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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

MEASUREMENTS OF THE FLYING QUALITIES OF
A BELL P-39D-1 AIRPLANE (A.A.F. No. 41-28378)

By Harold I. Johnson, C. J. Liddell, and H. H. Hoover

INTRODUCTION

At the request of the Army Air Forces, Materiel Command, a flight investigation of the flying qualities of a standard Bell P-39D-1 airplane was made by the NACA at Langley Field, Va. The tests were conducted during February and March of 1943 and consisted of 21 flights requiring a total flying time of approximately 23 hours. The present report is a summary covering all data obtained in the flying-qualities investigation.

The flight program, in general, was arranged in accordance with that suggested in the Army Air Forces stability and control requirements (reference 1). For convenience of the reader, the various items of stability and control investigated are given in the order of their presentation in reference 1.

AIRPLANE

The Bell P-39D-1 airplane is a single-place, single-engine, full-cantilever, low-wing, pursuit-type airplane having partial-span, split-trailing-edge type landing flaps and a retractable tricycle-type landing gear. Construction is of metal except for the fabric covering on control surfaces. Power is supplied by an Allison V-1710-35 engine mounted below and behind the pilot's compartment and is transmitted to the propeller by an extension shaft running to a reduction gear box in the nose of the airplane. Armament consists of two 30-caliber guns in each outer wing panel, two 50-caliber guns on the cowl, and a 20-millimeter cannon firing through the propeller hub. Photographs showing general views of the airplane are reproduced in figures 1, 2, and 3, respectively. A three-view drawing of the airplane is shown in figure 4 together with cross-sectional outline of each aerodynamic surface. Physical dimensions of the airplane, airplane weights, and engine power ratings are listed in the appendix.

Relations between cockpit control positions and control surface angles are given in figures 5 through 7. Figure 5(a) shows the variation of stick angle with elevator angle while figure 5(b) shows the variation of elevator trim tab angle with the cockpit tab indicator setting. Similar relations for the aileron control system are shown in figures 6(a) and 6(b) and figure 6(c) shows the gearing relations of the two balancing tabs on each aileron. Only the inboard tab on each aileron is used for trimming. Figures 7(a) and 7(b) show the gearing relations of the rudder control and rudder trim tab systems, respectively.

INSTRUMENTATION

Items pertinent to each phase of the flying-qualities investigation were measured with the following standard NACA instruments:

Item	NACA Instrument
1. Time	Timer
2. Airspeed	Airspeed recorder
3. Positions of the three control surfaces	Control-position recorders
4. Rolling velocity	Rolling-velocity recorder
5. Normal, longitudinal, and transverse acceleration	Three-component recording accelerometer and indicating accelerometer
6. Sideslip angle	Yaw-angle recorder
7. Bank angle or pitch angle	Recording inclinometer
8. Rudder pedal force	Rudder-force recorder

9.	Stick force	Stick-force recorder
10.	Free-air temperature	Electrical resistance-bulb type temperature indicator

The airspeed recording installation included an NACA free-swiveling static head mounted on the end of a boom extending one chord-length ahead of the right wing at the tip juncture and a shielded total-head meter located below and behind the static head. (See fig. 2.) Airspeed was read from the service airspeed indicator during the aileron characteristics tests because the airspeed boom was removed to eliminate any possible adverse interference effects on the right aileron. Both airspeed installations were calibrated for position error by flying by a known static reference point as described in reference 2. "Indicated airspeed" in miles per hour, as used in this report, is $45.08\sqrt{q_c}$, where q_c is the difference between static and total pressure in inches of water, as measured by the calibrated installations.

Elevator positions were measured from a point on a control cable close to the elevator and the measured angles were corrected for cable stretch. Aileron angles were measured directly at the ailerons. Rudder angles were measured from a control cable within a few feet of the rudder so that any error due to cable stretch is believed to be negligible.

Throughout the present report, elevator and rudder angles are given with respect to the thrust axis. The aileron angles are given with respect to their neutral positions.

The recording accelerometer was located about 6 feet ahead of the center of gravity so that angular accelerations affected recorded linear accelerations. Wherever absolute values of acceleration were used in analyzing data, however, the effect of angular acceleration was negligible.

Sideslip angles were measured by means of a small vane mounted at the end of a boom extending one chord length ahead of the left wing at the tip juncture. Although no straight-flight calibration of the sideslip vane was made, it can be assumed from previous calibration of similar installations that the error in measuring a given sideslip angle does not exceed $\pm 2^\circ$ and that the variations of sideslip angle at a given speed are essentially correct.

Indicating instruments were used to determine free-air temperatures and altitude. Indications of an electrical resistance-bulb type thermometer were corrected for the adiabatic rise to obtain free-air temperature. The service altimeter was calibrated prior to the tests in order to determine correct pressure altitude.

TESTS, RESULTS, AND DISCUSSION

A. Longitudinal Stability and Control Characteristics

(1-A) Dynamic Longitudinal Stability:

The dynamic stability was tested at indicated airspeeds of 210, 265, 315, and 375 miles per hour with the flaps and gear up and the center of gravity at 25.1 percent of the mean aerodynamic chord. The dynamic stability was not investigated at maximum limit diving speed (V_l = 468 mph) as suggested by reference 1. Tests were made by abruptly deflecting and releasing the elevator in both directions. Typical time histories, one of a pull-up and one of a push-down, are shown in figure 8.

Results showed that the stick-free longitudinal short-period oscillations always damped out completely in less than two cycles as required by reference 1.

(2-A) Static Longitudinal Stability:

The static longitudinal stability was measured with the center of gravity at 25.1 and 30.2 percent mean aerodynamic chord with flaps and gear up. Extension of the landing gear resulted in a forward shift of the center of gravity of 0.6 percent mean aerodynamic chord. Gross weights at take-off corresponding to these center-of-gravity locations were 7800 pounds for the forward position and 7600 pounds for the rearward position. The effect of fuel consumption on center-of-gravity location was found to be very small and, hence, was neglected. For purposes of analysis, average weights during a flight were assumed as 7620 and 7420 pounds for the forward and rearward center-of-gravity positions, respectively. Conditions in which the airplane was tested and figures that show the data obtained for both center-of-gravity positions are listed in table I.

TABLE I

Airplane Conditions for P-39D-1 Static Longitudinal Stability Tests

Condition	Flaps	Gear	Power	Trim speed	Figure No.
A. Maximum level-flight speed	Up	Up	100 percent rated (2600 rpm, 37.2 in. Hg at 10,000 ft)	Speed for level flight	9
B. Climbing	Up	Up	100 percent rated (2600 rpm, 37.2 in. Hg at 10,000 ft)	Approximate speed for best rate of climb	10
C. Cruising	Up	Up	75 percent rated (2500 rpm, 31 in. Hg at 10,000 ft)	Speed for level flight	11
D. Cruising maximum range	Up	Up	Power for maximum range (1600 rpm, 26 in. Hg at 9000 ft)	Speed for level flight	12
E. Gliding	Up	Up	Engine idling	Same tab setting as in condition A.	13
F. Landing approach	Down	Down	Power for level flight at V_i = 130 mph	V_i = 130 mph	14
G. Landing	Down	Down	Engine idling	V_i = 130 mph	15
H. Wave-off	Down	Down	100 percent rated (2600 rpm, 37.2 in. Hg)	Same tab setting as in condition G	16

In addition to figures 9 through 16, which show stability in the form of elevator angles and stick forces required for trim at various indicated airspeeds as well as corresponding directional trim characteristics where available, figure 17 presents an analysis of the static longitudinal stability. In obtaining figure 17, elevator angles (δ_e) and elevator stick forces divided by impact pressure (F/q_c) were first plotted against lift coefficient (C_L). The slopes of the resulting curves were then measured and plotted against center-of-gravity position as shown in figure 17. The slopes of these curves were measured at two lift coefficients for each airplane condition. These lift coefficients were $C_L = 0.3$ and the C_L at trim for the flap-up, gear-up conditions and $C_L = 1.2$ and the C_L at trim for the flap-down, gear-down conditions. In figure 17, the stick-fixed neutral points are the center-of-gravity positions at which $(d\delta_e/dC_L)$ is zero; similarly, the stick-free neutral points are the center-of-gravity positions at which $d/dC_L\ (F/q_c)$ is zero.

Several points of interest are apparent from an examination of the figures. Figures 9 through 16 and figure 17 show that in the high-speed range a rapid increase in stick-free stability is experienced with increasing speed. Possible explanations for this characteristic include elevator fabric bulging and distortion of the horizontal tail plane. In the low-speed range, where the stability characteristics were nearly linear and, hence, were better defined, the data for the flap-up, gear-up conditions show that the loss in stability due to freeing the elevator is a shift in the neutral point of about 3 percent mean aerodynamic chord. The loss in stability due to freeing the elevator with flaps and gear down is more difficult to determine because of the small variations in stick force experienced.

The requirements of reference 1 state that, for a definite speed range, depending on the airplane condition, the curve of elevator angle against speed must have a stable slope and the curve of elevator stick force against speed must cross zero only once and then with a stable slope - this being with the most rearward permissible center-of-gravity position. The most rearward center-of-gravity position tested was 0.3 percent mean aerodynamic chord forward of the most rearward permissible position (31.0 percent mean aerodynamic chord) listed in Army Air Forces Technical

Order No. 01-110FE-14. When the data of figures 10 to 15 (conditions covered in reference 1) for the center-of-gravity position of 30.2 percent mean aerodynamic chord are compared with the requirements, the following conclusions may be drawn: (Note: In conditions where stick forces were never zero, resort was made to figure 17 for determination of the stick-free stability.)

1. Climbing condition (fig. 10)

The airplane was stable both stick-fixed and stick-free from 90 to 120 percent of the speed for best rate of climb (V_i ≈ 160 mph) in compliance with the requirement.

2. Cruising condition (fig. 11)

The airplane was stable both stick-fixed and stick-free at all speeds tested down to the speed for best rate of climb. The data indicate that the stability would continue to be positive through maximum permissible diving speed (V_i = 468 mph), thus satisfying the requirement.

3. Cruising maximum range (fig. 12)

The airplane was stable stick-fixed but slightly unstable stick-free between the speed for best rate of climb and the stalling speed. Hence, the requirement was met with the stick fixed but not with the stick free.

4. Gliding or diving (fig. 13)

The airplane was stable both stick-fixed and stick-free from maximum level-flight speed to the highest speed tested. It appears that the stability would be positive through maximum permissible diving speed (V_i = 468 mph), thus complying with the requirement.

5. Landing-approach condition (fig. 14)

The airplane was stable stick-fixed but unstable stick-free at all permissible speeds down to 120 percent of the stalling speed. The requirement was therefore met with the stick fixed but not with the stick free.

6. Landing condition (fig. 15)

The airplane was stable both stick-fixed and stick-free at all permissible speeds down to the stalling speed in compliance with the requirement.

Two airplane conditions not included in reference 4 were also investigated. These were the maximum level-flight speed and the wave-off conditions. Results of these investigations are shown in figures 9, 16, and 17.

(3-A) Longitudinal Control:

1. Elevator-control characteristics in turning flight

The elevator-control characteristics in turning flight were investigated in the flap-down, gear-down, power-off condition and the flap-up, gear-up condition with normal rated power. Turns were made by the so-called "wind-up" procedure in which a chosen normal acceleration (shown by an indicating accelerometer) is quickly reached and held constant while the speed is decreased slowly until the stall occurs. The power-off landing-condition turns were entered from trim at V_i = 150 miles per hour and the rated-power clean condition turns were entered from trim in high-speed level flight ($V_i \approx 280$ mph). Data for the landing condition were analyzed only to obtain the elevator angles required to stall the airplane. Data for the clean condition are shown in figures 18, 19, and 20. Figure 18 shows the elevator angles required to trim in turns as a function of lift coefficient for the two center-of-gravity positions tested. Figure 19 shows the variation of change in stick force with change in normal acceleration for the two center-of-gravity positions tested. Figure 20 gives a summary of these characteristics by showing the variation of the maneuverability criteria with center-of-gravity position. The figure also shows how the measured values compare with the limits specified by reference 1

The elevator control characteristics in turning flight may be summarized as follows:

(a) The fact that only 12.5° up elevator was required to stall the airplane at various speeds during turns within the permissible speed range with flaps and gear down, power off, with the center of gravity at

24.0 percent mean aerodynamic chord, indicates that the elevator control is sufficient to attain the maximum lift coefficient at all speeds with the most forward permissible center-of-gravity position (23.0 percent mean aerodynamic chord). In the clean condition, the requirement was even more easily met as is indicated by figure 18.

(b) With the airplane in the clean, rated-power condition, balanced at the normal center-of-gravity position (30.2 percent mean aerodynamic chord), the stick movement required to change from a C_L of 0.2 to $C_{L_{max}}$ (approximately 1.4) during turns was only 1.0 inch. (See fig. 20.) With the center of gravity at 23 percent mean aerodynamic chord, the stick movement was 2.7 inches.

(c) The change in normal acceleration was approximately proportional to the change in elevator stick force as recommended by reference 1. (See fig. 19.)

(d) By extrapolating the data of figure 19 to an 8g turn, the elevator stick force per unit normal acceleration with the normal center-of-gravity position (30.2 percent mean aerodynamic chord) was about 1.8 pounds per g as compared to the minimum requirement of 3 pounds per g. (See fig. 20.)

2. Elevator-control characteristics in landing

Elevator-control characteristics in landing were investigated by making several flap-down, power-off landings at each of several center-of-gravity positions. In these landings, the airplane was held off the ground as long as possible by use of the elevator control. Data are presented only for cases in which the airplane attitude at impact was very close to that of the stall. The elevator angles measured at ground contact are plotted as a function of center-of-gravity position in figure 21.

Reference 1 requires that the elevator be capable of holding the airplane off the ground at 105 percent of the stalling speed with the center of gravity at its most forward position. Figure 21 shows that this requirement is easily met by the P-39D-1 airplane.

Elevator stick forces at landing were desirably small, these forces ranging from 3 to 7 pounds in all landings made (pilot's elevator tab control set 4 graduations nose up).

3. Elevator-control characteristics in take-off

Elevator control in take-off was investigated by holding the elevator in its full-up position and determining the speed at which the nose wheel rose from the runway for center-of-gravity positions of 24.3 and 29.4 percent mean aerodynamic chord.

The speeds at which the nose wheel rose were so small that accurate determination of them was difficult. However, it is known that these speeds never exceeded 50 miles per hour; and, on the basis of the data obtained, it is certain that the nose wheel can be raised with the most forward center-of-gravity position (23.0 percent mean aerodynamic chord) at a speed well under the maximum speed ($V_i = 70$ mph) allowed by reference 1.

4. Longitudinal-trimming-control characteristics

The effectiveness of the elevator trim tab was determined by making static longitudinal stability runs with the elevator tab at its extreme positions for three airplane conditions with one center-of-gravity position. Results from these tests are presented in figure 22, where the stick force per degree tab deflection is plotted as a function of indicated airspeed. Direct tests were not made to determine speed ranges in which the elevator stick force could be entirely trimmed out; so the capabilities of the elevator tab were determined from tab-effectiveness data (fig. 22), static-stability data (figs. 12, 13, and 15), and the indicator-tab relation (fig. 5(b)). The capabilities of the elevator trim tab compare with the requirements of reference 1 as follows:

(a) With flaps up, gear up, power for level flight, and center of gravity at the most forward or rearward position, the elevator stick force can be trimmed to zero at any speed between high level-flight speed and 120 percent of the stalling speed.

(b) With flaps and gear up, power off, and the center of gravity at the most forward or rearward position, the elevator force can be trimmed to zero at all speeds between high level-flight speed and the maximum permissible diving speed (from extrapolated data).

(c) With flaps and gear down, power off, and the center of gravity at its most forward position the minimum speed at which the elevator force can be trimmed to zero is not higher than 140 percent of the stalling speed.

The changes in stick force required to trim at 140 percent of the flap-down, gear-down, power-off stalling speed ($1.4\ V_{i_s} = 125$ mph) with changes in flap setting, gear setting, and power are shown below:

Flaps	Gear	Power	Elevator stick force required for trim, lb
Up	Up	Normal rated	0
Up	Up	Off	1 pull
Down	Down	Normal rated	3 pull
Down	Up	Normal rated	1 pull
Down	Down	Off	2.5 pull

It is immediately apparent that these desirably small trim changes are far below the maximum allowable force change of 35 pounds given in reference 1.

The elevator trim tab would retain any given setting indefinitely as is required.

5. Pitching moment due to sideslip

The pitching moment due to sideslip was such that more than 1° up-elevator movement was required to trim when the rudder was moved to 5° right from its straight-flight position corresponding to zero angle of bank with rated power, either flaps up or flaps down. For all other conditions, less than 1° elevator was required for 5° rudder deflection. The data for these determinations were obtained during tests of the static lateral and directional stability and may be seen in the figures for this item (figs. 25 through 36).

No tests were made to determine the pitching moment due to sideslip at 95 percent of the maximum permissible diving speed. At the highest speed at which sideslips were made, however (V_i = 330 mph), a pull stick force of 14 pounds was required to offset the pitching moment due to the sideslip caused by a left rudder force of 180 pounds. (See fig. 29.) It appears that a much higher pull stick force would be required to maintain longitudinal trim with a right rudder force of 180 pounds at the same speed because of the unsymmetrical rudder-force characteristics.

B. Lateral and Directional Stability and Control

(1-B) Dynamic Lateral and Directional Stability

a. Spiral mode

The P-39D-1 airplane was somewhat unstable in the spiral mode as is the case with most airplanes. No specific tests were made to determine the degree of spiral instability, but, according to pilot's opinion, the spiral divergence was mild in straight flight at the speed for maximum L/D at design gross weight. On this basis, the requirement of reference 1 is satisfied.

b. Short-period oscillation

The short-period control-free lateral and directional oscillation was investigated with flaps and gear up, using power for level flight or rated power in dives at speeds differing successively by about 50 miles per hour through the range V_i = 150 to V_i = 380 miles per hour. At each speed, disturbances were initiated by abruptly deflecting and releasing the rudder and ailerons separately. Typical time histories of airplane and control motion during and after these disturbances are shown in figure 33 for the lowest and highest speeds at which tests were made. When the lateral and directional oscillation characteristics of the P-39D-1 airplane are compared with the requirements for damping given in reference 1, pertinent results are:

1. The lateral oscillation always damped to less than one-half amplitude in two cycles at all speeds between that for maximum L/D and the highest speed tested (V_i = 380 mph). The average time to damp to one-half amplitude was approximately one cycle, no consistent variation of this value with indicated airspeed being noted.

2. The oscillations of both the rudder and the ailerons were completely damped within one cycle. The rudder always returned to its trim position but the ailerons did not. Aileron overbalance throughout the level-flight speed range and the control-system friction of about 2 pounds were responsible for this unsatisfactory characteristic. Figure 23 clearly shows that the ailerons remained in a deflected state after release at V_i = 154 miles per hour.

(2-B) Static Lateral and Directional Stability

1. Yawing moment due to sideslip

The yawing moment due to sideslip with rudder fixed was investigated by making full-deflection aileron rolls while holding the rudder in its trim position and noting the maximum angles of adverse yaw resulting from rolling. Both the clean and the landing conditions of flight were investigated with power off and power for level flight at speeds about 20 percent greater than the respective power-off stalling speeds. Data from these maneuvers are shown as time histories in figure 24. Significant results are:

(a) The maximum adverse yaw angles resulting from use of full aileron control always were, or were estimated to be, less than the 20° maximum allowed by reference 1.

(b) The decrease in rolling velocity from its maximum, due to yaw caused by rolling, was desirably small.

The yawing moment due to sideslip, as indicated by the variation of rudder angle with sideslip angle in essentially steady sideslips, was investigated at various speeds in four different airplane configurations instead of the three test conditions specified in reference 1.

All sideslips were made according to the following procedure. From a trimmed condition in straight laterally level flight at a chosen indicated airspeed, rudder was slowly applied in coordination with the amount of aileron and elevator control necessary to maintain a straight flight path and approximately constant indicated airspeed. The rate of yawing was restricted to about 1° per second or less in all runs. Data were evaluated at 2-second intervals from synchronized records of control positions, control forces, bank angle, sideslip angle, and indicated airspeed. Particular airplane conditions and speeds chosen for testing together with figures showing the data obtained are listed in table II.

TABLE II

Conditions for P-39D-1 Sideslip Tests

Condition	Flaps	Gear	Power	Indicated airspeed (mph)	Figure number
Clean	Up	Up	Normal rated	110	25
			(2600 rpm, 37.2 in. Hg.)	155	26
				210	27
				255	28
				330	29
Clean	Up	Up	Off	110	30
				150	31
				205	32
Landing	Down	Down	Normal rated	115	33
			(2600 rpm, 37.2 in. Hg.)	140	34
Landing	Down	Down	Off	115	35
				140	36

The data of figures 25 through 36 have been summarized in figure 37 which shows, quantitatively, the variation of static lateral and directional stability with power, flap deflection, and indicated airspeed, the items shown being measured at straight flight trim with zero angle of bank.

The yawing moment due to sideslip, as measured by the variation of rudder angle with sideslip angle, was always in the correct direction except at the lowest speed tested (V_i = 110 mph) in the clean condition, either with rated power or power off. In both of these conditions, there was a range of sideslip angles where the rudder-fixed directional stability was neutral (figs. 25 and 30). With the above exceptions, the sideslip angle was always nearly proportional to the change in rudder angle from trim for angles of sideslip between ±15°. In all tests where more than 15° sideslip was reached, an increase in rudder angle always resulted in an increase in the angle of sideslip in the range above 15° of sideslip. Full rudder deflection (35° right, 27.5° left) was never reached during the sideslip tests. Figure 37 shows how the rudder-fixed directional stability at normal straight-flight trim varies with power, flap deflection, and indicated airspeed.

The yawing moment due to sideslip with rudder free, as indicated by the variation of rudder pedal force with sideslip angle at any given speed, was unsatisfactory in the rated-power conditions with flaps up or down at low and moderate speeds. In left sideslips there was no definite force gradient while in right sideslip the pedal force began to lighten at about 15° sideslip. Furthermore, rudder-force reversal either occurred or was imminent in sideslips to either direction at low speeds with rated power (figs. 25, 26, 33, and 34). The force reversals were encountered at fairly large angles of sideslip, however, and the reversing forces were manageable. In the power-off clean condition at V_i = 110 miles per hour, the rudder force gradient was zero in the range of sideslip angles where the rudder-fixed directional stability was neutral (fig. 30). For all other power-off conditions tested, rudder-force characteristics were satisfactory.

2. Rolling moment due to sideslip

The rolling moment due to sideslip (ailerons fixed and free) was measured in the sideslip tests outlined in table II above. Results are shown in figures 25 through 36. The variation of the dihedral effect, as measured at normal straight flight trim, with indicated airspeed is given in figure 37.

The rolling moment due to sideslip (stick-fixed), as measured by the variation of aileron angle with sideslip angle, was always in the correct direction in right sideslips although it became marginal at large angles of sideslip. In certain ranges of left sideslip with rated power at low speeds, flaps up or down, the stick-fixed dihedral effect was neutral or slightly negative (figs. 25, 26, 33, and 34). As shown by figure 37, the stick-fixed dihedral effect at trim for zero bank angle was always in the correct direction. The rolling moment due to sideslip (stick-free), as measured by the variation of aileron stick force with sideslip angle, was in the wrong direction in all test conditions at speeds below about V_i = 200 miles per hour.

The rolling moment due to sideslip resulting from abrupt aileron deflections, rudder fixed, was never so great that a reversal in rolling velocity occurred. This is in accord with the requirements. Data illustrating the effect on rolling velocity of the yaw due to ailerons for critical low-speed flight conditions may be found on figure 24.

3. Side force due to sideslip

The variation of side force with sideslip angle was determined by measuring angles of bank during all the sideslip tests outlined in table II and the results are shown in figures 25 through 36. The effect of power, flaps, and speed on the side force near normal straight-flight trim (zero bank angle) is shown in figure 37.

Reference 1 requires that the side force should always be such that right bank accompanies right sideslip and left bank accompanies left sideslip. The P-39D-1 airplane definitely satisfied the requirements for all flight conditions tested.

(3-B) Static Directional and Lateral Control:

1. Rudder control

The ability of the rudder to overcome the adverse yaw resulting after the ailerons were abruptly moved from trim to their fully deflected position was investigated by making simulated turn entries in which enough rudder control was used to maintain zero sideslip. These tests were made with flaps and gear down using power for level flight at about 120 percent of the power-off stalling speed, and with flaps and gear up using power for level flight at about 120 percent of the power-off stalling speed.

The requirements state that the rudder control should be capable of neutralizing the adverse yaw and that rudder pedal forces necessary to accomplish this should be under 180 pounds. The P-39D-1 airplane complied with these requirements. The adverse yaw could be completely offset by using about half of the available rudder deflection from trim. Corresponding rudder pedal forces were approximately 100 pounds.

The rudder gave sufficient directional control to maintain straight ground paths during normal take-offs and landings with rudder pedal forces much lower than 180 pounds. These characteristics are in direct compliance with those required.

The variation of rudder force required to trim in straight flight with indicated airspeed when the rudder force was initially trimmed to zero at maximum level-flight speed with normal rated power is shown in figure 38. This figure includes the rudder-force variation for the power-off condition with the same trim tab setting. By extrapolating the rated-power curve to maximum permissible diving speed (V_i = 468 mph), it is seen that 60 to 70 pounds push on the left pedal would be required to trim. This is well within the 150-pound maximum allowed by reference 1. When the power was reduced from rated power to power off at high level-flight speed, a left pedal force of about 60 pounds was required to maintain straight flight. The minimum speeds at which the rudder force could be entirely trimmed out in straight laterally level flight using rated power were V_i = 123 miles per hour with flaps and gear up and V_i = 138 miles per hour with flaps and gear down.

The rudder-control characteristics of the P-39D-1 airplane, in general, were considered good.

2. Lateral control

The aileron control characteristics were determined according to the usual NACA procedure. The airplane was trimmed in laterally level steady flight at a chosen power and speed; then the ailerons were abruptly deflected a desired amount while the rudder was held fixed in its trim position. Data were evaluated on the basis of the maximum rolling velocity attained in any given roll and the corresponding aileron stick force.

Preliminary tests at low speeds gave indications that high stick forces would not provide insurance against dangerous aileron deflections at high speeds. Hence, an analysis of the aileron strength was made in order to establish a relation between permissible aileron deflections and indicated airspeed. Figure 39 presents the relation determined in self-explanatory fashion.

Airplane conditions used in the aileron tests are listed by number in table III according to the order in which the results will be discussed. Note that reference is made to the figure presenting the results for each test condition.

TABLE III

Airplane Conditions for Aileron Control Characteristics Tests

Condition number	Power	Flaps	Gear	Indicated airspeed	Figure showing results obtained
1	Level-flight	Down	Down	109	40
2	Level-flight	Down	Down	140	40
3	Level-flight	Up	Up	113	41
4	Level-flight	Up	Up	160	42
5	Level-flight	Up	Up	210	43
6	Level-flight	Up	Up	260	44
7	Normal-rated	Up	Up	310	45
8	Normal-rated	Up	Up	330	46
9	Normal-rated	Up	Up	410	47
10	Off	Down	Down	95	48
11	Off	Down	Down	165	48
12	Off	Up	Down	100	49
13	Off	Up	Down	150	49

The curves obtained by fairing the data collected in the tests made with flaps and gear up (conditions 3 through 9) have been duplicated on a common set of axes in figure 50 to show the effect of speed on aileron characteristics. Figure 51 summarizes the data for the clean condition in the form of aileron angle, rolling velocity at 10,000 feet, and pb/2V available for stick forces of both 30 and 50 pounds plotted against indicated airspeed. At speeds above 210 miles per hour, the summary figure is based on extrapolations of the data given in figure 50 to stick forces of 30 and 50 pounds or to full aileron deflection. These extrapolations were necessary at speeds above V_i = 210 miles per hour because it was usually possible to reach the calculated permissible aileron deflections with stick forces slightly under 30 pounds.

The aileron control characteristics of the P-39D-1 airplane may be summarized as follows:

(a) The maximum rolling velocity obtained from abrupt deflections of the aileron control varied smoothly with and was approximately proportional to aileron deflection from trim in all specified conditions (covered by conditions 1 through 9 in table III). The ailerons were overbalanced in the level-flight speed range, this overbalance covering a progressively smaller percentage of the total aileron travel as the speed increased. (See figs. 49 and 50.) Above maximum level-flight speed ($V_i \approx 280$ mph) the overbalance disappeared entirely and the variation of control force with aileron deflection became satisfactorily smooth.

(b) At approximately 120 percent of the respective power-off stalling speeds with flaps and gear up or down, gradients of aileron control force with deflection were such that the ailerons would tend to increase their deflection if released from an initial position near trim either while making aileron rolls or steady sideslips. Although the friction of about ±2 pounds in the aileron control system tends to make the overbalance less objectionable, the adverse stick forces were commented on by the pilot in these maneuvers. Furthermore, when high normal accelerations were reached during recovery from rolls at $V_i = 210$ miles per hour, the stick tended to whip violently from one side to the other. Whether this was a manifestation of the overbalance accompanying high angles of attack and accentuated by the higher speed or whether the effect resulted from yaw due to rolling is not known.

(c) The time required to reach maximum rolling acceleration after full aileron deflection was reached in the rolls for conditions 1 and 3 was extremely small. It is known that these time increments were much less than the maximum allowable given by reference 1. The variation of rolling acceleration with time was always in the correct direction up to the time of maximum rolling velocity.

(d) With power off, gear down, and flaps either up or down at 110 to 150 percent of the respective power-off stalling speeds, the ailerons were not sufficiently effective to meet the requirements. In these conditions, full aileron deflections to both right and left produced average values of $pb/2V$ of between 0.06 and 0.065 as compared with a specified minimum of 0.07 (data shown in figs. 48 and 49).

With flaps and gear up, the rolling velocity obtained by abrupt full deflection of the ailerons at all speeds between 110 percent of the power-off stalling speed and the speed at which a stick force of 50 pounds would be reached was such that $pb/2V$ was approximately 0.06 as compared with the minimum requirement of 0.09 (fig. 51). The speed at which a stick force of 50 pounds would be required to hold full aileron deflection was about 240 miles per hour indicated airspeed, which is somewhat in excess of 80 percent of maximum level-flight speed.

Aileron effectiveness at speeds approaching the maximum permissible diving speed was not investigated because of structural deformation and bulging of the aileron at speeds in excess of $V_i = 410$ miles per hour. These phenomena are believed responsible for the loss in $pb/2V$ of about 20 percent for a given aileron deflection at this speed. The bulging of the aileron fabric at $V_i = 410$ miles per hour was determined by visual observation from the cockpit.

With flaps and gear down, power off, at 110 percent of the stalling speed, $pb/2V$ for full aileron deflection was such that the product $p \times b$ was equal to about 18 feet per second as compared with a minimum requirement of 10 feet per second.

The aileron trim-force characteristics were determined by trimming the airplane for zero stick force at maximum level-flight speed with normal rated power and then obtaining continuous records of the aileron stick force as the airplane's speed was slowly changed from slightly above that of the stall to $V_i = 410$ miles per hour in laterally level flight. One run was made with rated power and one with power off using the same tab setting. Data from these tests showed that the aileron trim force change with power or speed was negligible (under 2 pounds) for speeds up to $V_i = 400$ miles per hour. At $V_i = 410$ miles per hour, however, a sudden erratic change in trim occurred requiring a left stick force of between 5 and 8 pounds. This phenomenon may have been caused by the distortion of the aileron fabric previously mentioned. Because the trim runs were not extended to cover speeds much in excess of $V_i = 410$ miles per hour, it is not possible to state whether or not the trim force at the highest permissible diving speed ($V_i = 468$ mph) would be under the maximum allowable value of 10 pounds.

3. Rudder and aileron trimming devices

The rudder and aileron trimming devices would retain a given setting indefinitely as required.

C. Stalling Characteristics

The stalling characteristics of the P-39D-1 airplane were investigated for five different airplane configurations with the center of gravity at 25.1 percent mean aerodynamic chord (gear up) at an estimated midflight gross weight of 7650 pounds.

1. Stalls entered from straight flight

Table IV presents the airplane configurations in which stalls entered from straight flight were made. The first four configurations listed are those for which the stalling requirements of reference 1 should be satisfied. All the stalls were approached by causing the speed to drop off slowly while laterally level, straight-flight was maintained by minimum use of the controls. When the first stall break occurred, one of the following three procedures for control manipulation was used, each procedure being used in at least two stalls in each configuration: (1) All three controls were fixed; (2) the rudder was fixed and the ailerons were used in an attempt to control the lateral attitude while the elevator was further raised; or, (3) the ailerons were fixed and the rudder was used in an attempt to control the lateral attitude while the elevator was further raised. A discussion of the straight-flight stalling characteristics follows.

TABLE IV

Airplane Conditions and Results of Straight-Flight Stall Tests

Airplane condition	Flaps	Gear	Power	Average indicated airspeed at stall approached from straight flight (mph)	Average $C_{L_{max}}$ at stall approached from straight flight
Landing	Down	Down	Engine idling	89	1.77
Landing approach	Down	Down	Power for level flight at V_i = 130 mph	79	2.24
Climbing	Up	Up	Normal rated 2600 rpm 37.2 in. Hg	85	1.94
Cruising maximum range	Up	Up	1600 rpm 30 in. Hg	89	1.77
Gliding	Up	Up	Engine idling	102	1.35
Take-off emergency[1]	Up	Down	Engine idling	95	1.55

---

[1] Stalling characteristics not investigated. Tested to determine stalling speed only.

(a) The appearance of the stall was always marked by the simultaneous occurrence of a mild roll in either direction and a downward pitching motion. If immediate action was taken to effect recovery by use of the controls at the first sign of stalling, the airplane still rolled through a certain angle depending on the airplane configuration. The airplane would roll in either direction for any given flight configuration and tuft studies made by the pilot indicated that the small degree of asymmetrical stalling was critically affected by the yaw angle existing at the time stalling occurred. At the stall, the tufts always suddenly reversed direction simultaneously over large varying areas of both wings from the root out to within about 4 feet of the tips. The tips were never observed in a stalled condition. After the initial roll occurred, the airplane would tend to return to laterally level flight with or without use of the controls and then a lateral and pitching oscillation would ensue as the stall progressed to higher normal accelerations and airspeeds.

(b) In every condition tested, the stall developed abruptly. There was no warning of the approaching stall either in the form of buffeting and shaking of the airplane or controls, or in the form of a marked increase in the rearward movement of or force on the control stick. At the stall break, the ailerons floated in such a manner that the stick tended to move in the direction of the initial roll. This action occurred too late to constitute a warning, however. The movements of the controls required for trimming during the stall approach were never great enough to be considered important as stall warnings. Figure 52 is a time history of a stall showing the typical absence of warning and ensuing motions of the airplane when the controls were fixed at the stall break.

(c) In any condition, at any time after the stall occurred, recovery could be effected promptly by applying down elevator. The ailerons were relatively ineffective in controlling the lateral attitude during the stall. If the elevator was held fixed or raised to a greater angle, the airplane would ultimately roll against full aileron control. The rudder appeared to be slightly more effective than the ailerons. However, use of the rudder generally resulted in extreme oscillatory rolling velocity and sideslip variations. An example of the large amplitude oscillations occurring in a rudder-controlled stall is shown in figure 53.

(d) The rolling and yawing moments due to stalling in landings were investigated by performing fully stalled landings. Uncontrollable yawing moments were not experienced during stalled landings, but the rolling motion was objectionable.

2. Stalls entered from turning flight

Stalls from turning flight were made with the airplane in each of the first five configurations given in table IV. For the flap-down configurations, the turns were entered from trim at an indicated speed of about 150 miles per hour. For the flap-up configurations, the corresponding trim speed was about V_i = 230 miles per hour. After instability due to stalling was encountered, the effectiveness of all the controls was investigated.

The stalling characteristics in turning flight were very similar to those of straight flight: The stalled turns were characterized by lateral, directional, and pitching oscillations which increased in intensity with increased up-elevator deflection; the ailerons tended to float in the direction of the roll, the adverse stick forces being greater because of the higher speeds; and tuft studies indicated that the flow breakdown occurred in a similar manner to that observed in the stalls entered from straight flight. A time history of a stalled turn made with the airplane in the clean condition using rated power is shown in figure 54.

There was no adequate warning of the approaching stall in any airplane configuration specified in the requirements of reference 1. In the clean condition with engine idling, there was a slight shuddering of the airplane immediately before the stall occurred.

Recovery could always be effected promptly during stalled turns by applying down elevator. The ailerons and rudder were effective in controlling the lateral attitude for some time after the initial stall occurred but continued application of up-elevator soon led to excessive yawing and rolling.

These tests indicate that the airplane does not make a good gun platform at angles of attack very near that of the stall because of the lateral instability which accompanies the stall. Although the stall can occur without complete loss of control, and recovery is positive, the rolling that occurs results in directional changes that would make following a target most difficult.

D. Control Friction

The friction in each of the three control systems was determined by obtaining continuous sychronized records of control position and force as the controls were slowly moved through their deflection ranges. These tests were made under static conditions with the temperature at about 70° F. The friction characteristics of the elevator and aileron controls are presented graphically in figure 55.

When the control friction of the P-39D-1 airplane is compared with the maximum allowable specifications of reference 1, the results may be expressed in tabular form as follows:

Control	Friction at neutral deflection (lb)	Maximum allowable friction at neutral deflection (lb)
Elevator	1.7	2.14
Aileron	2.3	1.07
Rudder	2.0	10.00

CONCLUSIONS

Results from the flying-qualities tests made with the Bell P-39D-1 airplane (A.A.F. No. 41-28378) may be summarized as follows:

A. Longitudinal Stability and Control Characteristics

1. The short-period, control-free longitudinal oscillations damp out completely in less than two cycles in all conditions tested.

2. The center-of-gravity positions (percent mean aerodynamic chord) at which static longitudinal stability is neutral, as determined by tests at two center-of-gravity positions, are as follows.

Airplane condition	C_L	Stick-fixed c.g.	Stick-free c.g.
Maximum level-flight speed	0.2 (trim) .8	33.0 33.8	36.7 30.2
Climbing	0.45 (trim) .8	32.5 32.5	32.0 32.5
75 percent rated power cruising	0.25 (trim) .8	33.2 33.6	33.4 30.2
Cruising maximum range	0.45 (trim) .8	33.0 31.7	30.2 29.0
Gliding	0.2 (trim) .8	35.6 35.6	38.1 31.8
Wave-off	0.75 (trim) 1.2	35.0 34.6	---- ----
Landing approach	0.75 (trim) 1.2	39.8 36.0	27.7 27.2
Landing	0.75 (trim) 1.2	36.0 36.0	34.0 34.0

3. A large increase in stick-free stability is experienced at high speed. It is suspected that this increase in stability is due to bulging of the elevator fabric or deformation of the tail plane.

4. A loss in stability due to freeing the elevator is experienced in all flight conditions at low and moderate speeds. As closely as is determinable from the data obtained this loss amounts to a shift in the neutral point of about 3 percent mean aerodynamic chord.

5. In the clean, rated-power condition, the stick movements required to change the C_L from 0.2 in straight flight to $C_{L_{max}}$ in steady turning flight at about 10,000 feet altitude for the two center-of-gravity positions tested are:

Center-of-gravity position, percent M.A.C.	Rearward stick movement, in. at stick grip
30.2	1.0
25.1	2.2

6. In the clean, rated-power condition, the elevator stick force gradients as measured in steady turning flight at about 10,000 feet altitude for the two center-of-gravity positions tested are:

Center-of-gravity position, percent M.A.C.	Stick-force gradient, (lb/g)
30.2	1.8
25.1	7.1

7. The elevator control is ample for landing and take-off with the center of gravity anywhere in the permissible range.

8. The effectiveness of the longitudinal trimming control is adequate.

9. At V_i = 125 miles per hour the changes in stick force required to trim due to changes in flap, gear, and power are never more than 3 pounds.

10. The elevator trimming device will keep a given setting indefinitely.

11. In the rated-power conditions the pitching moment due to sideslip is such that more than 1° change in elevator angle is required to trim when the sideslip is changed from that for straight, laterally level flight to an angle corresponding to a 5° change to the right in rudder angle. For a left rudder deflection of 5° from the same trim with rated power, and for power-off in either direction, less than 1° change in elevator angle is required to maintain the initial speed.

B. Lateral and Directional Stability and Control

1. The spiral divergence is not objectionable.

2. The control-free, short-period, lateral and directional oscillations damp to one-half amplitude

in less than two cycles in all conditions tested. Oscillations of the controls damp completely within one cycle but the ailerons do not return to trim after being abruptly deflected and released at low speeds.

3. When the ailerons are fully deflected with the rudder held fixed in its trim position at 120 percent of the stalling speed, either in the clean or landing condition of flight, the maximum angle of sideslip developed is less than 20°.

4. The yawing moment due to sideslip is such that the airplane exhibits satisfactory variations of rudder angle with sideslip angle in all conditions tested except in small ranges of sideslip angles near trim in the clean configuration, either with rated power or with power off. Mild rudder-force reversals occur or are imminent in sideslips to either direction at low speeds with rated power, either with flaps up or down.

5. The stick-fixed dihedral effect is neutral to negative in certain ranges of left sideslip angle with rated power at low speeds with flaps either up or down. The stick-free dihedral effect is negative in all flight conditions below an indicated speed of about 200 miles per hour.

6. With rudder fixed, the rolling velocity never reverses due to yaw resulting from full aileron deflection, the reduction in rolling velocity due to this effect being slight.

7. The side force due to sideslip is always in the correct direction.

8. The rudder-control characteristics are satisfactory in all respects for overcoming adverse aileron yaw, for maintaining straight ground paths during take-off and landing runs, and for maintaining straight flight paths with the wings level at any permissible speed in any configuration.

9. Although the response to abrupt application of aileron control is satisfactory, the aileron effectiveness is insufficient in nearly all flight conditions. Full aileron deflection at low speeds produces average values of $pb/2V$ of about 0.06 or 0.065 in any airplane

configuration as compared to desired values of 0.09 and 0.07 for the maneuvering and landing conditions of flight, respectively. At an indicated airspeed of 410 miles per hour, pronounced bulging of the aileron fabric was noted.

10. The ailerons are overbalanced throughout the level-flight speed range; this overbalance covers a progressively smaller percentage of the total deflection range as the speed increases. Above maximum level-flight speed, the overbalance entirely disappears. The speed at which full aileron deflection is accompanied by a stick force of 50 pounds is about 65 percent of the maximum level-flight speed.

11. In straight, laterally level flight, the variation of aileron stick force required to trim with a given tab setting is desirably small up to about 400 miles per hour indicated airspeed. At V_i = 410 miles per hour, however, a sudden increase in stick force of 5 to 8 pounds to the left is required to maintain trim.

12. The rudder and aileron trimming devices retain any given setting indefinitely.

C. Stalling Characteristics

1. The stall always occurs abruptly with essentially no warning whether entered from straight or turning flight.

2. Recovery from a stalled condition can always be promptly effected by the application of down elevator.

3. Uncontrollable yawing motions are not encountered in stalled landings although the rolling is objectionable.

4. The airplane does not constitute a good gun platform in the region of the stall because abrupt rolling occurs when the airplane stalls; this rolling results in directional changes which would make following a target very difficult.

D. Control Friction

Friction in the elevator and rudder control systems is desirably small. The aileron control system friction is about twice as great as the maximum amount considered desirable.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 21, 1943.

APPENDIX

GENERAL SPECIFICATIONS OF AIRPLANE

Name and type	Bell P-39D-1 (A.A.F. No. 41-28378)
Engine	Allison V-1710-35
Rating:	
Take-off	1150 hp at 3000 rpm at sea level
Maximum continuous	1000 hp at 2600 rpm at 10,800 ft
Military	1150 hp at 3000 rpm at 12,000 ft
Supercharger	Single-stage, single-speed
Supercharger gear ratio	8.8:1
Propeller	Curtiss constant-speed
Diameter	10 ft $4\frac{1}{2}$ in.
Number of blades	3
Gear ratio	1.8:1
Fuel capacity (without belly tank), gal.	120
Oil capacity (including 2 gal in gear box), gal.	11.7
Weight empty, lb	5599
Normal gross weight, lb	7847
Permissible c.g. range, percent M.A.C.	23 to 31
Weight as flown for tests (at take-off)	
c.g. at 30.2 percent M.A.C. (gear up),lb	7600
c.g. at 25.1 percent M.A.C. (gear up),lb	7800
Wing loading (normal gross weight),lb/sq ft	36.72
Power loading (normal gross weight, 1000 hp),lb/hp	7.83
Over-all height (taxying position)	9 ft $3\frac{1}{4}$ in.
Over-all length	30 ft 2 in.
Wing:	
Span, ft	34.0
Area (including ailerons and section through fuselage), sq ft	213.2
Airfoil section, root	NACA 0015
Airfoil section, tip	NACA 23009
Aspect ratio	5.42
Mean aerodynamic chord, ft	6.72
Leading edge M.A.C., in. aft L.E. root chord	5.41
Taper ratio	1.97
Dihedral (at 30 percent chord, upper surface)	4°
Incidence from thrust axis	2°

Wing flaps (split, trailing-edge type):	
Area, sq ft	26.20
Span (along hinge line), in.	$83\frac{41}{64}$
Travel, deg	43
Ailerons:	
Length (along hinge line), in.	79.55
Area (aft hinge line, each, including tabs), sq ft	5.91
Fixed balance area (each), sq ft	1.82
Balance tabs, inboard and outboard	
Area (each tab), sq ft	0.473
Span (each tab), in.	22.69
Horizontal tail:	
Span, ft	13
Area, sq ft	40.04
Incidence from thrust axis, deg, L.E. up	$2\frac{1}{4}$
Stabilizer area, sq ft	23.30
Elevator area (aft hinge line, including tab), sq ft	12.49
Elevator balance area, sq ft	3.65
Elevator trim tab area, sq ft	0.319
Distance elevator hinge line to leading edge M.A.C., ft	18.58
Vertical tail:	
Vertical span (along hinge line), ft	5.63
Area, sq ft	19.01
Offset from thrust axis, deg, L.E. left	$1\frac{1}{2}$
Fin area, sq ft	7.94
Rudder area (aft hinge line, including tab), sq ft	9.49
Rudder balance area, sq ft	1.58
Rudder trim tab area, sq ft	0.435
Distance rudder hinge to leading edge, M.A.C., ft	15.92

REFERENCES

1. Anon.: Stability and Control Requirements for U. S. Army Airplanes. Army Air Forces Specification, June 10, 1943.

2. Thompson, F. L., and Zalovcik, John A.: Airspeed Measurements in Flight at High Speeds. NACA A.R.R., Oct. 1942.

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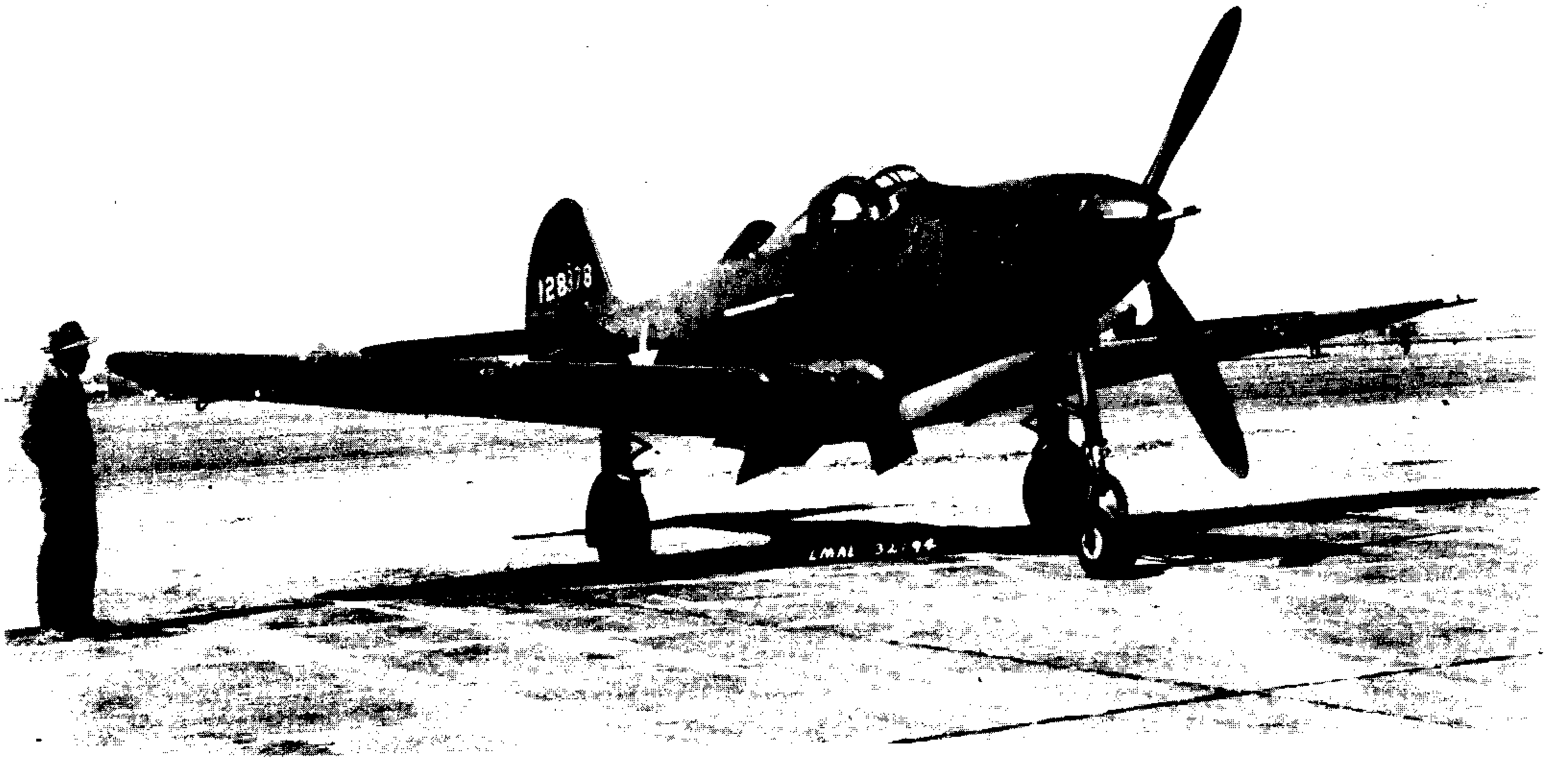

Figure 1.- Three-quarter front view of the Bell P-39D-1 airplane.

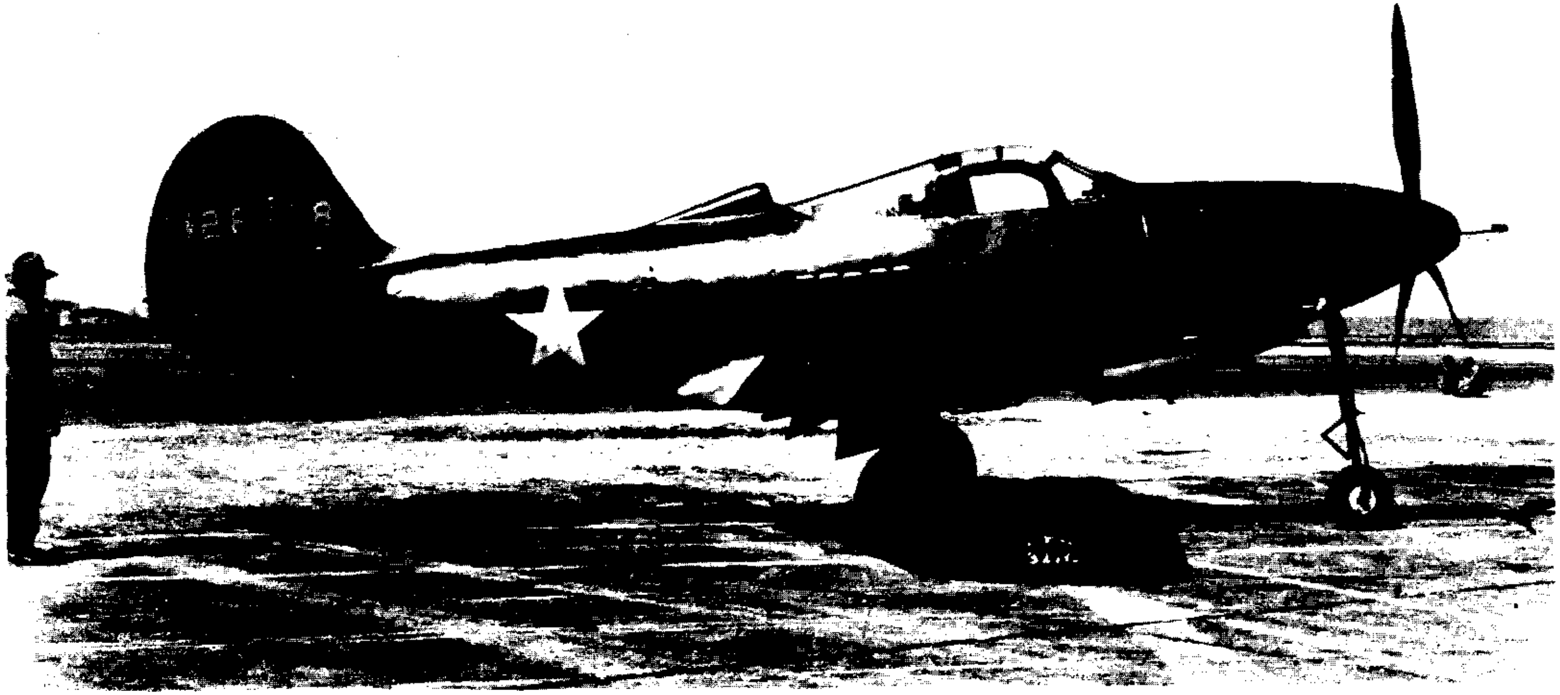

Figure 2.- Side view of the Bell P-39D-1 airplane.

Figure 3.- Three-quarter rear view of the Bell P-39D-1 airplane.

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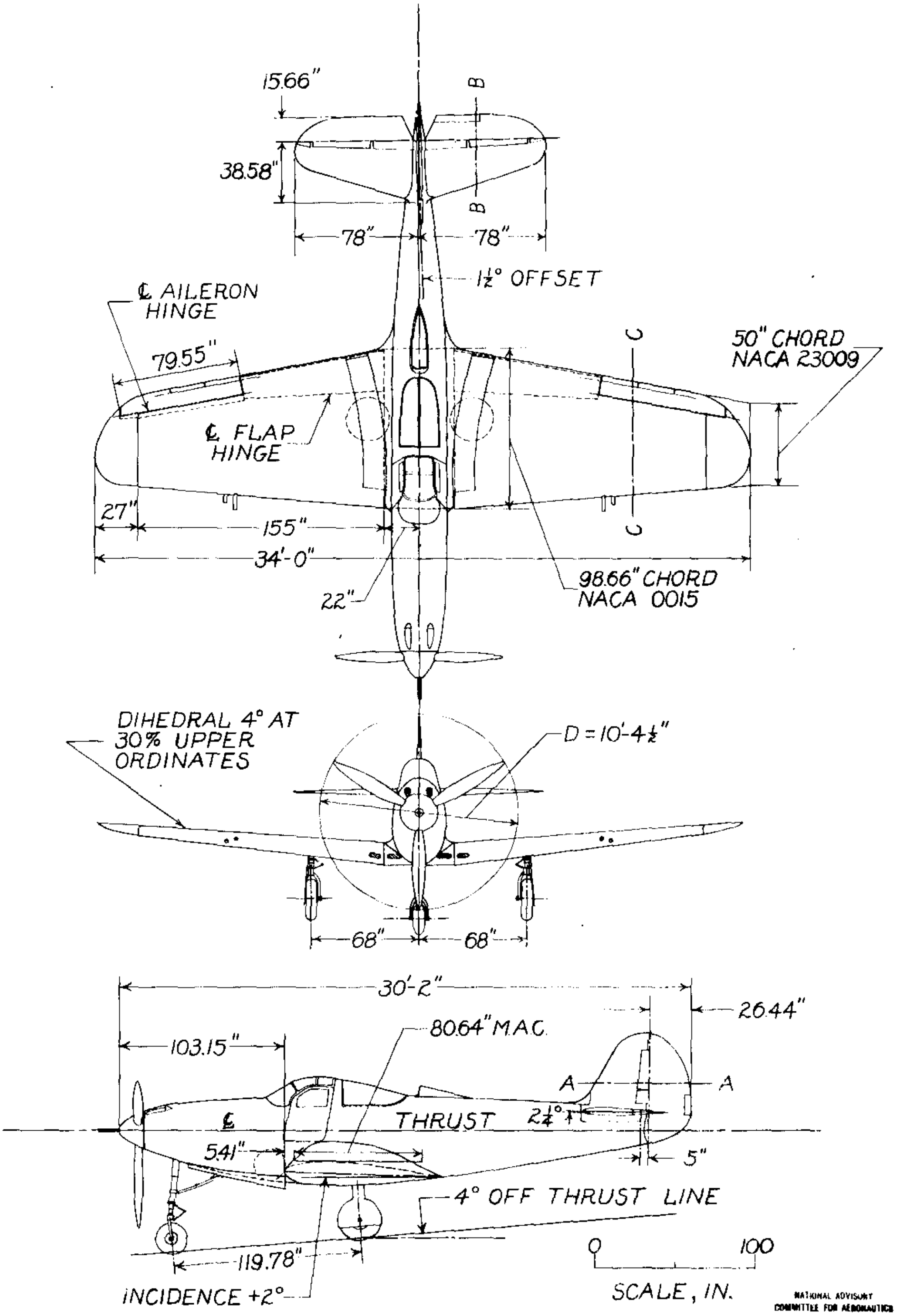

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FIGURE 4.- THREE-VIEW DRAWING OF BELL P-39D-1 AIRPLANE AND CROSS-SECTIONAL OUTLINES OF AERODYNAMIC SURFACES
(A.) THREE-VIEW DRAWING

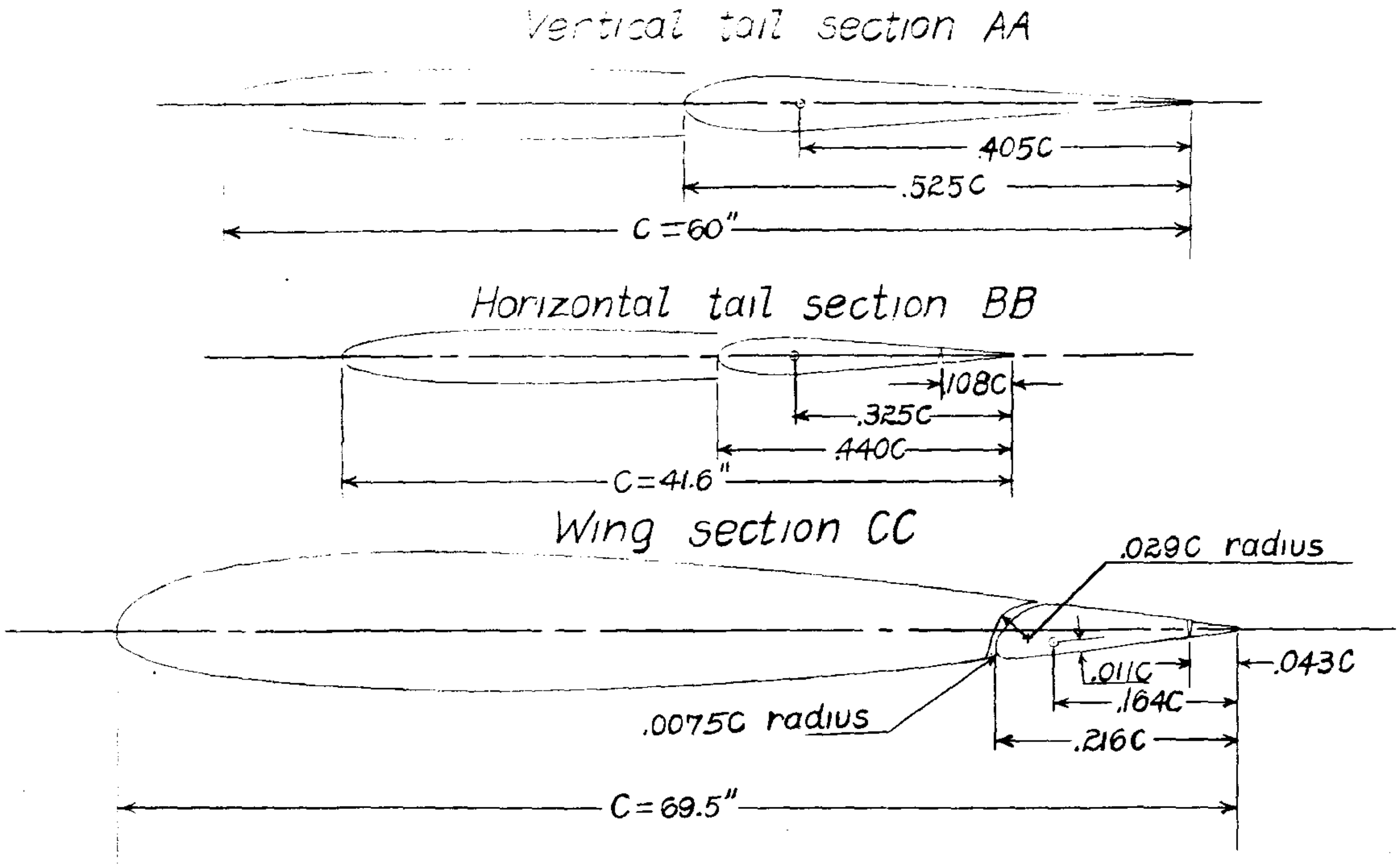

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Figure 4. - Continued.
(b) Cross-sectional outlines.

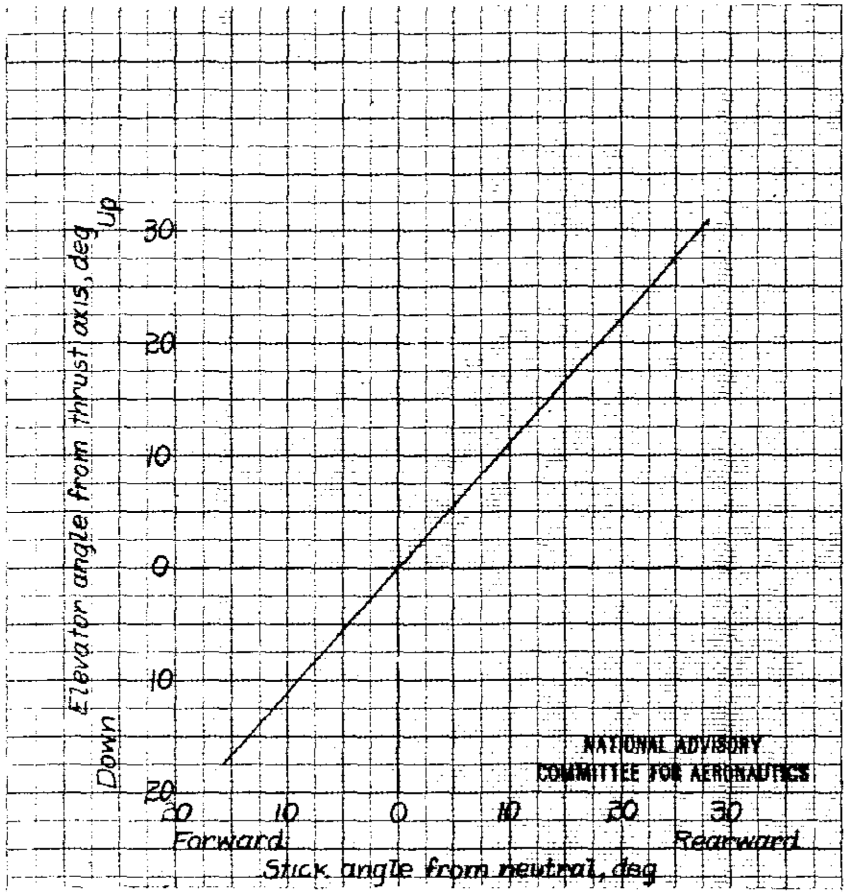

Figure 5(a). - Variation of elevator angle with stick angle for Bell P-39D-1 airplane. Effective stick length = 21-3/4 inches.

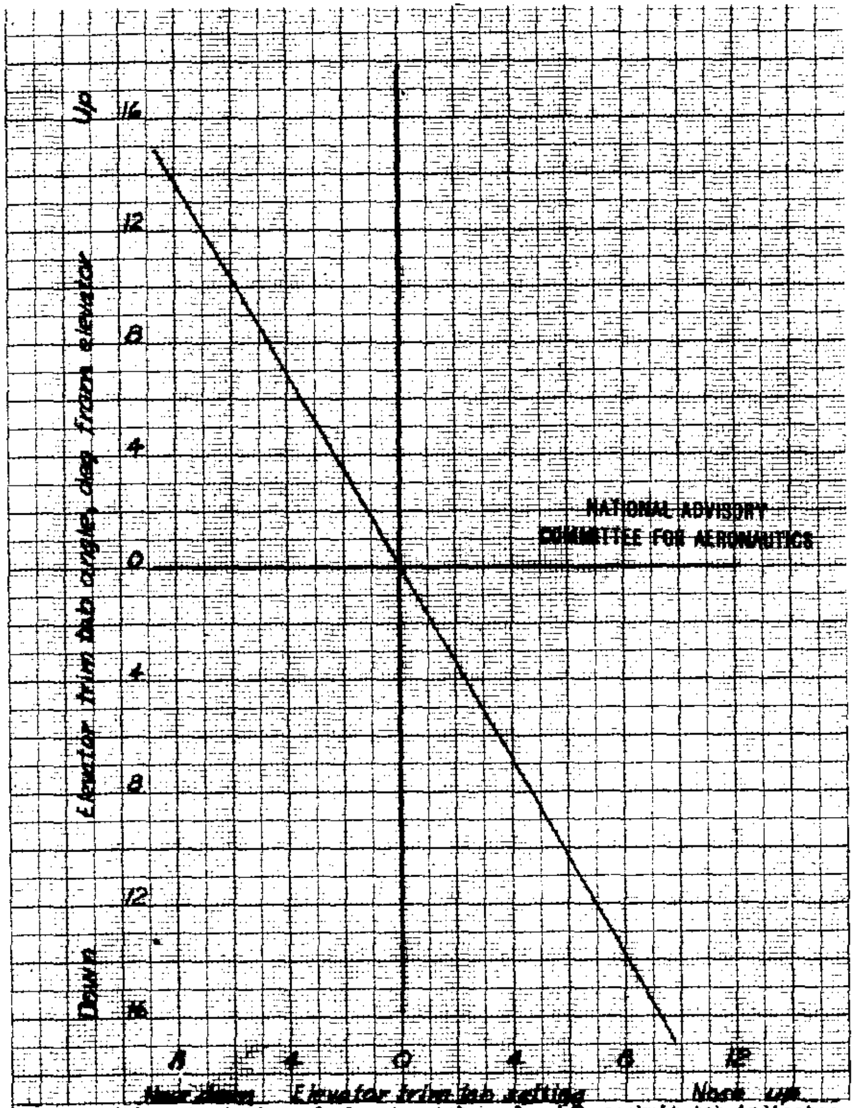

Figure 5(b). - Variation of elevator tab angle with cockpit tab indicator setting. Bell P-39D-1 airplane.

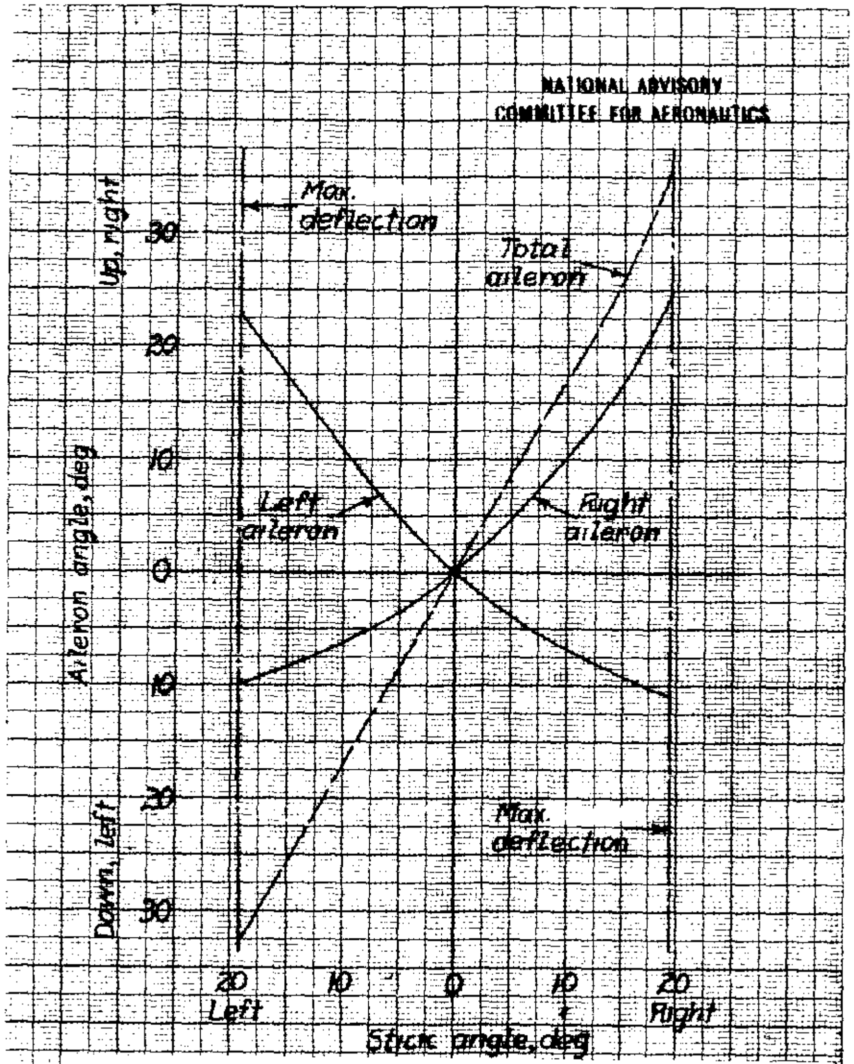

Figure 6(a). - Variation of aileron angle with stick angle under static no-load conditions. Bell P-39D-1 airplane. Effective stick length = 21-3/4 inches.

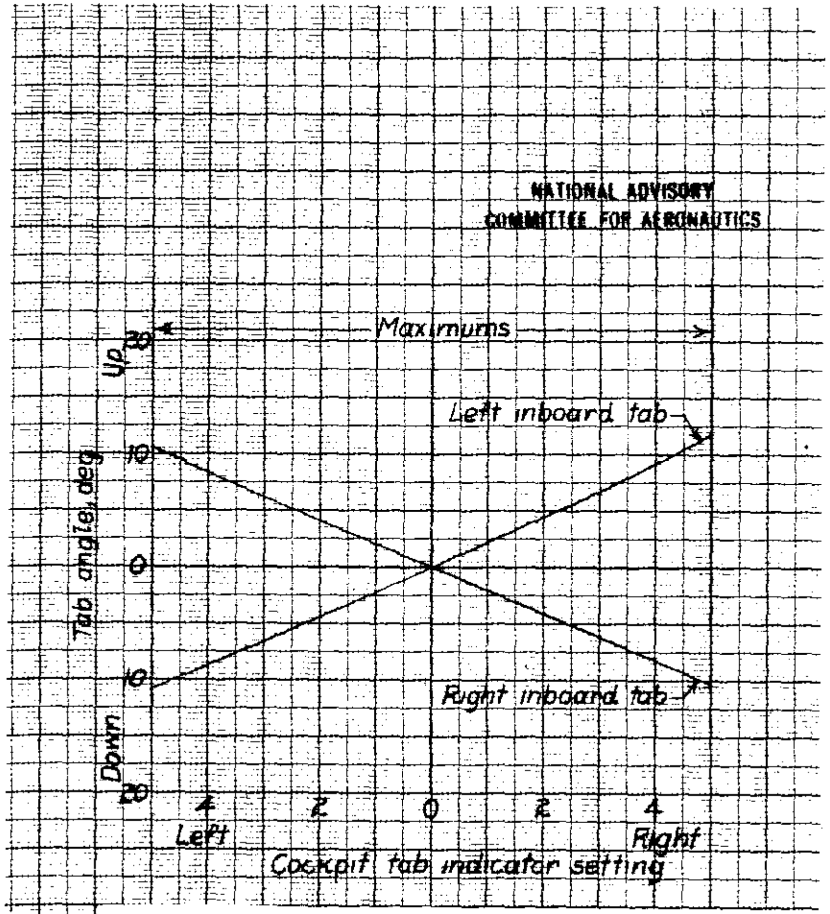

Figure 6(b). - Tab angles from initial position with ailerons neutral versus cockpit trim tab indicator setting. Bell P-39D-1 airplane.

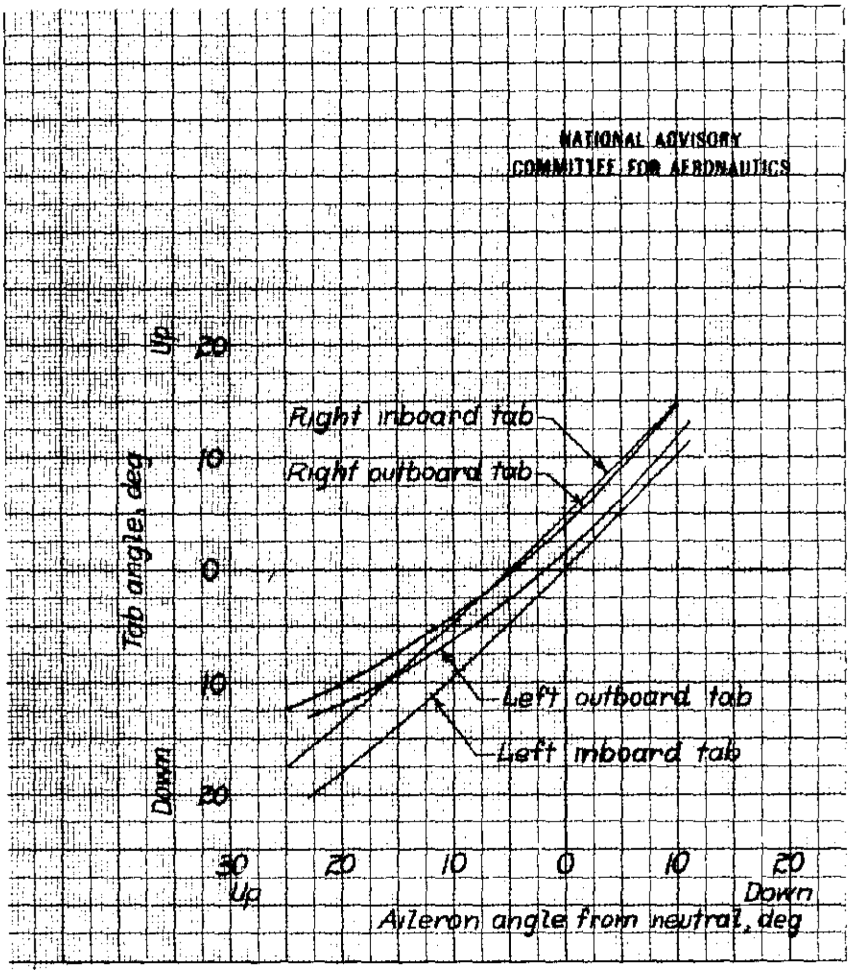

Figure 6(c). - Variation of aileron tab angles with aileron angle. Bell P-39D-1 airplane, cockpit aileron trim tab indicator set at 0.

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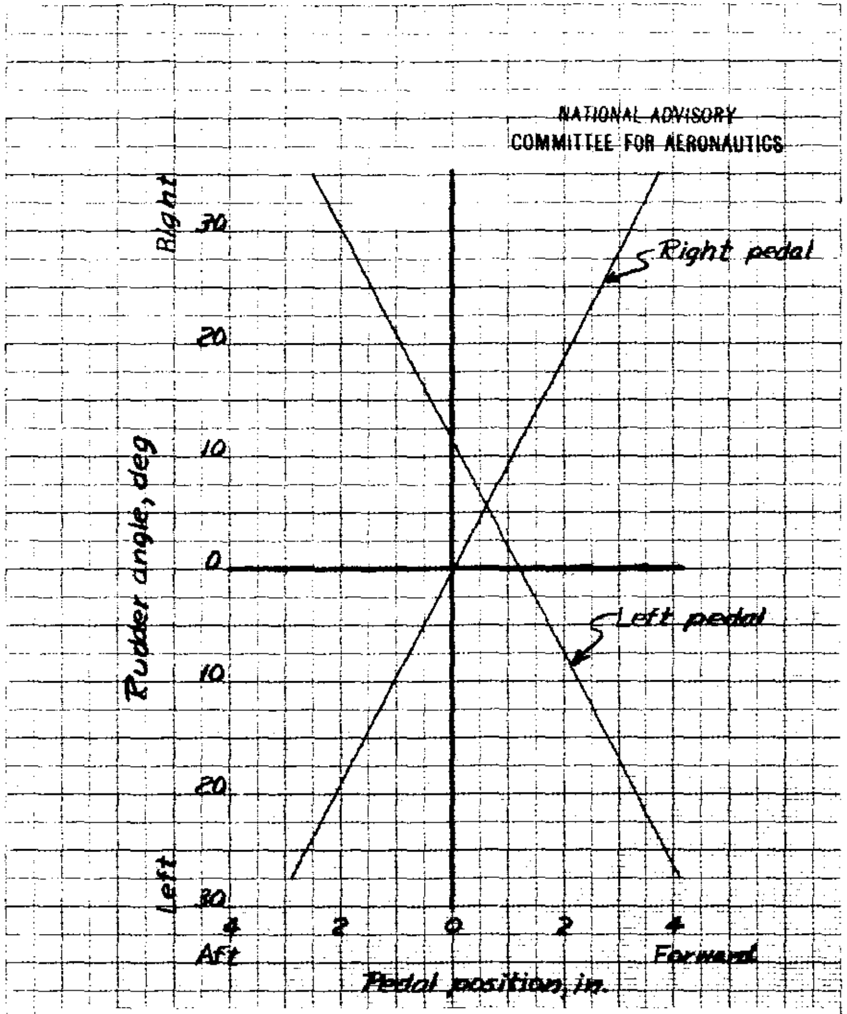


Figure 7(a). - Variation of rudder angle with rudder pedal positions. Bell P-39D-1 airplane.

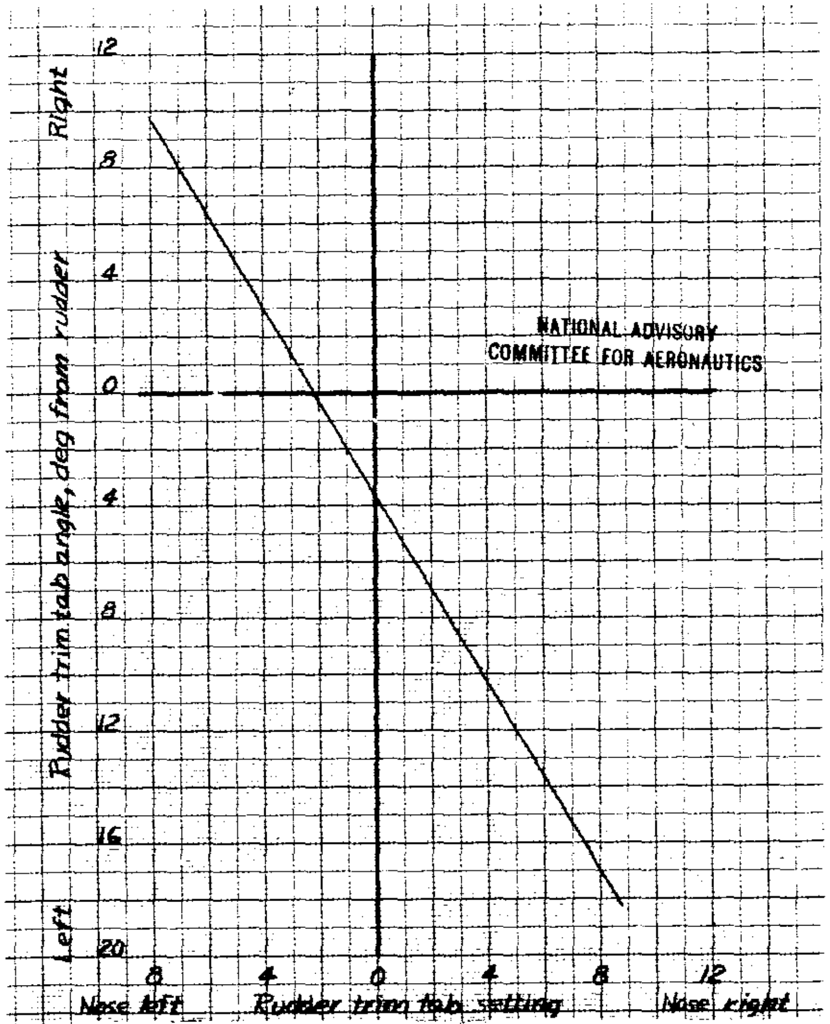


Figure 7(b). - Variation of rudder tab angle with cockpit tab indicator setting. Bell P-39D-1 airplane.

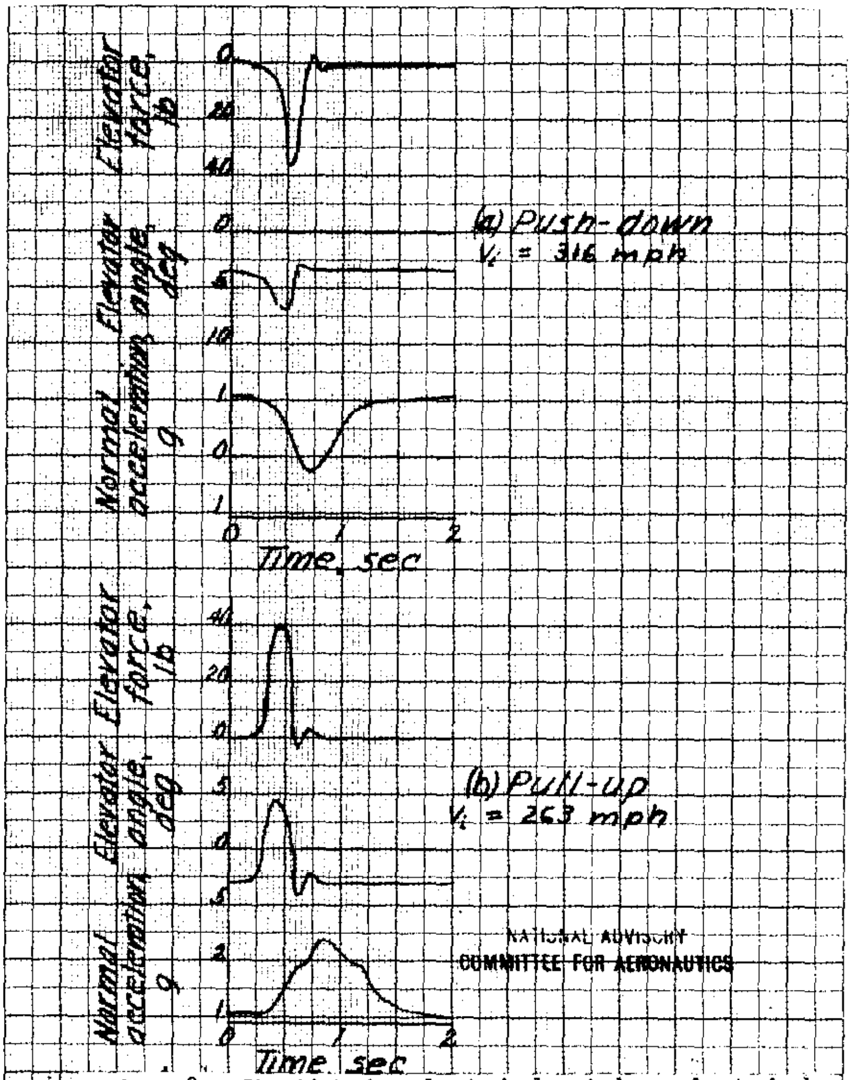
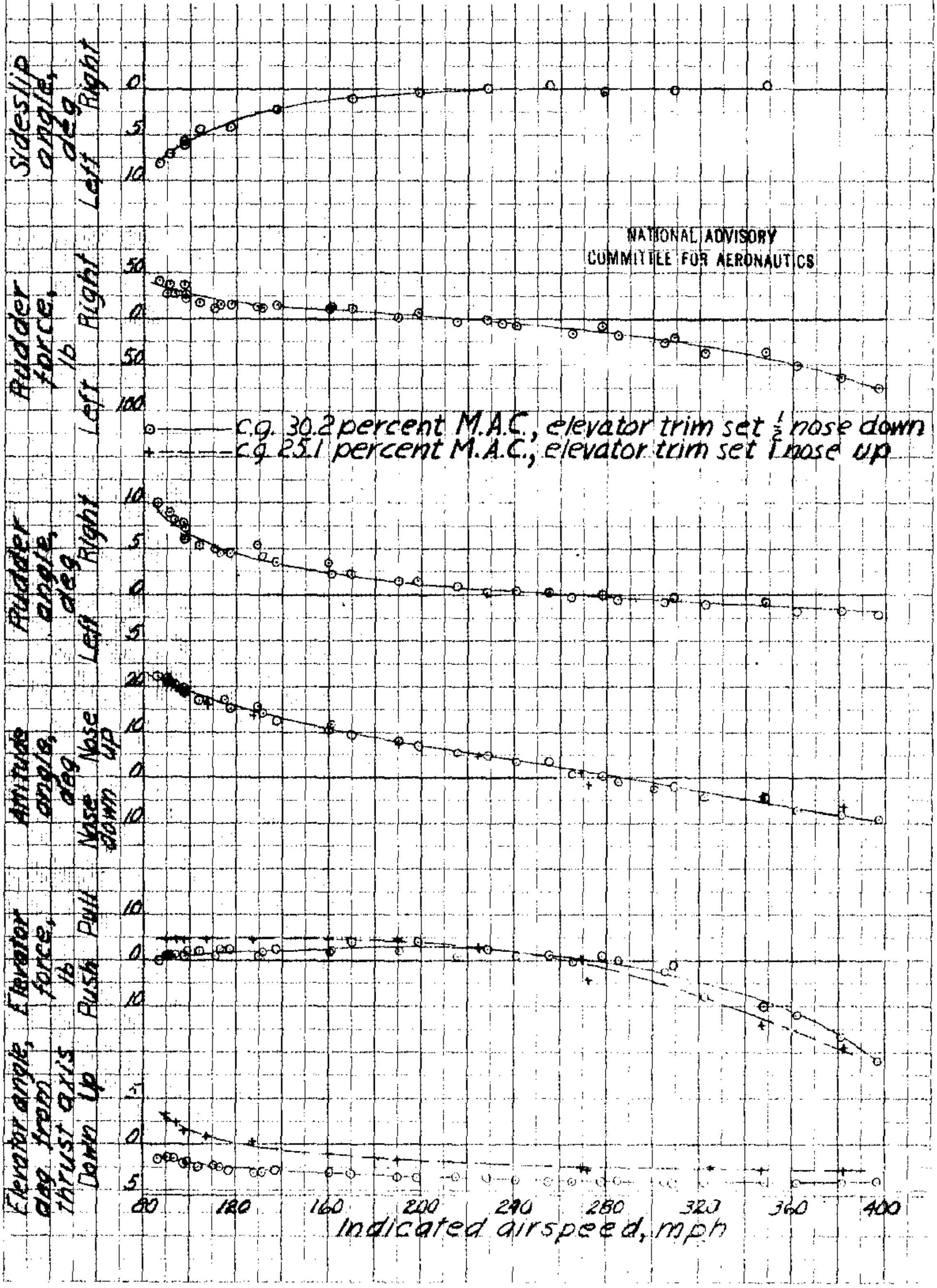


Figure 8. - Time histories of a typical push-down and a typical pull-up showing stick-free dynamic longitudinal stability. Bell P-39D-1 airplane, flaps and gear up, c.g. at 25.1 percent M.A.C.

Figure 9. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Maximum level flight speed condition: rated power (2600 rpm, 37.2 in. Hg at 10,000 feet), forces trimmed to zero at maximum level flight speed, flaps and gear up.



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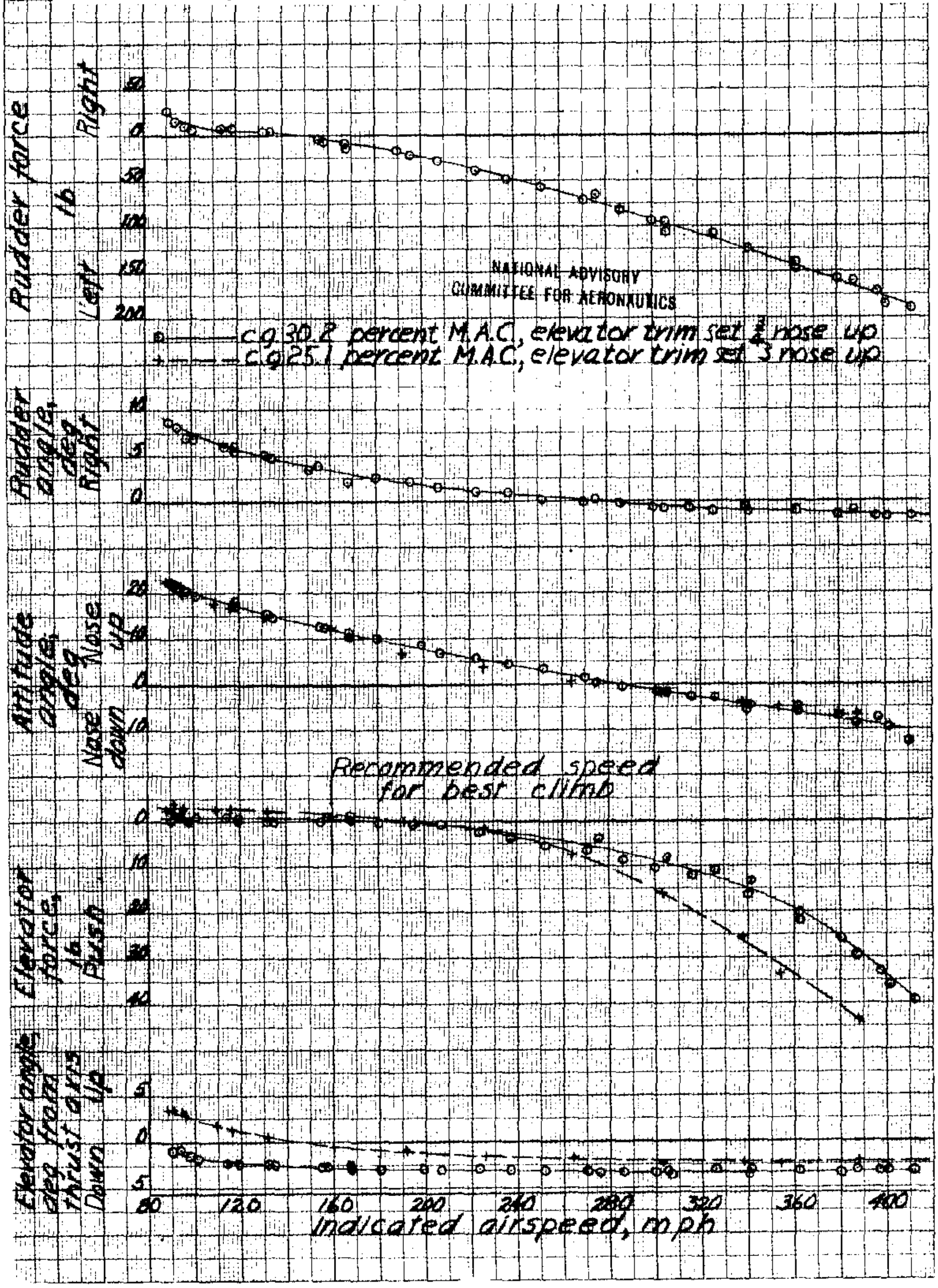

Figure 10. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Climbing conditions: rated power (2600 rpm, 37.2 in. Hg at 10,000 feet), forces trimmed to zero at approximate speed for best climb, flaps and gear up.

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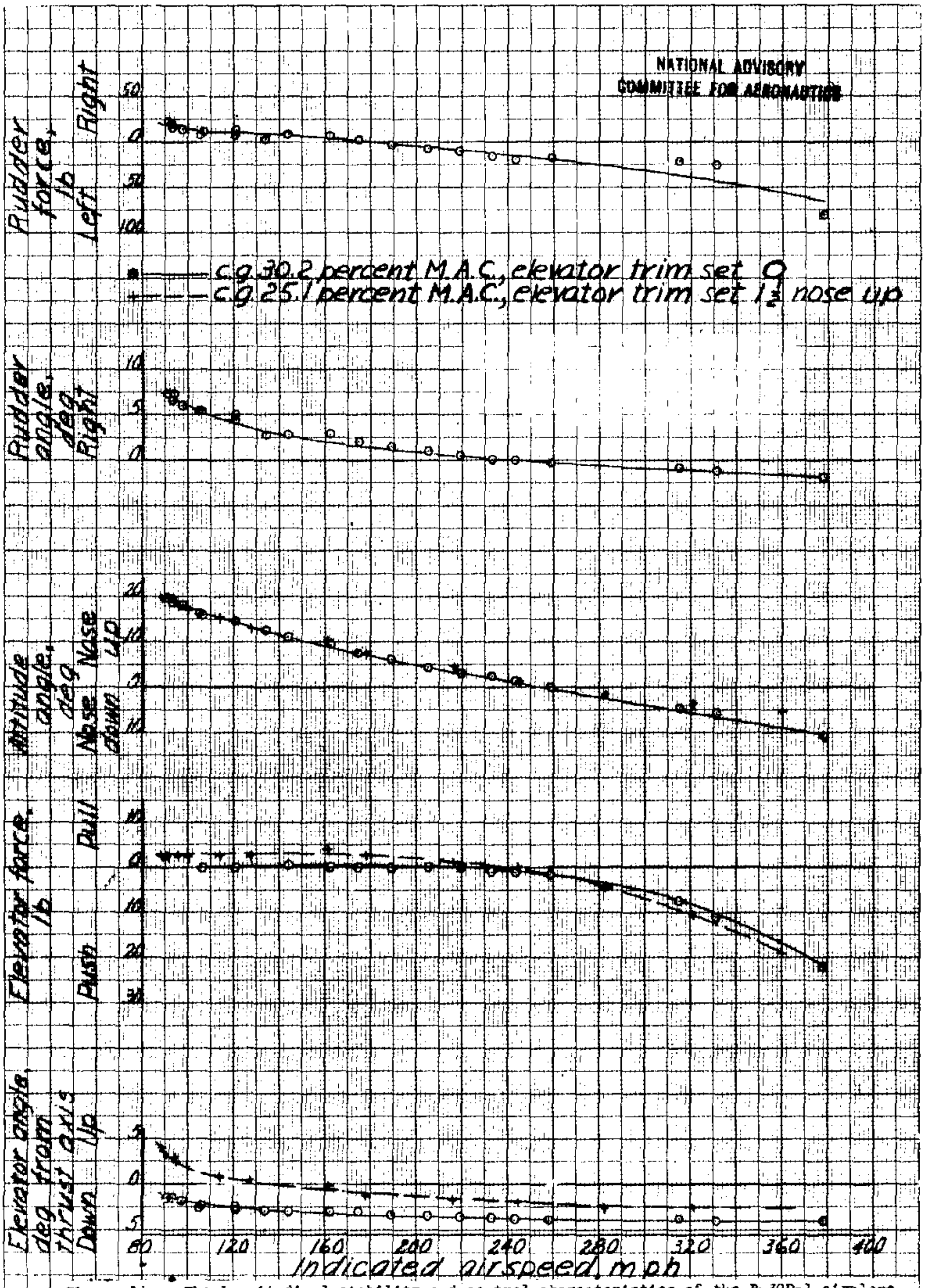
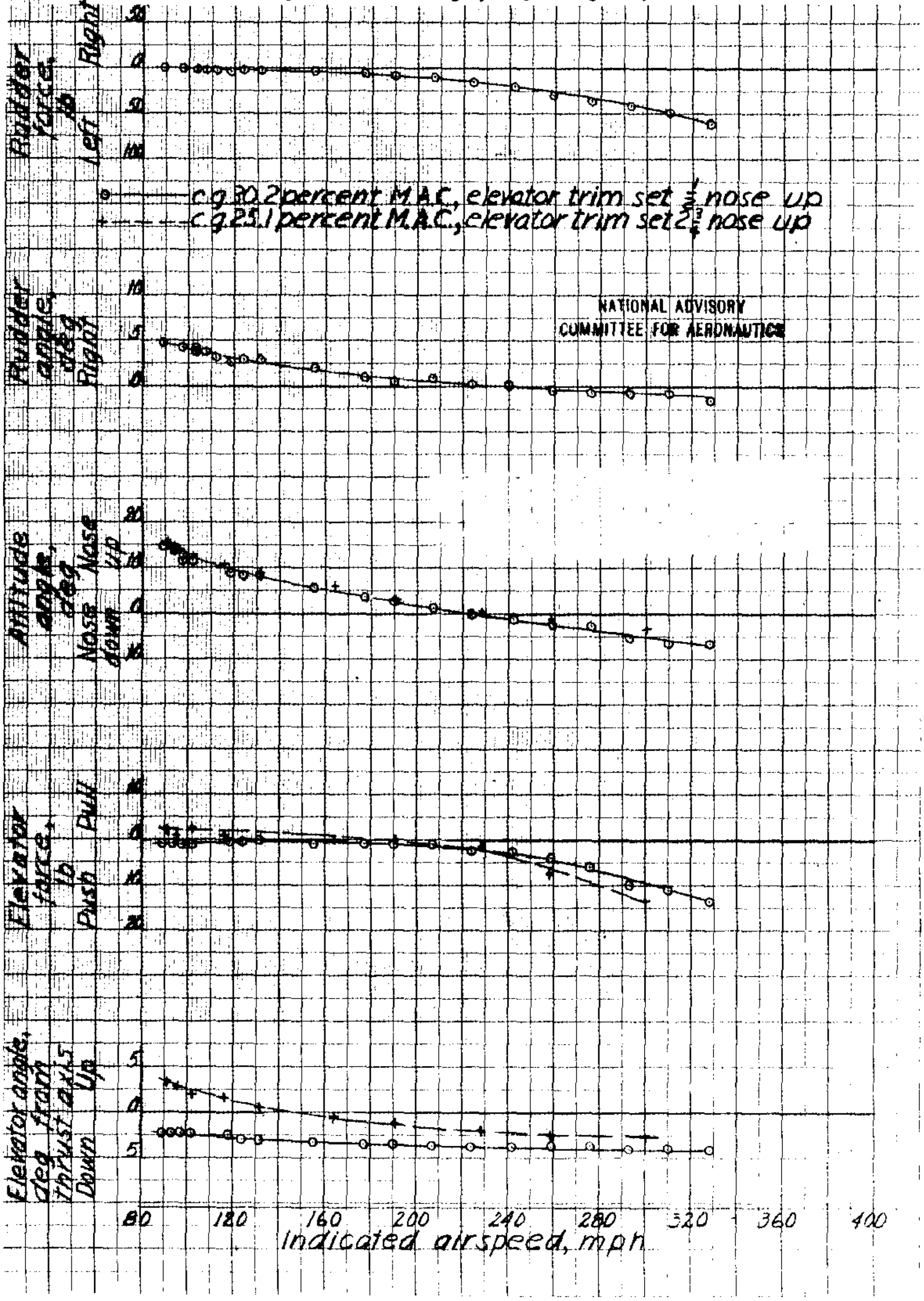


Figure 11. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Cruising condition: 75 percent rated power (2300 rpm, 31 in. Hg at 10,000 feet), forces trimmed to zero at speed for level flight, flaps and gear up.

Figure 12. - The longitudinal stability and control characteristics of the P-29D-1 airplane as measured in straight flight. Cruising maximum range condition: power for maximum range (1600 rpm, 26 in. Hg at 9000 feet), forces trimmed to zero at speed for level flight, flaps and gear up.



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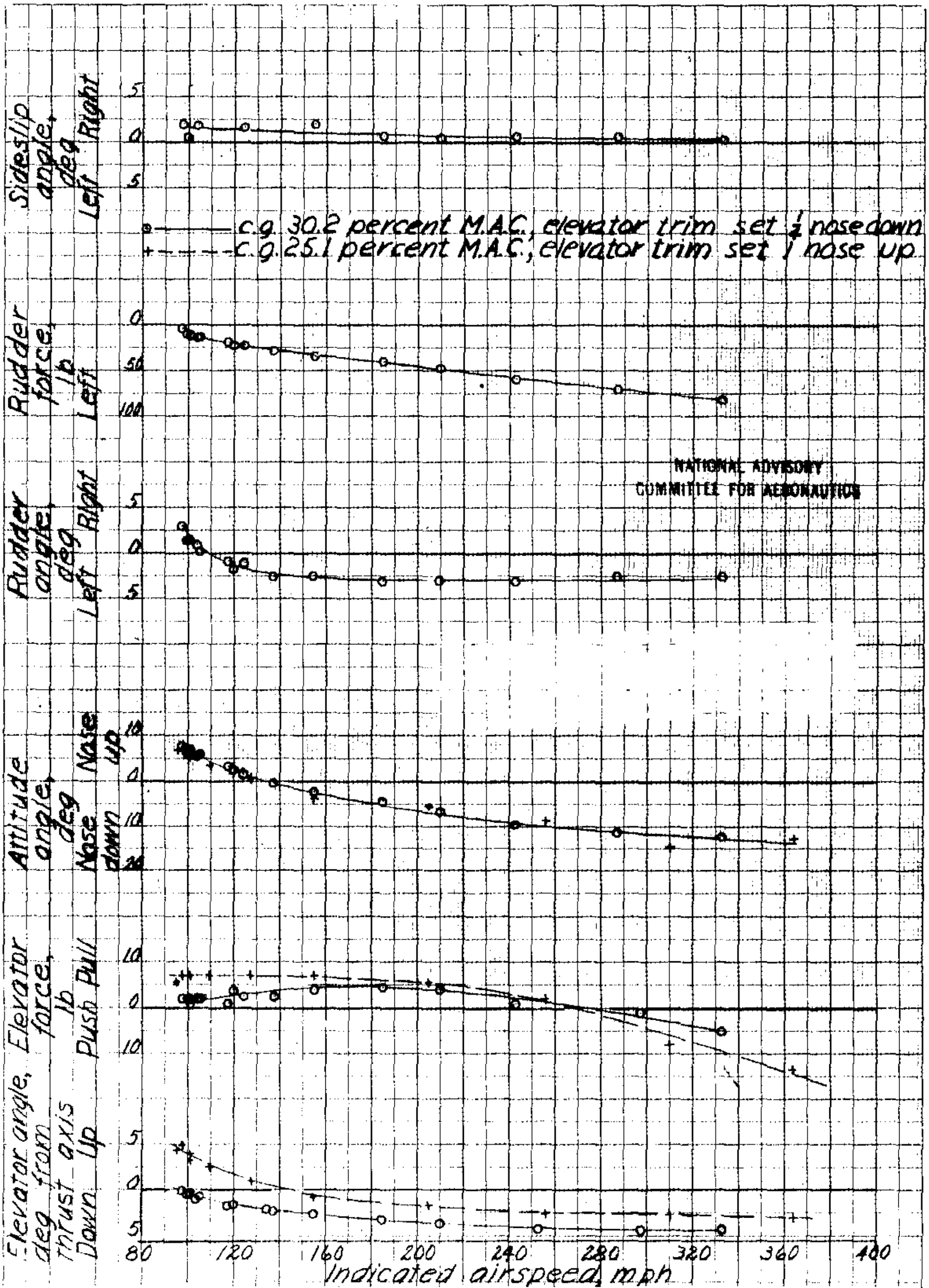
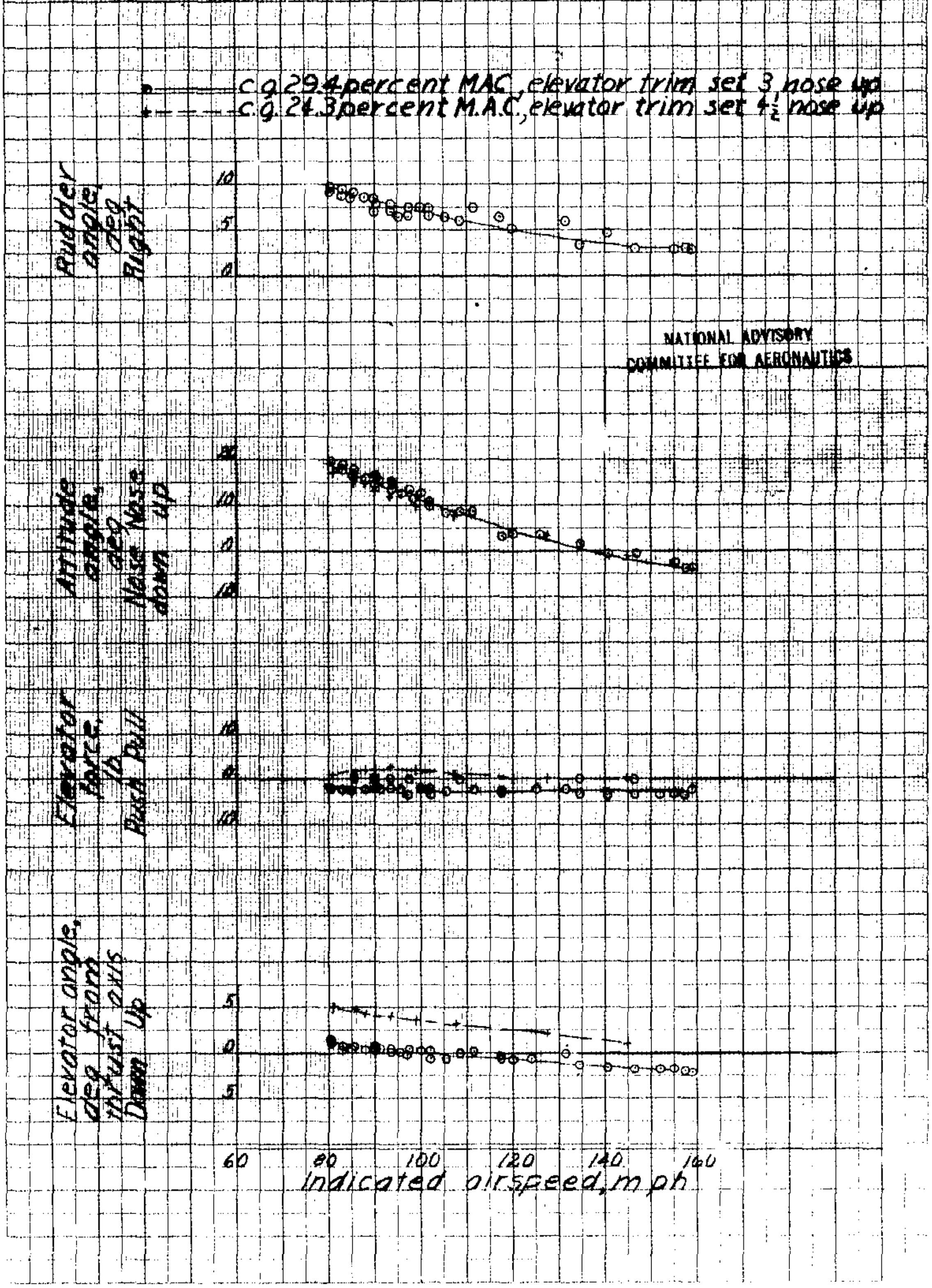


Figure 15. - The longitudinal stability and control characteristics of the P-59D-1 airplane as measured in straight flight. Gliding condition: engine idling, forces trimmed to zero with rated power at maximum level-flight speed, flaps and gear up.

Figure 14. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Landing approach condition: power for level flight at V_i = 130 miles per hour, forces trimmed to zero at V_i = 130 miles per hour, flaps and gear down.



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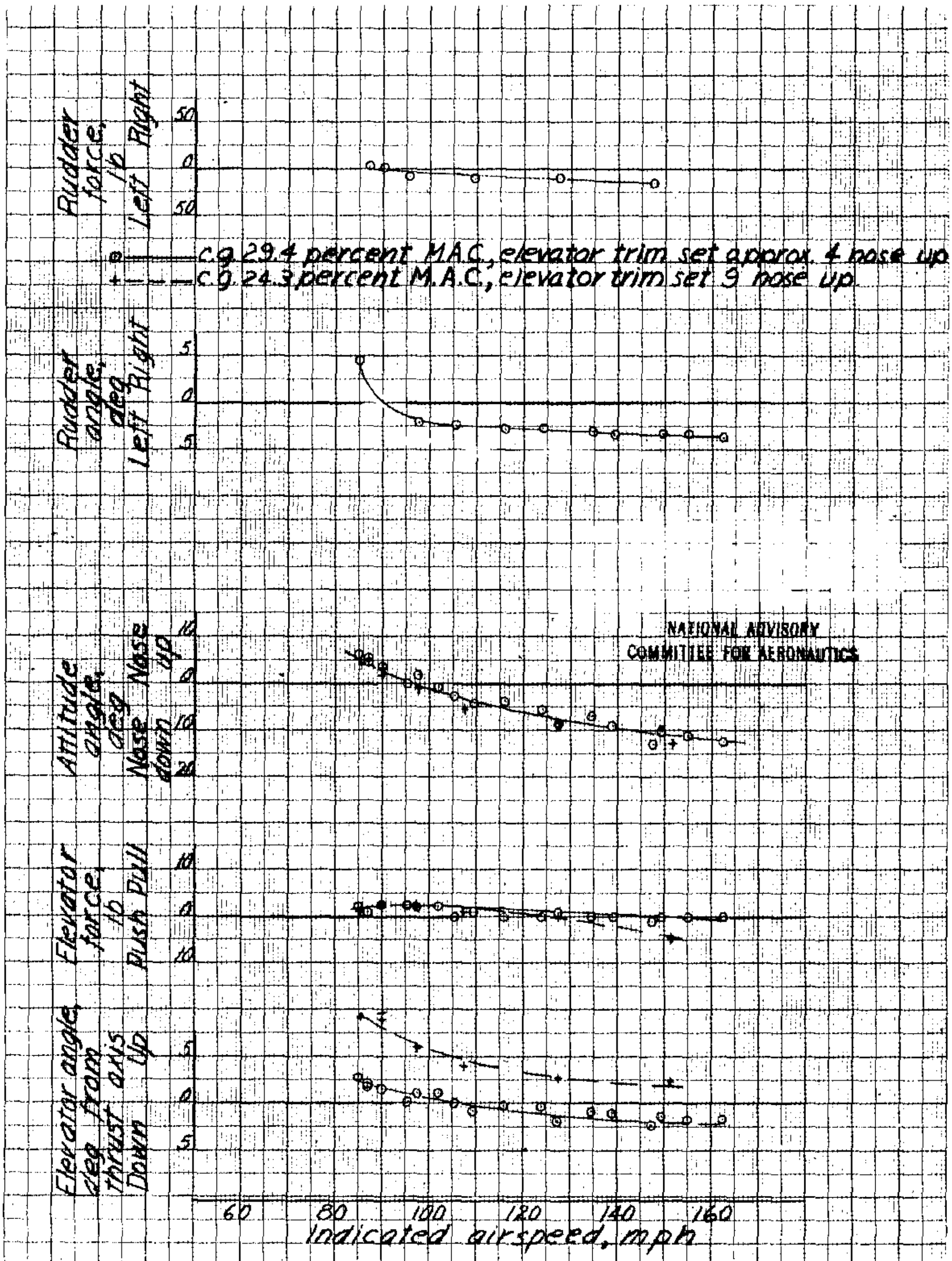

Figure 15. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Landing condition: engine idling, forces trimmed to zero at V_i = 130 miles per hour, flaps and gear down.

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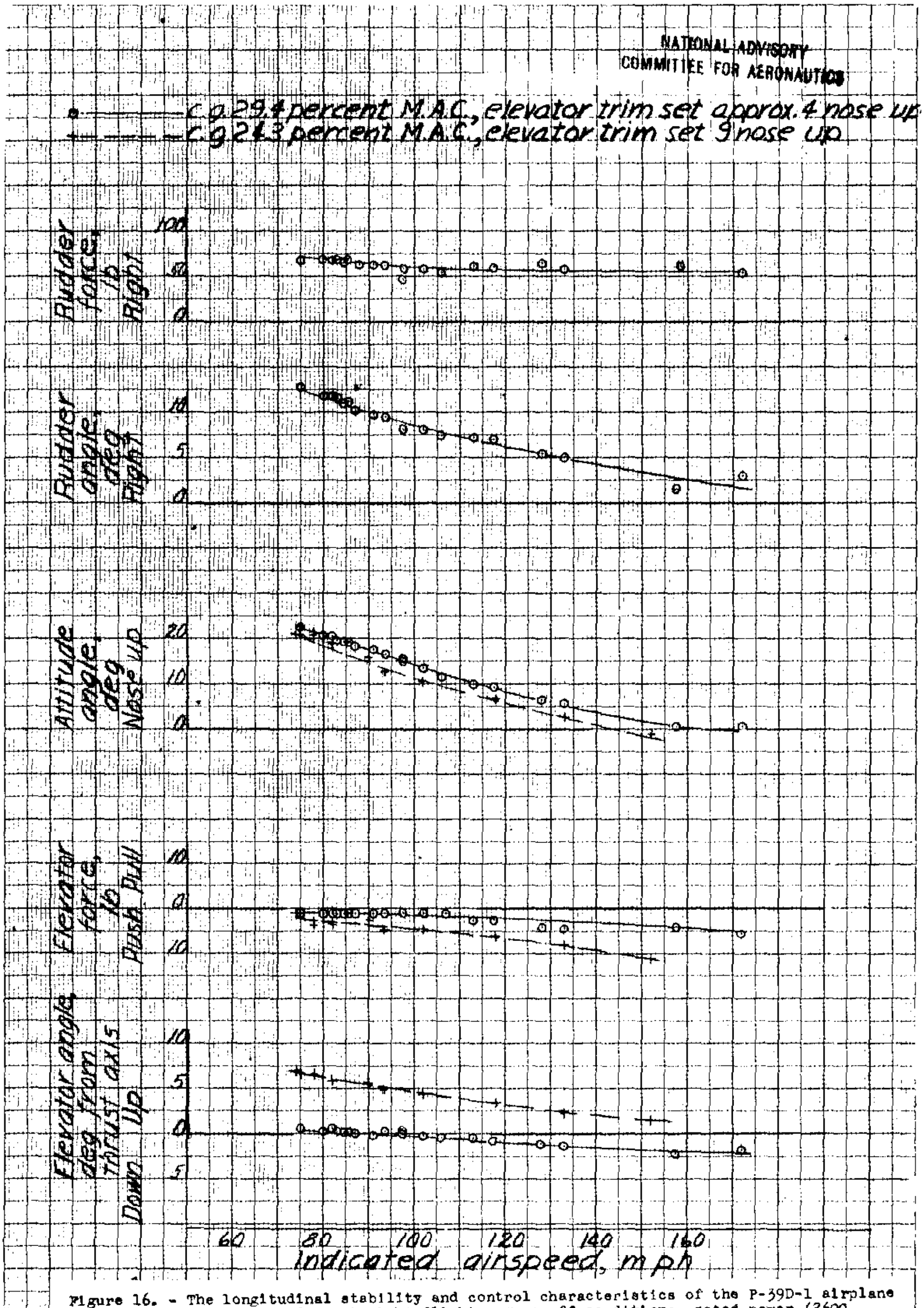

Figure 16. - The longitudinal stability and control characteristics of the P-39D-1 airplane as measured in straight flight. Wave-off condition: rated power (2600 rpm, 37.2 in. Hg at 10,000 feet) forces trimmed to zero with engine idling at V_1 = 130, flaps and gear down.

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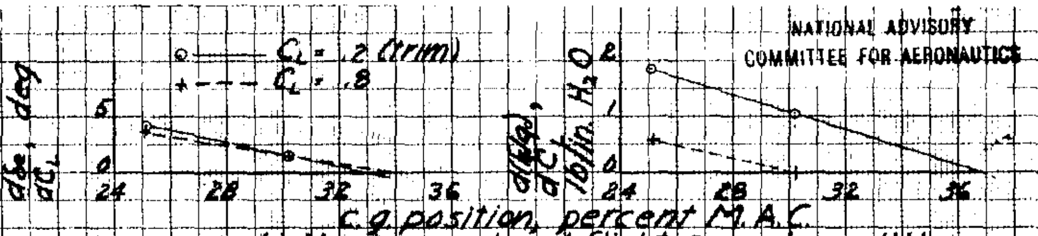
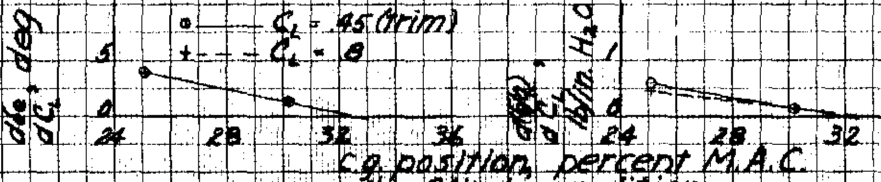
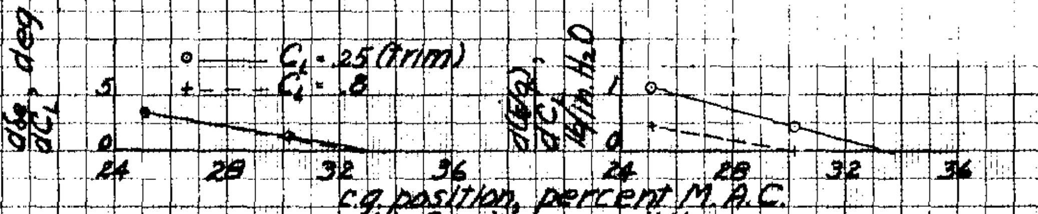


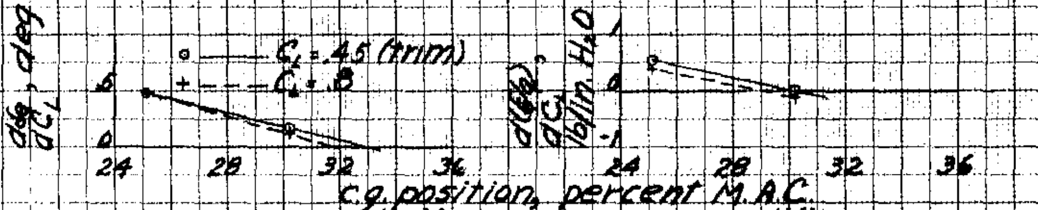
(a) Maximum level-flight speed condition



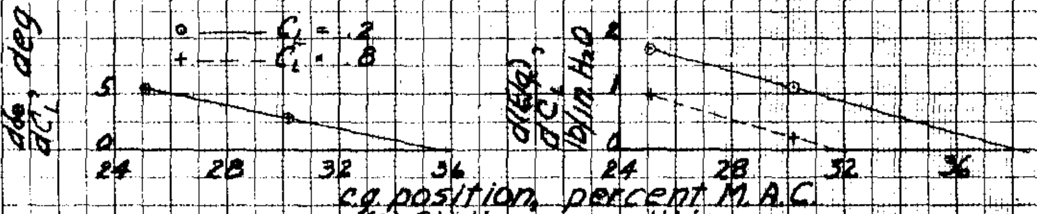
(b) Climb condition



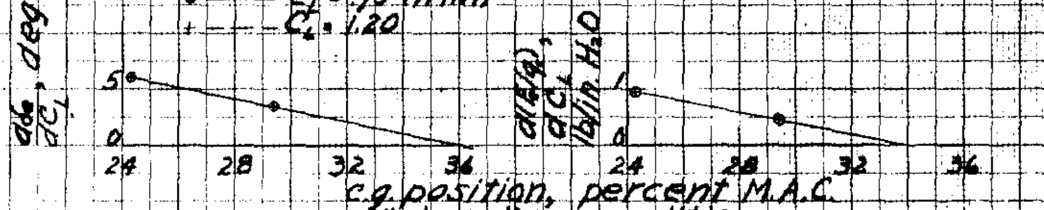
(c) Cruise condition



(d) Maximum range condition



(e) Gliding condition



(f) Landing condition

Figure 17. - Plots showing the stick-fixed and stick-free neutral points for the various airplane conditions tested.

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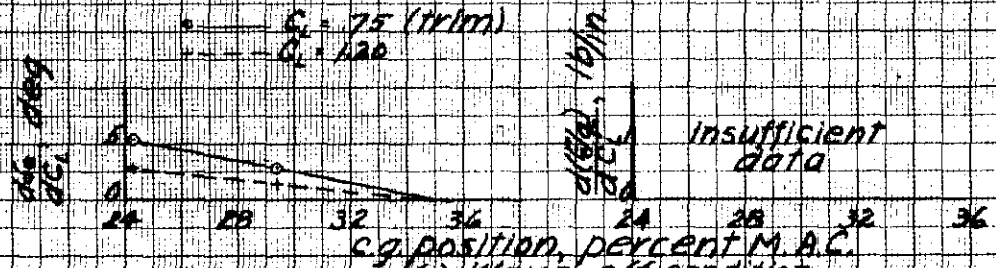
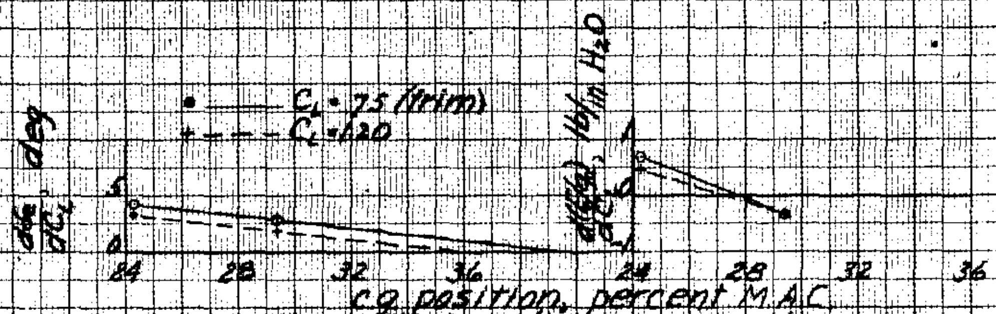


(g) Wave-off condition



(h) Landing approach condition

Figure 17.- Concluded.

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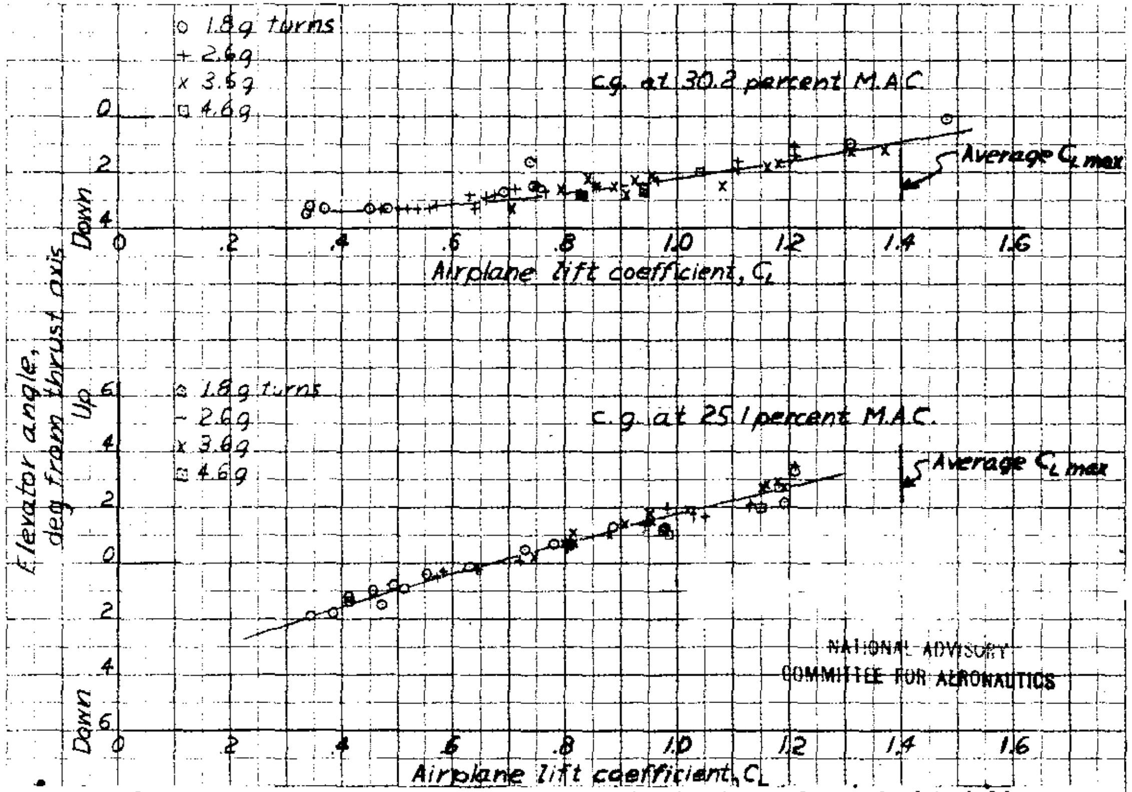

Figure 13. - The variation with lift coefficient of the elevator angle required to hold a constant acceleration turn. Turns made at approximately 10,000 feet with rated power (2600 rpm, 37.2 in. Hg). Forces trimmed to zero in straight flight at maximum level flight speed, flaps and gear up. P-39D-1 airplane.

Figure 19. - Change in elevator control force as a function of change in normal acceleration as measured in approximately constant acceleration turns at approximately 10,000 feet altitude. P-39D-1 airplane.

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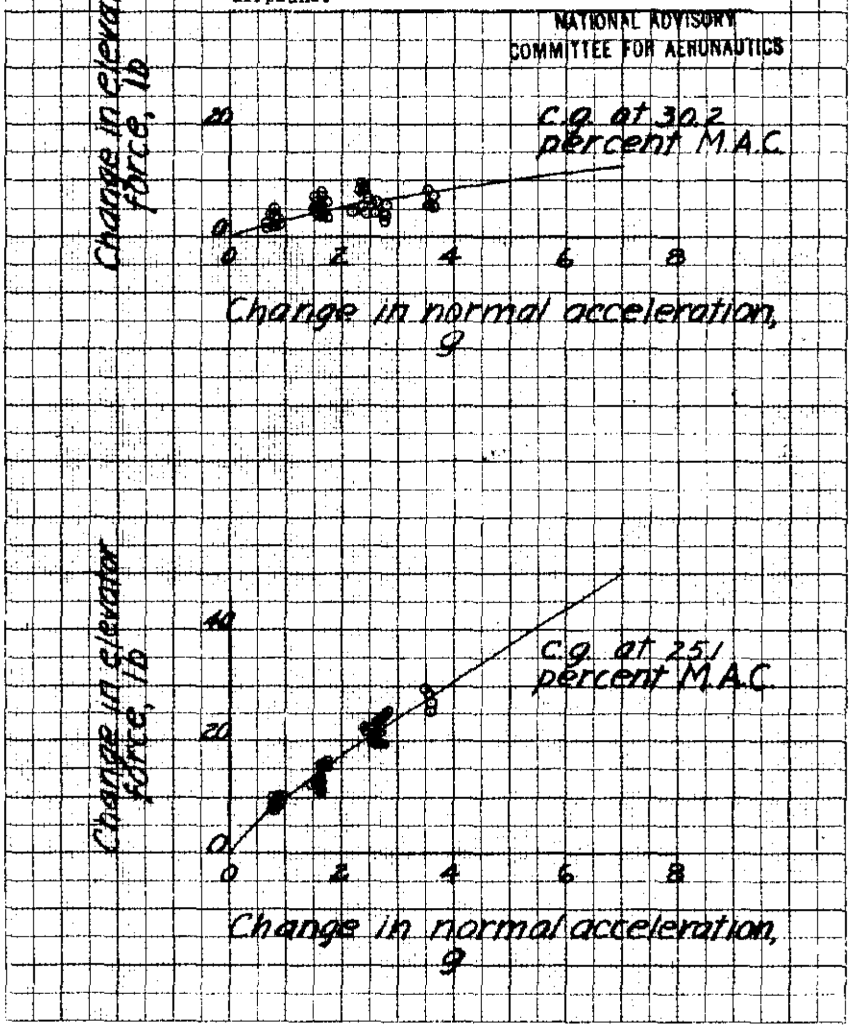

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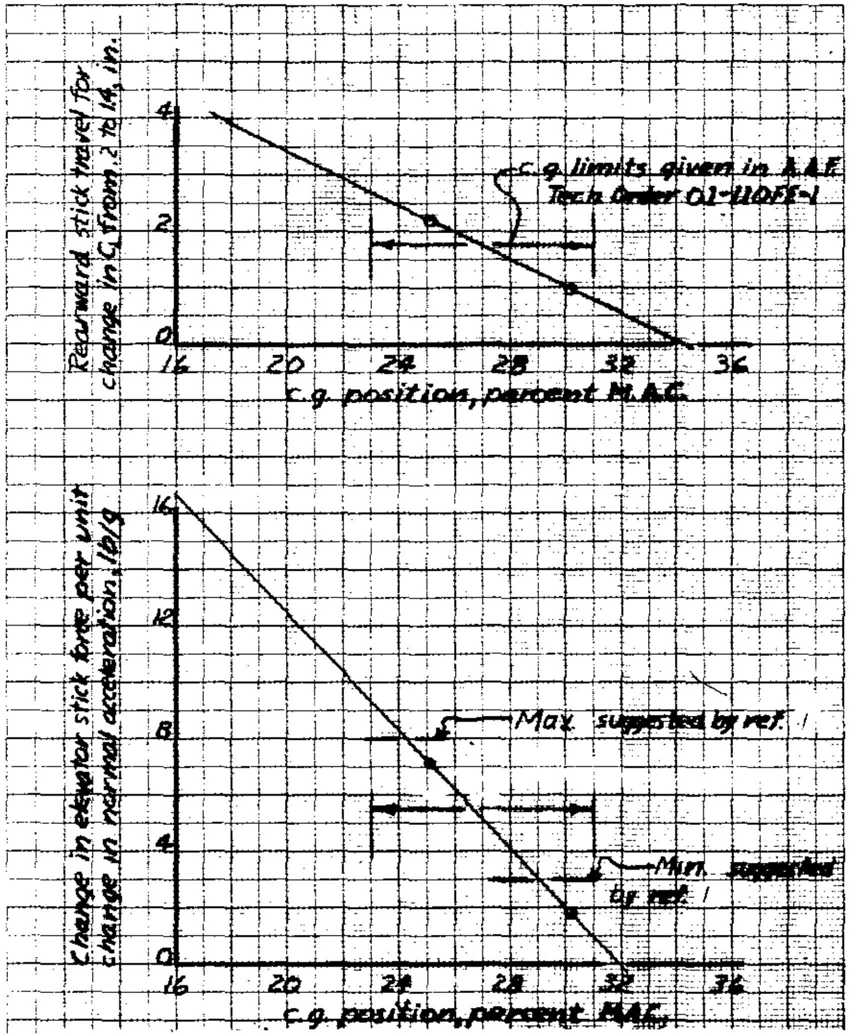


Figure 20. - Summary of longitudinal stability and control characteristics in turns. Turns made at approximately 10,000 feet with rated power (2600 rpm, 37.2 in. Hg). Forces trimmed to zero at maximum level flight speed, flaps and gear up. P-39D-1 airplane.

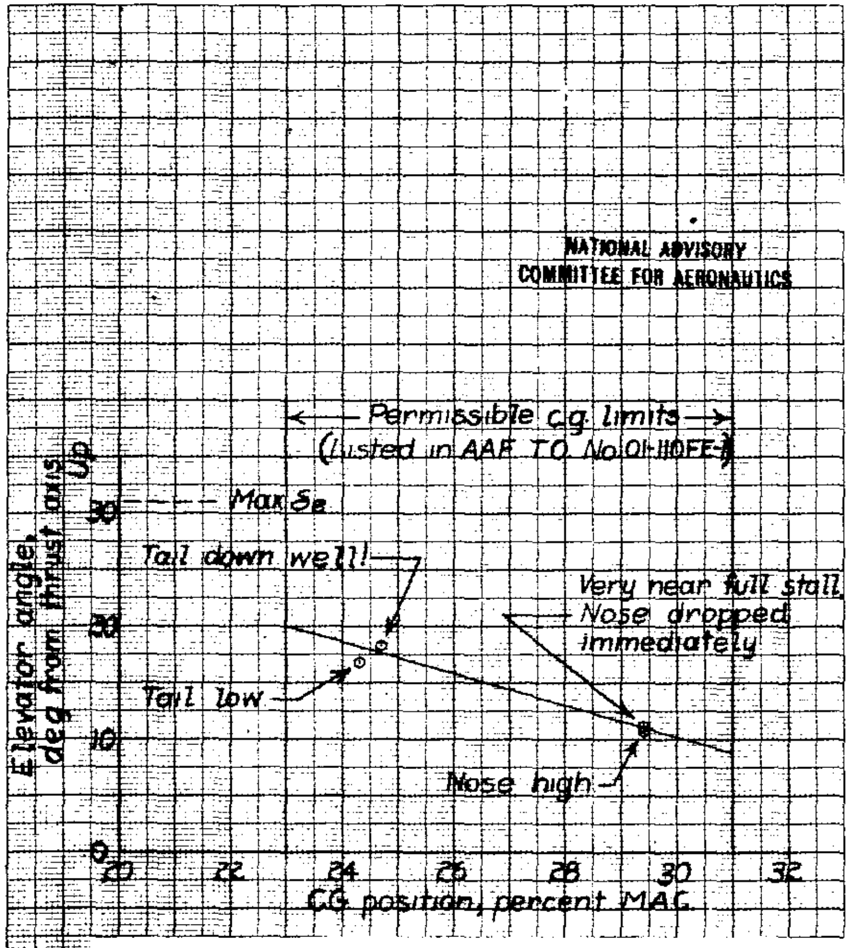
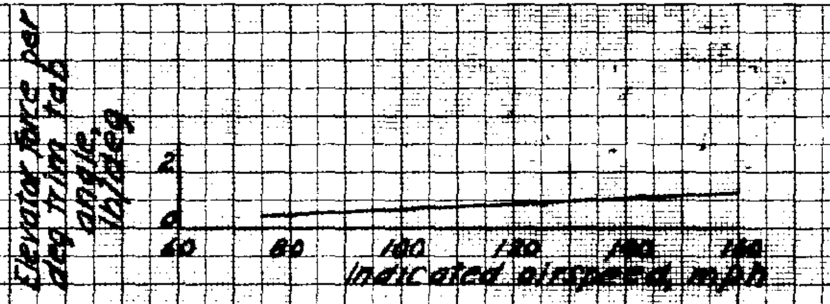
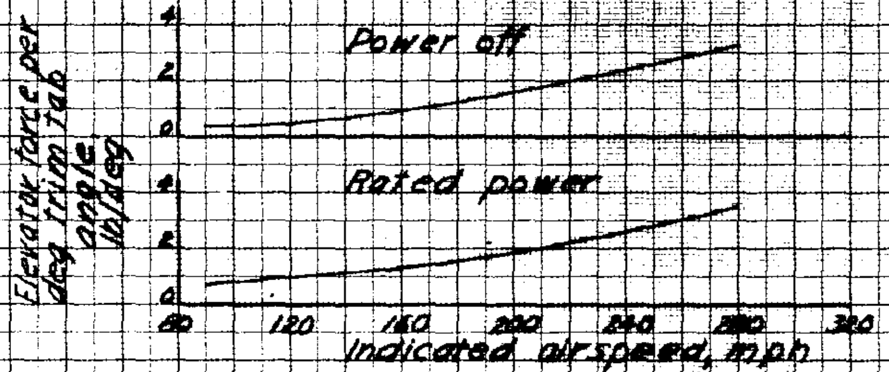


Figure 21. - Elevator angles required for minimum speed landings with flaps down and power off plotted against c.g. position. Bell P-39D-1 airplane. Pilot's comments included for each landing.



(a) Flaps, gear down, power off



(b) Flaps, gear up

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Figure 22. - Elevator trim tab effectiveness for (a) flaps and gear down and (b) flaps and gear up. P-39D-1 airplane.

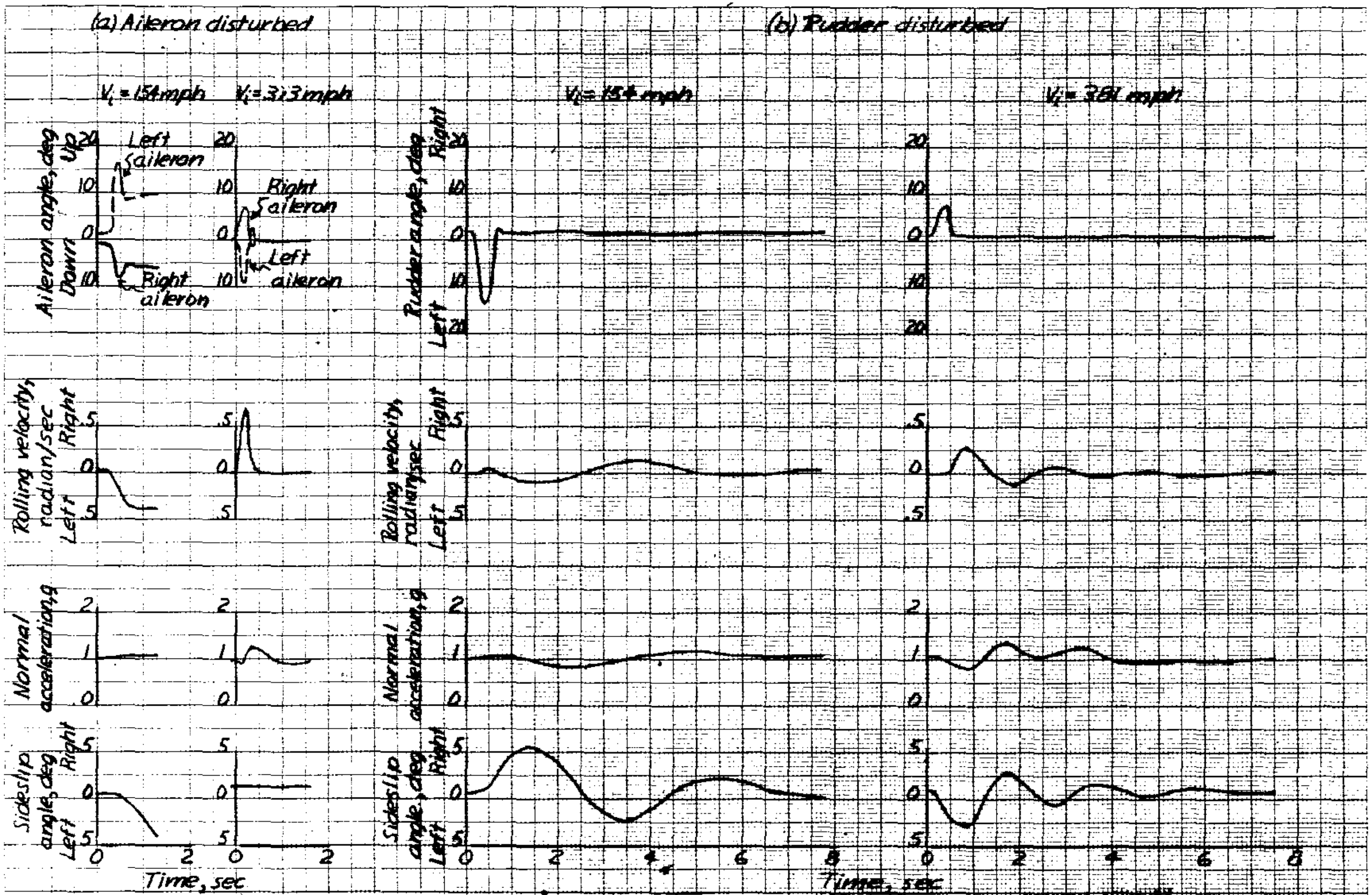

Figure 23. - Time histories of typical airplane motion during and after sudden deflection and release of (a) the ailerons and (b) the rudder.

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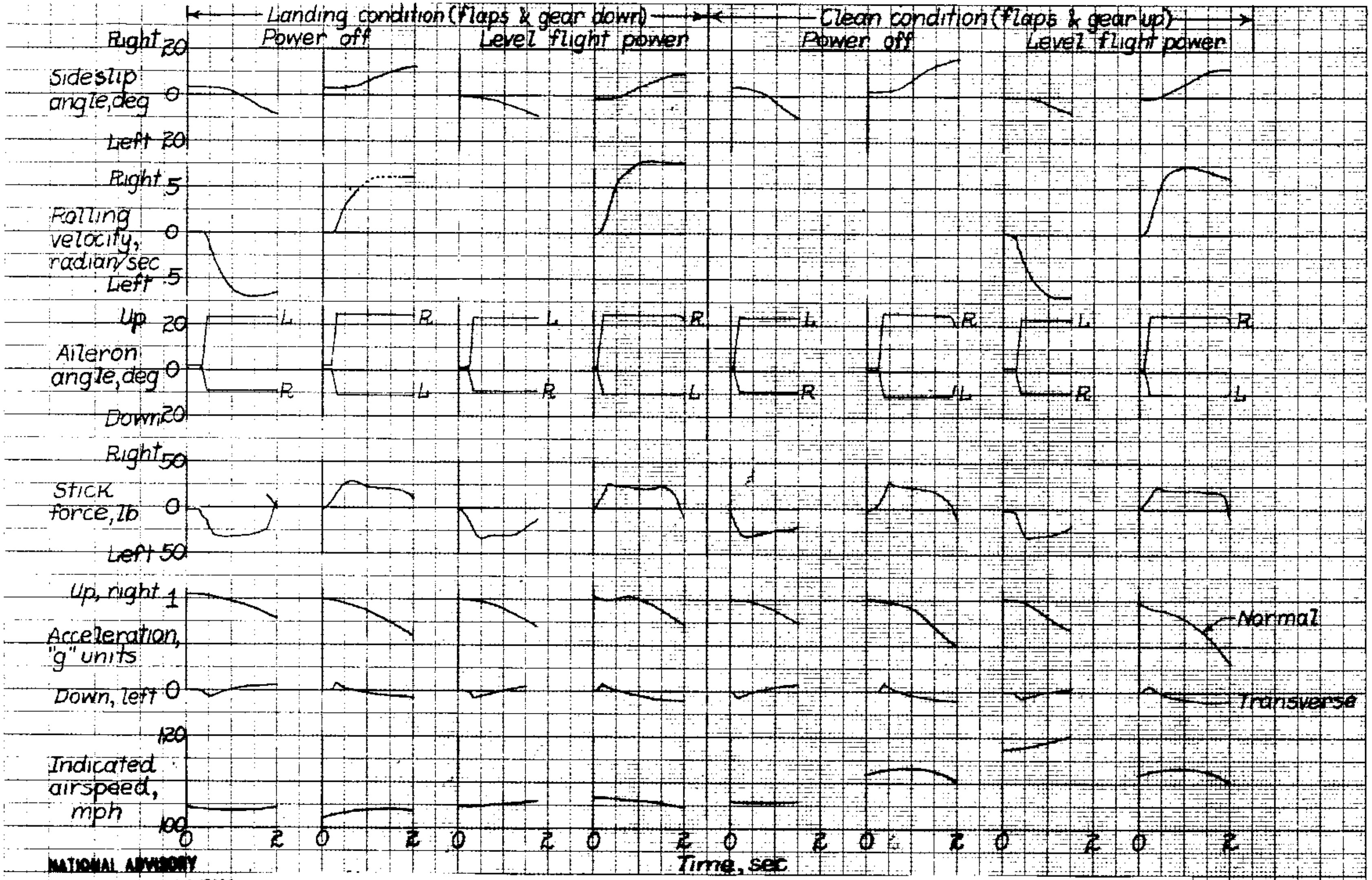

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Figure 24. - Time histories of full-deflection aileron rolls made with rudder held in trim position showing adverse aileron yaw at low speeds. Bell P-39D-1 airplane.
Note: Stick force includes force against aileron stop at full deflection.

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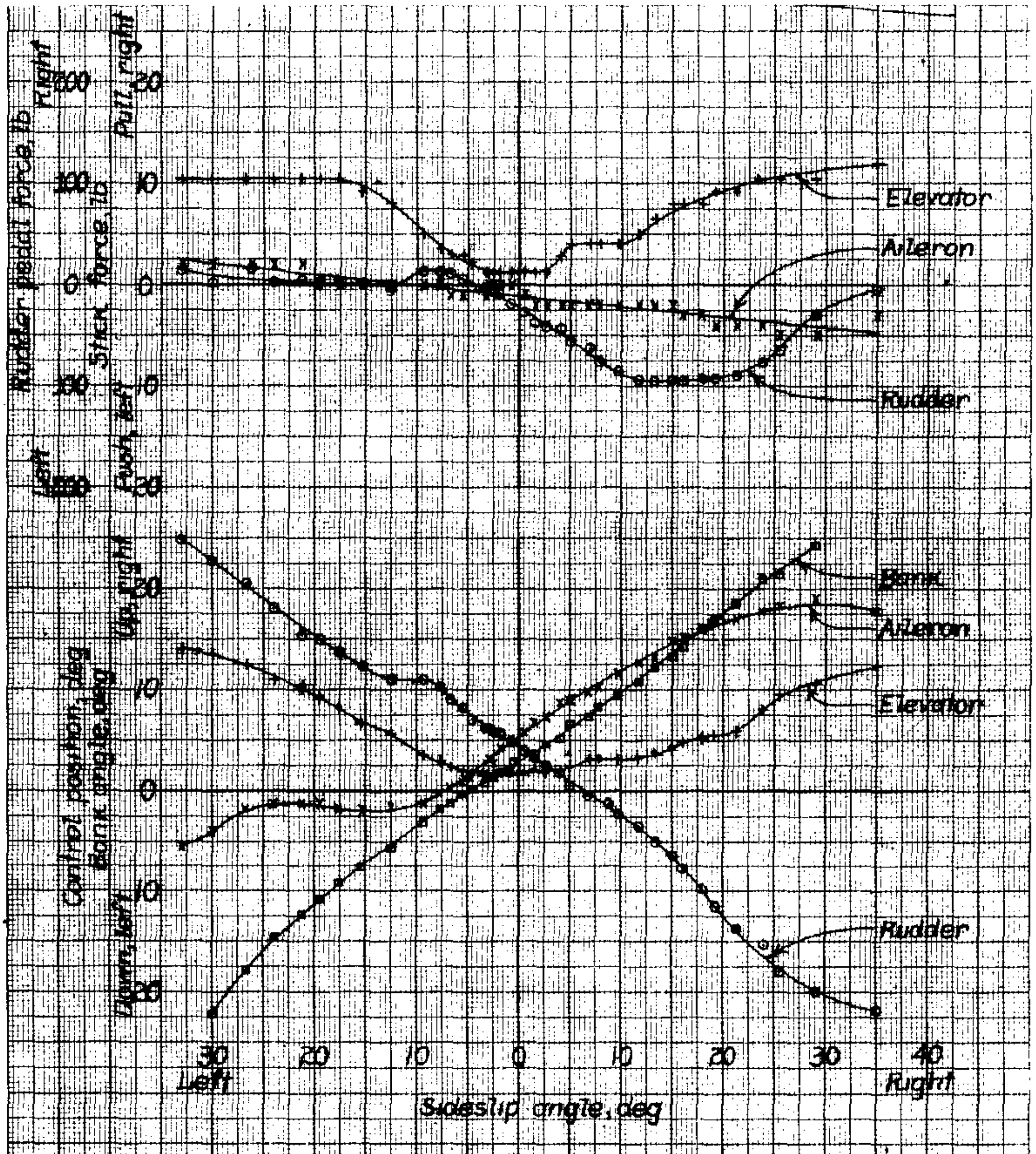

Figure 25. - Sideslip characteristics at indicated airspeed of 110 mph in the rated-power, clean condition. Bell P-39D-1 airplane.

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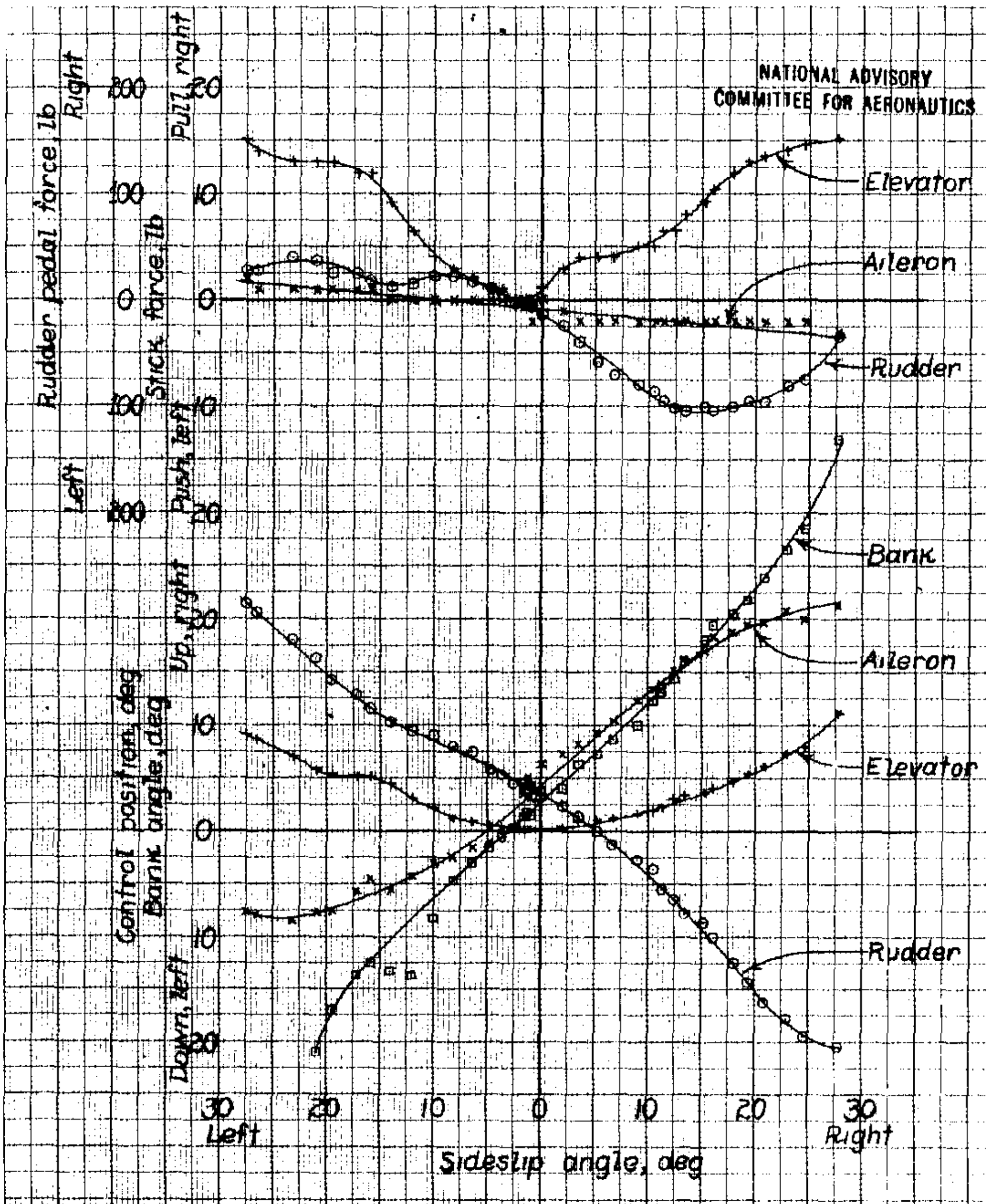

Figure 26. - Sideslip characteristics at indicated airspeed of 155 mph in the rated power, clean condition. Bell P-39D-1 airplane.

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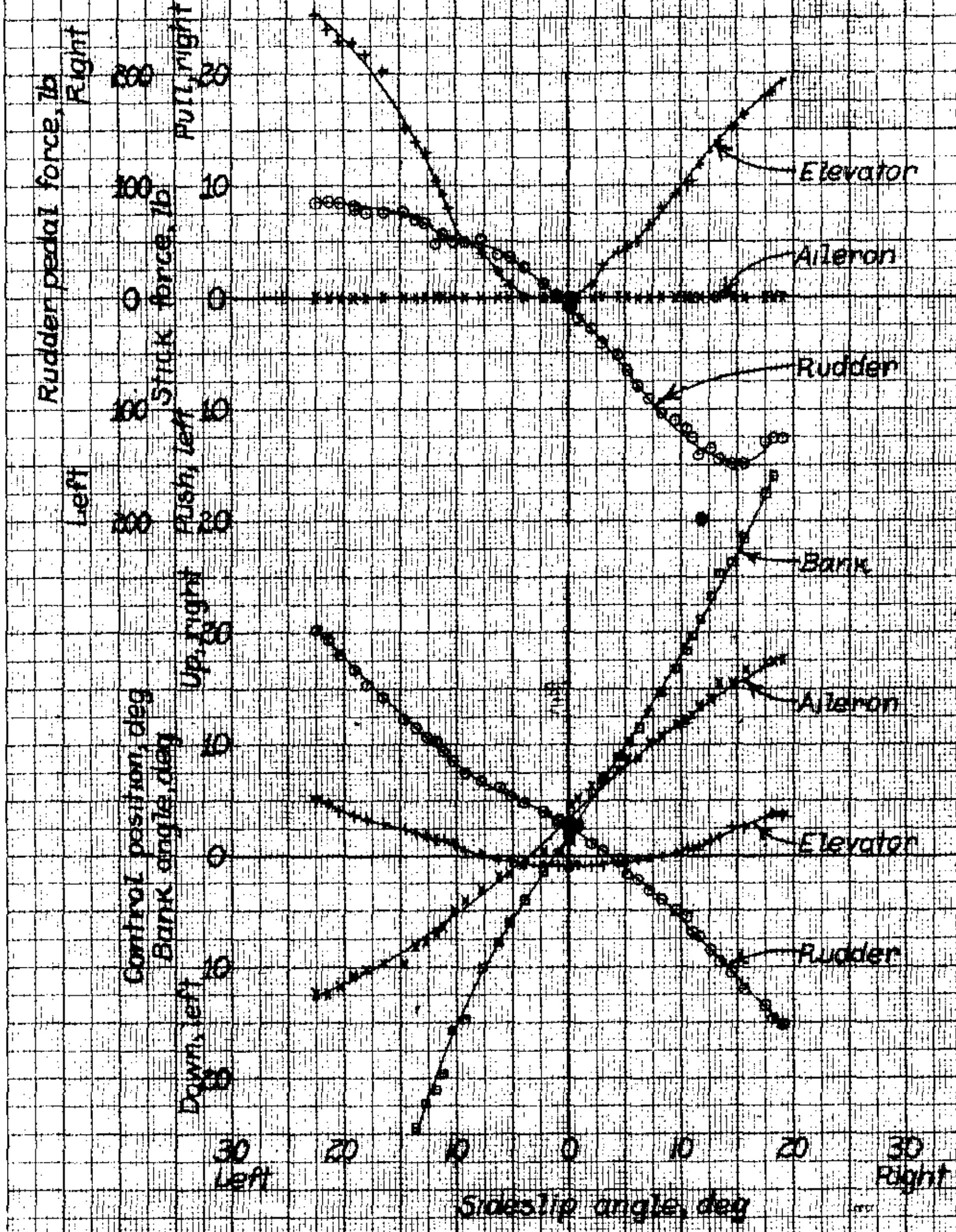

Figure 27. - Sideslip characteristics at indicated airspeed of 210 mph in the rated power, clean condition. Bell P-39D-1 airplane.

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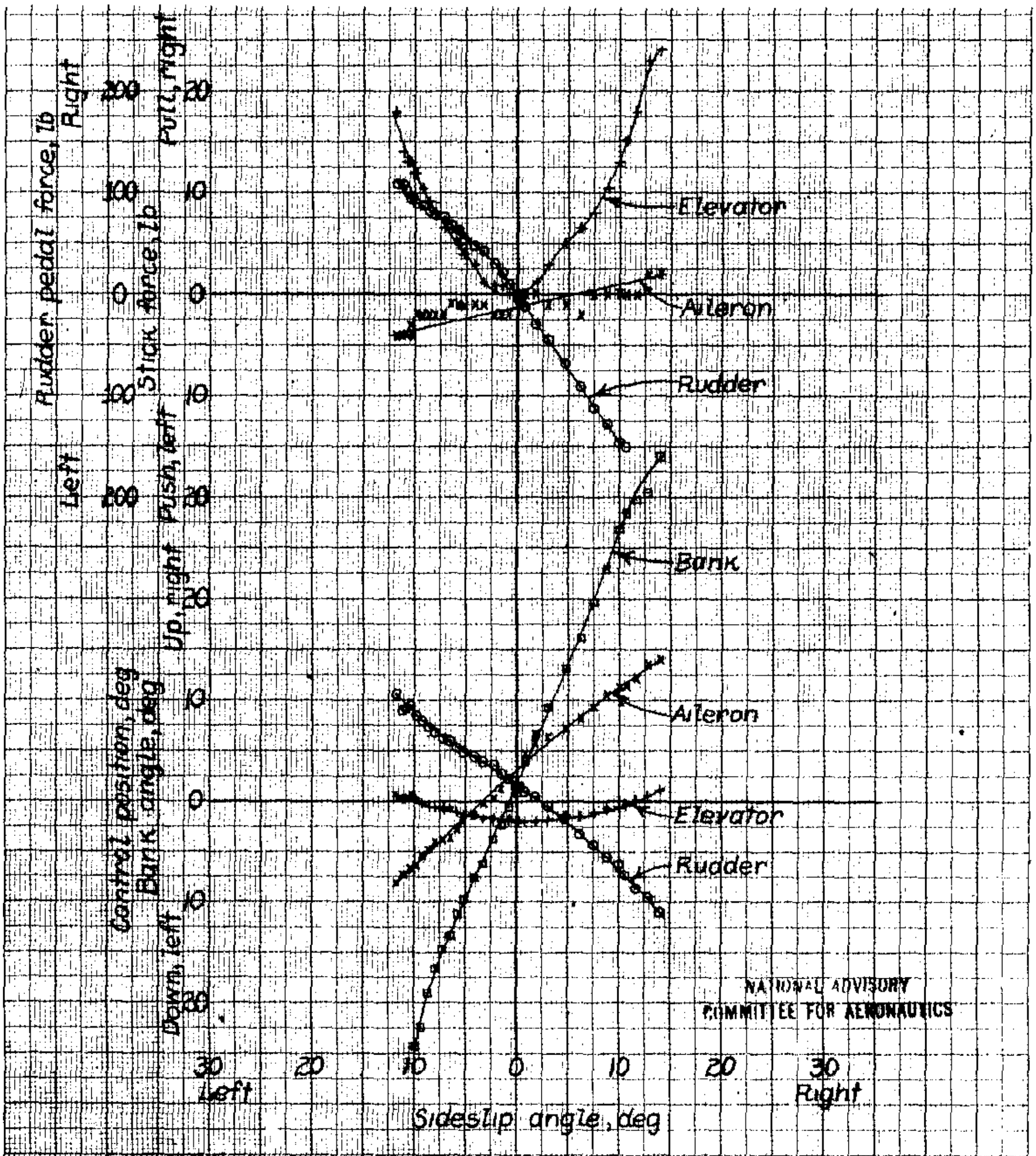

Figure 28. - Sideslip characteristics at indicated airspeed of 255 mph in the rated-power, clean condition. Bell P-39D-1 airplane.

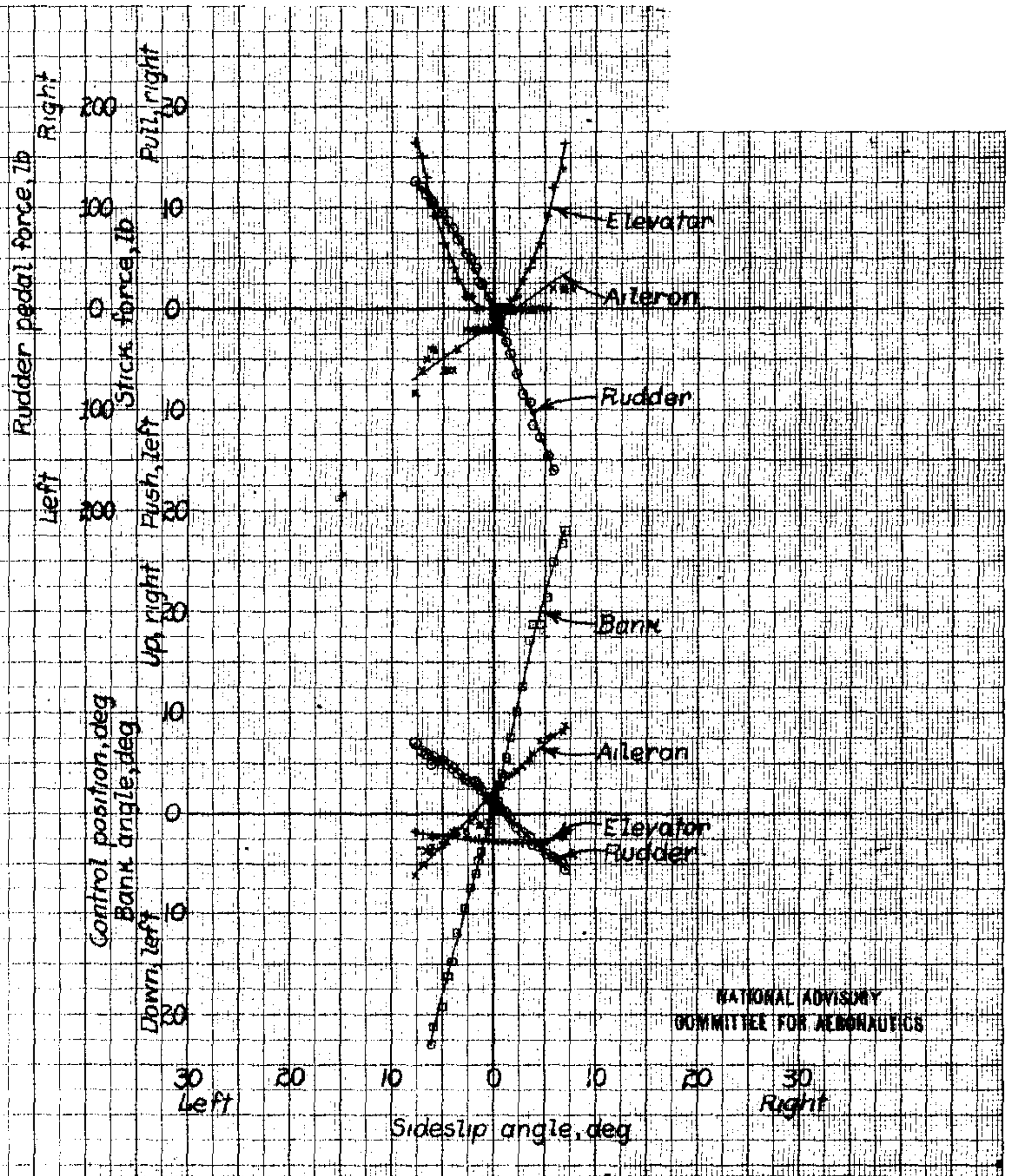

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Figure 29. - Sideslip characteristics at indicated airspeed of 330 mph in the rated power, clean condition. Bell P-39D-1 airplane.

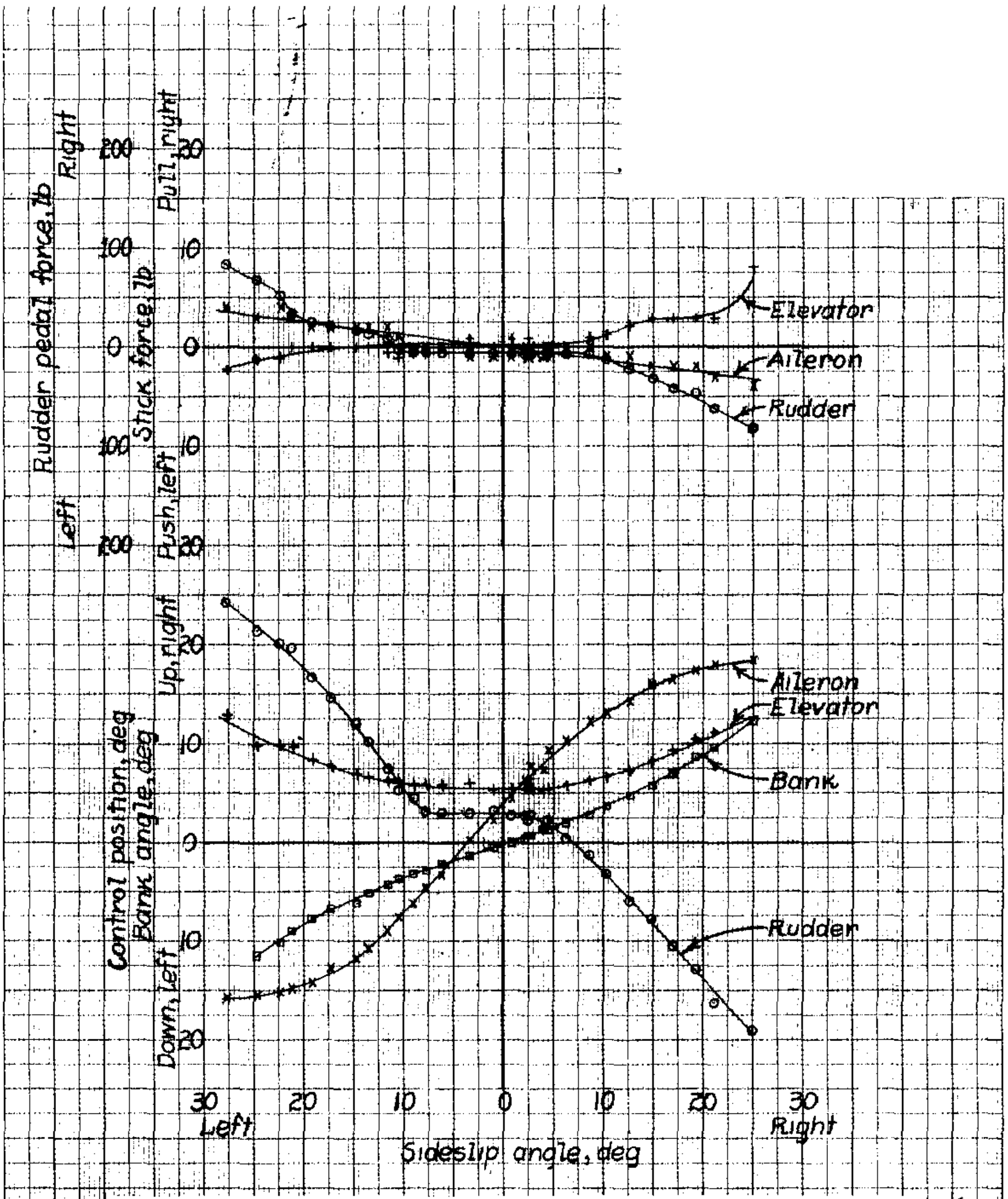

Figure 30. - Sideslip characteristics at indicated airspeed of 110 mph in the power-off, clean condition. Bell P-39D-1 airplane.

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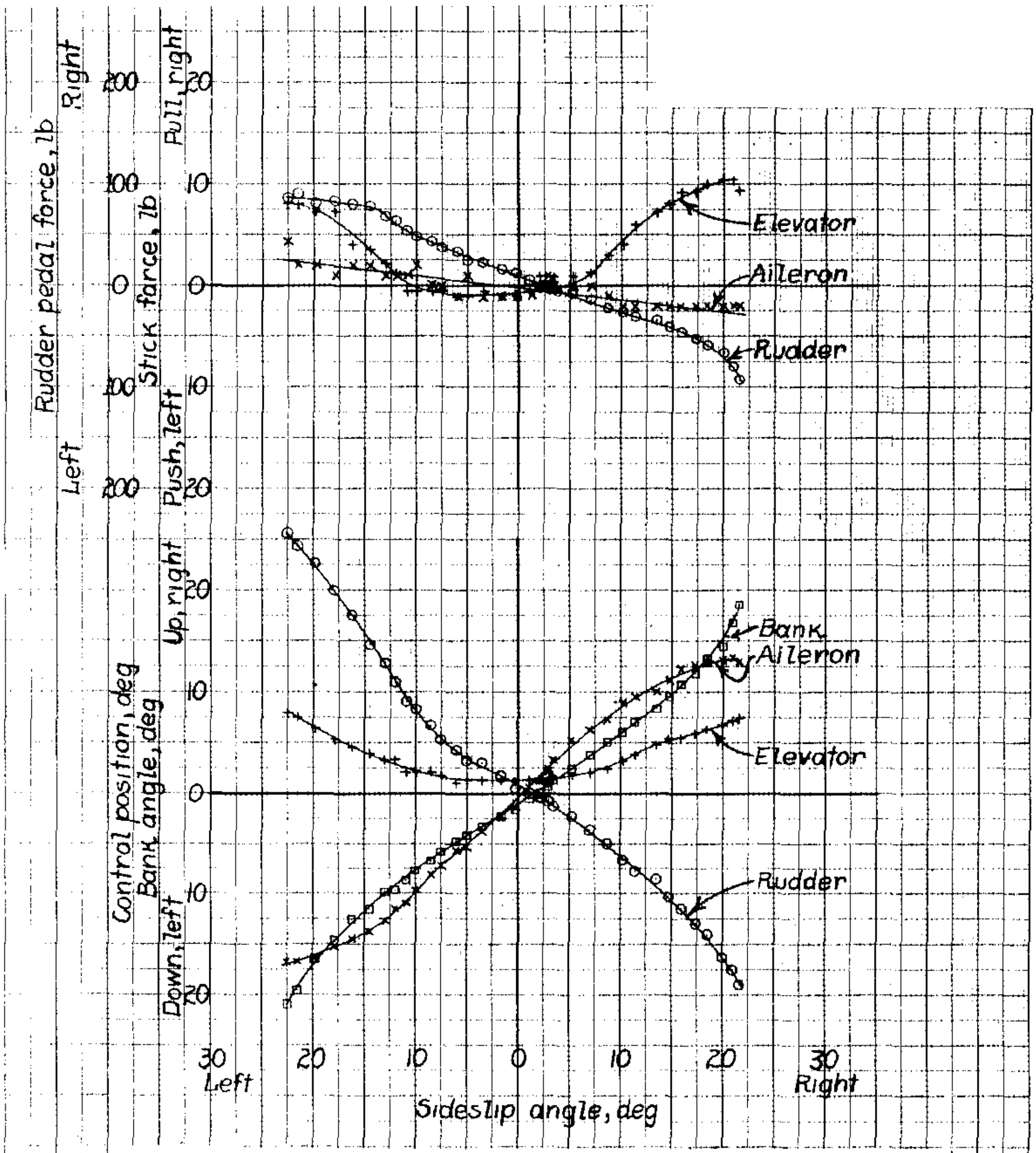

Figure 31. - Sideslip characteristics at indicated airspeed of 150 mph in the power-off, clean condition. Bell P-39D-1 airplane.

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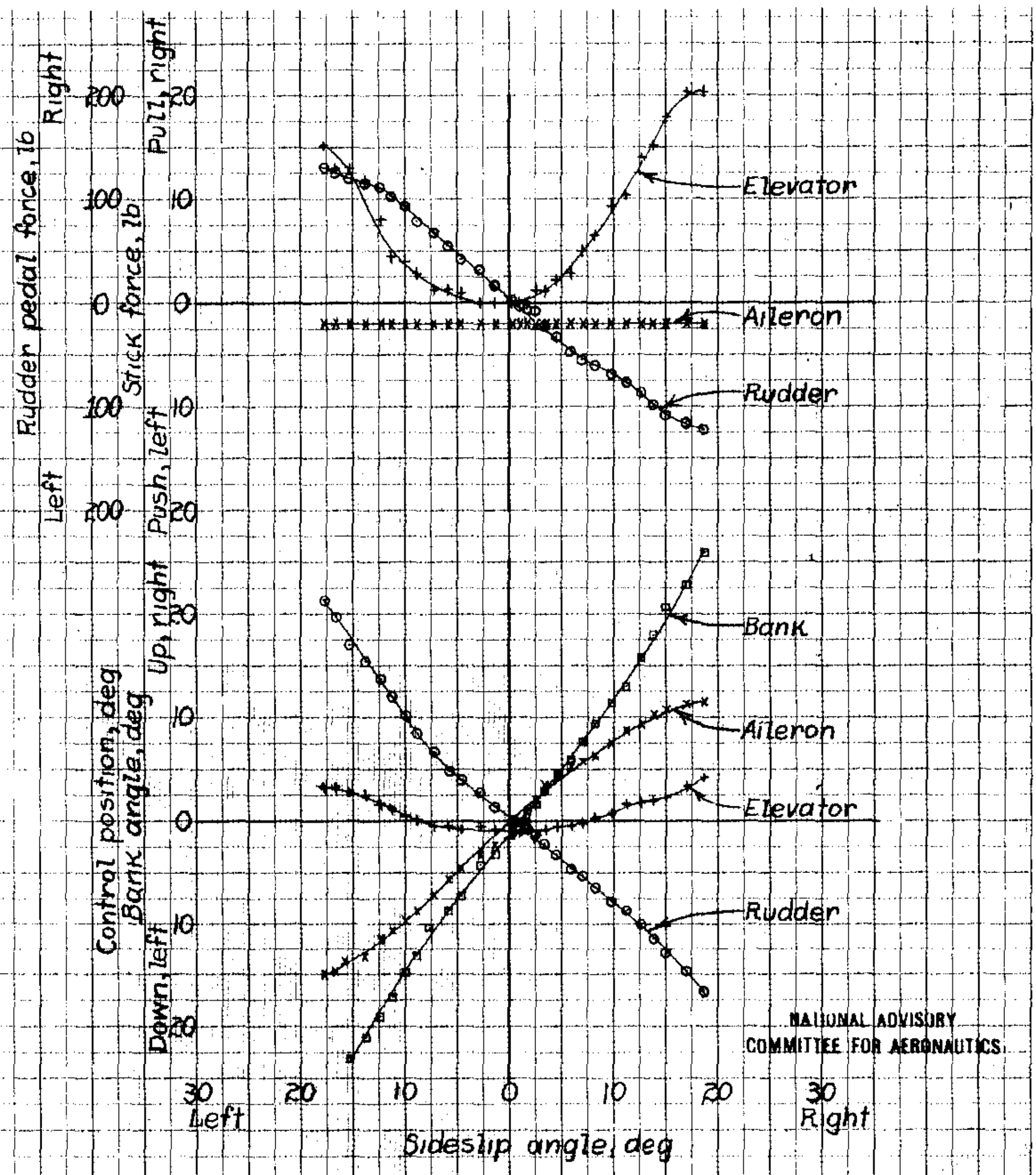

Figure 32. - Sideslip characteristics at indicated airspeed of 205 mph in the power-off, clean condition. Bell P-39D-1 airplane.

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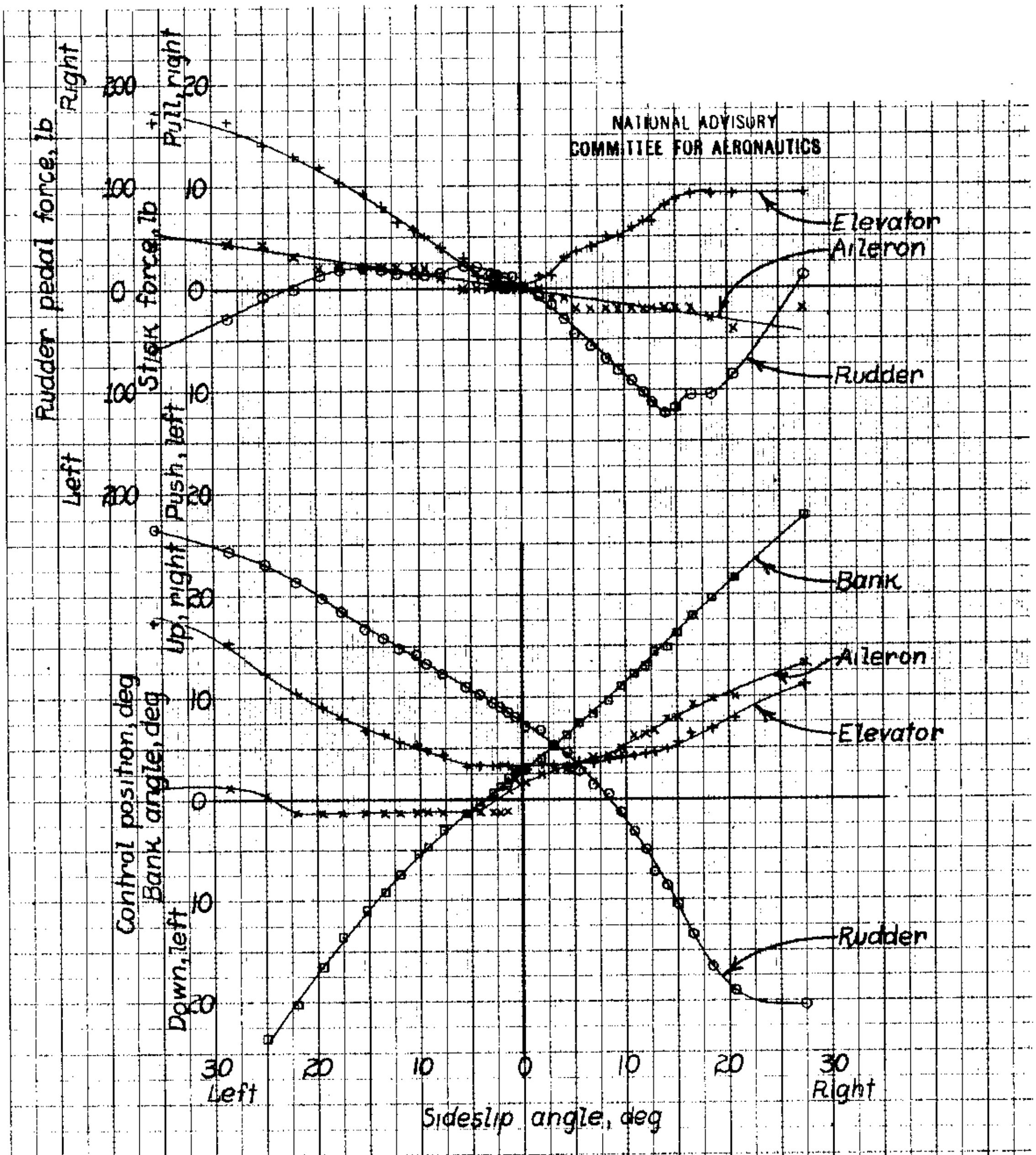

Figure 33. - Sideslip characteristics at indicated airspeed of 115 mph in the rated-power, landing condition. Bell P-39D-1 airplane.

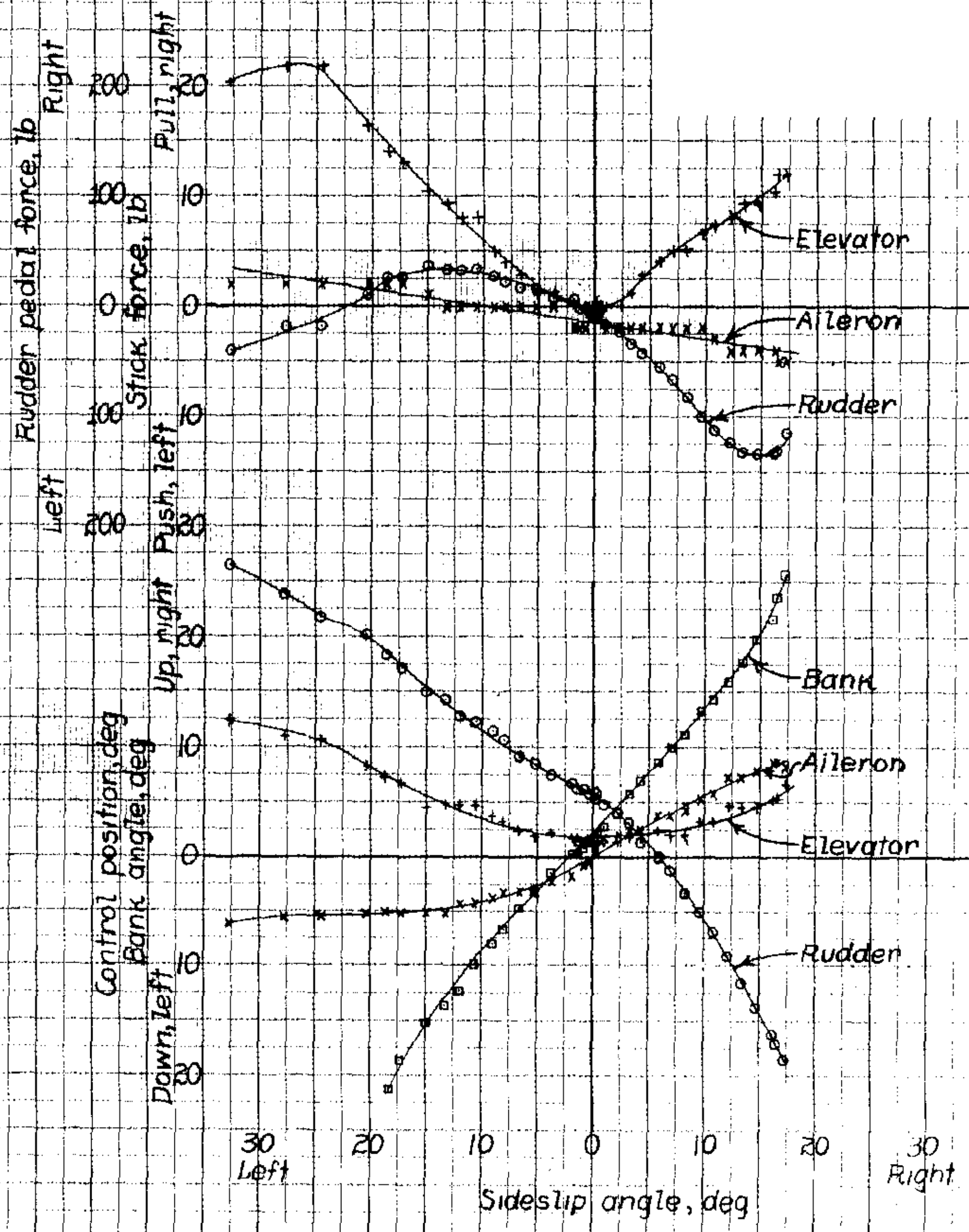

Figure 34. - Sideslip characteristics at indicated airspeed of 140 mph in the rated-power, landing condition. Bell P-39D-1 airplane.

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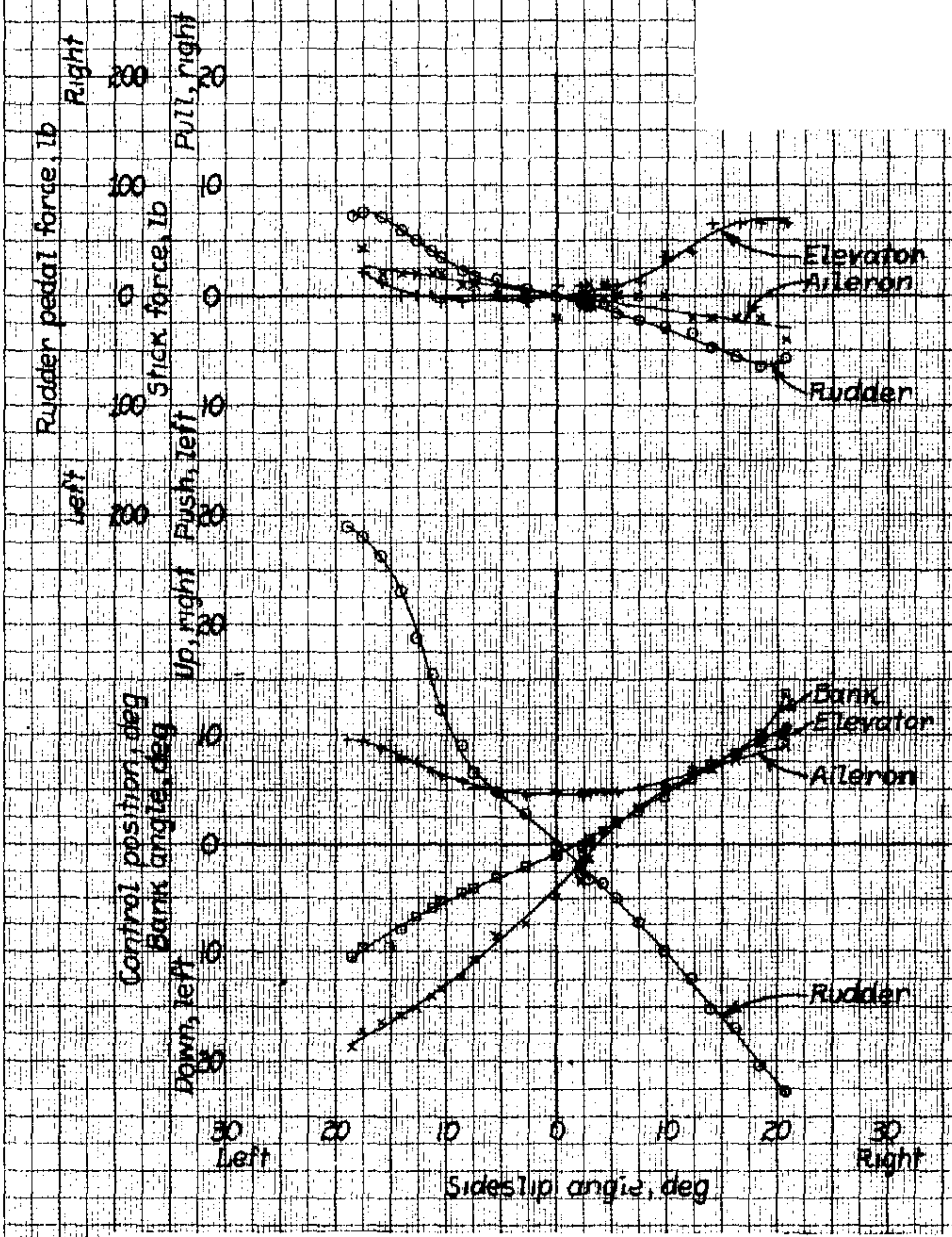

Figure 35. - Sideslip characteristics at indicated airspeed of 115 mph in the power-off, landing condition. Bell P-39D-1 airplane.

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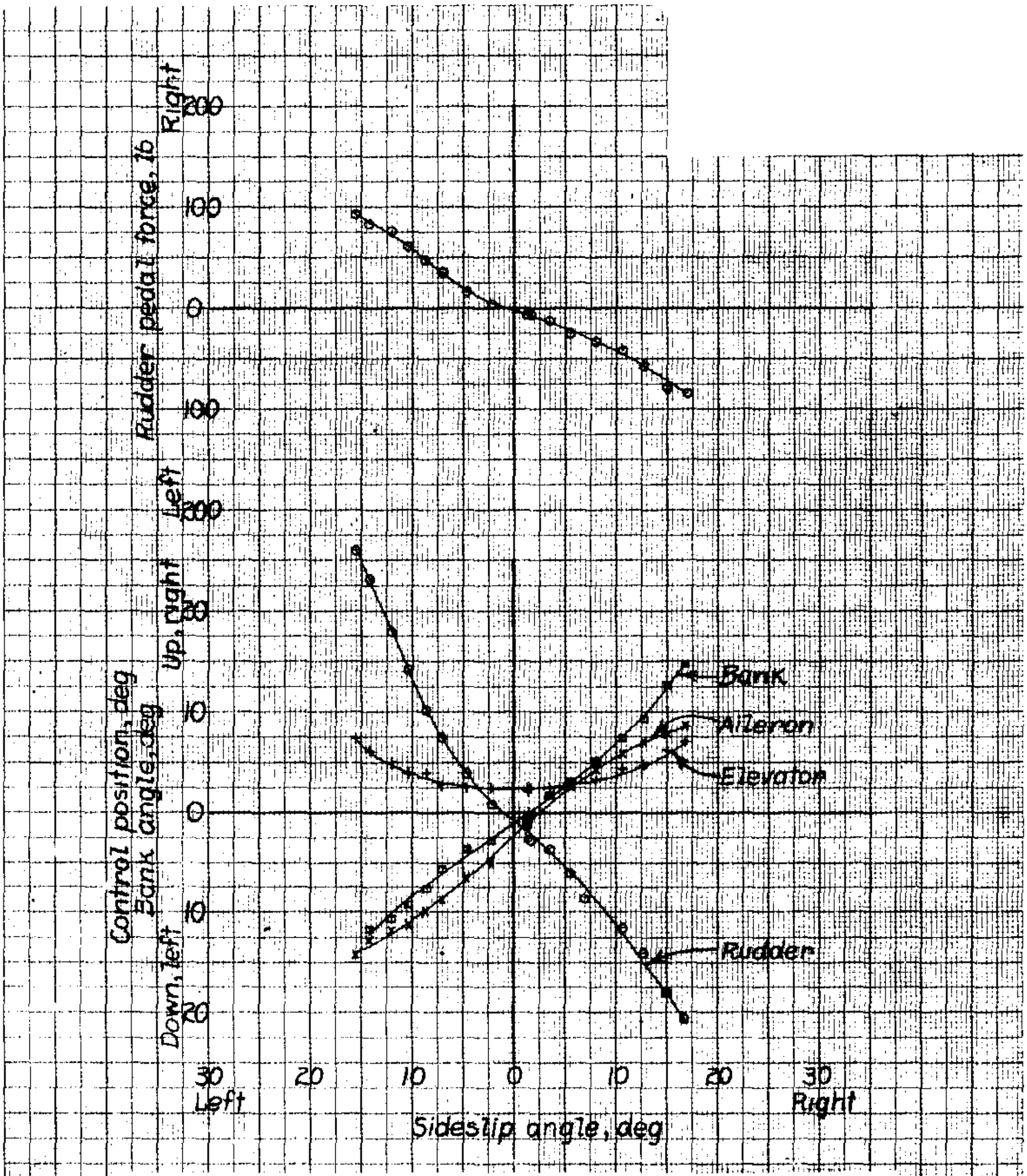

Figure 36. - Sideslip characteristics at indicated airspeed of 140 mph in the power-off, landing condition. Bell P-39D-1 airplane.

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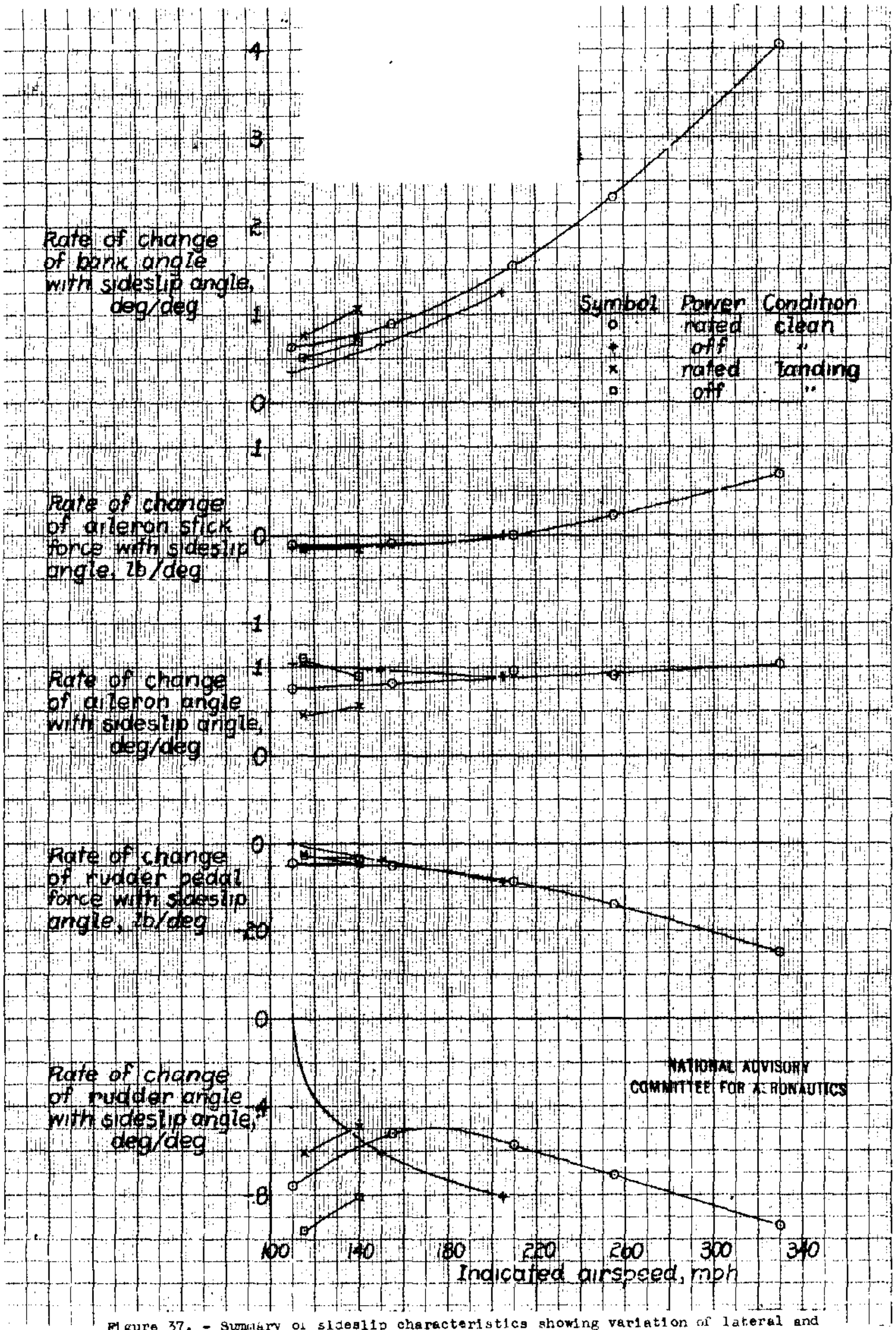

Figure 37. - Summary of sideslip characteristics showing variation of lateral and directional stability with indicated airspeed as measured at sideslip angles corresponding to zero angle of bank.

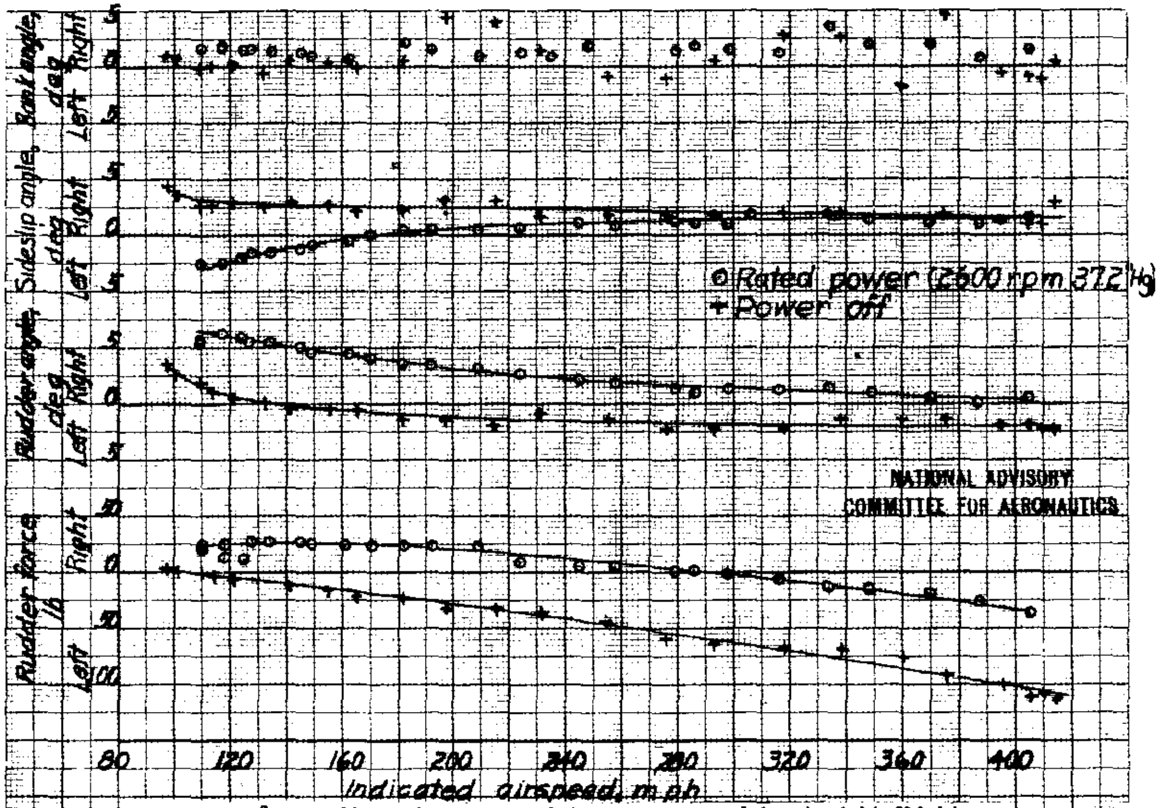

Figure 38. - Rudder trim characteristics as measured in straight-flight-path runs. P-39D-1 airplane, cockpit rudder tab indicator setting +1 3/4.

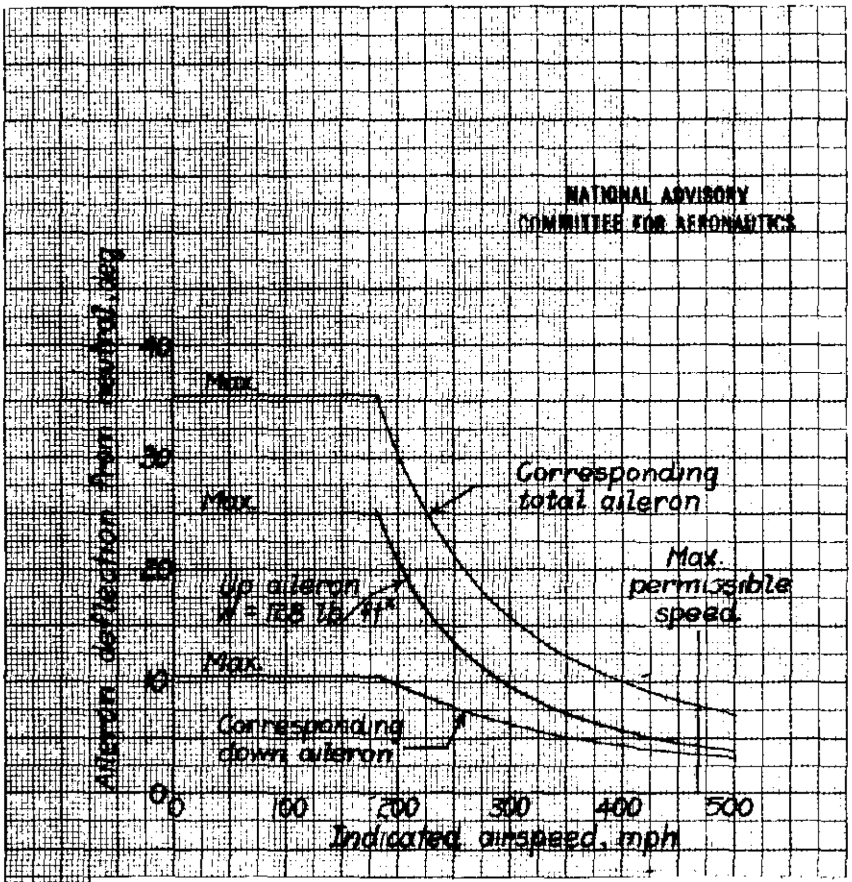

Figure 39. - Variation of permissible aileron deflection of P-39D-1 airplane with indicated airspeed as calculated for a design load of 128 lb/ft^2 on the critical up aileron. Curve for up aileron based on C_N values measured in wind-tunnel tests of similar wing-aileron combination at Mach number of 0.475. Effect of balancing tabs neglected.

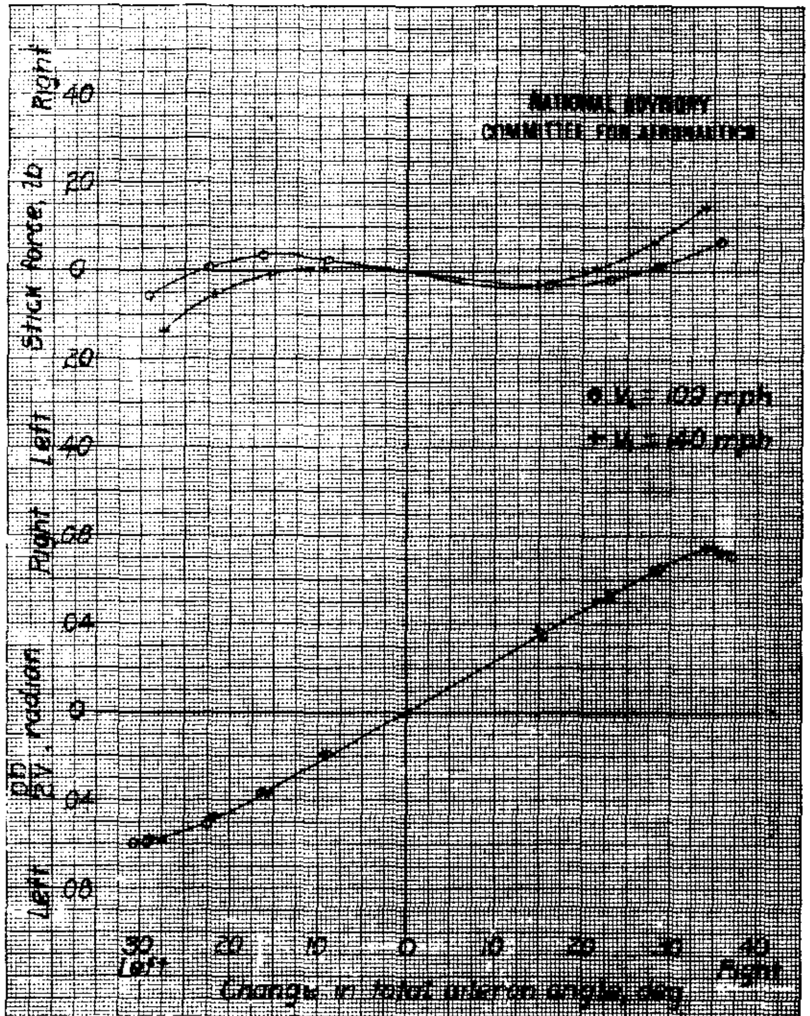

Figure 40. - Variation of aileron stick force and pb/2V with change in total aileron angle. Bell P-39D-1 airplane, flaps down, gear down, power for level flight.

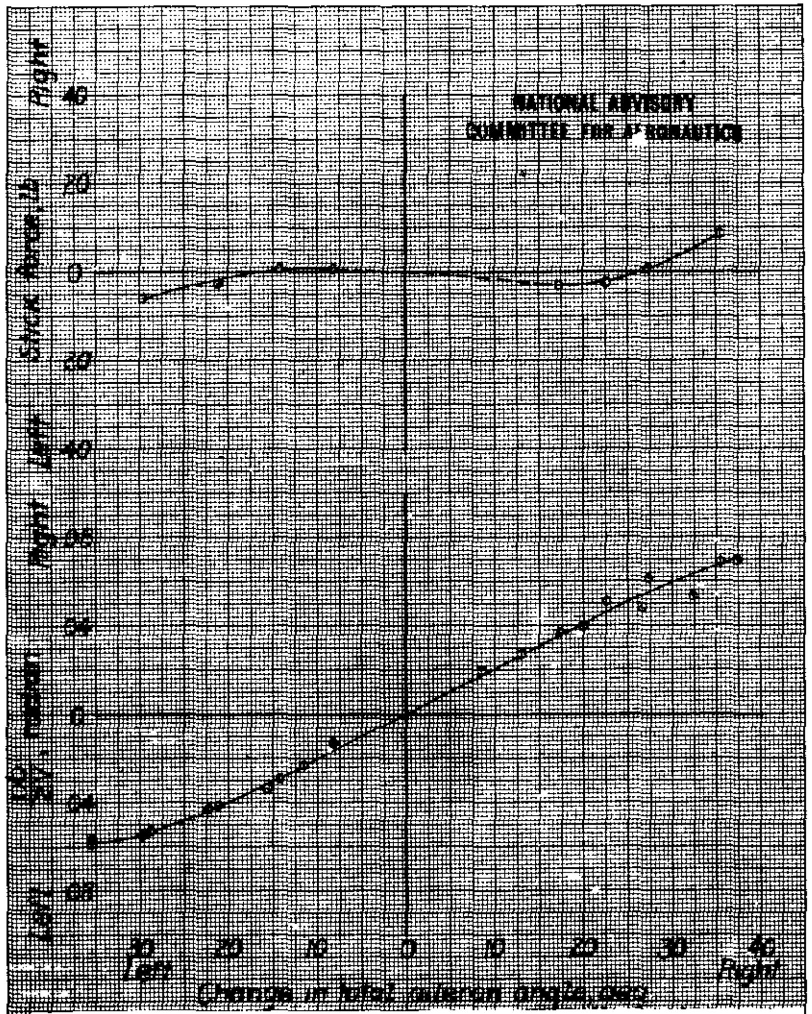

Figure 41. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 113 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, power for level flight.

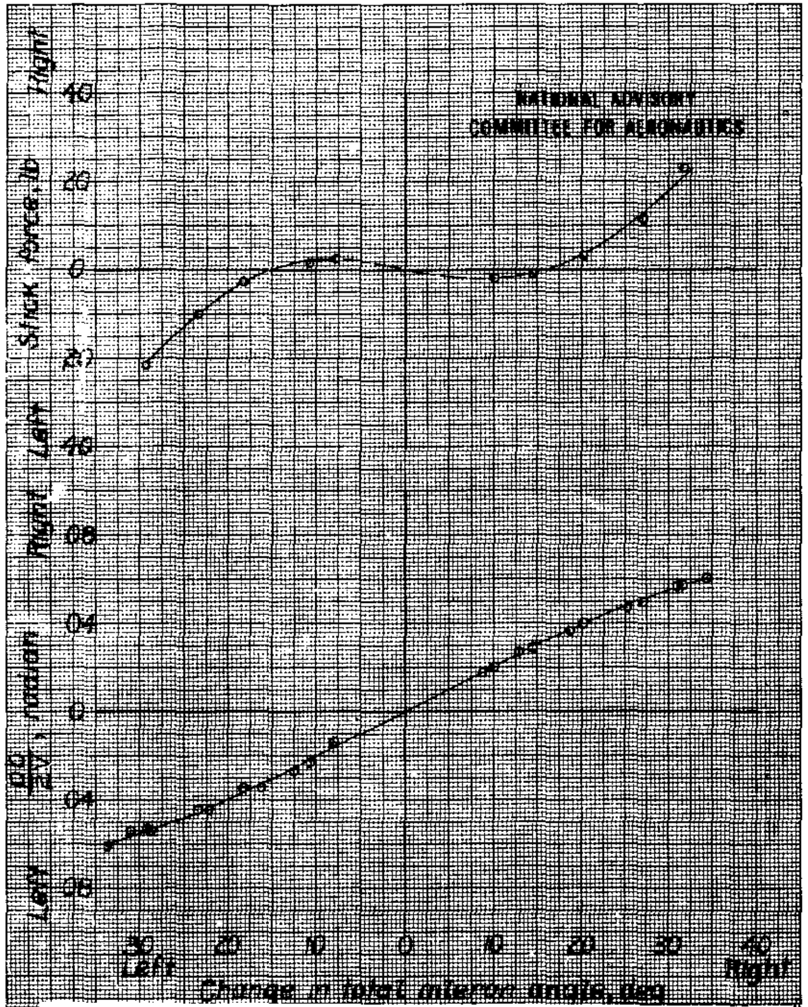

Figure 42. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 160 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, power for level flight.

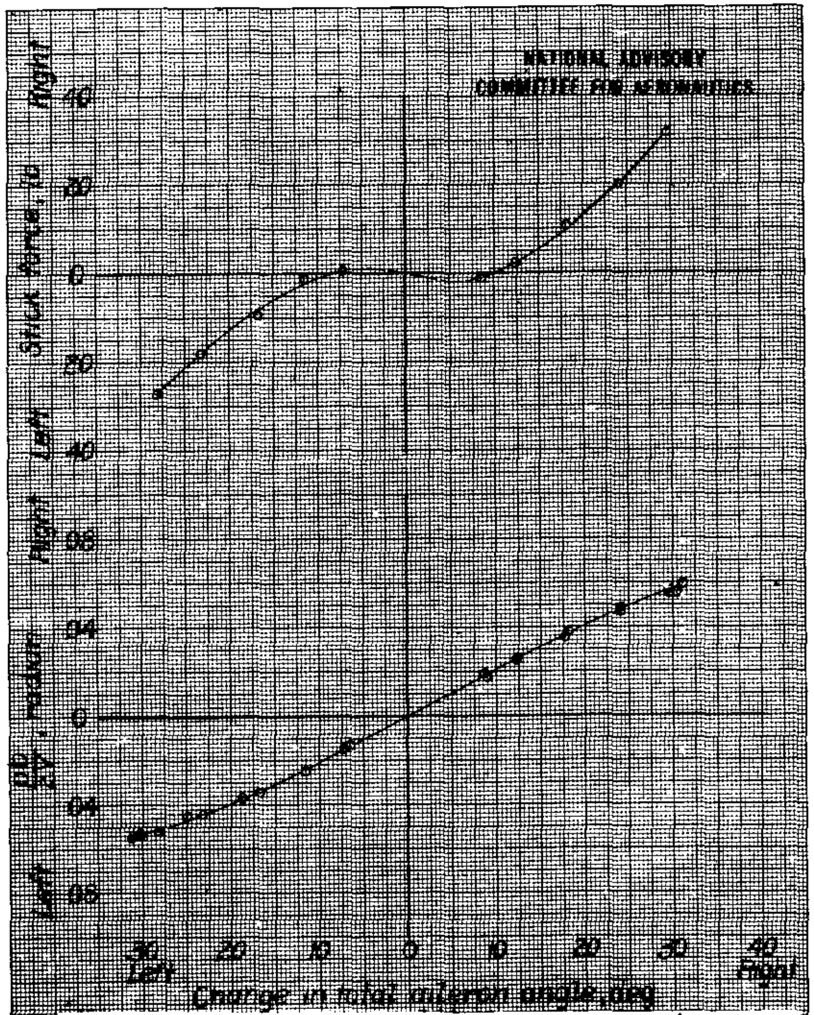

Figure 43. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 210 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, power for level flight.

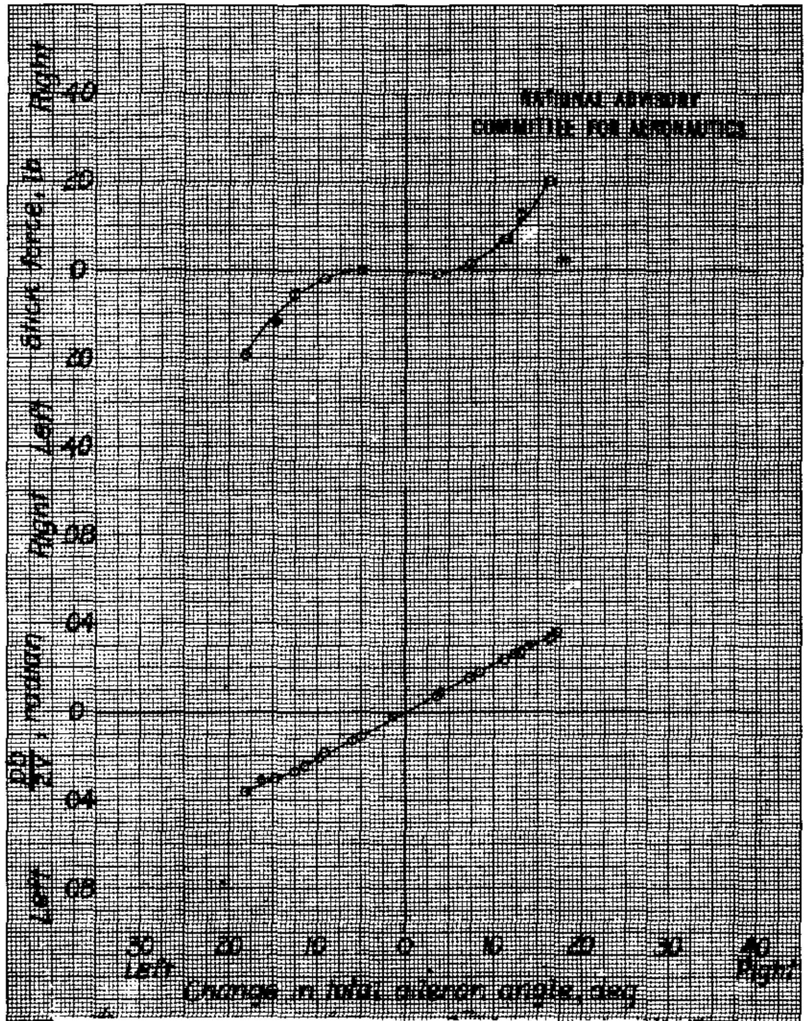

Figure 44. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 260 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, power for level flight.

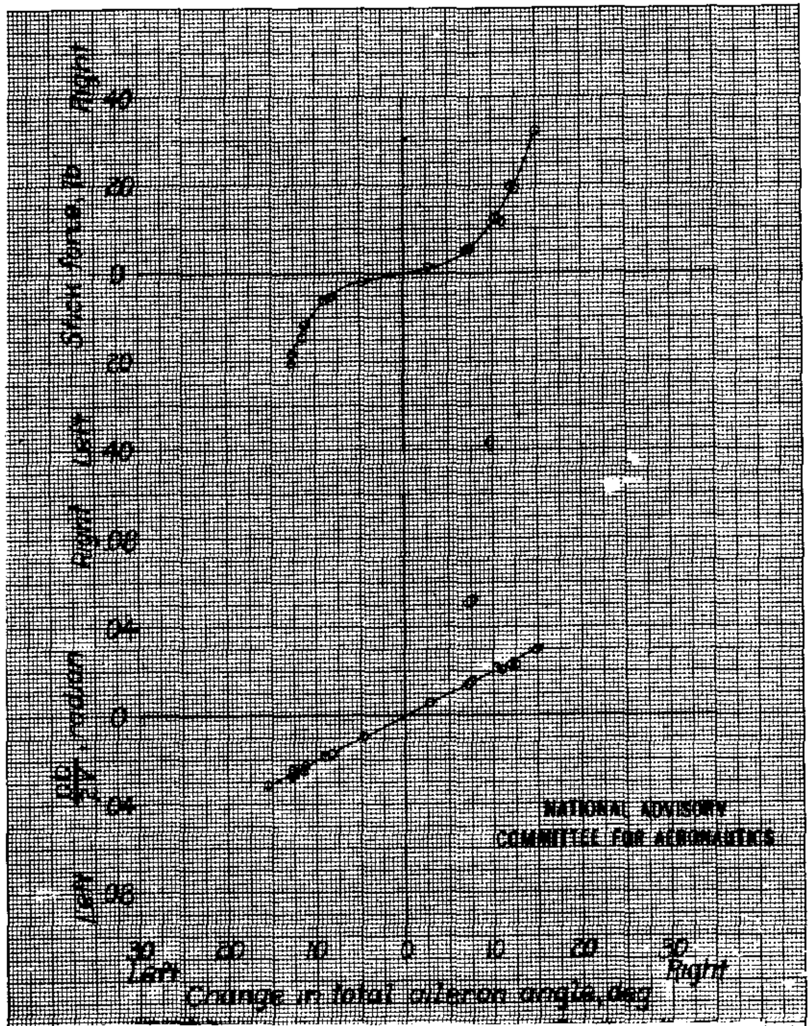

Figure 45. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 310 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, rated power.

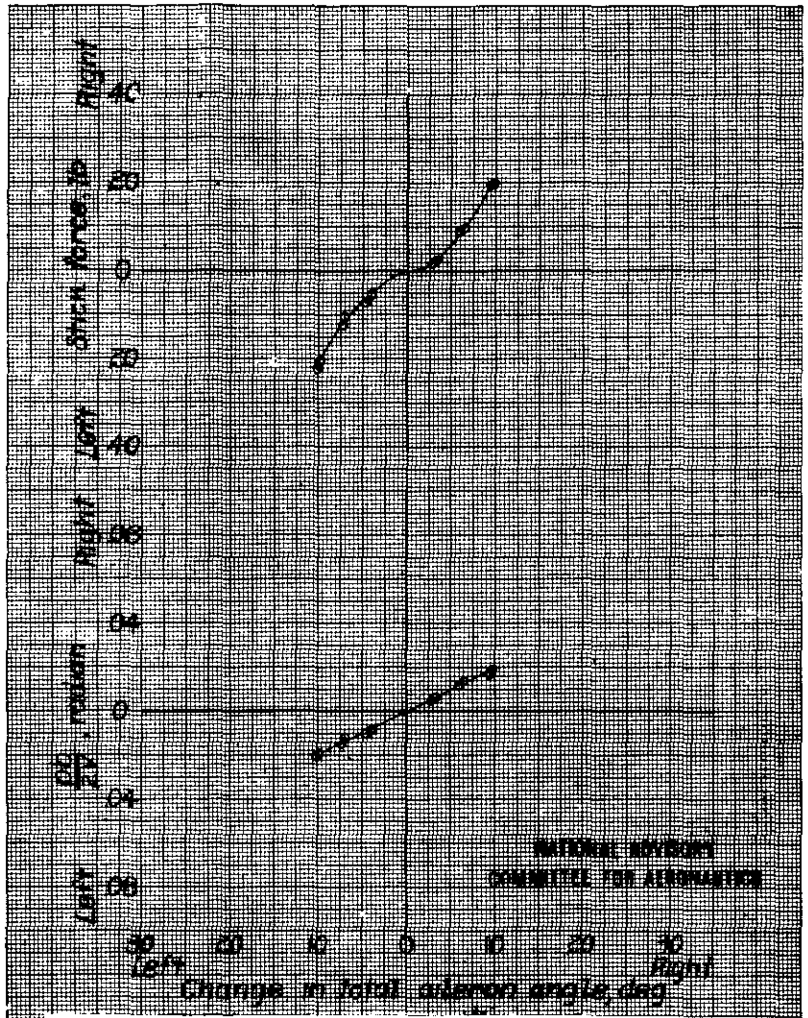

Figure 46. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 360 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, rated power.

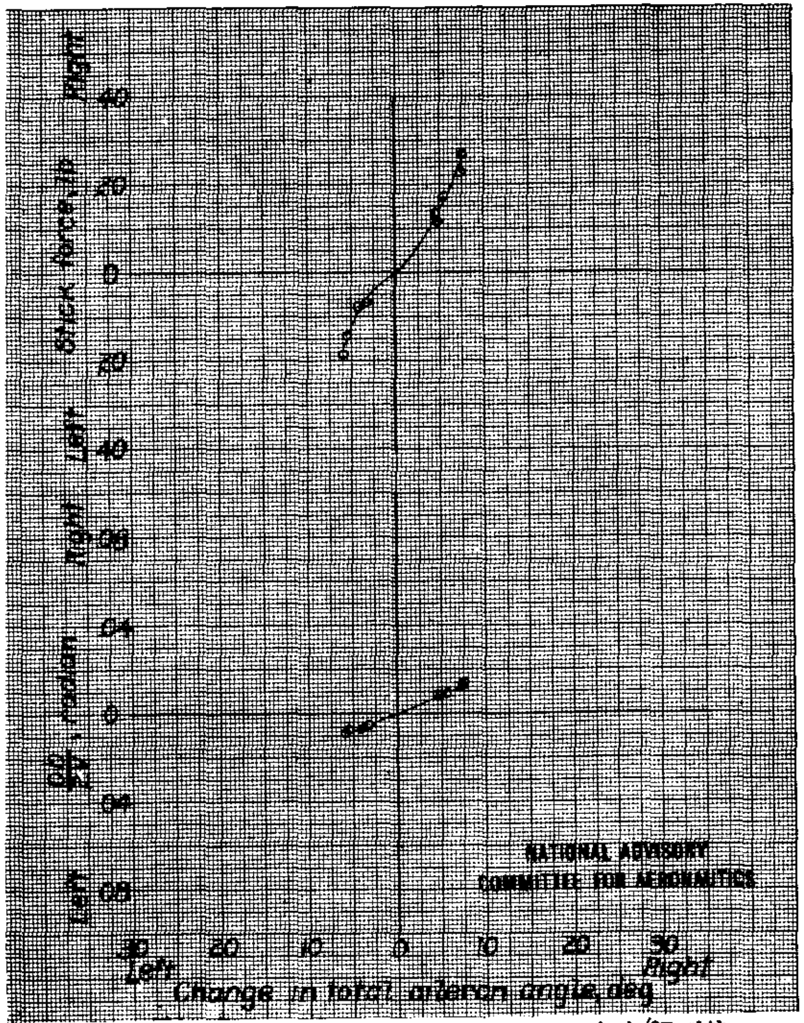

Figure 47. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeed of 410 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, rated power.

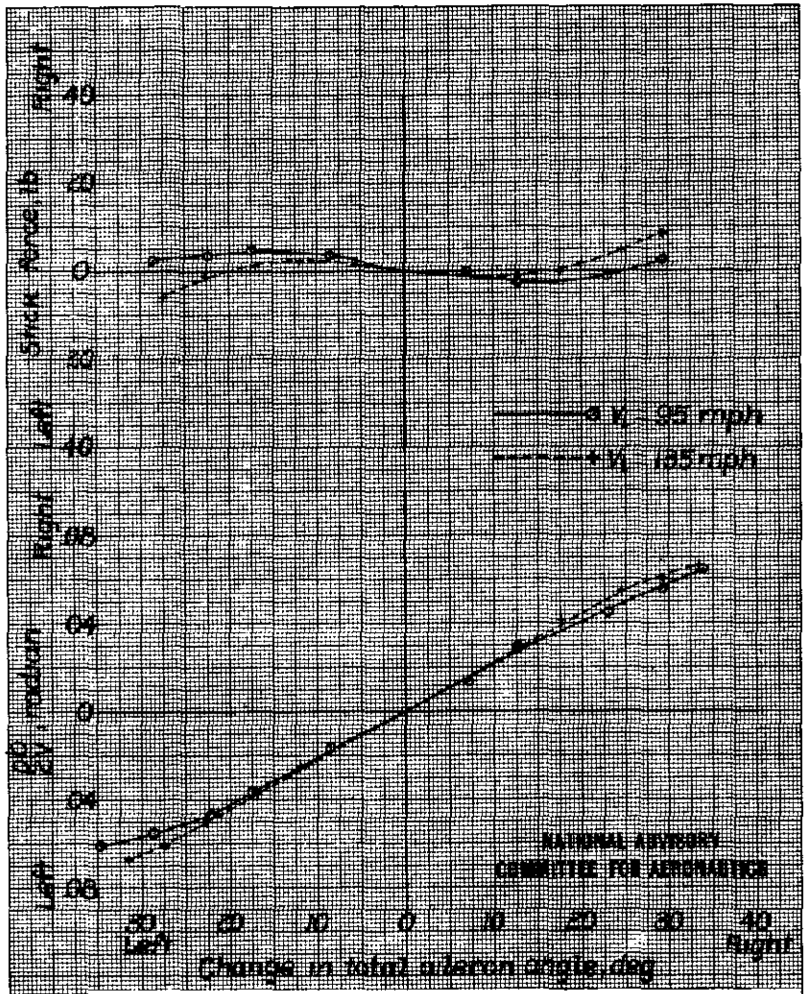

Figure 48. - Variation of aileron stick force and pb/2V with change in total aileron angle. Bell P-39D-1 airplane, flaps down, gear down, power off.

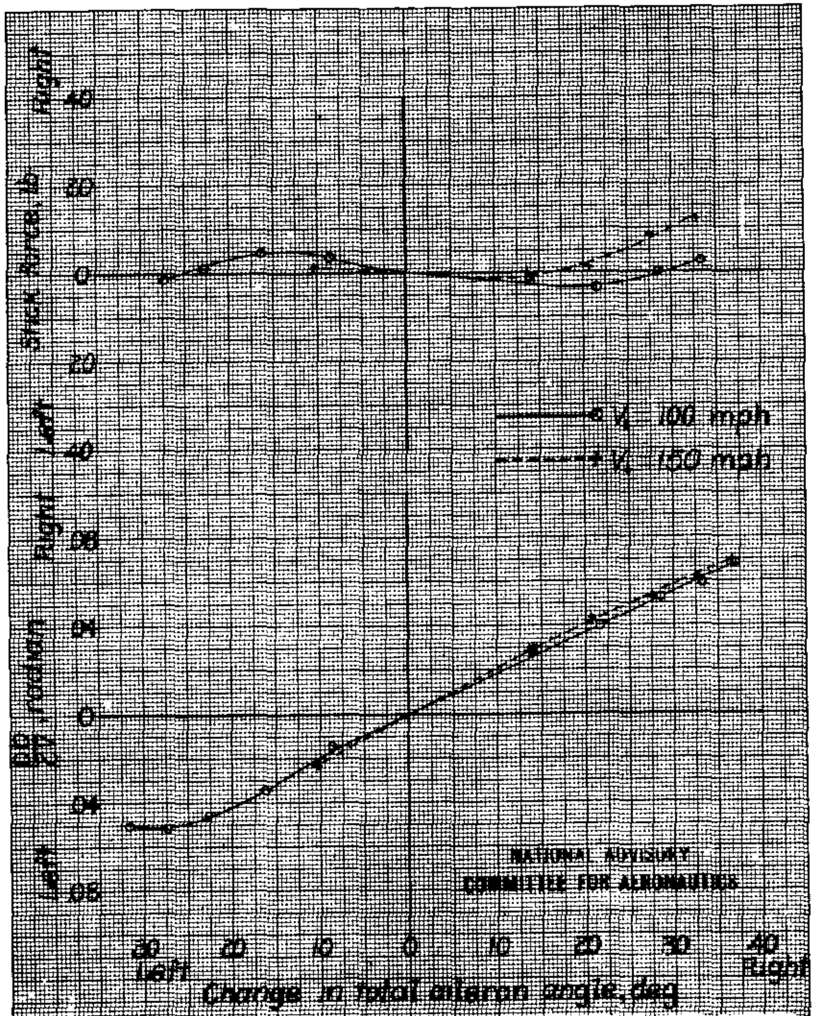

Figure 49. - Variation of aileron stick force and pb/2V with change in total aileron angle. Bell P-39D-1 airplane, flaps up, gear down, power off.

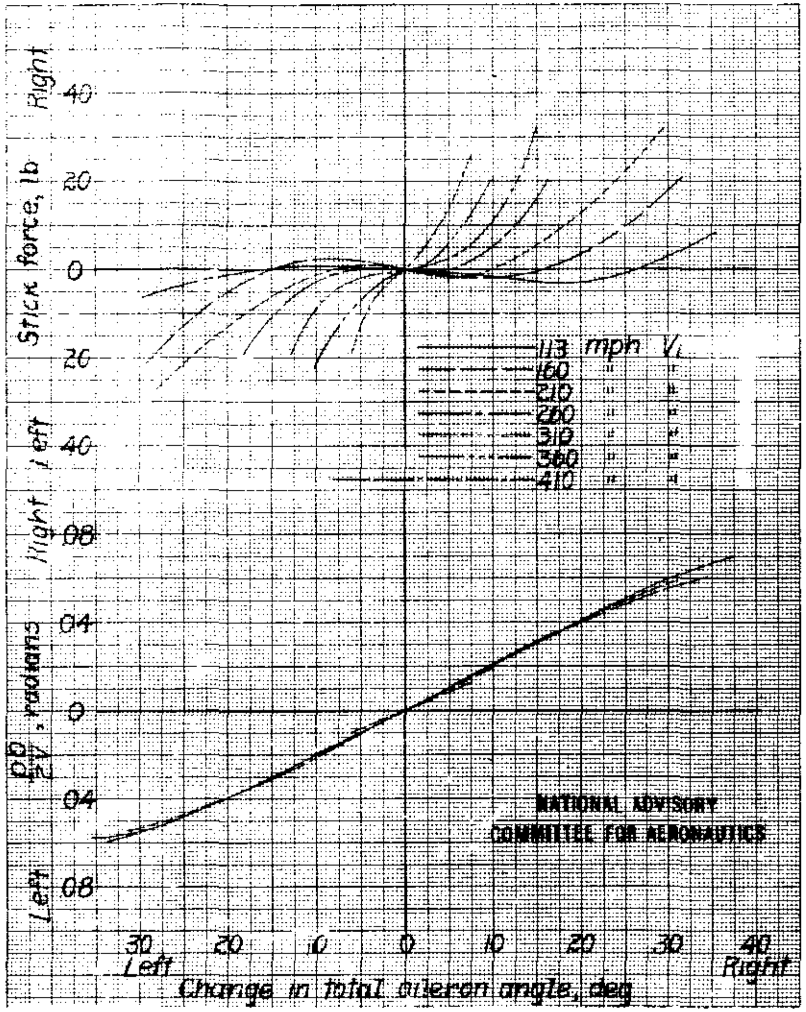

Figure 50. - Variation of aileron stick force and pb/2V with change in total aileron angle at indicated airspeeds of 113, 160, 210, 260, 310, 360, and 410 miles per hour. Bell P-39D-1 airplane, flaps up, gear up, power for level flight or rated power in dive.

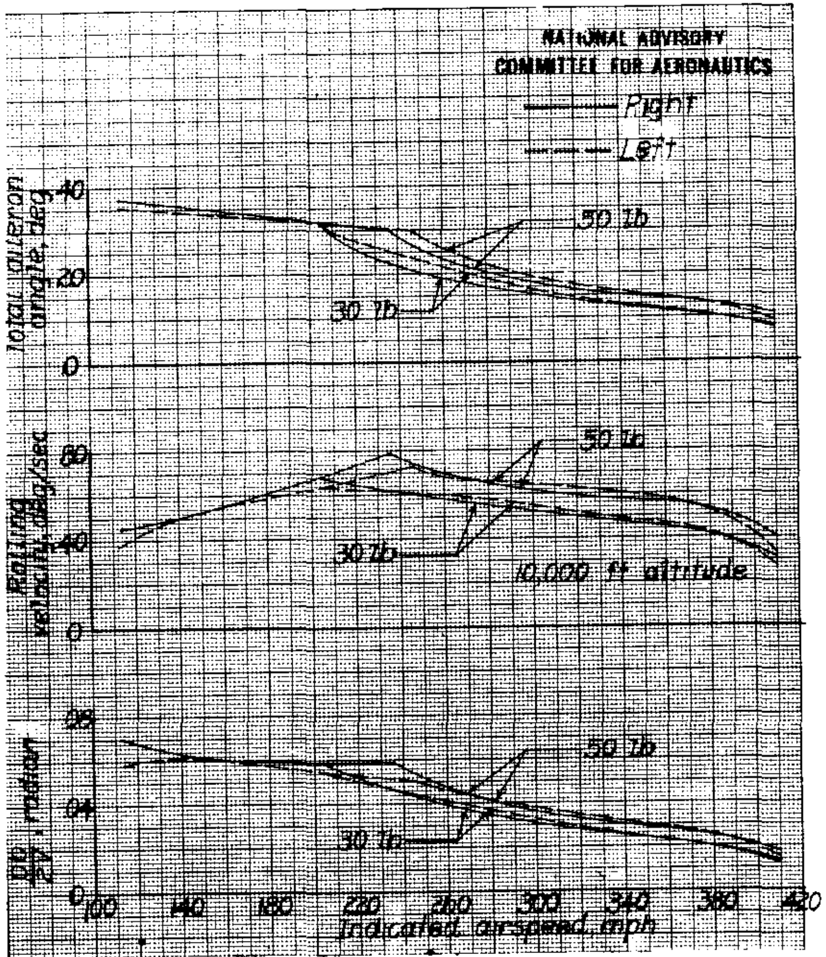

Figure 51. - Aileron characteristics with stick forces of 30 and 50 pounds. Bell P-39D-1 airplane, flaps up, gear up, power for level flight or rated power in dive (at speeds above V_i = 210 mph, curves obtained by extrapolating measured data).

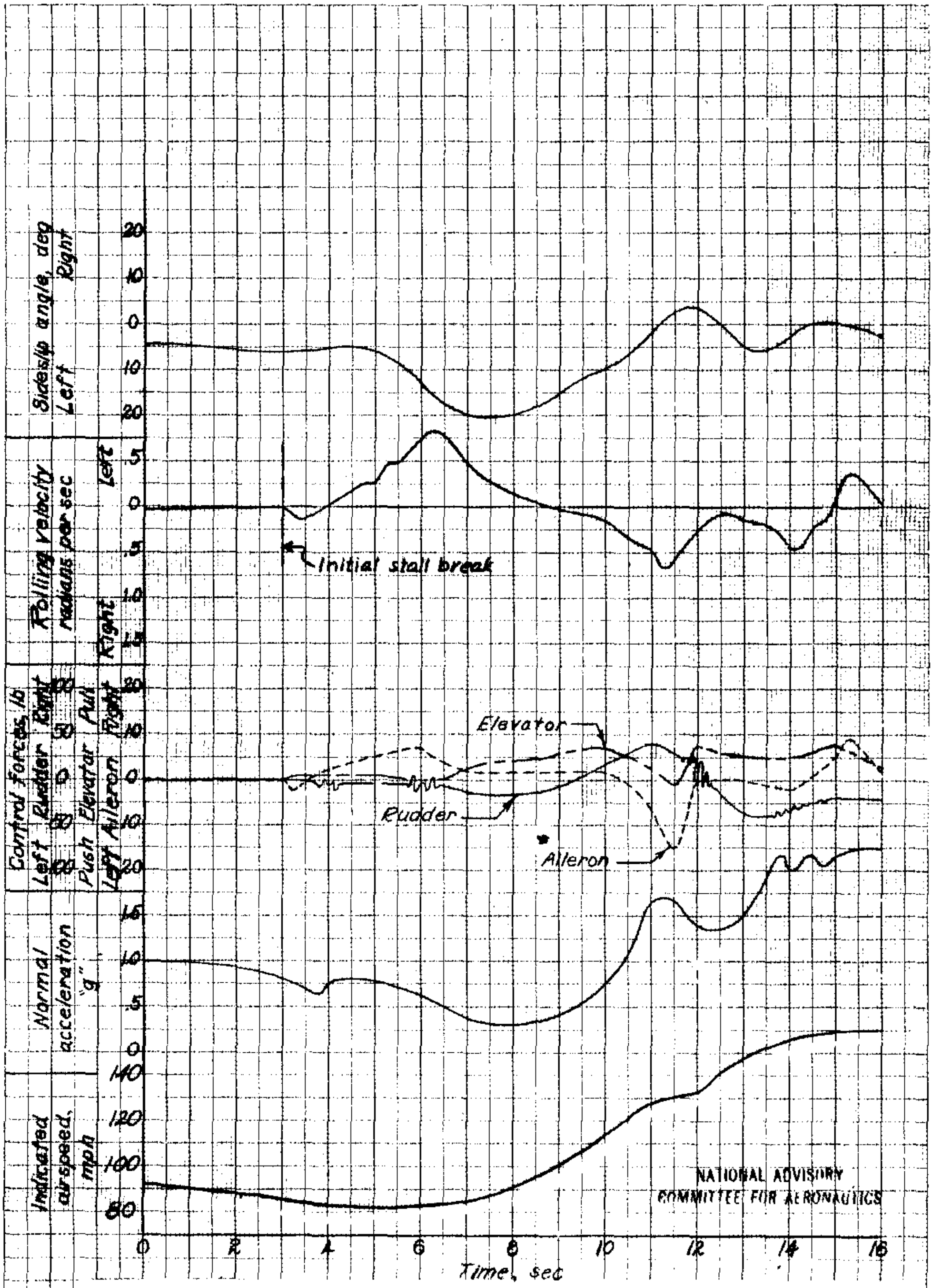

Figure 52. - Time history of stall from straight flight made with Bell P-39D-1 airplane in cruising maximum range configuration. Controls fixed at initial stall break. Note absence of stall warning. Sequence of rolling and pitching motion after stall break is typical. Note tendency of ailerons to float with roll.

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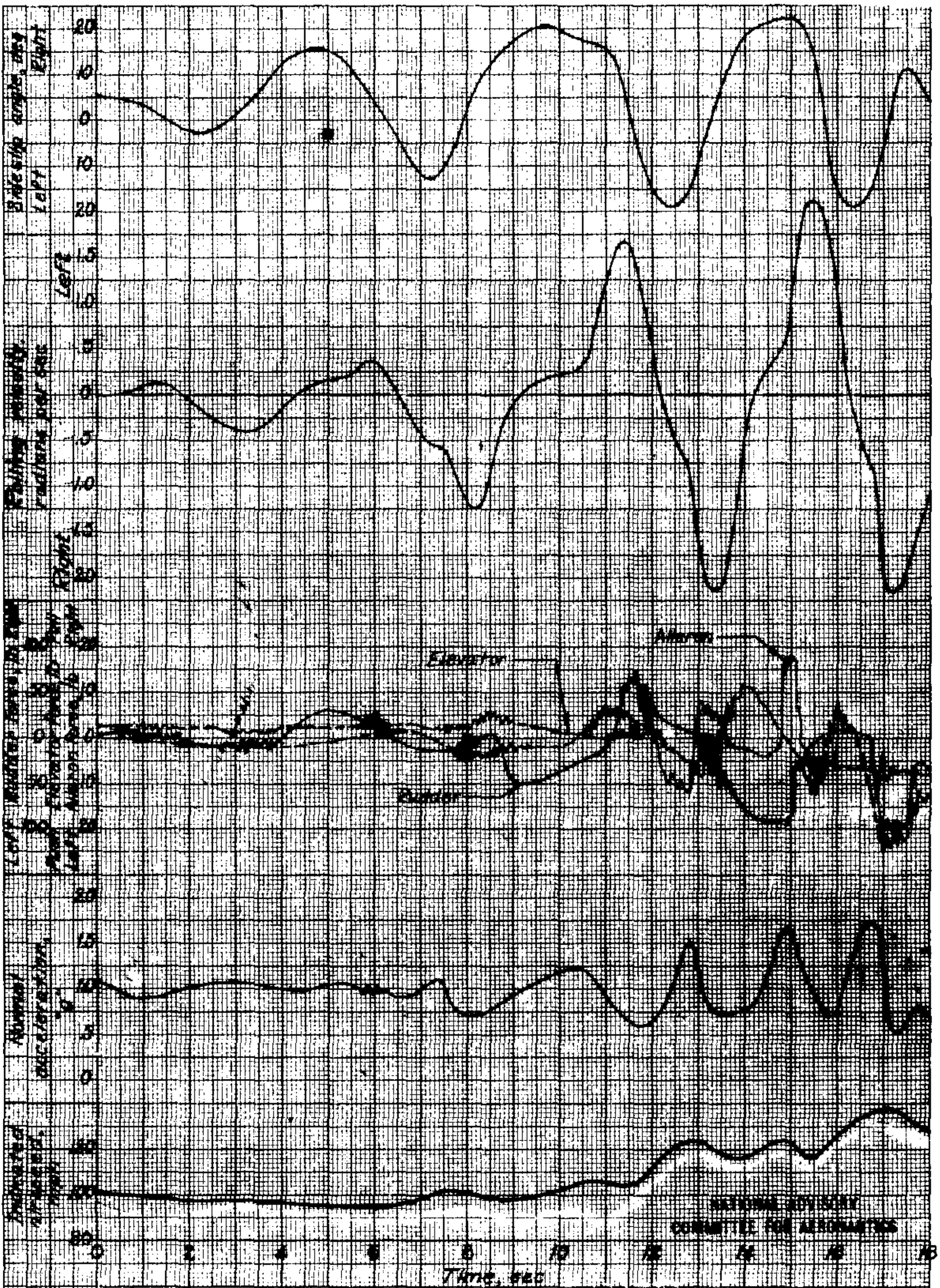

Figure 53. - Time history of stall from straight flight made with Bell P-39D-1 airplane in the gliding configuration. Rudder was used in attempting to maintain laterally level attitude as elevator was further raised. Note extreme amplitudes of rolling and yawing oscillations.

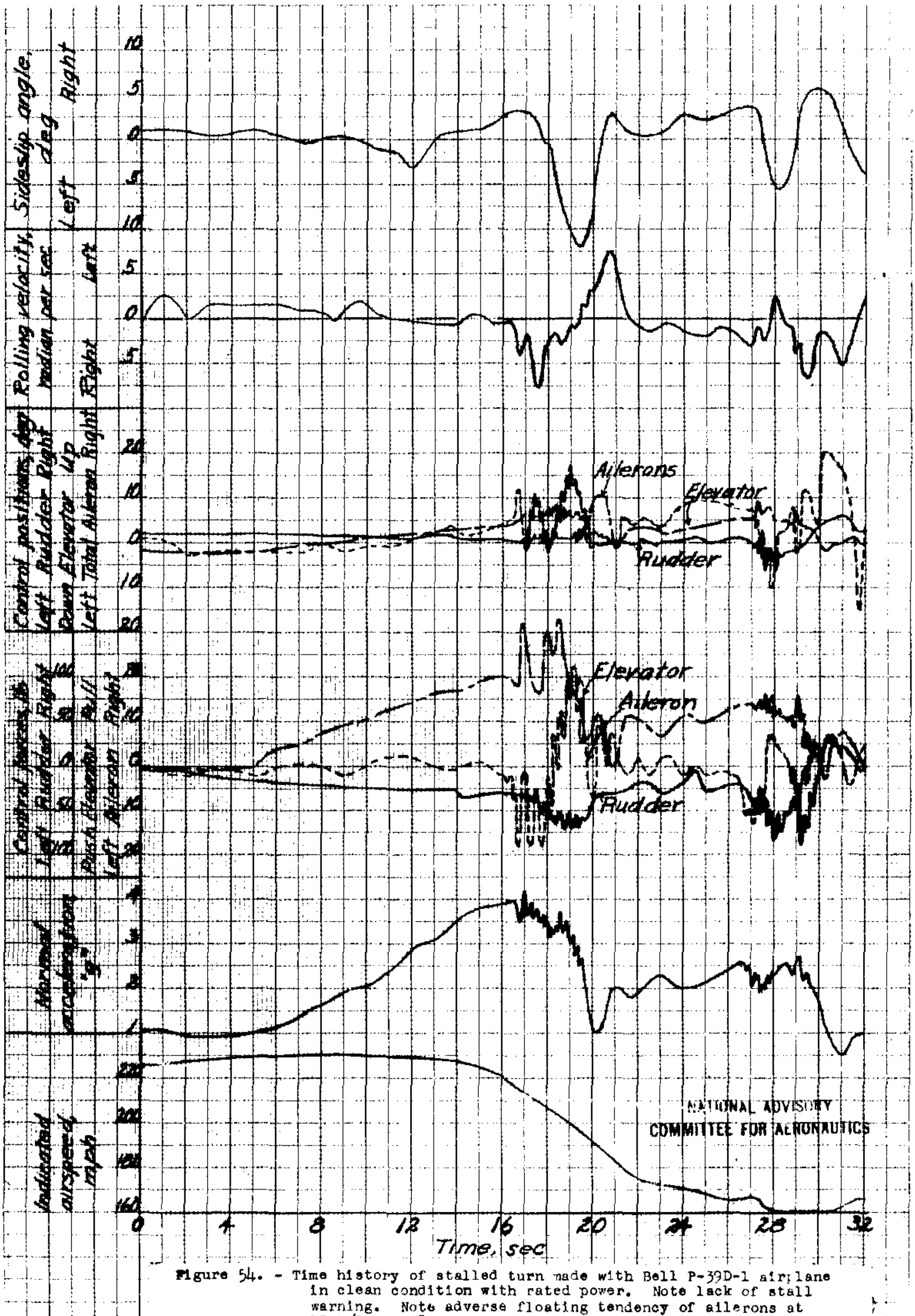

Figure 54. - Time history of stalled turn made with Bell P-39D-1 airplane in clean condition with rated power. Note lack of stall warning. Note adverse floating tendency of ailerons at 17-1/2 and 28 seconds. Note temporary recovery resulting from application of down elevator at 21 seconds.

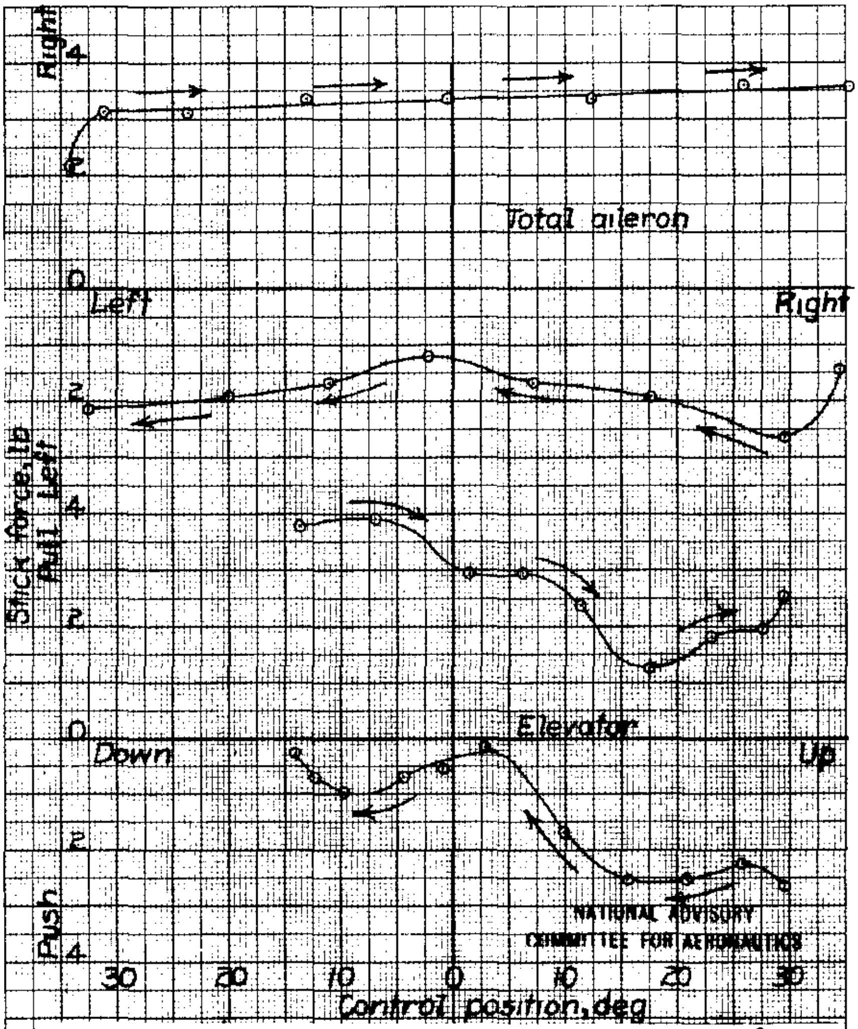

Figure 55. - Variation of stick forces required to move controls slowly as measured under static no-load conditions at temperature of approximately 70°F. Bell P-39D-1 airplane (A.A.F. No. 41-28378).