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RESEARCH MEMORANDUM

STABILITY RESULTS OBTAINED WITH DOUGLAS D-558-1 AIRPLANE (BuAero No. 37971) IN FLIGHT UP TO A MACH NUMBER OF 0.89

By

William H. Barlow and Howard C. Lilly

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

April 22, 1949

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STABILITY RESULTS OBTAINED WITH DOUGLAS D-558-1 AIRPLANE (BuAero No. 37971) IN FLIGHT UP TO A MACH NUMBER OF 0.89

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SUMMARY

Measurements have been made of some of the high-speed characteristics of the D-558-1 airplane up to a Mach number of 0.89. The results of these tests showed that the stabilizer incidence drastically affected the longitudinal trim characteristics above a Mach number of 0.80. With a stabilizer incidence of 2.3°, the airplane became nose heavy above a Mach number of 0.8. With a stabilizer incidence of 1.4°, the airplane became tail heavy above a Mach number of 0.83. The airplane also became right-wing heavy above a Mach number of 0.84 and the airplane felt uncertain laterally to the pilot. The longitudinal stability in accelerated flight was positive throughout the speed range from a Mach number of 0.50 to 0.80 and increased above a Mach number of 0.675. The buffet boundary was defined up to a Mach number of 0.84 and was similar to that for the Bell XS-1 airplane with the same wing section, 65-110.

INTRODUCTION

The NACA is engaged in a flight-research program in the transonic-speed range utilizing Douglas D-558-1 type airplanes which were procured for use by the NACA in high-speed flight. One of these airplanes (BuAero No. 37971) was being used for investigation of stability and control characteristics. This airplane was lost in an accident on May 3, 1948. Up to the time of the accident, two reports covering some measurements of longitudinal stability (reference 1) and measurements of the stability characteristics in sideslips (reference 2) had been published. This paper presents some of the more pertinent high-speed results obtained prior to the accident which were not reported in references 1 or 2.

SYMBOLS

H pressure altitude, feet

M' Mach number uncorrected for position error

M	Mach number corrected for position error
ΔM	Mach number error $(M-M')$
n	normal acceleration, g units
f_e	elevator force, pounds
δ_e	elevator position, degrees from stabilizer
δ_a	total aileron angle, difference in degrees between left and right aileron
δ_r	rudder position, degrees from neutral position with respect to fin
β	sideslip angle, degrees from arbitrary reference (approx. parallel to center line of airplane)
i_t	stabilizer setting, degrees from fuselage level line
C_N	normal-force coefficient (Wn/qS)
q	dynamic pressure, pounds per square foot
W	airplane gross weight, pounds
S	wing area, square feet

AIRPLANE

The Douglas D-558-1 airplane is a single-place low-wing monoplane powered by a General Electric TG-180 turbojet engine. General views of the airplane are given in figures 1(a), 1(b), and 1(c). A three-view drawing of the airplane is given in figure 2. Detailed specifications of the airplane are given in reference 1.

The force required to move the wheel controls slowly under static airplane conditions is shown in figure 3. The rudder friction is of the order of 7 pounds near neutral position. The elevator control has a bungee tending to return the elevator to the down position. All controls have hydraulic dampers at the control surface which necessitate high control force for rapid motion of control.

INSTRUMENTATION

Standard NACA recording instruments were used to measure the various quantities necessary to determine the stability and control characteristics

of the subject airplane. All records were synchronized by means of a common timing circuit. The instruments used and the quantities measured follow:

Recording instrument	Quantity measured
Airspeed-altitude recorder	Indicated airspeed, pressure altitude
Three-component accelerometer	Normal, longitudinal, and transverse acceleration
Angular-velocity recorder	Rolling velocity
Yaw-angle recorder	Sideslip angle
Wheel-force recorder	Aileron and elevator force
Pedal-force recorder	Rudder-pedal force
Control-position recorder	Aileron, elevator, rudder, and stabilizer position
Timer	Time

The yaw vane used with the yaw-angle recorder was mounted a distance of 1 chord ahead of the left wing tip. The airspeed head was mounted on a boom on the right wing tip of such length that the static orifices were at a distance of 1 chord ahead of the wing leading edge.

TESTS, RESULTS, AND DISCUSSION

A calibration of the airspeed system was made using the fly-by and radar tracking methods of reference 3. The results of the calibration are presented in figure 4 as a variation of percentage error in Mach number $\frac{\Delta M}{M}$, with corrected Mach number. The error increases above $M = 0.75$ due to blocking effects of the wing on static pressure at the airspeed head. These results are in general agreement with data obtained from a similar airspeed installation on the Bell XS-1 airplane, reference 4.

The stability measurements reported here were obtained for the most part from two high-speed runs to a Mach number of approximately 0.89 and several turns made at various Mach numbers up to 0.81. Time histories of the two high-speed runs made at altitudes of about 40,000 feet are given in figures 5 and 6. In the run shown in figure 5, the pilot used a stabilizer setting of 2.3°; in the run shown in figure 6, a stabilizer setting of 1.4° was used. As shown in figure 5, the airplane with a 2.3° stabilizer setting became increasingly nose heavy as the Mach number was increased above 0.80. During the initial phase of the recovery, (after 50 sec) an appreciable pull force was required to increase the normal-force coefficient and decrease the Mach number. As the Mach number decreased (time, 60 sec), the nose heaviness also decreased and the pilot was required to relieve the pull force to prevent reaching high values

of acceleration. With the 1.4° stabilizer setting in figure 6 the airplane became increasingly tail heavy above a Mach number of 0.83. During the recovery in this run (65 to 89 sec and M = 0.88 to 0.834) the pilot merely decreased the push force and a normal recovery was effected. The pilot reported that in both runs, there was buffeting which began at about a Mach number of 0.85. It is also interesting to note that above a Mach number of 0.84, the airplane becomes very right-wing heavy and the pilot applied control to correct it. The pilot reported that this wing heaviness was not continuous and it was difficult to determine the lateral control required for trim. As a consequence, the airplane felt uncertain laterally at the highest speeds as can be seen by the control motions used by the pilot, and the lateral oscillations which resulted. Some of this uncertainty in lateral trim may arise from aileron friction. (See fig. 3.)

In order to illustrate further the control required by the pilot to trim the airplane, control positions and forces and sideslip angle for steady flight were selected from figures 5 and 6 and plotted in figure 7 as functions of Mach number. In this figure, the difference in control required for trim caused by the two stabilizer settings is clearly shown. These trim changes, from the standpoint of pilot's forces, are large in that approximately 30 pounds force was required in either the pull or push direction, depending on the stabilizer setting. In the case of the Bell XS-1, data for two stabilizer settings showed no difference in the direction of the trim change as the airplane becomes nose heavy in both cases (reference 4) for this Mach number range. The right-wing heaviness is illustrated in this figure by the increased left aileron for trim required at the higher speeds. There was no appreciable change in rudder position or sideslip angle. (A similar phenomenon of wing heaviness was noted with the XS-1 airplane (reference 4).)

Some stability and control data in accelerated flight were obtained from steadily increasing turns made at an altitude of 30,000 feet in a Mach number range from 0.50 to 0.80 and one turn made at 10,000 feet at a Mach number of 0.71. The results of these measurements are given in figure 8 where the stick force per g and elevator angle required per unit C_N are plotted as functions of Mach number. These data show that the longitudinal stability is positive throughout the speed range and is lowest at about a Mach number of 0.675. Above a Mach number of 0.675, the stability increases with increasing Mach number. These results are in general agreement with the data obtained on the Bell XS-1 airplane (reference 5). Although data were available only at one speed for an altitude of 10,000 feet, it is interesting to note that the apparent stability is higher at 10,000 feet than at 30,000 feet. Some of this difference can be accounted for by the effect of altitude but it is also possible that, because of the higher dynamic pressure at the lower altitudes, the apparent stability is altered by distortion effects.

The buffet boundary for the D-558-1 airplane has been determined from straight stalls, turns, and high-speed runs. The results of these

measurements are given in figure 9 where the normal-force coefficients necessary for buffeting are plotted as functions of Mach number. The buffet boundary as presented in this figure defines the combination of Mach number and normal-force coefficient where buffeting begins. Below a Mach number of 0.70, the airplane was flown into the buffet boundary and the test points shown beyond the boundary represent maximum lift for a gradual maneuver at the test speed. Above a Mach number of 0.70, the airplane was flown into the buffet region but peak lift was not obtained during the tests. For comparison, the buffet boundary for the Bell XS-1 airplane with the same wing section 65-110 (references 4 and 6) is also shown in this figure. As might be expected, the buffet boundaries for the two airplanes are quite similar.

CONCLUSIONS

Data obtained in flight up to a Mach number of 0.89 with the D-558-1 airplane showed the following:

1. With a stabilizer incidence of 2.3°, a longitudinal trim change in the nose-down direction was experienced above a Mach number of 0.80. With a stabilizer setting of 1.4°, a longitudinal trim change in the nose-up direction was experienced above a Mach number of 0.83.

2. The airplane becomes right-wing heavy above a Mach number of 0.84. This lateral disturbance is such that the airplane and control feel very uncertain to the pilot.

3. The longitudinal stability in accelerated flight was positive from a Mach number of 0.50 to 0.80 and increased above a Mach number of 0.675.

4. The buffet boundary was determined up to a Mach number of 0.84 and is similar to that for the Bell XS-1 airplane with the same 65-110 wing section.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

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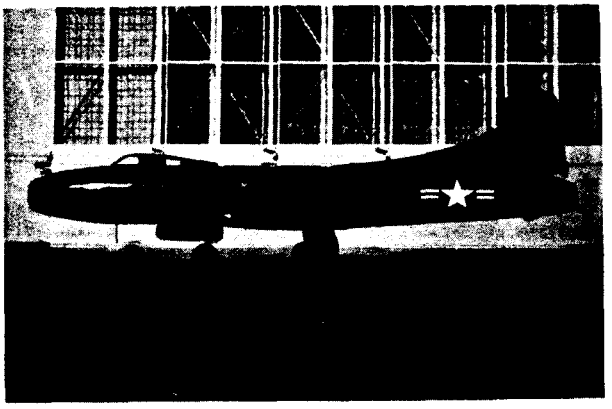
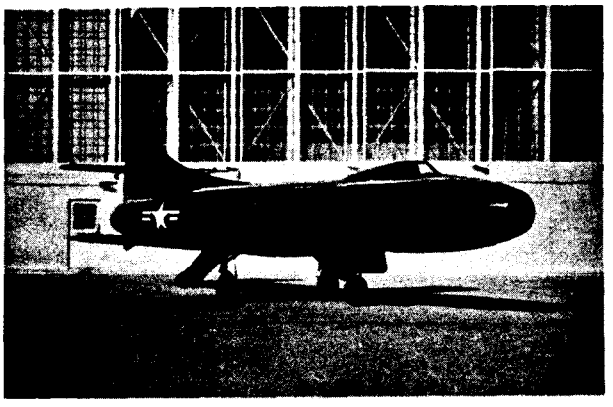
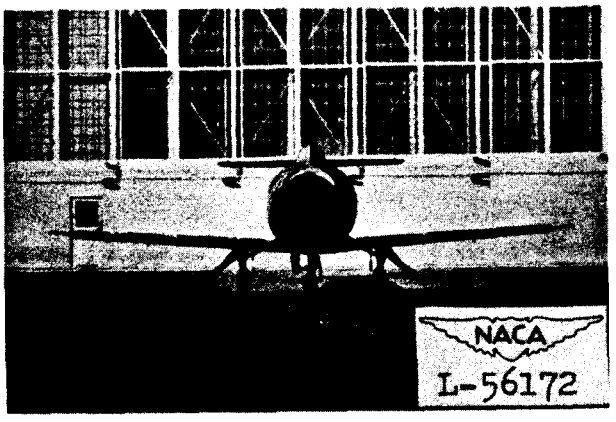


(a) Side view.



(b) Three-quarter front view.



(c) Front view.

Figure 1.- Photographs of D-558-1 airplane.

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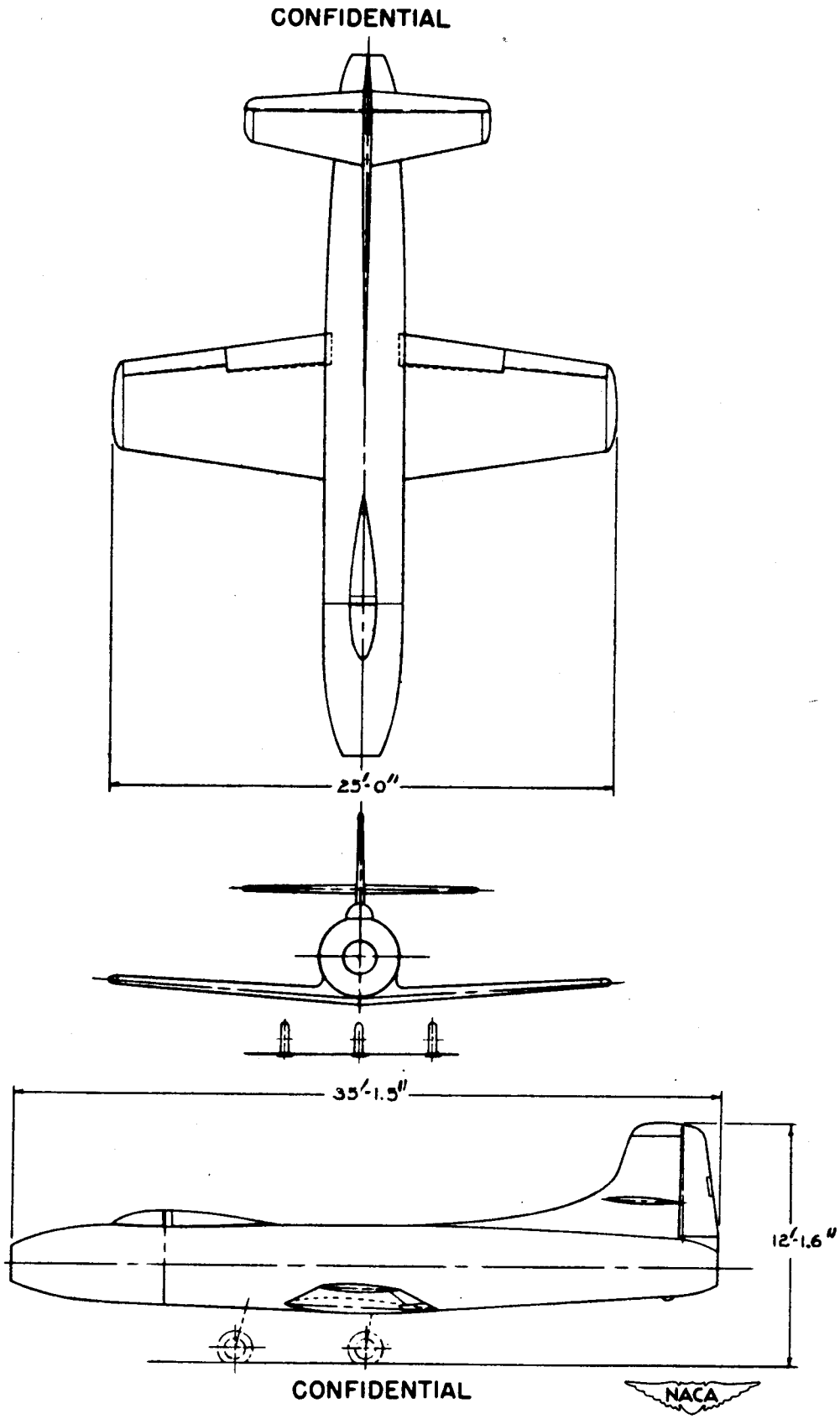

Figure 2.- Three-view drawing of D-558-1 airplane.

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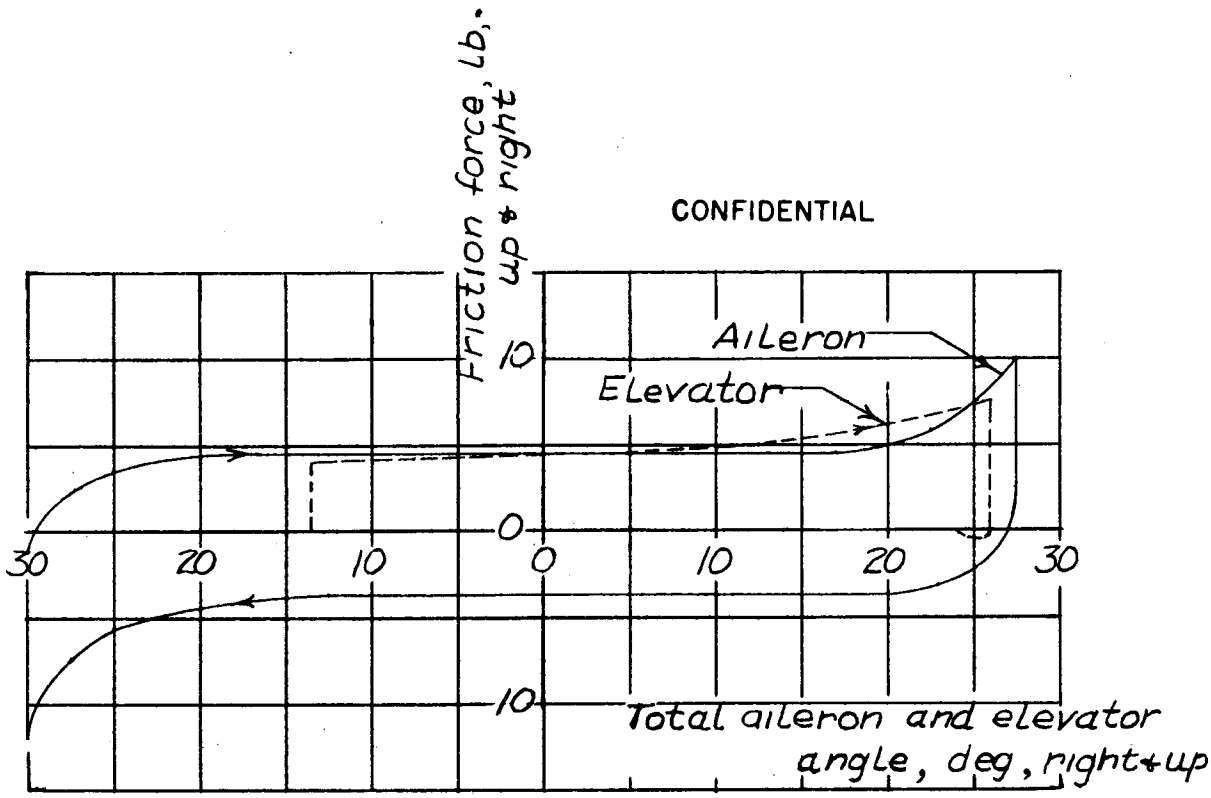

Figure 3.- Control friction forces obtained by moving controls slowly in direction shown. D-558-1 airplane.

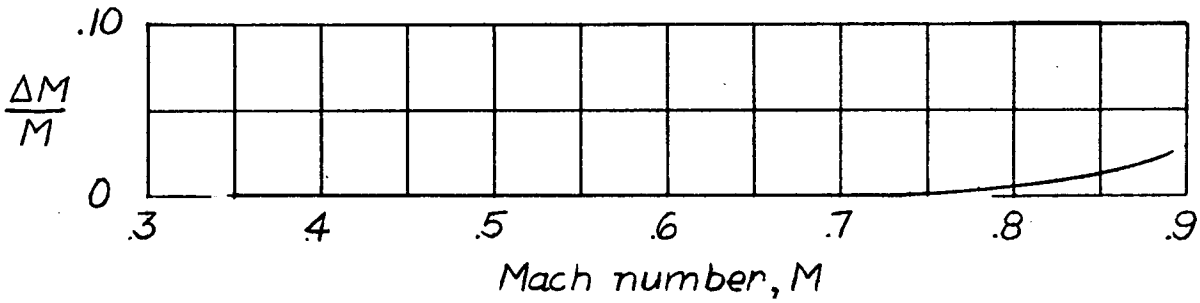

Figure 4.- Variation of percentage error in Mach number, $\frac{\Delta M}{M}$, with corrected Mach number.

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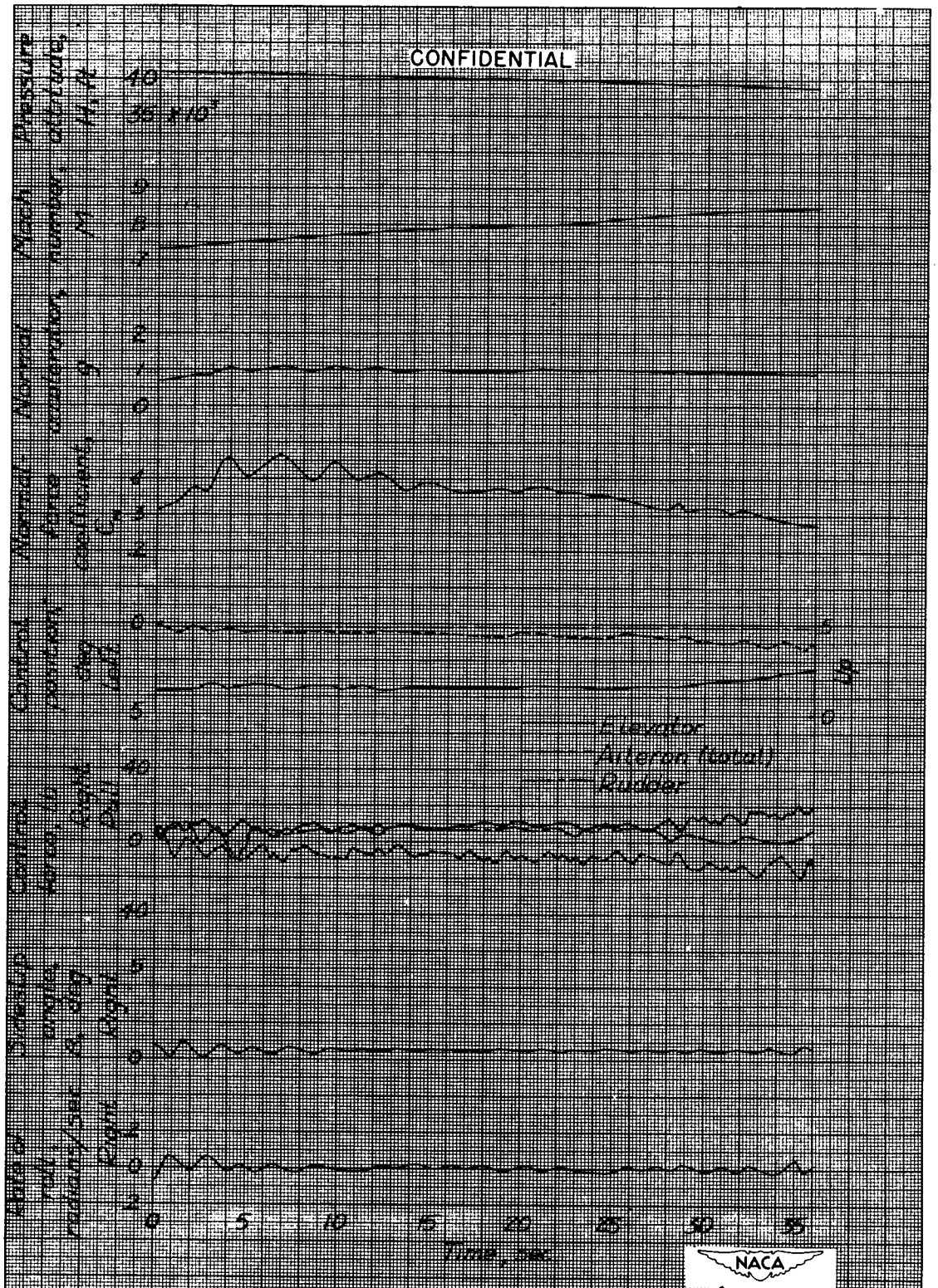

Figure 5.- Time history of measured quantities during high-speed run. D-556-1 airplane. $i_t = 2.3°$.

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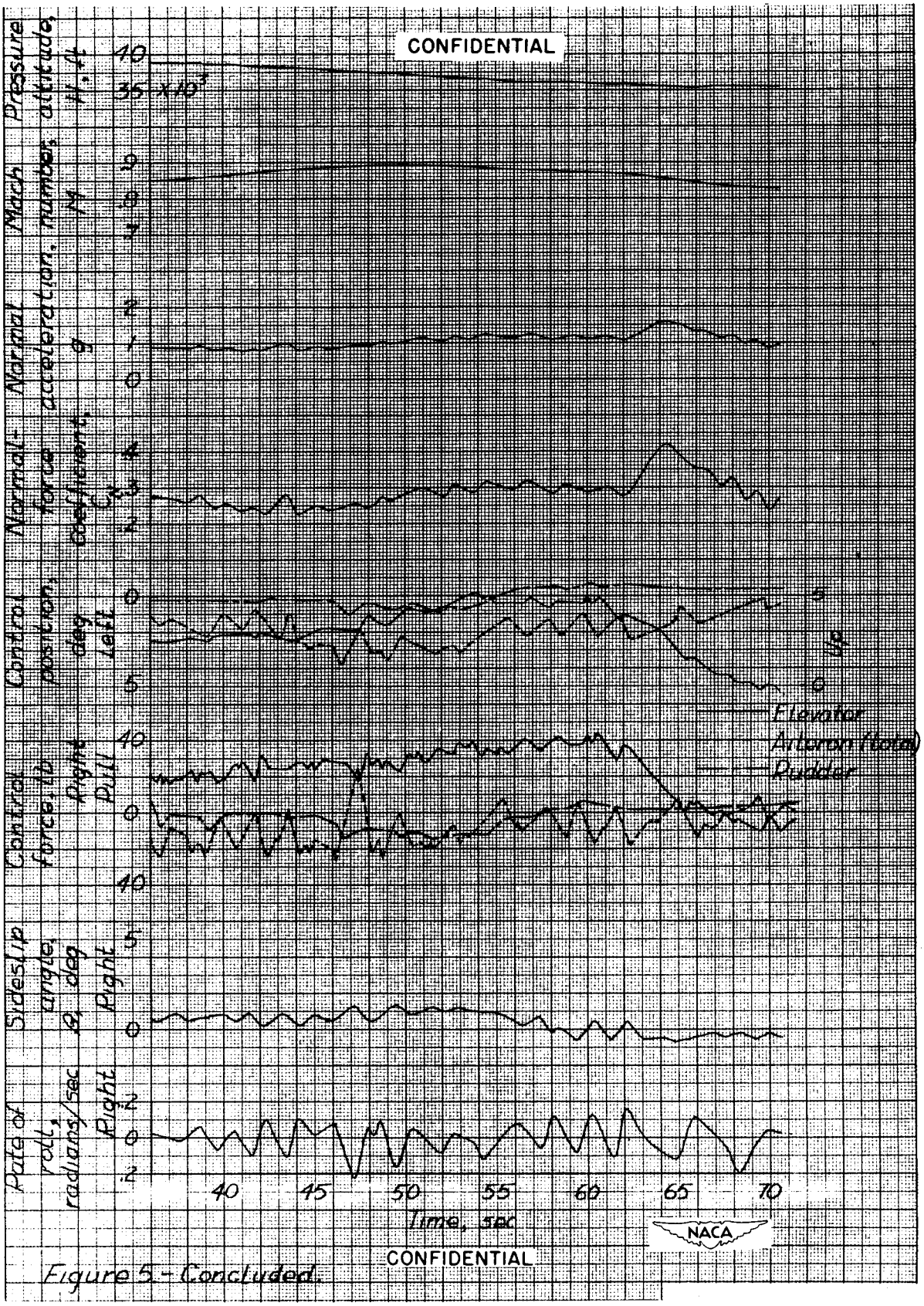

Figure 5.- Concluded.

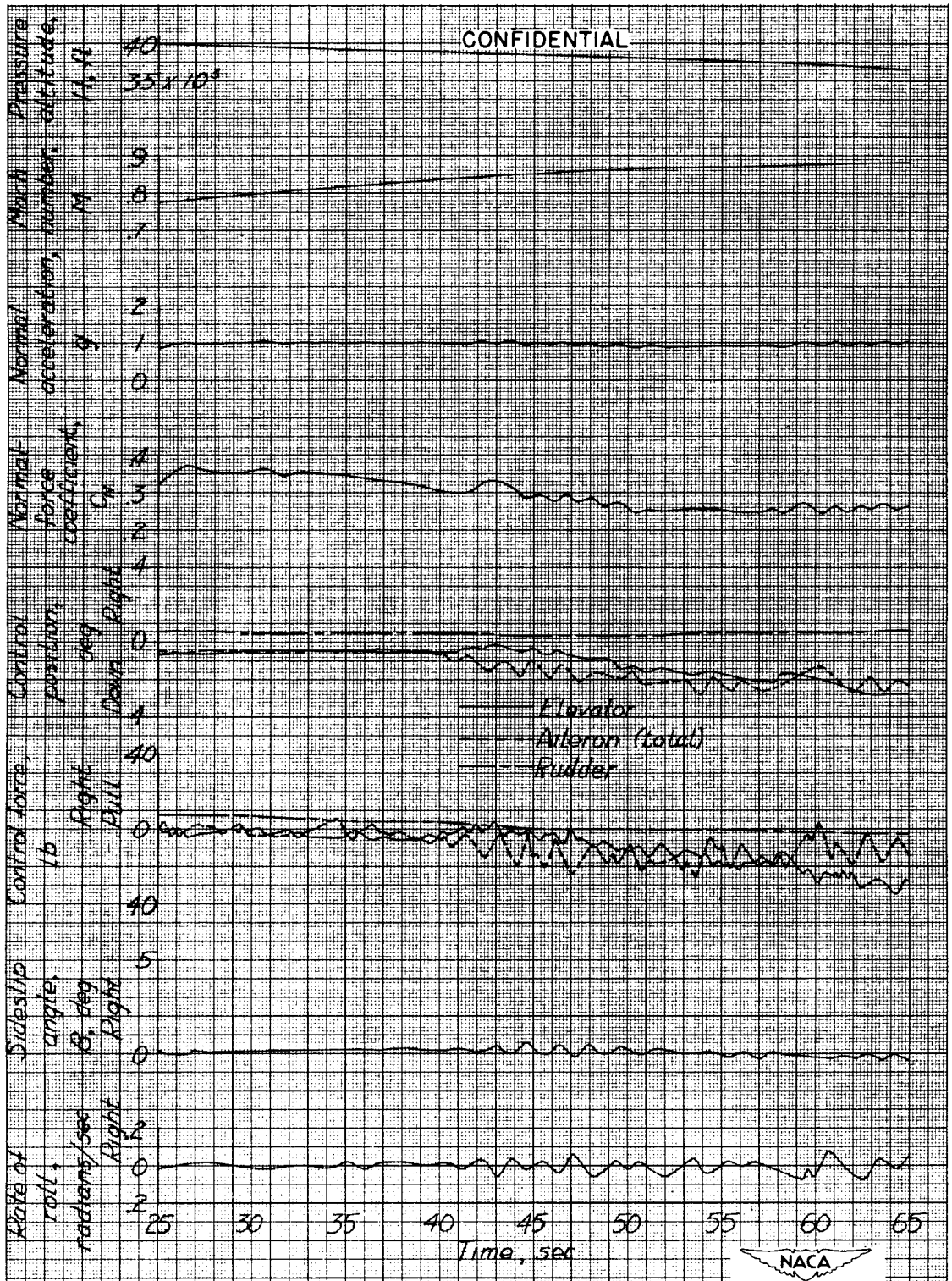

Figure 6 - Time history of measured quantities during high-speed run. D-558-1 airplane $i_t = 1.4°$

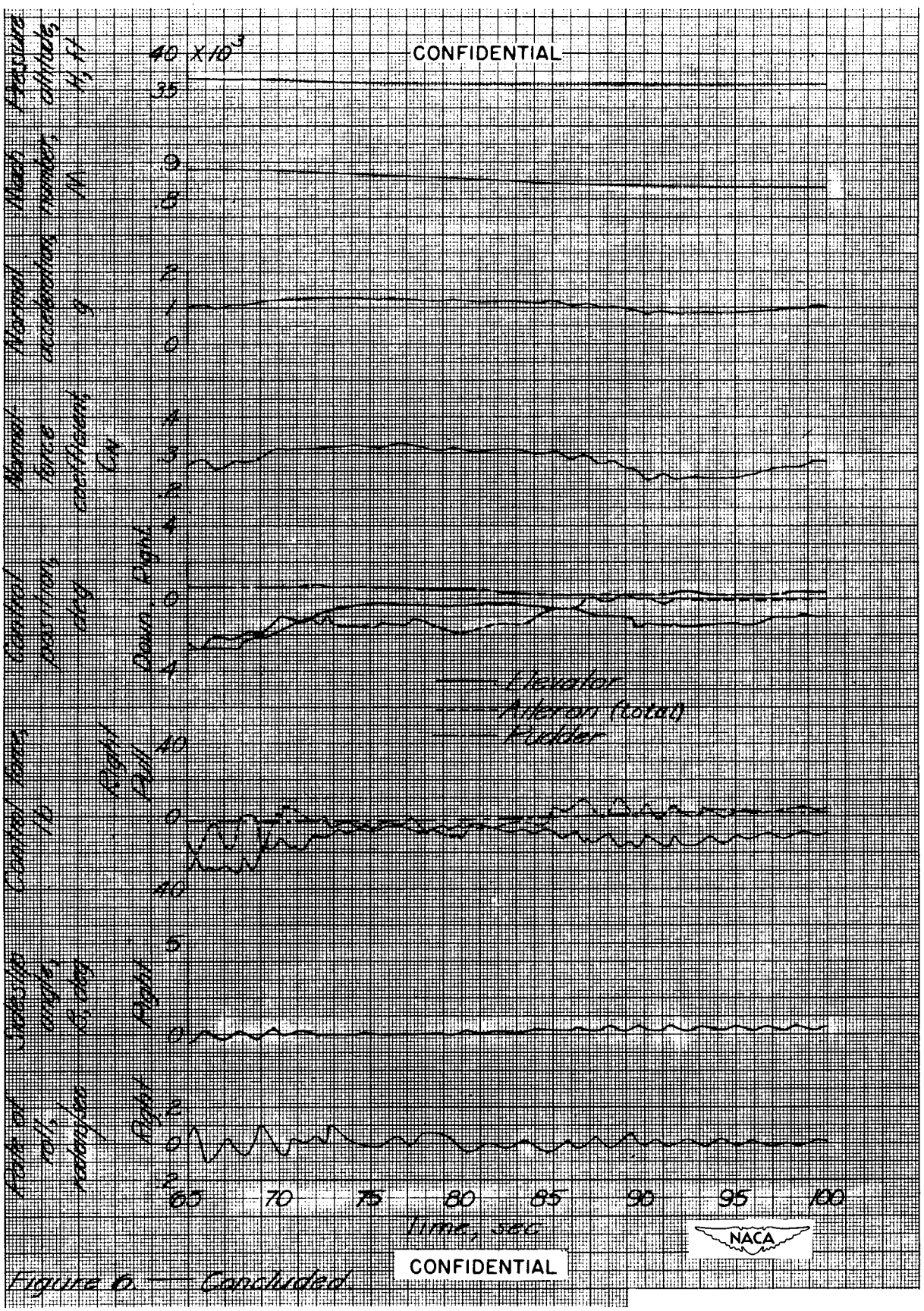

Figure 10.— Concluded.

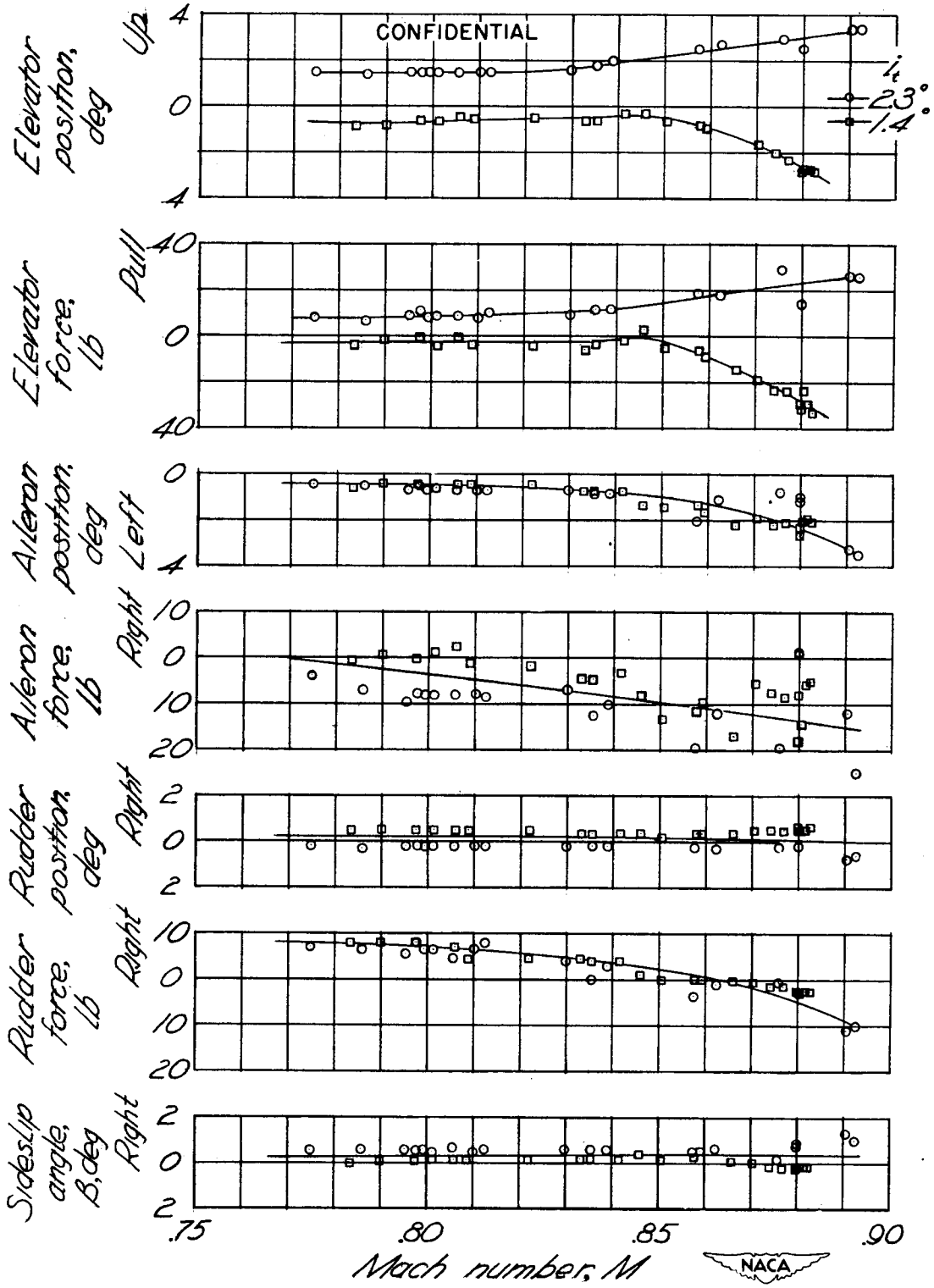

Figure 7.- Variation of airplane trim forces and positions with Mach number. ($C_N \approx .23$ to $.43$) D-558-1 airplane.

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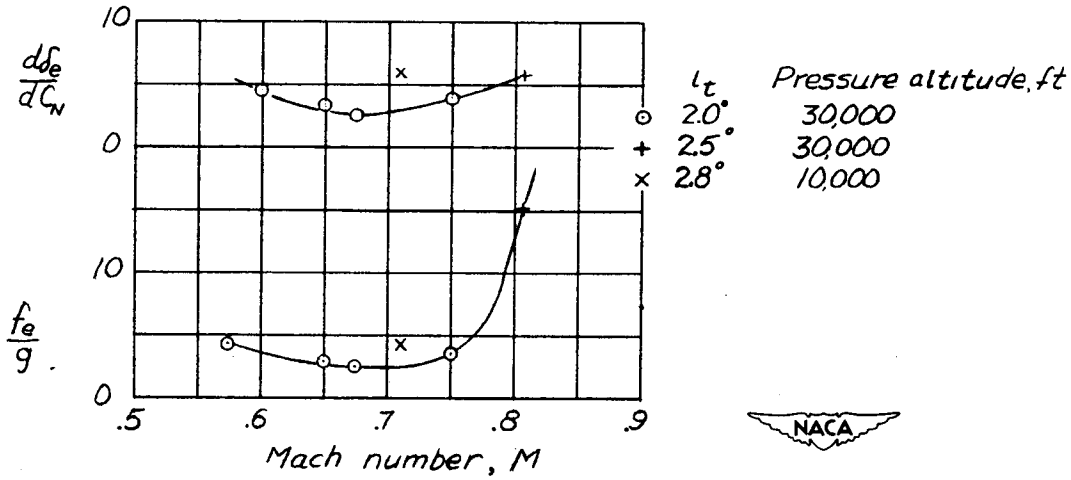

Figure 8.- The variation of stick force per g, f_e/g, and the change in elevator angle per unit C_N, $d\delta_e/dC_N$, with Mach number. D-558-1 airplane.

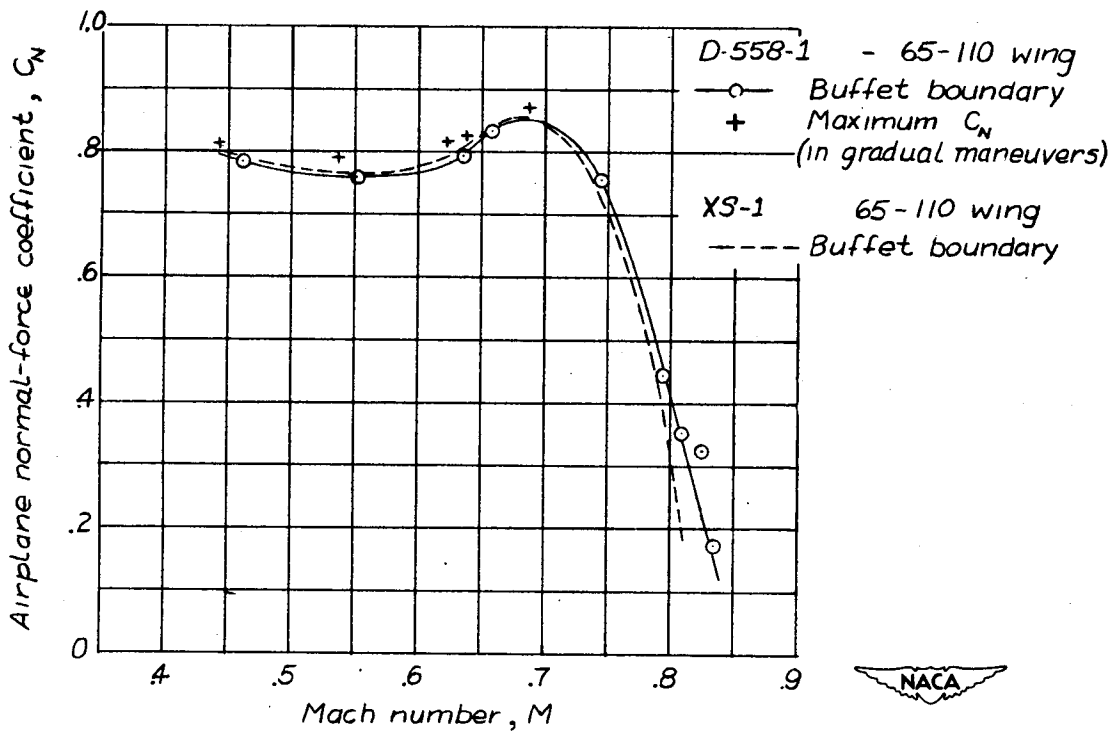

Figure 9.- Buffet boundary of D-558-1 airplane compared with buffet boundary of XS-1 airplane.

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