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RESEARCH MEMORANDUM

FLIGHT INVESTIGATION OF LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AND STALLING CHARACTERISTICS OF A C-54D AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The flying qualities of a C-54D airplane were measured as a preliminary to an investigation to determine the necessity of additions or revisions to flying-qualities requirements in view of the problems associated with making instrument approaches to low altitudes. This paper presents the longitudinal stability and control characteristics and the stalling characteristics of the test airplane.

The dynamic longitudinal stability was considered good inasmuch as the short-period oscillations with control free were well damped at all speeds. Both the stick-fixed and stick-free static longitudinal stability were also found to be satisfactory over the test center-of-gravity range (17.9 to 27.9 percent M.A.C.).

For two configurations tested with the center of gravity at the most rearward position, the elevator force per g was approximately 30 percent greater than the allowable maximum value specified in the Air Force and Navy handling-qualities requirements. All other conditions provided even larger forces per g throughout the center-of-gravity range.

The take-off characteristics were found to be satisfactory under normal operations where no attempt was made to raise the nose wheel until the minimum take-off speed had been exceeded. The elevator, however, apparently was not sufficiently powerful to raise the nose wheel during a take-off at 0.80 times the landing-condition stalling speed with a forward center-of-gravity position. It should be pointed out that the center-of-gravity position for normal operations is closer to the rearward limit where the nose wheel could be lifted from the runway at a speed low enough to meet the requirements.

The elevator was sufficiently powerful to fulfill power-off landing requirements at the forward center-of-gravity position, but during such landings, the elevator forces were about 80 pounds as compared with the maximum of 50 pounds specified in the Air Force and Navy handling-qualities requirements.

The trim characteristics were satisfactory throughout the speed range in all conditions.

The stalling characteristics were good except that in the landing and approach conditions the stall warning in the form of buffeting did not occur at a speed sufficiently above the stall to meet the Air Force and Navy handling-qualities requirements.

The control friction was found to be approximately twice that specified by the Air Force and Navy requirements, but a large part of this friction was caused by the servos in the autopilot system. The effects of this friction have been previously investigated and reported.

INTRODUCTION

In connection with a study of the problem of making instrument approaches to low altitudes in large airplanes, handling-qualities investigations were made of a Douglas C-54D, the military cargo version of the commercial DC-4 Skymaster. The tests were conducted at the Langley Aeronautical Laboratory in the latter part of 1946 and in the early part of 1947. Reference 1 discusses the instrument approach tests and shows that no abnormal flying techniques were used. It was concluded that the present handling-qualities requirements do not need additions or revisions in view of the necessity of performing precision flying in connection with making instrument approaches to low altitudes. The lateral and directional stability and control results are presented in reference 2. Reference 3 discusses the particularly troublesome effects of excessive friction in the control system. This paper presents the results of the tests of the longitudinal stability and control characteristics and stalling characteristics.

SYMBOLS

c.g. center of gravity, percent M.A.C.

M.A.C. mean aerodynamic chord

g acceleration due to gravity

n number of g acceleration

W	airplane weight, pounds
S	wing area, square feet
q_c	impact pressure, inches of water
δ_e	elevator deflection, degrees from neutral
F_e	elevator control force, pounds
C_N	normal-force coefficient $\left(\frac{Wn}{5.2q_c S}\right)$
F_e/q_c	stick-force parameter, pounds per inch of water
$d\delta_e/dC_N$	stick-fixed stability parameter
$\frac{dF_e/q_c}{dC_N}$	stick-free stability parameter
NRP	normal rated power
NU	nose up
ND	nose down

DESCRIPTION OF THE AIRPLANE AND INSTRUMENTATION

The C-54D test airplane is described and the general specifications are given in reference 2. The instrumentation is also described in reference 2. A photograph and a three-view drawing of the C-54D are given in figure 1 and the control-linkage characteristics with no load are presented in figure 2.

TESTS, RESULTS AND DISCUSSION

The discussion of results is based on the specification set forth in reference 4.

Similar tests were conducted on a C-54G airplane by the Air Force, the results of which are given in reference 5. Comparison of the results is made wherever possible.

Control friction.- The friction in the control system which existed during these tests was measured and found to be as shown in table I.

The measured friction was about twice that allowed by the specifications of reference 4. This high friction was the probable cause of scatter observed in the force data. A check was made on the CAA requirement relating friction and static stability (reference 6) which states that the airspeed shall return to within 10 percent of the original trim speed when the control force is slowly released from any speed within the allowable speed range. At a forward center-of-gravity position the airplane was trimmed for cruising at about 205 miles per hour. The speed was then slowly increased about 30 miles per hour by moving the control column forward; then, the wheel force was eased off gradually until with the stick free the airplane again trimmed at a steady speed. This speed was about 3 miles per hour higher than the initial speed, well within 10 percent of the original trim speed. However, the friction was considered excessive by the pilots. This result indicates that the specification for allowable friction should be given in terms of an absolute value of force rather than in terms of the ability of the airplane to return to a trim speed. Some tests were made later with friction amounting to approximately one-half that allowed by the specifications of reference 4. This lower friction was obtained by removing the autopilot servos from the control system. The effects of this reduction in friction were beneficial and are discussed in reference 3.

Dynamic longitudinal stability.- The short-period longitudinal oscillations were measured in the clean condition at 200 miles per hour. The elevator was abruptly deflected in the up and down directions and released and the motions of the control and the airplane were recorded. Time histories of a pull-up and release and a push-down and release are presented in figure 3. It can be seen that the elevator returned immediately to a position close to its trim position and did not oscillate. The friction in the control system probably prevented the elevator from returning completely to trim.

The oscillation of the airplane, as shown by the curve of the normal acceleration, damped out completely in less than one cycle. At slower speeds the short-period oscillations were also very well damped and therefore the requirements of reference 4 were met. The same characteristics were reported by the Air Force in reference 5.

Static longitudinal stability.- The static longitudinal stability was measured in straight level flight for three center-of-gravity positions in configurations given in table II. Figure 4 presents the variation of the elevator stick force and elevator angle with calibrated airspeed and figure 5 presents the corresponding variation of the stick-force parameter F_e/q_c and elevator angle with normal-force coefficient C_N at three center-of-gravity positions covering the allowable range in the listed flight conditions. Figure 6 shows a sample graphical determination of the stick-fixed and stick-free neutral points. The variation of the stick-fixed and stick-free neutral points with normal-force coefficient is given in figure 7.

The stick-fixed stability was positive in all conditions of flight tested except the wave-off condition at the rear center-of-gravity position at low speeds, where the airplane became neutrally stable. The stick-free stability was positive in all conditions tested; therefore, the requirements for the static stick-fixed and stick-free stability were satisfied.

Only fair agreement is found with reference 5 on the degree of stability indicated by the neutral-point variation with normal-force coefficient; however, small variations in the fairing of the curves of elevator angle and F_e/q_c with normal-force coefficient can cause comparatively large variations in the neutral point. Excessive scatter of the force data due to high friction caused some uncertainty in fairing the F_e/q_c against C_N curves in the present report.

Maneuvering stability.- The maneuvering stability was measured in steady turns to the left and right at varying normal accelerations and speeds. These tests were made at three center-of-gravity positions covering the allowable range in all the conditions listed in table II except the landing condition. Steady turns in the landing condition would have required excessive flight time due to the large rate of descent and necessary climb back to the test altitude. The variation of the elevator force and the elevator angle with normal acceleration in each of the tested conditions is given in figures 8 to 11. The maximum desirable value for the force per g, as given in reference 4, is $\frac{120}{n - 1}$ pounds per g, where n is the limit load factor. The lowest limit load factor, corresponding to the minimum allowable gasoline in the wing tanks at high gross weights, is 2.33g. Therefore the maximum desirable value of force per g would be 90 pounds per g. For normal loadings with more than the minimum allowable gasoline in the wing tanks, load factors up to 3g are permissible and therefore a maximum value of force per g of 60 pounds would be more representative. The force per g measured varied from about 160 pounds at the forward center-of-gravity position in the clean, power-on, and the approach conditions to 75 pounds at the rearward center-of-gravity position in the wave-off condition. The pilots considered the force per g to be undesirably large in all conditions including the wave-off condition at the rearward center-of-gravity position.

The altitude varied from about 7,000 to 11,000 feet for the tests. No tests were made at 25,000 feet altitude since in airline usage the altitude would rarely exceed 15,000 feet unless the airplane was redesigned with a pressurized cabin.

Although the limit load factor could not be reached due to the high stick forces, extrapolation of the curves of elevator angle variation with normal acceleration indicates that the elevator would probably be sufficiently powerful to develop a load factor of 3g or maximum lift coefficient, whichever is less, at all permissible speeds in the configurations tested.

The separation of the elevator angle curves for right and left turns was caused by the gyroscopic action of the propellers. Turning to the right causes a pitching down moment due to the propeller rotation requiring more up elevator to hold the same normal acceleration.

The Air Force conclusions as to the maneuvering stability agree with the findings in the subject tests.

Take-off and landing characteristics.- Take-offs were made at the forward center-of-gravity position (19.4 percent M.A.C.) to determine the ease with which the nose wheel could be raised from the ground during the take-off run. Figure 12 shows a time history of a take-off in which the pilot attempted to hold the elevator full up so that the nose wheel would leave the ground at the lowest possible speeds. The nose wheel left the ground at about 17 seconds (76 miles per hour) and the airplane pitched up abruptly. The data show that the elevator moved down about 4° by the time the nose wheel left the ground probably because the wheel force became too great for the pilot to hold. Control system stretch may also have been a factor contributing to the decrease in elevator deflection. The pilot reported that the airplane was in the air and flying by the time the abrupt pitching was checked. Since 80 percent of the stalling speed in the landing condition is 66 miles per hour, the requirement that the pilot be able to raise the nose wheel from the ground at 80 percent of the stalling speed in the landing condition apparently was not met. The force exerted by the pilot during this take-off was about 160 pounds. Difficulty in raising the nose wheel might be considered objectionable for operation from short runways or rough fields. However, in normal operations where no attempt was made to raise the nose wheel until minimum take-off speed had been exceeded, the take-off characteristics were found satisfactory. For normal loading conditions the center of gravity is near the rearward limit where the nose wheel could be raised from the ground below 80 percent of the stalling speed in the landing condition.

The Air Force made some take-off tests using different technique than used by the NACA. They did not use full-up elevator during their tests but extrapolated their results to cover the case of full-up elevator and concluded that the elevator was sufficiently powerful to raise the nose wheel at 80 percent of the landing condition stalling speed.

Several power-off landings were also made at the forward center-of-gravity position. A time history of a typical power-off landing is shown in figure 13. The airplane was trimmed at 120 miles per hour with the flaps full down, gear down, and engines idling. Some power was used during the approach but the engines were cut near the beginning of the record. The minimum speed at contact, 85 miles per hour, was easily reached without using full-up elevator. Therefore the requirement that the elevator be sufficiently powerful to hold the airplane off the ground at 105 percent of the stalling speed in the landing condition was fulfilled. The elevator control force, however, was about 80 pounds as compared with the specified maximum of 50 pounds for a wheel type of control.

The Air Force tests showed insufficient elevator control to meet the landing requirements. Differences in technique and airplane test center-of-gravity position were probably the factors responsible for the different conclusions.

Effectiveness of the trim tabs.- The effectiveness of the elevator trim tab to trim out the aerodynamic forces on the elevator was measured with power on and power off in the clean condition. The variation of elevator force with tab deflection in steady straight flight at several speeds throughout the speed range is shown in figure 14. The tab was sufficiently effective to trim out the elevator forces throughout the speed range in steady straight flight in all conditions.

Trim changes.- The longitudinal trim changes due to changing configuration were measured in steady straight flight at 140 miles per hour. The airplane was trimmed at 140 miles per hour with the flaps and landing gear up and with the engines delivering approximately 1/2 power (18 inches Hg. manifold pressure, 2550 rpm). Records were taken of the elevator control force after varying the power, flaps, and gear settings without altering the trim-tab settings. The results of the trim-change tests are presented in table III. None of the combinations tested produced over 41 pounds of stick force and therefore it is believed that the effect of changing any one variable would not exceed the specified limit of 50 pounds for wheel type of controls. However, in the pilot's opinion, it is undesirable for trim changes, even of the magnitude measured for this airplane, to be in the nose-up direction for lowering the flaps and gear, because of the possibility of inadvertent and rapid loss in speed. It should be noted that the trim changes encountered in accomplishing a wave-off added up favorably; that is, from an approach at 120 miles per hour with partial power and flaps and gear down, it was possible to add power, retract the gear and flaps, and be trimmed approximately for the climb-out without altering the elevator-trim-tab setting.

The trim changes were not measured in the same manner as in reference 5, but where comparison is possible, the agreement is very good.

<u>Stalling characteristics</u>.- Time histories of stalls in straight flight in five configurations are shown in figure 15 at center of gravity of 17.2 percent M.A.C., wheels up, and 19.5 percent M.A.C., wheels down. The margin of speed at which warning was noted was taken from the pilot's notes.

In the clean condition with normal rated power, increasing buffeting began about 5 to 10 miles per hour above the stall, becoming violent at the stall. Following the stall, which occurred in a steep nose-up attitude, the airplane nosed down with no tendency to roll. The force required to move the elevator up increased rapidly following the onset of buffeting.

With power off in the clean condition buffeting again preceded the stall by about 5 miles per hour. The stall was characterized by sudden settling and was accompanied by heavy buffeting and mild nose-down pitching with little tendency to roll. Although the elevator force gradient below trim speed was positive, it was small.

In the wave-off condition buffeting began about 10 miles per hour before the stall and became very severe with considerable forced motion of the elevator. In the case of the time history shown the pilot did not actually go to the stall because of the heavy buffeting. At the stall the airplane nosed down with no appreciable rolling and with heavy buffeting. Longitudinal stick-free stability below trim was low and the forces lightened before the stall.

In the landing and approach configurations heavy buffet began almost simultaneously with the stall. The airplane nosed down with very little tendency to roll. The elevator force gradient below trim was low. The stall warning in these configurations was considered insufficient. In the landing condition closing the cowl flaps from the trail position resulted in less nose-down pitching and less buffeting at the stall.

In all cases recovery from stalls was easily made by normal use of the controls, but it was usually necessary to increase speed about 10 miles per hour over stalling speed to complete the recovery.

Stalls in turning flight were generally similar to those in straight flight. The airplane nosed down with no appreciable roll, and buffeting during the stall was severe in most cases. Time histories of stalls from turns in the clean, normal-rated-power and the approach conditions are given in figure 16.

CONCLUSIONS

Longitudinal stability and control tests of a C-54D airplane led to the following conclusions:

1. Both the dynamic and static longitudinal stability were found to be satisfactory.

2. The elevator force per g in turning flight exceeded the maximum allowed as specified in the Air Force and Navy handling-qualities requirements in all conditions.

3. For normal operating conditions where the center of gravity is near the rearward limit, the take-off characteristics were found to be satisfactory. The elevator, however, apparently was not sufficiently powerful to raise the nose wheel during a take-off at 0.80 the landing-condition stalling speed with a forward center-of-gravity position.

4. The elevator fulfilled power-off landing requirements at the forward center-of-gravity position, but during such landings, the elevator forces were about 60 percent greater than the specified maximum of 50 pounds.

5. The trim characteristics were satisfactory throughout the speed range in all conditions.

6. The stalling characteristics were good except that, in the landing and the approach conditions, the stall warning (which was in the form of buffeting) did not occur at a speed sufficiently above the stall to meet the Air Force and Navy handling-qualities requirements.

7. The control friction was found to be approximately twice that specified by the Air Force and Navy requirements, but a large part of this friction was caused by the servos in the autopilot system. The effects of this friction have been previously investigated and reported.

8. The airplane was designed as a commercial airplane prior to the release of the present Air Force and Navy handling-qualities requirements and CAA airworthiness requirements. Although the airplane does not meet all the stability and control requirements of the Air Force and Navy, it does meet the requirements of the CAA.

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2. Talmage, Donald B., and Reeder, John P.: Lateral and Directional Stability and Control Characteristics of a C-54D Airplane. NACA RM L8K30, 1949.

3. Talmage, Donald B., and Reeder, John P.: The Effects of Friction in the Control System on the Handling Qualities of a C-54D Airplane. NACA RM L8G30a, 1948.

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

5. Edholm, Robert M., Cokeley, Edmond R., Hall, Clarence, Jr., and Payne, Louis A.: Stability and Control Flight Tests on the C-54G Airplane, AAF No. 45-477, MR No. TSFTE-2025, Air Materiel Command, Army Air Forces, Nov. 1, 1946.

6. Anon: Civil Air Regulations Amendment 04b-0. Part 04 - Airplane Airworthiness, Transport Categories. CAB, Nov. 9, 1945, regulation 04.1331(b).

TABLE I

Control	Control friction		
	On ground (lb)	In flight (lb)	Requirements[1] (lb)
Elevator	14 ± 1.5	15 ± 4	8
Aileron	13 ± 1	12 ± 2	6
Rudder	22 ± 3	30 ± 4	15

[1]Reference 4.

TABLE II

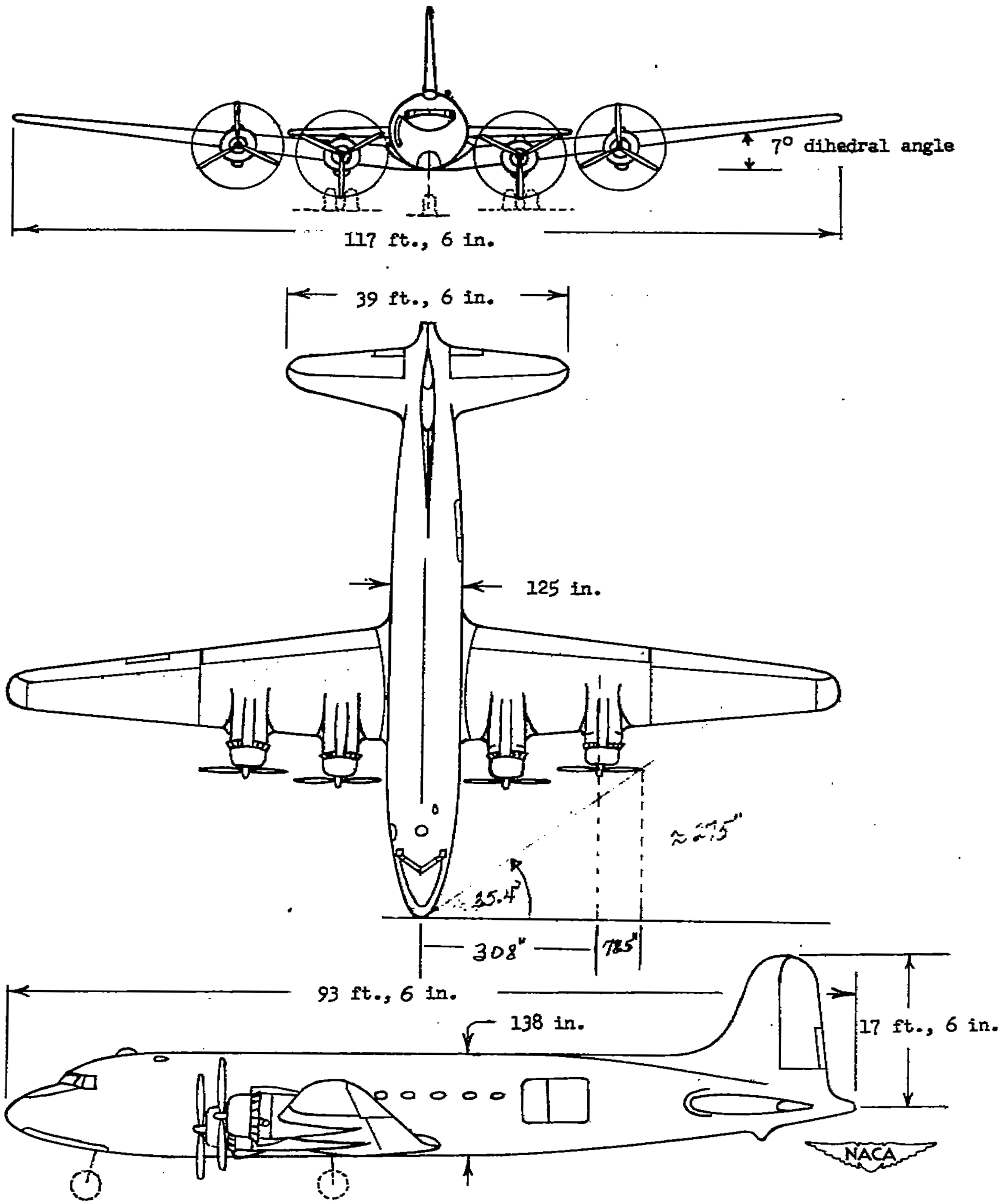
Configuration	Engine power	Flap position	Landing-gear position
Clean, normal rated power	41 in. Hg, 2550 rpm (Normal rated power)	up	up
Clean, power off	Idling	up	up
Wave off	41 in. Hg, 2550 rpm (Normal rated power)	40° (full down)	down
Landing	Idling	40° (full down)	down
Approach	20 in. Hg, 2550 rpm	20°	down

TABLE III

Condition	Elevator force (lb)
Trim, 140 mph; 18 in. Hg, 2550 rpm, flaps and gear up	0
140 mph, normal rated power, flaps and gear up	22.5 push
140 mph, normal rated power, flaps up, gear down	30.5 push
140 mph, normal rated power, flaps 20° down, gear down	38 push
140 mph, normal rated power, flaps 40° down, gear down	41 push
140 mph, power off, flaps 40°, gear down	30.5 push
140 mph, power off, flaps and gear up	32.5 pull

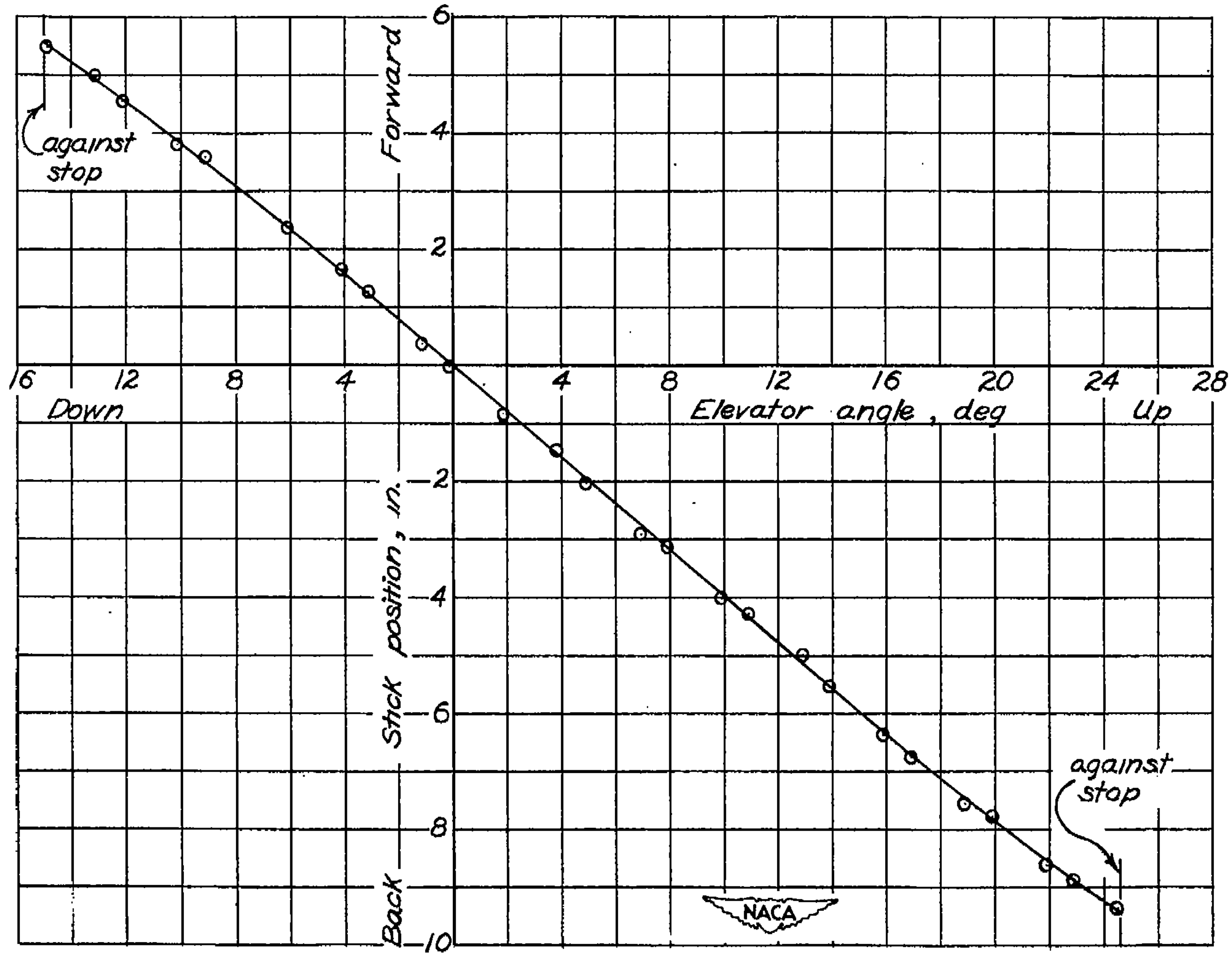
(a) Photograph.

Figure 1.— C-54D test airplane.



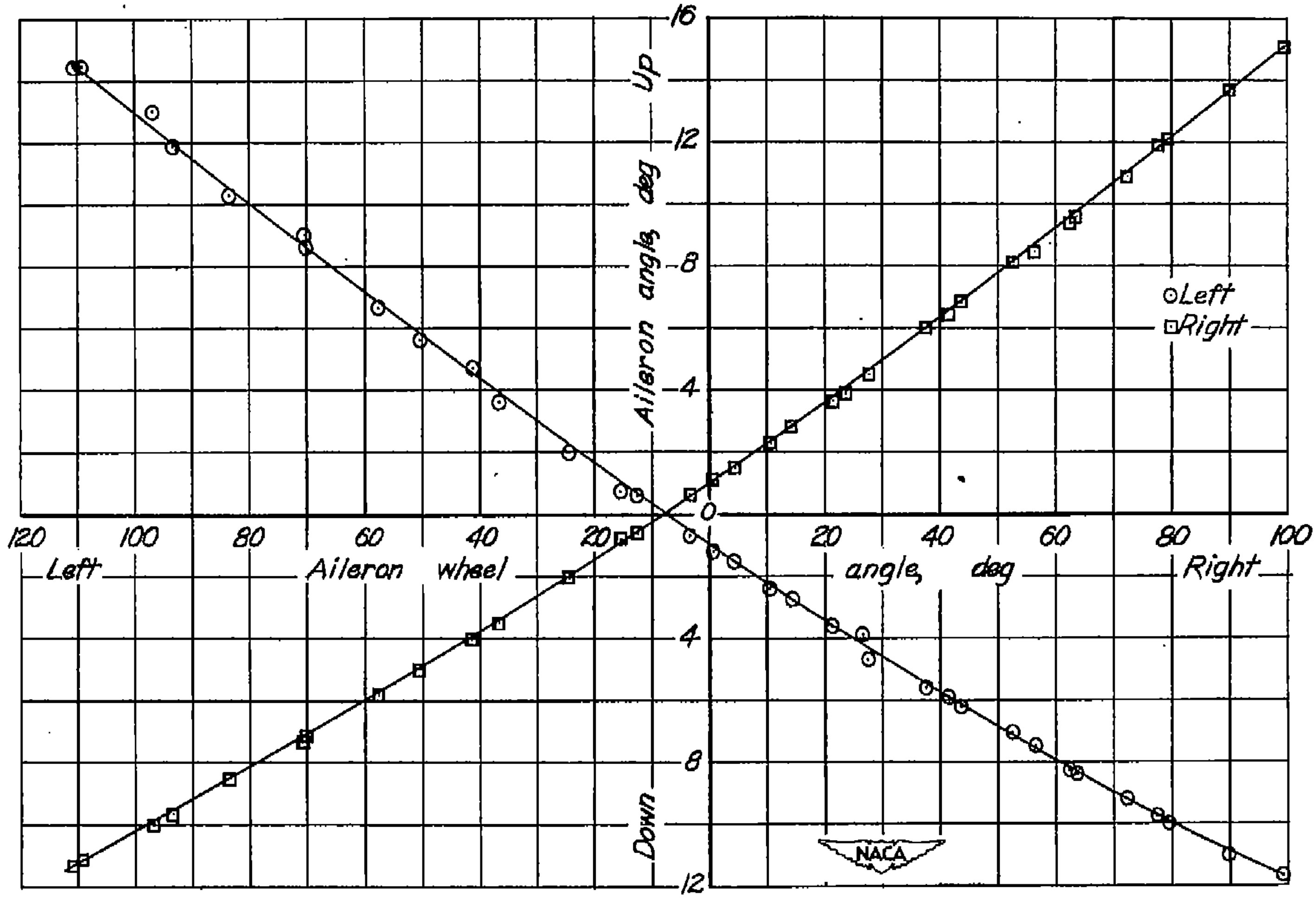
(b) Three—view drawing.

Figure 1.— Concluded.



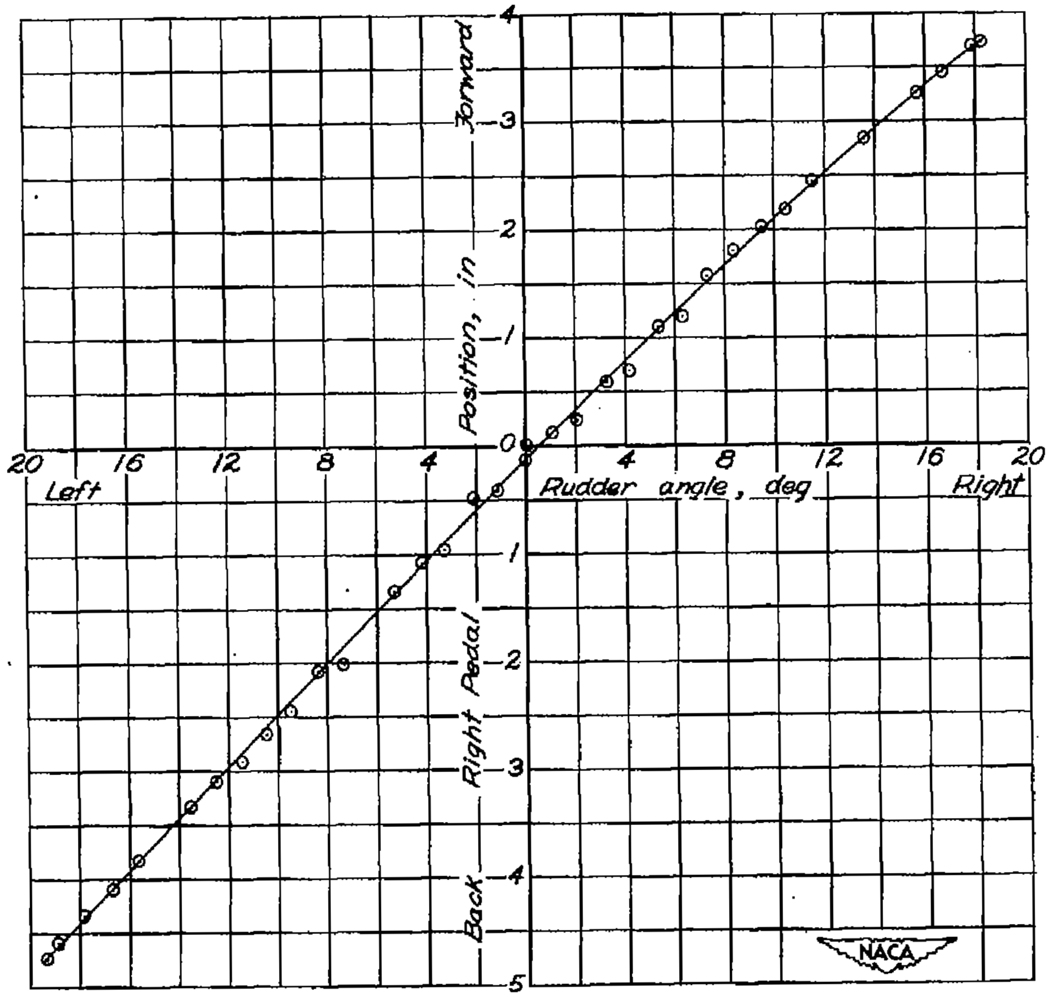
(a) Elevator control.

Figure 2.– Control linkage with no load. C-54D airplane.



(b) Aileron control.

Figure 2.– Continued.



(c) Rudder control.

Figure 2.- Concluded.

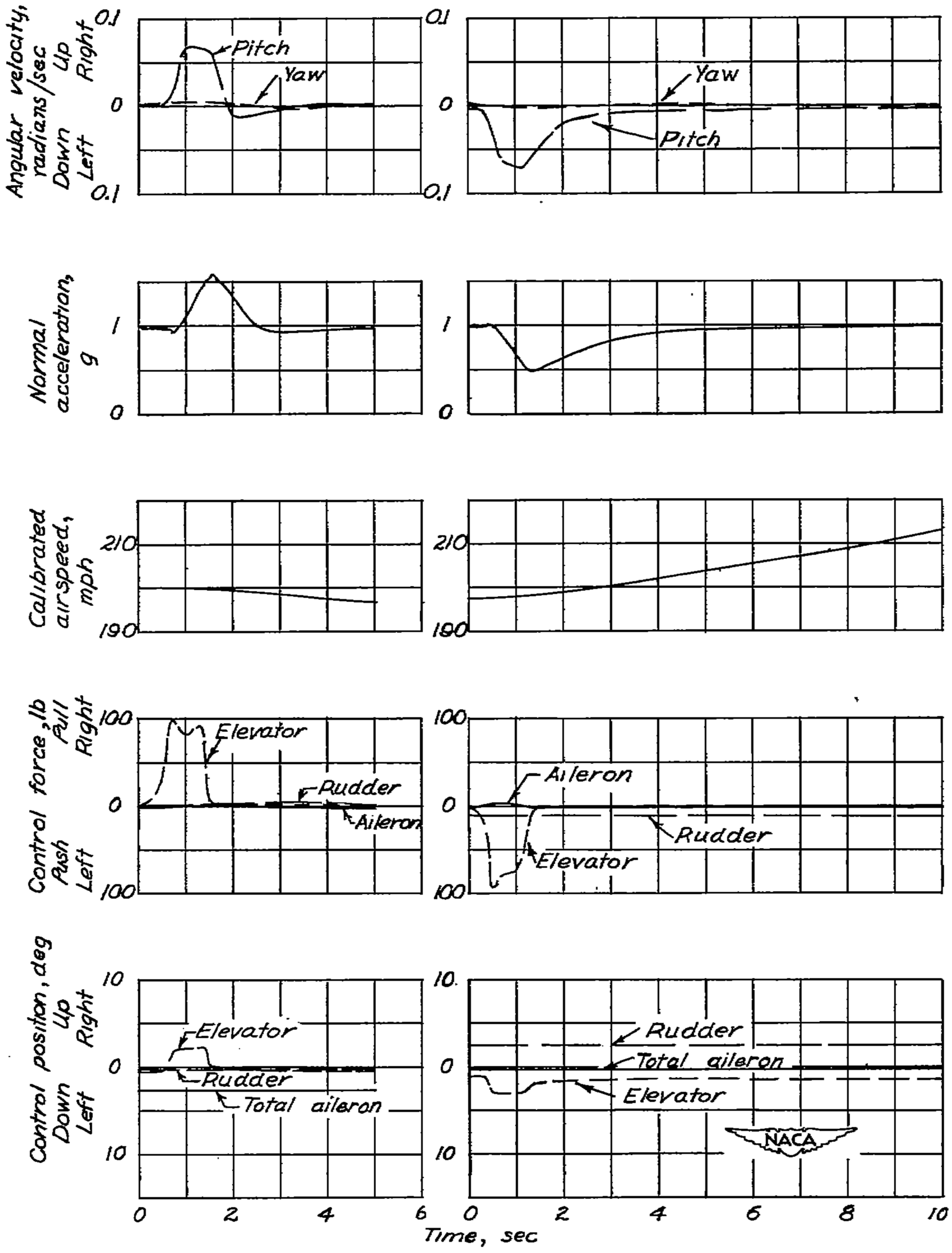
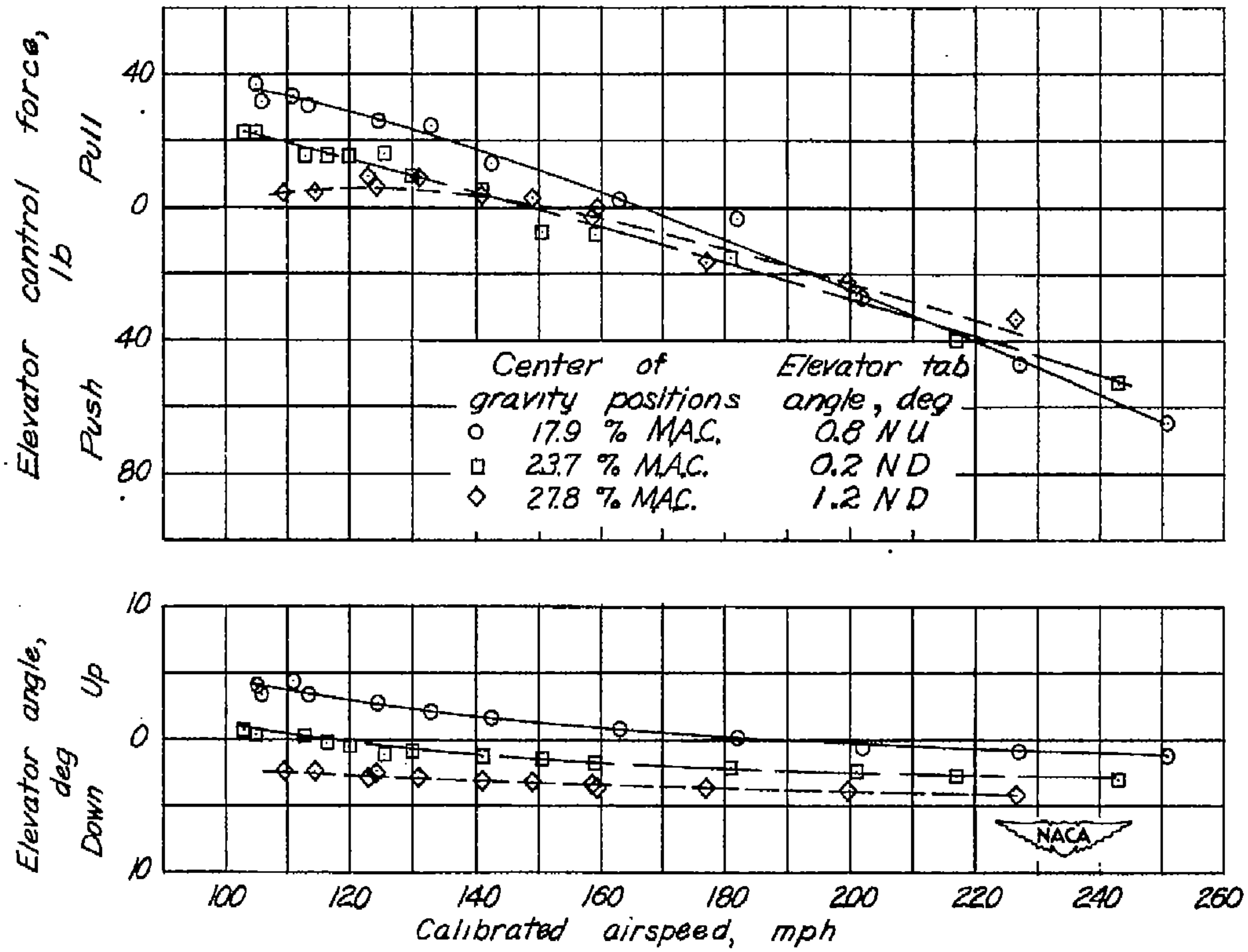
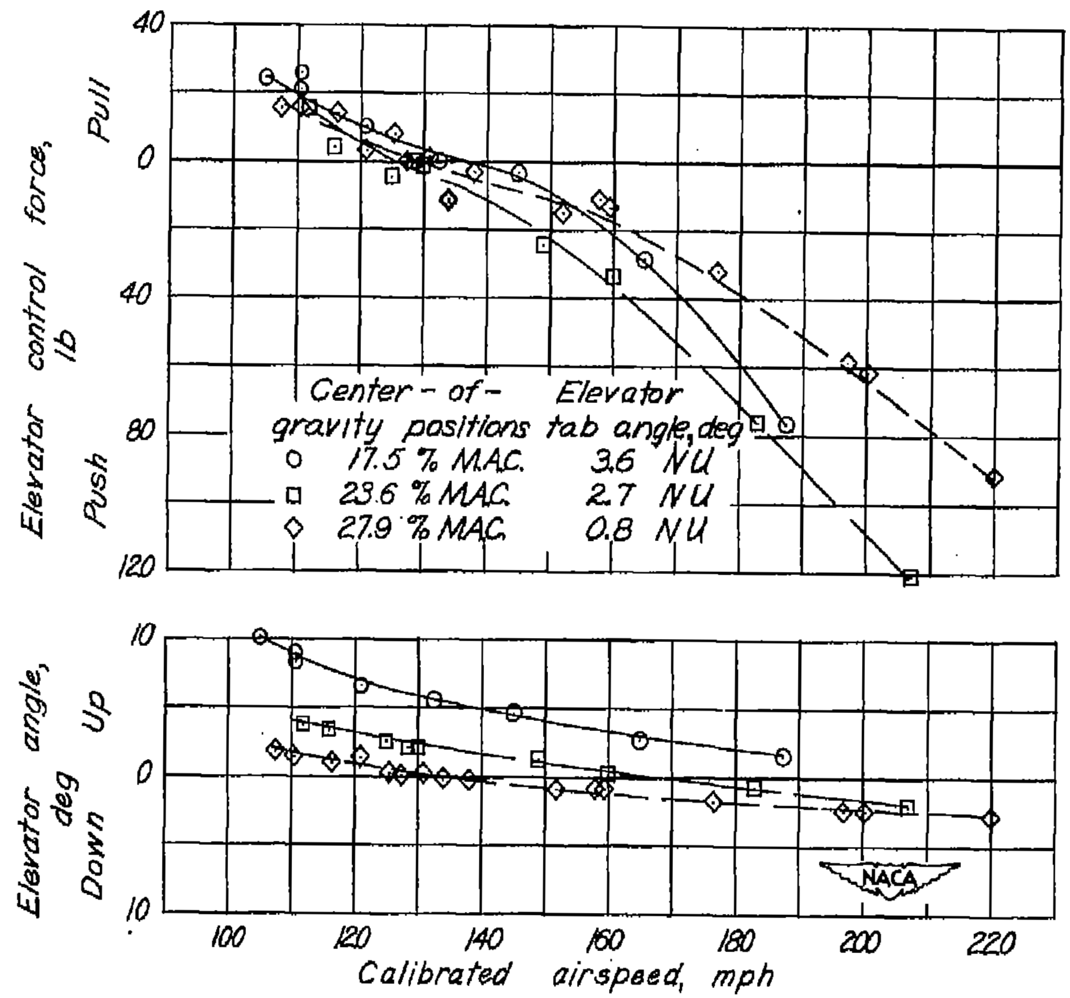


Figure 3.— Short-period longitudinal oscillations. C-54D airplane; clean condition; 200 miles per hour.



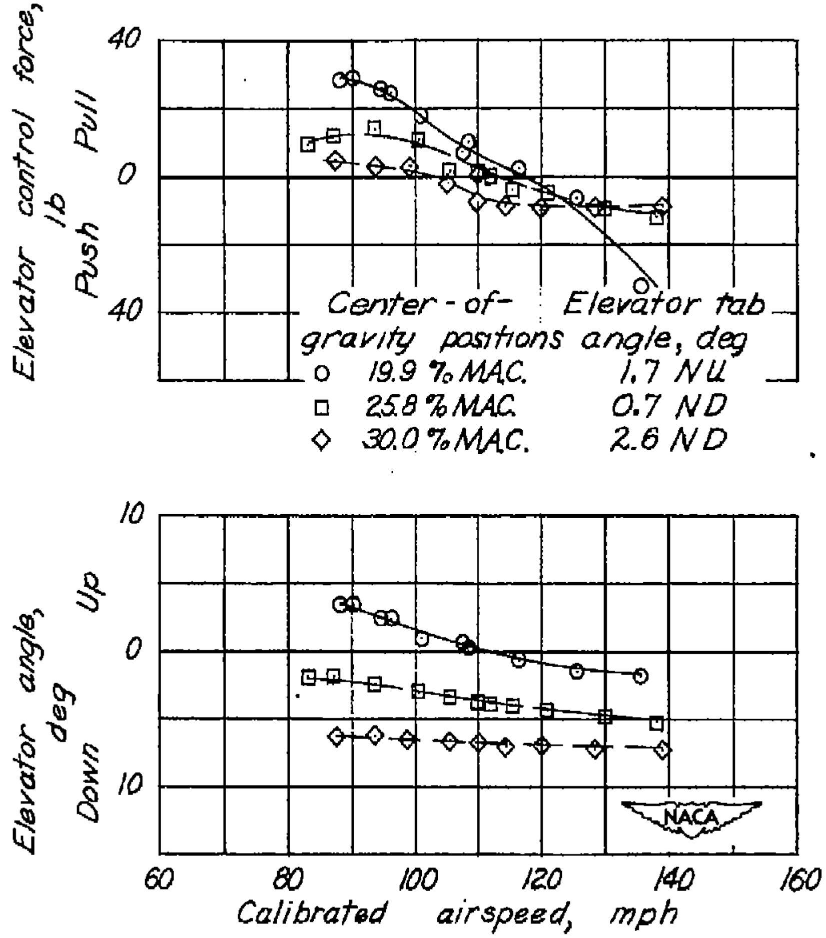
(a) Clean condition normal rated power.

Figure 4.– Static longitudinal stability characteristics of a C-54D airplane.



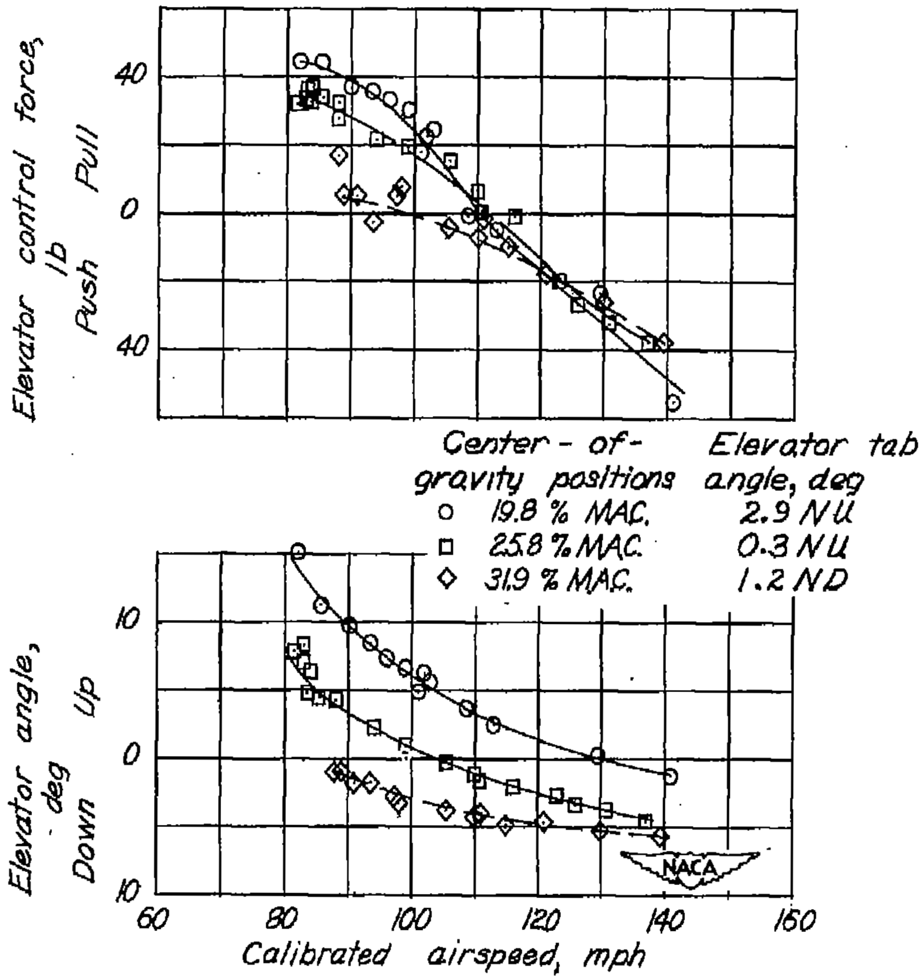
(b) Clean condition; engines idling.

Figure 4.– Continued.



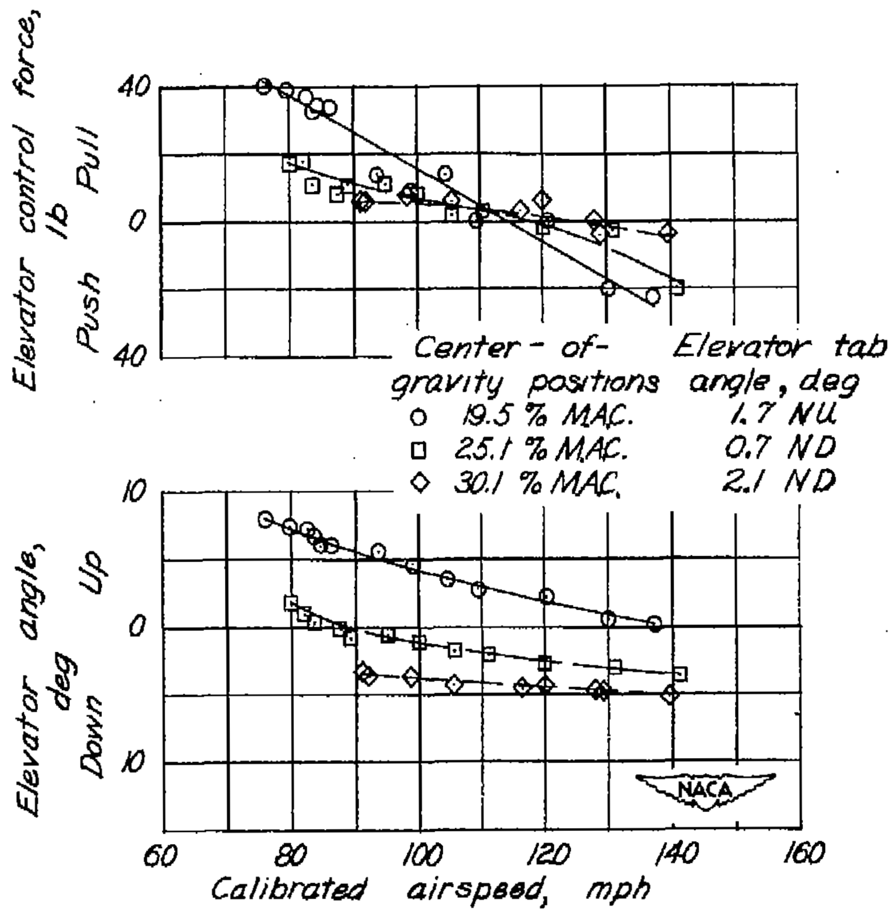
(c) Wave-off condition; flaps full down; gear down; normal rated power.

Figure 4.– Continued.



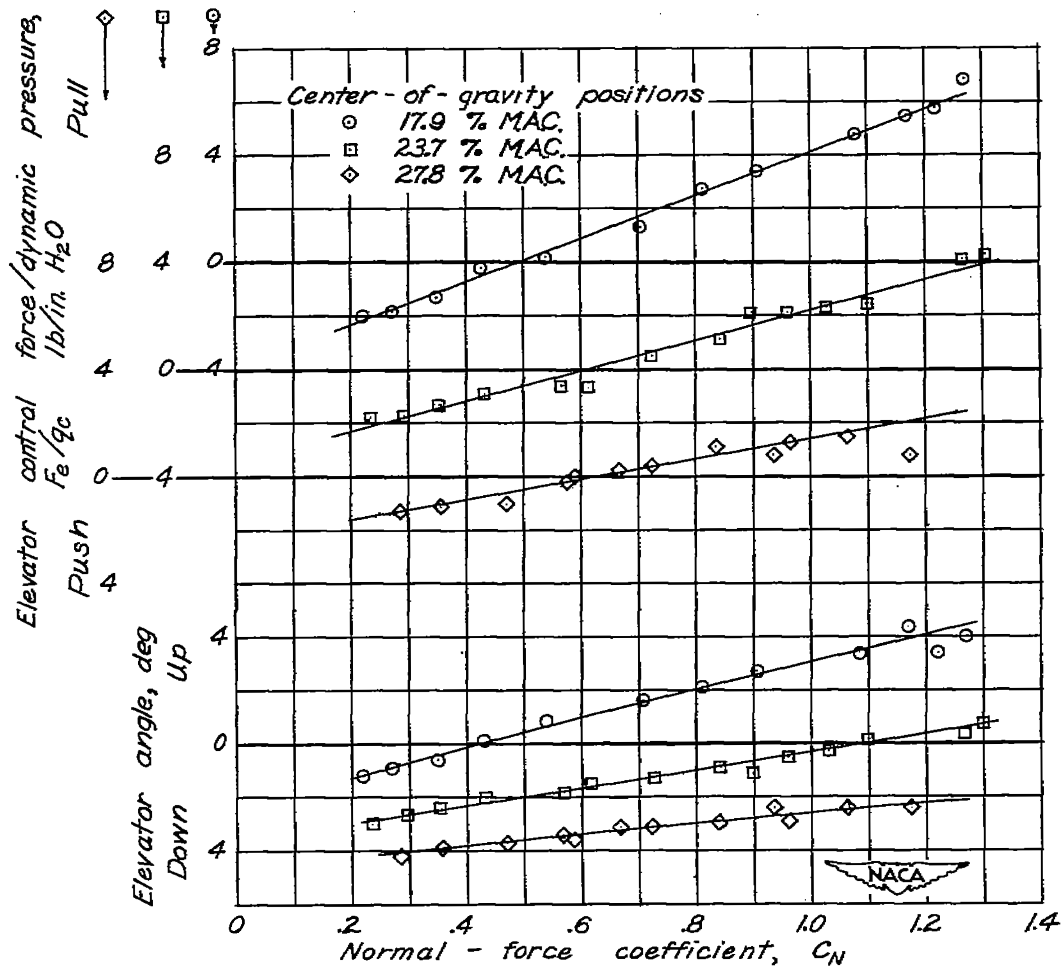
(d) Landing condition; flaps full down; gear down; engines idling.

Figure 4.– Continued.



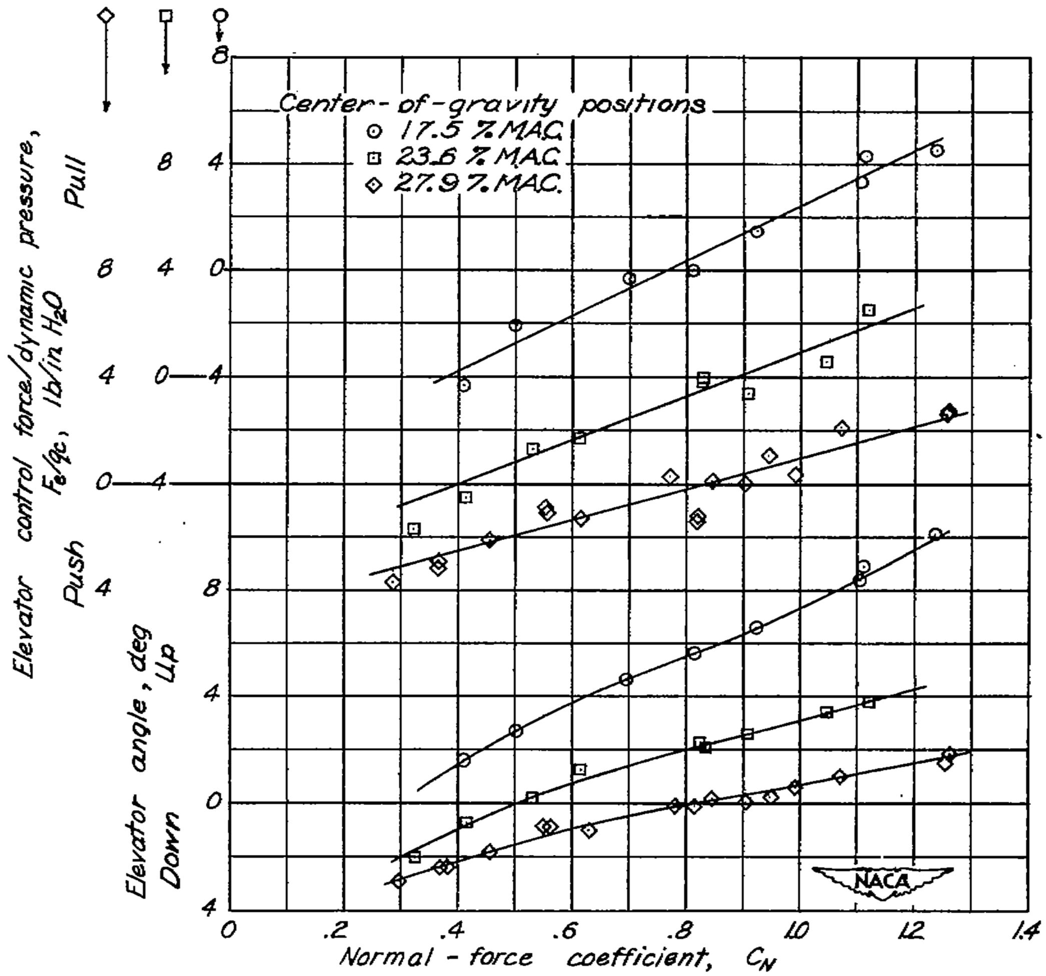
(e) Approach condition; flaps 20° down; gear down; power 20 in. Hg; 2550 rpm.

Figure 4.– Concluded.



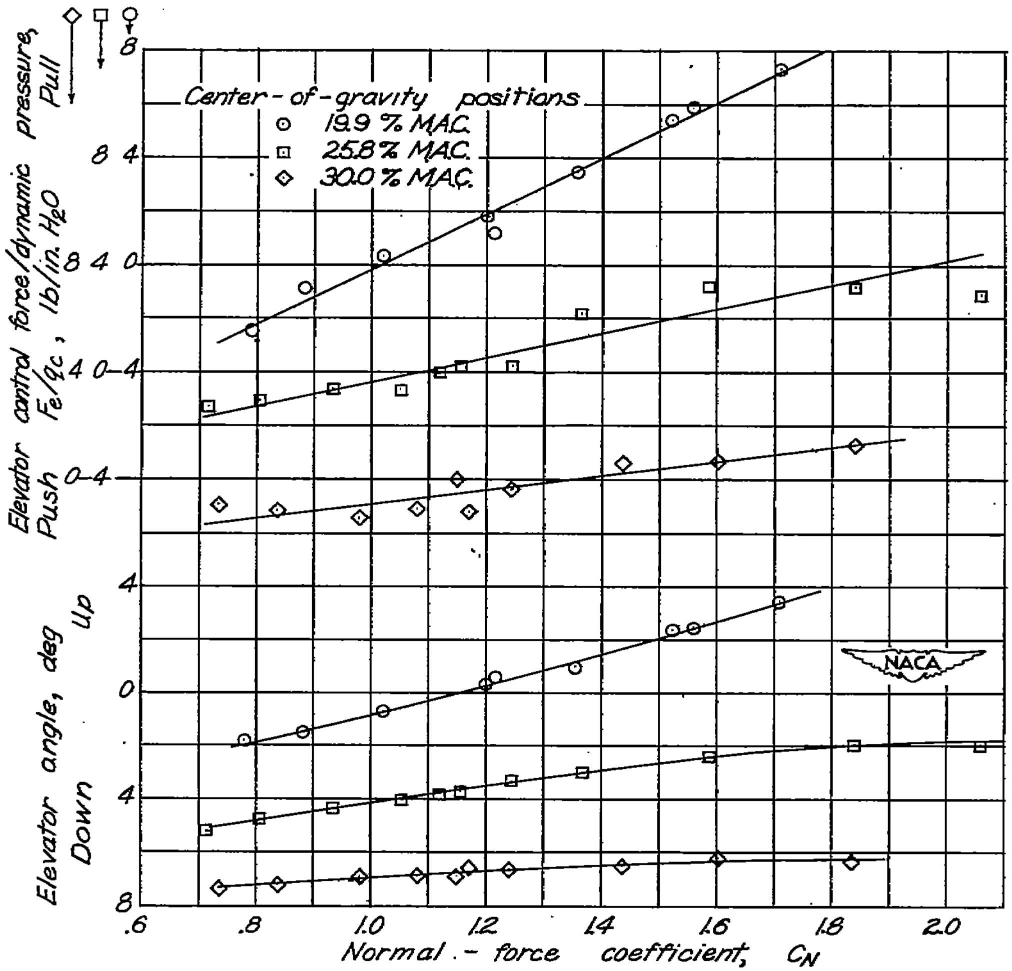
(a) Clean condition; normal rated power.

Figure 5.– Variation of elevator angle and elevator stick-force parameter, Fe/qc, with normal-force coefficient. C-54D airplane.



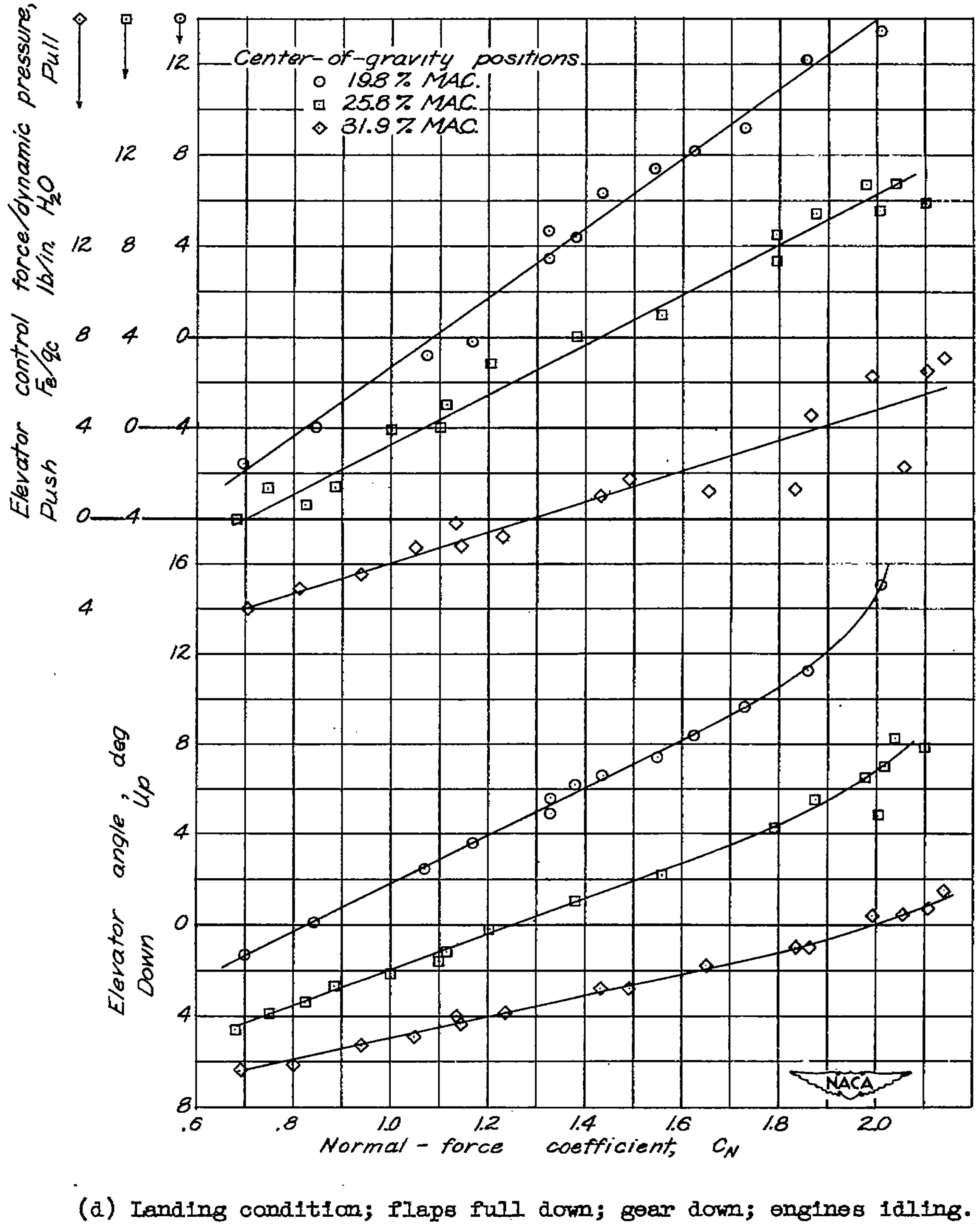
(b) Clean condition; engines idling.

Figure 5.– Continued.



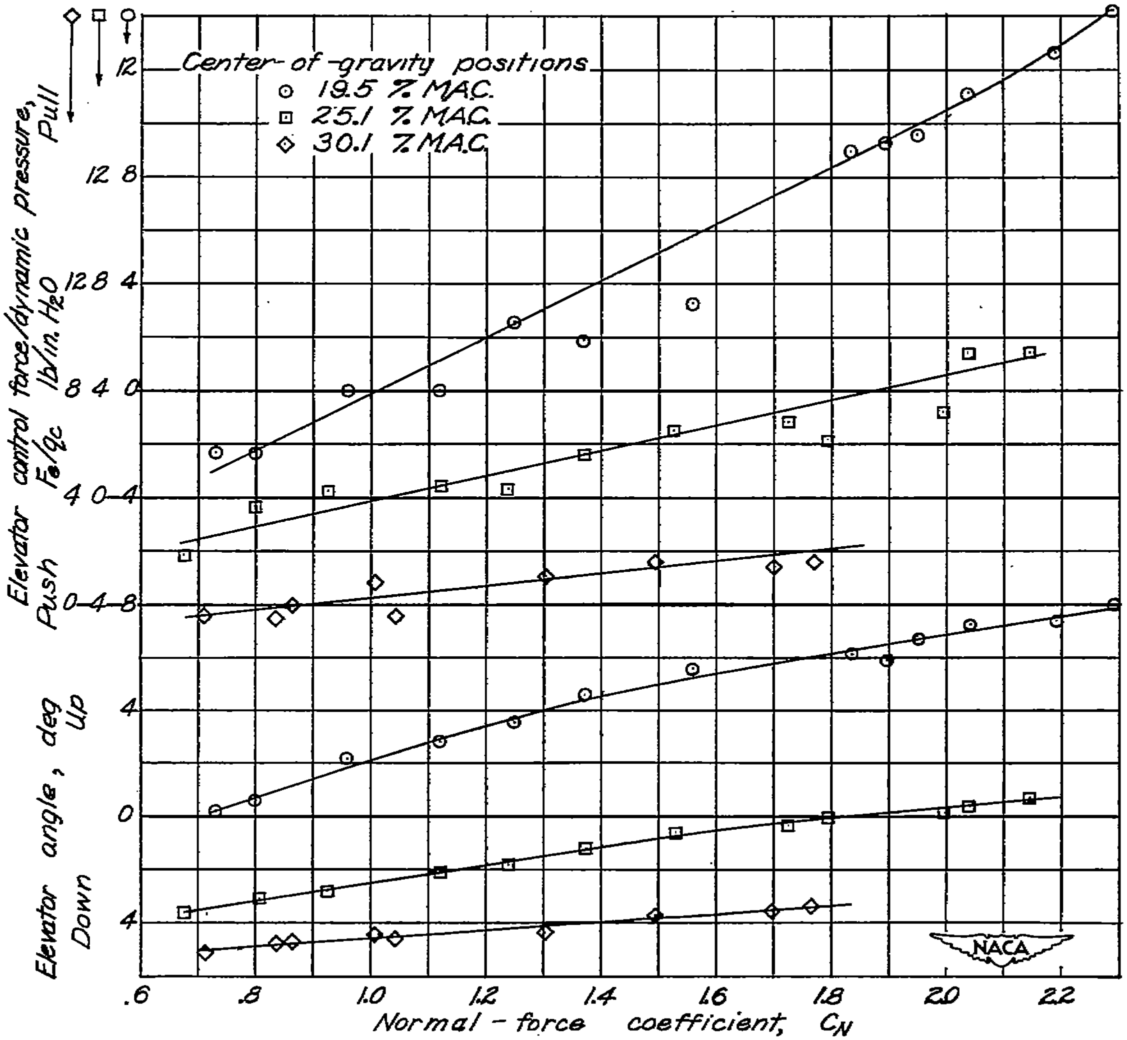
(c) Wave-off condition; flaps full down; gear down; normal rated power.

Figure 5.— Continued.



(d) Landing condition; flaps full down; gear down; engines idling.

Figure 5.– Continued.



(e) Approach condition; flaps 20° down; gear down; power 20 in. Hg; 2550 rpm.

Figure 5.– Concluded.

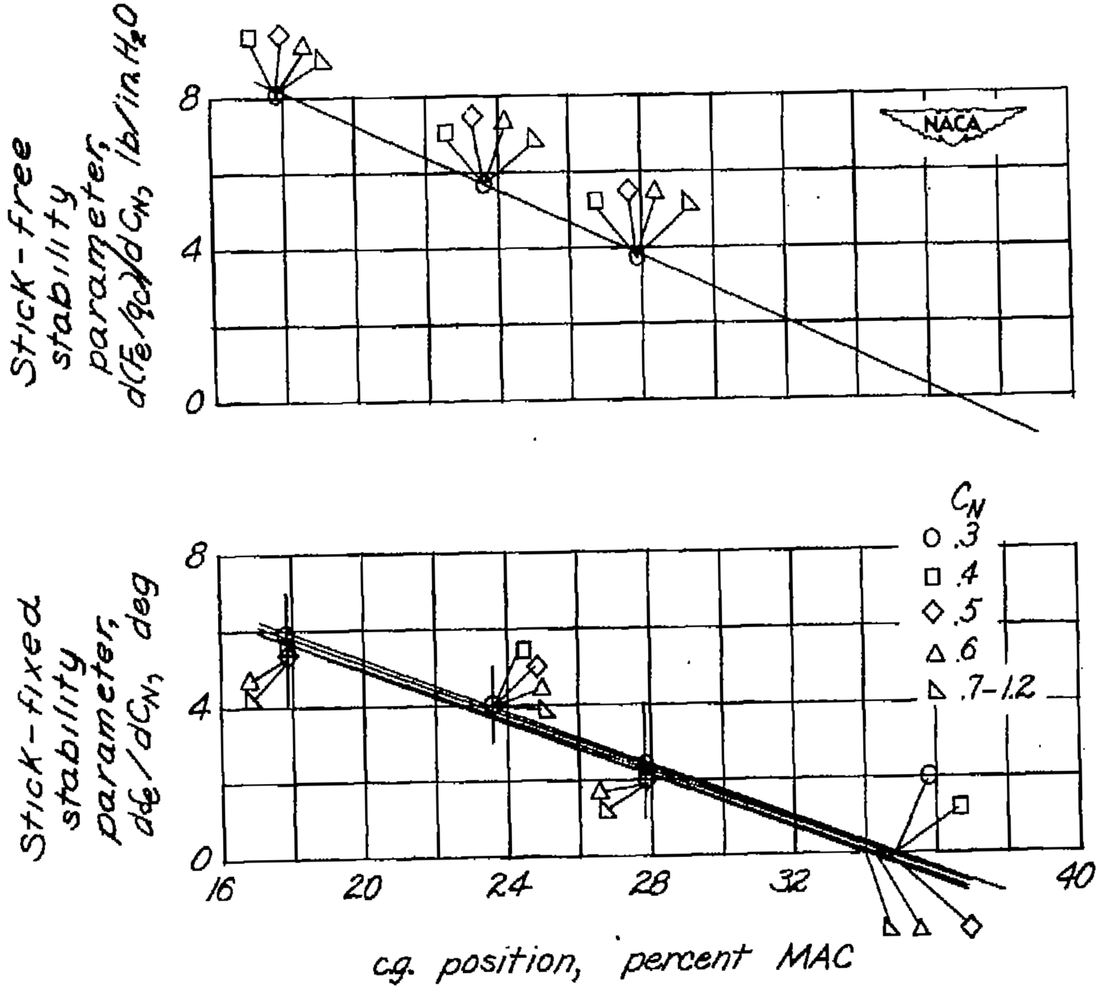
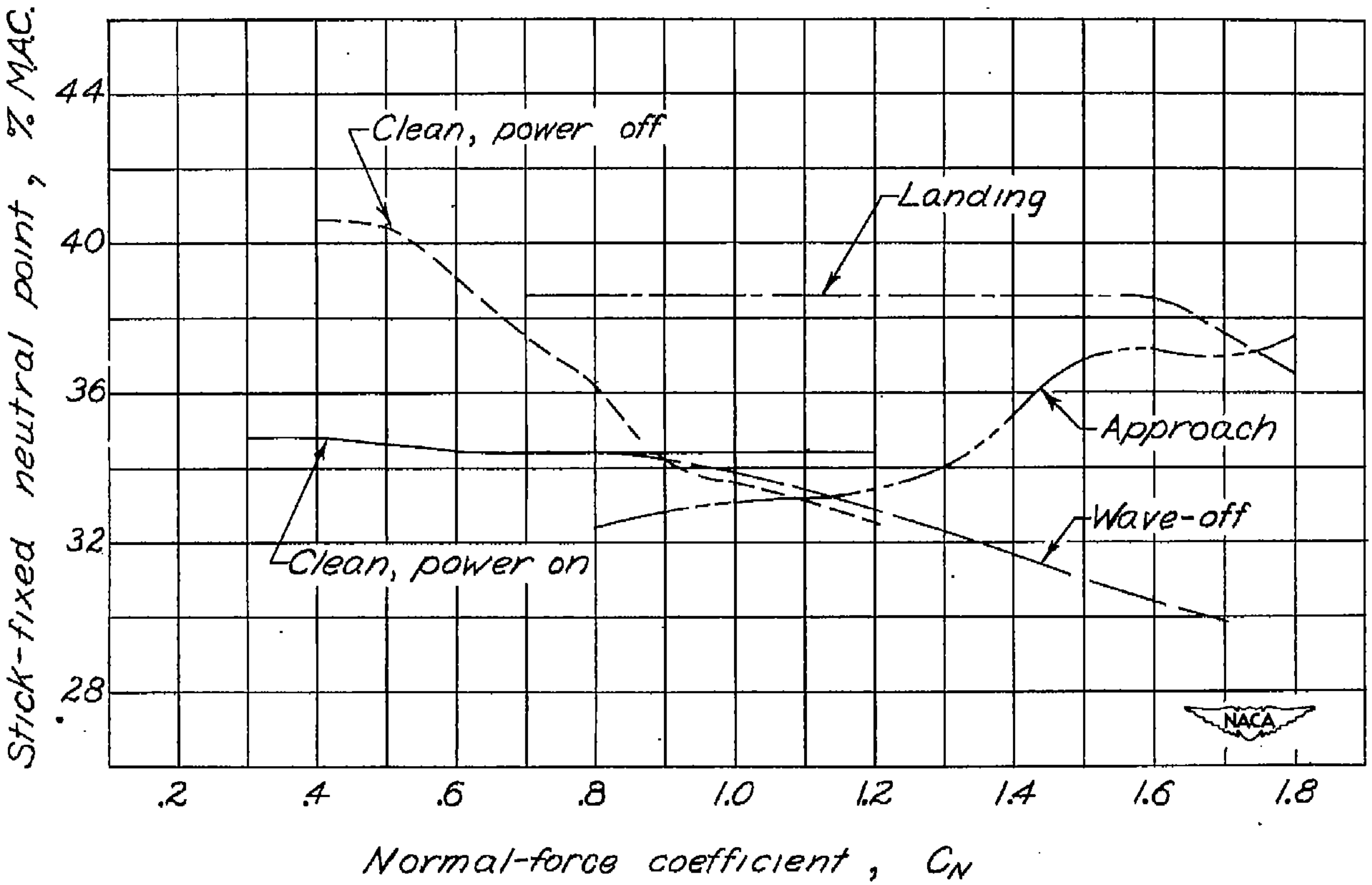
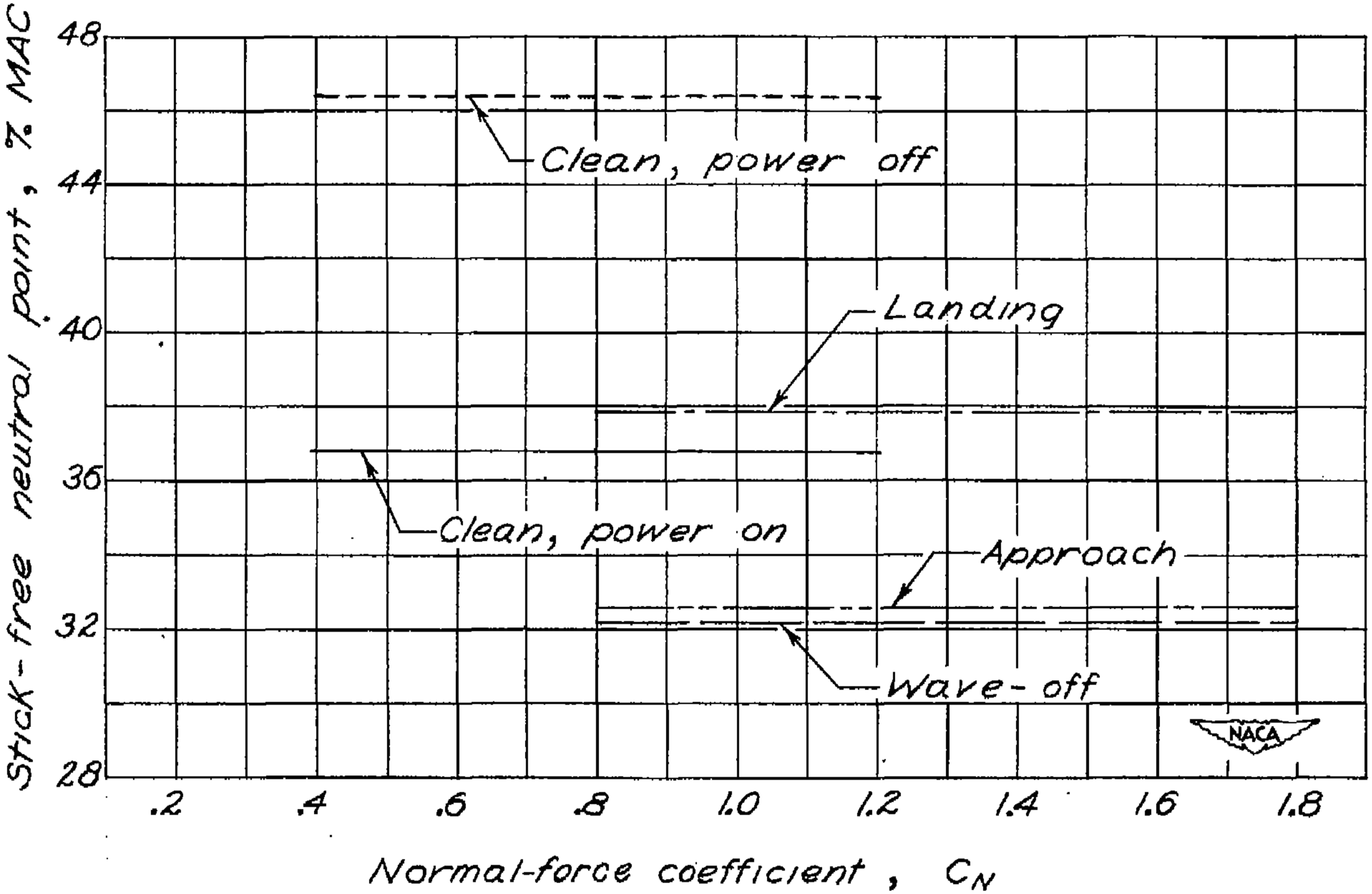


Figure 6.– Sample graphical determination of the stick-fixed and stick-free neutral points. Clean condition; power on; C-54D airplane.



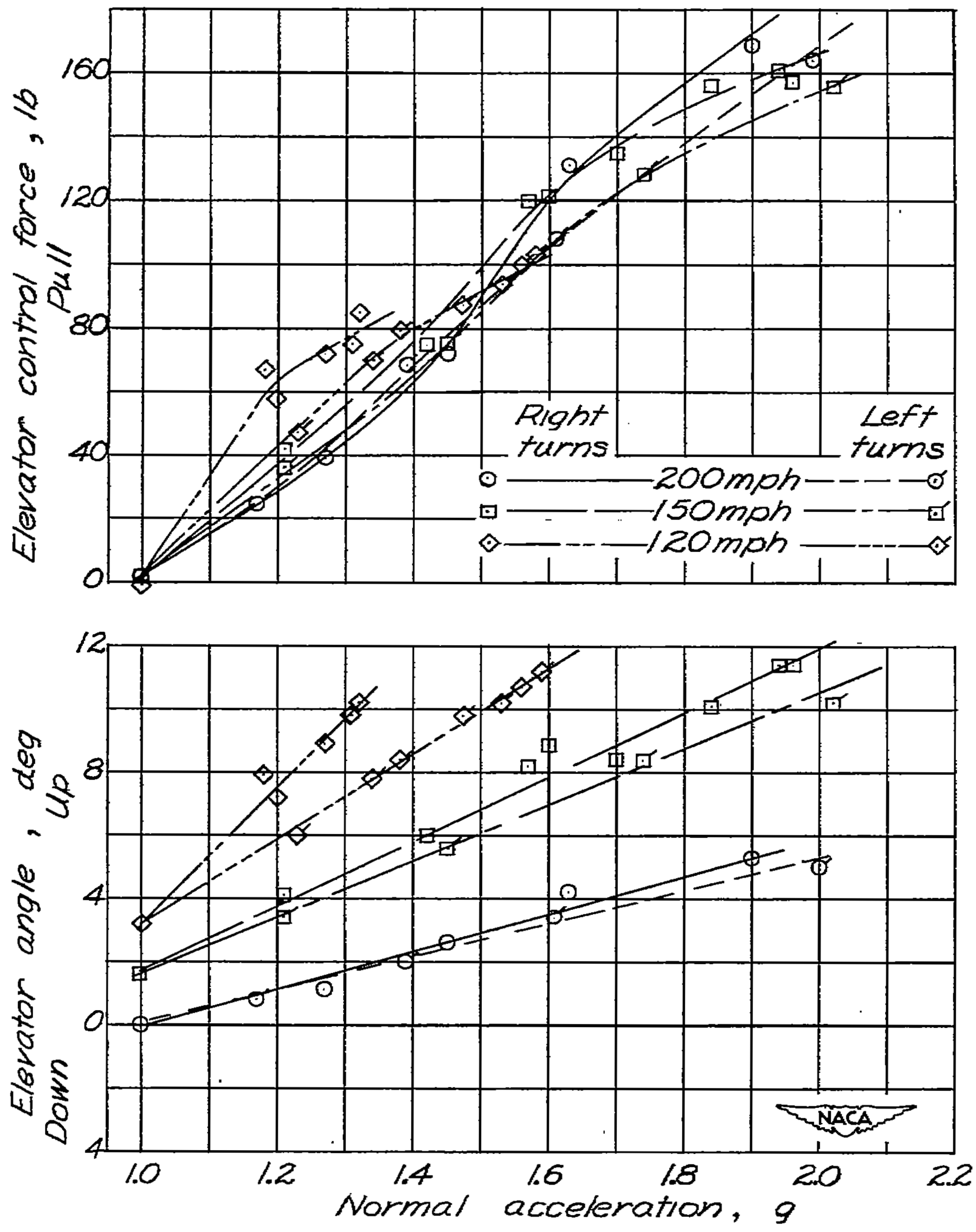
(a) Stick-fixed neutral points.

Figure 7.– Neutral-point variation with normal-force coefficient. C-54D airplane.



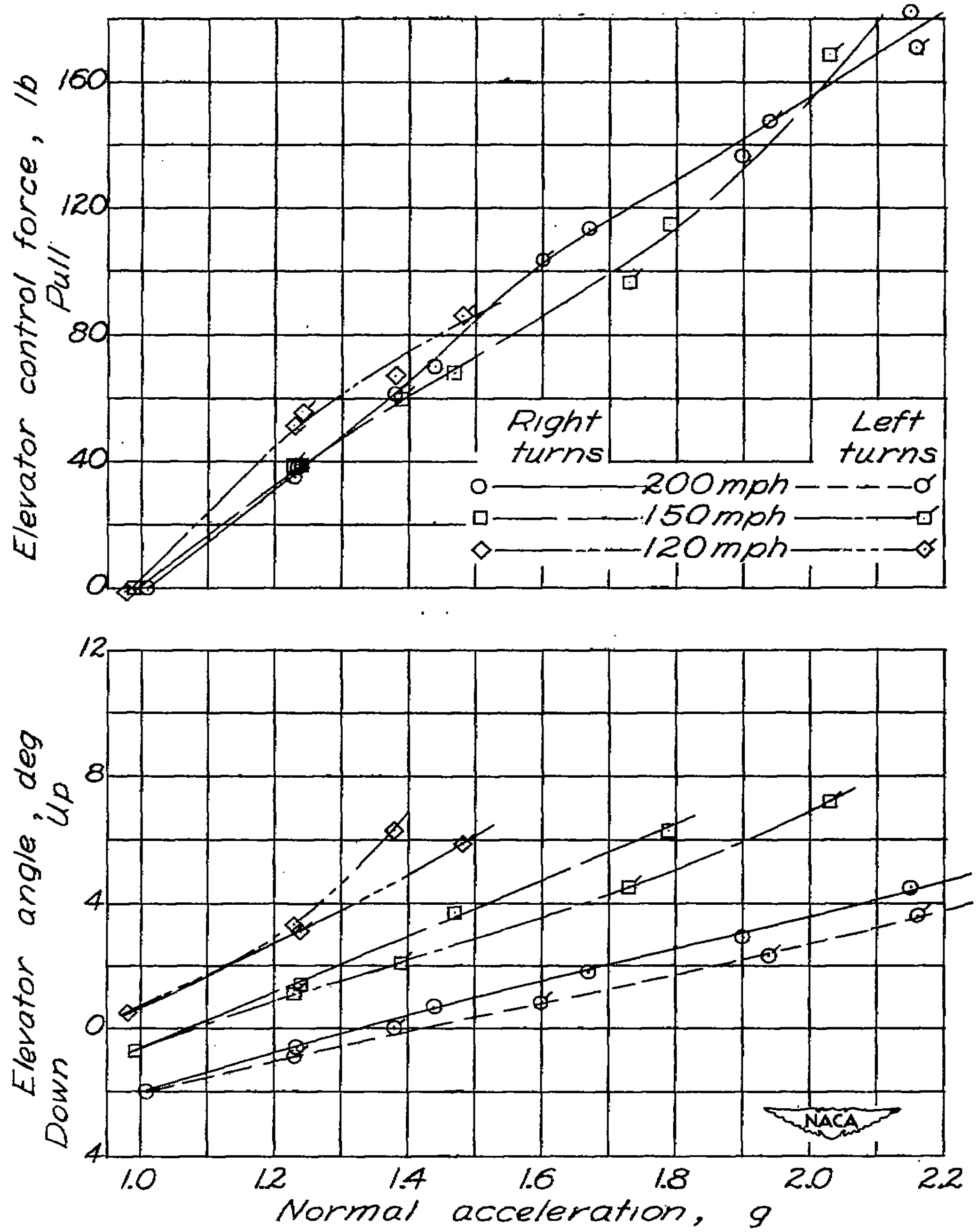
(b) Stick-free neutral-point variation.

Figure 7.– Concluded.



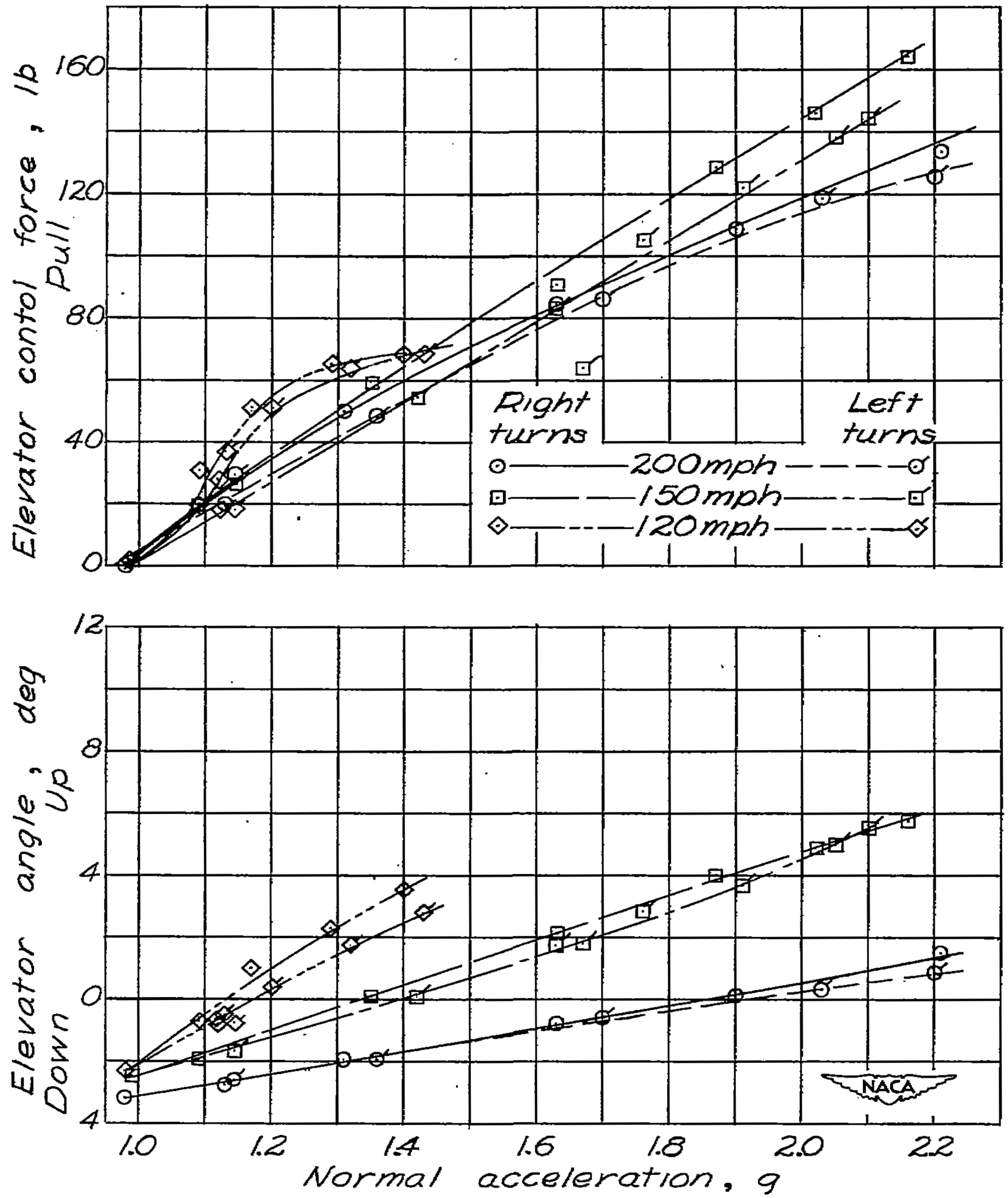
(a) Center of gravity at 16.8 percent M.A.C.

Figure 8.– Maneuvering stability characteristics as measured in stea turns. C-54D airplane; clean condition; power on.



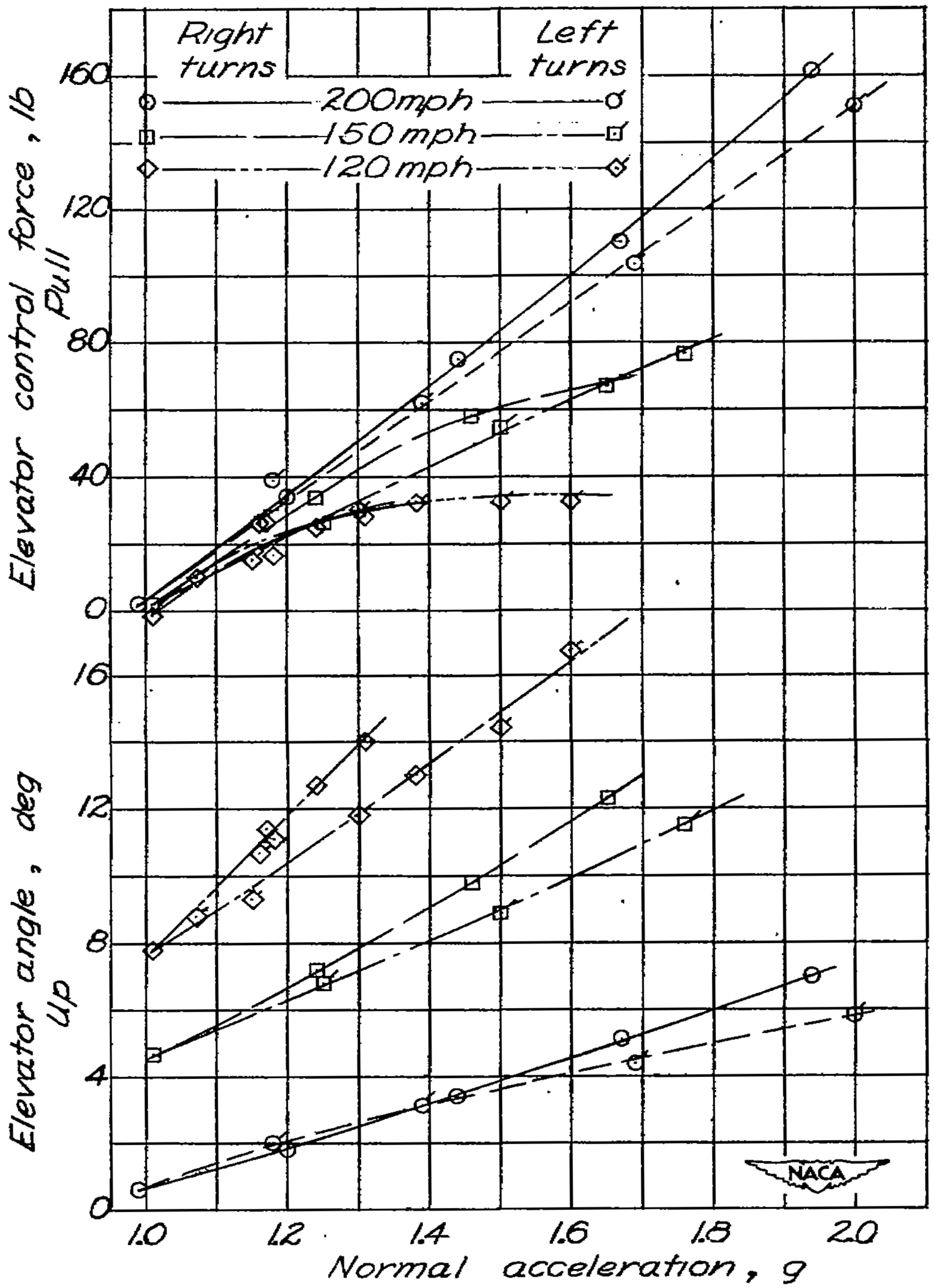
(b) Center of gravity at 23.1 percent M.A.C.

Figure 8.– Continued.



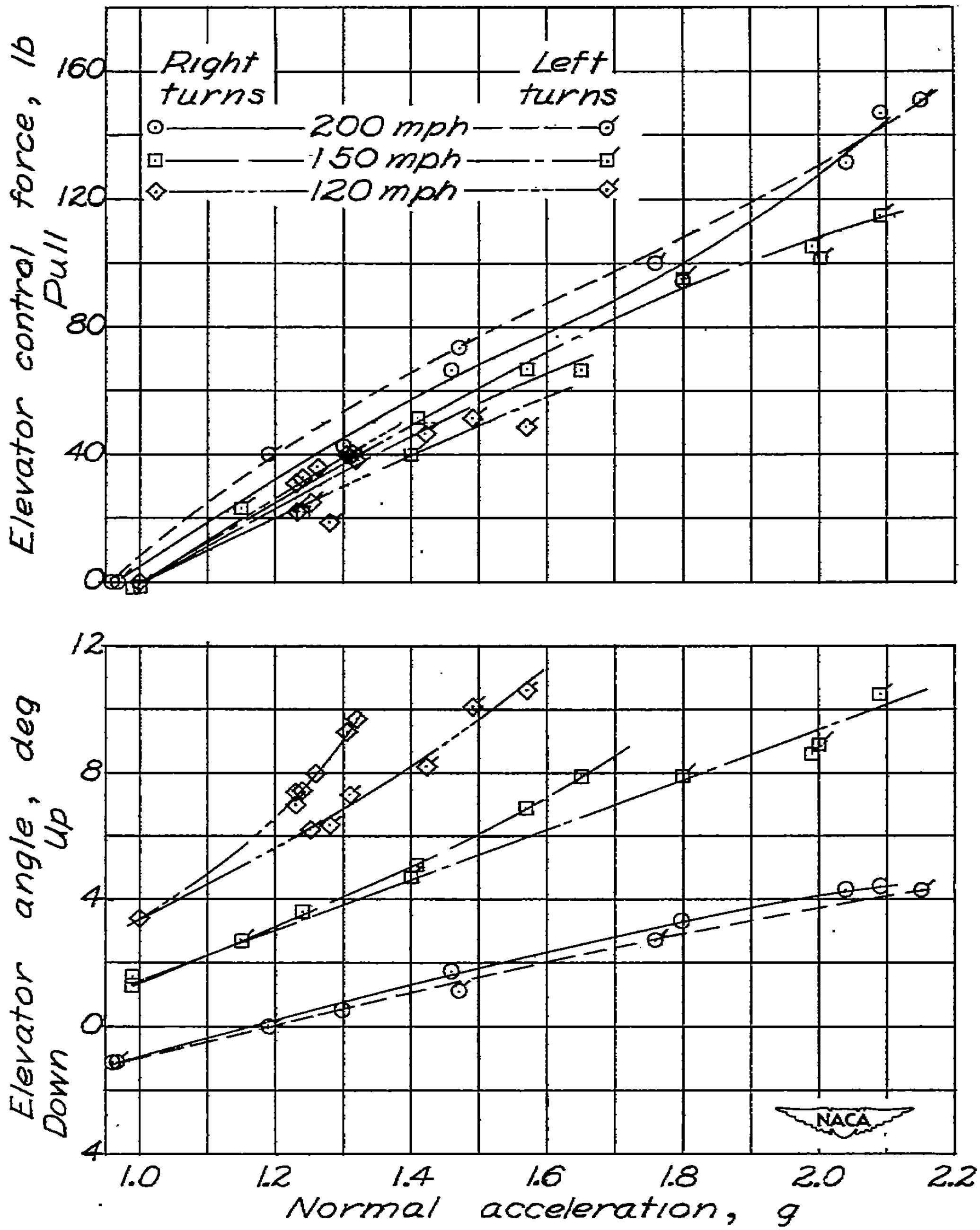
(c) Center of gravity at 27.9 percent M.A.C.

Figure 8.— Concluded.



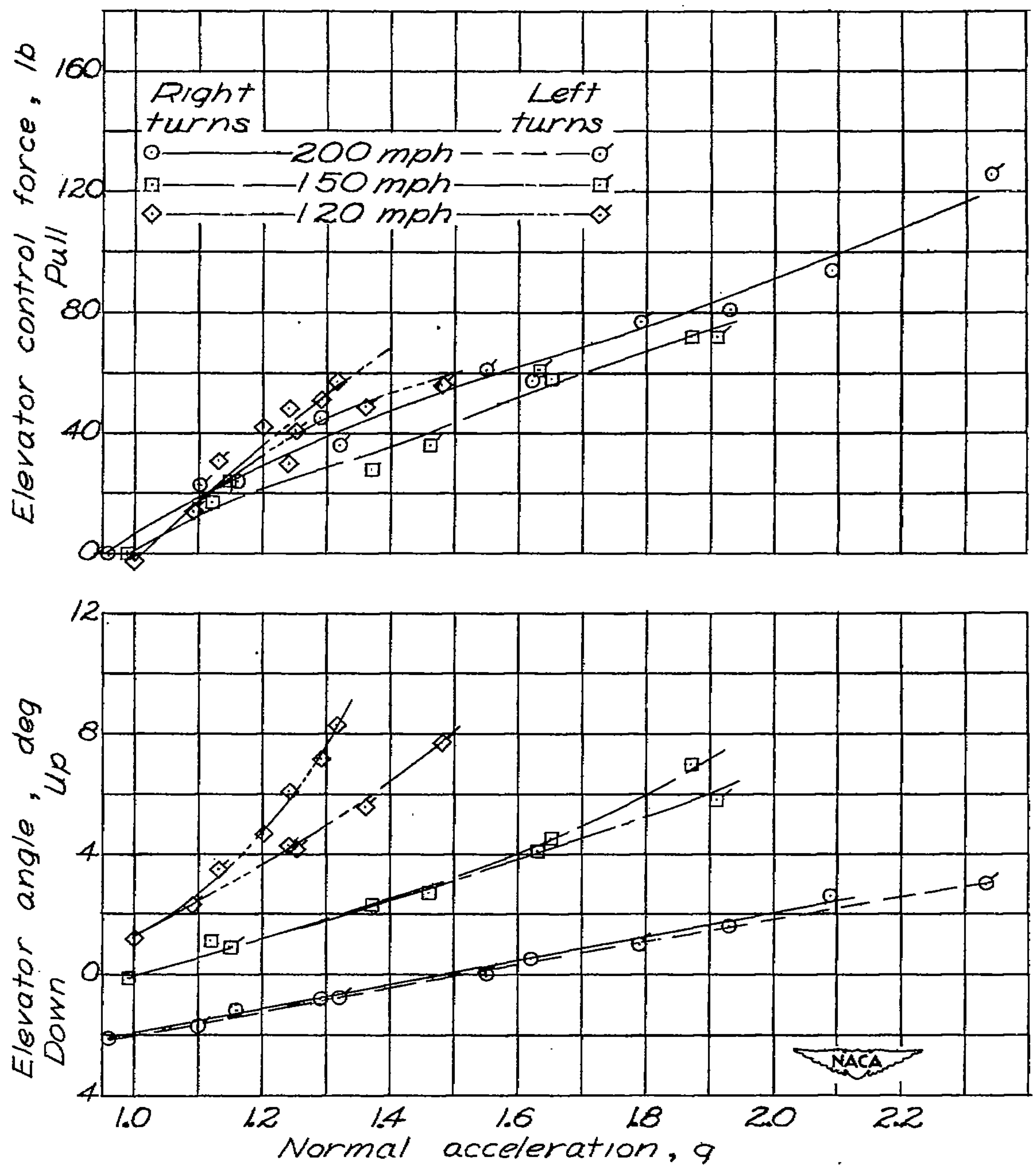
(a) Center of gravity at 16.7 percent M.A.C.

Figure 9.– Maneuvering stability characteristics as measured in steady turns. C-54D airplane; clean condition; power off.



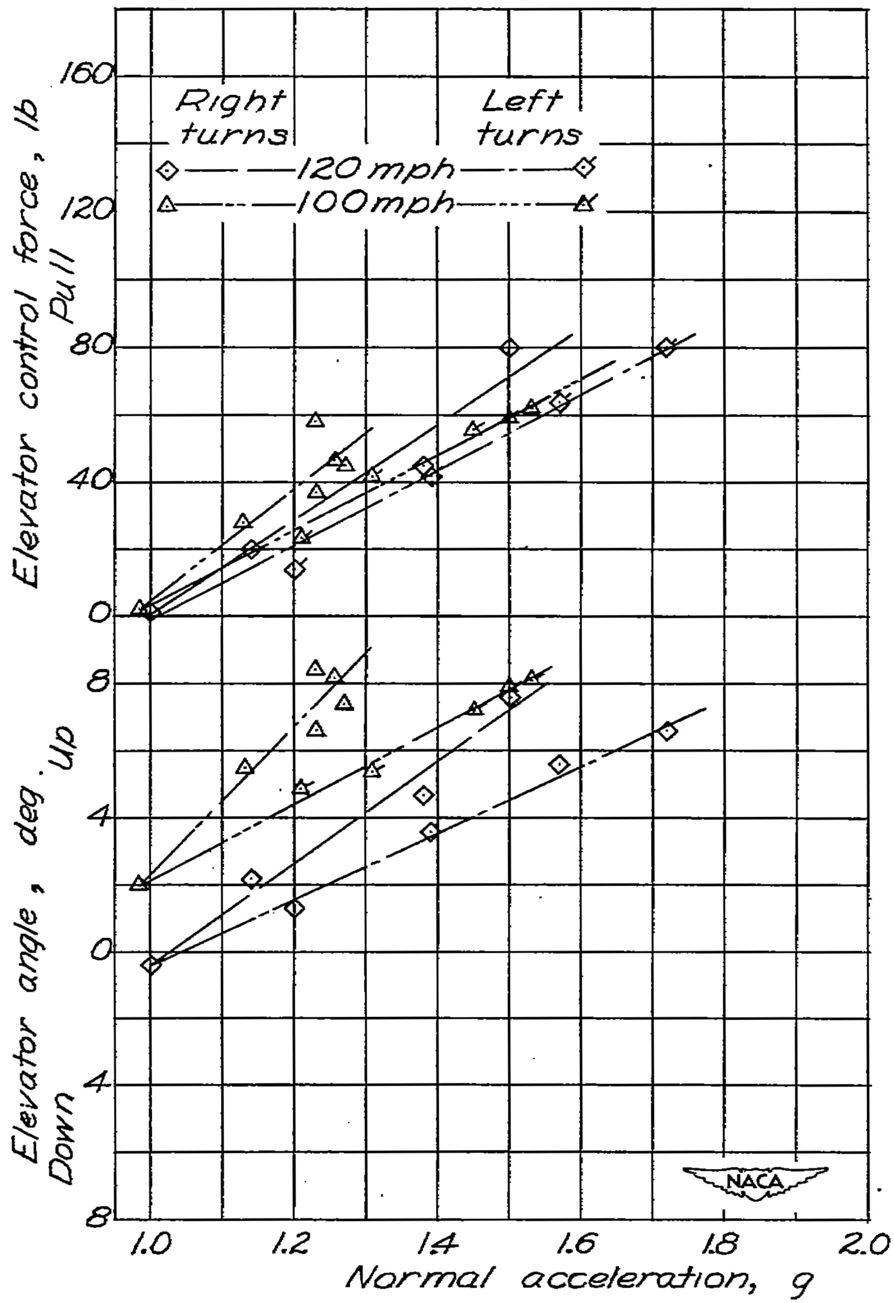
(b) Center of gravity at 23.1 percent M.A.C.

Figure 9.— Continued.



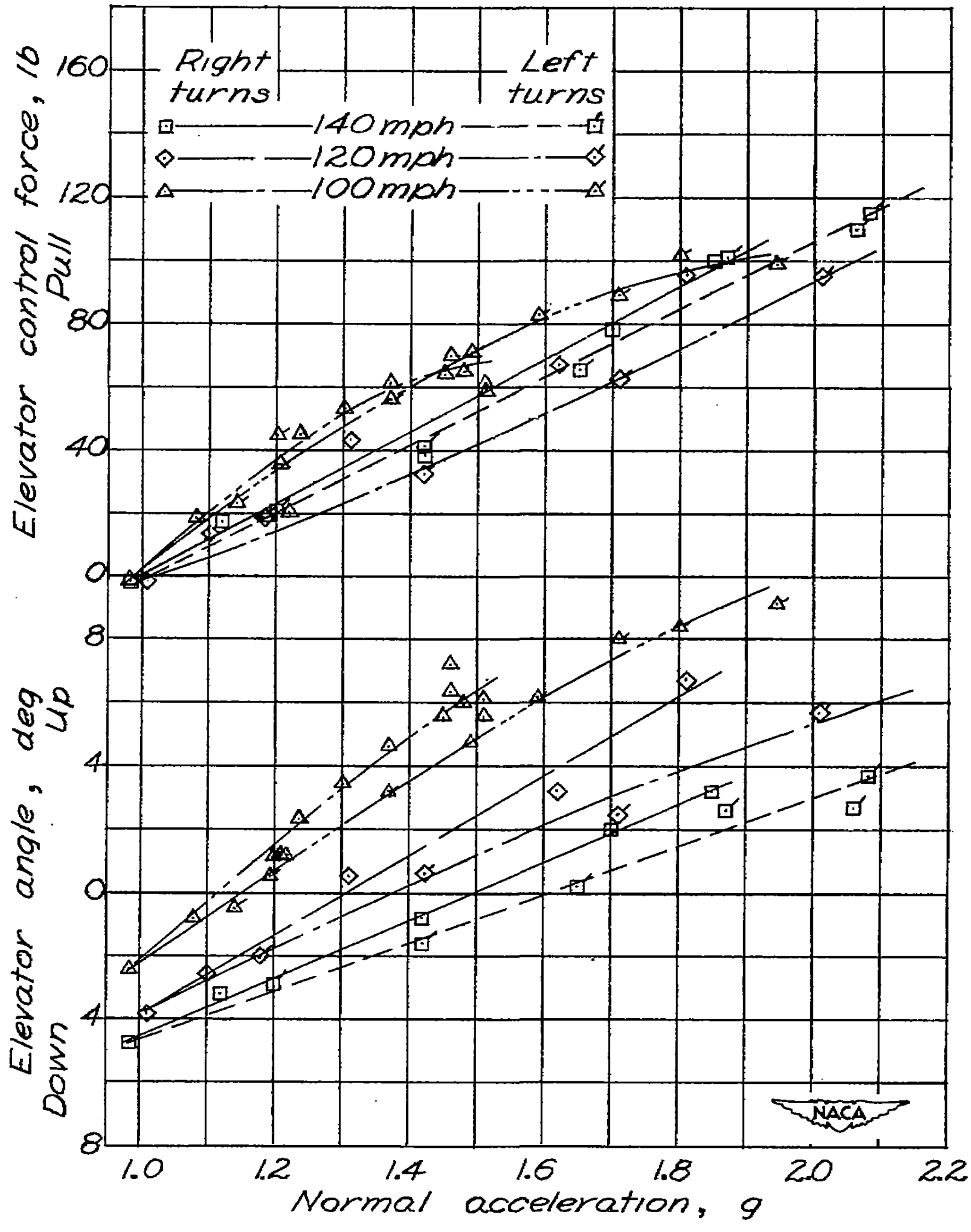
(c) Center of gravity at 27.8 percent M.A.C.

Figure 9.– Concluded.



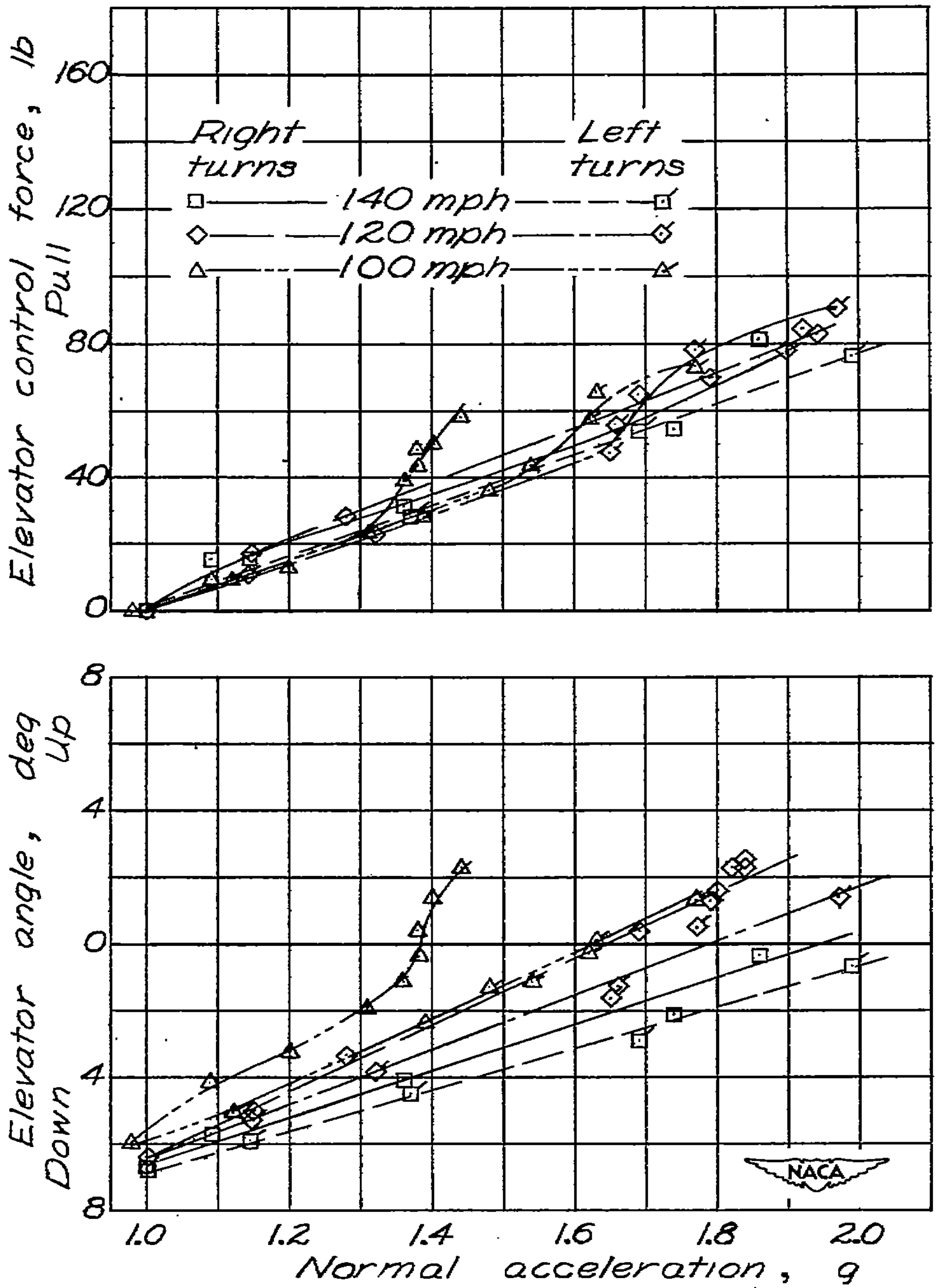
(a) Center of gravity at 18.9 percent M.A.C.

Figure 10.– Maneuvering stability characteristics as measured in steady turns. C-54D airplane; wave-off condition.



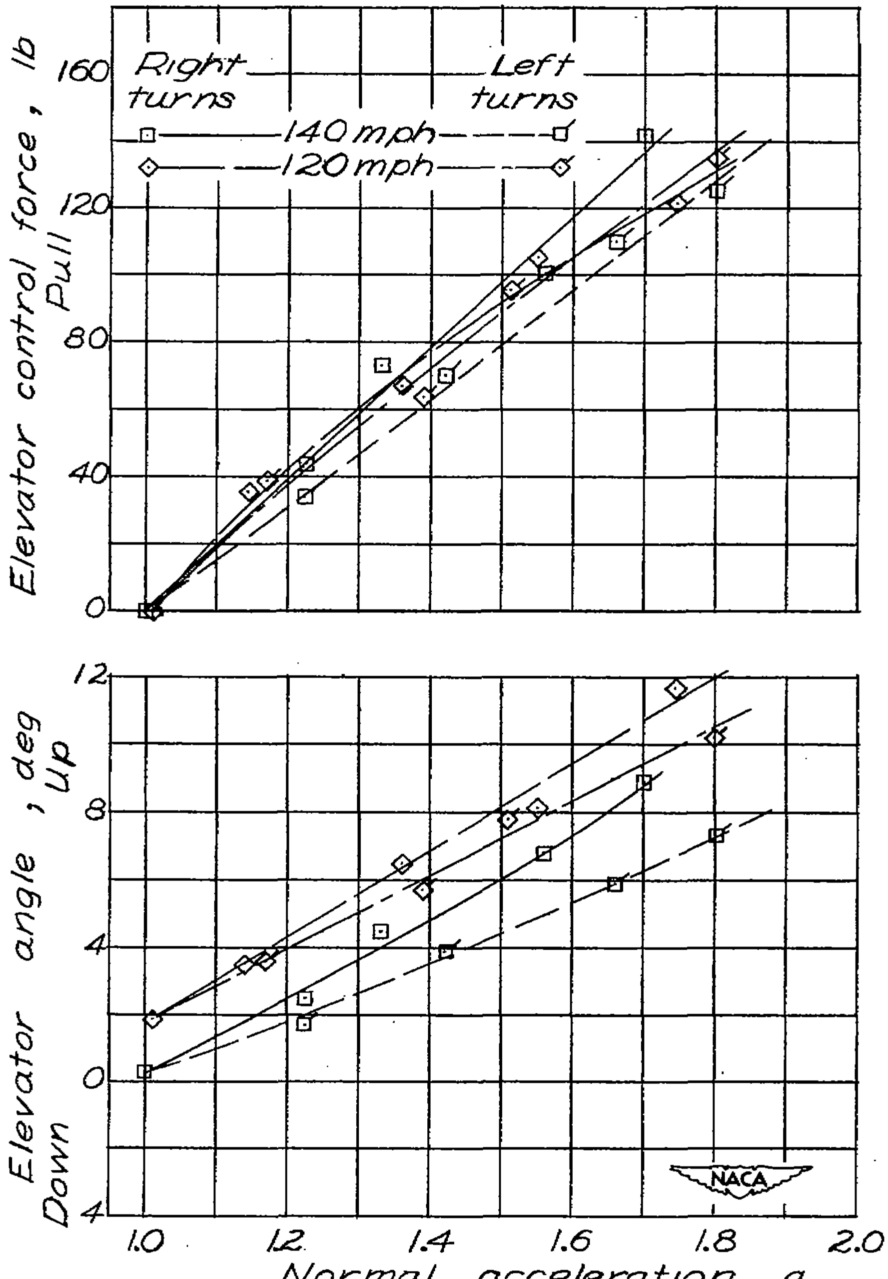
(b) Center of gravity at 25.4 percent M.A.C.

Figure 10.— Continued.



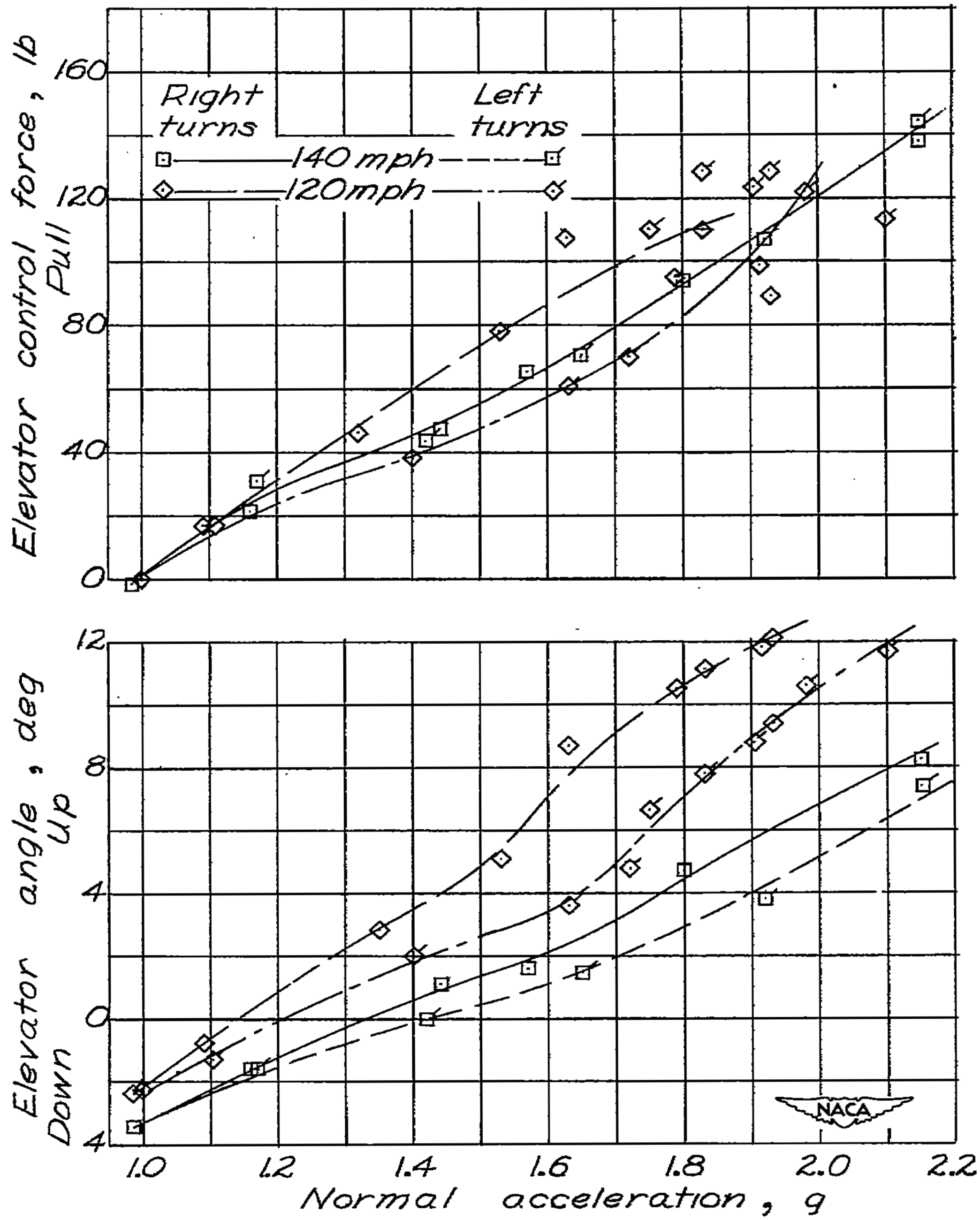
(c) Center of gravity at 30.1 percent M.A.C.

Figure 10.– Concluded.



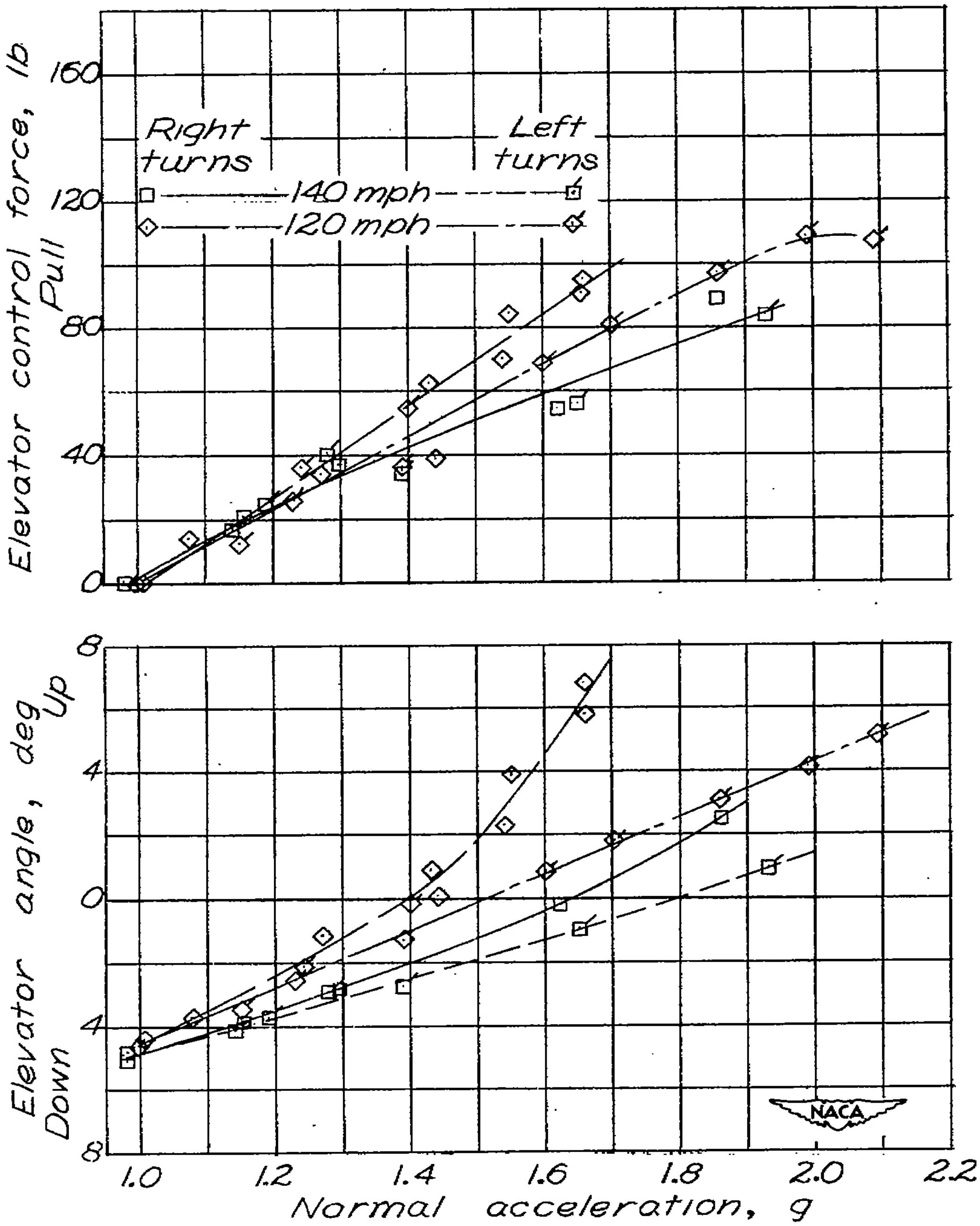
(a) Center of gravity at 19.2 percent M.A.C.

Figure 11.– Maneuvering stability characteristics as measured in steady turns. C-54D airplane; approach condition.



(b) Center of gravity at 25.4 percent M.A.C.

Figure 11.- Continued.



(c) Center of gravity at 30.1 percent M.A.C.

Figure 11.– Concluded.

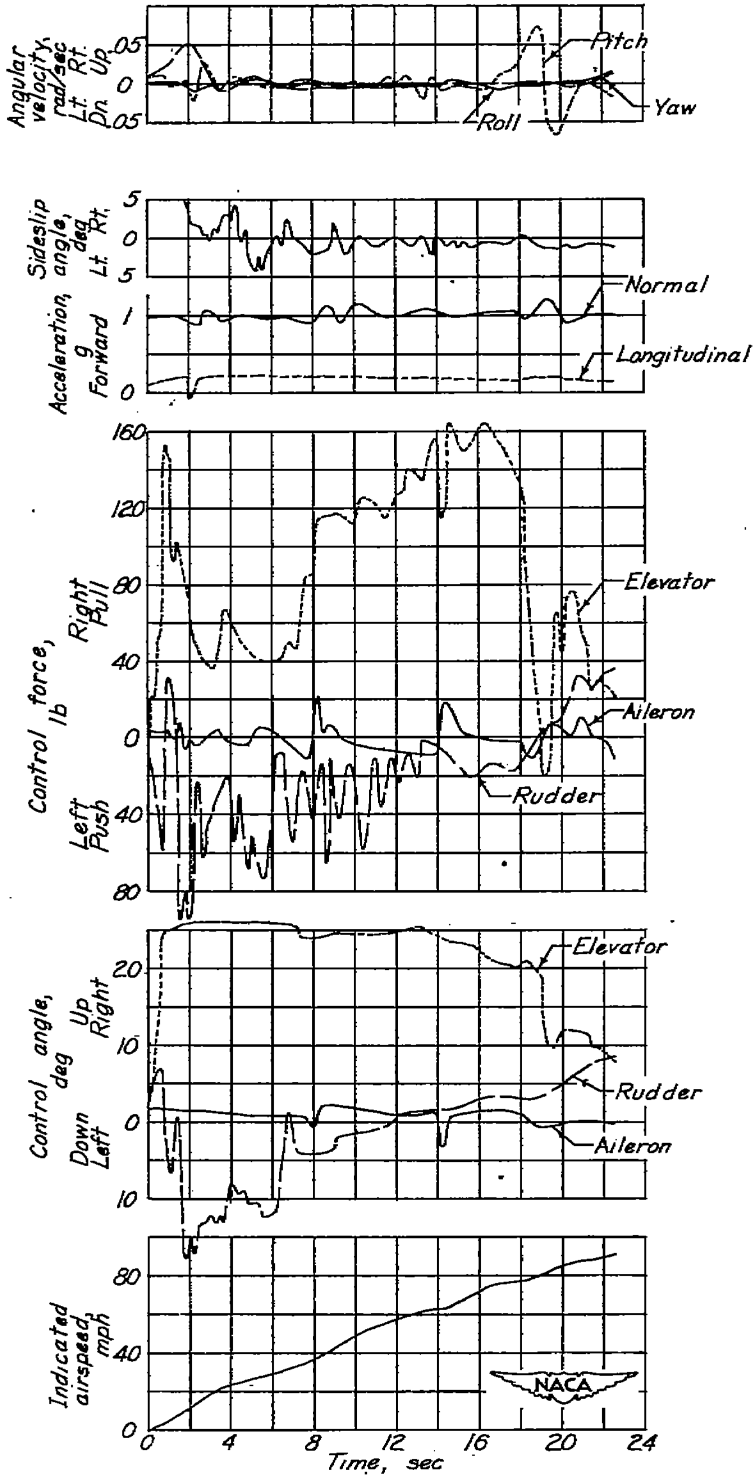


Figure 12.- Time history of a take-off with the elevator held full up until the nose wheel leaves the ground. C-54D airplane; center of gravity at 19.4 percent M.A.C.

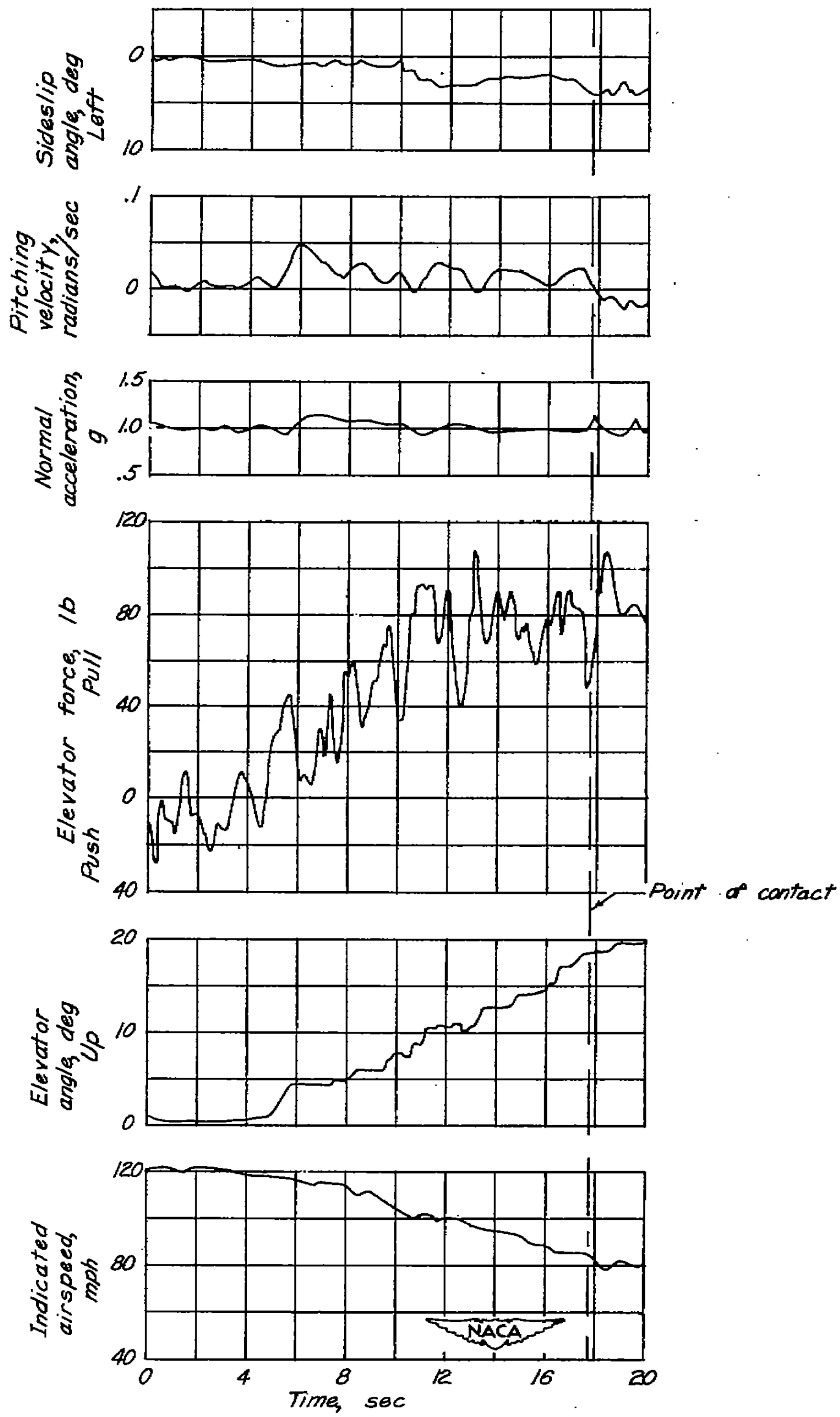
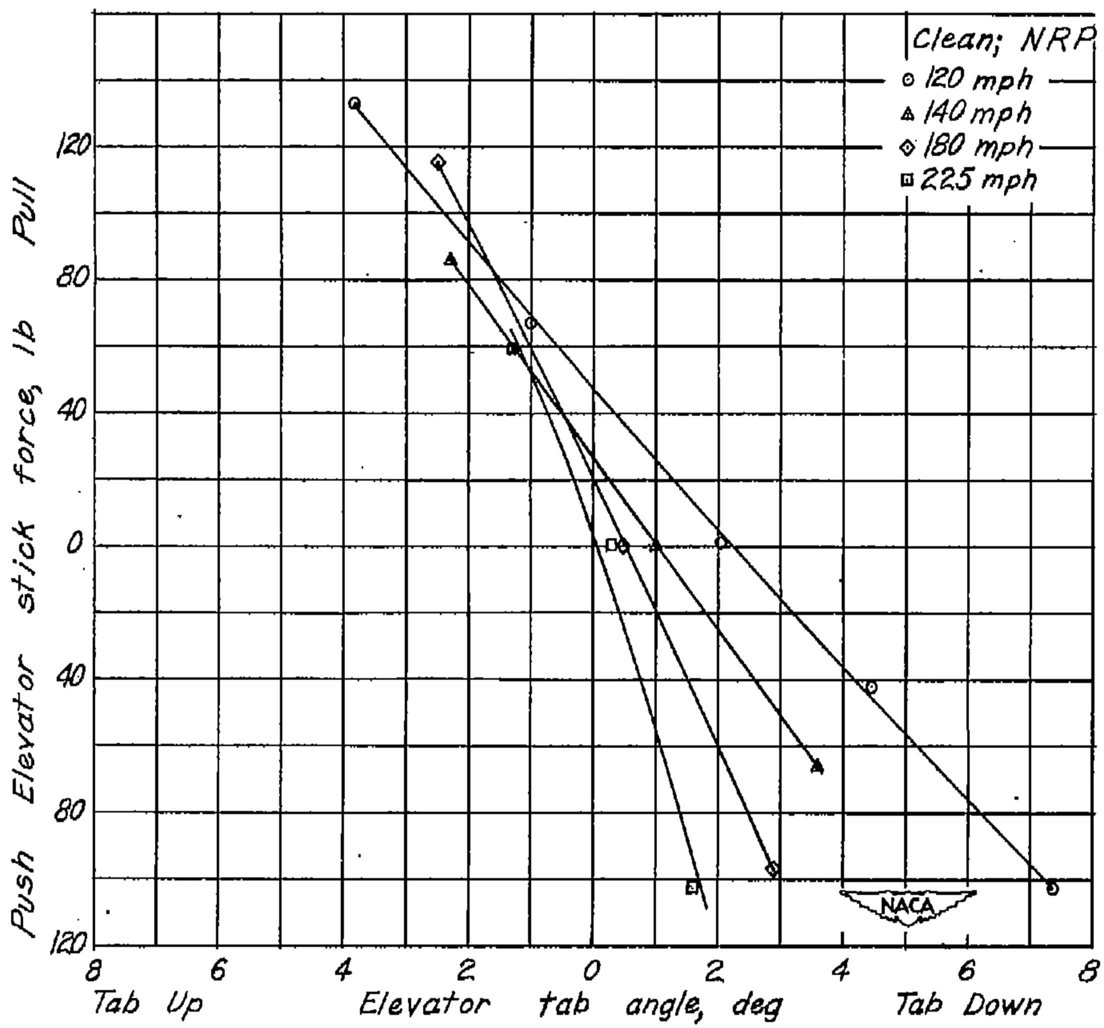
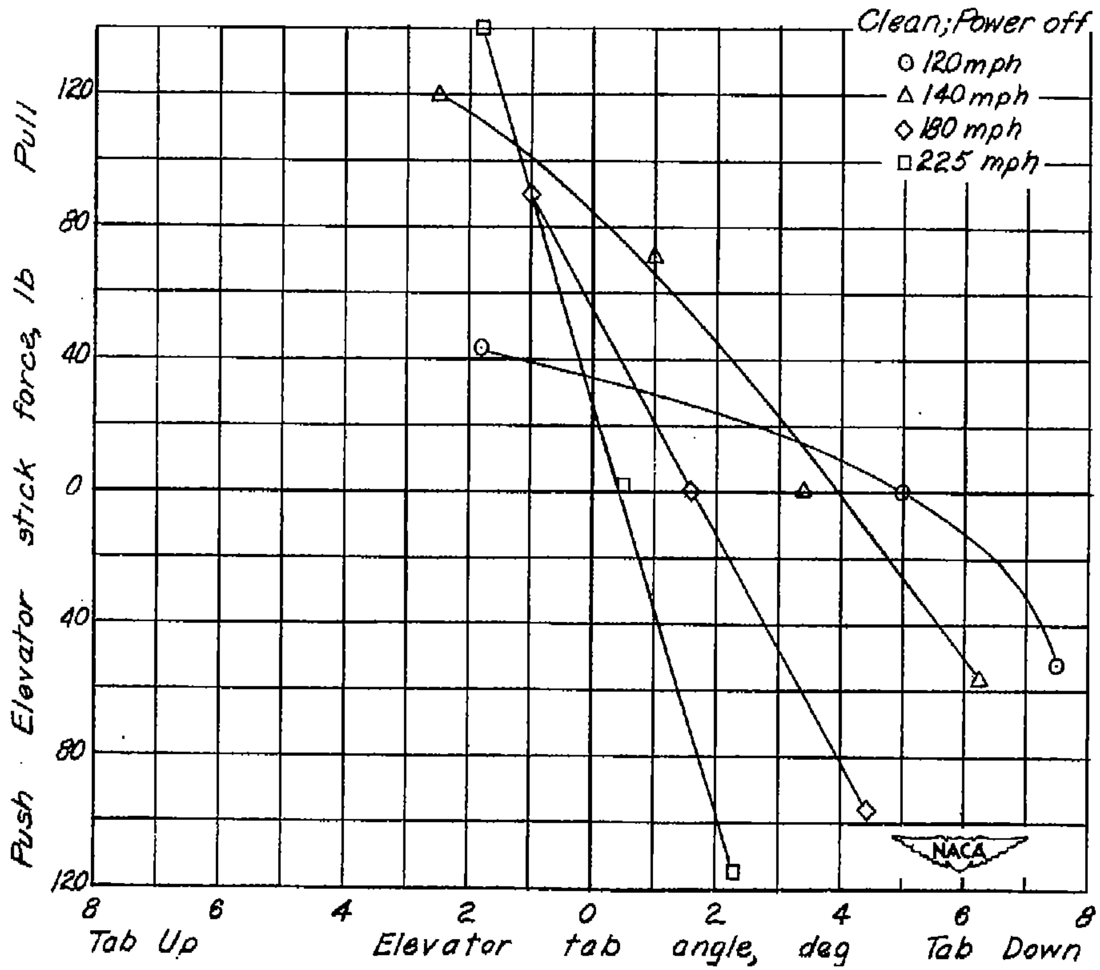


Figure 13.– Time history of a power-off landing. C-54D airplane; flaps full down (40°); gear down; engines idling; trimmed at 120 miles per hour; center of gravity at 19.1 percent M.A.C.



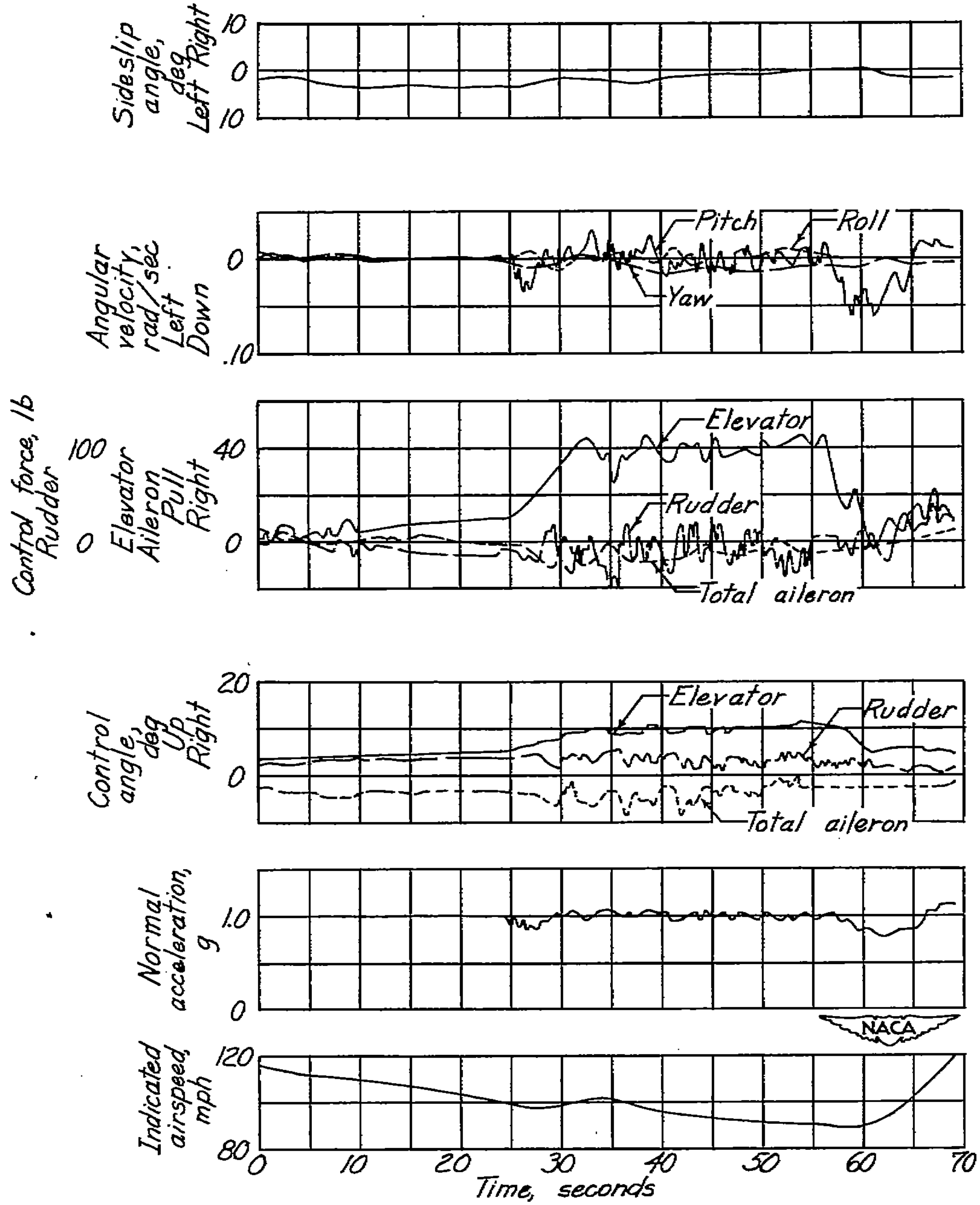
(a) Clean condition; normal rated power.

Figure 14.– Elevator-trim-tab effectiveness. C-54D airplane.



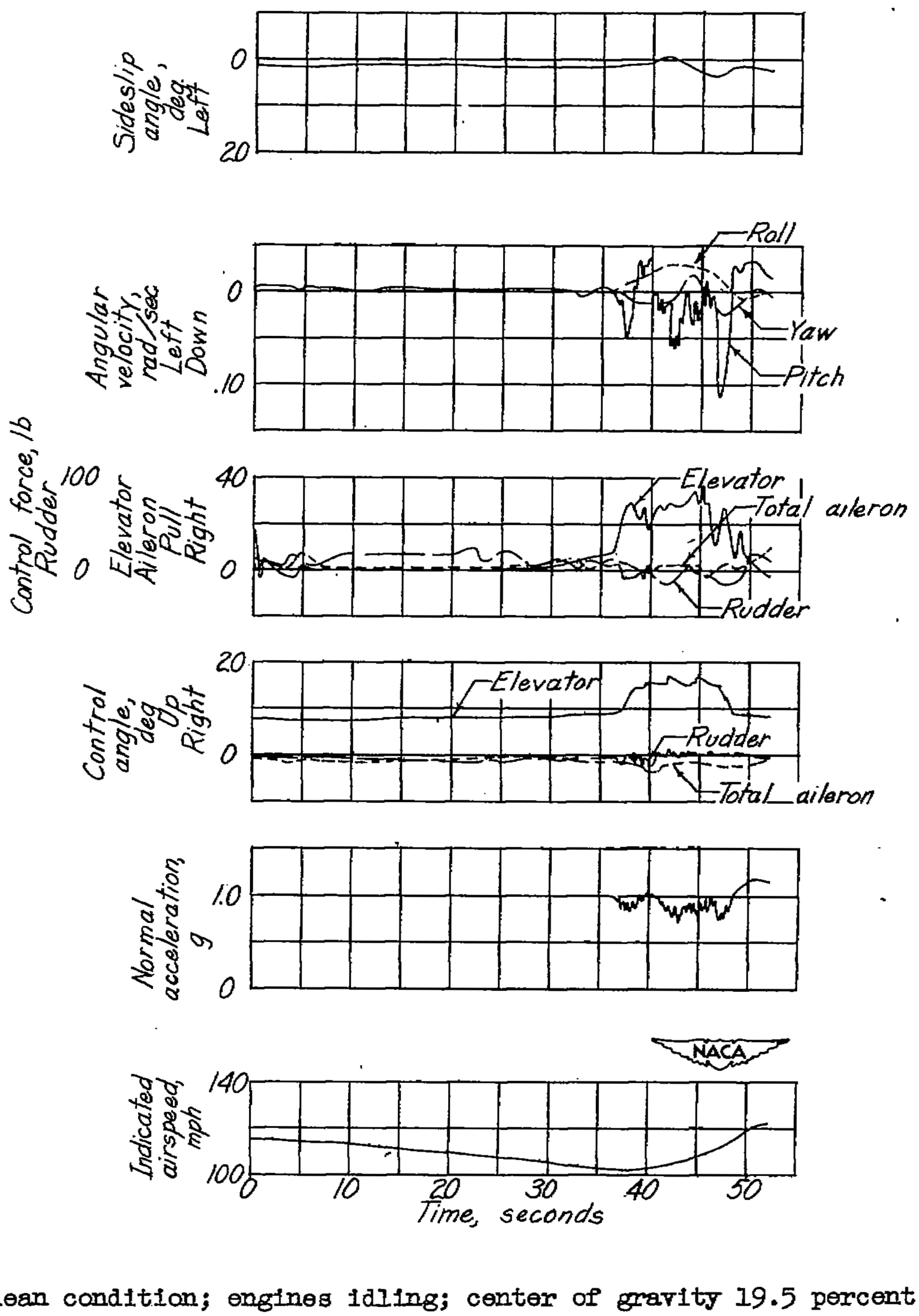
(b) Clean condition; engines idling.

Figure 14.– Concluded.



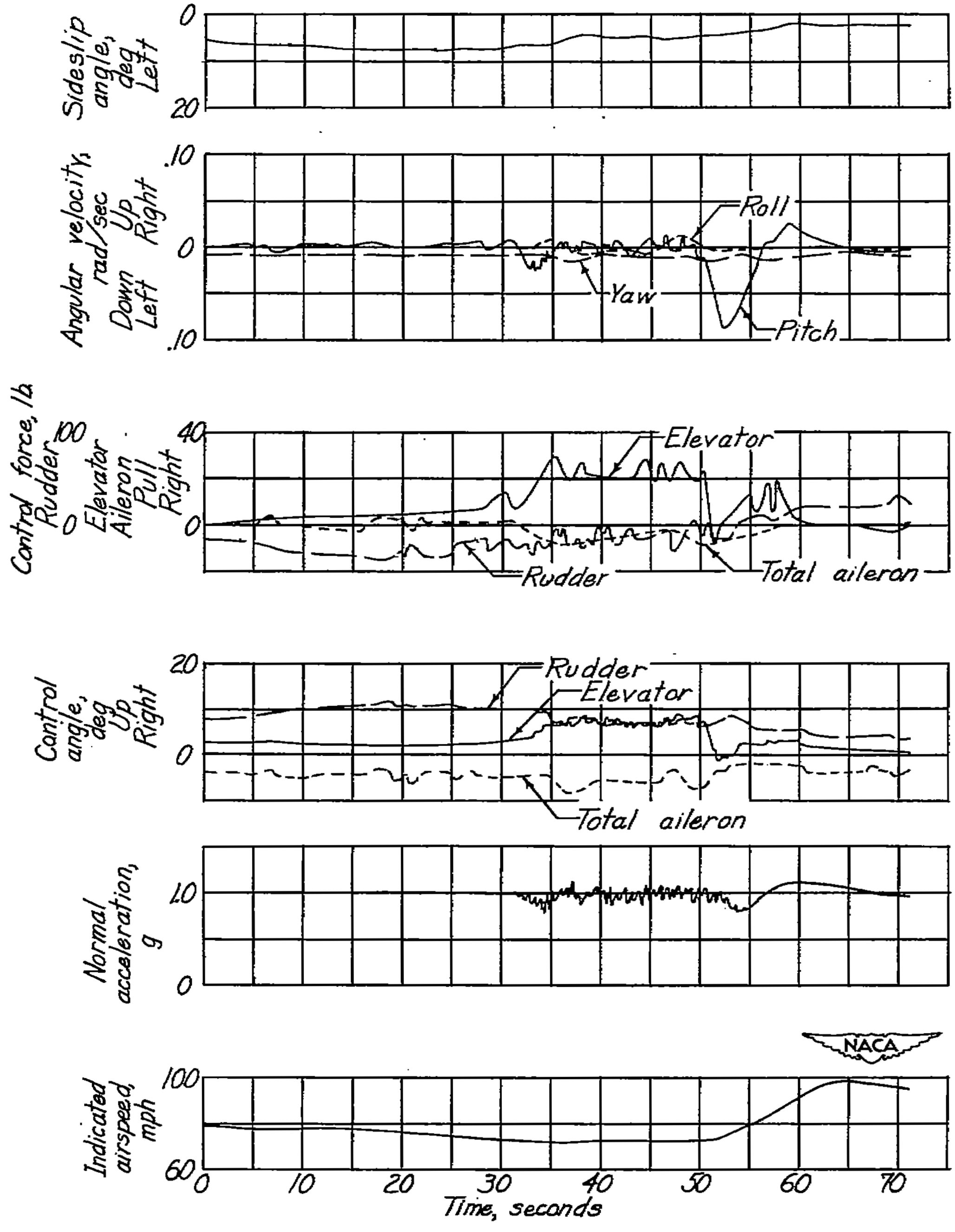
(a) Clean condition, normal rated power. Center of gravity at 19.5 percent M.A.C.

Figure 15.- Time histories of stalls from straight flight. C-54D airplane.



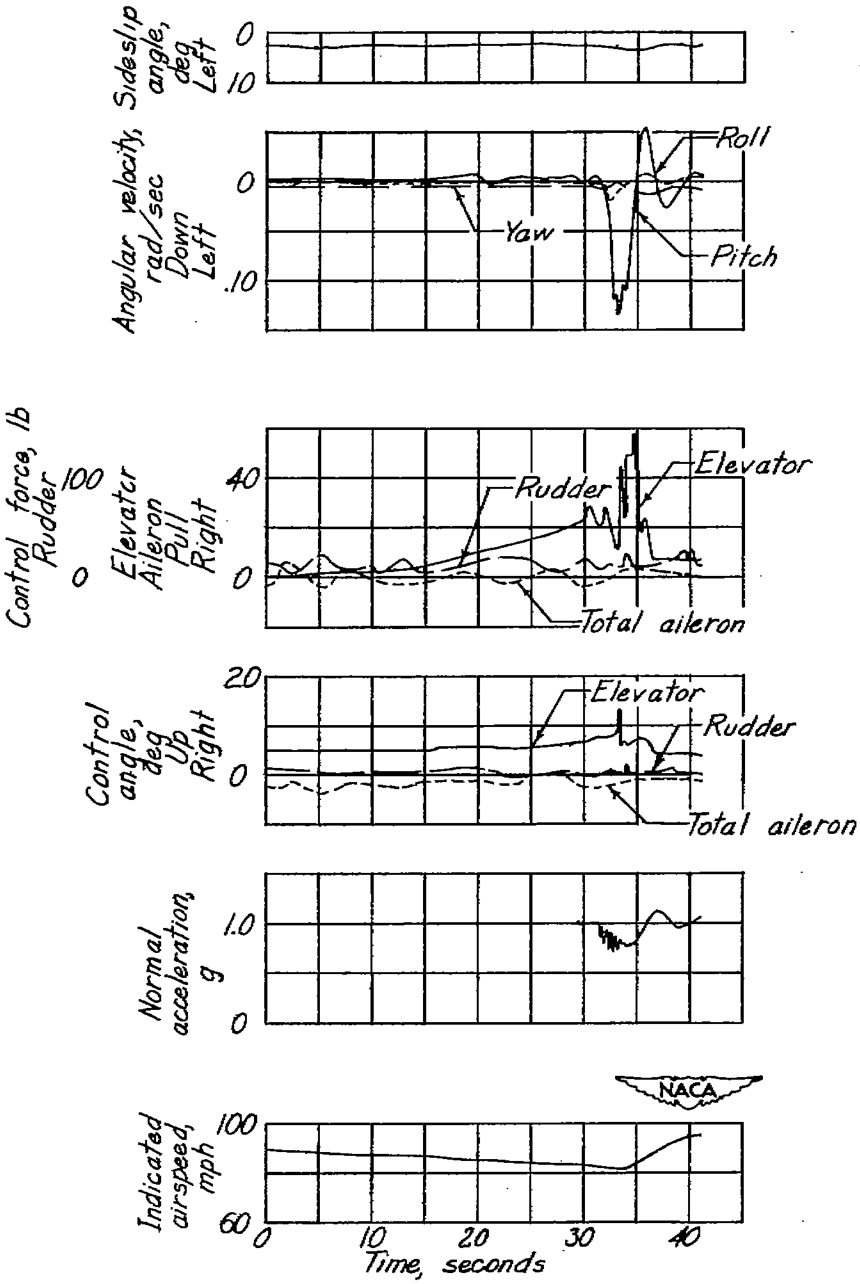
(b) Clean condition; engines idling; center of gravity 19.5 percent M.A.C.

Figure 15.– Continued.



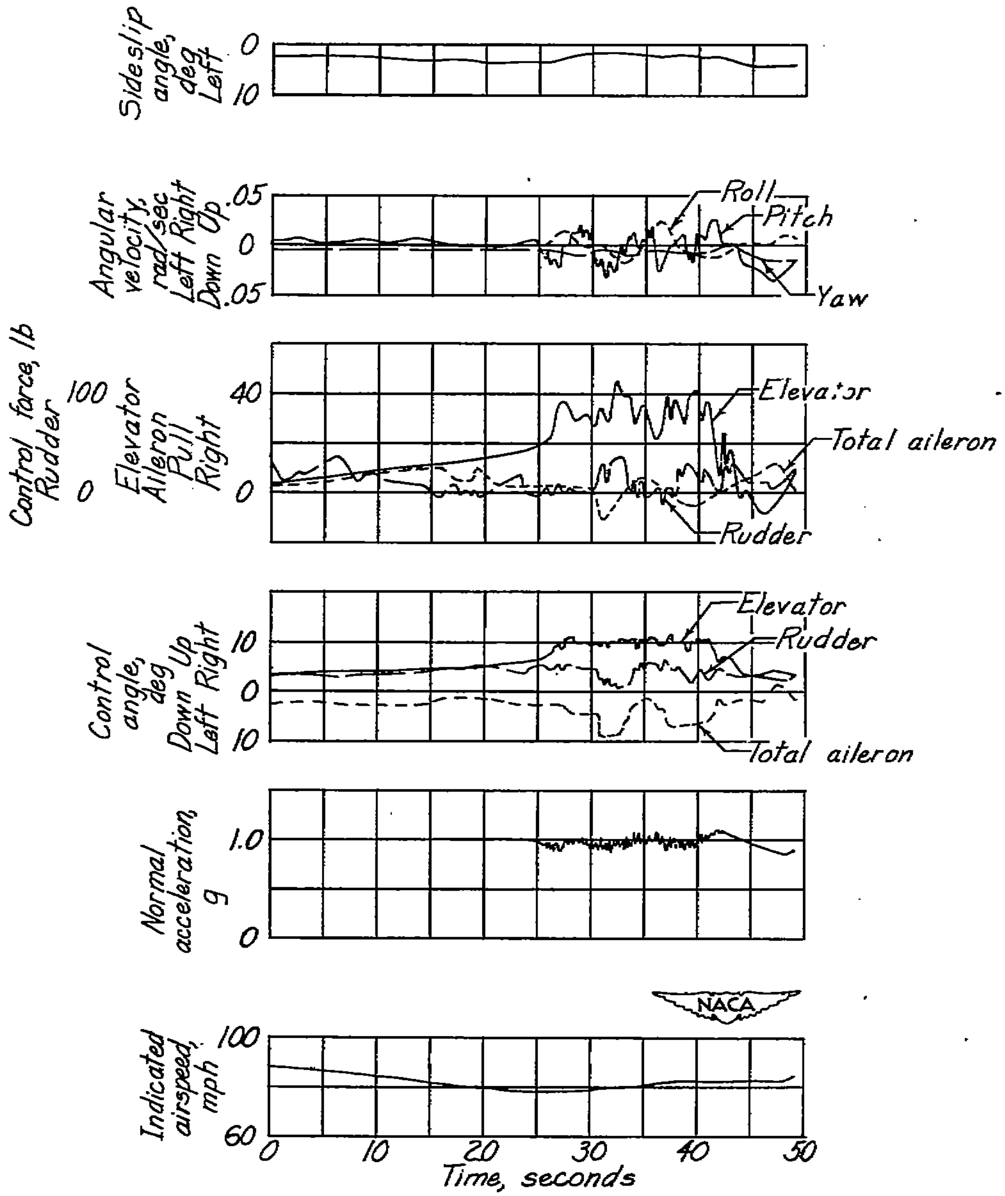
(c) Wave-off condition; flaps full down; gear down; normal rated power; center of gravity at 17.2 percent M.A.C.

Figure 15.— Continued.



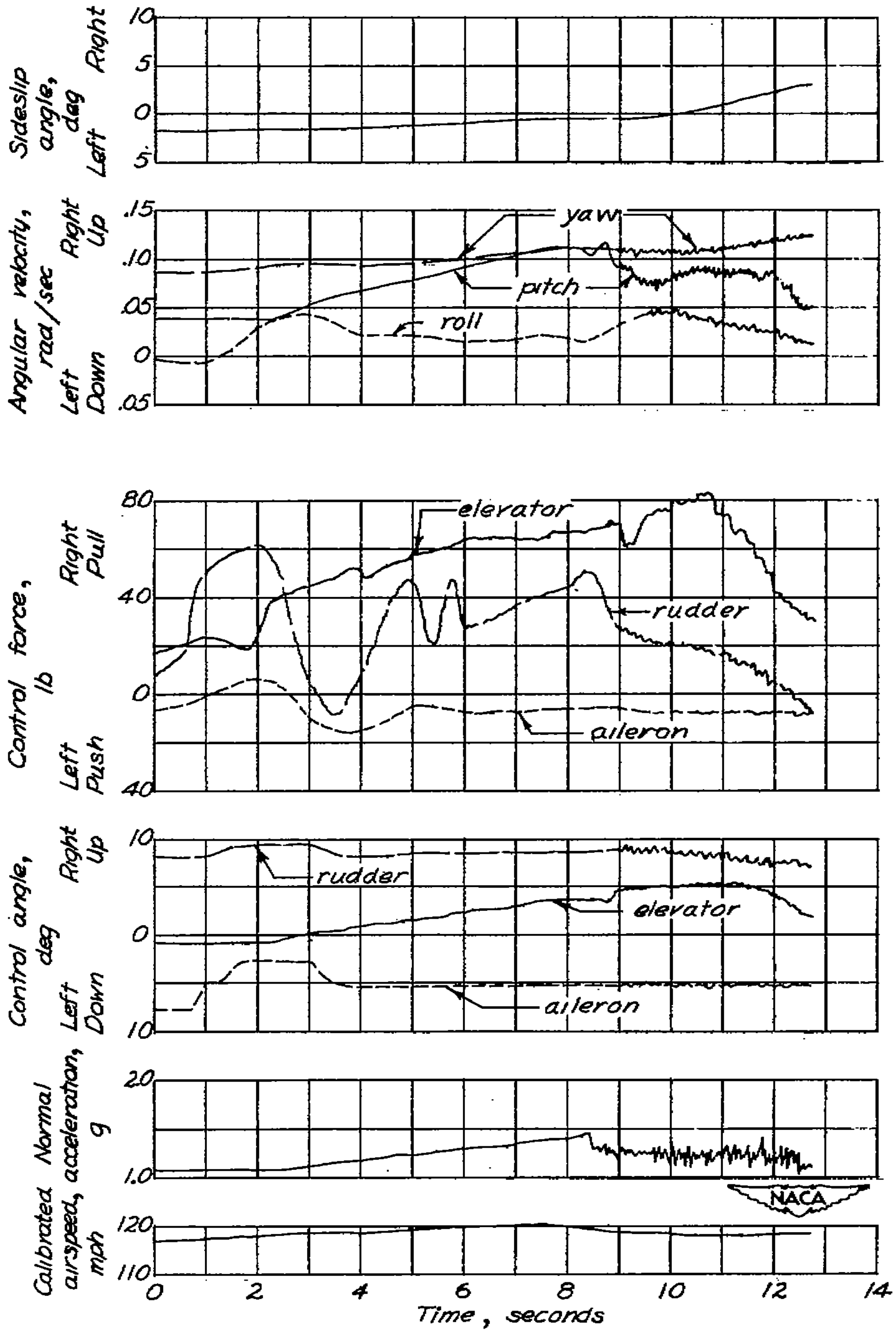
(d) Landing condition; flaps full down; gear down; engines idling; center of gravity at 17.2 percent M.A.C.

Figure 15.— Continued.



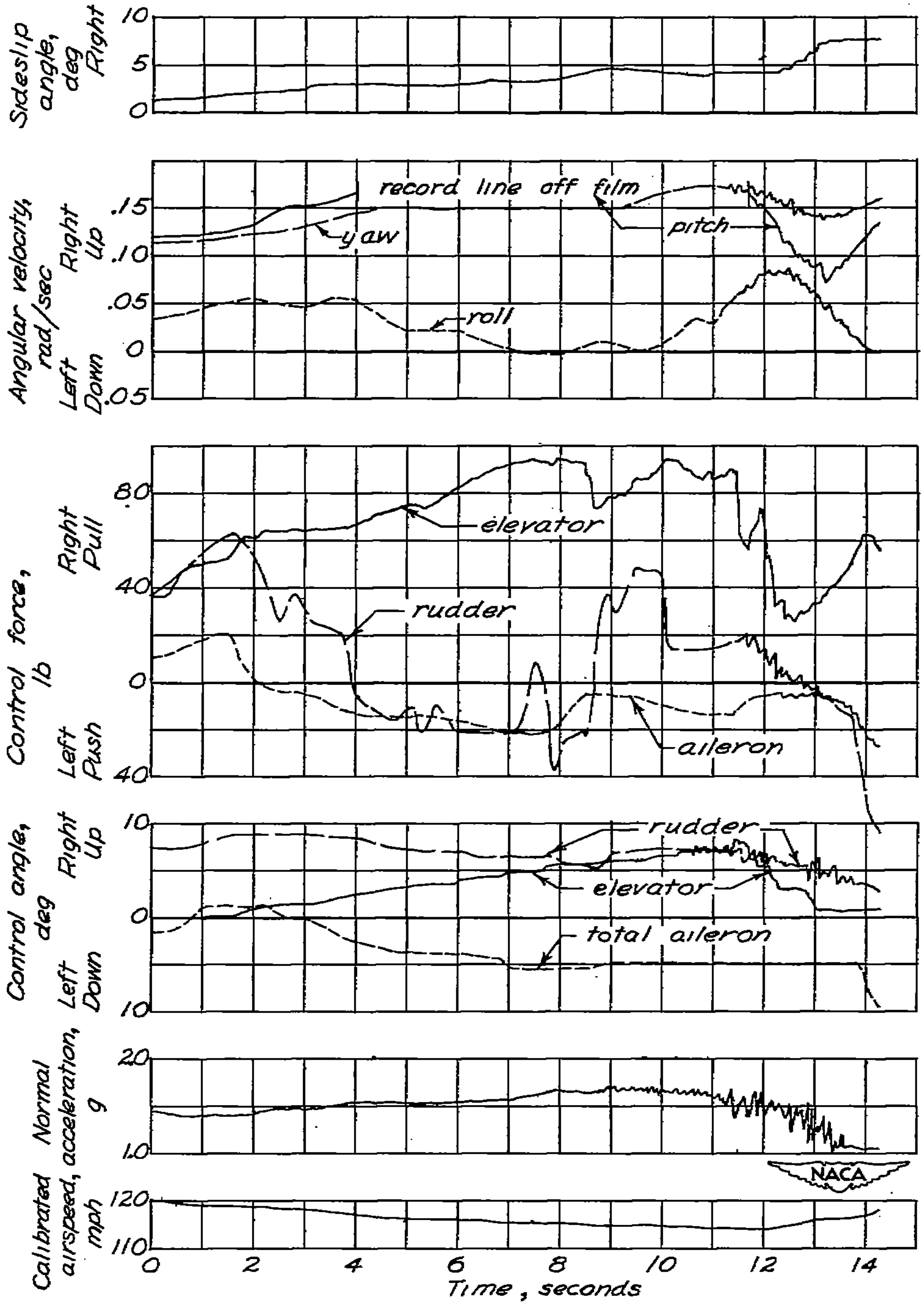
(e) Approach condition; flaps 20° down; gear down; engine power 20 in. Hg; 2550 rpm; center of gravity at 17.2 percent M.A.C.

Figure 15.— Concluded.



(a) Clean condition; normal rated power; center of gravity at 27.9 percent M.A.C.

Figure 16.– Time histories of stalls from turning accelerated flight. C–54D airplane.



(b) Approach condition; flaps 20° down; gear down; engine power 20 in. Hg; 2550 rpm; center of gravity at 30.1 percent M.A.C.

Figure 16.– Concluded.