Calculations show that the large dihedral effect combined with the rather low directional stability of the airplane for small sideslip angles accounts for the reduction in rolling velocity to almost zero in aileron rolls at low speeds and small aileron deflections for the 10° geometric-dihedral configuration. Unpublished wind-tunnel tests give $\frac{dC_n}{d\beta} = 0.0011$ per degree for a power-on clean condition at a speed of 109 miles per hour.

The aileron effectiveness (variation of helix angle $pb/2V$ with total aileron deflection) was measured in rudder-fixed aileron rolls for the 10° dihedral configuration in power-on flight and the results are presented in figure 9. Calculations were made to correct the aileron-effectiveness results for the rolling moment due to sideslip. The correction resulted in an increase in the variation of $pb/2V$ with total aileron deflection of about 14 percent for rudder-fixed rolls at an airspeed of 190 miles per hour and about 32 percent for rolls at an airspeed of 90 miles per hour. The sideslip angles are larger at the time of maximum rolling velocity for the low-speed rudder-fixed rolls than for the higher-speed rolls and hence the greater correction at low speeds.

As obtained in steady sideslips, the effective dihedral was calculated from the variation of $pb/2V$ with aileron deflection corrected to zero sideslip as shown in figure 9 and from the values of $d\delta_a/d\beta$ for airspeeds of 90 and 190 miles per hour in the clean condition using power for level flight. The effective dihedrals were calculated from the formula

$$\Gamma_{eff} = \frac{(57.3)^2 C_{l_p} \left(\frac{d\frac{pb}{2V}}{d\delta_a}\right)\left(\frac{d\delta_a}{d\beta}\right)}{\frac{C_{l_\beta}}{\Gamma}}$$

where values of $\frac{C_{l_\beta}}{\Gamma} = 0.74$ per radian^2 and $C_{l_p} = 0.47$ per radian are obtained from reference 4. The results are shown in the following table:

Flight condition	Γ_{eff} (deg)	
	$\Gamma_{geom} = 4.7^\circ$	$\Gamma_{geom} = 10^\circ$
Power for level flight; clean condition, $V_c = 90$ mph	2.3	6.1
Power for level flight; clean condition, $V_c = 190$ mph	3.9	7.6

Values of effective dihedral from wind-tunnel tests made in the Langley 7- by 10-foot tunnel for various amounts of wing geometric dihedral in the outer panels and the previously mentioned flight values for the test airplane are presented in figure 10 as the variation of measured effective dihedral with theoretical effective-dihedral angle. The $\frac{1}{5}$-scale wind-tunnel model of the airplane was tested with the tail removed and the effective dihedral was calculated by dividing the value of C_{l_β} obtained from the tunnel by C_{l_β}/Γ as obtained from reference 4. The theoretical effective-dihedral angle is defined as the constant geometric-dihedral angle from wing root to tip that would give the same values of C_{l_β} as a wing having the dihedral varied along the span. The theoretical effective-dihedral angles were obtained from reference 4. These theoretical values are for an isolated wing having a plan form and dihedral configuration of the test airplane. With 1.7° geometric dihedral in the inner panel and 4.7° and 10° in the outer panel, the theoretical effective-dihedral values would be 4.2° and 8.5°, respectively. The flight and wind-tunnel values of the variation of measured effective dihedral with theoretical effective dihedral show fair agreement (fig. 10).

Data obtained in rudder kicks are shown in figures 11 to 13. These figures present a comparison of the rolling moment due to yawing in the landing condition at about 100 miles per hour, in the gliding condition at 140 miles per hour, and in the power for level-flight condition at 140 miles per hour. As expected, the rudder kicks with 10° geometric dihedral showed the largest variation of rolling velocity with rudder deflection. The pilot, however, did not consider the variation of rolling velocity with rudder deflection to be excessive with 10° geometric dihedral.

In addition to the requirement that the rolling velocity shall not reverse in rudder-fixed aileron rolls, a further criterion placing an upper limit on dihedral angle F-1.2 (reference 3) states that the control-free lateral oscillation shall damp to 1/2 amplitude in 2 cycles. Consequently, the control-free lateral oscillation was investigated in the clean, cruising power condition. In these tests the rudder was deflected, held, and then released. In order to induce a dutch-roll oscillation the tests should be conducted control fixed, but in this case the rudder had no snaking tendencies and returned to its trim position with no oscillation of the control. The results for the two dihedral configurations appear in figure 14. No appreciable lateral oscillatory differences appear between the two configurations. For the airplane with 10° geometric dihedral the number of cycles to damp to 1/2 amplitude was slightly greater at an altitude of 20,000 feet than at 10,000 feet because of the increase in the airplane relative-density factor μ with altitude. For the airplane with 4.7° geometric dihedral the number of cycles for the oscillations to damp to 1/2 amplitude was slightly less than with 10° dihedral.

Rapid 180° turns were made to determine whether the pilot would experience difficulty in coordinating the controls to avoid any oscillatory motion because of the 10° geometric dihedral. As seen from the time histories of figures 15 and 16, no such difficulty was evidenced.

Rough-air tests were made for both configurations. No appreciable difference in the handling qualities was observed upon examination of the records, and the pilot declared the airplane satisfactory for rough-air flying with 10° dihedral.

CONCLUSIONS

Flight tests of a scout-bomber airplane with 4.7° and 10° geometric dihedral in the wing outer panel led to the following conclusions concerning the effect of the two geometric-dihedral angles on the handling qualities of the airplane:

1. No unusual or undesirable lateral control characteristics were observed with the combinations of directional- and lateral-stability parameters obtained with the two dihedral angles used. It is concluded that use of as much as 10° geometric dihedral in the wing outer panel did not lead to unsatisfactory lateral control characteristics of the airplane.

2. The only limitation experienced by the airplane with 10° dihedral was in rudder-fixed aileron rolls at low speeds and small aileron deflections when the rolling velocity approached zero. Inasmuch as the specification that the rolling velocity shall not reverse in rudder-fixed aileron rolls was met, the large dihedral effect would be acceptable. However, a slight increase in geometric dihedral above the 10° used in the test might cause a reversal of rolling velocity in rudder-fixed aileron rolls.

3. The control-free lateral oscillatory characteristics of the airplane with 10° geometric dihedral were not a factor in placing an upper limit on the wing dihedral for the airplane as tested even with its rather low directional stability at small sideslip angles.

4. With both dihedral configurations, the airplane possessed positive stick-fixed effective dihedral in all conditions tested.

5. The increase in measured effective dihedral with the change in theoretical effective dihedral agreed fairly well with wind-tunnel results.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 26, 1947

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1. Crane, H. L., and Reeder, J. P.: Flight Tests of Various Tail Modifications on the Brewster XSBA-1 Airplane. III - Measurements of Flying Qualities with Tail Configuration 3. NACA MR, July 12, 1944.

2. Phillips, W. H., and Nissen, J. M.: Flight Tests of Various Tail Modifications on the Brewster XSBA-1 Airplane. I - Measurements of Flying Qualities with Original Tail Surfaces. NACA ARR No. 3F07, 1943.

3. Anon.: Specification for Stability and Control Characteristics of Airplanes. SR-119A, Bur. Aero., April 7, 1945.

4. Pearson, Henry A., and Jones, Robert T.: Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. NACA Rep. No. 635, 1938.

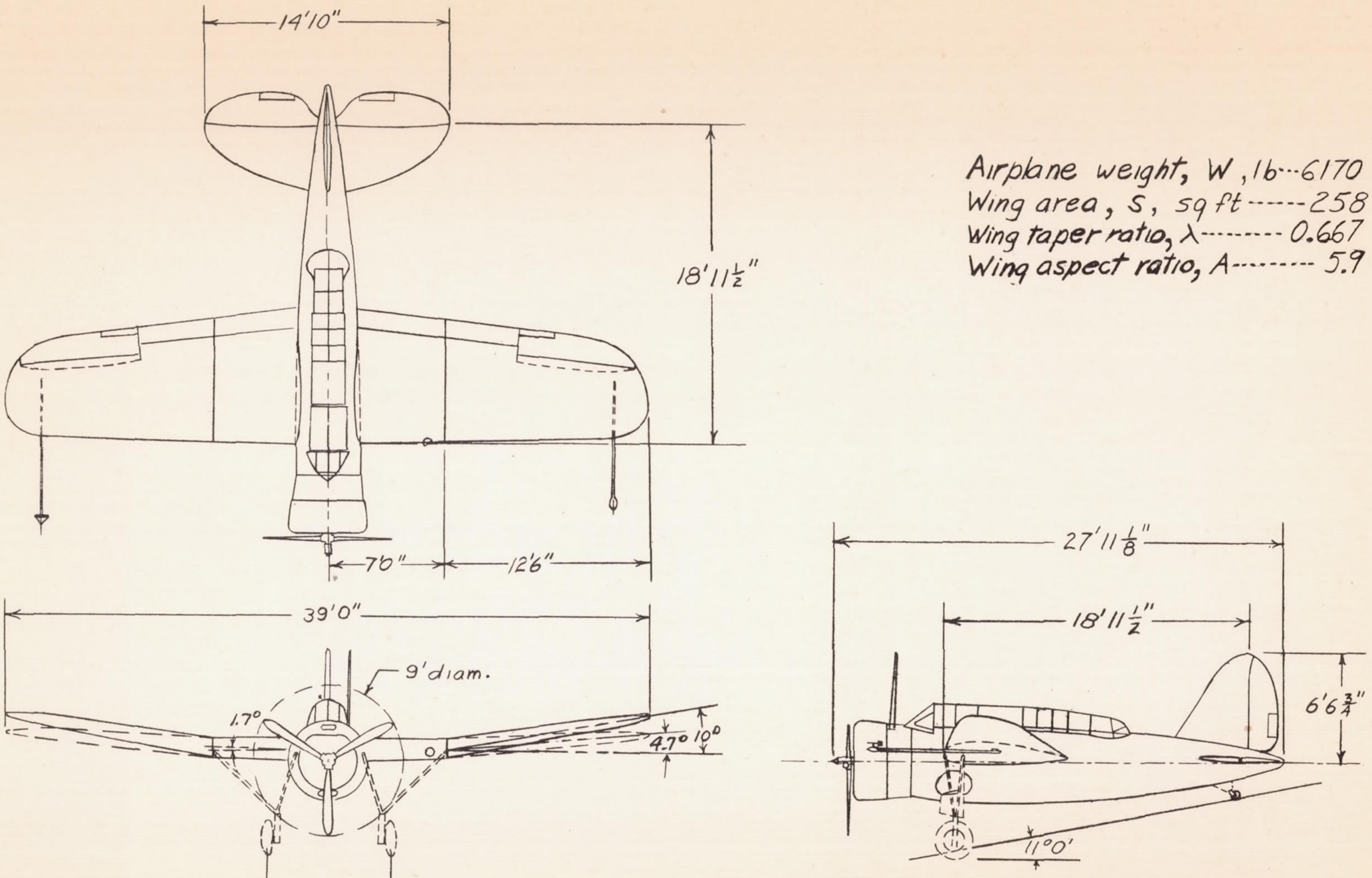

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Figure 1.- Three-view drawing of scout-bomber airplane with 4.7° and 10° geometric dihedral in wing outer panels.

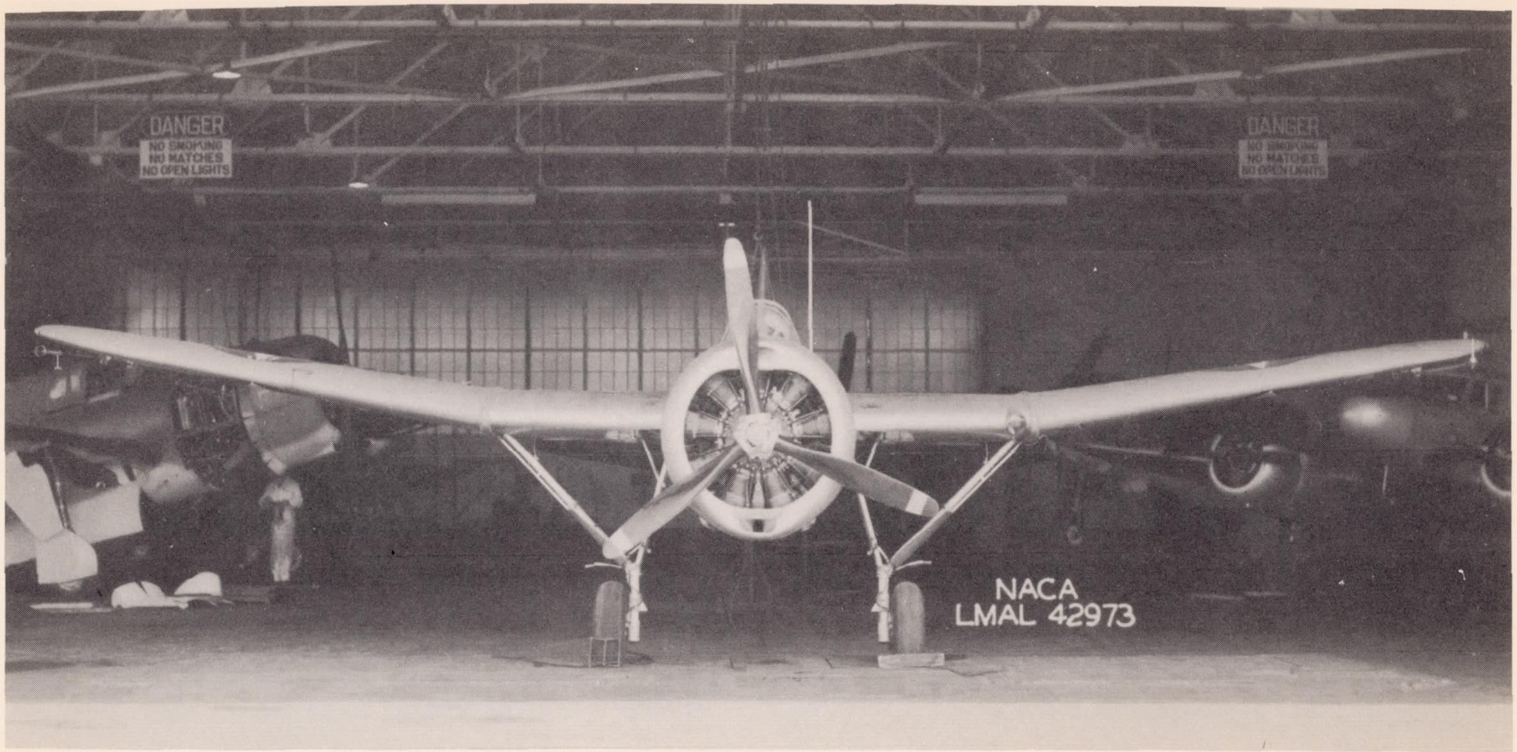
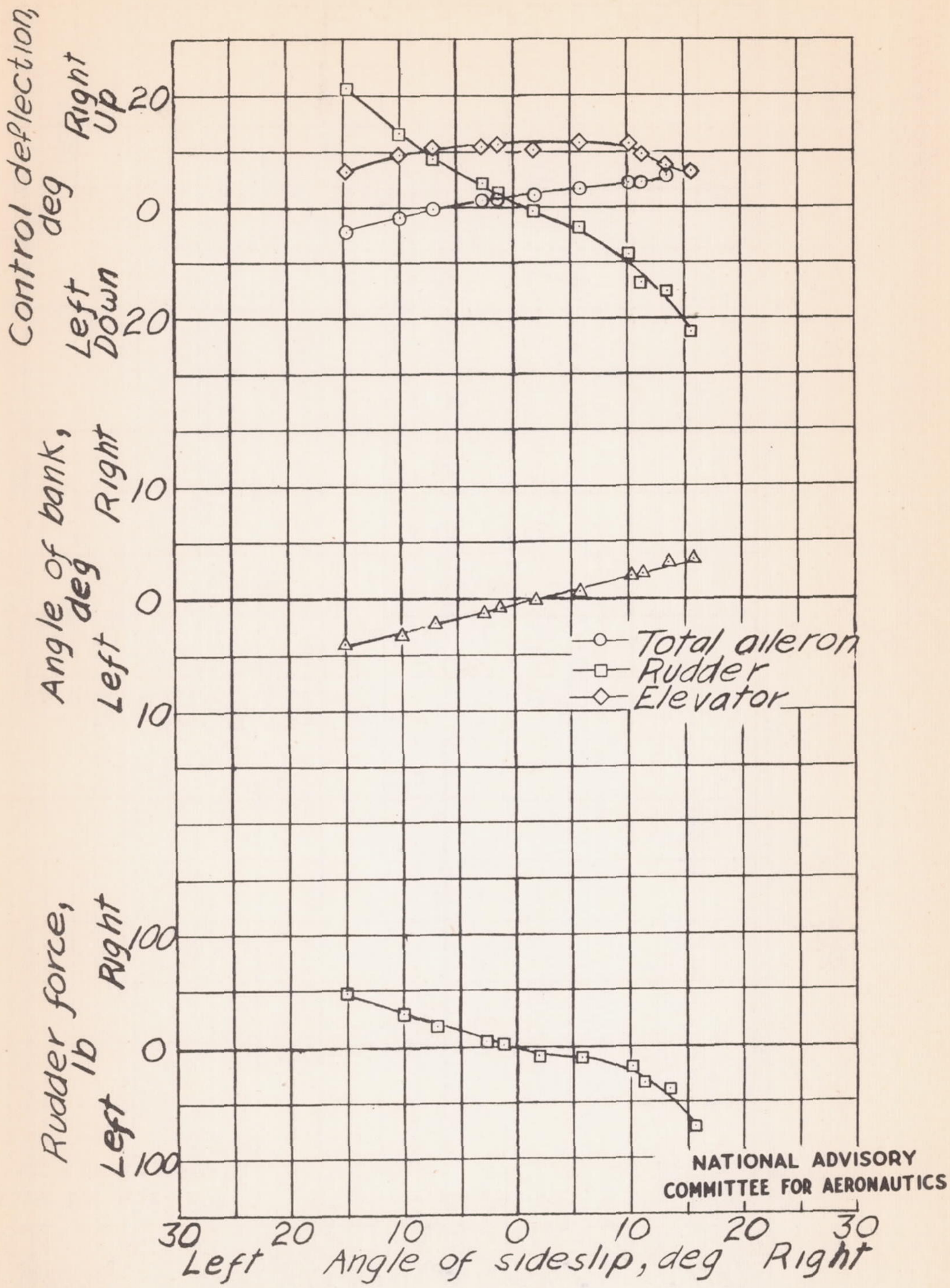
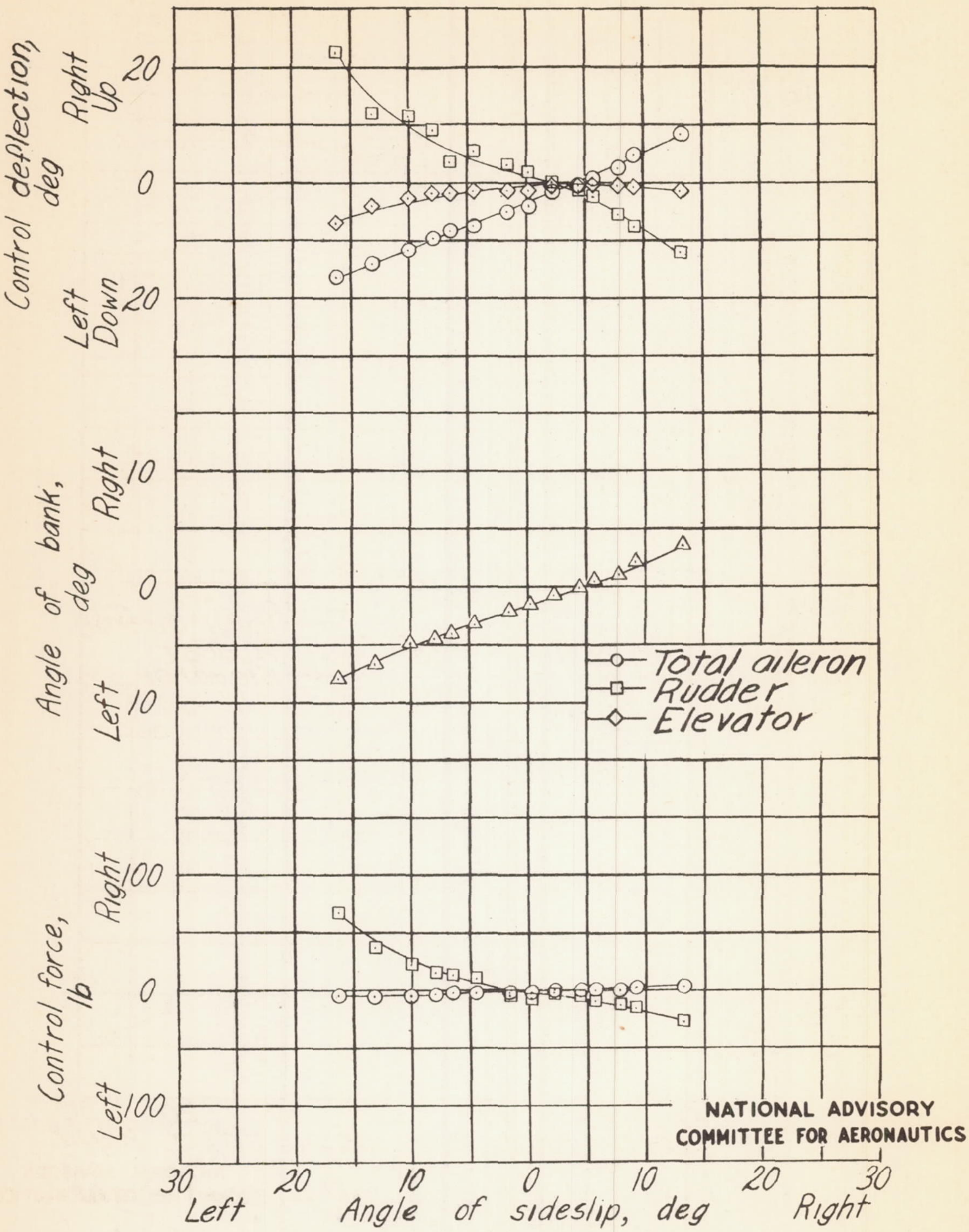


Figure 2.- Front view of test airplane with 10° geometric dihedral in wing outer panels.



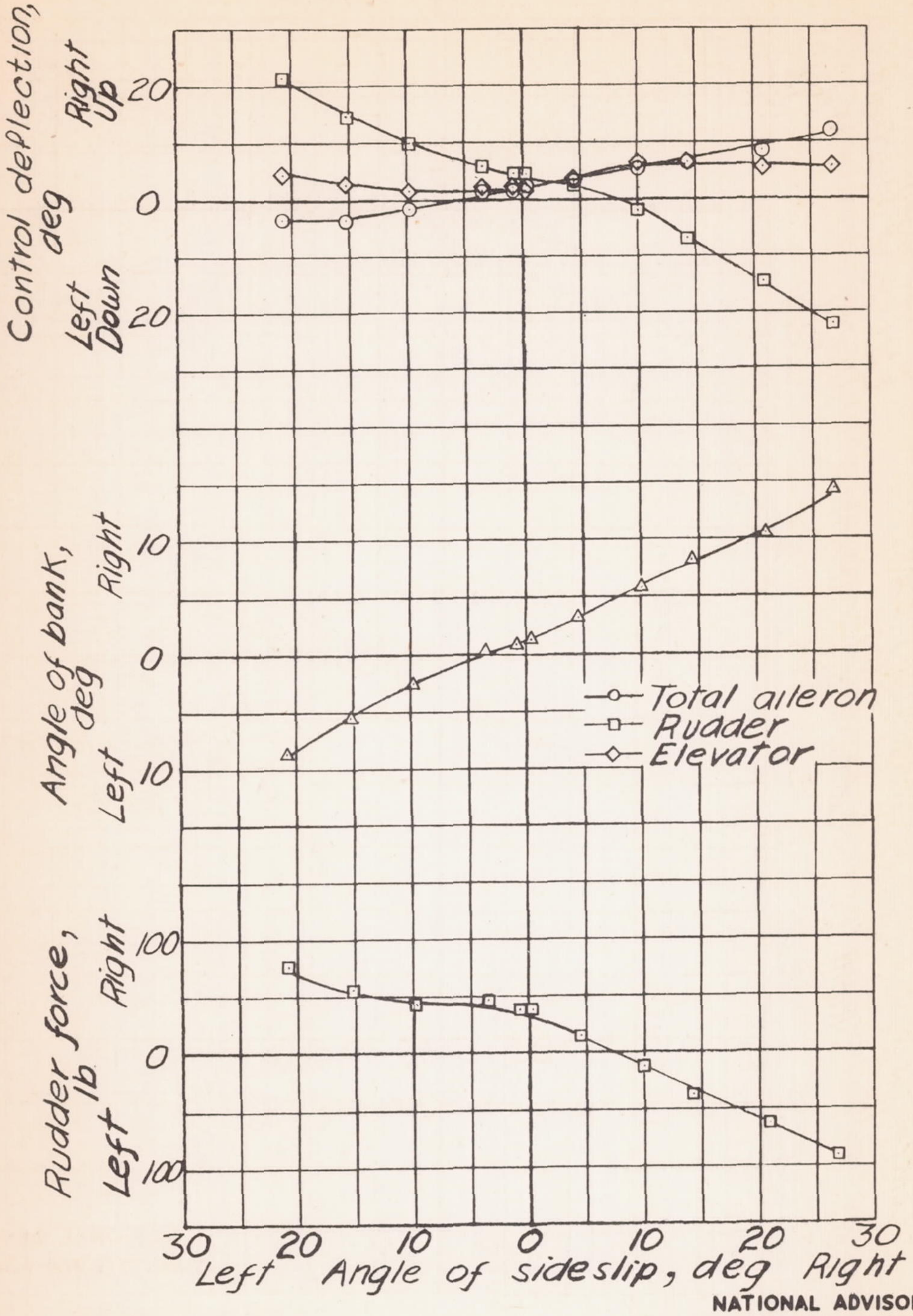
(a) $r_{geom} = 4.7^{\circ}$.

Figure 3.- Steady sideslip characteristics of scout-bomber airplane. Landing condition (flaps and landing gear down, power off); $V_c \approx 85$ miles per hour.



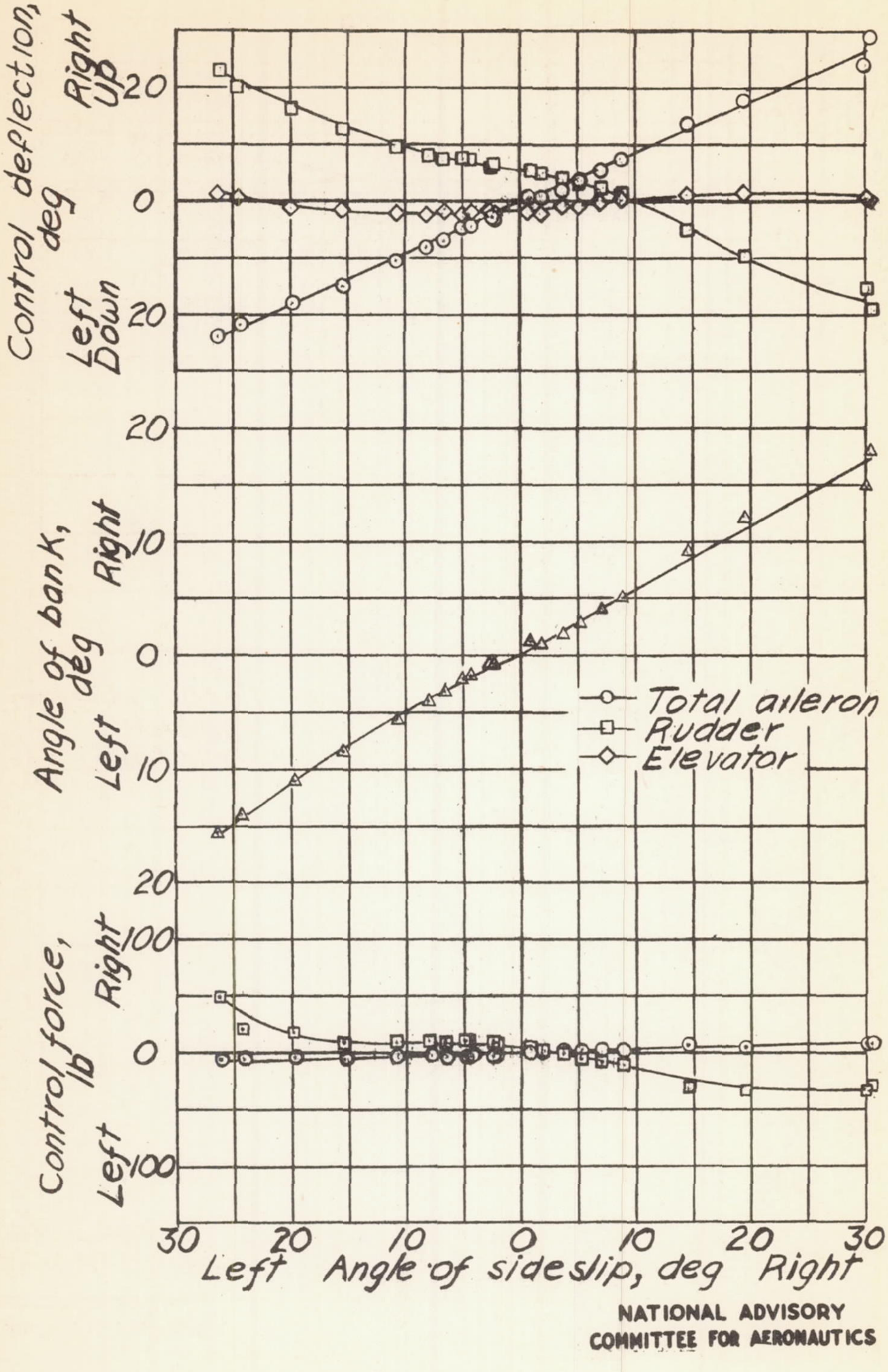
(b) $r_{geom} = 10^{\circ}$.

Figure 3.- Concluded.



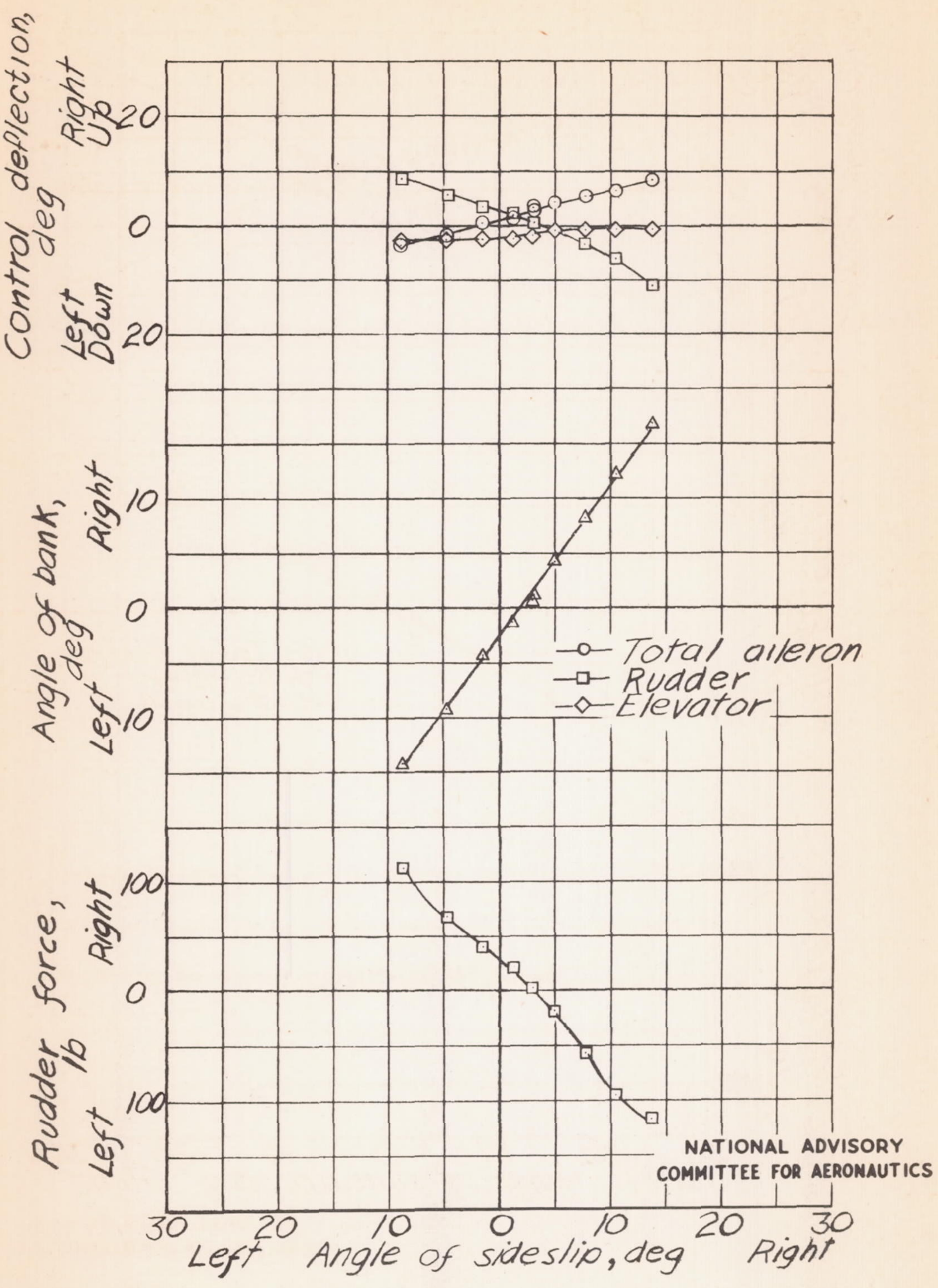
(a) $r_{geom} = 4.7^{\circ}$.

Figure 4.- Steady sideslip characteristics of scout-bomber airplane. Clean condition (flaps and landing gear up); power for level flight; $V_c \approx 90$ miles per hour.



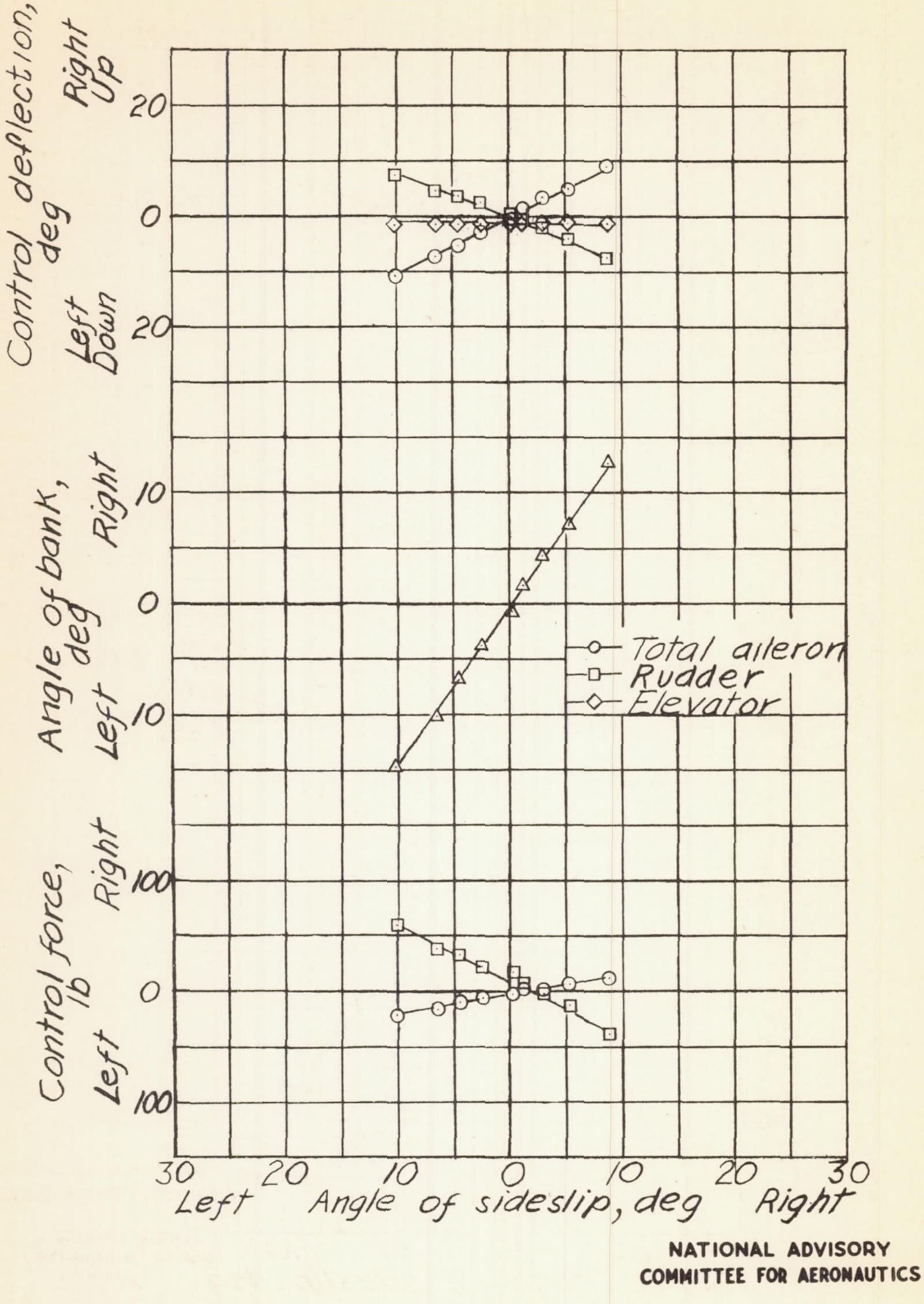
(b) $r_{geom} = 10^{\circ}$.

Figure 4.- Concluded.



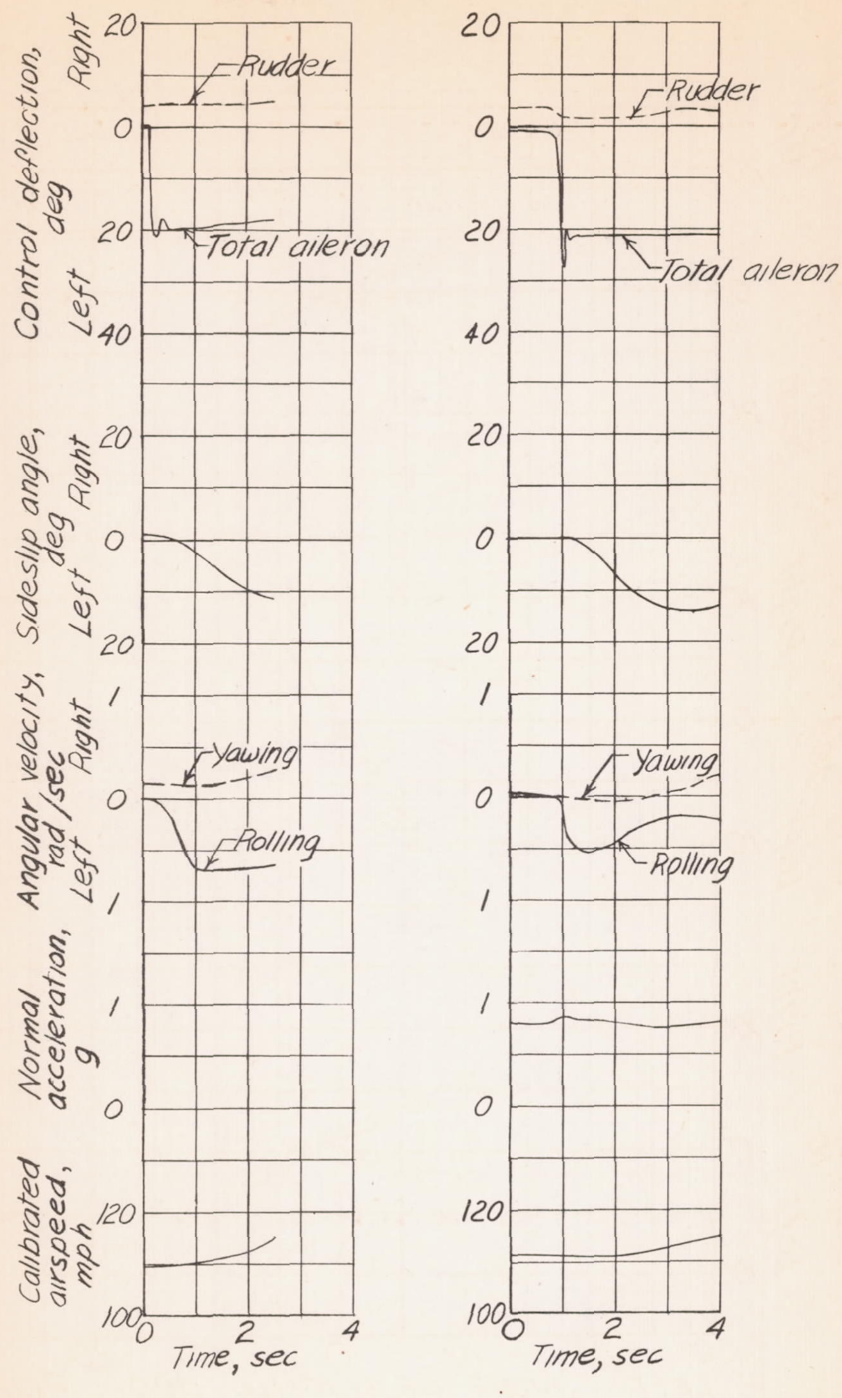
(a) $\Gamma_{geom} = 4.7^{\circ}$.

Figure 5.- Steady sideslip characteristics of scout-bomber airplane. Clean condition (flaps and landing gear up); power for level flight; $V_c \approx 190$ miles per hour.



(b) $r_{geom} = 10^{\circ}$.

Figure 5.- Concluded.



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(a) $\Gamma_{geom} = 4.7^{\circ}$.

(b) $\Gamma_{geom} = 10^{\circ}$.

Figure 6.- Time histories of scout bomber in rudder-fixed left rolls with approximately 2/3 full aileron deflection and power for level flight in clean condition.

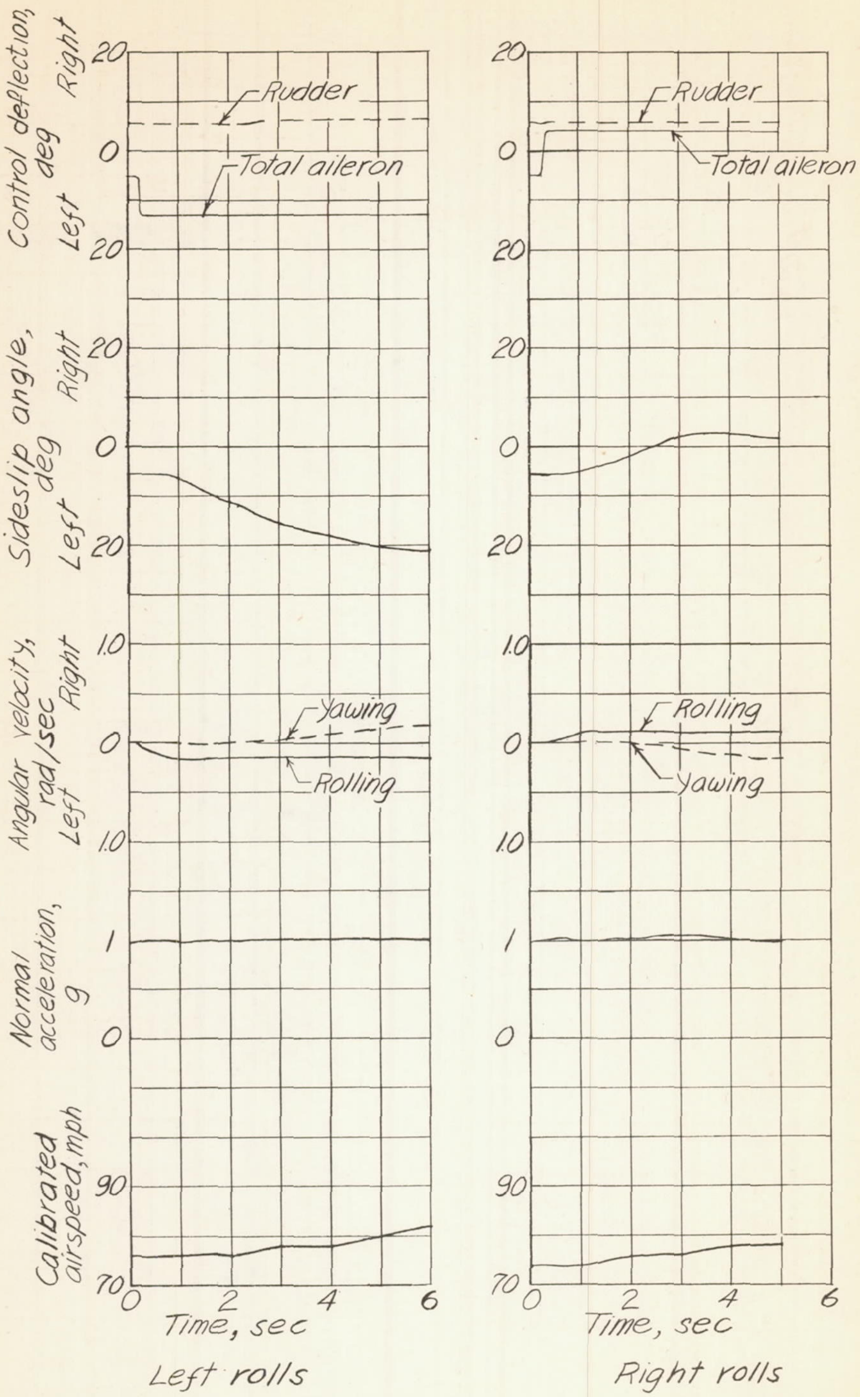

Figure 7.- Time histories of scout bomber in rudder-fixed aileron rolls with aileron partly deflected and power for level flight in clean condition. $\Gamma_{geom} = 4.7^{\circ}$.

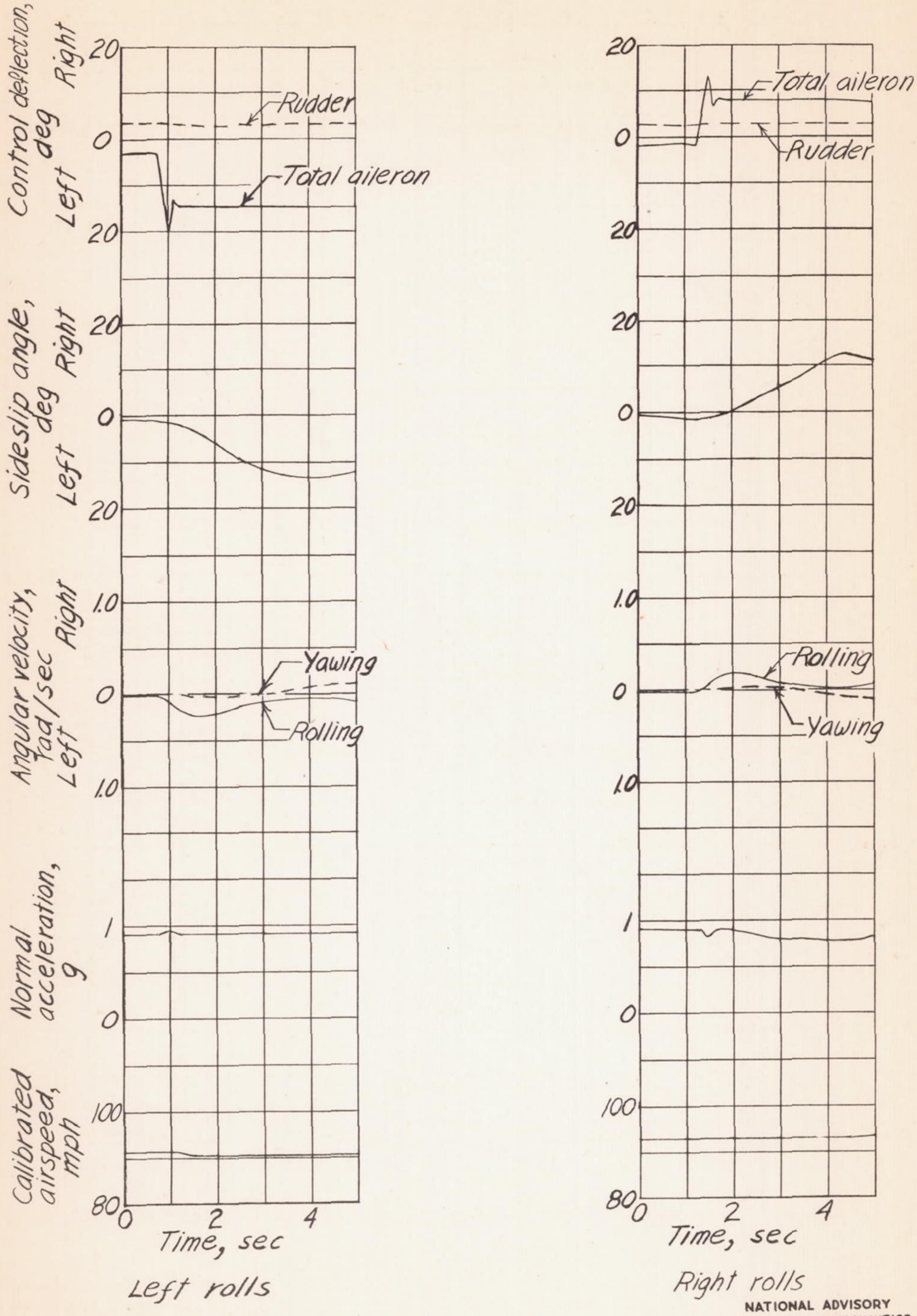

Figure 8.- Time histories of scout bomber in rudder-fixed aileron rolls with aileron partly deflected and power for level flight in clean condition. $\Gamma_{geom} = 10^{\circ}$.

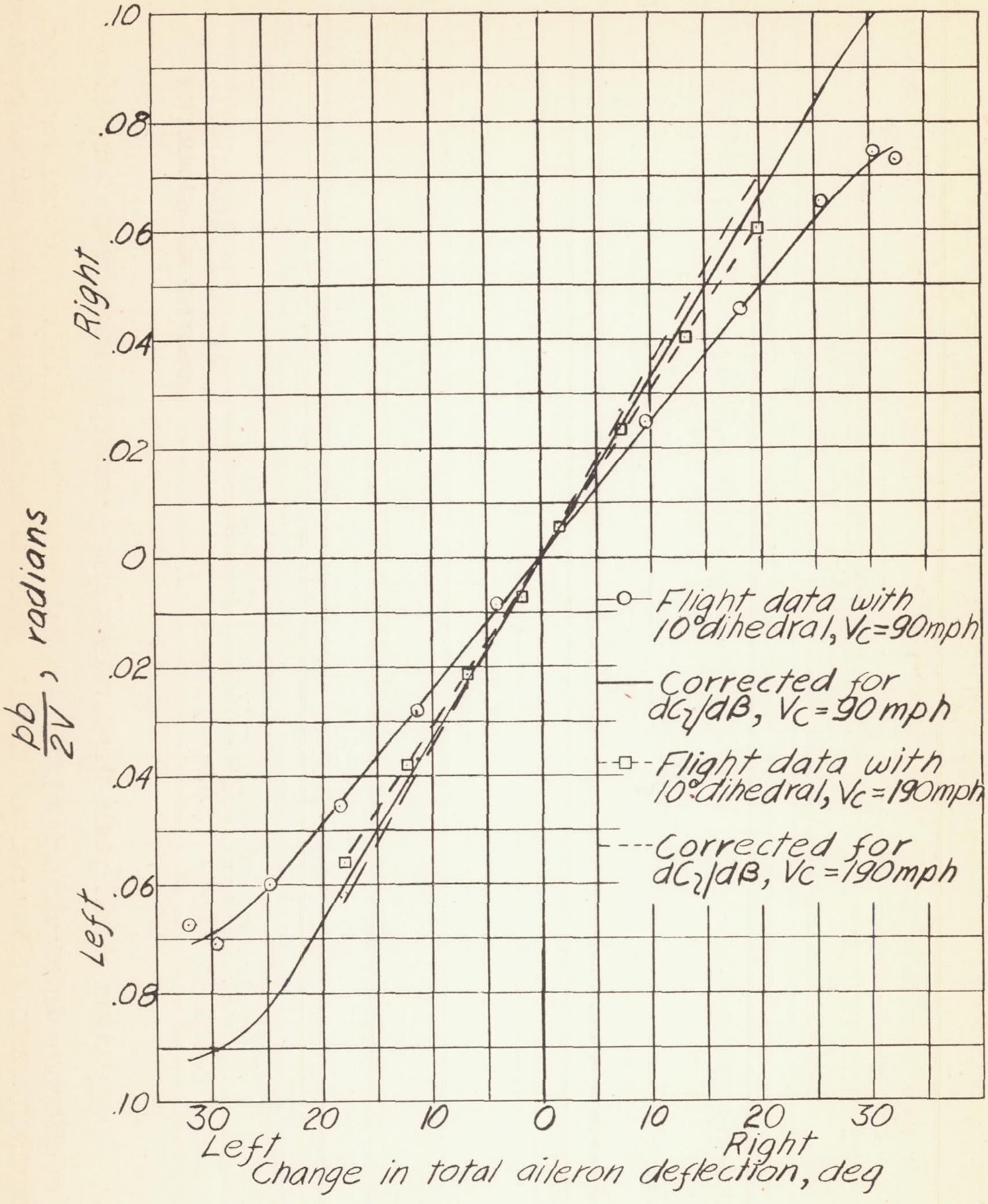

Figure 9.- Variation of helix angle pb/2V with total aileron deflection for scout bomber. Flaps and landing gear up; power for level flight; flight data for airplane with $r_{geom} = 10^{\circ}$ corrected for $dC_l/d\beta$.

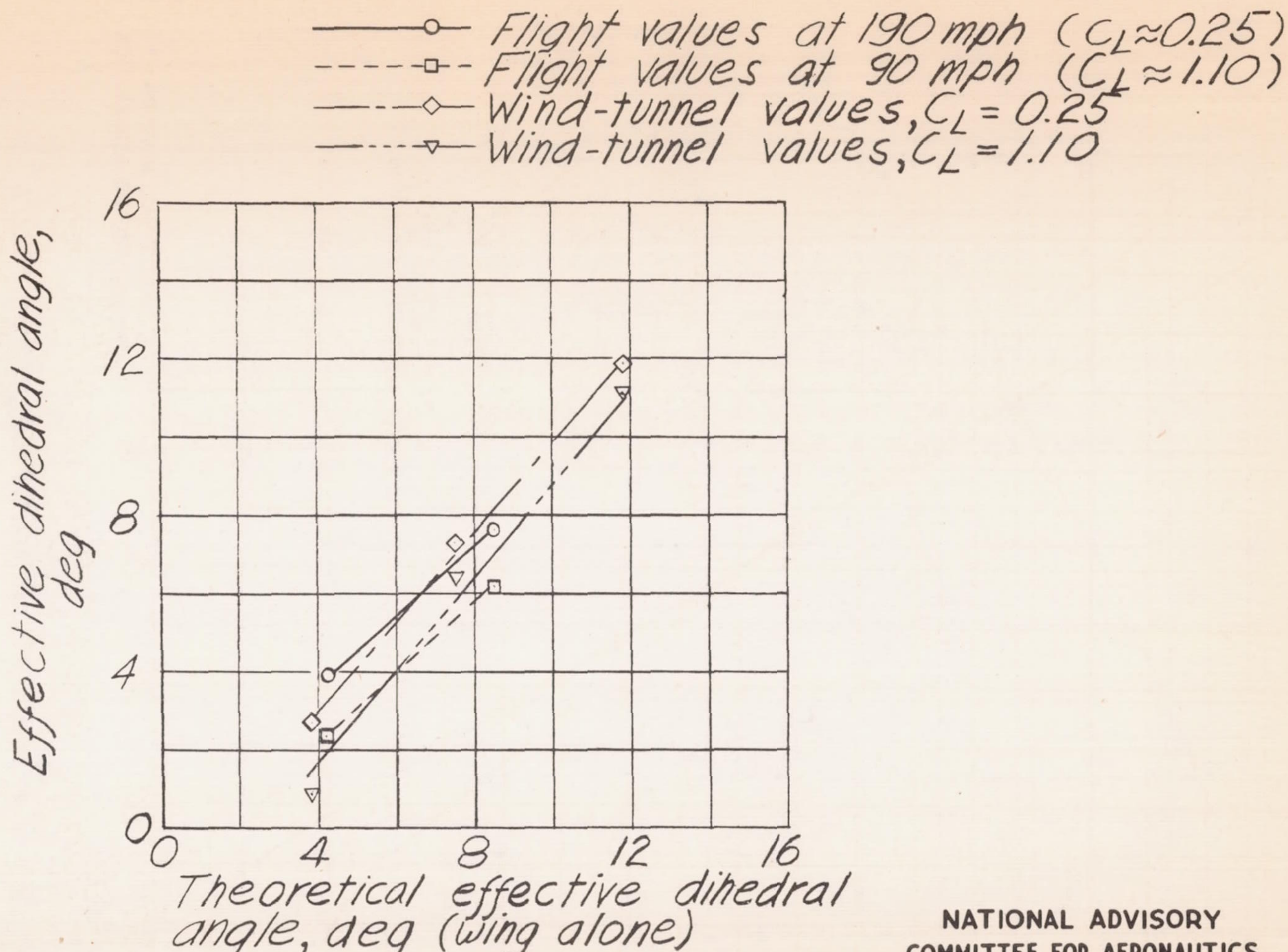

Figure 10.- Comparison of full-scale flight values and $\frac{1}{5}$-scale (tail removed) wind-tunnel values of effective dihedral angle plotted against theoretical effective dihedral angle for scout bomber tested. (Theoretical effective dihedral angle is defined as constant geometric dihedral angle from wing root to tip that would give the same value of C_{l_β} as a wing having dihedral varied along span.)

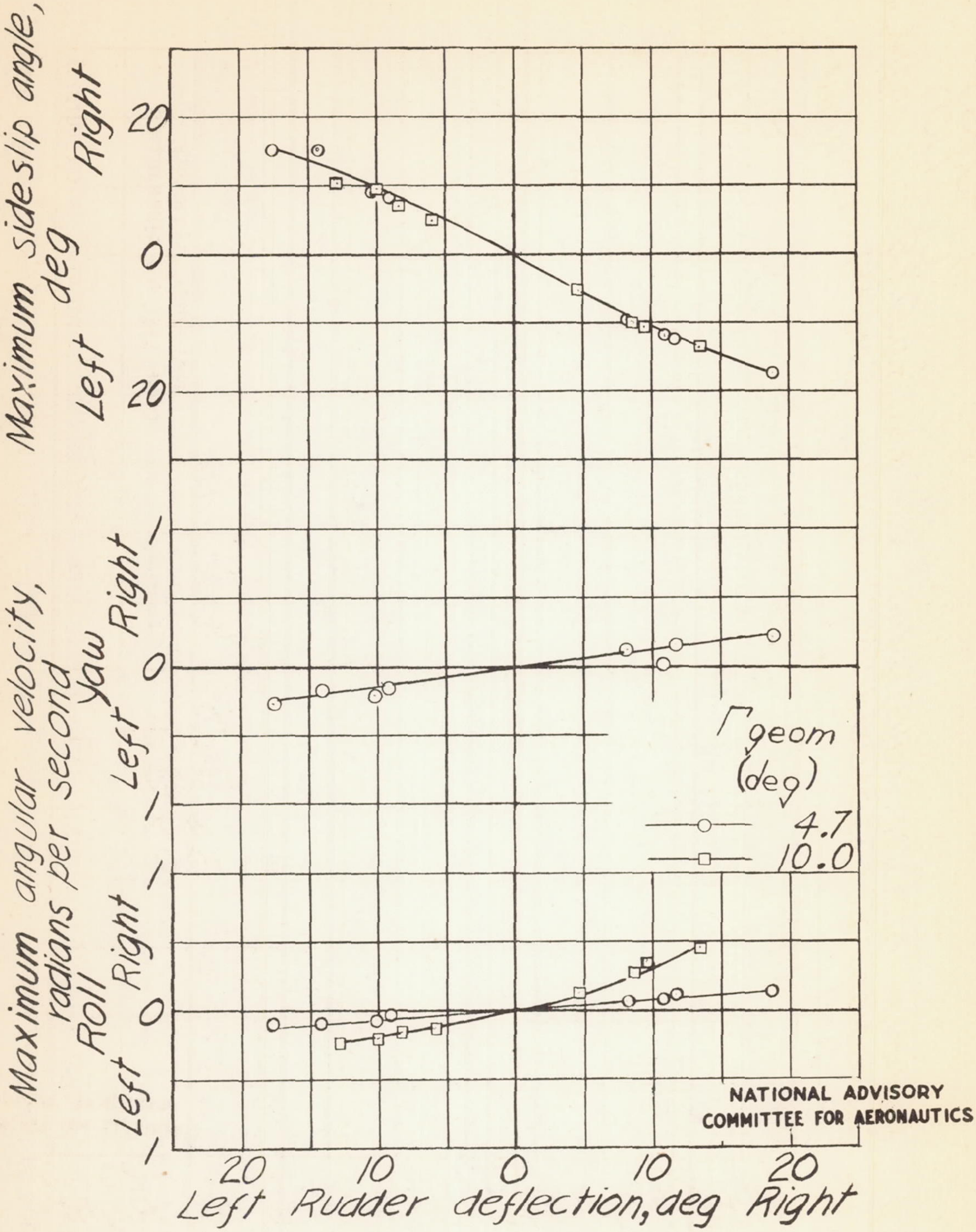

Figure 11.- Characteristics observed of scout bomber in landing condition with abrupt rudder kicks (flaps and landing gear down, power off) at an airspeed of 100 miles per hour. $\Gamma_{geom} = 4.7^{\circ}$ or 10°.

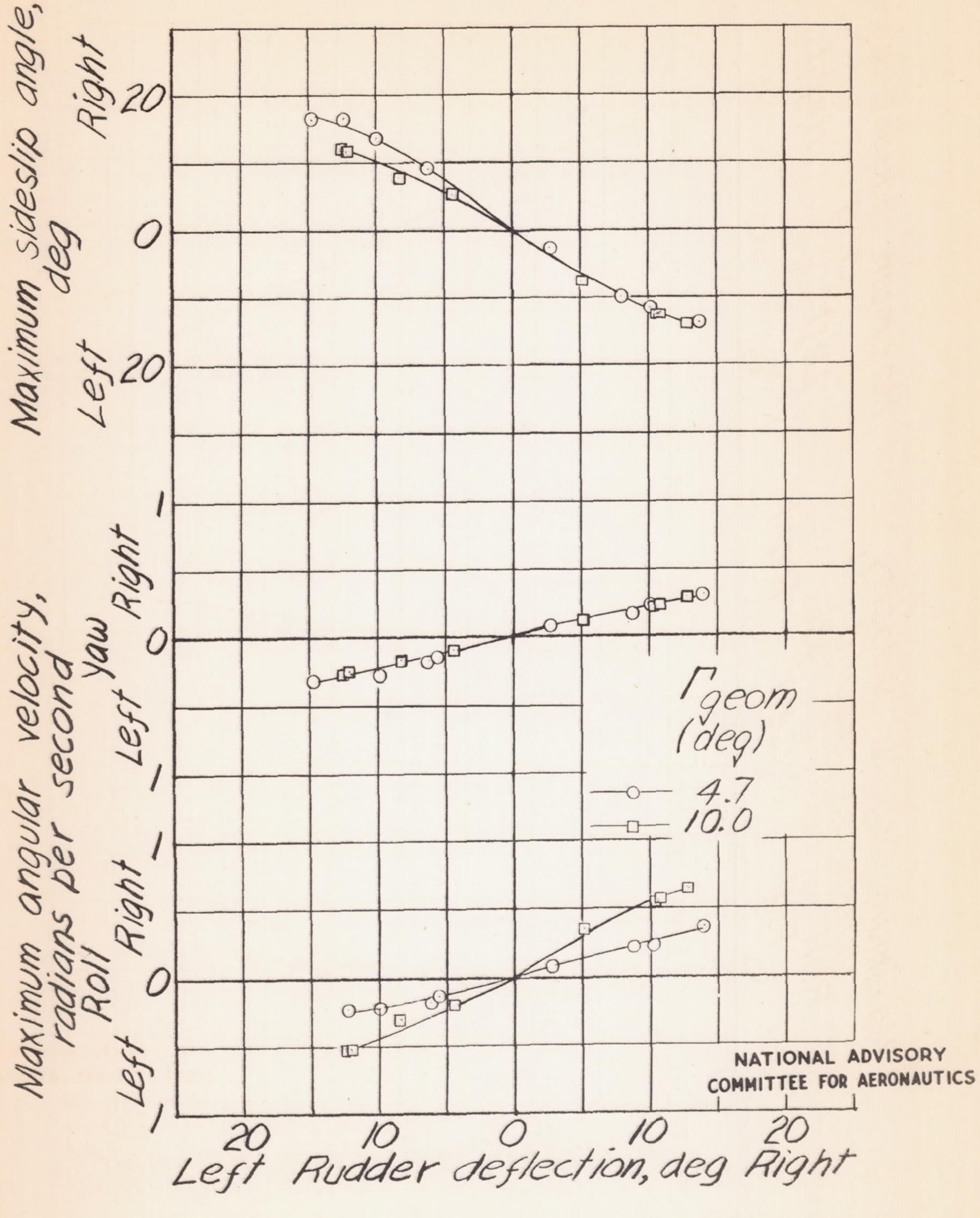

Figure 12.- Characteristics observed of scout bomber in gliding condition with abrupt rudder kicks (flaps and landing gear up, power off) at an airspeed of 140 miles per hour. $\Gamma_{geom} = 4.7^{\circ}$ or 10°.

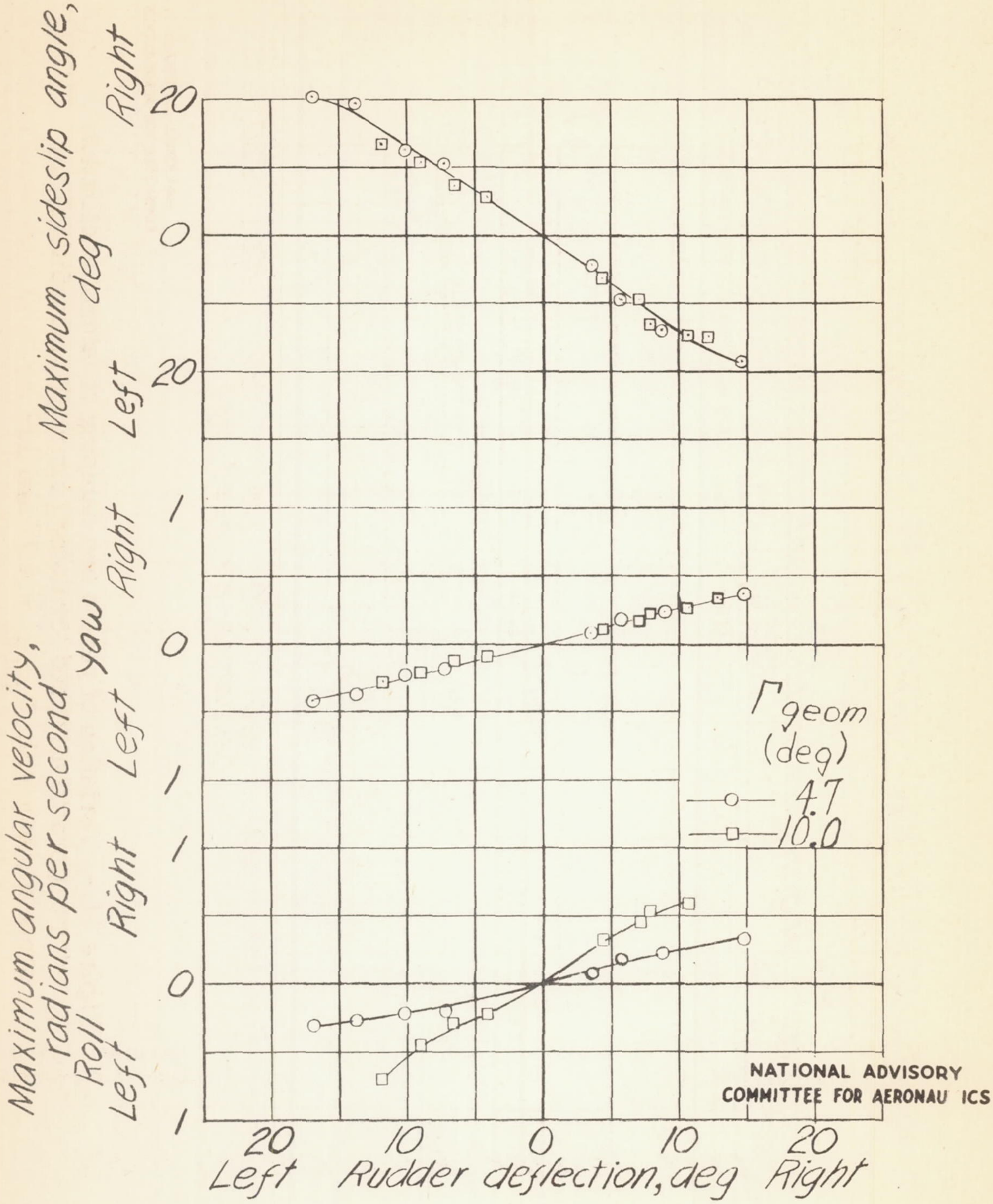

Figure 13.- Characteristics observed of scout bomber in level flight with abrupt rudder kicks at an airspeed of 140 miles per hour. $\Gamma_{geom} = 4.7^{\circ}$ or 10°.

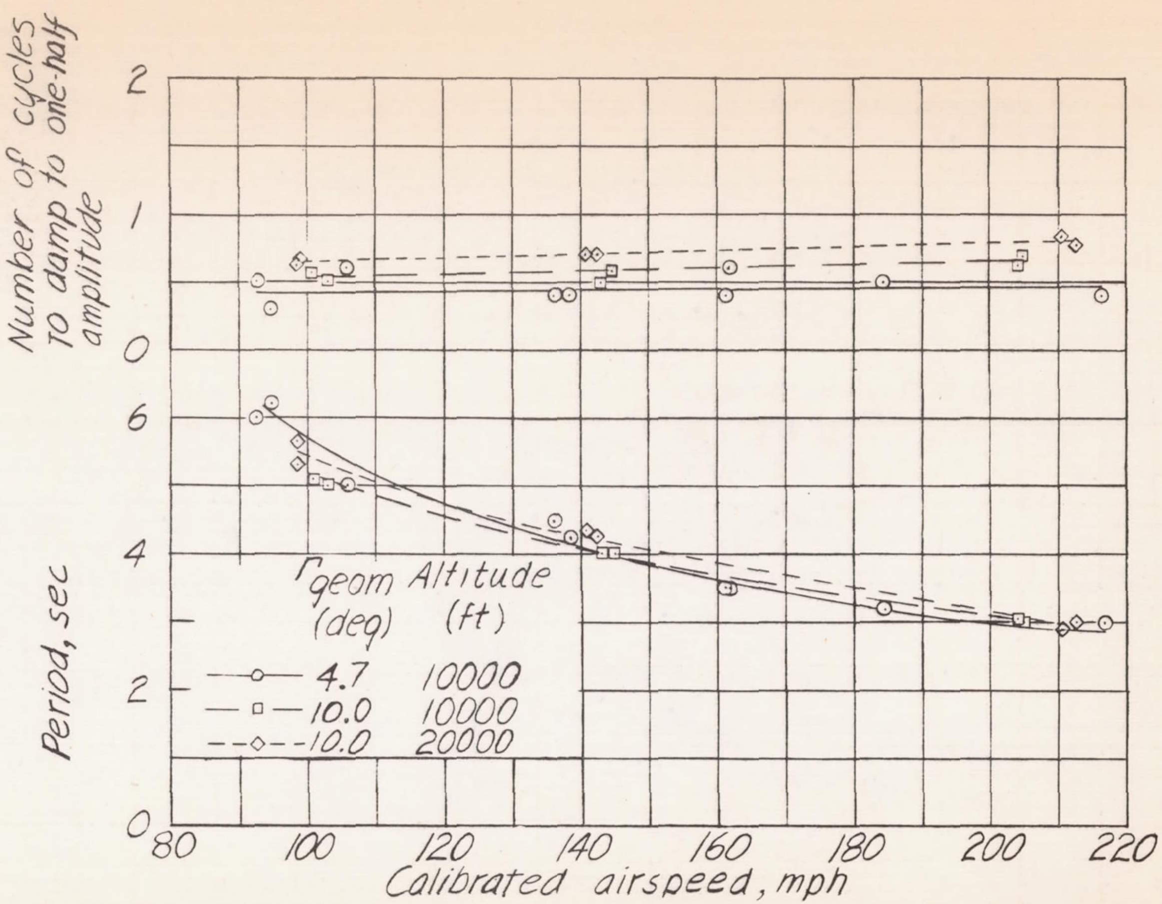

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Figure 14.- Variation of period and damping of lateral oscillation with calibrated airspeed (cruising power; clean condition) for scout bomber with $\Gamma_{geom} = 4.7^{\circ}$ and 10°.

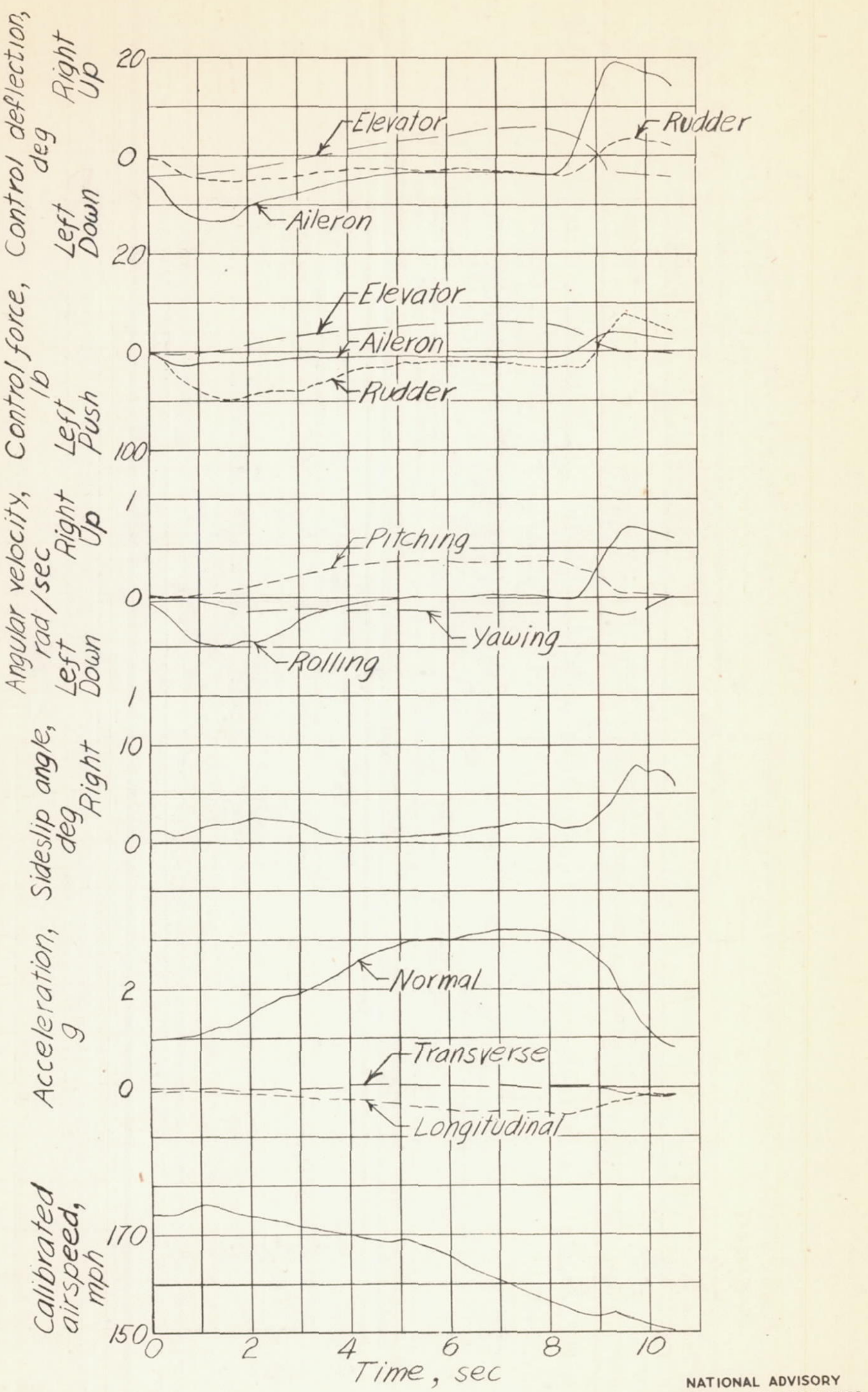

Figure 15.- Time history of scout bomber in an abrupt 180° turn at an airspeed of 174 miles per hour. $\Gamma_{geom} = 4.7^{\circ}$.

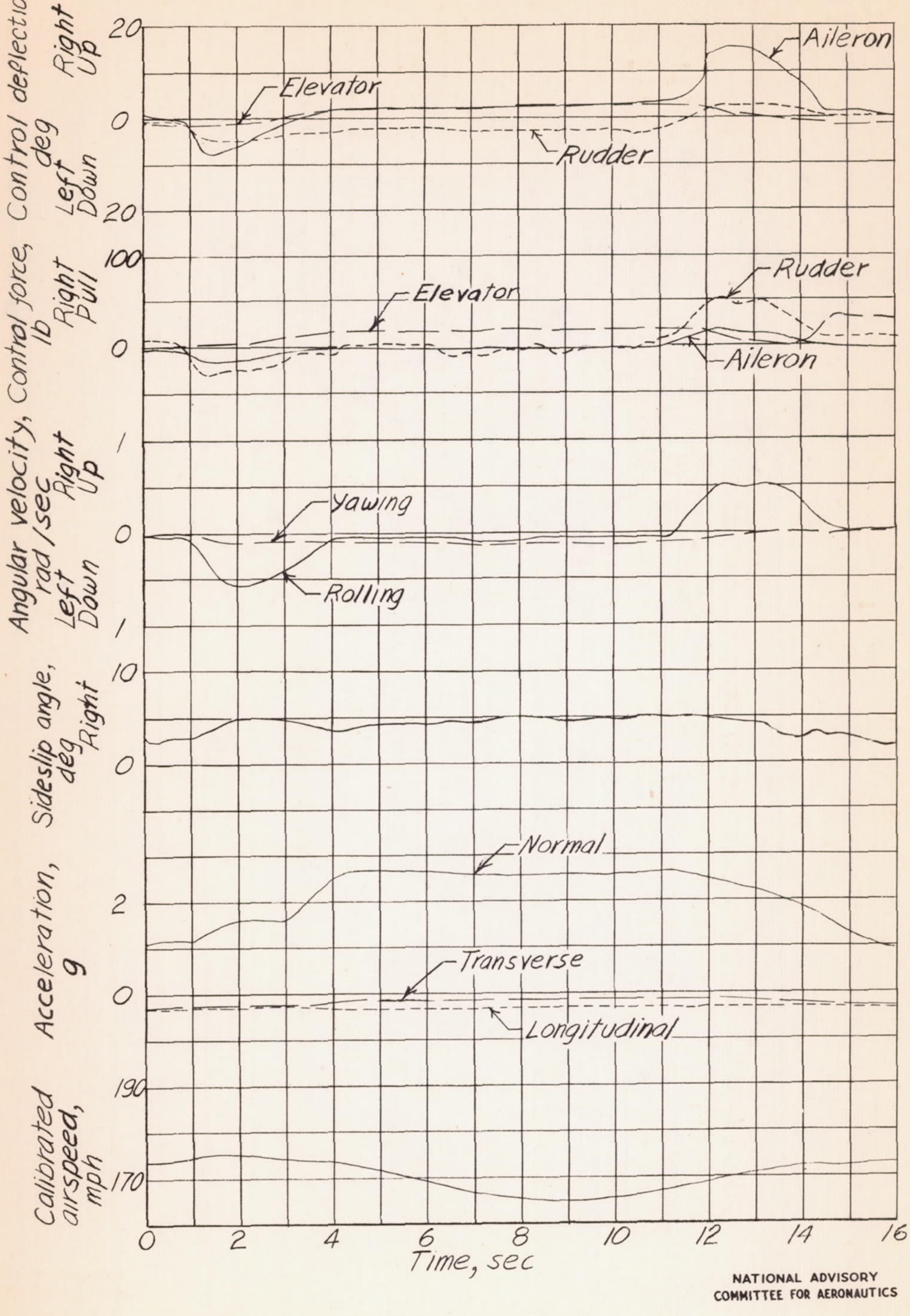

Figure 16.- Time history of scout bomber in an abrupt 180° turn at an airspeed of 174 miles per hour. $\Gamma_{geom} = 10^\circ$.