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RESEARCH MEMORANDUM

LONGITUDINAL-STABILITY CHARACTERISTICS OF THE NORTHROP X-4 AIRPLANE (USAF NO. 46-677)

By Melvin Sadoff and Thomas R. Sisk

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Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The results obtained from several recent flights on the Northrop X-4 No. 2 airplane are presented. Information is included on the longitudinal-stability characteristics in straight flight over a Mach number range of 0.38 to about 0.63, the longitudinal-stability characteristics in accelerated flight over a Mach number range of 0.43 to about 0.79, and the short-period longitudinal-oscillation characteristics at Mach numbers of 0.49 and 0.78.

It was shown that the stick-fixed and stick-free static longitudinal stability, as measured in straight flight, were positive over the test speed range with the center of gravity located at about 18.0 percent of the mean aerodynamic chord.

During the longitudinal-stability tests in accelerated flight an inadvertent pitch-up of the airplane occurred at a Mach number of about 0.79 and a normal-force coefficient of about 0.45 (normal acceleration factor, $A_Z = 5$), in which the acceleration built up rapidly to $A_Z = 6.2$ (which was in excess of the load factor, 5.2, required for demonstration of the airplane) before recovery could be initiated.

A comparison of the experimentally determined elevon angles required for balance and the elevon-angle gradients with values estimated from limited wind-tunnel data showed fairly good agreement. Wind-tunnel data, however, were not available in the region where the pitch-up occurred so that an evaluation in this regard was not possible.

The short-period oscillation was lightly damped and did not meet the Air Force requirements for satisfactory handling qualities. The pilot, however, did not object to the low damping characteristics of this airplane for small-amplitude oscillations. Theory predicted the period of the short-period longitudinal oscillation fairly well; however, the damping evaluated from the theory indicated considerably greater damping than was actually measured in flight, especially at the higher Mach numbers.

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INTRODUCTION

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

The airplane is currently undergoing demonstration flight tests by the Northrop Aircraft Corporation at Edwards Air Force Base, Muroc, California. During these tests NACA instruments have been installed for the measurement of stability and control characteristics. Previous results on the X-4 airplane are presented in references 1 through 6. The present report presents some results of the measurements of the longitudinal-stability characteristics of the airplane, which were obtained in flights 12, 13, and 15 of the acceptance tests of the second X-4 airplane (USAF No. 46-677).

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_Y	lateral acceleration factor
A_X	longitudinal acceleration factor
M	Mach number
q	dynamic pressure, pounds per square foot
F	stick force, pounds
S	wing area, square feet
M.A.C.	wing mean aerodynamic chord, feet
W	airplane weight, pounds
H_e	elevon hinge moment, inch-pounds
H_r	rudder hinge moment, inch-pounds

q pitching velocity, radians per second

p rolling velocity, radians per second

P period of longitudinal oscillation, seconds

$T_{1/2}$ 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

$\delta_{e_L} - \delta_{e_R}$ effective lateral control angle, degrees

δ_r rudder angle, degrees

β sideslip angle, degrees

C_N normal force coefficient $\left(\frac{WA_Z}{qS}\right)$

F/q stick-force factor, feet squared

Subscripts

L left elevon

R right elevon

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 altitude; airspeed; normal, longitudinal, and lateral accelerations; right and left elevon positions; rudder position; sideslip angle; pitching and rolling angular velocities; stick force; pedal force; and elevon and rudder hinge moments. In addition, normal acceleration, altitude, airspeed, right and left elevon positions, and rudder positions were telemetered to a ground station. All the internal records were correlated by a common timer. The hinge-moment data are included in this report to show only qualitative changes since there is some uncertainty regarding the validity of the absolute magnitudes of the measured hinge moments.

The airspeed and altitude recorder is connected to the airspeed head on the vertical fin. This installation has not as yet been calibrated.

TESTS, RESULTS, AND DISCUSSION

Longitudinal-Stability Characteristics in Straight Flight

The static longitudinal stability of the X-4 airplane was measured in straight flight by trimming the airplane at approximately 325 miles per hour and then making steady runs at 20-mile-per-hour increments over a speed range from about 220 to 400 miles per hour. Tests were conducted at 10,000 and 15,000 feet pressure altitude. The results of these measurements are shown in figure 3 where the elevon control position and elevon stick force are plotted as functions of indicated airspeed, and where the elevon-control position and stick-force factor F/q are plotted as functions of normal force coefficient. The data show that the airplane is statically stable stick fixed and stick free as shown by the increasing up-elevon control required as the speed was reduced, and by the pull forces required below trim speed and push forces required above trim speed. The positive stability is also indicated by the stable slopes of the variation of δ_e and F/q with C_N.

Longitudinal-Stability Characteristics in Accelerated Flight

The longitudinal-stability characteristics of the X-4 airplane in accelerated flight were measured in steady turns and gradual pull-ups. Measurements were made at steady increments of acceleration from trimmed conditions at a Mach number of 0.44 at 10,000 feet and at several Mach numbers from 0.5 to 0.79 at 20,000 feet. For the most part, data presented for values of normal-acceleration factor less than 2 were obtained in steady turns while the data for values of normal acceleration factor above 2 were obtained in gradual pull-ups.

Figure 4 gives several representative time histories of Mach number, elevon stick force, elevon position, normal acceleration factor, and normal-force coefficient during typical accelerated stability runs. These data in time-history form show an interesting item in connection with the booster control system. There are appreciable friction (±5 lb) and inertia forces inherent in the hydraulic control system, with the result that the elevon position does not necessarily follow the applied control forces. This characteristic of the control system can be easily seen in this figure where the elevon continues to move in the upward direction although the applied control force is being decreased. This characteristic of the control system makes the airplane very difficult to trim for given flight conditions and has been a source of annoyance to the pilot. The data in figure 4 show, however, that the airplane, aerodynamically speaking, has normal control characteristics.

At normal-force coefficients higher than those obtained in the runs given in figure 4 for a Mach number of 0.79 a longitudinal instability was encountered. A time history of this phenomenon is given in figure 5. In figure 5(a), which gives the quantities pertaining to the longitudinal characteristics, it can be seen that, although the elevon-control motion was stopped at 0.4 second when 5 A_Z was reached, the airplane continued to pitch upward. At 0.8 second, when 5.3 A_Z was reached, the pilot abruptly deflected the elevons downward but the airplane did not respond until a value of 6.2 A_Z was reached at 1.3 seconds. The pilot reported no warning such as buffeting before the airplane began to pitch upward, but did report that the right wing tended to drop as the pitching became evident. The accelerometer records taken during this run showed that a slight buffeting began at about 0.5 second prior to the longitudinal instability and continued well into the recovery. The wing heaviness reported by the pilot, however, is evident in figure 5(b) which gives the lateral and directional characteristics measured. The recovery from this unstable condition was marked by an oscillation about all three axes of the airplane, which the pilot probably reinforced by abrupt control motions. The objectionable large-amplitude longitudinal oscillations which were sustained during the latter part of the recovery apparently resulted from the poor damping-in-pitch characteristics of the airplane. This point will be discussed more fully in a subsequent section. It should be noted that, as in figure 4, the elevon-control motion does not follow exactly the control force. The maximum value of normal-acceleration factor reached (6.2) was in excess of that required for demonstration of the airplane (5.2).

From the data given in figures 4 and 5 and similar data not presented, figure 6 was prepared, which gives the variation of elevon-control angle with normal-force coefficient and the variation of elevon stick force with normal acceleration for the Mach numbers tested. These data show that for the Mach number range covered and for values of normal force up to about 0.45, the airplane is longitudinally stable stick fixed and stick free. At a Mach number of 0.79, the airplane is shown to be unstable above a normal-force coefficient of 0.45. The data illustrating this longitudinal instability were taken from the run presented in figure 5 prior to the abrupt control motions, but because of the abruptness of the pitching motion do not necessarily show the exact elevon angles required for balance. Data from earlier flights (reported in reference 6) show that at lower

Mach numbers (M = 0.28) the airplane does not exhibit a longitudinal instability even at values of normal-force coefficient approaching those for stall (C_N = 0.85). Wind-tunnel tests of an X-4 model at low Mach numbers (reference 7) indicated that chordwise fences would be required to eliminate longitudinal instability at the stall. It is possible that the fences are effective in delaying the longitudinal instability at low Mach numbers, but that increasing the flight Mach number decreases the effectiveness of the fences.

The apparent longitudinal stability of the X-4 airplane in accelerated flight is illustrated in figure 7 where values of $d\delta_e/dC_N$, as determined from the data of figure 6, are plotted as a function of Mach number for values of normal-force coefficient up to 0.4. The stability of the airplane at a normal-force coefficient of 0.5 was measured only at M = 0.28 (data from reference 6) and M = 0.79, and the values of $d\delta_e/dC_N$ under these conditions are indicated. The data given in figure 7 show that the longitudinal stability of the X-4 up to a C_N of 0.4 is essentially constant with Mach number up to a Mach number of 0.79. At a normal-force coefficient of 0.5, the airplane stability varies from a positive value at M = 0.28 to a negative value at M = 0.79. The exact variation with Mach number is not known since, as mentioned above, data were available only at two Mach numbers.

Comparison of Experimental and Estimated Data

A comparison of the experimental elevon angles required for balance at several values of C_N and the elevon-angle gradients with values estimated from the wind-tunnel data in reference 8 is presented in figure 8. The elevon-angle data are compared in figure 8(a), while the comparison of the control-angle gradients is shown in figure 8(b). The experimental elevon-angle data were derived as a cross plot of the data in figure 6 and from other data not presented (from reference 6).

The agreement shown between the estimated and the experimental elevon angles and elevon-angle gradients is considered fairly good in view of the fact that the wind-tunnel data, obtained with a center of gravity at 21.5 percent of the M.A.C., were corrected to an average flight value of 18.5 percent of the M.A.C. Unfortunately, no wind-tunnel data were available in the C_N range above 0.4 without a doubtful extrapolation of the data, so no reliable comparison could be made at the values of C_N and M where the longitudinal instability was encountered in flight.

Dynamic Longitudinal-Stability Characteristics

A measure of the dynamic longitudinal stability of the X-4 airplane was obtained in longitudinal oscillations which were excited by abruptly deflecting the elevon control and returning it to trim position at Mach numbers of 0.49 and 0.78. Time histories of these oscillations are given in figure 9. It can be seen from the data in this figure that the X-4 airplane will not meet the requirements for satisfactory damping of the longitudinal short-period oscillation which requires that the oscillation damp to one-tenth amplitude in one cycle (reference 9). The pilot did not consider the damping characteristics of the airplane objectionable for these small amplitude oscillations. However, as was pointed out previously, the poor damping characteristics were objectionable for large amplitude oscillations. The period P and the time to damp to one-half amplitude $T_{1/2}$ were determined from these oscillations and are presented as functions of Mach number in figure 10. Also presented in this figure are the variations of period and time to damp to one-half amplitude with Mach number as computed by the methods of reference 10. The data in this figure show that the theory predicts the period of the oscillation fairly well but that it overestimated the damping, especially at high Mach numbers.

CONCLUSIONS

The results of the longitudinal-stability measurements obtained on the second X-4 airplane during flights 12, 13, and 15 showed the following:

1. With the airplane center of gravity at approximately 18.0 percent of the M.A.C., the stick-fixed and stick-free longitudinal stability in straight flight were positive over a Mach number range of 0.38 to 0.63.

2. In accelerated flight, the airplane was stable up to values of normal-force coefficient of 0.4 throughout the speed range from Mach numbers of 0.44 to 0.79. At a Mach number of 0.79, the airplane became unstable at higher values of normal-force coefficient and a violent nose-up pitching was encountered.

3. In the run where the longitudinal instability occurred, the airplane reached a normal acceleration factor of 6.2 which is in excess of the load factor required for demonstration of the airplane (5.2).

4. The elevon angles required for balance at several values of normal-force coefficient and the elevon-angle gradients were estimated fairly well from available wind-tunnel data over the Mach number and normal-force-coefficient range considered.

5. The short-period longitudinal oscillation is lightly damped and does not meet the Air Force requirements for satisfactory handling qualities.

The pilot, however, did not object to low damping characteristics of this airplane for small-amplitude oscillations.

6. The theory estimated the period of the short-period longitudinal oscillation fairly well; however, it overestimated the damping, especially at high Mach numbers.

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2. Williams, Walter C.: Results Obtained From Second Flight of X-4 Airplane (A.F. No. 46-676). NACA RM L9F21, 1949.

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7. Pass, H. R., and Hayes, B. R.: Wind-Tunnel Tests of a 1/4-Scale Model of the Northrop XS-4 Airplane. Rep. No. A-WT-46, Northrop Aviation Corp., 1947.

8. Preliminary Report on High-Speed Wind-Tunnel Tests of a 1/4-Scale Reflection Plane Model of the Northrop XS-4 Airplane. Rep. No. 69, Southern California Cooperative Wind Tunnel, Calif. Inst. Tech., Pasadena, Calif., Oct. 28, 1948.

9. Anon.: Stability and Control Characteristics of Airplanes. AAF Specification No. R-1815-A, Apr. 7, 1945.

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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, pounds	1600
Airplane weight (average for flights 12, 13, and 15), pounds	
Maximum (238 gal fuel)	7847
Minimum (10 gal trapped fuel)	6477
Wing loading (average for flights 12, 13, and 15), pounds per square foot	
Maximum	39.2
Minimum	32.4
Center-of-gravity travel (average for flights 12, 13, and 15), percent M.A.C.	
Gear up, full load	19.10
Gear up, post flight	17.10
Gear down, full load	19.40
Gear down, post flight	17.50
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), degrees	41.57
Dihedral (chord plane), degrees	0
Wing boundary-layer fences	
Length, percent local chord	30.0
Height, percent local chord	5.0
Location, percent semispan	90.0

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TABLE I. – CONCLUDED

Wing flaps (split)	
Area, square feet	16.7
Span, feet	8.92
Chord, percent wing chord	25
Travel, degrees	30
Dive-brake dimensions as flaps	
Travel, degrees	±60
Elevons	
Area (total), square feet	17.20
Span (2 elevons), feet	15.45
Chord, percent wing chord	20
Movement, degrees	
Up	35
Down	20
Operation	Hydraulic with electrical emergency
Vertical tail	
Area, square feet	16
Height, feet	5.96
Rudder	
Area, square feet	4.1
Span, feet	4.3
Travel, degrees	±30
Operation	Direct

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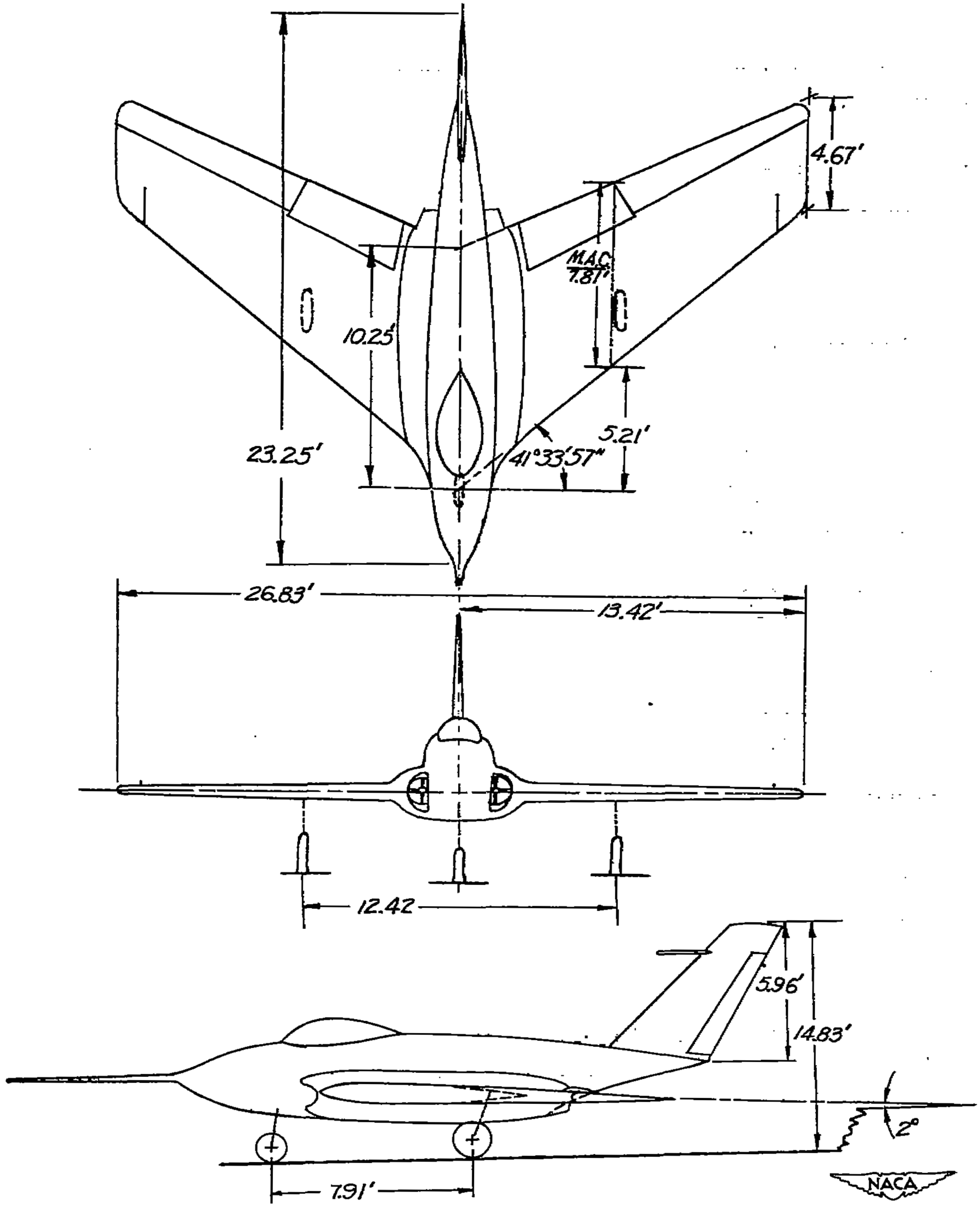
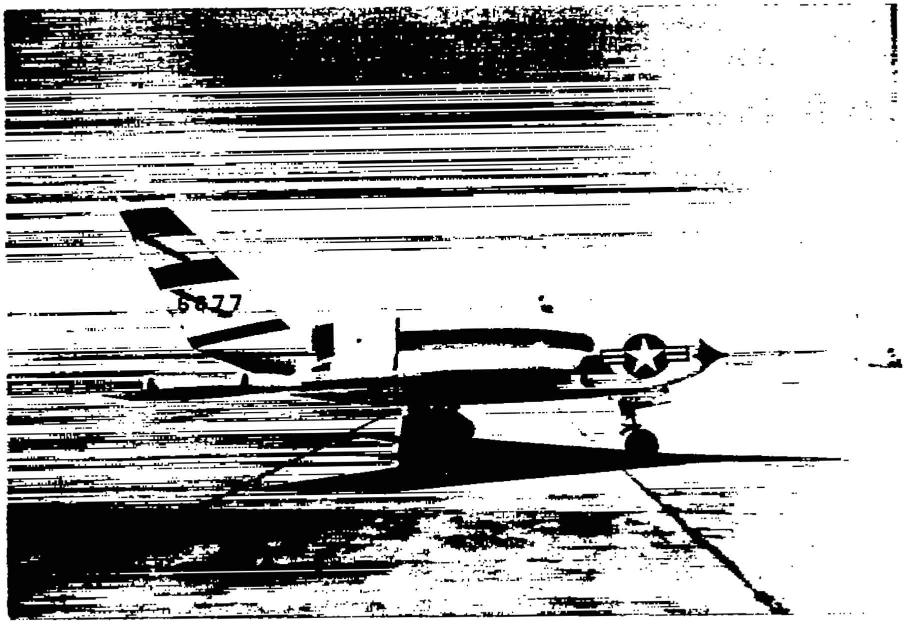
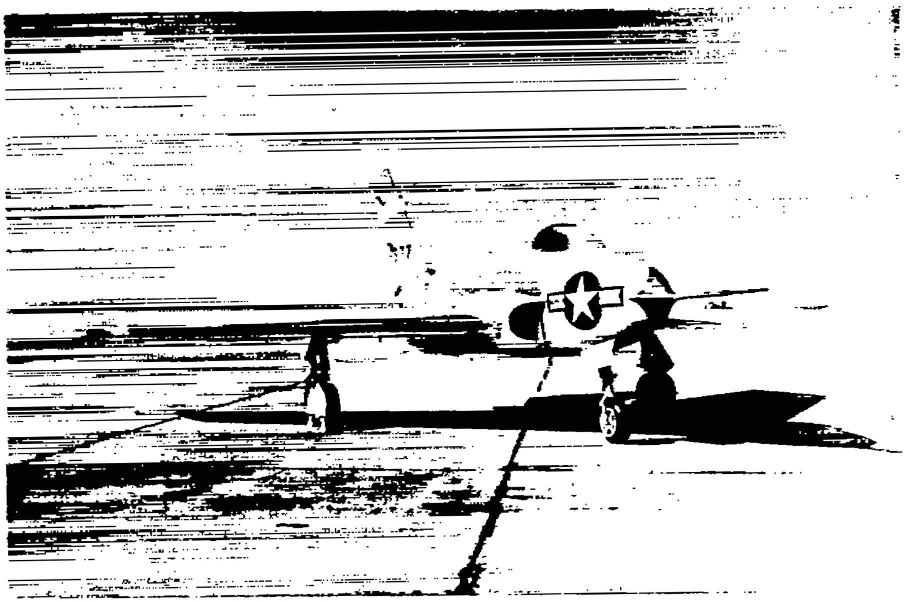


Figure 1.— Three-view drawing of X-4 airplane.



(a) Side view.



(b) Three-quarter front view.

Figure 2.- The X-4 No. 2 airplane.

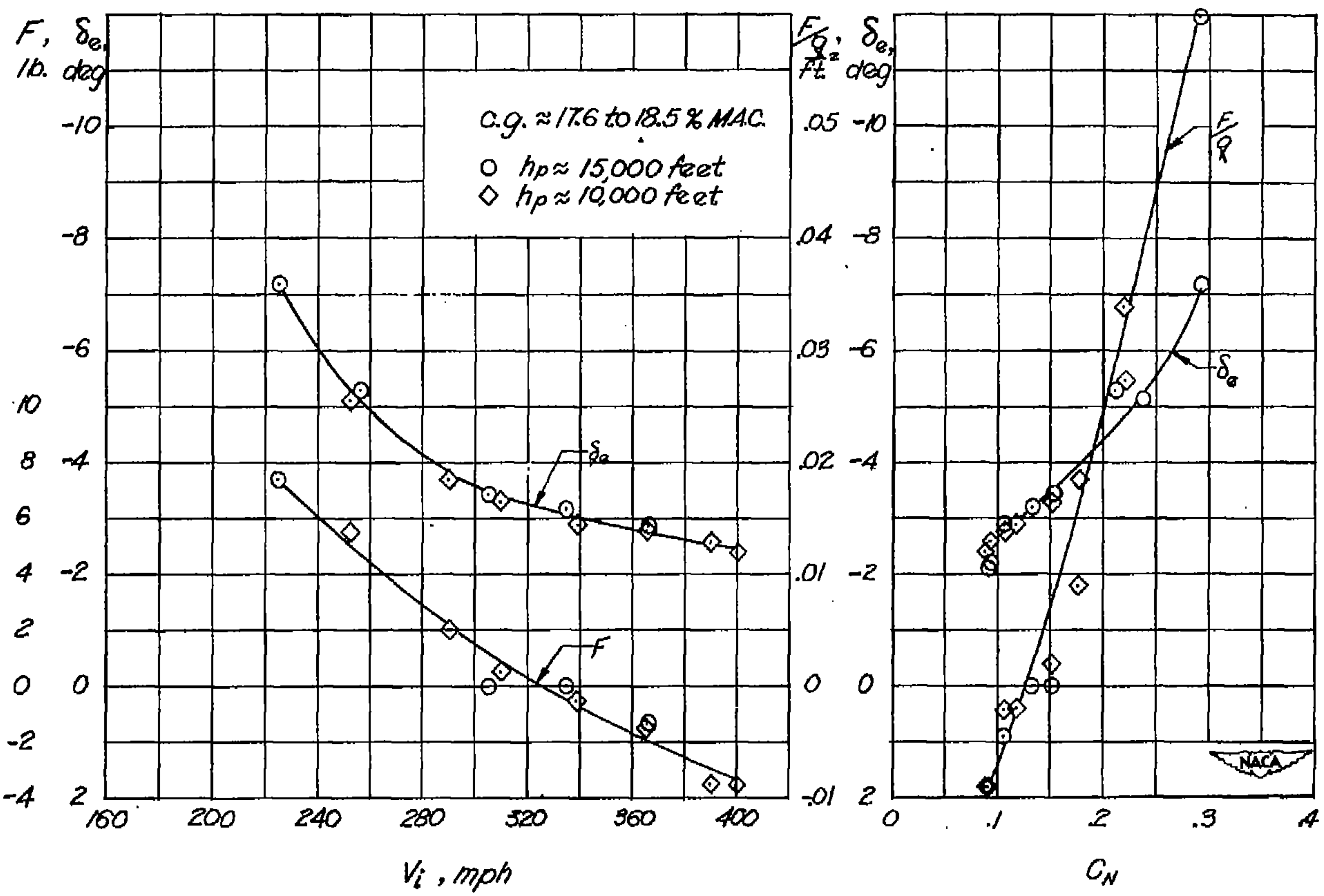
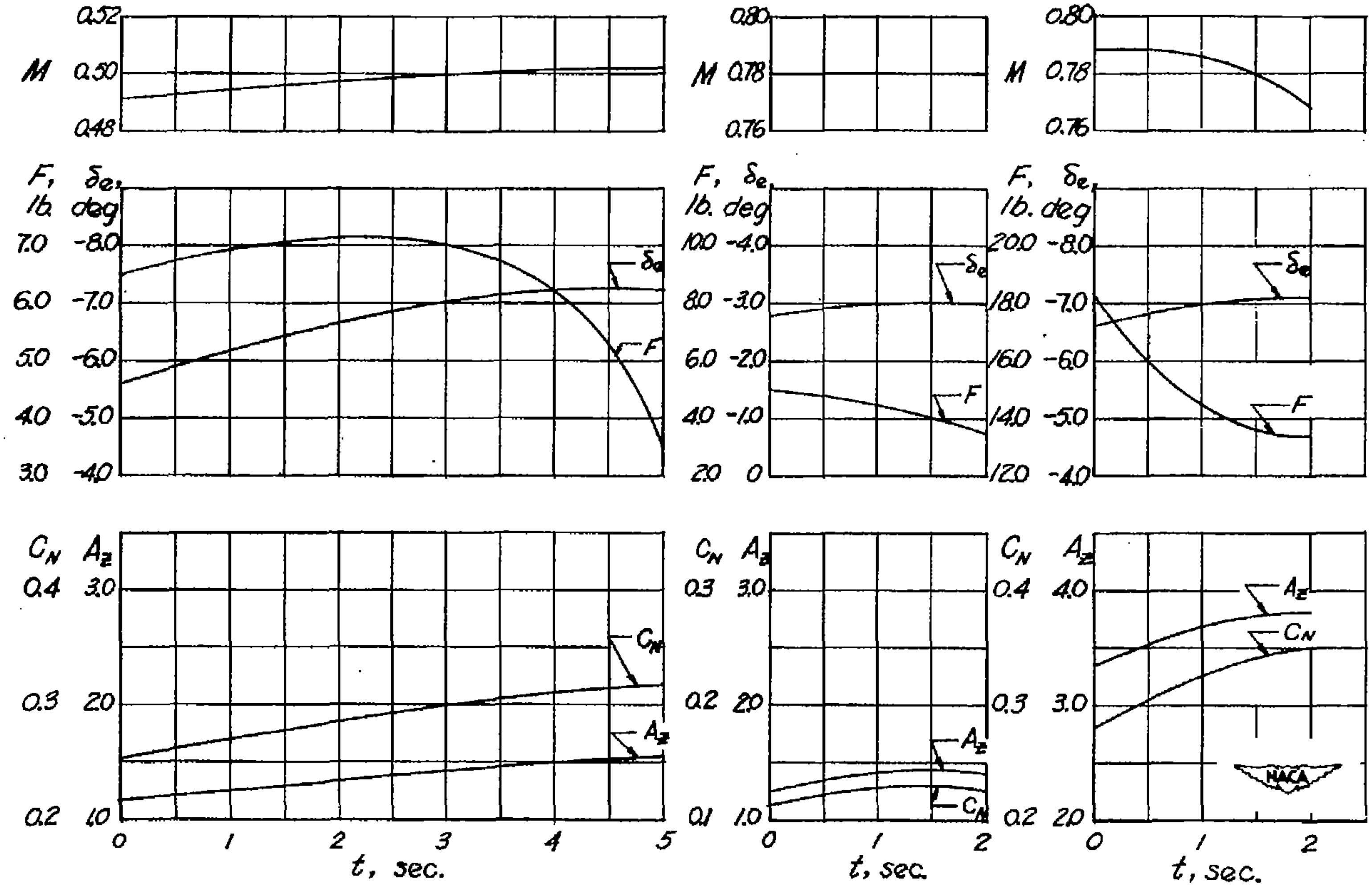
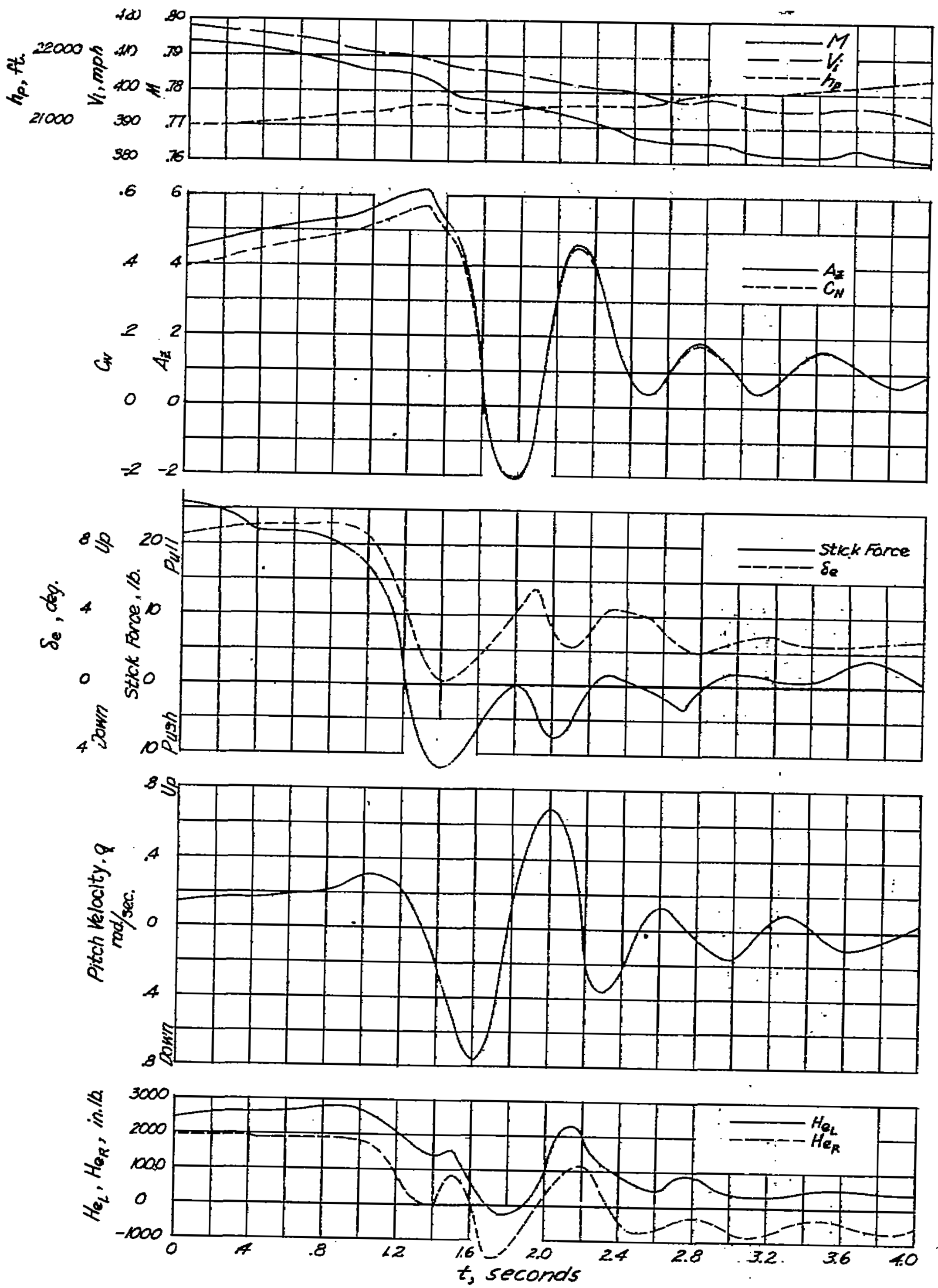


Figure 3.— Longitudinal-stability and-control characteristics in straight flight of X-4 airplane.



(a) $h_p \approx 20{,}000$ ft ; c.g. ≈ 17.8 % M.A.C.   (b) $h_p \approx 20{,}000$ ft ; c.g. ≈ 18.5 % M.A.C.   (c) $h_p \approx 20{,}000$ ft ; c.g. ≈ 18.4 % M.A.C.

Figure 4.— Time histories of pertinent variables during several accelerated stability runs. X-4 airplane.



(a) Longitudinal quantities.

Figure 5.– Detailed time history of pitch-up run. X-4 airplane.

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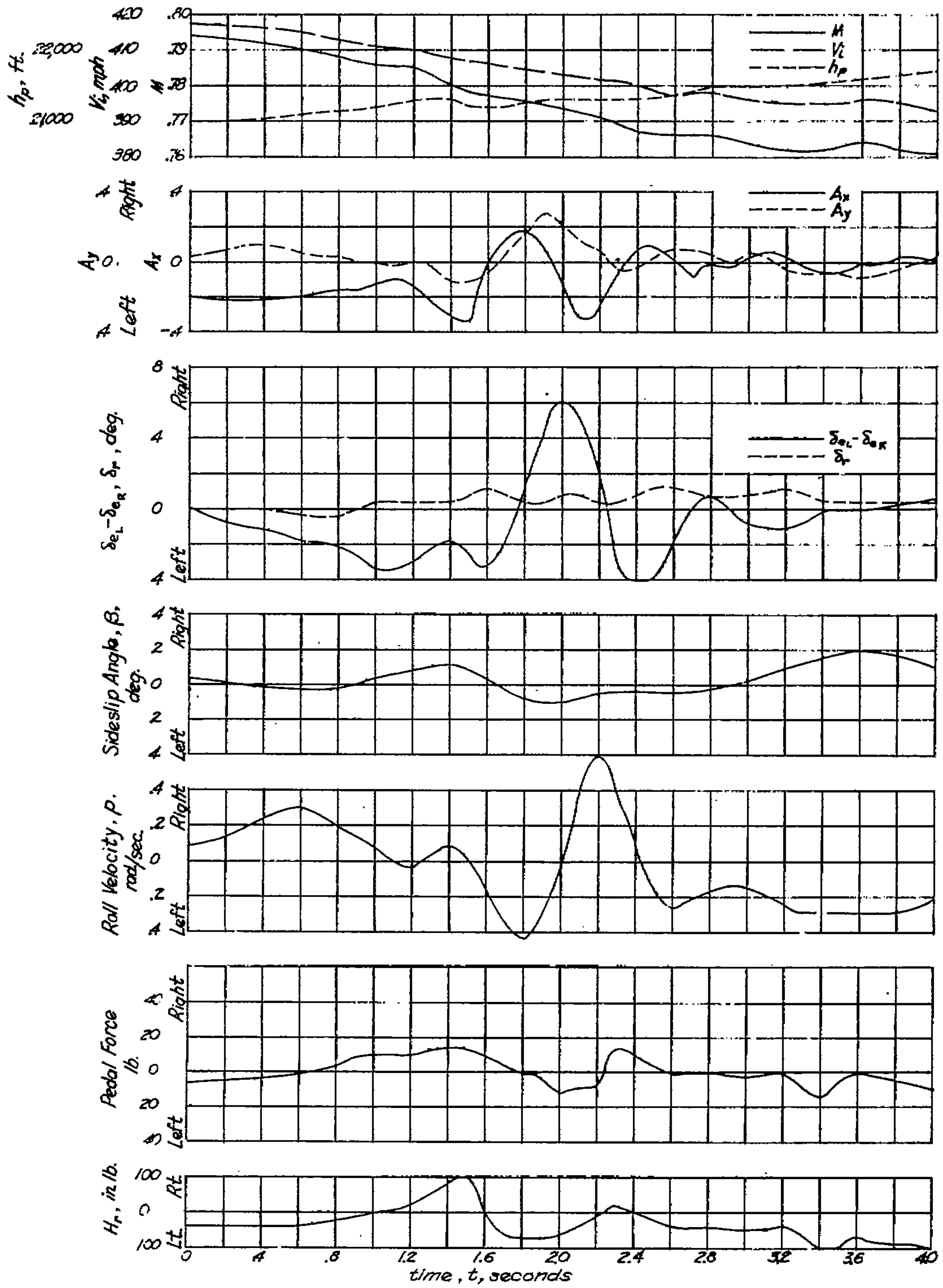

(b) Lateral and directional quantities.

Figure 5.— Concluded.

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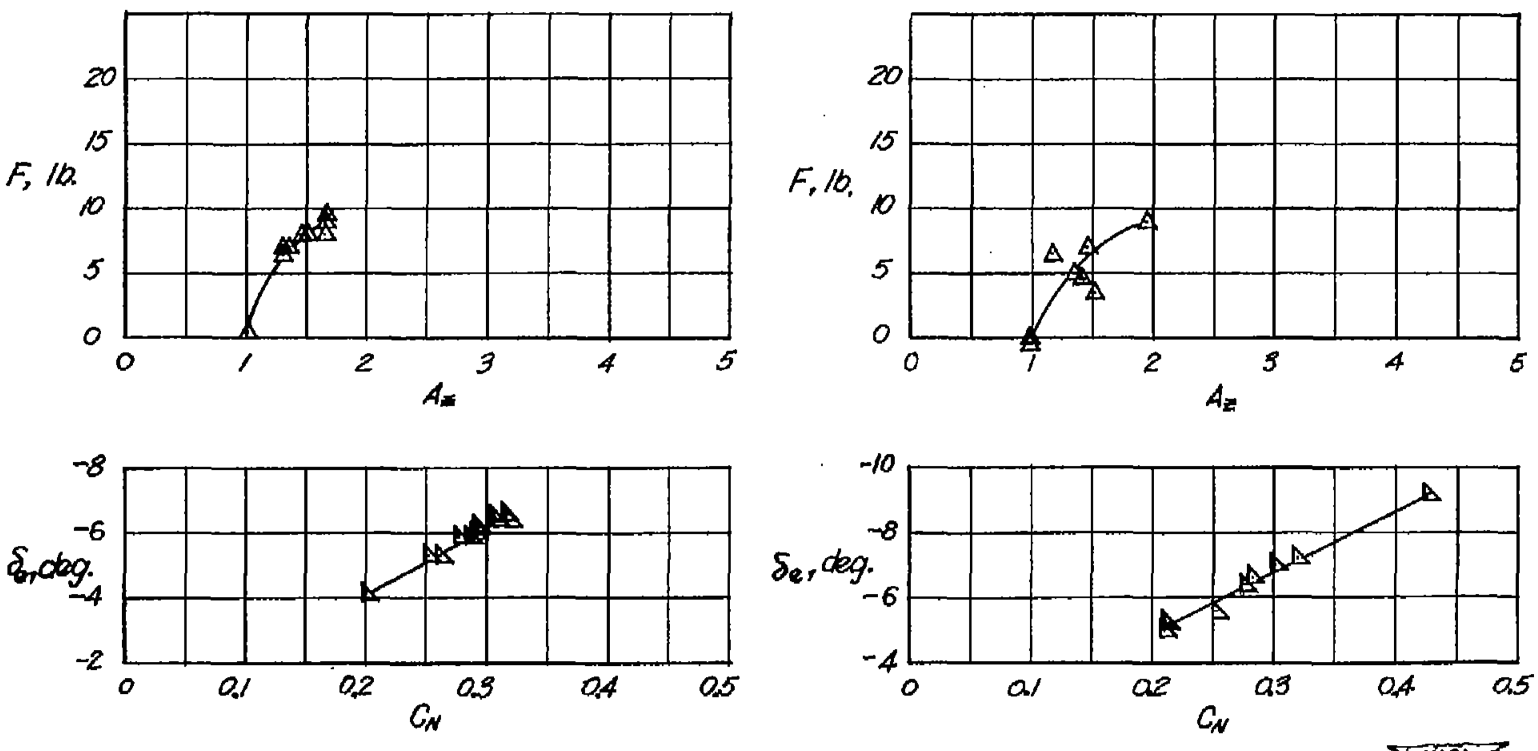
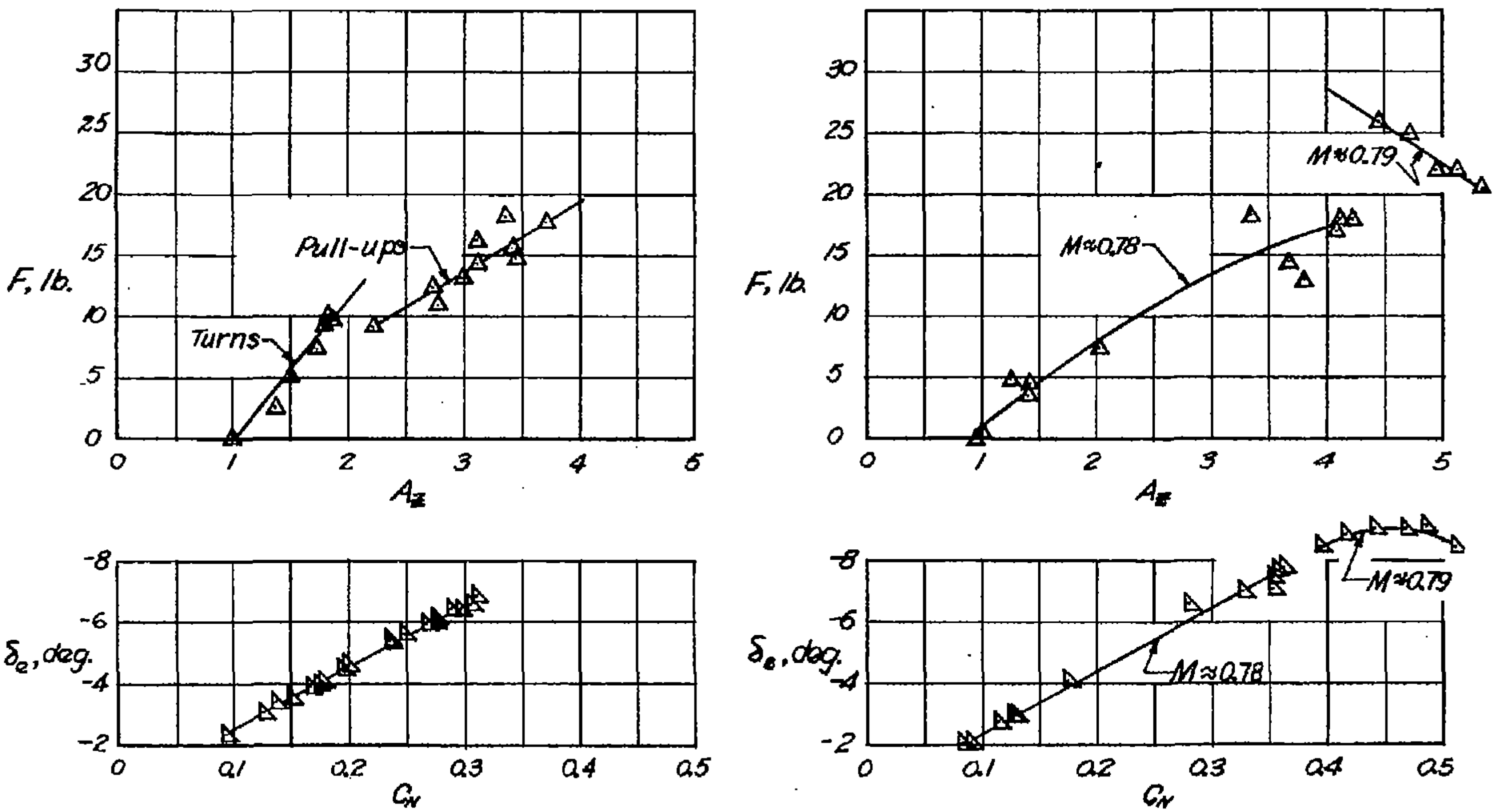


(a) $M \approx 0.435$; $h_p \approx 10{,}000$ feet.

(b) $M \approx 0.50$; $h_p \approx 20{,}000$ feet.

Figure 6.— Variation of elevon control angle and control force with airplane normal-force coefficient and normal-acceleration factor, respectively, for several values of Mach number. X-4 airplane.

[redacted]



(c) $M \approx 0.77$; $h_p \approx 20{,}000$ feet.

(d) $M \approx 0.78$; $h_p \approx 20{,}000$ feet.
$M \approx 0.79$; $h_p \approx 20{,}000$ feet.

Figure 6. – Concluded.

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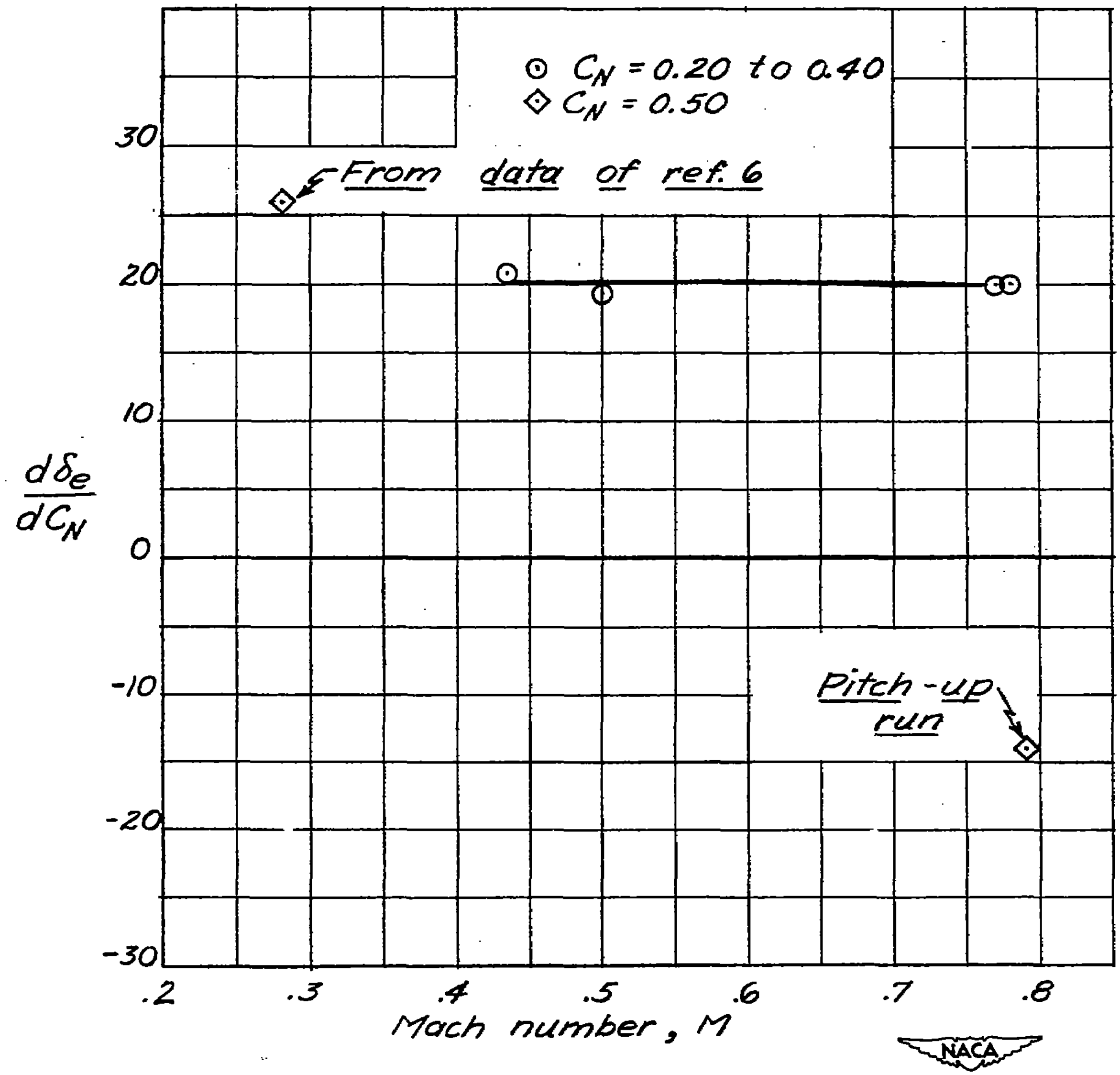

Figure 7.— Variation with Mach number of the elevon control-angle gradient. X-4 airplane.

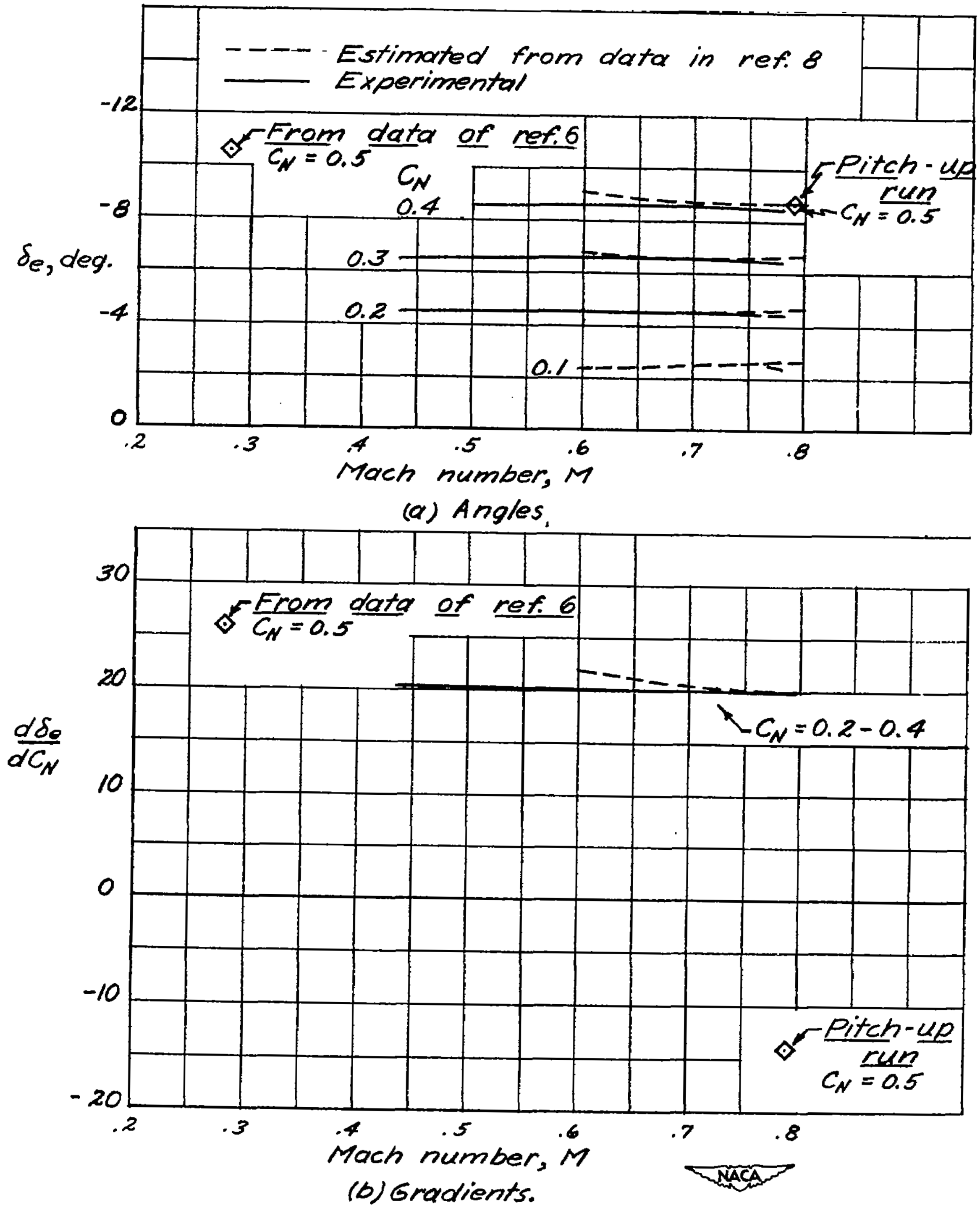

Figure 8.— Comparison of experimental elevon-control angles and control-angle gradients with values estimated from wind-tunnel data. X-4 airplane.

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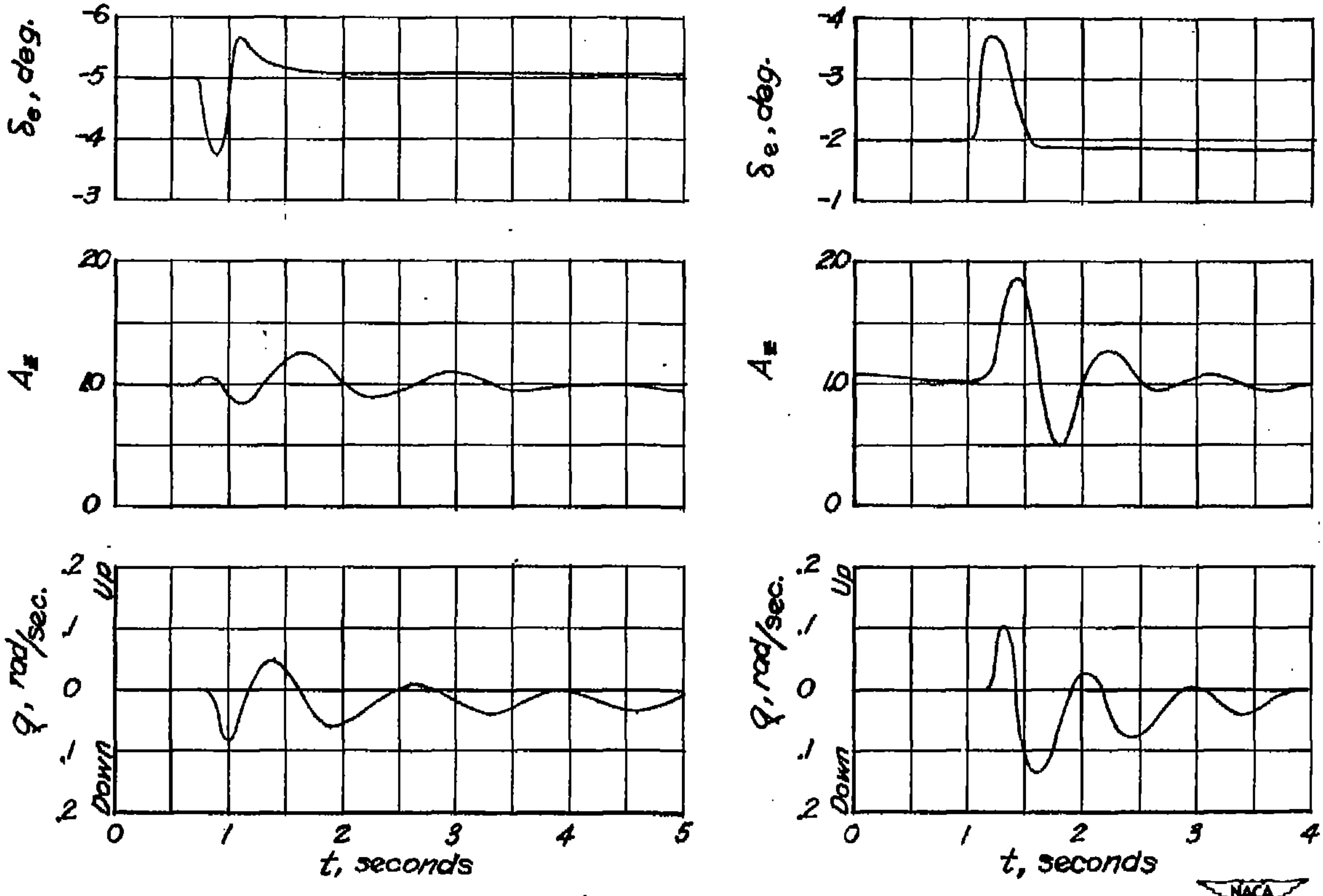

(a) $M \approx 0.49$. (b) $M \approx 0.78$.

Figure 9.— Representative time histories of longitudinal oscillations. $h_p \approx 20{,}000$ feet, X-4 airplane.

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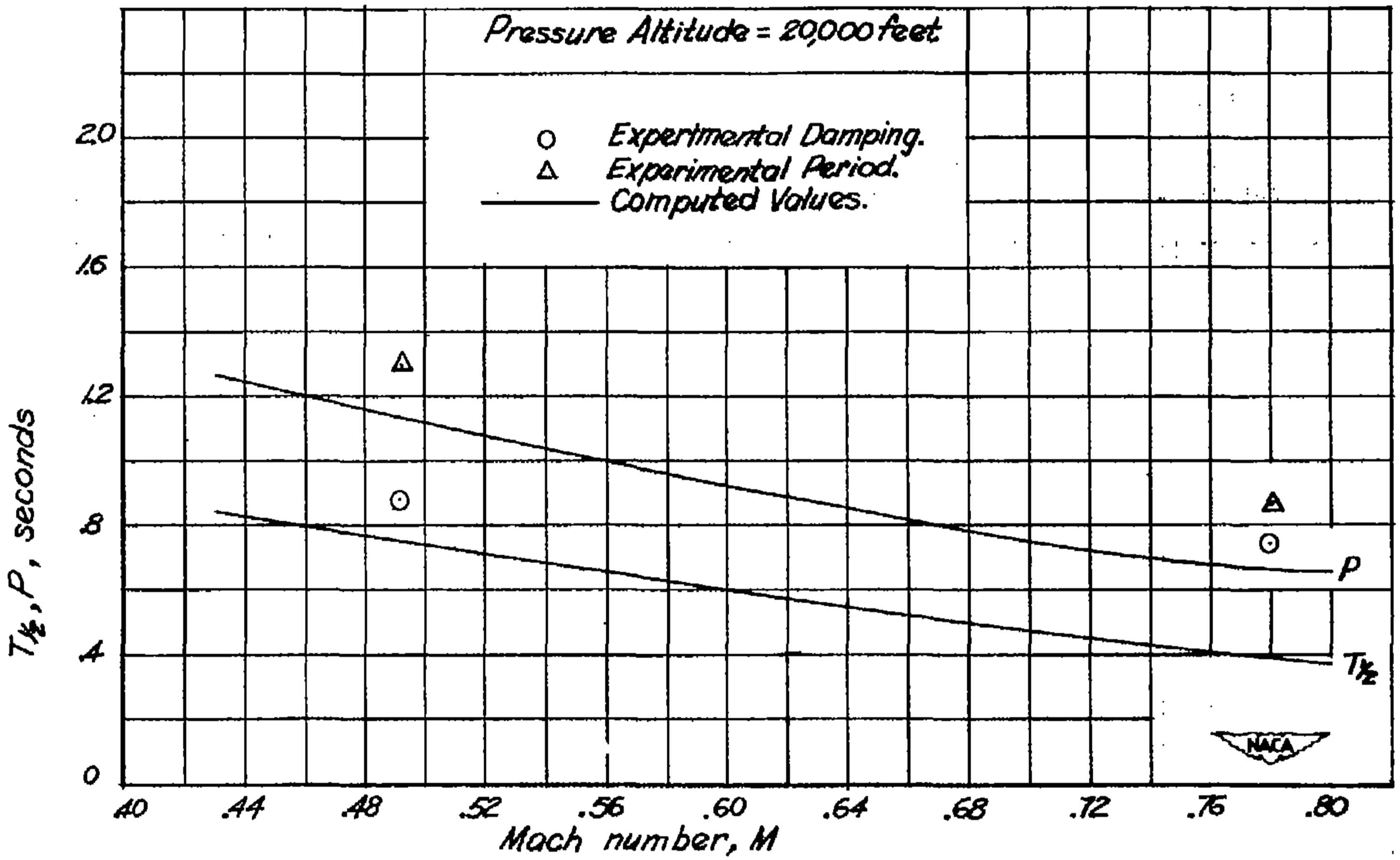

Figure 10.— Comparison of the experimental short-period longitudinal-oscillation period and damping with values computed from simplified theoretical considerations. X-4 airplane.

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