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RESEARCH MEMORANDUM

DETERMINATION OF LONGITUDINAL STABILITY IN SUPERSONIC ACCELERATED MANEUVERS FOR THE DOUGLAS D-558-II RESEARCH AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
February 17, 1954

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SUMMARY

Flight tests were performed with the Douglas D-558-II research airplane to investigate the longitudinal stability characteristics of the airplane in accelerated flight at supersonic speeds to a Mach number of 1.67 at altitudes above 45,000 feet.

At moderate values of angle of attack at supersonic speeds, the airplane experienced a decrease in stability which was in some cases followed by complete instability and a rapid uncontrolled increase in the angle of attack and normal acceleration.

The values of normal-force coefficient at which this instability and "pitch-up" occur are higher in the low supersonic region (normal-force coefficient approximately 0.9) than in the high subsonic region (normal-force coefficient approximately 0.45); but there is evidence that the normal-force coefficient at which instability occurs decreases as Mach number increases, reaching values below normal-force coefficient of 0.7 at a Mach number of about 1.6. The sparse data available indicate that the instability may be less severe at the higher supersonic speeds.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting transonic and supersonic flight research at the High-Speed Flight Research Station at Edwards Air Force Base, Calif., by using research-type aircraft. The D-558-II airplanes were obtained for the NACA by the Navy Department in order to conduct flight research on swept-wing high-speed airplanes. At the present time, two identical D-558-II airplanes are being used in this program, one powered by a turbojet engine and rockets and the other powered only by rocket engines. Both airplanes are launched at an altitude of about 30,000 feet from a Boeing B-29 airplane. This paper consists primarily of results obtained with the all-rocket D-558-II (BuAero No. 37974) airplane during power-off and power-on turns at supersonic speeds. Previous investigations have shown that changes in longitudinal stability and uncontrollable pitch-ups were obtained at high subsonic speeds at medium values of normal-force coefficient with the jet and rocket D-558-II airplane and have been reported in reference 1.

The purpose of the present investigation is to explore the range of high normal-force coefficient at supersonic speeds and to determine Mach numbers and normal-force coefficients where longitudinal stability changes and uncontrollable pitch-ups occur. This investigation is not complete but it was felt that the first results are of sufficient interest to warrant reporting.

SYMBOLS

C_{N_A}	airplane normal-force coefficient, Wn/qS
F_e	stick force, lb
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
i_t	stabilizer angle, deg
M	free-stream Mach number
n	normal acceleration, g units
p	static pressure, lb/sq ft
q	free-stream dynamic pressure, lb/sq ft
q_c'	uncorrected impact pressure, lb/sq ft
S	wing area, sq ft
t	time, sec
W	airplane weight, lb
α	angle of attack, deg

δ_e elevator angle, deg

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

INSTRUMENTATION AND METHODS

Standard NACA recording instruments are installed in the airplane to measure the following quantities:

Airspeed and altitude
Elevator, stabilizer, left and right aileron, and rudder positions
Angles of attack and sideslip
Normal, longitudinal, and lateral accelerations
Pitching, yawing, and rolling angular velocities
Pitching and rolling angular accelerations
Elevator and pedal forces
Aileron wheel force
Rudder hinge moment

A Statham accelerometer was installed at the center of gravity to measure the high-frequency buffeting accelerations. Also recorded were rocket time, radar time, and rocket chamber pressures. All recording instruments were synchronized by a common timer.

DESCRIPTION OF THE AIRPLANE

The airplane used in the present investigation is powered by a Reaction Motors, Inc., four-cylinder rocket engine which uses alcohol-water and liquid oxygen as propellants and has a design thrust of 1,500 pounds per cylinder at sea level.

The D-558-II airplanes have sweptback wing and tail surfaces and are equipped with adjustable motor-operated horizontal stabilizers, but no means are provided for trimming out aileron or rudder control forces. No aerodynamic balance or control boost is used in any of the control systems, although hydraulic dampers are linked to all control surfaces to minimize possible control surface "buzz." Dive brakes are located on the rear portion of the fuselage. Table I presents pertinent airplane physical characteristics, and figure 1 is a three-view drawing of the airplane. Shown in figures 2 and 3 are photographs of the airplane.

The angle of attack was measured from a vane mounted on the nose boom 42 inches ahead of the apex of the airplane nose. No corrections to angle of attack were made for boom bending or pitching velocity. The maximum probable error of angle of attack in the turns presented herein is about -3 percent at the higher angles of attack.

The airspeed-altitude system was calibrated by comparing the static pressure measured in the airplane and the altitude of the airplane measured by radar with the pressure and altitude determined from a radiosonde balloon sent up at the time of each flight. In the supersonic range, the accuracy of the position-error calibration is approximately 0.01 $\Delta p/q_c'$. This gives a possible Mach number error varying from ±0.007 at $M = 1.0$ to about ±0.02 at $M = 1.6$.

The airplane weight during flight was estimated from the drop weight and rocket running time.

TESTS, RESULTS, AND DISCUSSION

Maneuvers were made at altitudes between about 60,000 feet and 45,000 feet and at Mach numbers between 1.67 and 0.98. The center-of-gravity location varied from about 25 to 27 percent of the mean aerodynamic chord. In one flight (fig. 5(g)), the inboard fences, shown in figure 1, were not installed on the airplane. Tests at high subsonic speeds have indicated that the inboard fences have little effect on the pitch-up in that speed range and it is believed that they have little effect in the speed range covered in this paper. Previous tests of the D-558-II airplane reported in reference 1 have shown that changes in stability and pitch-up were encountered at normal-force coefficients as low as 0.47 at a Mach number of 0.94. These large stability changes at low values of C_{N_A} severely limit the maneuverability of the airplane in the high subsonic speed range.

Figure 4 shows the C_{N_A} and Mach number variation encountered during five power-off turns and three power-on turns at supersonic speeds. Figure 5 presents time histories and plots against angle of attack or C_{N_A} showing the stability characteristics of the airplane during these turns. (In the turn of fig. 5(b) the angle-of-attack record was not available; therefore, the plot was made as variations with C_{N_A}.) The values of C_{N_A} in figure 5(h) were taken from a relatively insensitive accelerometer, resulting in a decrease of accuracy to about ±0.03 C_{N_A} at low values of C_{N_A} and ±0.08 at values of C_{N_A} above 0.70.

In the power-off turns of figures 5(a) to 5(e), the turns were continued to high values of C_{N_A} until the airplane pitched up to much higher angles of attack than was intended even though the longitudinal controls were fixed or even reversed. It will be noted that the pitching velocities increased more rapidly at about the same time the pilot stopped the controls. It is not known how much of this pitch-up is due to a reduction of stability or to a change in trim inasmuch as the airplane is slowing down as C_{N_A} is increased and it is expected that the trim changes would be in a direction so as to pitch the airplane up as it slows down in this region. However, it is believed that the appreciable increase in pitching velocity when the controls are held fixed indicates that instability is present. The turn of figure 5(f) was apparently not continued to an angle of attack high enough to approach neutral stability.

The turns of figures 5(g) and 5(h) were made at Mach numbers above 1.3, at which speed the wings of the airplane are completely supersonic. During these turns the pilot used all available stabilizer control to pitch the airplane. In the turn of figure 5(h), the airplane continued to pitch slightly after the control movement stopped, but there was no large increase in pitching velocity as in the case of the turns of figures 5(a) to 5(e); and the pitch-up was not of the violent nature previously obtained. This suggests that the change of stability was much less in the turn at the highest Mach number; whereas, in the lower speed turns, the data indicate that a large change of stability occurred in a rather abrupt manner. The data further suggest that as the angle of attack increased further in the highest speed turn, the static stability did not change appreciably in either direction but remained fairly constant up to the highest angle of attack reached.

In the turn of figure 5(g) it is not certain that a reduction of stability even occurred as the elevator was moved about one second after the stabilizer stopped. However, the data from the turn are presented to show at least the regions where the airplane did not become unstable. It is also possible that power may have some effect on the stability. In this regard it must be noted that the rockets shut off shortly before the pitch-up of figure 5(h).

The approximate areas where the pitch-ups occurred are shown in figure 6. It is not possible to show exact points inasmuch as the first changes in stability and the resultant pitch-ups are not well-defined by the data; therefore, the line represents the approximate points at which the pilot fixed controls. Because of this, the line shown in figure 6 represents a region at about which the stability decreased appreciably. The data point at $M = 1.62$ represents the highest speed turn, which appeared to be of considerably different character from the lower speed turns, primarily in that the pitching velocity did not reach very high values.

Although the pitch-up at the highest supersonic speed did not appear to be as severe as those at lower speeds, the change in stability appears to occur at a lower value of C_{N_A}.

For comparison, points are added to figure 6 from reference 1 showing where the first decay of stability occurred at subsonic speeds. These points were all obtained in turns made using elevator control alone, with stabilizer fixed, and the points of instability for these data appeared to be almost coincident with the points of first decay of stability, rather than occurring at higher values of C_{N_A} as in most of the supersonic turns.

As can be seen in figure 6, the range of normal-force coefficient where the airplane can be maneuvered precisely is somewhat greater at low supersonic speeds than at high subsonic speeds. However, an airplane initiating a maneuver at a Mach number of about 1.2 may decelerate and perhaps encounter an uncontrollable pitch-up at Mach numbers near 1.0 at quite low values of C_{N_A}.

CONCLUSIONS

Results of data obtained during turns at Mach numbers up to 1.67 at altitudes above 45,000 feet with the Douglas D-558-II research airplane indicate the following:

1. At moderate values of normal-force coefficient in maneuvering flight at supersonic speeds, static longitudinal stability decays and the airplane becomes unstable resulting in severe pitch-ups at values of normal-force coefficient considerably below the maximum attainable.

2. The normal-force coefficients at which instability and pitch-up occur are higher in the low supersonic region $\left(C_{N_A} \approx 0.9\right)$ than in the high subsonic region $\left(C_{N_A} \approx 0.45\right)$; but there is evidence that the normal-force coefficient at which instability occurs decreases as Mach number

increases, reaching values near normal-force coefficients of approximately 0.68 at a Mach number of about 1.62. The data indicate that the pitch-up may be less severe at the higher supersonic speeds.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 6, 1953.

REFERENCE

1. Fischel, Jack, and Nugent, Jack: Flight Determination of the Longitudinal Stability in Accelerated Maneuvers at Transonic Speeds for the Douglas D-558-II Research Airplane Including the Effects of an Outboard Wing Fence. NACA RM L53A16, 1953.

TABLE I.- PHYSICAL 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.	87.301
Root chord (parallel to plane of symmetry), in.	108.51
Tip chord (parallel to plane of symmetry), in.	61.18
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 (rearward of hinge line), sq ft	9.8
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	
Up	25
Down	15
Stabilizer travel, deg	
Leading edge up	4
Leading edge down	5
Vertical tail:	
Airfoil section (normal to 0.30 chord)	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 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:	
Rocket	Reaction Motors, Inc.
Airplane weight, lb:	
Full rocket fuel	15,787
No fuel	9,421
Center-of-gravity locations, percent M.A.C.:	
Full rocket fuel (gear up)	24.6
No fuel (gear up)	27.3
No fuel (gear down)	26.7
Moments of inertia (no fuel), slug-ft^2:	
About normal axis	38,100
About longitudinal axis	5,025
About lateral axis	34,500

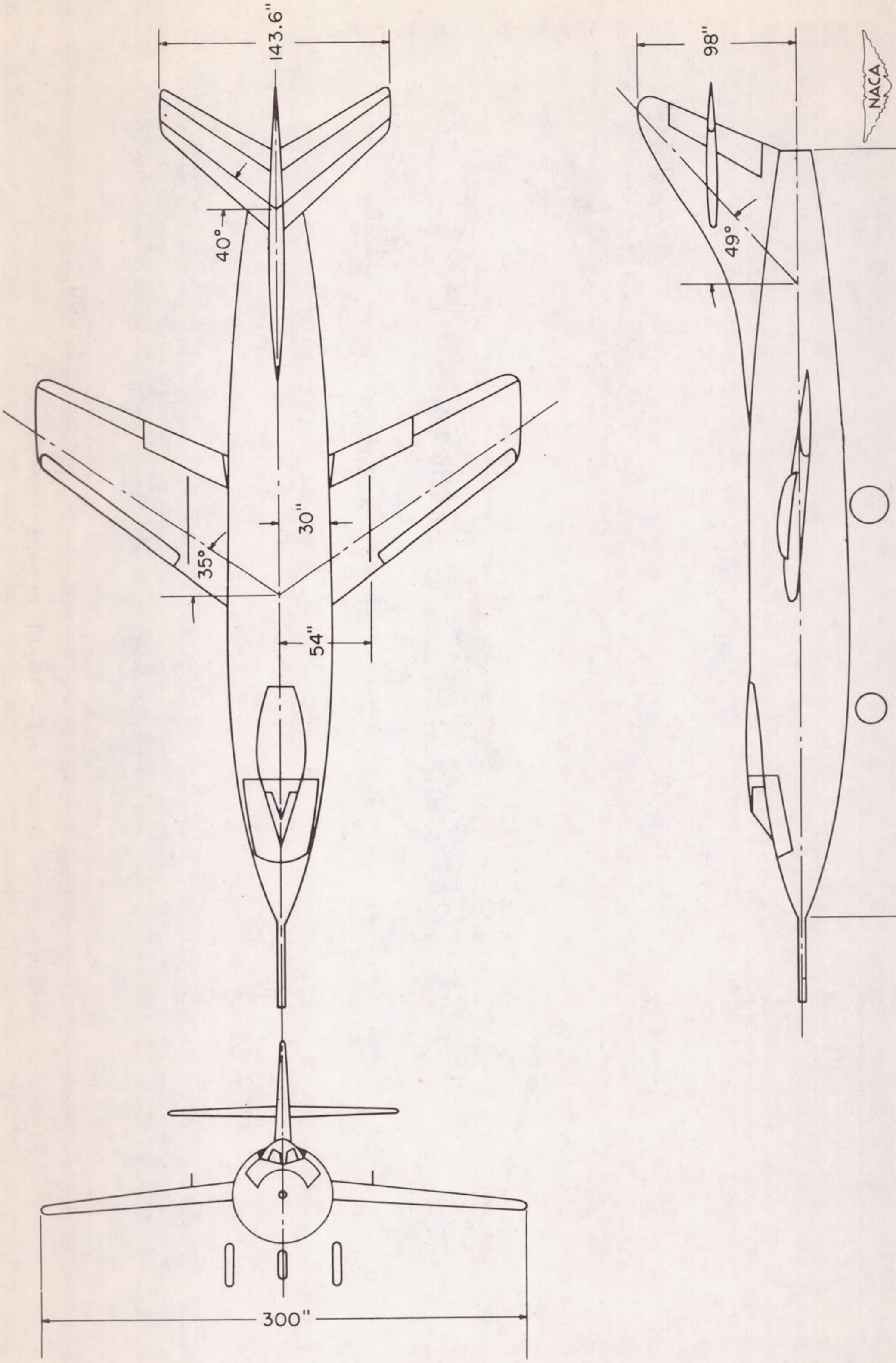

Figure 1.- Three-view drawing of the Douglas D-558-II research airplane.

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Figure 2.- Sideview of Douglas D-558-II research airplane.

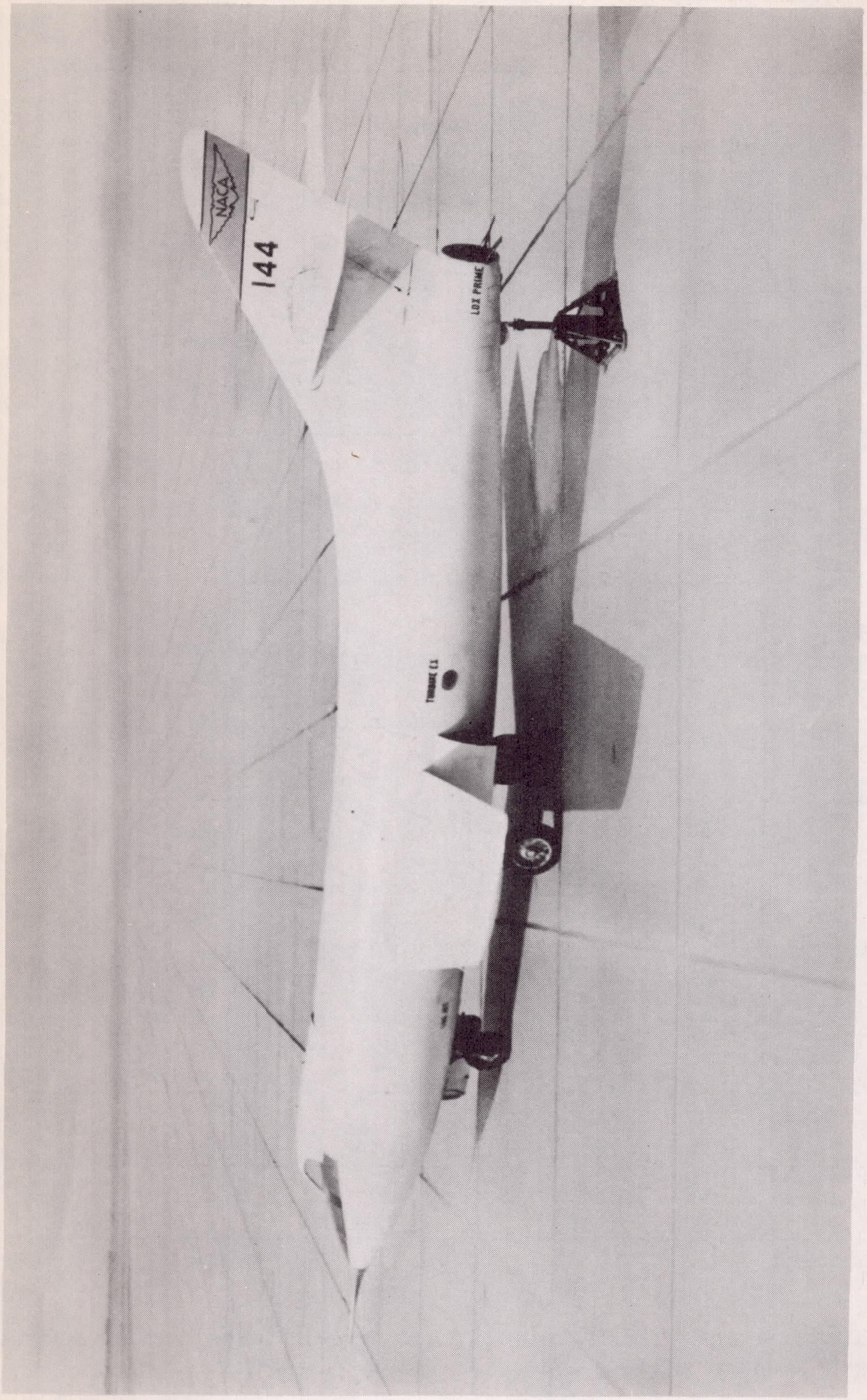

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Figure 3.- Three-quarter rear view of Douglas D-558-II research airplane.

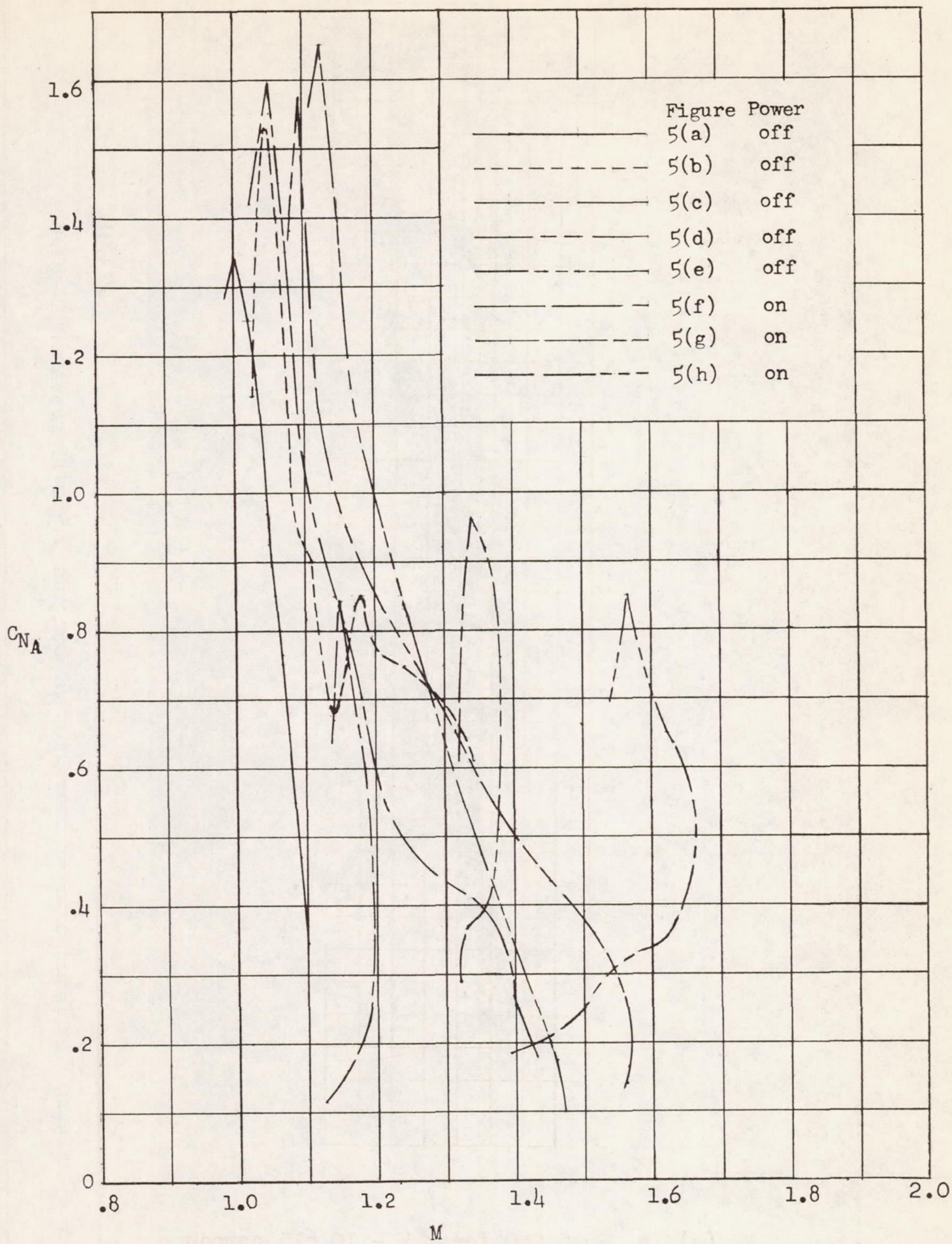
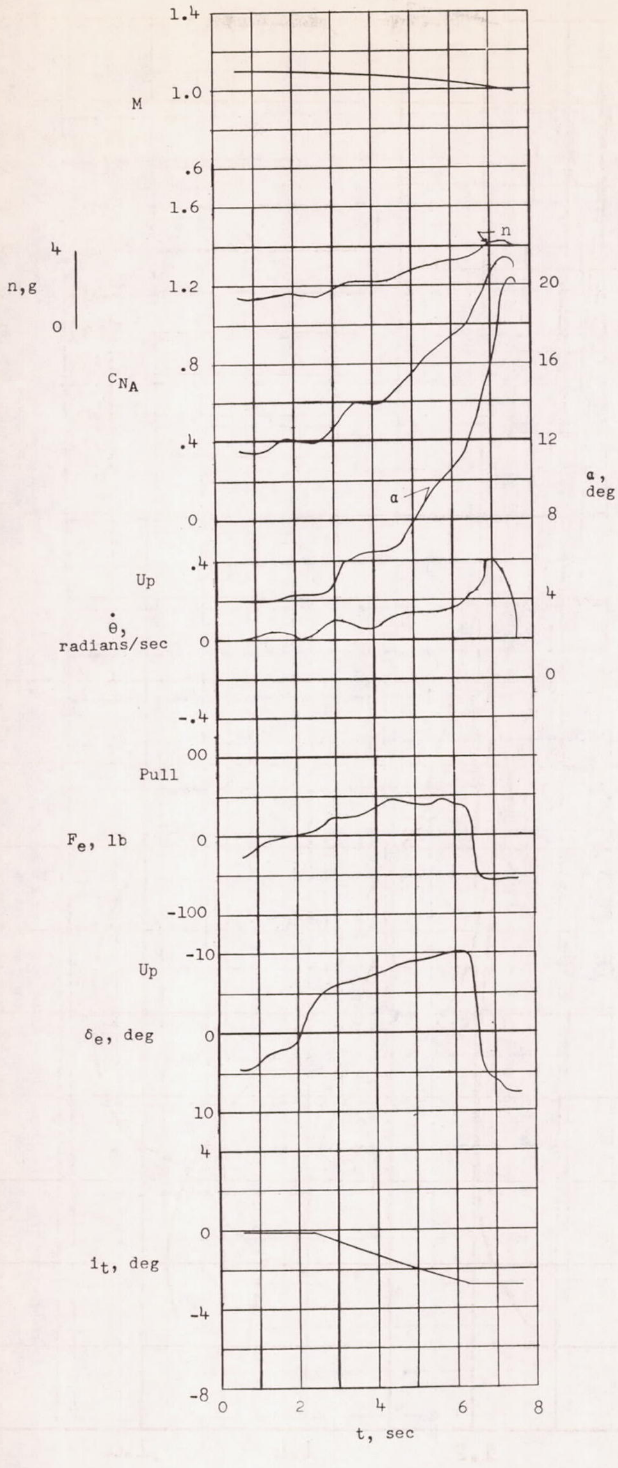
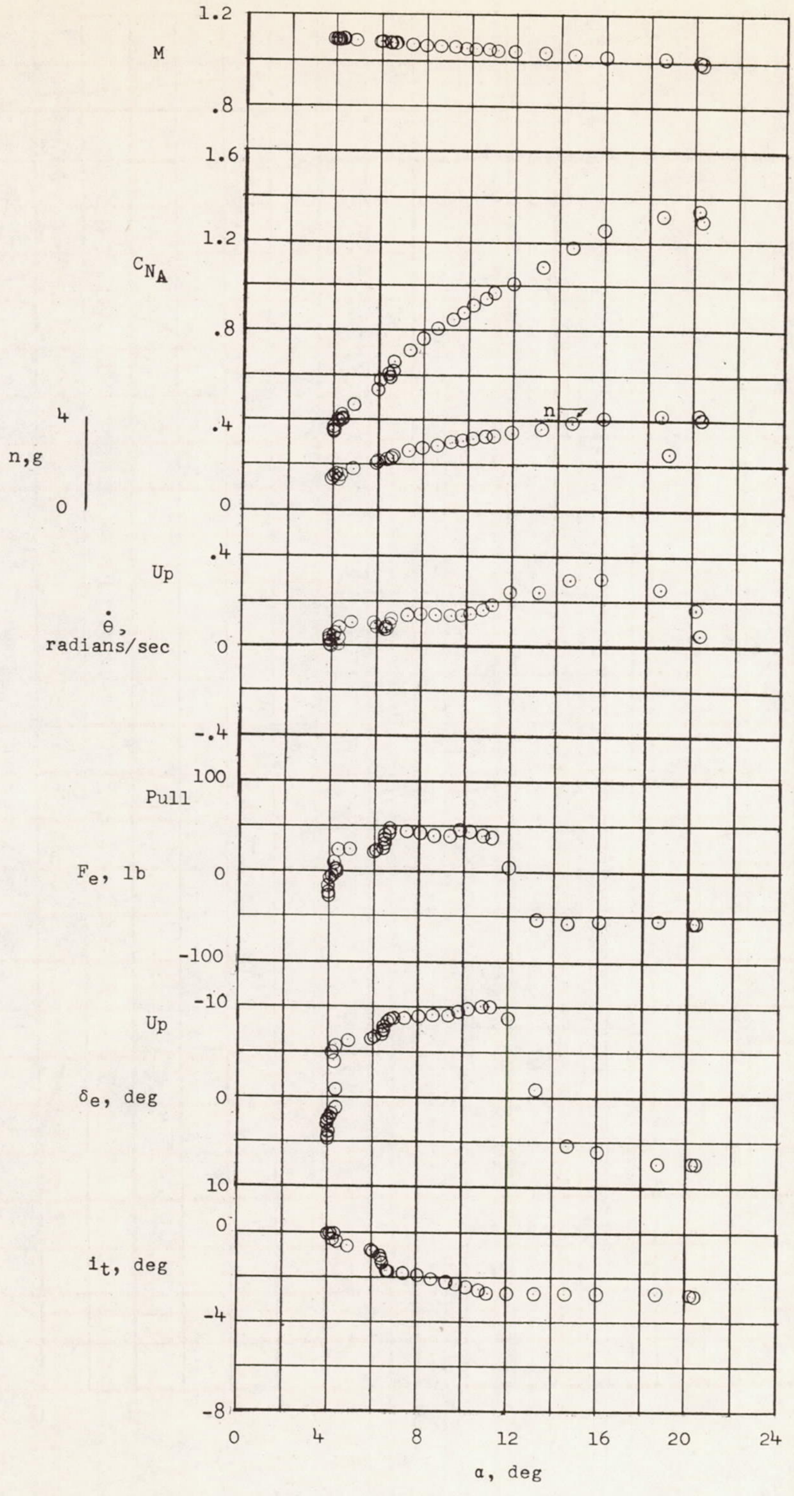


Figure 4.- Normal-force coefficient and Mach number range encountered in turns at supersonic speeds with the D-558-II airplane.



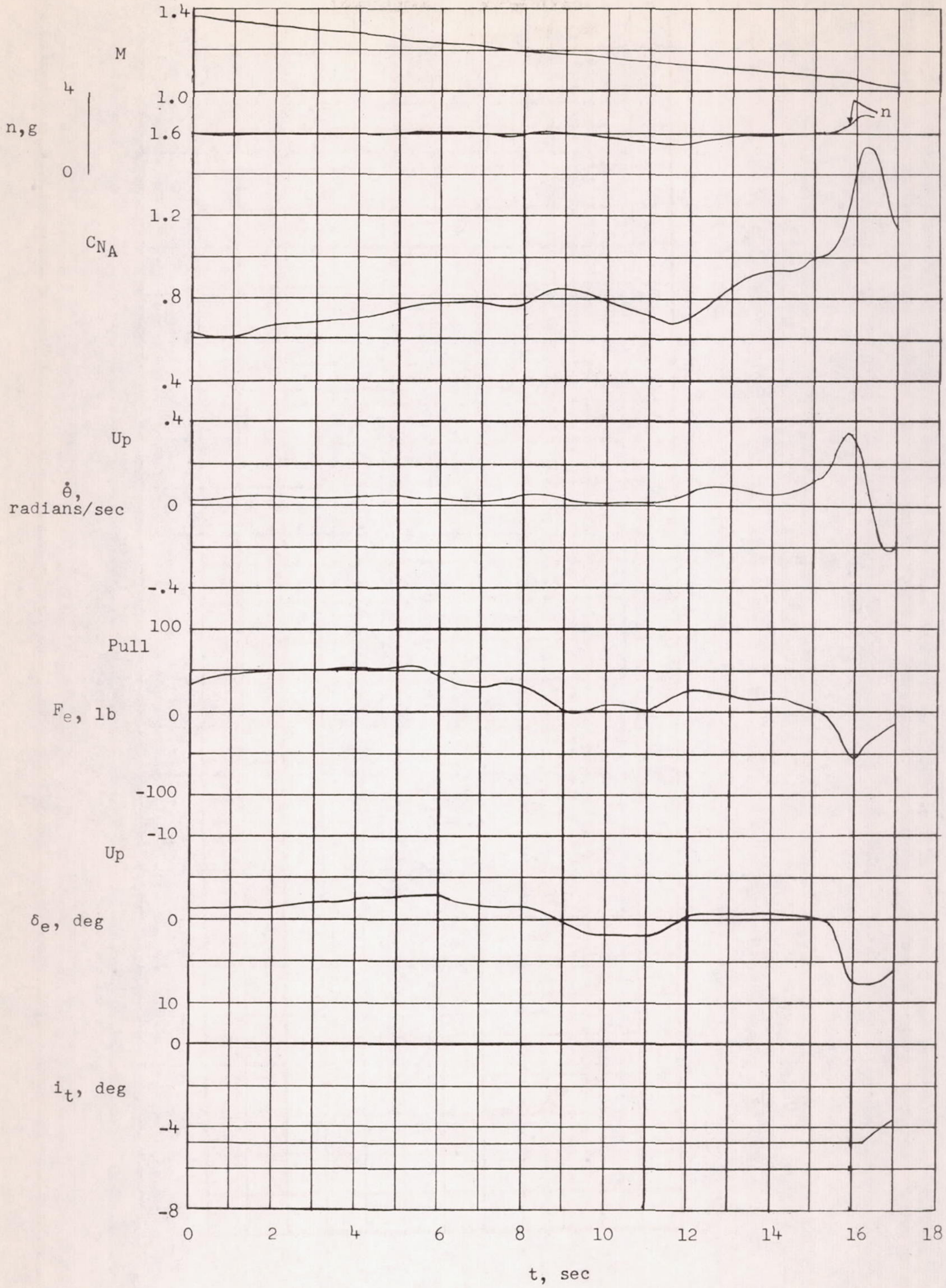
(a) h_p = 45,900 feet; W = 10,615 pounds.

Figure 5.- Static longitudinal characteristics of the D-558-II research airplane in turning flight at supersonic speeds.



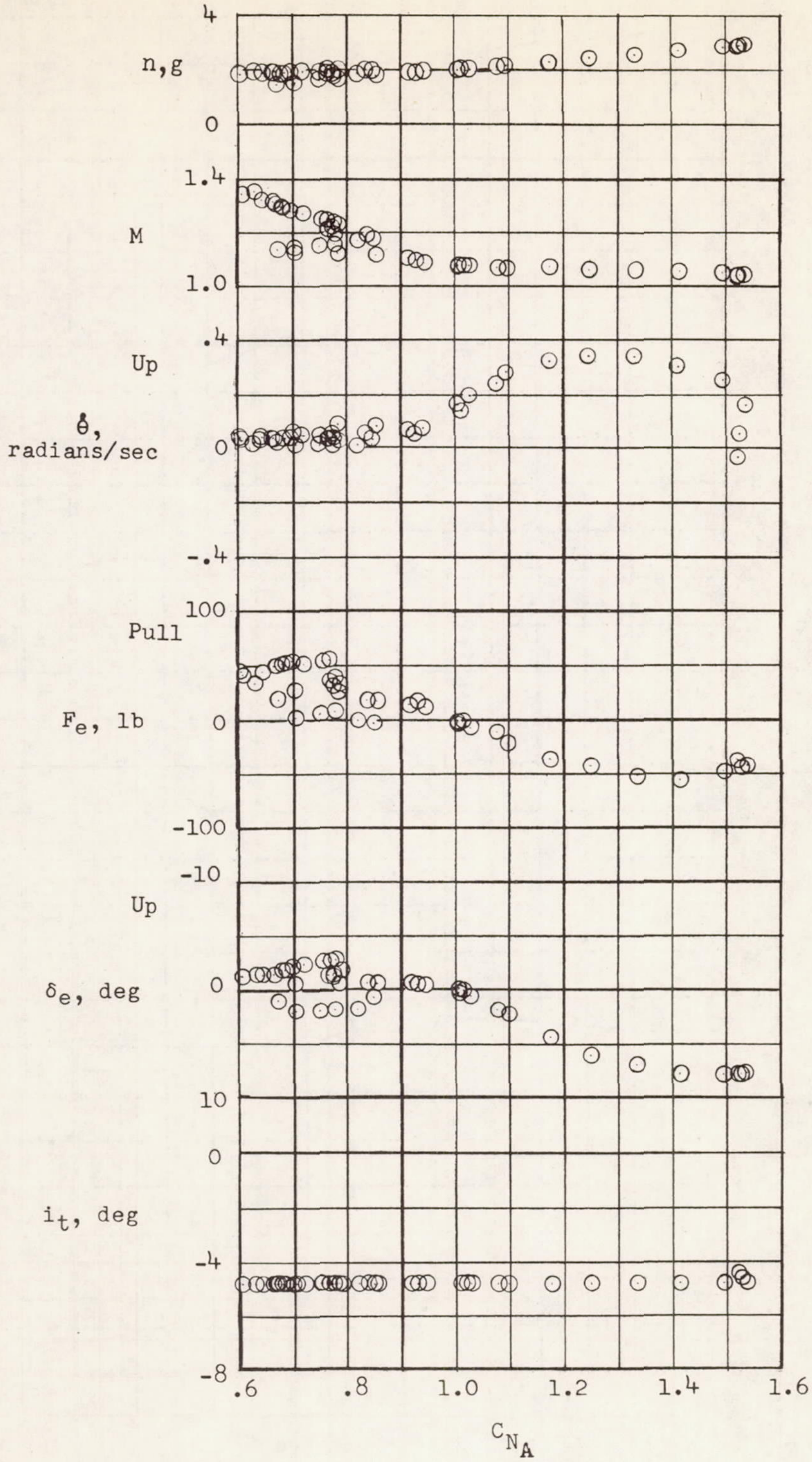
(a) Concluded.

Figure 5.- Continued.



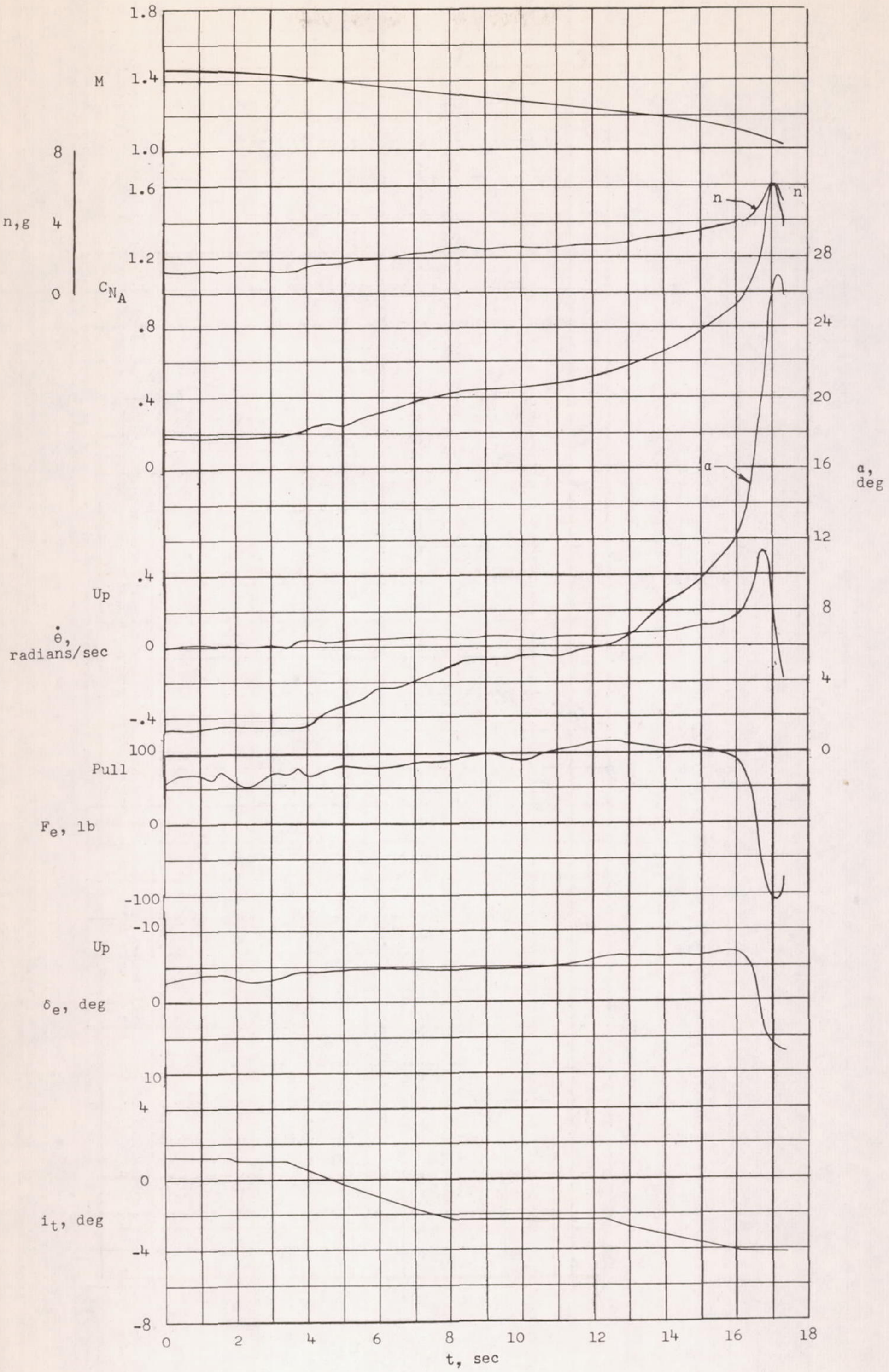
(b) h_p = 62,500 feet; W = 9,577 pounds.

Figure 5.- Continued.



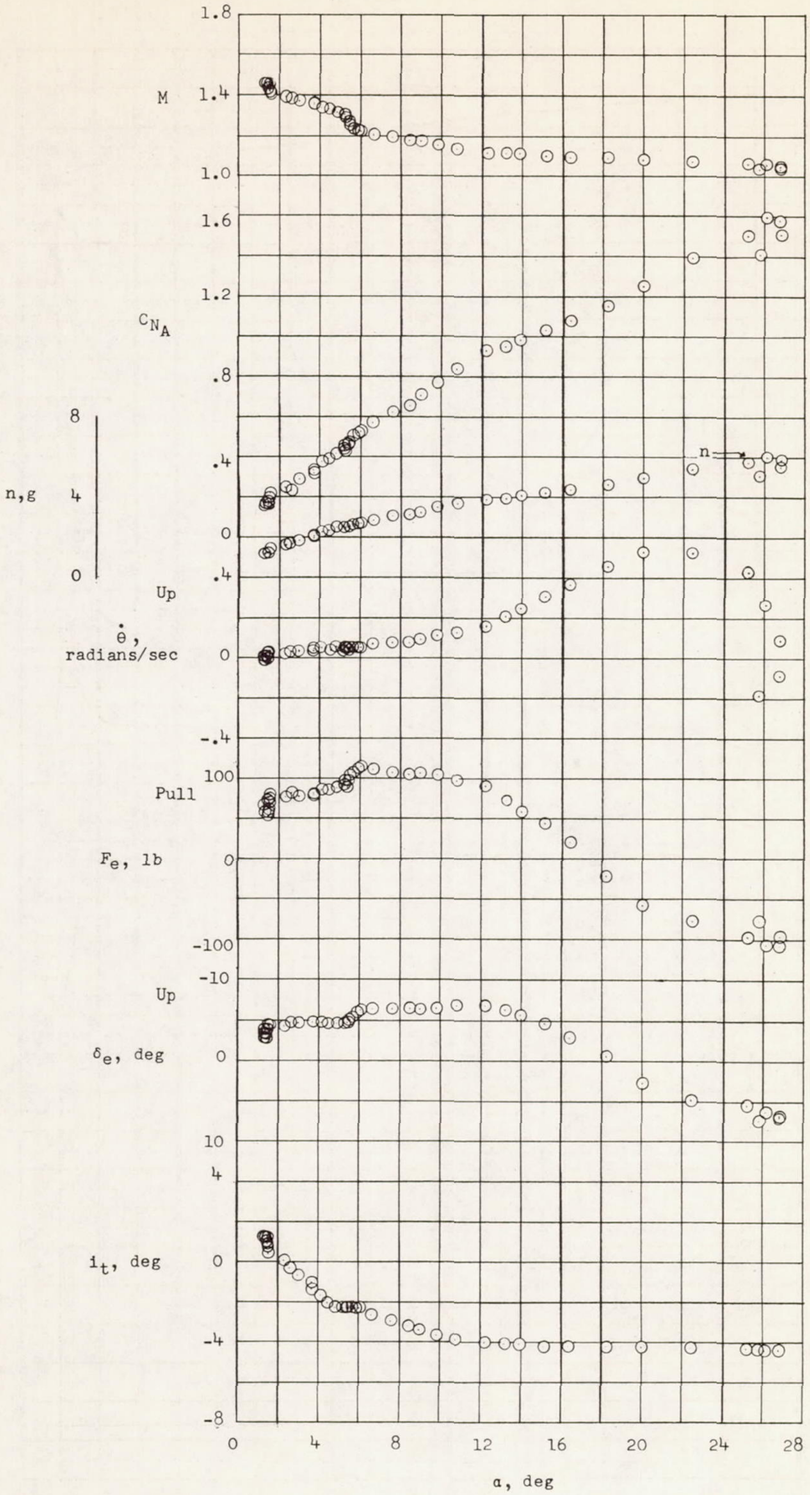
(b) Concluded.

Figure 5.- Continued.



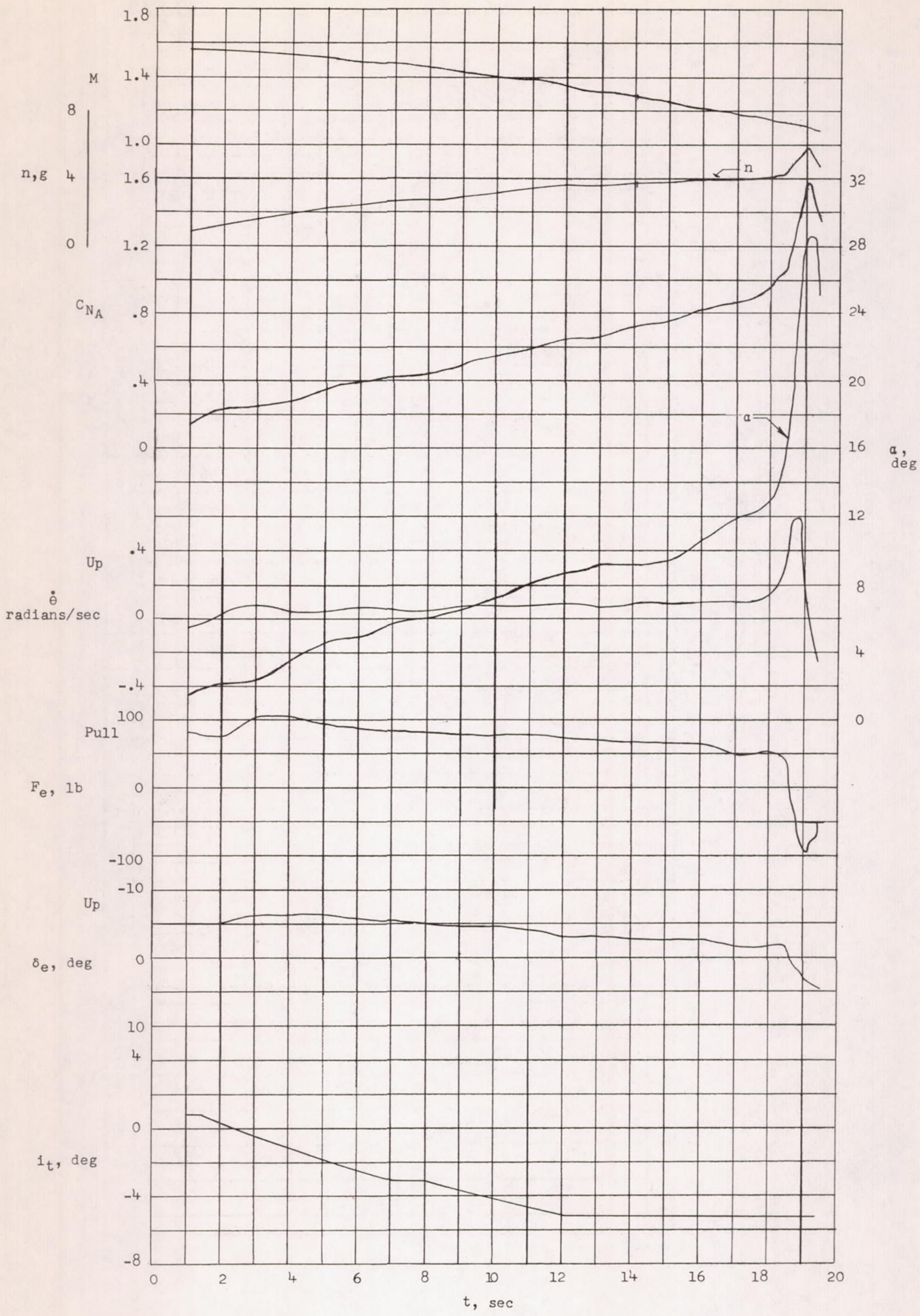
(c) h_p = 47,700 feet; W = 9,780 pounds.

Figure 5.- Continued.



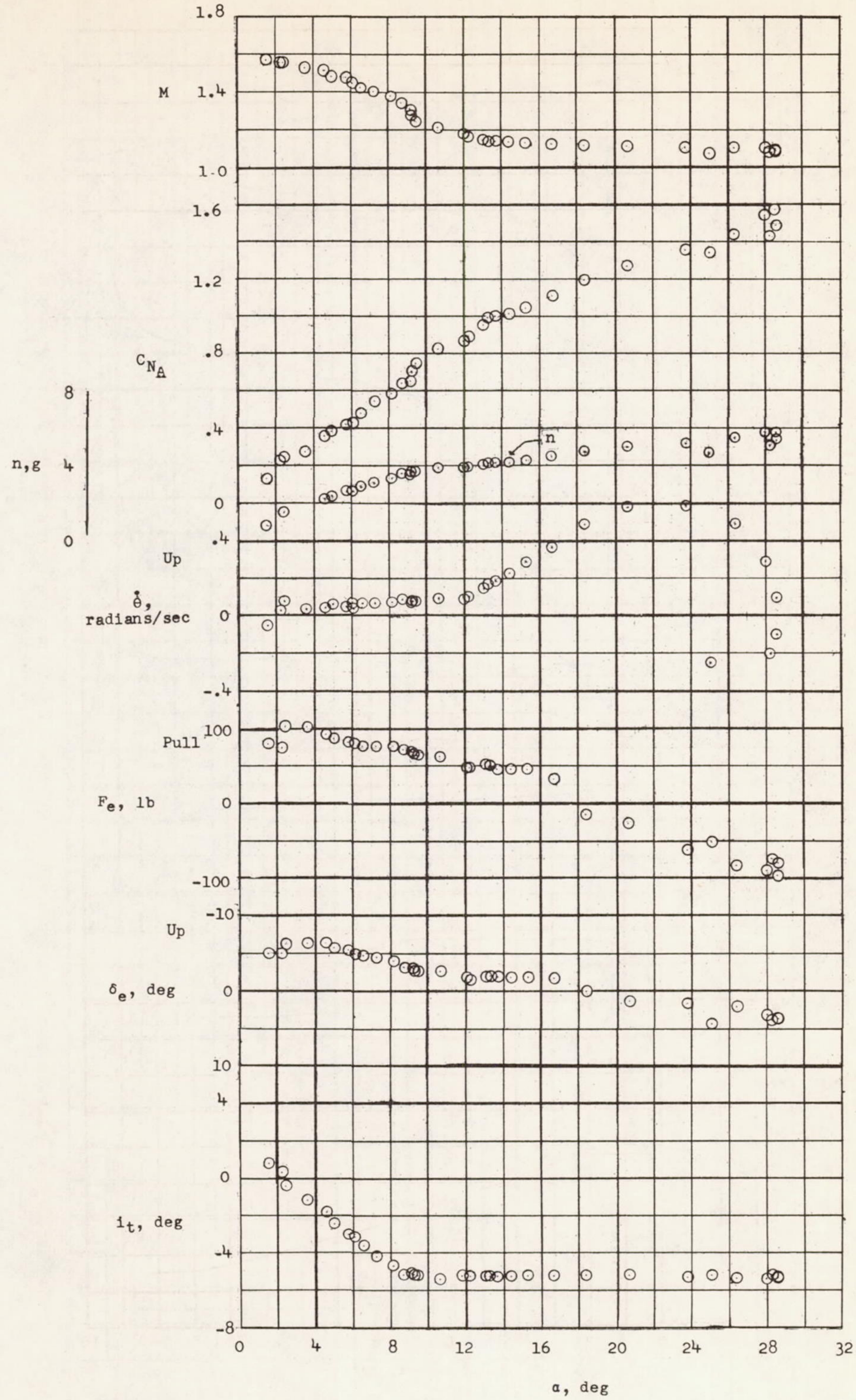
(c) Concluded.

Figure 5.- Continued.



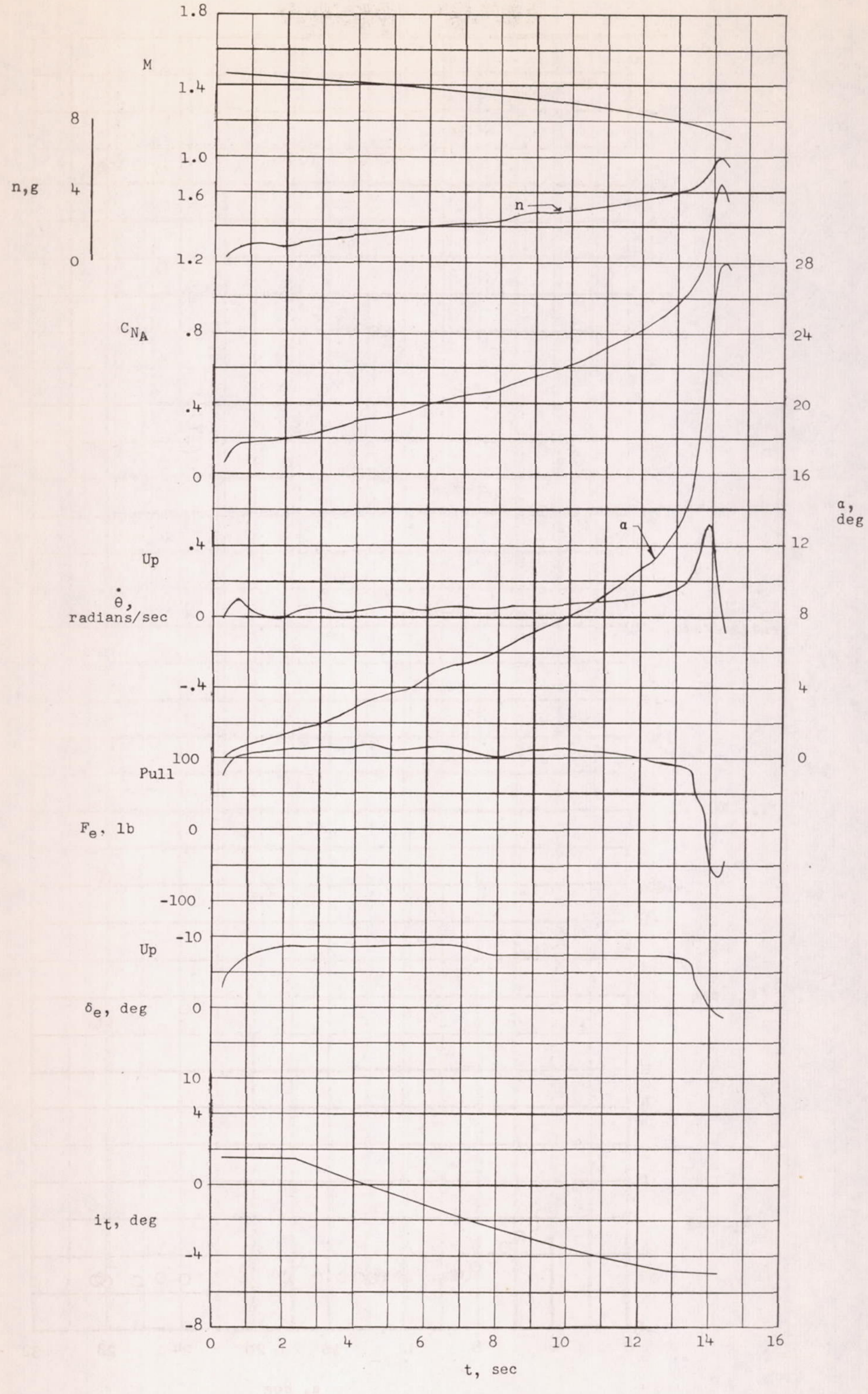
(d) h_p = 48,200 feet; W = 10,120 pounds.

Figure 5.- Continued.



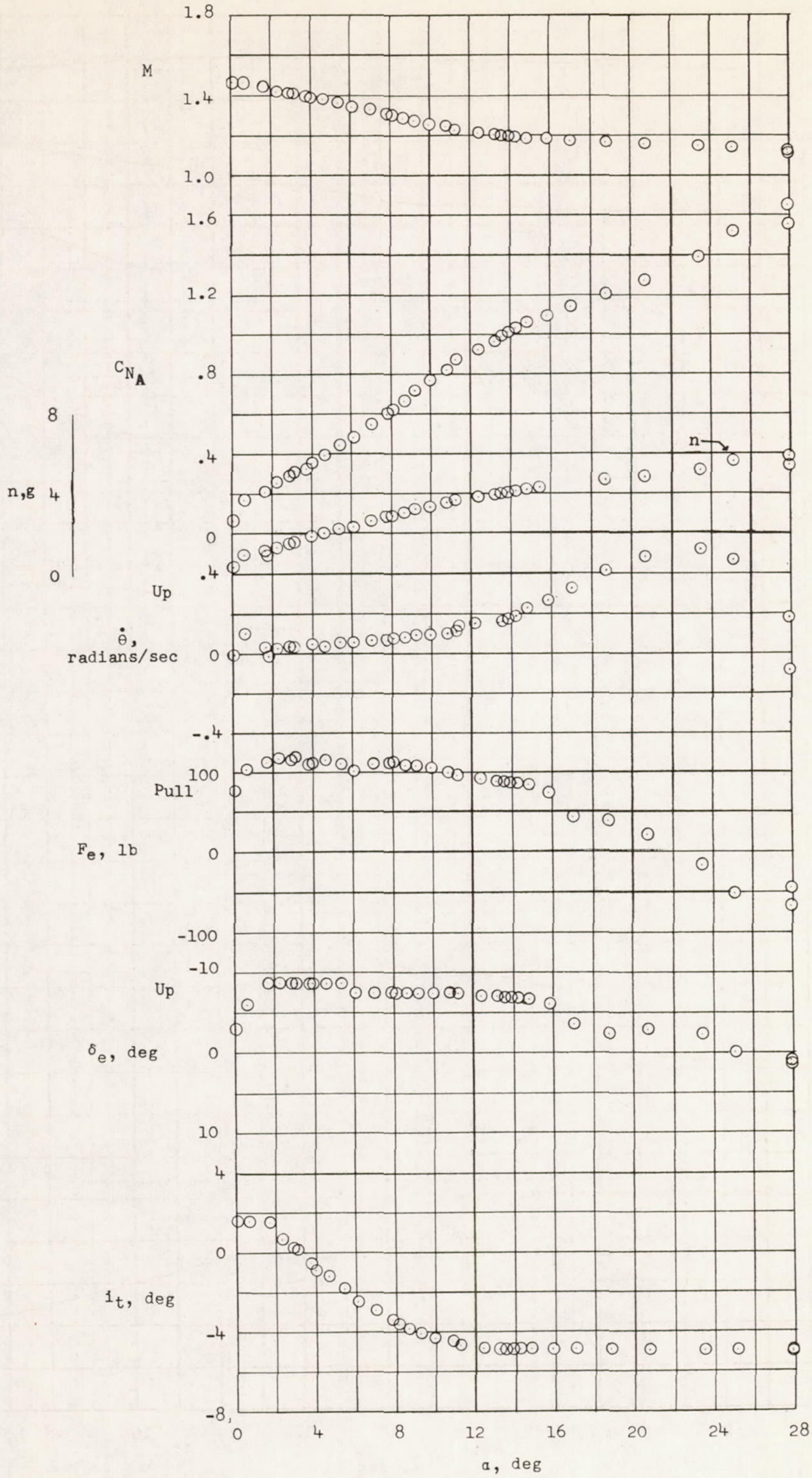
(d) Concluded.

Figure 5.- Continued.



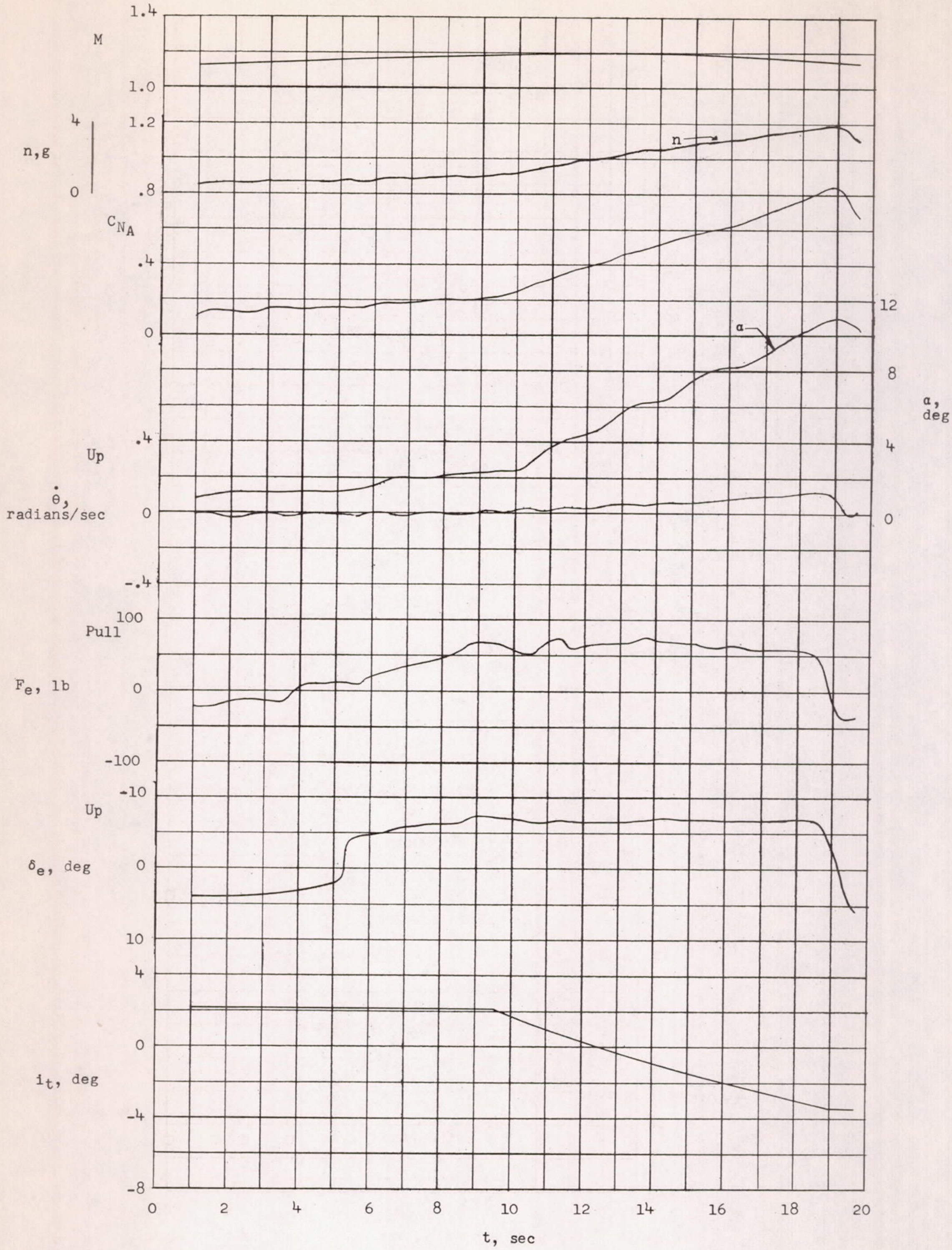
(e) h_p = 51,600 feet; W = 9,755 pounds.

Figure 5.- Continued.



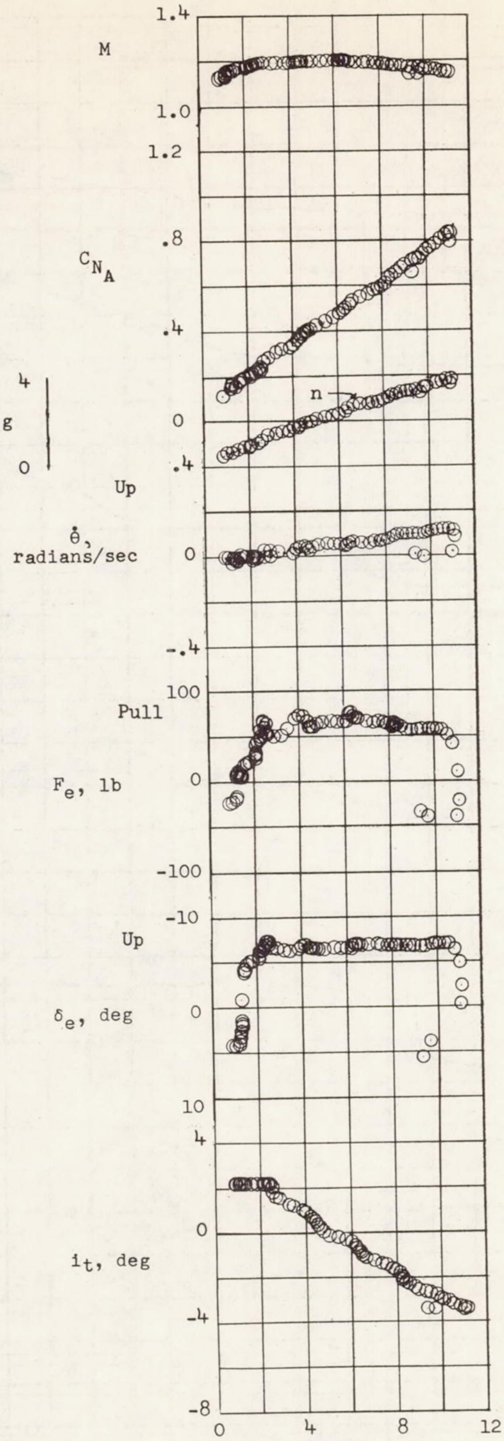
(e) Concluded.

Figure 5.- Continued.



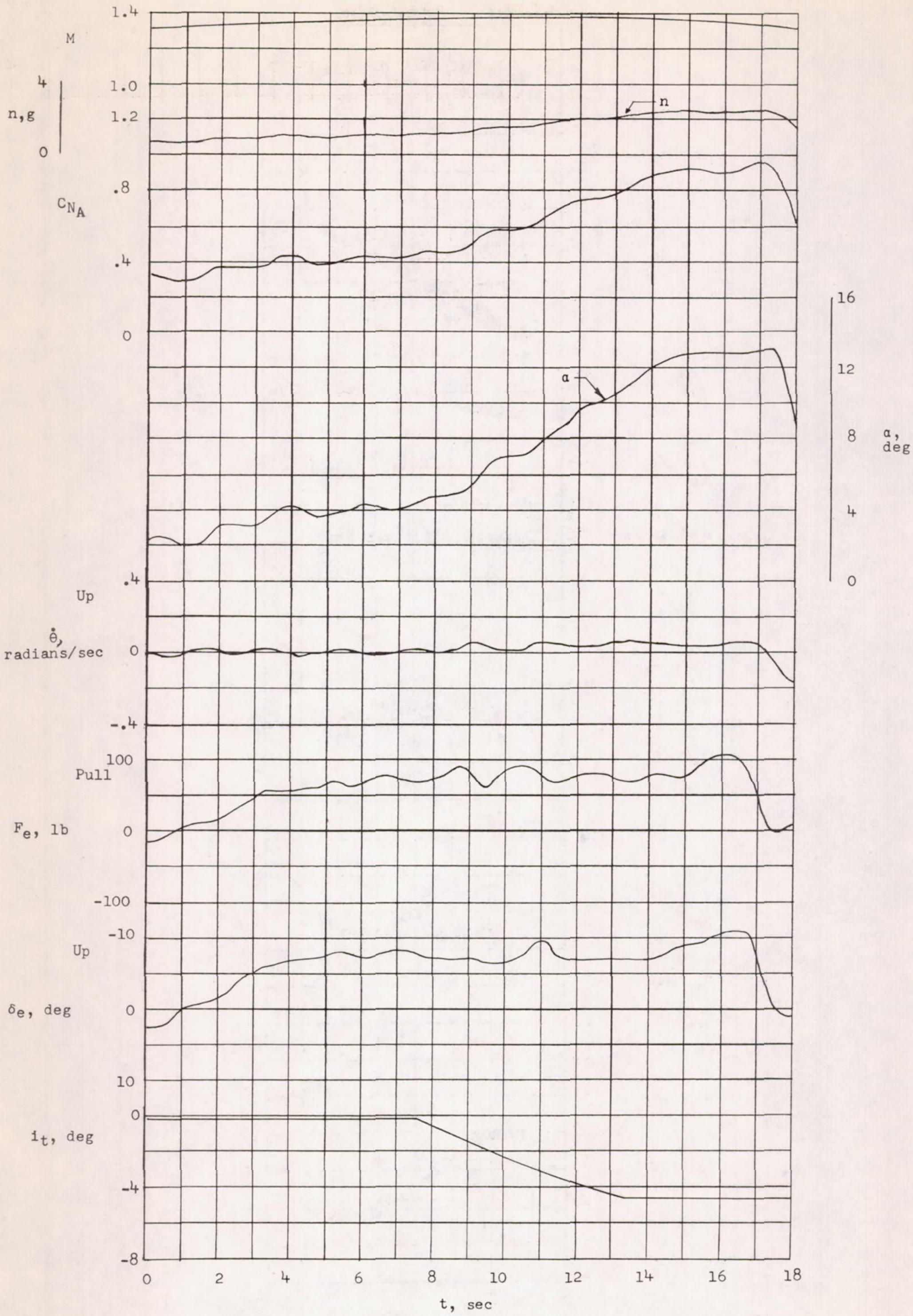
(f) h_p = 42,200 feet; W = 11,960 pounds.

Figure 5.- Continued.



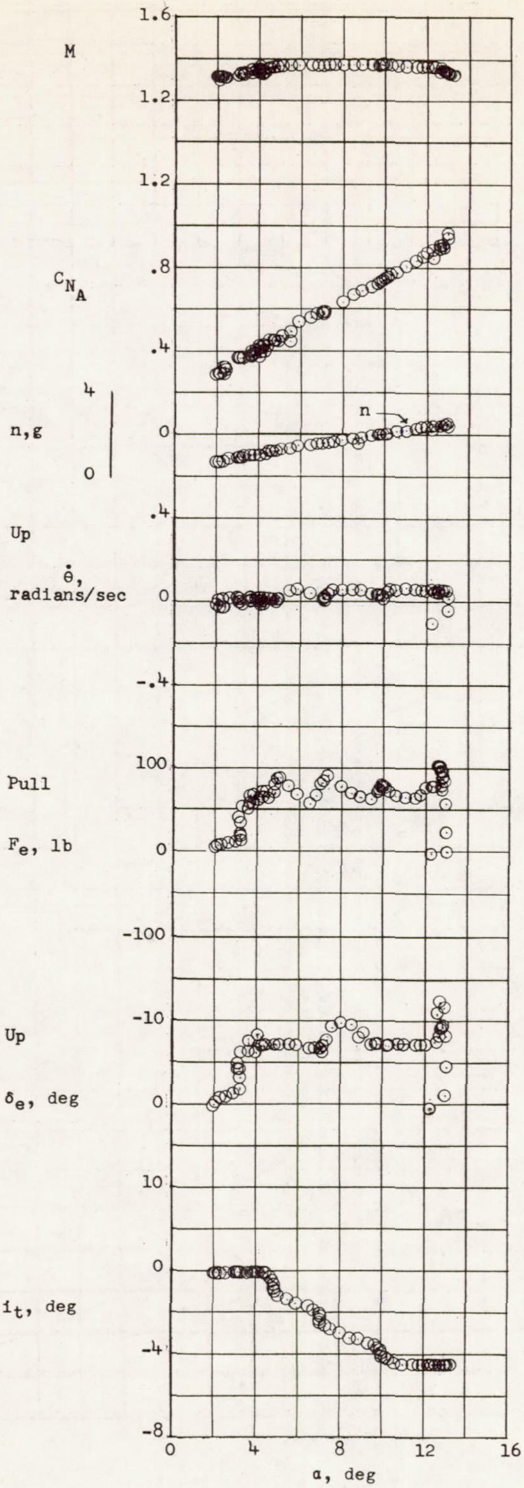
(f) Concluded.

Figure 5.- Continued.



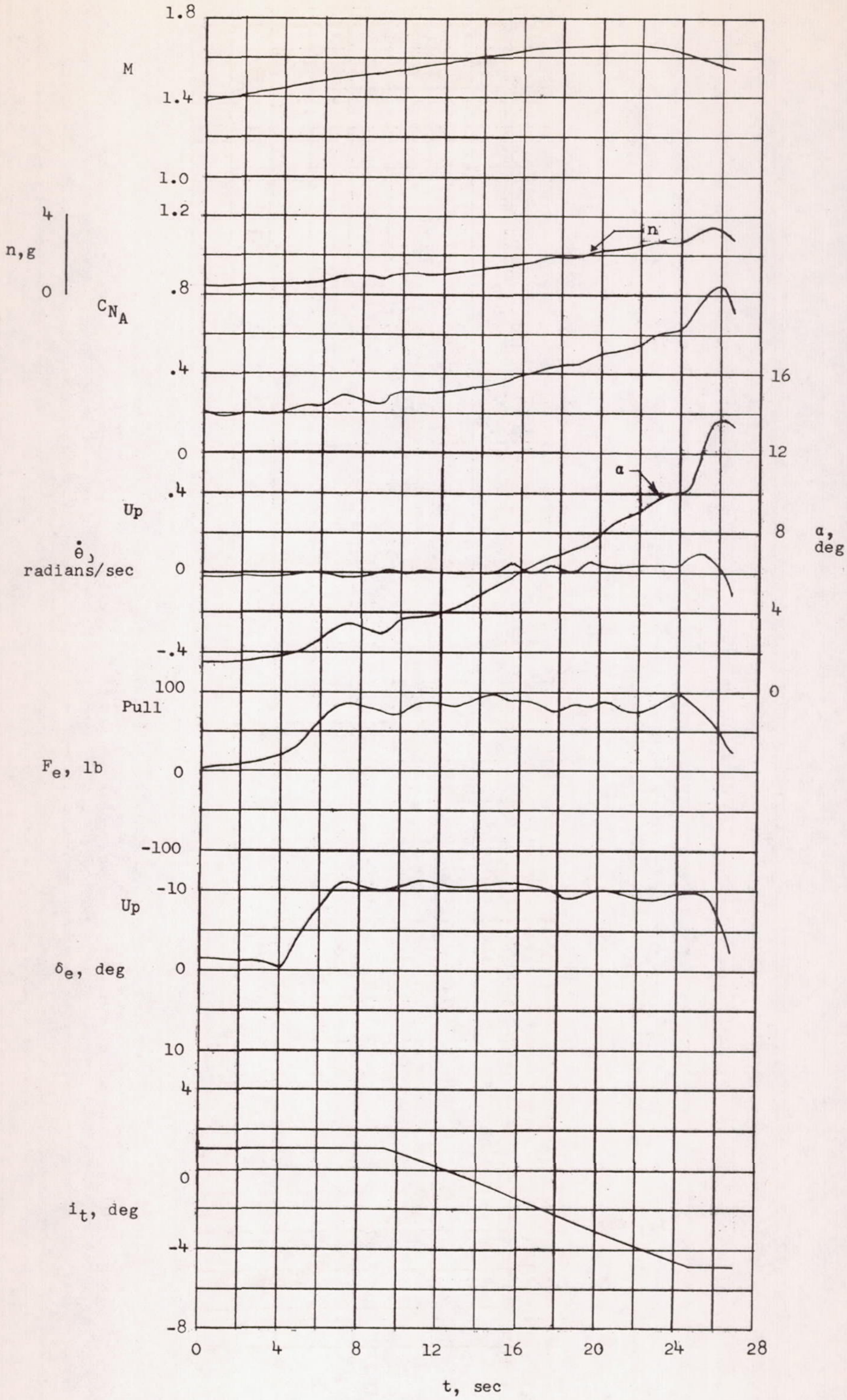
(g) h_p = 64,000 feet; W = 10,610 pounds.

Figure 5.- Continued.



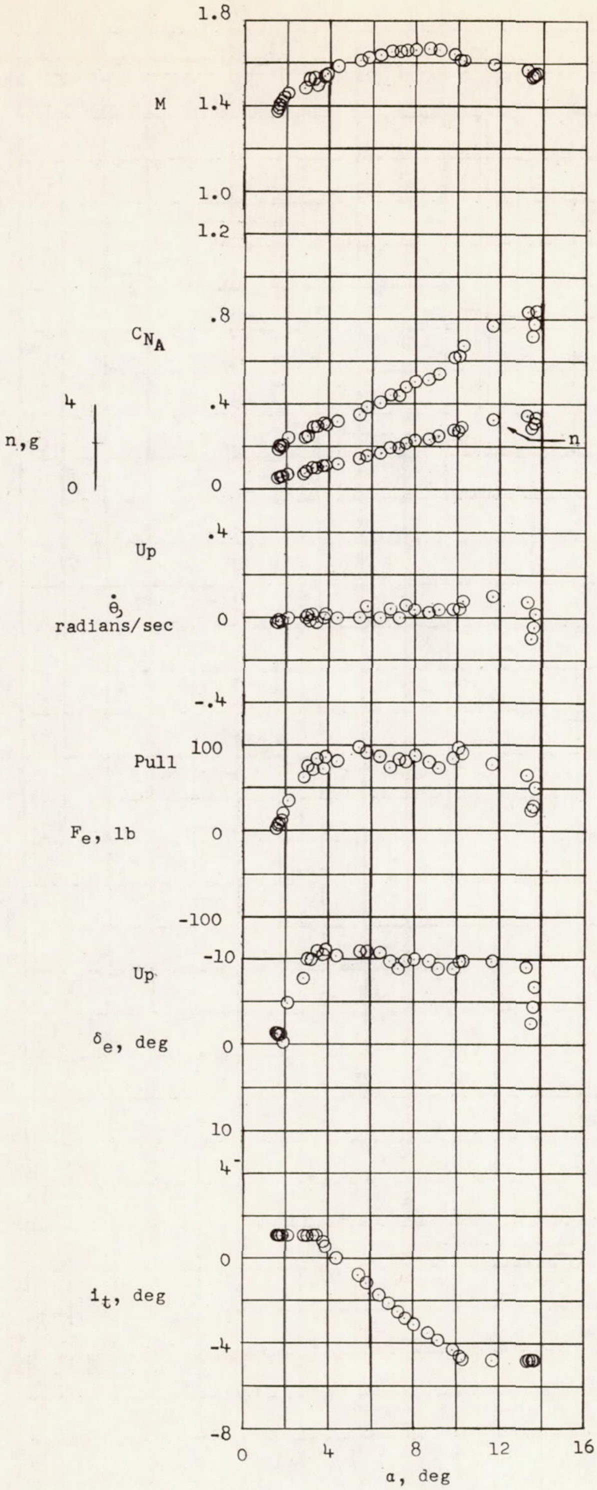
(g) Concluded.

Figure 5.- Continued.



(h) h_p = 63,000 feet; W = 9,970 pounds.

Figure 5.- Continued.



(h) Concluded.

Figure 5.- Concluded.

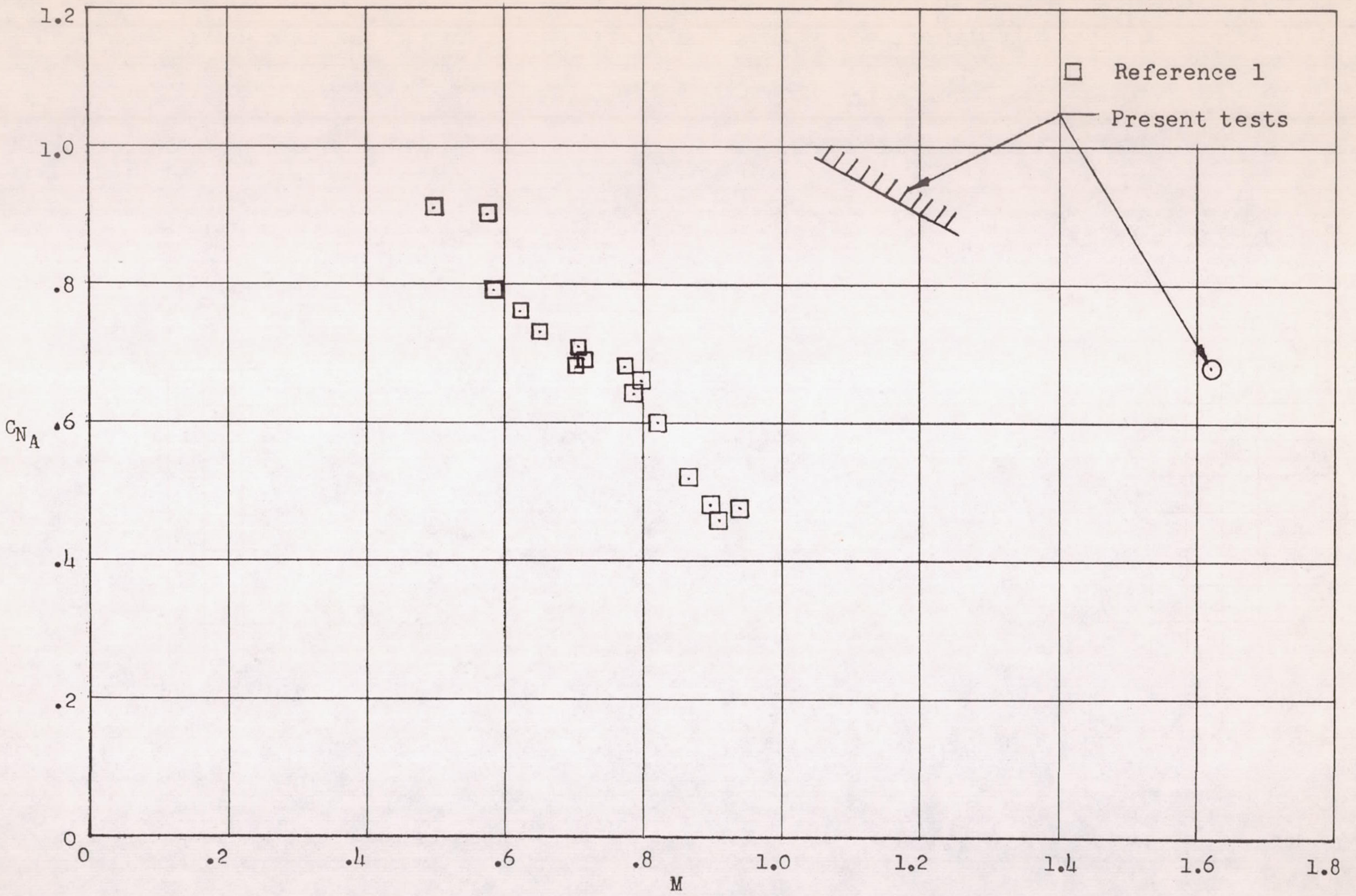


Figure 6.- Variation of normal-force coefficient and Mach number at which pitch-ups occur for the D-558-II airplane.

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