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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

MEASUREMENTS OF THE LONGITUDINAL STABILITY AND CONTROL AND STALLING CHARACTERISTICS OF A NORTH AMERICAN P-51H AIRPLANE

(AAF NO. 4 64164)

By

Christopher C. Kraft, Jr., and J. P. Reeder

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Flight tests have been made to determine the longitudinal stability and control and stalling characteristics of a North American P-51H airplane. The results indicate that the airplane has satisfactory longitudinal stability in all the flight conditions tested at normal loadings up to 25,000 feet altitude. At Mach numbers above 0.7, the elevator push force required for longitudinal trim decreased somewhat because of compressibility effects. The elevator stick force per g in accelerated turns at the forward center-of-gravity position of 24 percent mean aerodynamic chord above 250 miles per hour was in excess of the required limits at both 5,000 and 25,000 feet altitude. The longitudinal-trim-force changes due to flaps and power were small, but the rudder-trim-force change with power change was high. The stalling characteristics in all the conditions tested were satisfactory.

INTRODUCTION

At the request of the Air Materiel Command, U. S. Air Force, flight tests have been made to determine the flying qualities of a P-51H airplane (AAF No. 4-64164). The results of the tests to determine the longitudinal stability and control and stalling characteristics are presented herein. Data on the lateral and directional stability and control have been presented in reference 1.

DESCRIPTION OF AIRPLANE AND TESTS

The P-51H is a low-wing fighter airplane equipped with a Merlin V-1650-9 engine. The configuration used in making the longitudinal-stability tests was the final production airplane which incorporated a 7-inch fin extension, a short-span rudder with the travel limited to $\pm 25^\circ$, and a $\frac{1}{2}$-inch-chord extension strip added to the entire elevator trailing edge with the exception of the elevator tabs. Some initial tests were conducted without the elevator trailing-edge extension and with the original-vertical-tail configuration. The original vertical tail did not have the 7-inch fin extension nor the short-span rudder, and the rudder travel was $\pm 30^\circ$ (reference 1). A three-view drawing of the airplane is shown in figure 1 and photographs of the test airplane are shown in figures 2 to 5. Other pertinent dimensions of the airplane are presented in table I.

The airplane was tested with three different center-of-gravity positions; namely, 24, 26, and 30 percent of the mean aerodynamic chord. All of the center-of-gravity positions given in this paper are with the landing gear down. During all the tests, fuel was used from the wing tanks only. At the two aft center-of-gravity positions, the fuselage tanks were filled and used as ballast. The rearward center-of-gravity position was obtained by adding 125 pounds of lead to the tail compartment of the airplane. This center-of-gravity position was aft of any normal loading of the airplane but was used to determine the stability of the airplane more accurately. The normal center-of-gravity limits were approximately 20 to 28 percent of the mean aerodynamic chord. The airplane weight varied from 7500 pounds to 9800 pounds during the tests.

The physical characteristics of the airplane are shown in figures 6 to 10. The variations of the rudder deflection with rudder-pedal position and the elevator and aileron deflection with stick position are shown in figures 6 to 8. The friction in these various control systems is shown in figure 9. The friction in all of the controls was small and well within the required limits specified in reference 2. The stretch in each of the controls was measured and is presented in figure 10. These data showed the stretch in the aileron control system to be 2.5° per 20 pounds of stick force, the stretch in the elevator control system to be 1.2° per 20 pounds of control force, and the stretch in the rudder control system to be 7.5° per 100 pounds of rudder-pedal force.

The airplane was tested in the following flight configurations at approximately 5000 feet altitude:

Condition	Power	Flaps	Gear	Canopy
Power-on clean	46 inches Hg at 2700 rpm	Up	Up	Closed
Power-off clean	Engine idling	Up	Up	Closed
Landing	Engine idling	Down	Down	Open
Approach	23 inches Hg at 2700 rpm	Down	Down	Open
Wave-off	46 inches Hg at 2700 rpm	Down	Down	Open

Tests were also run at high altitude, approximately 25,000 feet, in the power-on clean and power-off clean conditions.

All of the tests made were performed by the steady-record method with the exception of the stall-approach data. In the steady-record method, records are taken at different speeds or accelerations, as the case may be, when the airplane is in a steady condition; whereas in the continuous-record method, records are taken continuously as the speed is varied slowly over a certain speed range. The continuous records are indicated by flagged symbols in this paper.

INSTRUMENTATION

Standard NACA photographically recording instruments were used to measure the data presented in this paper along with the pilot's readings of altitude, free-air temperature, and fuel-gage readings in the cockpit. A more complete description of the instrumentation used is presented in reference 1.

DISCUSSION AND RESULTS

The following discussion of the results obtained from these tests is based on the flying-qualities requirements of reference 2.

Longitudinal Stability and Control

Dynamic longitudinal stability.- The dynamic longitudinal stability of the airplane was tested by trimming the airplane at a given speed and in a particular configuration and abruptly deflecting and releasing the elevator. Typical time histories of this maneuver are presented in figures 11 to 14. The airplane was tested in all the flight configurations and it was found that the oscillation produced by this maneuver was completely damped in 1 cycle or less and that there was no oscillation of the elevator itself following its deflection. The airplane met the requirements of reference 2 for this particular test. No unstable oscillations were experienced during any of the tests performed, which were limited to Mach numbers below 0.6.

In flight-testing the first models of the P-51H airplane at Wright Field, several airplanes experienced violent longitudinal oscillations, termed "porpoising," at Mach numbers above approximately 0.6 when the elevator was abruptly deflected. The $\frac{1}{2}$-inch trailing-edge strips on the elevator were added to cure this deficiency. No short-period-oscillation tests were made by the NACA in the Mach number range in which porpoising was encountered because of the danger of this maneuver. No porpoising was experienced, however, in normal flight and dives up to a Mach number of 0.75 with the modified airplane.

Static longitudinal stability.- The static-longitudinal-stability data measured in the various configurations are shown in figures 15 to 21. These data were obtained by trimming the airplane at a given speed for zero control forces and flying the airplane through the speed range from the maximum speed obtainable in the various configurations to the stalling speed. The requirements state that the curves of elevator force and elevator position against airspeed shall have a stable slope at all normal center-of-gravity positions; that is, the stick-fixed and stick-free neutral points shall be aft of the most rearward center-of-gravity position of the airplane.

The stick-free and stick-fixed neutral points were obtained by the method illustrated in figure 22. The elevator force divided by impact pressure F_e/q and elevator deflection δ_e were plotted against airplane normal-force coefficient C_N. The slopes of these curves $\frac{dF_e/q}{dC_N}$ and $\frac{d\delta_e}{dC_N}$ were then plotted against center-of-gravity position. The center-of-gravity positions at which $\frac{dF_e/q}{dC_N}$ and $\frac{d\delta_e}{dC_N}$ are zero are the stick-free and stick-fixed neutral points, respectively. In cases in which the longitudinal stability was large, the actual values of the neutral points obtained cannot be considered accurate because they were so far aft of the center-of-gravity range tested. They do show, however, the large degree of stability that the airplane has.

(1) Power-on clean condition: The data shown in figures 15 and 16 indicate the airplane to be stable both stick free and stick fixed, the neutral points being aft of the most rearward center-of gravity position. The push forces encountered at high speeds with a trim speed of 185 miles per hour were practically the limit of the pilot's strength, but had the airplane been trimmed at a higher speed, the forces experienced at high speed would not have been as high. The effect of altitude on the longitudinal stability was negligible. However, at high speeds and high altitudes where higher Mach numbers were obtained, compressibility effects caused a tendency for the push force to decrease. (See fig. 16.)

(2) Power-off clean condition (figs. 17 and 18): The airplane was stable both stick fixed and stick free in this condition at the two forward center-of-gravity positions and met the requirements of reference 2. However, at the rearward center-of-gravity position tested, a slightly unstable elevator-angle variation was noted at high speed.

(3) Wave-off, approach, and landing conditions (figs. 19 to 21): The requirements of reference 1 were met in each of these three conditions. The curves of elevator force and angle against speed had a stable slope, the stick-free and stick-fixed neutral points being aft of the rearward center-of-gravity position tested.

Longitudinal control.- (1) Longitudinal control in accelerated flight: The longitudinal control in accelerated flight was measured by making accelerated turns both to the left and right at a constant airspeed and acceleration. The tests were made at the three center-of-gravity positions at speeds varying from 200 to 350 miles per hour at approximately 5,000 and 25,000 feet altitude. Time histories of short records taken in typical accelerated turns are shown in figure 23. The change in elevator force and angle obtained from these tests was plotted as a function of change in normal acceleration so that the force and angle per g could be determined. The elevator angle was also plotted as a function of airplane normal-force coefficient in order to obtain the stick-fixed maneuver points. The stick-free and stick-fixed maneuver points were determined by measuring the average values of the slopes dF_e/dg and $d\delta_e/dC_N$ and plotting these values as a function of the center-of-gravity position. The center-of-gravity positions at which these slopes became zero were the stick-free and stick-fixed neutral points, respectively. These data are given in figures 24 to 33. A graph of the center-of-gravity range as a function of altitude in which desirable values of stick force per g are obtained at 300 miles per hour is shown in figure 34.

The force per g with the center-of-gravity position at or forward of 27 percent of the mean aerodynamic chord above 250 miles per hour was in excess of the required limit of 8 pounds per g specified in the requirements of reference 2. Increasing the altitude from 5,000 to 25,000 feet slightly decreased these forces. At the two lower speeds tested, 200 and 250 miles per hour, the force-per-g characteristics were within the required 3 to 8 pounds per g limits specified in the requirements. The effect of altitude at these two speeds was to decrease the force per g approximately 1 to 2 pounds. The elevator angle required to produce the acceleration was always in the right direction and of a desirable magnitude at all the center-of-gravity positions, speeds, and altitudes tested and the elevator was always powerful enough to produce the maximum lift coefficient.

In general, the force-per-g characteristics of the airplane were acceptable. The variation of elevator force and angle was linear in all the conditions tested, but as was mentioned in the preceding paragraph, the forces experienced at the higher speeds were slightly greater than the required limits. The most forward stick-free maneuver point obtained was at 35 percent of the mean aerodynamic chord at 300 miles per hour and the higher test altitude. The most forward stick-fixed maneuver point was found to be at approximately 24.4 percent of the mean aerodynamic chord at 350 miles per hour at high altitude, approximately 20,000 feet. The stability was greater, however, at all the lower speeds tested where the maneuver point is at approximately 27 percent of the mean aerodynamic chord at this altitude.

(2) Longitudinal control in landing and take-off: The airplane met the requirements of reference 1 in both landing and take-off. With the

center-of-gravity position in the most forward position it was possible to hold the airplane off the ground at approximately 100 miles per hour with the airplane trimmed at 120 miles per hour. The elevator force required in this procedure did not exceed the 35-pound limit. It was also possible during take-off to maintain any attitude up to thrust axis level at approximately 50 miles per hour. These two results were determined from pilot's observations. The pilot considered the landing and take-off characteristics of the airplane acceptable, except that with engine idling the glide path was steep in the landing condition and the rate of descent very high.

(3) Trimming characteristics: It was possible to trim the airplane by use of the elevator tabs in all the conditions required according to reference 2. The longitudinal trim changes with power, flaps, and gear change are shown in table II. The elevator and aileron-trim-force changes were no more than 7 pounds, but the pilot objected to the nose-up trim change due to flap deflection. The rudder-trim-force change was high with change in power. The rudder-trim-force change with change in power, power-off to normal rated power, with the airplane trimmed at 135 miles per hour was approximately 93 pounds.

(4) Pitching moment due to sideslip: The pitching moment due to sideslip in this airplane was not excessive and was considered satisfactory. The variation of elevator force with sideslip angle in the power-on clean and power-off clean condition is shown in figure 35 for both the original and production configurations. The variation of elevator angle with sideslip angle is not shown since complete data were not obtained for all the conditions. The elevator-angle variation with sideslip was found to be small and essentially the same, however, with both tail configurations. The differences in the two tails were not of a type which would be expected to affect the elevator-angle variation with sideslip.

From the data presented in figure 35, it can be seen that the variation of elevator force with sideslip at 300 miles per hour was different for the two configurations. The original tail showed very little force variation with sideslip over the range of sideslip angles measured; whereas the production tail required pull forces as the sideslip was increased to the left or right. While this force variation was not considered objectionable on the P-51H airplane, this amount of force variation has been considered undesirable on airplanes with a smaller amount of longitudinal stability because it resulted in appreciable changes in normal acceleration when the rudder was deflected. The increased force variation with the trailing-edge extension on the elevator probably results from the more negative values of C_{h_α} and C_{h_δ} of the modified elevator. It was not thought previously, however, that this type of modification would have a pronounced effect on the elevator-force variation with sideslip.

Similar effects, though smaller in magnitude, are shown at 150 miles per hour in the power-on clean condition. There is very little difference between the two tails in the power-off clean condition at 150 miles per hour.

Stalling Characteristics

In the power-on clean condition (figs. 36 and 37) stall warning was afforded by buffeting approximately 5 miles per hour above the stall accompanied by mild pitching and rolling in either direction. A pitching and rolling oscillation developed near the stall, the airplane finally rolling slowly off. The lateral oscillation which occurred at the stall could be controlled with moderate difficulty. The stalling characteristics were considered statisfactory.

Stall warning was supplied by buffeting about 5 miles per hour above the stall in the power-off clean condition (figs. 38 and 39) which increased as the stall was approached. At the stall, mild pitching and roll to the right occurred after which the airplane either spiraled off or developed a mild pitching and rolling oscillation. The airplane could be easily controlled both laterally and directionally beyond the stall by normal use of the controls even to full-up elevator, and recovery from the stall was normal and prompt. The stalling characteristics were considered very satisfactory.

The stall in the wave-off condition (figs. 40 and 41) was preceded by mild buffeting about 5 miles per hour above the stall. During the stall approach the airplane became extremely left wing heavy and required considerable right rudder. At the stall a rather abrupt left roll occurred which checked itself at about 30° bank as the nose dropped. The airplane could not be satisfactorily controlled laterally during the stall. At the aft center-of-gravity position with the airplane trimmed at 135 miles per hour the stick force reversed and became slightly negative about 7 miles per hour above the stall. The stalling characteristics were considered acceptable.

In the approach condition (fig. 42) mild buffeting preceded the stall by about 5 miles per hour. Before the stall there was noticeable left wing heaviness and after the stall was reached the airplane rolled moderately to the left to about 30° bank, checked itself and rolled again. The airplane could be controlled laterally by the ailerons but there was a delay between application of control and recovery response. The stalling characteristics were satisfactory.

In the landing condition (figs. 43 and 44) stall warning was afforded by buffeting about 2 or 3 miles per hour above the stall. At the stall the nose of the airplane dropped with a mild right roll which resulted in pitching the airplane out of the stall. After this recovery the airplane sometimes spiraled but more often oscillated in roll and pitch, the pitching oscillations increasing, resulting in subsequent stalls being made under increasing acceleration. Recovery from the stall was normal. The airplane could be controlled both laterally and directionally beyond the stall with a little difficulty, even with full-up elevator. If the stall was prolonged, the airplane would roll off sharply. The stalling characteristics were satisfactory.

The stall in accelerated turns (fig. 45) was preceded by ample buffet warning and, if the stick was continued back, the buffeting became very heavy. The stall was accompanied by a slight lateral instability which could be easily controlled. At the aft center-of-gravity position tested, there was a noticeable control force lightening in both left and right turns. The stalling characteristics were satisfactory.

CONCLUSIONS

1. The short-period longitudinal oscillations of the airplane were stable in all the conditions and speeds tested. The longitudinal oscillations always damped in 1 cycle or less and there was no oscillation of the elevator itself. No short-period-oscillation tests were made at Mach numbers above 0.6, however.

2. The airplane had satisfactory stick-free and stick-fixed static longitudinal stability in all the conditions tested and met the handling-qualities requirements at altitudes up to approximately 25,000 feet. Compressibility effects indicated by decreased push forces were apparent at high Mach numbers in the power-on clean condition.

3. The longitudinal control in accelerated flight was in general satisfactory. However, the force per g with the center-of-gravity position at or forward of 27 percent of the mean aerodynamic chord above 250 miles per hour was in excess of the required limits. Increasing the altitude from 5,000 to 25,000 feet slightly decreased these forces. The most forward stick-free maneuver point was 35 percent of the mean aerodynamic chord and the most forward stick-fixed maneuver point was approximately 27 percent of the mean aerodynamic chord except at high speed and high altitude where the maneuver point moved forward to approximately 24 percent of the mean aerodynamic chord.

4. The characteristics of the airplane during take-off and landing were satisfactory.

5. It was possible to trim the airplane longitudinally by use of the elevator tabs at all the speeds and in all the conditions required.

6. The trimming characteristics with change in power and flaps and landing-gear position were satisfactory except that the rudder-trim-force change due to power was excessive.

7. The pitching moment due to sideslip was considered satisfactory.

8. The airplane had satisfactory stalling characteristics in all the conditions tested. There was ample stall warning in the form of buffeting and recovery was always normal and prompt.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

Christopher C. Kraft, Jr.
Christopher C. Kraft, Jr.
Aeronautical Research Scientist

John P. Reeder
John P. Reeder
Aeronautical Research Scientist

Approved:
Melvin N. Gough
Melvin N. Gough
Chief of Flight Research Division

MCF

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1. Kraft, Christopher C., Jr., and Reeder, J. P.: Measurements of the Lateral and Directional Stability and Control Characteristics of a P-51H Airplane (AAF No. 44-64164). NACA RM No. L7L11, Army Air Forces, 1947.

2. Anon.: Stability and Control Characteristics of Airplanes, AAF Specification No. R-1815-A, April 7, 1945. Restricted

TABLE I

PERTINENT AIRPLANE DIMENSIONS

Engine	Merlin V-1650-9
Propeller (4 blades)	Aeroproducts Model H-20-156-23M5
Wing area, sq ft	235.73
Wing span, ft	37.03
Aspect ratio	5.82
Wing-flap area (two), sq ft	31.53
Aileron area (one), sq ft	6.35
Total horizontal-tail area, sq ft	48.35
Elevator area (one), sq ft	6.43
Original vertical-tail area, sq ft	23.40
Original rudder area, sq ft	10.24
Production vertical-tail area, sq ft	24.76
Production rudder area, sq ft	9.77
Dorsal-fin area, sq ft	1.93

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TABLE II

LONGITUDINAL TRIM CHANGES DUE TO FLAPS AND POWER

[Center of gravity at 21.9 percent M.A.C.]

V_c (mph)	Power	Flaps	Gear	Control force (lb)			Change in sideslip (deg)
				Elevator	Rudder	Aileron	
151	[a]$\frac{1}{2}$ normal rated power	Up	Up	0	0	0	0
153	--------- do ---------	-do-	Down	3.0 pull	1 left	0.5 right	0.3 right
151	--------- do ---------	Down	-do-	4.2 push	2 right	1.0 right	0.5 right
151	Off	-do-	-do-	1.3 push	25 left	1.0 right	2.0 right
135	$\frac{1}{2}$ normal rated power	-do-	-do-	0	0	0	0
136	Off	-do-	-do-	0	35 left	0	1.7 right
150	--------- do ---------	Up	Up	0	0	0	0
148	--------- do ---------	-do-	Down	3.0 pull	4 right	0	0.9 right
149	--------- do ---------	Down	-do-	0.5 push	2 right	1.0 left	0.6 right
135	--------- do ---------	-do-	-do-	0	0	0	0
135	[b]Normal rated power	-do-	-do-	2.7 push	93 right	0.5 right	1.3 left
136	--------- do ---------	-do-	-do-	0	0	0	0
135	--------- do ---------	-do-	Up	0.5 push	0	0	0
133	--------- do ---------	Up	-do-	1.0 pull	20 right	1.5 left	1.8 left
115	--------- do ---------	-do-	Down	0	0	0	0
115	--------- do ---------	-do-	Up	0	11 left	0	0.2 left

[a]$\frac{1}{2}$ normal rated power — 23 in. Hg at 2700 rpm.

[b]Normal rated power — 46 in. Hg at 2700 rpm.

FIGURE LEGENDS

Figure 1.- Three-view drawing of the P-51H airplane with the production tail.

Figure 2.- Side view of North American P-51H airplane.

Figure 3.- Front view of North American P-51H airplane.

Figure 4.- Three-quarter rear view of North American P-51H airplane.

Figure 5.- Three-quarter front view of North American P-51H airplane.

Figure 6.- Variation of rudder angle with rudder pedal position, P-51H airplane.

Figure 7.- Variation of elevator angle with stick position, P-51H airplane.

Figure 8.- Variation of aileron angle with stick position, P-51H airplane.

Figure 9.- Variation of the friction force in the control systems with elevator, aileron, and rudder angle as measured on the ground in the no-load condition, P-51H airplane.

Figure 10.- The variation of stretch in the control systems with rudder, elevator, and aileron angle as measured on the ground, P-51H airplane.

Figure 11.- Time history of a short-period oscillation in the power-on clean condition started by an abrupt deflection and release of the elevator. Low altitude, c.g. at 21.15 percent M.A.C., P-51H airplane.

Figure 12.- Time history of a short-period oscillation in the power-off clean condition started by an abrupt deflection and release of the elevator. Low altitude, c.g. at 21.45 percent M.A.C., P-51H airplane.

Figure 13.- Time history of a short-period oscillation started from an abrupt deflection and release of the elevator. High altitude, c.g. = 22.77 percent M.A.C., P-51H airplane.

Figure 14.- Time history of a short-period oscillation in the landing condition started by an abrupt deflection and release of the elevator. c.g. = 23.60 percent M.A.C., P-51H airplane.

Figure 15.- Static longitudinal stability characteristics in the power-on clean condition at approximately 7000 feet altitude, P-51H airplane.

FIGURE LEGENDS - Continued

Figure 16.- Static longitudinal stability characteristics in the power-on clean condition at approximately 24,000 feet altitude, P-51H airplane.

Figure 17.- Static longitudinal stability characteristics in the power-off clean condition at approximately 7000 feet altitude, P-51H airplane.

Figure 18.- Static longitudinal stability characteristics in the power-off clean condition at approximately 22,000 feet altitude, P-51H airplane.

Figure 19.- Static longitudinal stability characteristics in the wave-off condition at approximately 5000 feet altitude, P-51H airplane.

Figure 20.- Static longitudinal stability charactertistics in the approach condition at approximately 5000 feet altitude, P-51H airplane.

Figure 21.- Static longitudinal stability characteristics in the landing condition at approximately 5000 feet altitude, P-51H airplane.

Figure 22.- Determination of the stick-free and stick-fixed neutral points.

(a) Variation of elevator angle and F_e/q with normal-force coefficient for the power-on clean, power-off clean, and landing conditions at low altitude.

Figure 22.- Continued.

(b) Variation of elevator angle and F_e/q with normal-force coefficient for the wave-off and approach conditions.

Figure 22.- Continued.

(c) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the power-on clean and power-off clean conditions.

Figure 22.- Continued.

(d) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the wave-off and approach conditions.

Figure 22.- Concluded.

(e) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the landing condition.

FIGURE LEGENDS – Continued

Figure 23.– Time histories of accelerated turns in the power-on clean condition at approximately 5000 feet altitude. Center-of-gravity position at 23.4 percent M.A.C., P-51H airplane.

Figure 24.– Variation of the change in elevator force and angle with change in normal acceleration at various speeds in turns made in the power-on clean condition at the forward center-of-gravity position, P-51H airplane.

Figure 25.– Variation of the change in elevator force and angle with change in normal acceleration at various speeds in turns made in the power-on clean condition at the middle center-of-gravity position, P-51H airplane.

Figure 26.– Variation of the change in elevator force and angle with change in normal acceleration at 200 and 300 miles per hour in turns made in the power-on clean condition at the aft center-of-gravity position, P-51H airplane.

Figure 27.– Variation of the change in elevator force and angle with change in normal acceleration in turns at various speeds made in the power-on clean condition at high altitude at the forward center-of-gravity position, P-51H airplane.

Figure 28.– Variation of the change in elevator force and angle with change in normal acceleration in turns at various speeds made in the power-on clean condition at high altitude at the middle center-of-gravity position, P-51H airplane.

Figure 29.– Variation of the elevator angle with normal-force coefficient in turns at various speeds in the power-on clean condition, P-51H airplane.

(a) Forward center-of-gravity position at low altitude.

Figure 29.– Continued.

(b) Middle center-of-gravity position at low altitude.

Figure 29.– Continued.

(c) Aft center-of-gravity position at low altitude.

Figure 29.– Continued.

(d) Forward center-of-gravity position at high altitude.

FIGURE LEGENDS - Continued

Figure 29.- Concluded.

(e) Middle center-of-gravity position at high altitude.

Figure 30.- Determination of the stick-free maneuver points at low altitude, P-51H airplane.

Figure 31.- Determination of the stick-free maneuver points at high altitude, P-51H airplane.

Figure 32.- Determination of the stick-fixed neutral points at low altitude, P-51H airplane.

Figure 33.- Determination of the stick-fixed neutral points at high altitude, P-51H airplane.

Figure 34.- A graph of the center-of-gravity range as a function of altitude in which desirable values of stick force per g are obtained in turns at 300 miles per hour (average of left and right turns), P-51H airplane.

Figure 35.- The variation of elevator force with sideslip angle as measured in steady sideslips at various speeds in the power-on clean and power-off clean conditions at approximately 22,000 feet altitude, P-51H airplane.

Figure 36.- Time history of a stall approach in the power-on clean condition in which only the elevator was used beyond the stall. Center of gravity at 23.6 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 37.- Time history of a stall approach in the power-on clean condition in which all the controls were used in attempt to control the airplane after the stall was reached. Center of gravity at 23.6 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 38.- Time history of a stall approach in the power-off clean condition in which only the elevator was used beyond the stall. Center-of-gravity position at 22.7 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 39.- Time history of a stall approach in the power-off clean condition in which all the controls were used in an attempt to control the airplane after the stall was reached. Center-of gravity position at 22.7 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

FIGURE LEGENDS - Concluded

Figure 40.- Time history of a stall approach in the wave-off condition in which only the elevator was used beyond the stall. Center-of-gravity position at 23.4 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 41.- Time history of a stall approach in the wave-off condition in which all the controls were used in an attempt to control the airplane after the stall was reached. Center-of-gravity position at 23.4 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 42.- Time histories of stall approaches in the approach condition. Center-of-gravity position at 23.1 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 43.- Time history of a stall approach in the landing condition in which only the elevator was used beyond the stall. Center-of-gravity position at 21.9 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 44.- Time history of a stall approach in the landing condition in which all the controls were used in attempt to control the airplane after the stall was reached. Center-of-gravity position at 21.9 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

Figure 45.- Time history of an accelerated stall approach in the power-on clean condition in a left turn. Center of gravity at 30 percent M.A.C. at approximately 6500 feet altitude, P-51H airplane.

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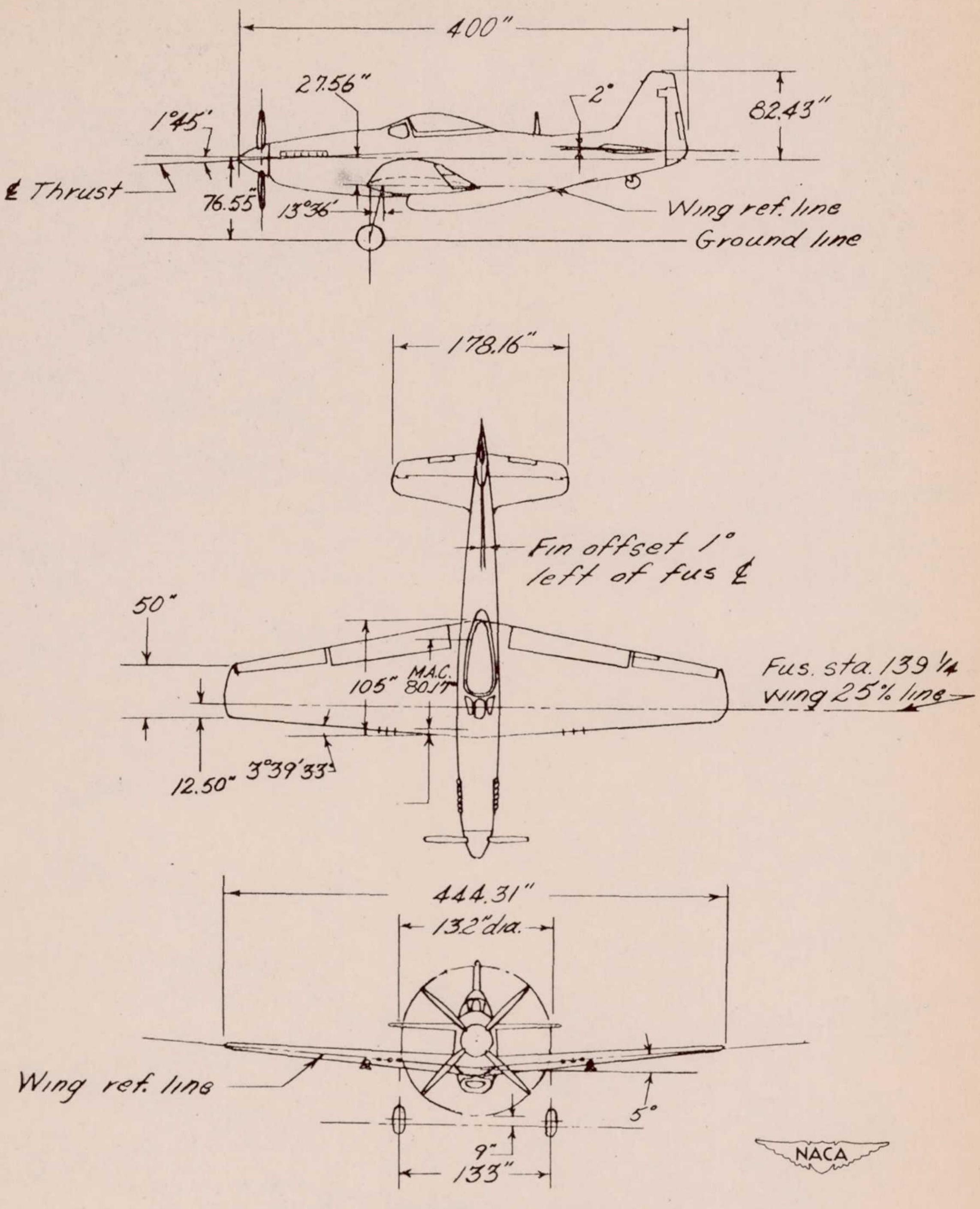

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Figure 1.- Three-view drawing of the P-51H airplane with the production tail.

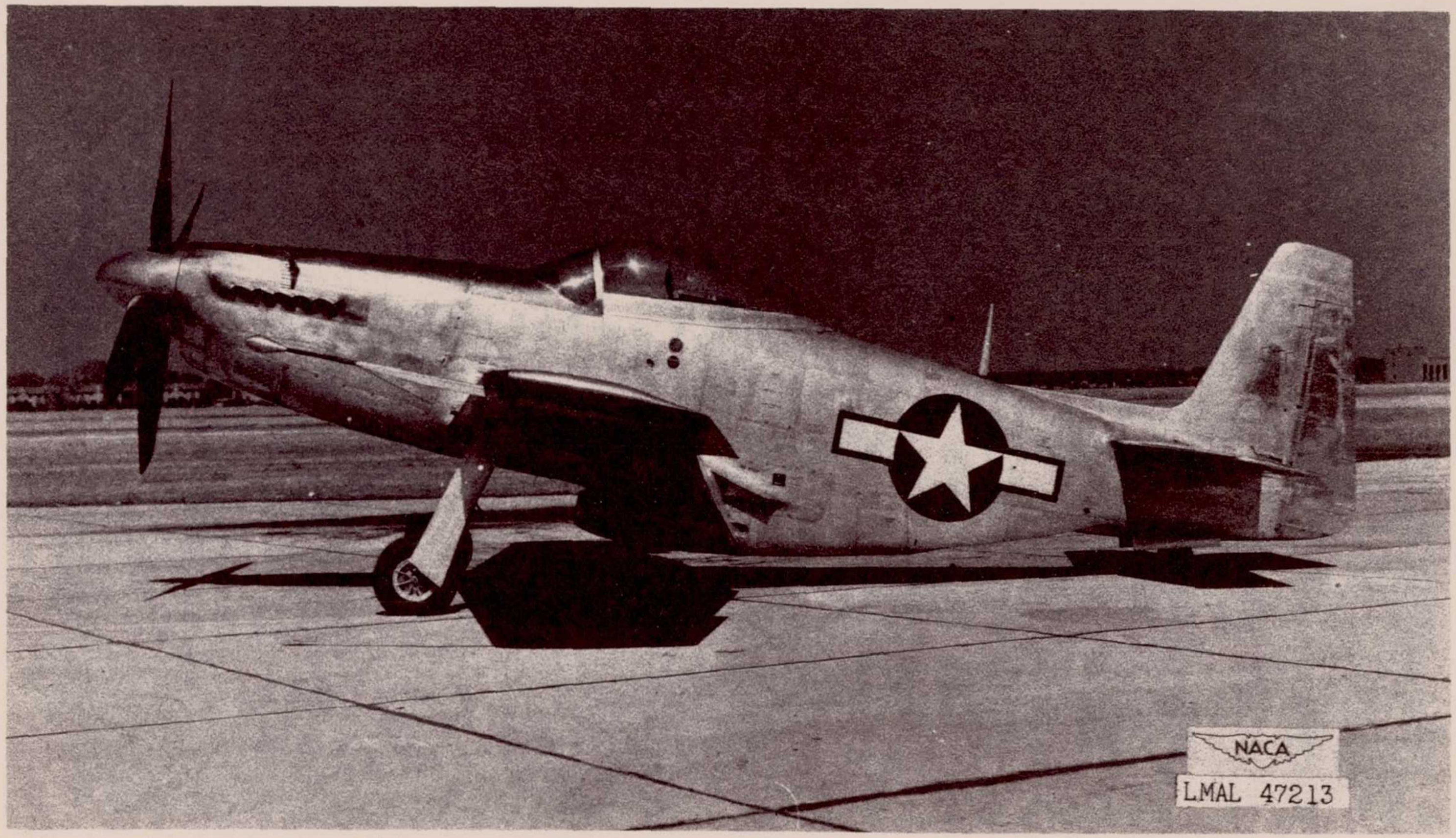

Figure 2.- Side view of North American P-51H airplane.

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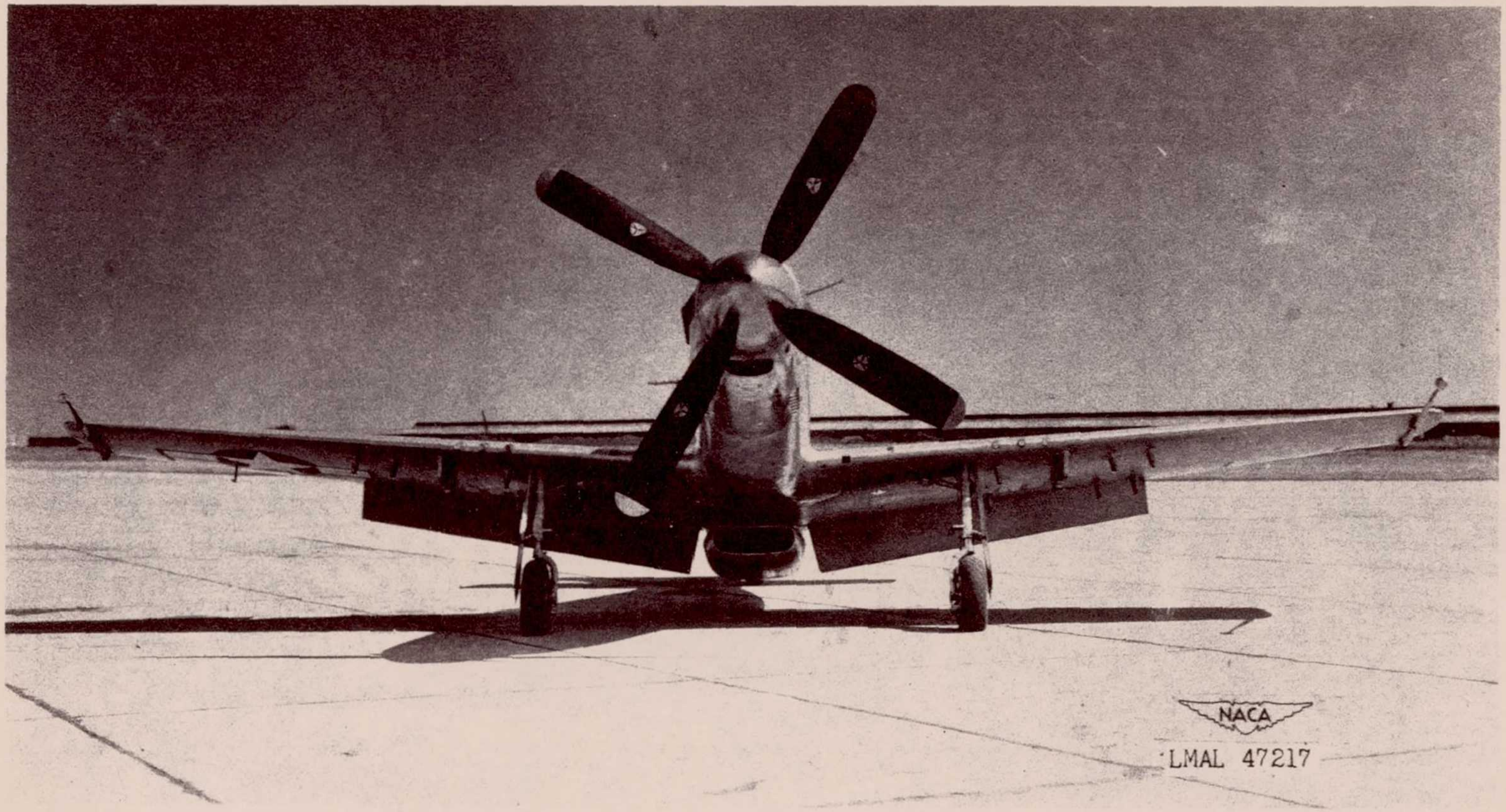

Figure 3.- Front view of North American P-51H airplane.

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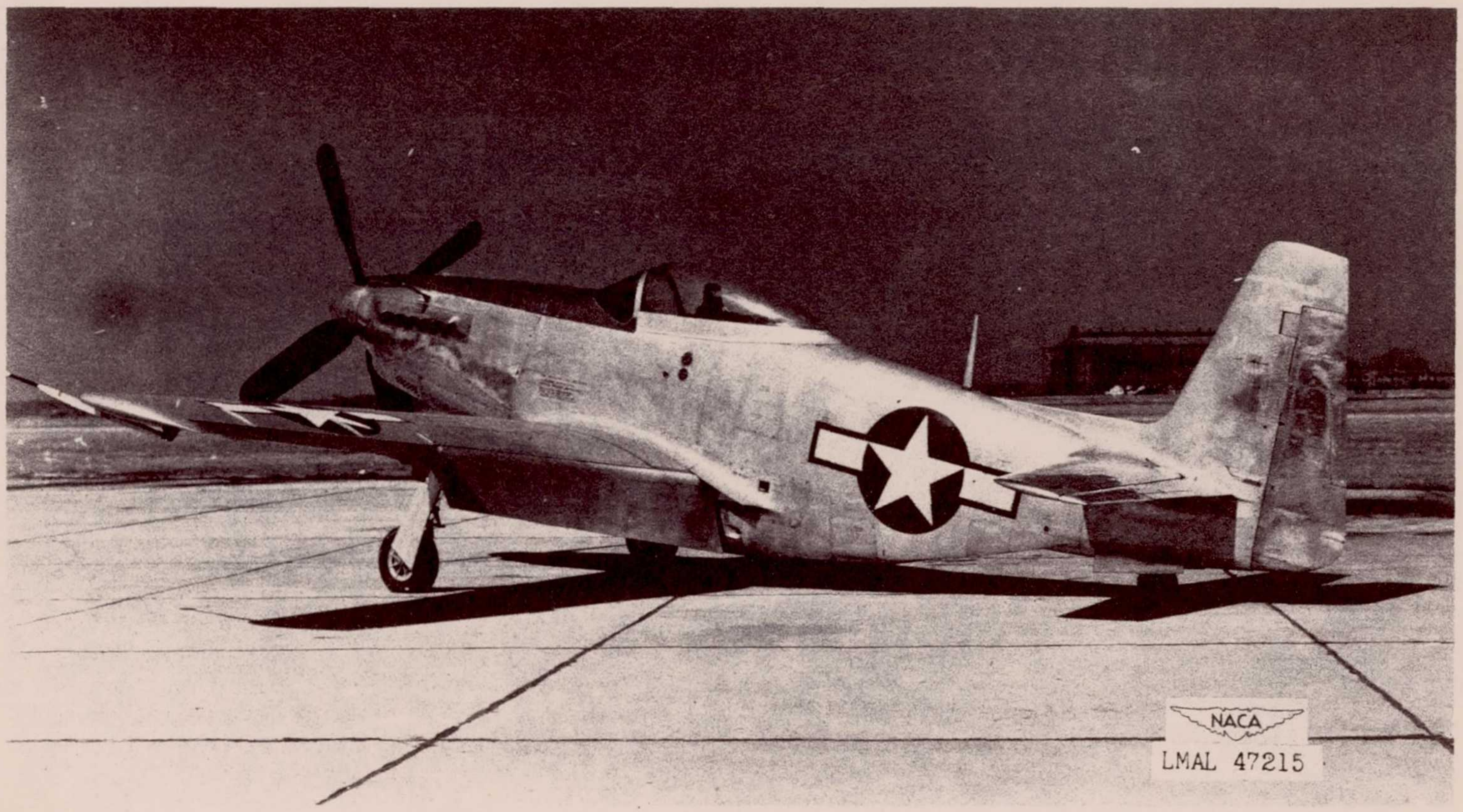

Figure 4.- Three-quarter rear view of North American P-51H airplane.

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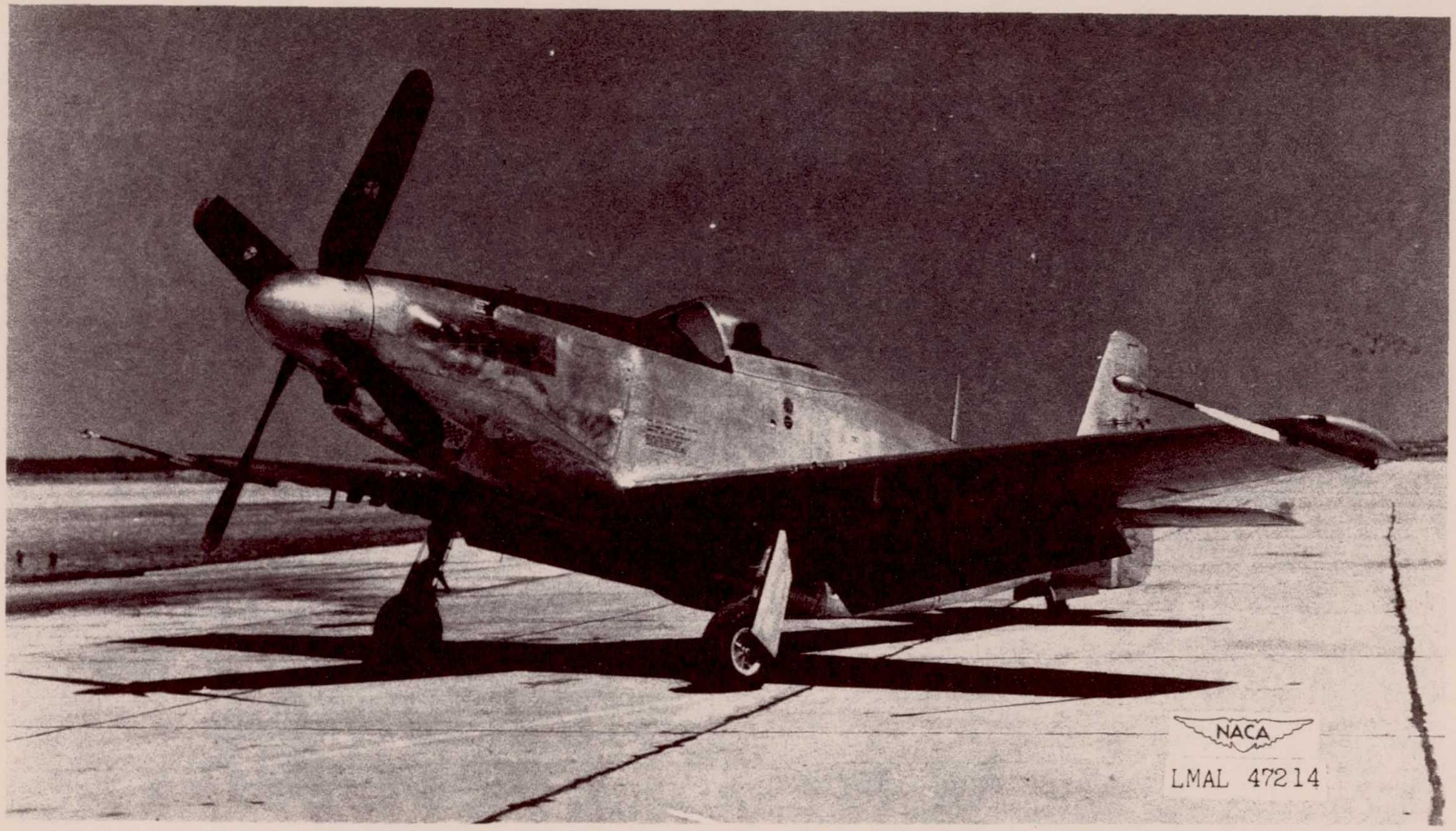

Figure 5.- Three-quarter front view of North American P-51H airplane.

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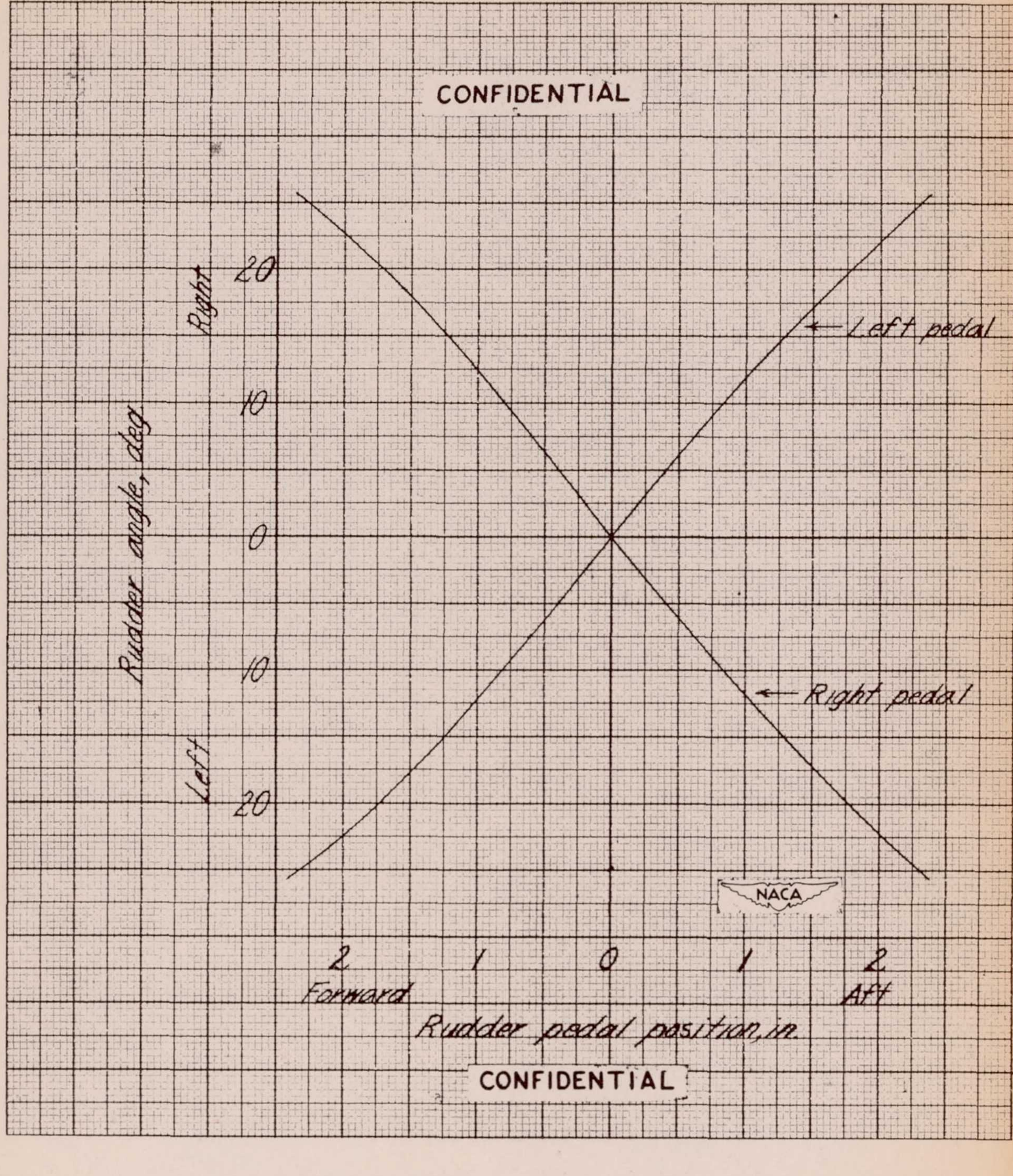


Figure 6.- Variation of rudder angle with rudder pedal position, P-51H airplane.

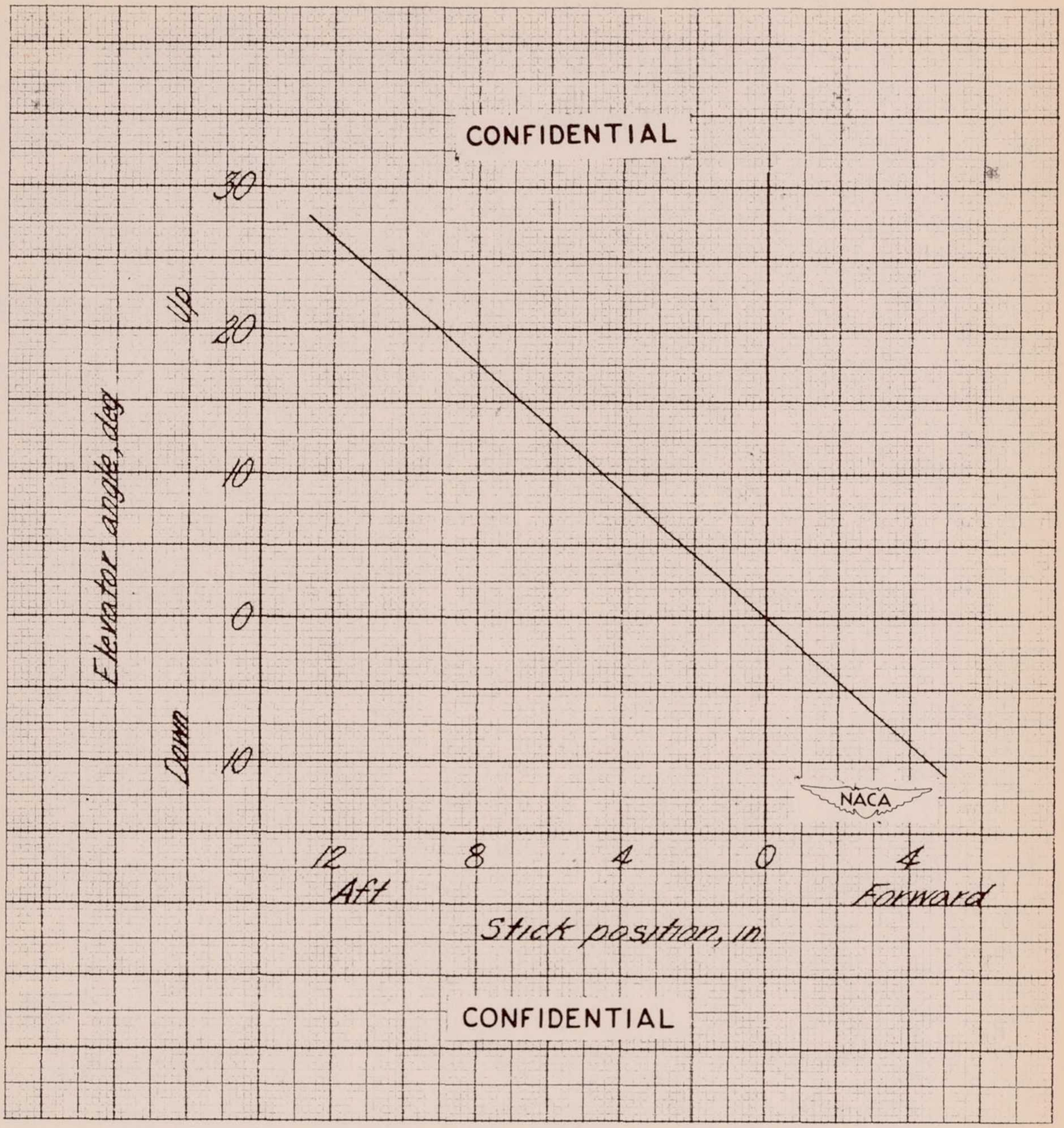


Figure 7.- Variation of elevator angle with stick position, P-51H airplane.

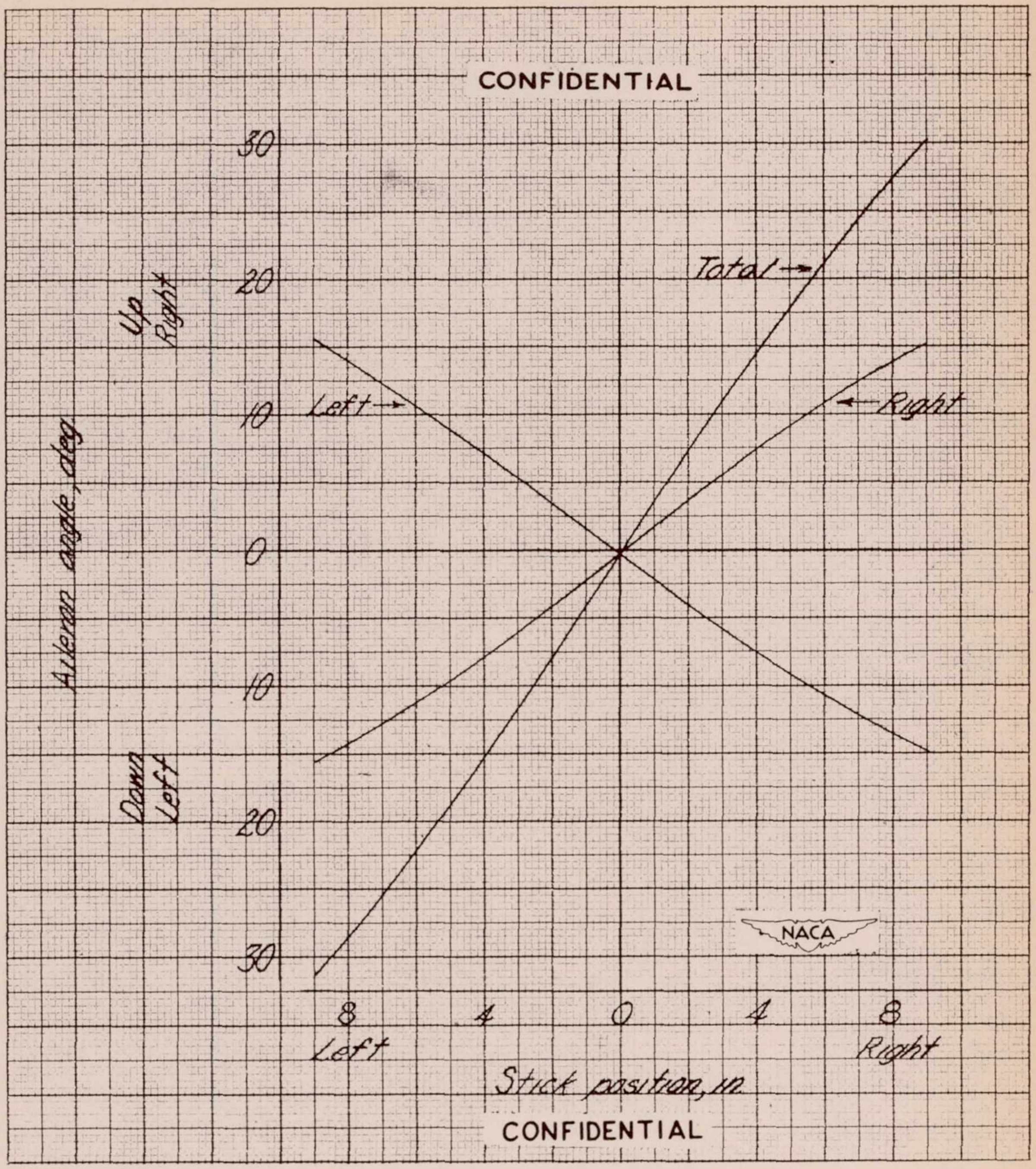


Figure 8.- Variation of aileron angle with stick position, P-51H airplane.

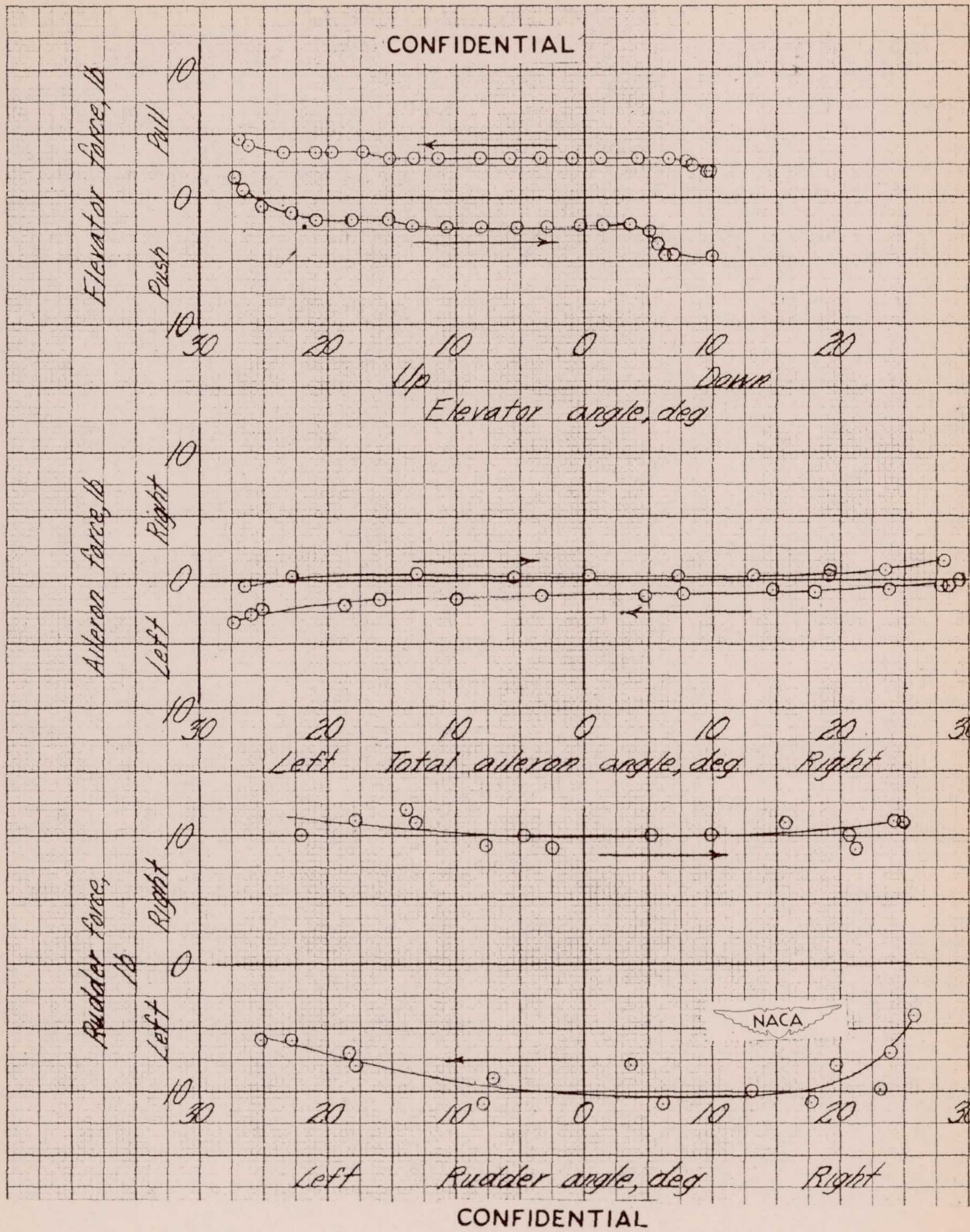


Figure 9.- Variation of the friction force in the control systems with elevator, aileron, and rudder angle as measured on the ground in the no-load condition, P-51H airplane.

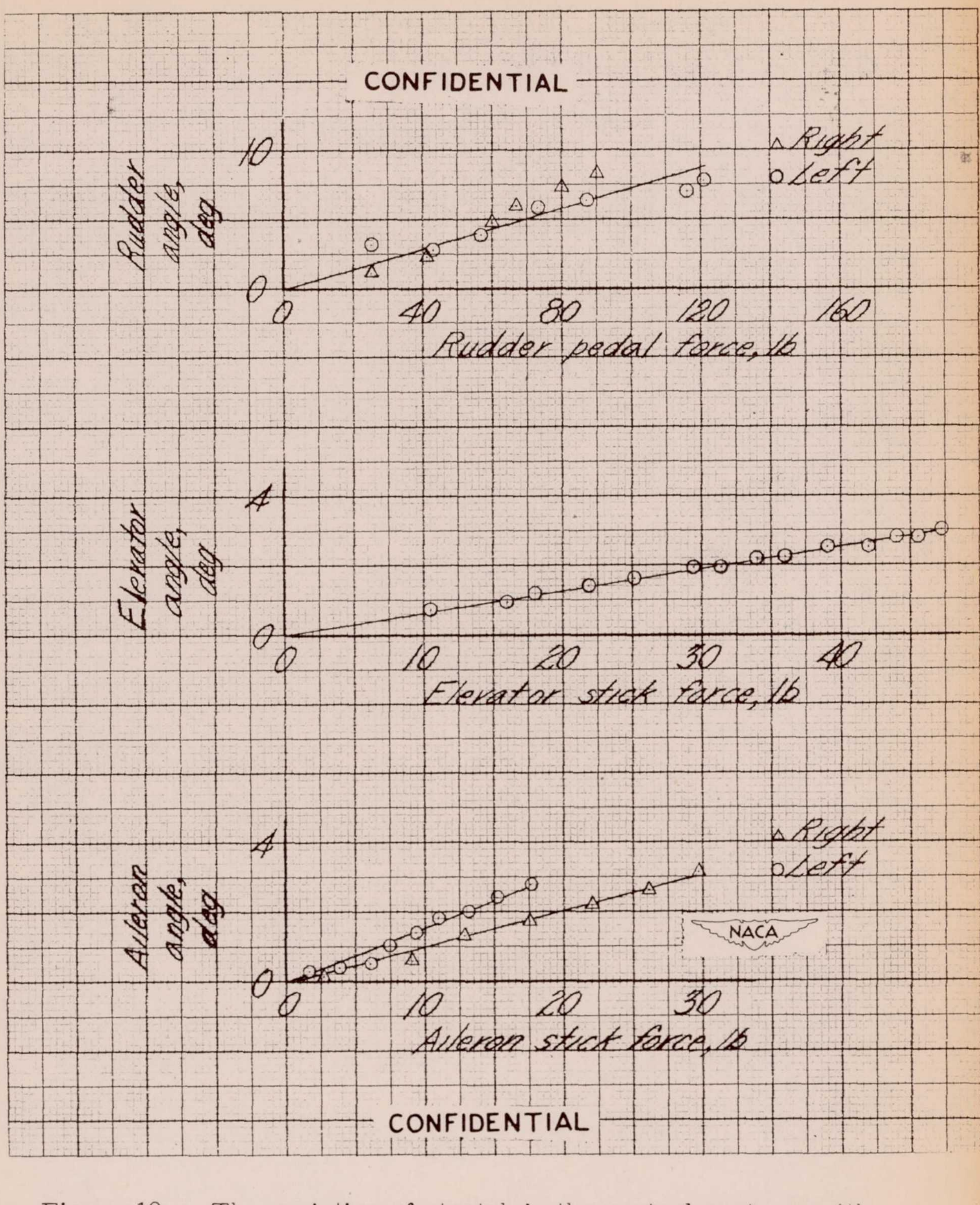


Figure 10.- The variation of stretch in the control systems with rudder, elevator, and aileron angle as measured on the ground, P-51H airplane.

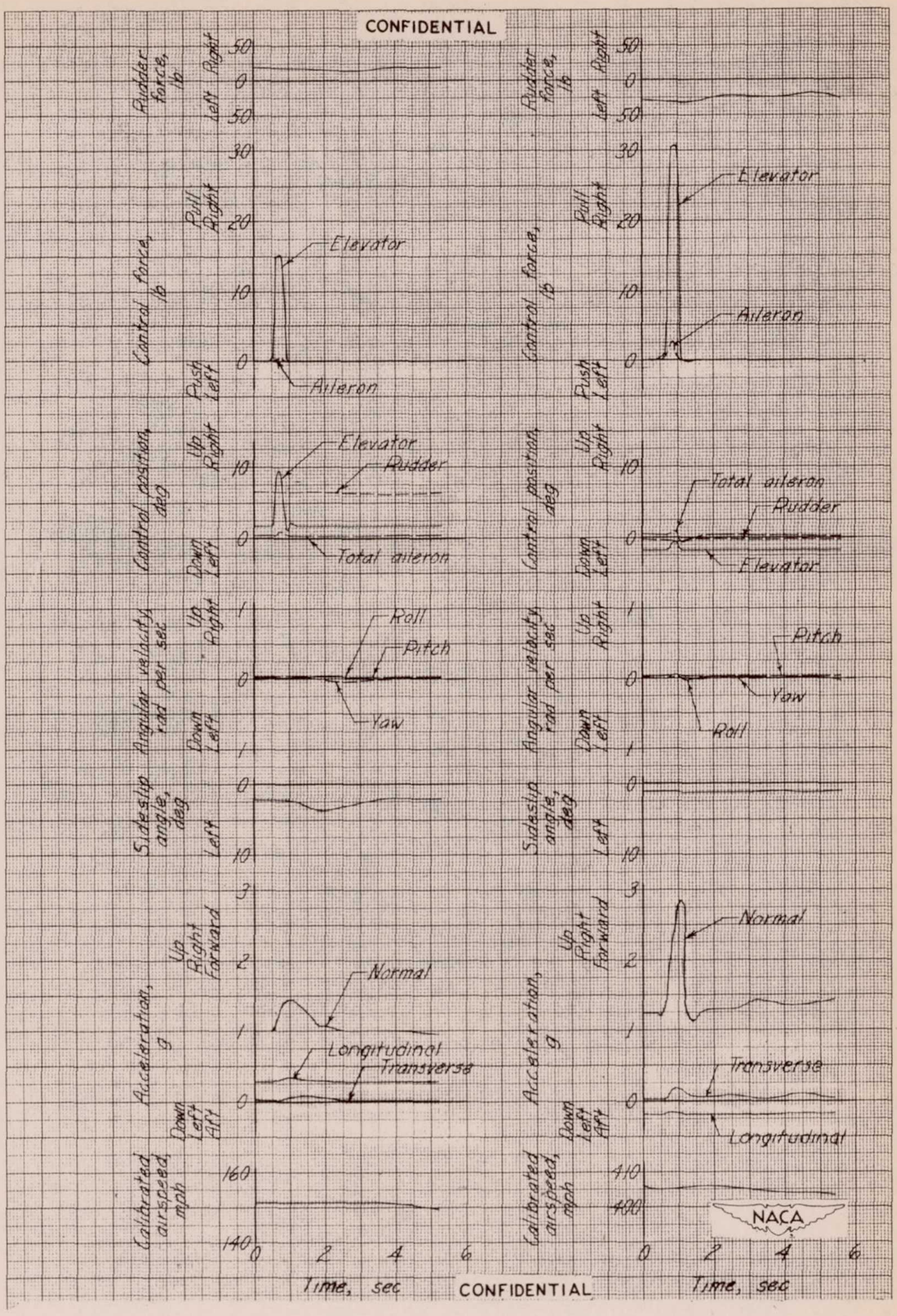


Figure 11.- Time history of a short-period oscillation in the power-on clean condition started by an abrupt deflection and release of the elevator. Low altitude, c.g. at 21.15 percent M.A.C., P-51H airplane.

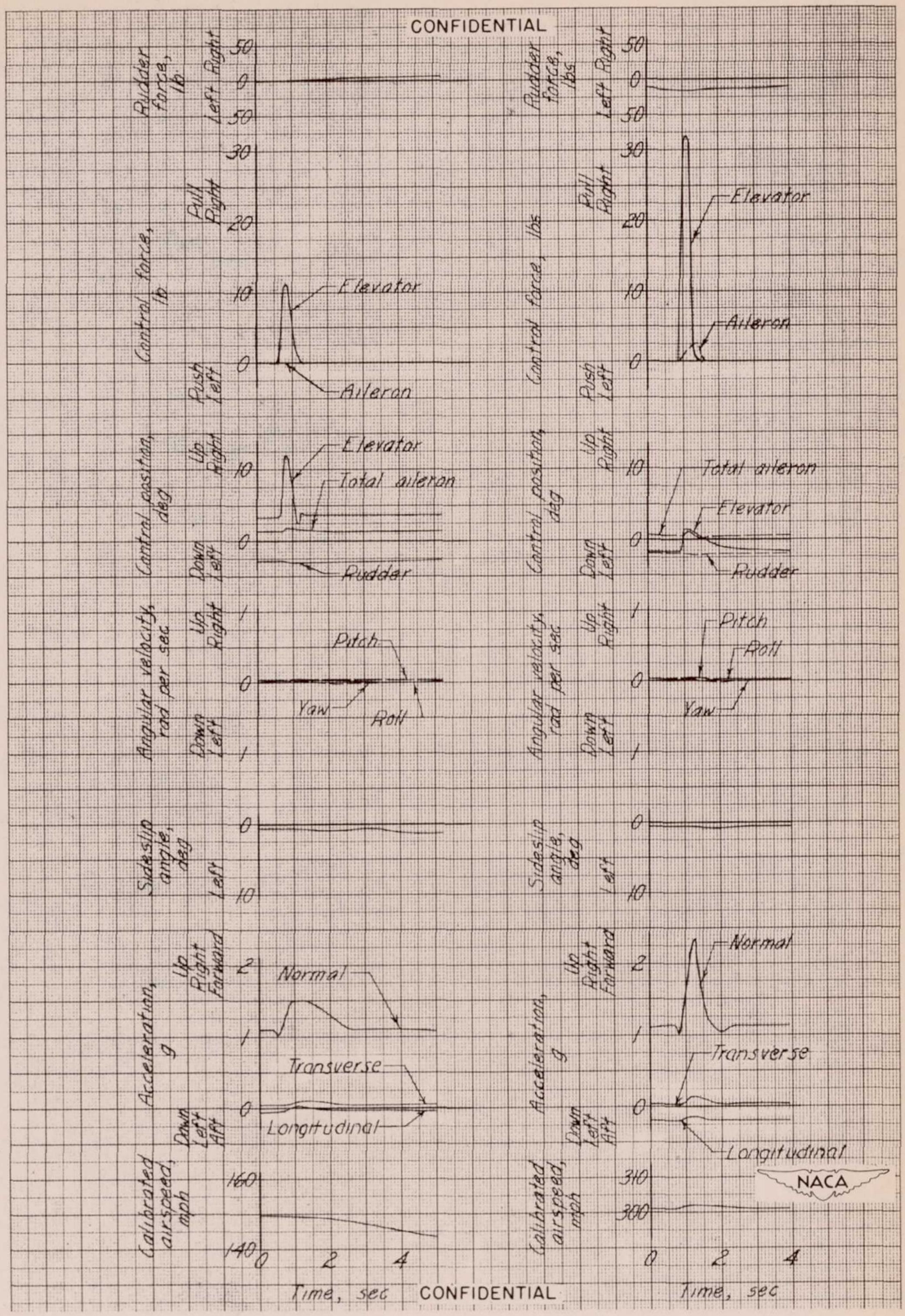
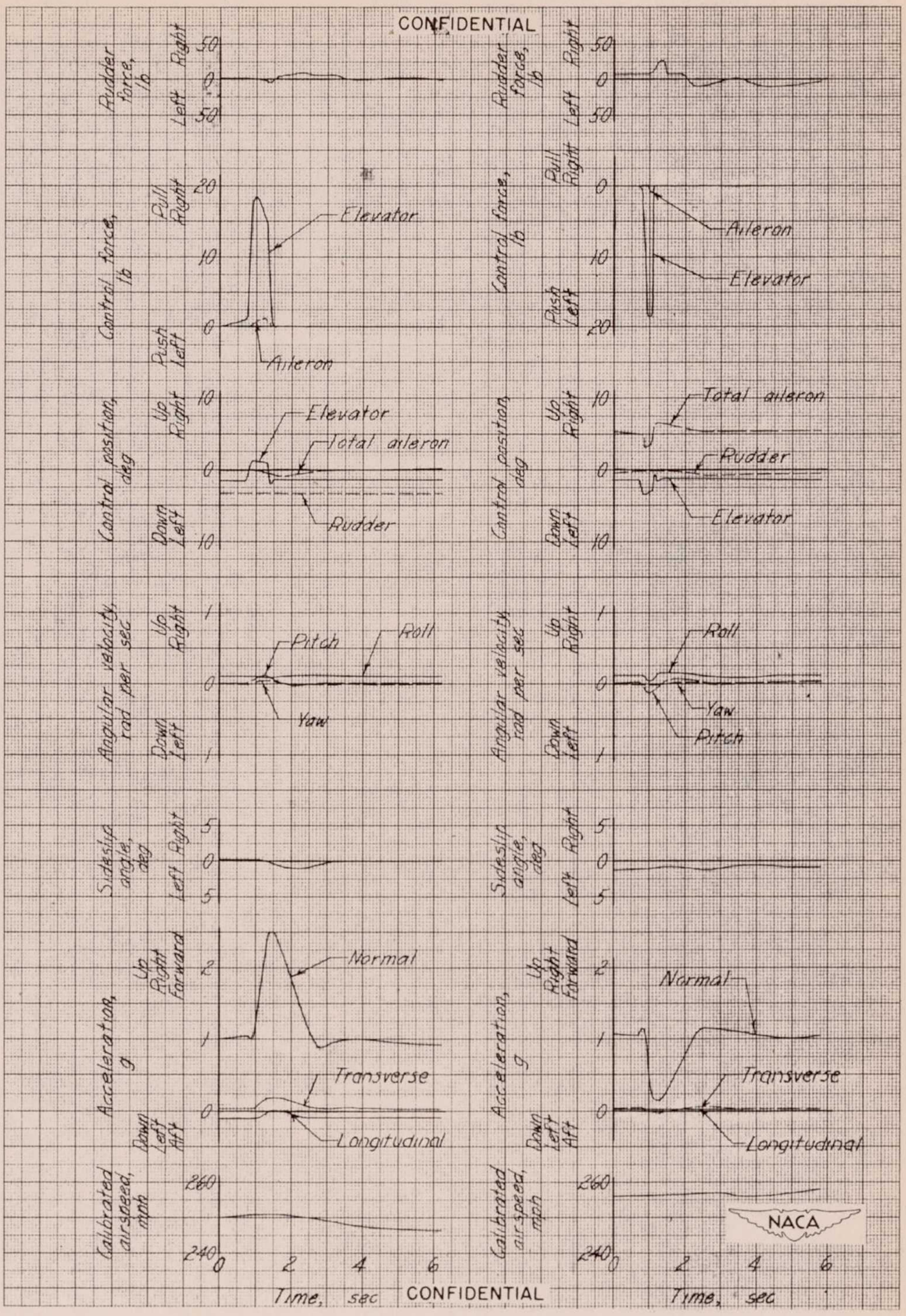


Figure 12.- Time history of a short-period oscillation in the power-off clean condition started by an abrupt deflection and release of the elevator. Low altitude, c.g. at 21.45 percent M.A.C., P-51H airplane.



(a) Power-off clean condition, c.g. = 22.77.

(b) Power-on clean condition, c.g. = 22.77.

Figure 13.- Time history of a short-period oscillation started from an abrupt deflection and release of the elevator. High altitude, c.g. = 22.77 percent M.A.C., P-51H airplane.

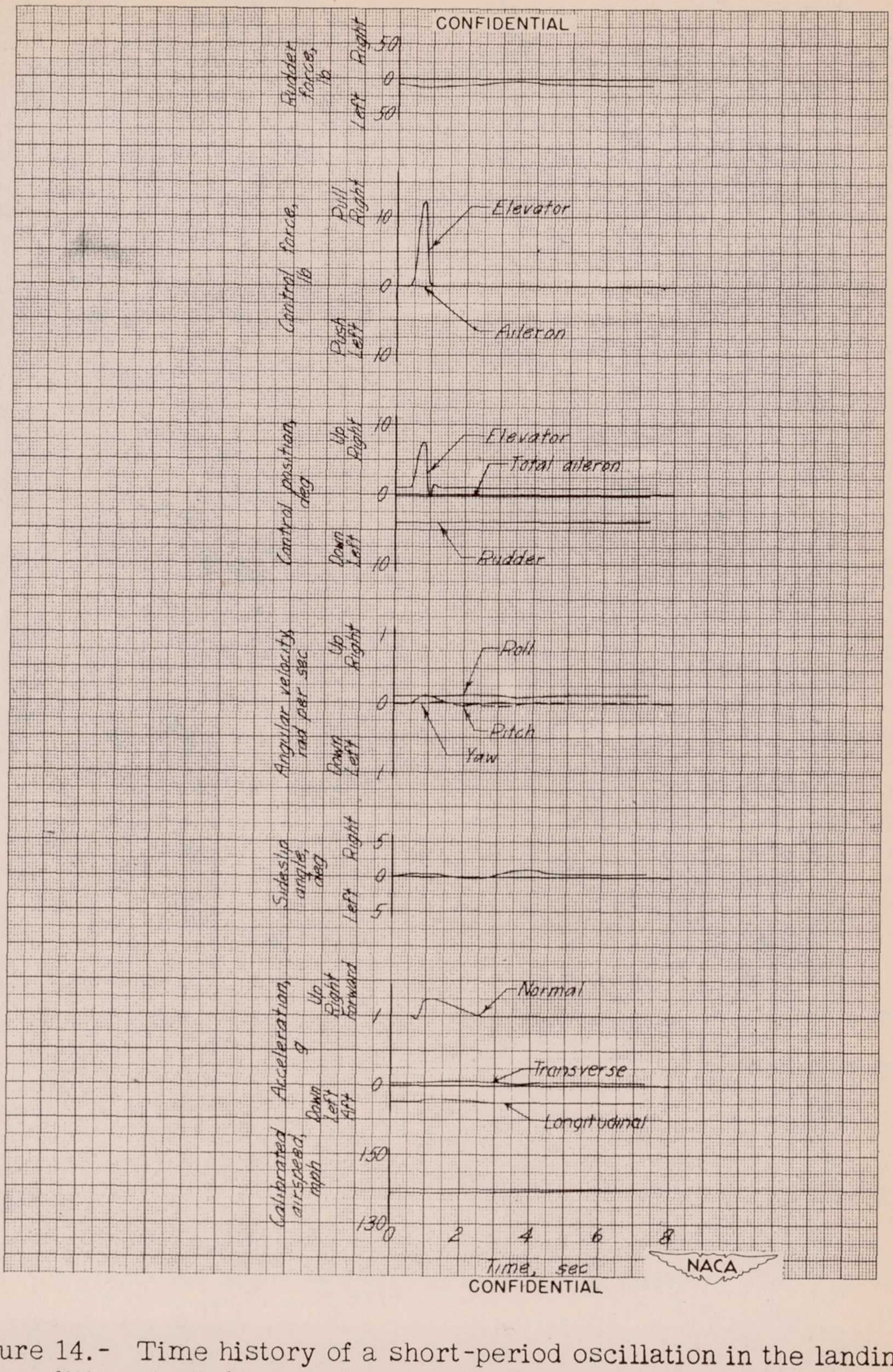


Figure 14.- Time history of a short-period oscillation in the landing condition started by an abrupt deflection and release of the elevator. c.g. = 23.60 percent M.A.C., P-51H airplane.

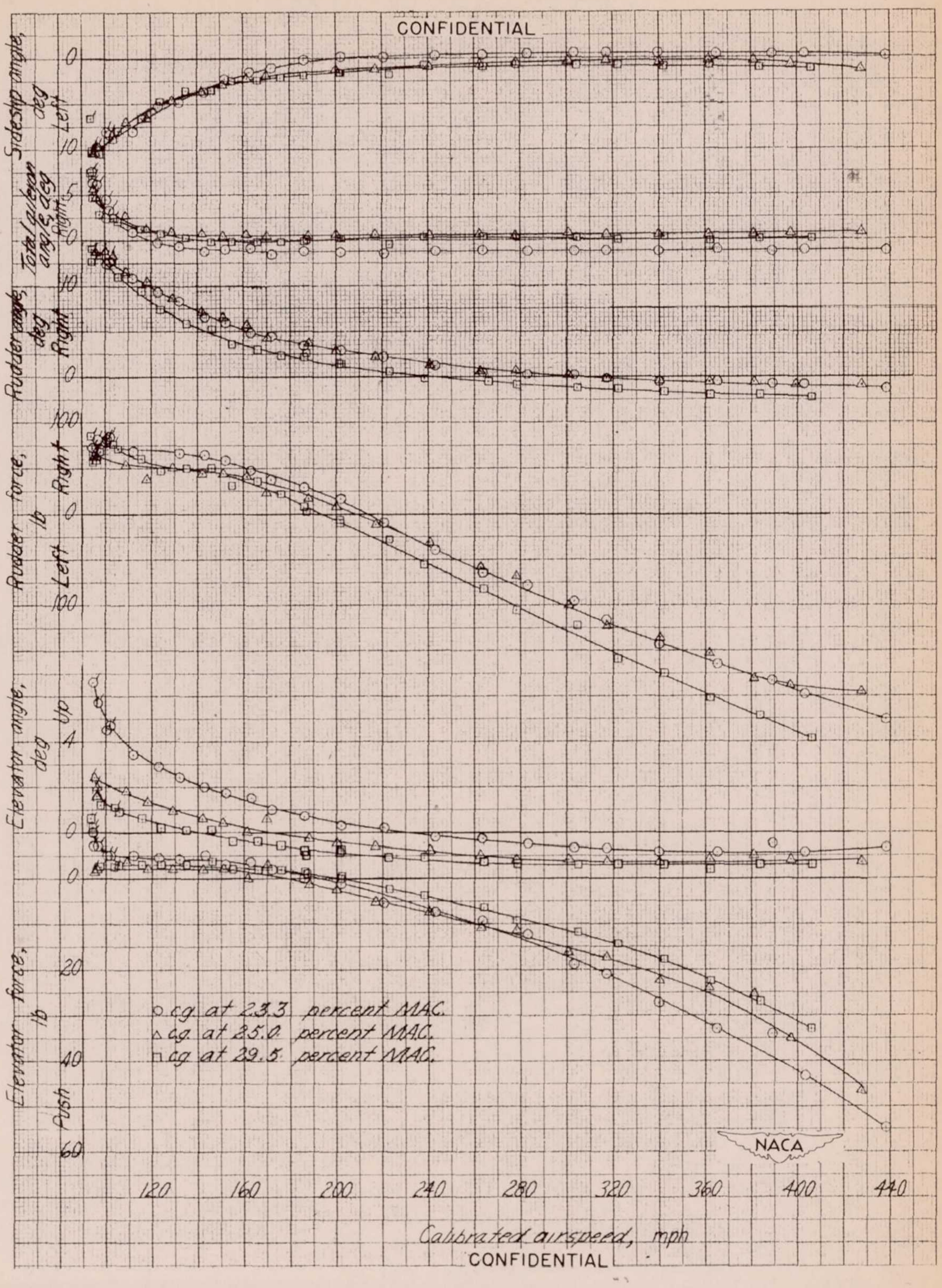


Figure 15.- Static longitudinal stability characteristics in the power-on clean condition at approximately 7000 feet altitude, P-51H airplane.

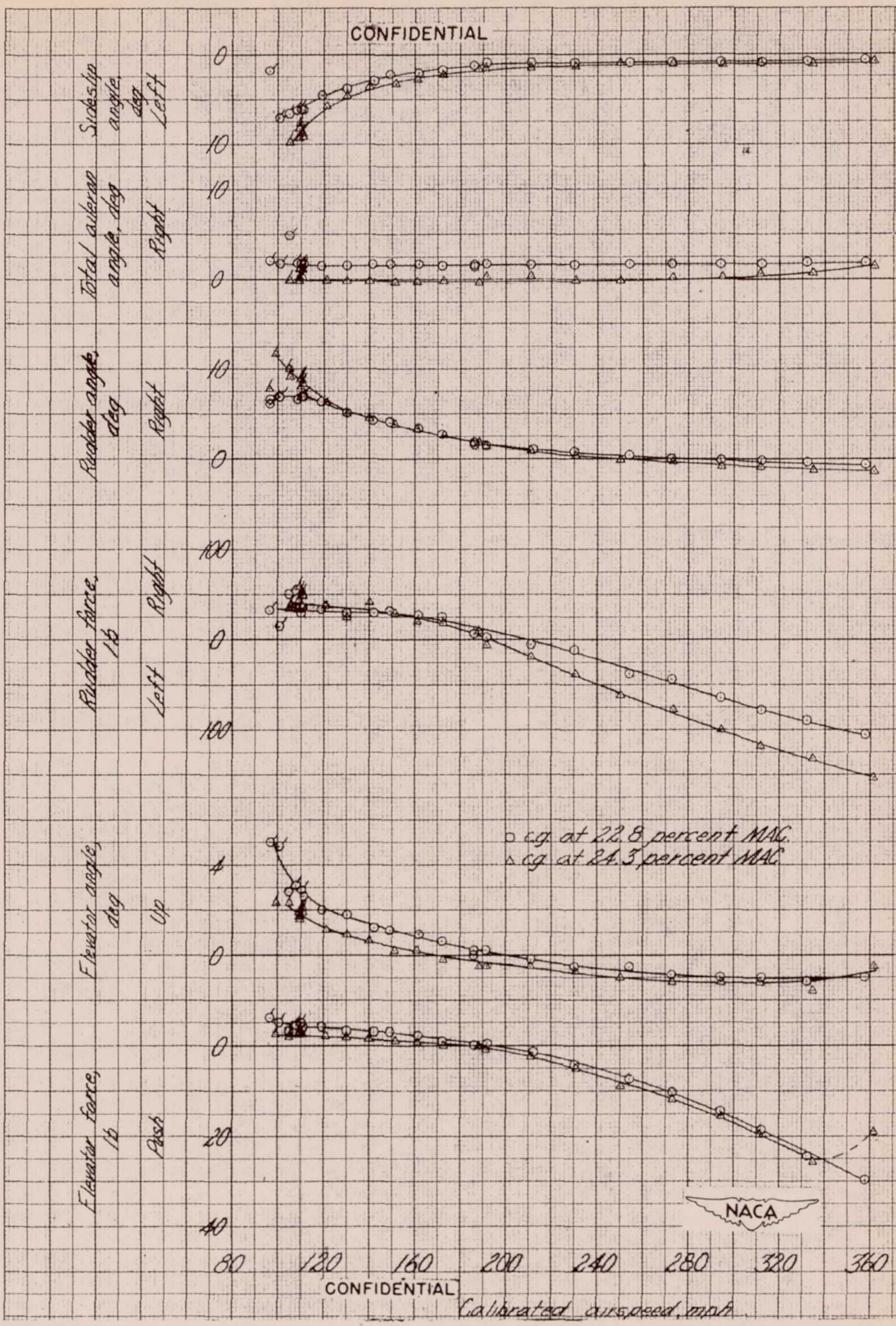


Figure 16.- Static longitudinal stability characteristics in the power-on clean condition at approximately 24,000 feet altitude, P-51H airplane.

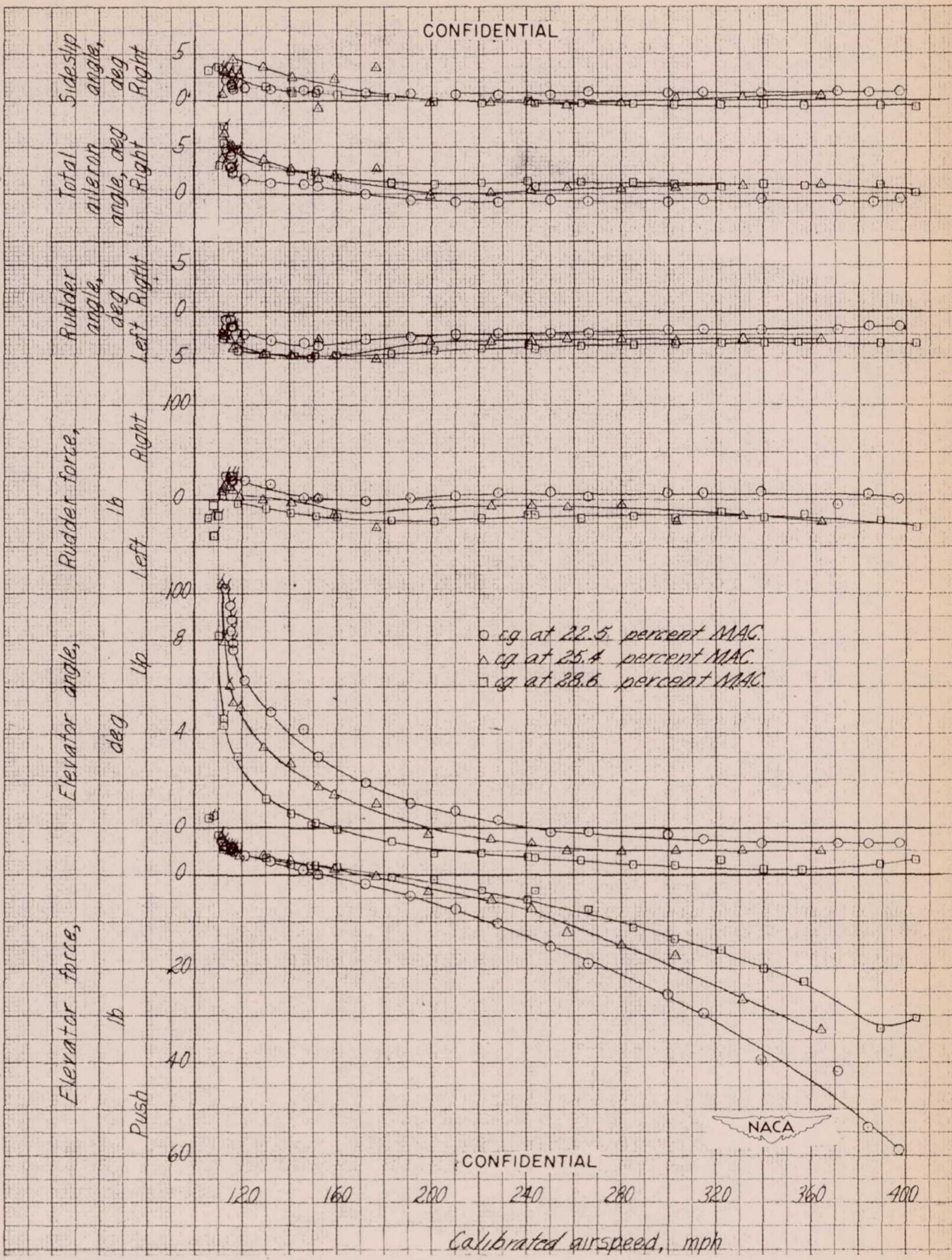


Figure 17.- Static longitudinal stability characteristics in the power-off clean condition at approximately 7000 feet altitude, P-51H airplane.

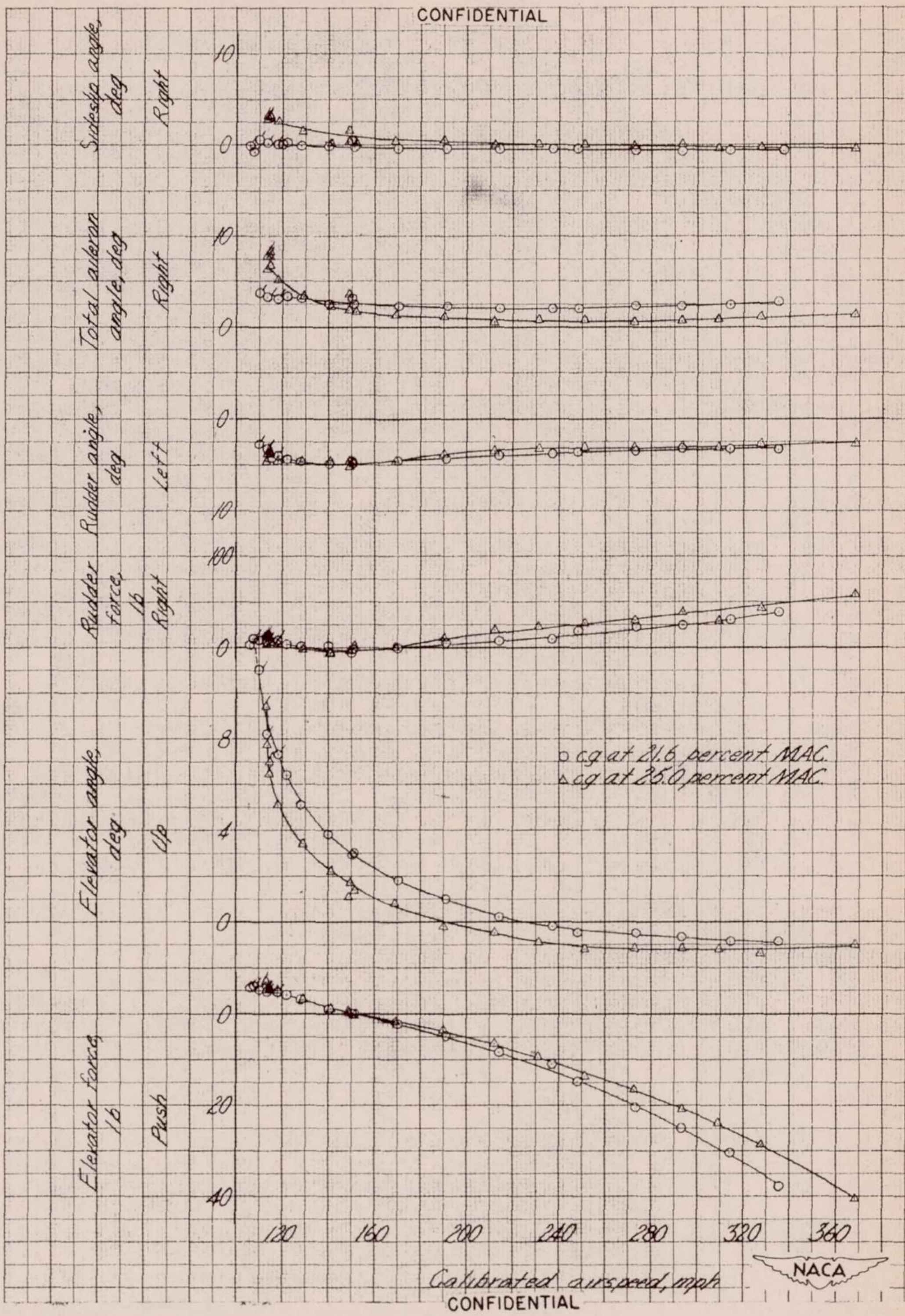


Figure 18.- Static longitudinal stability characteristics in the power-off clean condition at approximately 22,000 feet altitude, P-51H airplane.

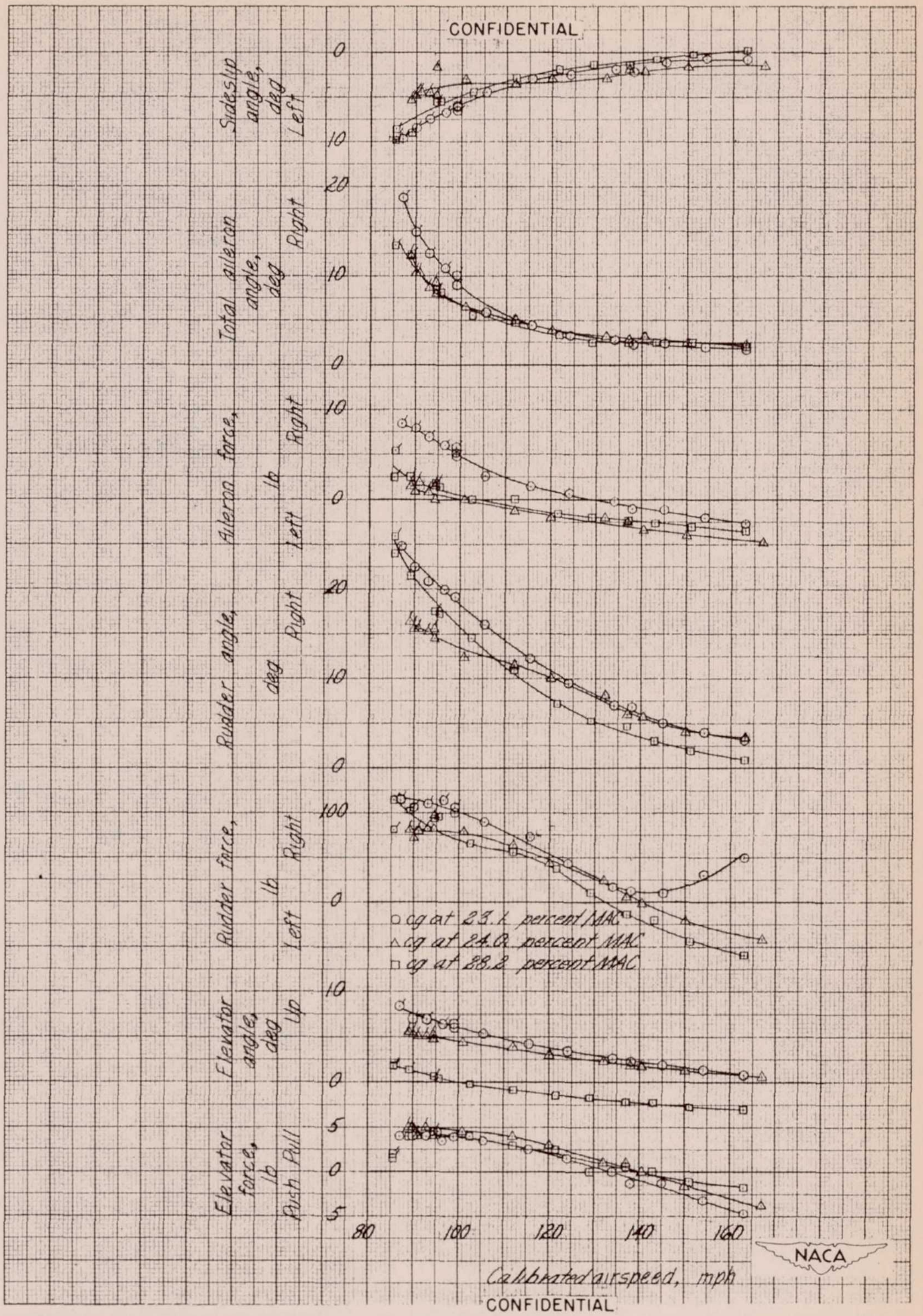


Figure 19.- Static longitudinal stability characteristics in the wave-off condition at approximately 5000 feet altitude, P-51H airplane.

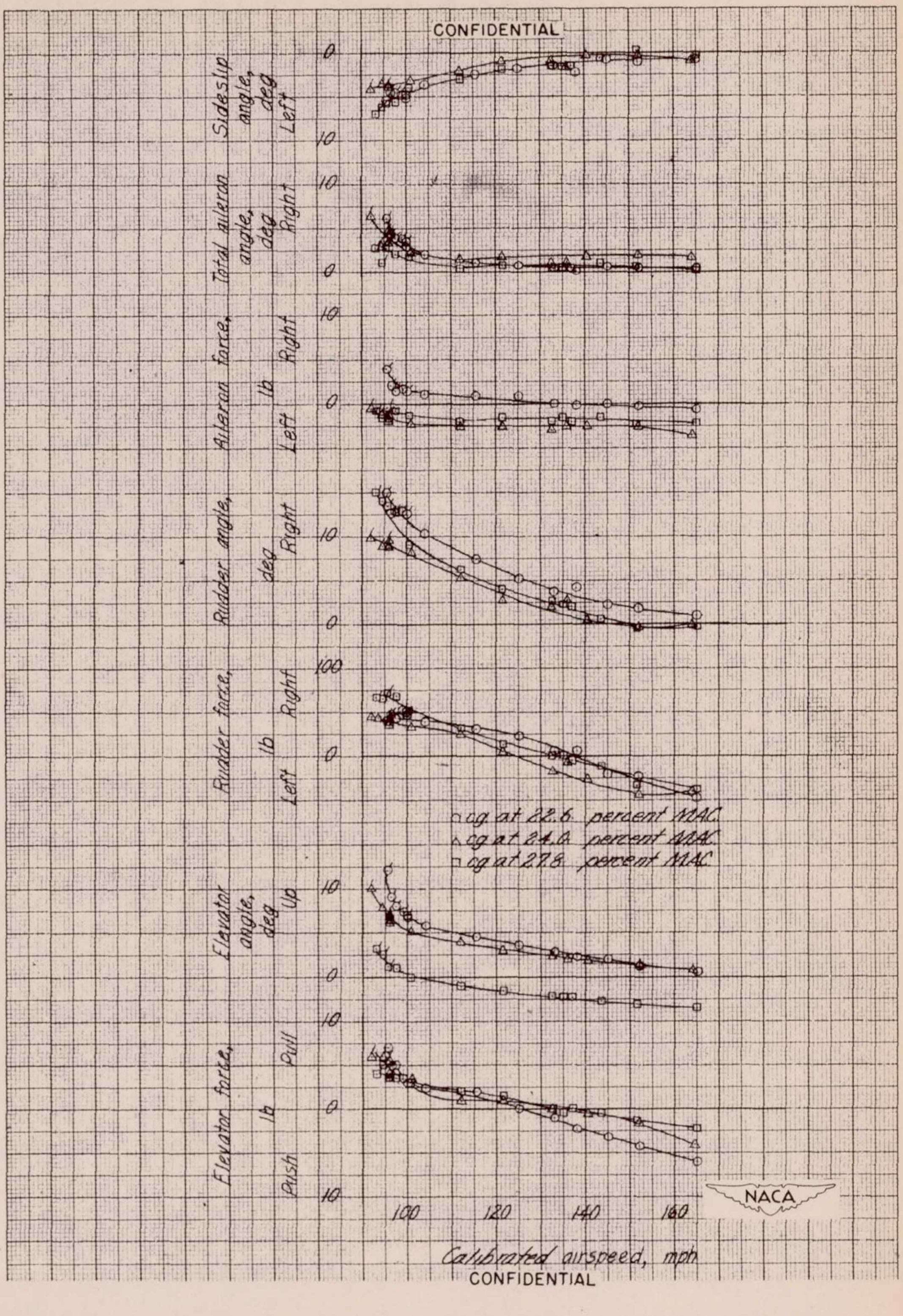


Figure 20.- Static longitudinal stability characteristics in the approach condition at approximately 5000 feet altitude, P-51H airplane.

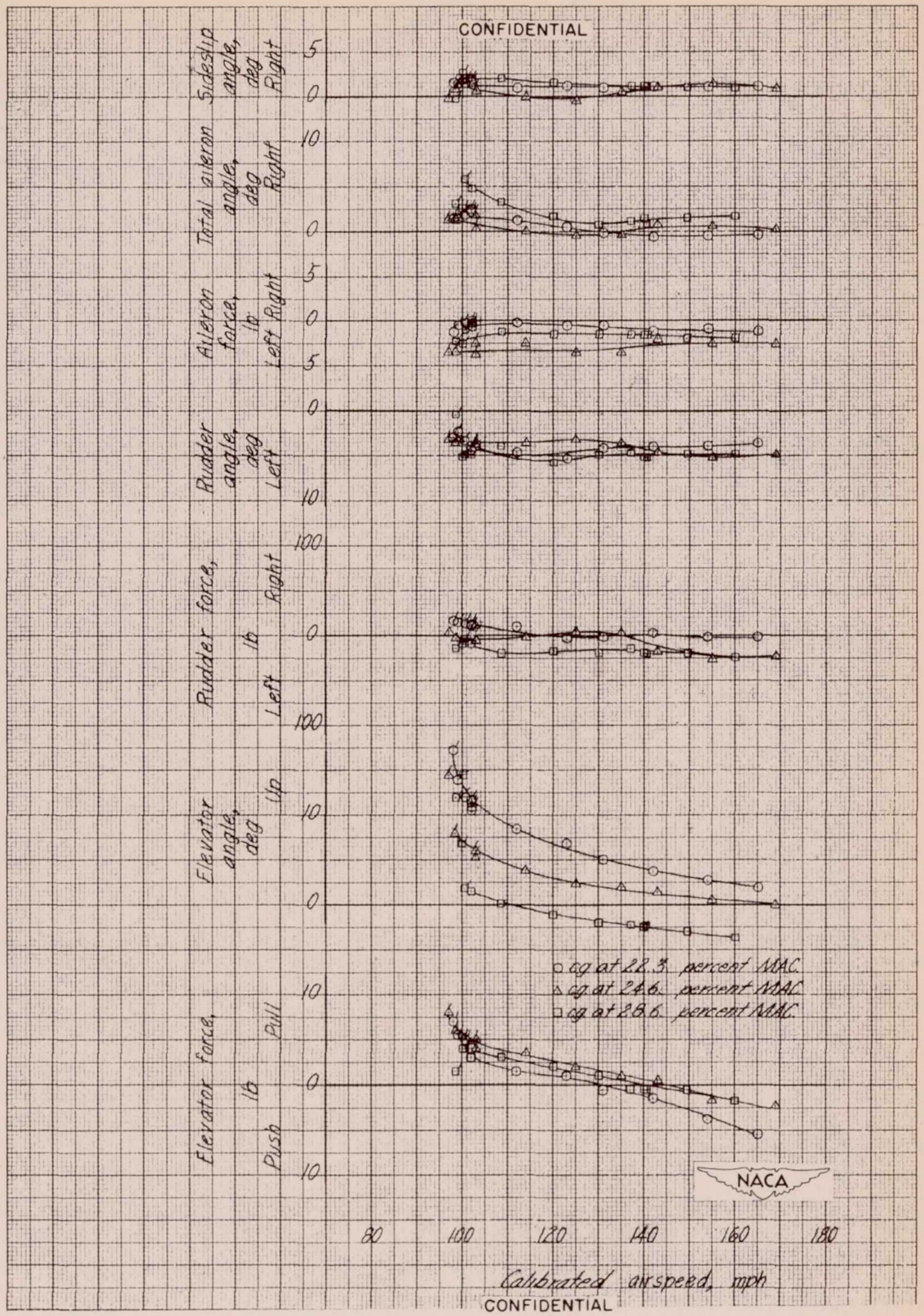
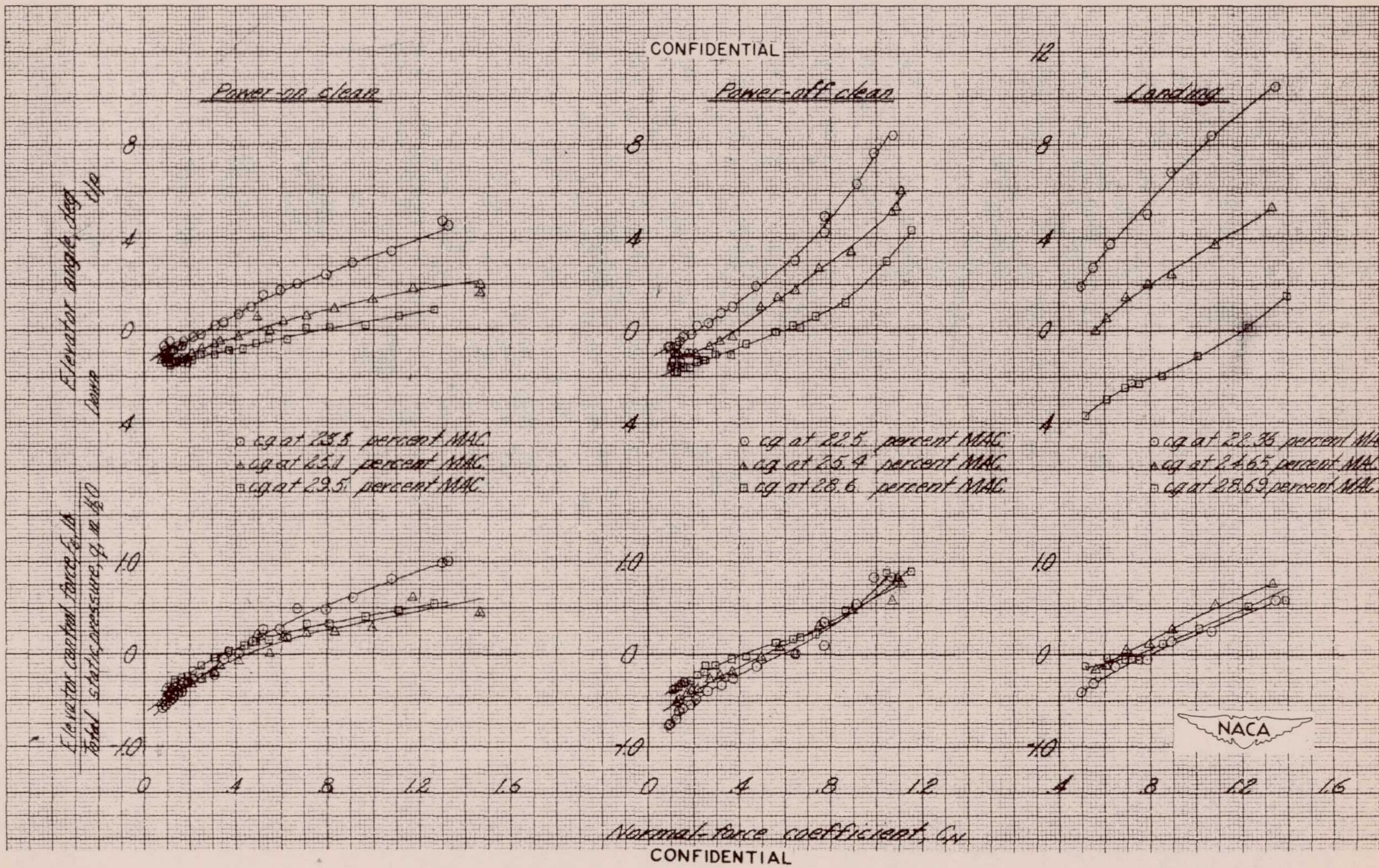


Figure 21.- Static longitudinal stability characteristics in the landing condition at approximately 5000 feet altitude, P-51H airplane.



(a) Variation of elevator angle and F_e/q with normal-force coefficient for the power-on clean, power-off clean, and landing conditions at low altitude.

Figure 22.- Determination of the stick-free and stick-fixed neutral points.

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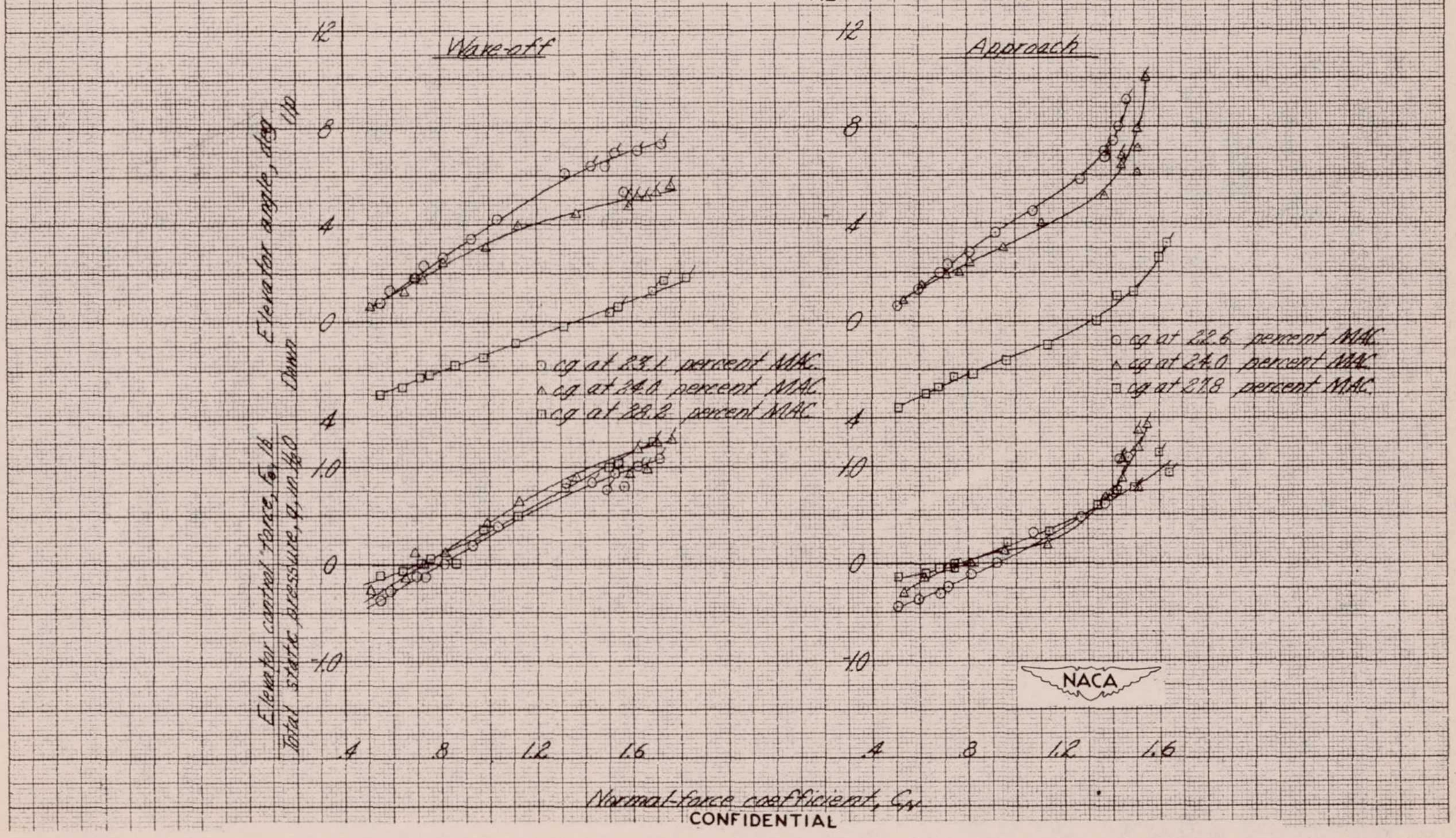

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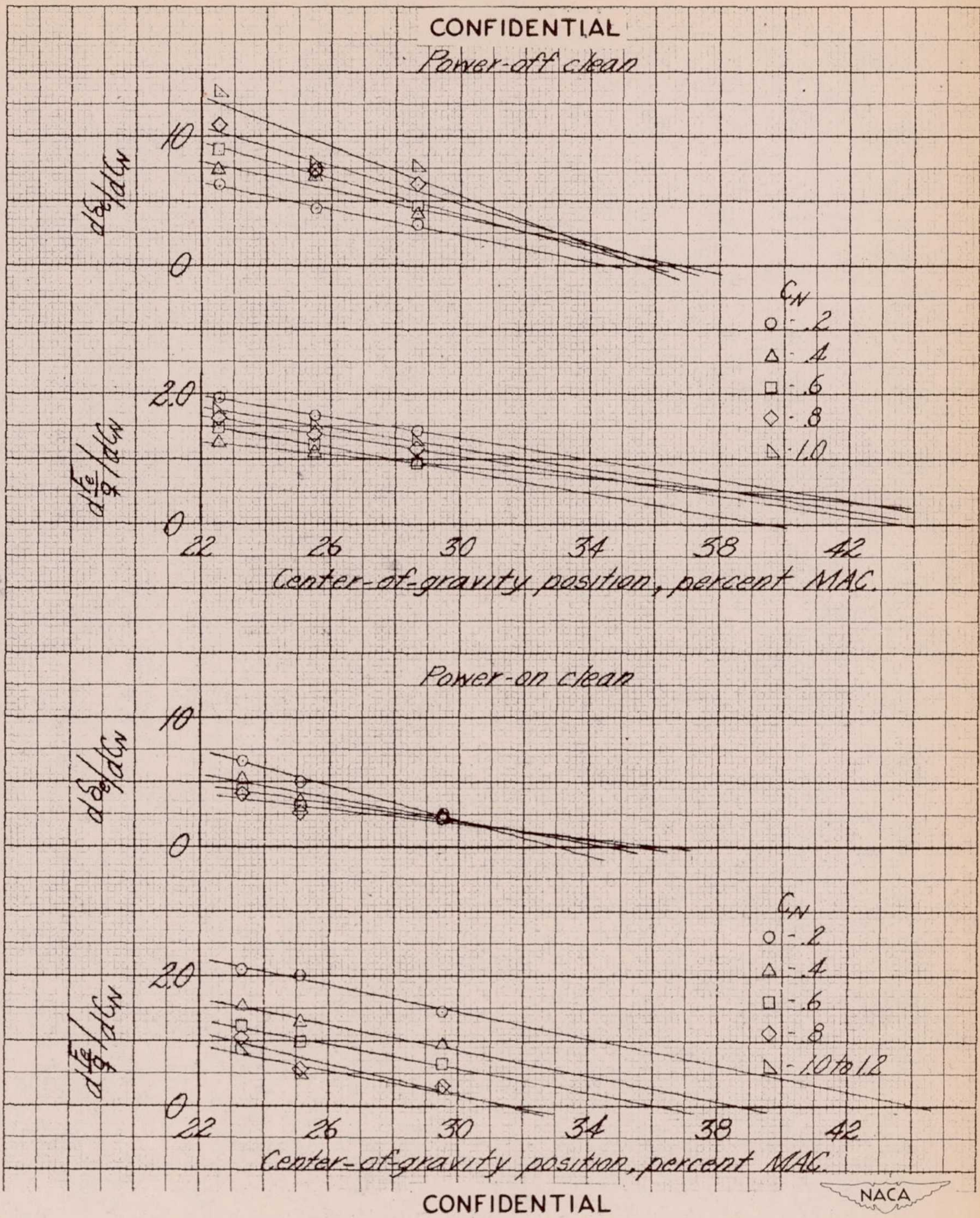
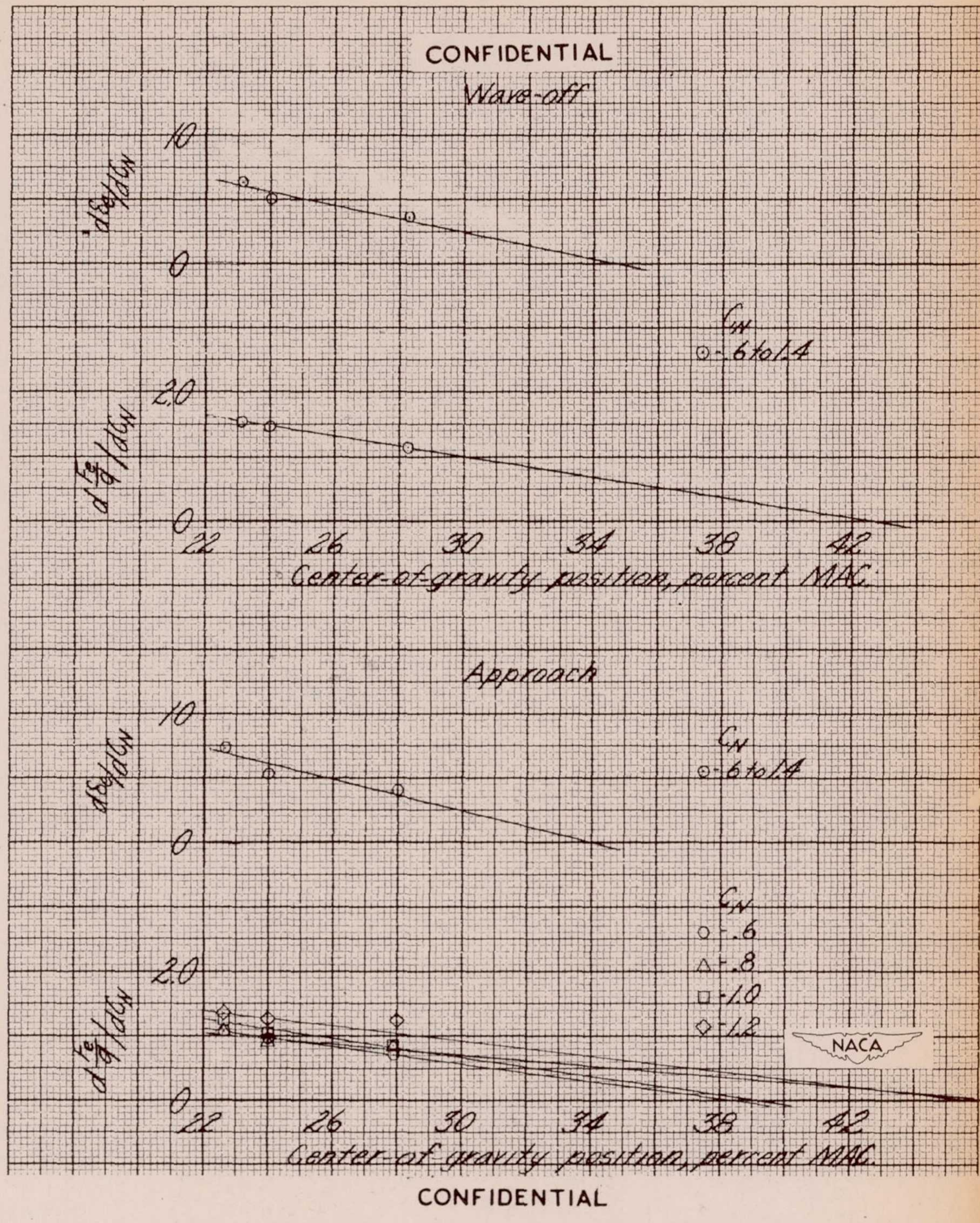
(b) Variation of elevator angle and F_e/q with normal-force coefficient for the wave-off and approach conditions.

Figure 22.- Continued.



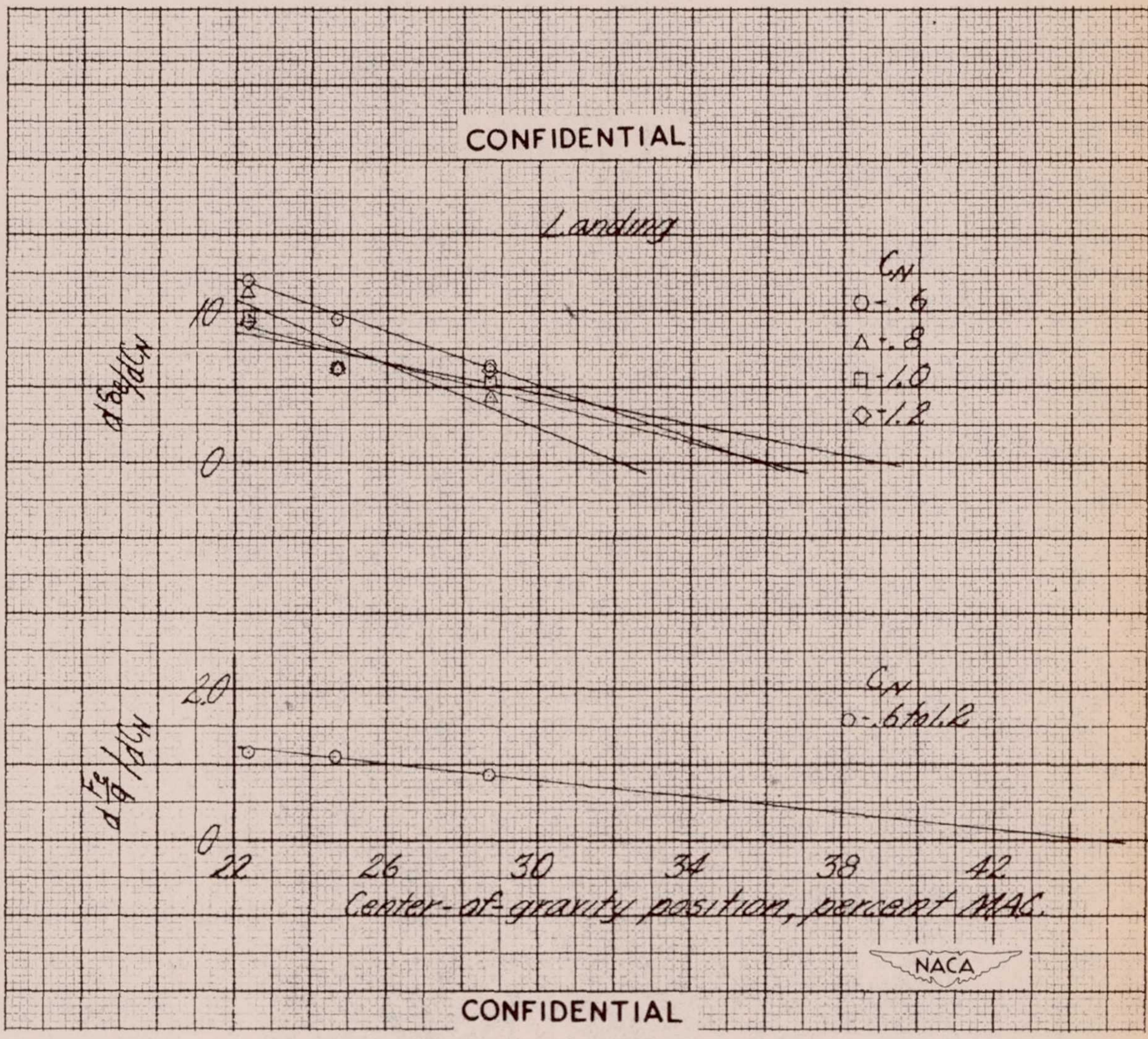
(c) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the power-on clean and power-off clean conditions.

Figure 22.- Continued.



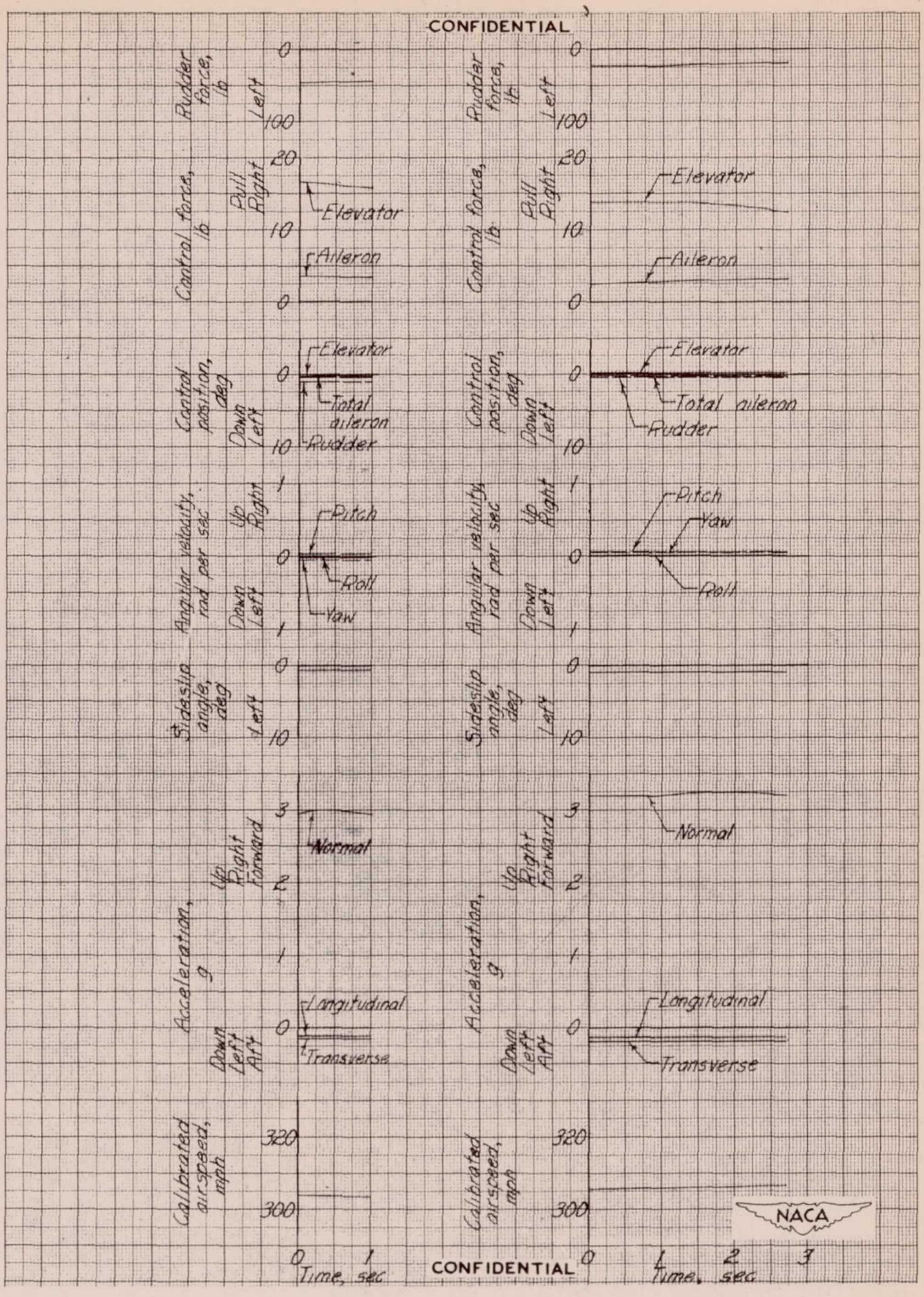
(d) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the wave-off and approach conditions.

Figure 22.- Continued.



(e) Variation of $\frac{d\delta_e}{dC_N}$ and $\frac{dF_e/q}{dC_N}$ with center-of-gravity position in the landing condition.

Figure 22.- Concluded.



(a) Left turn. (b) Right turn.

Figure 23.- Time histories of accelerated turns in the power-on clean condition at approximately 5000 feet altitude. Center-of-gravity position at 23.4 percent M.A.C., P-51H airplane.

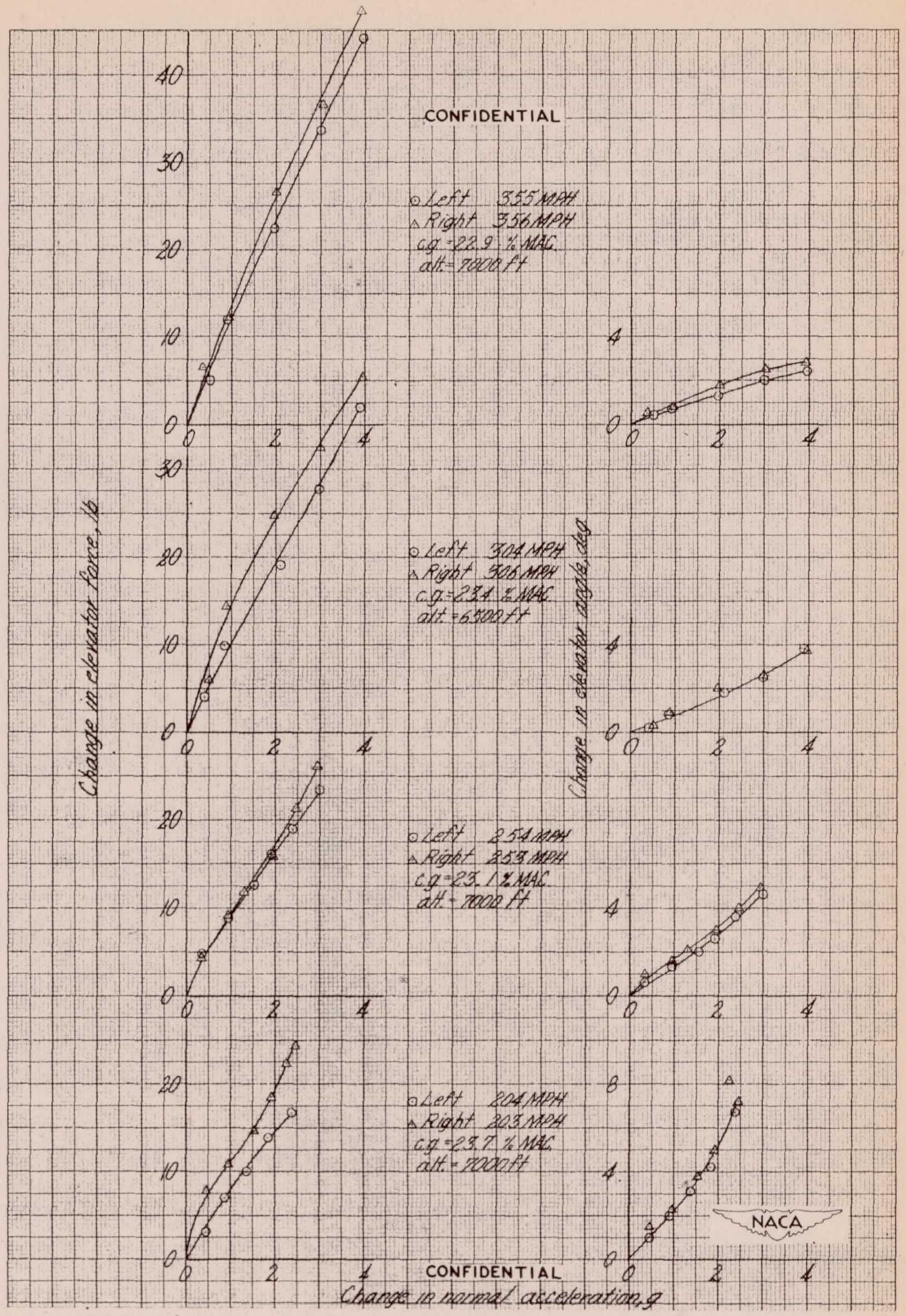


Figure 24.- Variation of the change in elevator force and angle with change in normal acceleration at various speeds in turns made in the power-on clean condition at the forward center-of-gravity position, P-51H airplane.

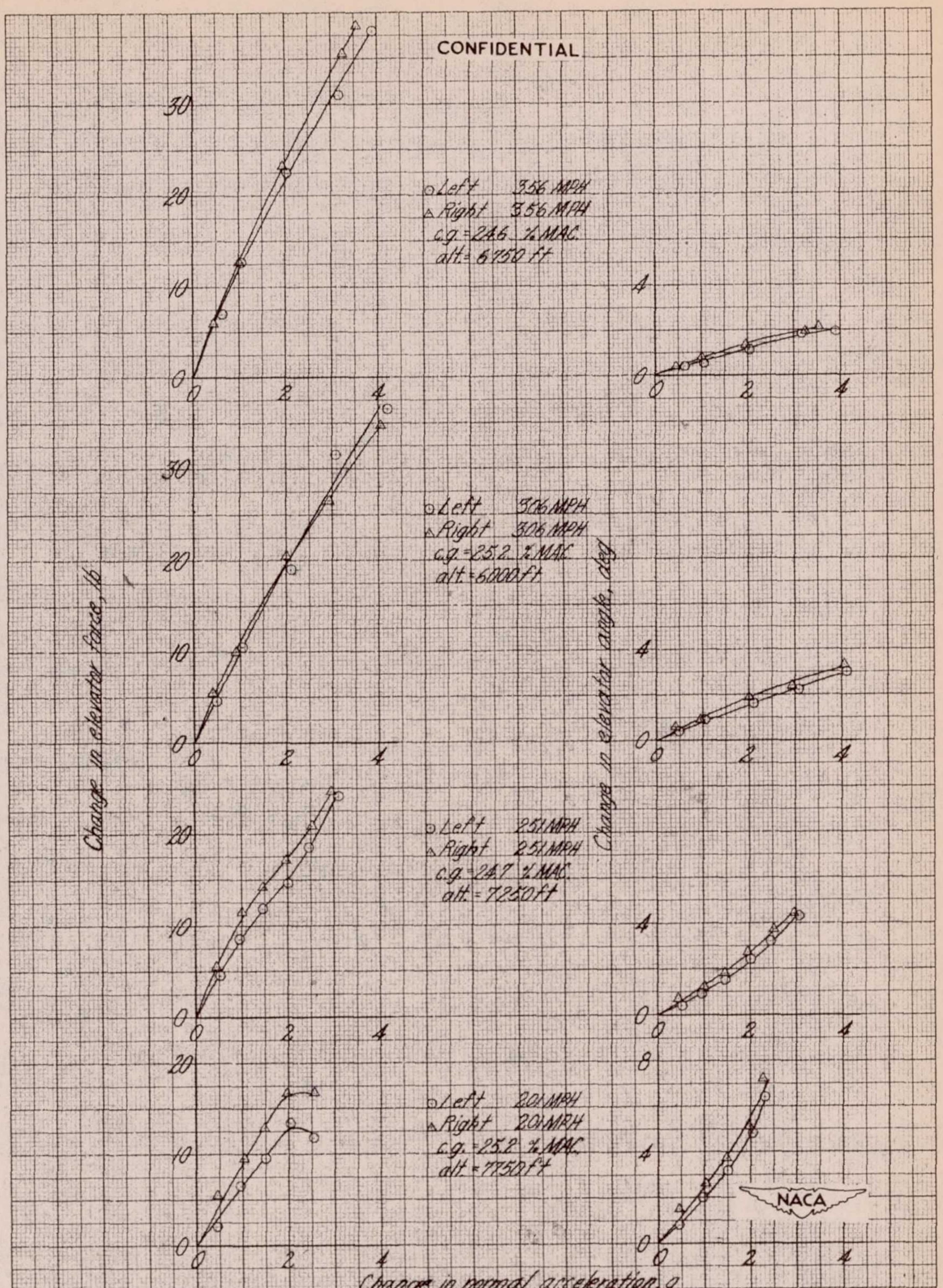


Figure 25.- Variation of the change in elevator force and angle with change in normal acceleration at various speeds in turns made in the power-on clean condition at the middle center-of-gravity position, P-51H airplane.

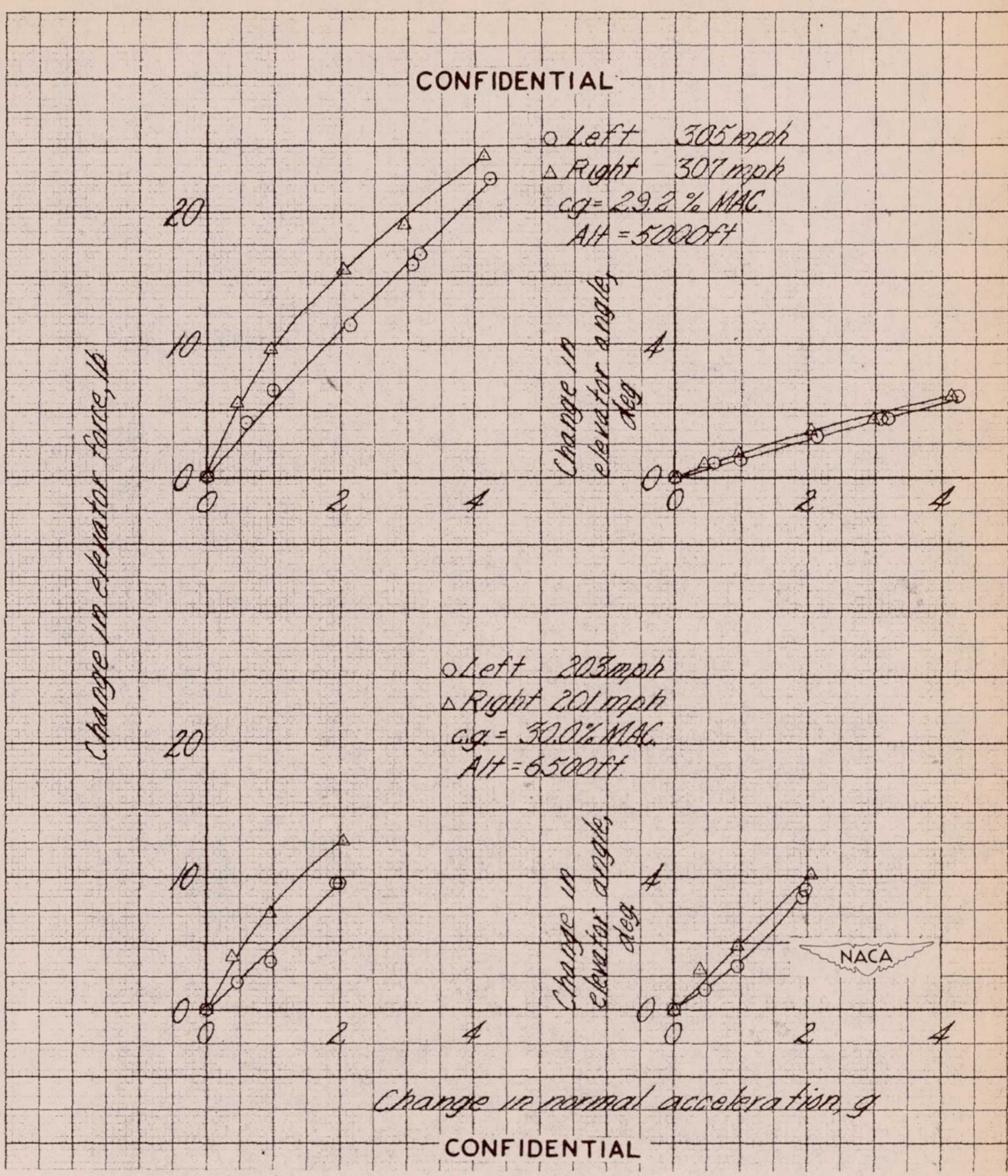


Figure 26.- Variation of the change in elevator force and angle with change in normal acceleration at 200 and 300 miles per hour in turns made in the power-on clean condition at the aft center-of-gravity position, P-51H airplane.

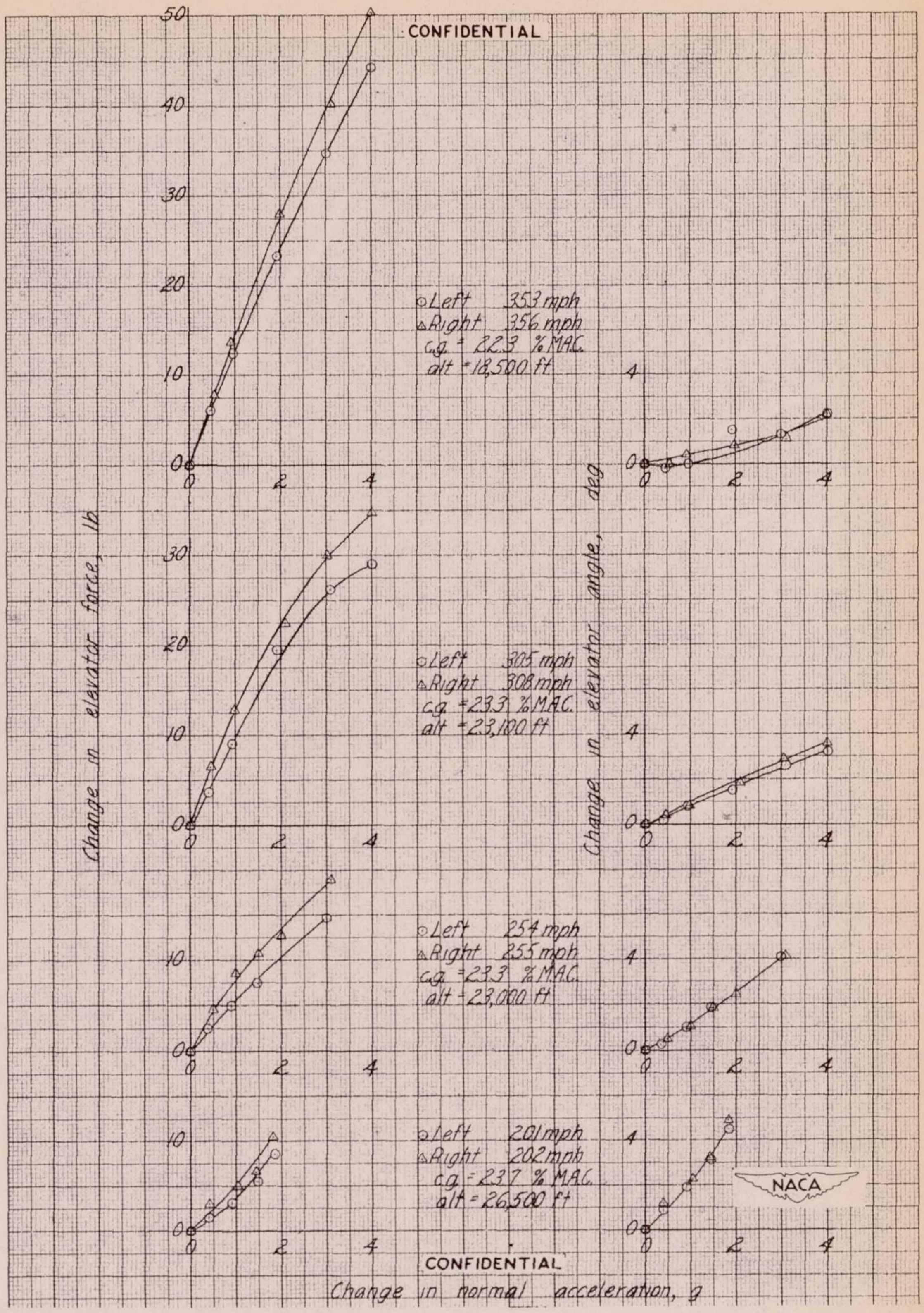


Figure 27.- Variation of the change in elevator force and angle with change in normal acceleration in turns at various speeds made in the power-on clean condition at high altitude at the forward center-of-gravity position, P-51H airplane.

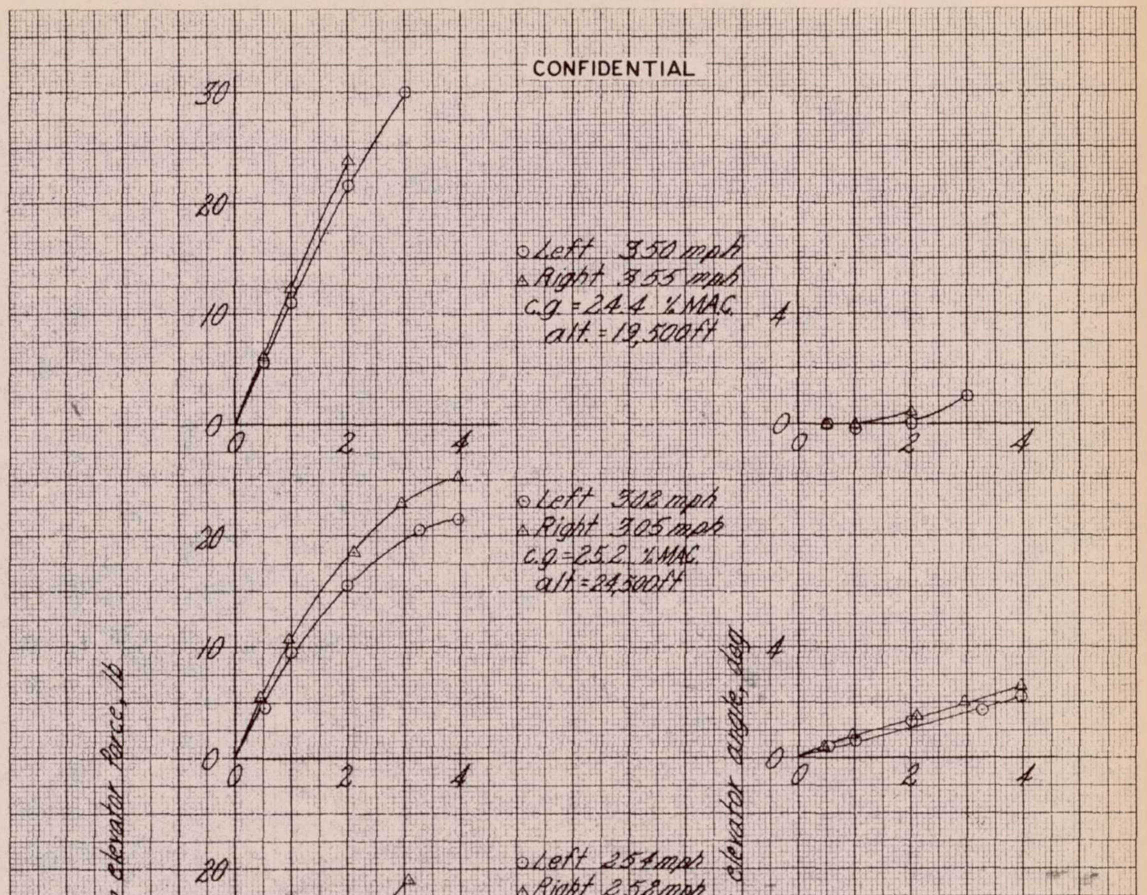
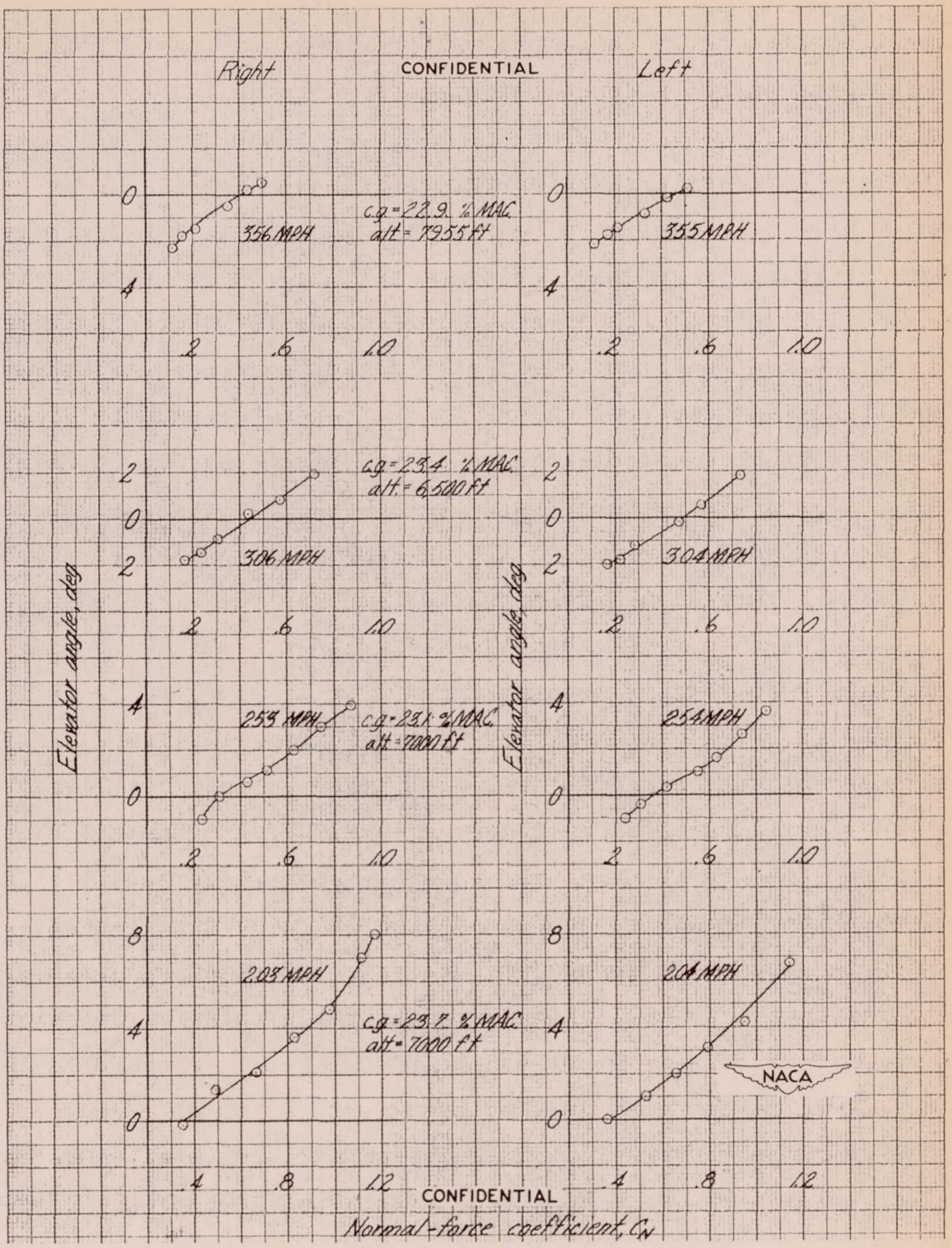
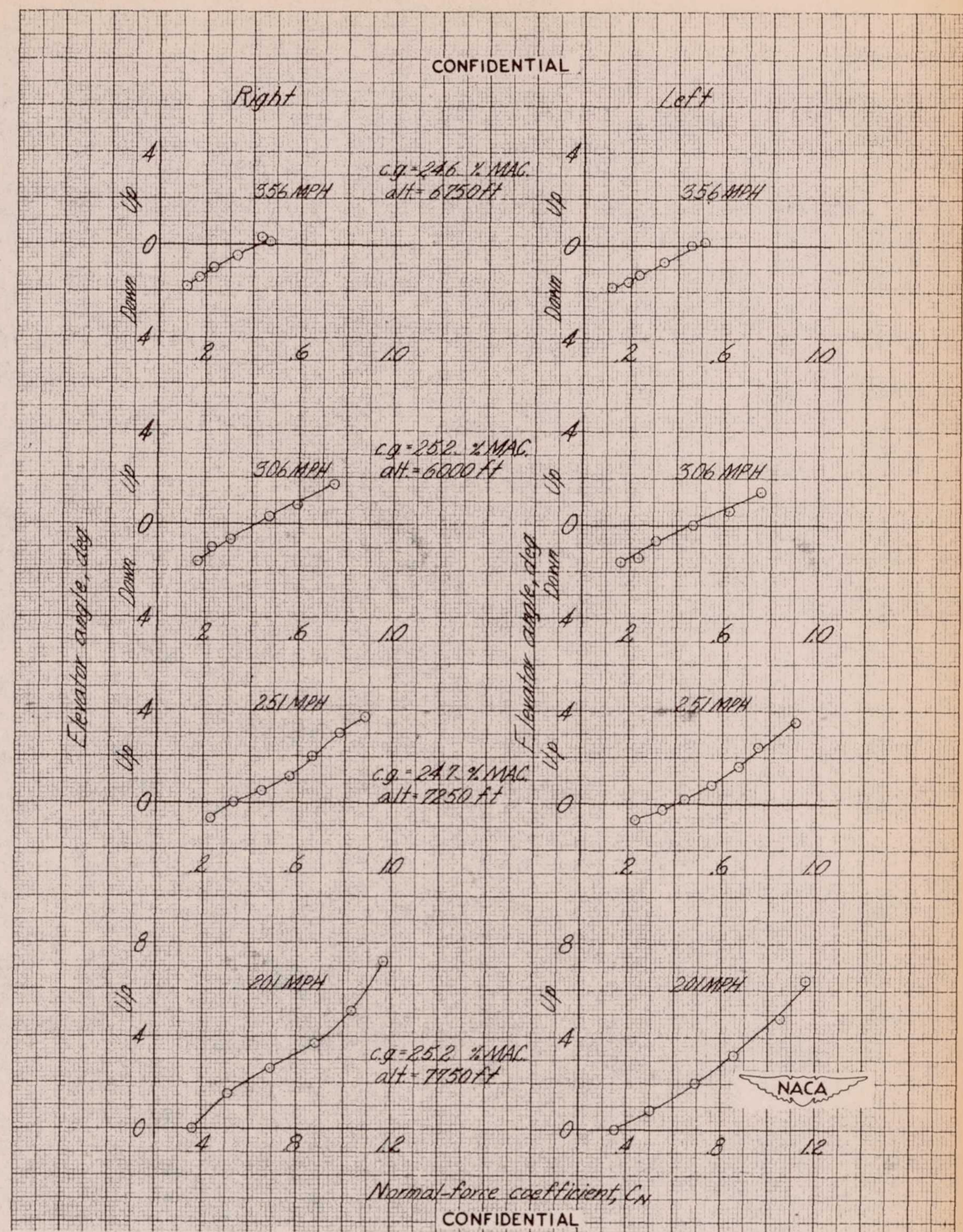


Figure 28.- Variation of the change in elevator force and angle with change in normal acceleration in turns at various speeds made in the power-on clean condition at high altitude at the middle center-of-gravity position, P-51H airplane.



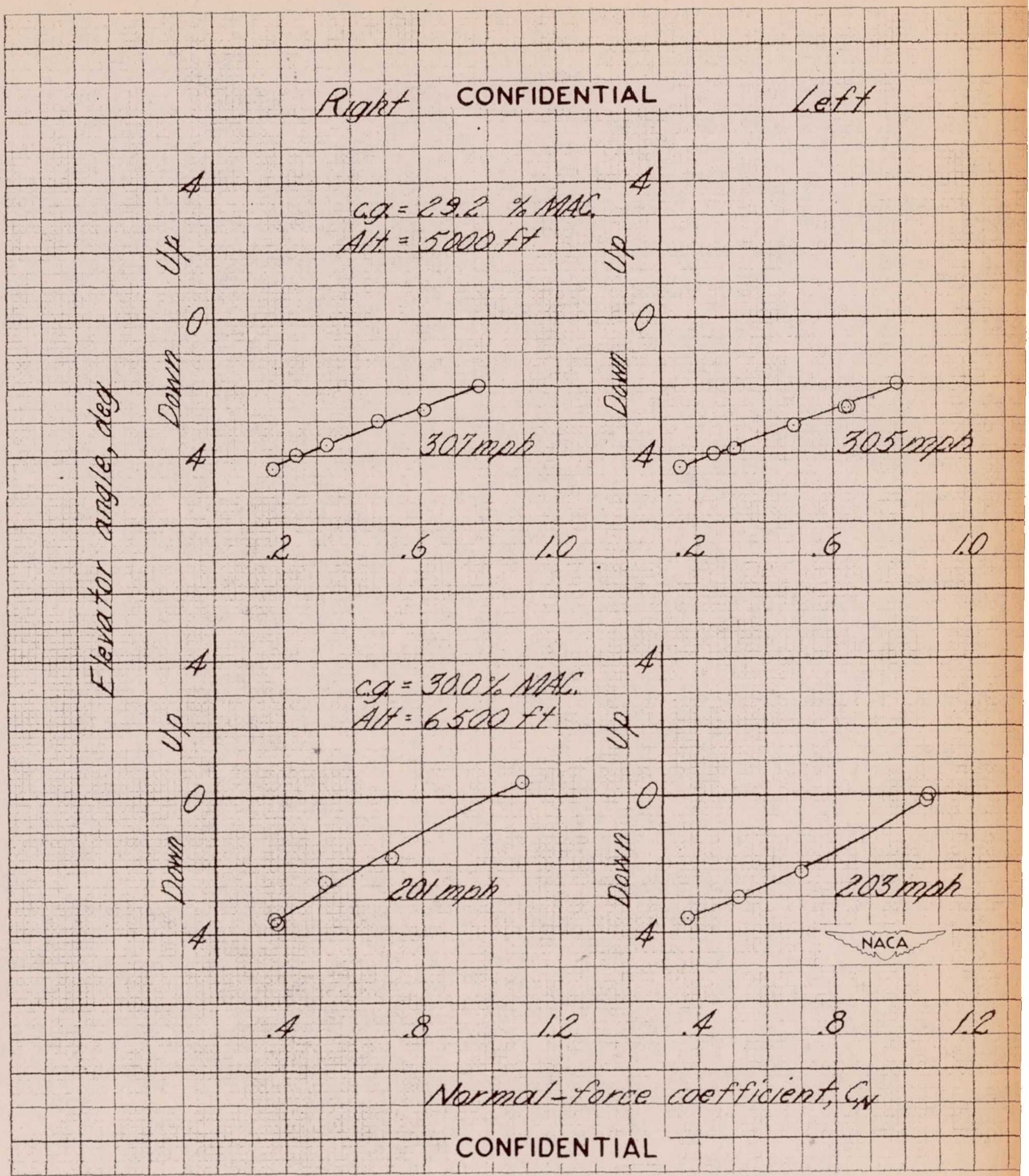
(a) Forward center-of-gravity position at low altitude.

Figure 29.- Variation of the elevator angle with normal-force coefficient in turns at various speeds in the power-on clean condition, P-51H airplane.



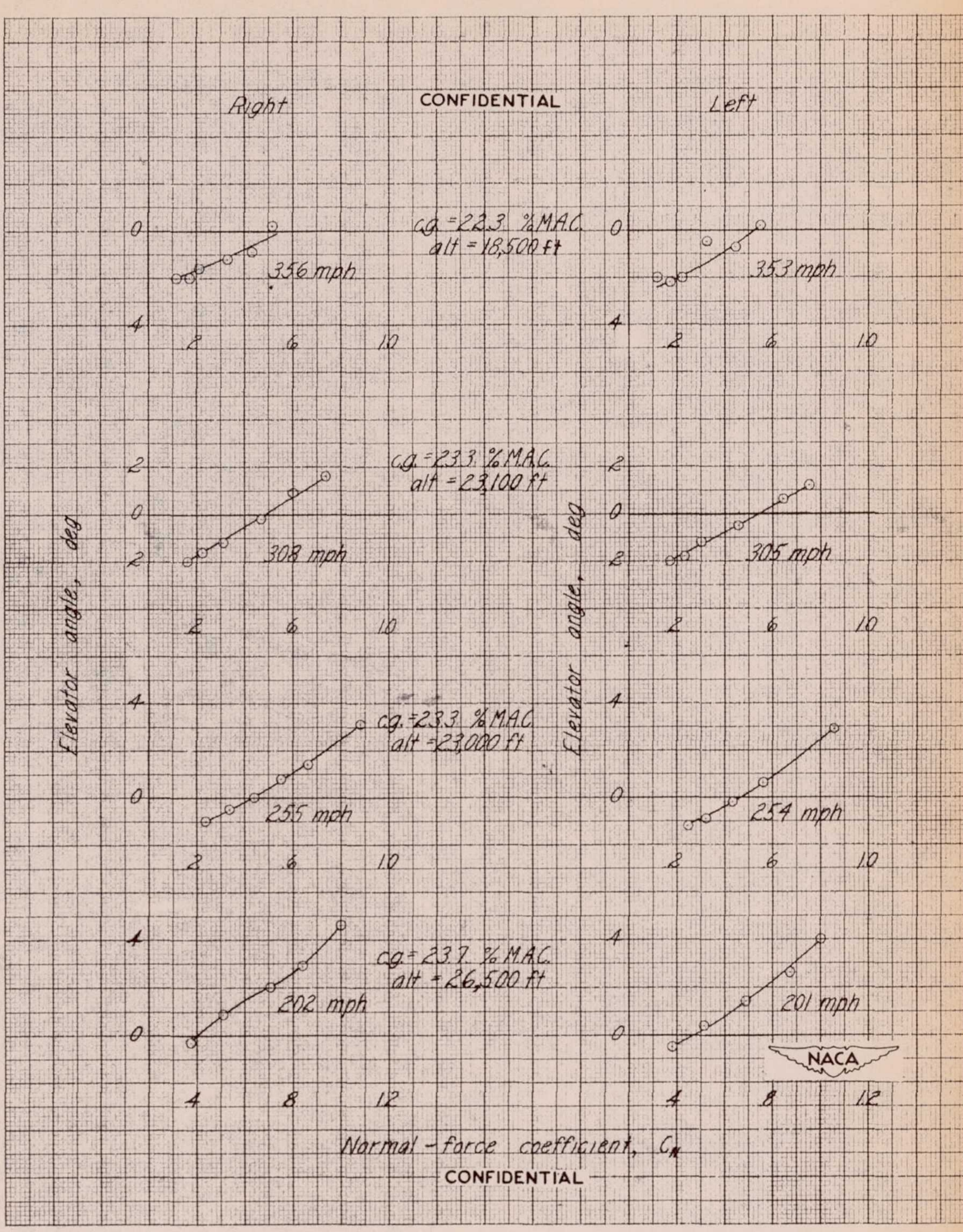
(b) Middle center-of-gravity position at low altitude.

Figure 29.- Continued.



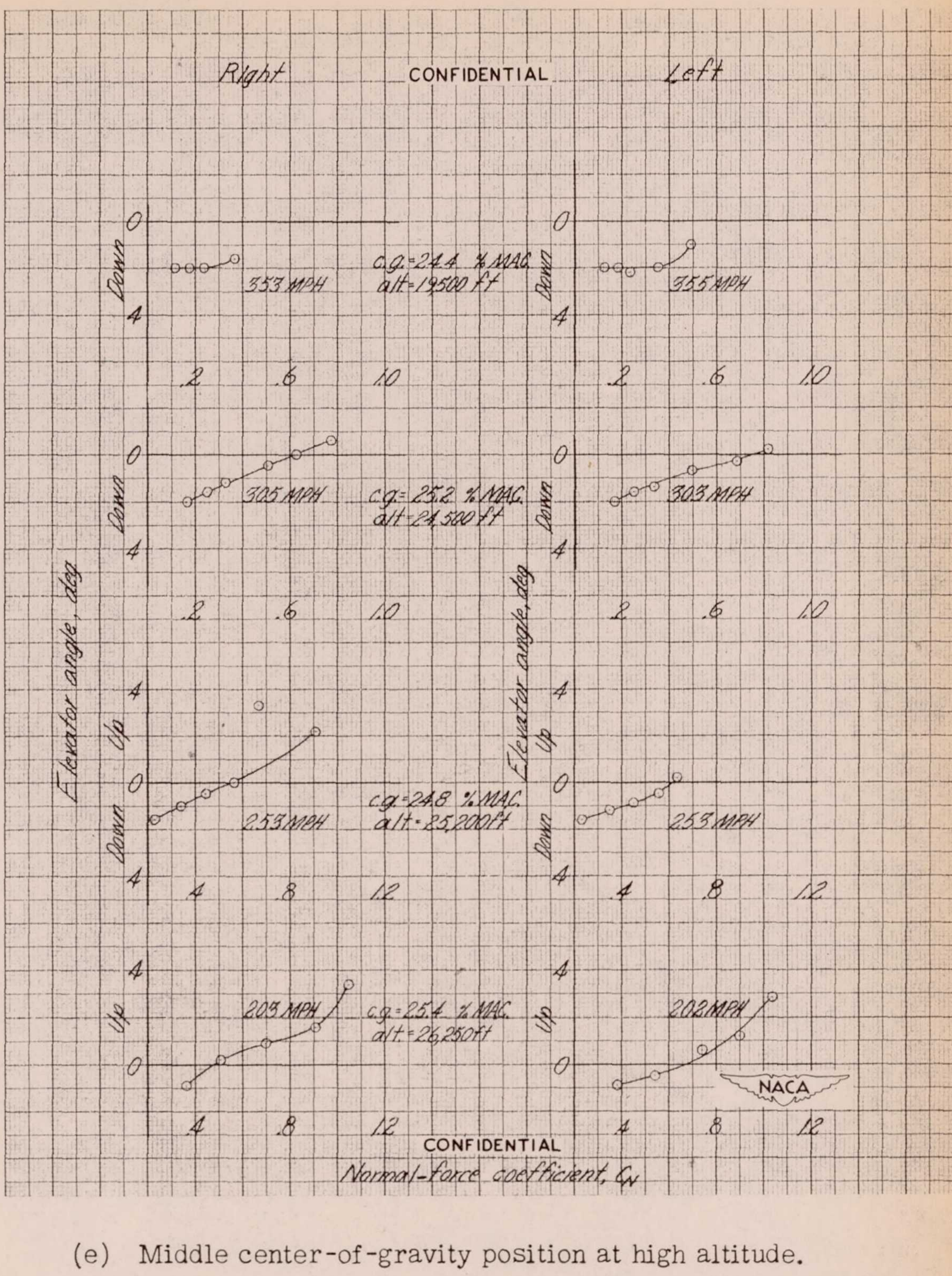
(c) Aft center-of-gravity position at low altitude.

Figure 29.- Continued.



(d) Forward center-of-gravity position at high altitude.

Figure 29.- Continued.



(e) Middle center-of-gravity position at high altitude.

Figure 29.- Concluded.

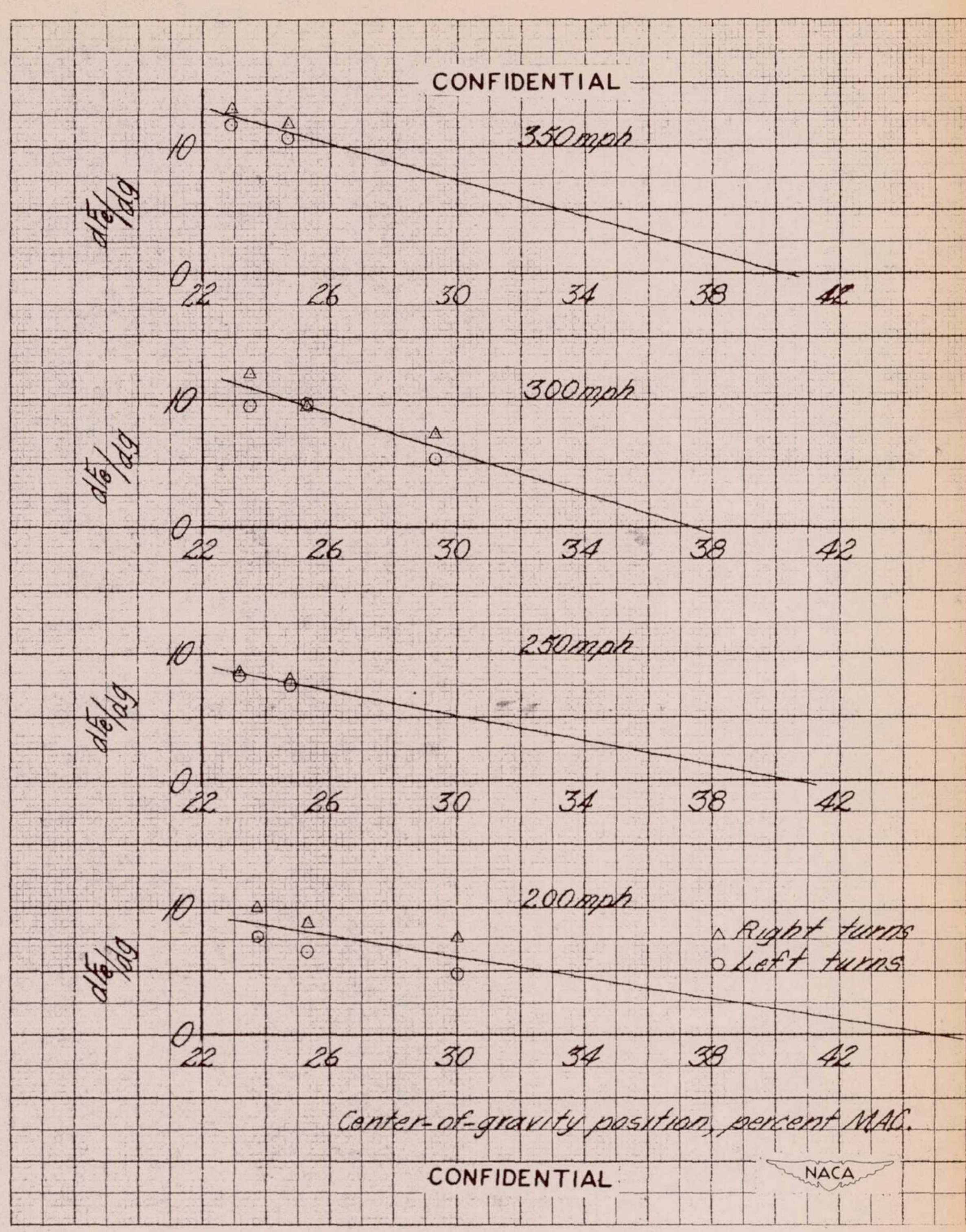


Figure 30.- Determination of the stick-free maneuver points at low altitude, P-51H airplane.

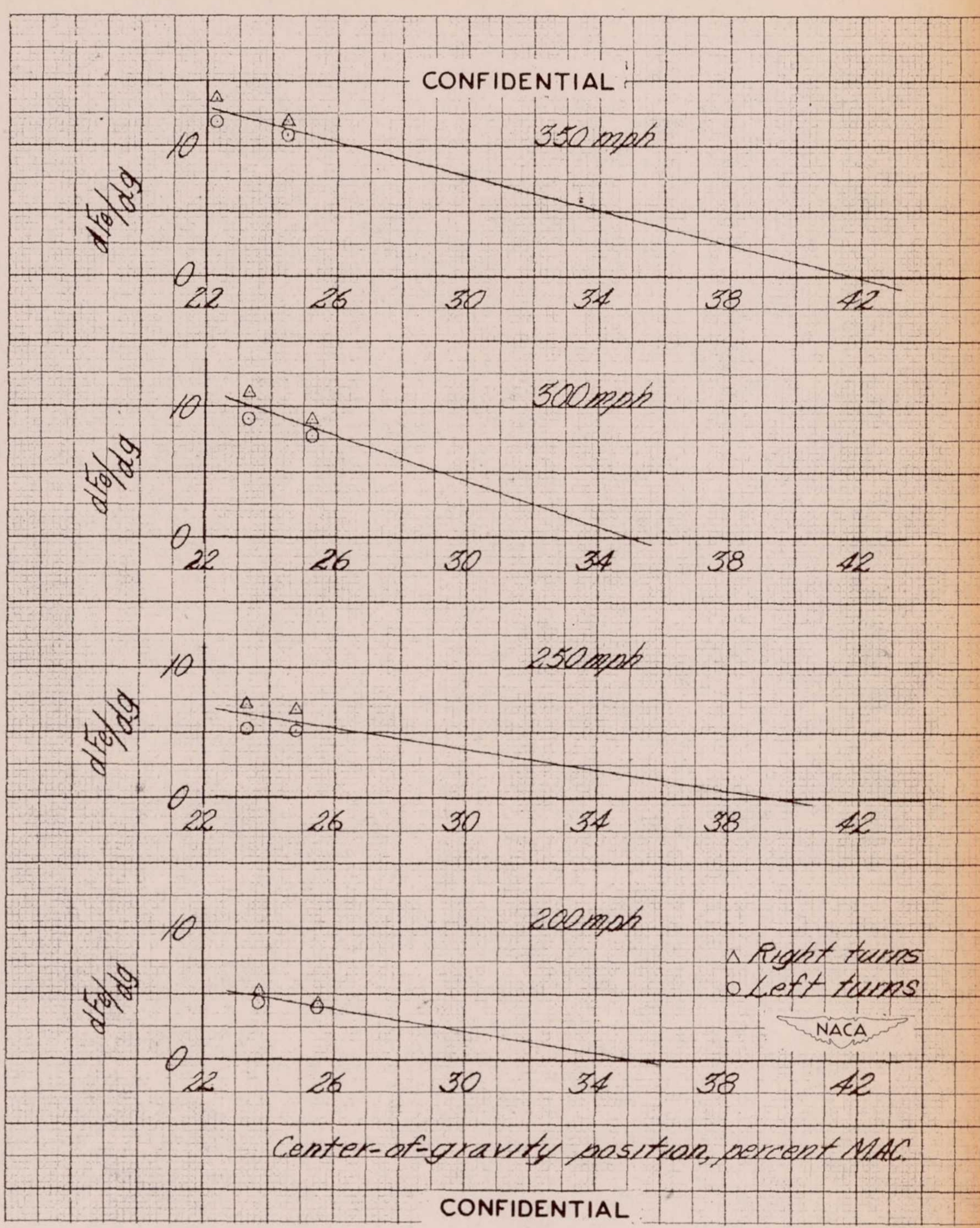


Figure 31.- Determination of the stick-free maneuver points at high altitude, P-51H airplane.

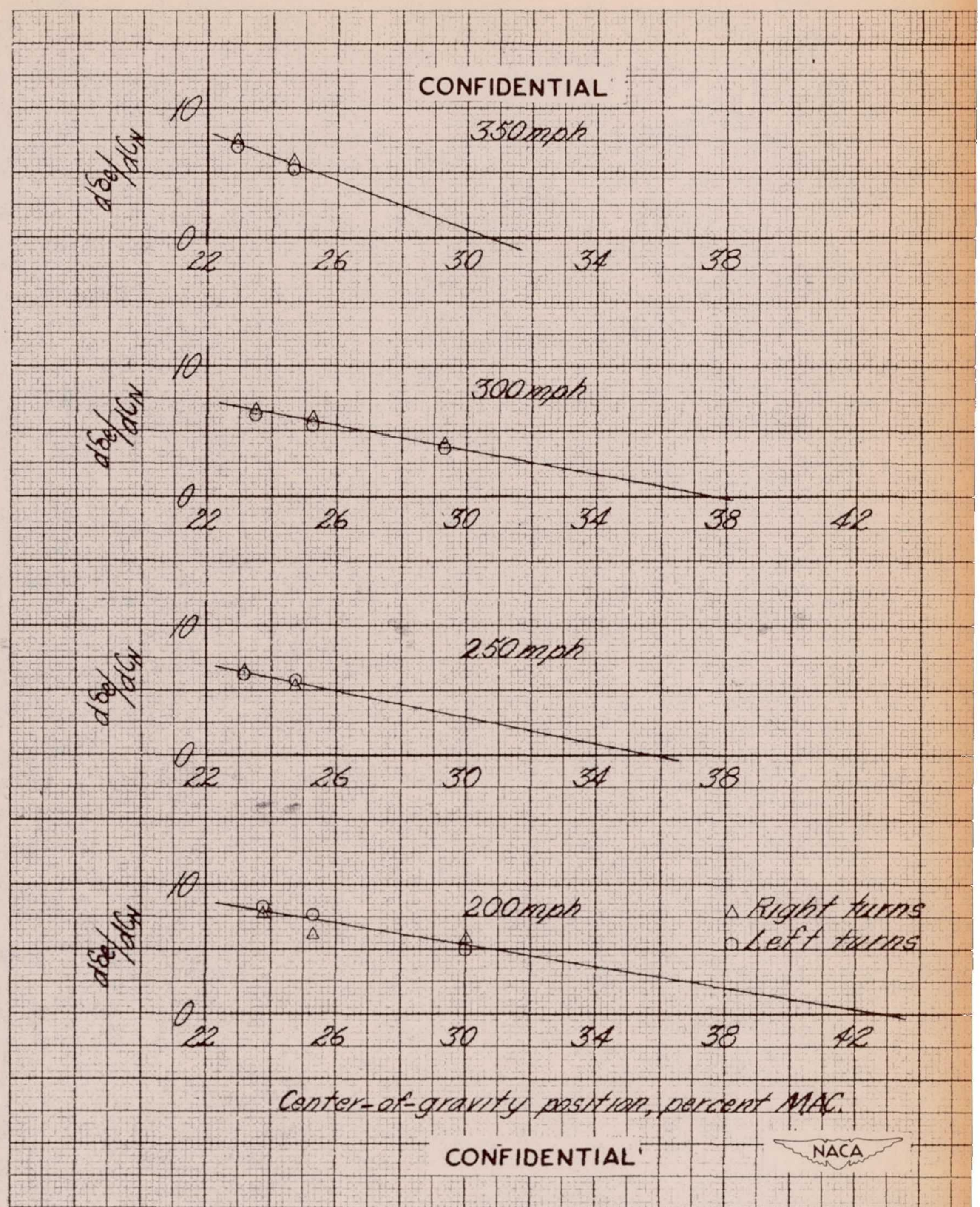


Figure 32.- Determination of the stick-fixed neutral points at low altitude, P-51H airplane.

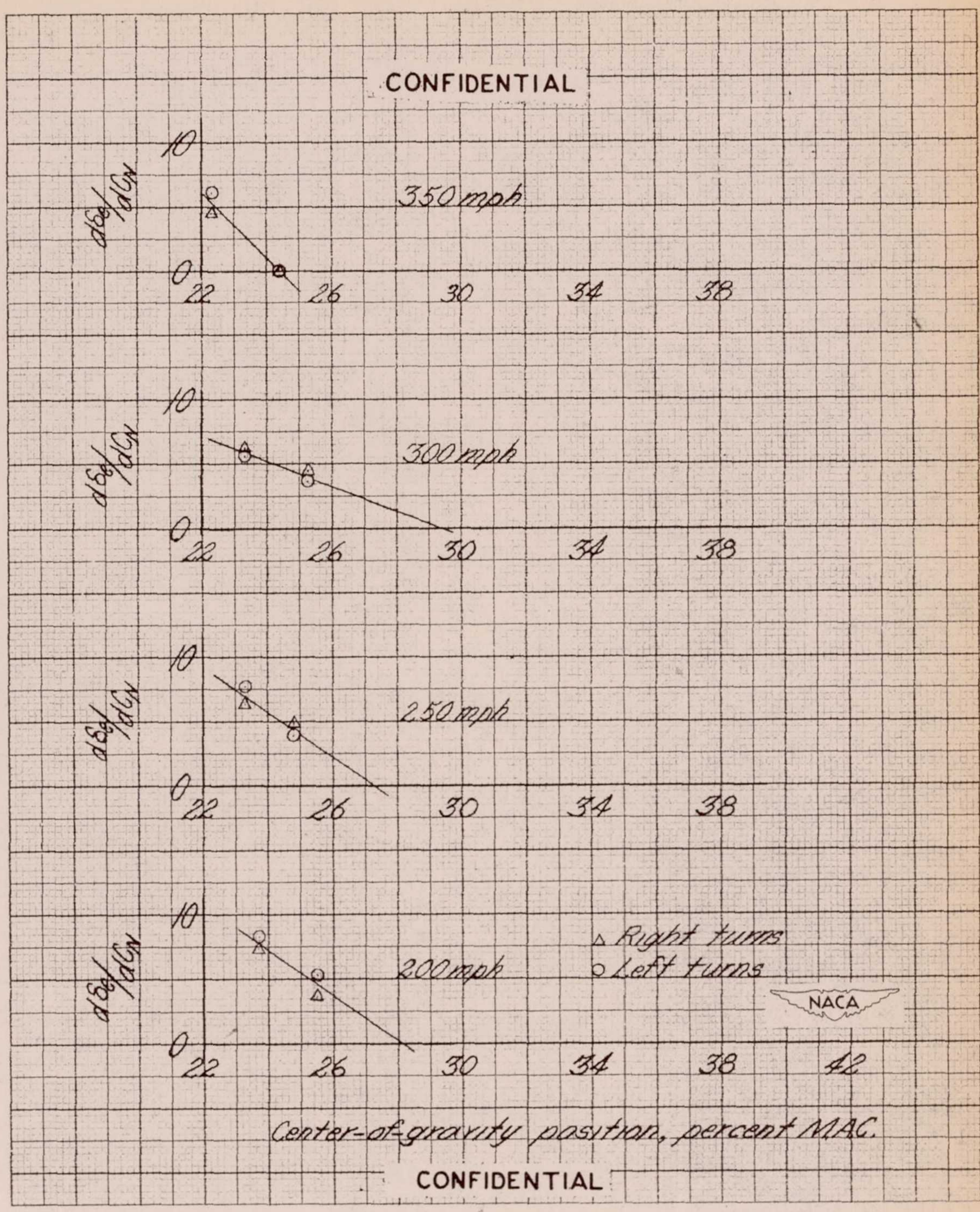


Figure 33.- Determination of the stick-fixed neutral points at high altitude, P-51H airplane.

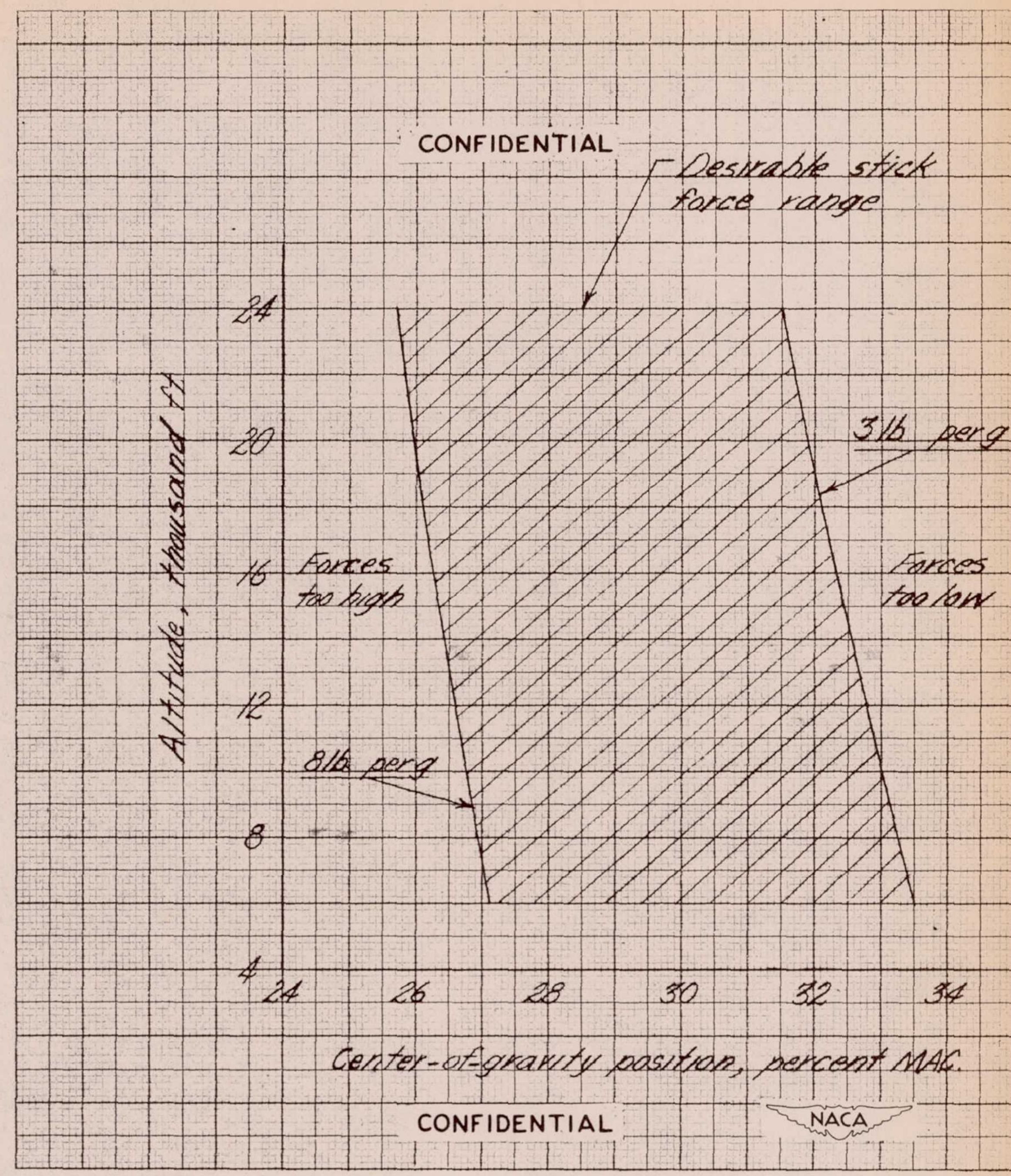


Figure 34.- A graph of the center-of-gravity range as a function of altitude in which desirable values of stick force per g are obtained in turns at 300 miles per hour (average of left and right turns), P-51H airplane.

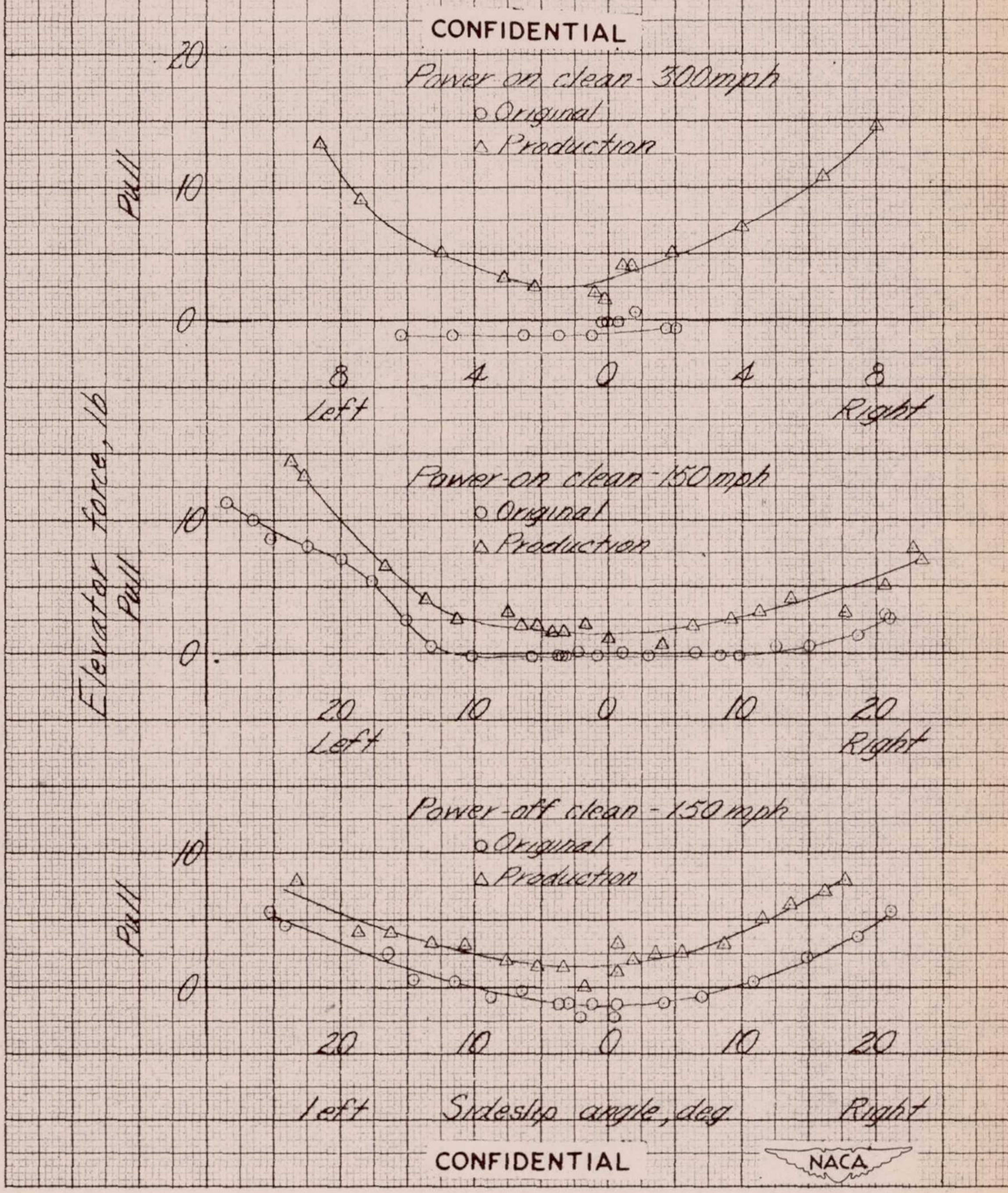


Figure 35.- The variation of elevator force with sideslip angle as measured in steady sideslips at various speeds in the power-on clean and power-off clean conditions at approximately 22,000 feet altitude, P-51H airplane.

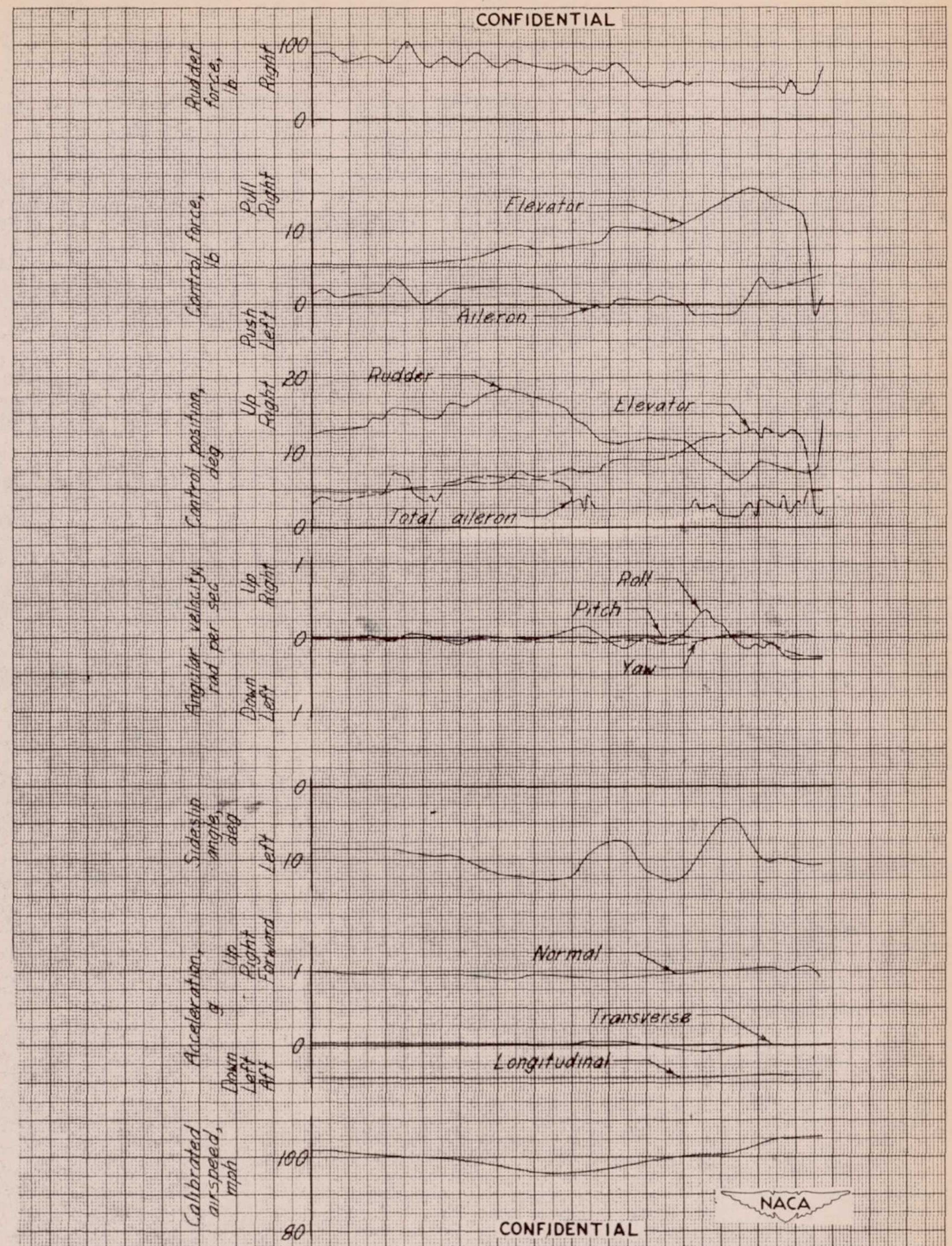


Figure 36.- Time history of a stall approach in the power-on clean condition in which only the elevator was used beyond the stall. Center of gravity at 23.6 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

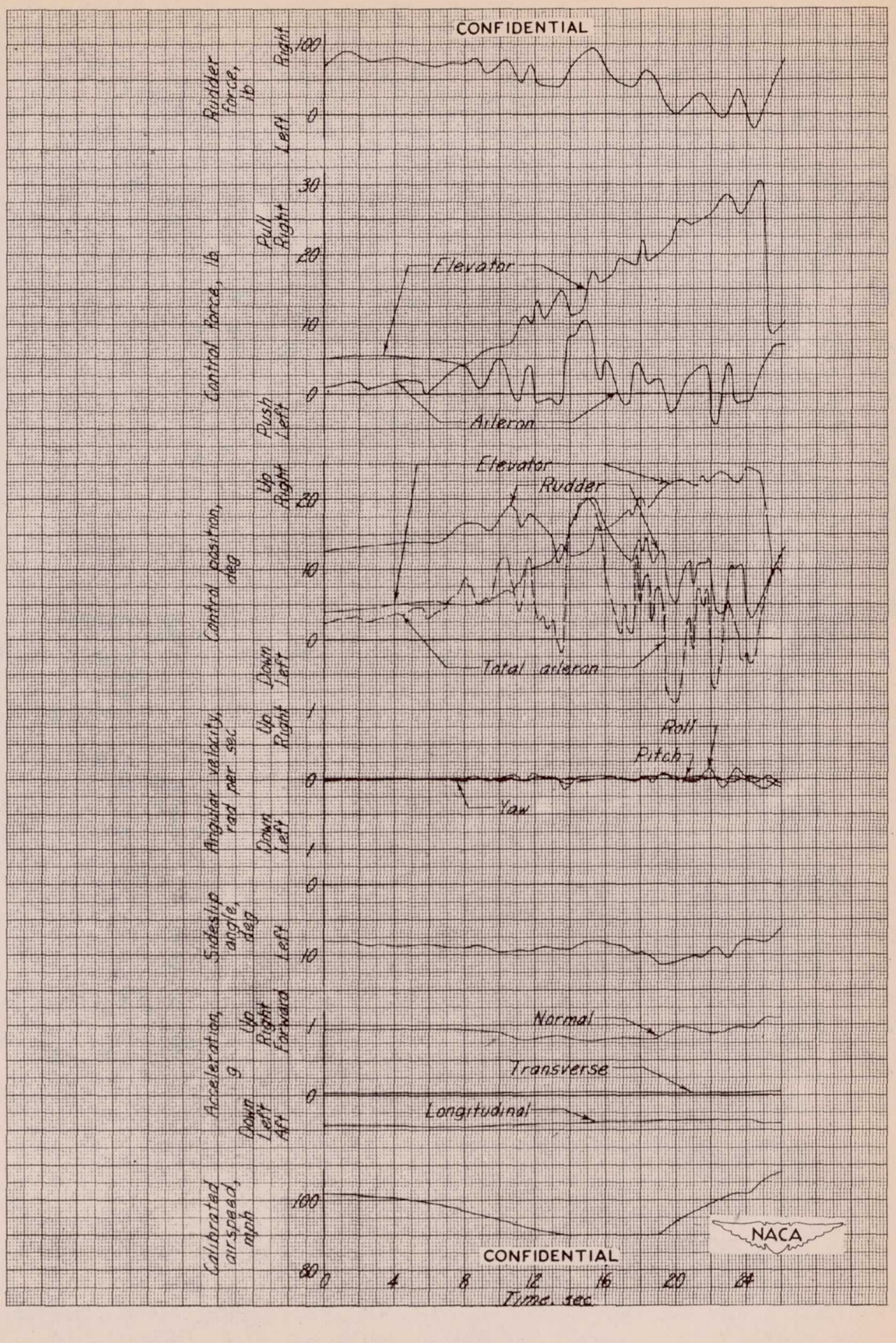


Figure 37.- Time history of a stall approach in the power-on clean condition in which all the controls were used in attempt to control the airplane after the stall was reached. Center of gravity at 23.6 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

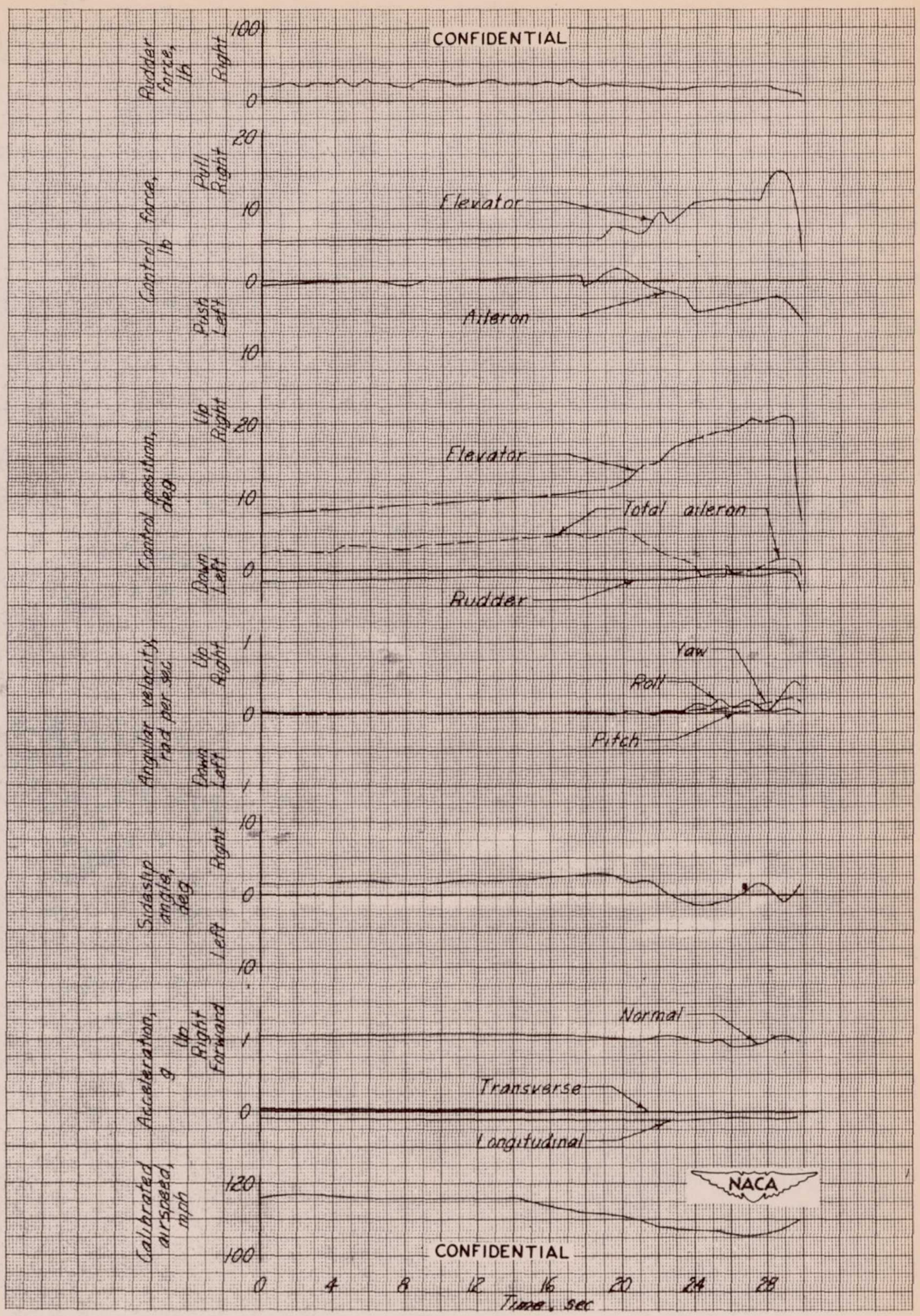


Figure 38.- Time history of a stall approach in the power-off clean condition in which only the elevator was used beyond the stall. Center-of-gravity position at 22.7 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

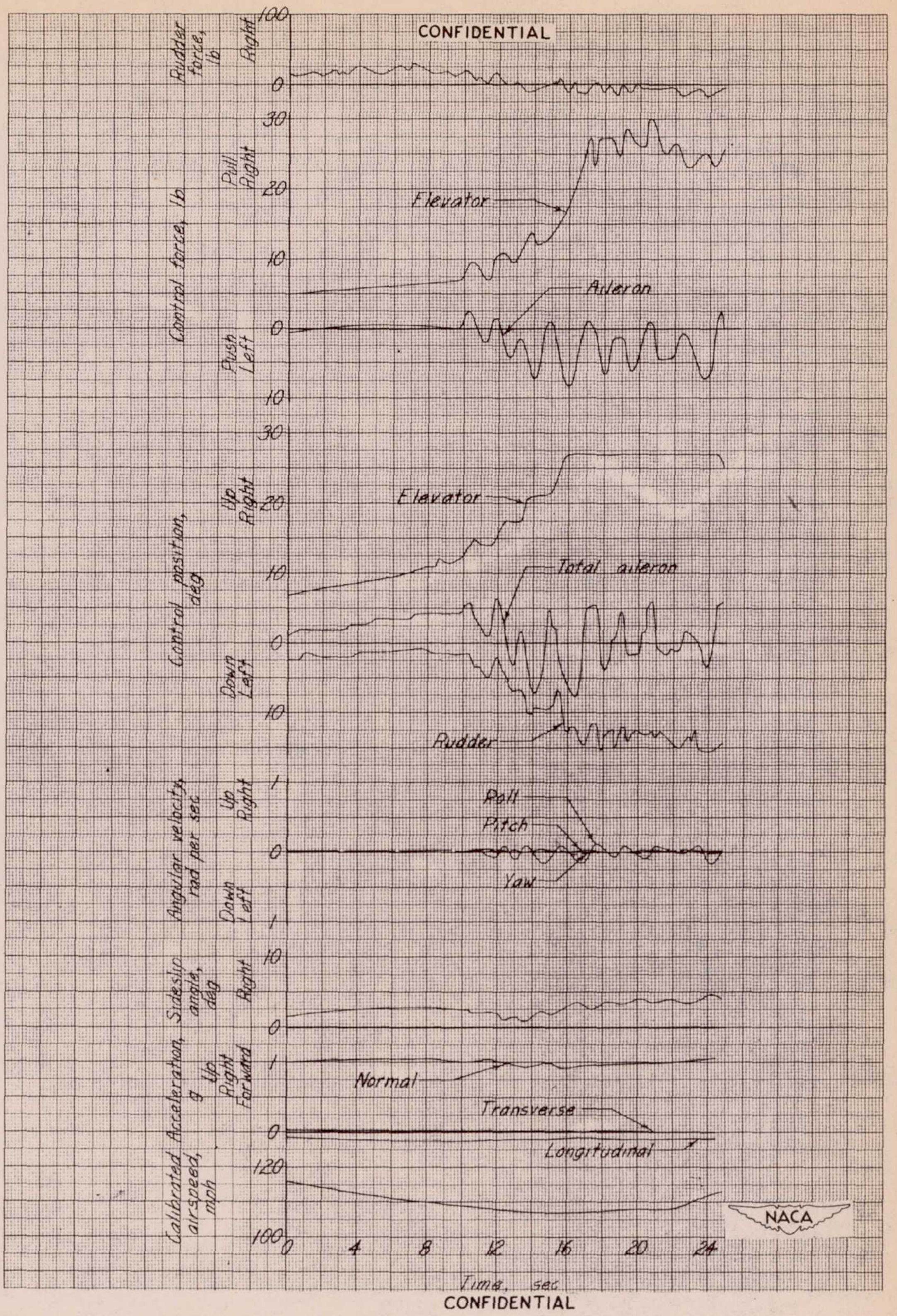


Figure 39.- Time history of a stall approach in the power-off clean condition in which all the controls were used in an attempt to control the airplane after the stall was reached. Center-of-gravity position at 22.7 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

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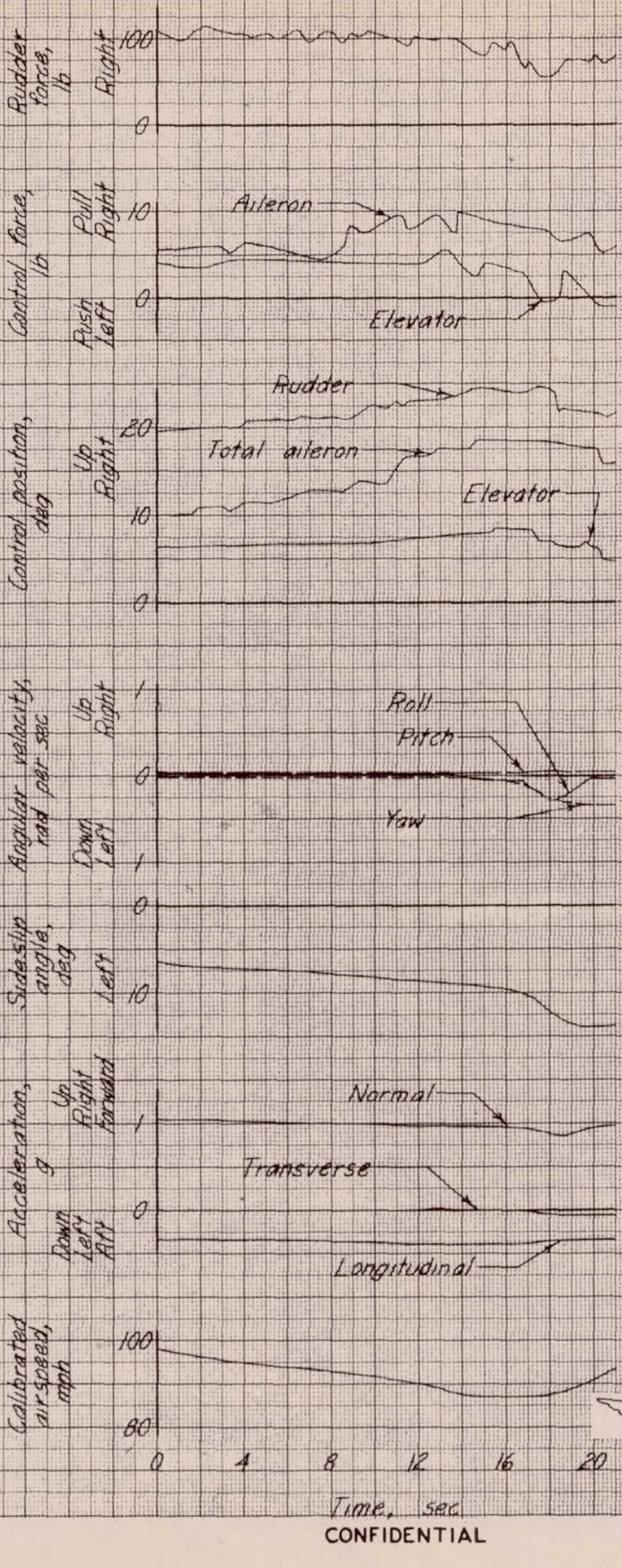

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Figure 40.- Time history of a stall approach in the wave-off condition in which only the elevator was used beyond the stall. Center-of-gravity position at 23.4 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

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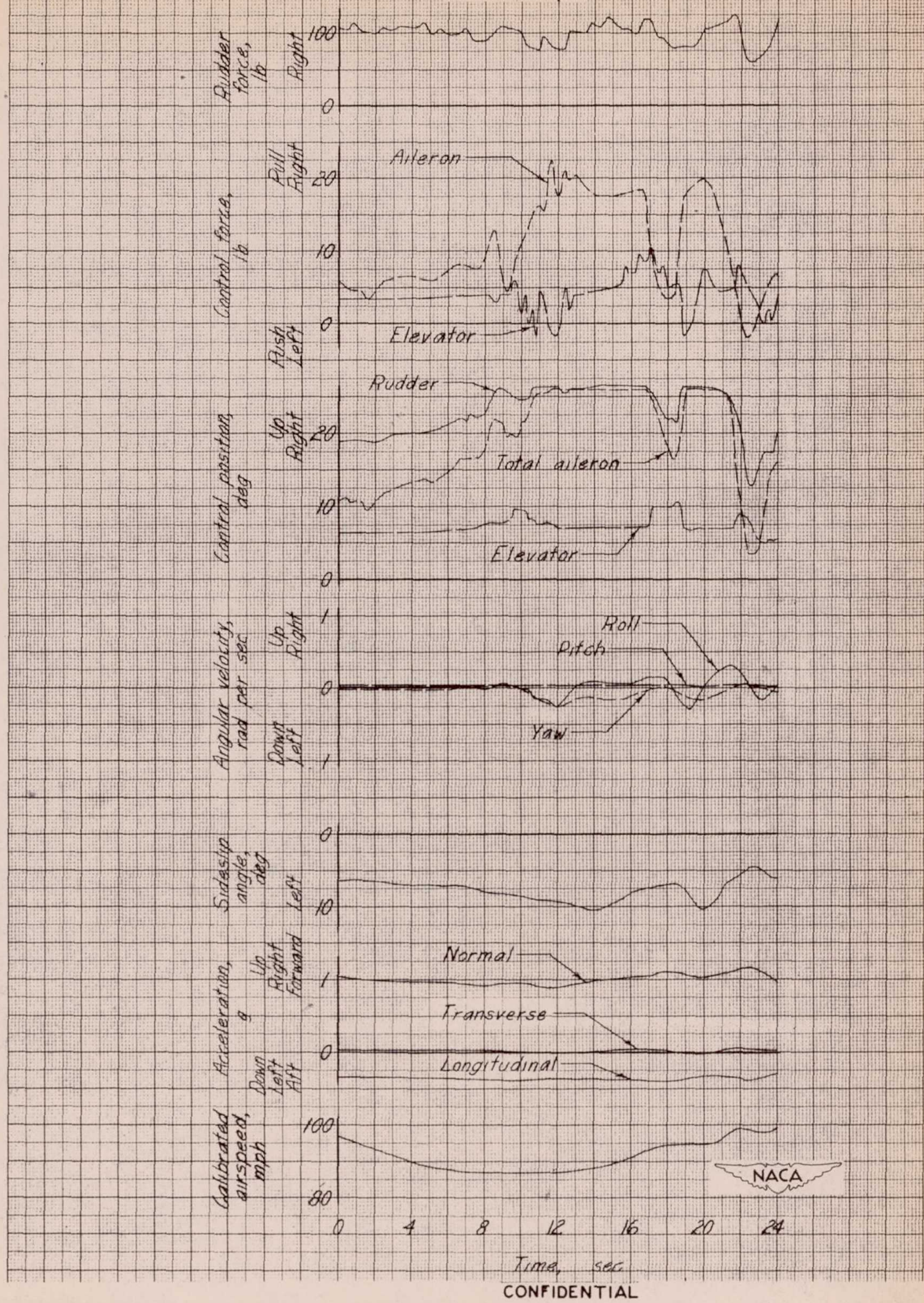

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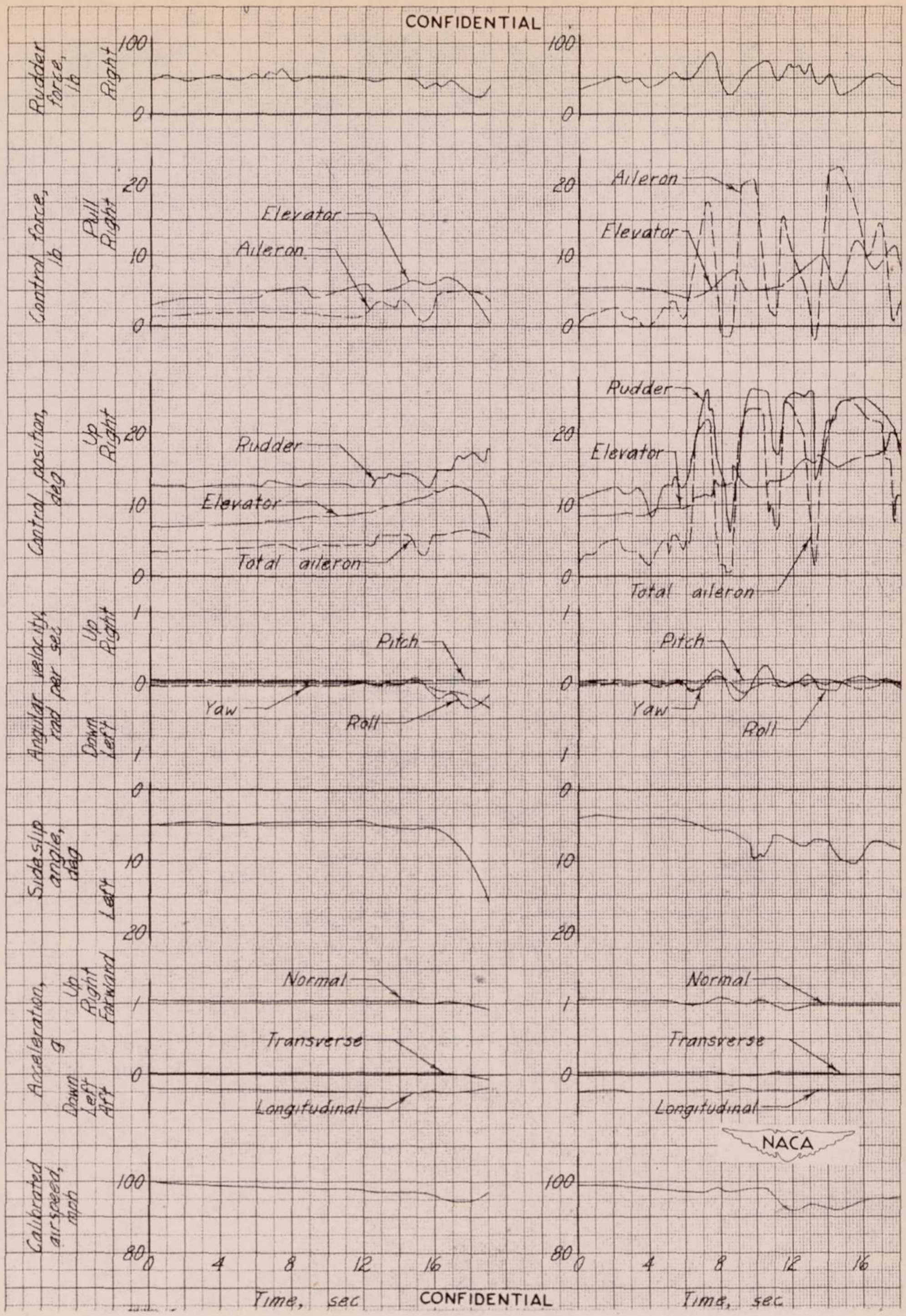
Figure 41.- Time history of a stall approach in the wave-off condition in which all the controls were used in an attempt to control the airplane after the stall was reached. Center-of-gravity position at 23.4 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.



(a) Only the elevator was used beyond the stall.

(b) All the controls were used in an attempt to control the airplane after the stall was reached.

Figure 42.- Time histories of stall approaches in the approach condition. Center-of-gravity position at 23.1 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

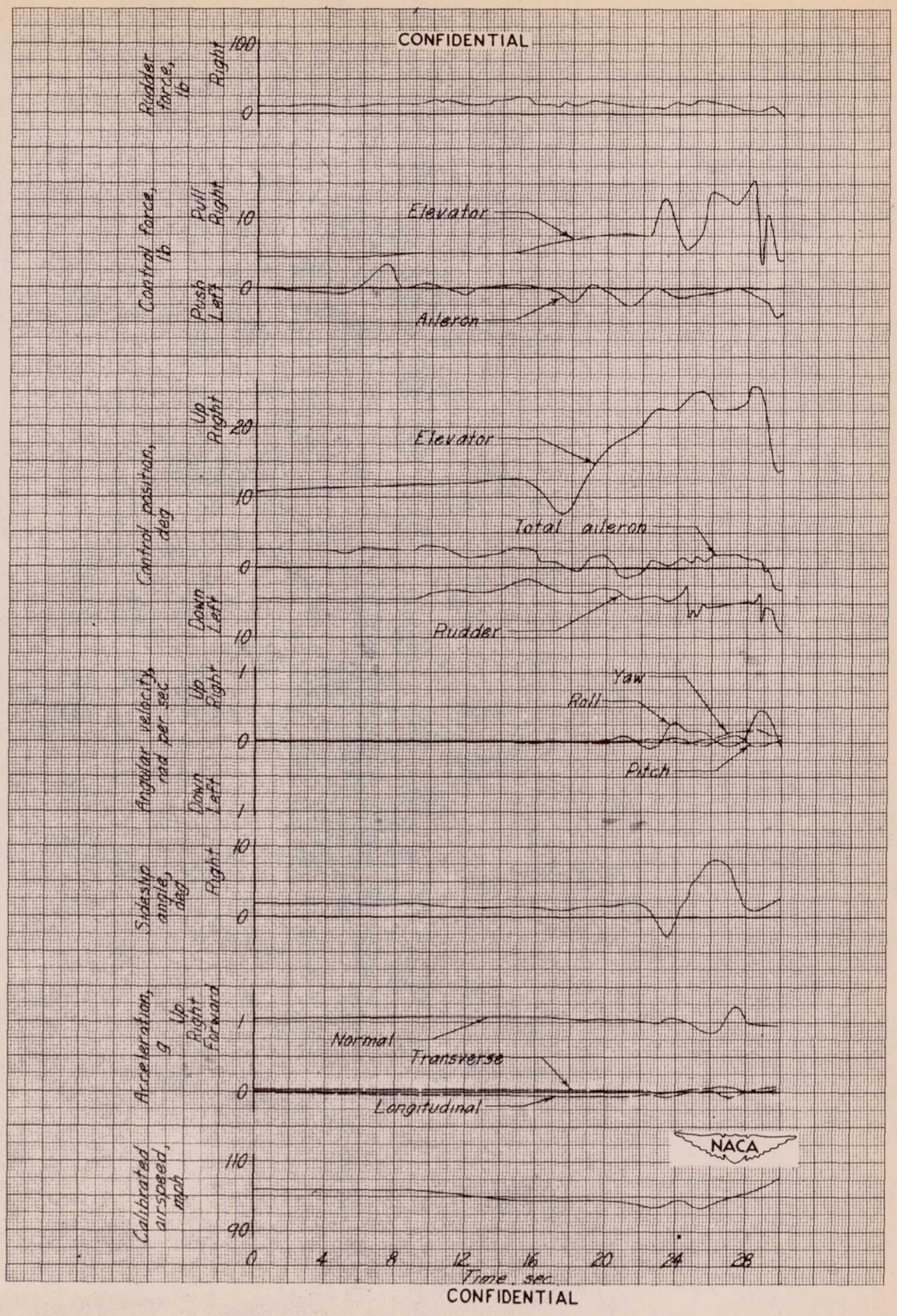


Figure 43.- Time history of a stall approach in the landing condition in which only the elevator was used beyond the stall. Center-of-gravity position at 21.9 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

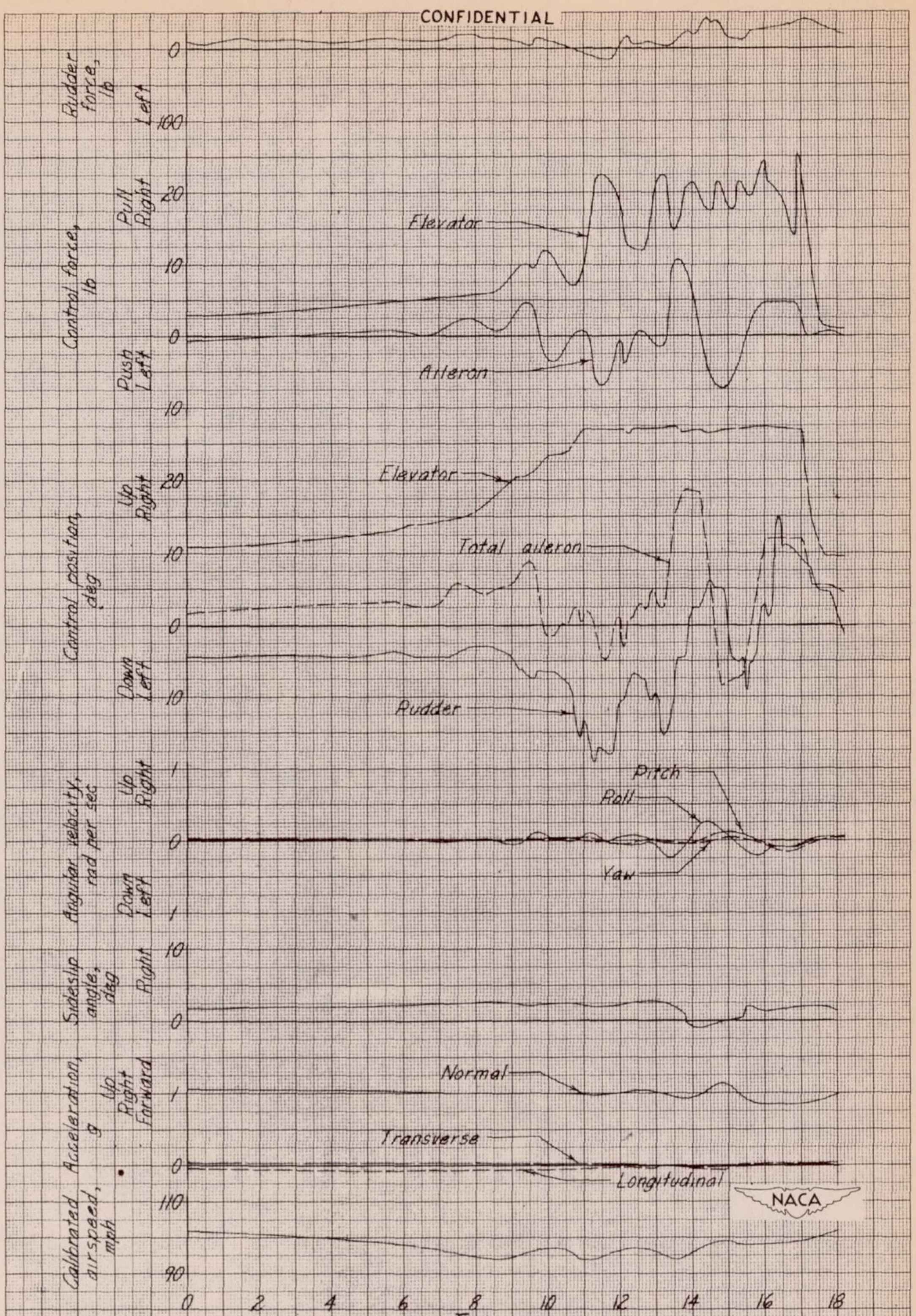


Figure 44.- Time history of a stall approach in the landing condition in which all the controls were used in attempt to control the airplane after the stall was reached. Center-of-gravity position at 21.9 percent M.A.C. at approximately 5000 feet altitude, P-51H airplane.

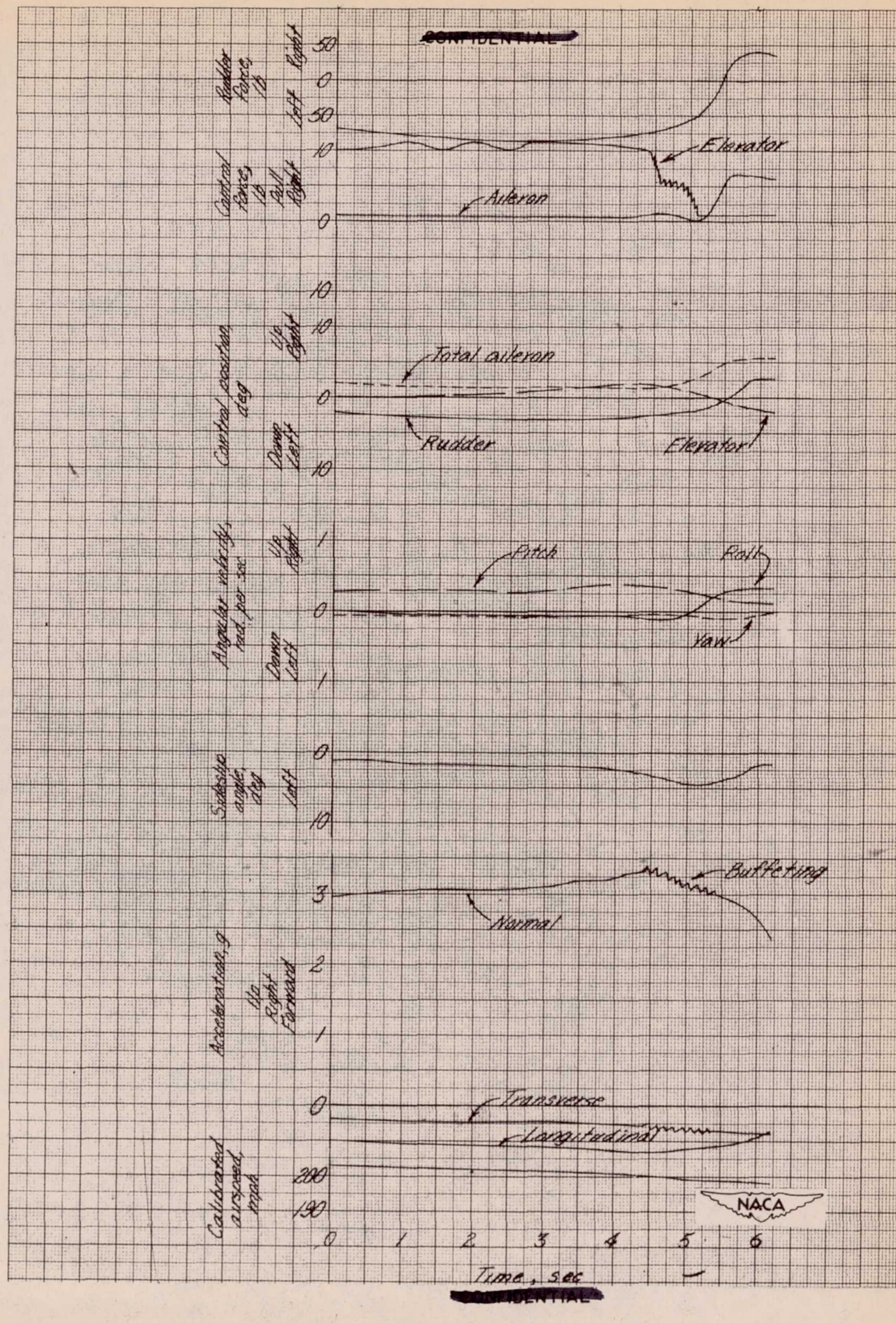


Figure 45.- Time history of an accelerated stall approach in the power-on clean condition in a left turn. Center of gravity at 30 percent M.A.C. at approximately 6500 feet altitude, P-51H airplane.