RM L50E17

RESEARCH MEMORANDUM

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LATERAL CONTROL CHARACTERISTICS AS MEASURED IN ABRUPT AILERON ROLLS AT MACH NUMBERS UP TO 0.86

By J. V. Wilmerding, W. H. Stillwell,
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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

July 20, 1950
Declassified May 8, 1957

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SUMMARY

Flight measurements were made of the lateral control characteristics of the Douglas D-558-II airplane in abrupt rudder-fixed aileron rolls. In the Mach number range from 0.50 to 0.86 the aileron rolling effectiveness is substantially constant and the rate of change of the maximum wing-tip helix angle with total aileron deflection $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ has a value of 0.0027 radian per degree. Extrapolated data indicate that in this Mach number range full aileron deflection of 30° will produce a maximum wing-tip helix angle $pb/2V$ of about 0.08 radian. As the speed is reduced below a Mach number of 0.50 a marked decrease occurs in the maximum value of $pb/2V$ obtainable with a given aileron deflection. This decrease occurs because the dihedral effect increases with decrease in speed and the adverse sideslip angles reached in the rolls at low speed are larger. At an indicated airspeed of 150 miles per hour in the landing condition, full aileron deflection will produce a maximum $pb/2V$ of 0.04 radian, which for standard sea-level conditions corresponds to a rolling velocity of 40° per second. In the opinion of the pilots this rolling velocity is sufficiently high for the landing condition with this airplane. It is the opinion of several NACA pilots that the maximum usable rolling velocity is on the order of 2.5 radians per second. In the Mach number range from 0.42 to 0.86 at an altitude of 15,000 feet rolling velocities greater than 2.5 radians per second can be obtained with less than full aileron deflection. The data indicate that in going from high to low lift coefficient the yawing moment

due to rolling changes direction. At high lift coefficients the sideslip due to roll is in the same direction as the roll (right roll produces right sideslip), but at low lift coefficients the opposite tendency is present.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting a flight research program utilizing the Douglas D-558-II (BuAero No. 37974) research airplane. The D-558-II airplanes were designed for flight research in the transonic speed range and were procured for the NACA by the Bureau of Aeronautics, Department of the Navy. The flight research program currently being conducted with the BuAero No. 37974 airplane consists of determining the stability and control characteristics and the aerodynamic loads acting on the wing and horizontal tail from the stalling speed up to a maximum Mach number of about 0.90. This paper presents the lateral control characteristics as measured in abrupt rudder-fixed aileron rolls. References 1 to 5 present results which have been obtained during the present flight research program on other aerodynamic characteristics of the D-558-II airplane.

SYMBOLS

M	Mach number
h	pressure altitude, feet
p	rolling velocity, radians or degrees per second
b	wing span, feet
V	true airspeed, feet per second
ΔF_a	change in aileron control force, pounds
$\Delta \delta_{a_T}$	change in total aileron deflection, degrees
V_c	calibrated indicated airspeed, miles per hour
$\frac{pb}{2V}$	wing-tip helix angle, radians

C_N	airplane normal-force coefficient $\left(\frac{nW}{qS}\right)$
n	normal acceleration, gravitational units
W	airplane weight, pounds
q	dynamic pressure, pounds per square foot
S	wing area, square feet
$\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$	rate of change of maximum wing-tip helix angle with total aileron deflection, radians per degree

AIRPLANE

The Douglas D-558-II airplanes have sweptback wing and tail surfaces and were designed for combination turbojet and rocket power. The airplane being used in the present investigation (BuAero No. 37974) does not yet have the rocket engine installed. This airplane is powered solely by a J-34-WE-40 turbojet engine which exhausts out of the bottom of the fuselage between the wing and the tail. Photographs of the airplane are shown as figures 1 and 2 and a three-view drawing is shown in figure 3. Pertinent airplane dimensions and characteristics are listed in table I.

Both slats and fences are incorporated on the wing of the airplane. The wing slats can be locked in the closed position, or they can be unlocked. When the slats are unlocked, the slat position is a function of the angle of attack of the airplane. Also, the slats on the left and right wings are interconnected and therefore, at any time, have the same position. A section view of the slat and the forward portion of the wing showing the motion of the slat with respect to the wing is shown in figure 4.

The airplane is equipped with an adjustable stabilizer but no means are provided for trimming out aileron or rudder control forces. No aerodynamic balance or control-force booster system is used on any of the controls. Hydraulic dampers are installed on all control surfaces to aid in preventing control-surface flutter. Dive brakes are located on the rear portion of the fuselage.

The variation of aileron position with control-wheel position is shown in figure 5, and the friction in the aileron-control system as measured on the ground under no load is shown in figure 6. The friction measurements were obtained by measuring the aileron positions and the aileron control force as the ailerons were deflected slowly. The rate of aileron deflection was sufficiently low so that the control force resulting from the hydraulic dampers in the control system was negligible.

INSTRUMENTATION

Standard NACA recording instruments were installed in the airplane to measure the following quantities: airspeed; altitude; elevator and aileron wheel forces; rudder pedal force; normal, longitudinal, and transverse accelerations; rolling, pitching, and yawing velocities; sideslip angle; stabilizer, elevator, rudder, left and right aileron, and slat positions.

Strain gages were installed in the airplane to measure wing and tail loads. The strain-gage deflections were recorded on the oscillograph. All instruments were synchronized by means of a common timer.

A free-swiveling airspeed head was used to measure both static and total pressure. This airspeed head was mounted on a boom 7 feet forward of the nose of the airplane. A vane which was used to measure sideslip angle was mounted below the same boom $4\frac{1}{2}$ feet forward of the nose of the airplane. (See fig. 1.) The indicated airspeeds and Mach numbers presented in this paper have been corrected for the position error of the airspeed head and the error due to the airspeed head itself. The method of obtaining the airspeed calibration is given in reference 3.

The left and right aileron positions were measured on bell cranks about 1 foot forward of the ailerons. The stabilizer, rudder, and elevator positions were measured on the control surfaces. The elevator positions presented were measured with respect to the stabilizer and the stabilizer position was measured with respect to the fuselage center line. All control positions were measured perpendicular to the control hinge line.

TESTS, RESULTS, AND DISCUSSION

The aileron rolling effectiveness of the D-558-II airplane was measured in rudder-fixed aileron rolls at various speeds with the airplane in both the clean and landing configurations. In the clean condition (landing gear up, flaps up, slats locked, inlet duct flaps closed) rolls were made at eight different Mach numbers in the range from 0.33 to 0.86. In the landing condition (landing gear down, flaps down, slats unlocked, inlet duct flaps open) rolls were made at indicated airspeeds of 149 to 175 miles per hour. The data were obtained in the altitude range from 12,500 to 21,000 feet.

Typical time histories of left and right aileron rolls at Mach numbers of 0.33, 0.50, and 0.86 with the airplane in the clean condition are presented in figure 7. Similar time histories of rolls at an indicated airspeed of 150 miles per hour with the airplane in the landing condition are presented in figure 8.

Inspection of the time histories indicates that in going from low to high speed or from high to low lift coefficient, the yawing moment due to rolling changes direction. In the rolls at the lowest speeds (figs. 7(a) and 8), the sideslip due to rolling is in the same direction as the rolling motion; that is, right roll produces right sideslip. With positive dihedral effect, which the D-558-II airplane has throughout the speed range tested, the sideslip tends to decrease the rolling velocity. In the rolls at a Mach number of 0.50 (fig. 7(b)) the sideslip immediately following the abrupt aileron deflection is in the same direction as the rolling motion, but as the rolling velocity increases the sideslip reverses and causes a further increase in rolling velocity. At a Mach number of 0.86 (fig. 7(c)) the sideslip immediately following the abrupt aileron deflection is in the opposite direction from the rolling motion. In the rolls at the higher Mach numbers or lower lift coefficient the sideslip angles reached are smaller and the dihedral effect is less than at low speeds, and therefore the effect of sideslip on rolling is smaller. The change in direction of the yawing moment due to rolling which occurred with change in lift coefficient is in agreement with unpublished results obtained on a model of the Douglas D-558-II airplane in the Langley stability tunnel.

From the aileron rolls previously presented as time histories and from additional aileron rolls, the aileron rolling effectiveness was evaluated in terms of the variation of maximum wing-tip helix angle $pb/2V$ and the change in aileron control force with change in total aileron deflection. Figure 9 presents the data for the various Mach numbers with the airplane in the clean condition, and figure 10 presents the data for the airplane in the landing condition. In some of the rolls, because of the favorable sideslip which accompanied the rolling motion, no definite peak occurred in the rolling-velocity curve (see fig. 7(b)). In these instances, the first maximum which occurred in the rolling velocity was used. For example, in determining the maximum $pb/2V$ for the rolls in figure 7(b), the rolling velocity at 1.5 seconds was used for the left roll and 2.5 seconds for the right roll. The aileron-control-force data of figures 9 and 10 were determined at the same times as the maximum rolling velocities. It should be noted that the peaks in the aileron-force curves, which occur when the ailerons are abruptly deflected, (see figs. 7 and 8) result from the hydraulic dampers in the control system.

At all test speeds in both the clean and the landing conditions, the variations of pb/2V and aileron control force F_a with aileron deflection are approximately linear for the entire aileron deflection range tested. The aileron control forces are light at low speeds. A control force of the order of 5 to 10 pounds is required for 15° of total aileron deflection at the lower speeds investigated in both the clean and landing conditions. At the highest Mach numbers investigated, 0.82 and 0.86, about 50 to 60 pounds of aileron force are required for 15° of total aileron deflection.

In the Mach number range from 0.50 to 0.86 the aileron effectiveness is substantially constant and the value of $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ is 0.0027 radian per degree. As a matter of general interest it is pointed out that with the D-558-I and X-1 airplanes little or no reduction in aileron effectiveness has occurred at Mach numbers up to 0.86. As the speed is reduced below a Mach number of 0.50 a marked decrease occurs in the maximum value of pb/2V obtainable with a given aileron deflection. This decrease occurs because the dihedral effect increases with decrease in speed and the adverse sideslip angles reached in the rolls at low speed are larger. At an indicated airspeed of 150 miles per hour in the landing condition, full aileron deflection will produce a maximum pb/2V of about 0.04 radian. For standard sea-level conditions this corresponds to a rolling velocity of 40° per second. Although the maximum values of pb/2V are relatively low at low speeds, in the pilot's opinion the rolling velocities are still sufficiently high. At the higher Mach numbers investigated, aileron rolls were not made using aileron deflections greater than about one-half the full deflection (15° of total aileron deflection) because the rolling velocities would be higher than desirable from the pilot's standpoint. Extrapolation of the data obtained from aileron rolls made with the smaller deflections indicates that in the Mach number range from 0.50 to 0.86 full aileron deflection will produce a maximum pb/2V of about 0.08 radian.

From the data previously presented and extrapolation of these data, the rolling velocities which could be obtained using one-half and full aileron deflection at an altitude of 15,000 feet were estimated and are presented in figure 11. In the opinion of several NACA pilots the maximum usable rolling velocity is of the order of 2.5 radians per second (about 140° per second). Inspection of figure 11 shows that at an altitude of 15,000 feet full aileron deflection will produce a rolling velocity higher than this value at Mach numbers from 0.42 to the highest Mach number investigated, 0.86. The flying-quality specifications of the Navy (reference 6) and the Air Force (reference 7) state that the minimum acceptable value of pb/2V for fighter-type airplanes is 0.09 radian with the further stipulation that the rolling velocity need never exceed 220° per second. This specification, as applied to the D-558-II airplane, is shown in figure 11. It is evident that the D-558-II airplane meets the specification at Mach numbers greater than 0.57 but does not at the lower Mach number. It should be pointed out, however, that because of the short wing span the rolling velocities encountered are high for a given value of pb/2V. The minimum requirement, as set forth on a basis of pb/2V in references 6 and 7, therefore loses some of its significance. For example, even though the maximum value of pb/2V was only 0.04 at 150 miles per hour in the landing condition, the rolling velocity was 40° per second, which the pilots considered adequate for low-speed control.

For comparison with the flight measurements an estimate has been made of the value of $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ using the design charts of reference 8 and unpublished data obtained in an investigation in the Langley stability tunnel of a model of the D-558-II airplane. The value of $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ was estimated from the formula

$$\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}} = \frac{\frac{dC_l}{d\Delta\delta_{a_T}}}{\frac{dC_l}{d\frac{pb}{2V}}}$$

A value of $\frac{dC_l}{d\Delta\delta_{a_T}} = 0.00063$ was obtained from reference 8 and the value of $\frac{dC_l}{d\frac{pb}{2V}}$ obtained from the wind-tunnel measurements was 0.28. Therefore the estimated value of $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ is 0.0023 radian per degree. At low lift coefficient where the effects of sideslip on rolling were small, the flight value of $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ was 0.0027 radian per degree. The agreement between the flight and estimated value is considered fair.

CONCLUDING REMARKS

Flight measurements were made of the lateral control characteristics of the Douglas D-558-II airplane in abrupt rudder-fixed aileron rolls. In the Mach number range from 0.50 to 0.86 the aileron rolling effectiveness is substantially constant and the rate of change of the maximum wing-tip helix angle with total aileron deflection $\frac{d\frac{pb}{2V}}{d\Delta\delta_{a_T}}$ has a value of 0.0027 radian per degree. Extrapolated data indicate that in this Mach number range full aileron deflection of 30° will produce a maximum wing-tip helix angle $pb/2V$ of about 0.08 radian. As the speed is reduced below a Mach number of 0.50 a marked decrease occurs in the maximum value of $pb/2V$ obtainable with a given aileron deflection. This decrease occurs because the dihedral effect increases with decrease in speed and the adverse sideslip angles reached in the rolls at low speed are larger. At an indicated airspeed of 150 miles per hour in the landing condition full aileron deflection will produce a maximum $pb/2V$ of 0.04 radian, which for standard sea-level conditions corresponds to a rolling velocity of 40° per second. In the opinion of the pilots, this rolling velocity is sufficiently high for the landing condition with this airplane. It is the opinion of several NACA pilots that the maximum usable rolling velocity is on the order of 2.5 radians per second. In the Mach number range from 0.42 to 0.86 at an altitude of 15,000 feet rolling velocities greater than 2.5 radians per second can be obtained with less than full aileron deflection. The data indicate that in going from high to low lift coefficient the yawing moment due to rolling changes direction. At high lift coefficients the sideslip due to roll is in the same direction as the roll (right roll produces right sideslip) but at low lift coefficients the opposite tendency is present.

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TABLE I

DIMENSIONS AND CHARACTERISTICS OF THE DOUGLAS D-558-II AIRPLANE

Wing:

Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63_1-012
Total area, sq ft	175.0
Span, ft	25.0
Mean aerodynamic chord, in.	87.3
Root chord (parallel to plane of symmetry), in.	108.5
Tip chord (parallel to plane of symmetry, in.	61.2
Taper ratio	0.565
Aspect ratio	3.570
Sweep at 0.30 chord, deg	35.0
Incidence at fuselage center line, deg	3.0
Dihedral, deg	-3.0
Geometric twist, deg	0
Total aileron area (aft of hinge), sq ft	9.8
Aileron span, perpendicular to plane of symmetry, in.	66
Aileron travel (each), deg	±15
Total flap area, sq ft	12.58
Flap travel, deg	50

Horizontal tail:

Root airfoil section (normal to 0.30 chord)	NACA 63-010
Tip airfoil section (normal to 0.30 chord)	NACA 63-010
Area (including fuselage) sq ft	39.9
Span, in.	143.6
Mean aerodynamic chord, in.	41.75
Root chord (parallel to plane of symmetry) in.	53.6
Tip chord (parallel to plane of symmetry) in.	26.8
Taper ratio	0.50
Aspect ratio	3.59
Sweep at 0.30 chord line, deg	40.0
Dihedral, deg	0
Elevator area, sq ft	9.4
Elevator travel, deg	25 up 15 down
Stabilizer travel, deg	4 L.E. up 5 L.E. down

TABLE I

DIMENSIONS AND CHARACTERISTICS OF THE

DOUGLAS D-558-II AIRPLANE - Concluded

Vertical tail:	
Airfoil section (parallel to fuselage center line)	NACA 63-010
Area, sq ft	36.6
Height from fuselage center line, in.	98.0
Root chord (parallel to fuselage center line), in.	146.0
Tip chord (parallel to fuselage center line), in.	44.0
Sweep angle at 0.30 chord, deg	49.0
Rudder area (aft of hinge line), sq ft	6.15
Rudder travel, deg	±25
Fuselage:	
Length, ft	42.0
Maximum diameter, in.	60.0
Fineness ratio	8.40
Speed-retarder area, sq ft	5.25
Power plant	J-34-WE-40 2 jatos for take-off
Airplane weight (full fuel), lb	10,645
Airplane weight (no fuel), lb	9,085
Airplane weight (full fuel and 2 jatos), lb	11,060
Center-of-gravity locations:	
Full fuel (gear down), percent mean aerodynamic chord	25.3
Full fuel (gear up), percent mean aerodynamic chord	25.8
No fuel (gear down), percent mean aerodynamic chord	26.8
No fuel (gear up), percent mean aerodynamic chord	27.5
Full fuel and 2 jatos (gear down), percent mean aerodynamic chord	29.2

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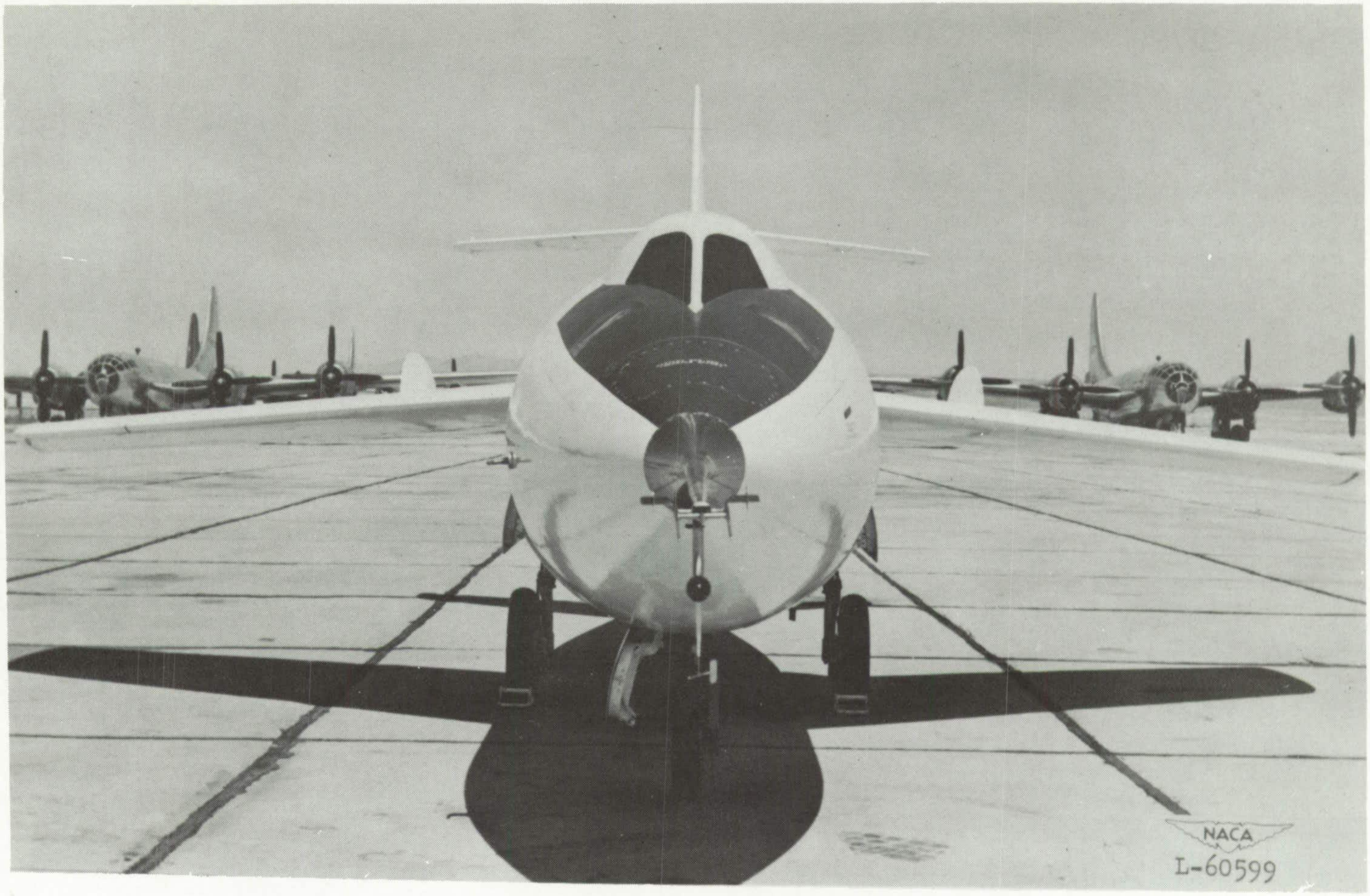

Figure 1.- Front view of Douglas D-558-II (BuAero No. 37974) research airplane.

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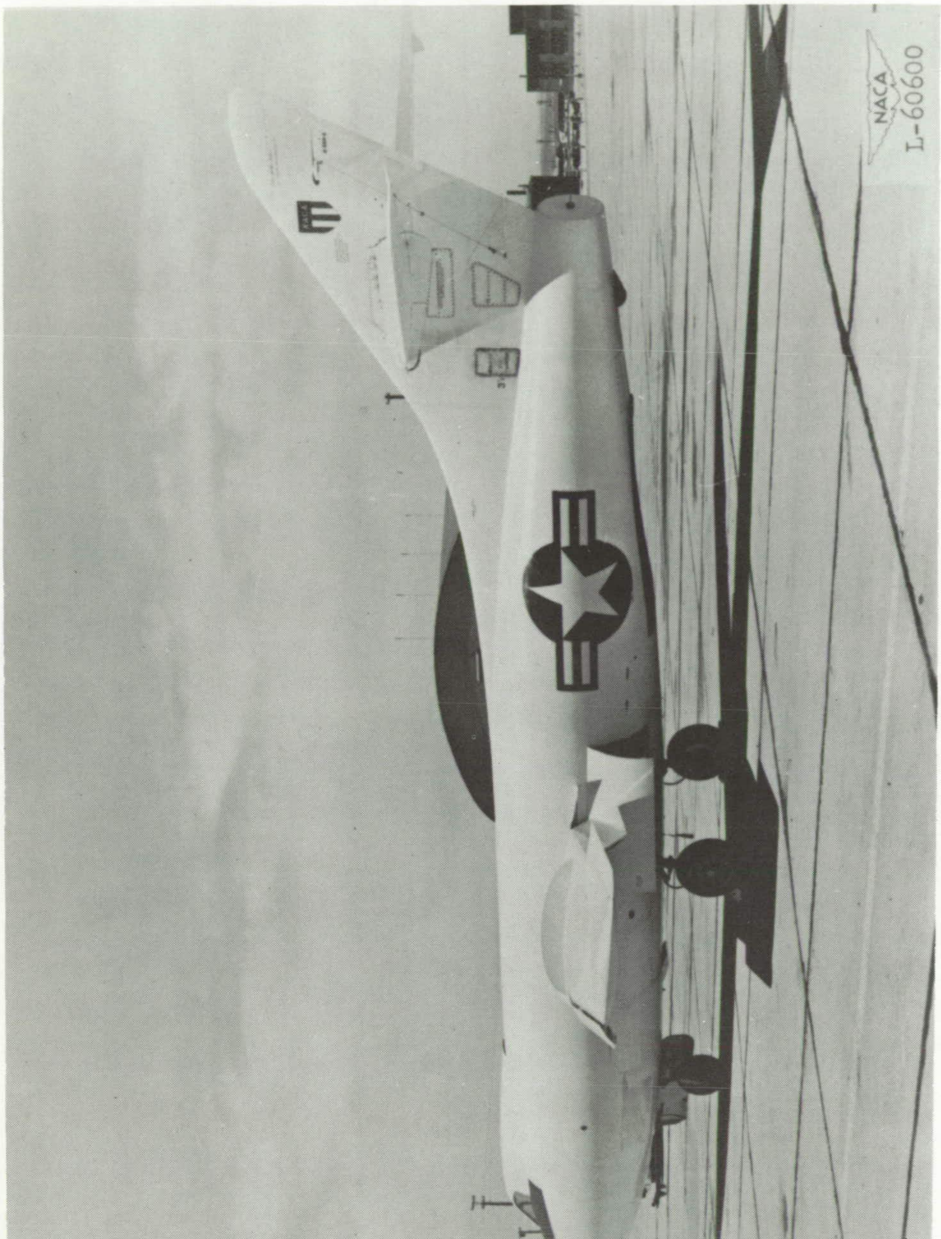

Figure 2.- Three-quarter rear view of Douglas D-558-II (BuAero No. 37974) research airplane.

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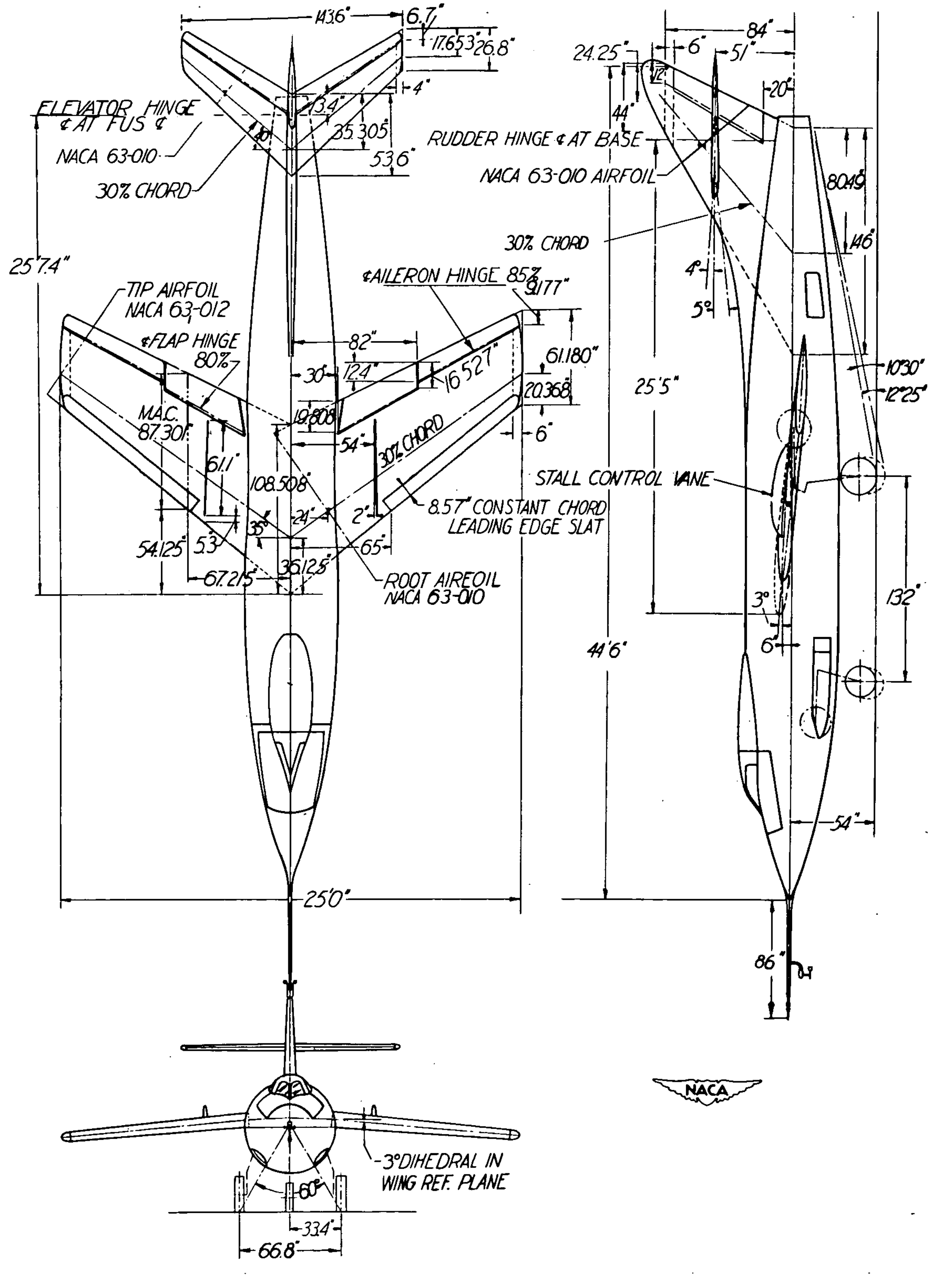


Figure 3.- Three-view drawing of the Douglas D-558-II (BuAero No. 37974) research airplane.

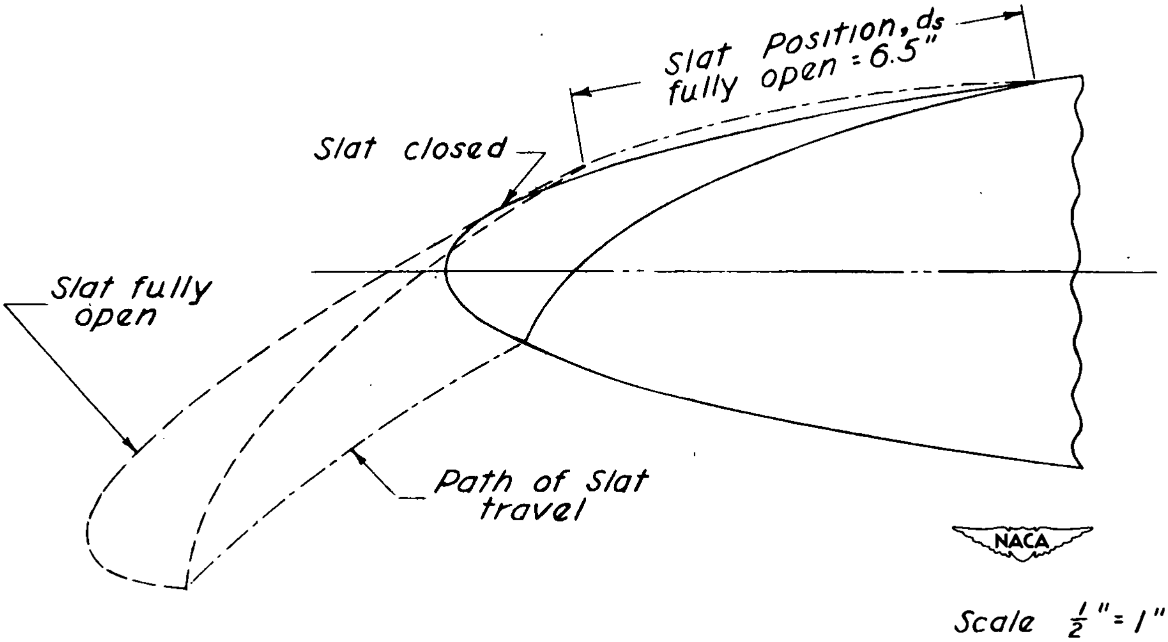


Figure 4.- Section of wing slat of Douglas D-558-II (BuAero No. 37974) research airplane perpendicular to leading edge of wing.

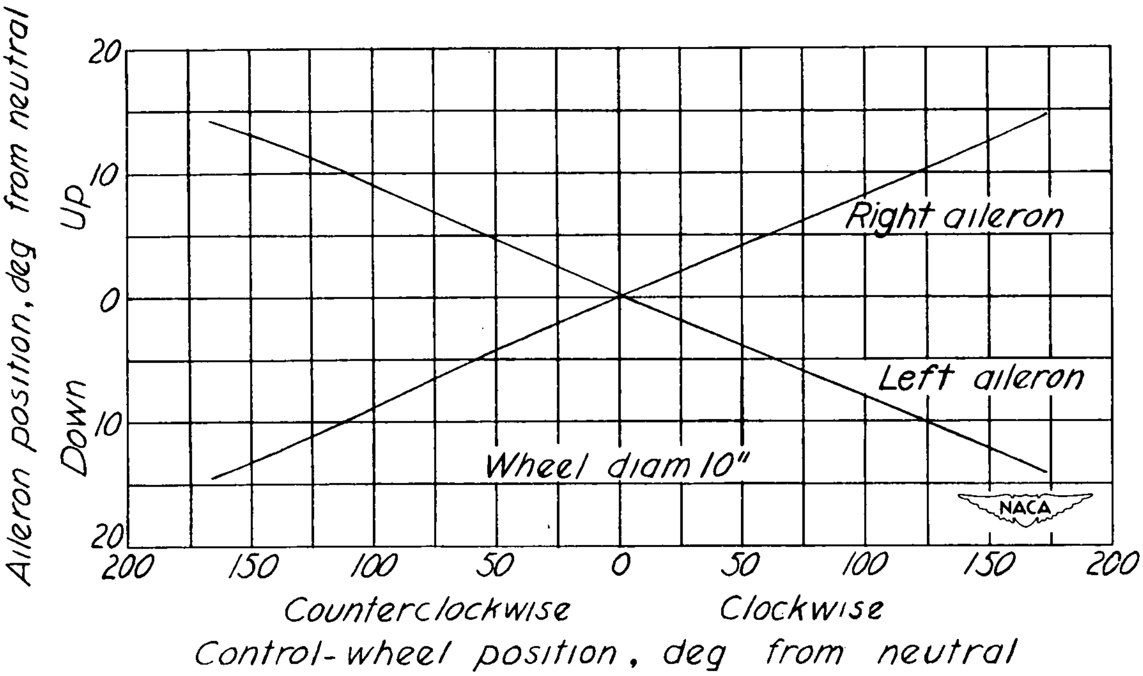


Figure 5.- Variation of left and right aileron positions with control-wheel position. No load on system.

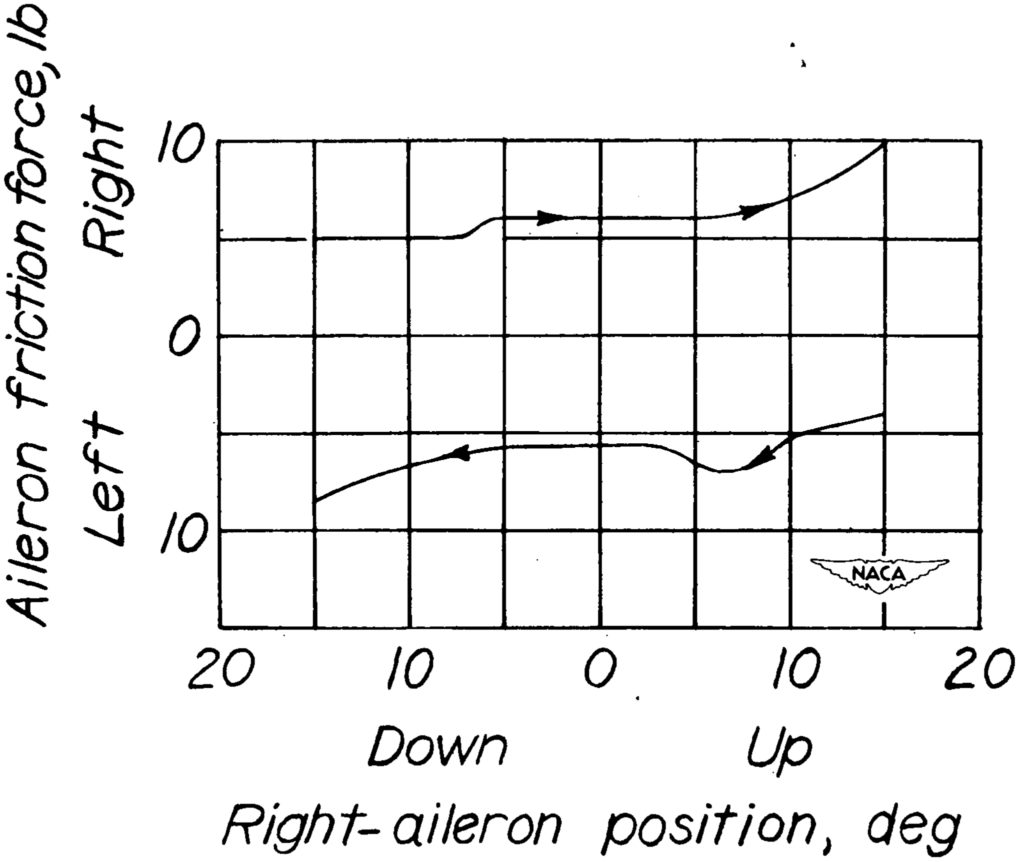
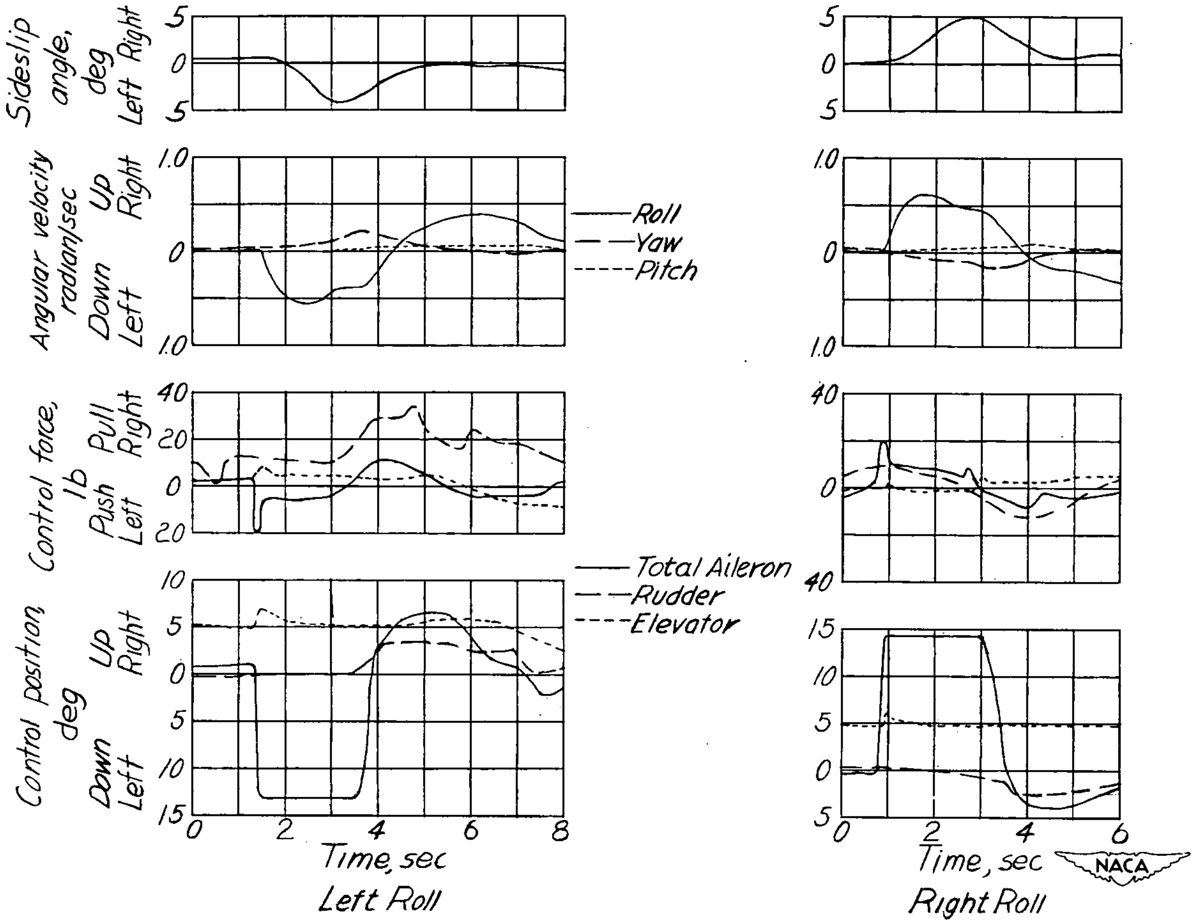
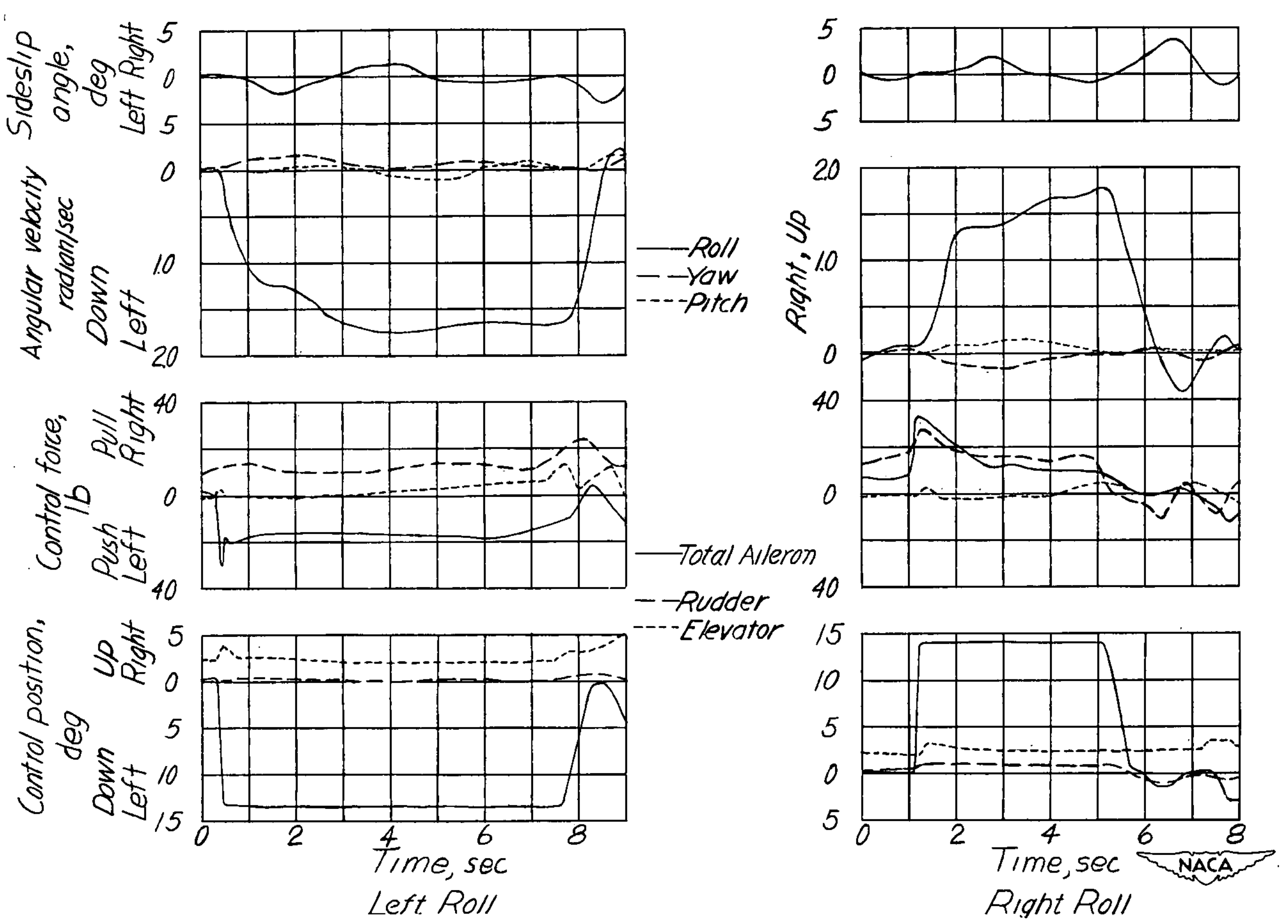


Figure 6.- Aileron control force required to deflect ailerons on the ground under no load.



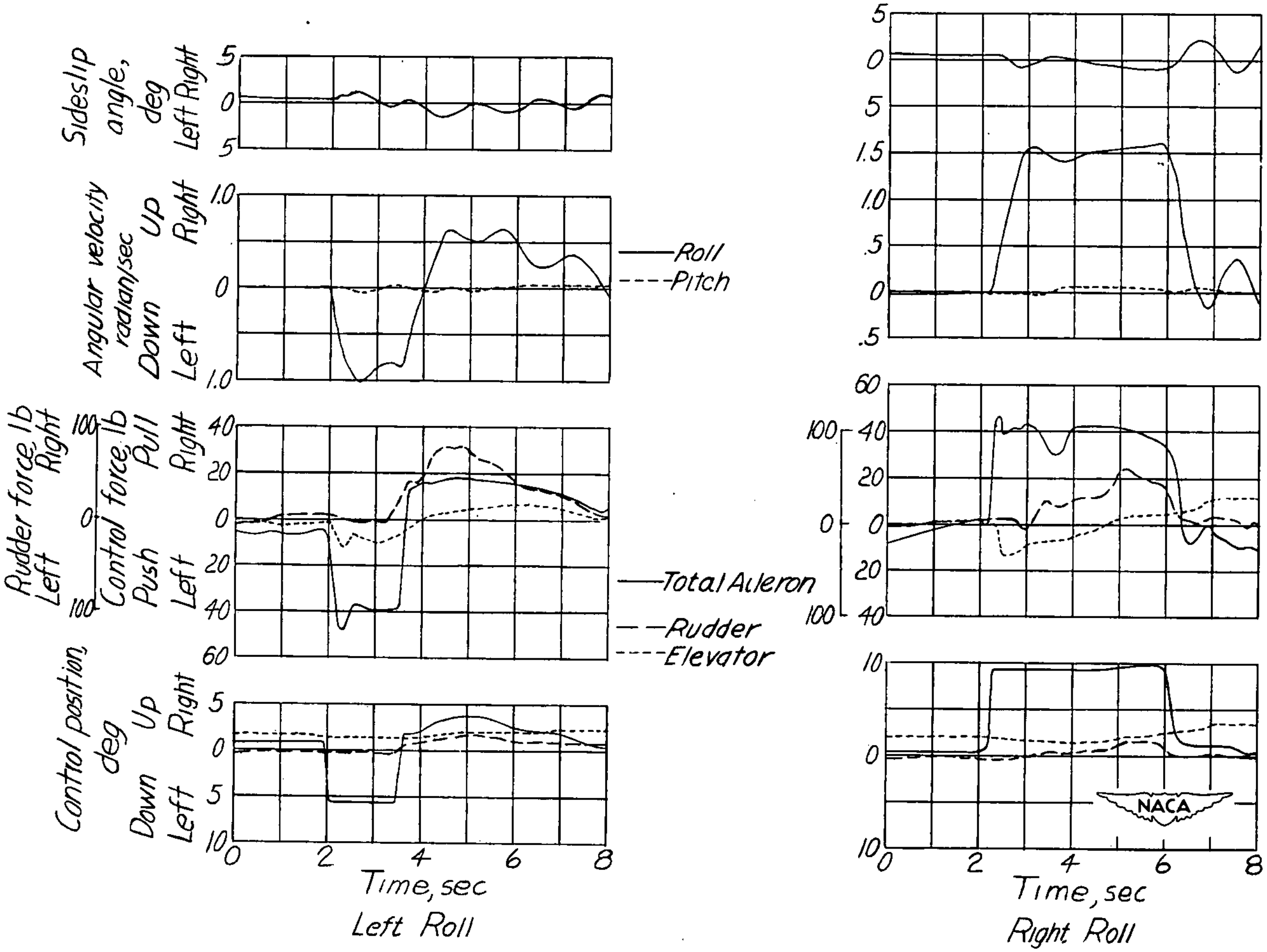
(a) M = 0.33; V_c = 176 mph; C_N = 0.75.

Figure 7.- Time histories of rudder-fixed left and right aileron rolls with the D-558-II (BuAero No. 37974) airplane. Flaps up, gear up, slats locked, inlet duct flaps closed.



(b) $M = 0.50$; $V_c = 262$ mph; $C_N = 0.37$.

Figure 7.- Continued.



(c) $M = 0.86$; $V_c = 506$ mph; $C_N = 0.09$.

Figure 7.- Concluded.

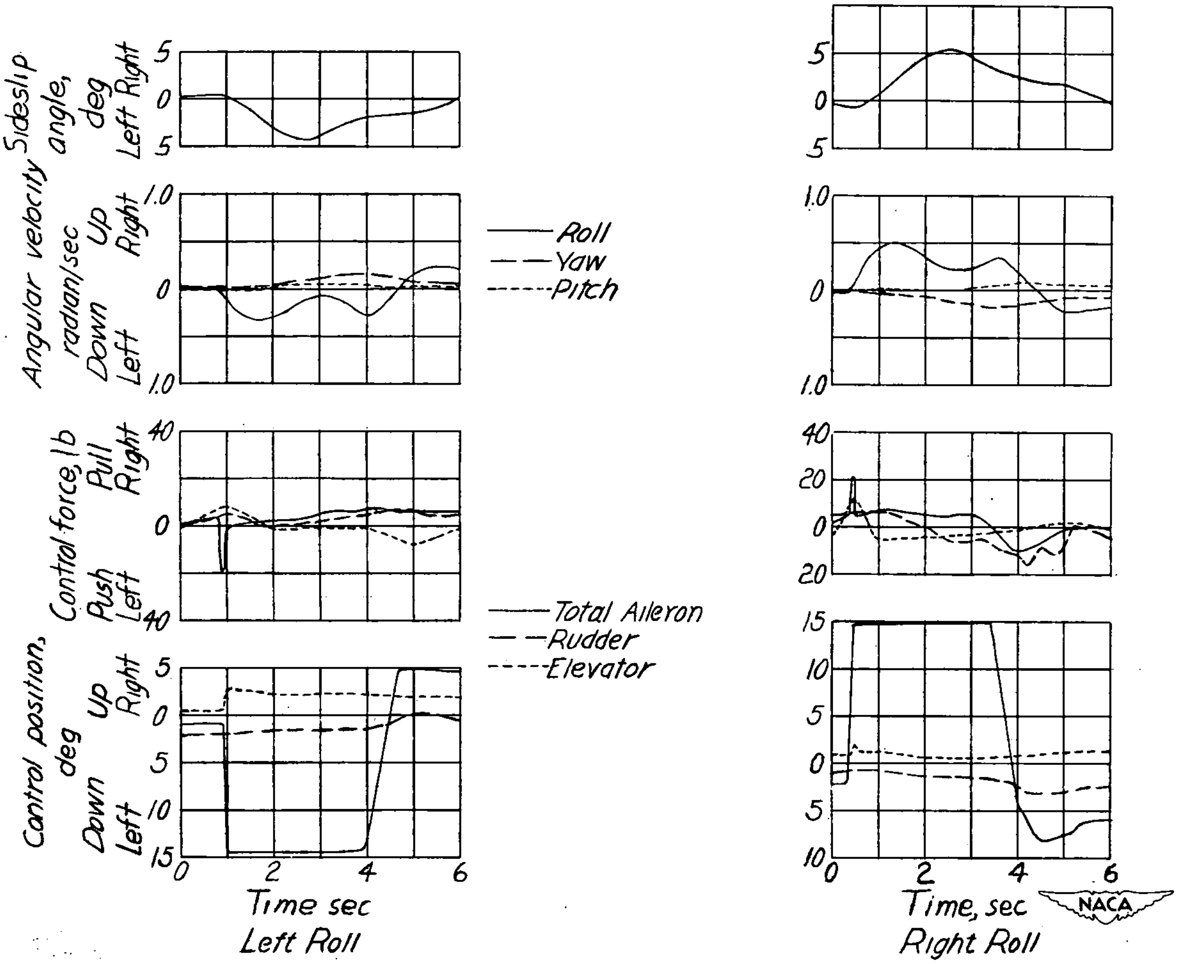


Figure 8.- Time histories of rudder-fixed left and right aileron rolls with the Douglas D-558-II (BuAero No. 37974) airplane. Flaps down, gear down, slats unlocked, inlet duct flaps open.

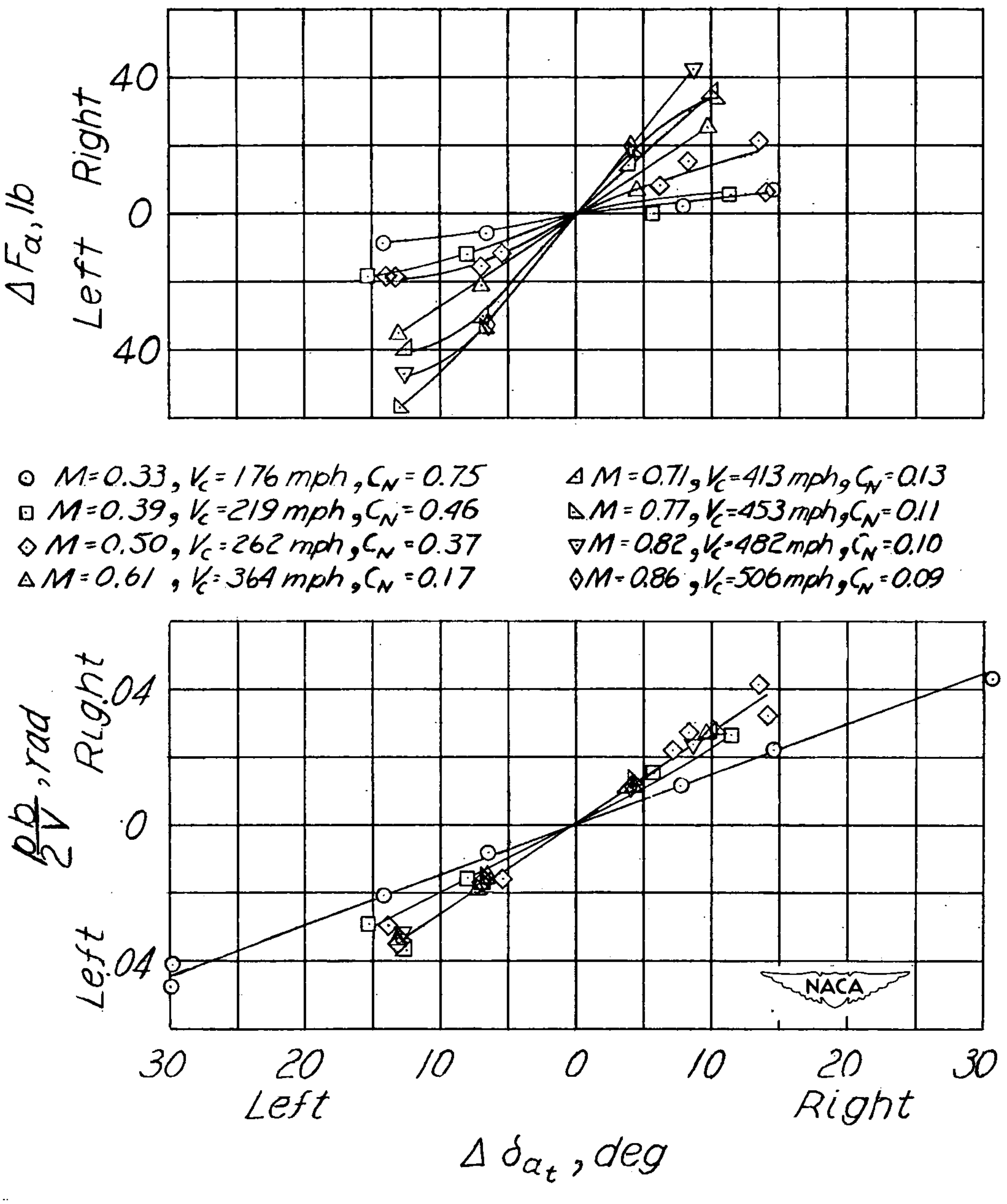


Figure 9.- Variation of maximum $\frac{pb}{2V}$ and aileron control force with change in total aileron deflection in rudder-fixed aileron rolls with the Douglas D-558-II (BuAero No. 37974) airplane. Flaps up, gear up, slats locked, inlet duct flaps closed.

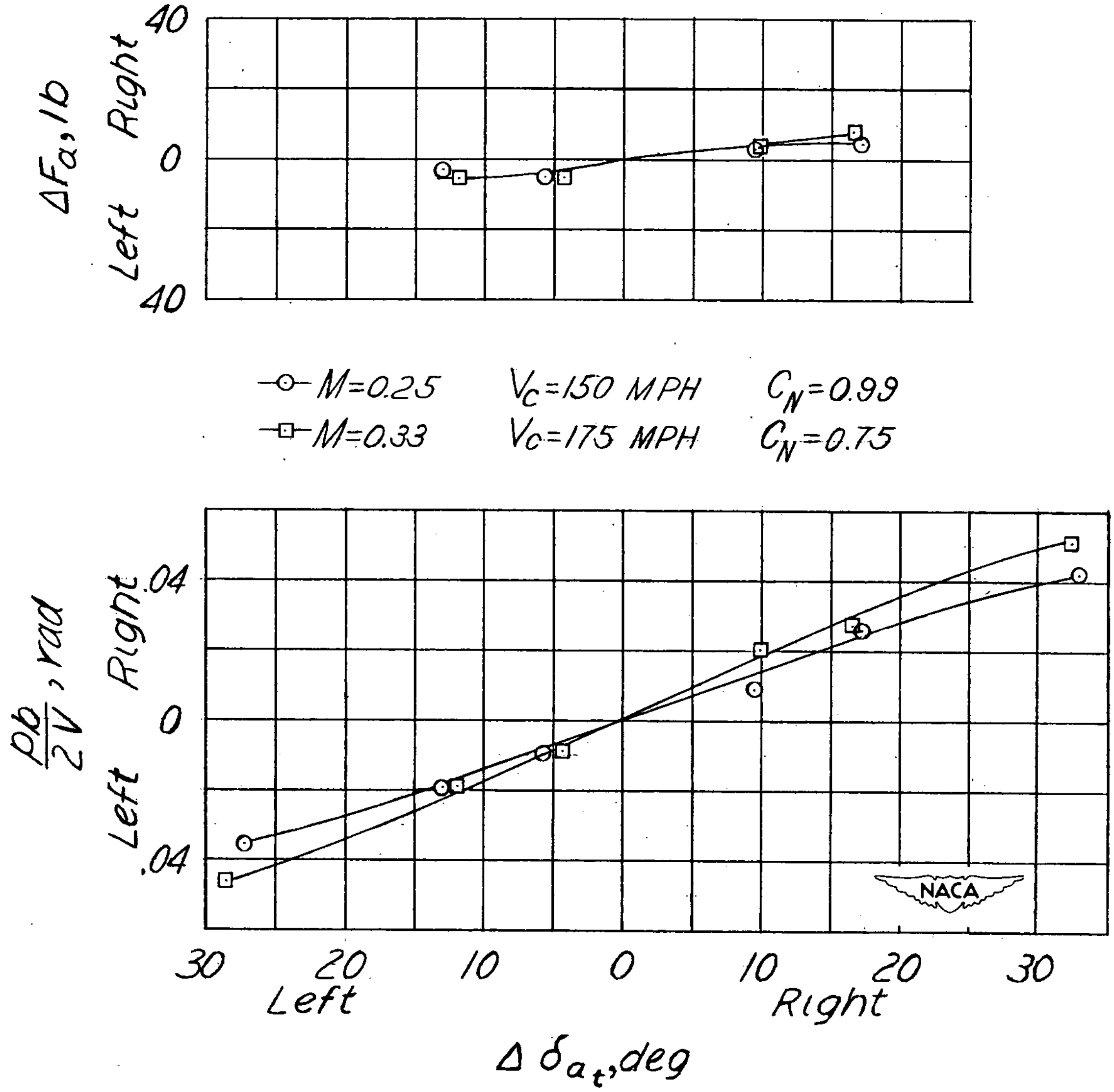


Figure 10.- Variation of maximum $\frac{pb}{2V}$ and aileron control force with change in total aileron deflection in rudder-fixed aileron rolls with the Douglas D-558-II (BuAero No. 37974) airplane. Flaps down, gear down, slats unlocked, inlet duct flaps open.

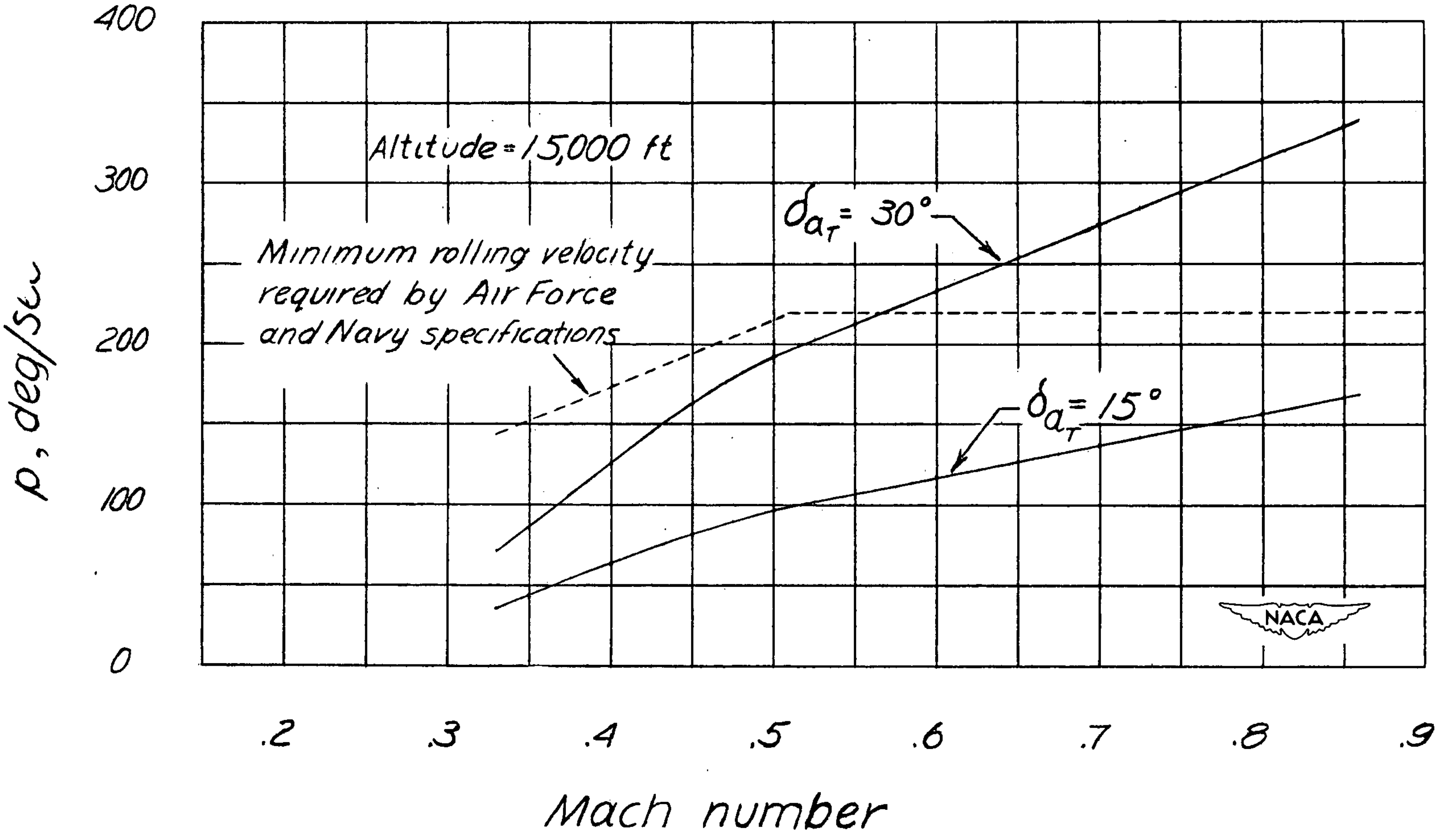


Figure 11.- The variations with Mach number of the rolling velocities obtainable with 15° and 30° of total aileron deflection at an altitude of 15,000 feet for the Douglas D-558-II (BuAero No. 37974) airplane. Flaps up, gear up, slats locked, inlet duct flaps closed.