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RESEARCH MEMORANDUM

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DATA OBTAINED IN THE FLIGHT MEASUREMENTS TO DETERMINE THE STABILITY AND CONTROL CHARACTERISTICS OF A C-54D AIRPLANE (AAF NO. 42-72713) AND A SUMMARY OF THE TEST PROGRAM

By

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Langley Field, Va.

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RESEARCH MEMORANDUM

DATA OBTAINED IN THE FLIGHT MEASUREMENTS TO DETERMINE THE STABILITY AND CONTROL CHARACTERISTICS OF A C-54D AIRPLANE (AAF NO. 42-72713) AND A SUMMARY OF THE TEST PROGRAM

By Donald B. Talmage and John P. Reeder

SUMMARY

The flight investigation of the C-54D airplane was initiated to determine the necessity of changes or additions to existing handling-qualities requirements to cover the case of instrument approaches with large airplanes. This paper gives a brief synopsis of the results and presents the measured data of tests to determine the stability and control characteristics. It was found that no new requirements were necessary to cover the problems of instrument approaches. The C-54D airplane tested met the Army and Navy stability and control requirements except for the following items. The control-system friction with autopilot installed was double that allowed by the requirements. The amount of friction was found to impair the controllability of the airplane in precision flying. The lateral and directional characteristics were good except that the maximum $pb/2V$ was slightly below the minimum required, and the aileron-control forces to obtain the maximum $pb/2V$ at low speeds were above the Army and Navy requirements. The longitudinal stability and control characteristics were good except that the elevator-control forces exceeded the limits of the Army and Navy requirements in turns and in landings. The stalling characteristics were considered good in all conditions with the stall warning in the form of tail buffeting occurring at speeds approximately 5 miles per hour above the stall.

INTRODUCTION

Because of the reduced maneuverability of large airplanes, the problem of landing the airplane and of making blind approaches becomes more difficult with increasing airplane size. A test program was initiated using a C-54D airplane (AAF No. 42-72713) to determine the problems involved with this typical large airplane and to determine

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whether or not additional handling-qualities requirements would be necessary to provide for the conditions of precision flying such as necessary in landings, blind approaches, and general instrument flying.

As a preliminary step in this test program the flying qualities of the test airplane were recorded under normal flight conditions. These recorded data are presented herein. Comparable data on the normal flight conditions obtained by the Army for a C-54G airplane, which became available shortly after the NACA measurements were made, are contained in reference 1.

Time histories of control operation recorded during blind approaches have been reported in reference 2. Papers are being prepared covering the lateral and directional stability and control characteristics, the longitudinal stability and control characteristics, the stalling characteristics, and the effect of friction in the control system on the control characteristics in precision flying. The purpose of the present paper is to make the recorded data describing the handling qualities of the test airplane available while further analysis of these data is in progress.

INSTRUMENTATION AND TESTS

All quantities were measured by NACA photorecording instruments. The airspeed was measured on an NACA free-swiveling static head and shielded total head mounted on a boom 1-chord length ahead of the left wing tip. The airspeed system was calibrated by a trailing airspeed head. The accelerations were measured by a sensitive normal accelerometer and by a three-component accelerometer. The control surface, tab, and pilot control-position recorders and the control forces were measured by electrical strain-gage-type control-force recorders. The angular velocities were measured by turnmeters, and the sideslip angle, by a vane mounted on a boom 1-chord length ahead of the right wing tip. The angle of bank was measured by an air-damped inclinometer or by a camera mounted rigidly in the nose. Figures 1 through 3 show a photograph of the airplane, the control linkage, and the rudder-spring-tab characteristics.

The tests to determine the characteristics in blind landings are reported in reference 2. The tests to determine the effects of friction consisted of measurements of control application and airplane response while bracketing a beam and making landings. These tests were made with two amounts of friction in the control system; one double that specified by the Army and the Navy in references 3 and 4, respectively, and one about one-half the amount specified.

The tests to determine the lateral and [redacted] directional stability and control characteristics followed the requirements as put forth in references 3 and 4 except that several conditions were covered more fully. The approach condition was changed to coincide with the condition used by most commercial airplanes, and the wave-off condition, normal rated power with flaps and gear full down, was included. Special tests were conducted to evaluate the pitch due to yawing velocity and sideslip since it was thought that during instrument approaches, particularly at low altitude where the greatest precision is necessary in flying the radio signals, the pilot might turn the airplane by making skid turns rather than by normal banked turns. Other special tests included a more extensive investigation of the asymmetric power condition and an investigation of the asymmetric load condition.

The tests to determine the longitudinal stability and control characteristics also followed the requirements of references 3 and 4 except for the approach condition which was modified as previously noted and except that a wave-off condition was included.

The stalling characteristics were studied by making stall approaches and stalls from straight and level flight in different conditions.

RESULTS AND DISCUSSION

The measurements of friction showed that the control-system friction with autopilot servos installed was about double the maximum allowed by the Army and Navy handling-qualities requirements. This amount of friction impaired the controllability of the airplane in precision flying.

The lateral and directional dynamic characteristics are shown in figures 4 and 5. The directional and sideslip characteristics are shown in figures 6 to 13.

The conditions of asymmetric power were investigated more fully than the regular handling-qualities requirements specify. Dynamic tests were conducted in the take-off and approach conditions to determine the time interval for the airplane to reach a dangerous attitude when no corrective control was applied after an engine failure. It was found that the rate of deviation from level flight was low enough to allow the pilot to analyze the situation and apply the proper corrective control. The data for the asymmetric power conditions are presented in figures 14 to 18.

The rolling effectiveness data are presented in figures 19 and 20 and show that the maximum $pb/2V$ attainable is less than the required amount and that the aileron control forces for maximum $pb/2V$ exceeded the 80-pound limit even at low speeds.

Tests were made with asymmetric load to determine the feasibility of taking off with one outboard tank empty. The only disadvantage found was the restricted aileron travel in one direction due to the amount of aileron necessary to balance the asymmetric load. It was thought that the aileron travel might be limited to such an extent as to make balancing at large angles of sideslip impossible. This was not the case at speeds above 120 miles per hour as shown by the sideslip characteristics with asymmetric load presented in figure 21.

Concern was expressed by the Air Transport Association Subcommittee on Handling Qualities about the tendency to pitch down in flat skid turns. The sideslip characteristics tests (figs. 9 to 13) showed that the pitch due to sideslip was small compared to other airplanes for which the characteristics have been measured and was easily controllable. A special series of tests, however, was instigated to measure the pitch due to yawing. The data from these tests are presented in figure 22 and indicate that any pitch due to yawing was not noticeable until fairly high rates of yawing (corresponding to an abrupt 10° heading change) were used, and then nose-down pitch was encountered only in right turns. This would indicate that this pitch due to yawing was due to the gyroscopic action of the propellers.

The dynamic longitudinal characteristics are shown in figure 23. The static longitudinal stability characteristics in five different conditions of flight and at three different center-of-gravity positions for each condition are shown in figures 24 to 28. The maneuvering longitudinal characteristics are presented in figures 29 to 32 and show that the force g greatly exceeded the limits of the handling-qualities requirements. The characteristics of the elevator tab are shown in figures 33 and 34. Time histories of two landings and a take-off are presented in figures 35 to 37 and show that the elevator forces on landing exceed the limits.

The stalling characteristics were considered good in all conditions. Buffet warning generally preceded the stall by about 5 miles per hour with heavy buffeting at the stall and mild nose-down pitching. The stall in the clean, power-off condition was accompanied by rapid settling, and only in the landing condition was there a very mild roll following the

stall. Heavy buffeting in all cases continued during recovery until a 5- to 10-mile-per-hour increase over initial stalling speed.

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1. 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.

2. Talmage, Donald B.: A Time History of Control Operation of a C-54 Airplane in Blind Landing Approaches. NACA RM No. L7F20, 1947.

3. Anon: Stability and Control Characteristics. AAF Specification No. R-1815-A, April 7, 1945.

4. Anon: Specification for Stability and Control Characteristics of Airplanes. SR-119A, Bur. Aero., April 7, 1945.

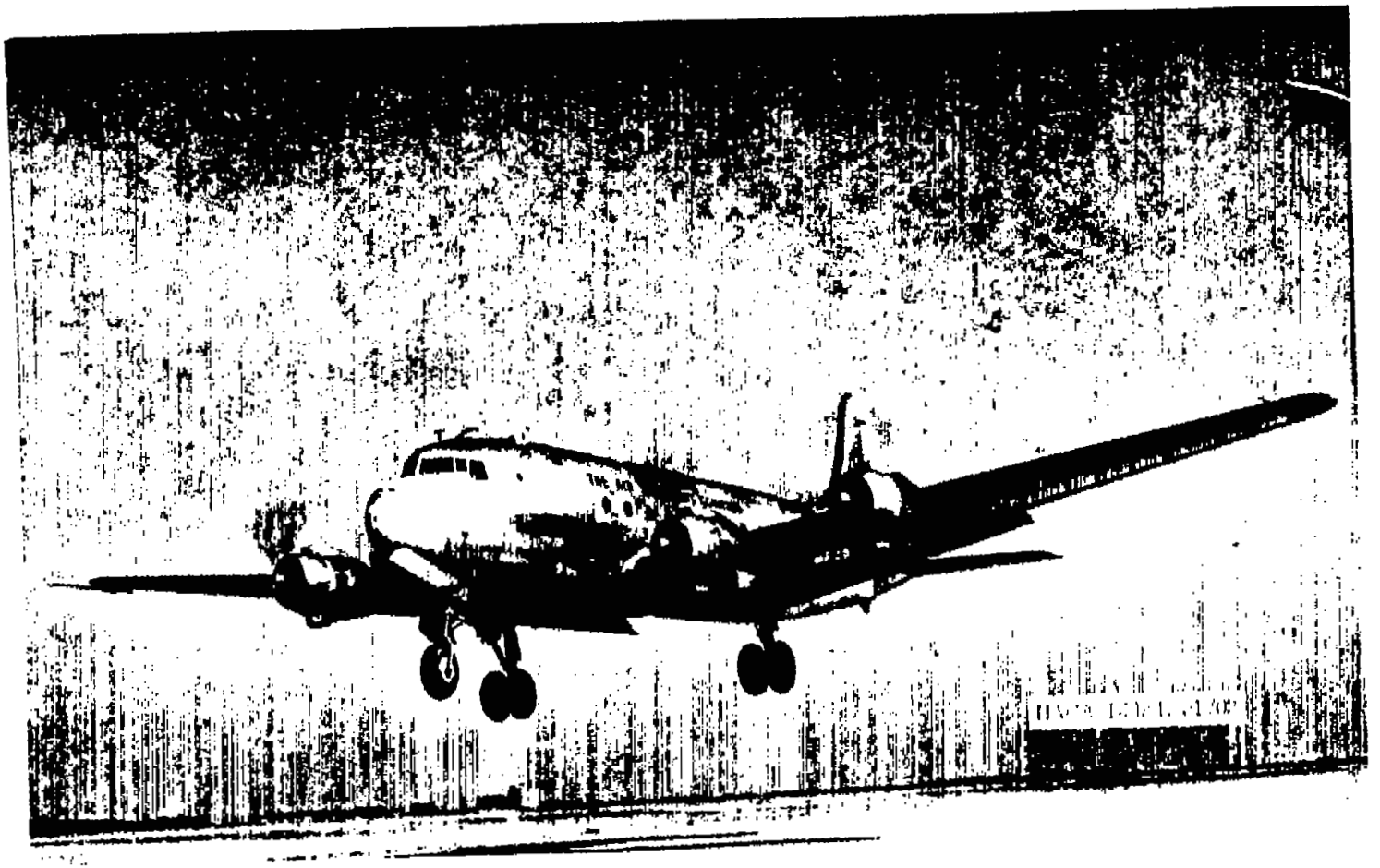

Figure 1.- Photograph of C-54D airplane on which tests were conducted.

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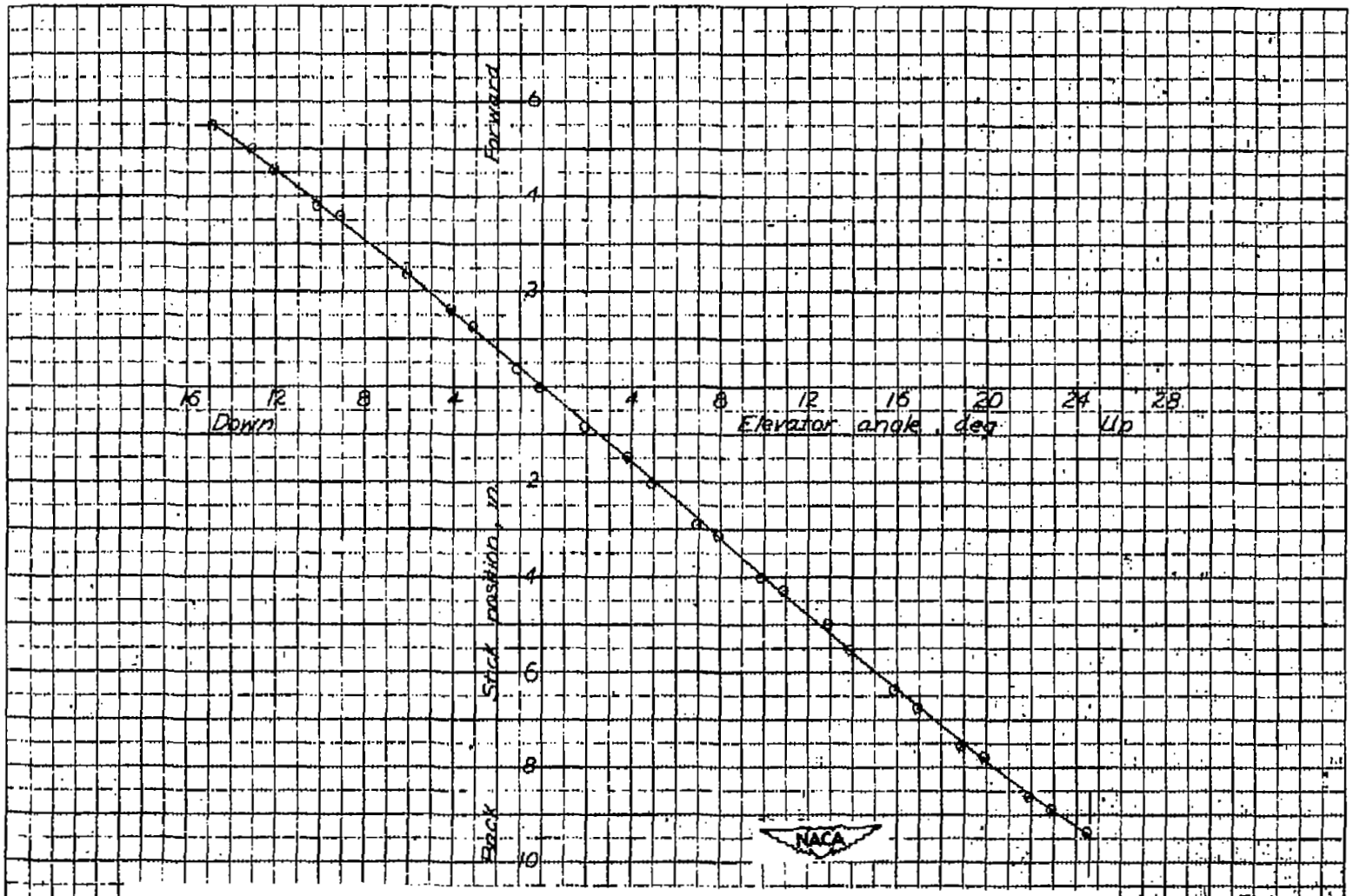
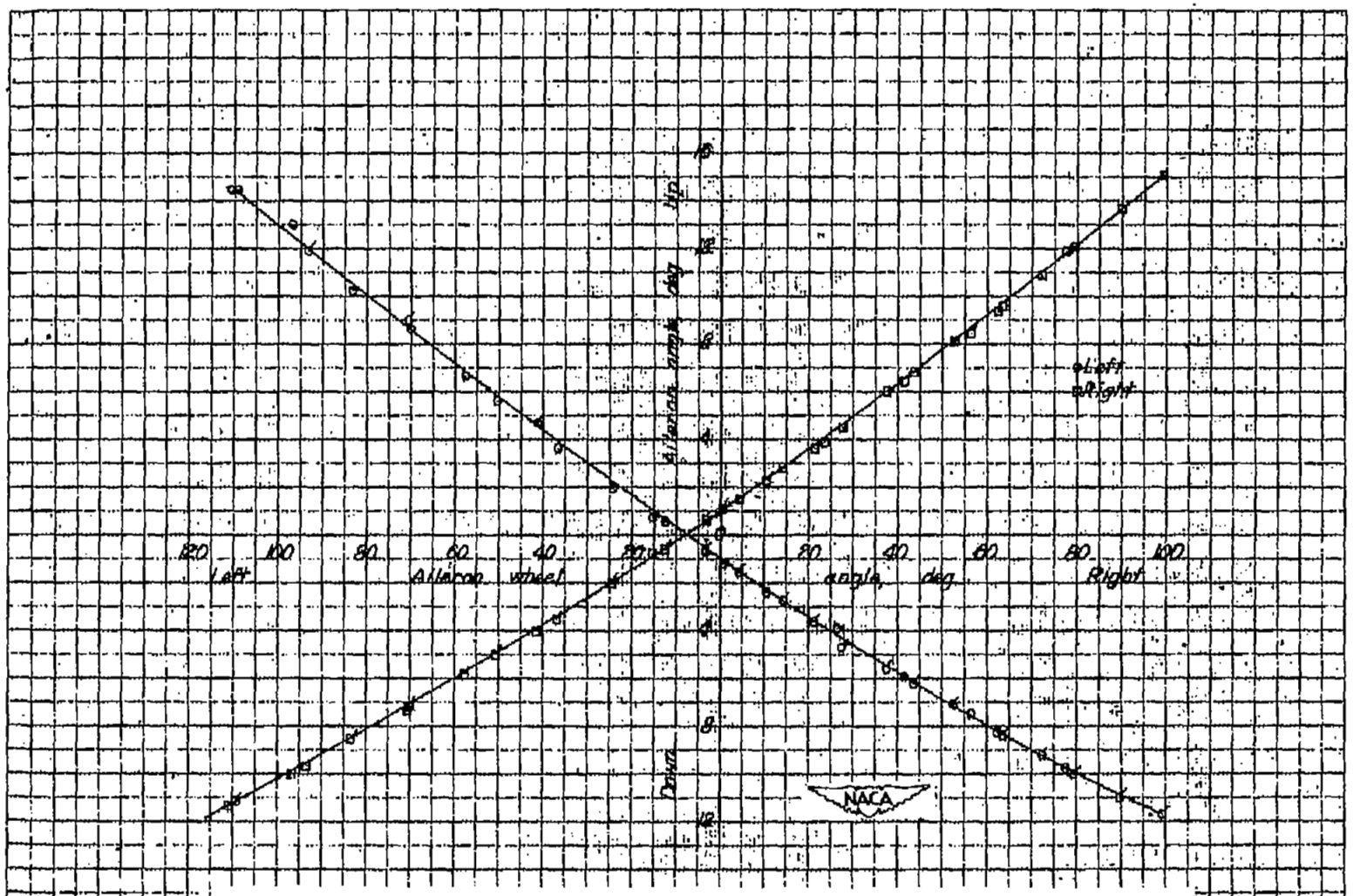


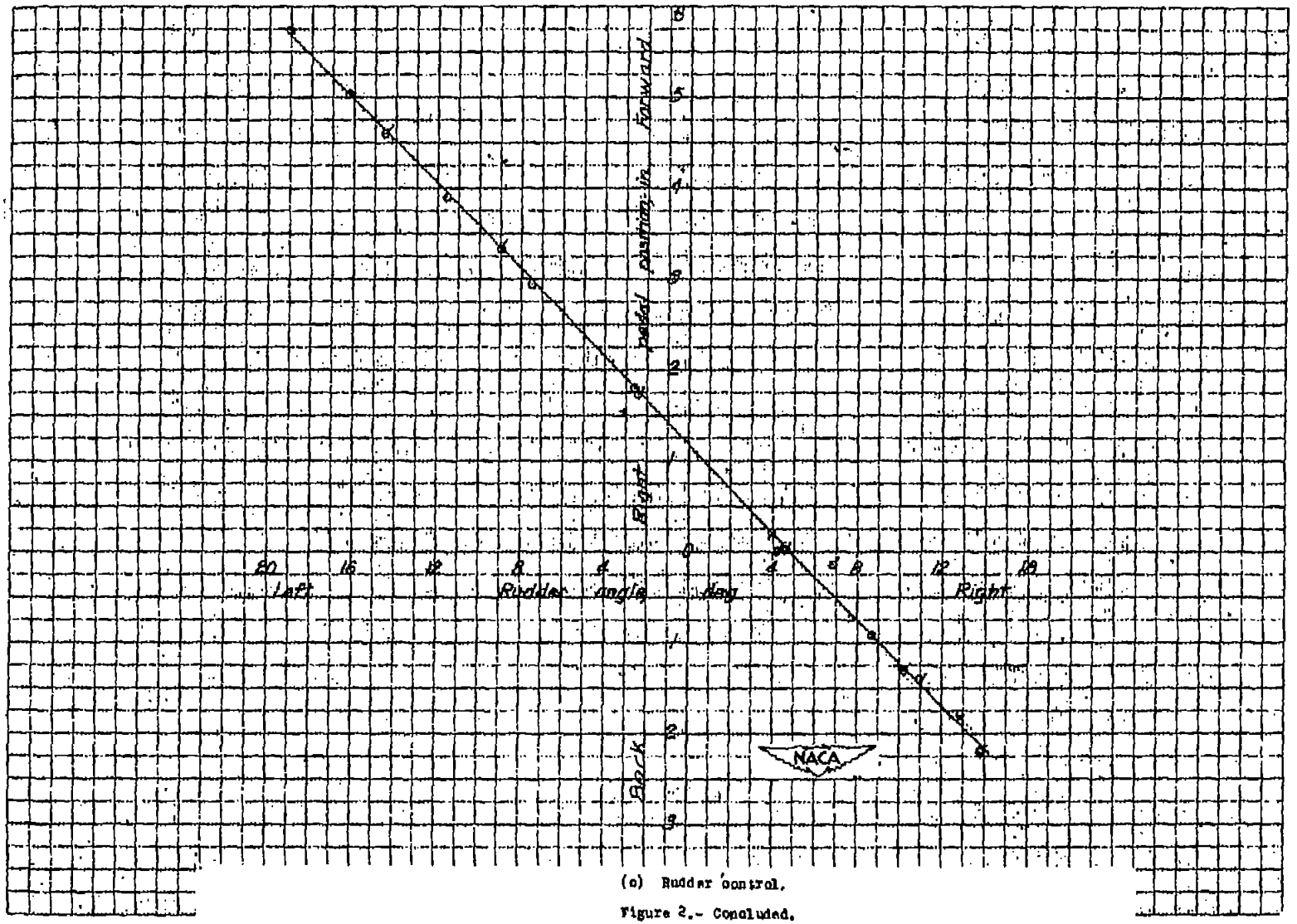
(a) Elevator control.

Figure 2.- Control linkage, O-54D airplane.



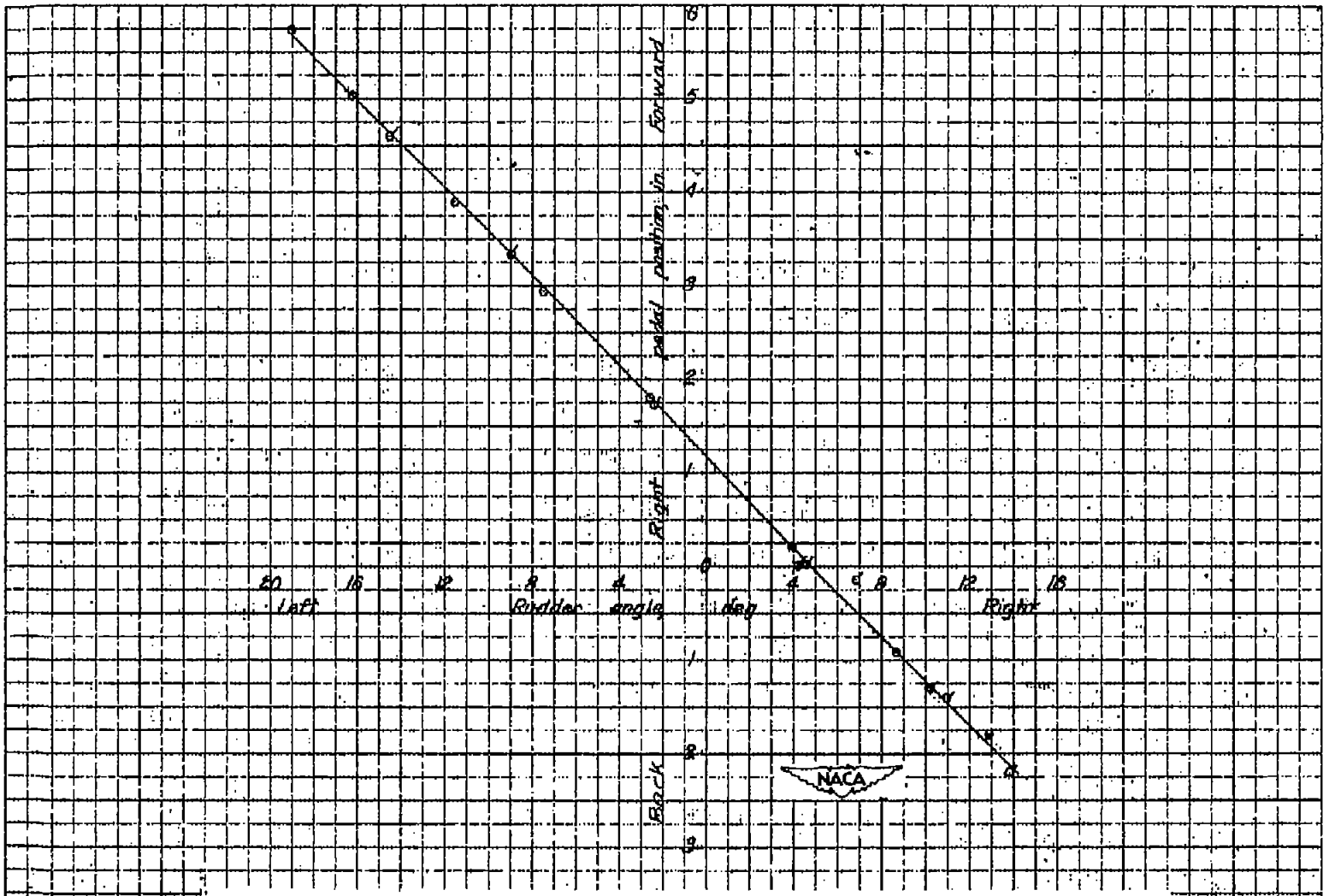
(b) Aileron control.

Figure 2.- Continued.



(o) Rudder control.

Figure 2.- Concluded.



(c) Rudder control.

Figure 2.- Concluded.

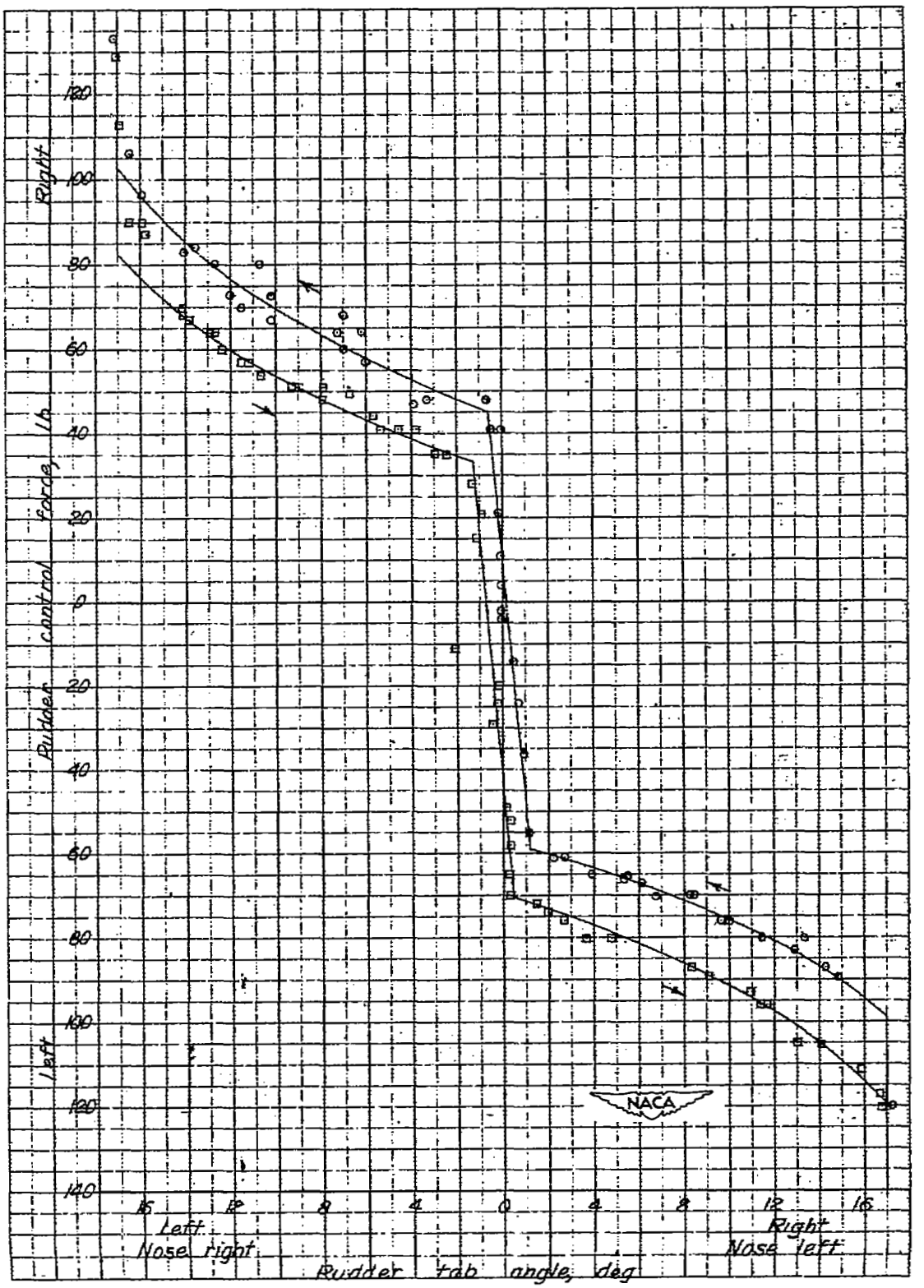
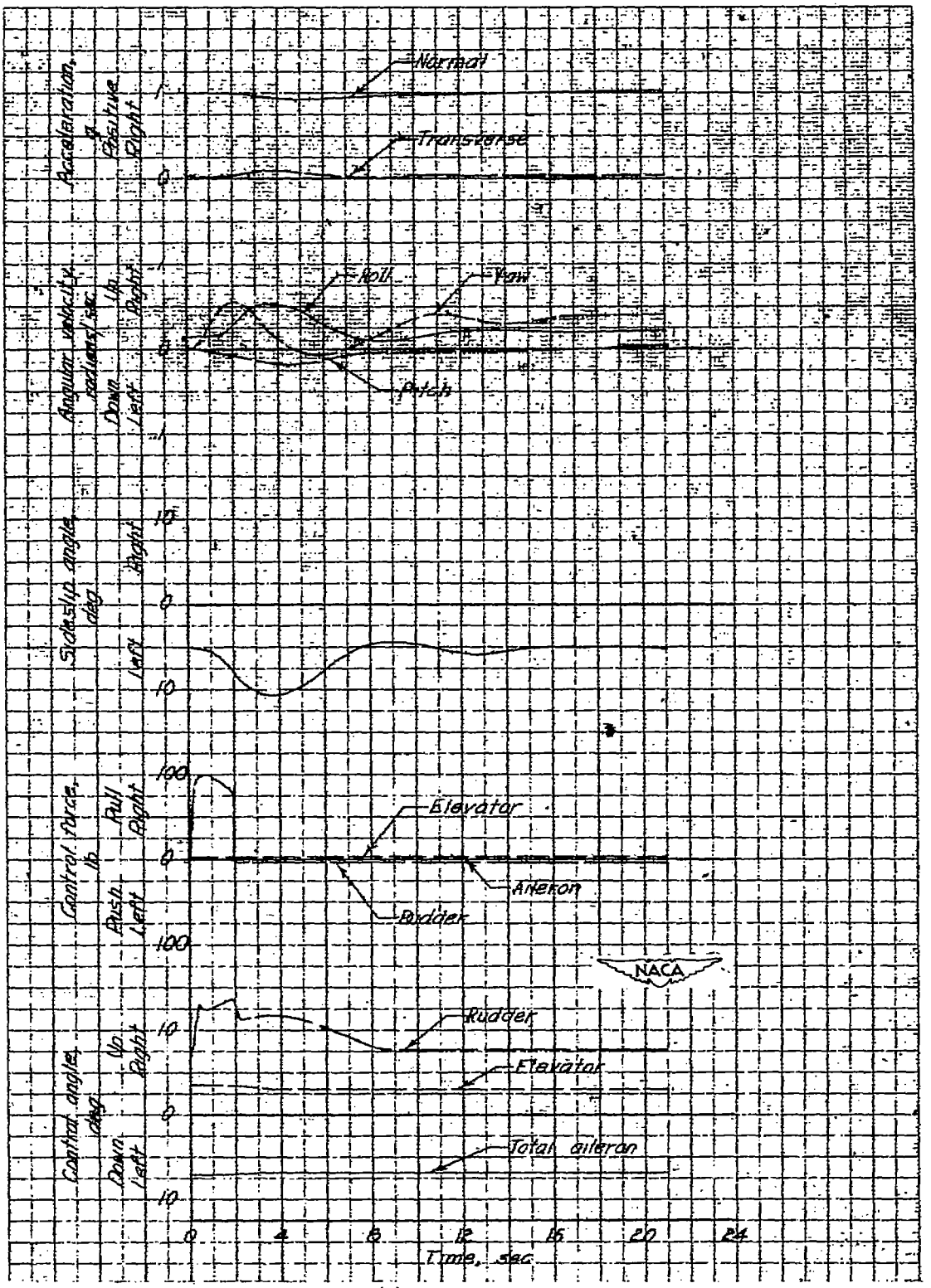
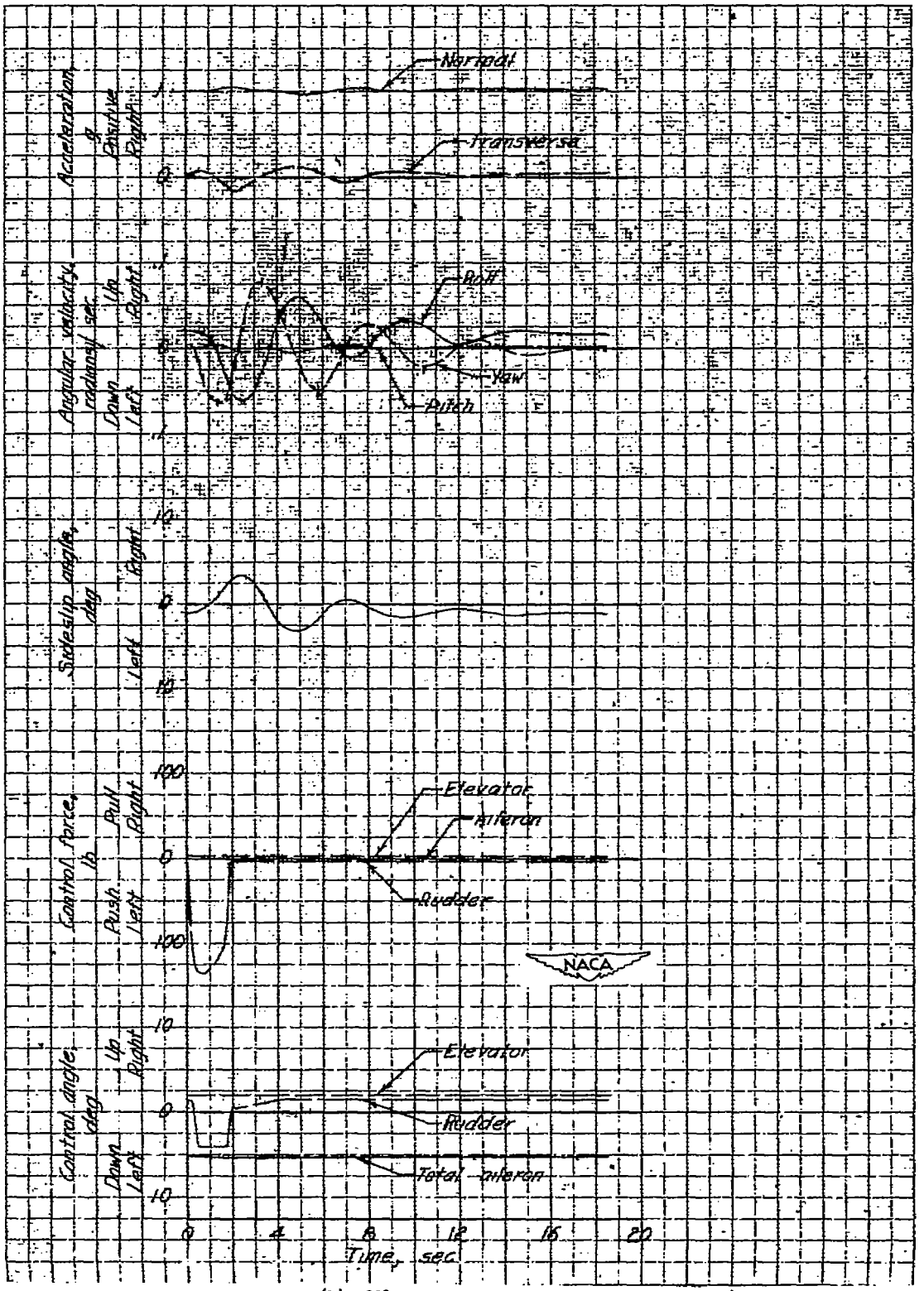


Figure 3.- Characteristics of the rudder spring tab with no load on the tab. O-54D airplane. Rudder fixed at neutral.



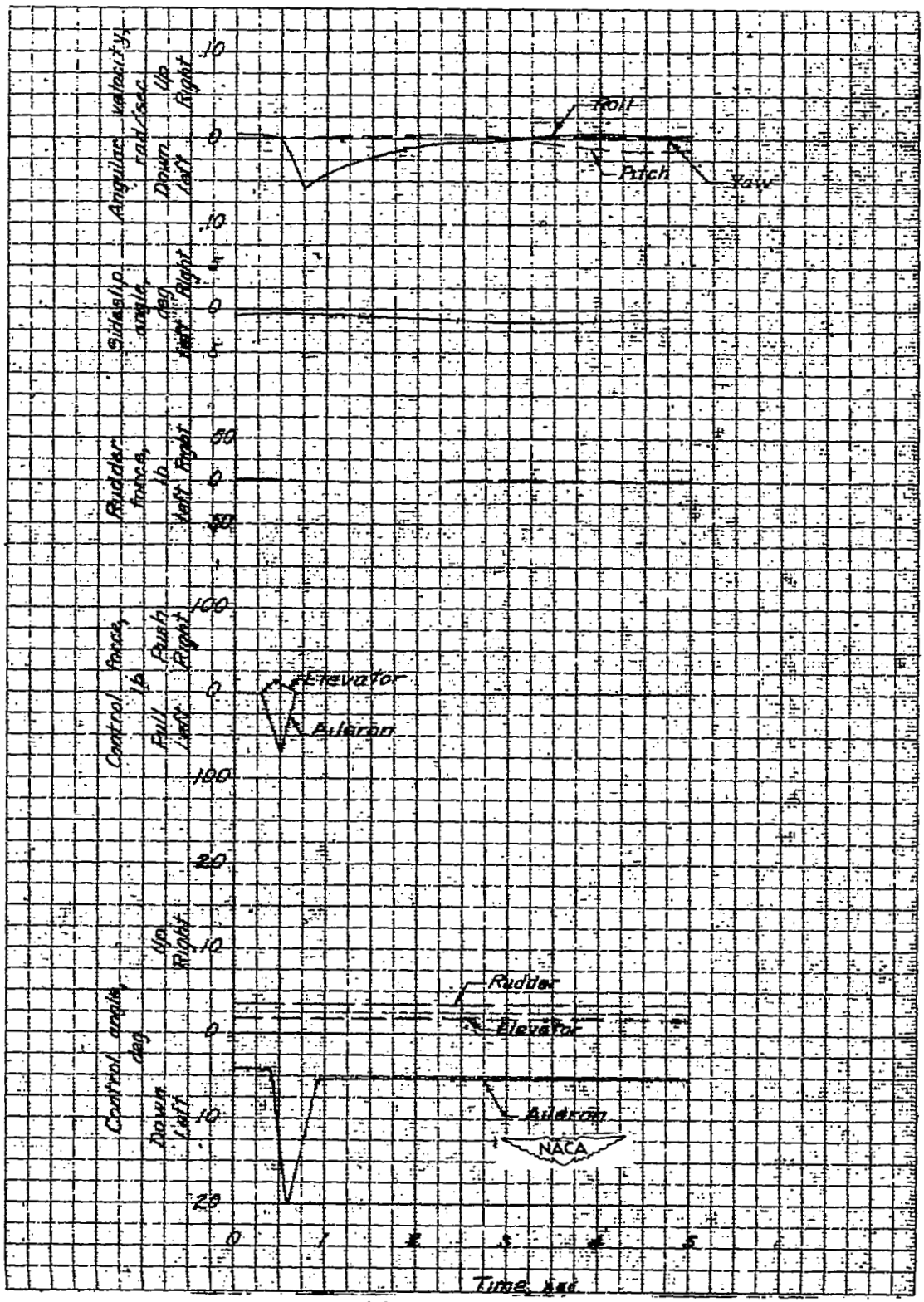
(a) 120 miles per hour.

Figure 4.- Time history of a rudder kick and release. Airplane condition, clean; normal rated power; O-54D airplane.



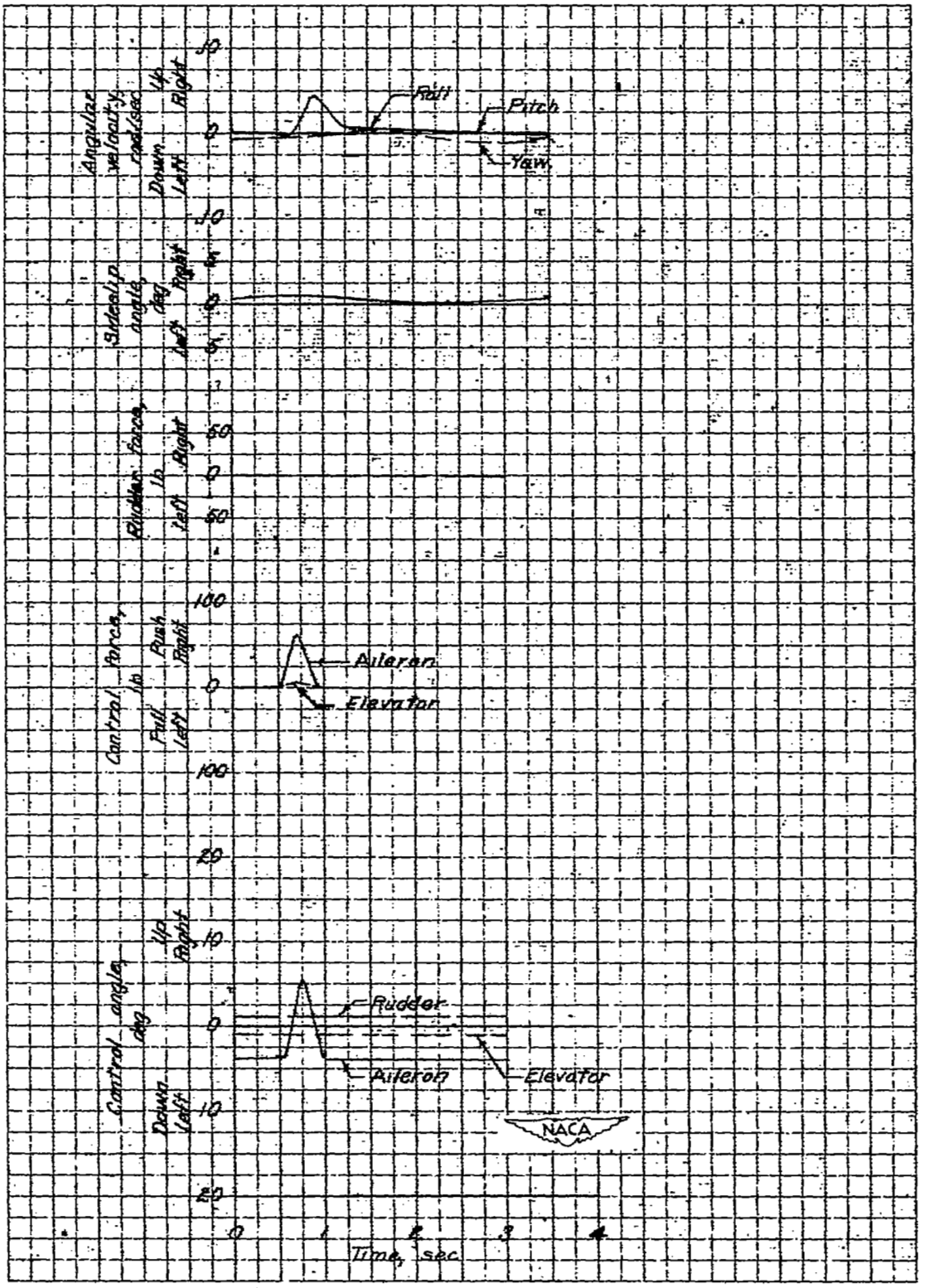
(b) 202 miles per hour.

Figure 4.- Concluded.



(a) 151 miles per hour.

Figure 5.- Time history of an aileron deflection and release. Airplane condition, clean; power for level flight. O-54D airplane.



(b) 237 miles per hour.

Figure 5.- Concluded.

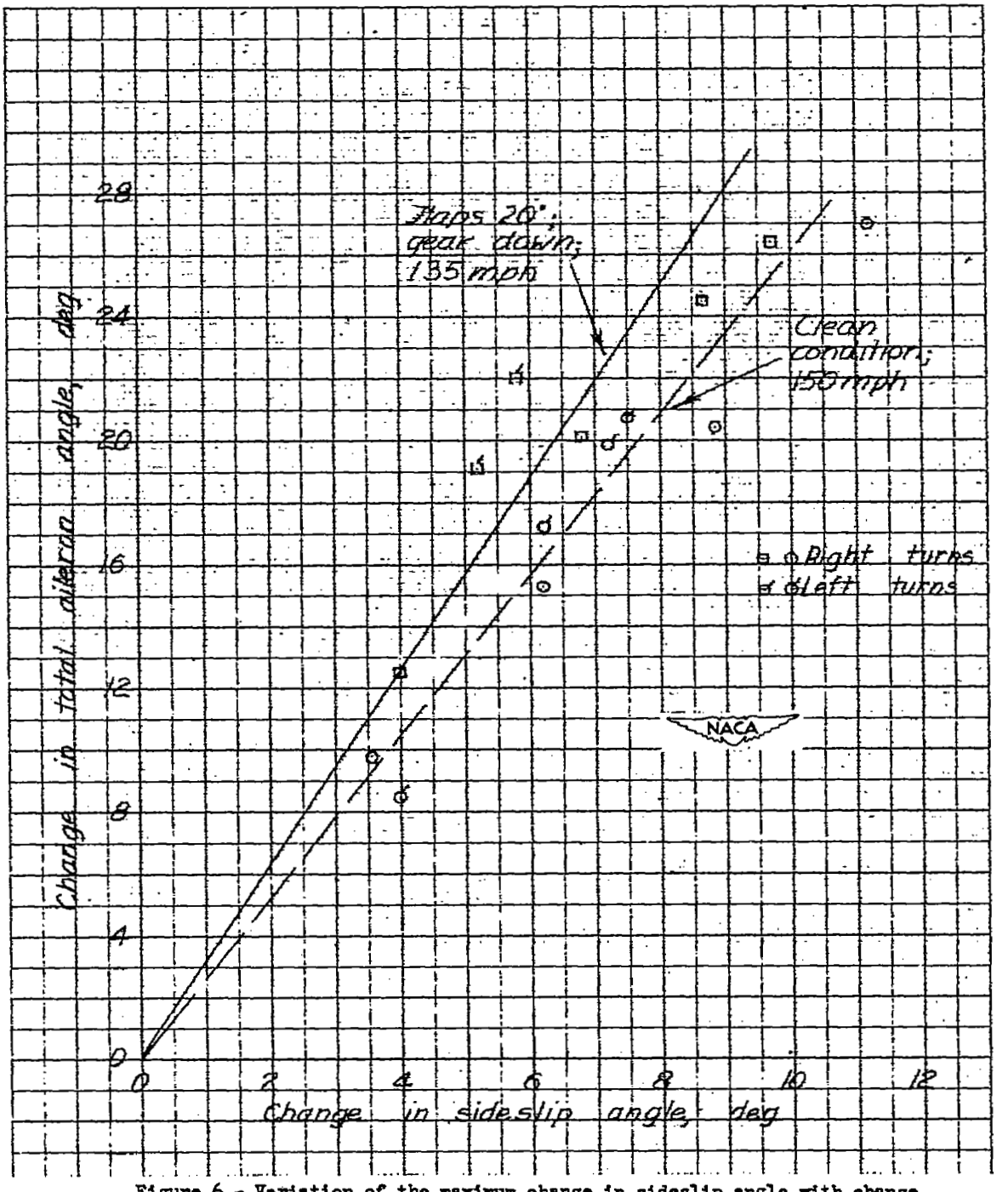
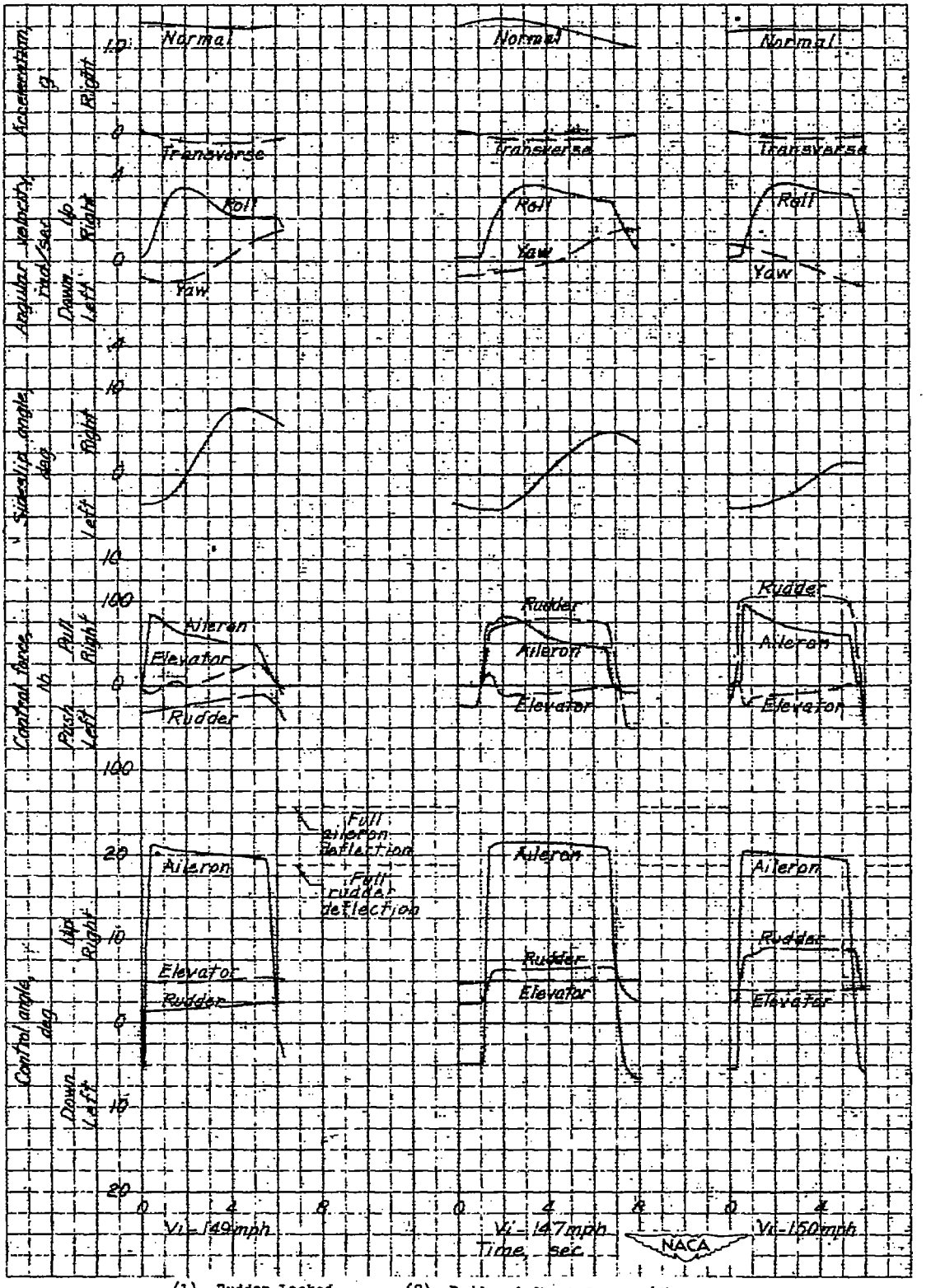


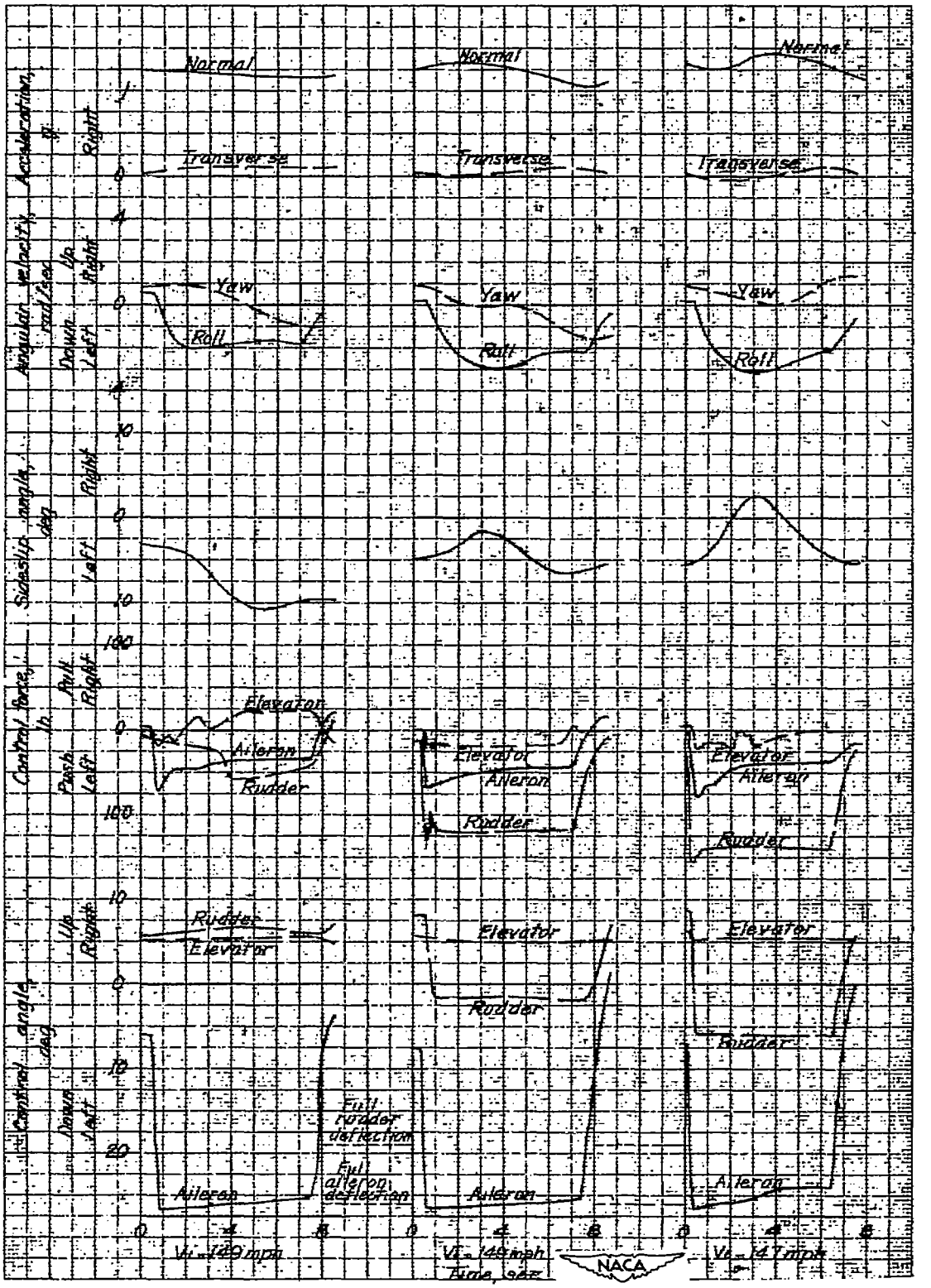
Figure 6.- Variation of the maximum change in sideslip angle with change in aileron angle in rudder locked rolls out of 45° banked turns. C-54D airplane.



(1) Rudder locked. (2) Rudder deflected. (3) Rudder deflected farther.

(a) Rolls out of left turns.

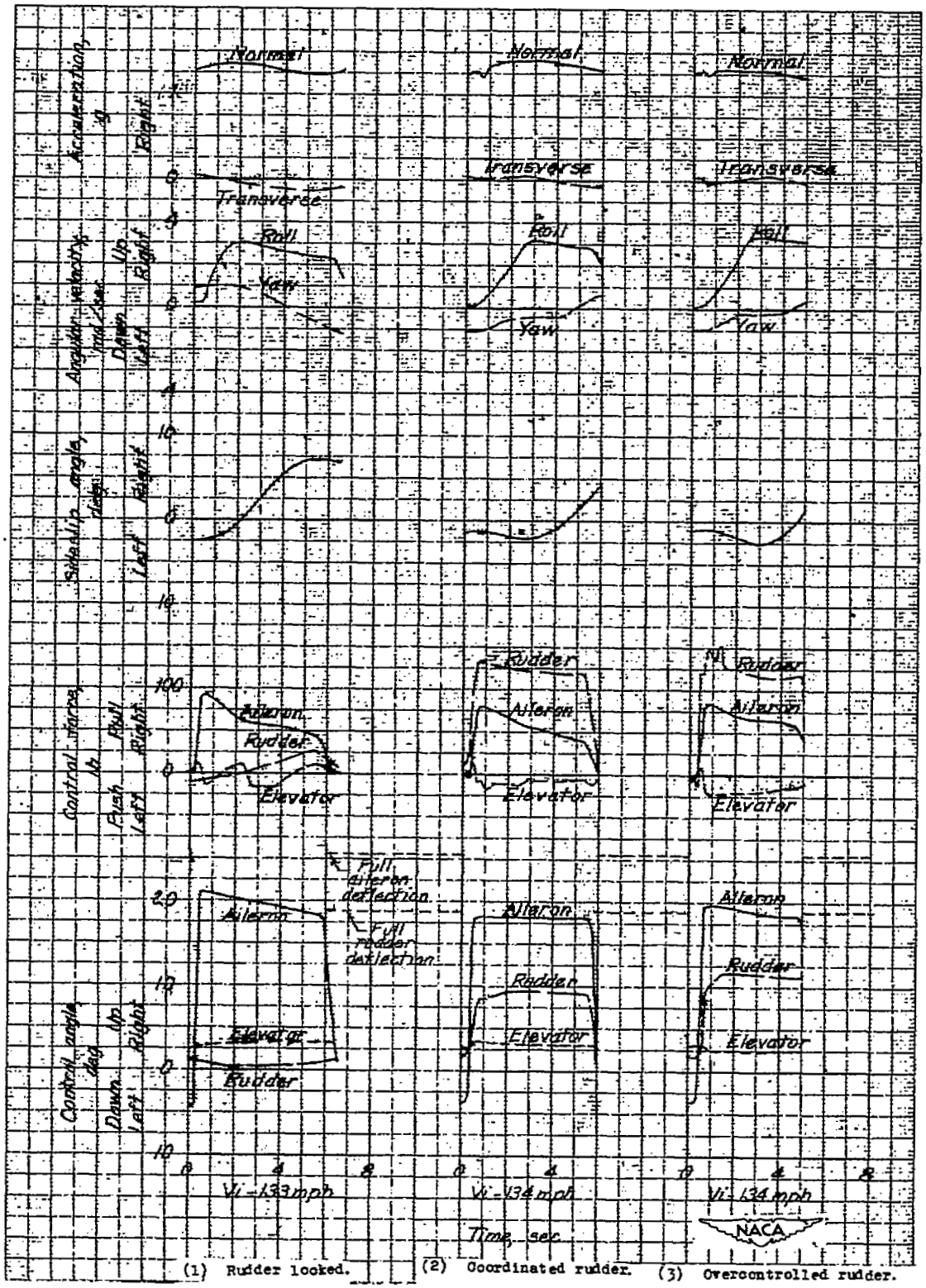
Figure 7.- Time histories of rolls out of 45° banked turns. Clean condition; power for level flight; O-54D airplane.



(1) Rudder locked. (2) Coordinated rudder. (3) Overcontrolled rudder.

(b) Rolls out of right turns.

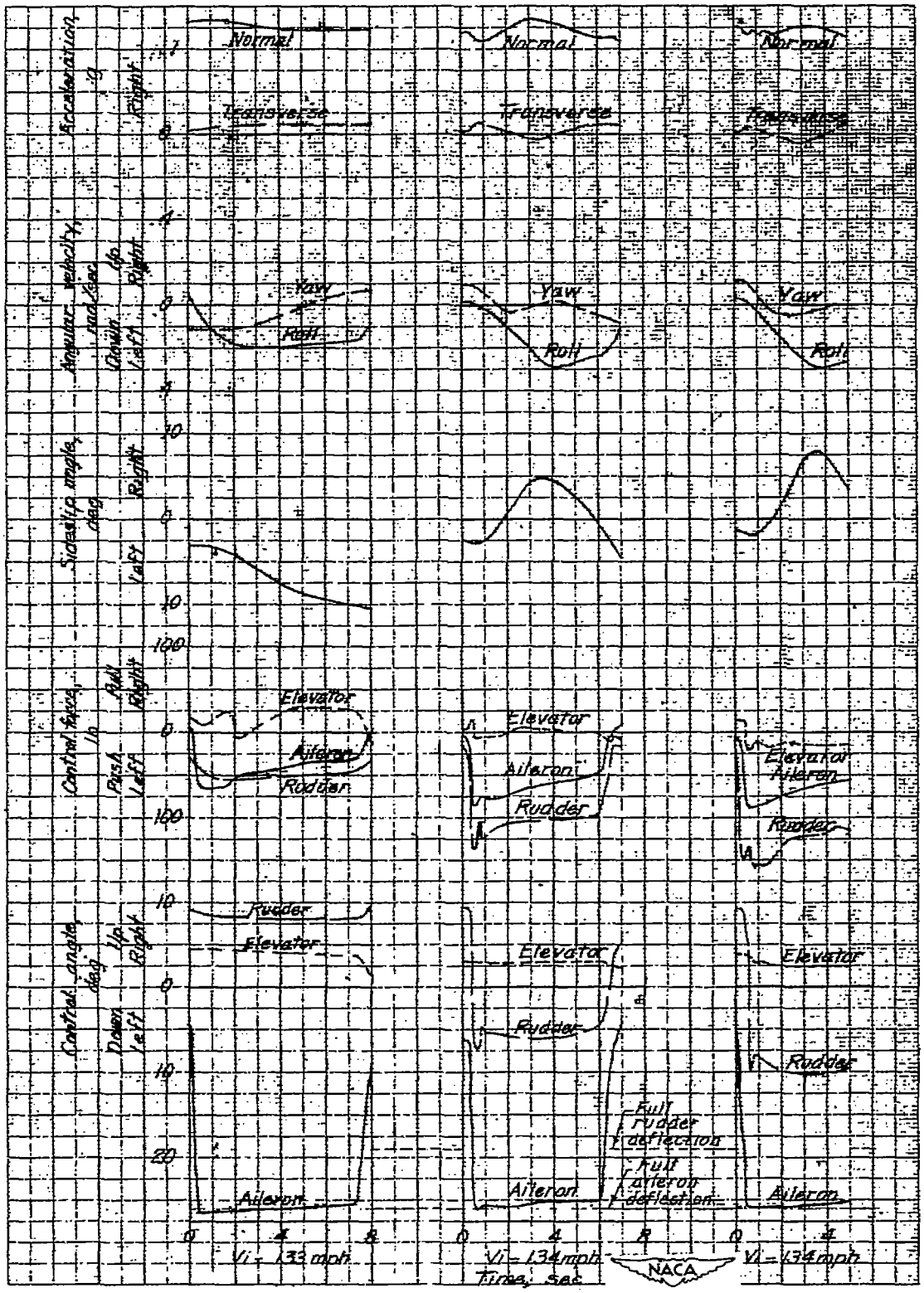
Figure 7.- Concluded.



(1) Rudder locked. (2) Coordinated rudder. (3) Overcontrolled rudder.

(a) Rolls out of left turns.

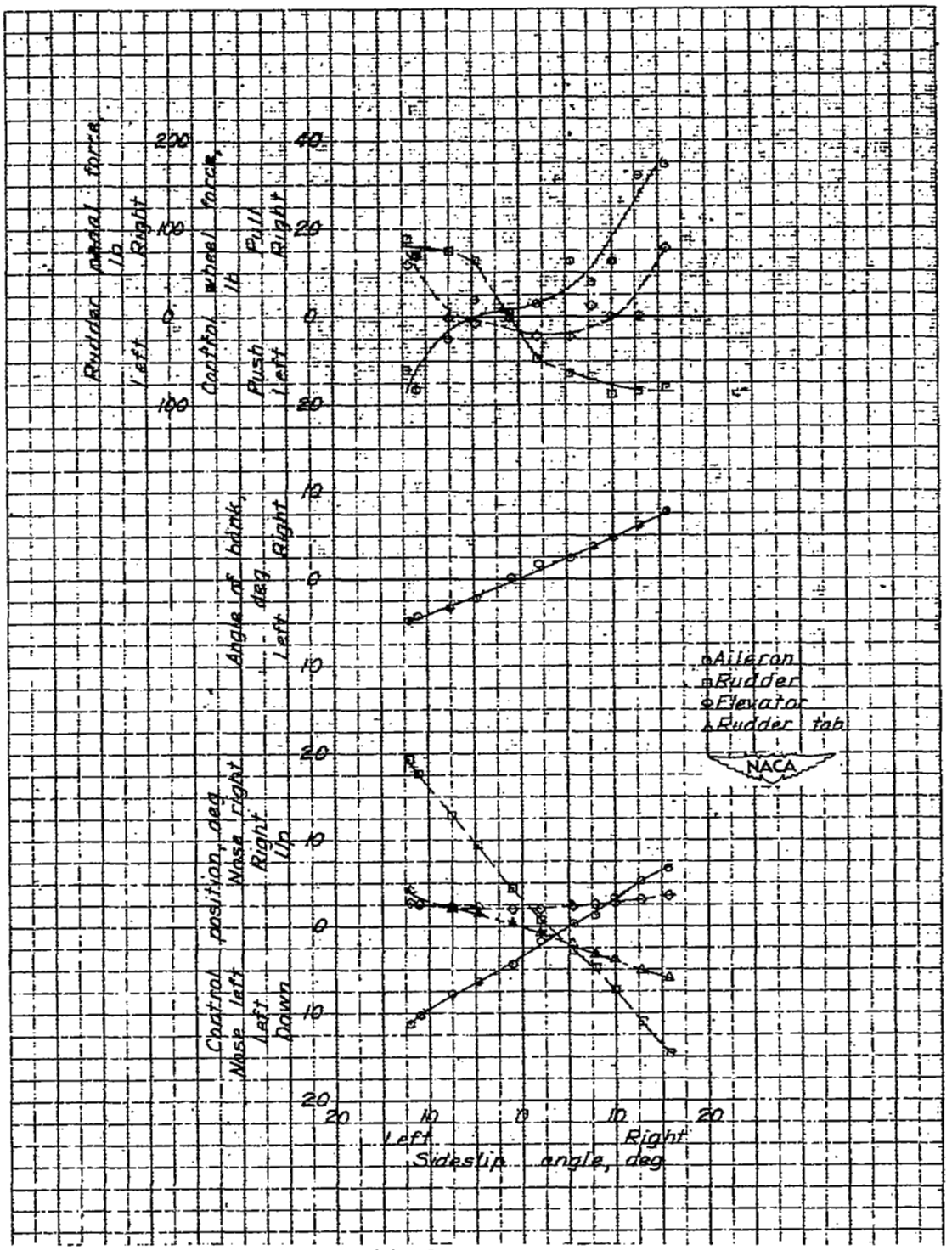
Figure 5.- Time histories of rolls out of 45° banked turns. Flaps down; gear down; power for level flight. O-54D airplane.



(1) Rudder locked. (2) Coordinated rudder. (3) Overcontrolled rudder.

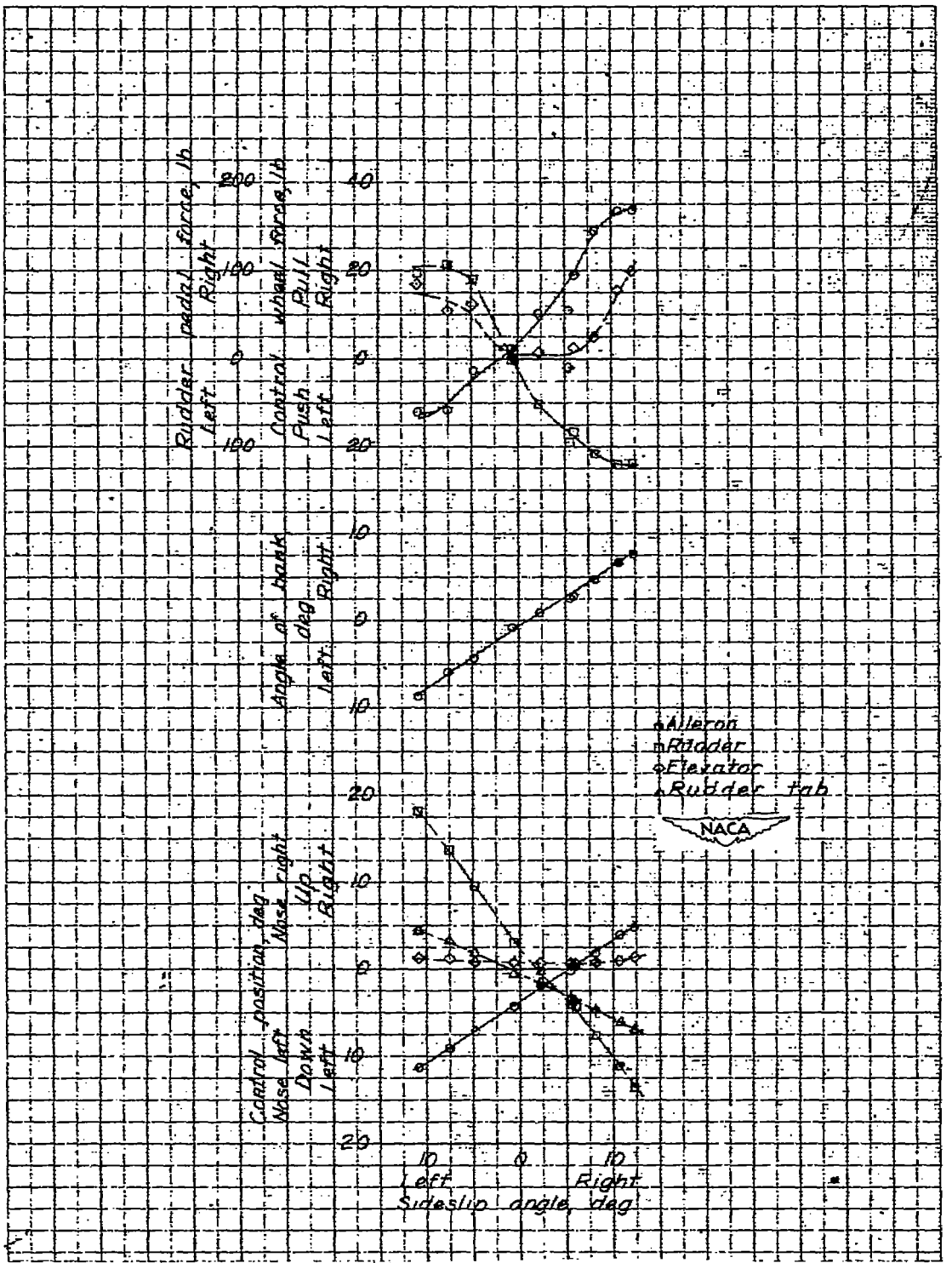
(b) Rolls out of right turns.

Figure 8.- Concluded.



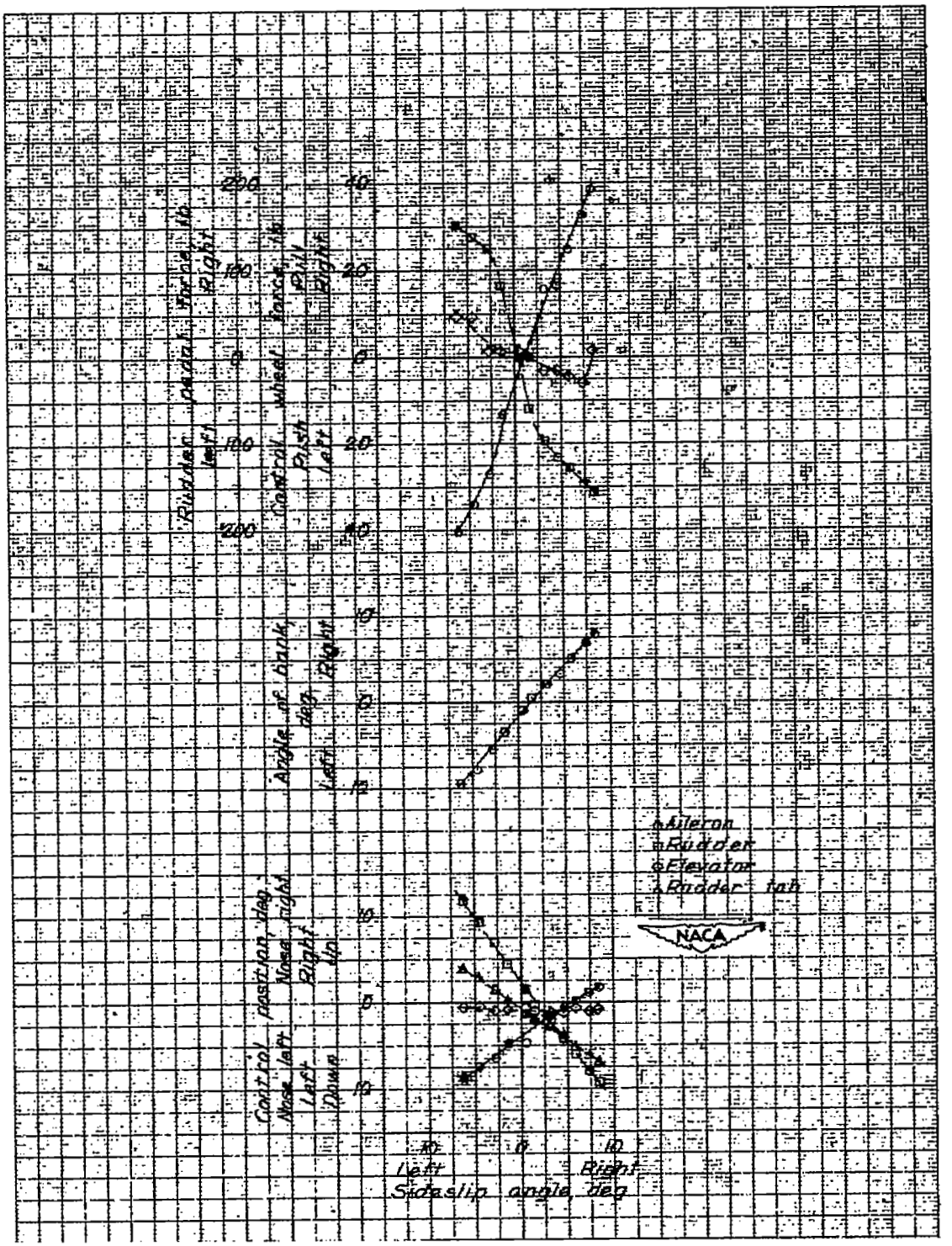
(a) 120 miles per hour.

Figure 9.- Sideslip characteristics. C-54D airplane; clean condition; normal rated power.



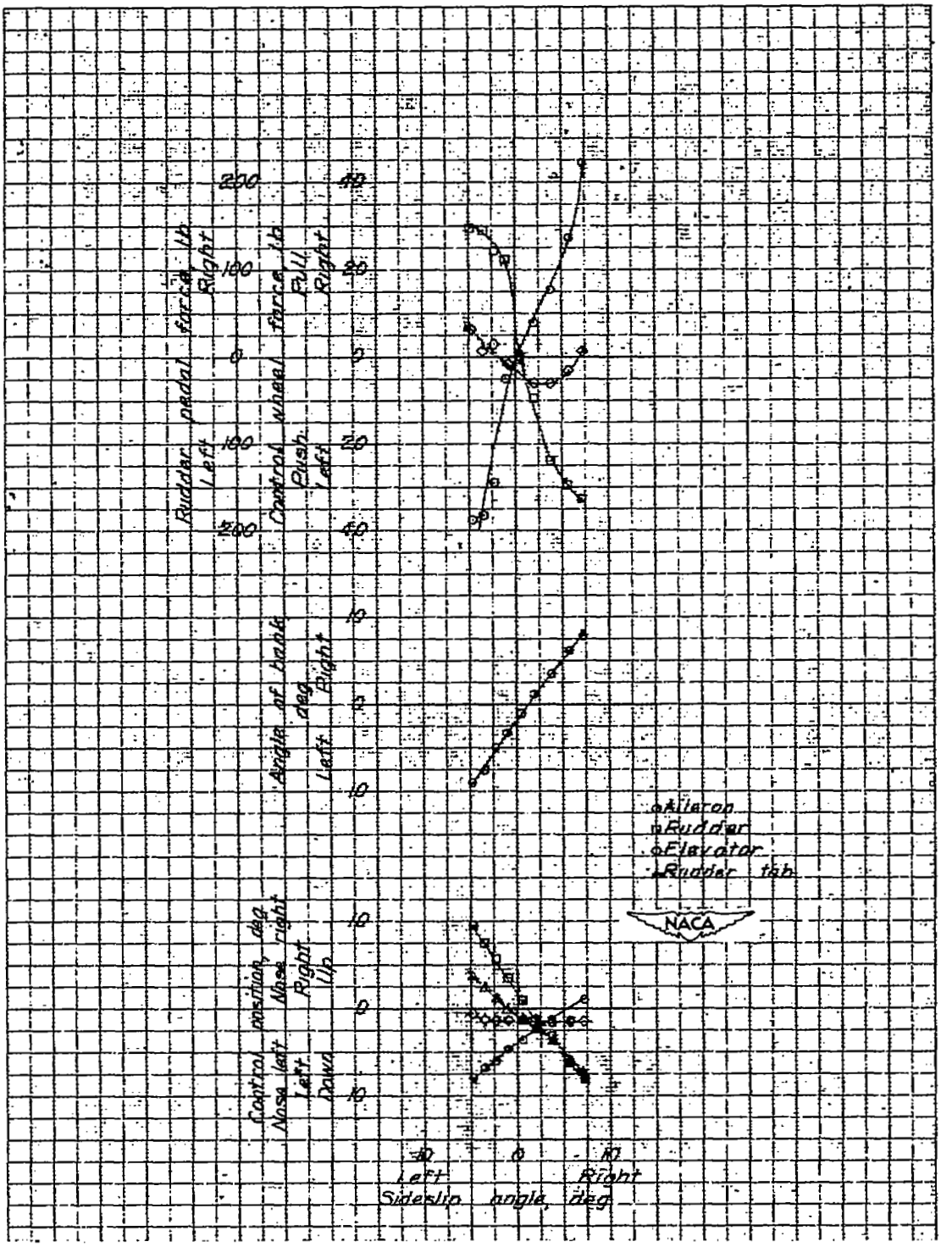
(b) 150 miles per hour.

Figure 9.- Continued.



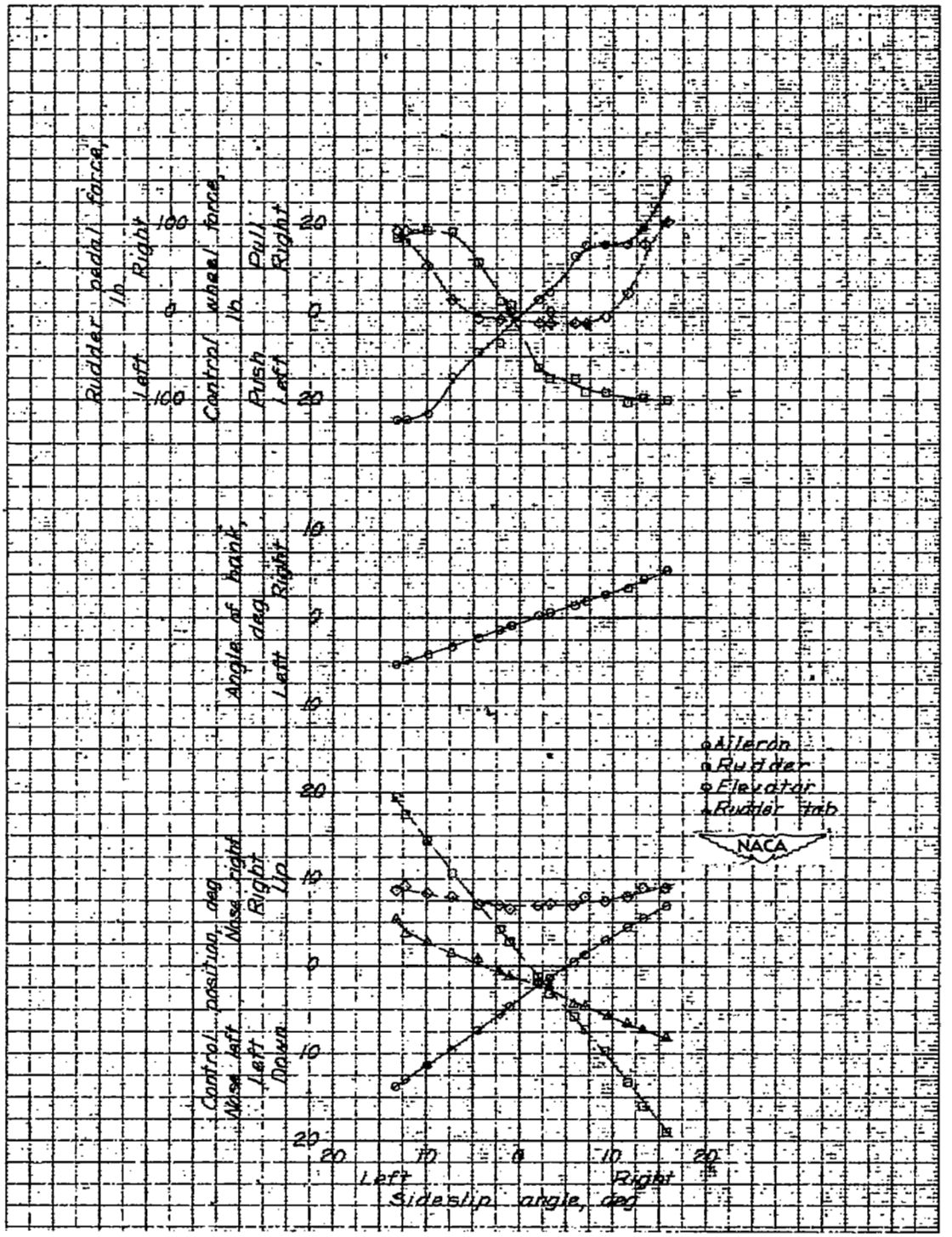
(c) 200 miles per hour.

Figure 9.- Continued.



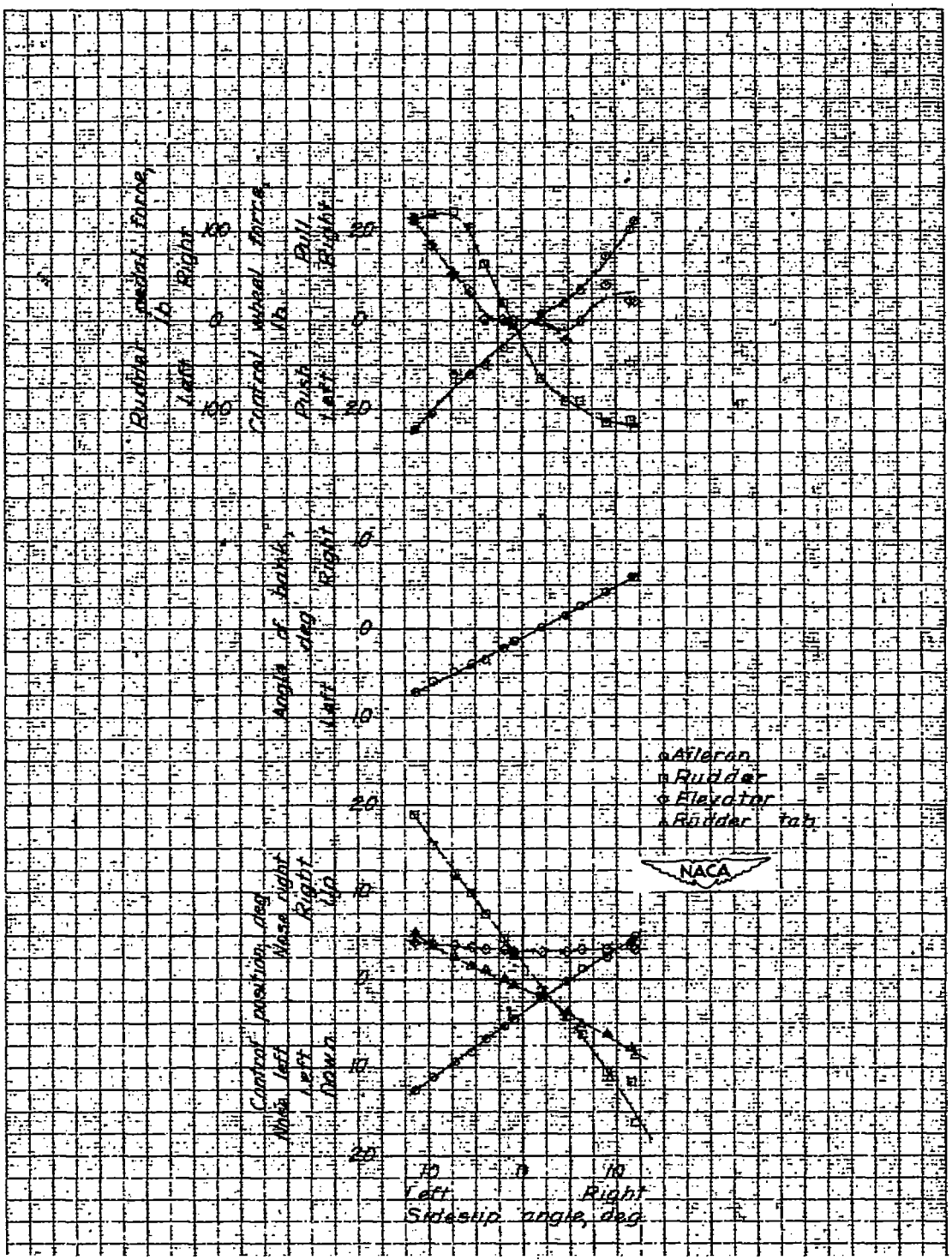
(d) 225 miles per hour.

Figure 9.- Concluded.



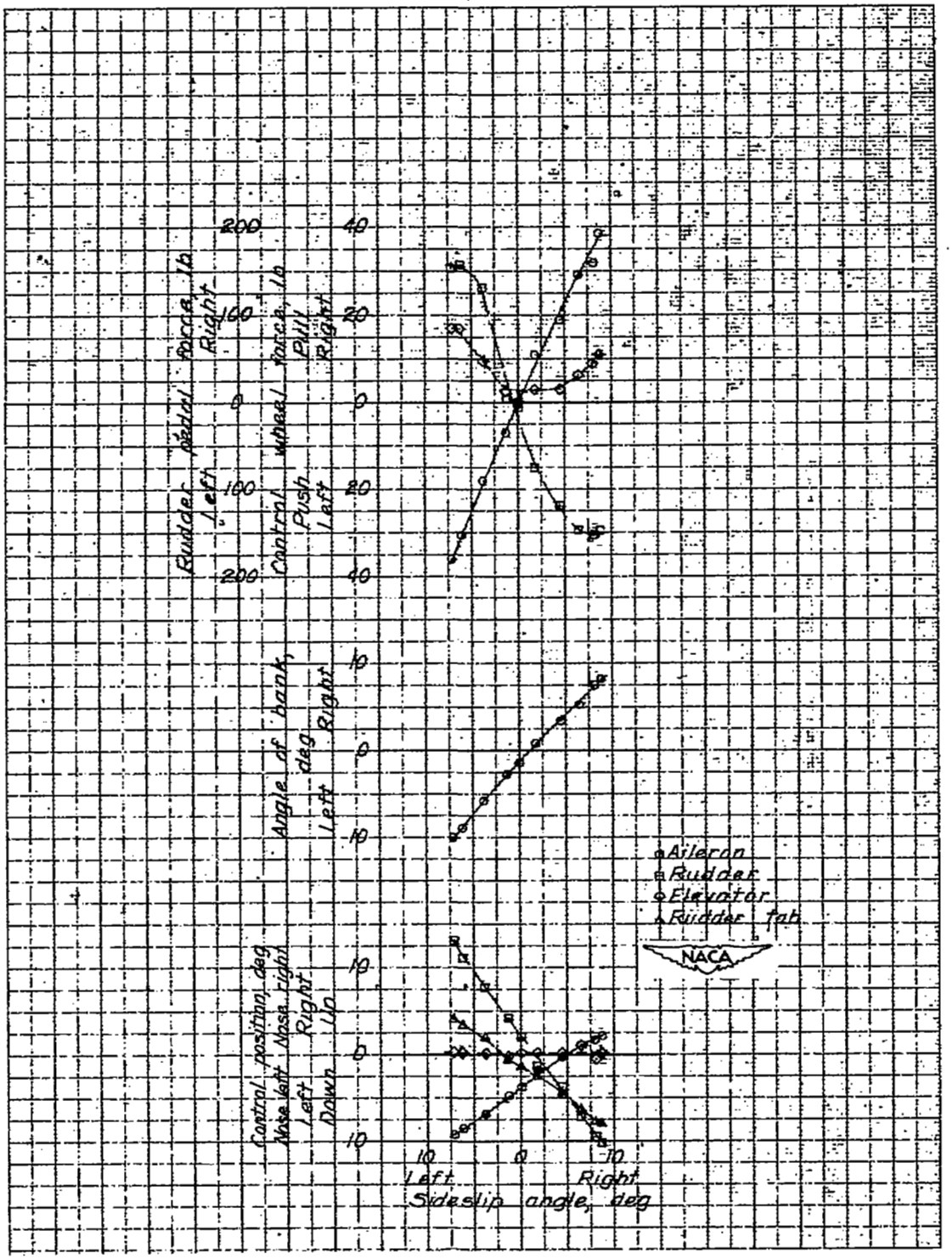
(a) 120 miles per hour.

Figure 10.- Sideslip characteristics. C-54D airplane; flaps and gear up; power off.



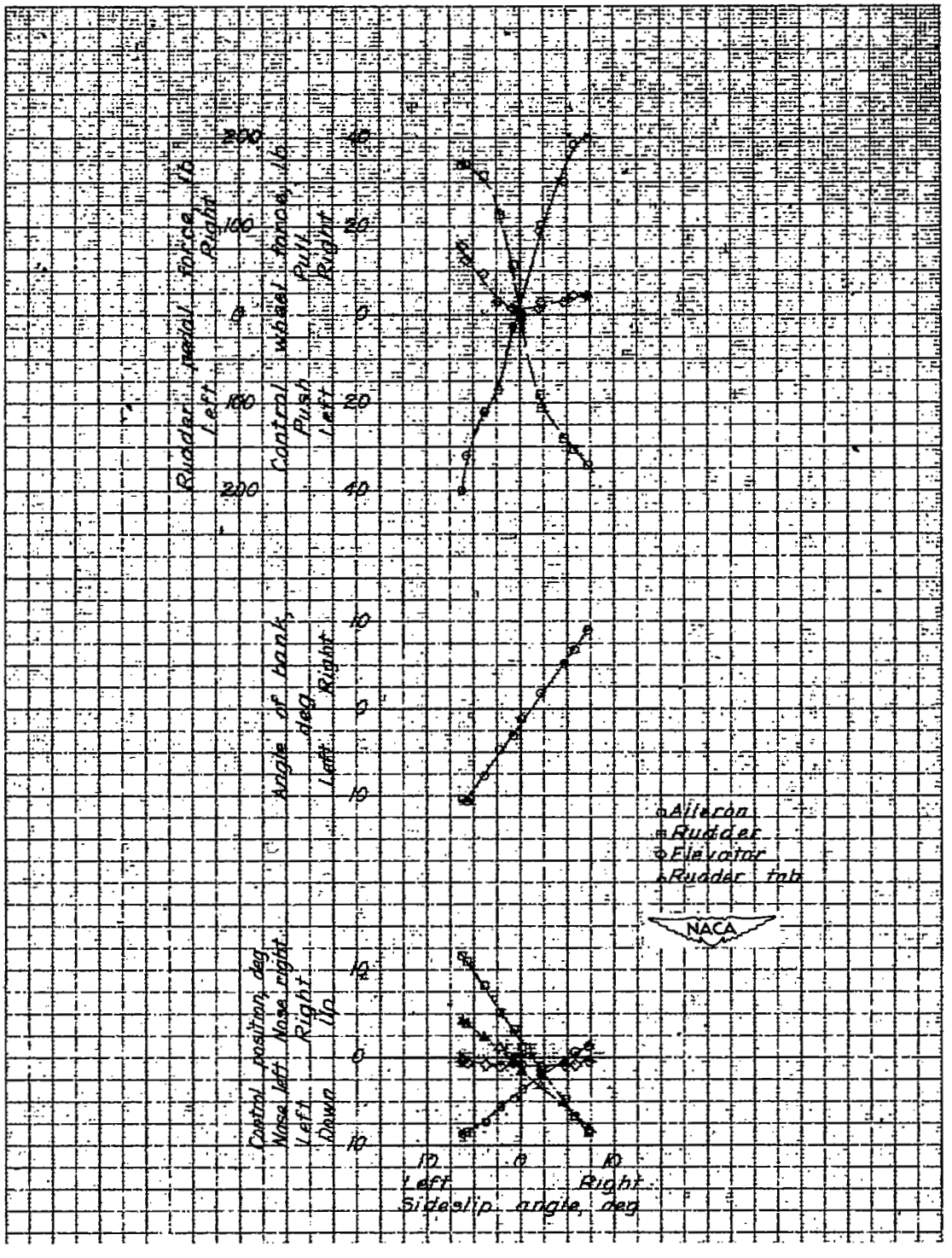
(b) 150 miles per hour.

Figure 10.- Continued.



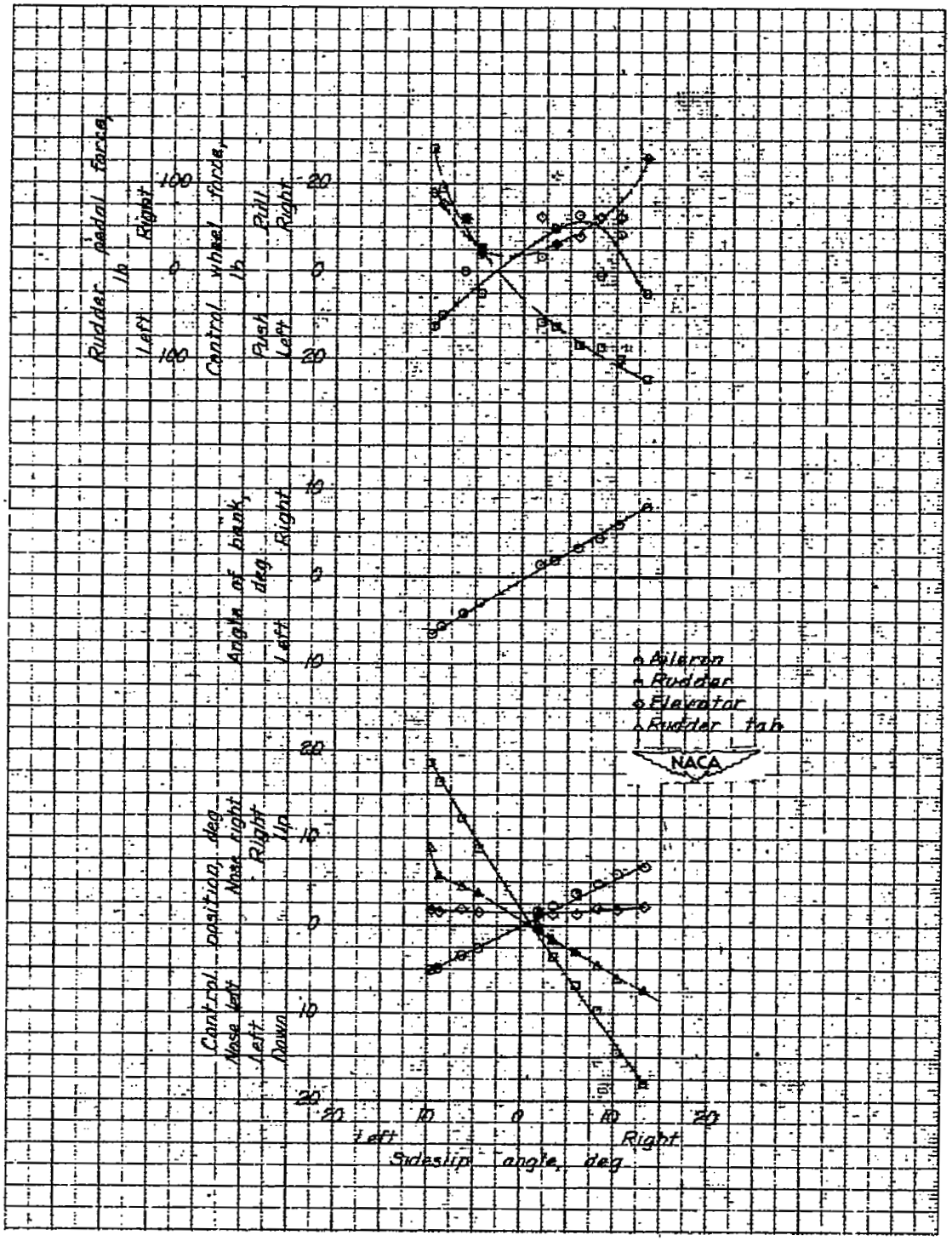
(c) 200 miles per hour.

Figure 10.- Continued.



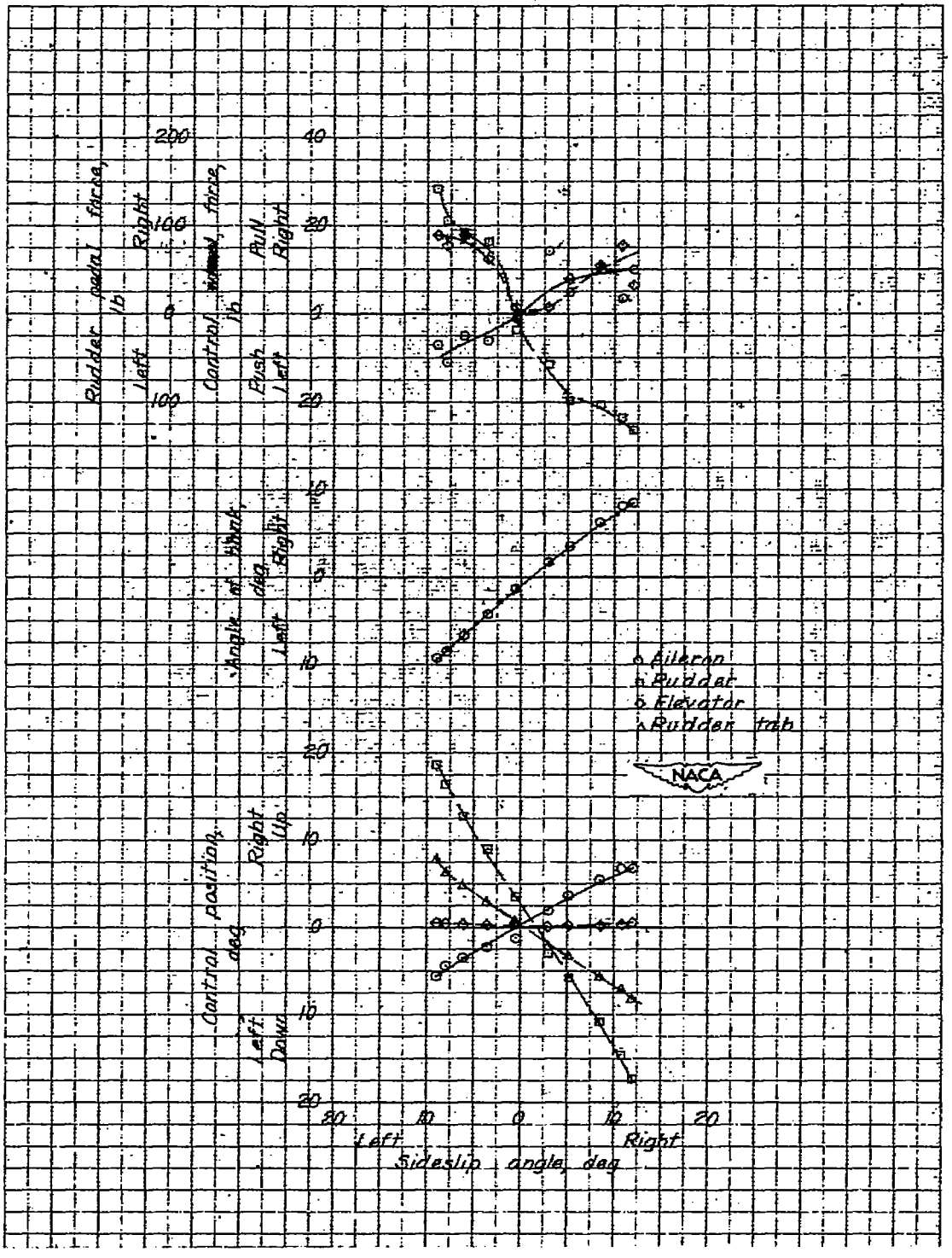
(d) 225 miles per hour.

Figure 10.- Concluded.



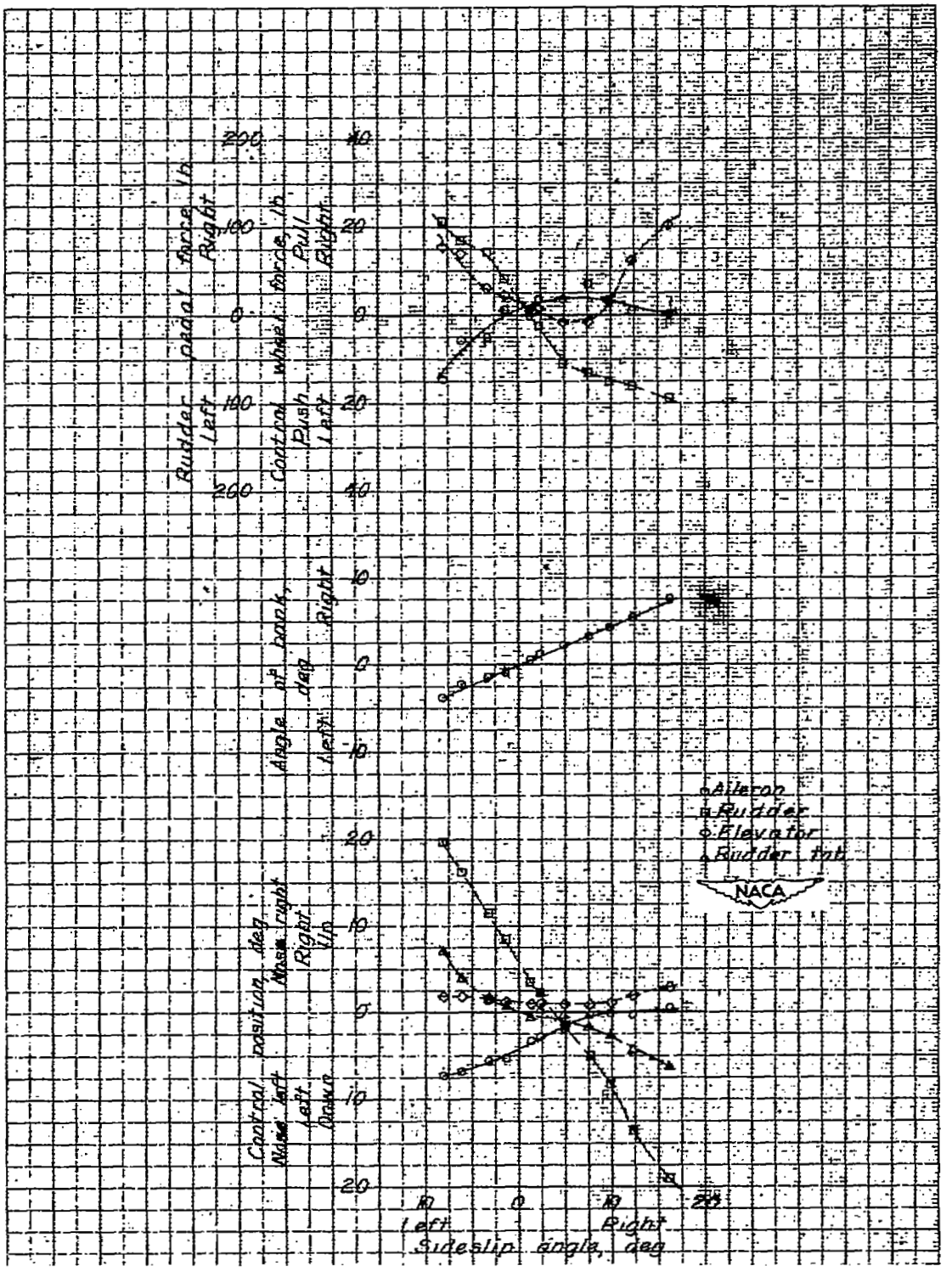
(a) 120 miles per hour.

Figure 11.- Sideslip characteristics. G-54D airplane; flaps 20°; gear down; power 20"; 2550 rpm.



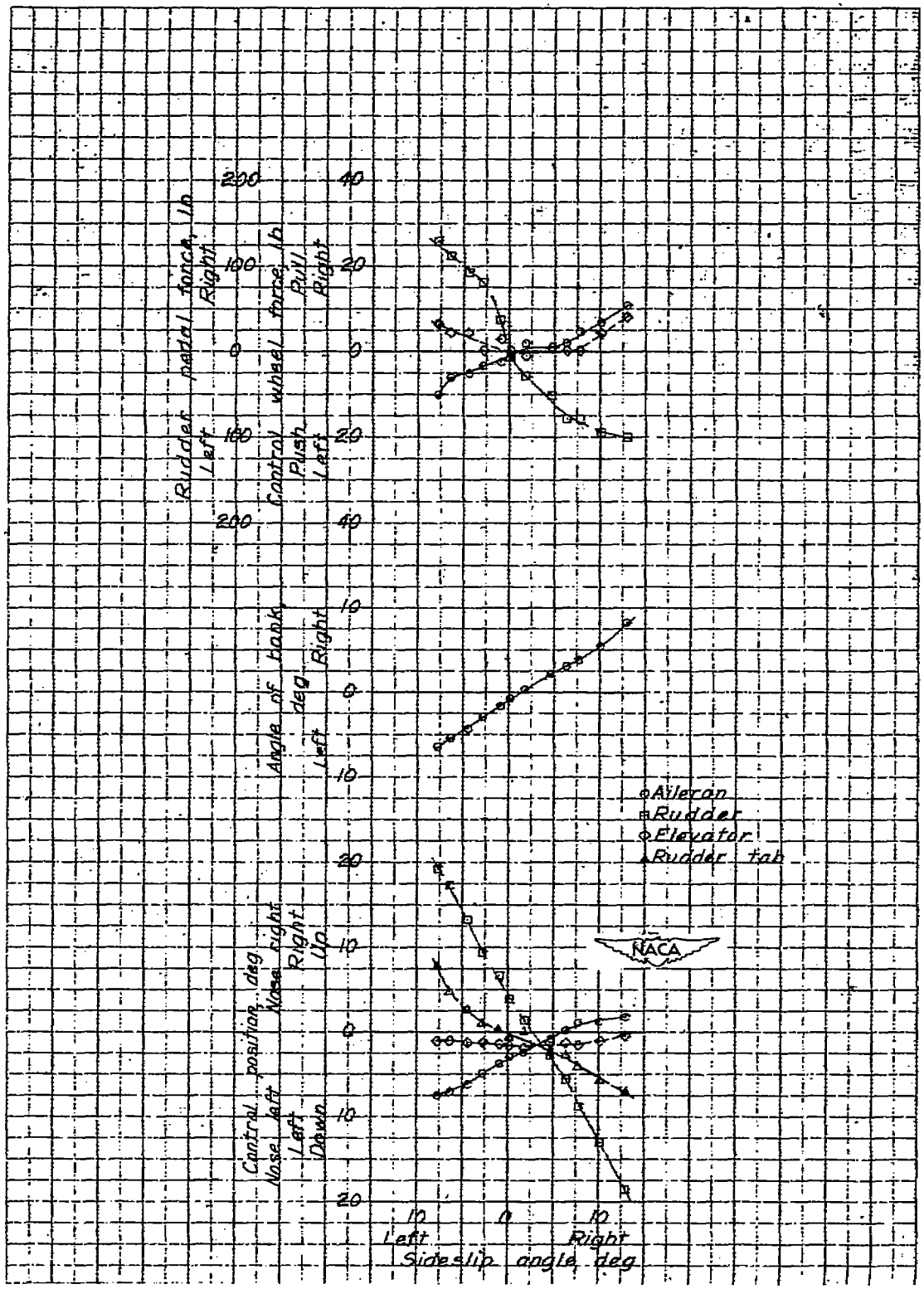
(b) 140 miles per hour.

Figure 11.- Concluded.



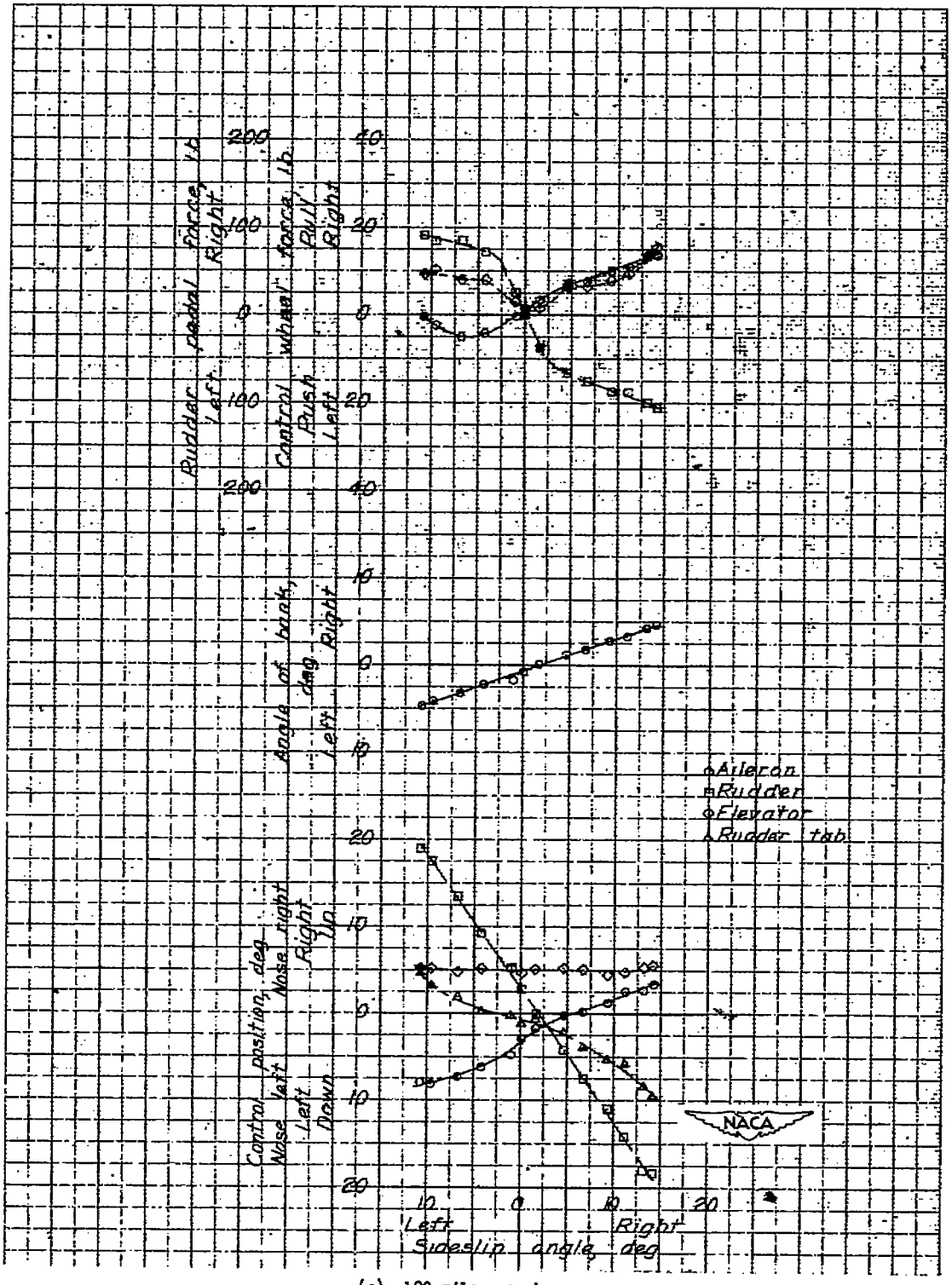
(a) 100 miles per hour.

Figure 12.- Sideslip characteristics. C-54D airplane; flaps and gear down; normal rated power.



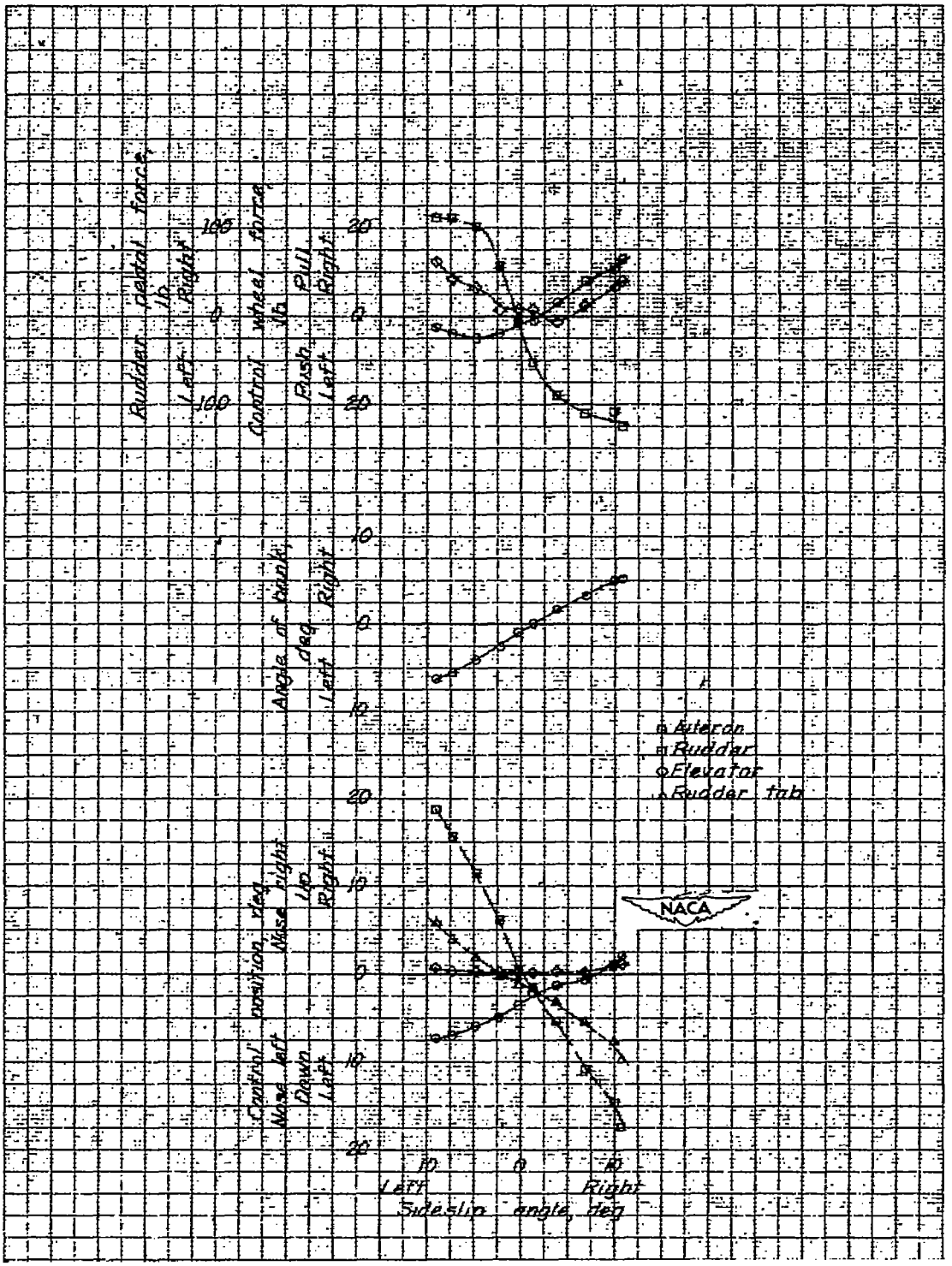
(b) 120 miles per hour.

Figure 12.- Concluded.



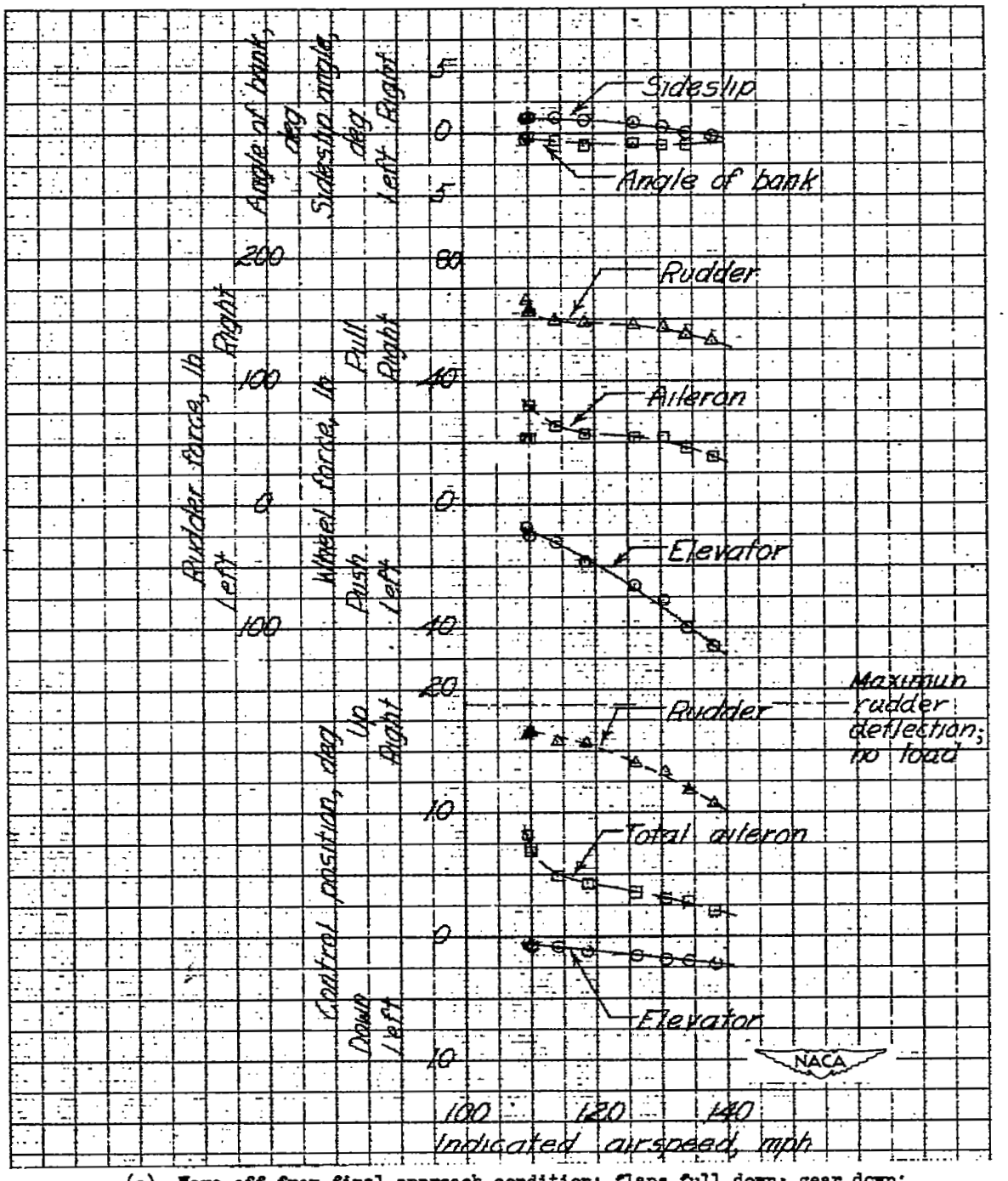
(a) 100 miles per hour.

Figure 13.- Sideslip characteristics. C-54D airplane; flaps and gear down; power off.



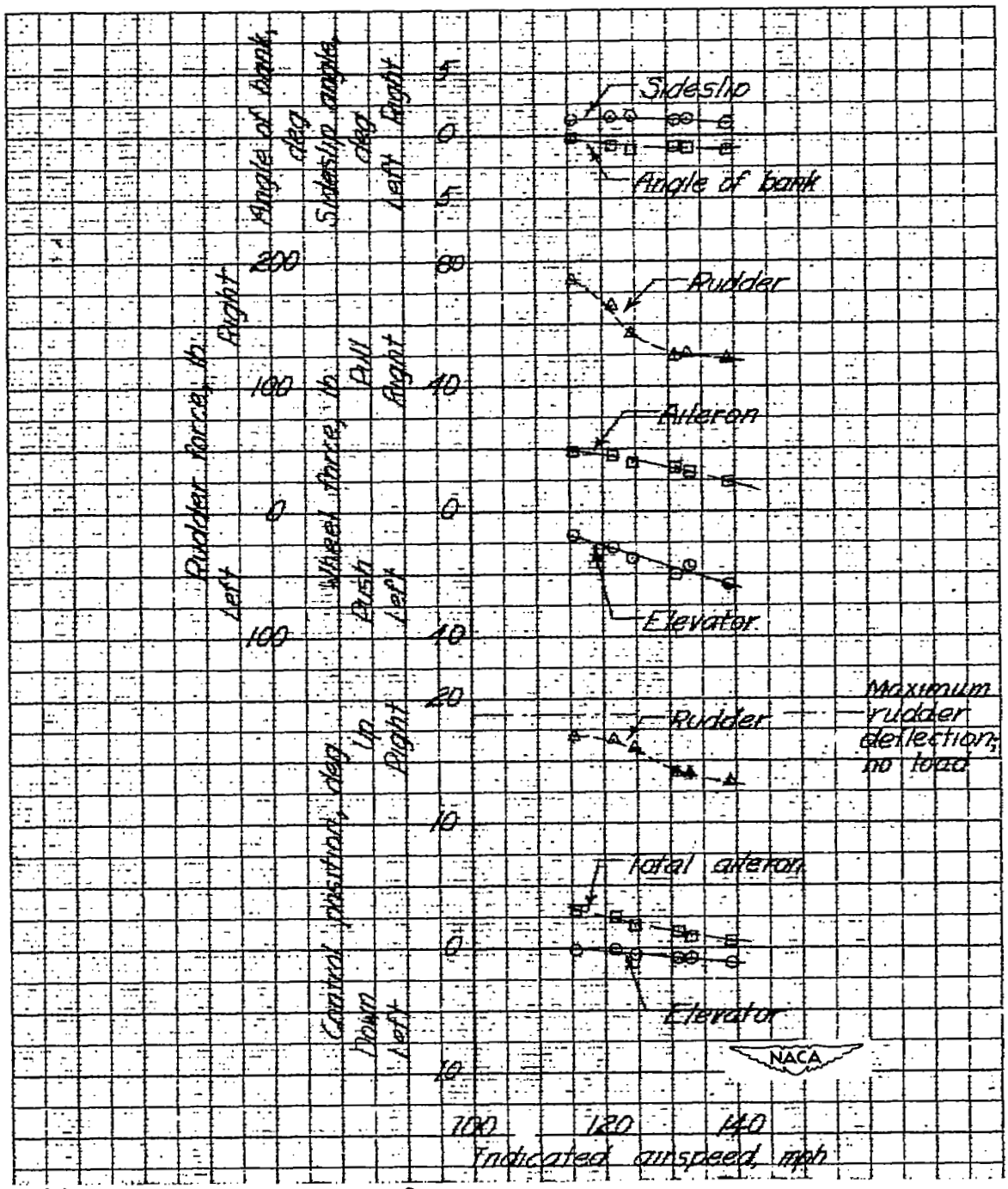
(b) 120 miles per hour.

Figure 13.- Concluded.



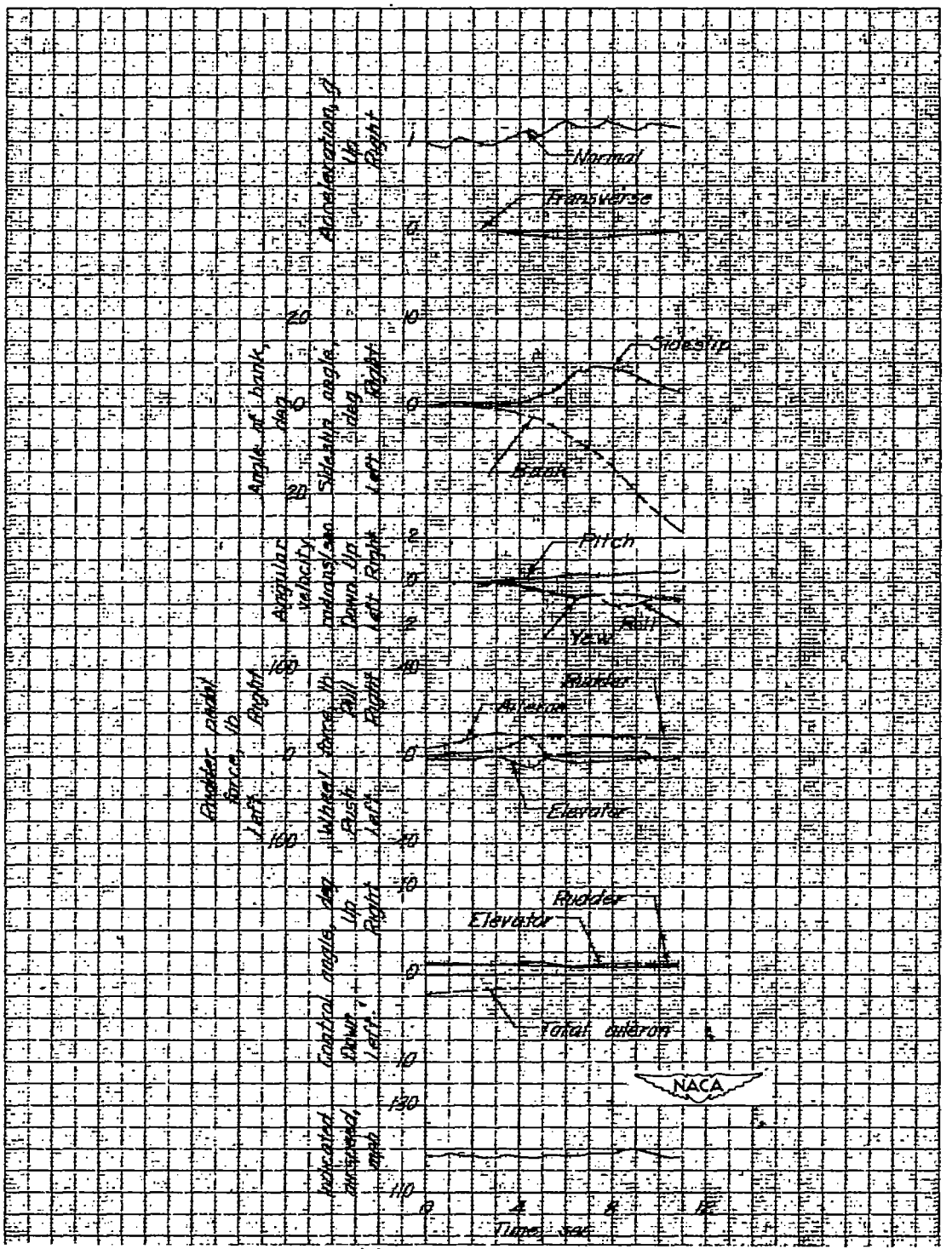
(a) Wave-off from final approach condition; flaps full down; gear down; No. 1 engine idling; No. 2, 3, and 4 engines 45 in. Hg; 2550 rpm. Trimmed for symmetrical power in approach condition.

Figure 14.- Lateral and longitudinal trim characteristics with assymetric power. C-54D airplane.



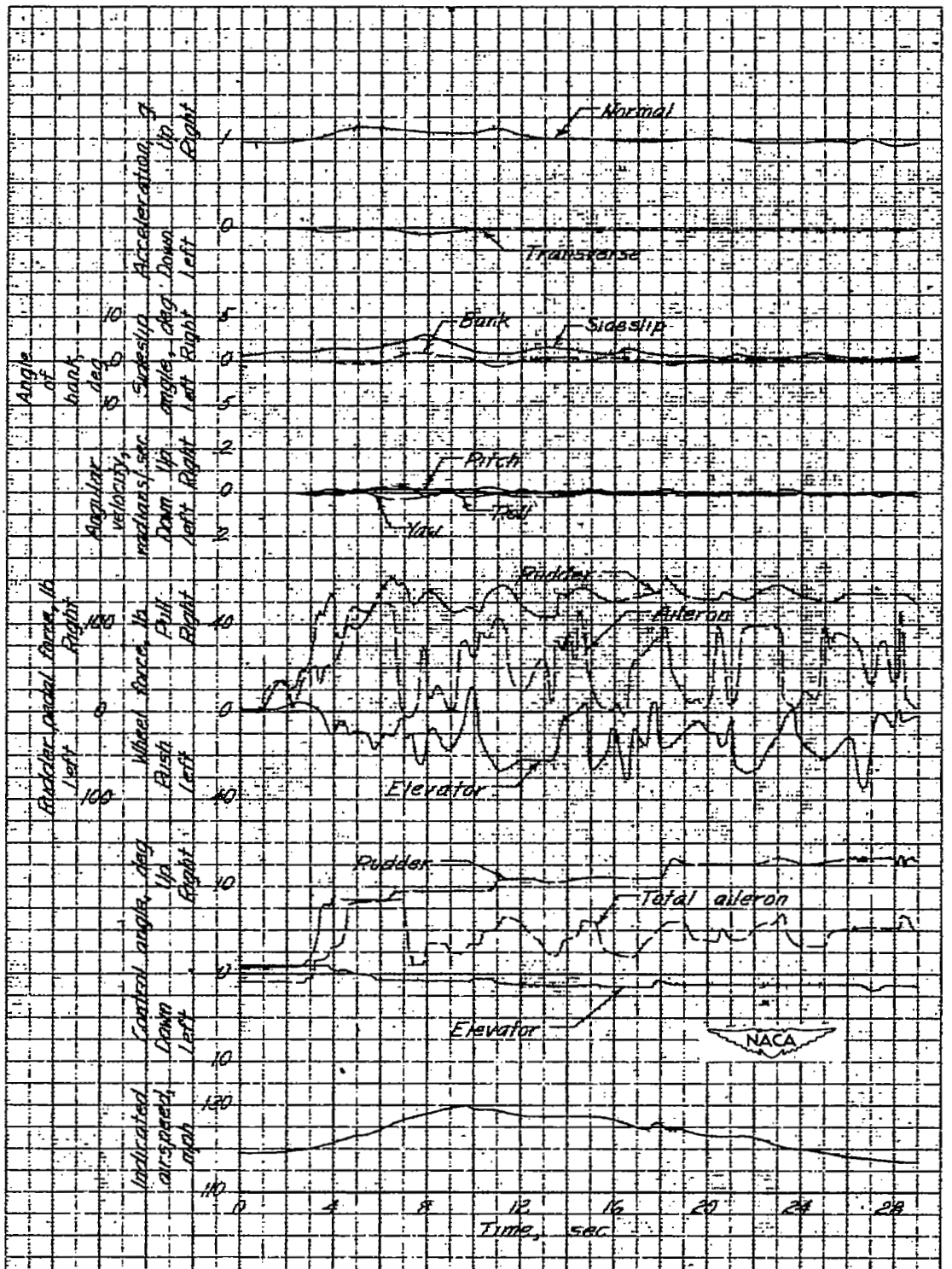
(b) Take-off condition; flaps 20°; gear down; No. 1 engine idling; No. 2, 3, and 4 engines 45 in. Hg; 2550 rpm. Trimmed for symmetrical power in take-off condition.

Figure 14.- Concluded.



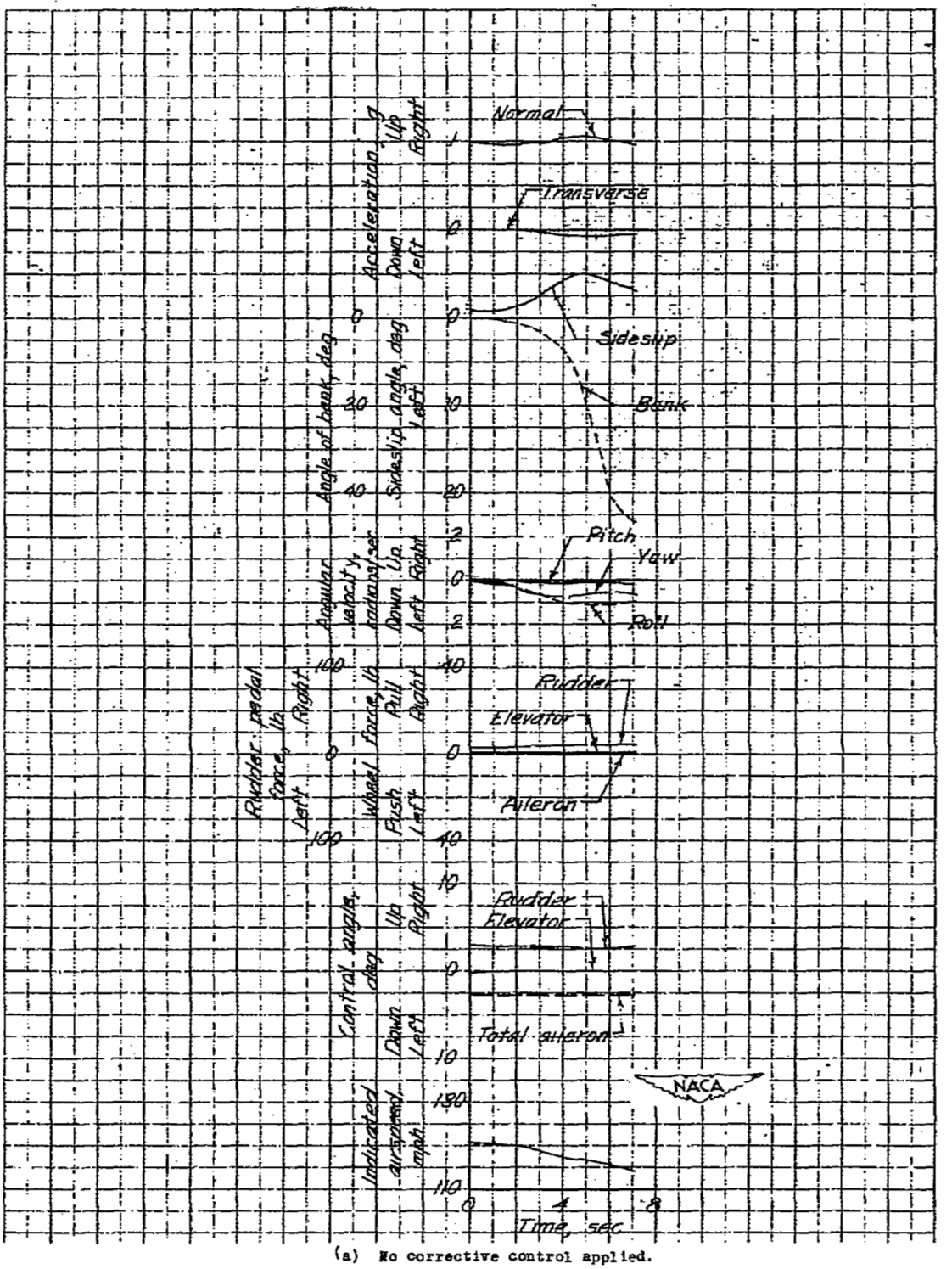
(a) No corrective control applied.

Figure 15.- Time histories of airplane motions during a wave-off in which No. 1 engine fails as power is applied. C-54D airplane; flaps full down; gear down; power initially off, but increased to 45" Hg during first three seconds.



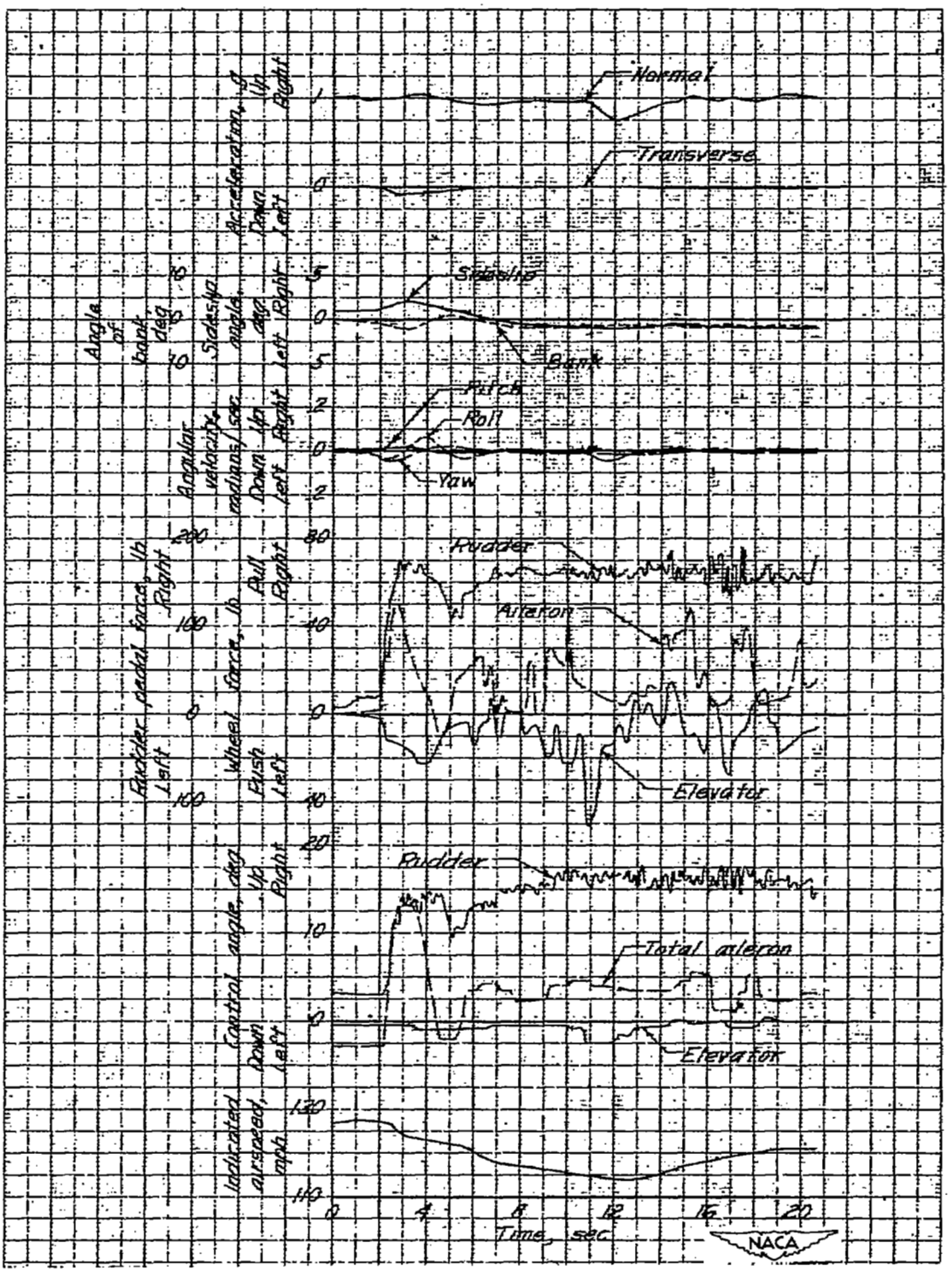
(b) Corrective control applied.

Figure 15.- Concluded.



(a) No corrective control applied.

Figure 16.- Time histories of airplane motions during a simulated take-off in which No. 1 engine fails. C-54D airplane; flaps 20°; gear down; power 43 in. Hg; 2550 rpm; No. 1 engine cut to idling.



(b) Corrective control applied.

Figure 16.- Concluded.

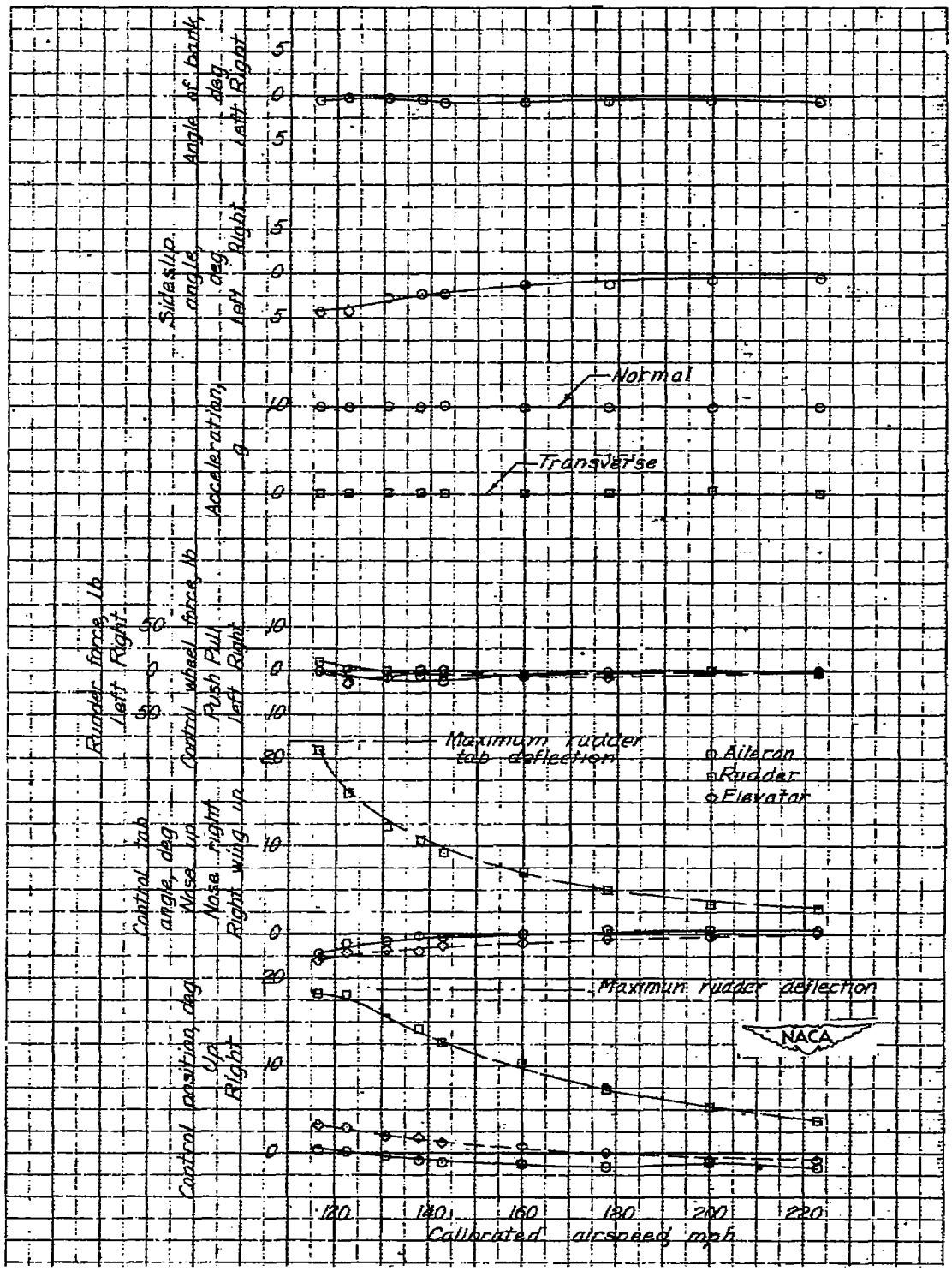


Figure 17.- Lateral and longitudinal trim characteristics with assymetric power; trim with trim tabs; O-54D airplane. Clean condition; power; No. 1 engine idling; No. 2, 3, and 4 normal rated power.

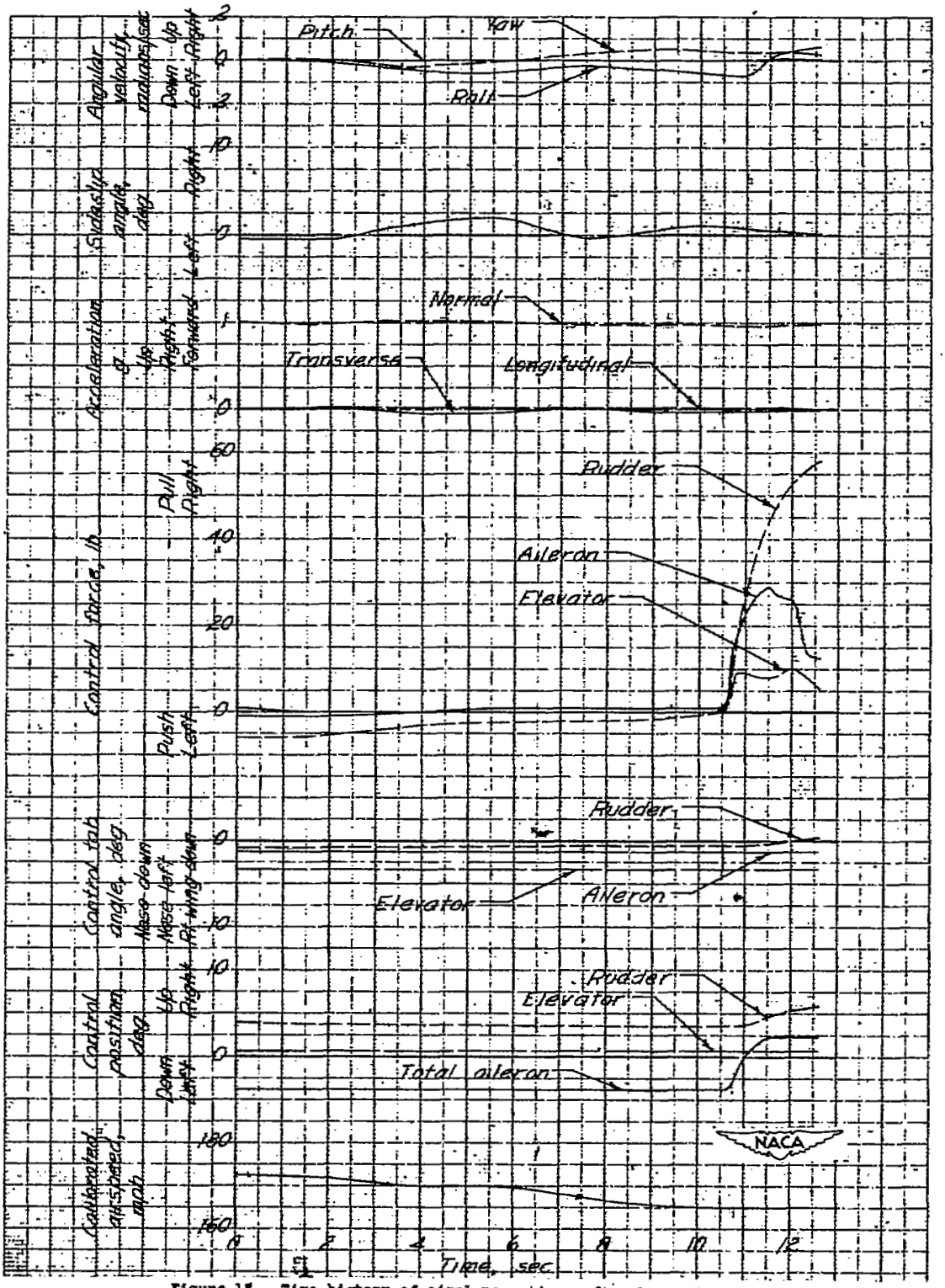
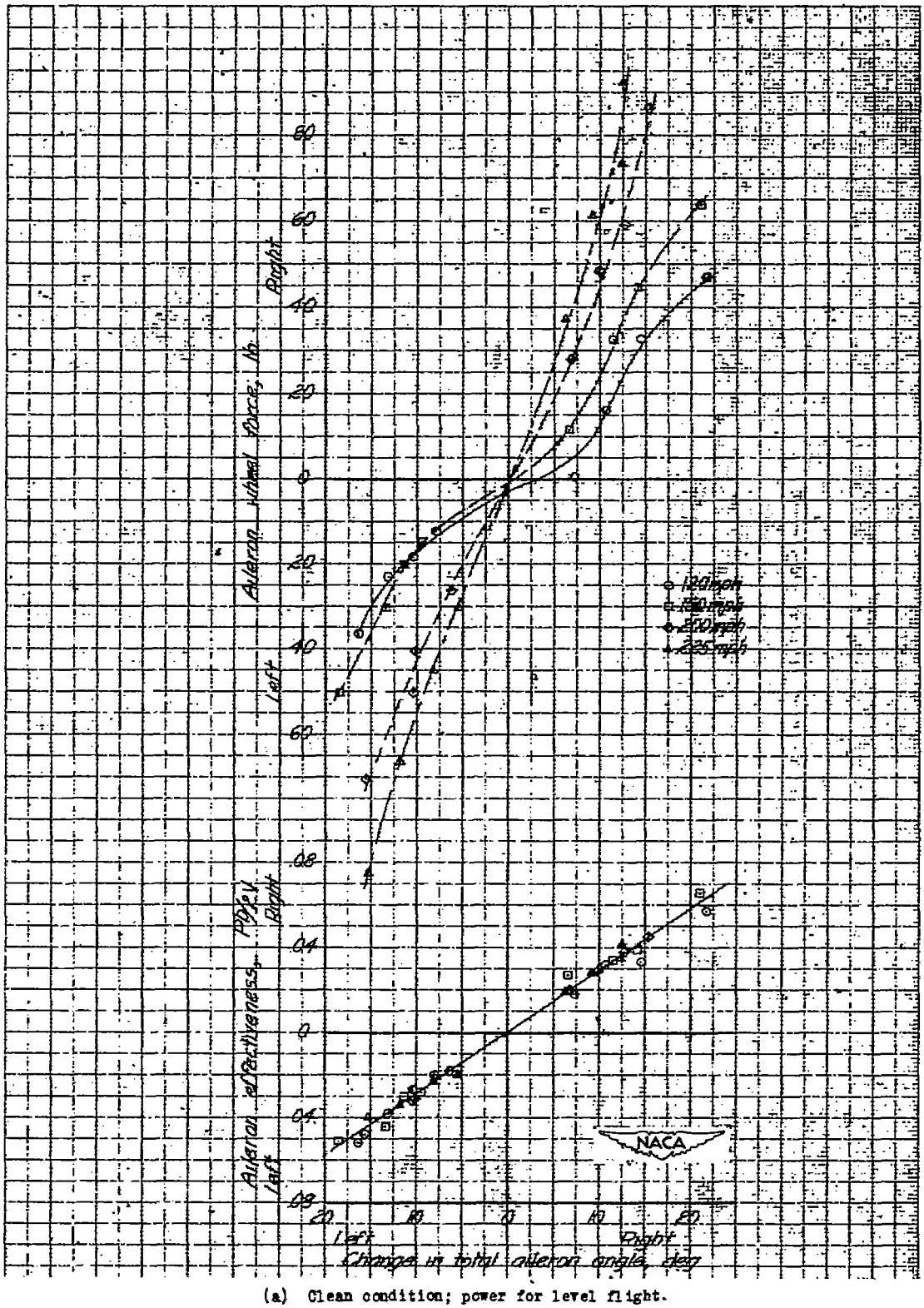
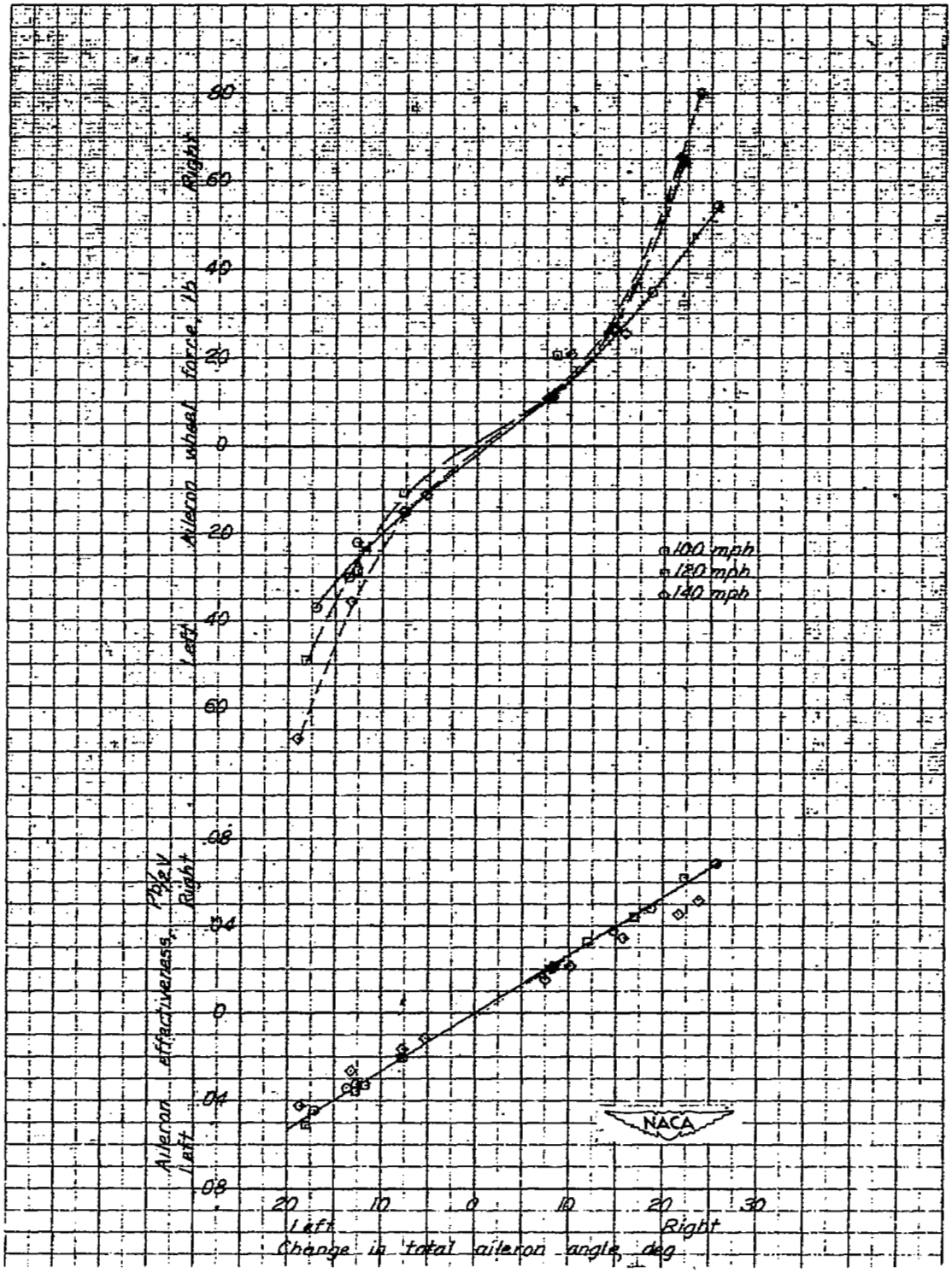


Figure 18.- Time history of airplane motions after loss of power on No. 1 engine in the cruise condition. C-54D airplane; clean power for level flight before No. 1 engine cut to idling at start of record; corrective control started at 10.5 seconds.



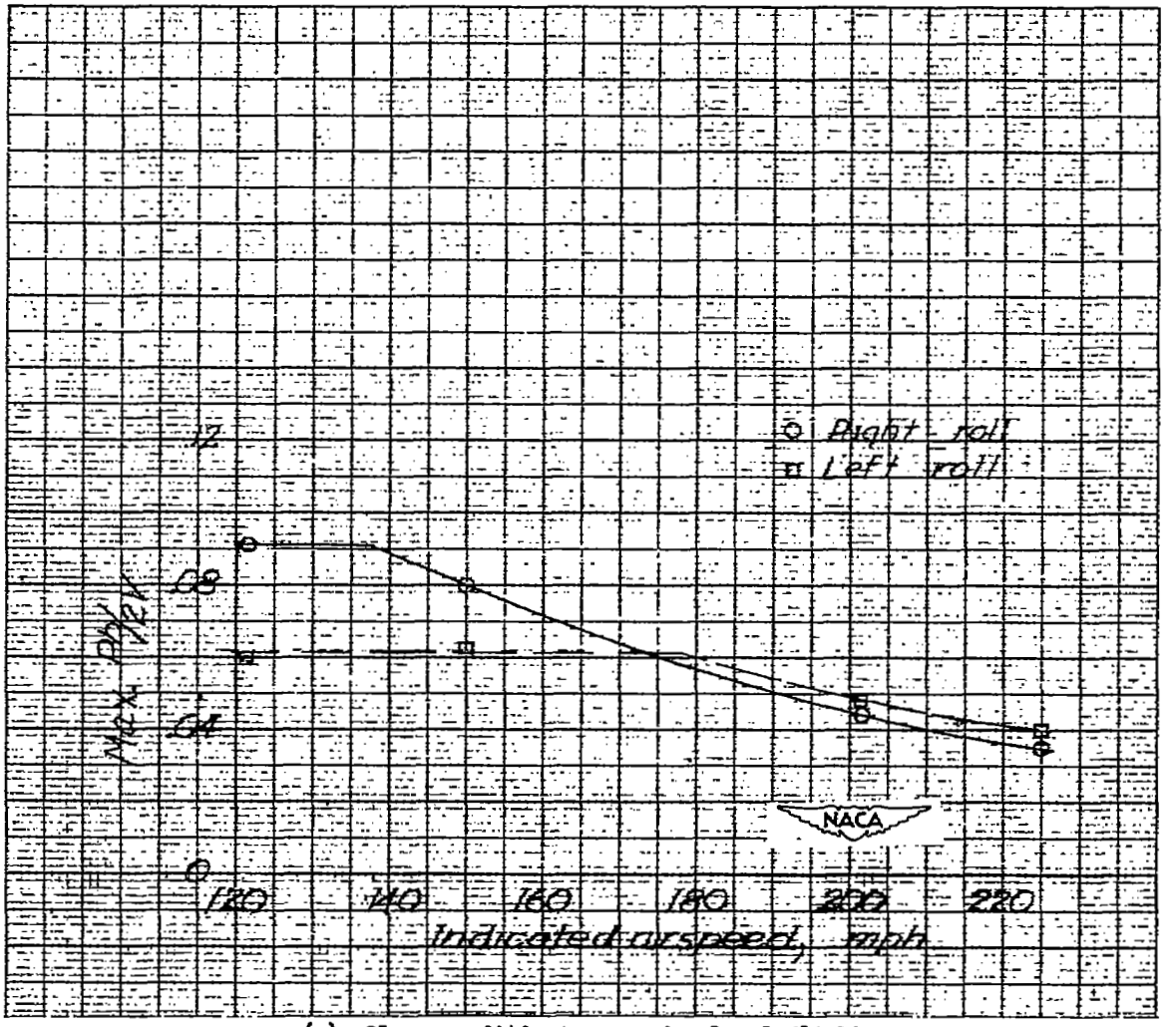
(a) Clean condition; power for level flight.

Figure 19.- Variation of aileron wheel force and aileron effectiveness parameter with change in total aileron angle at various speeds. C-54D airplane.



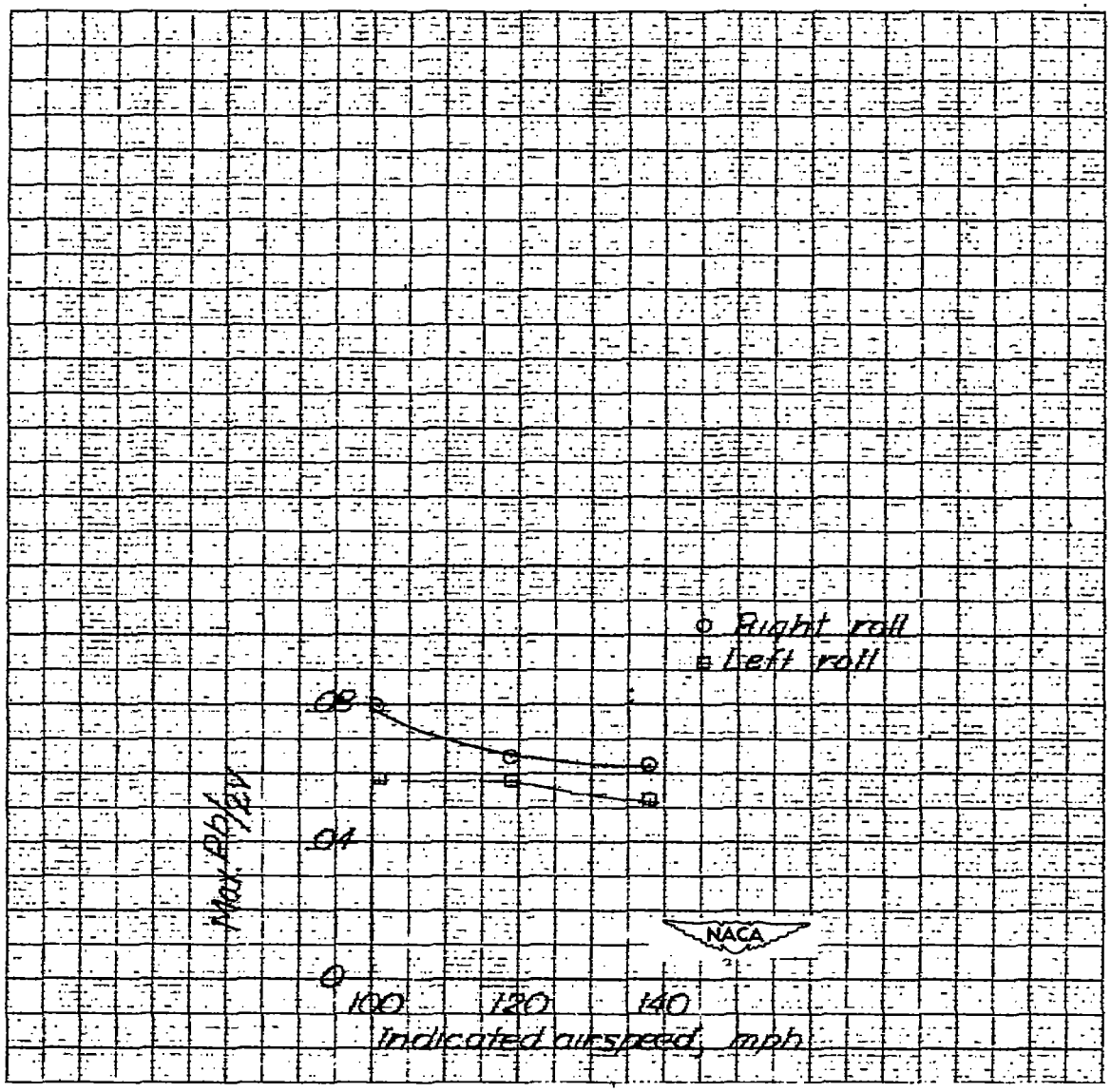
(b) Flaps and gear down; power for level flight.

Figure 19.- Concluded.



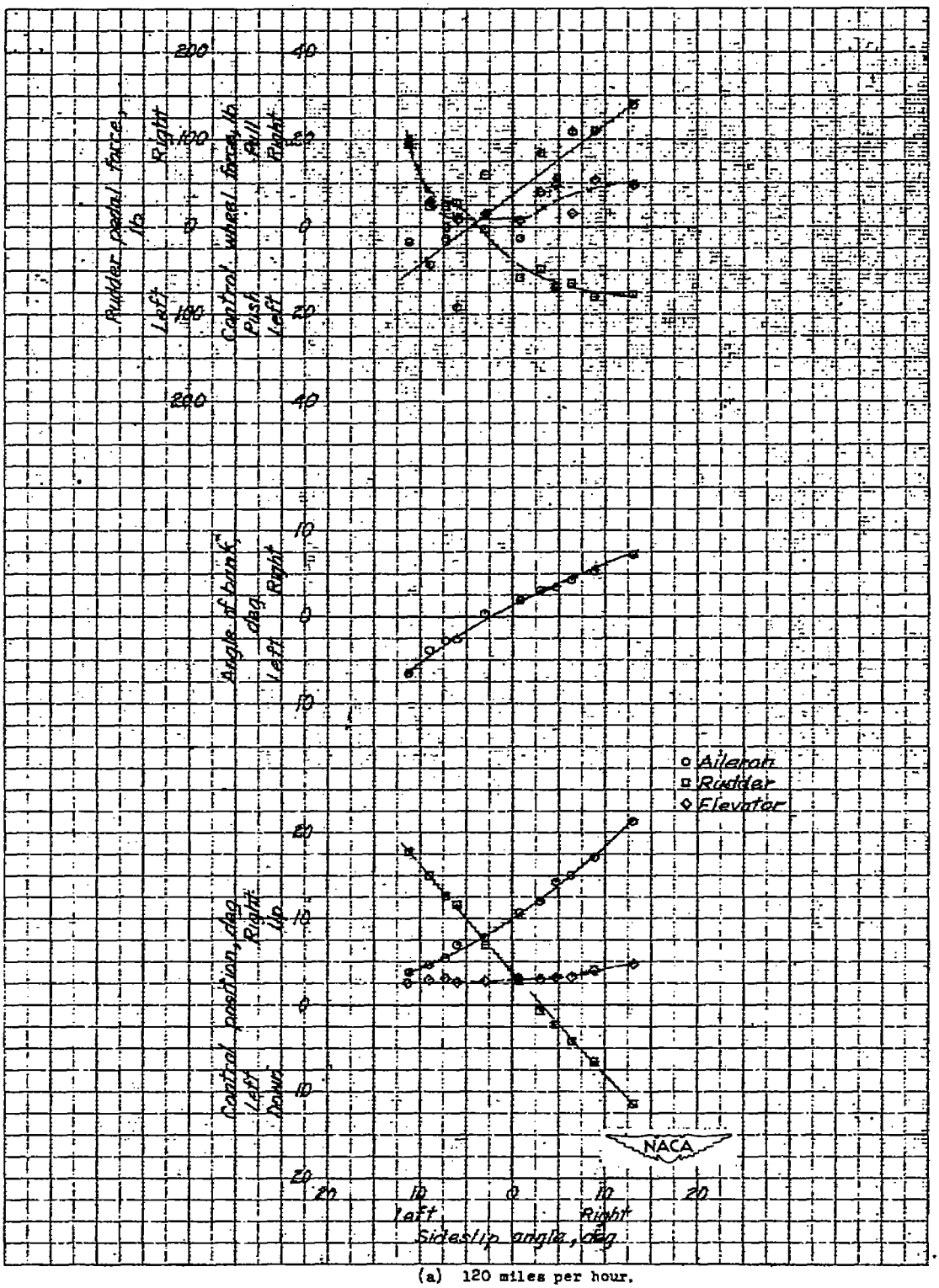
(a) Clean condition; power for level flight.

Figure 20.- Variation of maximum pb/2V available without exceeding 80 pounds of wheel force with indicated airspeed. C-54D airplane.



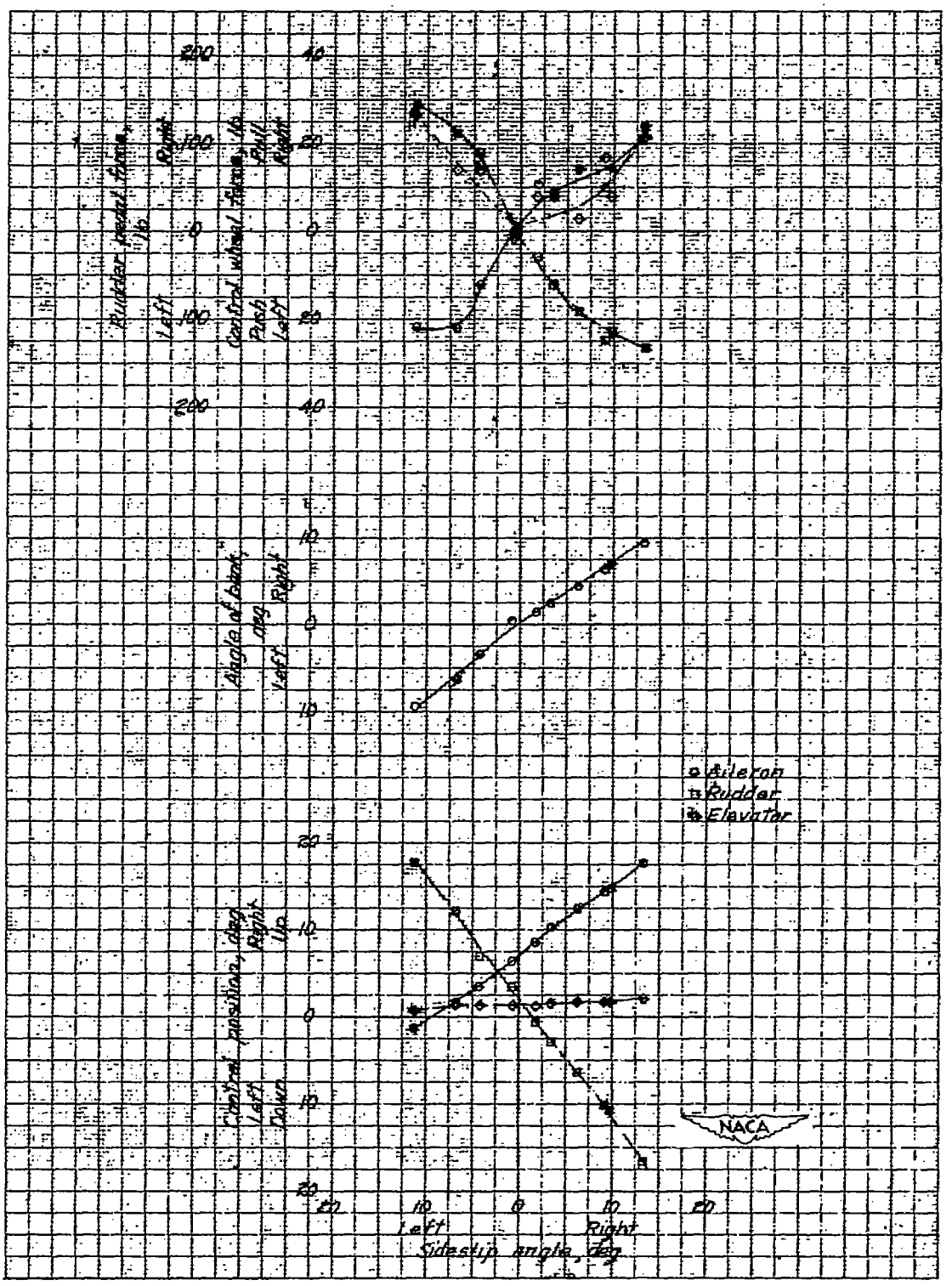
(b) Flaps and gear full down; power for level flight.

Figure 20.- Concluded.



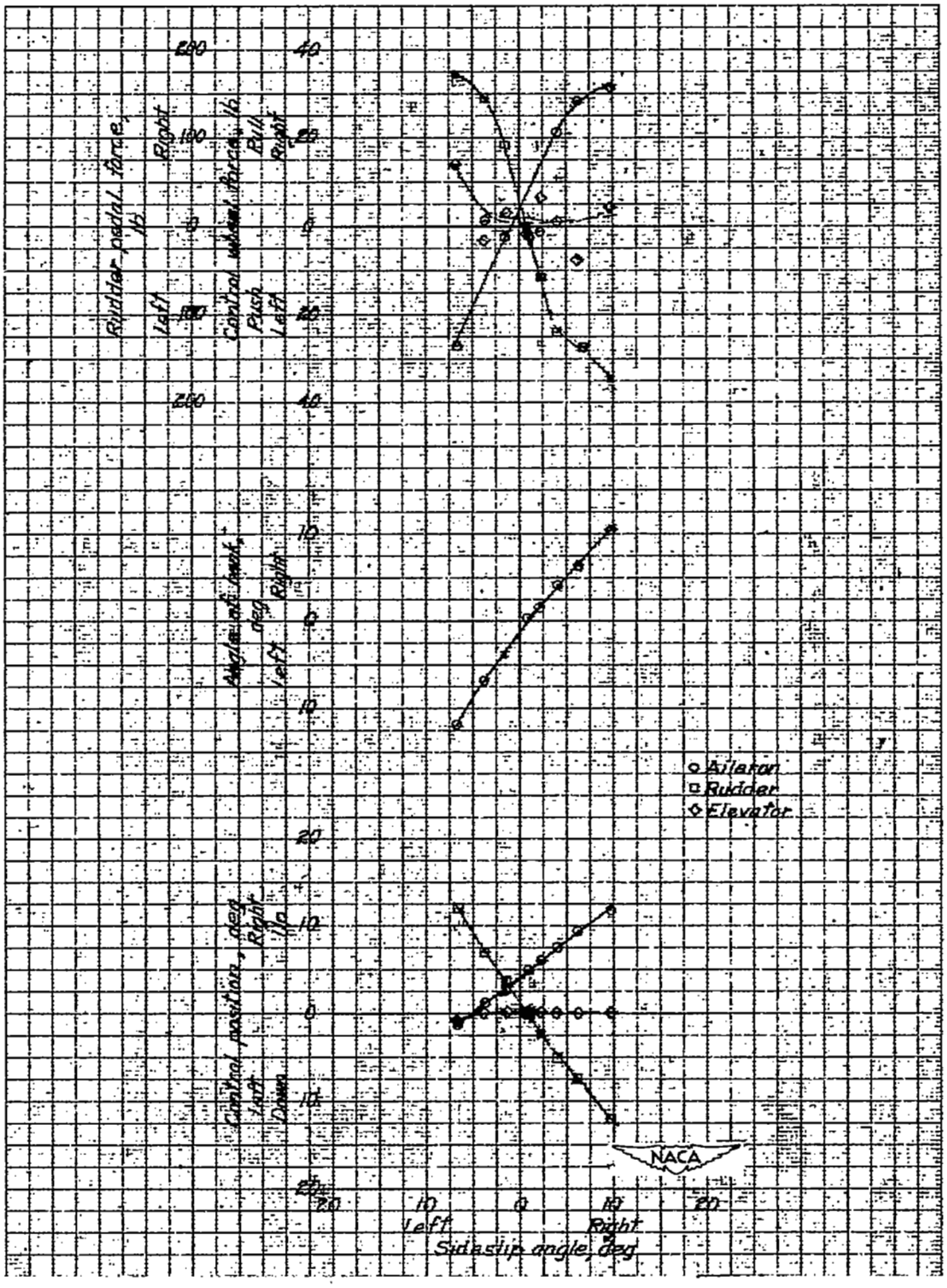
(a) 120 miles per hour.

Figure 21.- Sideslip characteristics with asymmetric load. C-54D airplane; clean condition; normal rated power; right wing tip gas tank empty.



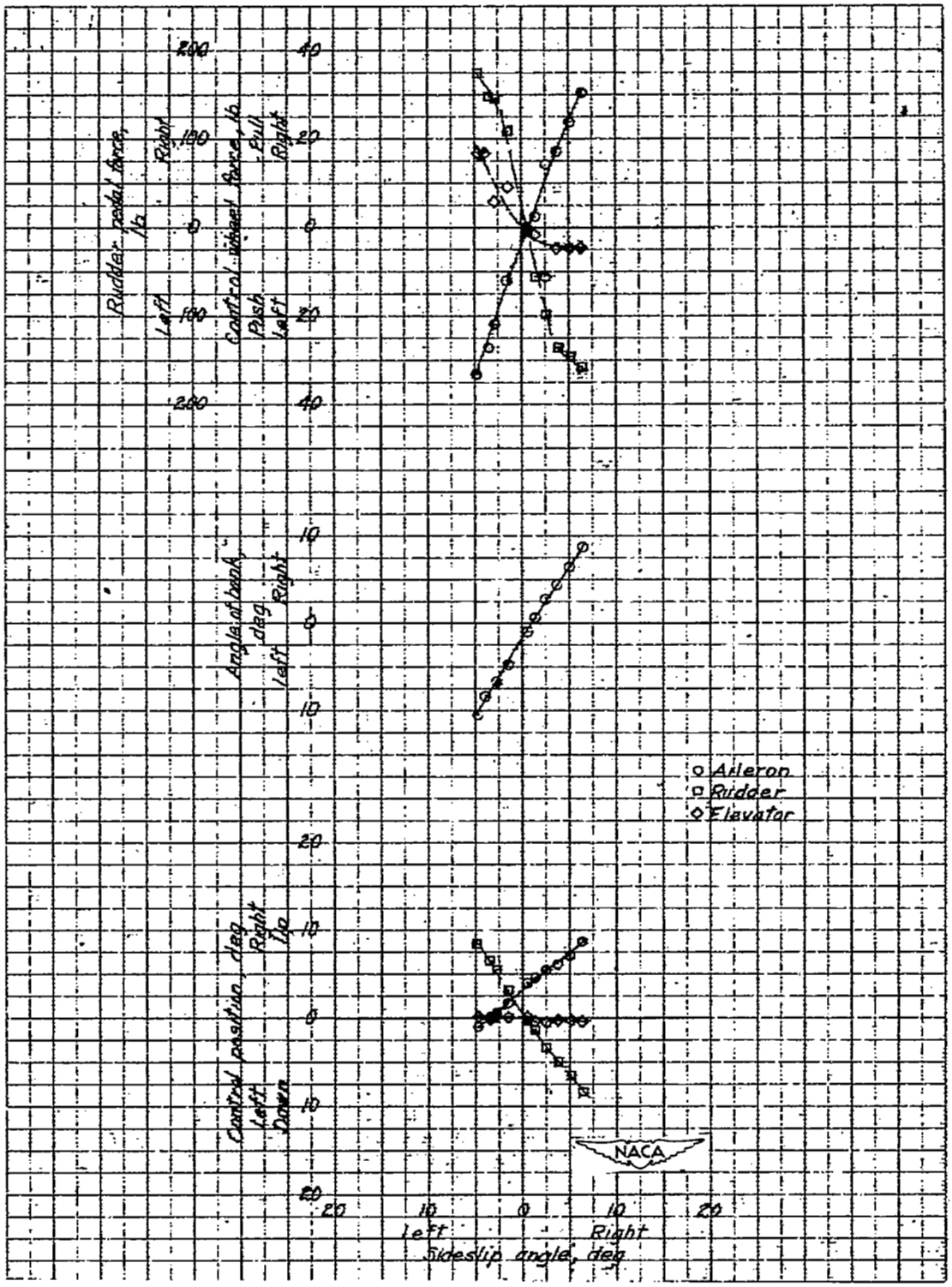
(b) 150 miles per hour.

Figure 21.- Continued.



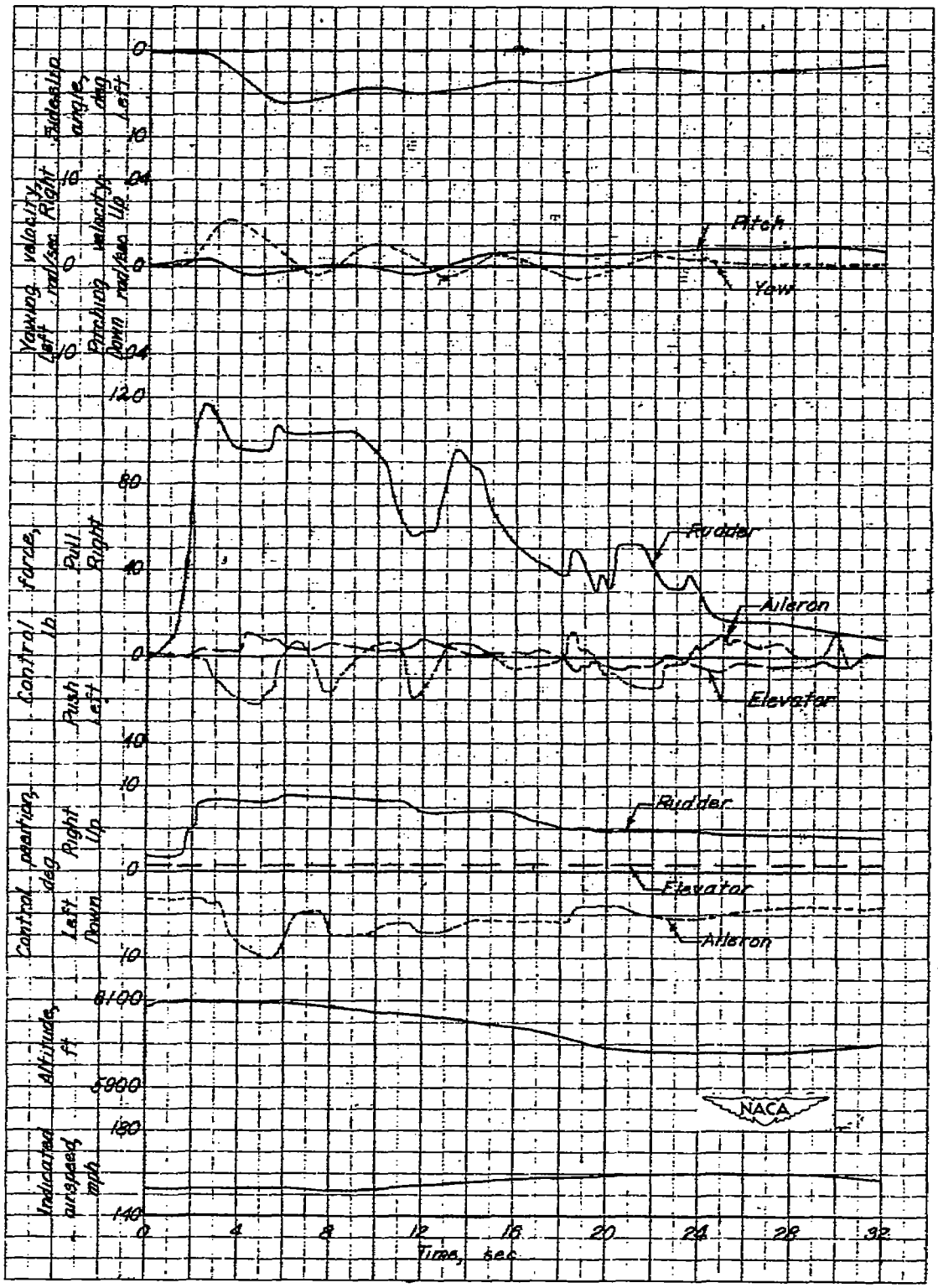
(c) 200 miles per hour.

Figure 21.- Continued.



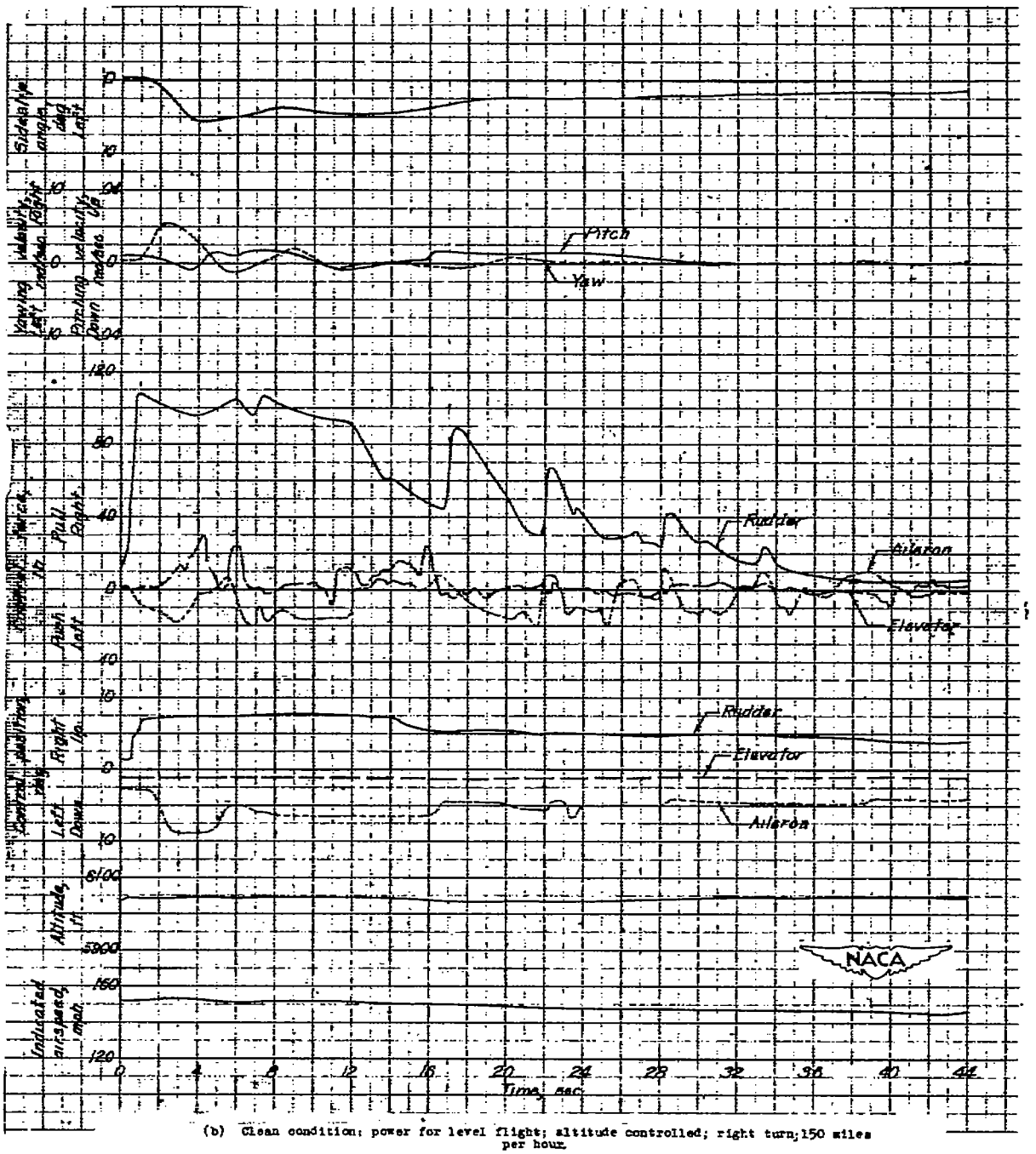
(d) 225 miles per hour.

Figure 21.- Concluded.



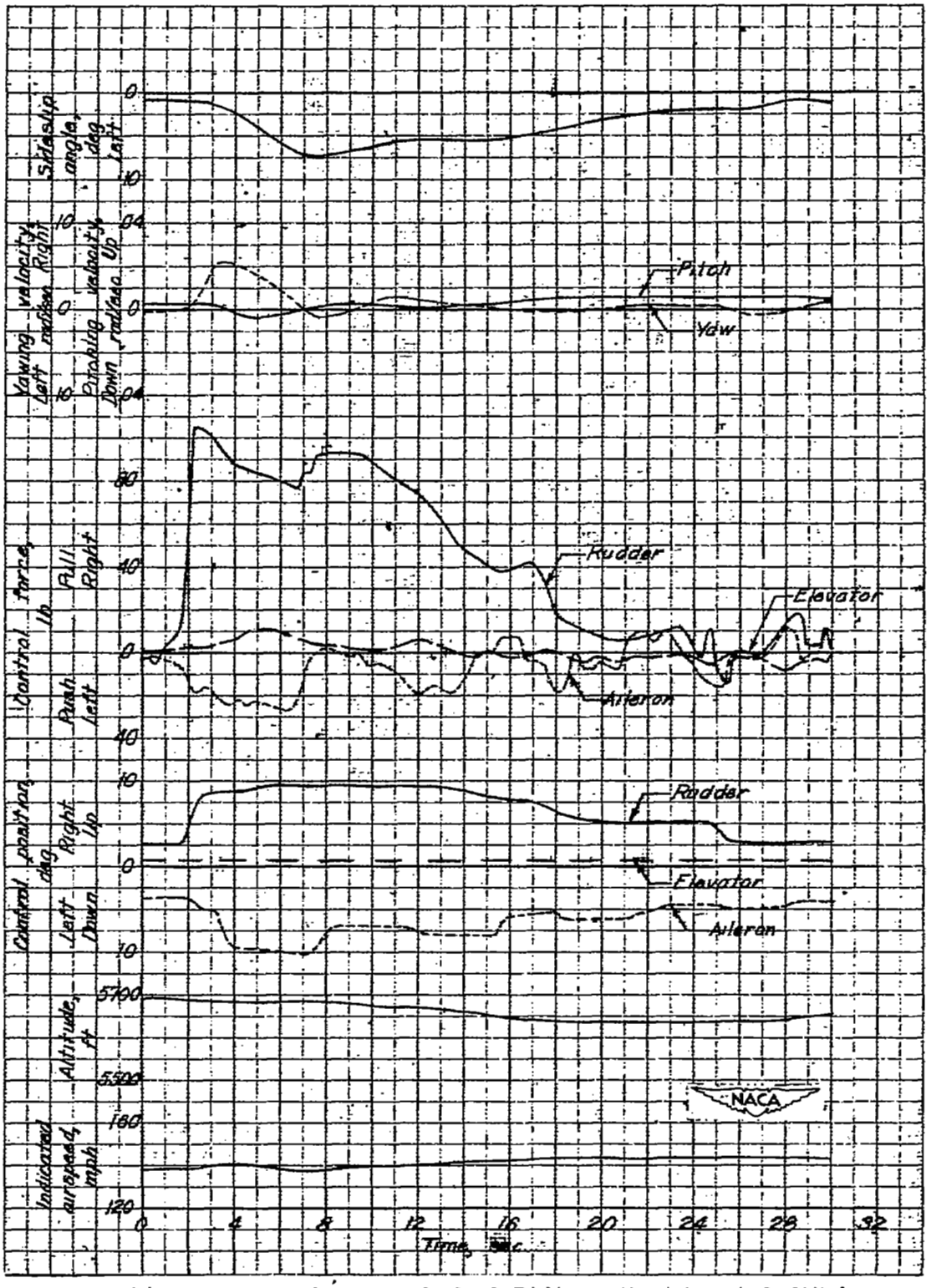
(a) Clean condition; power for level flight; no attempt made to control altitude; right turn; 150 miles per hour.

Figure 22.- Time histories of 10° heading changes holding the wings level. C-54D airplane.



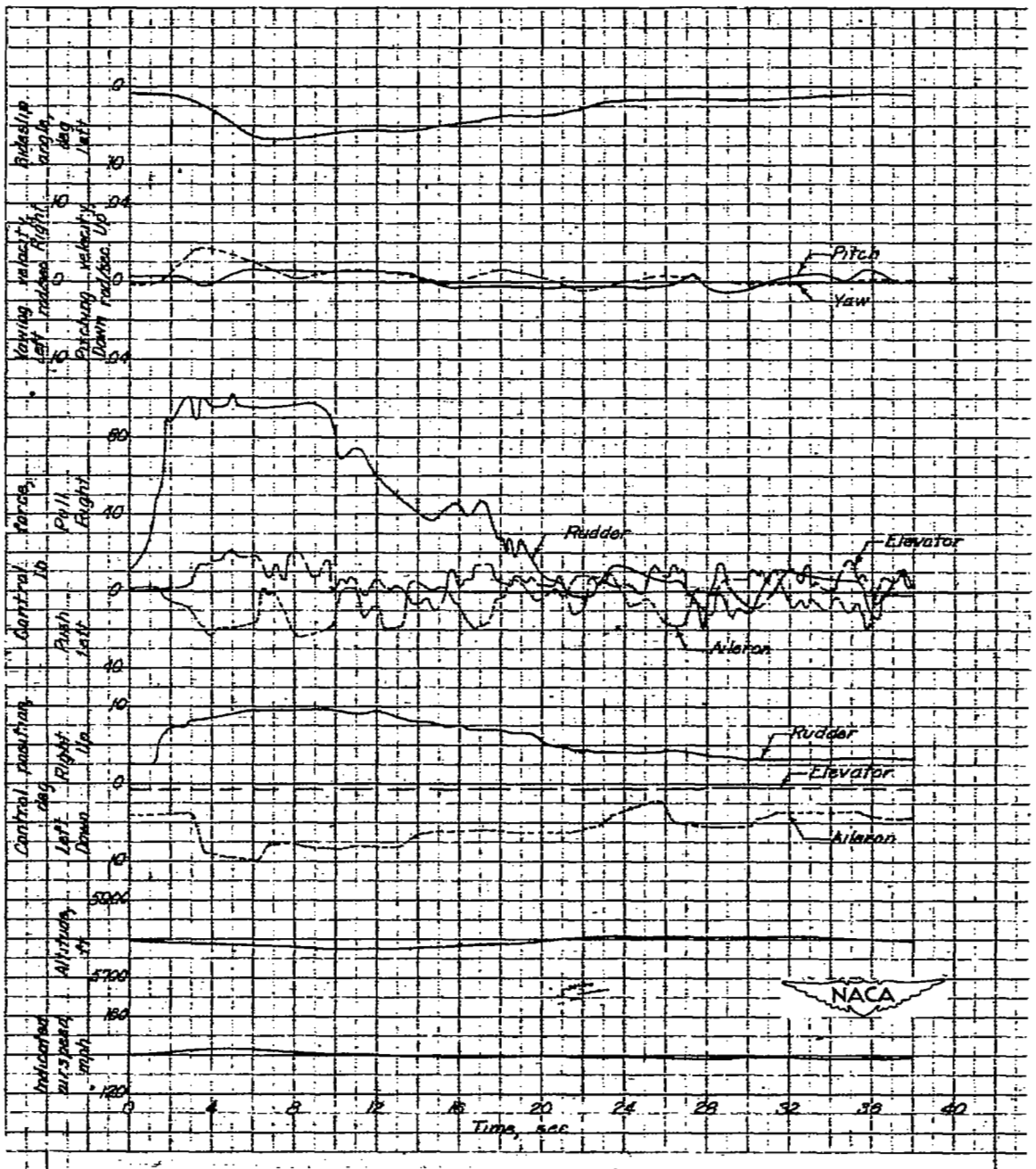
(b) Clean condition; power for level flight; altitude controlled; right turn; 150 miles per hour.

Figure 22.- Continued.



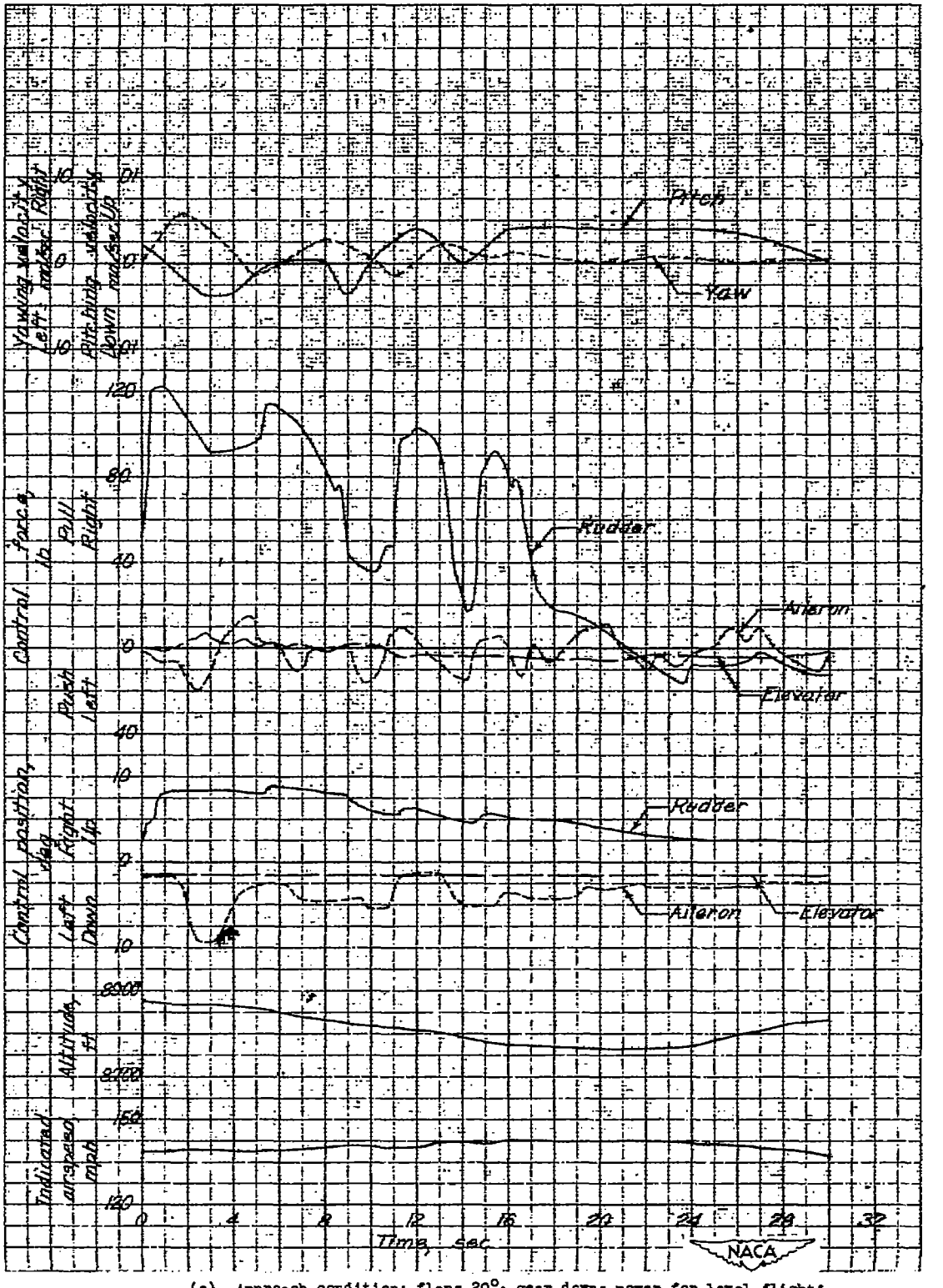
(c) Flaps up; gear down; power for level flight; no attempt to control altitude; right turn; 140 miles per hour.

Figure 22.- Continued.



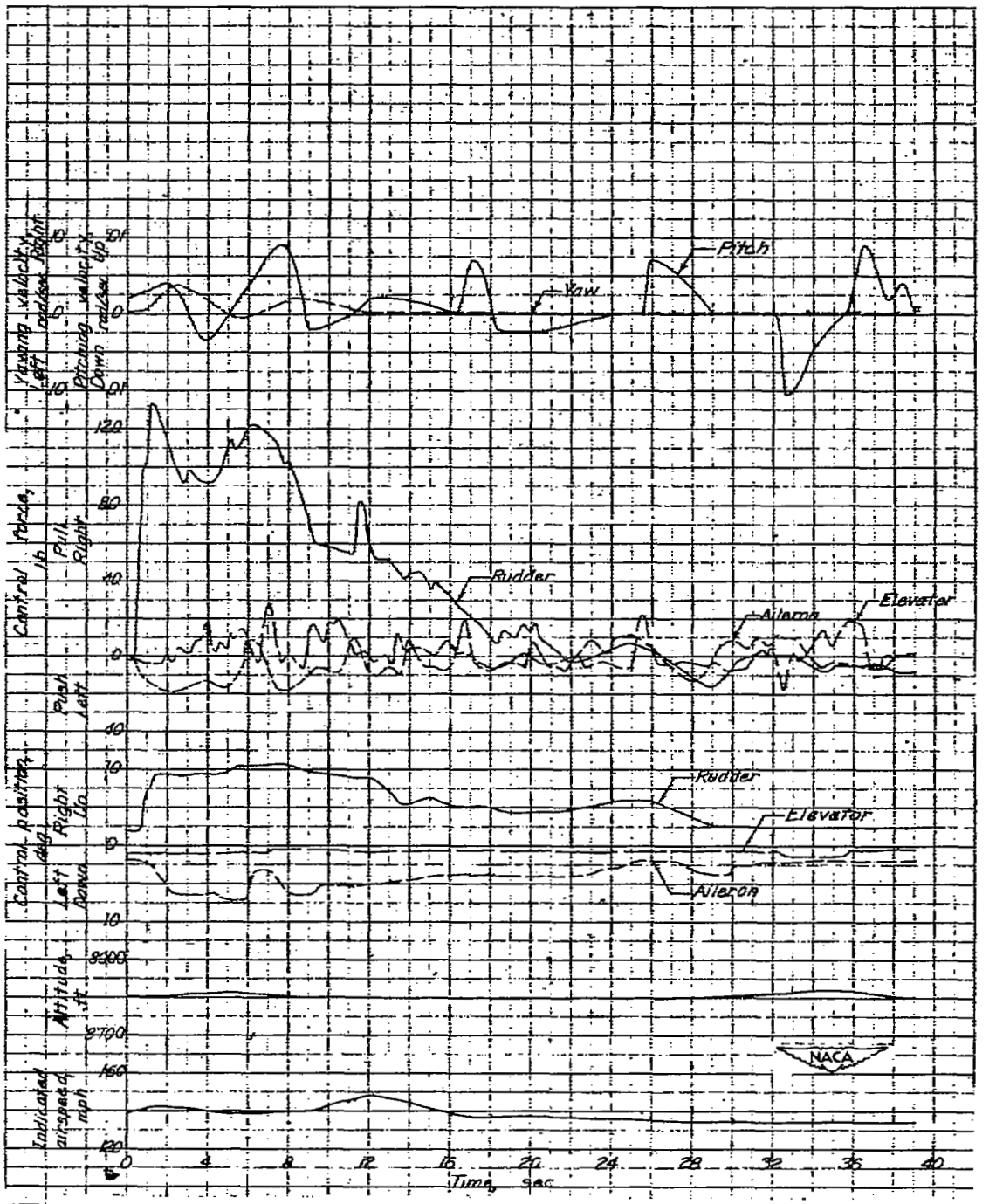
(d) Flaps up; gear down; power for level flight; altitude controlled; right turn; 140 miles per hour.

Figure 22.- Continued.



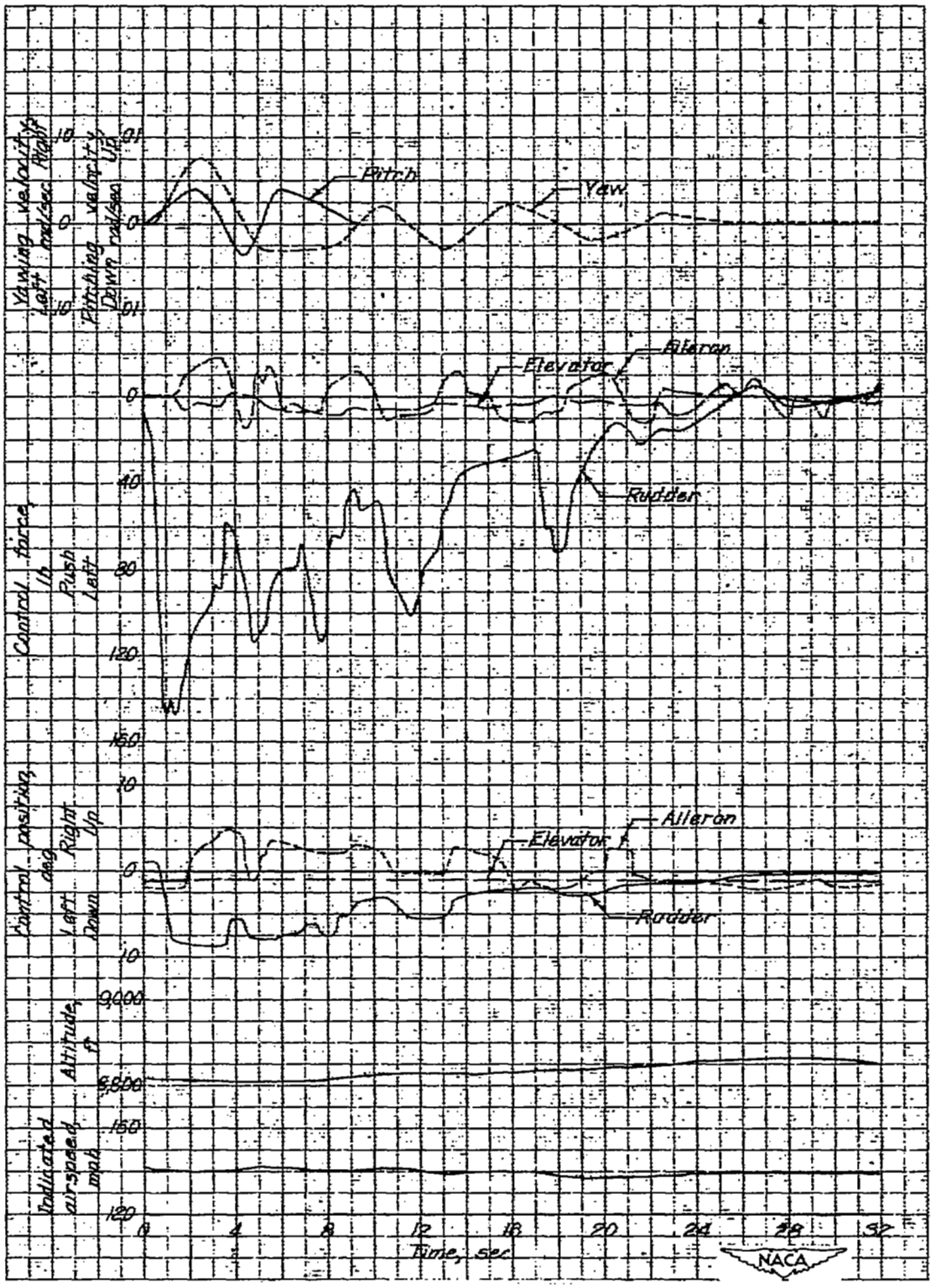
(e) Approach condition; flaps 20°; gear down; power for level flight; no attempt to control altitude; right turn; 140 miles per hour.

Figure 22.- Continued.



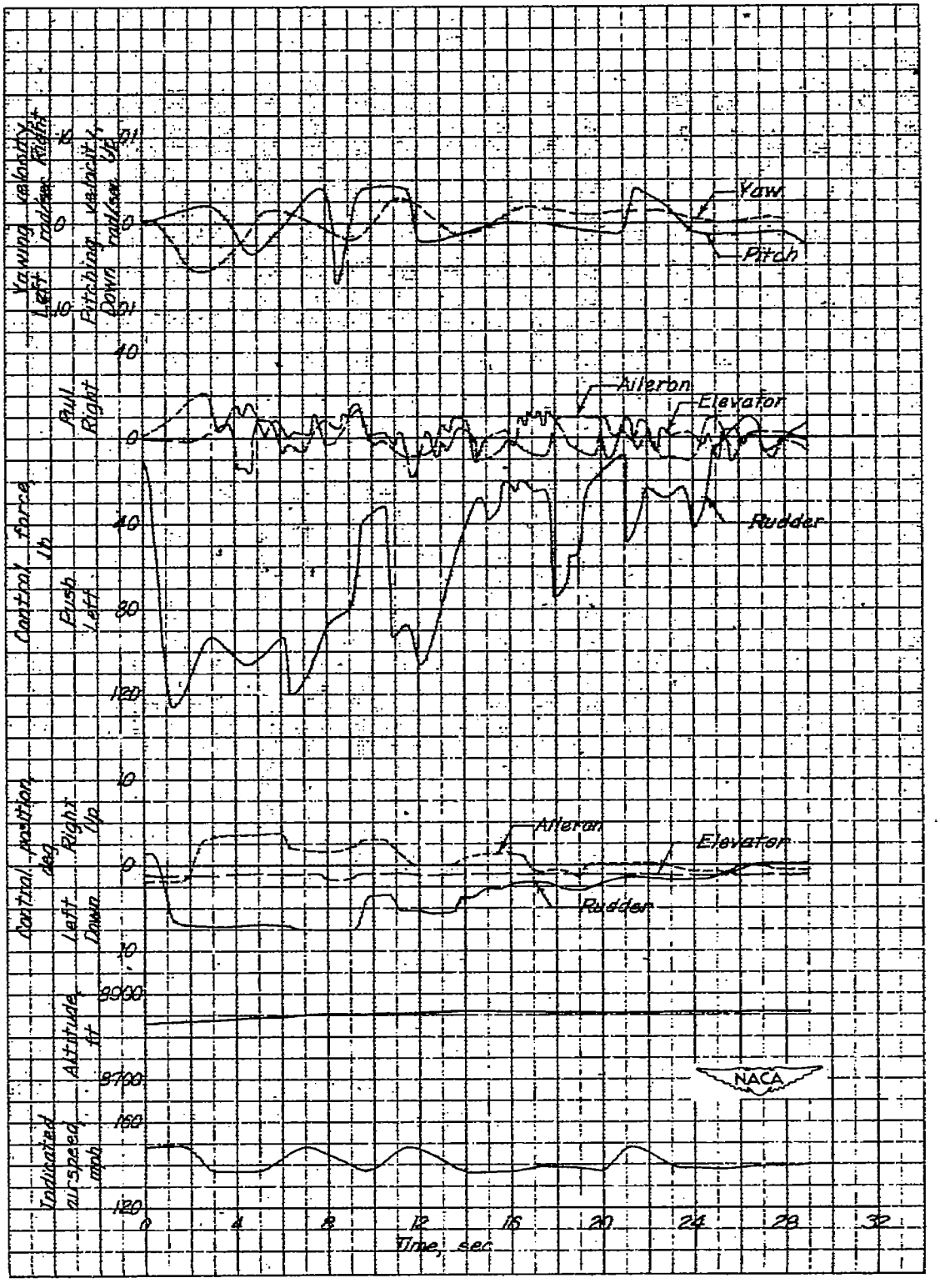
(f) Approach condition; flaps 20°; gear down; power for level flight; altitude controlled; right turn; 140 miles per hour.

Figure 22.- Continued.



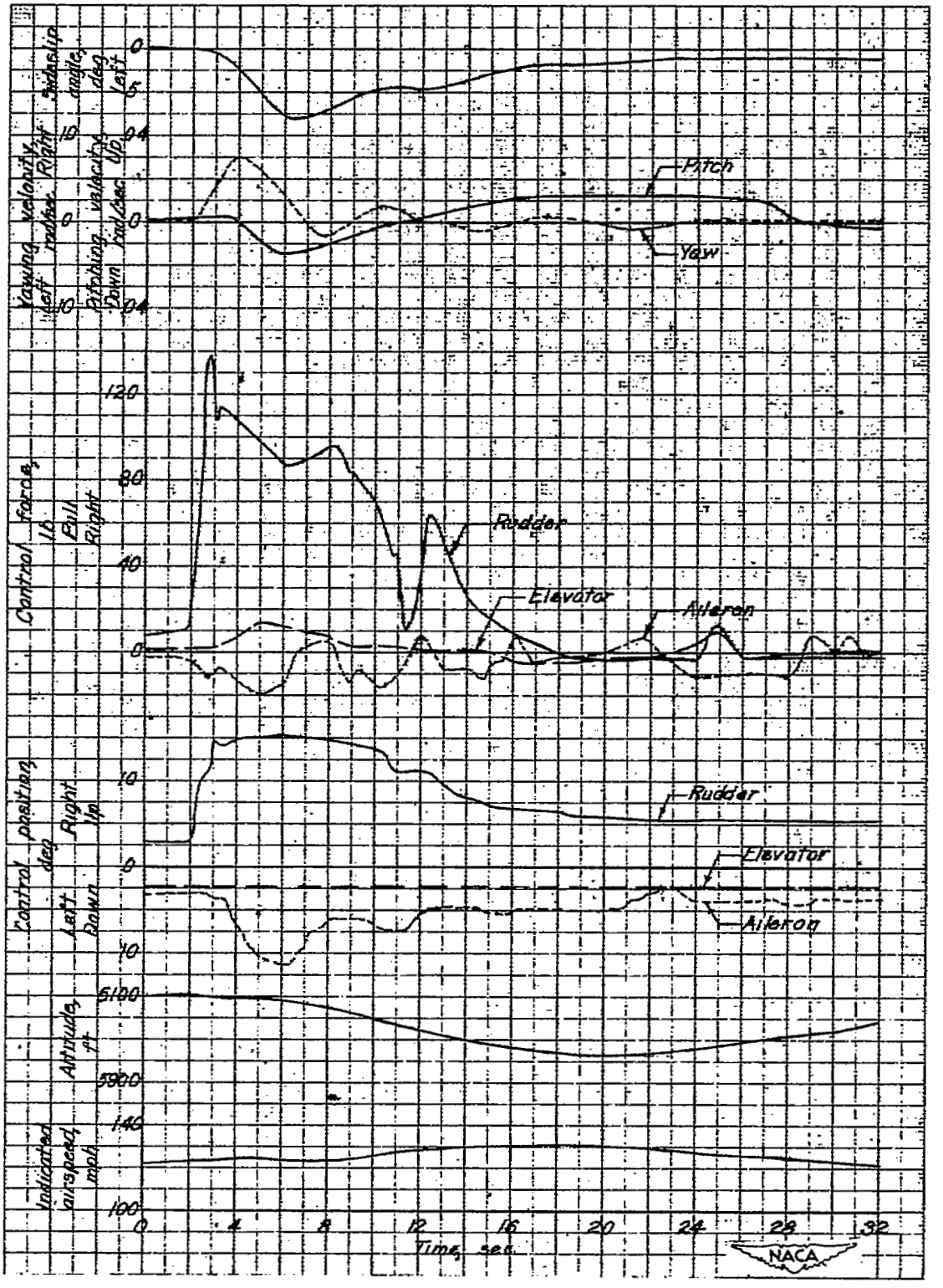
(g) Approach condition; flaps 20°; gear down; power for level flight; no attempt to control altitude; left turn; 140 miles per hour.

Figure 22.- Continued.



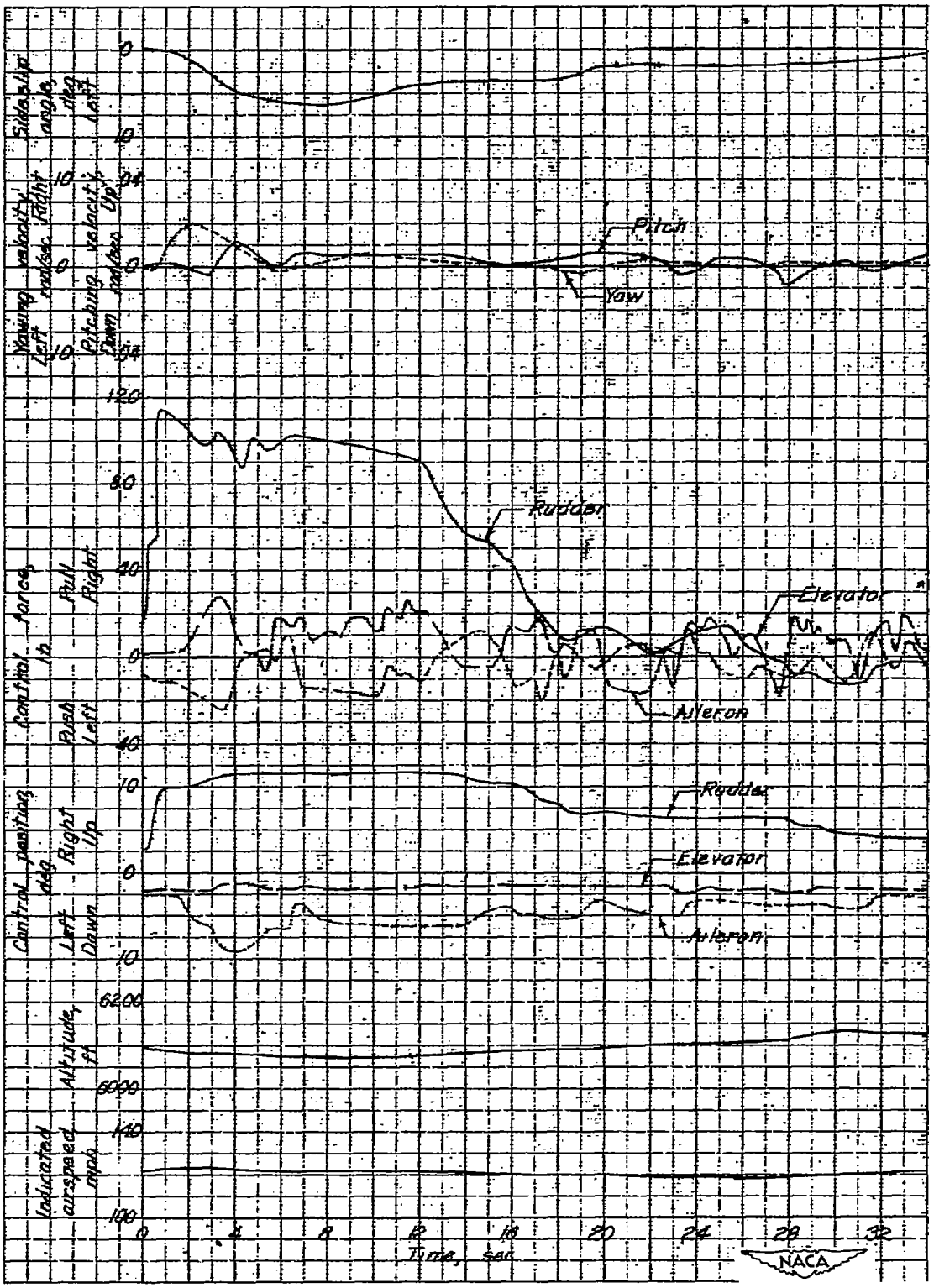
(h) Approach condition; flaps 20°; gear down; power for level flight; altitude controlled; left turn; 140 miles per hour.

Figure 22.- Continued.



(i) Final approach condition; flaps full down; gear down; power for level flight; no attempt to control altitude; right turn; 120 miles per hour.

Figure 22.- Continued.



(j) Final approach condition; flaps full down; gear down; power for level flight; altitude controlled; right turn; 120 miles per hour.

Figure 22.- Concluded.

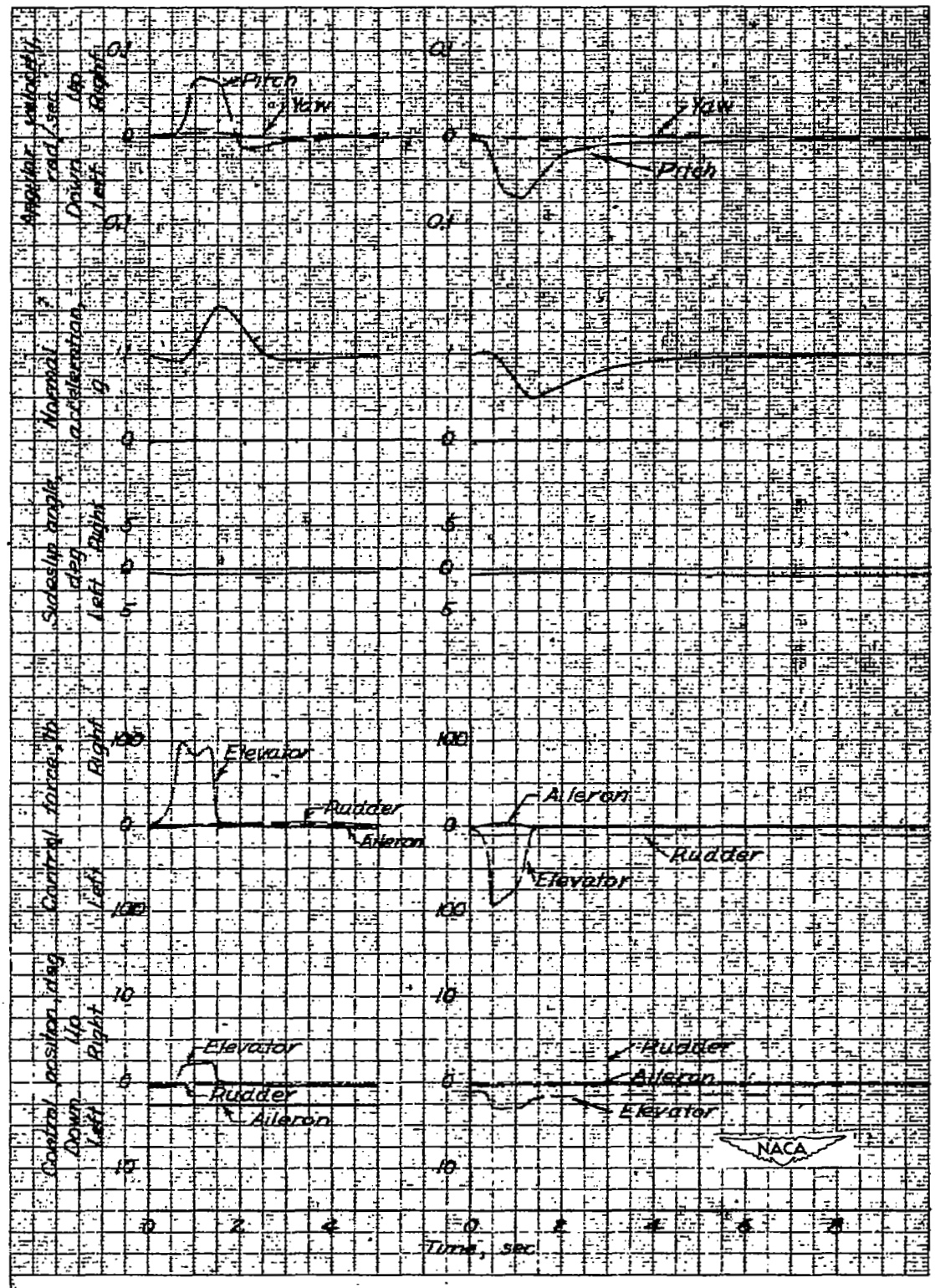
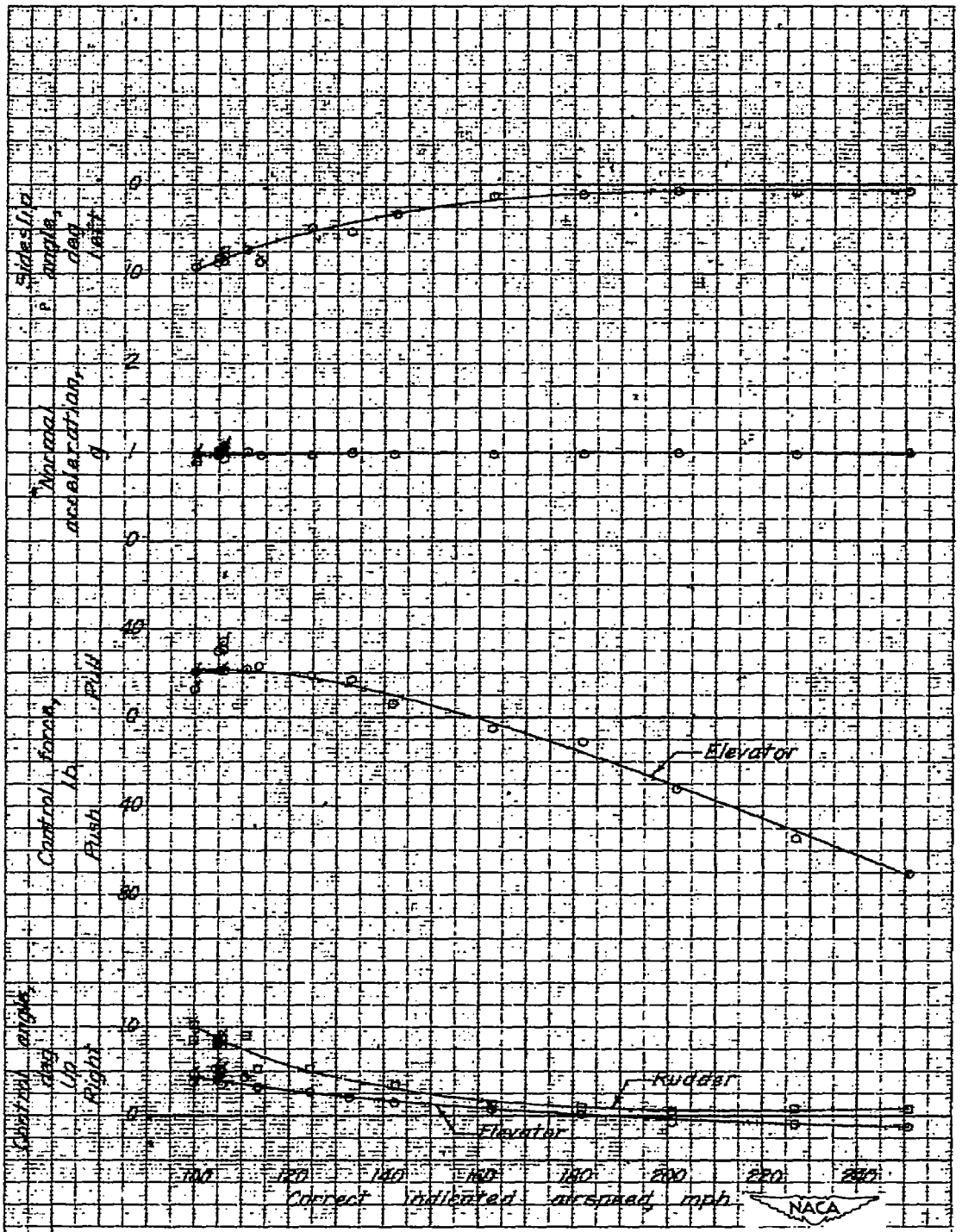
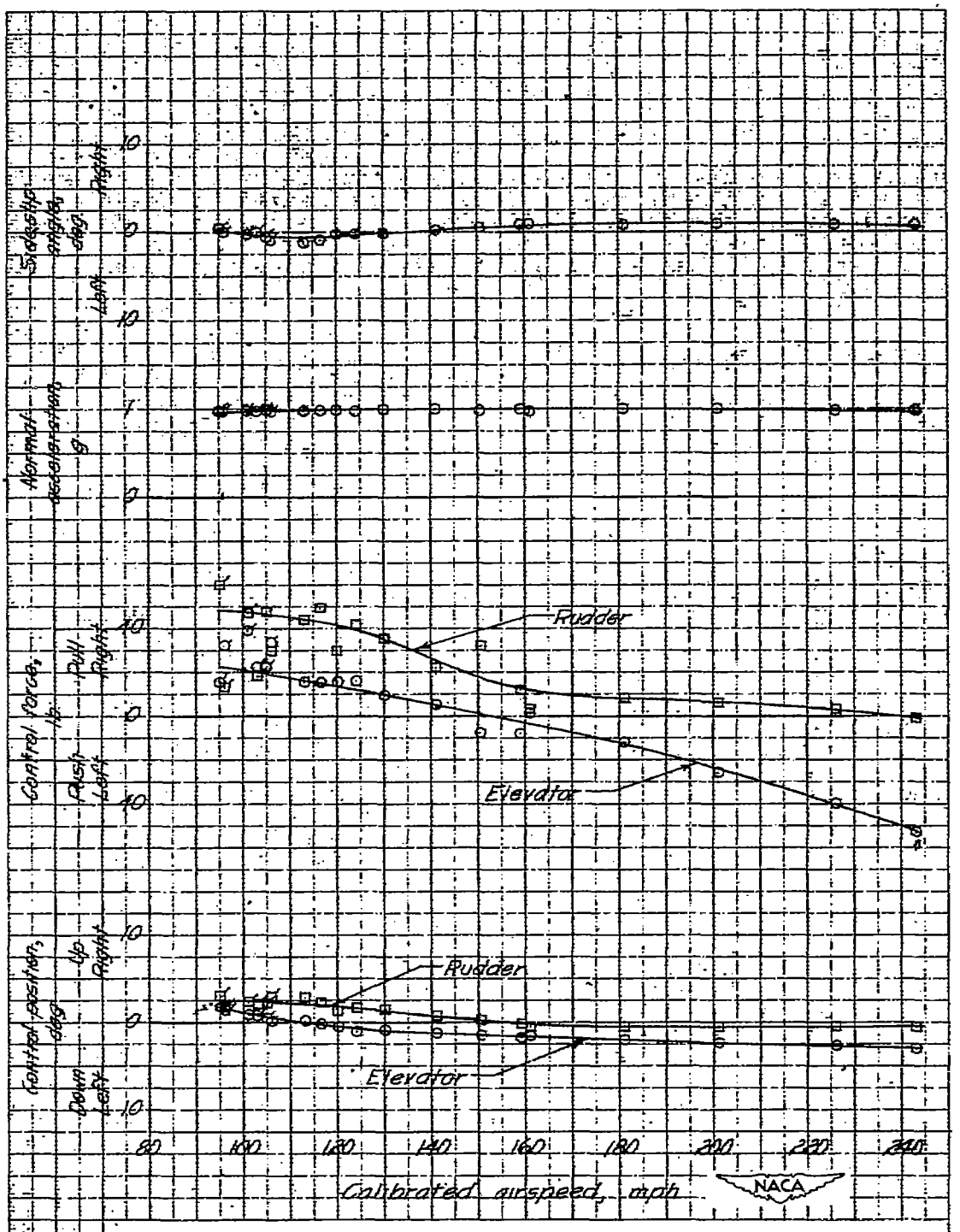


Figure 23.- Short period longitudinal oscillations. C-54D airplane; clean condition; 200 miles per hour.



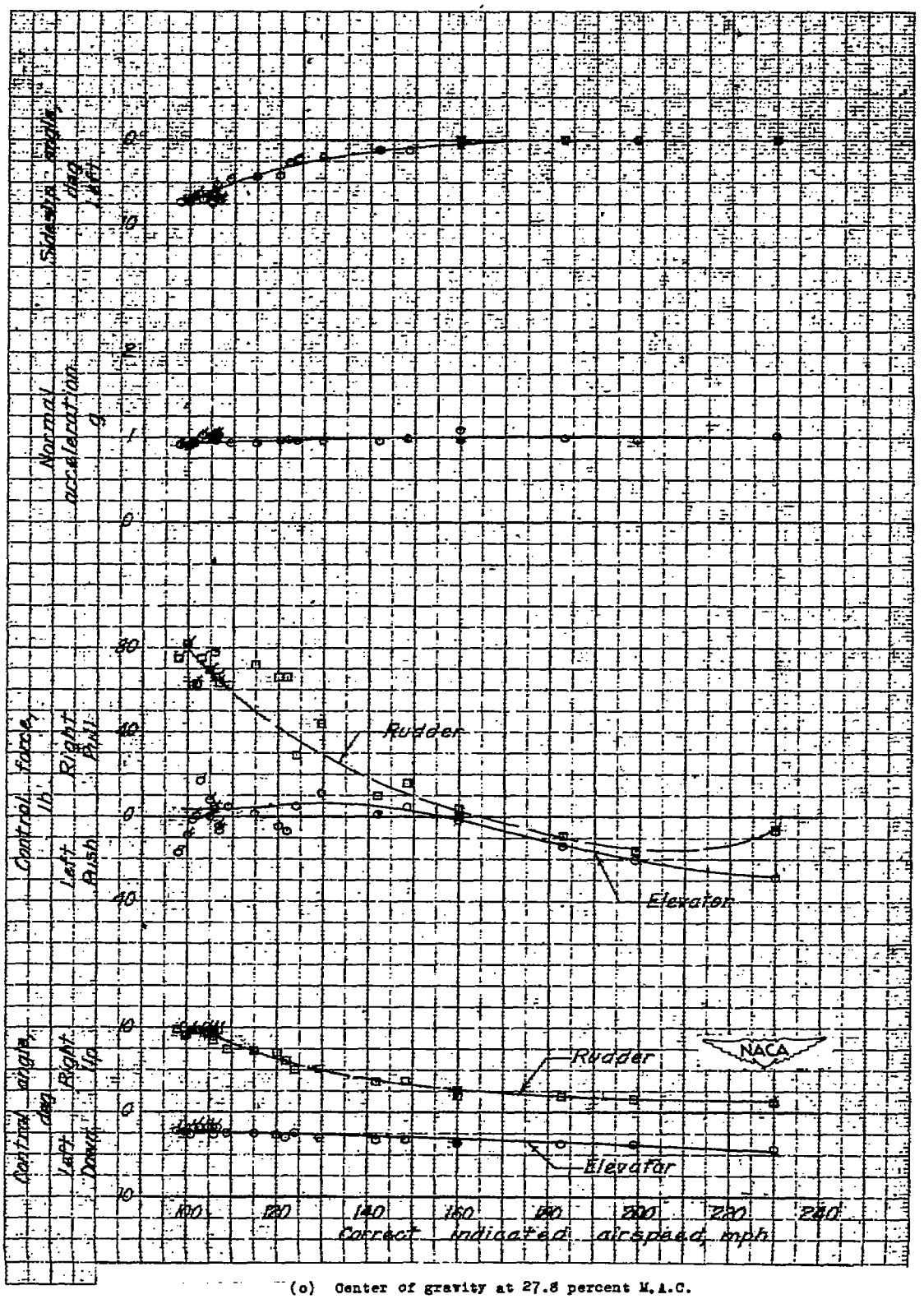
(a) Center of gravity at 17.9 percent M.A.C.

Figure 24.- Static longitudinal stability characteristics, in the clean, normal rated power condition. C-54D airplane.



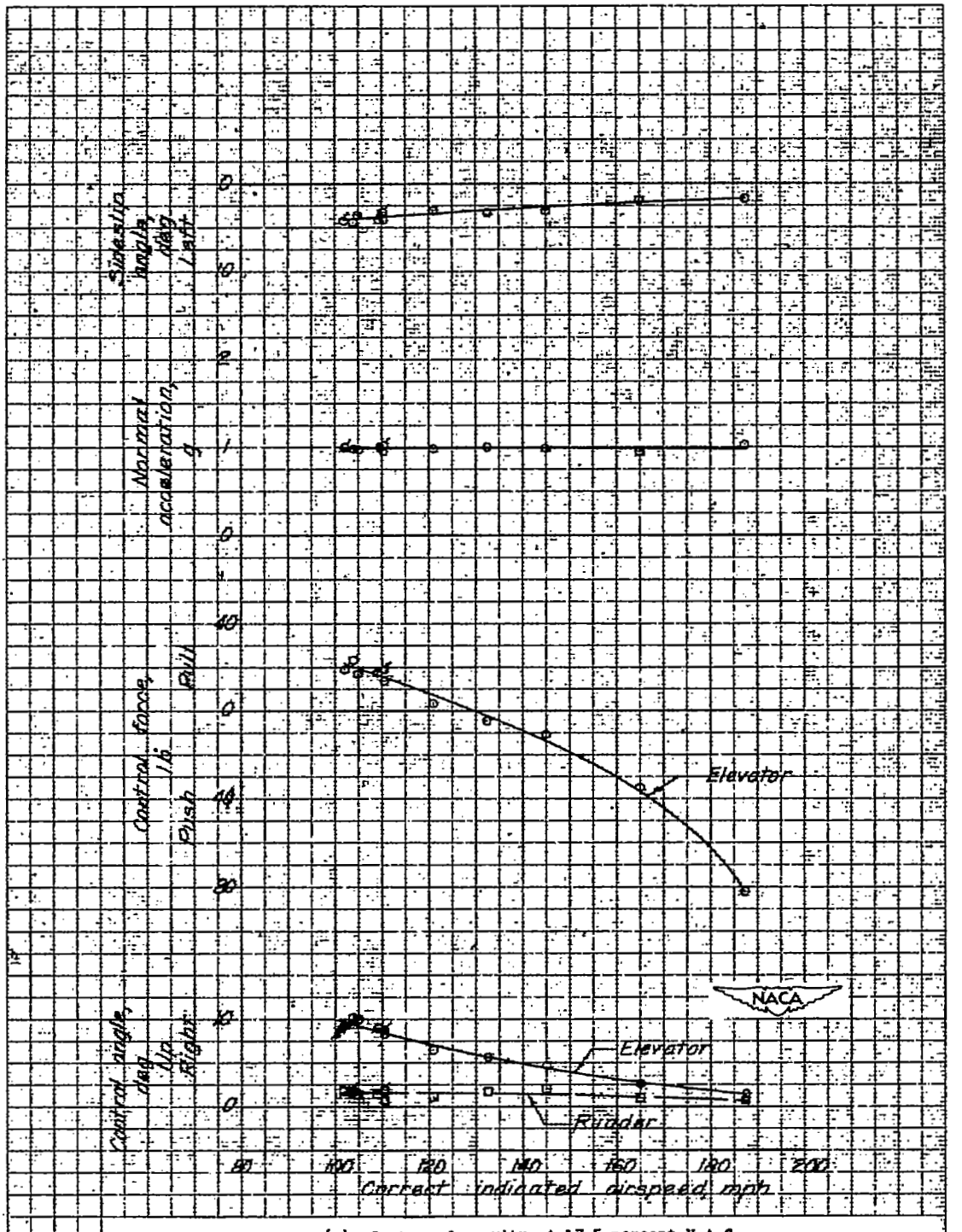
(b) Center of gravity at 23.7 percent M.A.C.

Figure 24.- Continued.



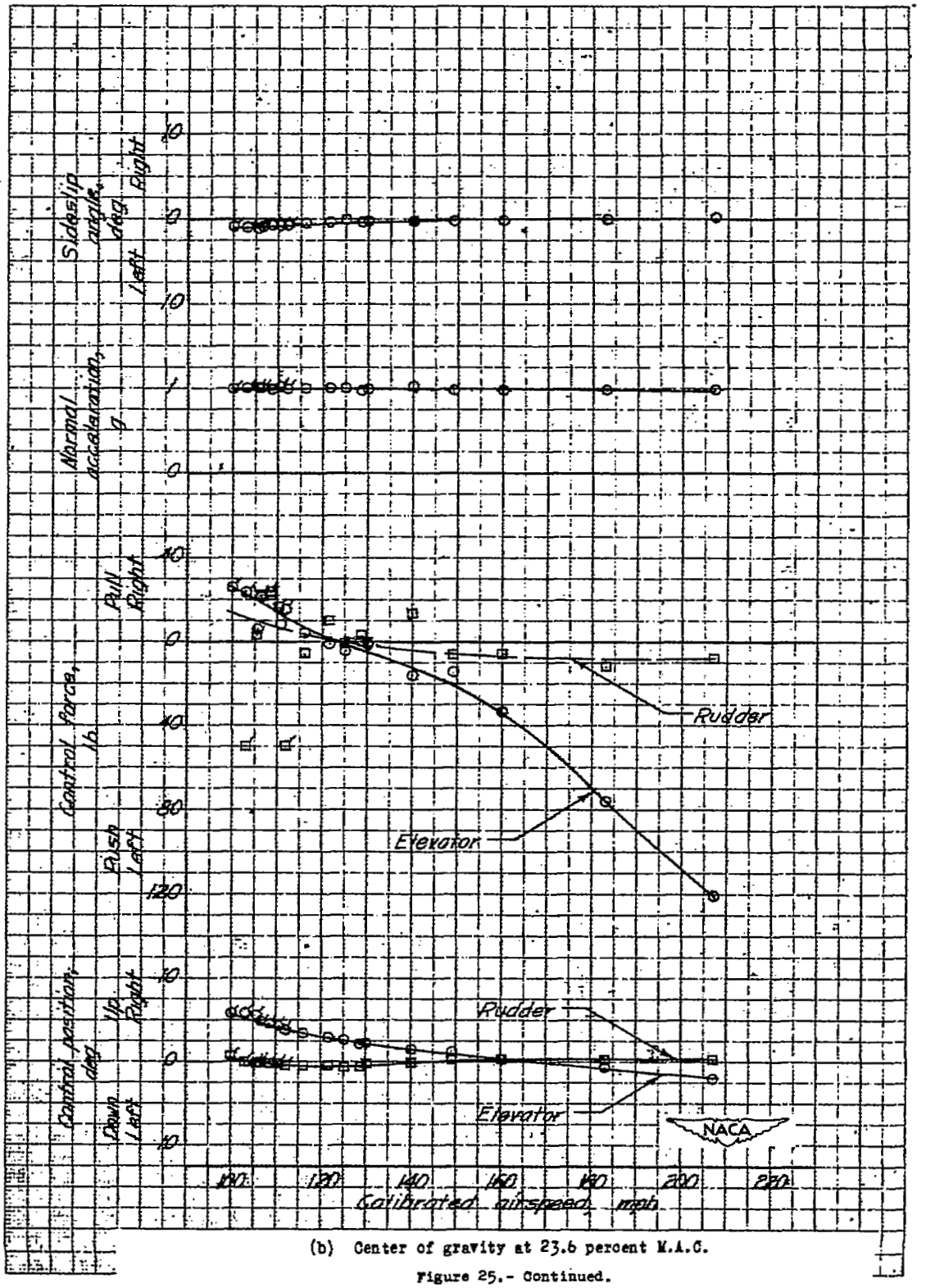
(o) Center of gravity at 27.8 percent M.A.C.

Figure 24.- Concluded.



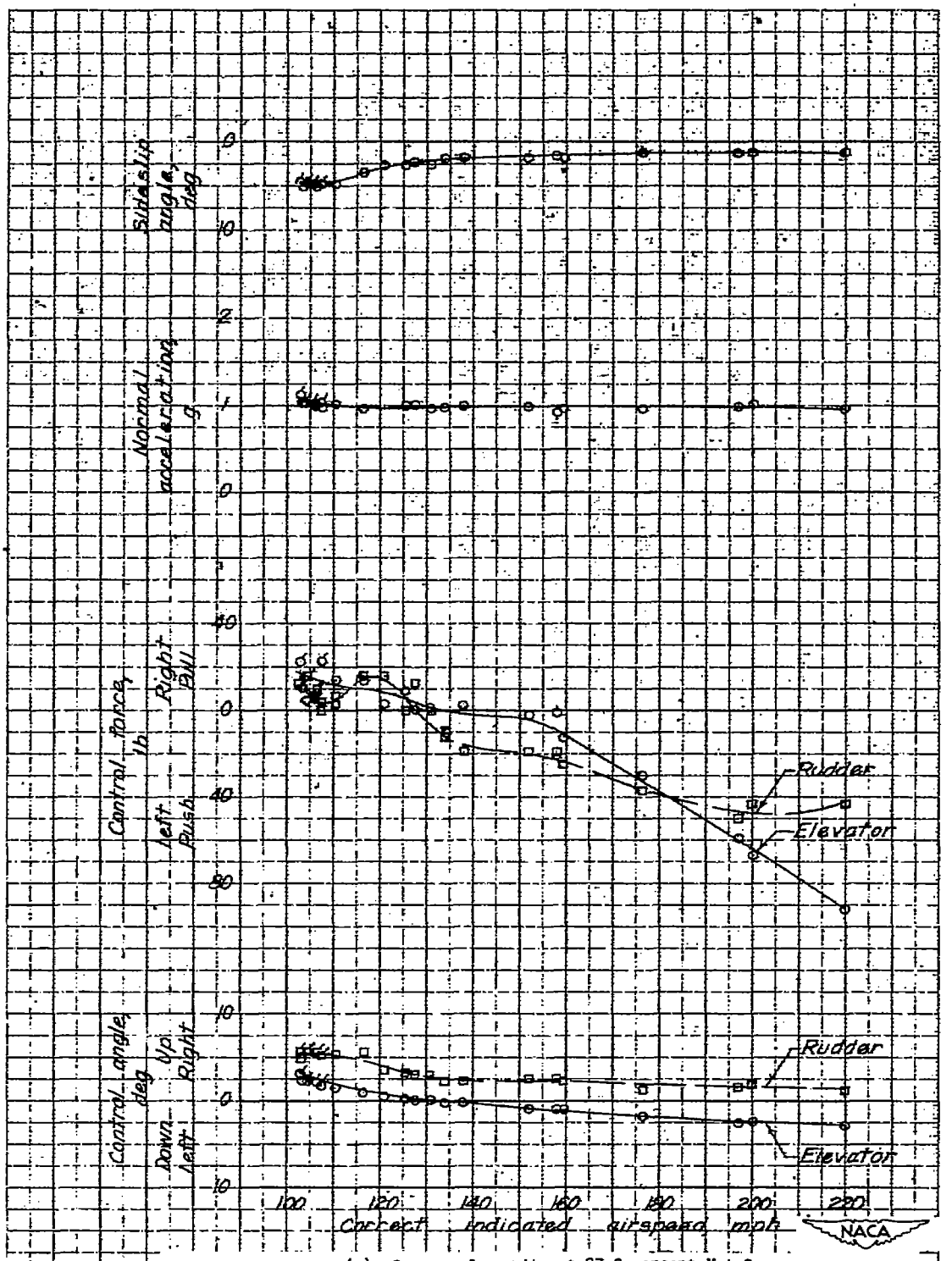
(a) Center of gravity at 17.5 percent M.A.C.

Figure 25.- Static longitudinal stability characteristics, in the clean, power off condition. C-54D airplane.



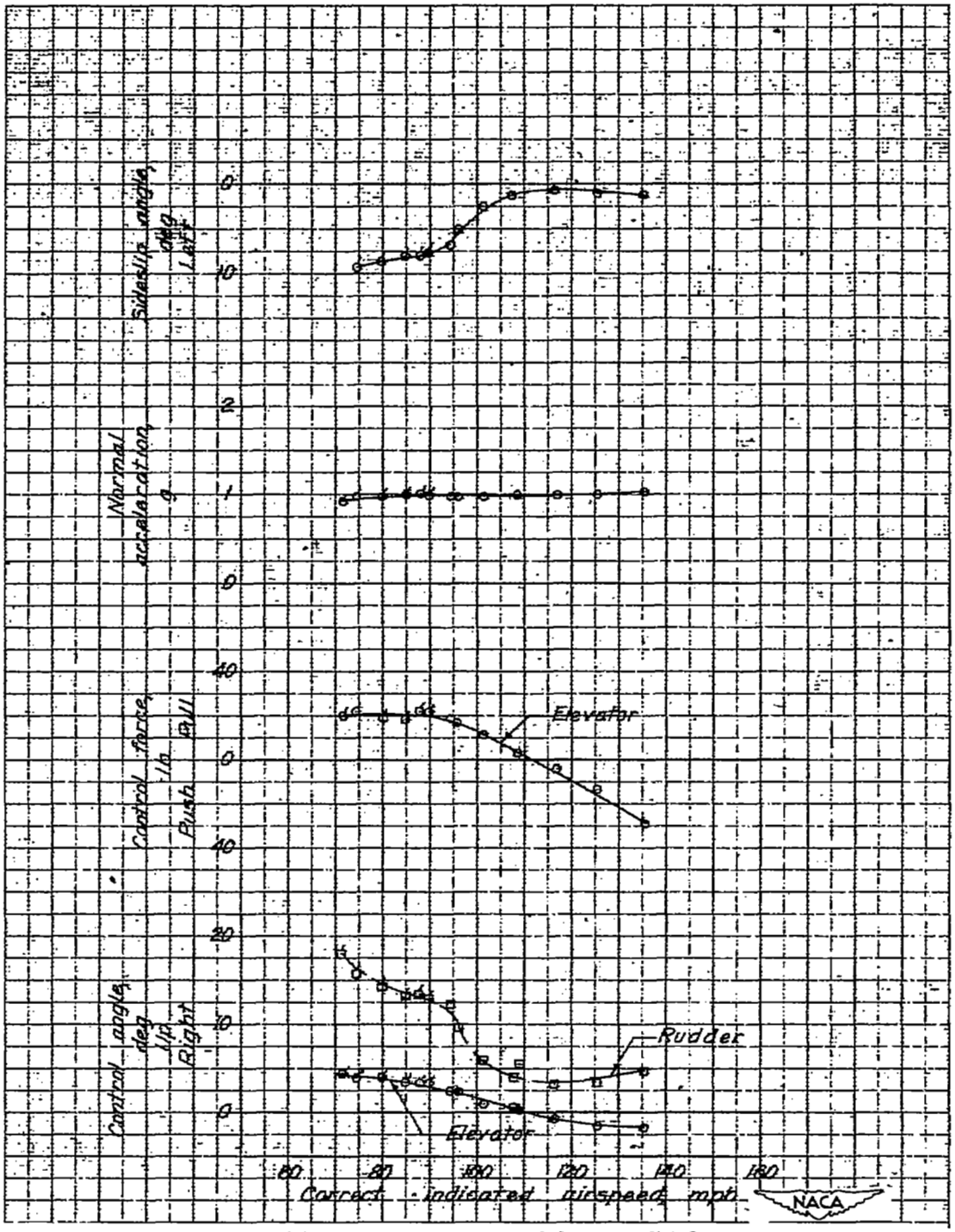
(b) Center of gravity at 23.6 percent M.A.C.

Figure 25.- Continued.



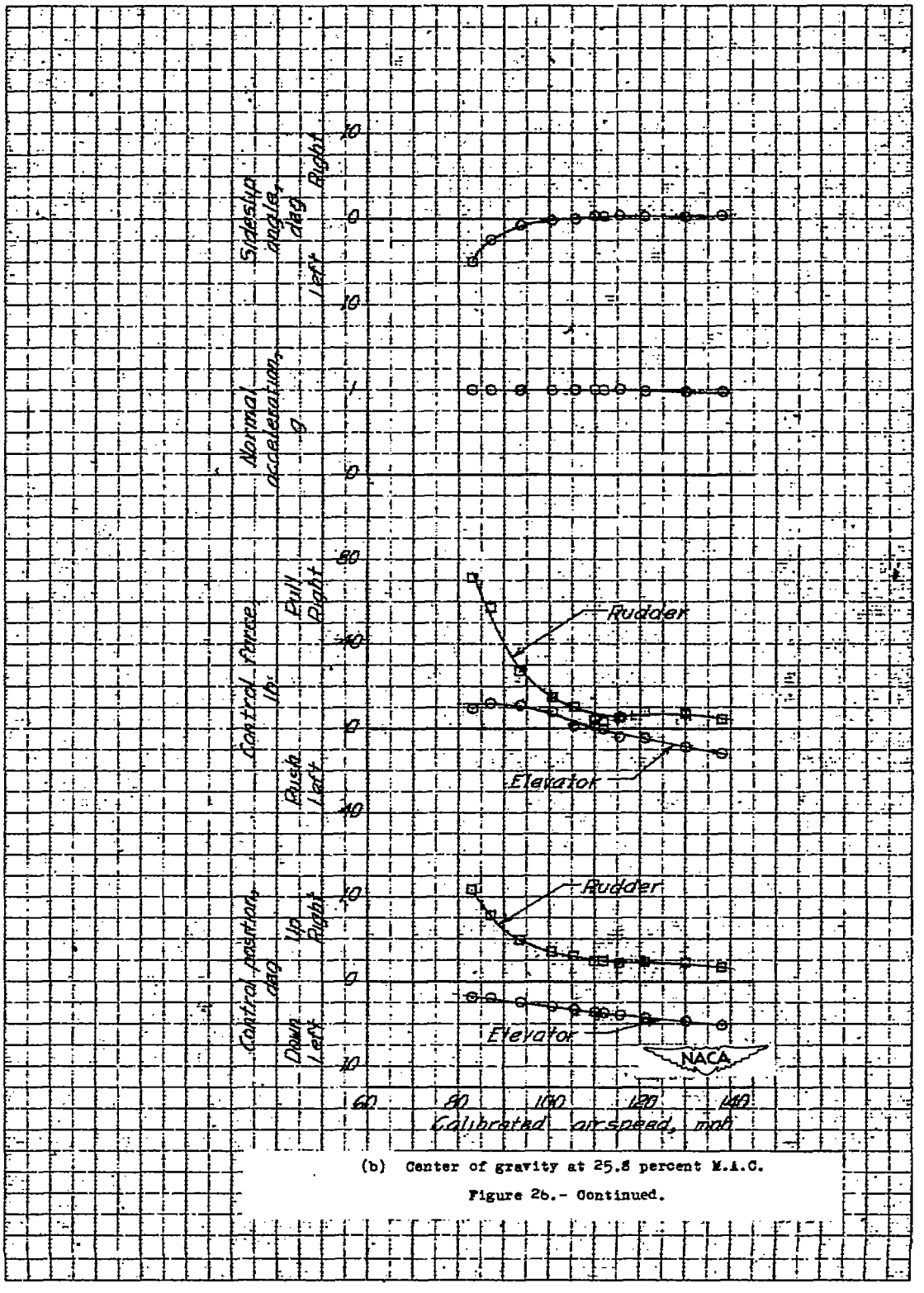
(c) Center of gravity at 27.9 percent M.A.C.

Figure 25.- Concluded.



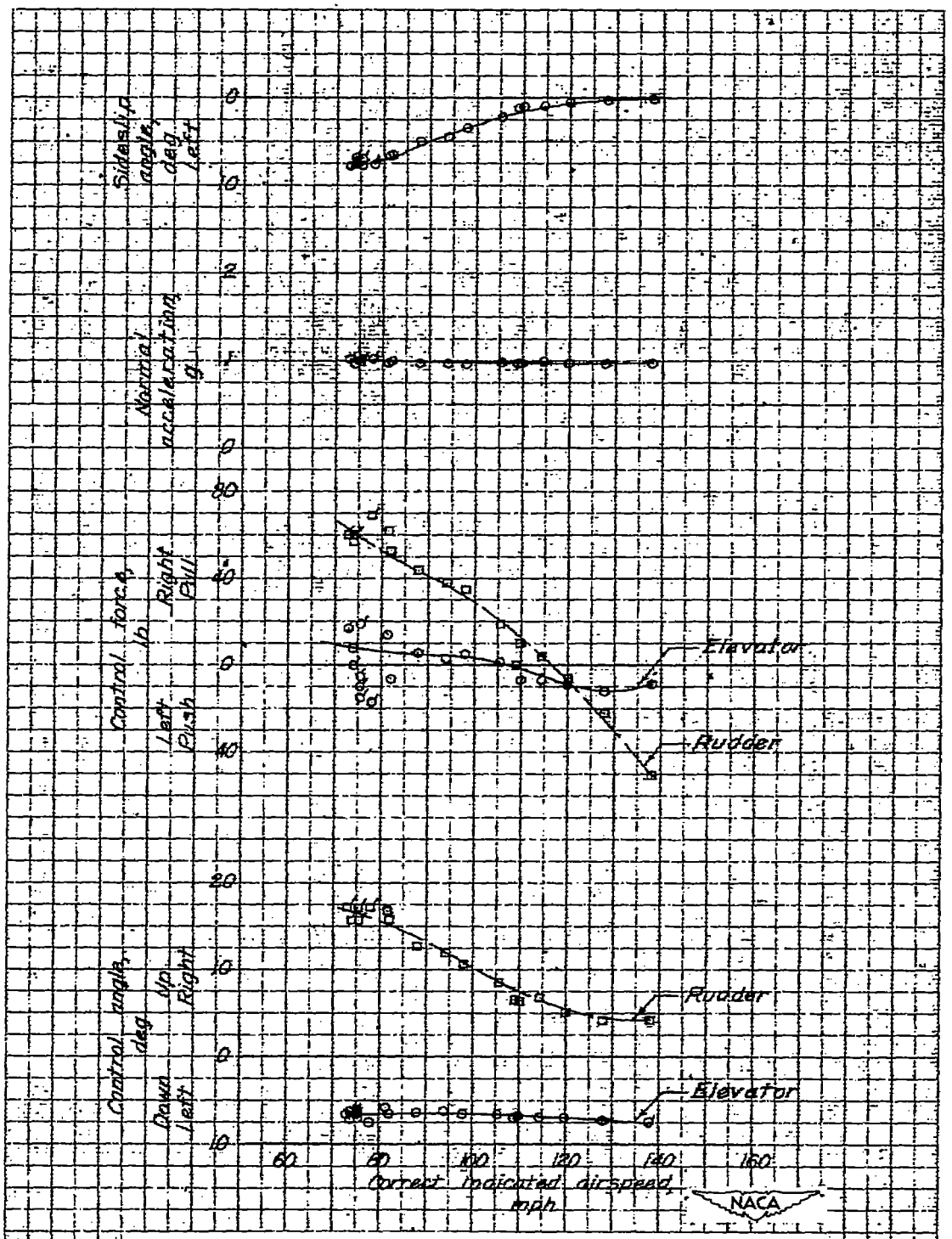
(a) Center of gravity at 19.9 percent M.A.C.

Figure 26.- Static longitudinal stability characteristics in the wave-off condition; flaps full down; gear down; normal rated power. G-54D airplane.



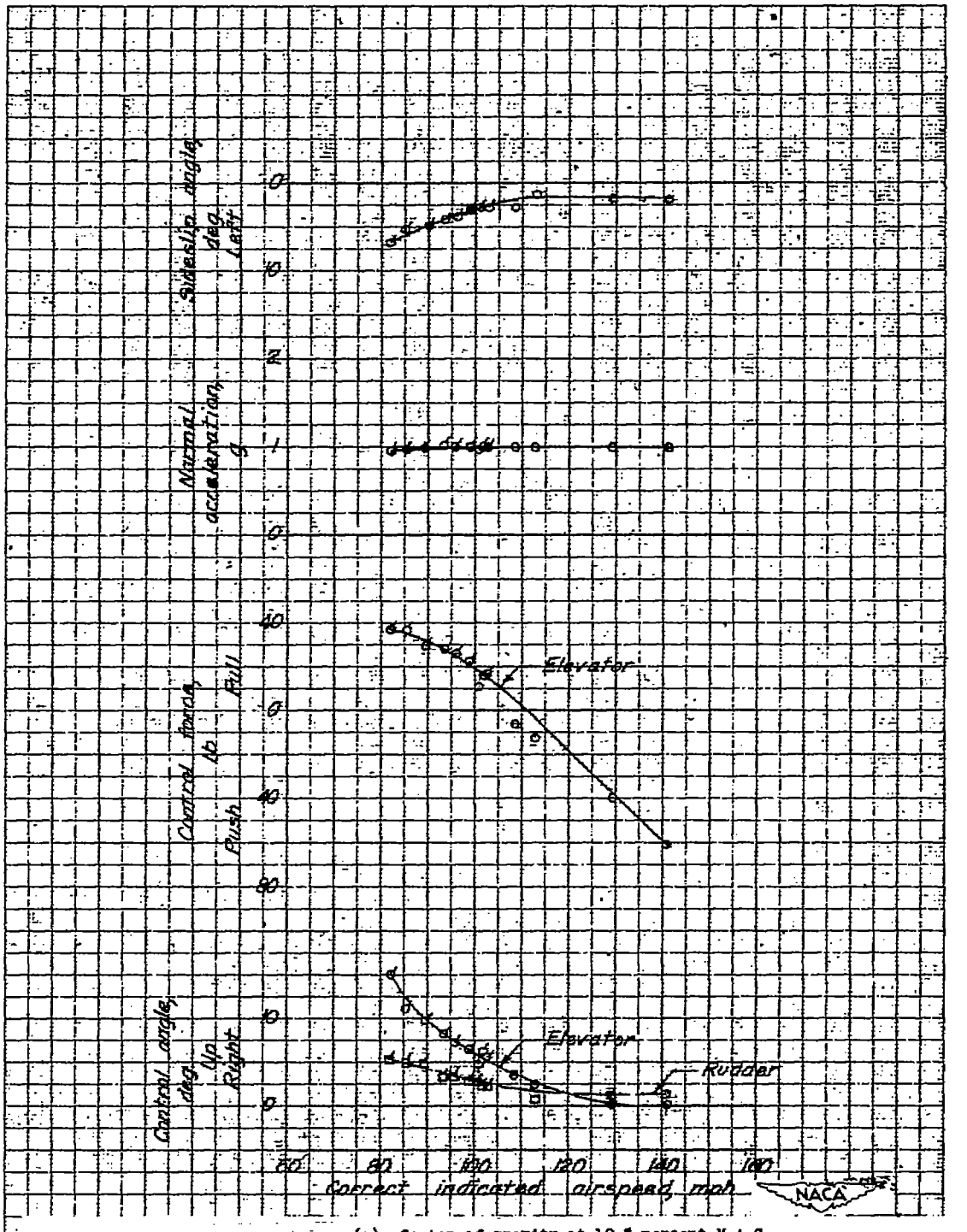
(b) Center of gravity at 25.8 percent M.A.C.

Figure 26.- Continued.



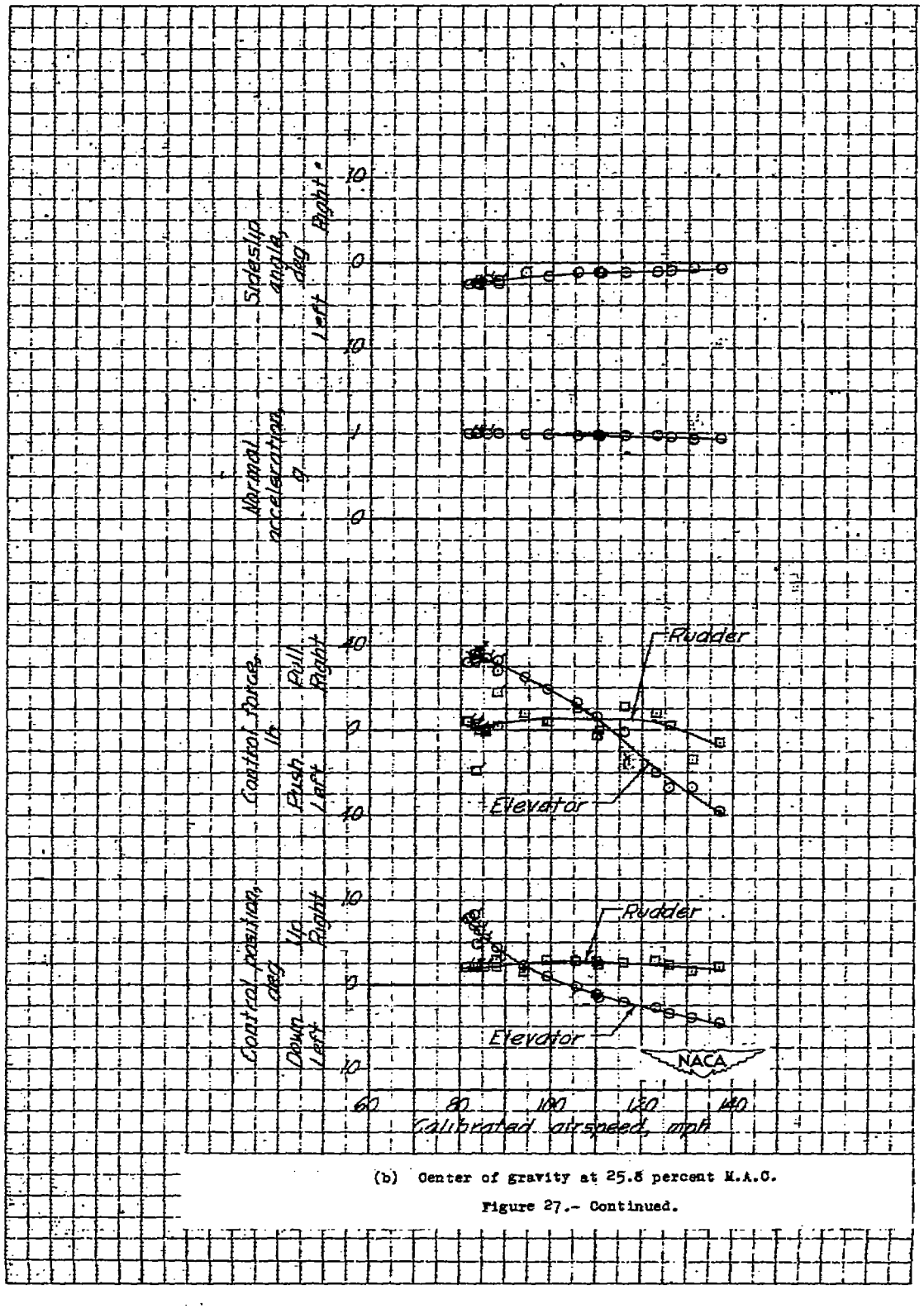
(c) Center of gravity at 30.0 percent M.A.C.

Figure 26.- Concluded.



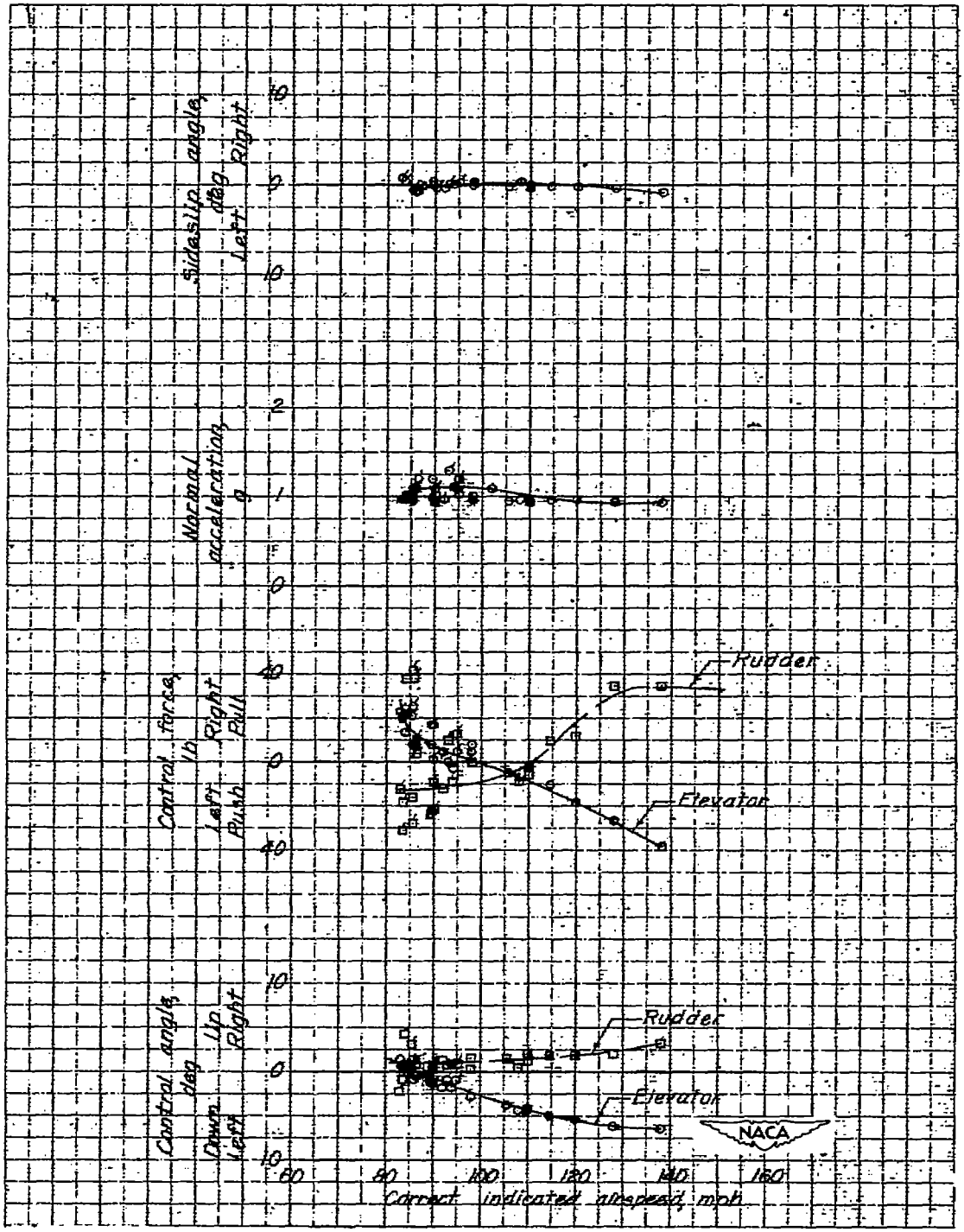
(a) Center of gravity at 19.6 percent M.A.C.

Figure 27.- Static longitudinal stability characteristics in the landing condition; flaps full down; gear down; engines idling. C-54D airplane.



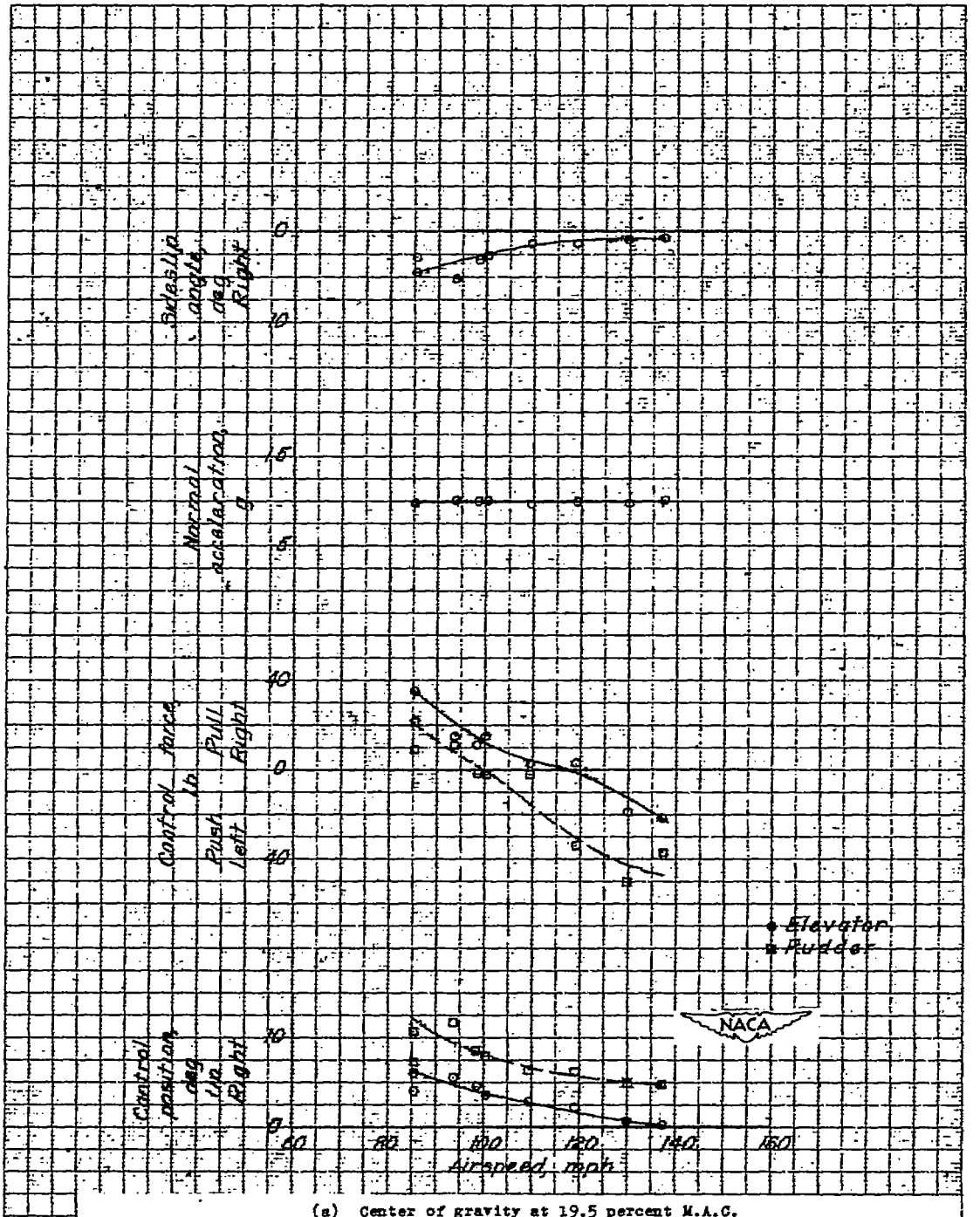
(b) Center of gravity at 25.8 percent M.A.C.

Figure 27.- Continued.



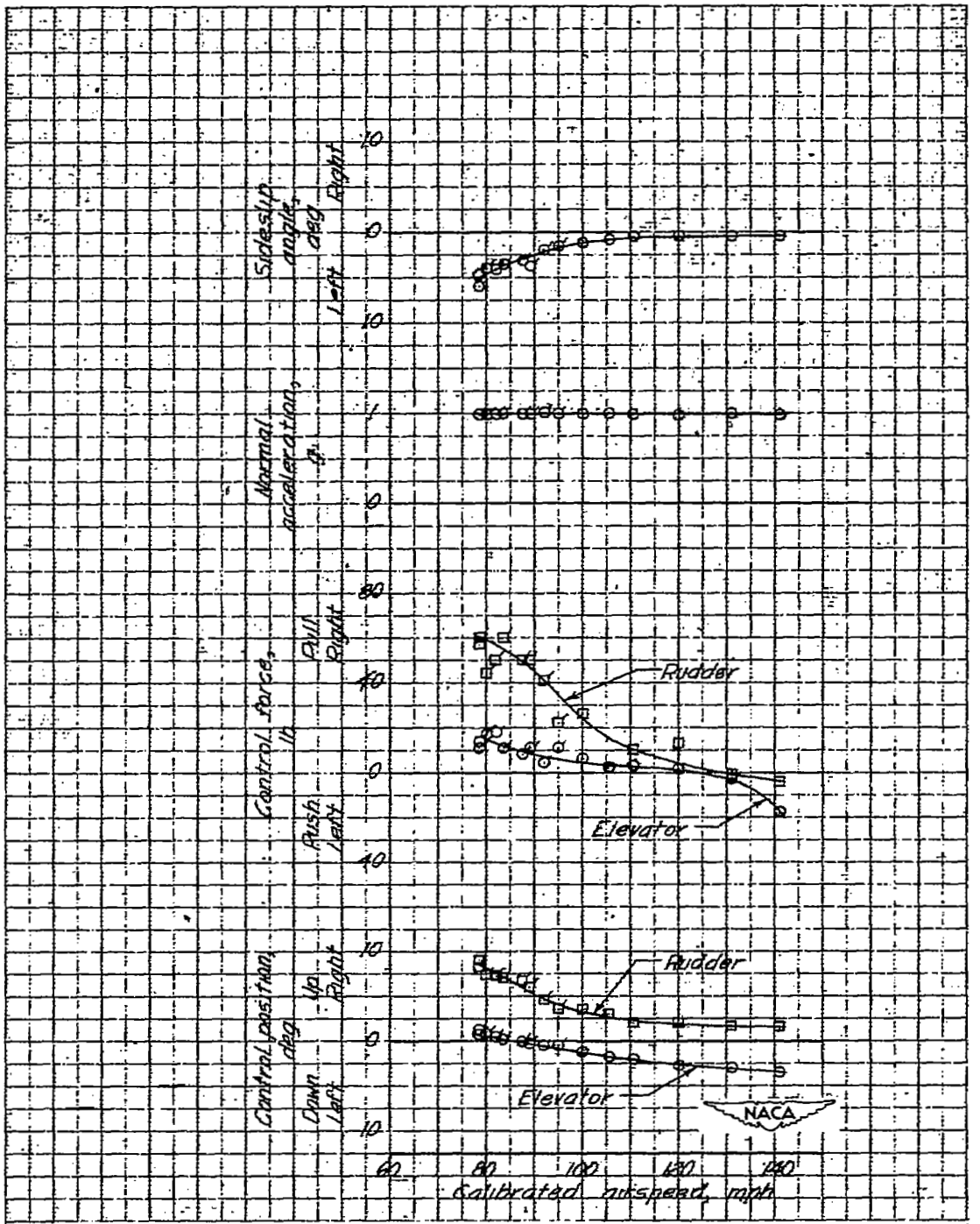
(c) Center of gravity at 31.9 percent M.A.C.

Figure 27.- Concluded.



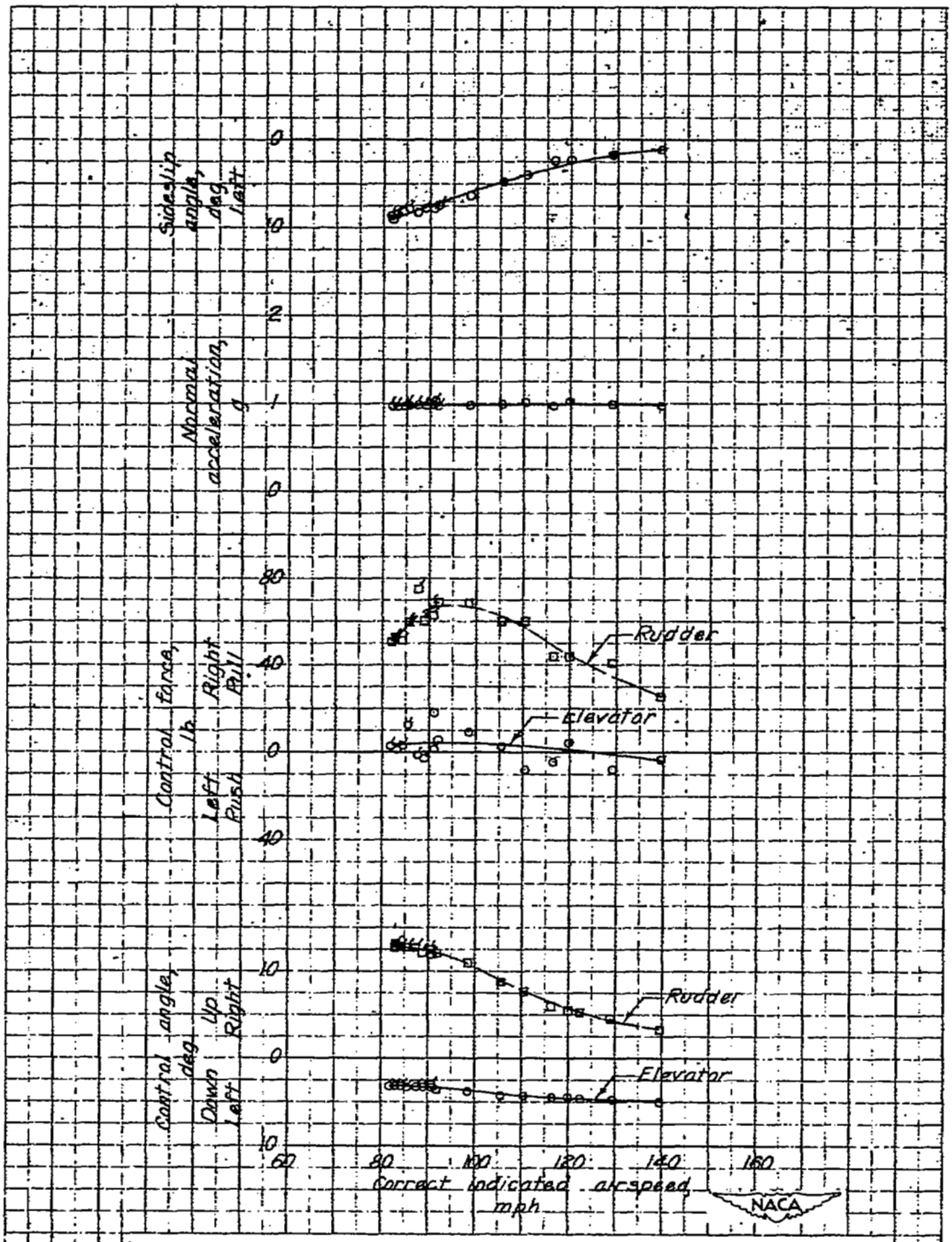
(a) Center of gravity at 19.5 percent M.A.C.

Figure 28.- Static longitudinal stability characteristics in the approach condition. Flaps 20°; gear down; power 20 in. Hg; 2550 rpm. O-54D airplane.



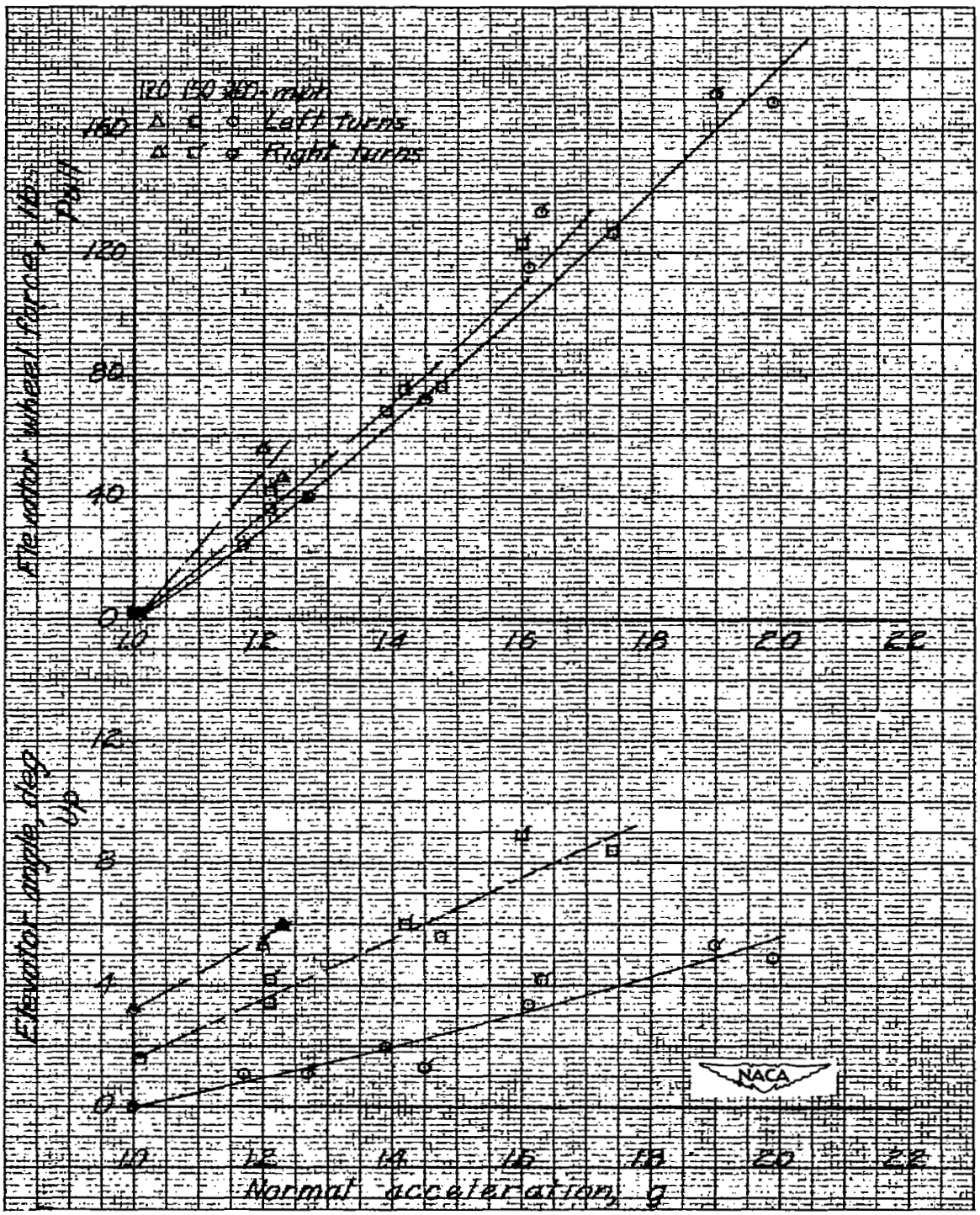
(b) Center of gravity at 25.6 percent M.A.C.

Figure 26.- Continued.



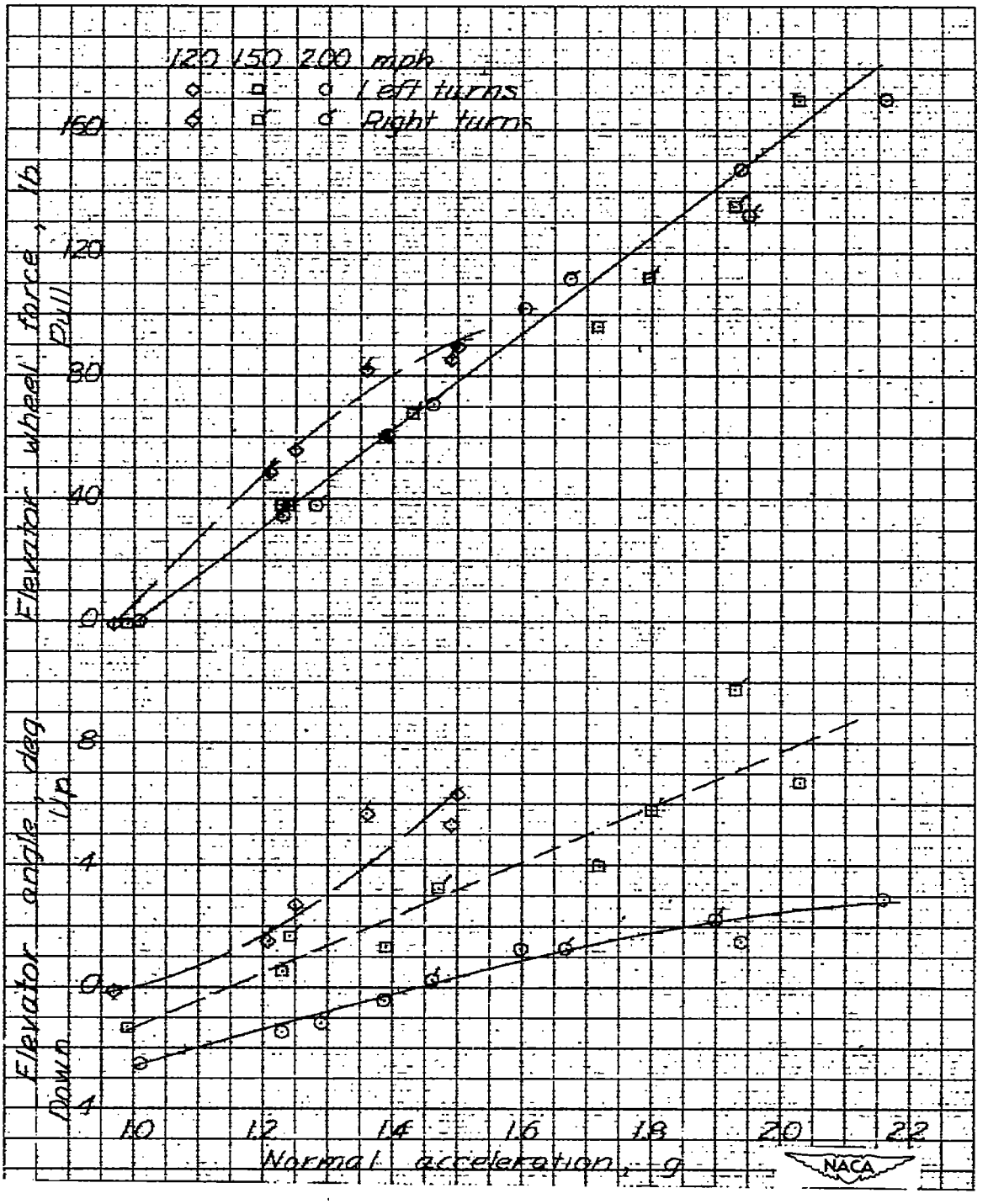
(c) Center of gravity at 30.1 percent M.A.C.

Figure 25.- Concluded.



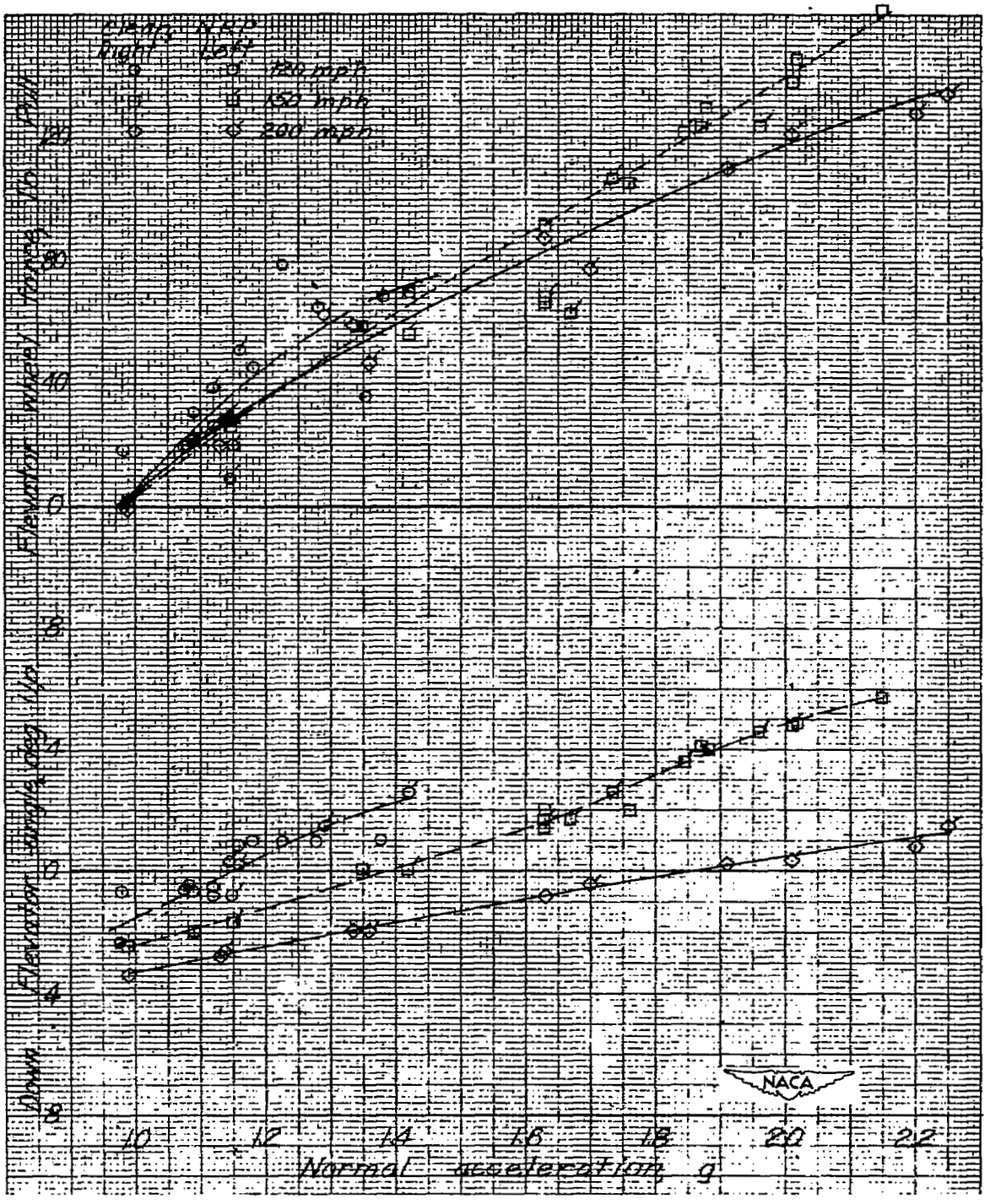
(a) Center of gravity at 16.8 percent M.A.C.

Figure 29.- Maneuvering longitudinal stability characteristics in the clean condition; normal rated power. C-54D airplane.



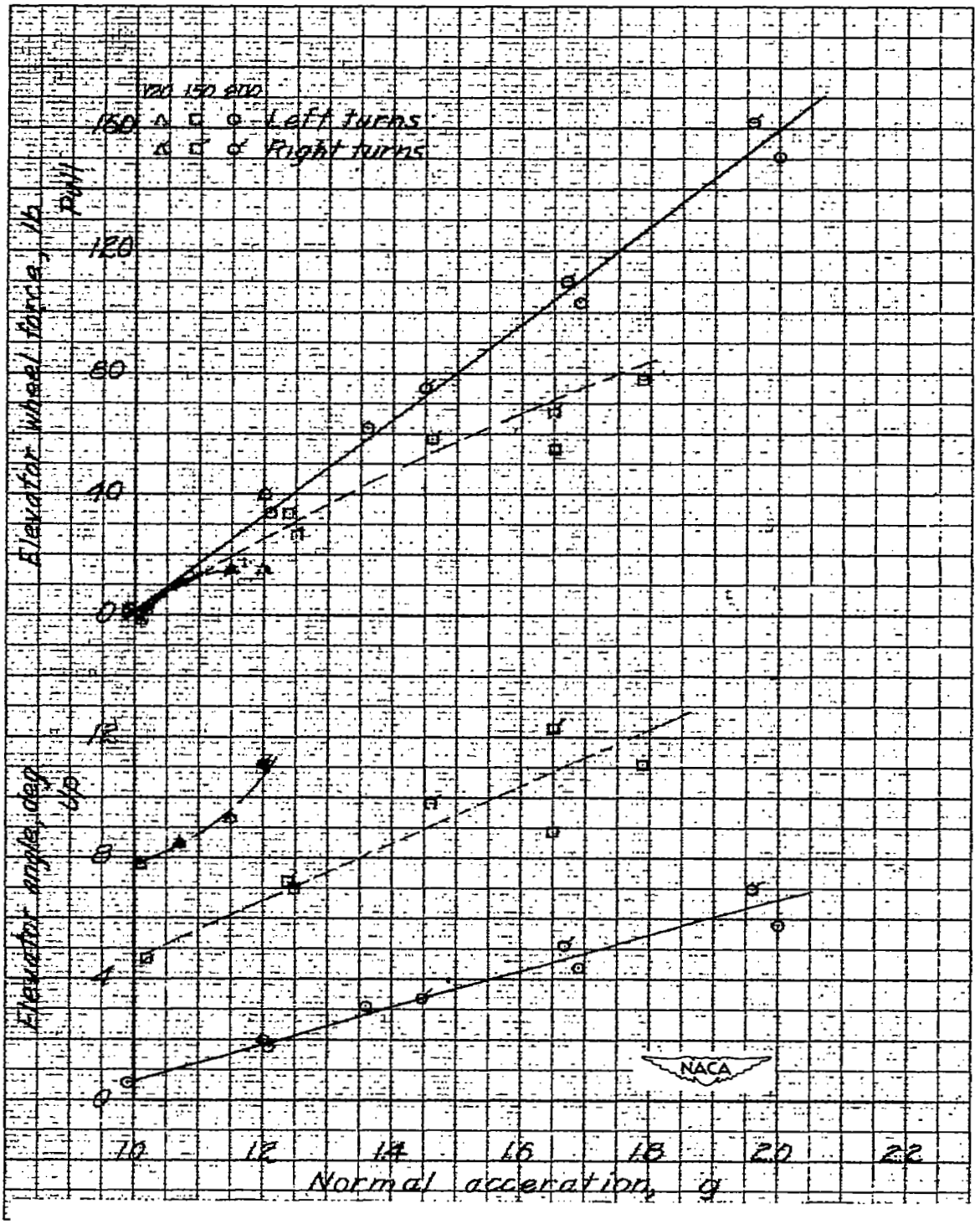
(b) Center of gravity at 23.6 percent M.A.C.

Figure 29.- Continued.



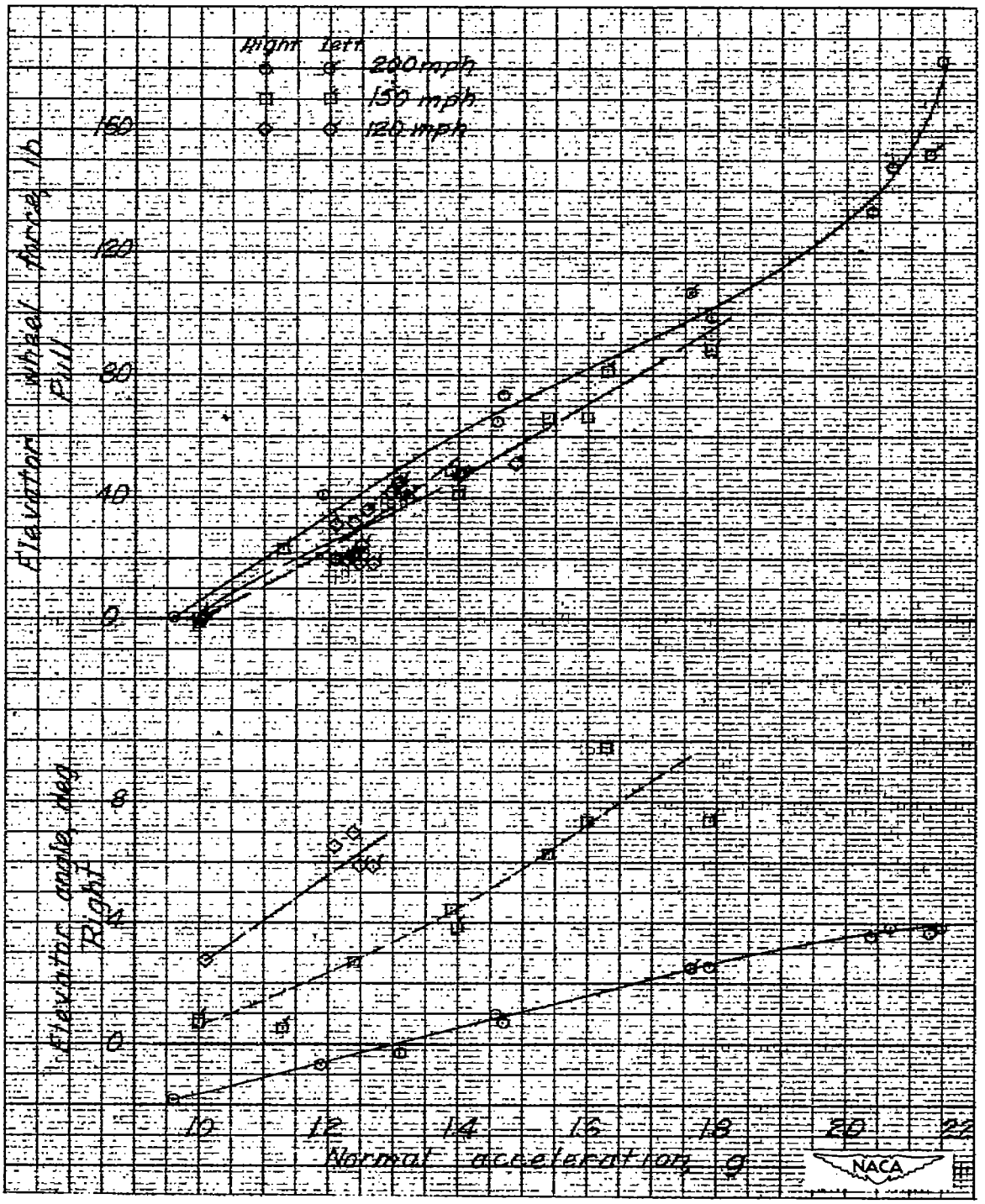
(c) Center of gravity at 27.8 percent M.A.C.

Figure 29.- Concluded.



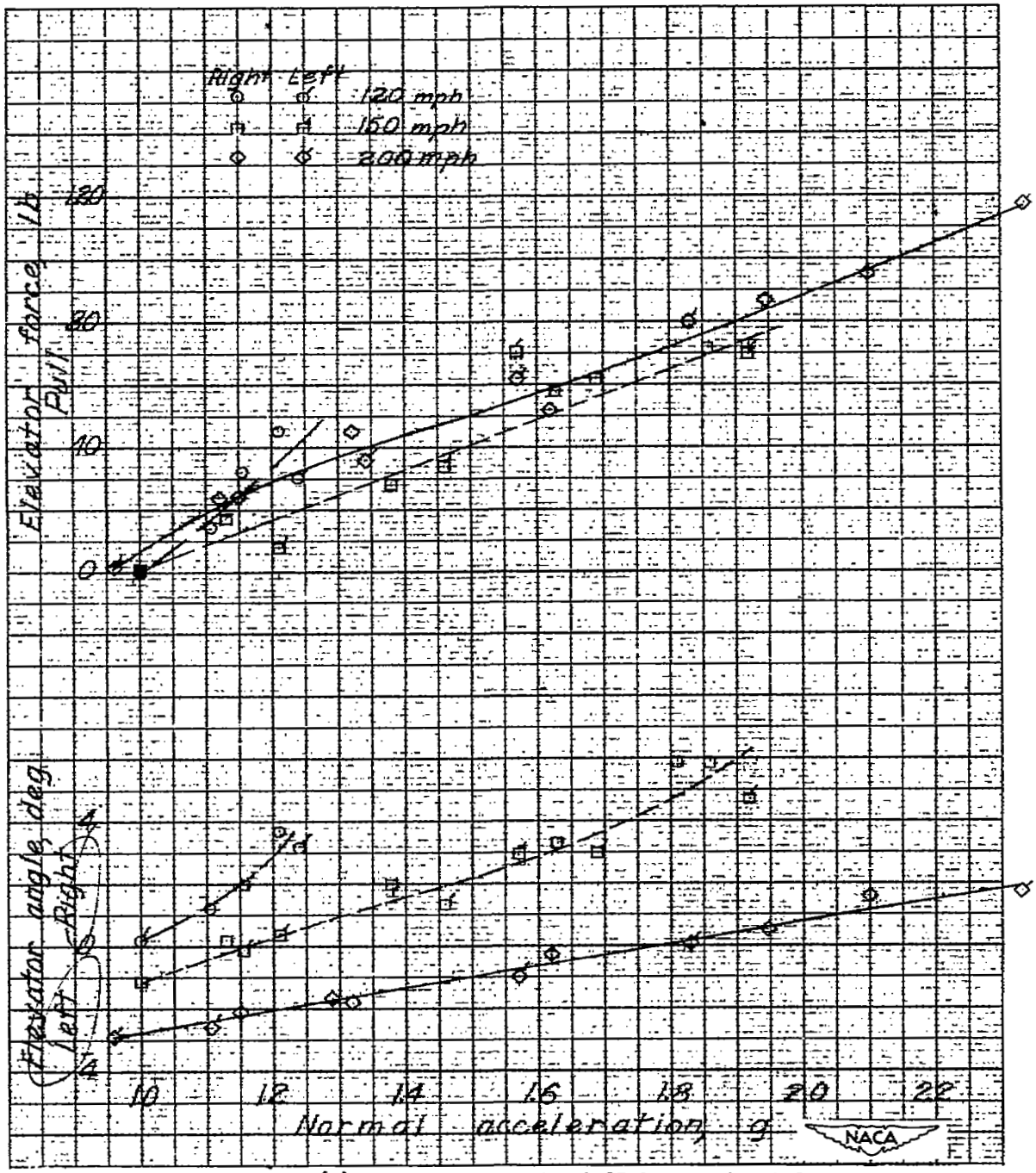
(a) Center of gravity at 16.7 percent M.A.C.

Figure 30.- Maneuvering longitudinal stability characteristics in the clean condition with engines idling. C-54D airplane.



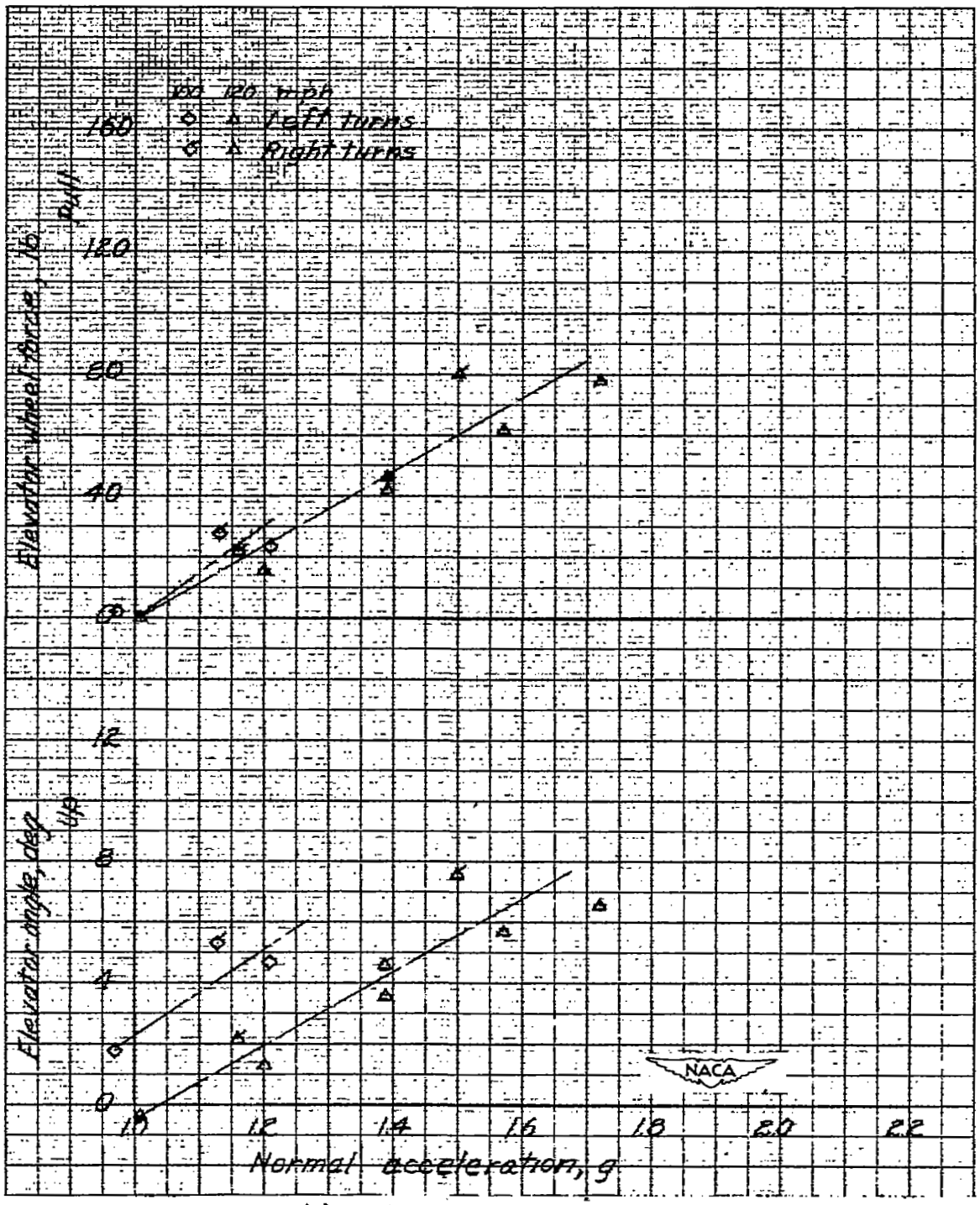
(b) Center of gravity at 23.5 percent M.A.C.

Figure 30.- Continued.



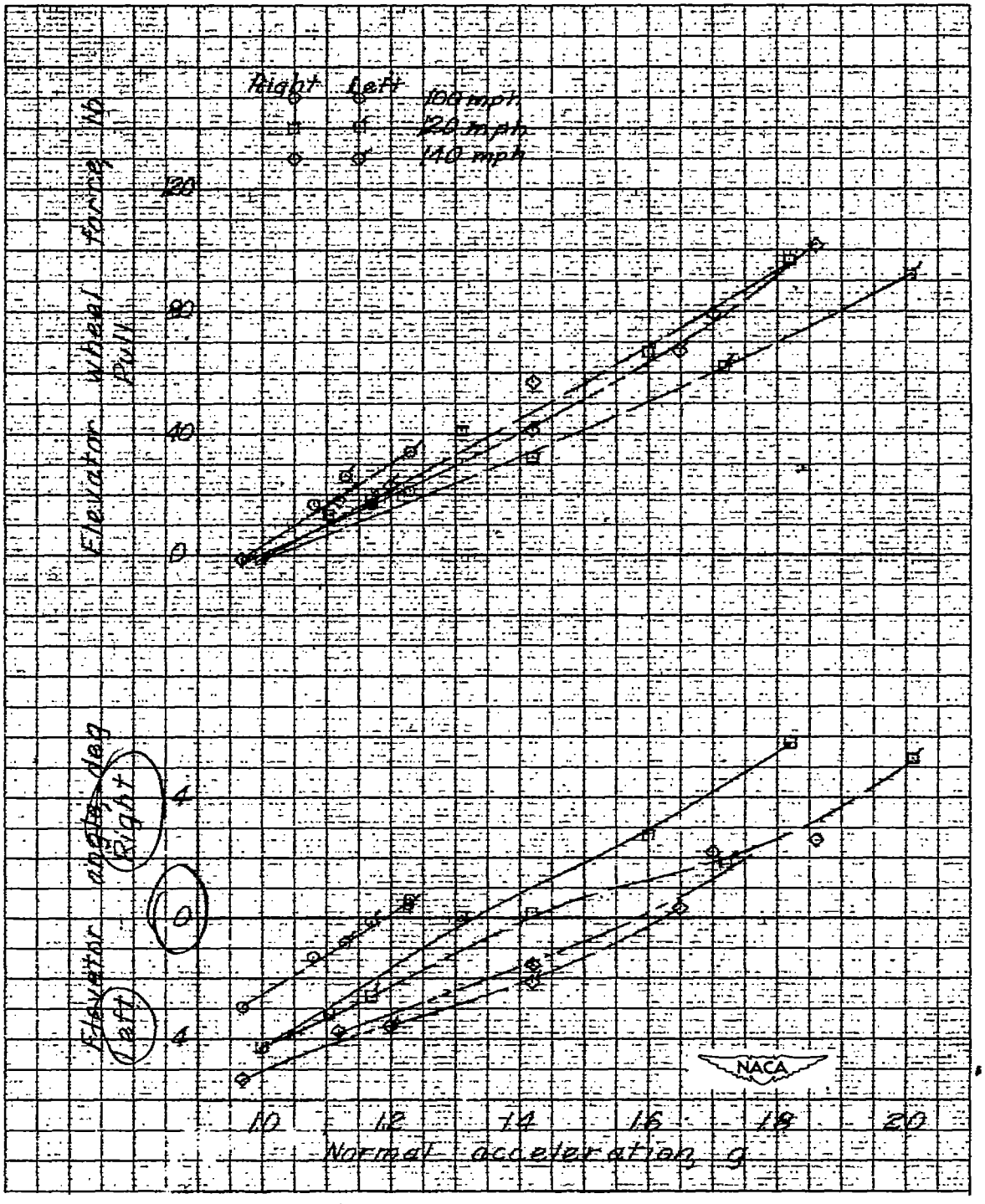
(c) Center of gravity at 27.8 percent M.A.C.

Figure 30.- Concluded.



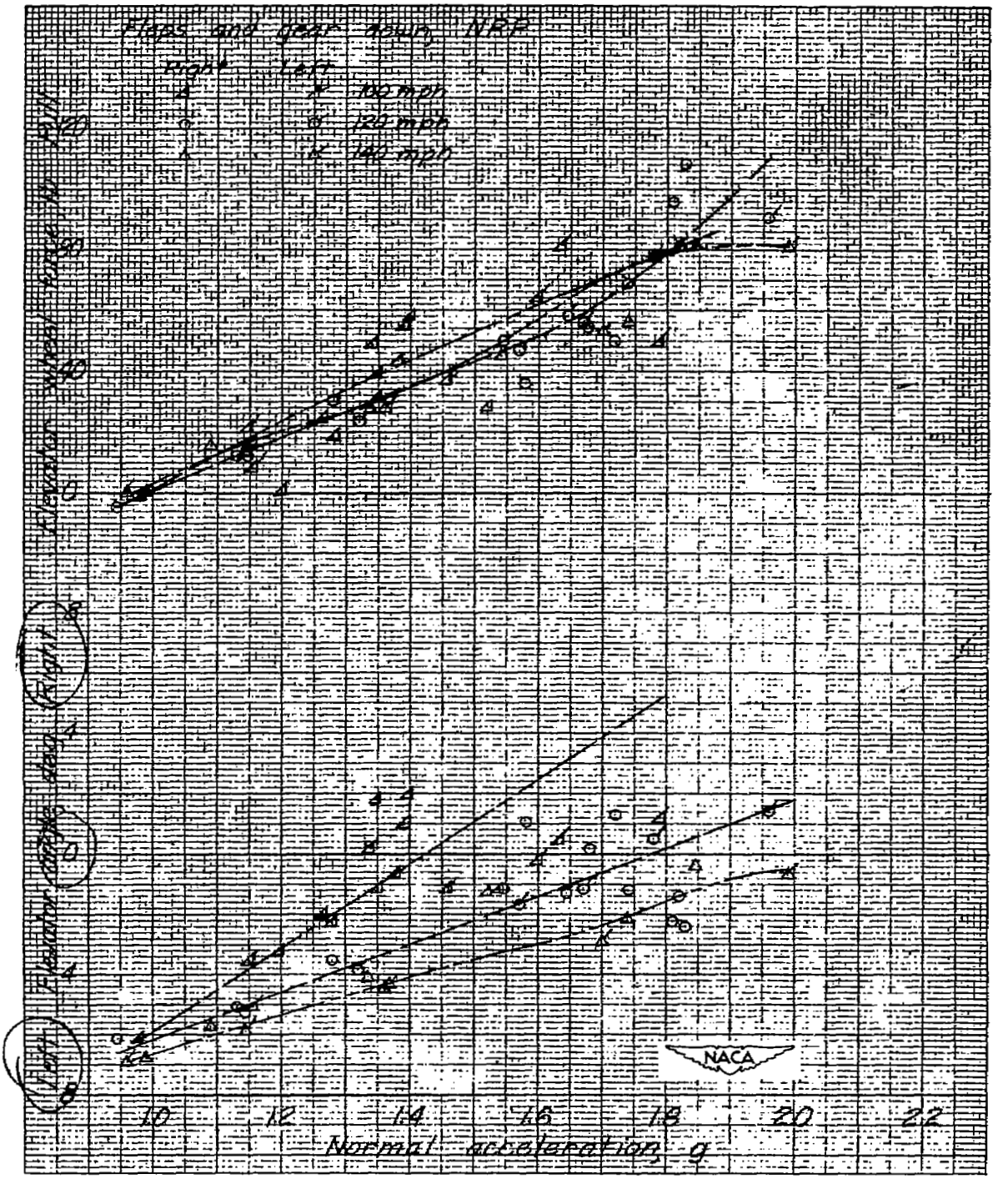
(a) Center of gravity at 19.0 percent M.A.C.

Figure 31.- Maneuvering longitudinal stability characteristics in the wave-off condition. Flaps full down; gear down; normal rated power. C-54D airplane.



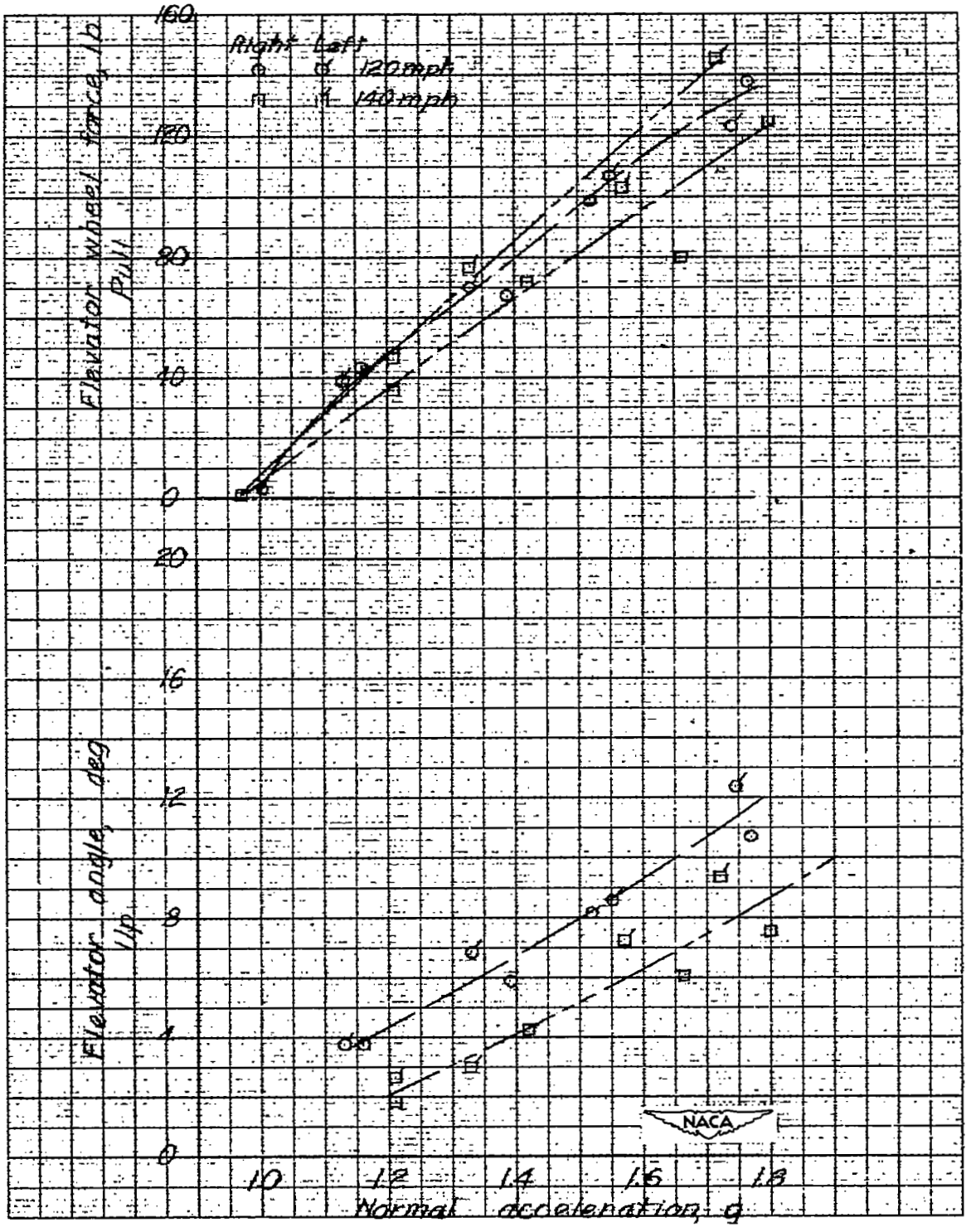
(b) Center of gravity at 25.7 percent M.A.C.

Figure 31.- Continued.



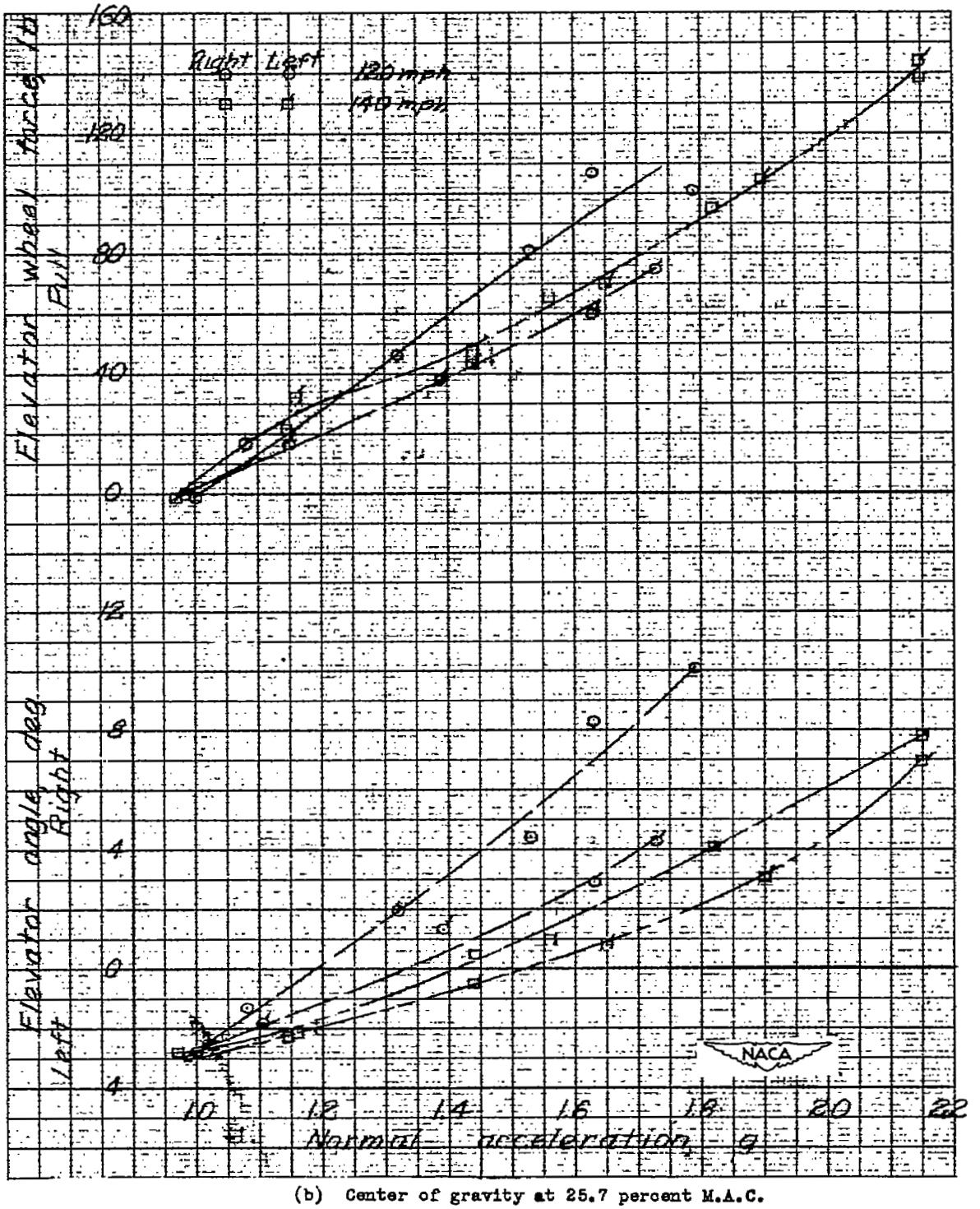
(c) Center of gravity at 31.9 percent M.A.C.

Figure 31.- Concluded.



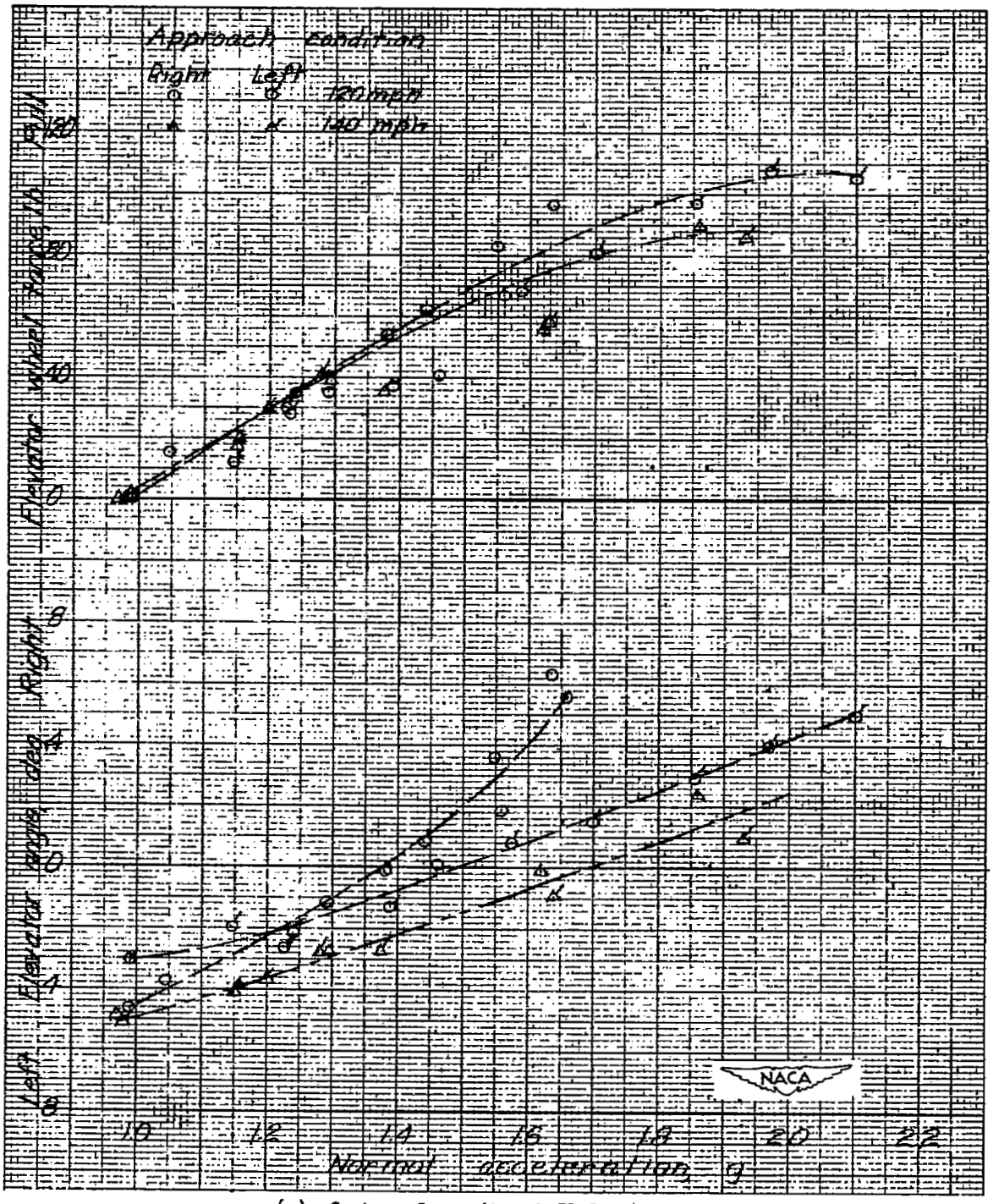
(a) Center of gravity at 19.8 percent M.A.C.

Figure 32.- Maneuvering longitudinal stability characteristics in the approach condition. Flaps 20°; gear down; power 20 in. Hg; 2550 rpm. C-54D airplane.



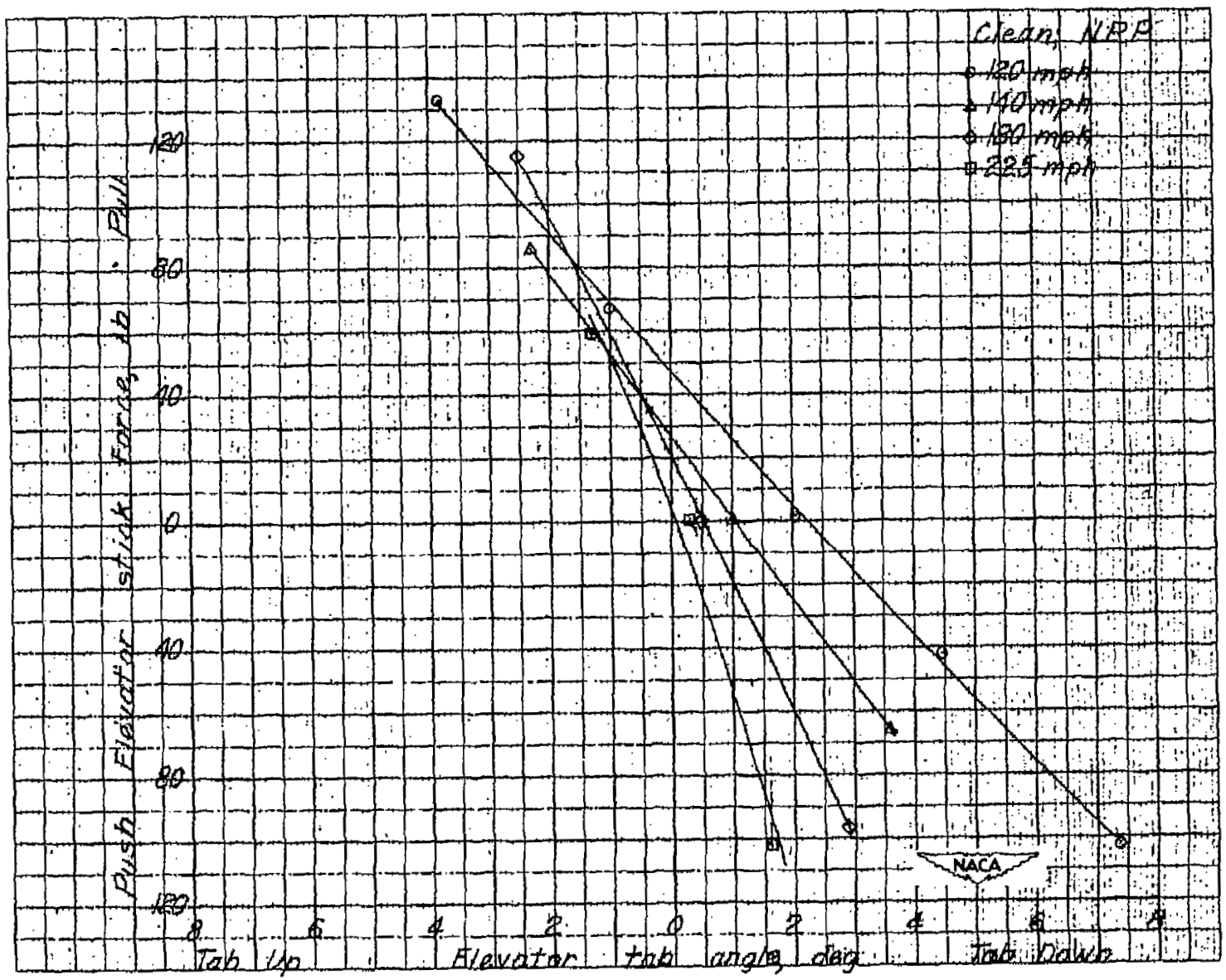
(b) Center of gravity at 25.7 percent M.A.C.

Figure 32.- Continued.



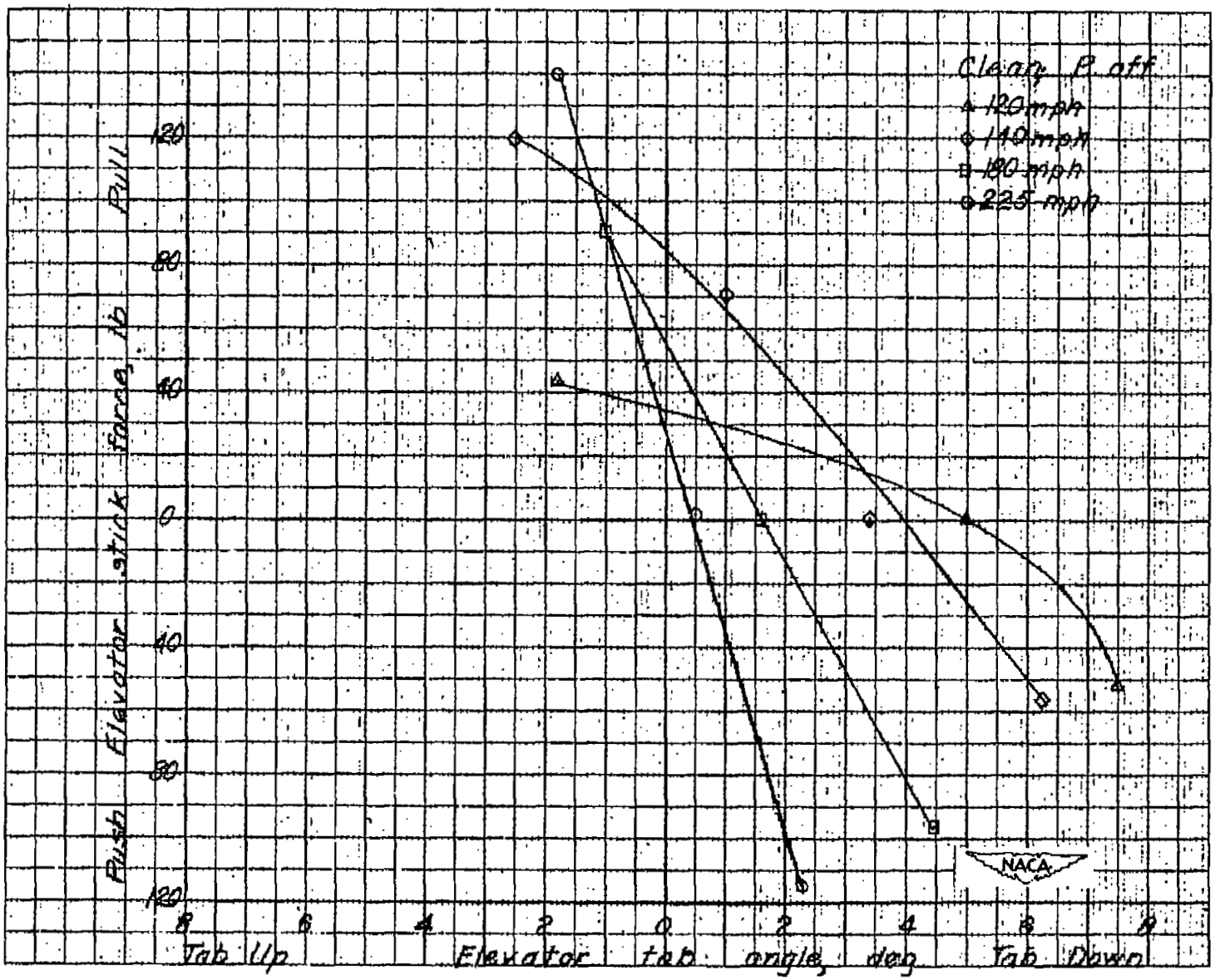
(c) Center of gravity at 31.9 percent M.A.C.

Figure 32.- Concluded.



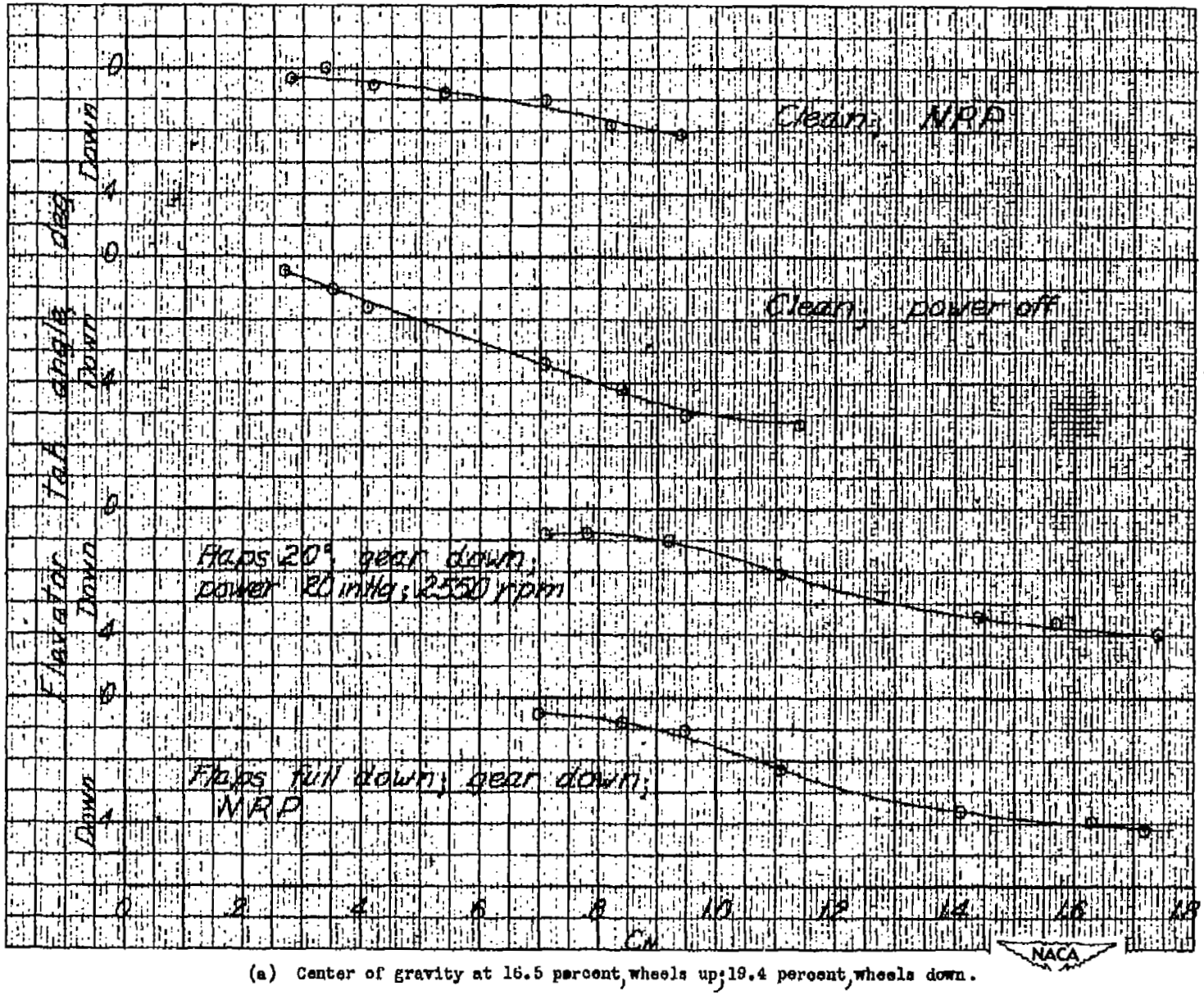
(a) Clean condition; normal rated power.

Figure 33.- Elevator-trim-tab effectiveness. C-54D airplane.



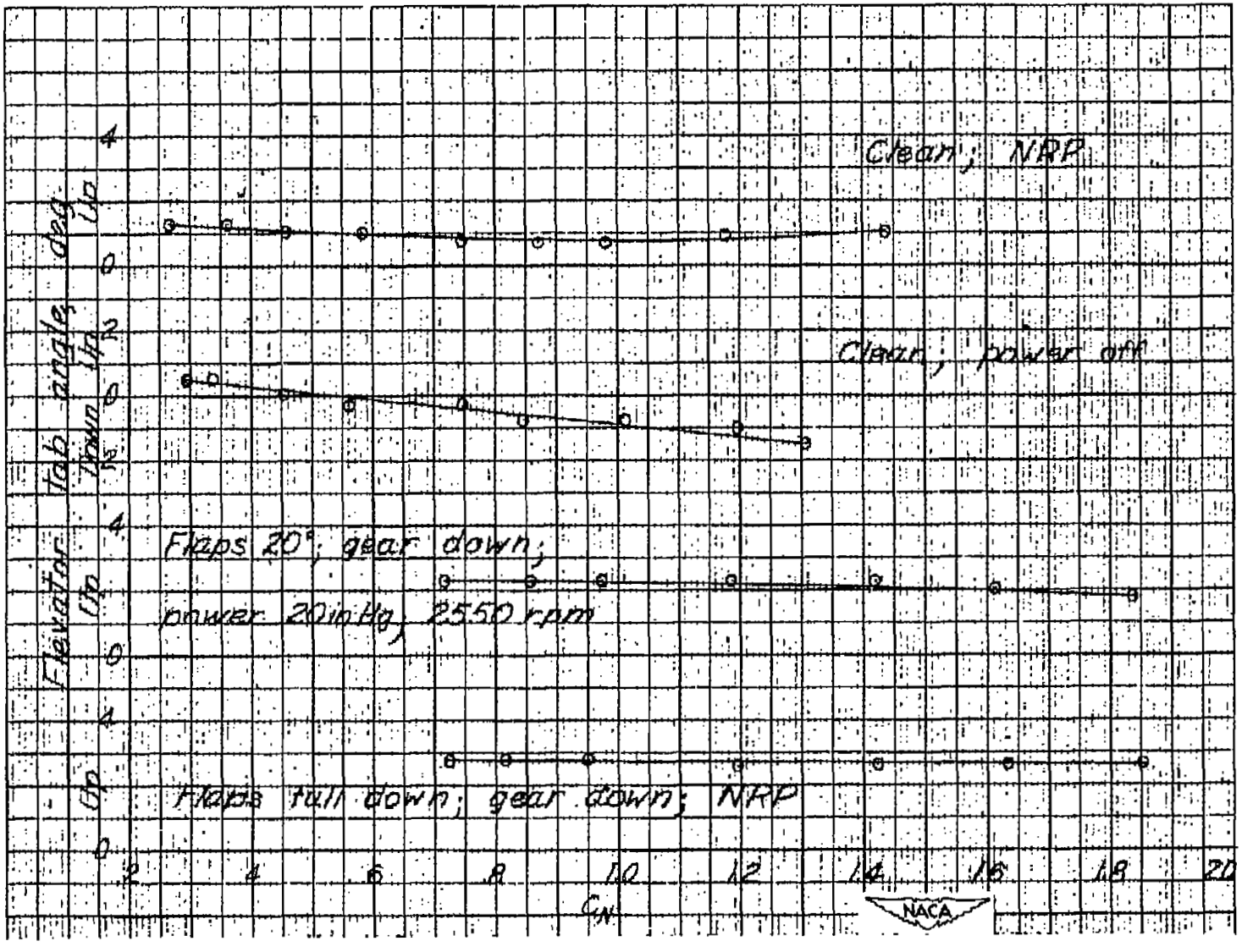
(b) Clean condition; engines idling.

Figure 33.- Concluded.



(a) Center of gravity at 16.5 percent, wheels up; 19.4 percent, wheels down.

Figure 34.- Variation of elevator trim tab angle for zero stick force in straight flight with normal force coefficient. C-54D airplane.



(b) Center of gravity at 28.3 percent, wheels up; 30.5 percent, wheels down.

Figure 34.- Concluded.

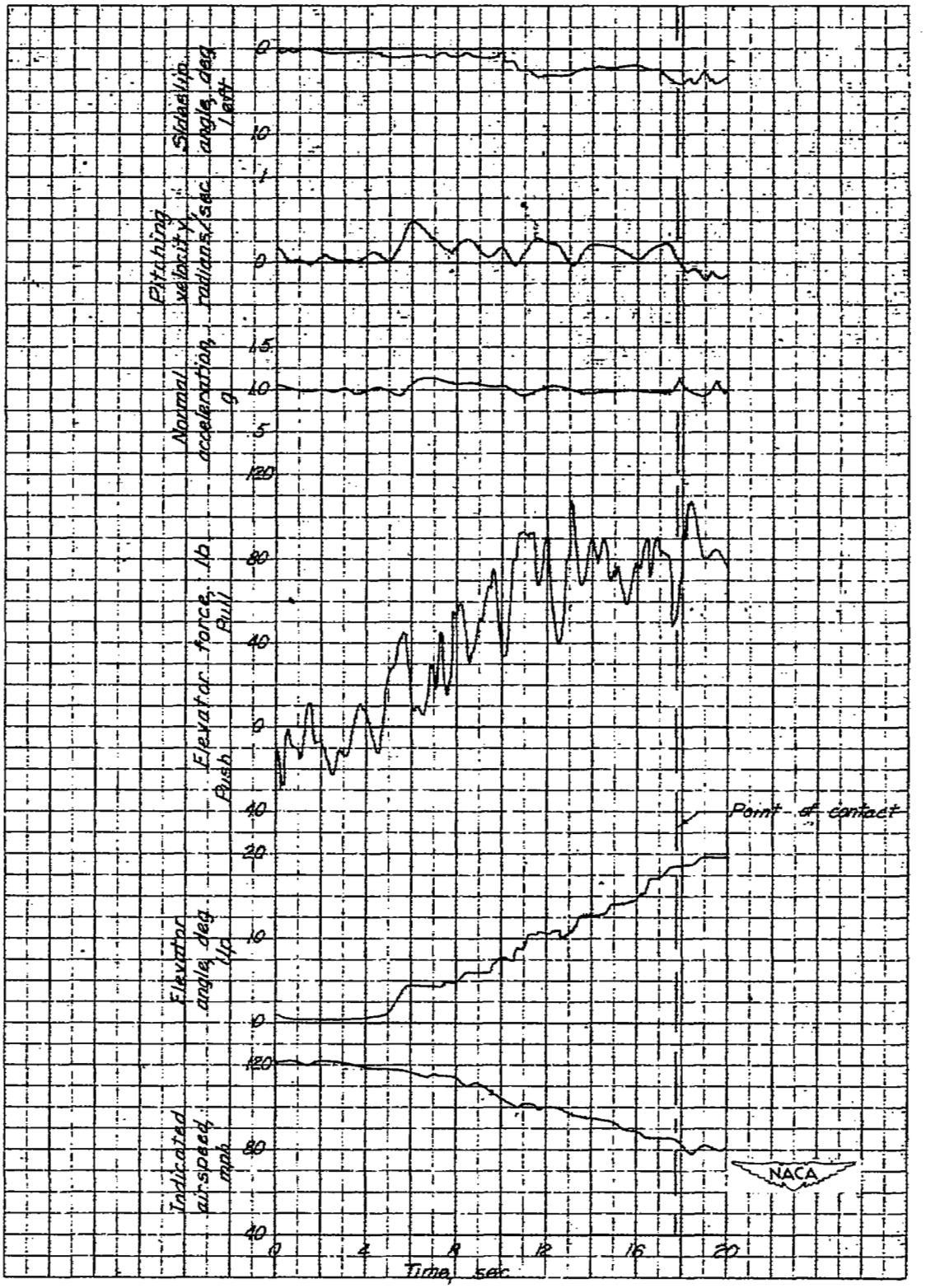


Figure 35.- Time history of a power-off landing. O-54D airplane; center of gravity at 20.0 percent M.A.C.

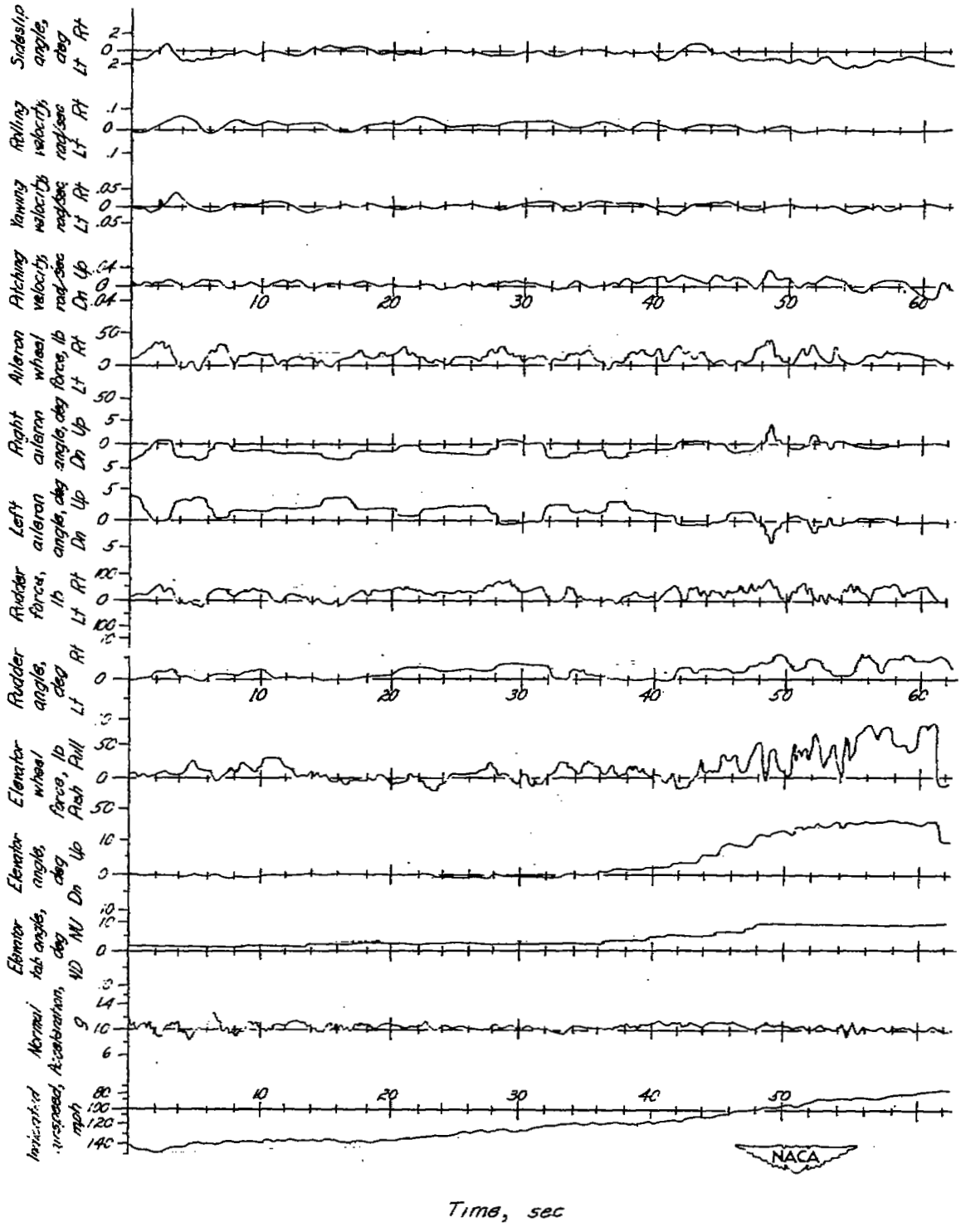


Figure 36.- Time history of a partial power approach and landing C-54D airplane. Center of gravity at 19.8 percent M.A.C.

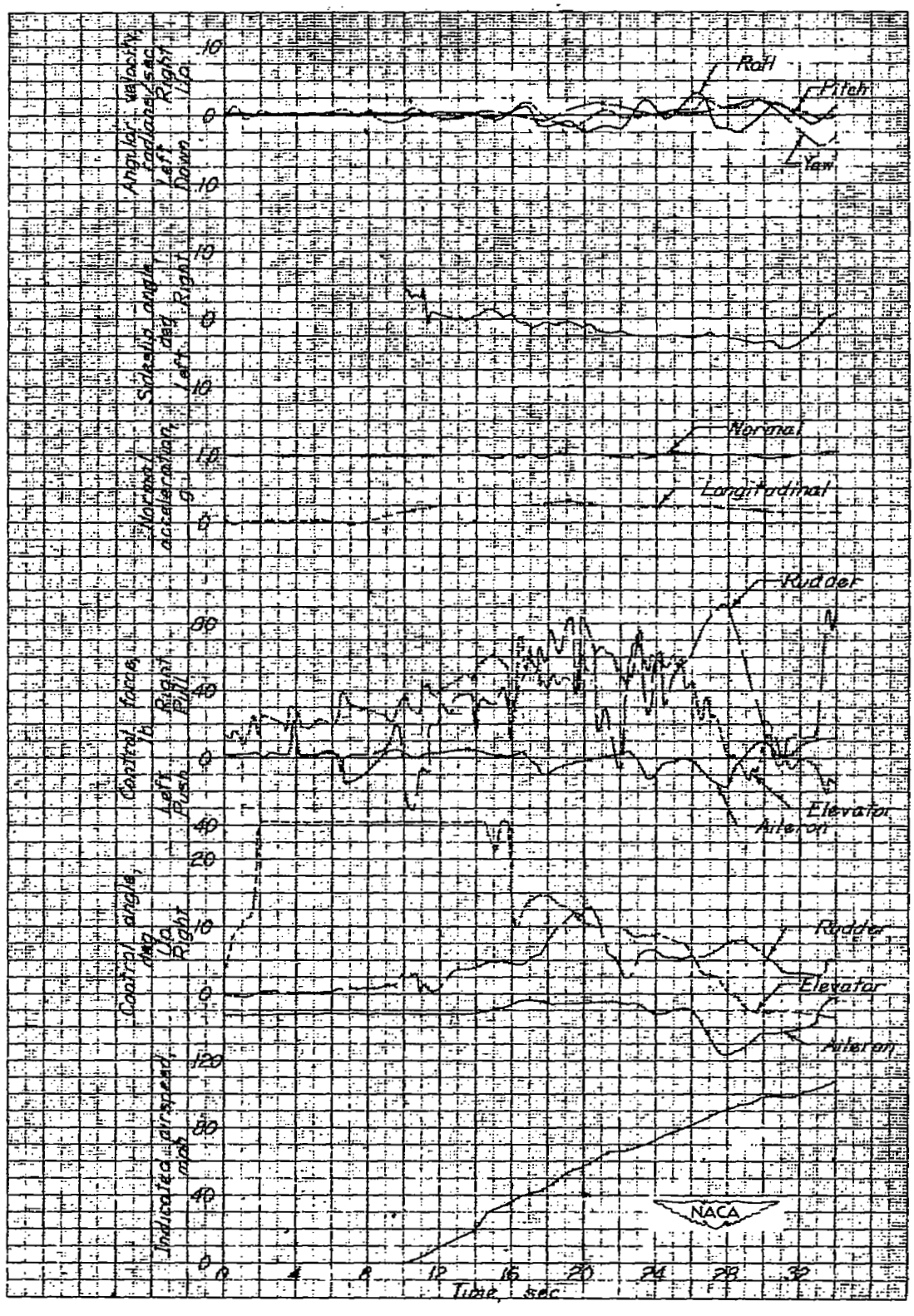


Figure 37.- Time history of take-off run. J-5AD airplane; center of gravity at 30.5 percent M.A.C.

INDEX

Subject	Number
Airplanes – Specific Types	1.7.1.2
Stability, Longitudinal – Static	1.8.1.1.1
Stability, Lateral – Static	1.8.1.1.2
Stability, Directional – Static	1.8.1.1.3
Stability, Longitudinal – Dynamic	1.8.1.2.1
Stability – Lateral and Directional – Dynamic	1.8.1.2.2
Controls, Longitudinal	1.8.2.1
Controls, Lateral	1.8.2.2
Controls, Directional	1.8.2.3
Flying Qualities	1.8.5

ABSTRACT

This paper contains a summary of the results of the C-54D program to determine the necessity of new or revised handling-qualities requirements for large aircraft in precision flying and presents the measured data for the handling qualities with a discussion limited to pointing out the airplane's deficiencies.

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