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RESEARCH MEMORANDUM

STABILITY AND CONTROL MEASUREMENTS OBTAINED DURING USAF-NACA COOPERATIVE FLIGHT-TEST PROGRAM ON THE X-4 AIRPLANE (USAF No. 46-677)

By Melvin Sadoff, Herman O. Ankenbruck, and William O'Hare

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

October 26, 1951

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SUMMARY

Results obtained during the Air Force testing of the Northrop X-4 airplane are presented. Information is included on the stalling characteristics, the static and dynamic longitudinal- and lateral-stability characteristics, and the lateral-control characteristics.

The data indicated that the stalling characteristics of the X-4 airplane in straight flight and in accelerated flight at low Mach numbers were satisfactory, but that at Mach numbers above 0.68, the airplane became longitudinally unstable at moderate lift coefficients.

The maximum normal-force coefficient attained varied from about 0.84 at a Mach number of 0.25 to 0.63 at a Mach number of 0.60. The buffet boundary in this Mach number interval occurred at approximately 0.1 lower normal-force coefficient, and coincided nearly with the instability boundary at higher Mach numbers.

The directional stability tended to decrease at small angles of sideslip as Mach number was increased until, at a Mach number of 0.73, the stability was about neutral for small angles of right sideslip.

The X-4 airplane does not satisfy the Air Force criteria for damping of the short-period longitudinal or lateral oscillations. At high Mach numbers undamped small-amplitude oscillations about all three axes were experienced so the Air Force tests were limited to a Mach number of 0.88.

Based on the Air Force criterion, the lateral control, as measured in rudder-fixed aileron rolls, was inadequate. The pilots, however, considered the aileron rolling power entirely satisfactory over the test Mach number range.

INTRODUCTION

The X-4 airplane was constructed as part of the joint NACA-Air Force-Navy research airplane program to provide information on the stability and control characteristics of a semitailless configuration at high subsonic Mach numbers.

The results obtained during 30 flights made by Northrop are reported in references 1 to 8. The present paper presents additional stability and control information obtained during 15 flights flown by Air Force pilots for the phase II testing of the X-4 airplane.

During these tests, the airplane was instrumented and maintained by the NACA. The reduction and analysis of the stability and control data were made by NACA personnel.

SYMBOLS

V_i	indicated airspeed, miles per hour
h_p	pressure altitude, feet
A_Z	normal acceleration factor (the ratio of the net aerodynamic force along the airplane Z axis to the weight of the airplane)
A_X	longitudinal acceleration factor
A_Y	lateral acceleration factor
M	Mach number
V	airspeed, feet per second
ρ	atmospheric density, slugs per cubic foot
$\frac{\rho V^2}{2}$	dynamic pressure, pounds per square foot
F_e	stick force, pounds
F_r	rudder-pedal force, pounds
S	wing area, square feet

b	wing span, feet
$\bar{c}$	wing mean aerodynamic chord, feet
W	airplane weight, pounds
q	pitching angular velocity, radians per second
p	rolling angular velocity, radians per second
$\frac{pb}{2V}$	wing-tip helix angle
P	period of oscillation, seconds
$T_{\frac{1}{2}}$	time to damp to one-half amplitude, seconds
δ_e	effective longitudinal control angle $\left(\frac{\delta_{e_L} + \delta_{e_R}}{2}\right)$, degrees
δ_a	effective lateral control angle $\left(\delta_{e_L} - \delta_{e_R}\right)$, degrees
δ_r	rudder angle, degrees
S. P.	stick position, inches from neutral
β	sideslip angle, degrees
α	angle of attack of nose boom, degrees
C_N	normal-force coefficient $\left[\frac{WA_Z}{(\rho V^2/2)S}\right]$
C_{N_α}	airplane lift-curve slope, per degree
C_{m_α}	static stability parameter, per radian
$C_{m_q} + C_{m_{\dot{\alpha}}}$	rotational damping factor $\left[\frac{dC_m}{d(q\bar{c}/2V)} + \frac{dC_m}{d(\dot{\alpha}\bar{c}/2V)}\right]$

Subscripts

L left elevon

R right elevon

t total

AIRPLANE

The Northrop X-4 airplane is a semitailless research airplane having a vertical tail but no horizontal-tail surfaces. It is powered by two Westinghouse J-30-WE-7-9 engines and is designed for flight research in the high subsonic speed range. A three-view drawing of the airplane is shown in figure 1 and photographs of the airplane are presented as figure 2. The physical characteristics of the airplane are listed in table I.

INSTRUMENTATION

Standard NACA instruments were used to record, as a function of time, the following:

Fin boom airspeed
Fin boom altitude
Nose boom altitude
Right and left elevon positions
Rudder position
Fore and aft stick position
Sideslip angle
Angle of attack
Stick force
Rudder pedal force
Pitching and rolling angular velocities
Normal, lateral, and longitudinal accelerations

In addition, the normal accelerations at the center of gravity and at the left wing tip were measured by means of high-frequency accelerometers connected to a recording oscillograph.

The airspeed and altitude were corrected for the position error of the fin-boom system on the basis of calibrations made during the X-4 demonstration tests. (See reference 8.) The angle-of-attack data presented herein are the values measured with respect to the center line of the nose boom, which is 1° nose down relative to the fuselage center line. These data were not corrected for position error or boom deflection.

TESTS, RESULTS, AND DISCUSSION

Static Longitudinal-Stability Characteristics

In low Mach number stalls.- The static longitudinal-stability characteristics at low Mach numbers were measured in straight-flight stalls in the clean and gear-down configurations at an altitude of 20,000 feet and in wind-up turns to the stall in the clean configuration at Mach numbers of 0.50 and 0.60 at 30,000 feet. The center of gravity for these tests and for all subsequent tests described herein was located at about 17.5 percent of the mean aerodynamic chord.

The results of these tests are presented in figures 3 to 6. Figures 3(a) and 3(b) present time histories of the motions of the airplane and the controls during the clean and the gear-down straight-flight stalls, respectively. It is shown in these figures that both stalls were characterized by a right roll-off which was controlled by flying at moderate angles of right sideslip. With full-up longitudinal control, the airplane in the clean configuration oscillated with increasing amplitude in pitch with a period corresponding closely to the expected value of 2.3 seconds for the short-period oscillation at this speed. In the time interval during which this oscillation occurred, a maximum of two-thirds the available directional control and about one-half the available lateral control were used in an effort to maintain straight flight. Recovery was readily effected and the oscillation terminated by forward movement of the stick. The stall with the gear down was considerably milder than the stall in the clean configuration in that the initial roll-off was less severe and smaller angles of right sideslip were required to control the wing-dropping tendency. Furthermore, the unstable oscillation in pitch was absent. A maximum value of normal-force coefficient of about 0.84 was obtained for the gear-down stall as compared to a value of 0.81 for the stall in the clean configuration. The pilots considered the stalls mild and controllable and observed that a stall warning in the form of mild buffet was present about 0.10 normal-force coefficient below the maximum values attained.

From the data presented in figure 3 the static longitudinal-stability characteristics in the straight-flight stalls were determined. The results shown in figures 4(a) and 4(b) present the variation of effective longitudinal control angle δ_e and angle of attack α with normal-force coefficient for the clean and gear-down configurations, respectively. The stick-fixed stability for both stalls remained positive over most of the normal-force coefficient range, increasing sharply immediately before becoming neutral about 0.05 normal-force coefficient below the maximum values attained. It may also be seen in figure 4 that the angle-of-attack data do not indicate a peak on the lift curve. Higher lift coefficients could probably be obtained if more longitudinal control were available or if the airplane were flown with more rearward positions of the center of gravity. The attainment of higher lift coefficients on this airplane is not considered of great interest since, in a practical maneuver, the pilots would not normally proceed beyond a normal-force coefficient of 0.7, the point at which the first change in lateral trim (roll-off) occurred.

The static longitudinal-stability characteristics in accelerated stalls are presented in figure 5. It may be noted in this figure that the stick-fixed stability again increased sharply near the stall. The stability in the accelerated stalls, however, remained positive and high up to the stall rather than decreasing to a small range of neutral stability as in the straight-flight stalls just before the maximum values of normal-force coefficient were reached.

In high Mach number maneuvers.- The higher Mach number static longitudinal-stability characteristics were measured in wind-up turns over a Mach number range of 0.68 to 0.80 at a pressure altitude of 30,000 feet. The results of these tests are shown in figure 6. It is of interest to note (fig. 6(a)) that at a normal-force coefficient of 0.55, the stick-fixed stability varies from a high positive value at a Mach number of 0.68 to neutral at a Mach number of 0.70. There appears to be no differentiation in the angle-of-attack data at these two Mach numbers. At a Mach number of 0.80 (fig. 6(b)), stick-fixed longitudinal instability is indicated at values of normal-force coefficient above 0.52. The lift-curve slope in this region of instability is small.

As a matter of interest, the variation of the X-4 lift-curve slope with Mach number is shown in figure 7. The slopes were taken at a C_N of 0.60 for the lowest Mach number of 0.28 and at a C_N of 0.20 for the other Mach numbers.

Instability and buffet boundaries.- The buffet boundary presented in figure 8 was determined from the high-frequency wing-tip accelerometer and from the standard NACA accelerometer at the center of gravity. The onset of buffeting, as obtained from these two sources, occurred at practically the same values of normal-force coefficient. The instability boundary or the values of normal-force coefficient for the occurrence of neutral stick-fixed stability (fig. 8) was obtained from the data in figure 6 and from reference 8. The maximum values of normal-force coefficient which are also shown in figure 8 were obtained from the data contained in figures 4 and 5. The value of C_N of the buffet boundary decreases as the Mach number increases up to a Mach number of about 0.60. Between Mach numbers of 0.60 and 0.80 there is a slight increase in the C_N at which buffeting first occurs. As the Mach number is further increased, the buffet boundary decreases sharply reaching level-flight values of C_N at a Mach number of about 0.87. The maximum values of normal-force coefficient attained in these tests varied from about 0.84 at a Mach number of 0.25 to 0.63 at a Mach number of 0.60. At higher Mach numbers between 0.70 and 0.82, the instability boundary very nearly coincided with the buffet boundary.

Static Lateral- and Directional-Stability Characteristics

The static lateral- and directional-stability characteristics were measured in gradually increasing sideslips to the right and left at Mach numbers of 0.49, 0.61, and 0.73 at a pressure altitude of about 30,000 feet. The results of these measurements are shown in figure 9 which gives the variation of the effective longitudinal control angle, the effective lateral control angle, the rudder angle, and the rudder pedal force with sideslip angle. Several noteworthy observations regarding figure 9 are (1) the measure of directional stability $d\delta_r/d\beta$ is positive and high over the test Mach number range at sideslip angles greater than about $\pm 4^{\circ}$; (2) the stability is lower for small angles of sideslip reaching a minimum at small angles of right sideslip, and, at a Mach number of 0.73, the directional stability appears to be neutral over a small range of right sideslip angles; and (3), as expected for swept-wing airplanes, the measure of dihedral effect $d\delta_a/d\beta$ decreases with increasing Mach number due primarily to the decrease in normal-force coefficient for steady straight flight.

Dynamic Stability Characteristics

Longitudinal.- The longitudinal dynamic stability data were obtained in longitudinal oscillations produced by abruptly deflecting the elevons and returning them to the original position. The oscillations were obtained over a Mach number range of 0.48 to about 0.80 at 30,000 feet and from Mach numbers of 0.39 to 0.61 at 10,000 feet. The results of these tests are presented in figures 10 and 11 for altitudes of 30,000 and 10,000 feet, respectively. The measured period and damping characteristics of the X-4 airplane are presented in these figures as a function of Mach number for the two test altitudes. The data above a Mach number of 0.80 at 30,000 feet were obtained from reference 8 and from a speed run to M = 0.88 during the present tests. The data in figures 10 and 11 indicate that the X-4 airplane does not satisfy the Air Force criterion (reference 9) for satisfactory damping characteristics. The criterion specifies that the longitudinal short-period oscillation damp to one-tenth amplitude in one cycle. Actually, about three cycles are required for the X-4 airplane to damp to one-tenth amplitude. Also presented in figures 10 and 11 for comparison with the experimental results are the theoretical period and damping characteristics computed by standard methods (reference 10). It may be observed in these figures that the measured and computed periods agree very well, while the measured damping is considerably less than that predicted by the theory. The reason for the discrepancy in damping may be clearly seen in figure 12 which presents a comparison of the estimated values of the damping-in-pitch parameter $C_{m_q} + C_{m_{\dot{\alpha}}}$ (reference 11) and the static stability parameter C_{m_α} (reference 12) with the values derived from the experimental data. Figure 12 shows that the values of C_{m_α} agree fairly well, while the experimental values of $C_{m_q} + C_{m_{\dot{\alpha}}}$ are much lower than the estimated values over the Mach number range. It is also noteworthy that while the experimental values of $C_{m_q} + C_{m_{\dot{\alpha}}}$ decrease with increasing Mach number, the theoretical values increase slightly. The relatively large positive value of $C_{m_q} + C_{m_{\dot{\alpha}}}$ at a Mach number of 0.88 corresponds to the undamped porpoising oscillation characteristic of the X-4 airplane at this speed. For this reason the values of $T_{\frac{1}{2}}$ (fig. 10) and $C_{m_q} + C_{m_{\dot{\alpha}}}$ (fig. 12) given at a Mach number of 0.88 are valid only for small-amplitude motions. Also presented in figure 12 are data computed from flight results obtained at an altitude of 35,000 feet on the conventional F-86 airplane. (See reference 13.) A comparison of these results with those for the X-4 in figure 12 indicates that the rotational damping of the X-4 is only about 5 percent of that for the F-86. It is interesting to note, however, that despite the relatively low rotational damping of the X-4, the pilots considered the damping of the short-period longitudinal oscillation satisfactory up to Mach numbers where porpoising was experienced.

Lateral.- The lateral dynamic stability tests were made over a Mach number range of 0.47 to about 0.79 at a pressure altitude of about 30,000 feet. The oscillations were excited by abruptly deflecting and returning the rudder to the trim position (rudder-fixed kick), and by abruptly deflecting and releasing the rudder (rudder-free kick). Analysis indicated no appreciable difference in the data obtained from these two types of oscillations, indicating that no rudder-free oscillations occurred over the Mach number range investigated, so they are not differentiated in the following discussion. The results of these tests are presented in figure 13 which gives the measured period and damping characteristics of the short-period lateral oscillation as a function of Mach number at a pressure altitude of 30,000 feet. The data at a Mach number of 0.88 were obtained from an undamped small-amplitude directional oscillation experienced during a high-speed run. Also shown in figure 13 are the predicted characteristics computed by standard methods (reference 14). An examination of the experimental data in figure 13 indicates that the X-4 airplane does not satisfy the USAF criterion (reference 9) for satisfactory damping characteristics. This criterion specifies that the time for the lateral-directional oscillation to damp to one-half amplitude shall be equal to or less than the value given by the relationship $2.5P - 3.5$ for values of P greater than 2 seconds. For values of P less than 2 seconds, $T_{\frac{1}{2}}$ should be equal to or less than 1.5 seconds. The agreement shown between the measured and calculated periods in figure 13 is fairly good over most of the Mach number range. The agreement between the calculated and the measured damping, however, is poor over most of the Mach number range. The experimental data exhibit considerable scatter, due possibly to the combination of low damping and the effects of fuel motion. The damping reaches a minimum value at a Mach number of 0.73, then increases again at higher Mach numbers. The measured decrease in damping to a minimum at a Mach number of approximately 0.73 coincides with the occurrence of an unusual oscillation. During the static directional- and lateral-stability tests at a Mach number of about 0.73, an undamped oscillation occurred when increasing sideslip gradually to the right. This oscillation which had a period about 1 second less than the natural period of the short-period lateral oscillation at this Mach number damped out when the sideslip angle was maintained at a value of about 7°. No similar oscillation was observed when increasing sideslip gradually to the left. A time history of the oscillation experienced in the present tests is shown in figure 14. Also presented in this figure is the time history of the corresponding run in left sideslip where no appreciable oscillation was observed.

High Mach Number Oscillations

During the Air Force testing of the X-4 airplane, Mach numbers up to 0.87 were attained with no significant deterioration of the dynamic stability. Although it was shown in a previous section that the damping of the short-period longitudinal oscillation did not meet the Air Force criterion for satisfactory damping, the several pilots who flew the airplane considered the damping adequate up to a Mach number of about 0.87. It was also shown that the damping of the lateral-directional oscillation did not meet the Air Force criterion for satisfactory damping; in this case the pilots considered the damping characteristics of the airplane to be poor. It should be pointed out that other research airplanes of more conventional configuration have also exhibited poor lateral-directional damping characteristics. At Mach numbers above about 0.87, however, an undesirable oscillation about all three axes occurred limiting the speed of the present series of tests to a Mach number of about 0.88. A time history of several of the pertinent quantities measured during this oscillation is shown in figure 15 where it may be seen that the airplane oscillated with an average amplitude of ±0.2 normal acceleration factor and $\pm 0.5^{\circ}$ sideslip. The oscillation experienced was quite similar to that reported in reference 8 where it was noted that the undamped motions of approximately ±0.25 normal acceleration factor and $\pm 1.5^{\circ}$ sideslip might limit the X-4 airplane to a Mach number of 0.88.

Since no stick-impulse or rudder-kick maneuvers were performed at the highest speed of the present tests, it is not known whether very low or zero damping would also be experienced for the higher-amplitude longitudinal and lateral-directional oscillations. For this reason the data presented for the highest test Mach number of 0.88 in figures 10, 12, and 13 are valid only for the amplitude-range of the undamped oscillations experienced at this Mach number.

Lateral-Control Characteristics

The lateral-control characteristics of the X-4 airplane were obtained in rudder-fixed aileron rolls over a Mach number range of 0.48 to 0.72 at a pressure altitude of 30,000 feet. Typical time histories of aileron rolls to the right and left at a Mach number of about 0.60 using full lateral control deflection are presented in figure 16. From the data in figure 16 and from similar data obtained at other speeds but not presented, the variation of wing-tip helix angle $pb/2V$ with change in total aileron angle $\Delta\delta_{a_t}$ was determined. The results are presented in figure 17 for the several test Mach numbers. It is to be noted in this figure that the maximum rate of roll for a given total aileron deflection is obtained at a Mach number of 0.60. At lower Mach numbers, the rolling power of the ailerons is less, probably due to the adverse effects of an increase in dihedral effect; at higher Mach numbers, the rolling effectiveness of the ailerons is reduced due perhaps to combined aeroelastic and Mach number effects. The maximum value of $pb/2V$ of 0.08 was attained in a right roll at a Mach number of 0.60 with a total aileron deflection of 33°. The wing-tip helix angle per degree total aileron deflection is shown as a function of Mach number in figure 18. The slopes were obtained from figure 17 over a total aileron-angle range of $\pm 10^{\circ}$. The experimental data are compared with the Air Force criterion (reference 9) for adequate aileron rolling effectiveness in figure 19. It is readily seen that the X-4 airplane does not satisfy this criterion below a Mach number of about 0.70. The criterion specifies that the rate of roll correspond to a value of $pb/2V$ of 0.09 or 220° per second. The pilots reported that the aileron rolling power of the X-4 airplane was entirely satisfactory over the Mach number range investigated.

CONCLUSIONS

From the results obtained during the Air Force testing of the Northrop X-4 airplane, the following conclusions were drawn:

1. The stalling characteristics of the airplane in straight flight were satisfactory for both the clean and the gear-down configurations. In the clean configuration the stall was characterized by a right roll-off, which was mitigated by flying at moderate angles of right sideslip. At maximum up-control, the airplane oscillated with increasing amplitude in pitch until the oscillation was terminated by forward movement of the stick. The stall in the gear-down configuration was characterized by a considerably milder roll-off to the right, and smaller angles of right sideslip were required, consequently, to keep the right wing up after the initial roll-off. No oscillation in pitch was encountered in the gear-down configuration.

2. The static longitudinal stability in the straight-flight stalls was positive up to normal-force coefficients of about 0.75 and 0.77 for the clean and the gear-down configurations, respectively. At higher values of normal-force coefficient, the airplane was neutrally stable near the stall.

3. In accelerated stalls at Mach numbers of about 0.50 and 0.60, the airplane was longitudinally stable over the normal-force coefficient range with the stability increasing sharply at the stall.

4. In accelerated maneuvers between 0.68 and 0.70 Mach number, the longitudinal stability varied from a high positive value to neutral at a normal-force coefficient of about 0.55.

5. The maximum normal-force coefficient of the X-4 airplane varied from about 0.84 at a Mach number of 0.25 to 0.63 at a Mach number of 0.60. The buffet boundary in this Mach number interval was at approximately 0.1 lower normal-force coefficient. At Mach numbers higher than 0.68 the longitudinal instability limited the values of normal-force coefficient that could be attained. The beginning of the instability occurred fairly close to the buffet boundary over the Mach number range covered.

6. The directional stability and the dihedral effect, as measured in gradually increasing sideslips by the variation of rudder position and effective lateral-control angle with sideslip angle, respectively, were positive over the Mach number range tested. The directional stability tended to decrease at small angles of sideslip and at a Mach number of 0.73 the stability was about neutral for small angles of right sideslip.

7. The X-4 airplane does not satisfy the Air Force criteria for damping of the short-period longitudinal and lateral oscillations. The damping of the lateral oscillation deteriorated rapidly between Mach numbers of 0.60 and 0.73 and increased sharply between 0.73 and 0.79 Mach number. At a Mach number of 0.88, the dynamic stability about all three axes was close to zero for small-amplitude motions. The oscillation about all three axes limited the speed of the present series of tests to a Mach number of 0.88.

8. Based on the Air Force criterion, the lateral control of the X-4 was inadequate below a Mach number of 0.7 at 30,000 feet. The pilots, however, considered the aileron rolling power satisfactory over the test Mach number range.

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TABLE I. - PHYSICAL CHARACTERISTICS OF X-4 AIRPLANE

Engines (two)	Westinghouse J-30-WE-7-9
Rating (each), static thrust at sea level, pound	1600
Airplane weight, pound	
Maximum (238 gal fuel)	7820
Minimum (10 gal trapped fuel)	6452
Wing loading, pound per square foot	
Maximum	39.1
Minimum	32.2
Center-of-gravity travel, percent M.A.C.	
Gear up, full load	18.3
Gear up, post flight	16.3
Gear down, full load	18.6
Gear down, post flight	16.7
Height, over-all, feet	14.83
Length, over-all, feet	23.25
Wing	
Area, square feet	200
Span, feet	26.83
Airfoil section	NACA 0010-64
Mean aerodynamic chord, feet	7.81
Aspect ratio	3.6
Root chord, feet	10.25
Tip chord, feet	4.67
Taper ratio	2.2:1
Sweepback (leading edge), degree	41.57
Dihedral (chord plane), degree	0
Wing boundary-layer fences	
Length, percent local chord	30.0
Height, percent local chord	5.0
Location, percent semispan	90.0
Wing flaps (split)	
Area, square feet	16.7
Span, feet	8.92
Chord, percent wing chord	25
Travel, degree	30
Dive-brake dimensions as flaps	
Travel, degree	±60

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TABLE I. - CONCLUDED

Elevons	
Area (total), square foot	17.20
Span (two elevons), feet	15.45
Chord, percent wing chord	20
Movement, degree	
Up	35
Down	20
Operation	Hydraulic with electrical emergency
Vertical Tail	
Area, square feet	16
Height, foot	5.96
Rudder	
Area, square feet	4.1
Span, foot	4.3
Travel, degree	±30
Operation	Direct

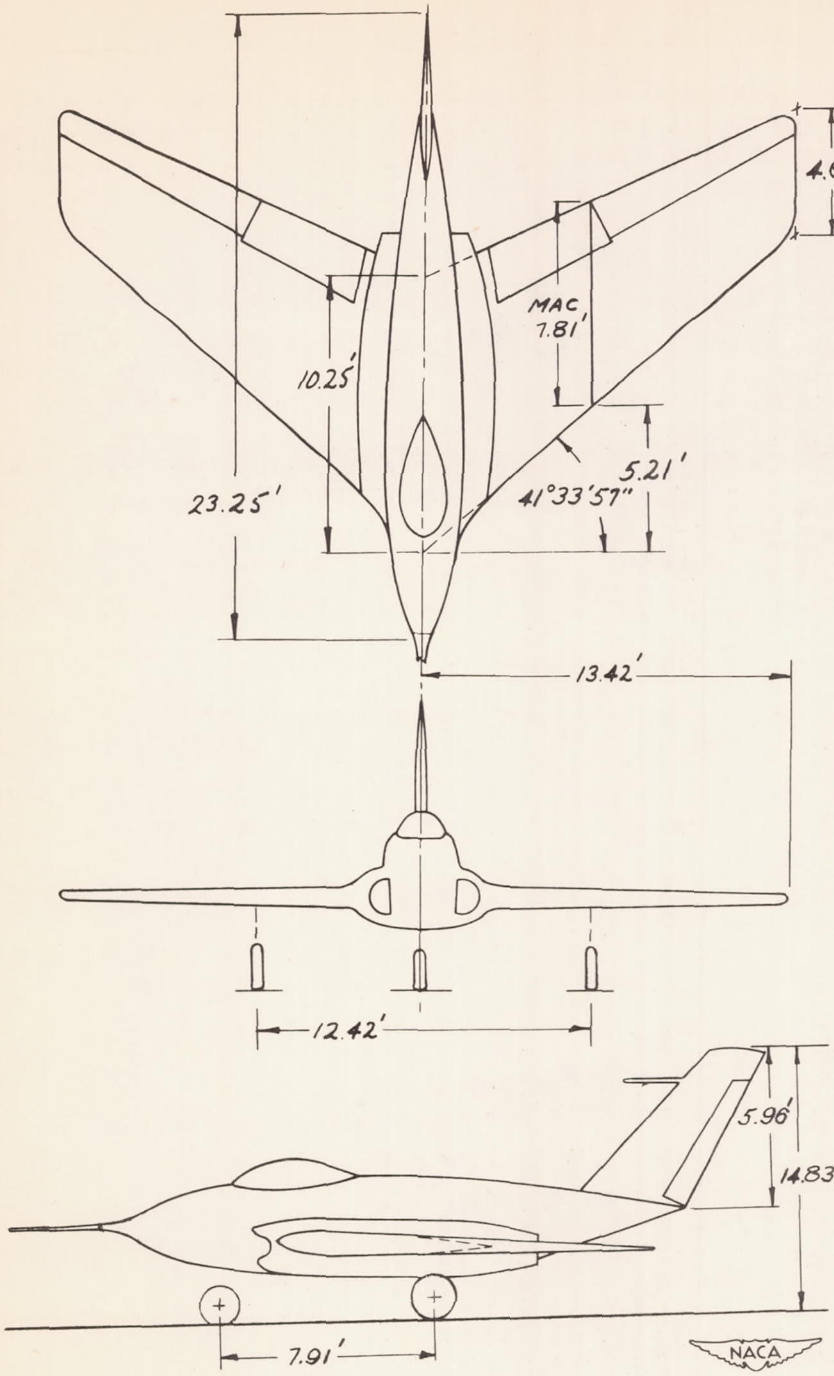
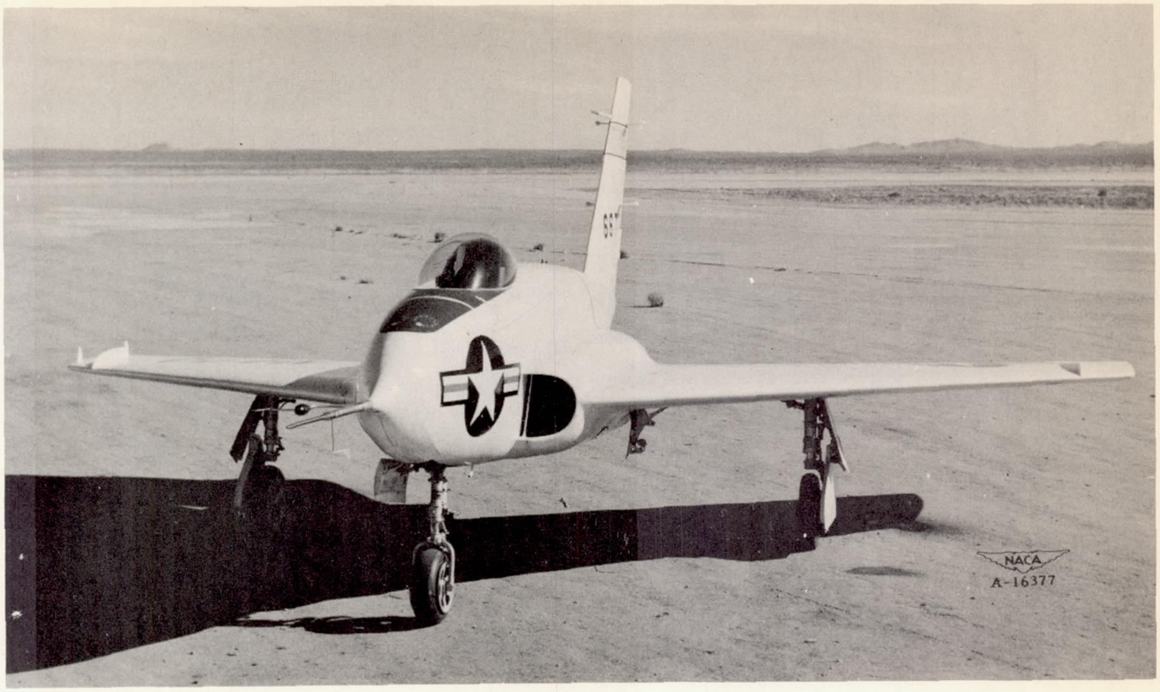
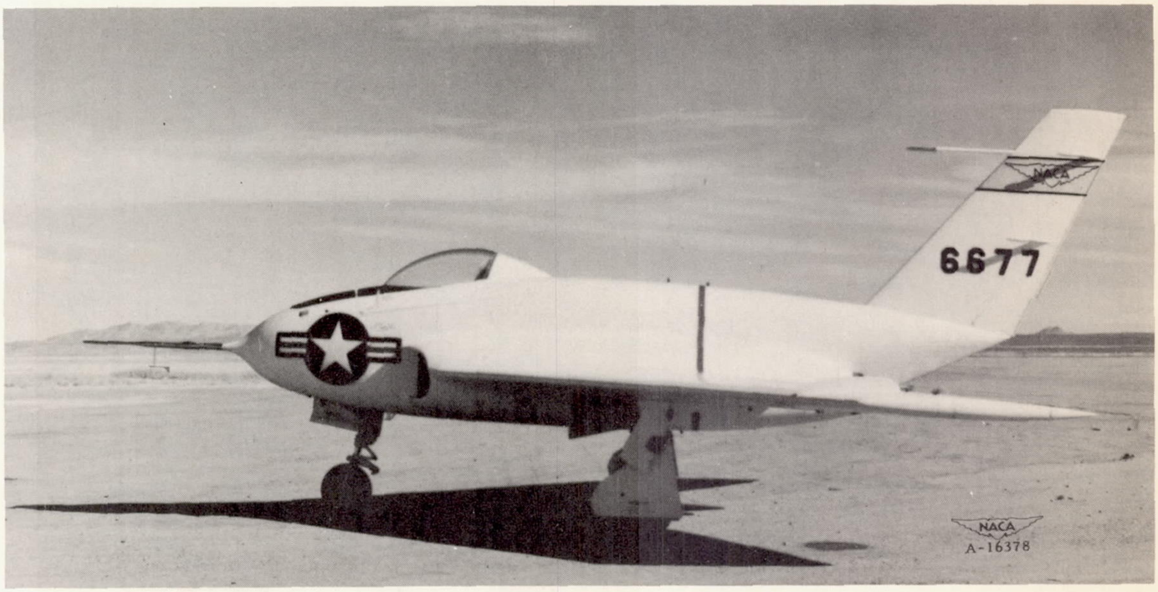


Figure 1.- Three-view drawing of the Northrop X-4 airplane.

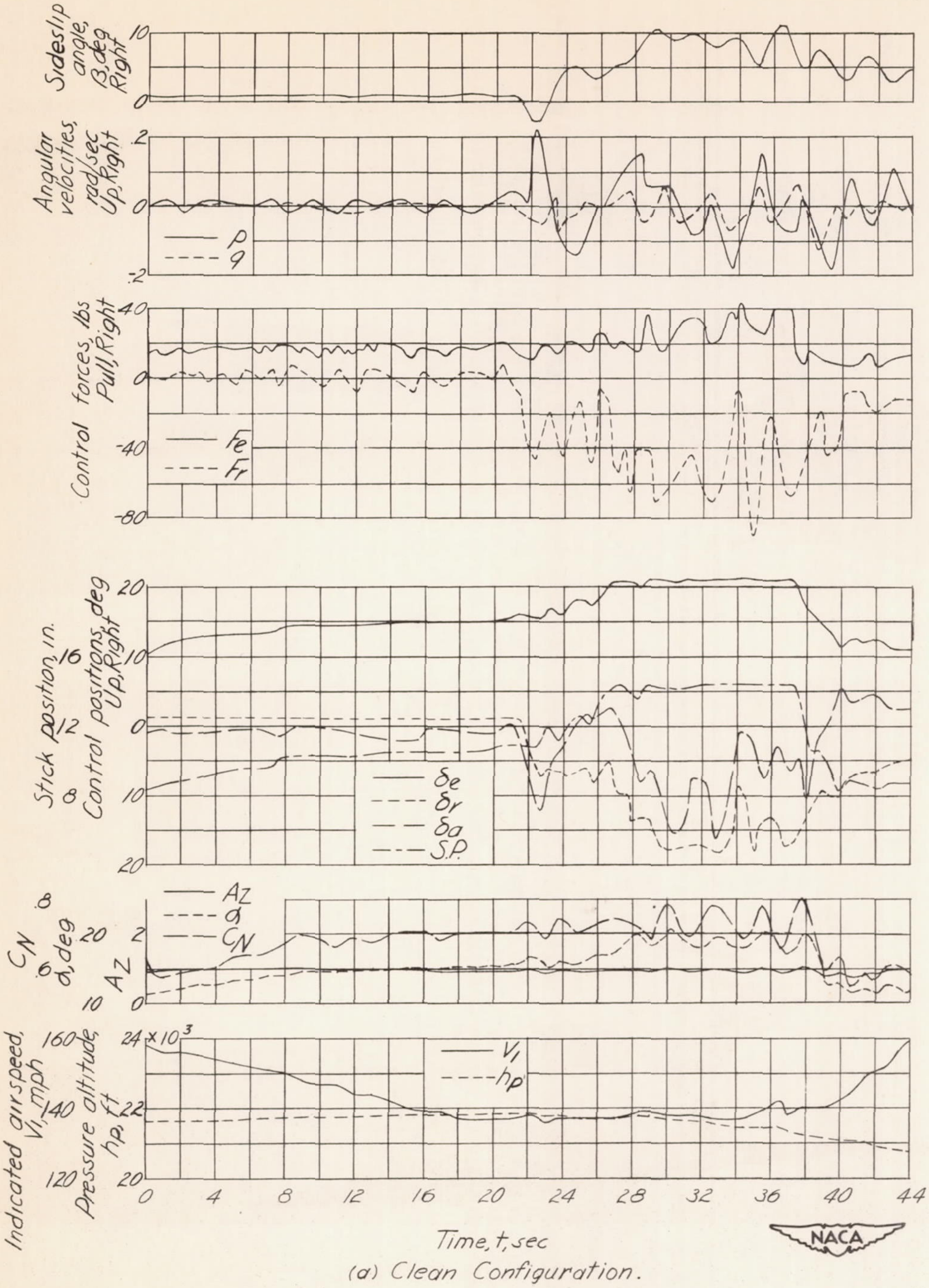


(a) Three—quarter front view.



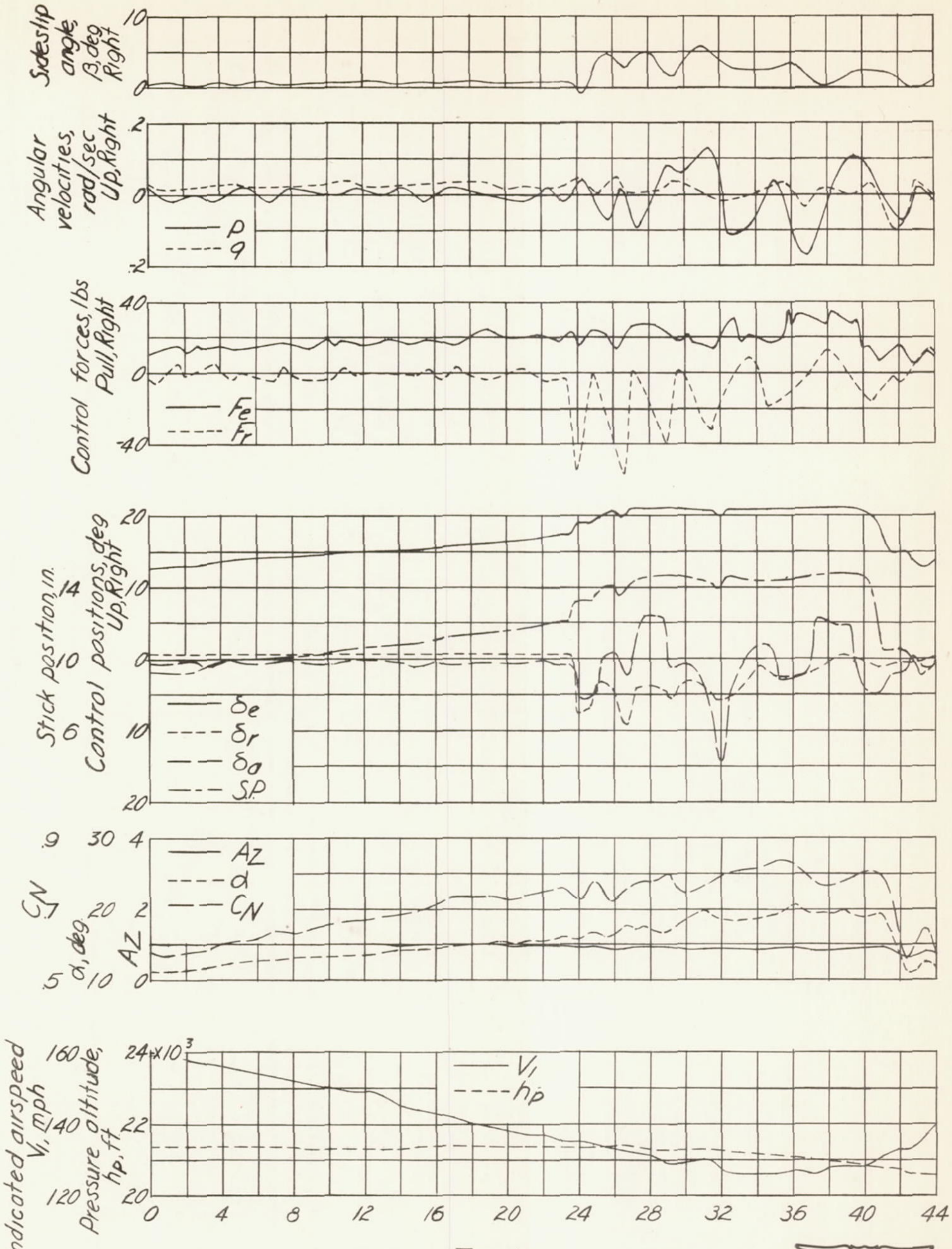
(b) Side view.

Figure 2.— The Northrop X—4 airplane.



(a) Clean Configuration.

Figure 3.– The histories of straight-flight stalls. X-4 airplane.



(b) Gear down.

Figure 3.– Concluded.

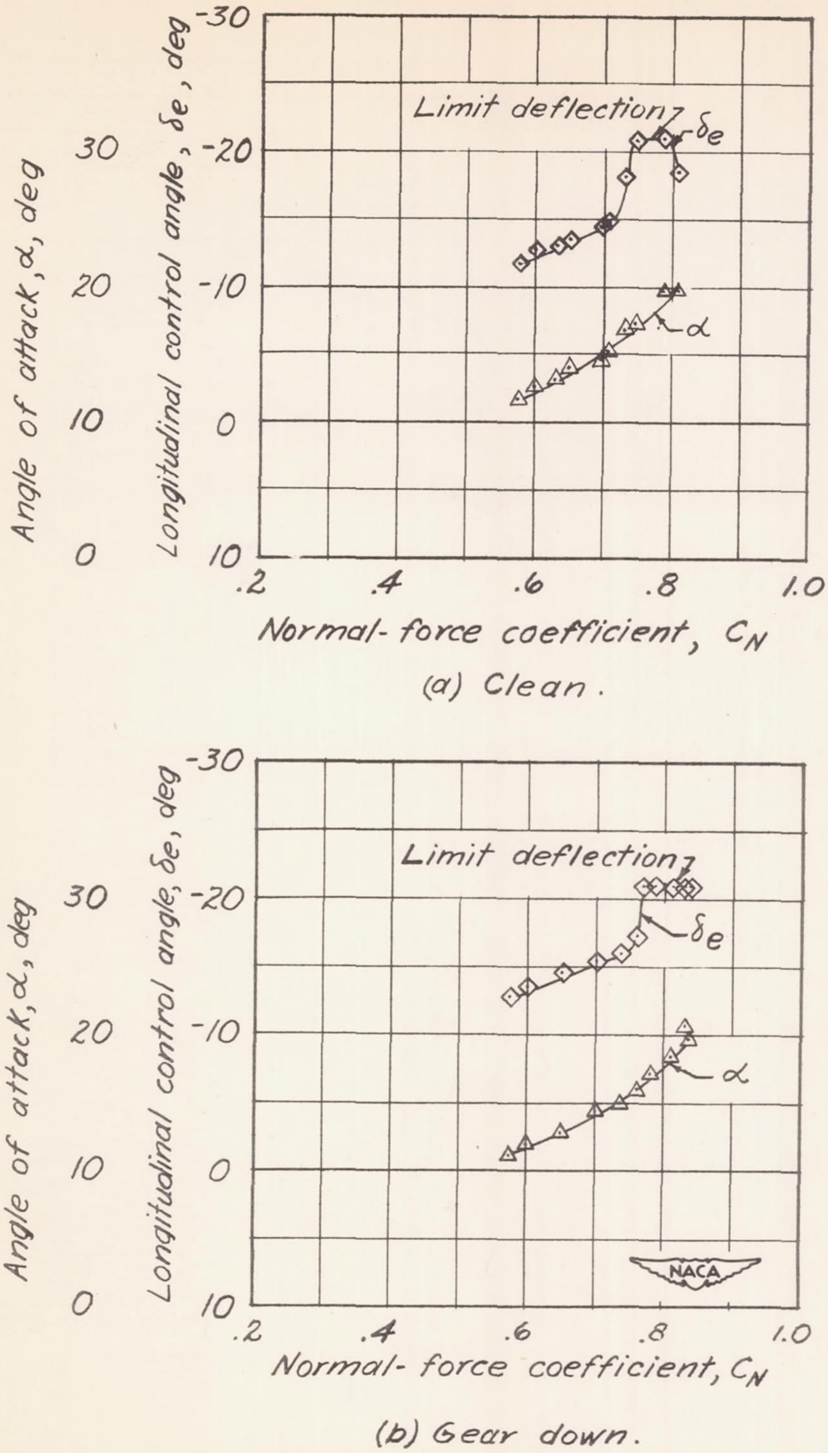


Figure 4.– Static longitudinal-stability characteristics of the X-4 airplane in unaccelerated stalls at an altitude of 20,000 feet.

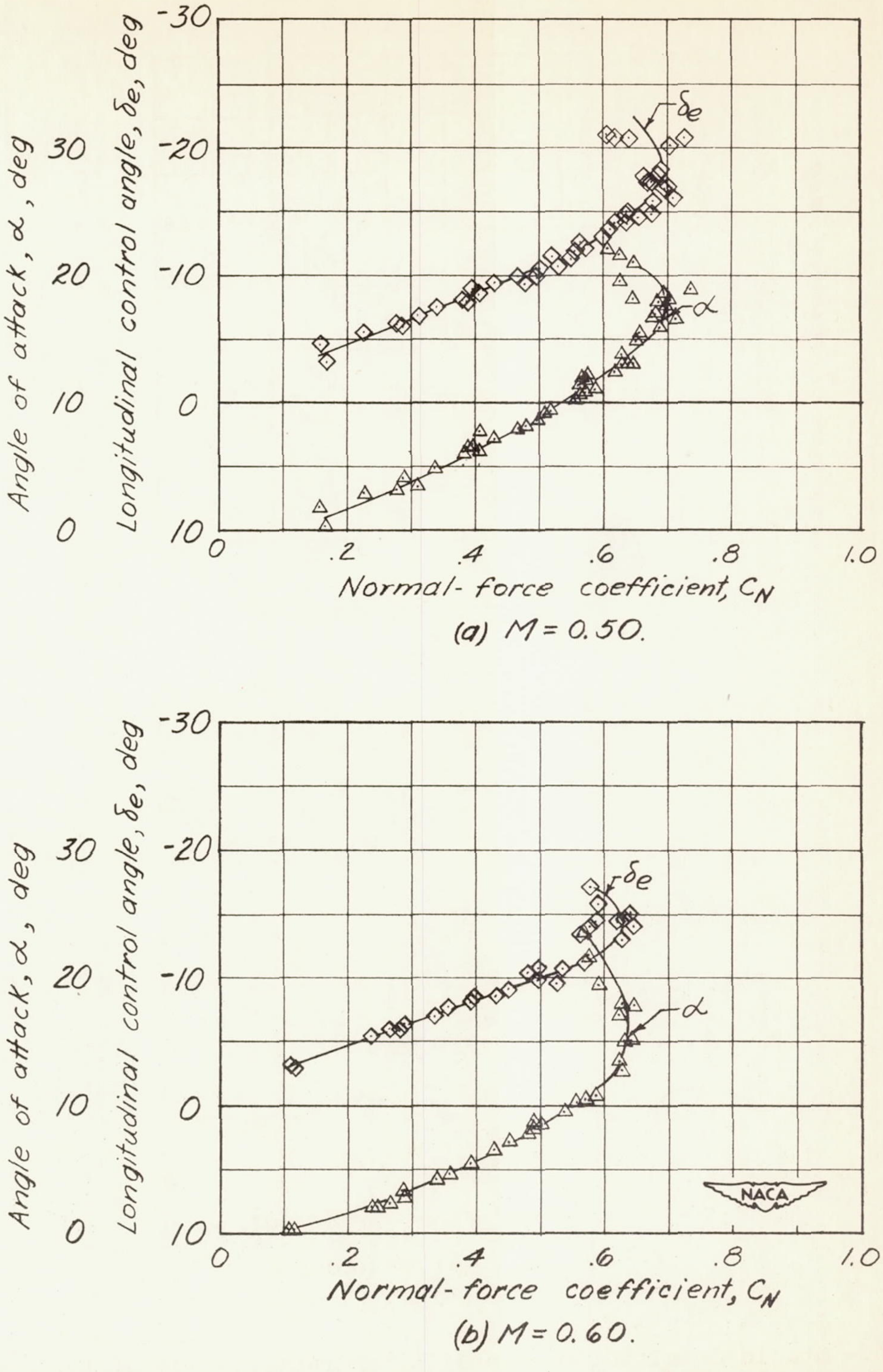
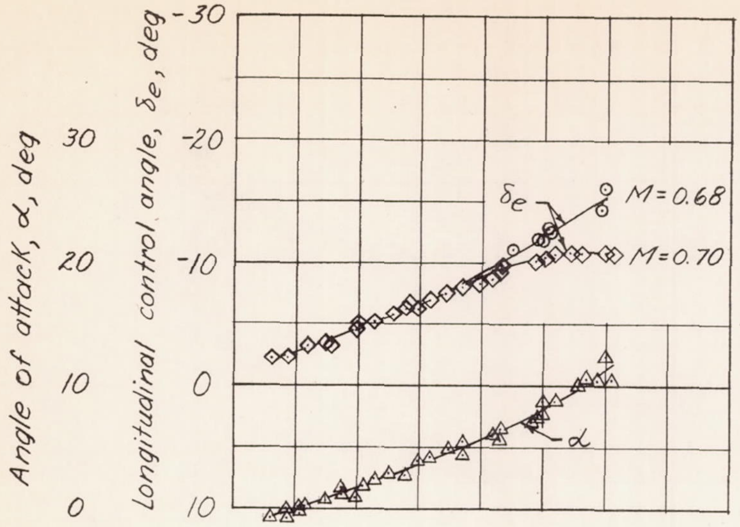
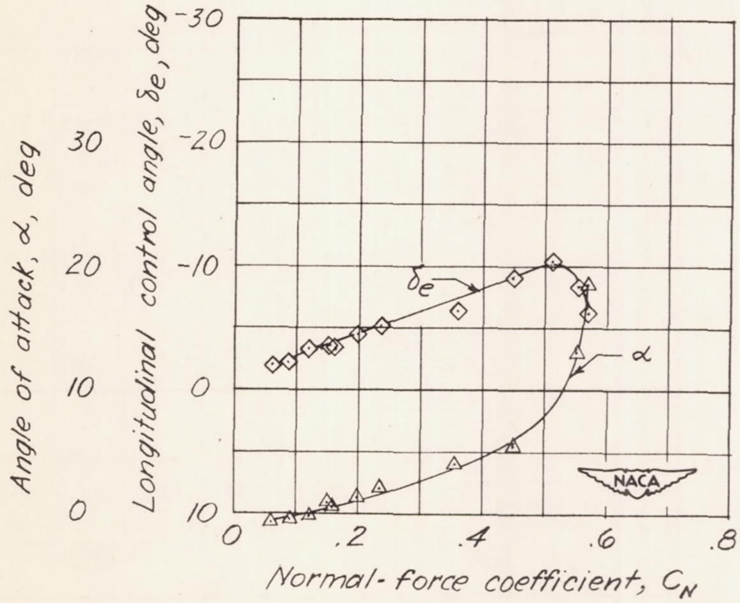


Figure 5.– Static longitudinal–stability characteristics of the X–4 airplane in lower Mach number accelerated stalls at an altitude of 30,000 feet.



(a) M = 0.68 and 0.70.



(b) M = 0.80.

Figure 6.– Static longitudinal–stability characteristics of the X–4 airplane in maneuvering flight at higher Mach numbers at an altitude of 30,000 feet.

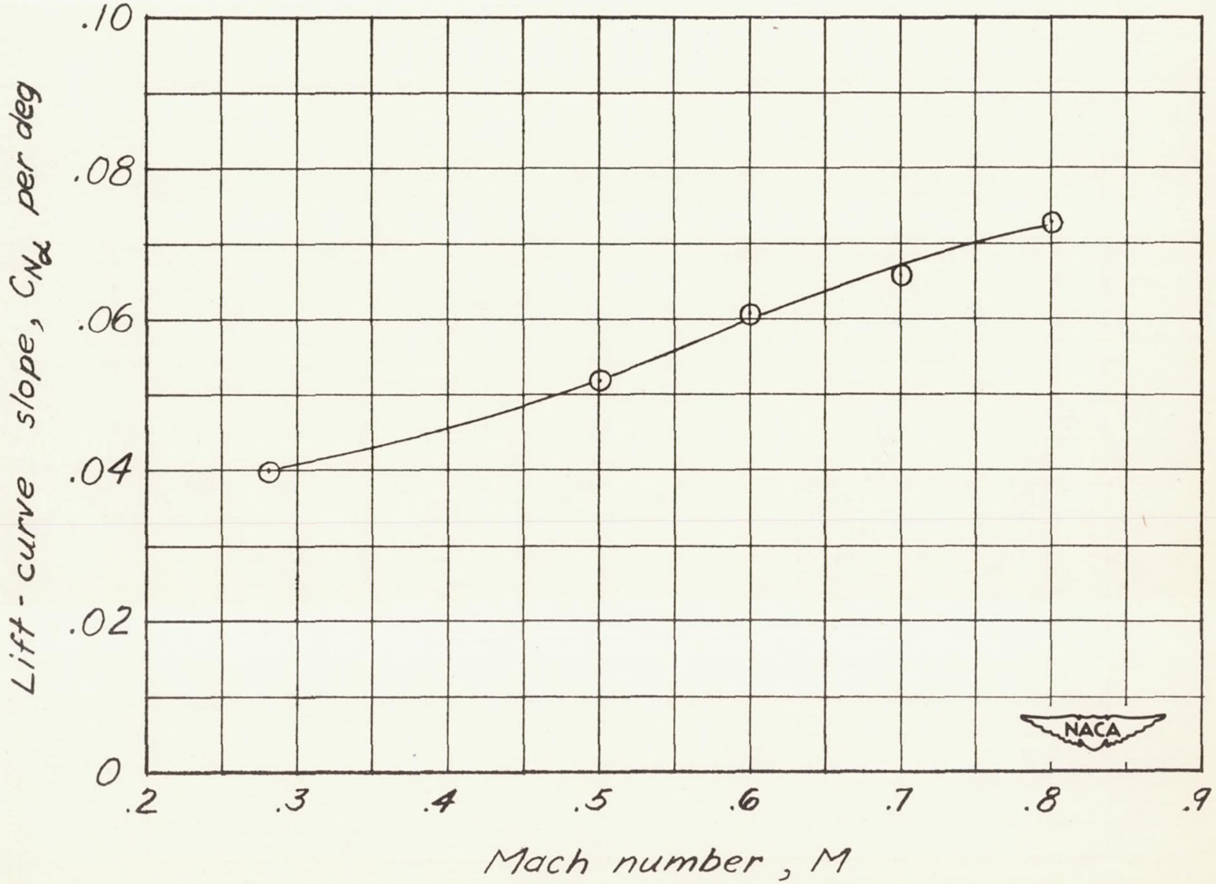


Figure 7.– Variation of lift–curve slope with Mach number. h_p = 20,000 30,000 feet. X-4 airplane.

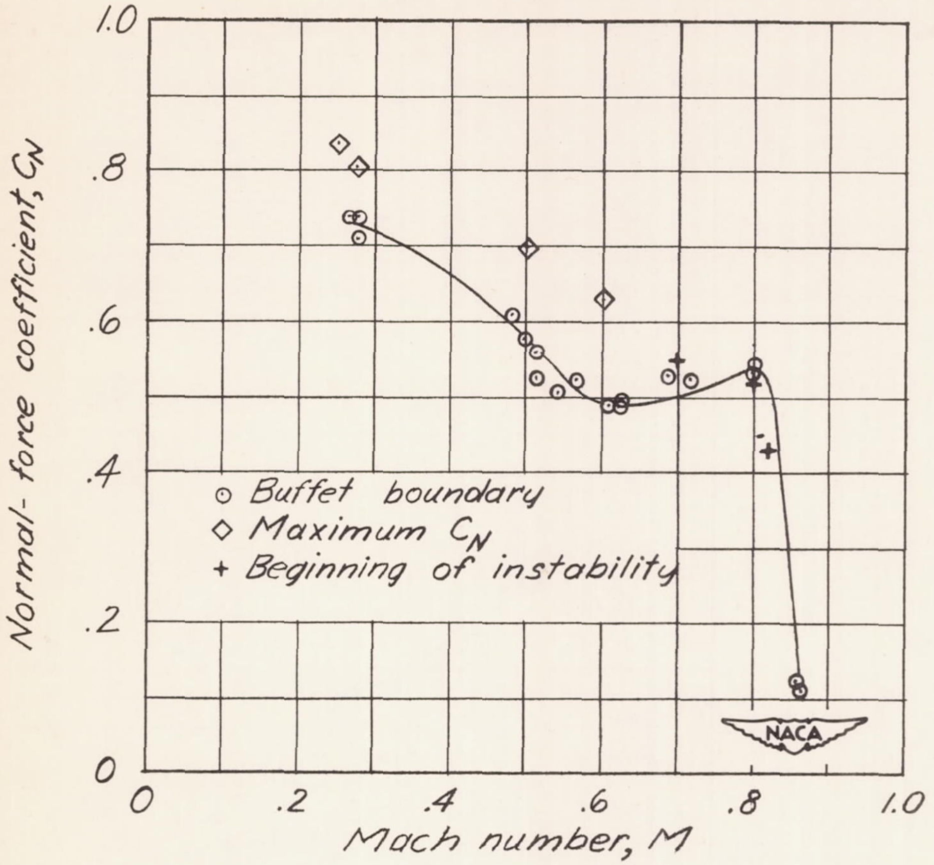
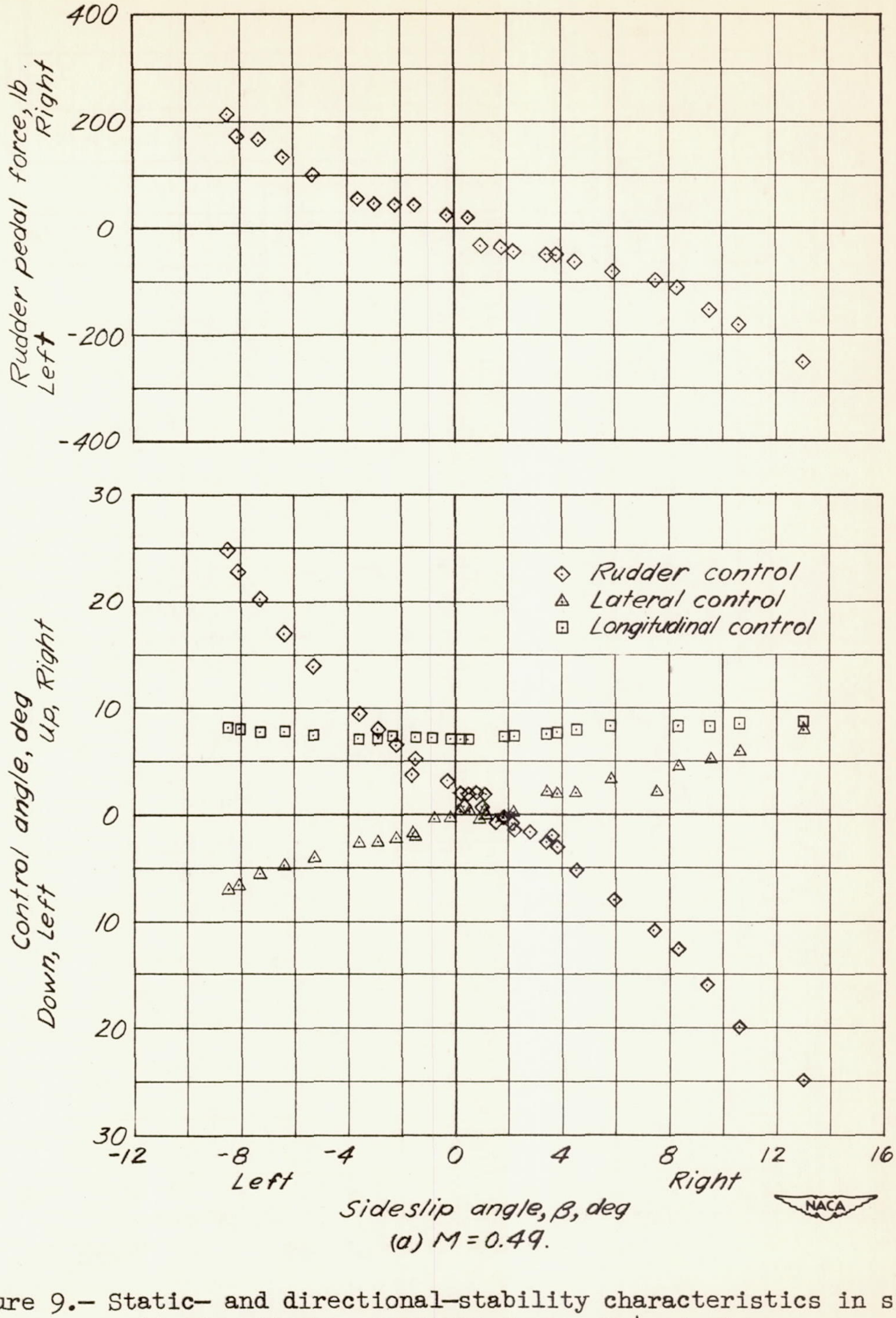
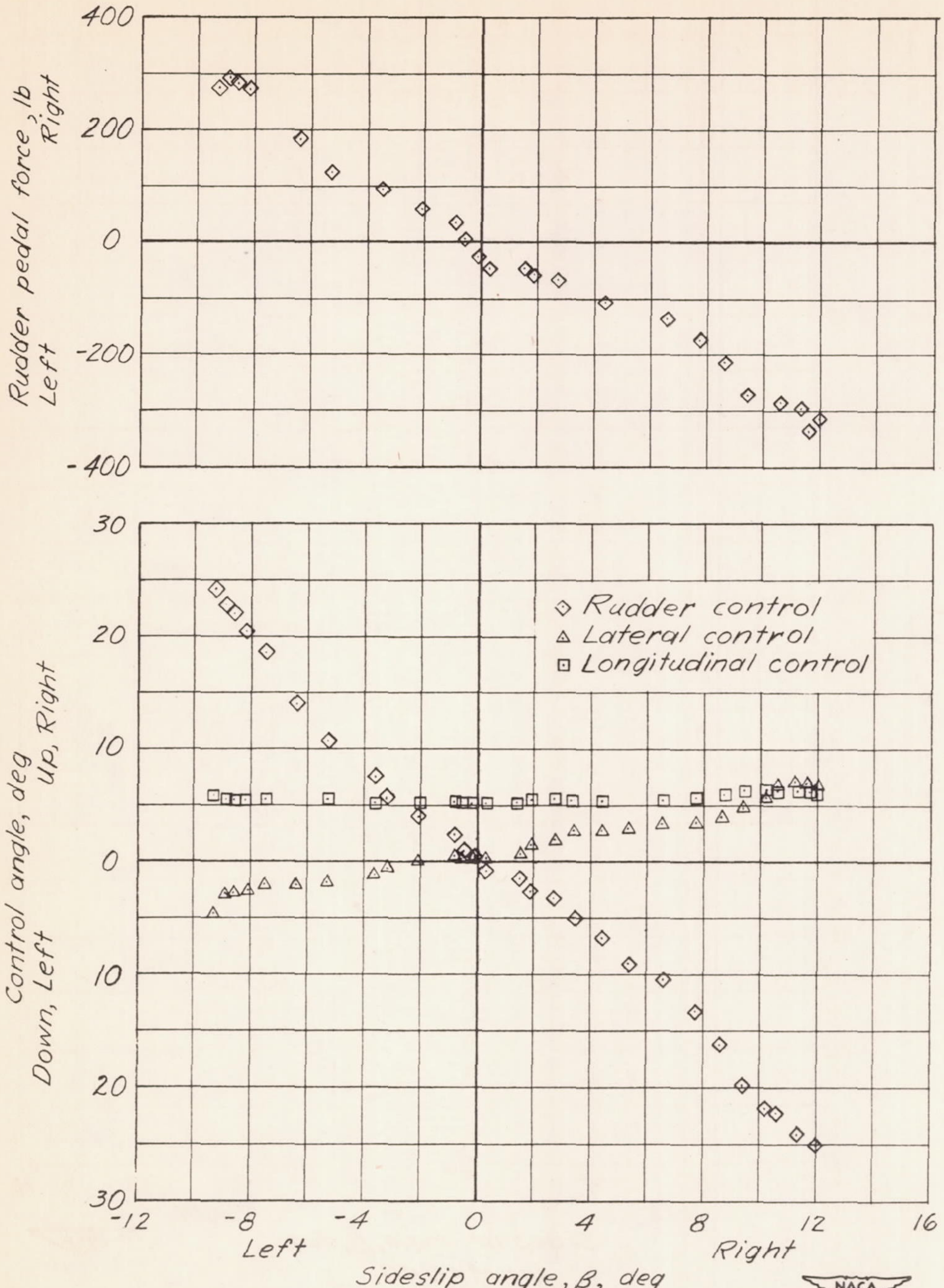


Figure 8.– Variation with Mach number of the normal-force coefficient at which static longitudinal instability and buffeting first occur. h_p = 20,000 and 30,000 feet. X-4 airplane.



(a) $M = 0.49$.

Figure 9.- Static- and directional-stability characteristics in sideslipping flight at 30,000 feet. X-4 airplane.



(b) $M = 0.61$.

Figure 9.– Continued.

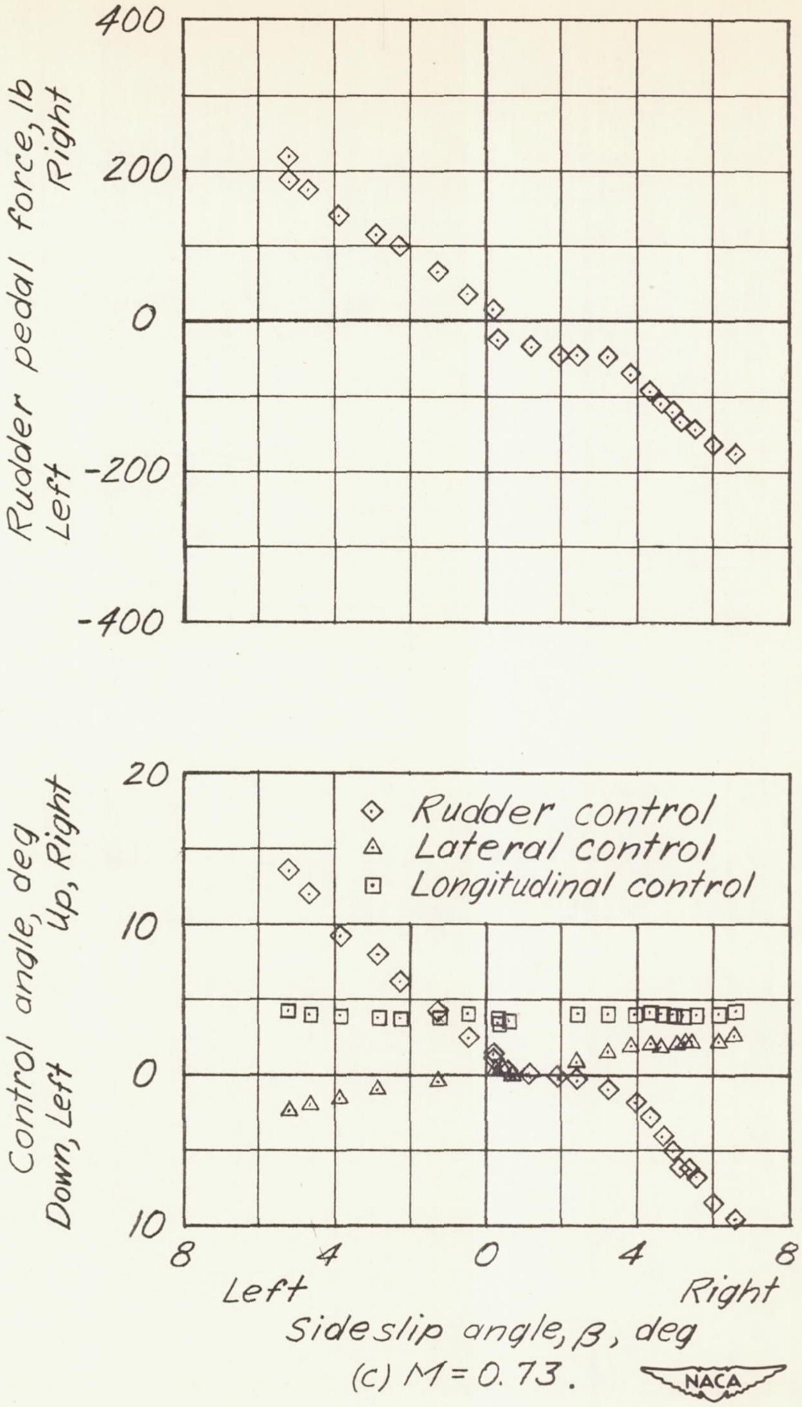
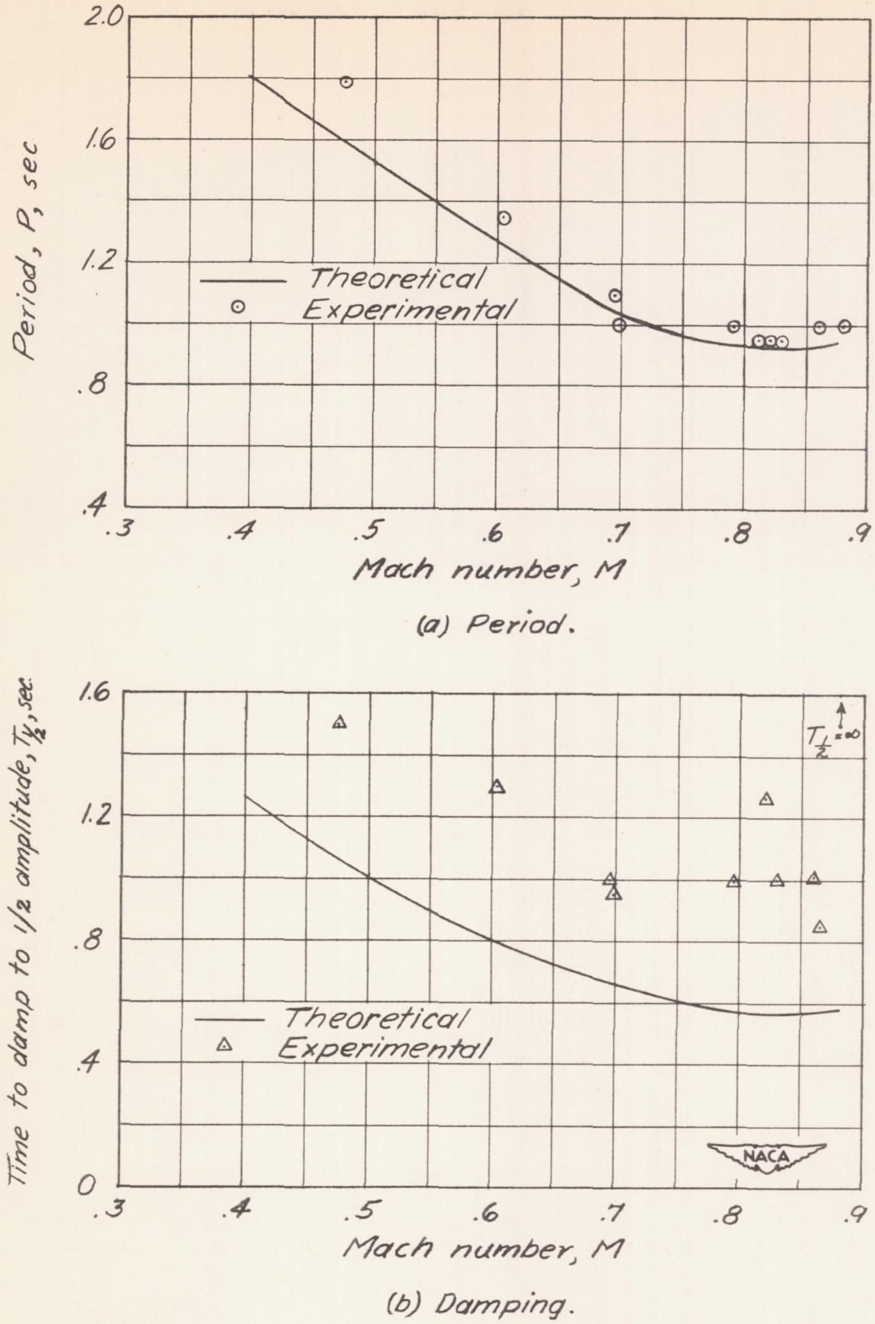


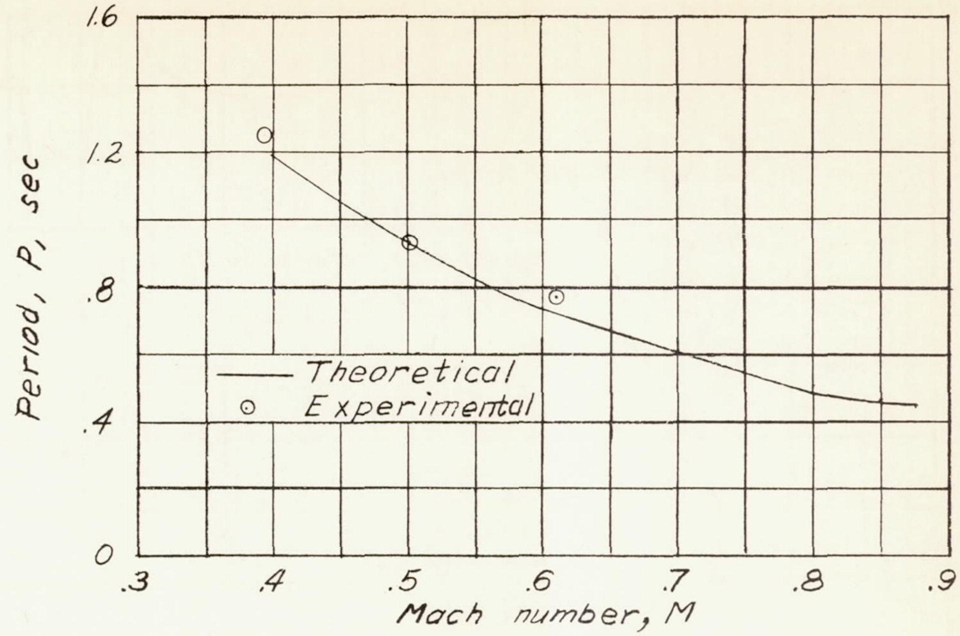
Figure 9.- Concluded.



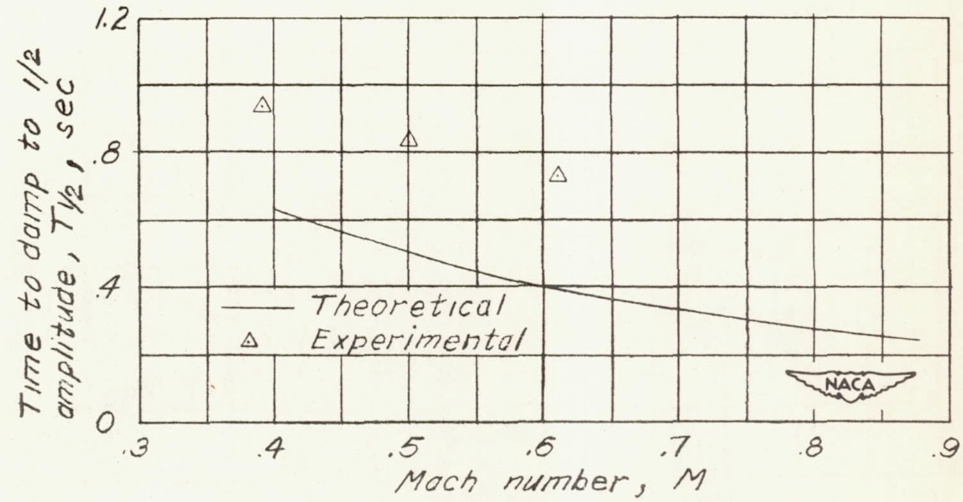
(a) Period.

(b) Damping.

Figure 10.- Comparison of the experimental short-period longitudinal oscillation period and damping with values computed by the simplified theory. h_p = 30,000 feet. X-4 airplane.

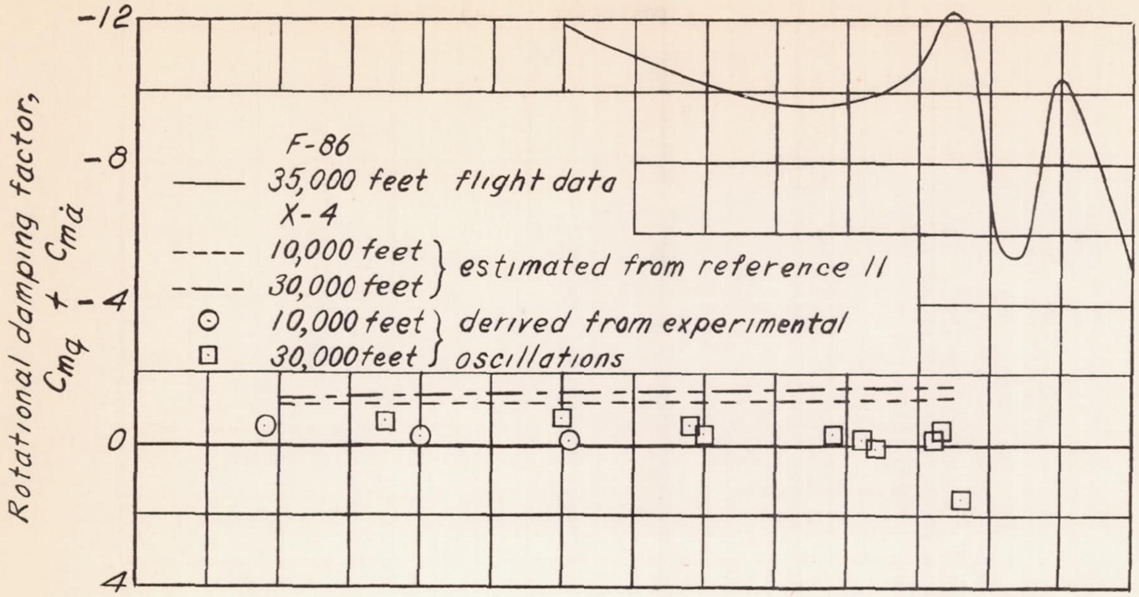


(a) Period.

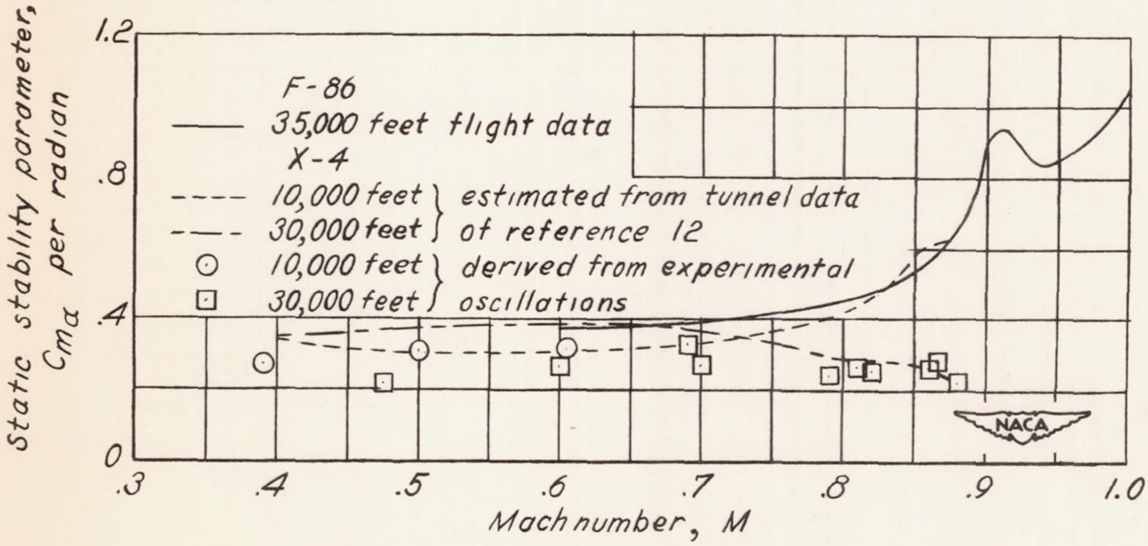


(b) Damping.

Figure 11.– Comparison of the experimental short-period longitudinal oscillation period and damping with values computed by the simplified theory. h_p = 10,000 feet. X-4 airplane.



(a) $C_{m_q} + C_{m_{\dot{\alpha}}}$.



(b) C_{m_α}.

Figure 12.- Variation with Mach number of the static stability parameter and rotational damping factor. X-4 and F-86 airplanes.

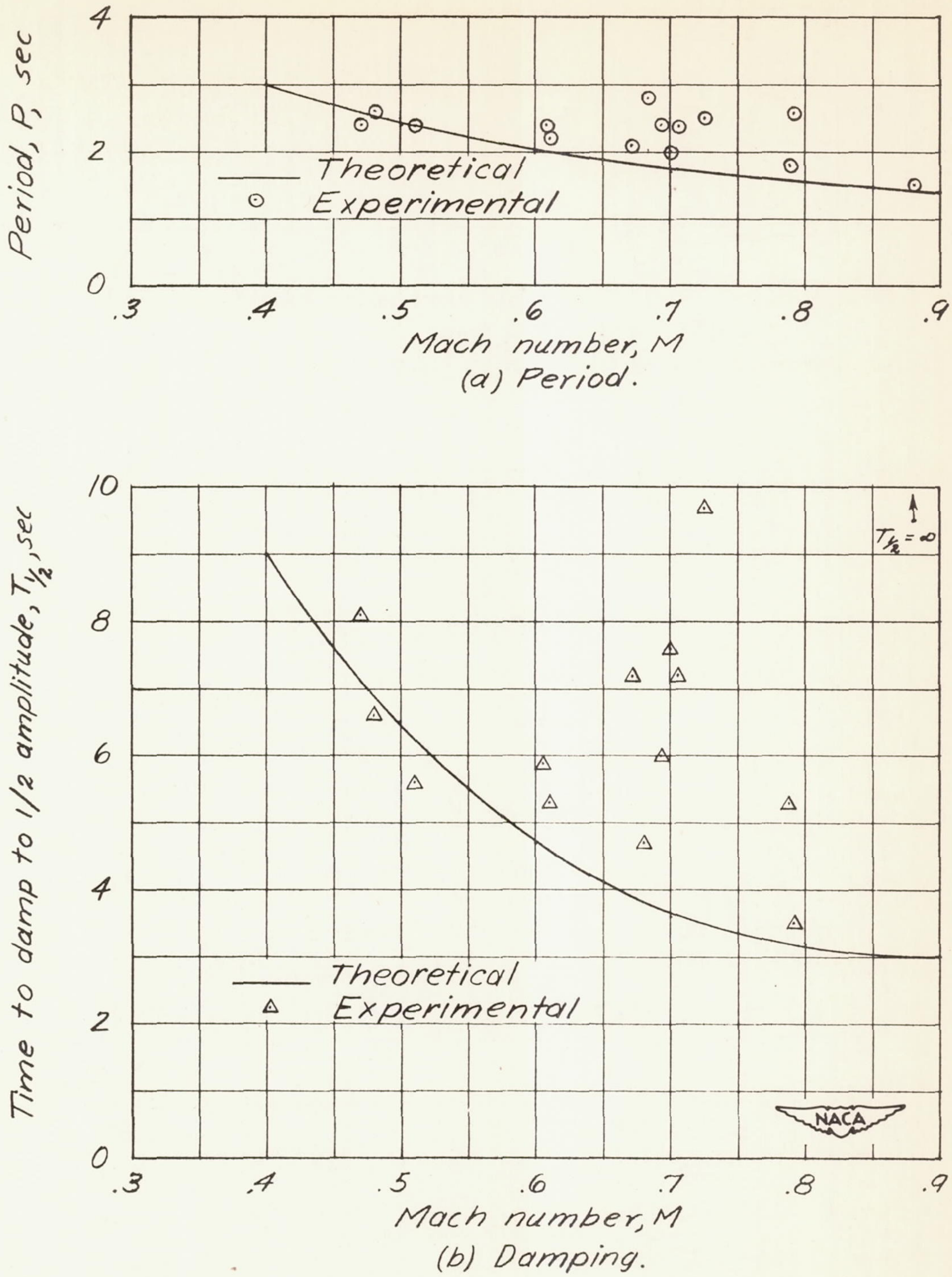
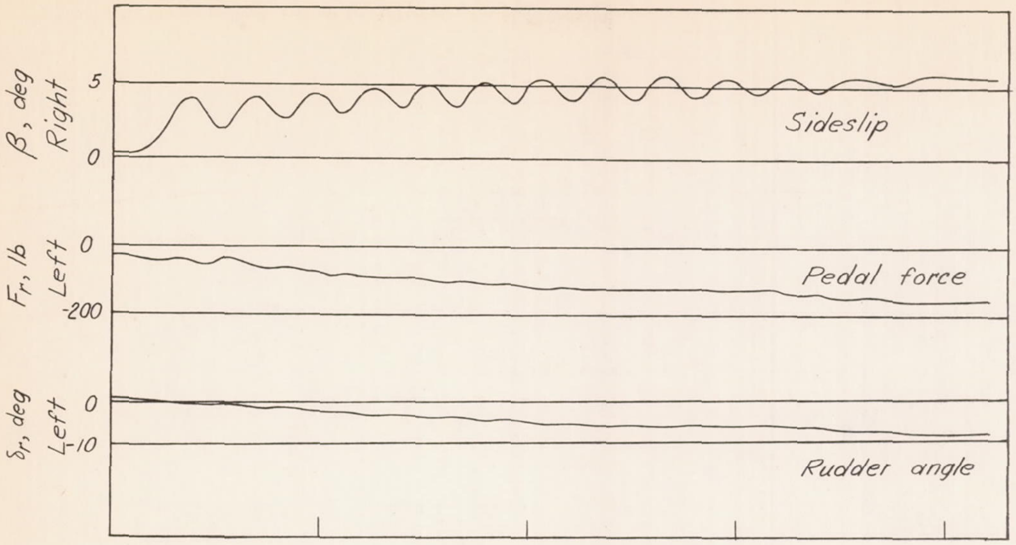
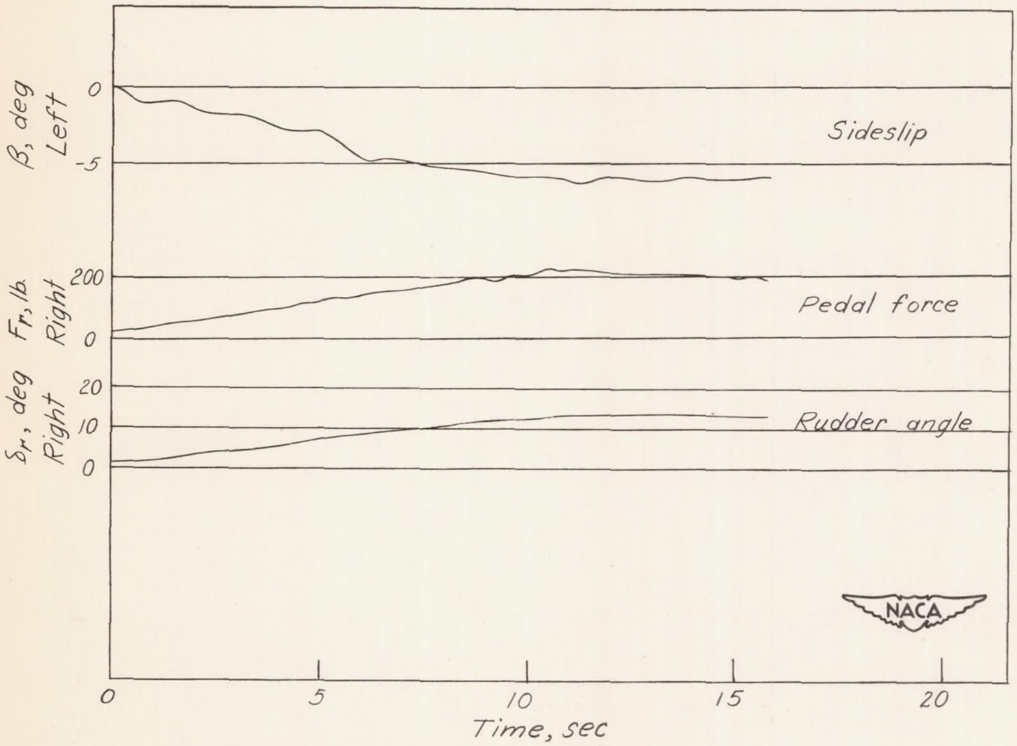


Figure 13.- Period and damping lateral-dynamic-stability characteristics of the X-4 airplane at an altitude of 30,000 feet.



(a) Right sideslip.



(b) Left sideslip

Figure 14.- Time history of left sideslip and of unusual oscillation in right sideslip experienced at a Mach number of about 0.73 at an altitude of 30,000 feet. X-4 airplane.

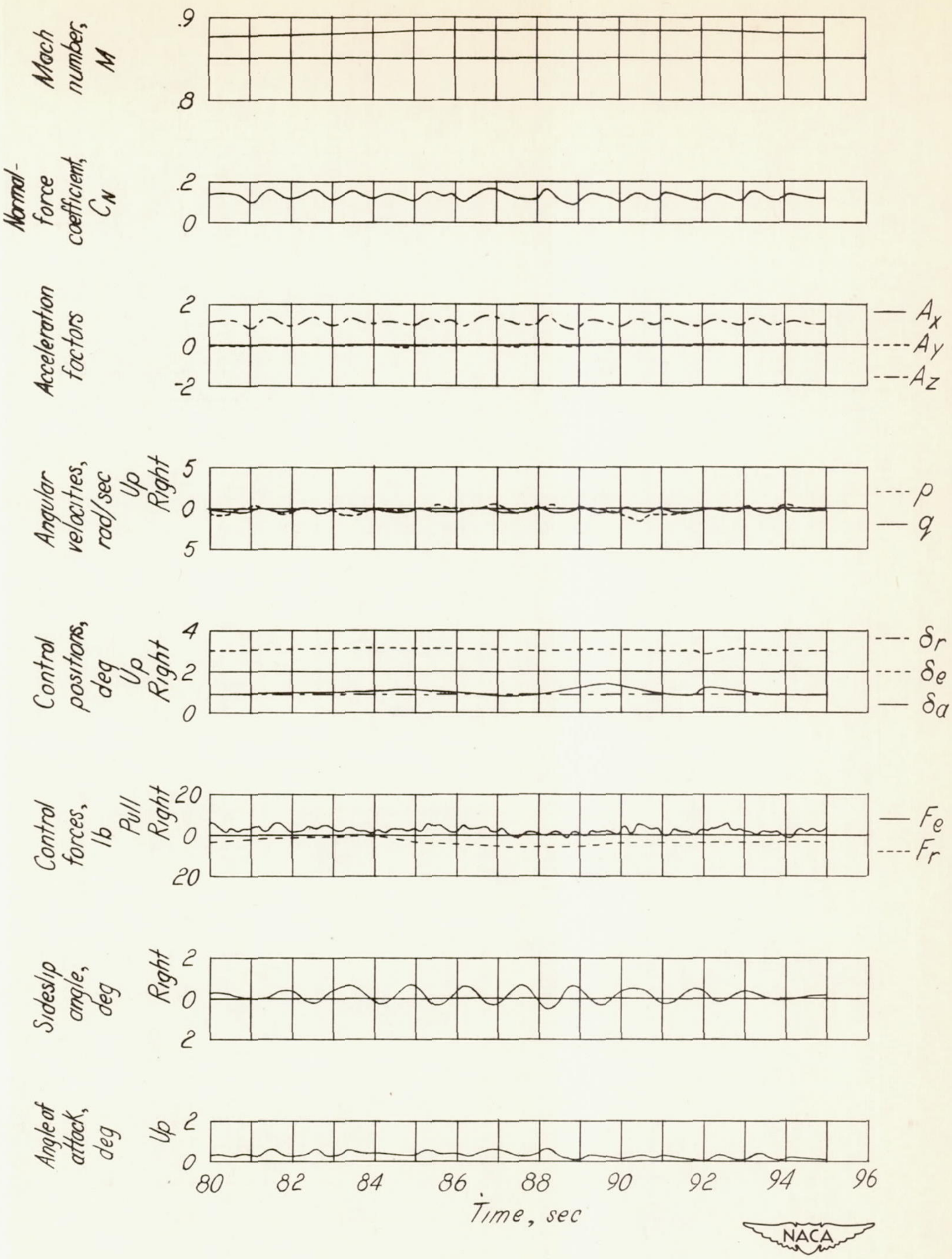


Figure 15.– Time history of undamped oscillation about all three axes experienced in straight flight at a Mach number of 0.88 at 30,000 feet. X-4 airplane.

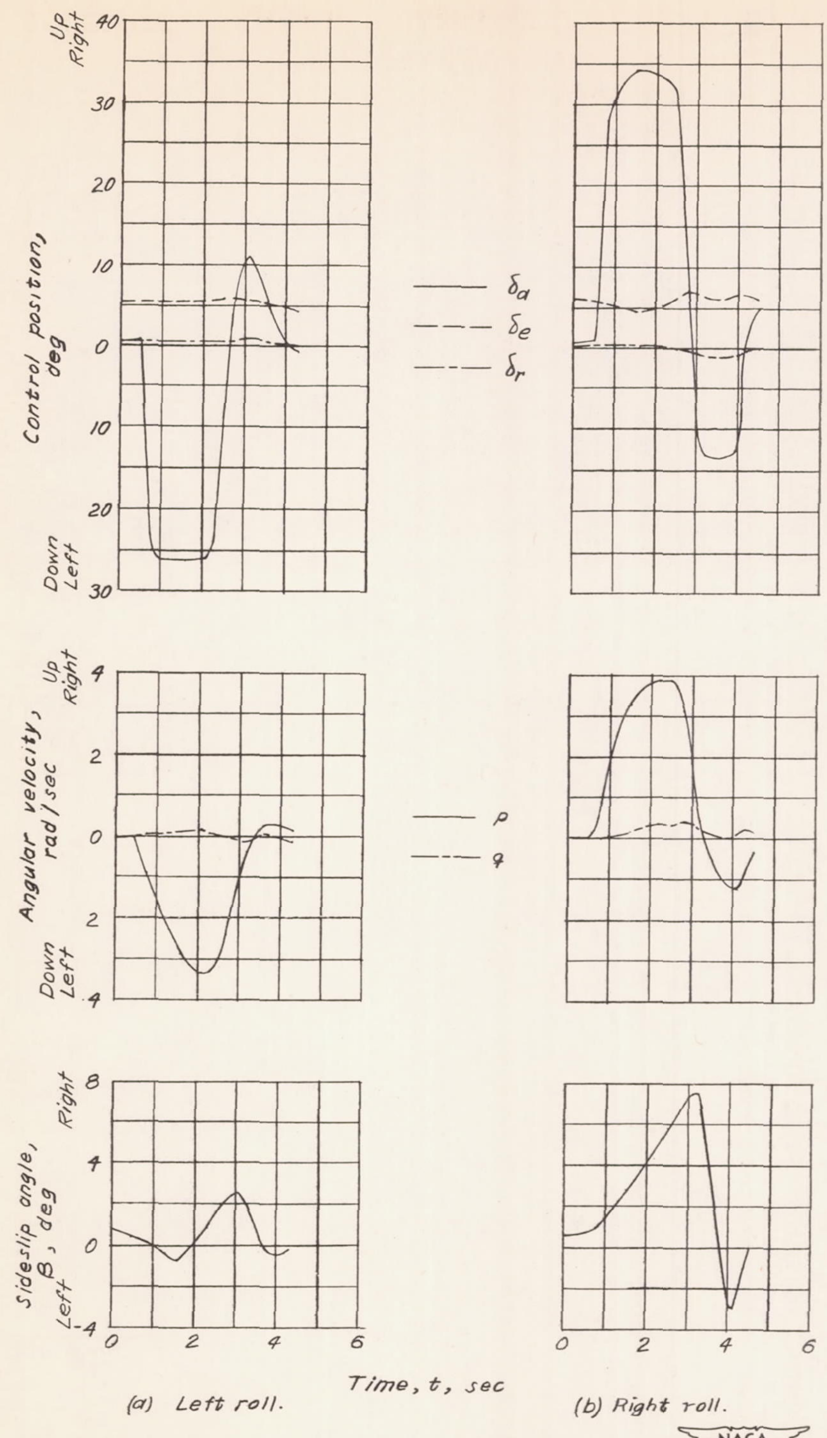


Figure 16.- Typical time histories of rudder-fixed aileron rolls at a Mach number of 0.60 at 30,000 feet. X-4 airplane.

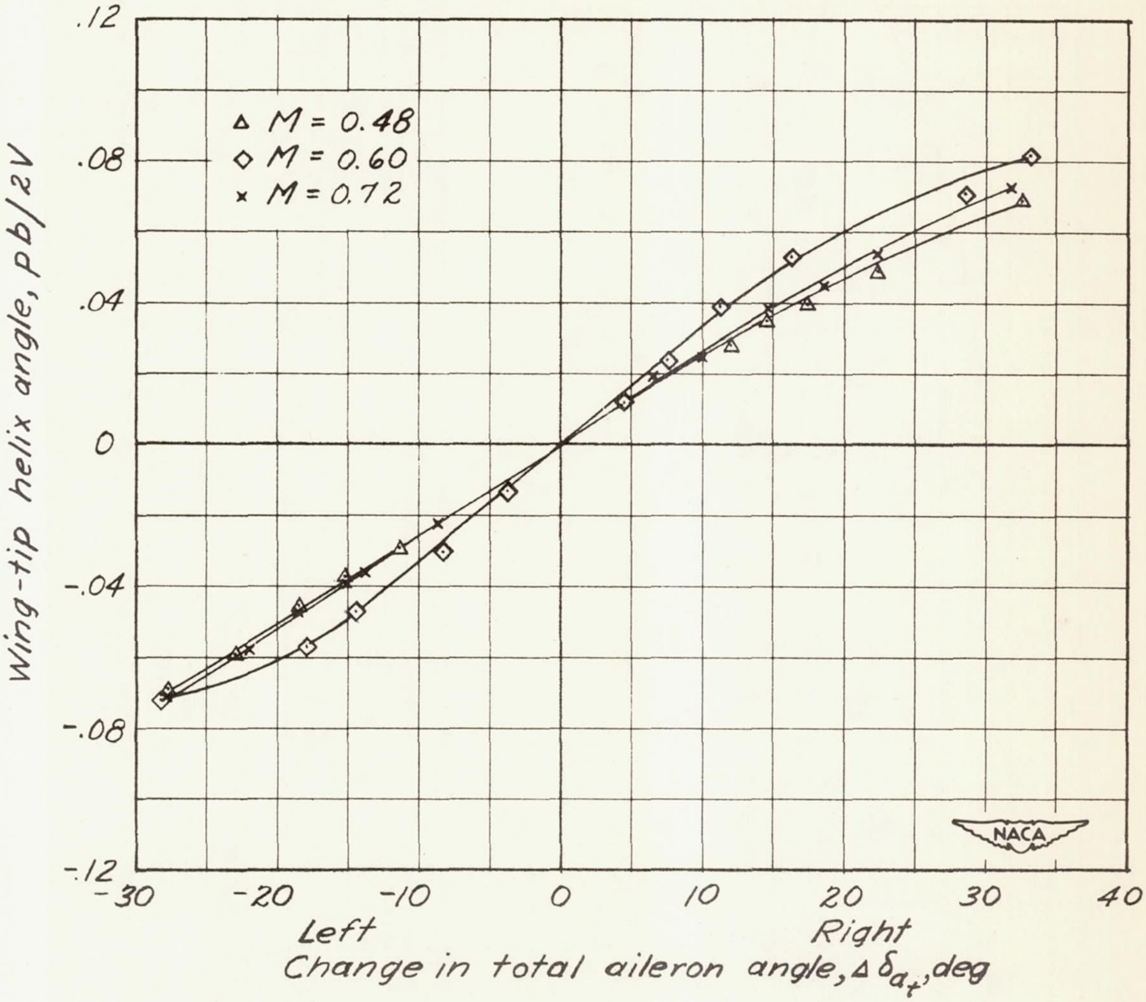


Figure 17.- Variation of wing-tip helix angle with change in total aileron angle at several values of Mach number at an altitude of 30,000 feet. X-4 airplane.

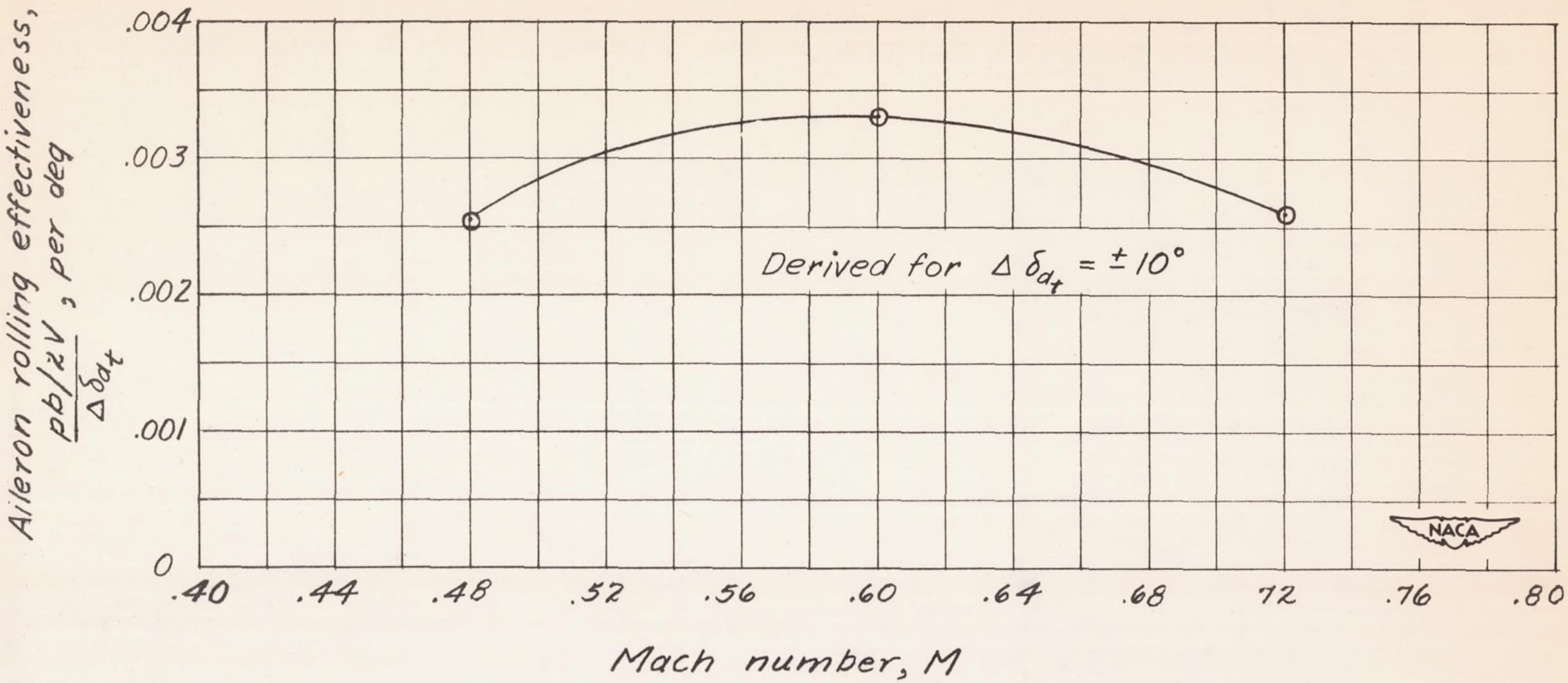


Figure 18.- Variation with Mach number of wing-tip helix angle per degree total aileron deflection at an altitude of 30,000 feet. X-4 airplane.

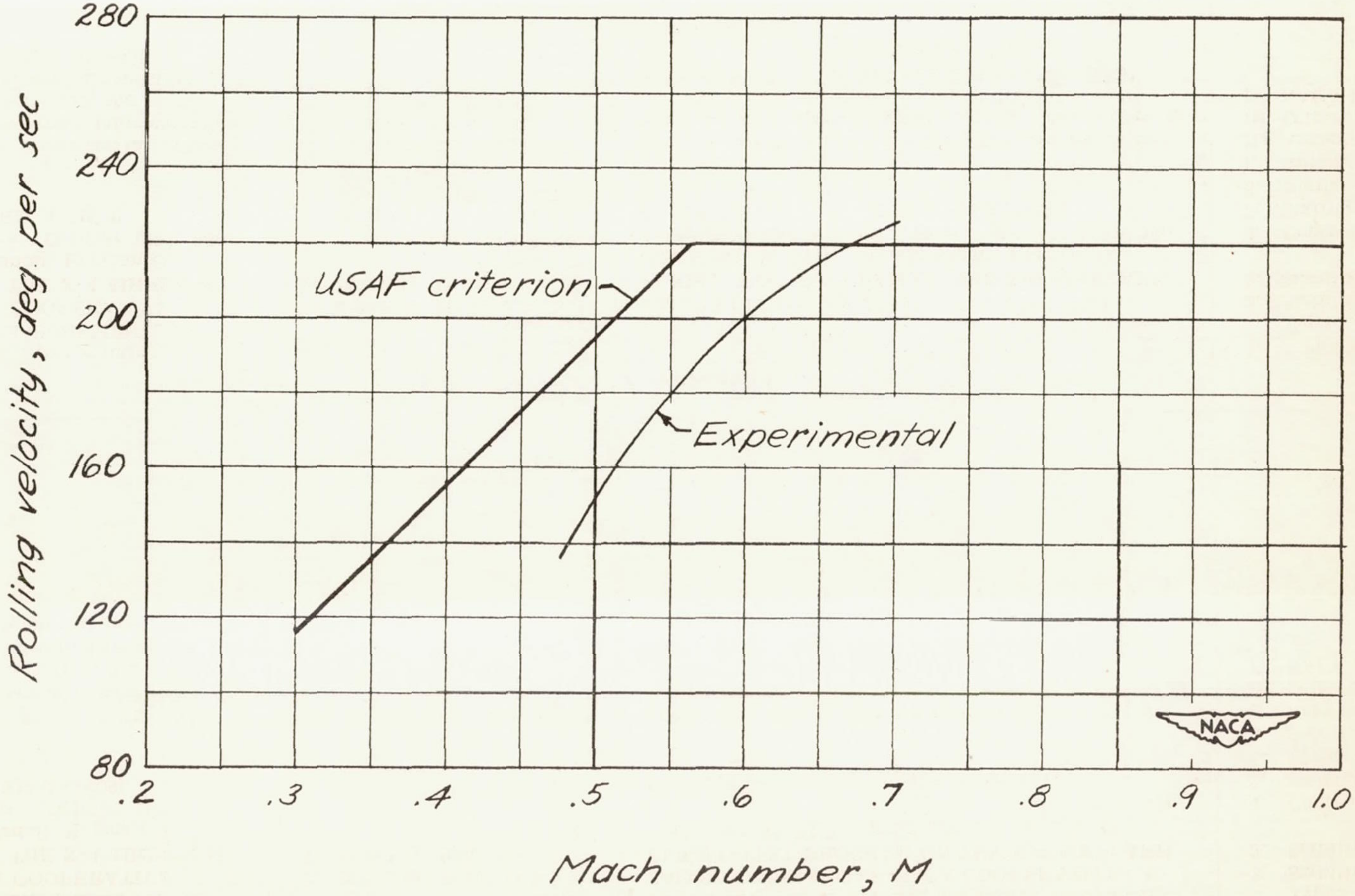


Figure 19.– Comparison of maximum rates of roll in X-4 airplane with USAF criterion for satisfactory characteristics. $\Delta\delta_{a_t} = 30^{\circ}$; $h_p = 30{,}000$ feet.