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RESEARCH MEMORANDUM

FLIGHT DETERMINATION OF THE STATIC LONGITUDINAL STABILITY BOUNDARIES OF THE BELL X-5 RESEARCH AIRPLANE WITH 59° SWEEPBACK

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT DETERMINATION OF THE STATIC LONGITUDINAL STABILITY BOUNDARIES OF THE BELL X-5 RESEARCH AIRPLANE WITH 59° SWEEPBACK

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SUMMARY

During the flight program on the Bell X-5 airplane with 59° sweepback to determine the practical Mach number and normal-force coefficient limits of this configuration, a reduction in static longitudinal stability was encountered in maneuvering flight. A determination of the boundary for reduction of longitudinal stability extending to a Mach number of 0.98 is presented in this paper.

A reduction of static longitudinal stability existed for all elevator and all stabilizer-executed maneuvers. The reduction of stability existed for maneuvers executed with elevator near a normal-force coefficient of 0.6 for a Mach number range of about 0.31 to 0.76. Above a Mach number of 0.76 the normal-force coefficient for reduction of stability gradually decreased to a value of 0.2 at a Mach number of 0.98. For stabilizer-executed maneuvers the stability boundary was the same as for elevator maneuvers up to a Mach number of 0.88. Above this Mach number the reduction of stability occurred at slightly higher normal-force coefficients decreasing from about 0.51 at a Mach number of 0.92 to a value of 0.34 at a Mach number of 0.97. The airplane has been flown to a Mach number of 1.04 at a normal-force coefficient of about 0.15 without encountering any reduction of stability.

The pilot did not consider the reduction of stability to be dangerous at altitudes above 30,000 feet; however, precise flight was impossible. At angles of attack above that at which the reduction of longitudinal stability occurred, directional instability and aileron control overbalance were encountered.

INTRODUCTION

The Bell X-5 variable-sweep airplane was procured for the National Advisory Committee for Aeronautics by the U. S. Air Force as part of the joint Air Force-Navy-NACA high-speed flight research program. Upon completion of the demonstration tests by the Bell Aircraft Corp. and the Air Force, the airplane was assigned to the NACA for research purposes. It was decided that immediate emphasis should be placed upon obtaining flight data at the maximum wing sweep angle. A series of flights were initiated by the NACA High-Speed Flight Research Station at Edwards Air Force Base, Calif. to explore the practical Mach number and the normal-force-coefficient limits of the 59° sweep configuration. A reduction in static longitudinal stability which limited the usable value of normal-force coefficient was encountered in these exploratory flights. One of the first aims of the research investigation, therefore, was the determination of the boundary for reduction in longitudinal stability. The results of the investigation to determine this boundary for the 59° sweep condition are presented in this paper.

SYMBOLS

a_y	transverse acceleration, g units
C_{N_A}	airplane normal-force coefficient, nW/qS
c	chord at any section along the span, ft
c.g.	center of gravity
$d\delta_e/d\alpha$	measured slope of variation of elevator deflection with angle of attack
F	control force, lb
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
i_t	angle of tail incidence measured from line parallel to longitudinal axis of airplane, deg
M	Mach number
M.A.C.	mean aerodynamic chord, ft
n	normal acceleration, g units
q	dynamic pressure, lb/sq ft

S wing area of sweep angle tested, sq ft

t time, sec

W airplane weight, lb

α angle of attack, measured from longitudinal axis of airplane, deg

β angle of sideslip, deg

δ control deflection, deg

$\dot{\theta}$ pitching velocity, radians/sec

$\Lambda_{c/4}$ sweep angle of quarter chord of wing measured between the normal to the airplane line of symmetry and the quarter-chord line, deg

$\dot{\varphi}$ rolling velocity, radians/sec

$\dot{\psi}$ yawing velocity, radians/sec

Subscripts:

a aileron

e elevator

L left

R right

r rudder

DESCRIPTION OF THE AIRPLANE

The Bell X-5 airplane is a transonic research airplane incorporating a wing which has sweepback variable in flight between 20° and 59°. It is a single-place fighter-type airplane powered by an Allison J-35-A-17 turbojet engine. A photograph of the airplane is given in figure 1 and a three-view drawing is presented in figure 2. A complete description of the airplane and wing sweep angle and translation characteristics is given in reference 1. The airplane physical characteristics are given in table I.

INSTRUMENTATION AND ACCURACY

The following quantities were recorded on NACA internal recording instruments synchronized by a common timer:

- Vertical, longitudinal, and transverse acceleration
- Sensitive longitudinal acceleration
- Rolling angular velocity
- Pitching angular velocity and acceleration
- Yawing angular velocity and acceleration
- Airspeed and altitude
- Angle of sideslip and angle of attack
- Control positions
- Wing sweep angle
- Elevator and aileron stick force
- Rudder pedal force

Strain gages were installed to record shear and bending moments on the horizontal tail.

A complete description of the airspeed system is given in reference 1. The system includes an NACA high-speed type A-6 total pressure head described in reference 2. With an estimated error of ±100 pounds in the weight determination and an estimated error of ±0.02g in normal acceleration, the maximum error in the determination of airplane normal-force coefficient would be about ±0.03.

The accuracy of Mach number obtained from the airspeed calibration is within ±0.01.

TESTS

The tests were conducted in the clean configuration and consisted of gradual turns and pull-ups performed by use of either the elevator control or the stabilizer control over a Mach number range of 0.67 to 0.98. Diving the airplane was necessary to obtain data above M = 0.93. The altitude range of these tests was between 32,000 and 42,500 feet.

RESULTS AND DISCUSSION

Time histories of the measured quantities obtained during maneuvers executed by use of elevator over a Mach number range of 0.67 to 0.98 are presented in figure 3. Examination of these time histories shows that each maneuver has a stable range characterized by increasing up-elevator deflection and pull stick force with increasing normal-force coefficient or angle of attack. In this region the rates of pitching and control movement are sufficiently low that the airplane can be considered to be in trimmed flight. This region is followed by a range generally characterized by an increase in the pitching rate with the same or decreasing rate of change of elevator deflection. There is usually a reduction or reversal of the stick force at the same or slightly later time, indicating a stick-free instability. In this region the pitching accelerations are generally too great to permit the maintaining of trimmed flight; the data, therefore, cannot be used to indicate the degree of stick-fixed stability. It is apparent from these time histories that there is a variation with Mach number of the angle of attack and normal-force coefficient at which the reduction in stability occurs. The points at which the reduction in stability occurs are indicated on the time histories.

The change in stick-fixed stability is also shown in figure 4 which presents the variations of elevator deflections with angle of attack for the maneuvers performed and the change of stick-free stability as shown by stick force plotted against angle of attack is presented in figure 5. The points at which the stability decreased as shown by the abrupt decrease of the slope are indicated in figures 4 and 5. It may be noted that the reduction of stick-free stability occurs almost simultaneously with the reduction of stick-fixed stability. Because the data at angles of attack above this point were obtained as the airplane was pitching, the true degree of stability is not indicated by $d\delta_e/d\alpha$ at the higher angles of attack. The conditions which indicate stick-fixed stability after the change of $d\delta_e/d\alpha$ (figs. 4(f) to 4(i)) are unstable stick free and the variation of stick-fixed stability may, therefore, be masked to the pilot. It may be noted in figure 4 that, for most of the maneuvers performed above $M = 0.92$, there was only a small increase in angle of attack above the point of reduction in stability. This inability to obtain higher angles of attack was associated with the loss of Mach number occurring during these maneuvers. This is illustrated in figure 6 where the variation of C_{N_A} with Mach number is shown for all the maneuvers of figure 4. The Mach number decreases rapidly for those maneuvers above $M = 0.92$ because of the rapid increase in drag due to lift. A more rapid pull-up into the region of reduced stability cannot be performed easily with the elevator because of the reduced control effectiveness and the high stick forces.

In order to penetrate into the region of reduced stability at a relatively constant Mach number, it was necessary to perform pull-ups utilizing the motor-driven stabilizer. This meant, however, some loss of the pilot's evaluation of the severity of the maneuver because of lack of feel. Maneuvers were executed with the stabilizer over the range of Mach numbers from 0.71 to 0.97. As is shown on figure 7, use of the stabilizer permitted the maneuvers to be made with little loss of speed. Examination of the time histories of figure 8 shows that the behavior of the airplane is generally similar to that measured during elevator pull-ups with the exception that the pitching velocities are generally higher because of the increased control effectiveness and rate of application. The reduction in stability as determined by the increased rate of change of angle of attack with a constant rate control application is indicated on the time histories. The reduction in stability is more sharply defined by the variations of stabilizer deflection with angle of attack as presented in figure 9. The angles of attack for reduction in stability as defined by an abrupt decrease in the slope $di_t/d\alpha$ are indicated.

The boundary for the reduction in stick-fixed longitudinal stability is presented in figure 10 as the variation with Mach number of the normal-force coefficient corresponding to the angle of attack for decreased stability selected in figures 4 and 9. No data are available in maneuvering flight at Mach numbers below $M = 0.67$; however, the low-speed stall approach data, as presented in reference 1, indicate neutral stability existed above normal-force coefficients of 0.6 at Mach numbers less than 0.31. Therefore, the present data indicate that the normal-force coefficient for the reduction of stability remains at about 0.6 to a Mach number of 0.76. Above this Mach number there is a steady decrease in C_{N_A} for both elevator and stabilizer pull-ups to a value of about 0.47 at $M = 0.88$. Above $M = 0.88$, C_{N_A} continues to decrease for elevator pull-ups to a value of 0.2 at $M = 0.98$. For stabilizer pull-ups C_{N_A} increases above $M = 0.88$ to a value of about 0.51 at $M = 0.92$ and then decreases to 0.34 at $M = 0.97$. Although the airplane has been flown to a Mach number of 1.04 at a normal-force coefficient of about 0.15 without any reduction of stability, the boundary near $M = 0.98$ approaches level-flight normal-force coefficients resulting in a very small stable range for maneuvering flight.

The pilot's impressions of the reduction of longitudinal stability are somewhat complicated by the almost simultaneous occurrence of a directional instability followed by aileron overbalance. Figure 11 presents a time history of the lateral quantities measured during one elevator executed maneuver (fig. 3(c)) which shows the directional divergence which reached a sideslip of 20° before it could be controlled. The rapid rolling and rapid aileron motions associated with the maneuver are also shown. As the airplane pitches, it generally yaws and rolls, and then aileron overbalance occurs causing the stick to jerk from side to side if not restrained. The low-speed stall approach is generally characterized by a tendency to roll-off which is more difficult to control with decreasing speed because of low aileron effectiveness, and by decreasing directional stability with a decrease in speed which generally causes the airplane to yaw to the left. The combination of the change in longitudinal stability and directional instability has on occasion caused accidental spins following elevator pull-ups. The pilot felt that the severity of the motions after the reduction of stability increased as the initial rate of change of angle of attack was increased. The most severe pitching occurred during those maneuvers performed at Mach numbers below 0.92.

All of these tests were made at altitudes above 30,000 feet so that the overshoot in acceleration was not excessive, being a minimum of about 1g. Although the pitching motion could be stopped, with this amount of overshoot, continued flight in this region was not possible because of the directional instability and aileron overbalance. In the pilot's opinion the airplane would not be suitable for use as a gun platform or any other precision work while flying in the lift region above the boundary for reduction of longitudinal stability. Should the airplane be flown into this region at low altitudes the reduction of stability would be dangerous, with loads of sufficient magnitude to break the airplane being produced.

It should be pointed out and emphasized that the X-5 in the region below the boundary has a high degree of longitudinal stability, as was mentioned in reference 1 and can be seen in figures 4 and 9. Should a lower and more normal value of static margin be used the pitching motions at angles of attack above the boundary might very well be much more violent.

CONCLUSIONS

From the results obtained during flight investigations of the Bell X-5 airplane at 59° sweepback at altitudes above 30,000 feet, it may be concluded that:

1. A reduction of static longitudinal stability both stick fixed and stick free existed for maneuvers executed with the elevator near a normal-force coefficient of 0.6 for a Mach number range of about 0.31 to 0.76. Above a Mach number of 0.76 the normal-force coefficient for a reduction in stability gradually decreased to a value of 0.2 at a Mach number of 0.98.

2. The reduction in stability during stabilizer maneuvers occurred at the same normal-force coefficients as for elevator pull-ups at Mach numbers up to 0.88. The normal-force coefficient for reduction in

stability then decreased from a value of about 0.51 at a Mach number of 0.92 to a value of 0.34 at a Mach number of 0.97.

3. The airplane has been flown to a Mach number of 1.04 at a normal-force coefficient of about 0.15 without encountering any reduction of stability.

4. The pilot considered that the longitudinal motions following the reduction of stability were not dangerous at the high altitude of the tests, but would prevent accurate gunnery or other precise maneuvers. It was felt that at low altitude the motions would be dangerous.

5. A directional instability and aileron overbalance occur after the reduction of longitudinal stability.

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National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Finch, Thomas W., and Briggs, Donald W.: Preliminary Results of Stability and Control Investigation of the Bell X-5 Research Airplane. NACA RM L52K18b, 1953.

2. Gracey, William, Letko, William, and Russell, Walter R.: Wind-Tunnel Investigation of a Number of Total-Pressure Tubes at High Angles of Attack. Subsonic Speeds. NACA TN 2331, 1951. (Supersedes NACA RM L50G19.)

TABLE I

PHYSICAL CHARACTERISTICS OF BELL X-5 AIRPLANE

Airplane:	
Weight, lb:	
Full fuel	9960
Less fuel	7850
Power plant:	
Axial-flow turbojet engine	J-35-A-17
Guaranteed rated thrust at 7800 rpm and static sea-level conditions, lb	4900
Center-of-gravity position, percent M.A.C.:	
Full fuel	45.6
Less fuel	46.2
Moments of inertia for 59° sweep (clean configuration-full fuel), slug-ft^2:	
About Y-axis	9495
About Z-axis	8040
Over-all height, ft	12.2
Over-all length, ft	33.6
Wing:	
Airfoil section (perpendicular to 38.02-percent-chord line):	
Pivot point	NACA $64_{(10)}$A011
Tip	NACA $64_{(08)}$A008.28
Sweep angle at 0.25 chord, deg	59
Area, sq ft	184.3
Span, ft	20.0
Span between equivalent tips, ft	19.2
Aspect ratio	2.16
Taper ratio	0.4095
Mean aerodynamic chord, ft	10.05
Location of leading edge of mean aerodynamic chord, fuselage station	100.2
Incidence root chord, deg	0
Dihedral, deg	0
Geometric twist, deg	0
Wing flaps (split):	
Area, sq ft	15.9
Span, parallel to hinge center line, ft	6.53
Chord, parallel to line of symmetry at 20° sweepback, in.:	
Root	30.8
Tip	19.2
Travel, deg	60

TABLE I.- Continued

PHYSICAL CHARACTERISTICS OF BELL X-5 AIRPLANE

Slats (leading edge divided):	
Area, sq ft	14.6
Span, parallel to leading edge, ft	10.3
Chord, perpendicular to leading edge, in.:	
Root	11.1
Tip	6.6
Travel, percent wing chord:	
Forward	10
Down	5
Aileron (45 percent internal-seal pressure balance):	
Area (each aileron behind hinge line), sq ft	3.62
Span parallel to hinge center line, ft	5.15
Travel, deg	±15
Chord, percent wing chord	19.7
Moment area rearward of hinge line (total), in.^{3}	4380
Horizontal tail:	
Airfoil section (parallel to fuselage center line)	NACA 65A006
Area, sq ft	31.5
Span, ft	9.56
Aspect ratio	2.9
Sweep angle at 0.25-percent chord, deg	45
Mean aerodynamic chord, in.	42.8
Position of 0.25 mean aerodynamic chord, fuselage station	355.6
Stabilizer travel, (power actuated), deg:	
Leading edge up	4.5
Leading edge down	7.5
Elevator (20.8 percent overhang balance, 31.5 percent span):	
Area rearward of hinge line, sq ft	6.9
Travel from stabilizer, deg:	
Up	25
Down	20
Chord, percent horizontal tail chord	30
Moment area rearward of hinge line (total), in.^{3}	4200
Vertical tail:	
Airfoil section (parallel to rear fuselage center line)	NACA 65A006
Area, sq ft	29.5
Span, perpendicular to rear fuselage center line, ft	6.25
Aspect ratio	1.32
Sweep angle of leading edge, deg	43

TABLE I.- Concluded

PHYSICAL CHARACTERISTICS OF BELL X-5 AIRPLANE

Fin:	
Area, sq ft	24.8
Rudder (23.1 percent overhang balance, 26.3 percent span):	
Area rearward of hinge line, sq ft	4.7
Span, ft	4.43
Travel, deg	±35
Chord, percent horizontal tail chord	22.7
Moment area rearward of hinge line, in.^{3}	3585

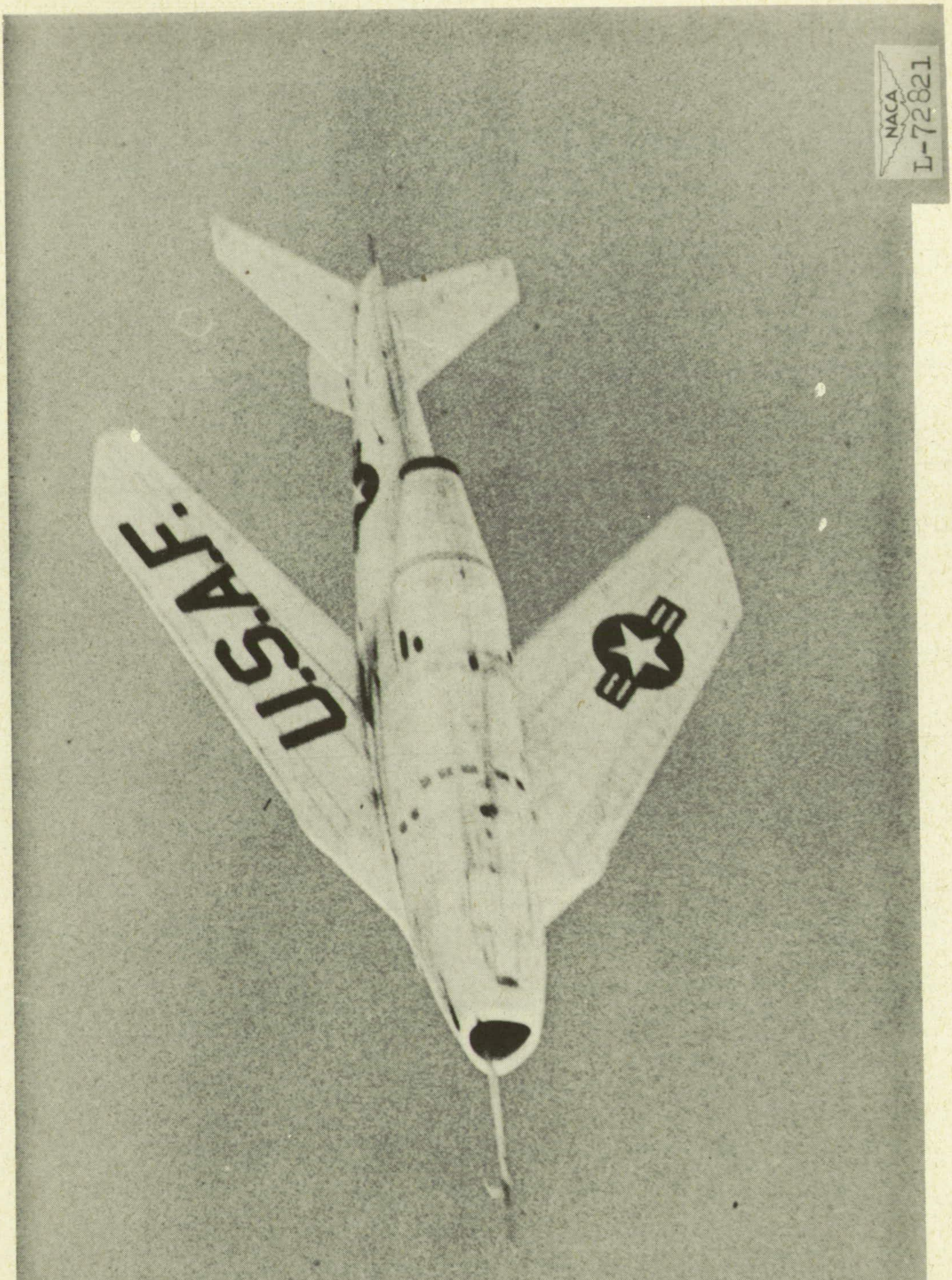


Figure 1.- Photograph of Bell X-5 airplane.

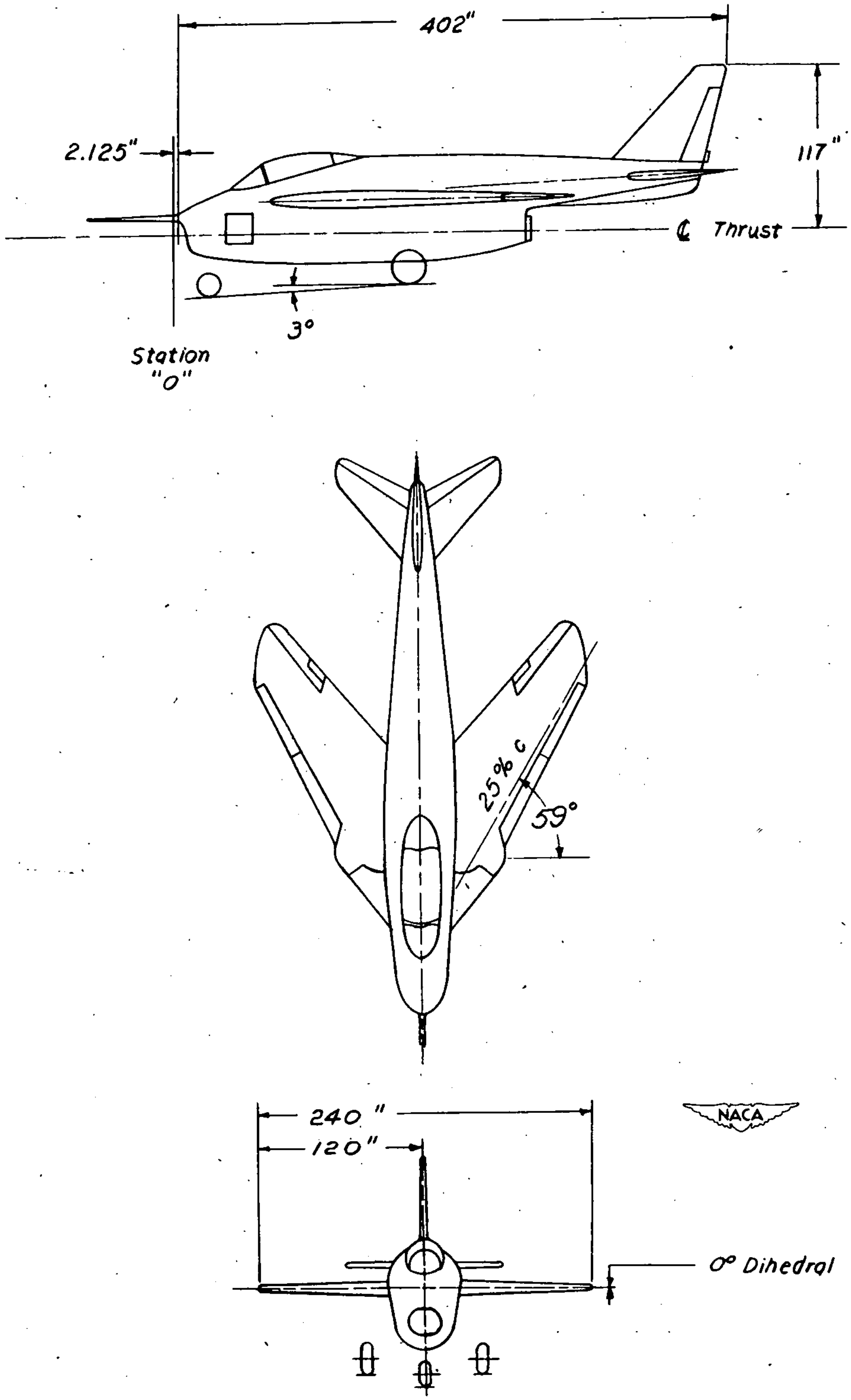
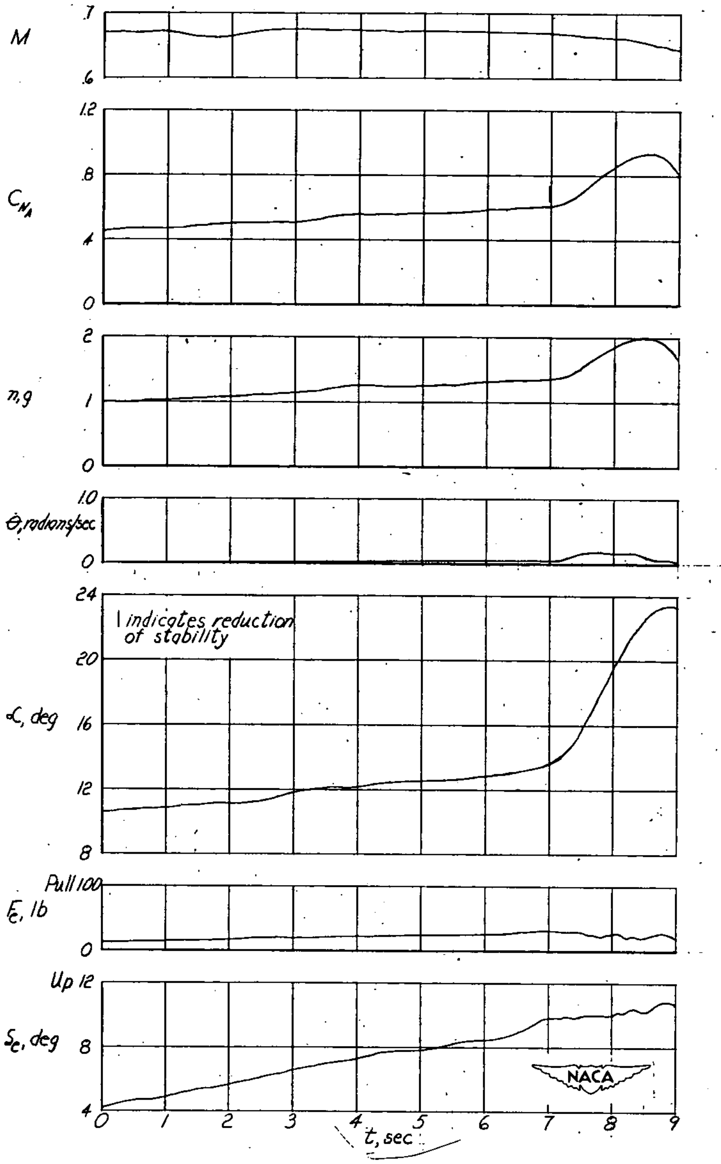
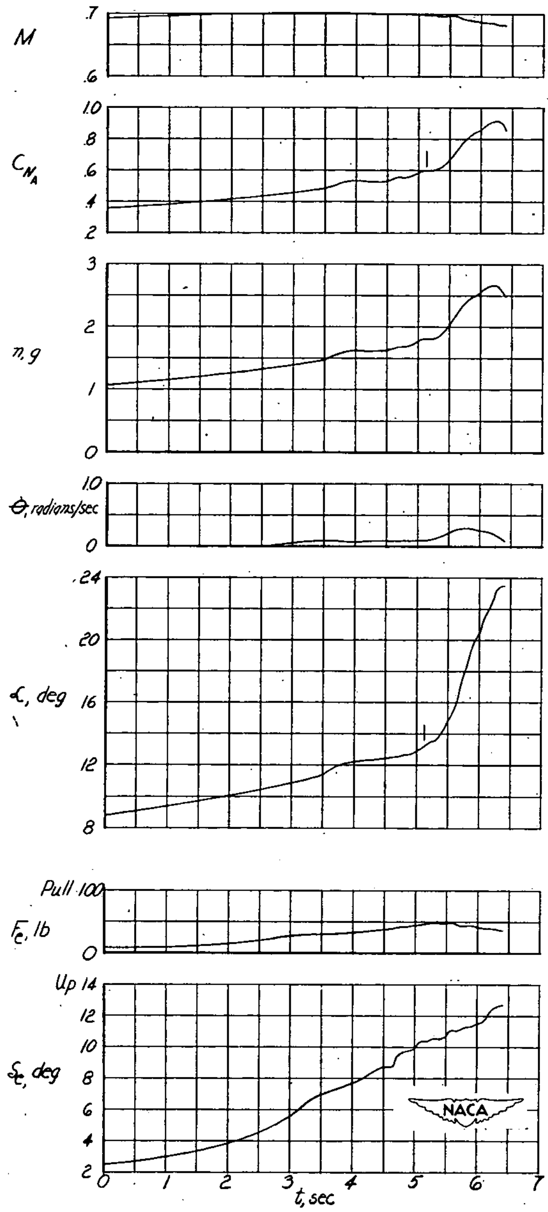


Figure 2.- Three-view drawing of Bell X-5 research airplane at 59° sweepback.



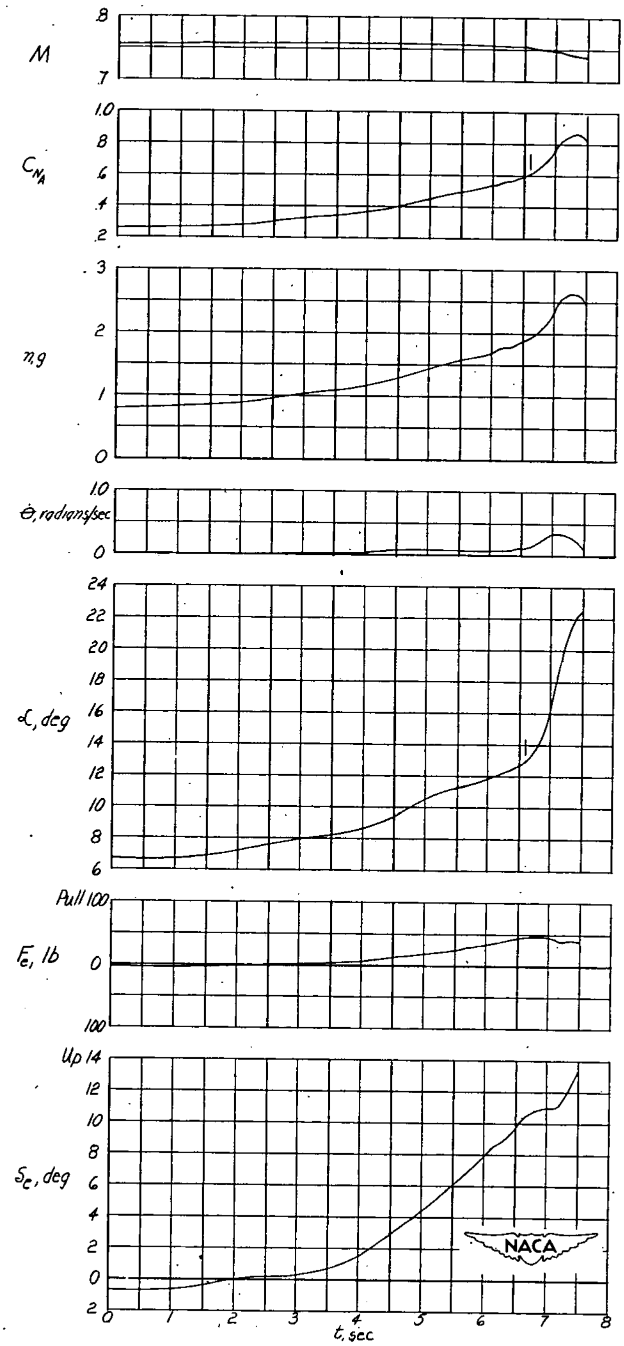
(a) Accelerated turn; initial $M \approx 0.67$; $h_p = 42{,}000$ feet; $i_t = -2.5^{\circ}$; c.g. at 44.7 percent M.A.C.

Figure 3.- Time histories of maneuvers executed with the elevator control.



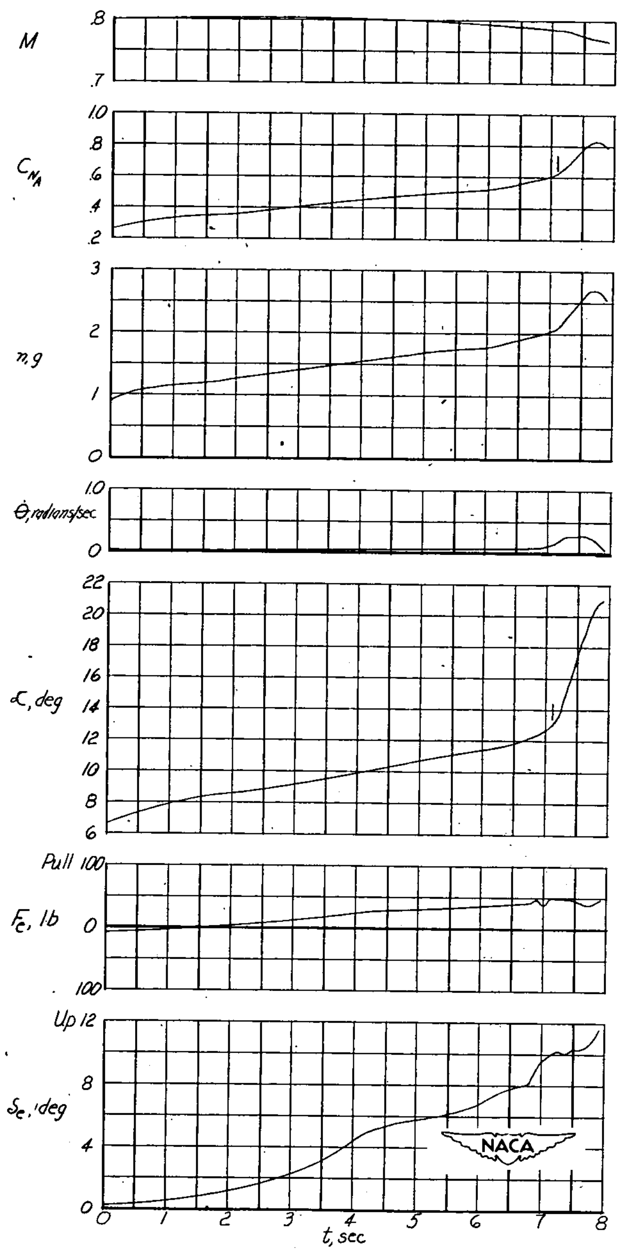
(b) Accelerated turn; initial $M \approx 0.69$; $h_p = 38{,}500$ feet; $i_t = -2.5^{\circ}$; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



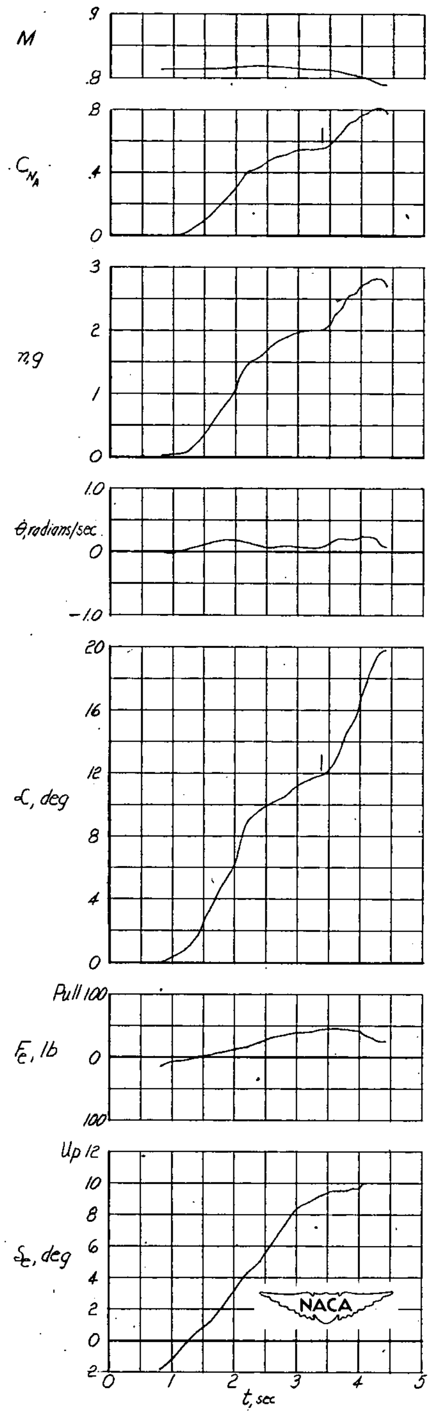
(c) Accelerated turn; initial $M \approx 0.76$; $h_p = 41,500$ feet; $i_t = -2.5^{\circ}$; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



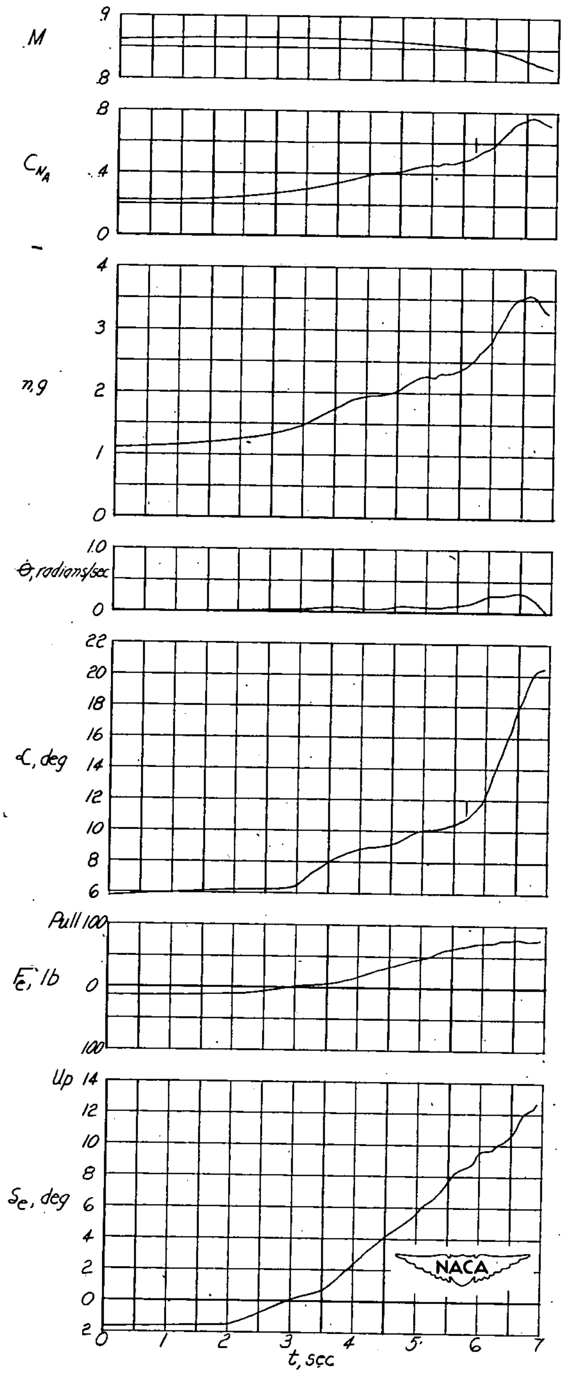
(d) Accelerated turn; initial $M \approx 0.80$; $h_p = 41{,}000$ feet; $i_t = -2.5^\circ$; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



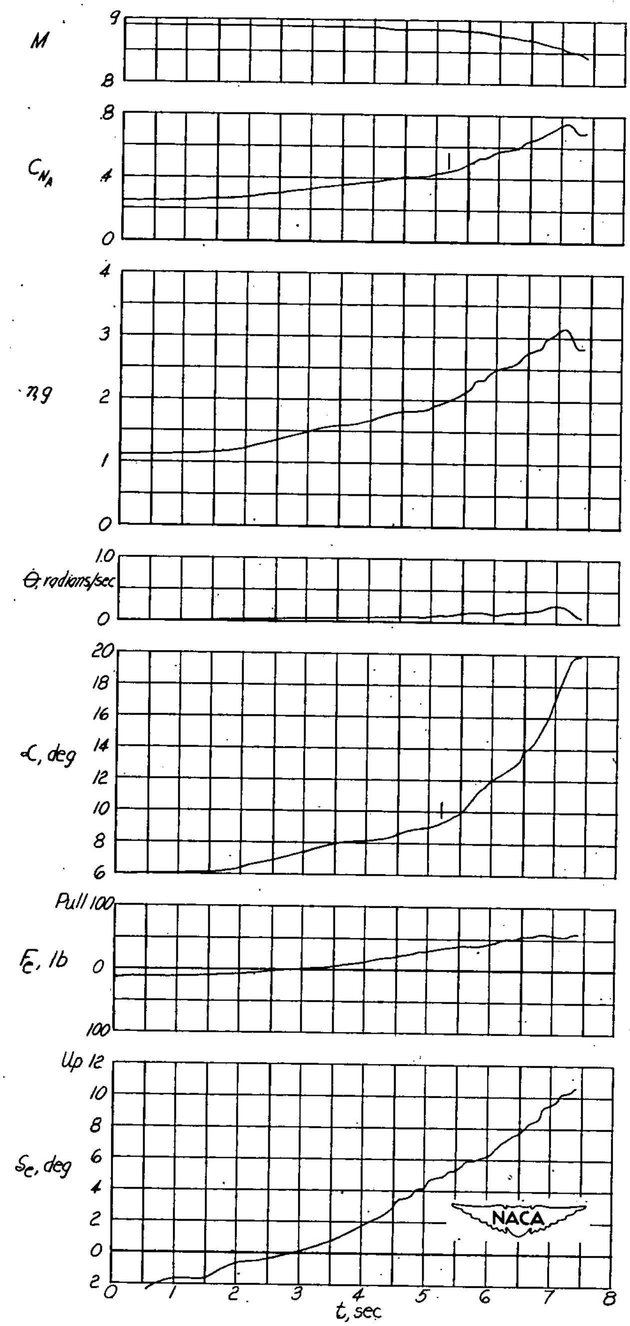
(e) Accelerated turn; initial $M \approx 0.82$; $h_p = 41{,}500$ feet; $i_t = -2.2^{\circ}$; c.g. at 45.5 percent M.A.C.

Figure 3.- Continued.



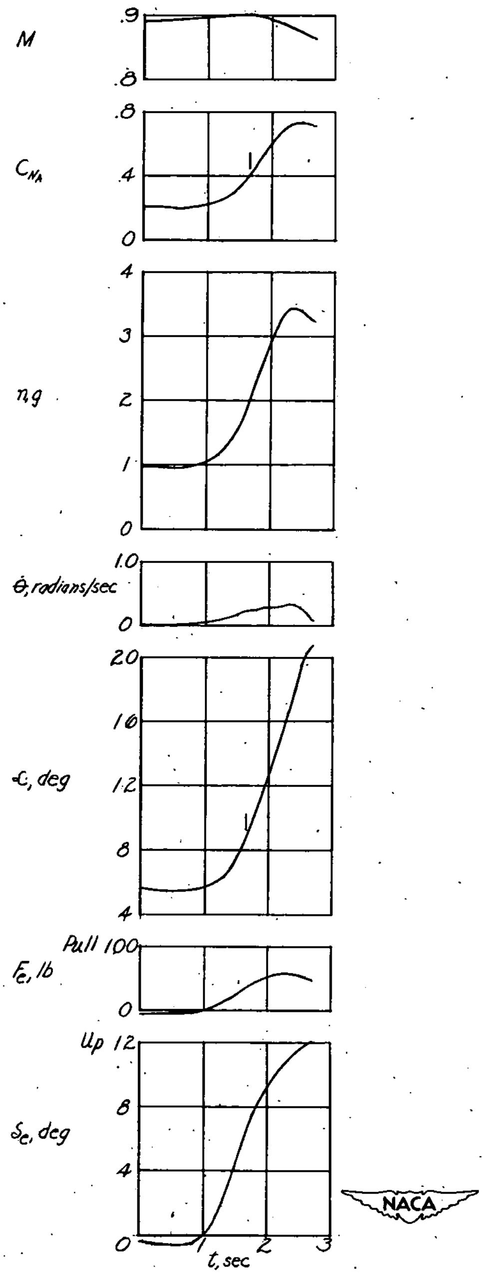
(f) Accelerated turn; initial $M \approx 0.87$; h_p = 37,000 feet; i_t = -2.5°; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



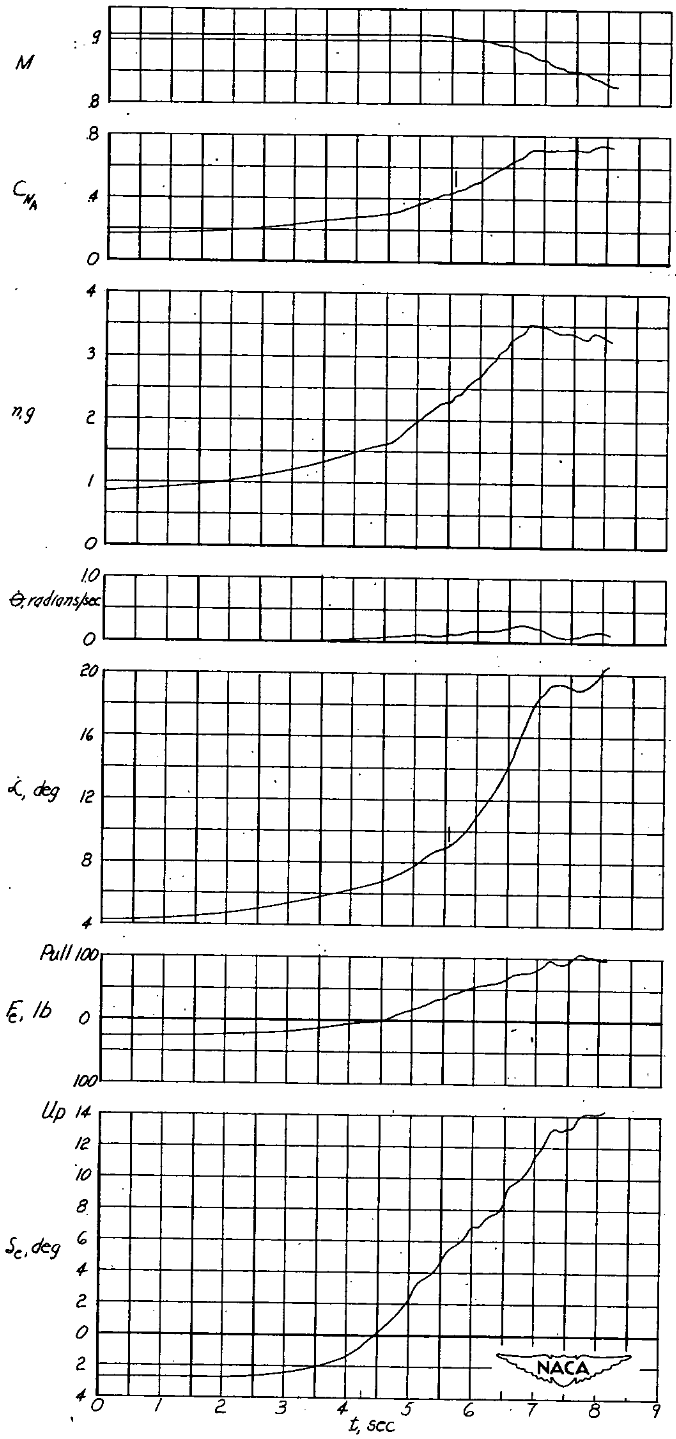
(g) Accelerated turn; initial $M \approx 0.89$; $h_p = 41,000$ feet; $i_t = -2.5^{\circ}$; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



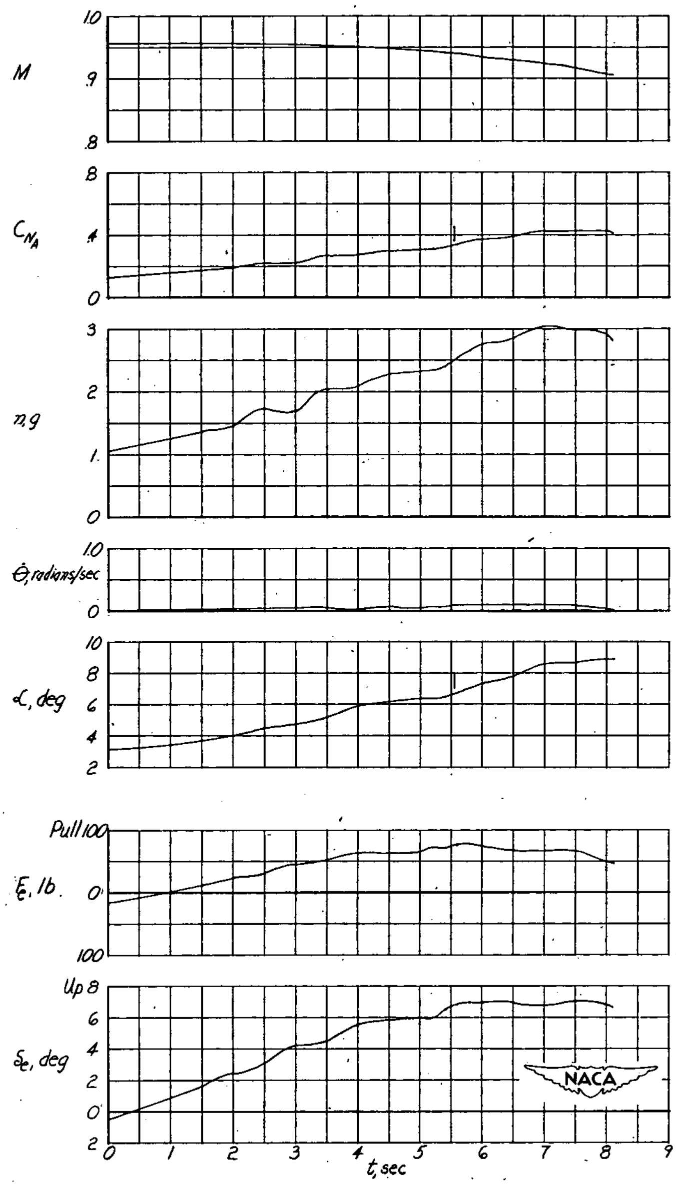
(h) Accelerated turn; initial $M \approx 0.89$; $h_p = 40{,}500$ feet; $i_t = -2.3^{\circ}$; c.g. at 45.1 percent M.A.C.

Figure 3.- Continued.



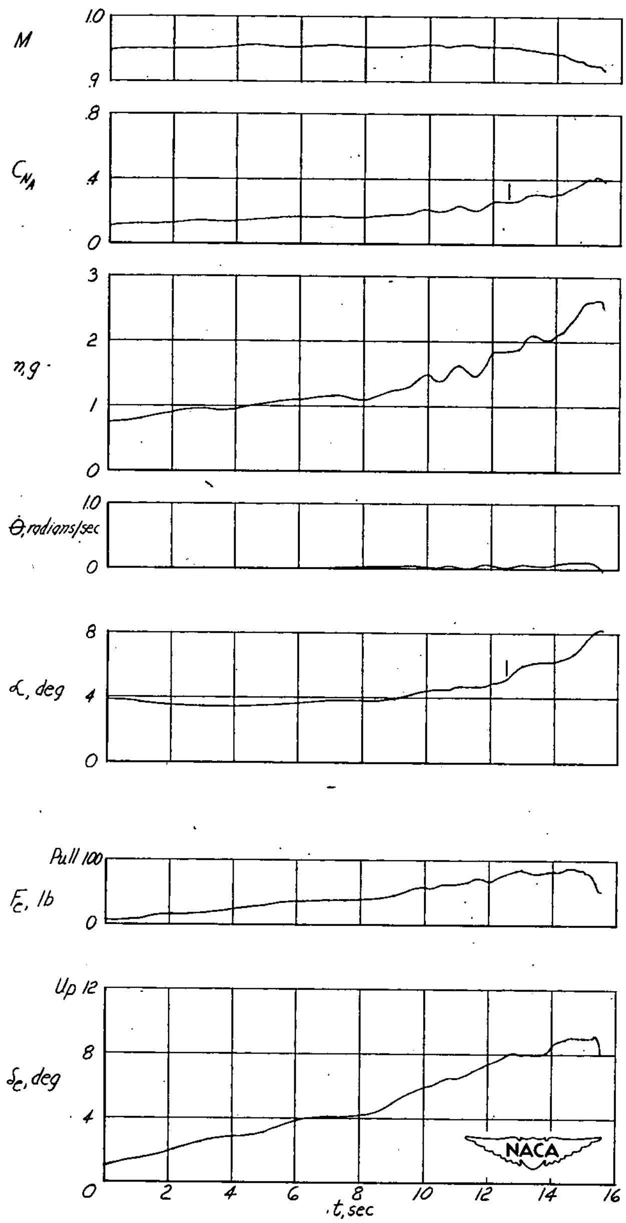
(i) Accelerated turn; initial $M \approx 0.91$; h_p = 38,500 feet; $i_t = -2.5^\circ$; c.g. at 44.8 percent M.A.C.

Figure 3.- Continued.



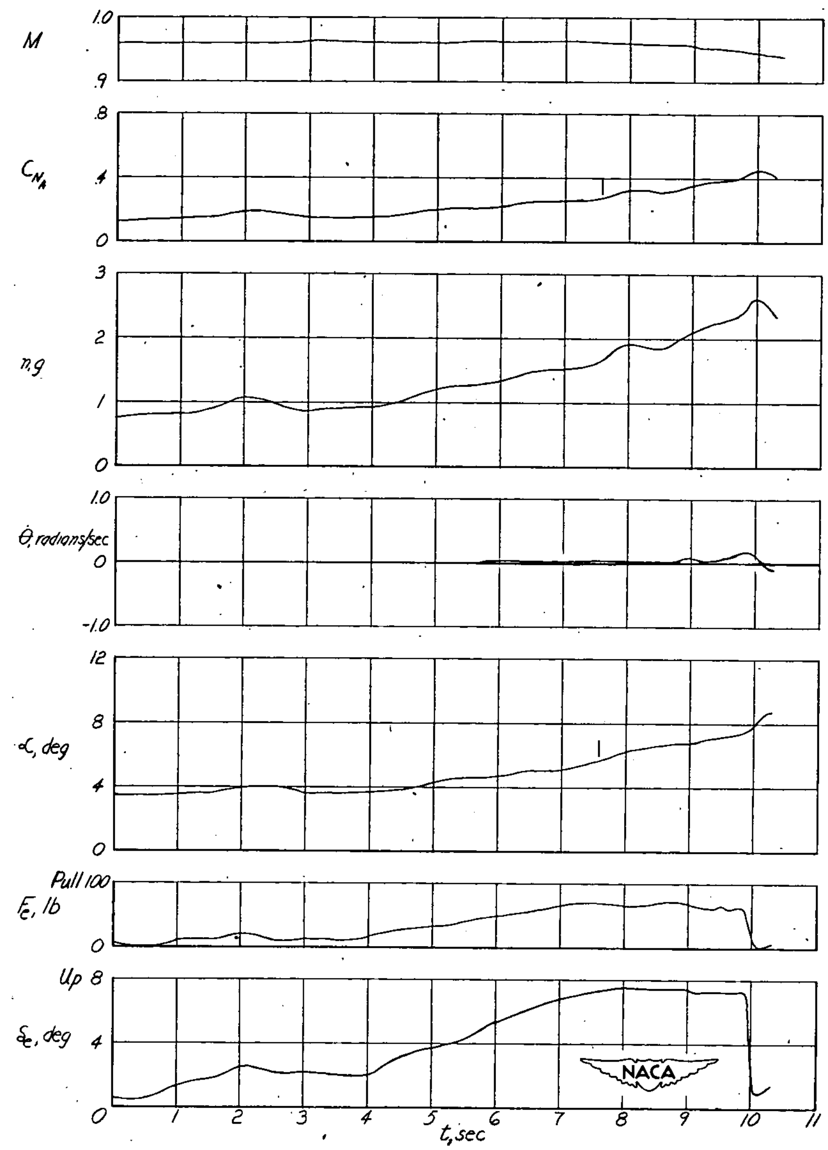
(j) Accelerated turn; initial $M \approx 0.96$; $h_p = 32{,}000$ feet; $i_t = -2.5^{\circ}$; c.g. at 44.7 percent M.A.C.

Figure 3.- Continued.



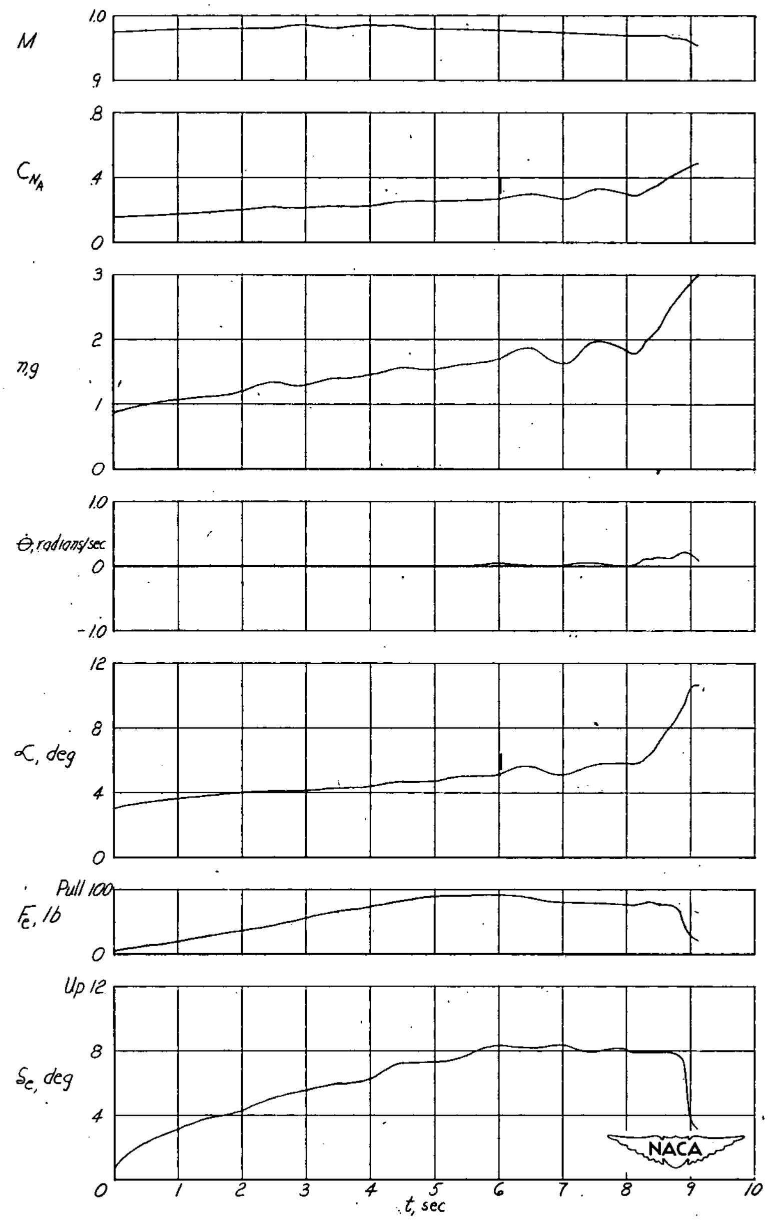
(k) Accelerated turn; initial $M \approx 0.95$; $h_p = 35,000$ feet; $i_t = -1.4^\circ$; c.g. at 44.7 percent M.A.C.

Figure 3.- Continued.



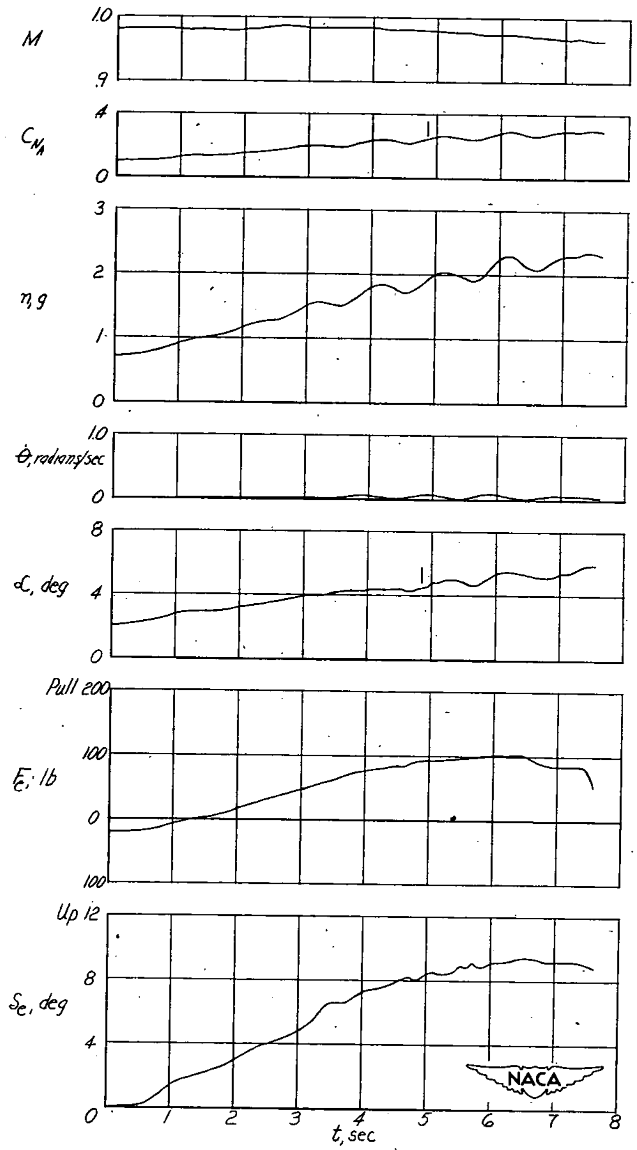
(l) Accelerated turn; initial $M \approx 0.96$; $h_p = 38{,}000$ feet; $i_t = -2.1^{\circ}$; c.g. at 46.5 percent M.A.C.

Figure 3.- Continued.



(m) Accelerated turn; initial $M \approx 0.97$; $h_p = 37{,}000$ feet; $i_t = -2.8^\circ$; c.g. at 45.4 percent M.A.C.

Figure 3.- Continued.



(n) Accelerated turn; initial $M \approx 0.98$; $h_p = 32,500$ feet; $i_t = -2.5^{\circ}$; c.g. at 45.3 percent M.A.C.

Figure 3.- Concluded.

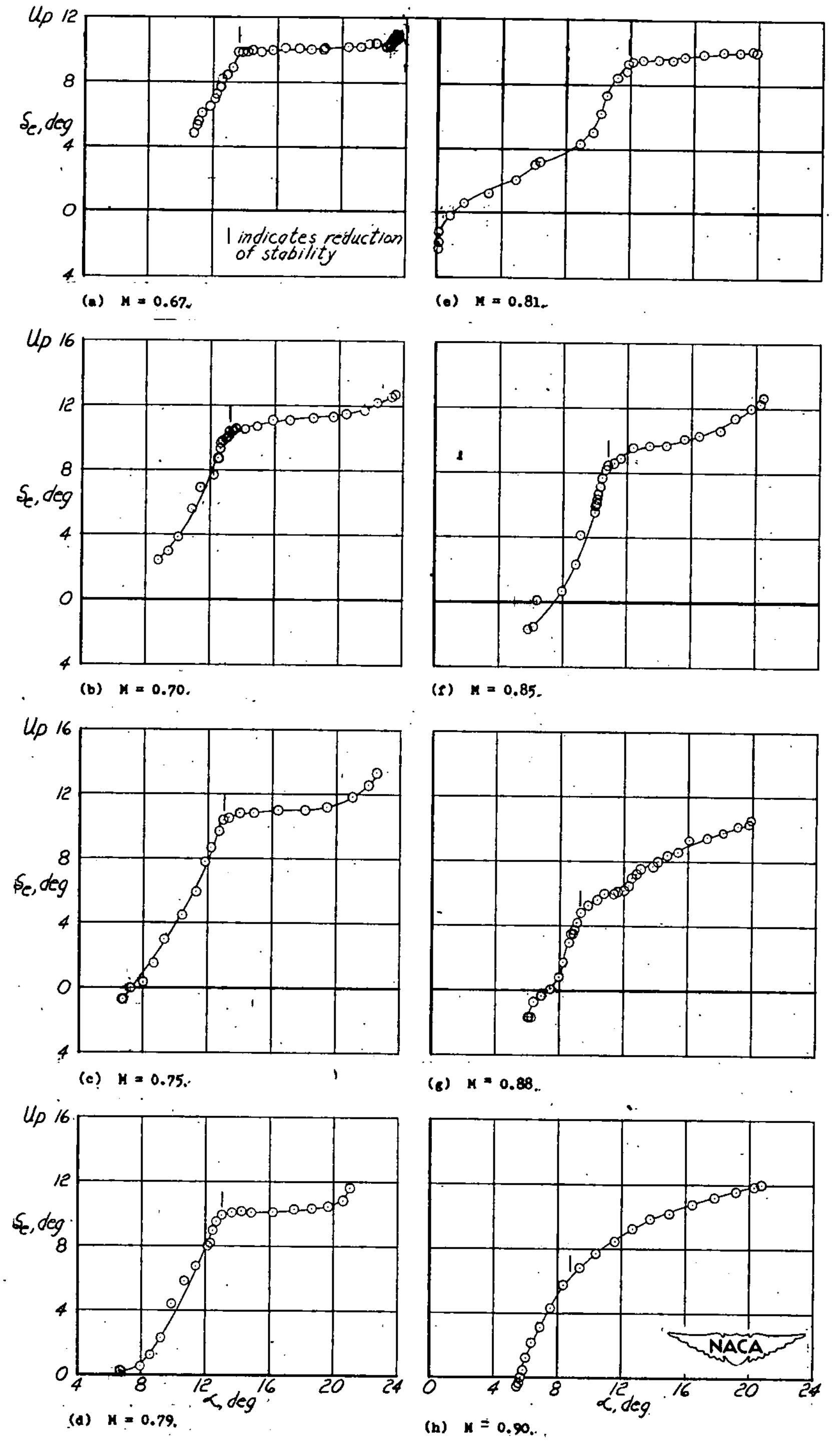


Figure 4.- Variation of elevator deflection with angle of attack for maneuvers executed with the elevator control.

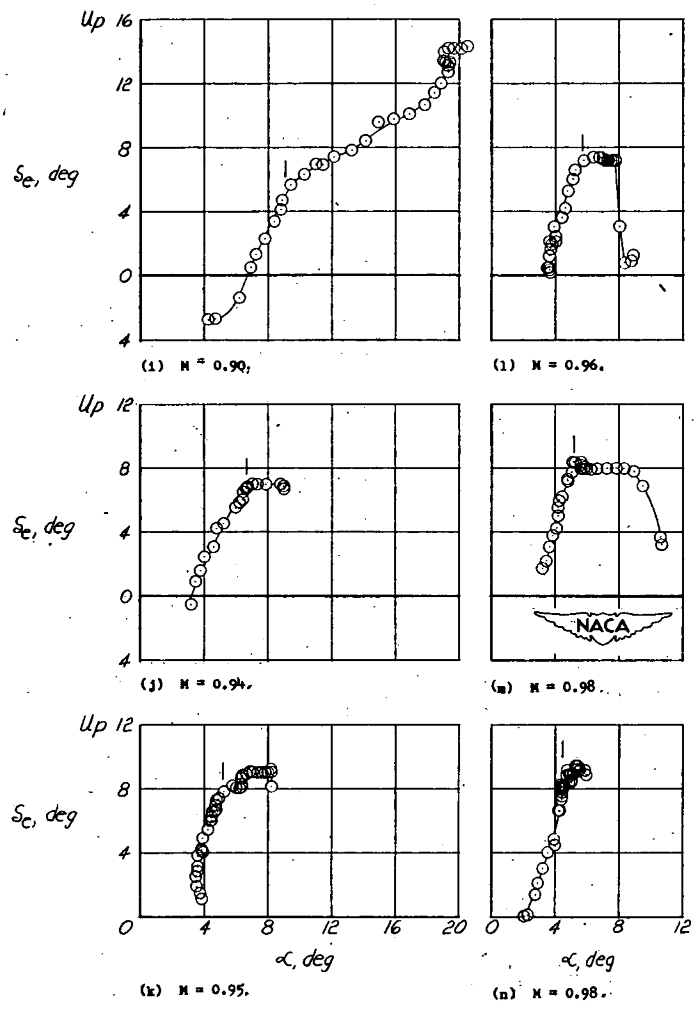


Figure 4.- Concluded.

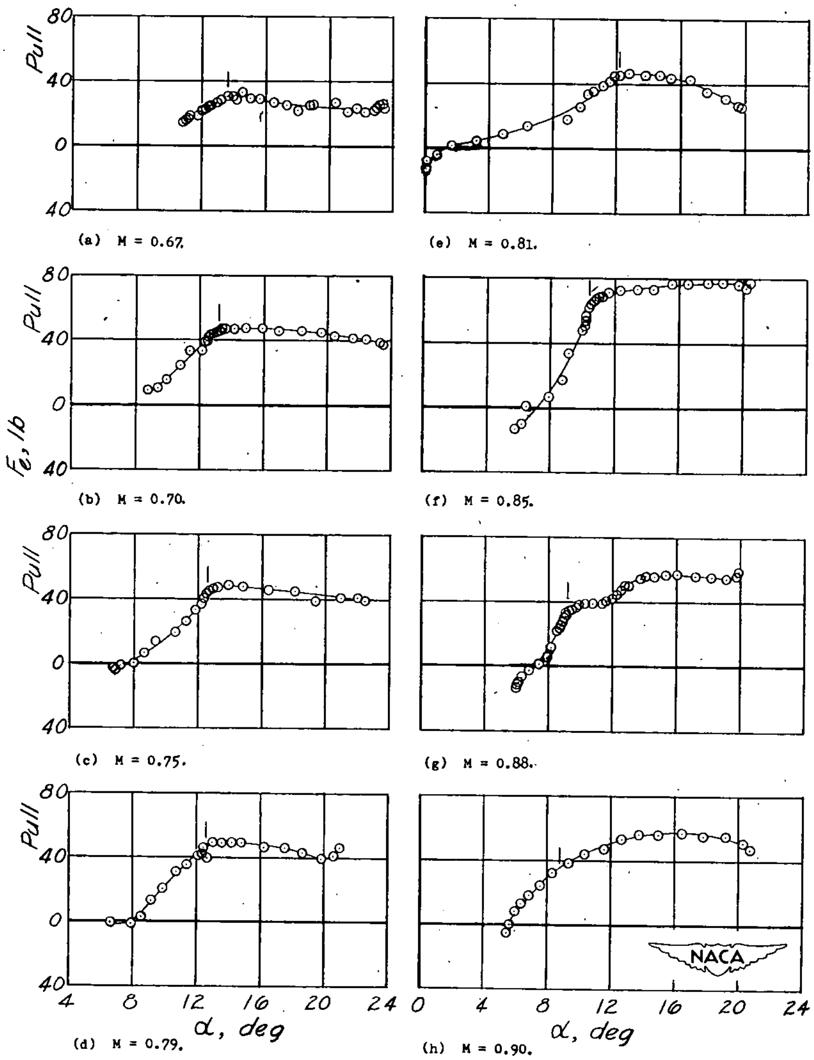


Figure 5.- Variation of elevator stick force with angle of attack for maneuvers executed with the elevator control.

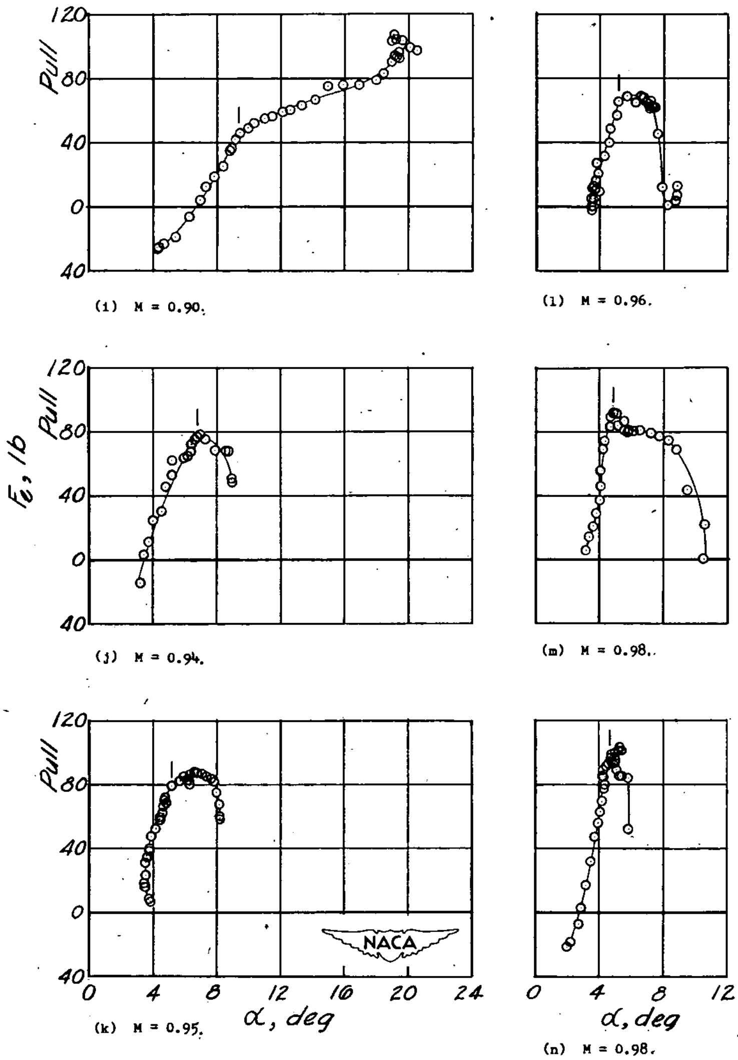


Figure 5.- Concluded.

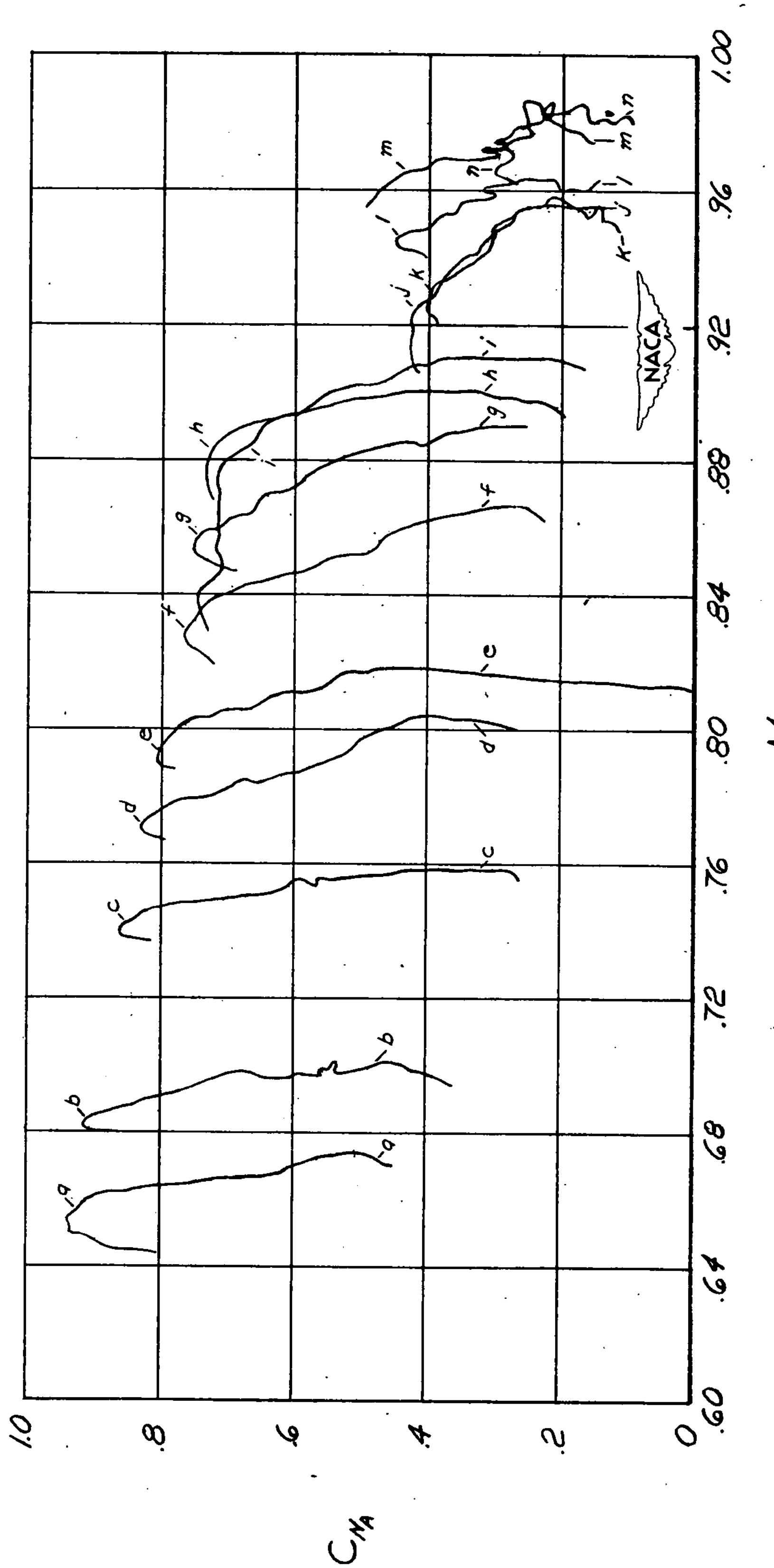


Figure 6.- Variation of airplane normal-force coefficient with Mach number for maneuvers executed with the elevator control.

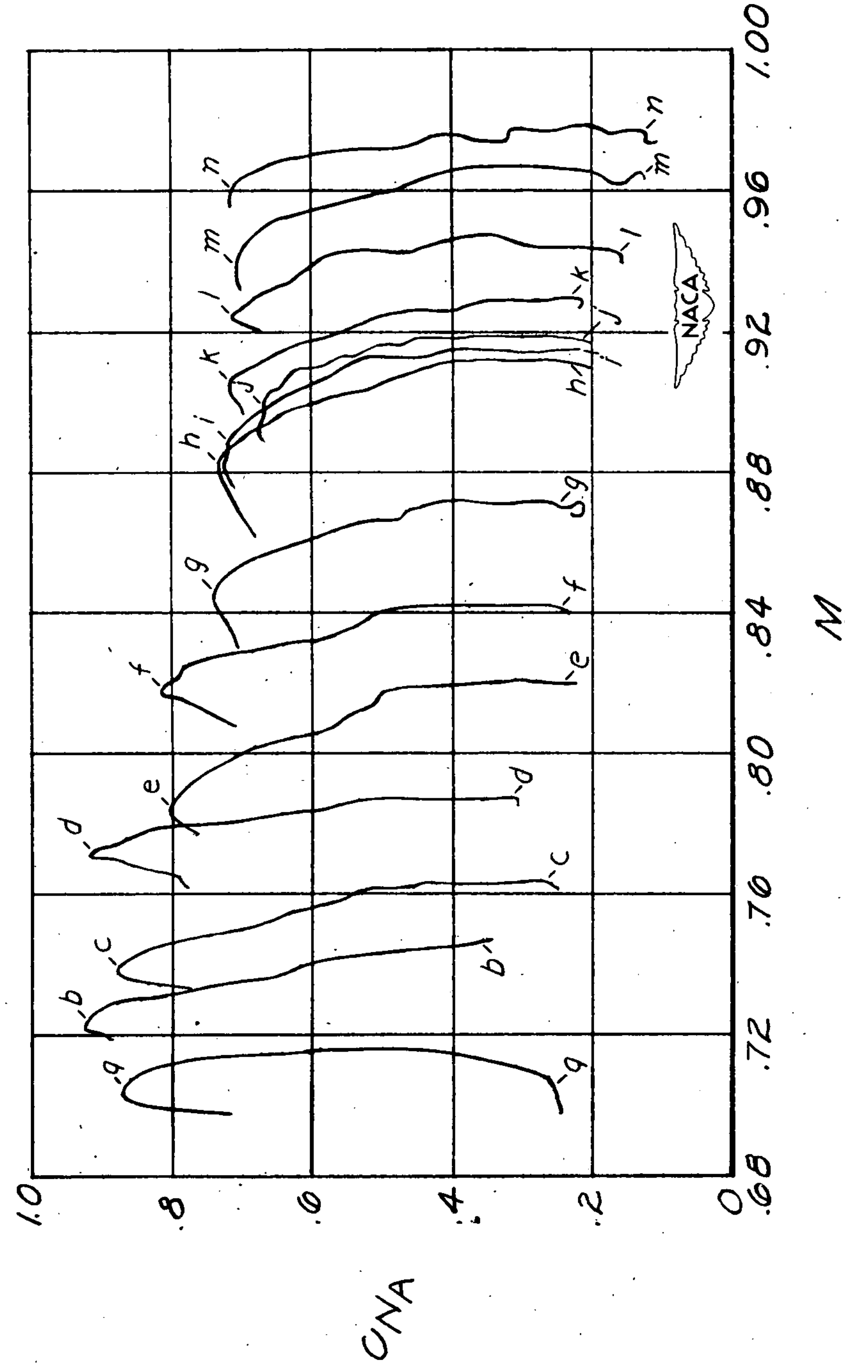
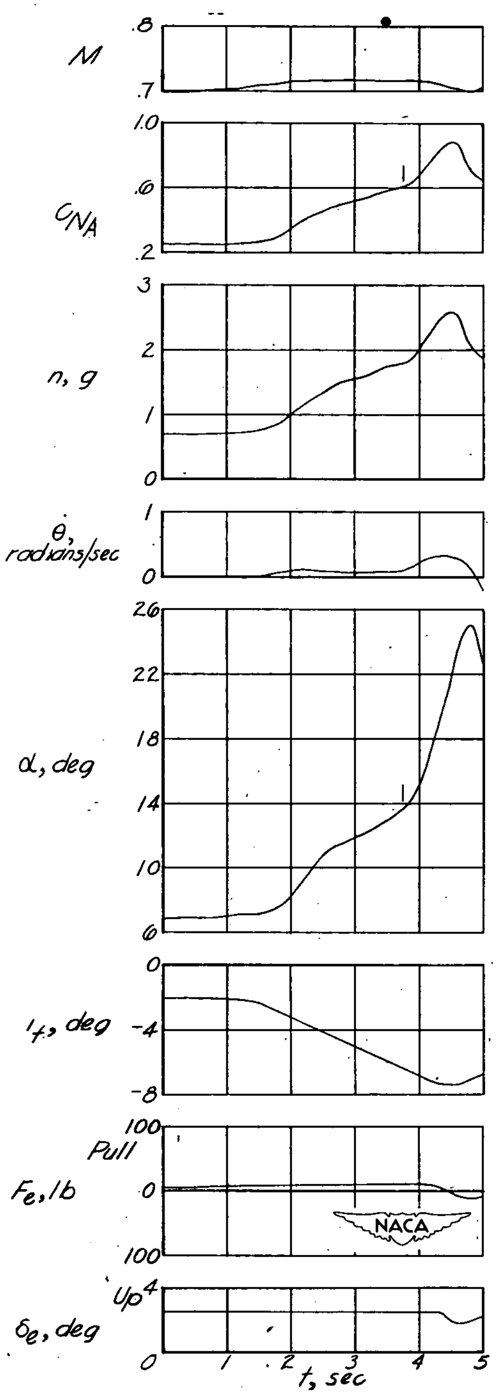
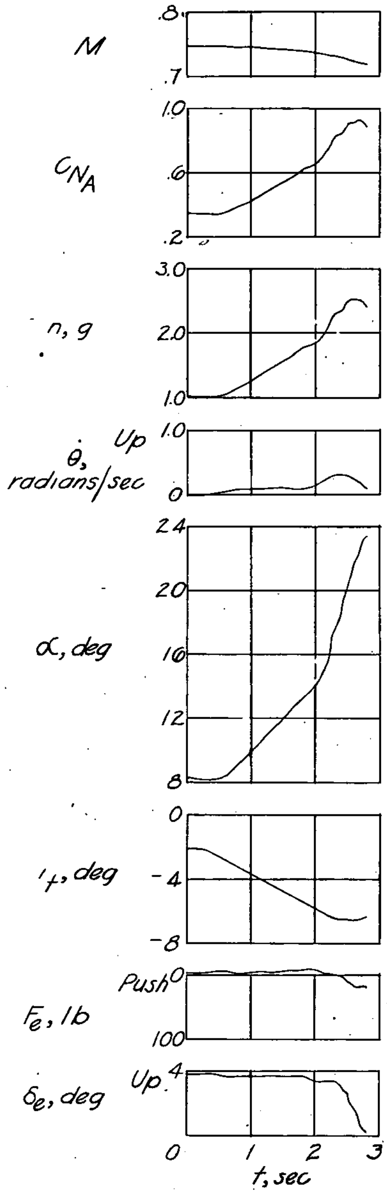


Figure 7.- Variation of airplane normal-force coefficient with Mach number for maneuvers executed with the stabilizer control.



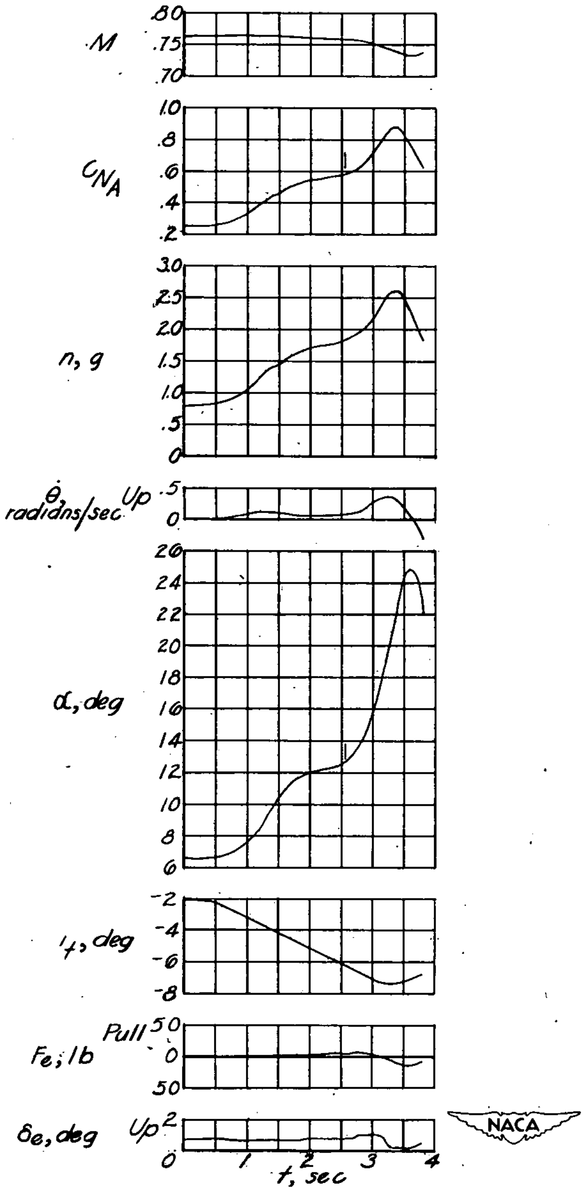
(a) Initial $M \approx 0.70$; h_p = 41,000 feet; c.g. at 44.6 percent M.A.C.

Figure 8.- Time histories of maneuvers executed with the stabilizer control.



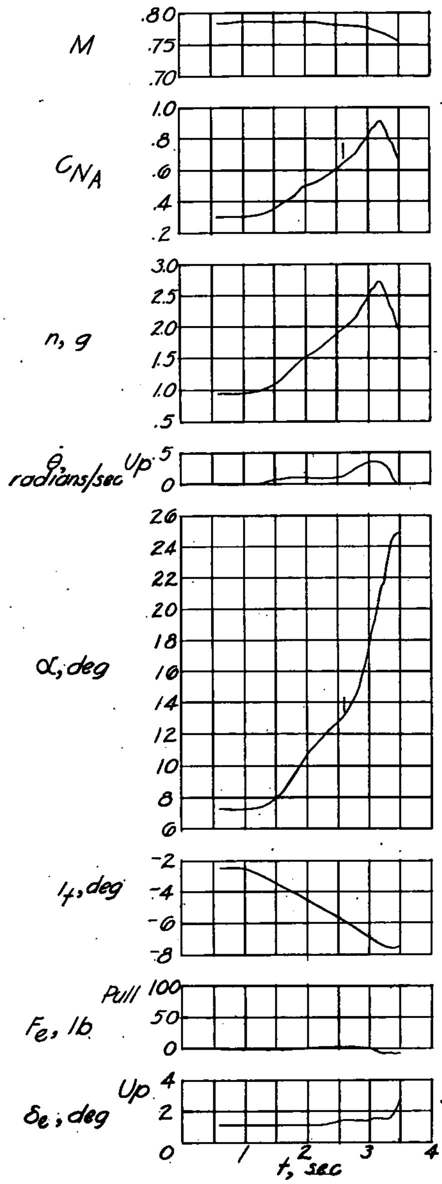
(b) Initial $M \approx 0.74$; h_p = 41,500 feet; c.g. at 44.9 percent M.A.C.

Figure 8.- Continued.



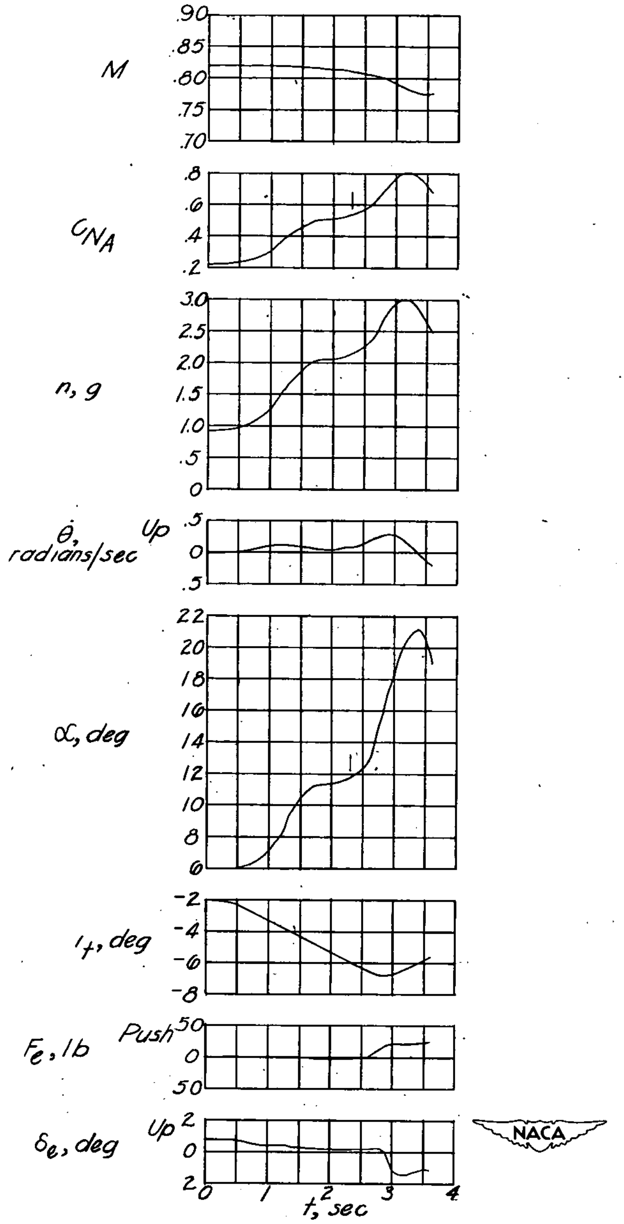
(c) Initial M ≈ 0.77; h_p = 42,000 feet; c.g. at 45.0 percent M.A.C.

Figure 8.- Continued.



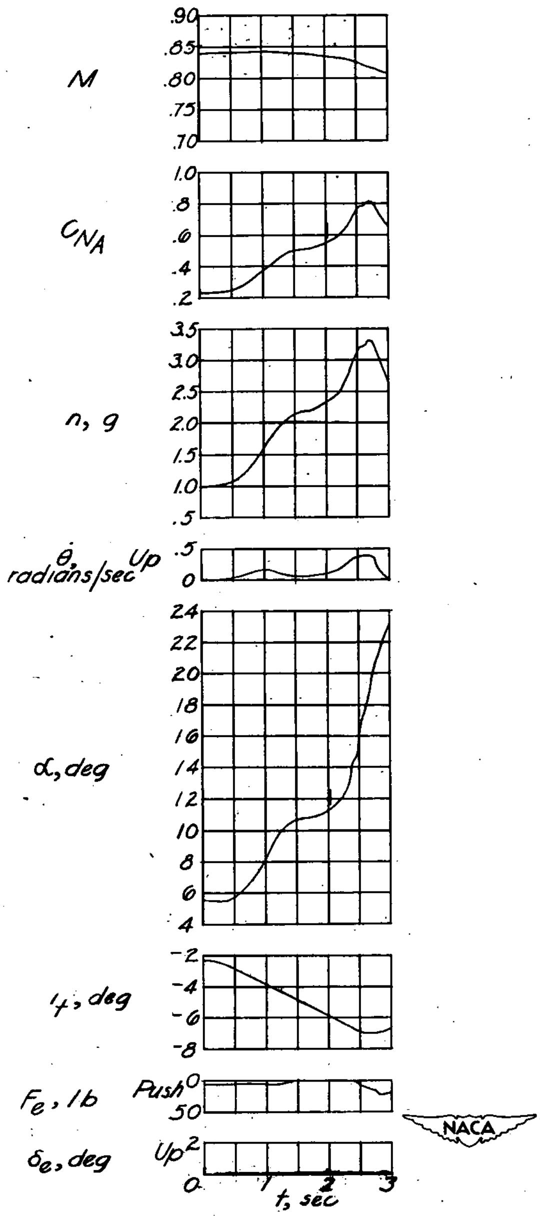
(d) Initial M $\approx$ 0.78; h_p = 42,500 feet; c.g. at 44.9 percent M.A.C.

Figure 8.- Continued.



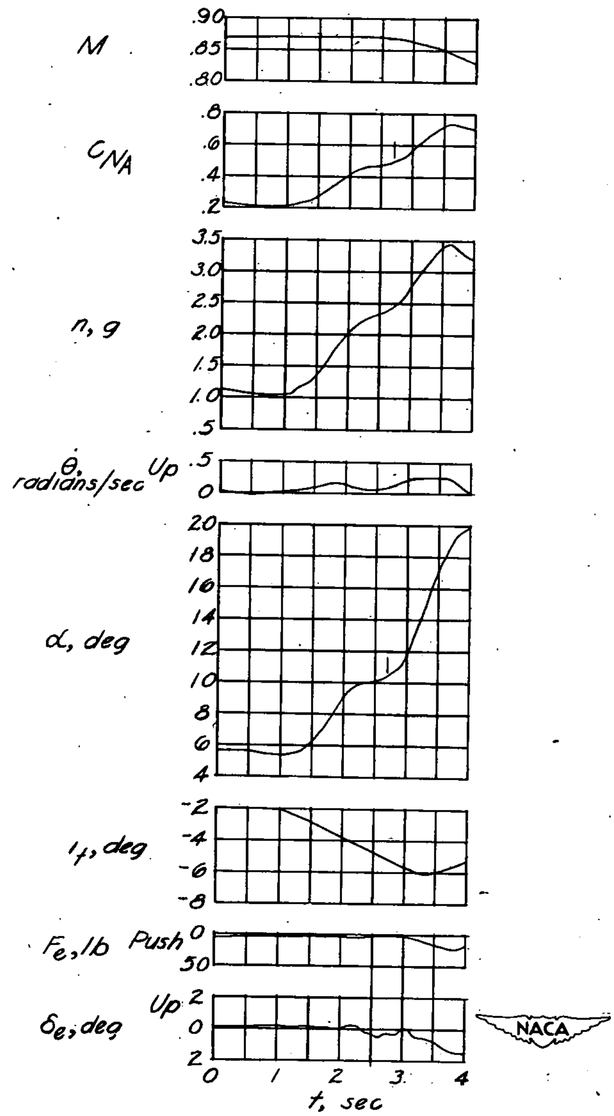
(e) Initial $M \approx 0.82$; h_p = 39,500 feet; c.g. at 45.0 percent M.A.C.

Figure 8.- Continued.



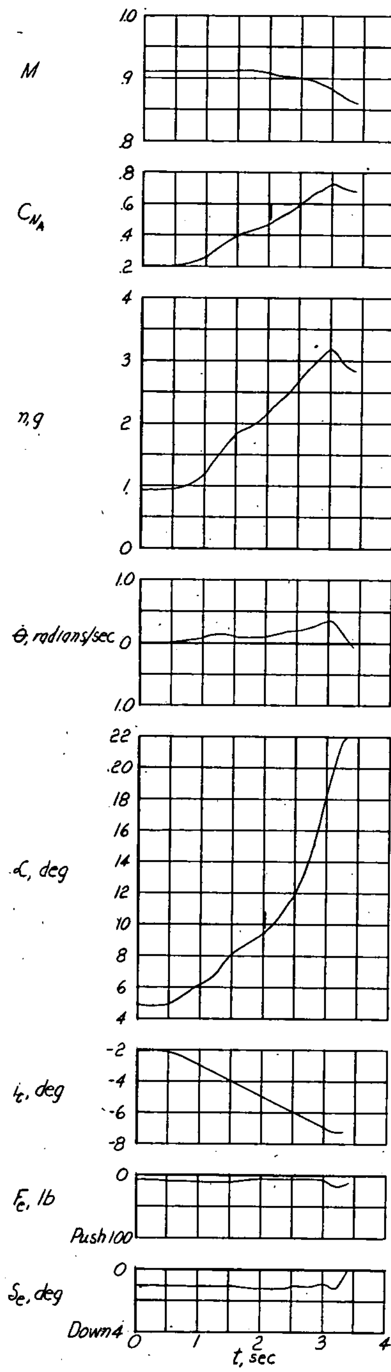
(f) Initial $M \approx 0.84$; $h_p = 39{,}000$ feet; c.g. at 45.0 percent M.A.C.

Figure 8.- Continued.



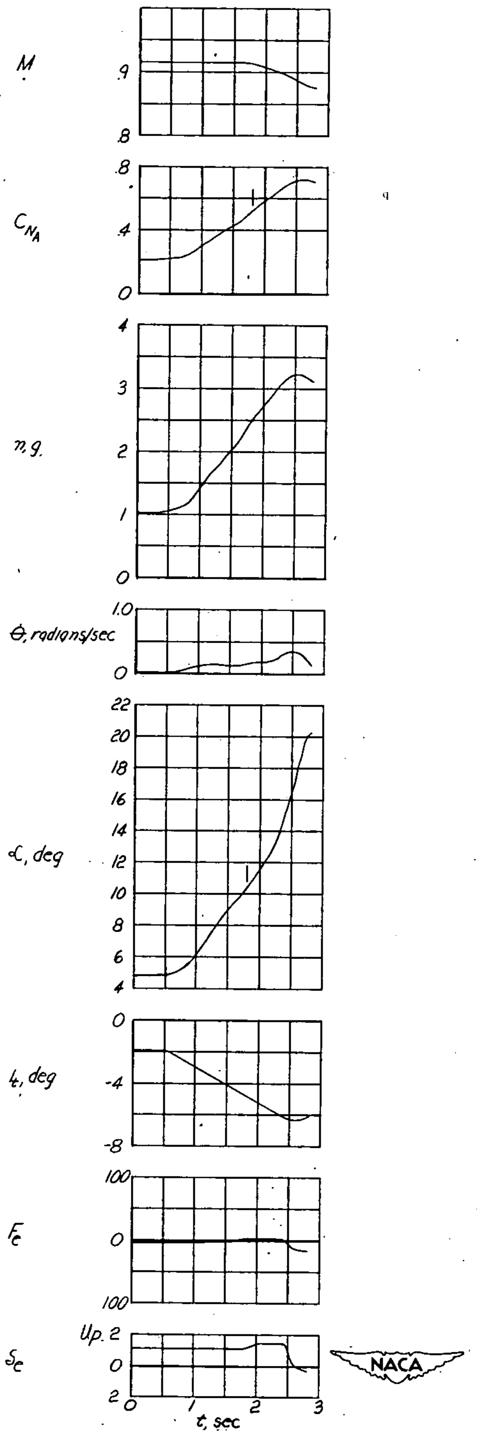
(g) Initial M ≈ 0.87; h_p = 38,000 feet; c.g. at 45.0 percent M.A.C.

Figure 8.- Continued.



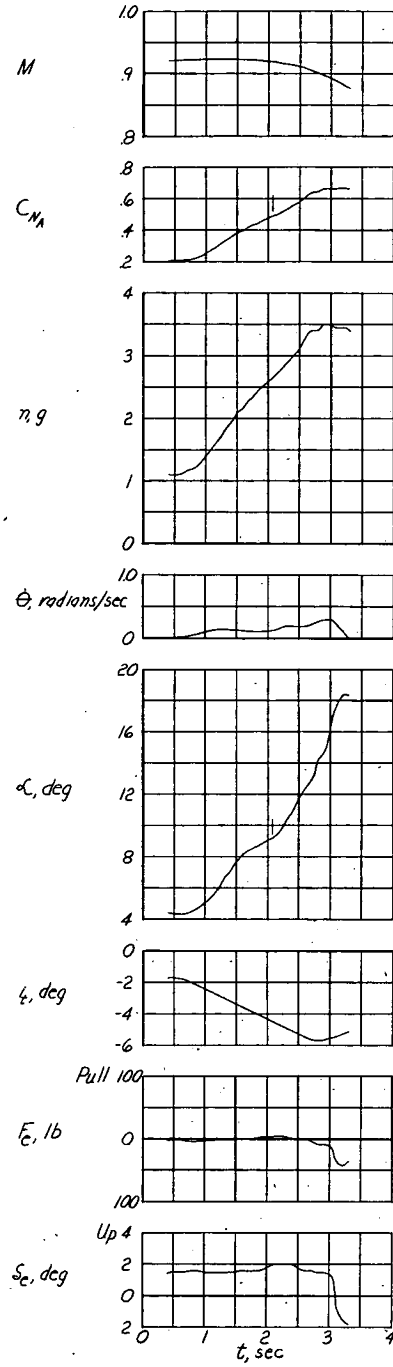
(h) Initial $M \approx 0.91$; h_p = 41,000 feet; c.g. at 45.3 percent M.A.C.

Figure 8.- Continued.



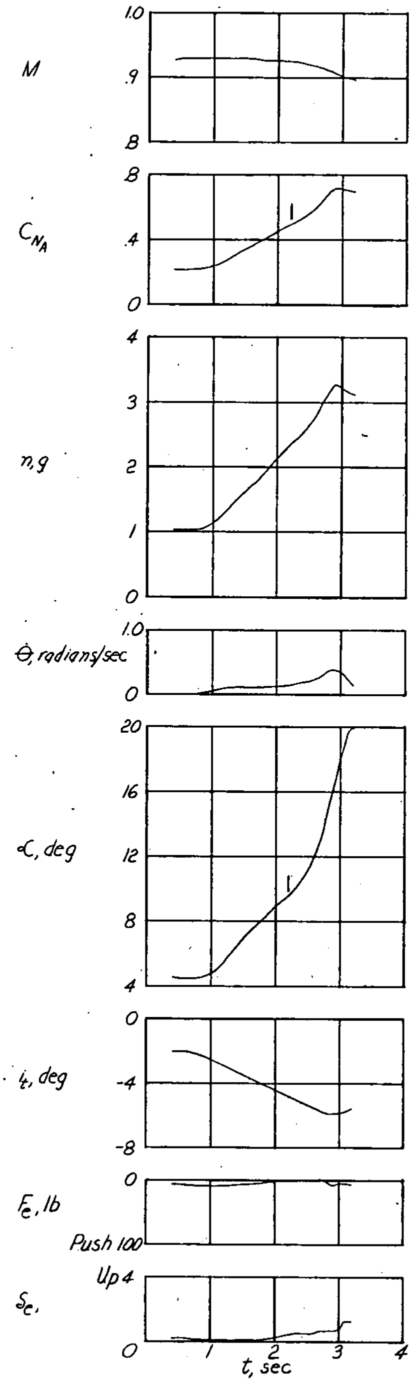
(i) Initial $M \approx 0.92$; h_p = 39,500 feet; c.g. at 44.6 percent M.A.C.

Figure 8.- Continued.



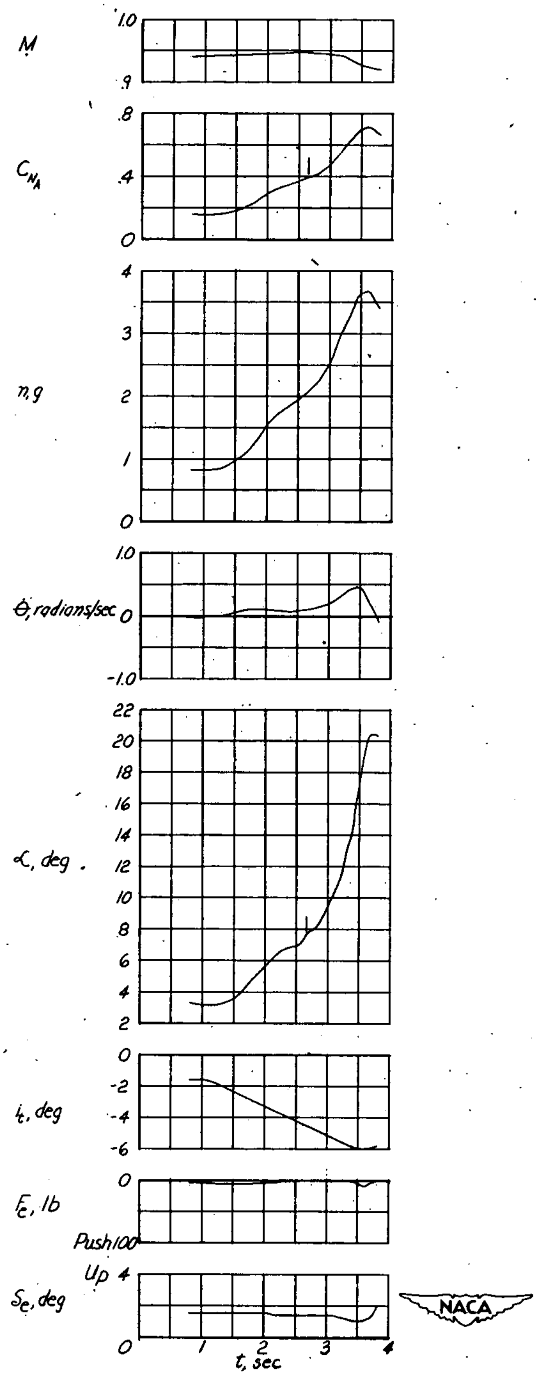
(j) Initial M ≈ 0.92; h_p = 38,000 feet; c.g. at 45.2 percent M.A.C.

Figure 8.- Continued.



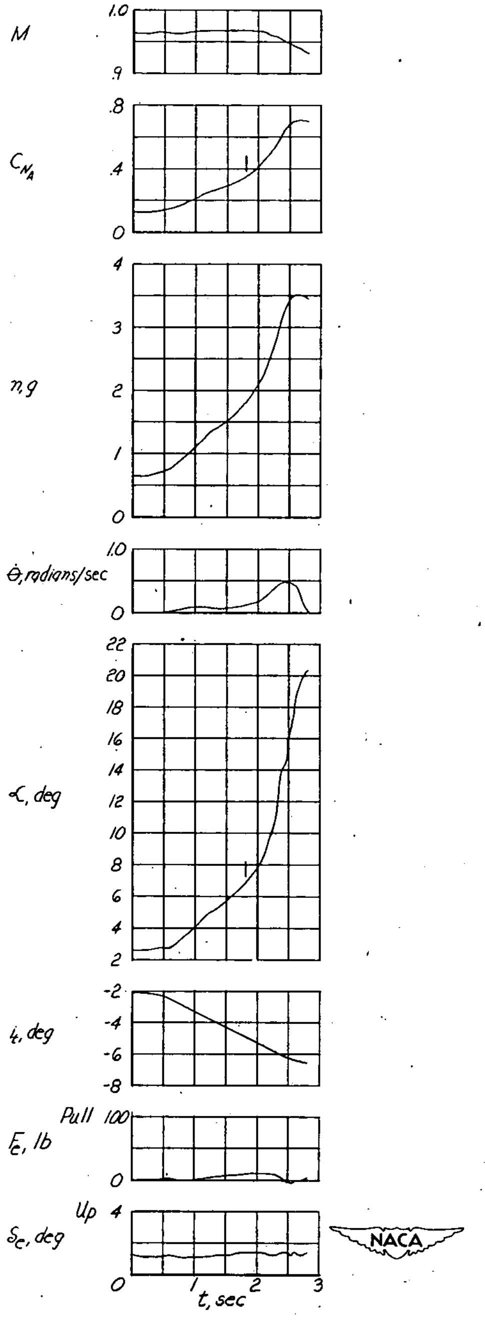
(k) Initial $M \approx 0.93$; $h_p = 38,000$ feet; c.g. at 45.2 percent M.A.C.

Figure 8.- Continued.



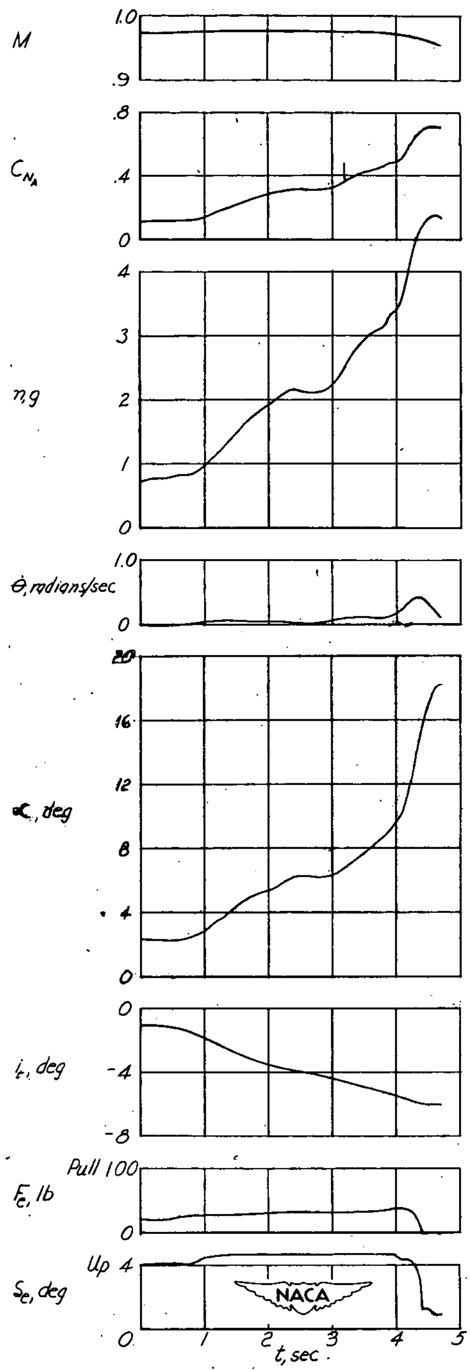
(l) Initial $M \approx 0.94$, h_p = 39,500 feet; c.g. at 44.8 percent M.A.C.

Figure 8.- Continued.



(m) Initial M ≈ 0.97; h_p = 40,000 feet; c.g. at 44.6 percent M.A.C.

Figure 8.- Continued.



(n) Initial $M \approx 0.97$; $h_p = 36{,}500$ feet; c.g. at 45.4 percent M.A.C.

Figure 8.- Concluded.

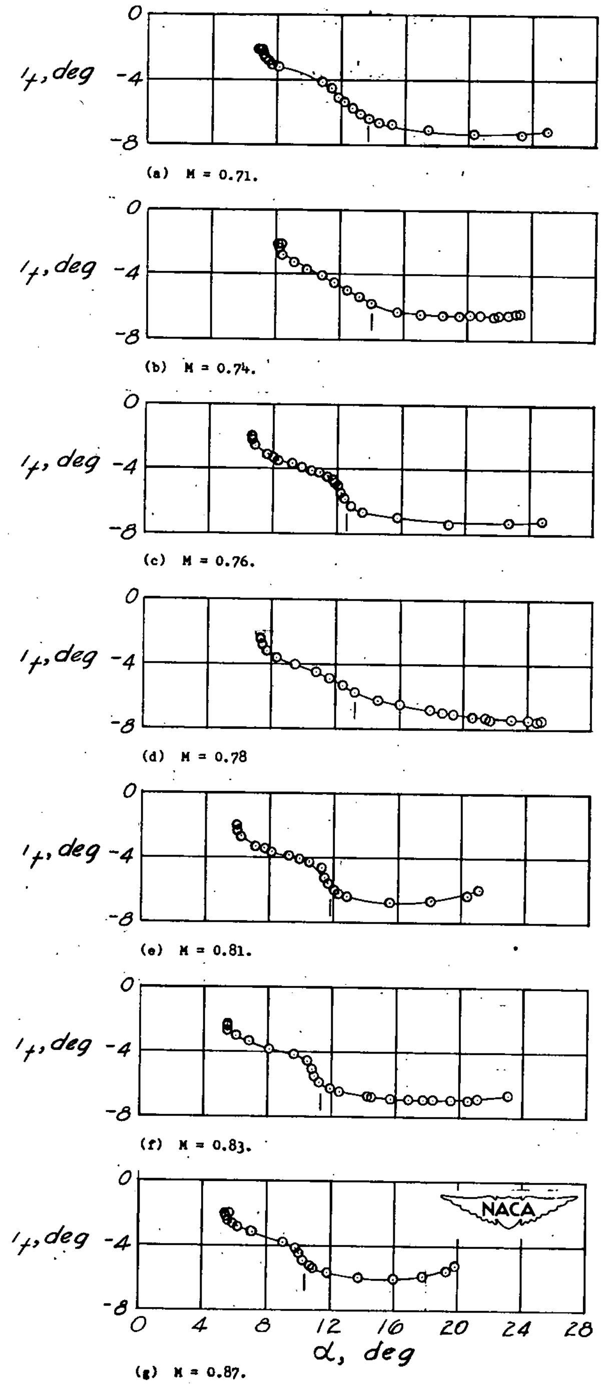


Figure 9.- Variation of stabilizer deflection with angle of attack for maneuvers executed with the stabilizer control.

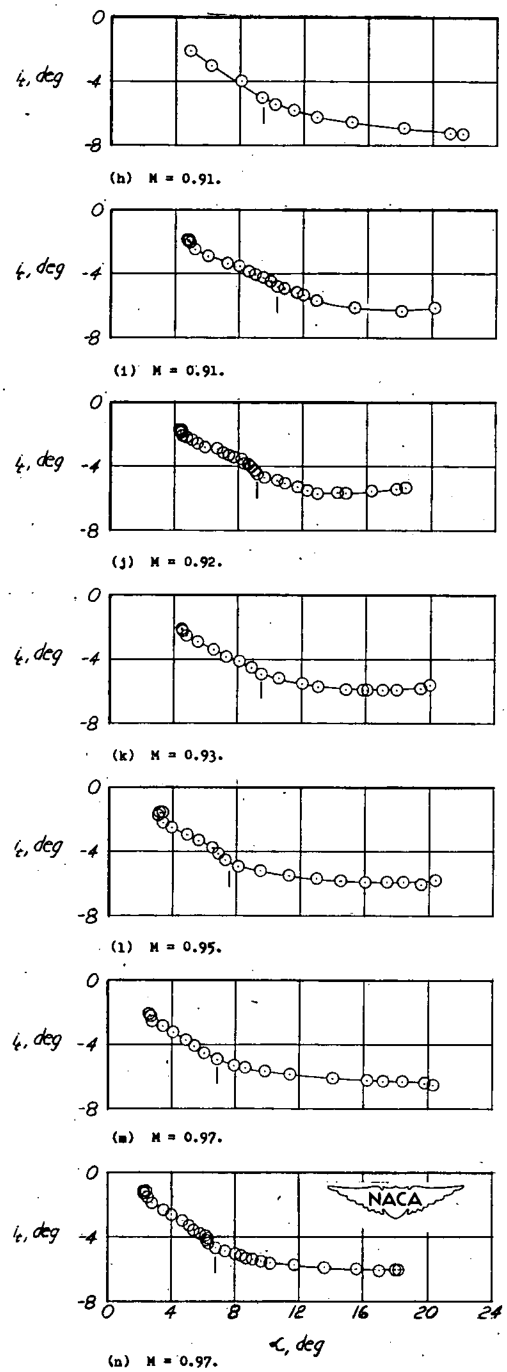


Figure 9.- Concluded.

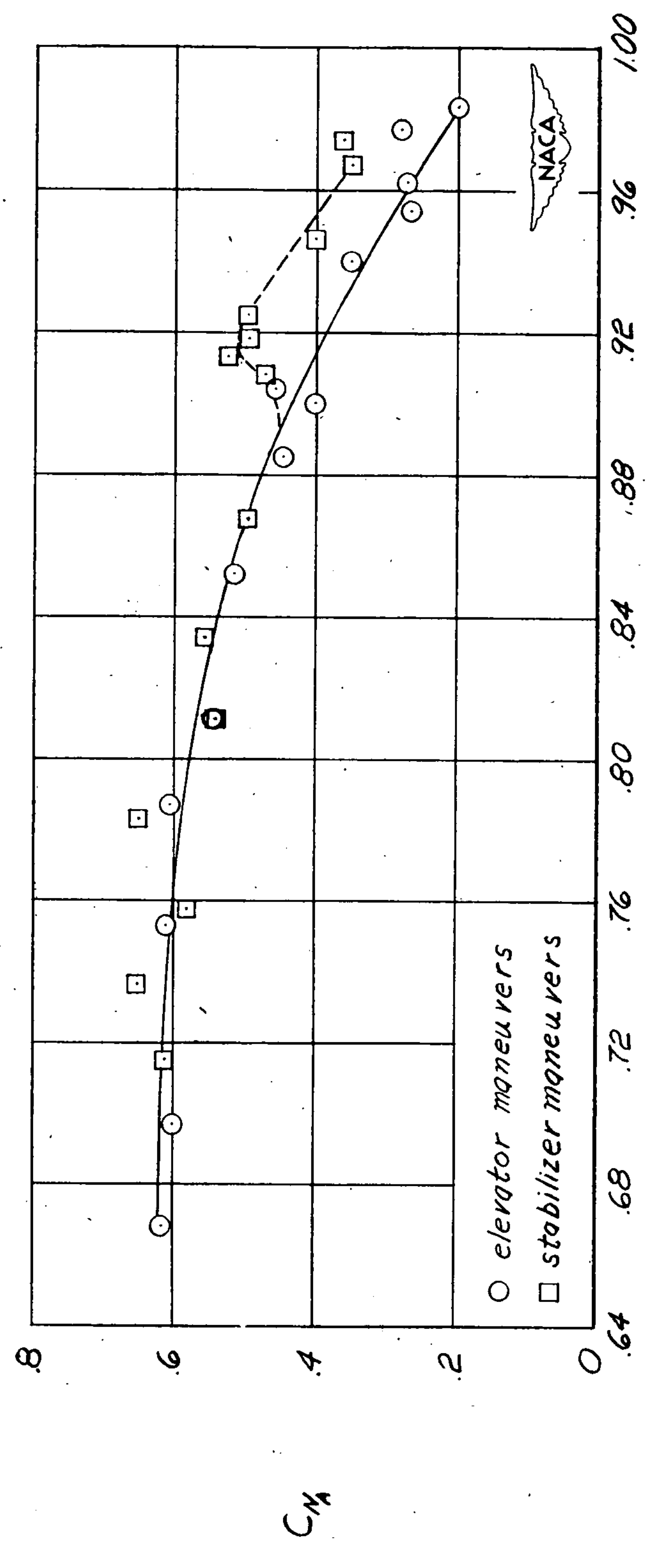


Figure 10.- Boundary for reduction of longitudinal stability for the X-5 airplane at 59° sweepback.

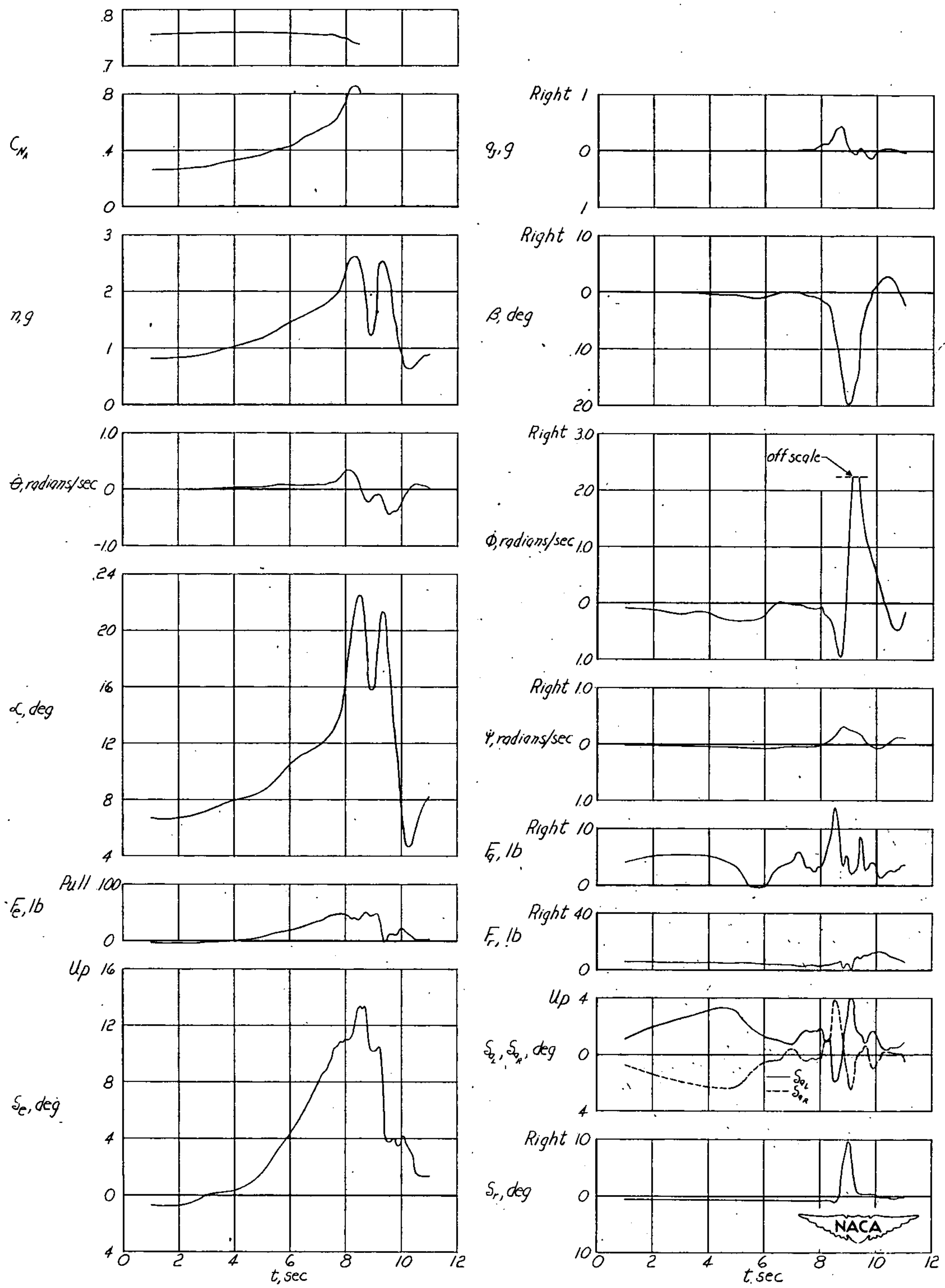


Figure 11.- Time history of a maneuver executed with the elevator control. h_p = 41,500 feet; i_t = -2.5°; c.g. at 44.8 percent M.A.C.

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