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RESEARCH MEMORANDUM

PRELIMINARY FLIGHT MEASUREMENTS OF THE DYNAMIC LONGITUDINAL STABILITY CHARACTERISTICS OF THE CONVAIR XF-92A DELTA-WING AIRPLANE

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SUMMARY

Some longitudinal maneuvers obtained during the U. S. Air Force performance tests of the Convair XF-92A airplane have been analyzed by using measured period and time to damp to half amplitude and by Reeves Electronic Analog Computer (REAC) study to give a preliminary measurement of the airplane stability and damping at Mach numbers from 0.59 to 0.94. For the range of these tests, no loss in control effectiveness $C_{m_{\delta_e}}$ was shown, the static stability C_{m_α} increased with Mach number, the damping was light but positive, and the damping factor $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ was low.

INTRODUCTION

The XF-92A airplane was constructed by the Consolidated-Vultee Aircraft Corp. to provide information on the flight characteristics of a 60° delta-wing configuration at subsonic speeds. Increased interest in the delta-wing configuration for supersonic flight prompted the replacement of the original J-33-A-23 engine with a J-33-A-29 engine with afterburner. Air Force demonstration and performance tests have been conducted since this change with the National Advisory Committee for Aeronautics providing instrumentation and engineering assistance.

During these tests random longitudinal disturbances were obtained which were considered suitable for stability analysis although these maneuvers were not performed specifically to obtain this type of information. Under certain flight conditions undesirable lateral and longitudinal oscillations have been observed and were believed to indicate the possibility of cross coupling between the lateral and longitudinal modes of motion. Presented in this paper are preliminary results obtained by analyzing maneuvers at Mach numbers from 0.59 to 0.94. It should be emphasized that these results are preliminary and are to be followed by a detailed research program designed to investigate completely the stability characteristics of the airplane.

SYMBOLS

A_Y	transverse acceleration, g units
A_Z	normal acceleration, g units
C_o, C_1, k, and b	transfer-function coefficients
C_L	lift coefficient
C_m	pitching-moment coefficient about airplane center of gravity
C_{L_α}	$dC_L/d\alpha$
C_{m_α}	$dC_m/d\alpha$
$C_{m_{\dot{\theta}}}$	$dC_m \Big/ d\dot{\theta}\frac{\bar{c}}{2V}$
$C_{m_{\dot{\alpha}}}$	$dC_m \Big/ d\dot{\alpha}\frac{\bar{c}}{2V}$
$C_{m_{\delta_e}}$	$dC_m/d\delta_e$
C_N	airplane normal-force coefficient
$\bar{c}$	mean aerodynamic chord, ft
$C_{1/10}$	cycles for oscillation to damp to 1/10 amplitude
g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft

I_Y	airplane moment of inertia in pitch, slug-ft^2
M	Mach number
m	airplane mass, slugs
P	period of oscillation, sec
S	wing area, sq ft
$T_{1/2}$	time for oscillation to damp to 1/2 amplitude, sec
t	time, sec
V	forward velocity, ft/sec
α	angle of attack, radian
β	sideslip angle, deg
δ_e	elevon control angle, deg, radian
δ_r	rudder control angle, deg
θ	pitch angle, radian
ρ	air density, slugs/cu ft
φ	roll angle, radian
D	d/dt
$\dot{\alpha}$	$d\alpha/dt$
$\dot{\theta}$	$d\theta/dt$
$\dot{\varphi}$	$d\varphi/dt$

Subscripts:

L	left
R	right

AIRPLANE AND INSTRUMENTATION

The Consolidated-Vultee XF-92A airplane is a single-place 60° delta-wing airplane powered by a turbojet engine with afterburner. Table I lists the physical characteristics and figure 1 presents a three-view drawing of the airplane. The inertia values used were supplied by the manufacturer. Weights and center-of-gravity positions for the airplane were determined from the quantity of fuel remaining.

The airplane is controlled longitudinally by full-span elevons and laterally by the same surfaces operating differentially and by a conventional rudder. Controls are operated by an irreversible hydraulic system.

Standard NACA recording instruments were used and were synchronized by a common timer. Airspeed measurements were recorded from a total-pressure tube mounted on a boom approximately 5.4 feet ahead of the airplane nose inlet. Center-of-gravity accelerations and velocities were measured by direct recording accelerometers and rate gyros. Accuracies of the recorded quantities are:

M	±0.03
$\dot{\theta}$, radians per sec	±0.005
A_Z, and A_Y, g units	±0.05
Control position, deg	±0.1
Airplane weight, lb	±100

TESTS AND METHODS OF ANALYSIS

During Air Force performance tests of the XF-92A airplane several longitudinal maneuvers suitable for dynamic stability analysis were obtained. Time histories of representative runs are presented in figure 2. The maneuvers were obtained at Mach numbers of about 0.59, 0.80, 0.81, 0.91, and 0.94 at 6,700 feet, 23,000 feet, 36,000 feet, 30,000 feet, and 35,000 feet, respectively. About 20 seconds of each record are shown to emphasize the nature of the airplane oscillation, the sensitivity of the control system, and the effectiveness of the control surfaces and to show the results of REAC studies.

Since no flight tests have been made specifically to obtain stability data, maneuvers were selected which could be analyzed by either of two methods. The first was the simple method described in reference 1 in which the period and time to damp of the airplane motion are measured directly from the control-fixed portion of the time histories. The second method makes use of the REAC (Reeves Electronic Analog Computer); actual control deflections are used as an input to the REAC and a solution (time history in $\dot{\theta}$) for the transfer-function equation $\frac{\dot{\theta}}{\delta_e} = \frac{C_1 D + C_o}{D^2 + bD + k}$ (ref. 2) is obtained for a particular set of values of transfer-function coefficients C_o, C_1, b, and k. These coefficients are then varied as necessary until the output $\dot{\theta}$ most nearly duplicates the actual flight record.

Both methods of analysis are based on the usual assumptions that the aerodynamic forces and moments vary linearly with certain variables and that the forward velocity is constant during the maneuver. In addition, the simple analysis is valid only for a free airplane oscillation with controls fixed. In each of the runs the pilot is attempting to damp the airplane oscillation; consequently, only the small-amplitude portion of the oscillation approached a controls-fixed condition. To assure greater accuracy in the REAC analysis it was necessary to use the large-amplitude portions of the flight records where the control motions were of significant magnitudes. The effects of changes in the trim δ_e due to Mach number and altitude change during the test were not included in the REAC computations.

RESULTS AND DISCUSSION

Figure 2(a) presents a time history of an airplane oscillation obtained in a climb at about 36,000 feet and at a Mach number of about 0.81. The oscillation was analyzed by the simple method beginning at time 12 seconds, whereas the REAC analysis was made from time 1 to 14 seconds. Figure 2(b) shows a gradual dive recovery at about 30,000 feet with Mach number varying from 0.95 to 0.90 and with normal acceleration varying from 1g to 2g. The initial disturbance appears to have been lateral with attempts to control this motion exciting the longitudinal oscillation. Analysis by the simple method was attempted beyond time 15 seconds. The results of the REAC studies are shown from time 6 to 16 seconds. Figure 2(c) shows a time history of a dive from 38,000 feet to 34,000 feet at a Mach number of 0.94. Control deflection during the maneuver, like the other example histories, are small. Following time 18 seconds an analysis by the simple method was attempted. From time 2 to 16 seconds results of the REAC analysis are shown. Since the results of the REAC studies obtained by using the longitudinal control as the only input to the system are in good agreement with actual flight records, it would appear that no serious coupling between the lateral and longitudinal modes exist, although the airplane underwent lateral as well as longitudinal motion.

For the simple analysis the period and time to damp were measured directly from the controls-fixed portion of the time histories and for the REAC analysis the same information was calculated from the coefficients k and b. These data were corrected to a standard altitude of 35,000 feet and were combined to give the cycles required to damp to 1/10 amplitude. The results of these measurements are presented in figure 3 and show the measured periods and time to damp for an altitude of 35,000 feet to decrease with Mach number. Although it is not possible to define clearly the variation of cycles to damp to 1/10 amplitude with Mach number it is apparent that the airplane, at an altitude of 35,000 feet, does not meet the Air Force dynamic stability requirement that the short-period longitudinal oscillation damp to 1/10 amplitude in one cycle (ref. 2).

Figure 4 presents the results of figure 3 in the form of stability derivatives C_{m_α} and $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ as functions of Mach number. Also shown is a plot of $C_{m_{\delta_e}}$ obtained from the REAC analysis. For the simple analysis, C_{m_α} and $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ were calculated from

$$C_{m_\alpha} = -\frac{2I_Y}{\rho V^2 S\bar{c}}\left[\left(\frac{2\pi}{P}\right)^2 + \left(\frac{0.693}{T_{1/2}}\right)^2\right]$$

$$C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}} = \frac{8I_Y}{\rho S V\bar{c}^2}\left(C_{L_\alpha}\frac{\rho VS}{4m} - \frac{0.693}{T_{1/2}}\right)$$

Similar equations from reference 3 are used to convert the transfer-function coefficients C_1, k, and b to stability derivatives, as follows:

$$C_{m_{\delta_e}} = -\frac{2C_1 I_Y}{\rho V^2 S\bar{c}}$$

$$C_{m_\alpha} = \frac{2kI_Y}{\rho V^2 S\bar{c}}$$

$$C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}} = \frac{8I_Y}{\rho VS\bar{c}^2}\left(C_{L_\alpha}\frac{\rho VS}{4m} - \frac{b}{2}\right)$$

The lift-curve slope C_{L_α} used in the computation was obtained from flight data and is presented also in figure 4. The control effectiveness derivative $C_{m_{\delta_e}}$ has a value of about -0.55. No loss in control effectiveness is indicated for the range of these tests. The simple analysis affords no way of obtaining this parameter. Results of both analyses show C_{m_α} to have a value of about -0.2 at the lower test Mach number and to increase to about -0.5 at the highest test Mach number. Results of the simple analysis show the damping factor $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ to be of the order of -0.3 with a positive value for the derivative at the highest test Mach number. REAC results for this derivative are of the order of -1.3.

Agreement between the period and static stability obtained by the two methods of analysis is considered good but differences are apparent in the time and cycles to damp and damping factor. These differences are probably the result of one or more of the following: method of analysis, presence of small control motions during the maneuver, or nonlinear damping. Since the damping factor is computed from the difference in two numbers of comparable magnitudes, uncertainty in either gives unreliable results. For the REAC analysis increments of 1/2 unit in the coefficient b were used so that the results presented are not necessarily the best obtainable. The presence of small control motions give erroneous results in either method of analysis especially for an airplane such as the XF-92A which has a control surface area which is 18 percent of the wing area. It should be noted that maximum deflections during the maneuvers presented are of the order of 1°. Since the portions of the flight record analyzed by the simple method are of lower amplitude than those used in the REAC analysis, it appears that the damping may be nonlinear, that is, may decrease with amplitude. Further testing will be necessary to verify these indications.

Shown also in figures 3 and 4 are the results of rocket-model tests (ref. 1) with a similar airplane configuration and some results of wind-tunnel tests (ref. 4). The rocket-model tests were conducted with a geometrically scaled model and were corrected to a full-scale airplane configuration of less gross weight and pitch inertia than the XF-92A airplane. The model center-of-gravity location was at 20 percent mean aerodynamic chord, whereas the flight-test center of gravity was located at 28 percent mean aerodynamic chord. Period and time and cycles to damp from the flight-test results (fig. 3) are somewhat higher than the model results and the flight-test stability derivatives (fig. 4) are generally lower than the rocket-model test results. Differences in test conditions could account for differences of the order shown. Also shown are some Convair estimates for the XF-92A airplane and results of wind-tunnel tests on a similar configuration. The flight test C_{m_δ} and C_{m_α} agree favorably with the manufacturer estimates (unpublished). Results of tunnel oscillation tests on 63° delta configuration (ref. 4) with the axis of rotation at the 35 percent mean aerodynamic chord show $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ to be of the order of -1.0. The damping factor from the REAC studies agrees well with the tunnel test but the damping factor from the simple analysis is lower.

CONCLUSIONS

Preliminary results from the analysis of some longitudinal oscillations obtained during the U. S. Air Force performance tests of the Convair XF-92A delta-wing airplane show the following conclusions:

1. The control effectiveness $C_{m_{\delta_e}}$ had a value of -0.55 with no loss in effectiveness over the range of these tests.

2. The period of the longitudinal oscillation decreased rapidly with Mach number and computed values of C_{m_α} that ranged from -0.2 at a Mach number of 0.59 to -0.5 at a Mach number of 0.94 were obtained.

3. The longitudinal damping was light but positive over the range of these tests with a damping factor $C_{m_{\dot{\theta}}} + C_{m_{\dot{\alpha}}}$ of the order of -1.0.

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2. Anon: Flying Qualities of Piloted Airplanes. Spec. No. 1815-B, U. S. Air Force, June 1, 1948.

3. Triplett, William C., and Van Dyke, Rudolph D., Jr.: Preliminary Flight Investigation of the Dynamic Longitudinal-Stability Characteristics of a 35° Swept-Wing Airplane. NACA RM A50J09a, 1950.

4. Mitchell, Jesse L.: The Static and Dynamic Longitudinal Stability Characteristics of Some Supersonic Aircraft Configurations. NACA RM L52A10a, 1952.

TABLE I

PHYSICAL CHARACTERISTICS OF THE XF-92A AIRPLANE

Wing:	
Area, sq ft	425
Span, ft	31.33
Airfoil section	NACA $65_{(06)}$-006.5
Mean aerodynamic chord, ft	18.09
Aspect ratio	2.31
Root chord, ft	27.13
Tip chord	0
Taper ratio	0
Sweepback (leading edge), deg	60
Incidence, deg	0
Dihedral (chord plane), deg	0
Elevons:	
Area (total, both, aft of hinge line) sq ft	76.19
Span (1 elevon), ft	13.35
Chord (aft of hinge line, constant except at tip), ft	3.05
Movement, deg	
Elevator:	
Up	15
Down	5
Aileron, total	10
Operation	Hydraulic
Vertical tail:	
Area, sq ft	75.35
Height, above fuselage center line, ft	11.50
Rudder:	
Area, sq ft	15.53
Span, ft	9.22
Travel, deg	±8.5
Operation	Hydraulic
Fuselage:	
Length, ft	42.80
Power plant:	
Engine	Allison J-33-A-29 with afterburner
Rating:	
Static thrust at sea level, lb	5600
Static thrust at sea level with afterburner, lb	7500

TABLE I.- Concluded

PHYSICAL CHARACTERISTICS OF THE XF-92A AIRPLANE

Weight:	
Gross weight (560 gal fuel), lb	15,560
Empty weight, lb	11,808
Center-of-gravity locations:	
Gross weight (560 gal fuel), percent M.A.C.	25.5
Empty weight, percent M.A.C.	29.2
Moment of inertia in pitch, slug-ft^2	35,000

NACA

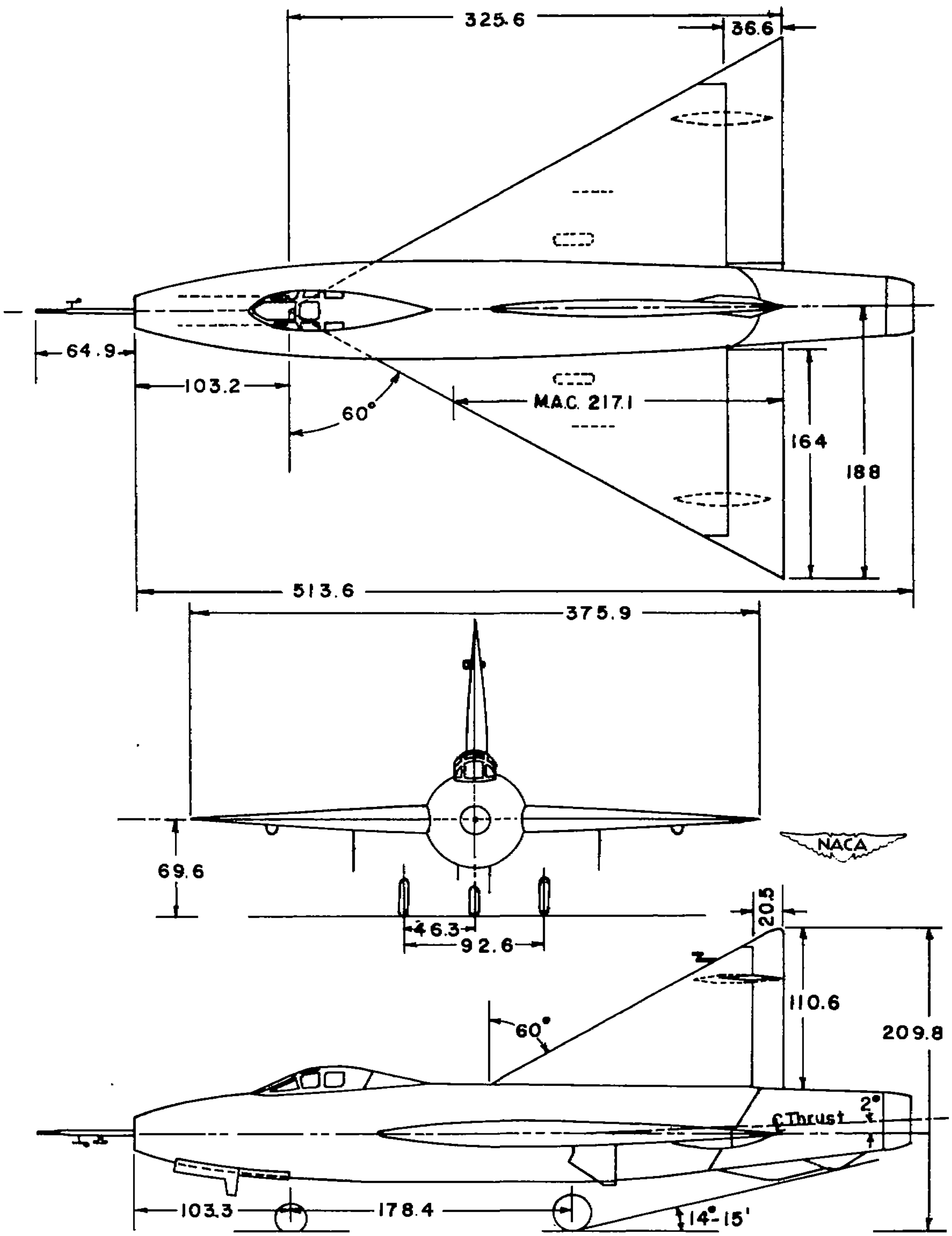
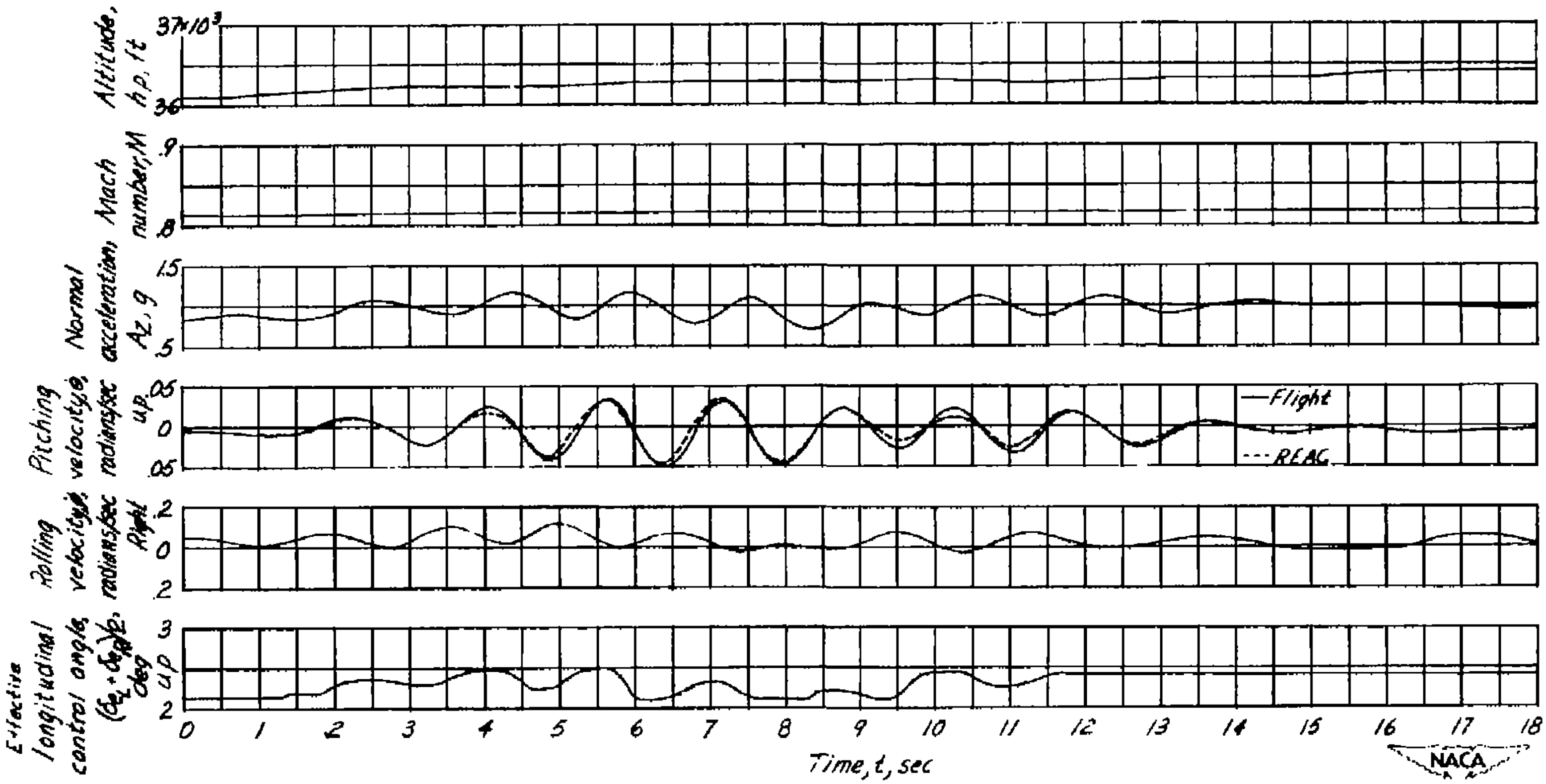
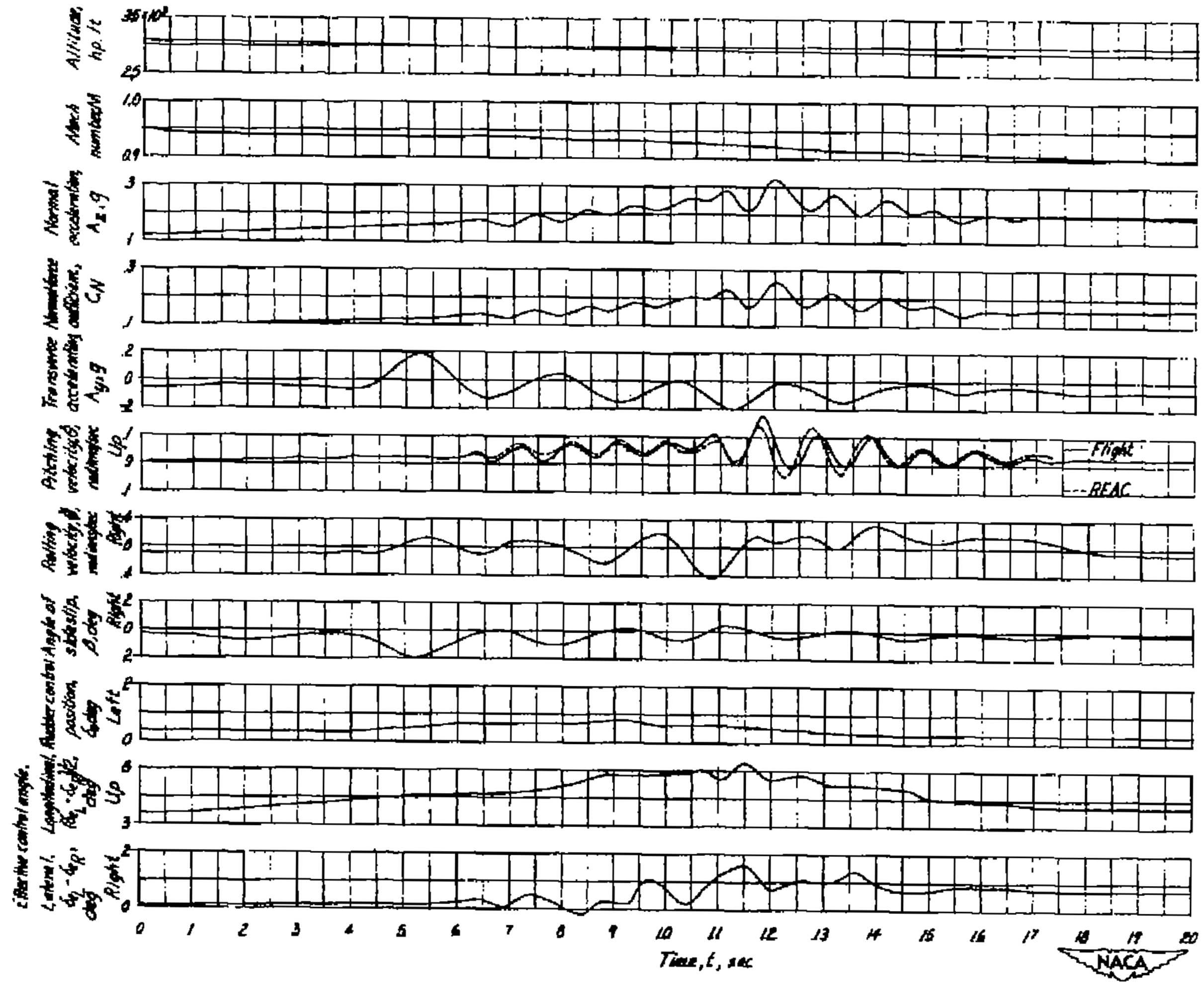


Figure 1.- Three-view drawing of the XF-92A airplane. (All dimensions in inches.)



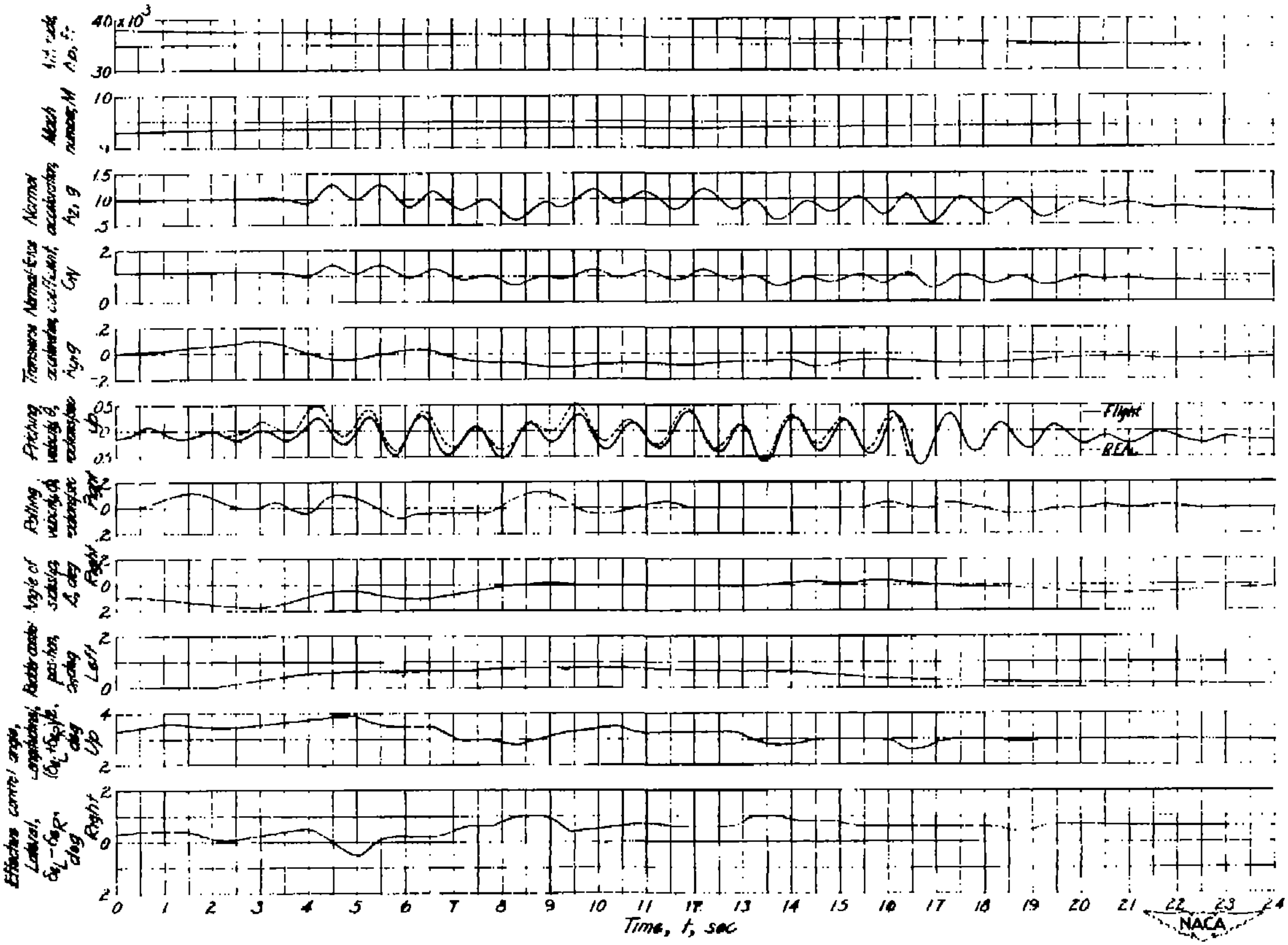
(a) Climb at 36,000 feet. M = 0.81.

Figure 2.- Representative time histories of longitudinal airplane oscillations.



(b) Dive recovery at 30,000 feet. M varying from 0.95 to 0.90.

Figure 2.- Continued.



(c) Dive from 38,000 feet to 34,000 feet. M = 0.94.

Figure 2.- Concluded.

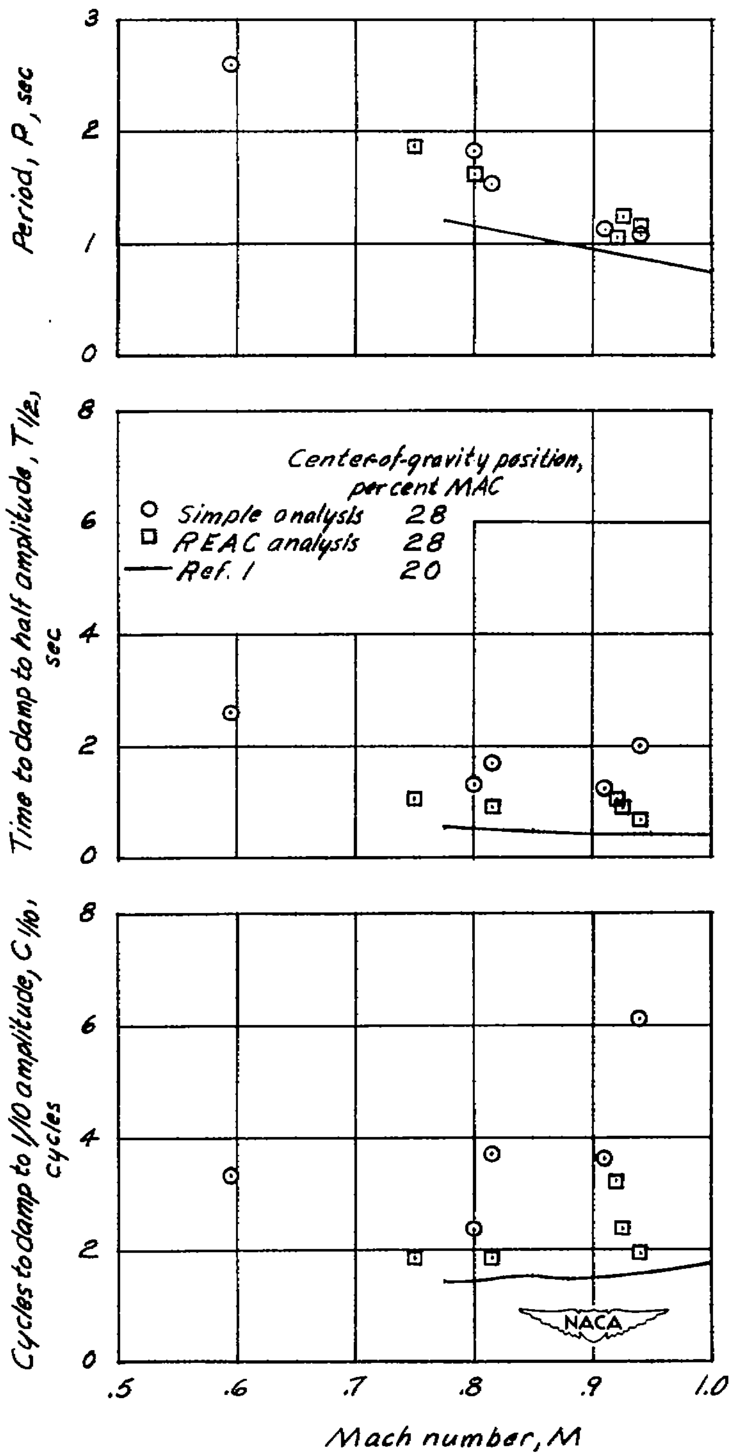


Figure 3.- Period, time to damp to half amplitude, and cycles to damp to 1/10 amplitude for the XF-92A airplane at 35,000 feet.

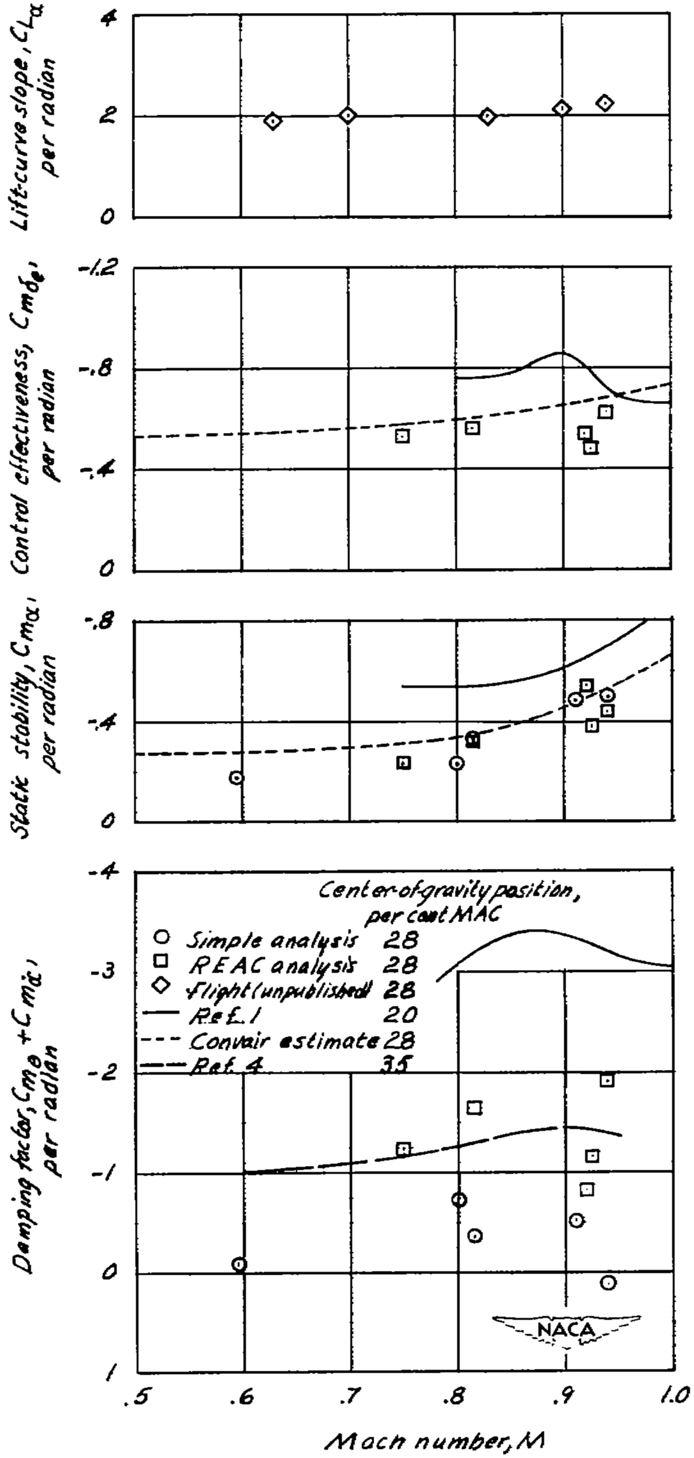


Figure 4.- Variation of flight test stability derivatives with Mach number.