MR Dec. 1943

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

December 1943 as
Memorandum Report

MEASUREMENTS IN FLIGHT OF THE STABILITY, LATERAL-CONTROL, AND STALLING CHARACTERISTICS OF AN AIRPLANE EQUIPPED WITH FULL-SPAN ZAP FLAPS AND SPOILER-TYPE AILERONS

By J. Richard Spahr and Don R. Christophersen

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

MEASUREMENTS IN FLIGHT OF THE STABILITY, LATERAL-CONTROL, AND STALLING CHARACTERISTICS OF AN AIRPLANE EQUIPPED WITH FULL-SPAN ZAP FLAPS AND SPOILER-TYPE AILERONS

By J. Richard Spahr
and
Don R. Christophersen

SUMMARY

The stability, lateral-control, and stalling characteristics of an airplane modified to accommodate full-span Zap flaps were measured in flight at the Ames Aeronautical Laboratory.

The static and dynamic longitudinal and lateral stability was, in general, satisfactory. However, the airplane exhibited some undesirable lateral-control characteristics including excessive friction and elasticity in the lateral-control system and insufficient aileron effectiveness in producing desirable rolling characteristics.

By setting the control-force-regulating vanes, with which the upper-surface-type ailerons were equipped, in the nose-up position and by reducing the area of the aileron upper surfaces, it was possible to lighten the lateral control forces without appreciably decreasing the corresponding aileron effectiveness. However, these aileron modifications were not sufficient to effect satisfactory rolling characteristics for all flight conditions.

The maximum lift coefficients of the airplane calculated from flight-test data with the full-span flaps up, half extended, and fully extended are 2.01, 2.42, and 2.78, respectively, with rated power applied and 1.48, 2.05, and 2.27, respectively, with power off.

INTRODUCTION

The need for increased maximum lift coefficient and consequent decreased landing speed has led to considerable interest in the use of flaps extending along the entire wing span. Extensive wind-tunnel investigations and some flight tests have been conducted to develop a satisfactory combination of full-span flaps and lateral-control devices. Of the devices tested, the plug-type spoiler-slot ailerons, tests of which are reported in references 1 and 2, appeared to produce the most desirable lateral-control characteristics.

The investigation reported herein was conducted to determine the stability, lateral-control, and stalling characteristics of a test airplane equipped with wings employing modified plug-type spoiler-slot ailerons and full-span Zap flaps. The investigation also included flight tests of the airplane with various modifications to the lateral-control system made in an attempt to improve the lateral-control characteristics of the airplane.

DESCRIPTION OF THE AIRPLANE

The airplane used in this investigation is a two-place, single-engine, midwing, cantilever monoplane with fixed landing gear. The airplane is equipped with folding wings, full-span Zap flaps, upper-surface ailerons, and modified horizontal tail surfaces.

General views of the airplane are shown in figures 1, 2, and 3. Details of the wing, Zap flaps, and upper-surface ailerons are presented in figures 4 to 8.

The upper-surface ailerons, shown in their original condition in figure 6, are actuated by the lateral-control system, as shown in figure 8. The ailerons operate in tracks located within the wing structure and, when actuated by the control system, deflect about a center of rotation exterior to the wing surface. The aileron differential linkage located in the fuselage is shown in figure 9 for two positions of the control stick. The lateral-control system includes a small vane located beneath each aileron surface in the spanwise gap created between the aileron surface and the upper wing surface by deflecting the ailerons (fig. 6). These vanes are adjustable in pitch at three positions: nose-up, neutral, and nose-down as indicated in figure 8. The purpose of the vanes is to regulate the lateral-control forces. The vanes were set in the nose-up position for the original test condition.

The full-span Zap flaps, as shown in figures 4, 5, and 7, differ materially from the earlier version referred to in various aerodynamic publications as the Zap flap and which was in reality a split flap, the hinge line of which moved aft along the wing chord as the flap was deflected. The present design is a device for simultaneously increasing the area and camber of the basic wing for the purpose of stimulating and controlling the lift of the wing. The flap is constructed as a segment of a circular arc which is tangent to the upper contour of the wing near the trailing edge of the wing when the flap is extended. When retracted within the wing, the trailing edge of the flap forms the trailing edge of the wing. The extension of the flap is accomplished by rotation about a center coincident with the center of its own structural arc, thus maintaining an unbroken mean camber throughout the basic airfoil and flap in all stages of rotation (fig. 7).

General specifications of the airplane as originally delivered for test, are as follows:

Airplane	
Length (over-all)	31.0 ft
Height (thrust line level).	12 ft, 11-1/8 in.
Normal center-of-gravity position .	25.7 percent aft of the leading edge of the mean aerodynamic chord
Engine	
Type.	No. R-985-48
Ratings	
Normal	400 bhp at 2200 rpm at sea level and 5500 ft
Take-off	450 bhp at 2300 rpm and 35.5 inches of mercury at sea level
Propeller	
Type.	Two-blade, constant-speed
Diameter.	8.50 ft

Wing	
Span.	36.0 ft
Area (including ailerons and 24.5 sq ft of fuselage)	205.8 sq ft
Airfoil section	Zap section, tapered in thickness from 17.25 percent at the center line of the airplane to 12 percent at the wing tip
Dihedral.	7.0°
Sweepback (leading edge).	$2^\circ 51'$
Incidence	3.0°
Mean aerodynamic chord.	72.5 in.
Wing flaps (each)	
Area (aft of hinge).	19.16 sq ft
Span	15 ft 7 in.
Deflection	$41^\circ 55'$ rotation, trailing edge 21.5 percent chord aft, 23 percent chord down
Ailerons	
Length (along each wing) . . .	10 ft, 4.8 in.
Total area aft of hinge. . . .	13.46 sq ft
Deflection	
Left.	*37.8° up * 0.75° down
Right	*42.0° up * 2.2° down
Horizontal tail surfaces	
Total area.	59.3 sq ft
Span.	14.5 ft
Stabilizer	
Total area including 4.3 sq ft of fuselage and 4.4 sq ft of elevator balance. . .	35.8 sq ft
Dihedral	7.0°
Incidence.	3.0° from thrust line (leading edge up)
Elevators	
Total area aft of hinge including trim tabs	23.5 sq ft
Deflection.	*28.2° up *24.3° down

Tabs

Total area.	2.6 sq ft
Deflection of trailing edge from neutral	*11.9° up *12.9° down

Vertical tail surfaces

Total area.	20.4 sq ft
Fin	
Total area including 1.18 sq ft of rudder balance. . . .	8.9 sq ft
Rudder	
Total area aft of hinge including trim tab	11.5 sq ft
Deflection	*27.2° left and right
Tab	
Area.	0.35 sq ft
Deflection.	*20° left and right

*Values measured at the laboratory

The kinematics of the longitudinal- and lateral-control systems with the surfaces unloaded are presented in figures 10, 11, and 12.

Minor modifications made to the lateral-control system during the course of the tests in an attempt to improve the lateral-control characteristics of the airplane include:

Modification 1.- Vanes placed in nose-down position

Modification 2.- Vanes removed from all aileron surfaces

Modification 3.- Axes of rotation of vanes lowered an average of 1/4 inch; vanes set in nose-up position

Modification 4.- Upper surface of outer and inner aileron panels cut back, thereby reducing the original upper-surface area by approximately 44 percent (fig. 5); vanes set in the nose-down position

Modification 5.- Upper surfaces as in modification 4 with vanes set in nose-up position

Modification 6.- Upper surfaces of central aileron panels reduced in area as in modification 4 with vanes set in nose-up position; the modified upper surfaces are shown in figures 13 and 14.

Modification 7.- Upper surfaces as in modification 6 with vanes set in nose-down position

Modification 8.- Upper-surface slots (fig. 14), originally covered with fabric, opened; vanes set in nose-down position.

INSTRUMENTATION

NACA photographically recording instruments were installed in the airplane to obtain records from which the following quantities were evaluated: indicated airspeed; elevator, aileron, and rudder angles; rolling and yawing velocities; elevator and aileron control forces; angle of sideslip; and normal and lateral acceleration factors. Standard airplane indicating instruments were used to determine manifold pressure, engine speed, and free-air temperature.

The airspeed recorder was connected to a vaned airspeed head which was free to rotate in pitch and yaw. The airspeed head was mounted on the forward end of a boom which was located near the left wing tip and extended approximately one wing-chord length ahead of the wing leading edge (fig. 1).

The elevator- and rudder-angle recorders were attached to the control systems as close to the control horns as possible, thereby minimizing the effects of control-system elasticity on the recorded values of control positions.

Due to the absence of sufficient space to accommodate an aileron-angle recorder in the wing near the ailerons, this instrument was mounted in the fuselage at the differential mechanism.

The control-force recorder was installed on a specially constructed control stick, the grip of which was in the same location as that of the normal stick.

The sideslip-angle recorder vane was mounted on the forward end of a boom which extended approximately one wing-chord length ahead of the right wing near the wing tip (fig. 1).

All records were synchronized by means of a timer.

TESTS

The stability- and lateral-control characteristics of the airplane were determined in flight with the center of gravity located at 28.4 percent of the mean aerodynamic chord and with an average gross weight of 4960 pounds.

The dynamic longitudinal stability, as indicated by the degree of damping of the short-period oscillation, was investigated for various combinations of power, flap positions, and airspeed by deflecting and quickly releasing the elevator control and recording the resulting motions. Tests for the determination of static longitudinal stability were made in steady straight flight for the following configurations: (1) climb condition - rated power, flaps up; (2) glide condition - power off, flaps up; (3) wave-off condition - rated power, flaps down; and (4) landing condition - power off, flaps down. Records were taken of several three-point landings to ascertain the elevator control characteristics in landing.

The elasticity in the lateral-control system was determined on the ground by measuring the deflections of the left and right ailerons when they were separately subjected to various static loadings with the control stick fixed in several positions. In order to estimate the friction in the lateral-control system from the records of aileron angle and control force, the control stick was moved slowly from left to right several times both on the ground with no load on the surfaces and in flight at various conditions.

Records were made of the motions of the airplane and control surfaces resulting from quickly pushing and releasing the stick laterally with the airplane in flight at several power, flap, and speed conditions to indicate the characteristics of the control-free lateral oscillation. In order to determine the aileron control characteristics, records were also taken for the following conditions in abrupt rudder-fixed aileron rolls in which a constant aileron deflection was maintained until the rolling velocity had attained its maximum value:

Power	Flap position	Indicated airspeed (mph)
Rated	Up 1/2 down Down	92 and 155 92 and 122 92 and 122
Off	Up 1/2 down Down	92 and 155 92 and 122 92 and 122

Rudder-fixed aileron rolls were also made with the airplane in rated-power flight for each modification to the lateral-control system. With flaps up the rolls were made at approximately 92 and 155 miles per hour, and with flaps down the airspeed averaged 122 miles per hour.

Records were taken with the airplane in steady sideslips to determine the characteristics of rolling moment due to sideslip (dihedral effect). These flight tests were made with the airplane in its original condition for the several combinations of power, flap position, and airspeed shown below.

Power	Flap position	Indicated airspeed (mph)
Rated	Up Down	92 and 155 92 and 121
Off	Up Down	92 and 155 92 and 121

Stalls were made in straight flight for the determination of the stalling characteristics of the airplane. The tests were carried out with the airplane in the original condition and with the center of gravity located at approximately 31.1 percent of the mean aerodynamic chord and an average gross weight of 5120 pounds. The following types of stall and control in the stall were attempted for all combinations of power (rated and off) and flap position (up, one-half down, and down):

1. Control stick brought back and held at first warning of stall, ailerons and rudder fixed

2. Stick pulled full back and held, ailerons and rudder fixed

3. Stick brought back to point of stall and held, control by means of ailerons alone, rudder fixed

4. Stick brought back to point of stall and held, control by means of rudder alone, ailerons fixed

In order to study the air flow over the wing during the various stalls, 6-inch wool tufts were placed over the upper surface of the right wing, enabling an observer in the rear cockpit to note the manner and progression of the flow breakaway.

RESULTS AND DISCUSSION

The stability and stalling characteristics of the test airplane in general impressed the pilots favorably, but several features of the lateral control were considered undesirable. Most of the flight-test results are presented and discussed in relation to the recommendations for satisfactory stability and control characteristics given in references 3 and 4.

Longitudinal Stability

Characteristics of uncontrolled longitudinal motion.- From the time histories of the short-period oscillations shown in figure 15, it is observed that in every condition investigated the oscillation of elevator angle and normal acceleration following the release of the elevator control completely disappeared after one cycle.

Characteristics in steady flight.- The elevator control characteristics in steady straight flight are shown for four flight configurations in figures 16 to 19. From the variation of elevator angle with airspeed, it is seen that the airplane exhibited stick-fixed stability over the test speed range for all four flight conditions.

The stick-free stability of the airplane, as indicated by the slopes of the control-force airspeed curves at the trim speeds, appeared to be satisfactory over the speed range for the climb, glide, and landing conditions. In each case the control-force gradient at trim speed was greater than the minimum value of 0.05 pound per mile per hour as recommended in reference 3 when friction in the control system is low. The friction in the elevator control system of this airplane is approximately 0.75 pound which is less than the maximum value of 2 pounds prescribed in reference 3. For the wave-off condition it is observed from figure 18 that neutral stick-free stability exists at the trim speed.

Characteristics of the elevator control in landing.- The elevator control characteristics in landing are indicated by the time histories of two landings shown in figures 20 and 21. From the time history of the landing shown in figure 20, it is seen that the amount of pull force necessary to bring the tail down was in excess of the 35 pounds maximum force recommended in reference 3. However, these forces could possibly have been reduced by making use of the additional 12° tab angle available. Figure 21 indicates that the elevator control was sufficiently powerful to hold the airplane off the ground until three-point contact was made.

Lateral-Control Characteristics

Control-system characteristics.- The elasticity or stretch in the lateral-control system in terms of the aileron angle as a function of the aileron control force as determined on the ground is presented in figure 22. From this relationship and from an average variation of aileron control force with total uncorrected aileron angle obtained in rudder-fixed aileron rolls, the ratio of the stretch to the corresponding static no-load uncorrected aileron angle is shown as a function of control force in figure 23 for three airspeeds. From these curves it is observed that the stretch in the system is considerably in excess of the limiting requirement (reference 4) that the stretch corresponding to a stick force of 30 pounds shall not exceed 20 percent of the static no-load aileron deflection.

The major portion of the lateral-control-system stretch results from excessive torsional deflection of the aileron-actuating torque tube (fig. 8). The remainder of the stretch may be attributed to deflection in the differential linkage and bending in the fuselage torque tube. This stretch could be reduced considerably by using aileron torque tubes having a greater cross-sectional moment of inertia. The use of push pull rods in place of the torque tubes would eliminate a large amount of stretch, but this type of installation would involve several structural difficulties. It should be noted that considerable play was present in the aileron control system; that is, with the stick in a fixed position, it was possible to move the aileron surfaces through 10° to 15°. This large degree of play resulted from loose fits in the several links of the differential mechanism and the aileron torque-tube universal joints at the fold line of the wing. Although not particularly objectionable from a pilot's standpoint, a reduction in the play in the system could be effected by closer fits in the installation.

The friction in the lateral-control system with no load on the surfaces is shown in figure 24 to have an average value of 7.5 pounds. With the airplane in flight the average friction was 5.1 pounds for various power, flap, and speed conditions. A typical friction curve as obtained in flight is presented in figure 25. The friction in flight was slightly lower with power on than that with power off, due to the effects of engine and propeller vibrations. These friction forces are in excess of the maximum values of 1 and 4.5 pounds specified in references 3 and 4, respectively, as upper limits of friction in the lateral-control system.

The principal source of friction in the lateral-control system appears to be in the six sets of tracks and rollers in each wing guiding the aileron movements (section B-B, fig. 8). Other sources of friction lie in the various links in the differential mechanism and other pivot points. The lateral-control friction could be reduced considerably by eliminating the tracks and rollers and using a direct connection between the surfaces and the torque tube.

It may be remarked that the exceptionally heavy aileron structure and accompanying mass balance necessitated by the unconventional aileron and support design was responsible for unusually high inertia in the control system. The high inertia forces offered relatively great resistance to any sudden motion of the control stick and for this reason was considered objectionable by the pilots. The inertia could be reduced by a revised aileron design using a simplified operating mechanism and support.

Characteristics of uncontrolled lateral motion.- The characteristics of the control-free lateral oscillation are indicated by the time histories of figures 26 to 29. It is seen that in every test condition the motions damped to one-half amplitude in less than two cycles as recommended by the requirements of reference 3 except in the case of rated power, flaps up, and 207 miles per hour where the yawing velocity was not adequately damped. When the ailerons were deflected and released quickly, they returned to their trim position in all cases except at low deflections and low speeds. The fact that the ailerons were able to overcome the high friction force and return to neutral was undoubtedly due to the large inertia in the system. Any oscillations of the ailerons themselves in all cases disappeared after one cycle.

Aileron control characteristics.- The variation of maximum rolling velocity, maximum pb/2V (the tangent of the helix angle generated by the wing tips), and aileron control force with total aileron angle corrected for stretch in the system is shown in figures 30 to 35 with the ailerons in their original condition. It may be seen that the maximum rolling velocity varied smoothly with, and was approximately proportional to, the aileron angle for all conditions investigated except in the rated-power, flaps-down condition at 122 miles per hour. The rolling acceleration, in every case, attained its maximum value within 0.2 second after the controls had reached their given deflection and was always in the correct direction, thus satisfying the requirement of references 3 and 4. The rolling criterion, expressed by the maximum value of pb/2V resulting from an aileron control force of 30 pounds (figs. 30 to 35), is tabulated below for each flight condition.

Power	Flap position	Indicated airspeed (mph)	pb/2V for 30-pound control force		Figure number
			Left	Right	
Rated	Up	92	0.040	0.060	30
		155	.046	.040	
	1/2 down	92	.060	.063	31
		122	.060	.047	
	Down	92	.062	.058	32
		122	.032	.010	
Off	Up	92	.040	.047	33
		155	.040	.035	
	1/2 down	92	.061	.071	34
		122	.058	.064	
	Down	92	.070	.074	35
		122	.043	.048	

It is observed that in only two conditions (power off, flaps one-half and full down at 92 mph) did the above values reach the minimum of 0.07 recommended by the requirement of references 3 and 4. The flap position seemed to have no marked effect on the rolling criterion; the optimum position, however, appears to be one-half deflection. No consistent difference exists between the values in right rolls and those in left rolls.

The variation of the aileron control force with aileron angle, as shown in figures 30 to 35, for all flight conditions is a smooth curve having a flat portion on either side near neutral position. The combined effects of this force characteristic and the high friction force in the control system tend to produce poor self-centering characteristics and insufficient control feel, which is objectionable from a pilot's standpoint.

A comparison at this point of the aileron control characteristics with those of the original unmodified airplane may be of some interest. For all flight conditions the curves relating both maximum rolling velocity and aileron control force with aileron angle were more linear in the case of the original unmodified airplane, but in general the maximum values of pb/2V for 30 pounds of control force were less than those for the Zap version of the airplane. The self-centering characteristics of the original unmodified airplane were superior to those of the Zap airplane, due to the greater slope of the control-force curve at the neutral position and the smaller amount of friction in the control system.

The aileron control characteristics of the airplane with the several modifications of the aileron surfaces are indicated by the curves of figures 36 to 38. Corresponding curves for the original condition have been included for purposes of comparison. The maximum values of pb/2V resulting from a lateral-control force of 30 pounds are tabulated below for rated-power flight for each aileron modification.

Modification	Flaps	Indicated airspeed (mph)	pb/2V for 30-pound control force		Figure number
			Left	Right	
1	Up	92	0.028	0.065	36(a)
		155	.024	.038	37(a)
	Down	122	.022	.041	38(a)
2	Up	92	.029	.047	36(a)
		155	.028	.036	37(a)
	Down	122	.010	.020	38(a)
3	Up	92	.030	.047	36(b)
		155	.035	.040	37(b)
	Down	122	.035	.038	38(b)
4	Up	92	.042	.059	36(b)
		155	.037	.042	37(b)
5	Up	92	.040	.052	36(c)
		155	.039	.046	37(c)
	Down	122	.034	.047	38(c)
6	Up	92	.044	.069	36(c)
		155	.054	.056	37(c)
	Down	122	.056	.080	38(c)
7	Up	92	.040	.064	36(d)
		155	.040	.045	37(d)
	Down	122	.042	.054	38(d)
8	Up	92	.046	.060	36(d)
		155	.040	.045	37(d)
	Down	122	.047	.055	38(d)

The characteristics of the aileron control with modified aileron surfaces as compared to those in the original condition are as follows:

Modification 1.- The effectiveness of the vanes in changing the lateral-control-force characteristics is indicated by a comparison of the results of the aileron rolls made with the vanes in the nose-down position with the corresponding results for the original nose-up vane condition (figs. 36(a), 37(a), and 38(a)). It is seen that, as a result of this vane adjustment, the control forces were increased without any appreciable increase in the corresponding rolling velocities. This is to be expected as the vanes in their nose-up position act as lifting surfaces tending to produce aerodynamic balance and consequent reduction in the aileron hinge moments. From the above table it may be observed that the resulting rolling criterion was reduced by this modification. However, the general shapes of the several curves remained unchanged.

Modification 2.- The effects of removing the vanes from the surfaces, as shown by a comparison of the pertinent curves of figures 36(a), 37(a), and 38(a), included both an increase in control forces for given aileron angles (averaging approximately the same magnitude as that of modification 1) and a small decrease in the corresponding rolling velocities. The increase in control force may be attributed to the absence of the balancing effects of the vanes in their original nose-up position. The decrease in rolling velocity was probably due to the gap in the aileron surfaces created by the removal of the vanes which tended to reduce the lateral-control effectiveness.

From the results of the tests with the first two modifications, it is apparent that the presence of the vanes set in the nose-up position has a desirable effect on the lateral-control characteristics of the airplane.

Modification 3.- The vane axis of rotation in each wing was lowered in an attempt to improve the air flow over the vanes and increase their control-force-reduction effectiveness. The vanes were set at the same nose-up angle as in the original condition. Thus, from a comparison of the curves for this modification with those of the original condition (figs. 36(b), 37(b), and 38(b)), it may be seen that this adjustment had no marked effect on the lateral-control characteristics except in the flaps-down condition (fig. 38(b)), the curves being practically coincidental with those for the original condition. Thus, the effectiveness of the vanes appeared to be independent of the position of their axis of rotation.

Modification 4.- The areas of the upper surfaces of two aileron panels were reduced for the purpose of lightening the control forces without lowering the corresponding rolling velocities. As the vanes were set in the nose-down position, a comparison of the curves for this modification (figs. 36(b) and 37(b)) with the corresponding curves of modification 1 (figs. 36(a) and 37(a)) indicates the effect of the aileron upper-surface reduction on the lateral-control characteristics. From these curves it may be seen that the aileron control forces were considerably reduced without a change in the corresponding rolling velocities and, as shown in the above table, the rolling-criterion values were improved by this alteration of the lateral-control surfaces. A reduction of the aileron upper-surface area, then, indicates a favorable trend in modifications.

Modification 5.- From a comparison of the curves for modification 5 (figs. 36(c) and 37(c)) with those of modification 4 (figs. 36(b) and 37(b)) it may be seen that slight additional reduction in the control force was effected by placing the vanes in their nose-up position with the aileron upper surfaces altered as in modification 4.

Modification 6.- In order to decrease the control forces further, the upper surface of the remaining panel was reduced in area. From a comparison of the curves pertaining to this modification with those of modification 5 (figs. 36(c), 37(c), and 38(c)), it may be observed that the control forces were reduced from those of the previous modification with no accompanying decrease in rolling velocities. From the above table it is noted that the rolling criterion is, in general, higher for this modification than for any of the preceding changes and in a few flight conditions nearly satisfies the requirement of 0.07 recommended in references 3 and 4.

Modification 7.- With the aileron surfaces in the same condition as modification 6 but with the vanes in the nose-down condition, the aileron control characteristics are shown in figures 36(d), 37(d), and 38(d). These curves, when compared to the corresponding curves for modification 6, indicate the effectiveness of the vane in regulating the control forces without changing the rolling velocity.

Modification 8.- For the same condition as in modification 7 but with the aileron upper-surface slots open, the control forces were lowered slightly, as shown in figures 36(d), 37(d), and 38(d), over those of modification 7.

From the results of these modifications, it appears that for maximum rolling velocities and minimum control forces, the optimum combination of conditions would consist of those in modification 8, that is, with the aileron upper-surface area reduced and the upper-surface slots open, but with the force-regulating vanes set in the nose-up position.

Yaw due to ailerons.- From the flight-test records taken in rudder-fixed aileron rolls, the sideslip angle developed as a result of full aileron deflection for all flap and power conditions investigated was less than 20° at 110 percent of the stalling speed, thereby satisfying the requirement of reference 3 for this characteristic.

Rolling moment due to sideslip.- Lateral characteristics of the airplane as measured in steady sideslips were determined in the following flight conditions:

Power	Flap position	Indicated airspeed (mph)	Figure
Rated	Up	92 and 155	39
	Down	92 and 121	40
Off	Up	92 and 155	41
	Down	92 and 121	42

From the figures it is seen that the variation of aileron angle with sideslip angle is progressive and fairly smooth on either side of neutral aileron angle for all flight conditions investigated. Although no control-force records were taken, it is probable that the curves relating aileron control force with sideslip angle would have a flat portion near zero control force as in the case of aileron control characteristics tending to produce poor centering characteristics.

Stalling Characteristics

The stalling characteristics of the airplane for the various types of control and flight conditions investigated are indicated by the time histories of figures 43 to 66. The more important data and pilot's notes for these stalls are tabulated in table I.

From the recorded data, pilot's notes, and tuft studies it is seen that, for all of the flight conditions, the stall warning was adequate. Buffeting and shaking of the airplane and controls usually provided a definite warning before instability was reached. The instability experienced developed in a gradual but unmistakable manner and in most cases was accompanied by a marked increase in the elevator pull force and rearward travel of the control stick. After the complete stall had developed, it was possible to recover promptly by normal use of the controls. Thus, the stalling characteristics of the airplane in general appear to be satisfactory in relation to the requirements of reference 3.

For both power conditions and with the flaps either up or one-half down, it was not possible to maintain the wings level in a stall by means of the ailerons or rudder alone. However, with the flaps full down, control appeared to be possible.

In connection with the tuft studies made with the airplane in stalling flight, it was observed that flow breakaway originated, desirably, at the inboard and trailing-edge portions of the upper surface, thence progressing forward and outboard toward the wing tip. There appeared to be no tendency toward tip stalling even with the flap fully extended. The absence of tip stalling in this condition appeared to be due to the small slots in the forward part of the flaps near the wing tips.

Maximum lift coefficients.- The lift characteristics as affected by the extension of the Zap flaps are indicated by the average stalling speeds from table I and the corresponding calculated lift coefficients shown in the following table:

Power	Flap position	Stalling speed (mph)	Maximum lift coefficient
Rated	Up 1/2 down Down	67 60 58.5	2.01 2.42 2.78
Off	Up 1/2 down Down	80 68 65	1.48 2.05 2.27

The values for maximum lift coefficient were calculated by the following approximate relationship:

$$C_{L_{max}} = 391 \frac{W}{S} \frac{A_Z}{{V_s}^2}$$

where

$C_{L_{max}}$ maximum lift coefficient

$\frac{W}{S}$ wing loading of airplane, pounds per square foot

V_s indicated airspeed at stall, miles per hour

A_Z normal acceleration factor, reading of acceleration in direction of Z axis in feet per second per second divided by g in feet per second per second, at the time of V_s

g 32.2 feet per second per second

This formula neglects the effect of the attitude of the airplane on the values of lift coefficient. However, this effect was not considered to have sufficient significance to warrant the relatively difficult measurement in flight of the angle of attack.

From the above table it may be observed that lowering the flaps to one-half deflection increased the maximum lift coefficient more than half of the increase due to full flap deflection, especially in power-off flight. From this it appears that the effectiveness of the flaps in increasing the maximum lift coefficient decreases with flap deflection.

CONCLUSIONS

The stability and stalling characteristics of the test airplane, in general, impressed the pilots favorably, but several features of the lateral-control characteristics were considered undesirable.

From the results of the investigations in flight and on the ground, the following conclusions may be drawn:

1. Damping of the uncontrolled longitudinal motion was satisfactory.

2. The stick-fixed static longitudinal stability was adequate for the climb, glide, wave-off, and landing conditions.

3. The stick-free longitudinal stability was sufficient in the climb, glide, and landing conditions for the trim speeds at which the airplane was tested.

4. The elevator control was satisfactory in landings.

5. The stretch in the lateral-control system was unusually high, principally due to the use of a torque tube in each wing to actuate the ailerons.

6. The friction in the lateral-control system was excessive, having values of 7.5 and 5.1 pounds measured on the ground and in flight, respectively.

7. Because of the large aileron weight and resulting high mass balance, the inertia in the lateral-control system was undesirably high.

8. The control-free lateral oscillations were adequately damped in all flight conditions investigated.

9. When the ailerons were deflected and released quickly, they returned to their trim position, and any oscillation of the ailerons themselves disappeared after one cycle.

10. The maximum rolling velocity obtained by the abrupt use of ailerons varied smoothly with the aileron angle and was nearly proportional to the aileron angle for all conditions investigated except in the rated-power, flaps-down condition at 122 miles per hour.

11. The rolling acceleration following an abrupt aileron deflection was always in the correct direction and reached its maximum value within 0.2 second after the controls had reached their given deflection.

12. The maximum values of $pb/2V$ resulting from a force of 30 pounds applied at the control stick did not reach 0.07 except in the landing condition.

13. The aileron control force varied smoothly with aileron deflection for all conditions of flight, but, due to the large value of friction and the low forces near neutral stick position, the system had poor self-centering characteristics which did not give sufficient control feel.

14. It was possible to reduce the aileron control forces without an accompanying decrease in the corresponding rolling velocities by (a) setting the aileron vanes in their nose-up position, (b) reducing the size of the aileron upper surfaces, and (c) opening the slots in the upper surfaces.

15. The sideslip angle developed as a result of full aileron deflection was satisfactorily less than 20° at the critical low-speed condition in rudder-fixed aileron rolls.

16. The stalling characteristics of the airplane, in general, satisfied the requirements of reference 3.

17. The effectiveness of the flaps in increasing the maximum lift coefficient was reduced with flap deflection, especially with power off.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif., December 5, 1943.

REFERENCES

1. Rogallo, Francis M., and Swanson, Robert S.: Wind-Tunnel Development of a Plug-Type Spoiler-Slot Aileron for a Wing with a Full-Span Slotted Flap and a Discussion of its Application. NACA ARR, Nov. 1941

2. Lowry, John G., and Liddell, Robert, B.: Wind-Tunnel Investigation of a Tapered Wing with a Plug-Type Spoiler-Slot Aileron and Full-Span Slotted Flaps. NACA ARR, July 1942.

3. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA ACR, April 1941 (Classification changed to "Restricted" Oct. 1943).

4. Anon.: Specification for Stability and Control Characteristics of Airplanes. Spec. No. SR-119, Bur. of Aero., Oct. 1, 1942.

TABLE I
STALLING CHARACTERISTICS OF THE TEST AIRPLANE IN ITS ORIGINAL CONDITION

Power	Flap position	Fig. no.	Type of stall control requested of pilot	Type of stall warning (pilot's notes)	Type of stall and control (pilot's notes)	Ability of aileron or rudder to control roll off after first sign of stall	Stalling speed (mph)	Elevator angle at time of stall (deg)	Elevator control force at time of stall (lb)	Elevator tab angle (deg)
Rated	Up	43	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Noticeable buffeting at 73.5 mph, pitched down slightly	No roll off, all controls smooth	Rudder held fixed, ailerons moved inadvertently	70	6 up	5 pull	8 up
		44	Stick full back; attempt made to hold aileron and rudder fixed	Some buffeting at 69 mph	Roll and sideslip to right	Rudder held fixed, ailerons moved inadvertently	66	18 up	38 pull	8 up
		45	Stick back to stall; aileron alone used to attempt control	Began to roll left at 70 mph	Rolled left against large right aileron	No control with ailerons, rolled left against ailerons	69	18 up	40 pull	8 up
		46	Stick back to stall; rudder alone used to attempt control	Mild left roll	Controlled to uncontrolled roll, left to right	At 69 mph rudder controlled left roll but following right roll was uncontrolled; ailerons moved inadvertently	67	13 up	31 pull	8 up
Rated	1/2 down	47	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Buffeting occurred at 63 mph, no roll off	Controls smooth, forces low	Rudder and ailerons held fixed	60	3 up	0	8 up
		48	Stick full back; attempt made to hold aileron and rudder fixed	At 61 mph a left roll occurred before the stick was full back	Roll followed by a slight yaw	Rudder held fixed, ailerons moved inadvertently	60	8 up	0	8 up
		49	Stick back to stall; aileron alone used to attempt control	Slight roll and buffeting	Mild roll starting at 62 mph, controlled by aileron	Good aileron control at 62 mph, followed by uncontrolled left roll	60	7.5 up	4 pull	8 up
		50	Stick back to stall; rudder alone used to attempt control	Pronounced right roll	Control difficult, rudder control forces heavy	Small rudder control possible at first, after stall no control; ailerons moved inadvertently	61	12 up	20 pull	8 up
Rated	Down	51	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Actions smooth preceding stall	Buffet, left roll	Ailerons and rudder held fixed	58	2 up	2 pull	-
		52	Stick full back; attempt made to hold aileron and rudder fixed	Stall mild	Definite left roll, small elevator deflection	Ailerons moved inadvertently	59	4 up	5 pull	-
		53	Stick back to stall; aileron alone used to attempt control	No definite motions	Rolls against ailerons at first	Ailerons control first roll off all right, then overbalance	59.5	7 up	6 pull	-
		54	Stick back to stall; rudder alone used to attempt control	Slight rolls	Rolled right, rudder ineffective for control	No rudder control possible; ailerons moved inadvertently	58	3 up	8 pull	-
Off	Up	55	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Buffeting with slight right roll	At 84 mph buffeting occurred, but with no roll off	Ailerons and rudder held fixed	82.5	13 up	22 pull	2.5 up
		56	Stick full back; attempt made to hold aileron and rudder fixed.	Buffeting at 80 mph	Slow roll to the left occurred at 80 mph	Ailerons and rudder moved inadvertently	77.5	29 up	48 pull	2.5 up
		57	Stick back to stall; aileron alone used to attempt control	Buffet combined with roll	Uncontrolled rolling motions, high aileron deflections used	Ailerons could not stop rolling to left	80	16 up	29 pull	2.5 up
		58	Stick back to stall; rudder alone used to attempt control	Slight rolling, left to right	At 80.5 mph first roll off was controlled, but not beyond this	Rudder unable to maintain control at stall; ailerons moved inadvertently	80	19 up	34 pull	2.5 up
Off	1/2 down	59	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Buffeting and slight rolling occurred	Continuous rolling and pitching with increasing airspeed	Ailerons and rudder held fixed	70	19 up	29 pull	2.5 up
		60	Stick full back; attempt made to hold aileron and rudder fixed	Rolling began at 70 mph	Rolled left into steep spiral	Ailerons and rudder held fixed	68	19 up	30 pull	2.5 up
		61	Stick back to stall; aileron alone used to attempt control	Small amount of pitching	At 73 mph rolled left against ailerons	No control with ailerons alone	67	13 up	24 pull	2.5 up
		62	Stick back to stall; rudder alone used to attempt control	Airplane rolled in oscillating motion	Delayed motions, large amount of left roll; reactions rough	Rudder control difficult during stall; ailerons moved inadvertently	68	19 up	28 pull	2.5 up
Off	Down	63	Stick back and held at first warning of stall; attempt made to hold aileron and rudder fixed	Control possible throughout maneuver, no buffeting	Mild pitch down, no roll off	Ailerons and rudder held fixed	66	10 up	15 pull	-
		64	Stick full back; attempt made to hold aileron and rudder fixed	Mild rolling	Pitch oscillation once or twice, then rolled off to right	Ailerons and rudder held fixed	64	13 up	22 pull	-
		65	Stick back to stall; aileron alone used to attempt control	Mild pitch-down motion	Rolling oscillation, but little pitching until end of stall	Aileron control possible with two-thirds maximum deflection	65	20 up	20 pull	-
		66	Stick back to stall; rudder alone used to attempt control	Small control motions set up	Pronounced pitching and rolling during entire stall	Control with rudder possible at high deflections	65	17 up	27 pull	-

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

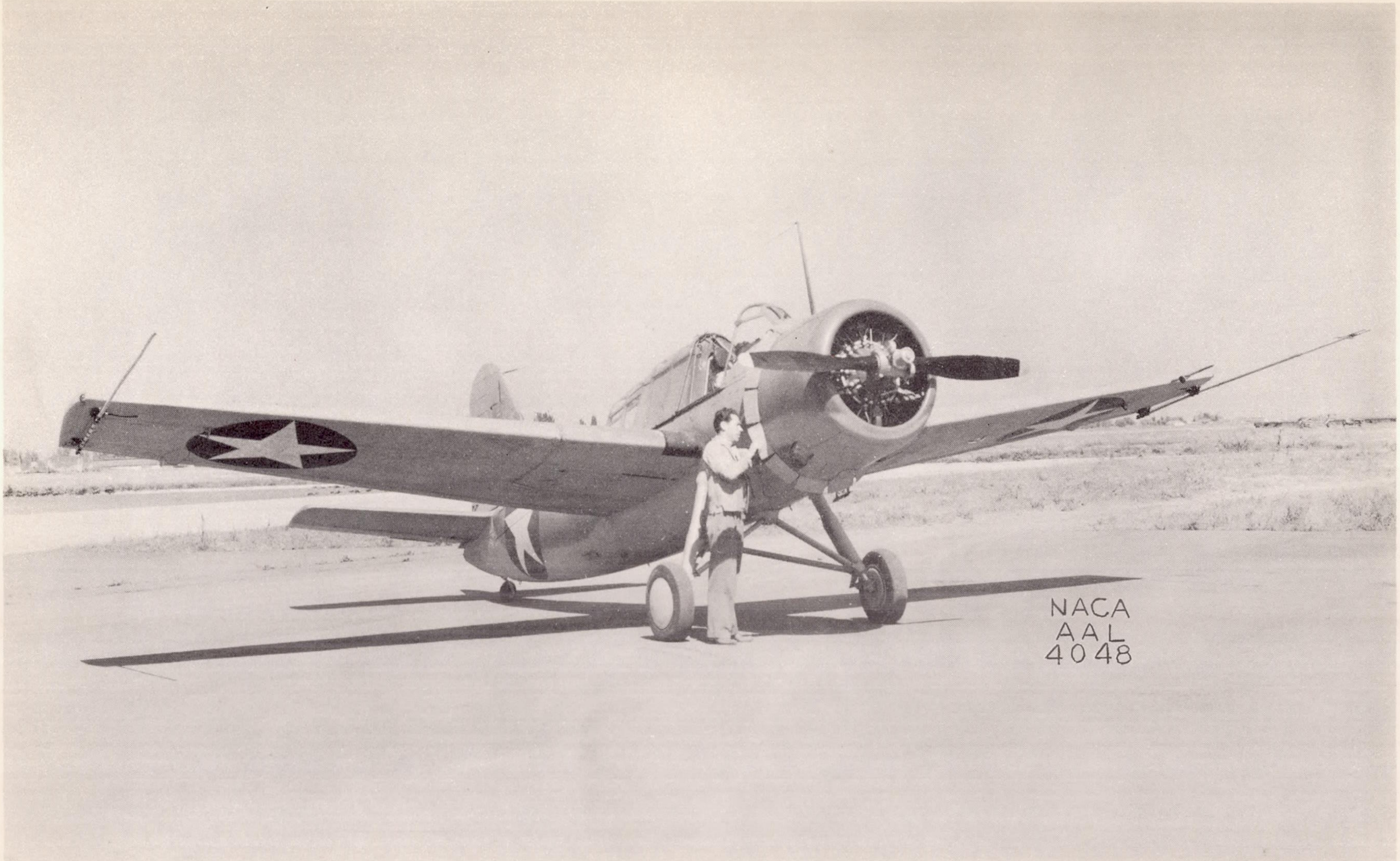


Figure 1. - Front view of the test airplane as instrumented for flight.

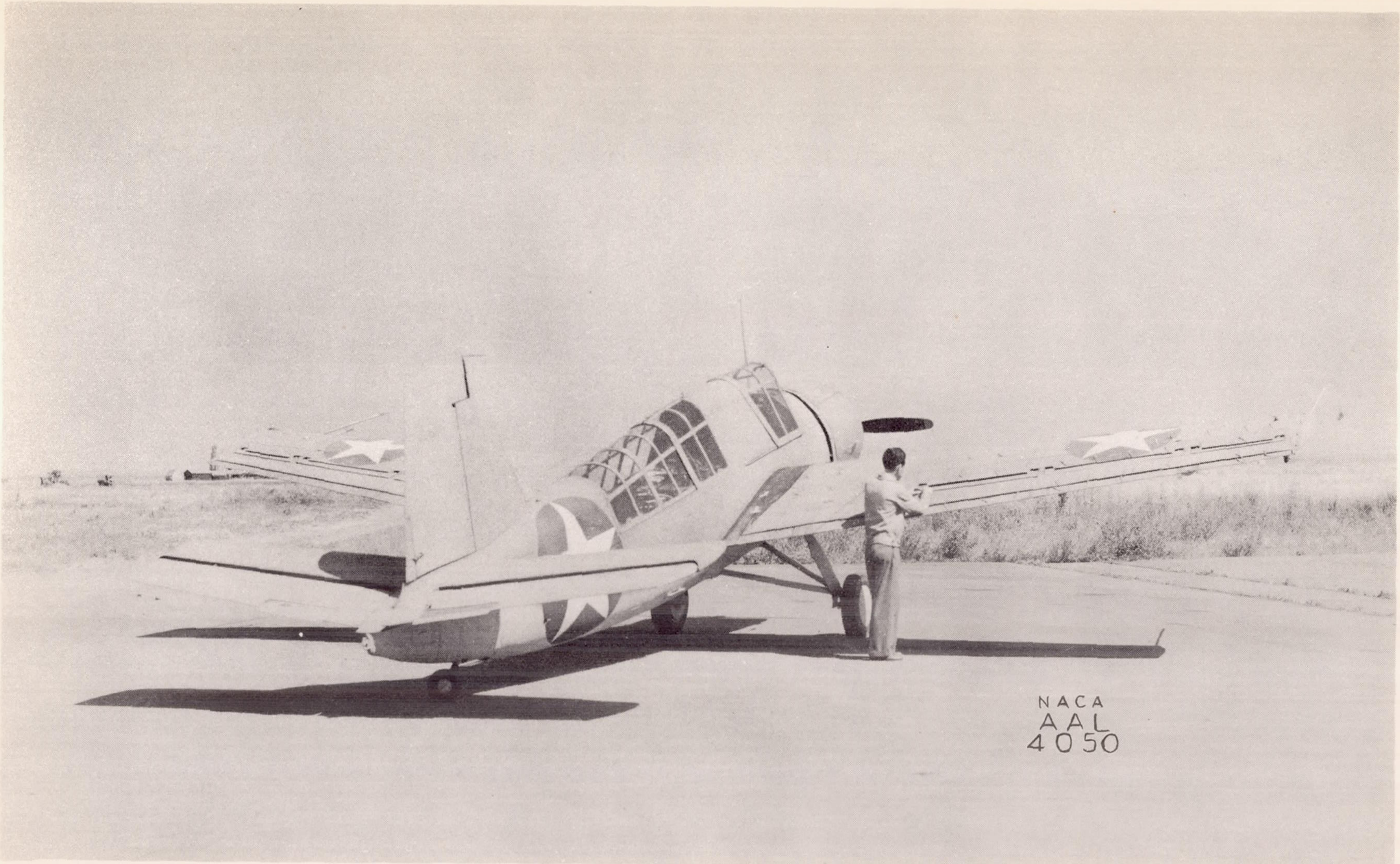


Figure 2. - Rear view of the test airplane as instrumented for flight.

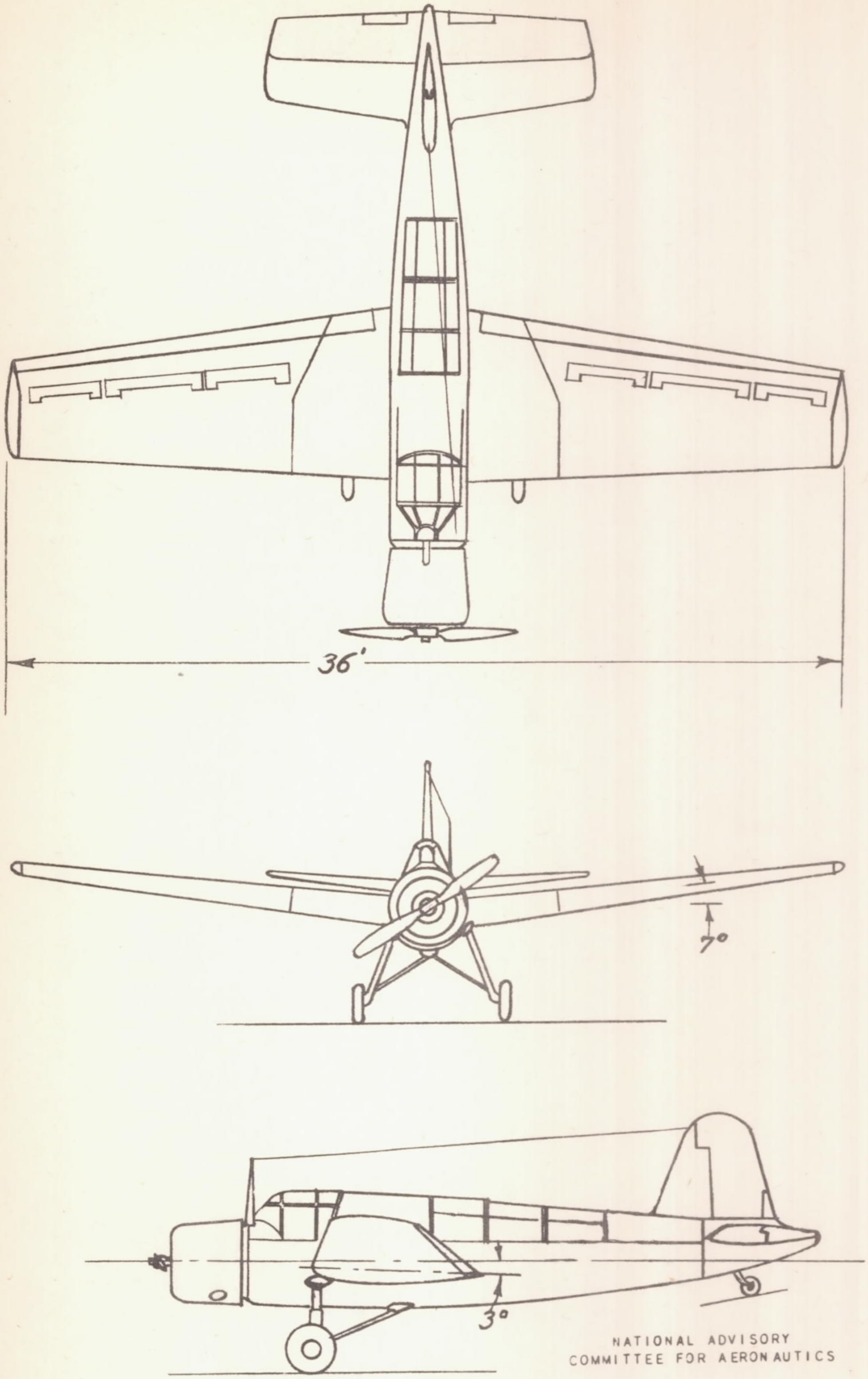


FIGURE 3. – THREE-VIEW DRAWING OF THE TEST AIRPLANE.

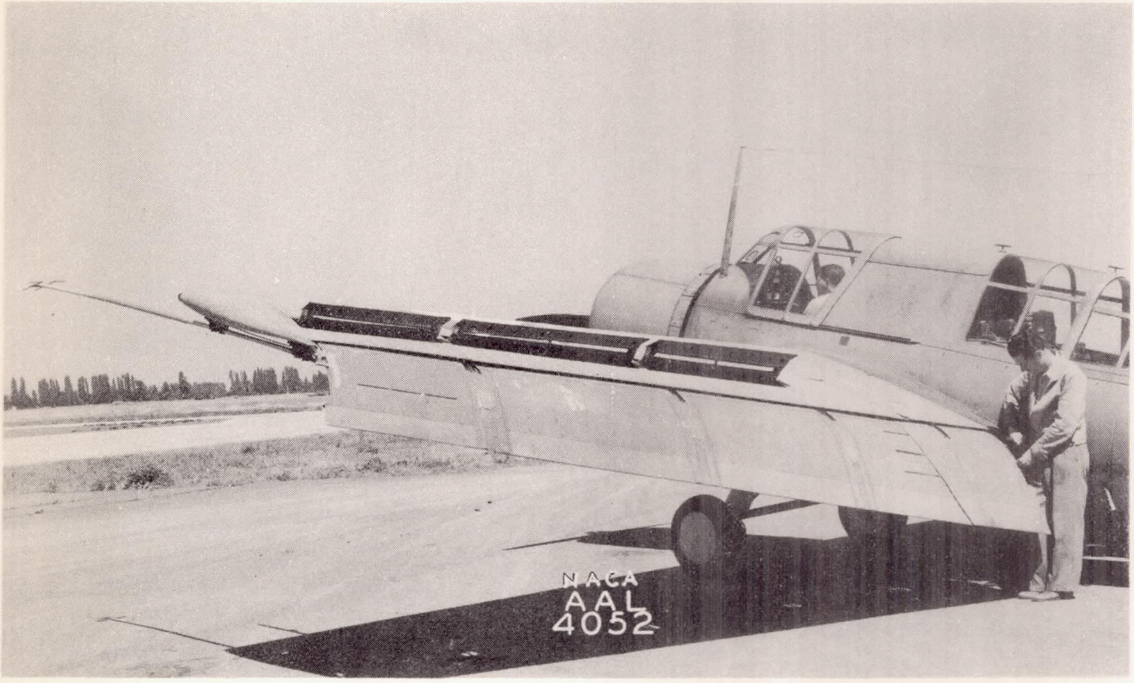


Figure 4. - Left wing with flaps and ailerons fully extended.

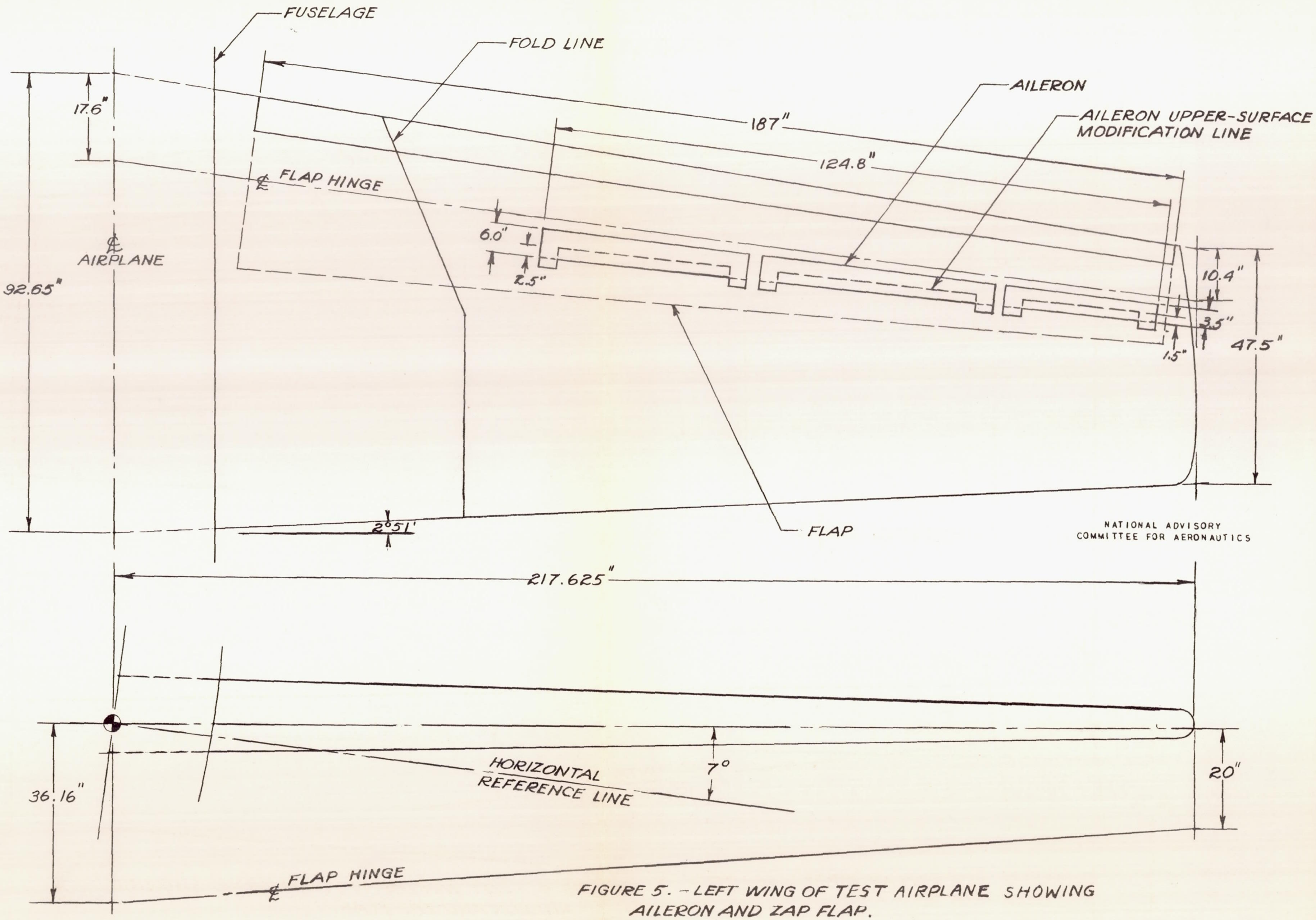


FIGURE 5. - LEFT WING OF TEST AIRPLANE SHOWING AILERON AND ZAP FLAP.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

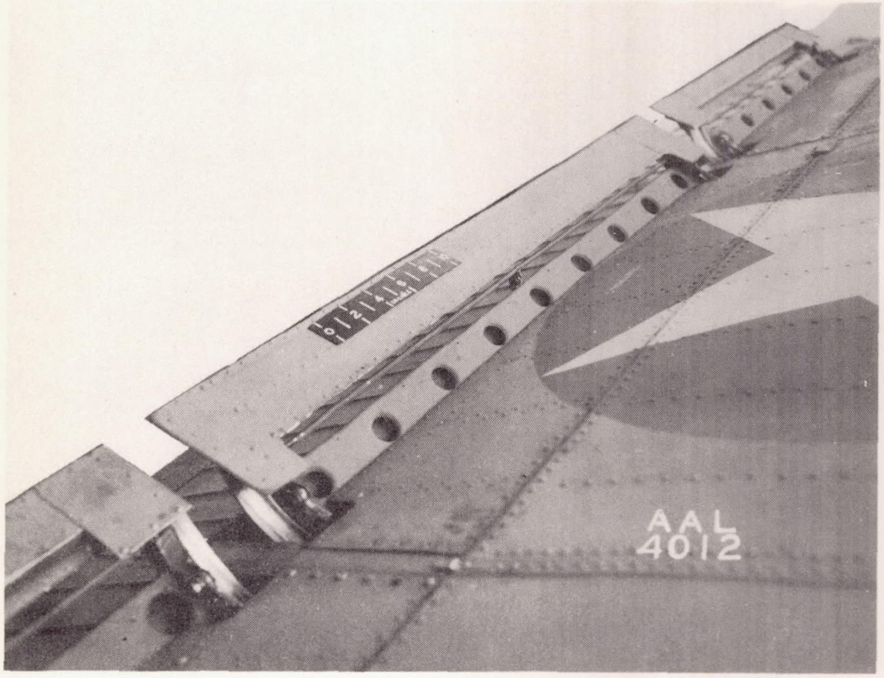
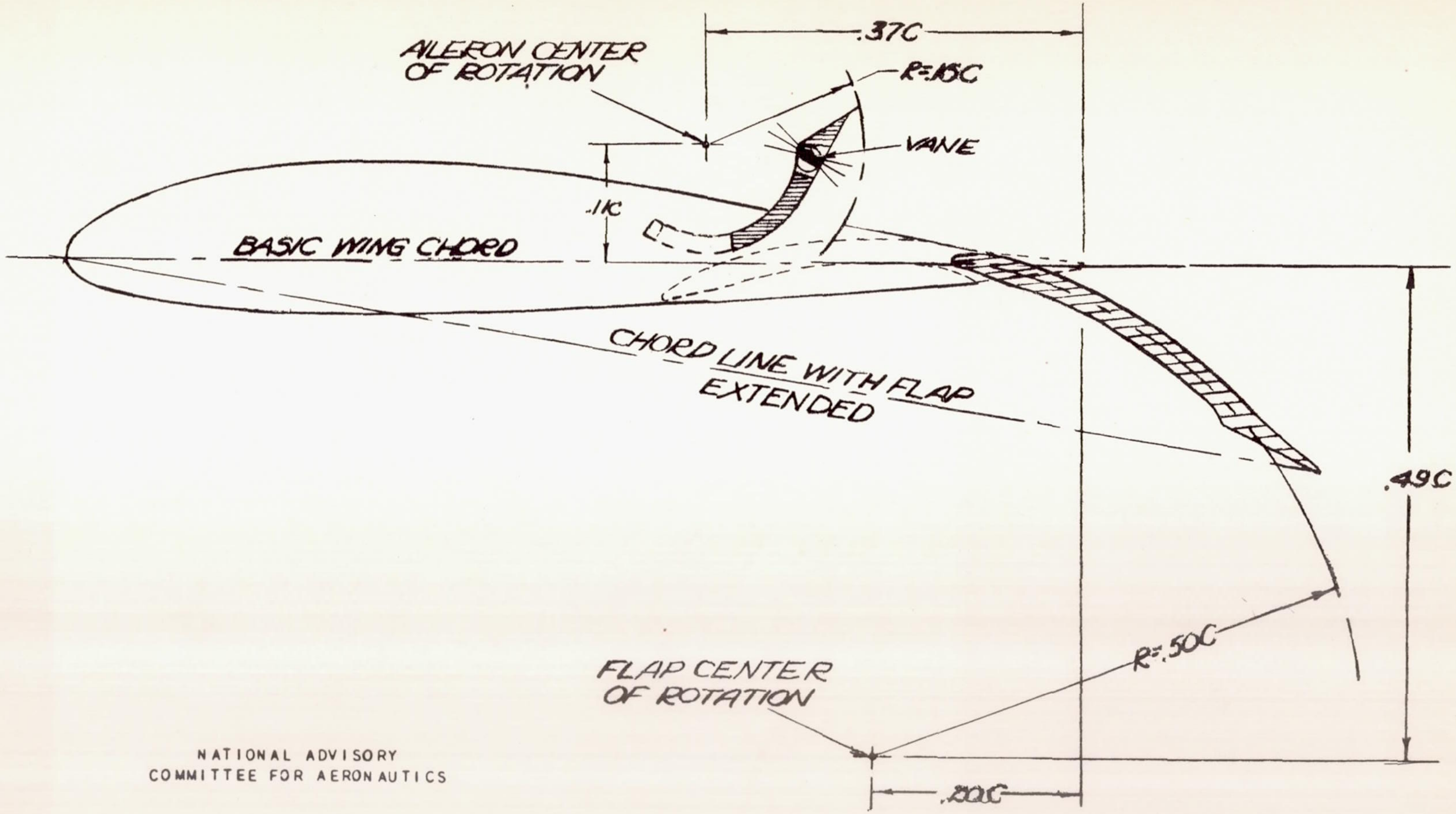
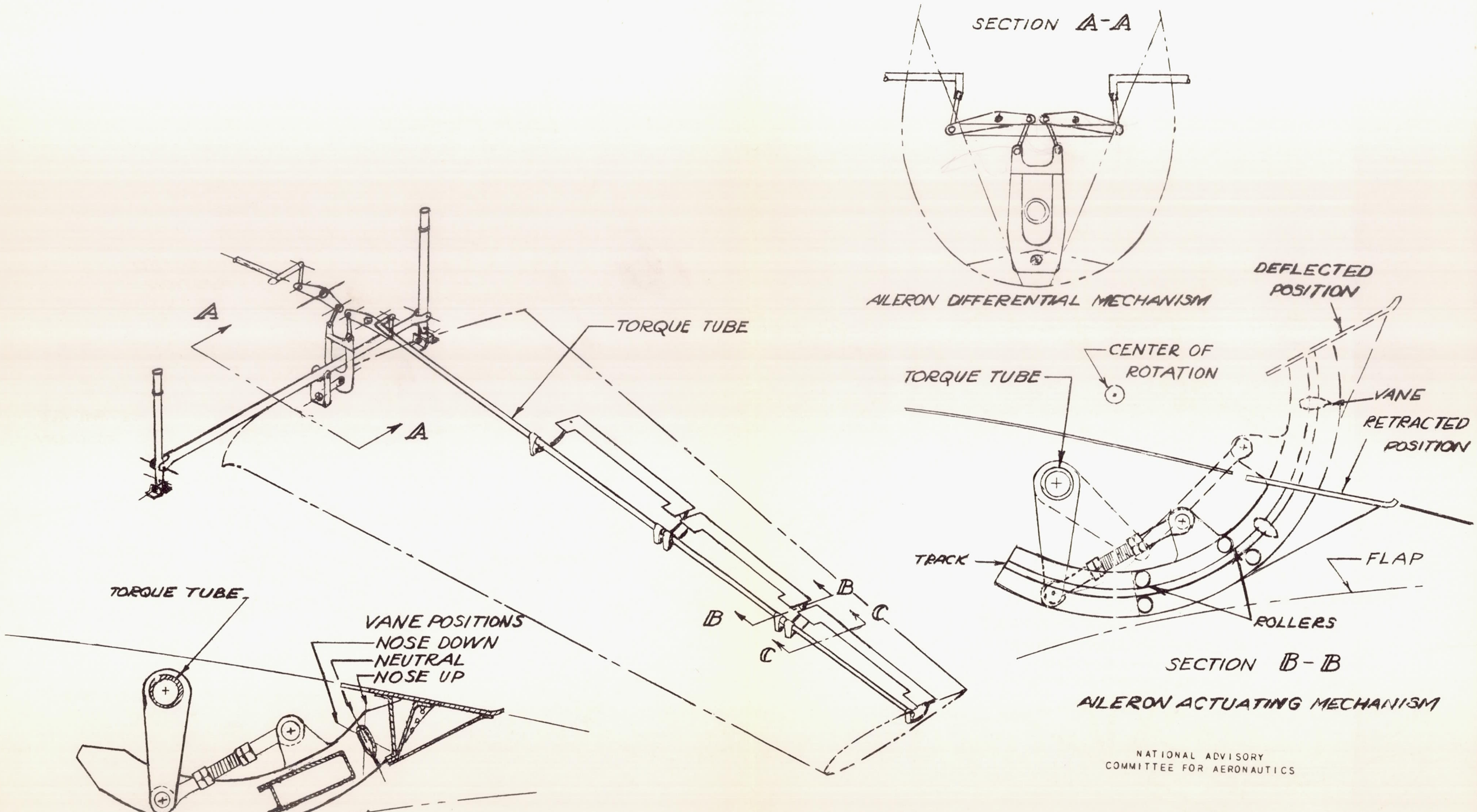


Figure 6. - Left-central aileron panel in original condition with vane in neutral position.



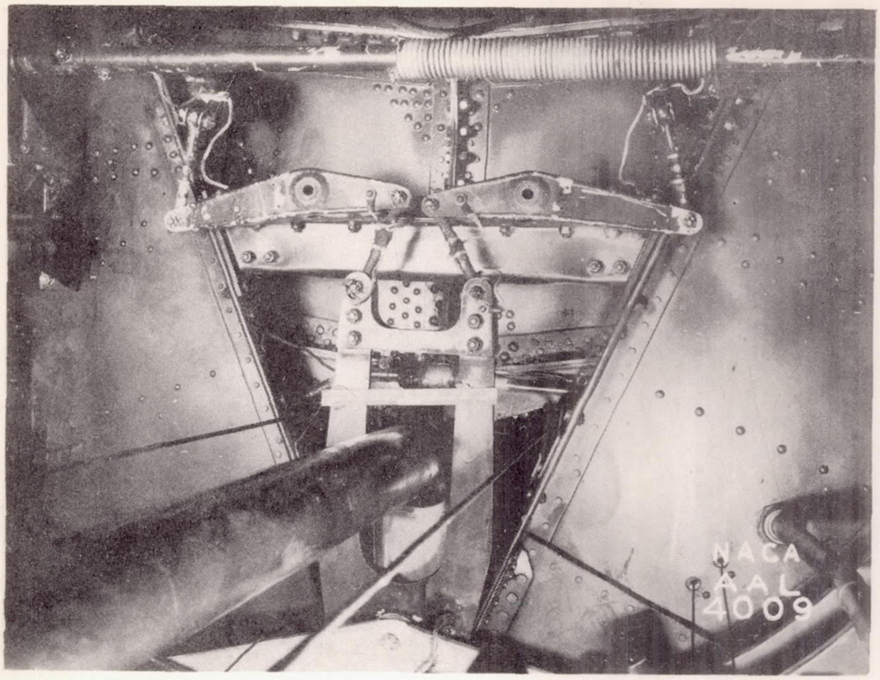
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 7. — CROSS-SECTIONAL DRAWING OF THE WING SHOWING THE AILERON AND FLAP EXTENDED AND RETRACTED.

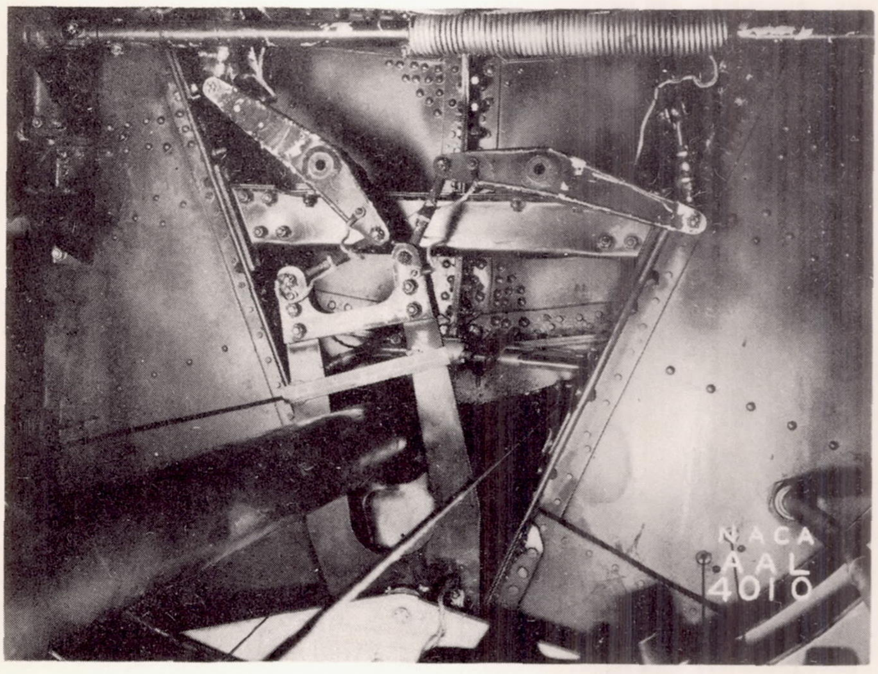


NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 8.- SCHEMATIC SKETCH OF THE AILERON CONTROL SYSTEM.



(a) Control stick neutral.



(b) Control stick full left.

Figure 9. - Lateral-control differential linkage in fuselage, view looking forward.

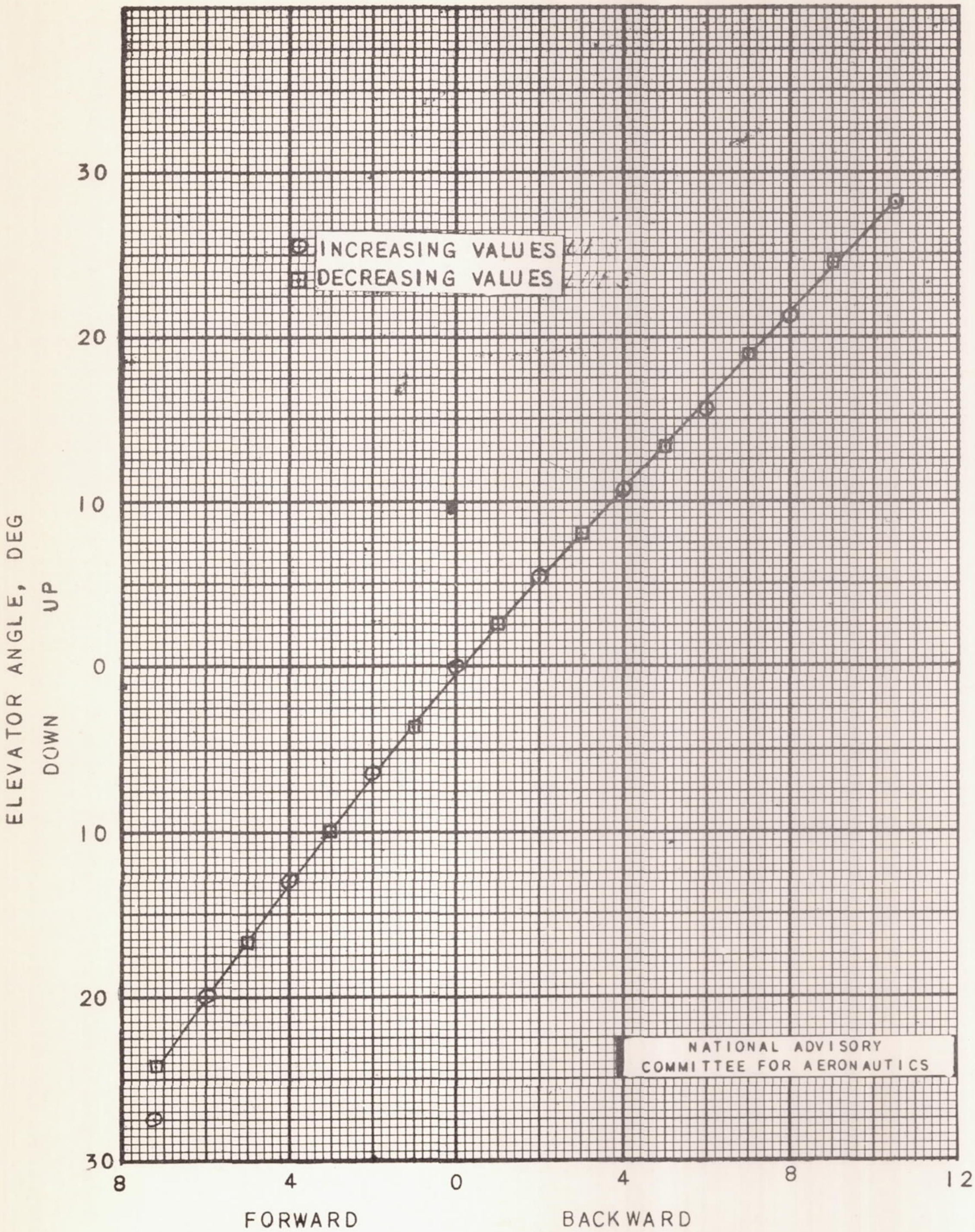


FIGURE 10. - VARIATION OF ELEVATOR ANGLE WITH STICK DEFLECTION.

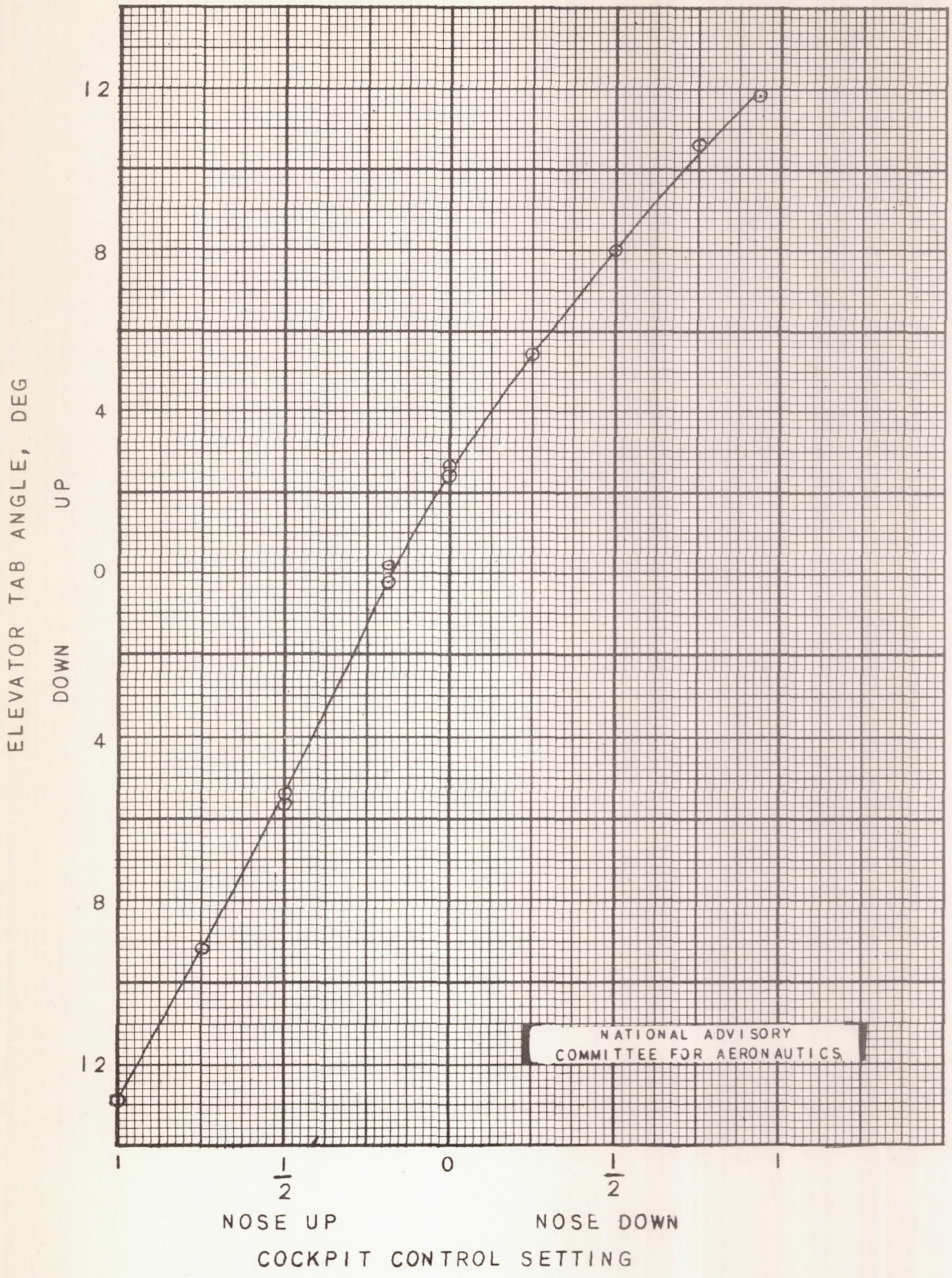


FIGURE 11. - VARIATION OF ELEVATOR TAB ANGLE WITH COCKPIT CONTROL SETTING.

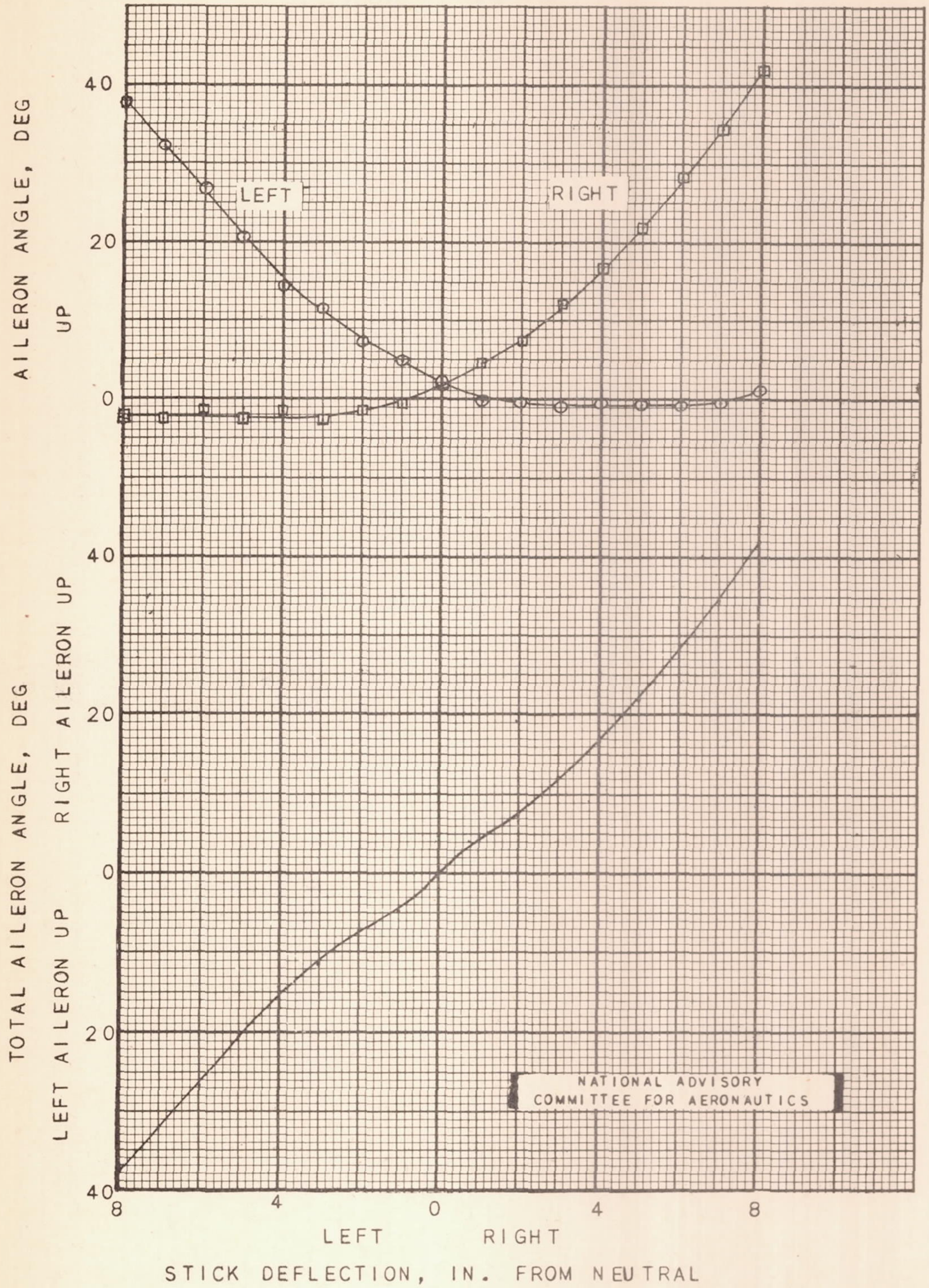


FIGURE 12. - VARIATION OF AILERON ANGLE WITH STICK DEFLECTION.

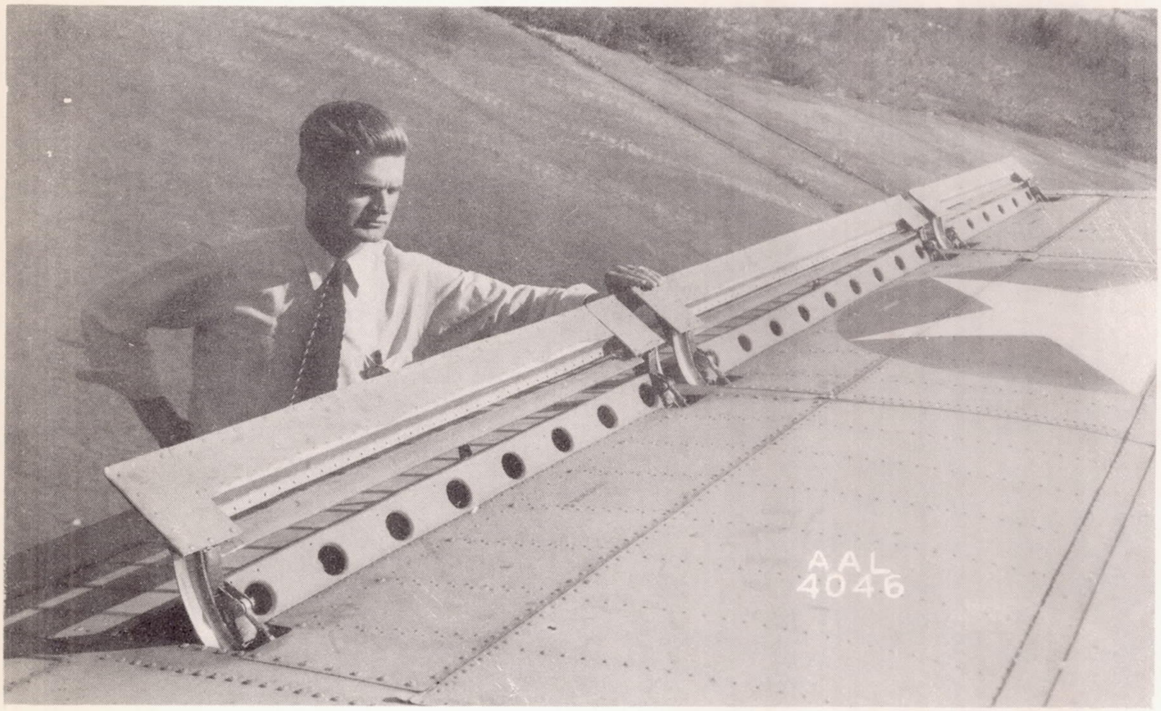


Figure 13. - Left aileron with modified upper surfaces, vanes in nose-down position, upper-surface slots covered with fabric.

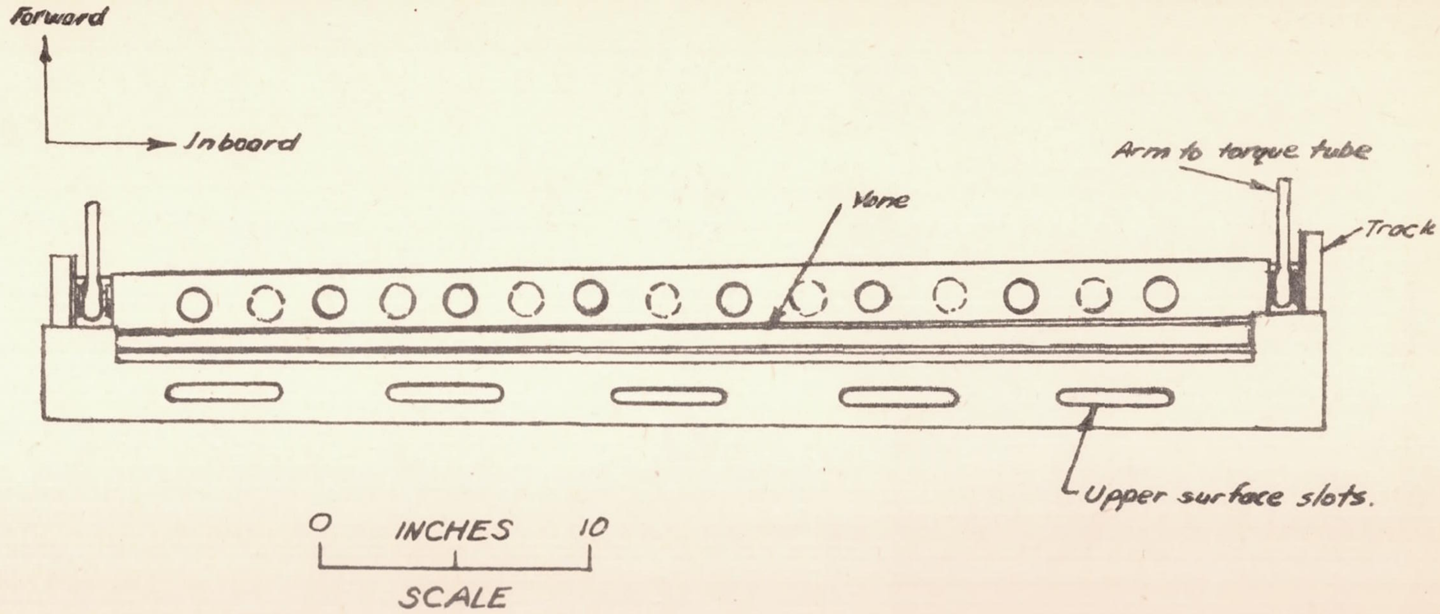
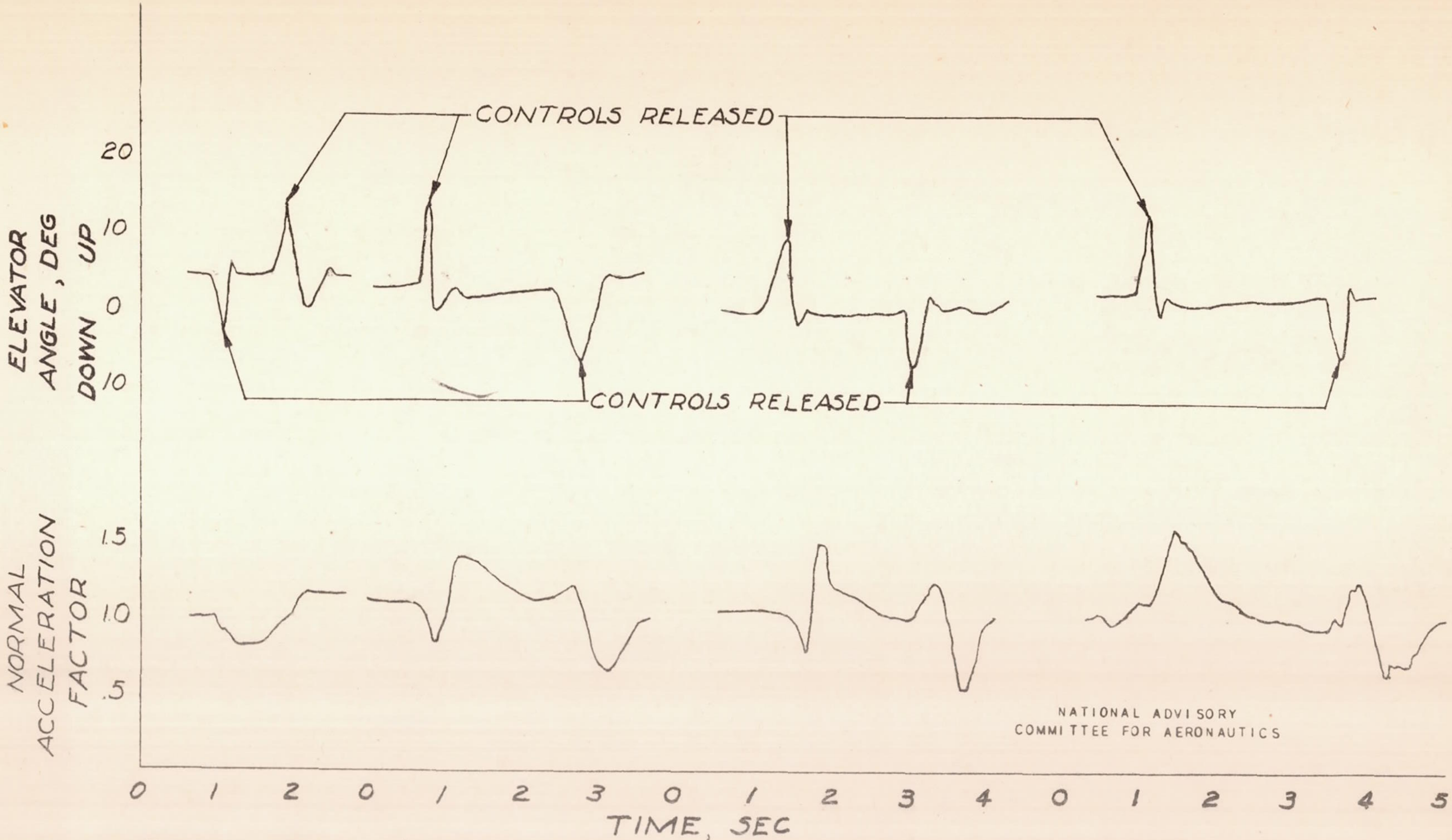


FIGURE 14 - SKETCH OF A TYPICAL AILERON PANEL WITH MODIFIED UPPER SURFACE.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



a. RATED POWER FLAPS UP 80.5 MILES PER HOUR
b. RATED POWER FLAPS UP 114 MILES PER HOUR
c. RATED POWER FLAPS UP 153 MILES PER HOUR
d. POWER OFF FLAPS UP 141 MILES PER HOUR

FIGURE 15. – CHARACTERISTICS OF UNCONTROLLED LONGITUDINAL MOTION.

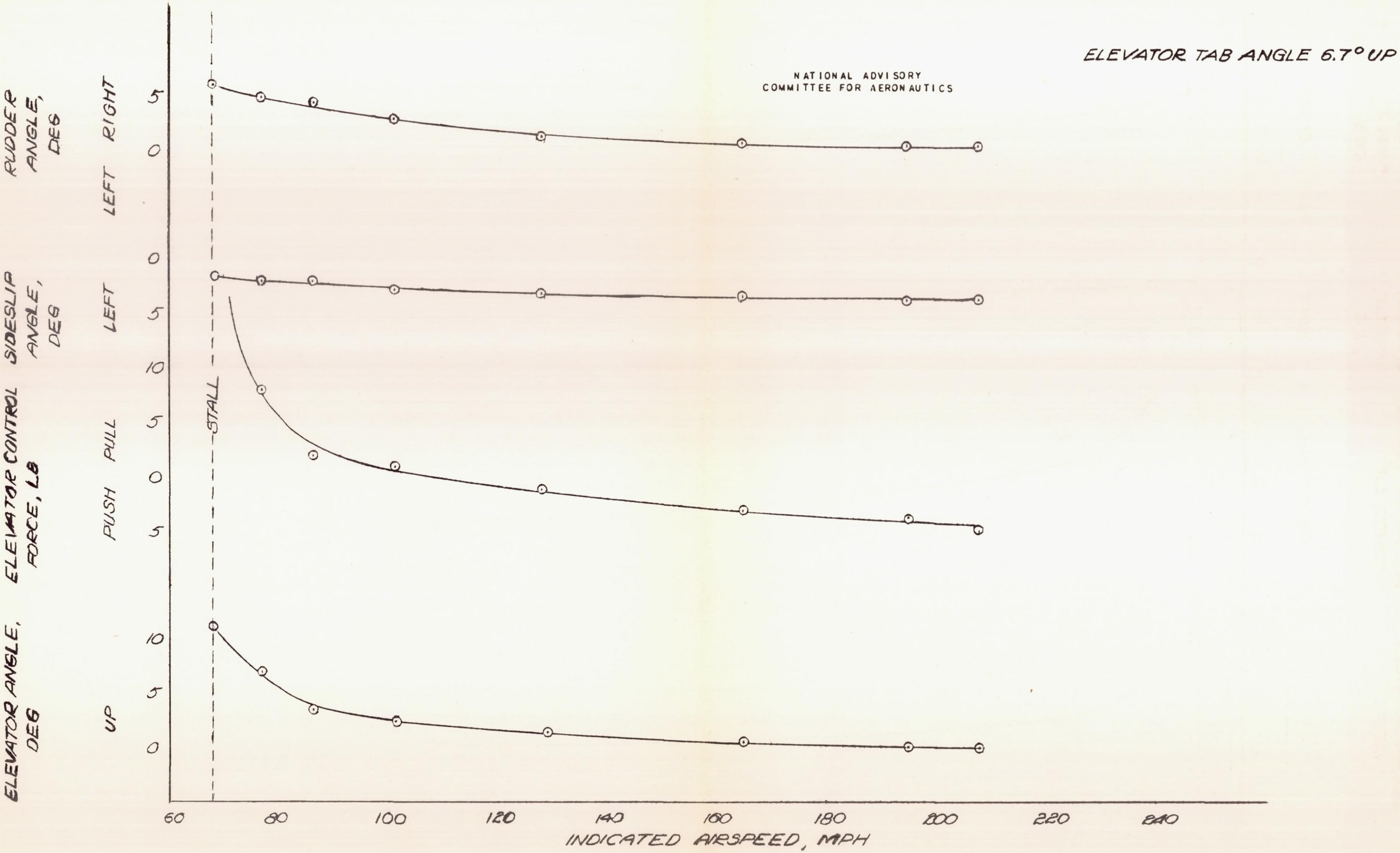


FIGURE 16.- ELEVATOR CONTROL CHARACTERISTICS IN STEADY FLIGHT, CLIMB CONDITION, RATED POWER, FLAPS UP.

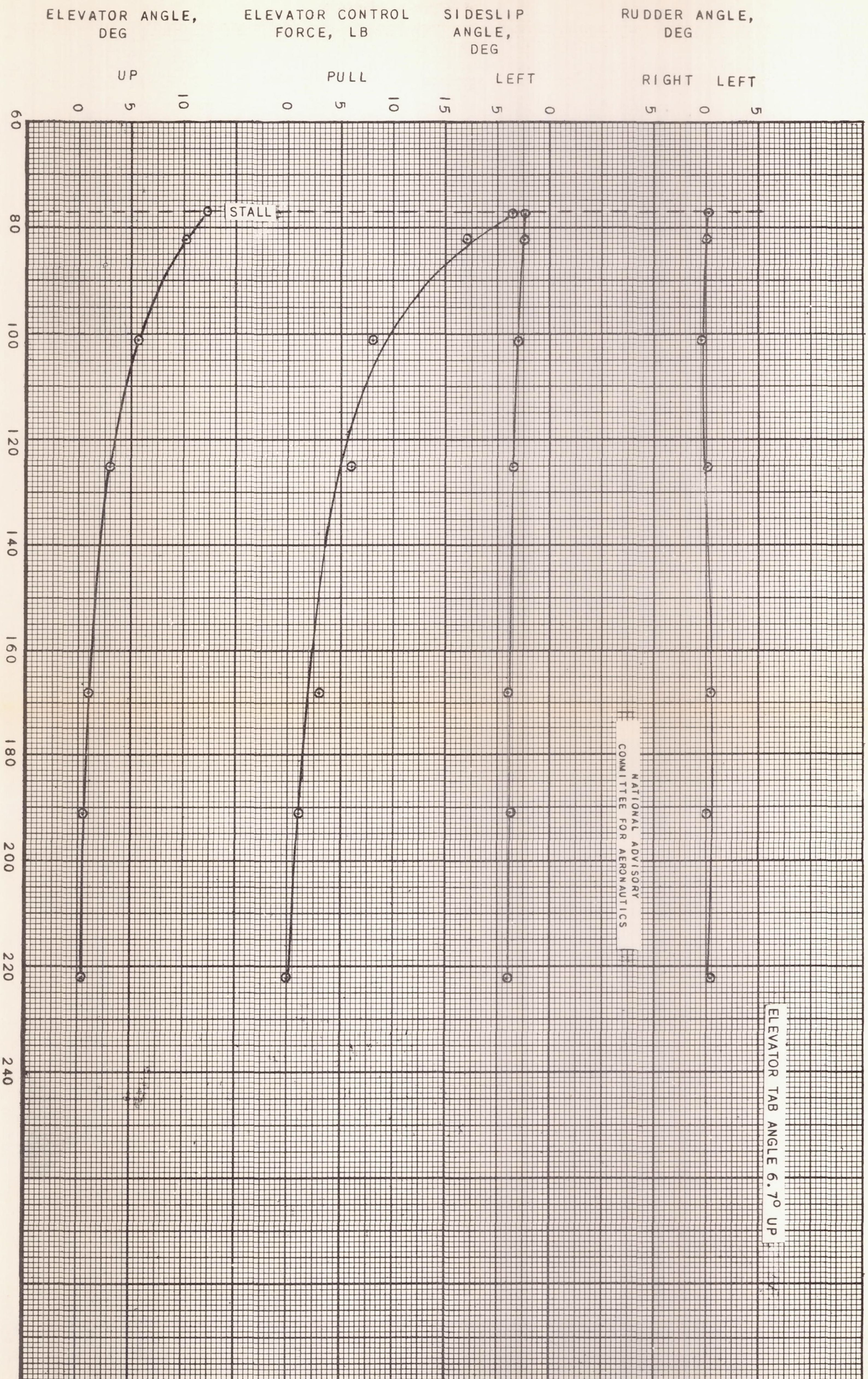


FIGURE 17. - ELEVATOR CONTROL CHARACTERISTICS IN STEADY FLIGHT, GLIDE CONDITION, POWER OFF, FLAPS UP.

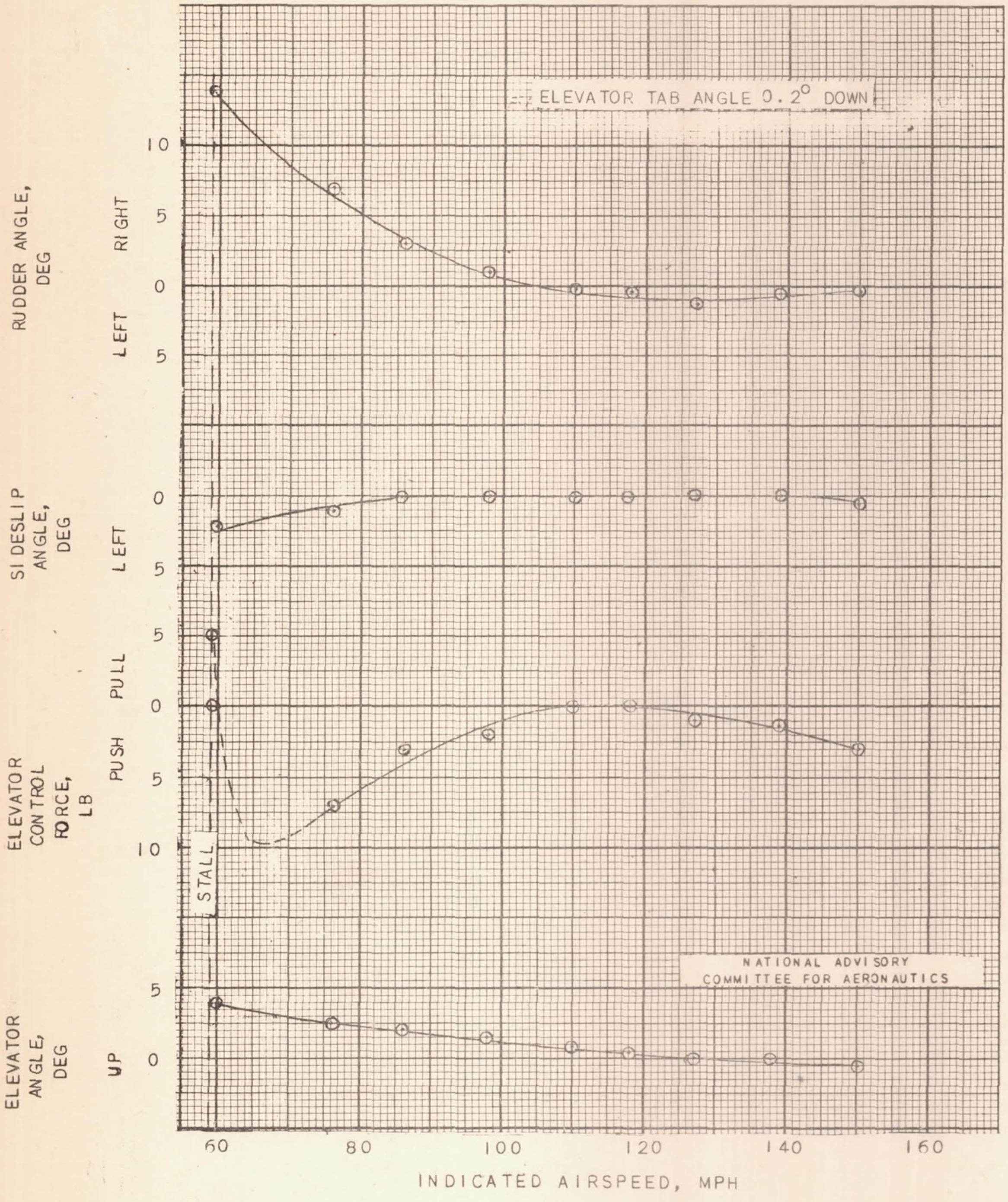


FIGURE 18. - ELEVATOR CONTROL CHARACTERISTICS IN STEADY FLIGHT, WAVE-OFF CONDITION, RATED POWER, FLAPS DOWN.

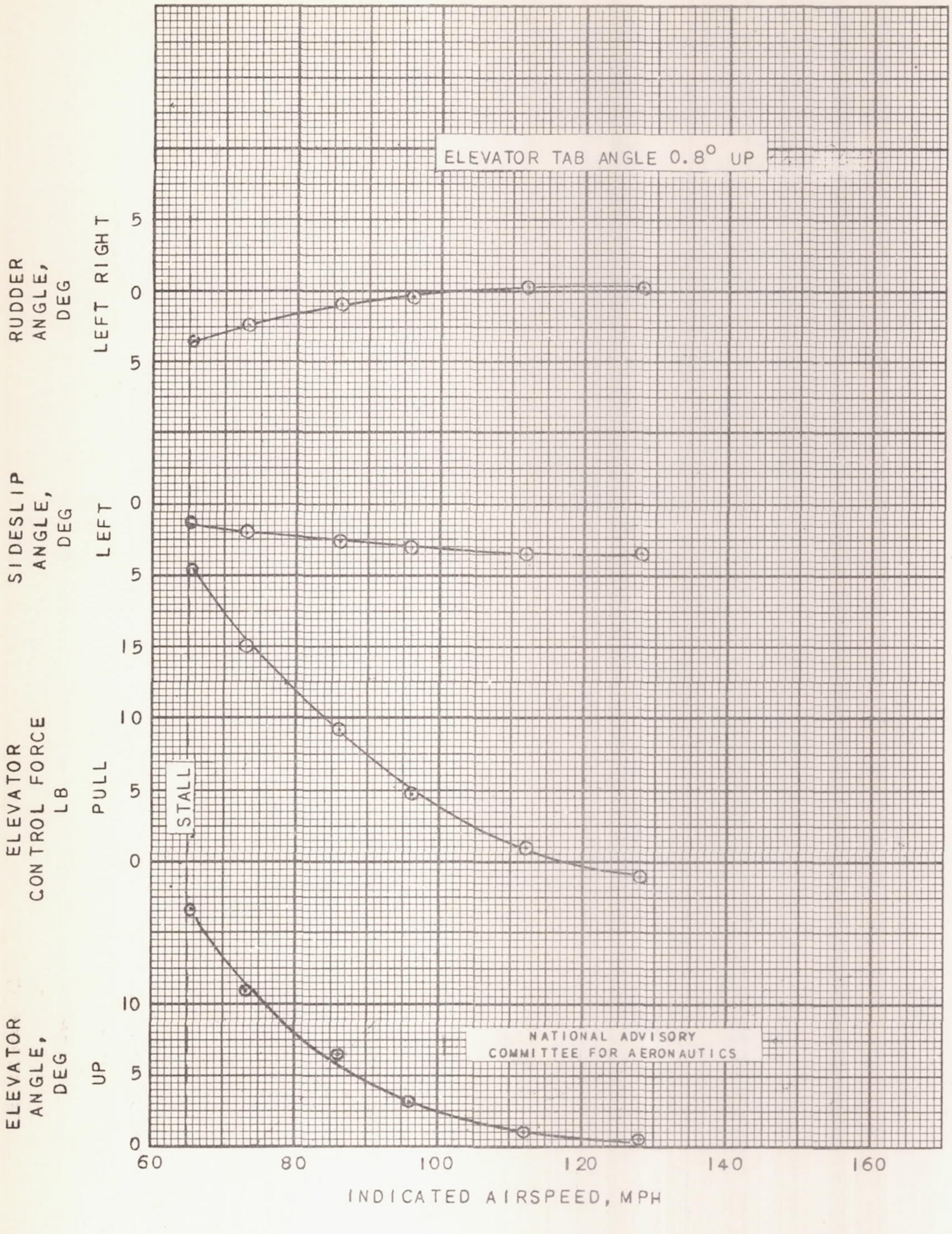


FIGURE 19. - ELEVATOR CONTROL CHARACTERISTICS IN STEADY FLIGHT, LANDING CONDITION, POWER OFF, FLAPS DOWN.

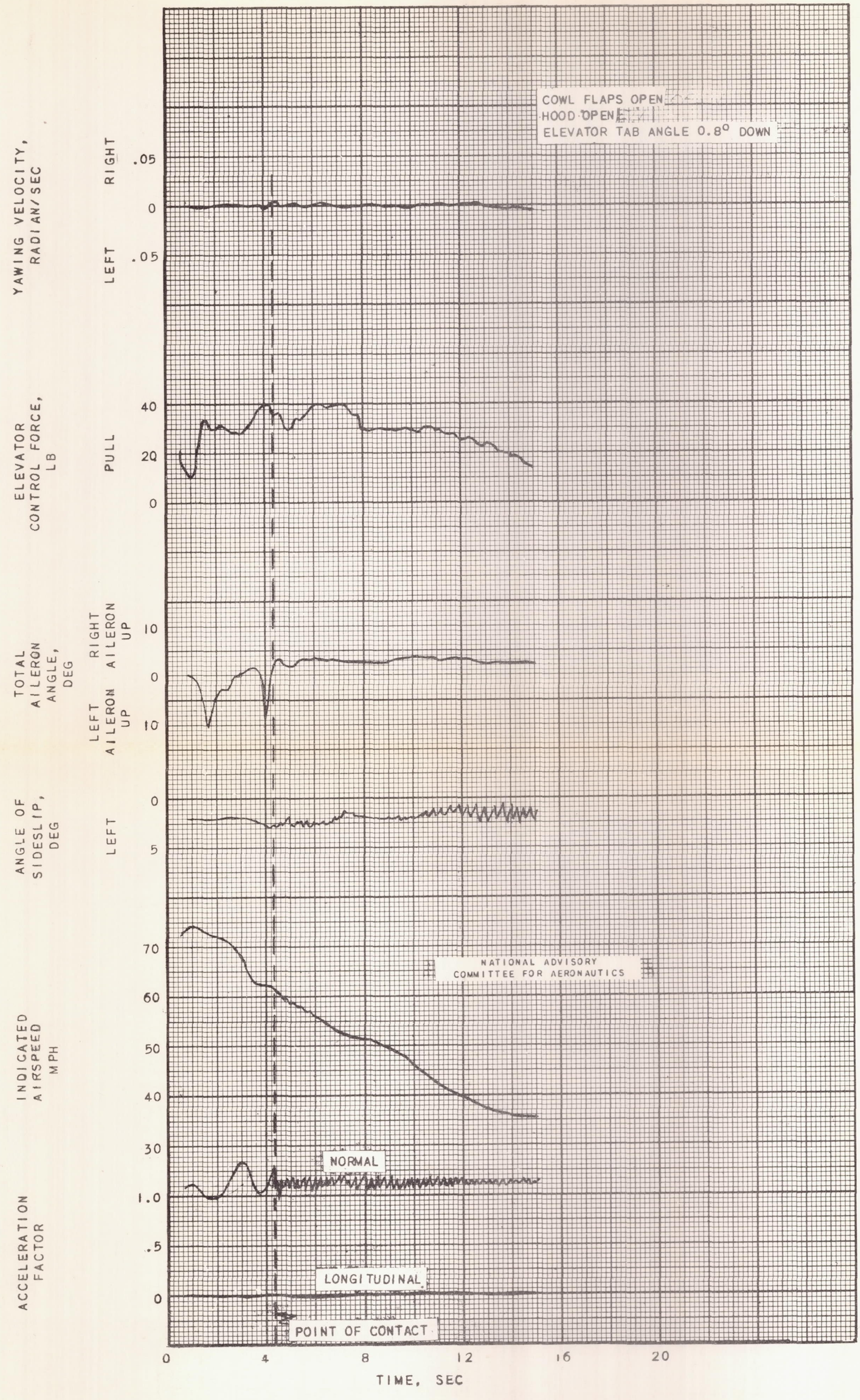


FIGURE 20. - TIME HISTORY OF A THREE-POINT LANDING, POWER OFF, FLAPS DOWN.

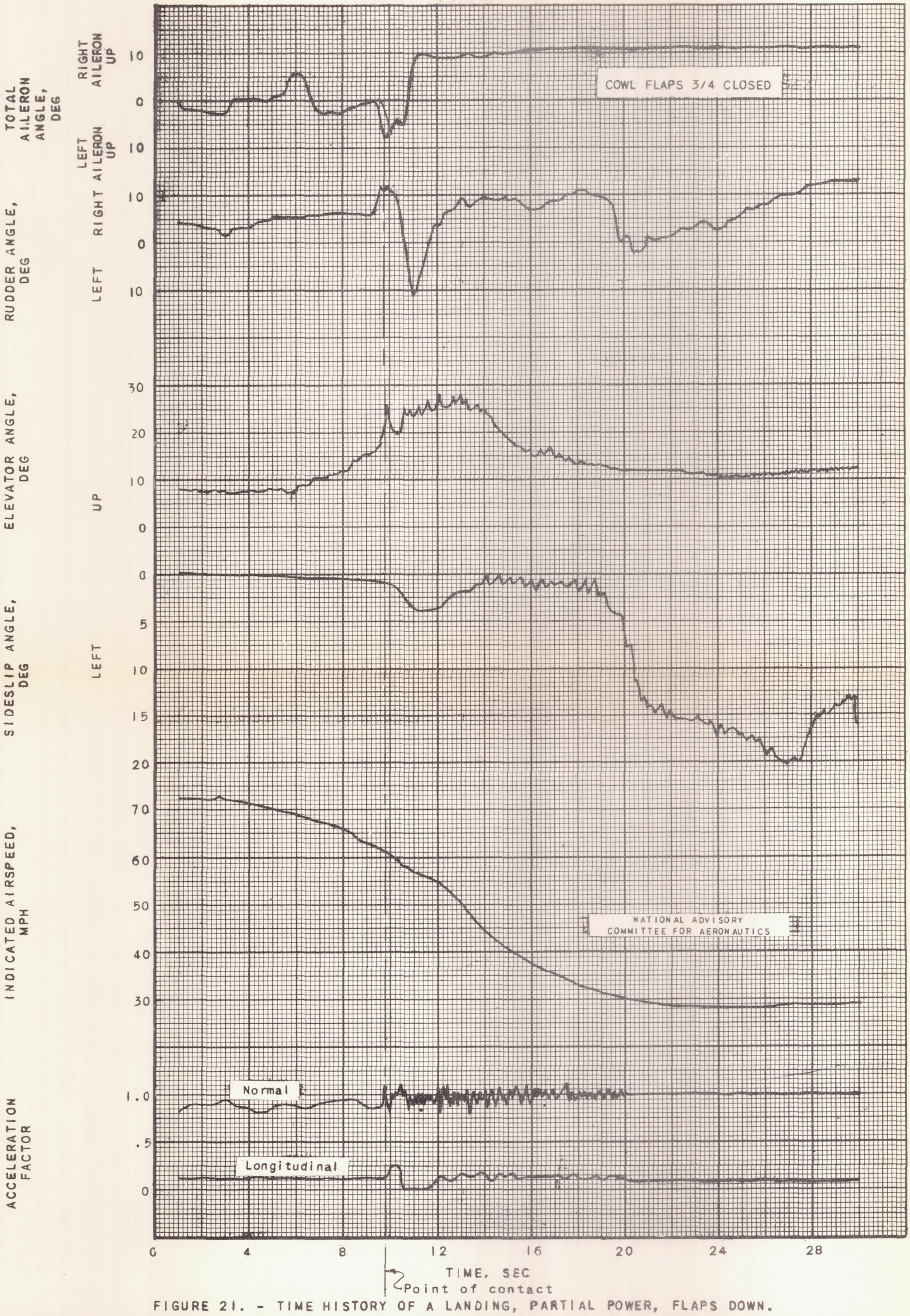


FIGURE 21. - TIME HISTORY OF A LANDING, PARTIAL POWER, FLAPS DOWN.

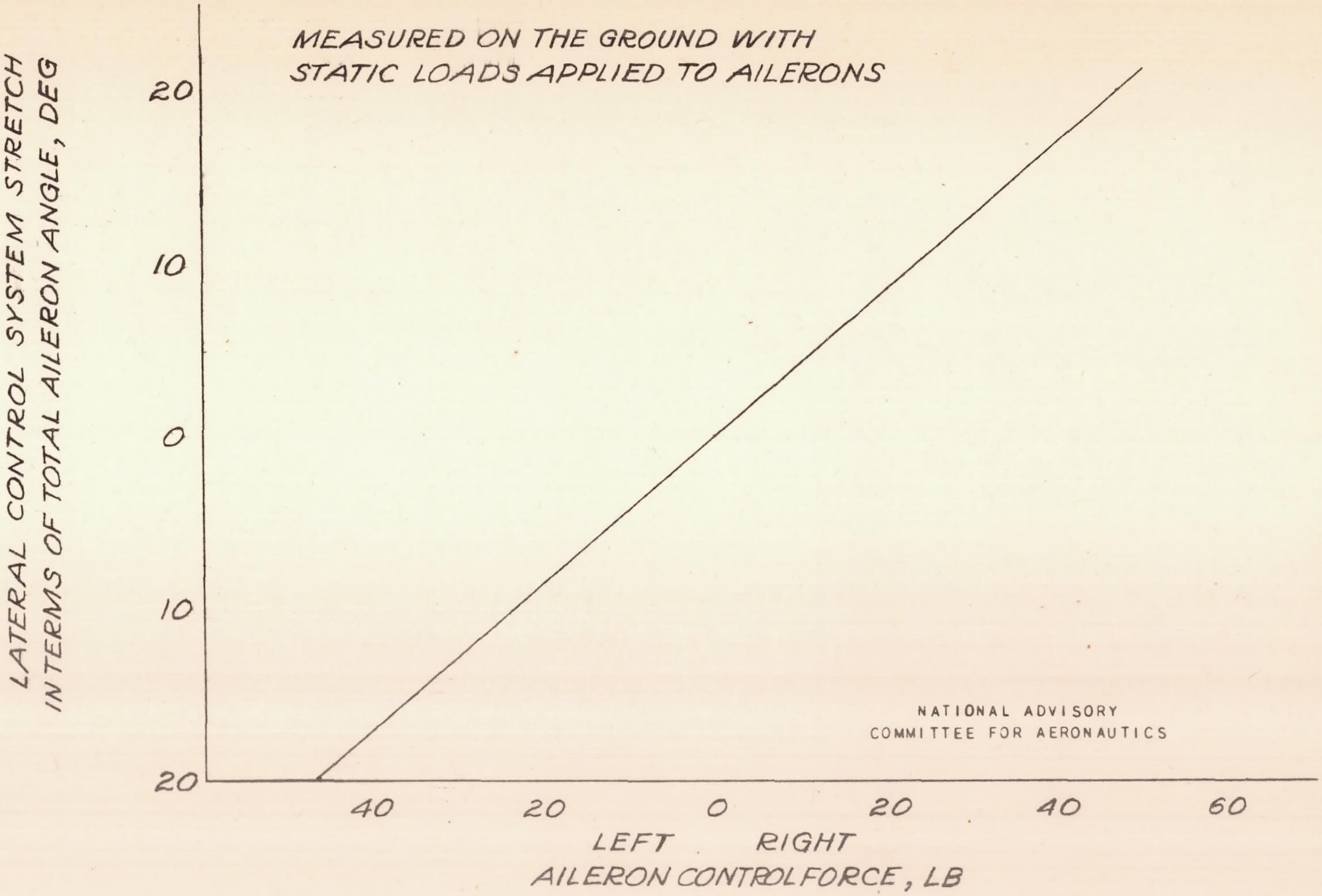


FIGURE 22.- VARIATION OF LATERAL CONTROL SYSTEM STRETCH WITH AILERON CONTROL FORCE, CONTROL STICK NEUTRAL.

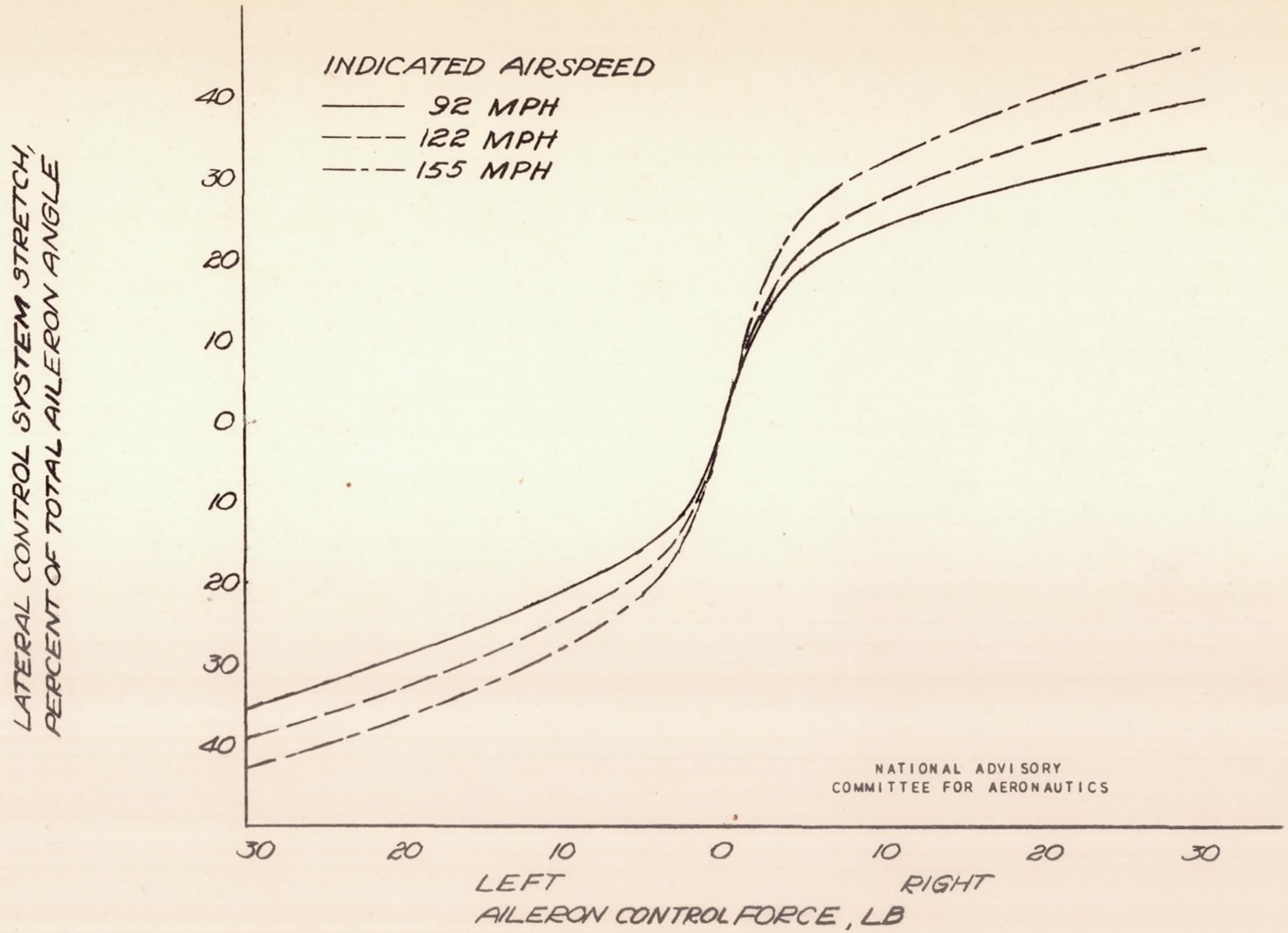


FIGURE 23.- VARIATION OF LATERAL CONTROL SYSTEM STRETCH IN PERCENT OF TOTAL AILERON ANGLE WITH AILERON CONTROL FORCE.

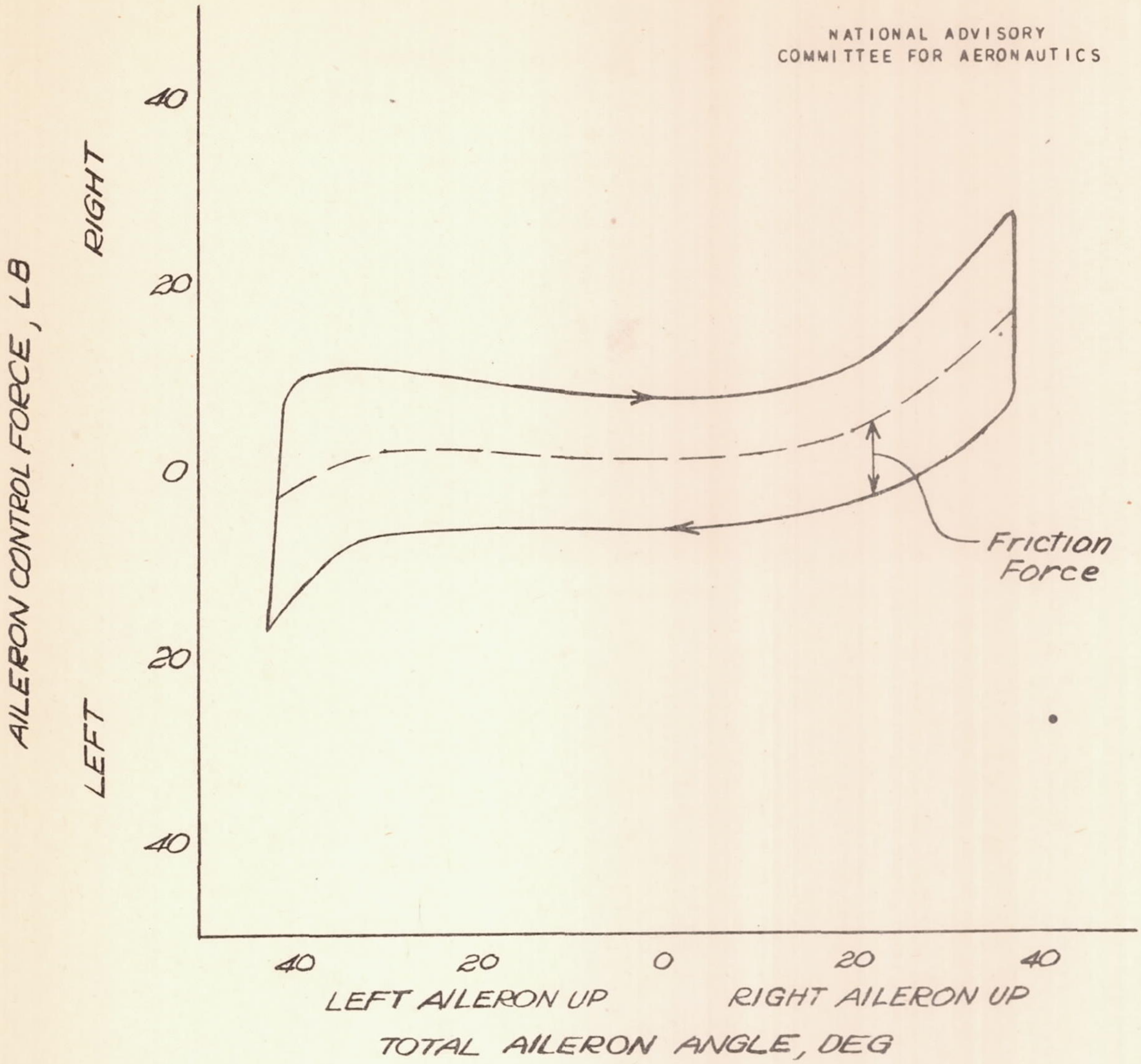


FIGURE 24.- VARIATION OF AILERON CONTROL FORCE WITH TOTAL AILERON ANGLE, NO LOAD ON SURFACES.

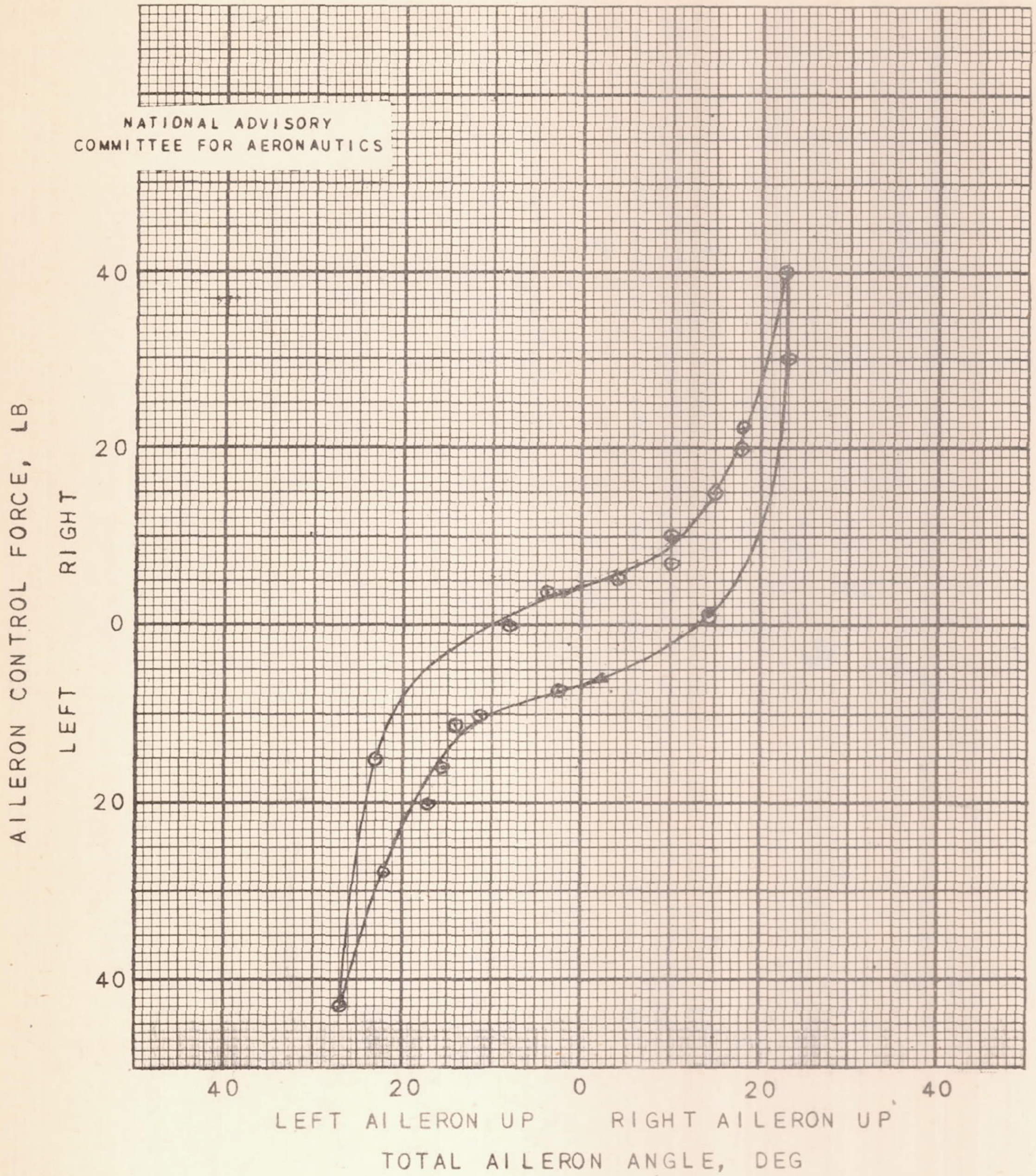


FIGURE 25. - VARIATION OF AILERON CONTROL FORCE WITH TOTAL AILERON ANGLE, IN FLIGHT AT 92 MPH.

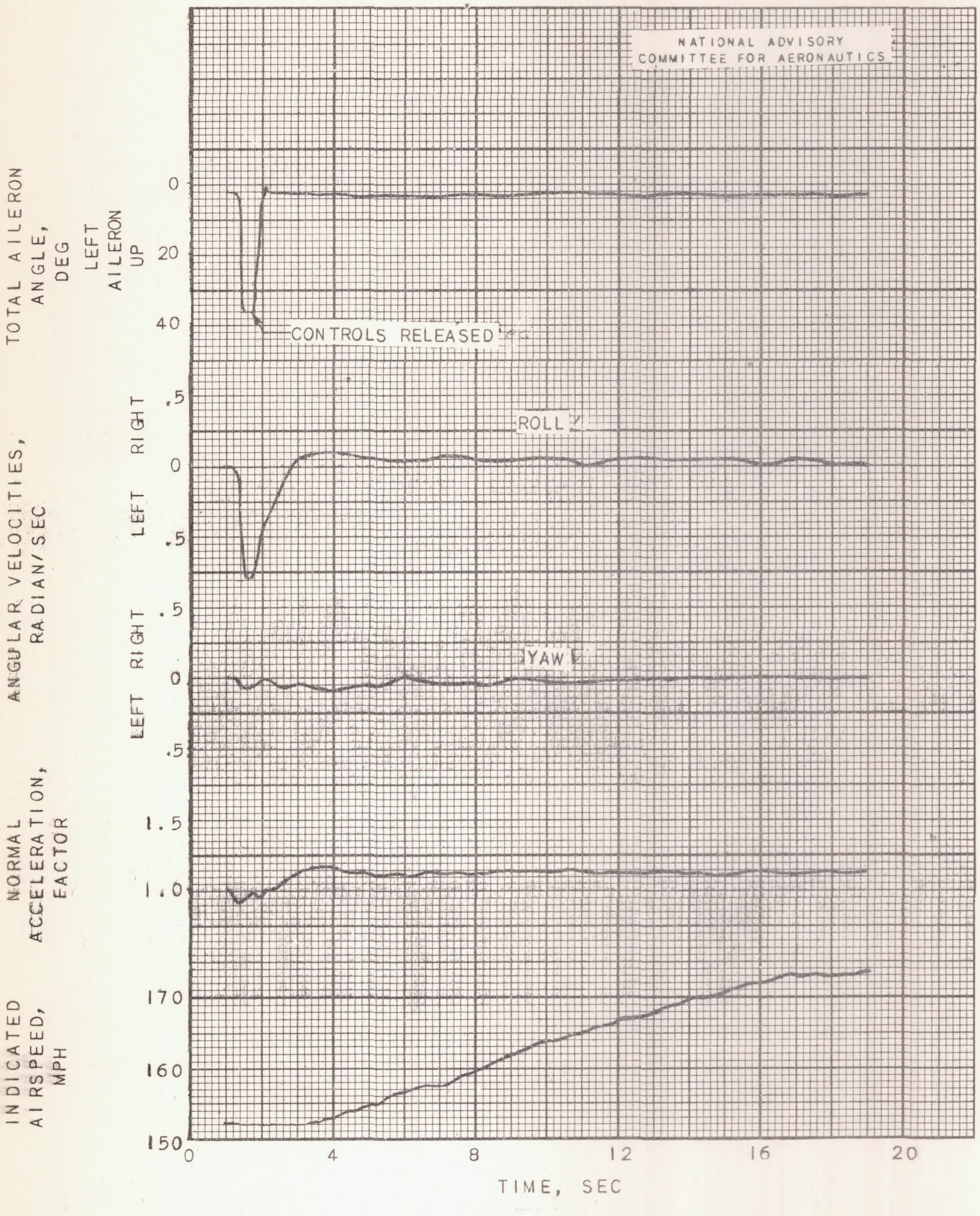


FIGURE 26. - CHARACTERISTICS OF UNCONTROLLED LATERAL MOTION, RATED POWER, FLAPS UP, 152 MPH.

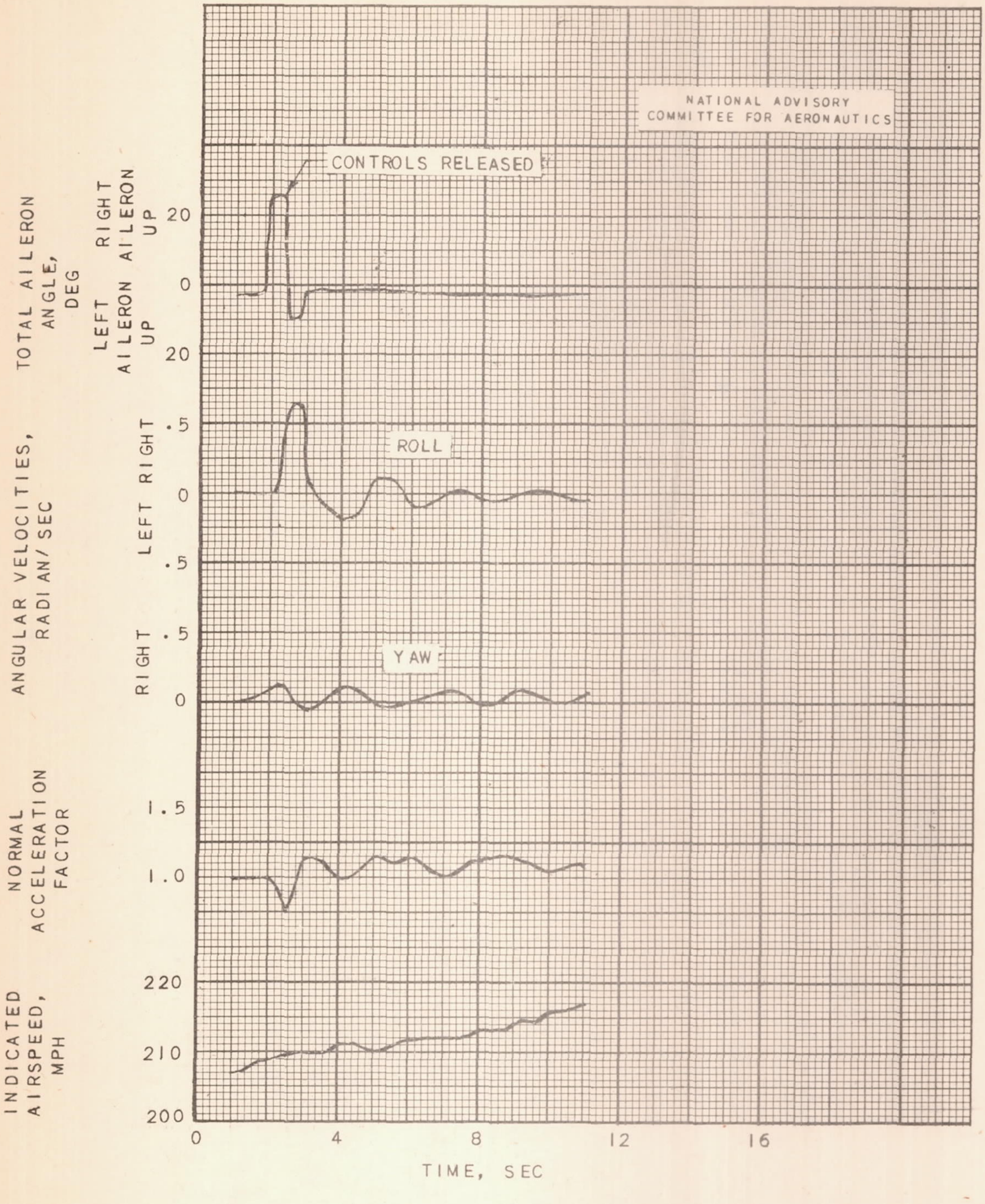


FIGURE 27. - CHARACTERISTICS OF UNCONTROLLED LATERAL MOTION, RATED POWER, FLAPS UP, 207 MPH.

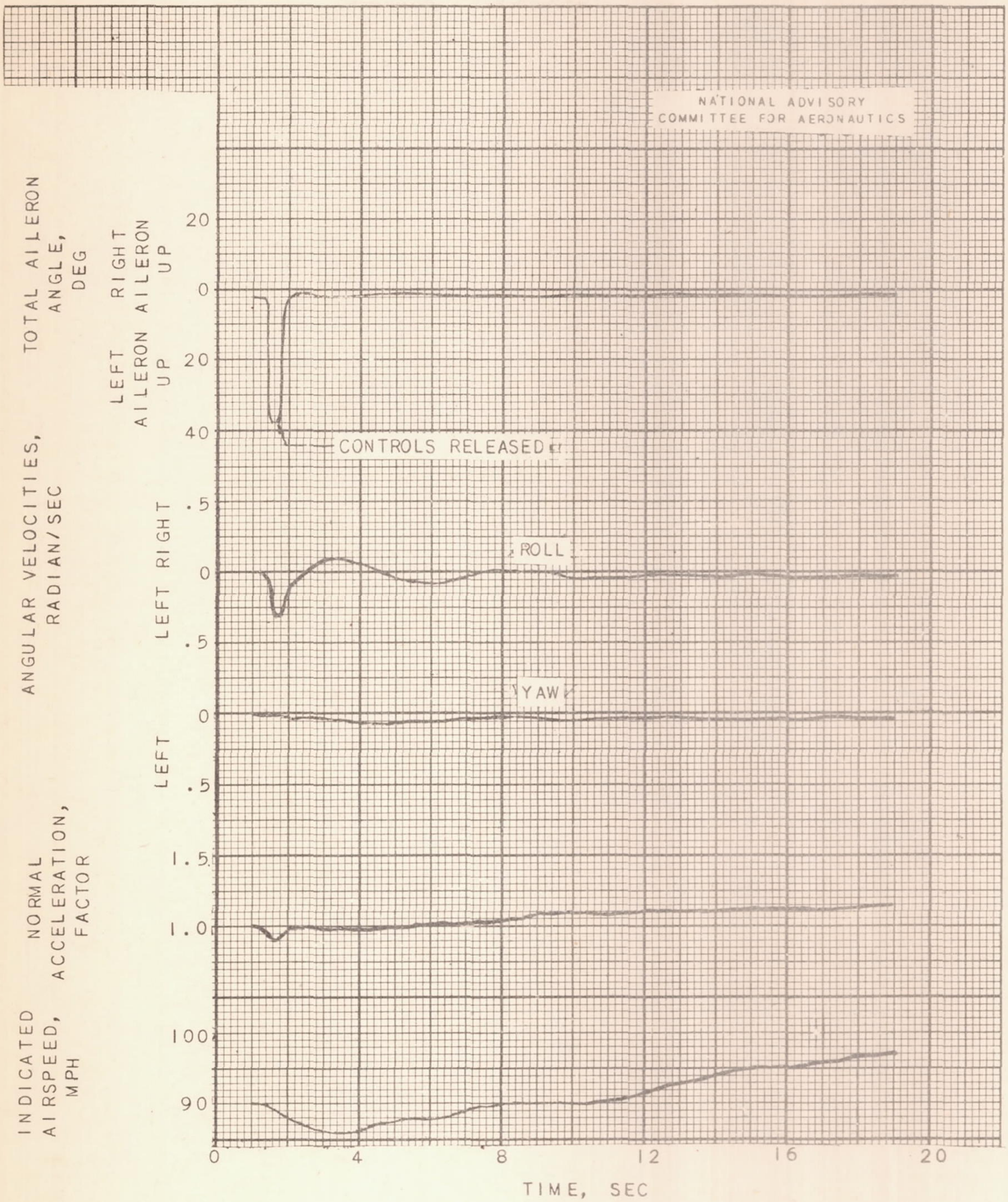


FIGURE 28. - CHARACTERISTICS OF UNCONTROLLED LATERAL MOTION, POWER OFF, FLAPS UP, 92 MPH.

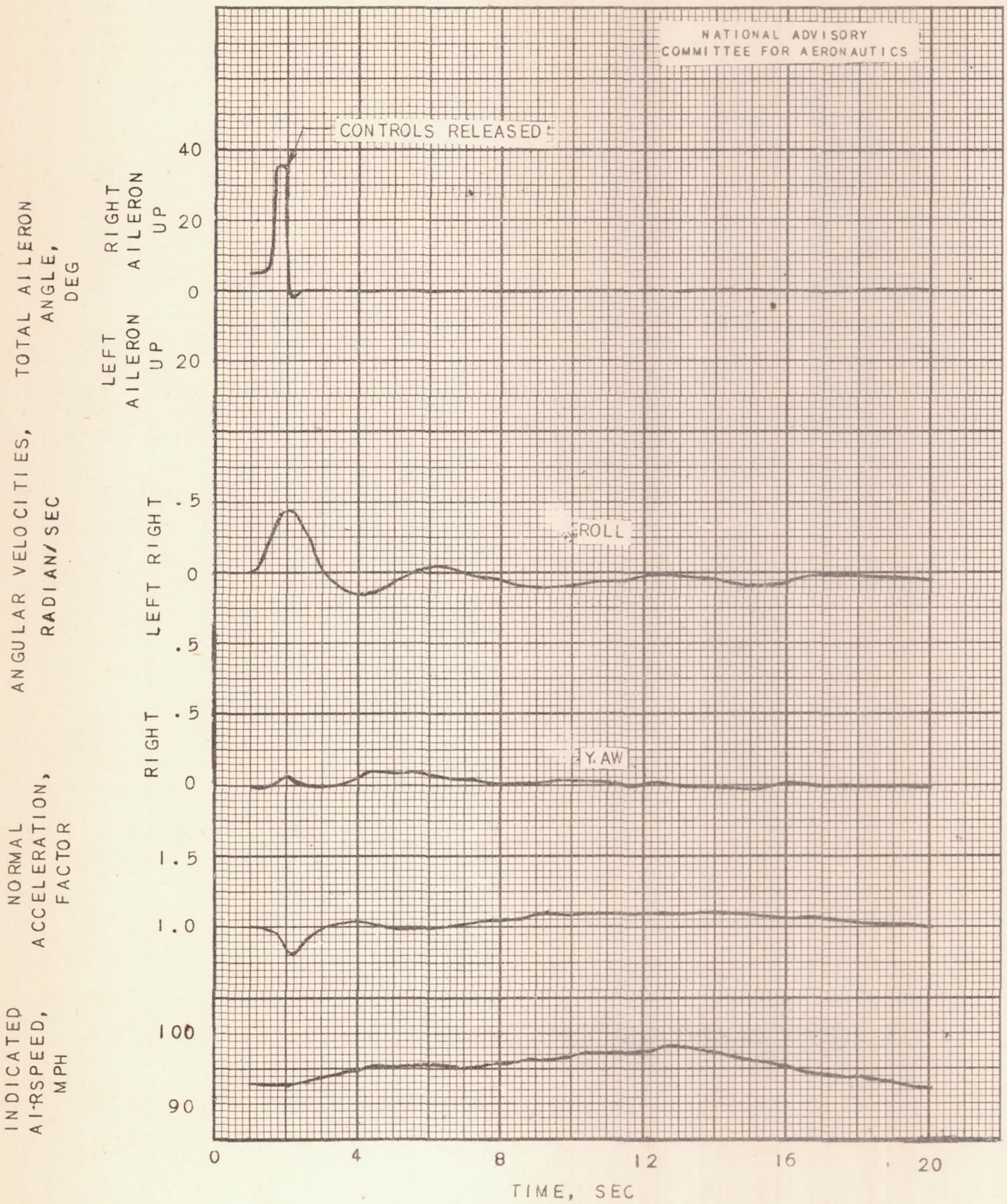


FIGURE 29. - CHARACTERISTICS OF UNCONTROLLED LATERAL MOTION, POWER OFF, FLAPS DOWN, 92 MPH.

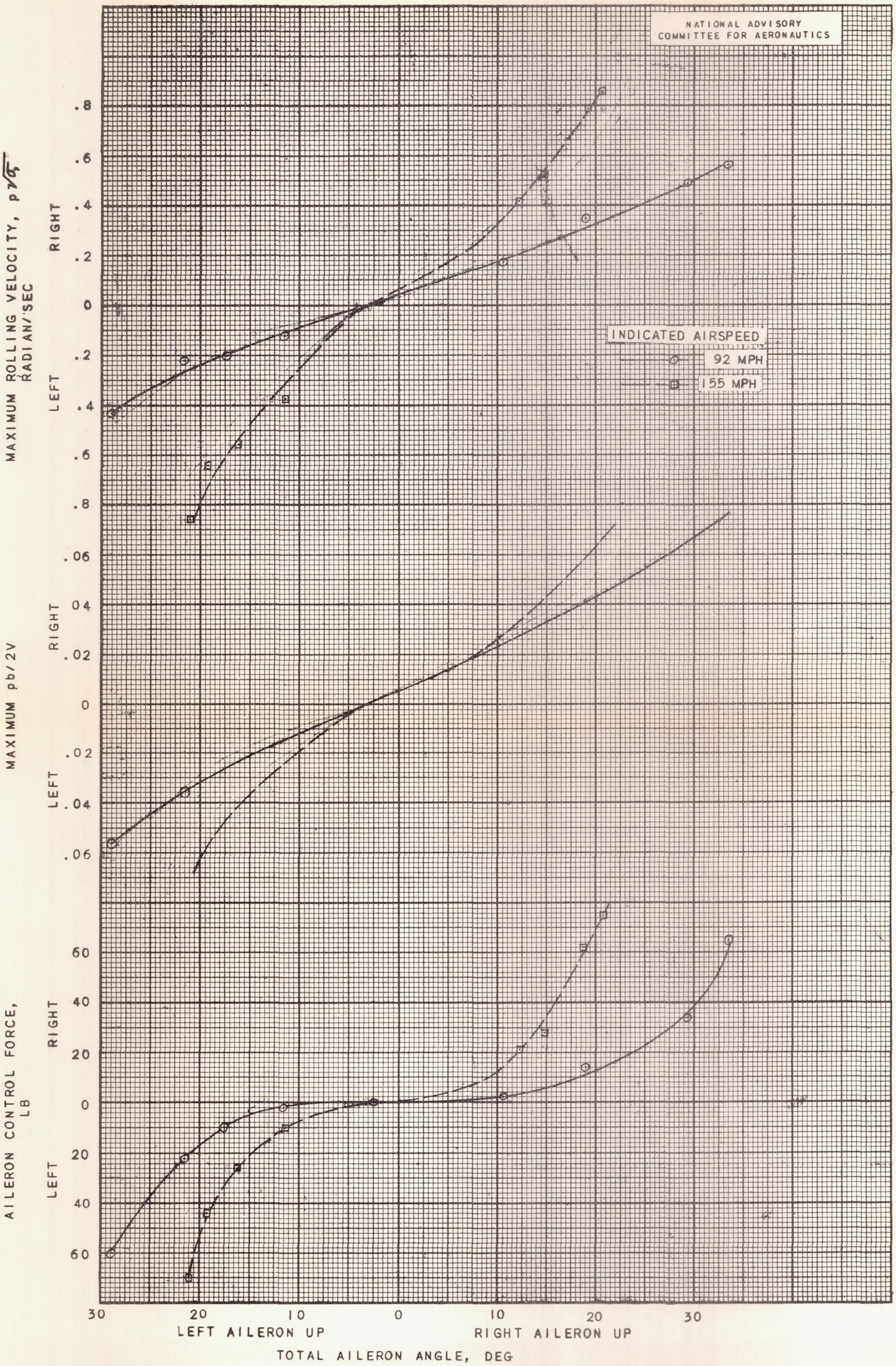


FIGURE 30. - AILERON CONTROL CHARACTERISTICS, RATED POWER, FLAPS UP.

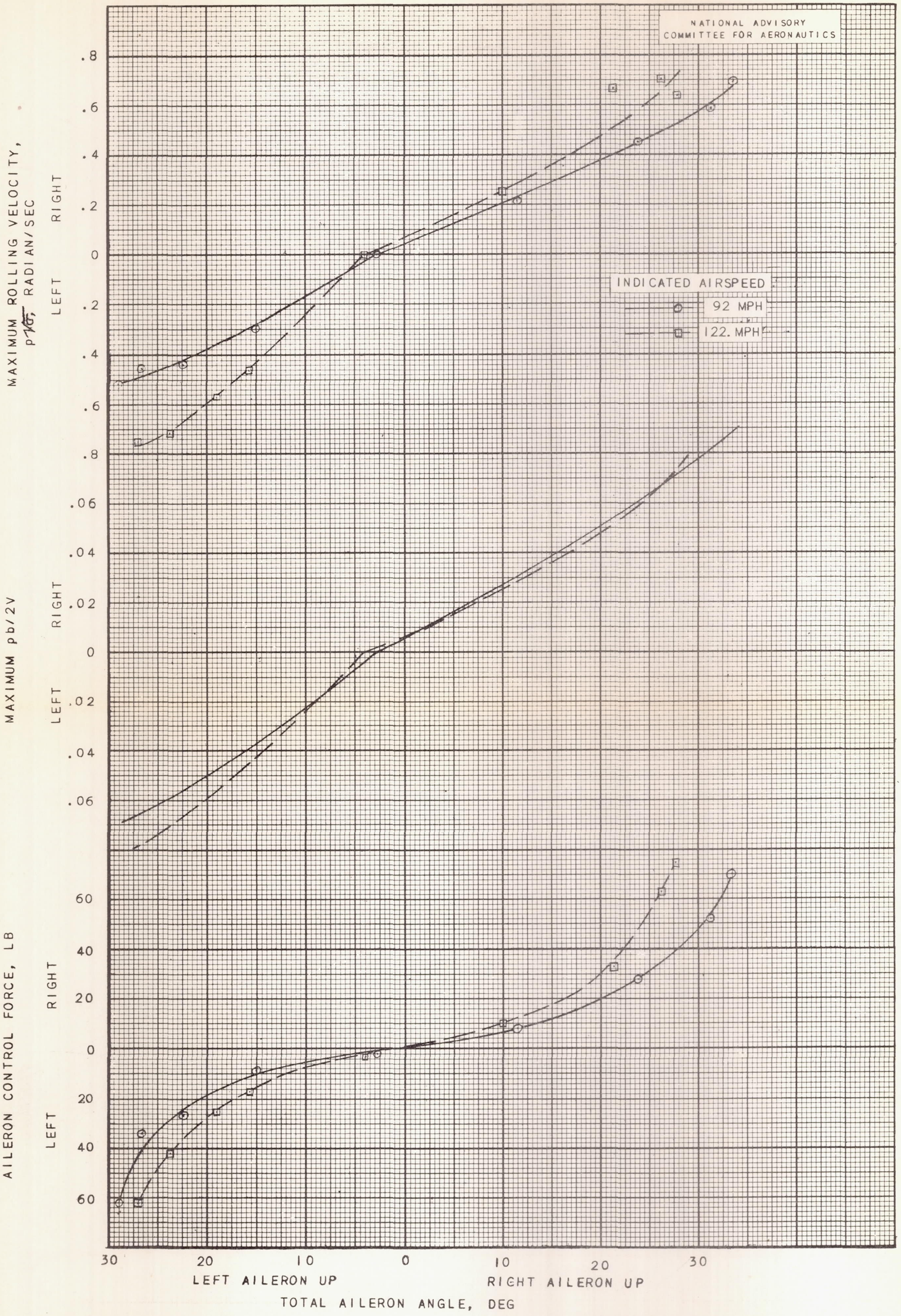


FIGURE 31. - AILERON CONTROL CHARACTERISTICS, RATED POWER, FLAPS ONE-HALF DOWN.

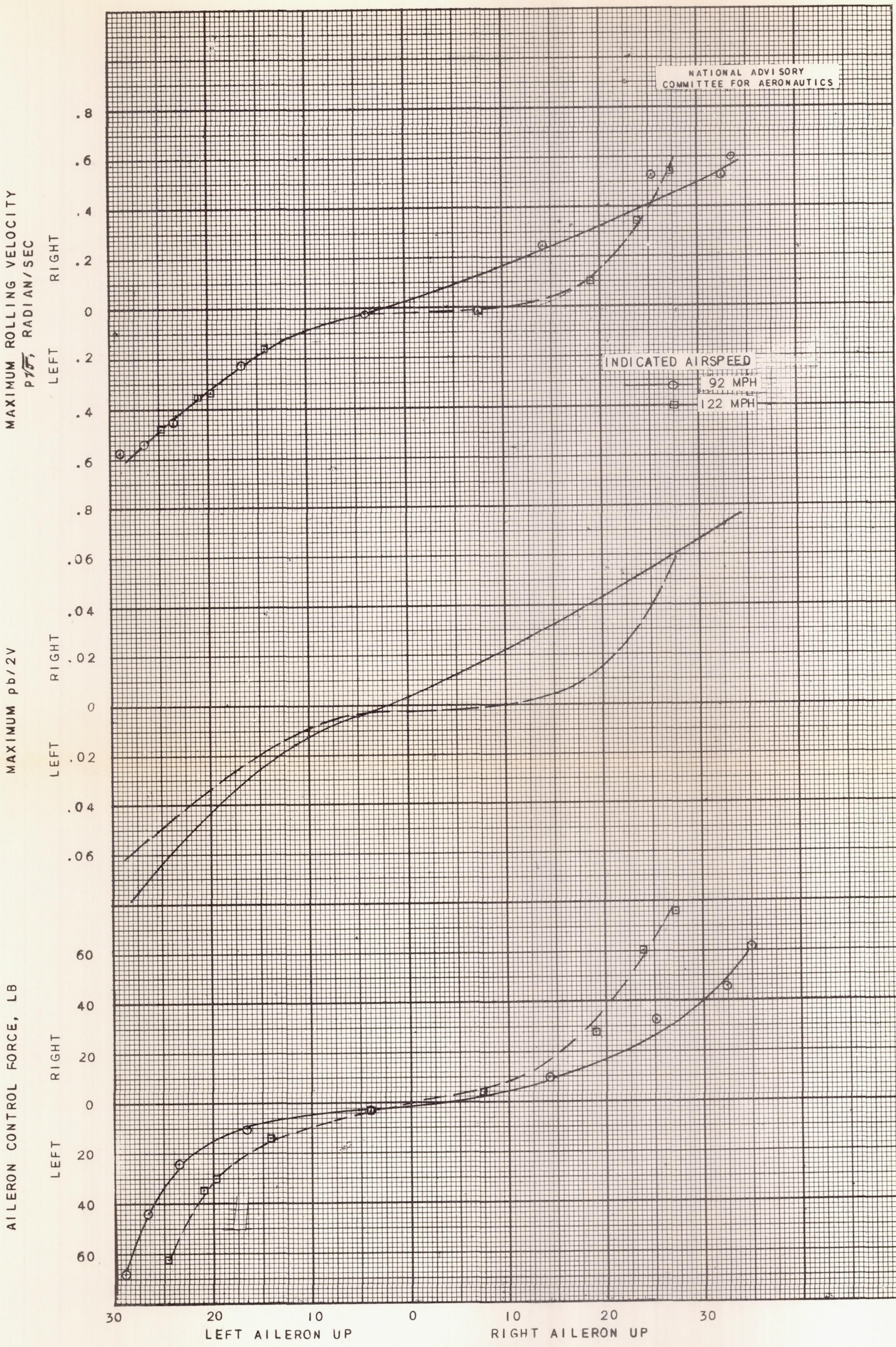


FIGURE 32. - AILERON CONTROL CHARACTERISTICS, RATED POWER, FLAPS DOWN.

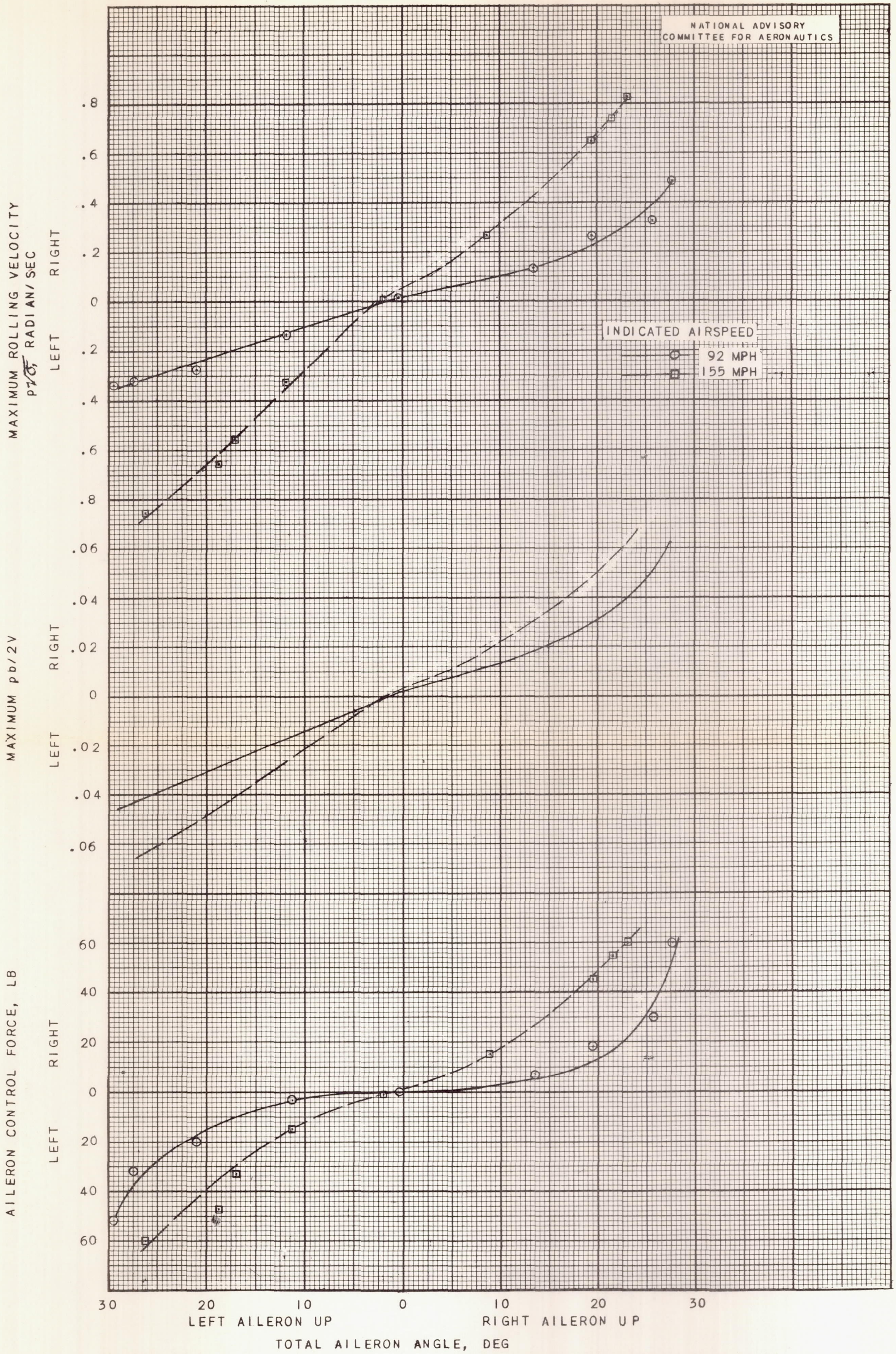


FIGURE 33. - AILERON CONTROL CHARACTERISTICS, POWER OFF, FLAPS UP.

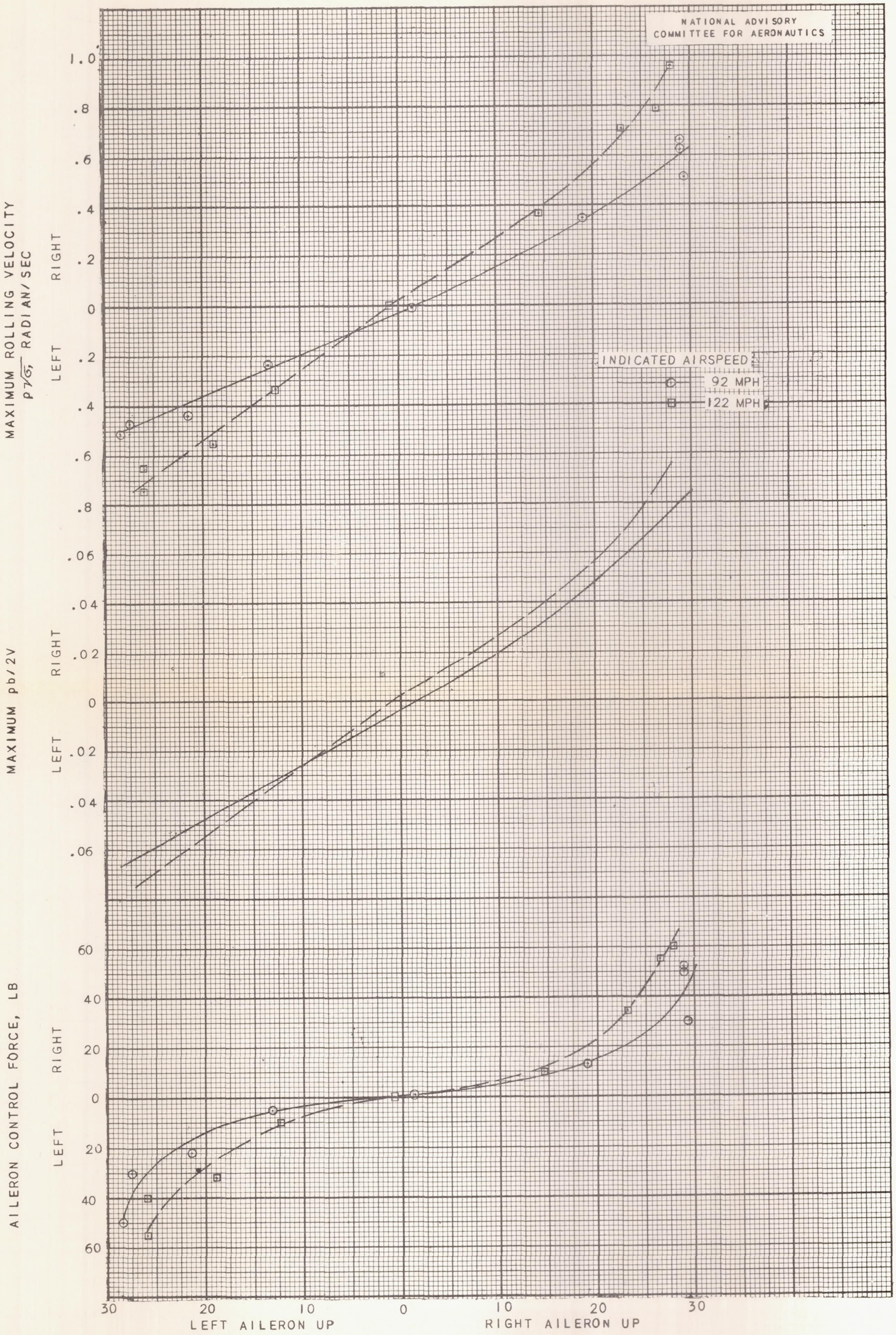


FIGURE 34. - AILERON CONTROL CHARACTERISTICS, POWER OFF, FLAPS ONE-HALF DOWN.

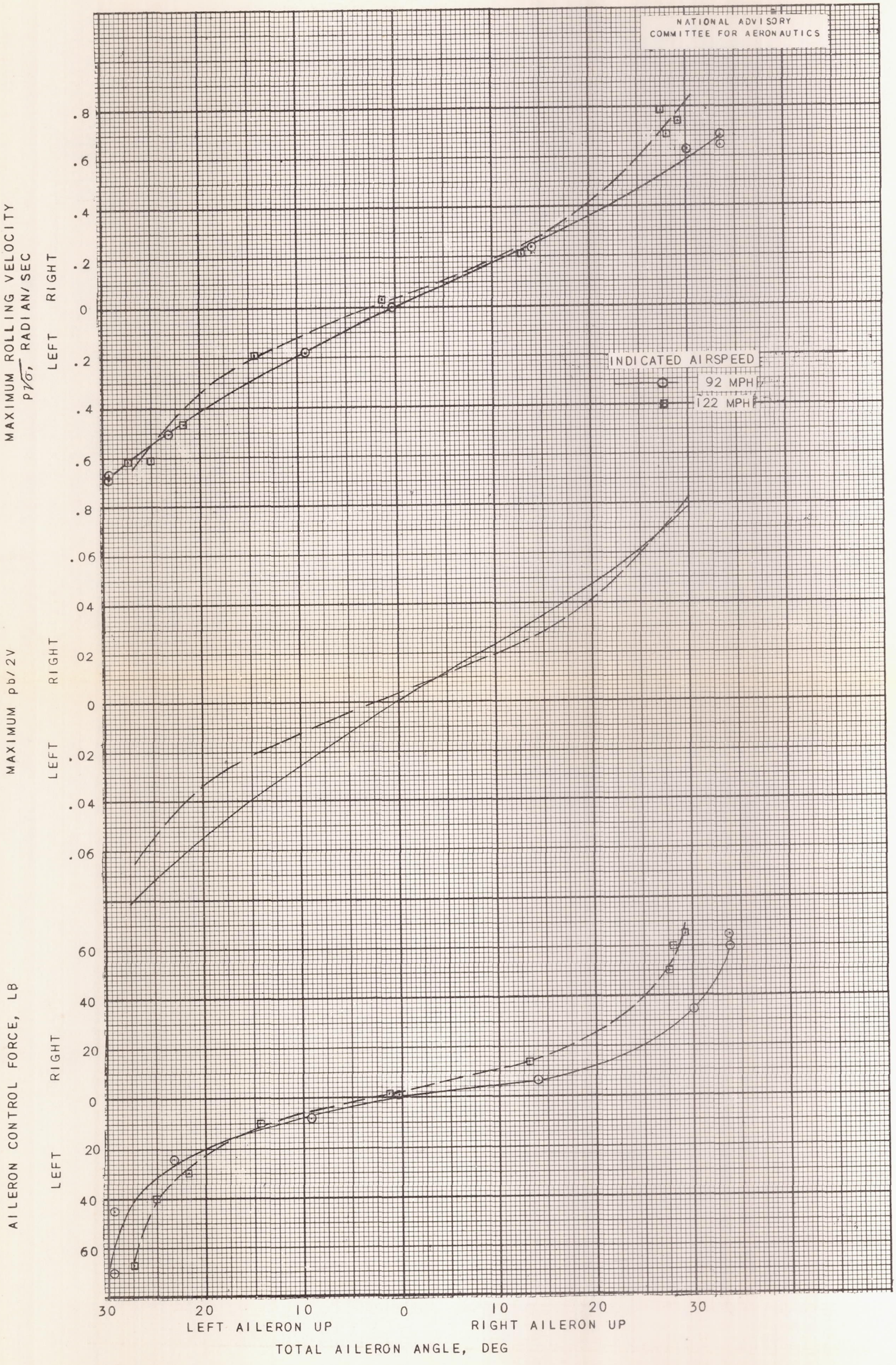
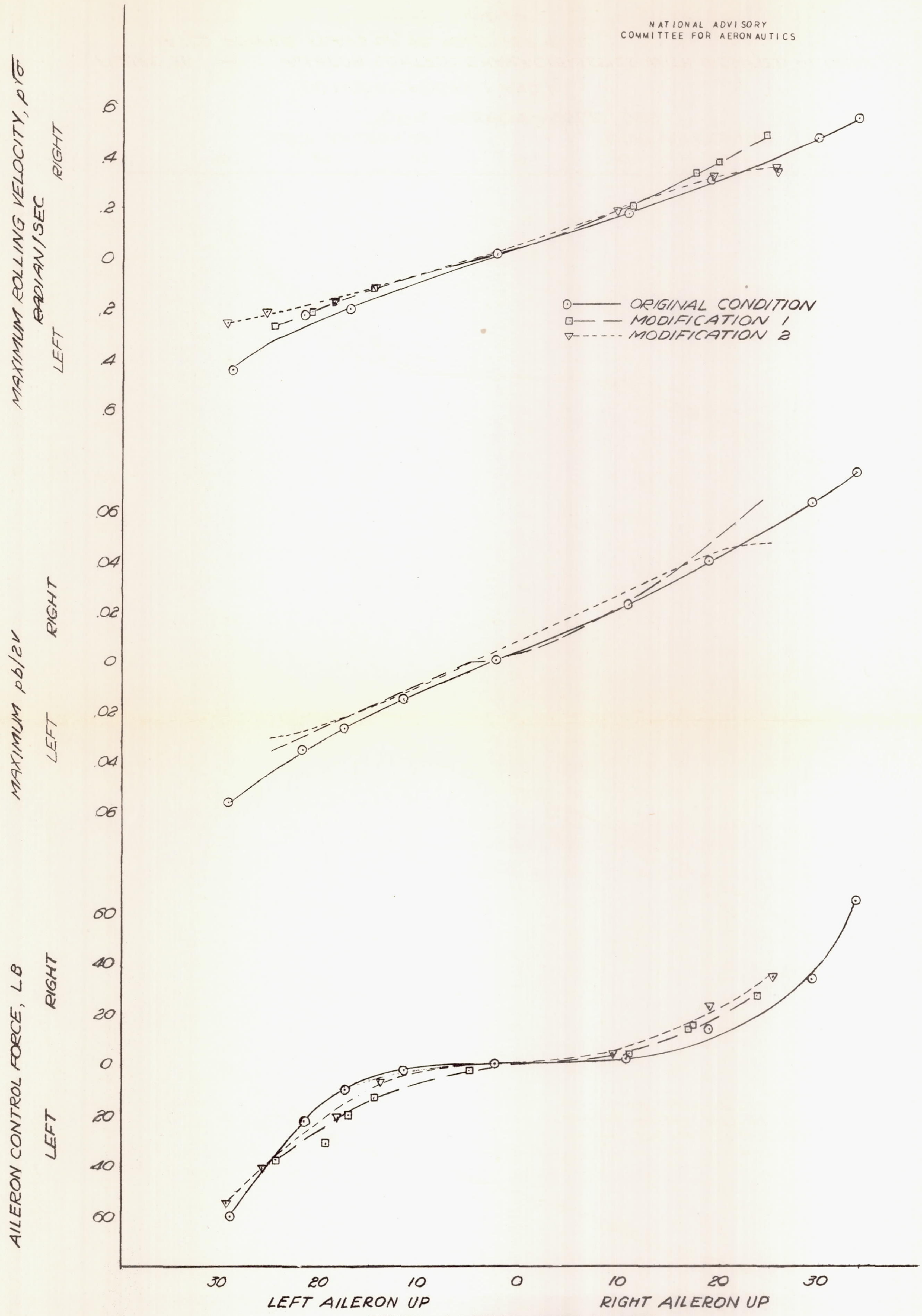
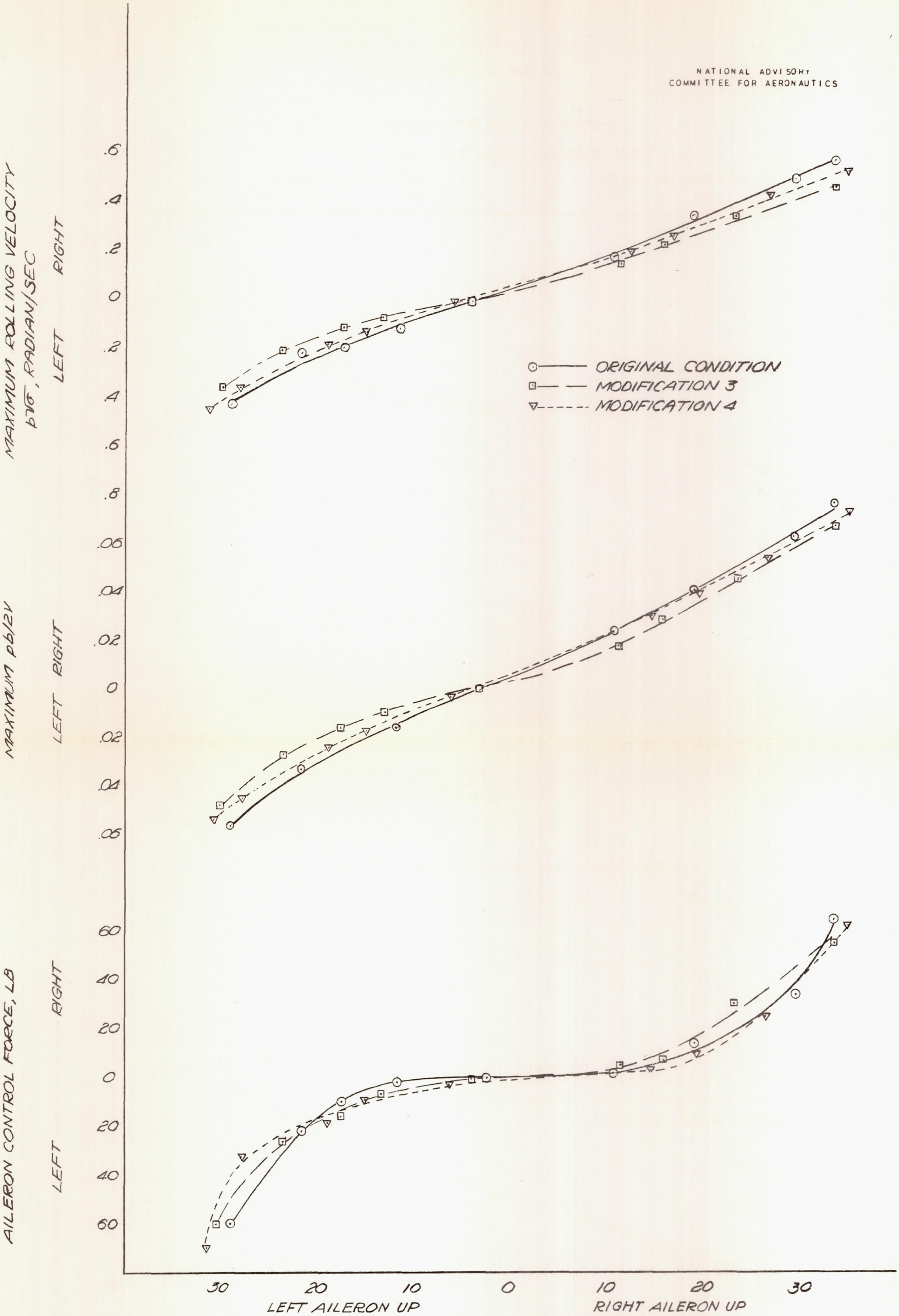


FIGURE 35. - AILERON CONTROL CHARACTERISTICS, POWER OFF, FLAPS DOWN.



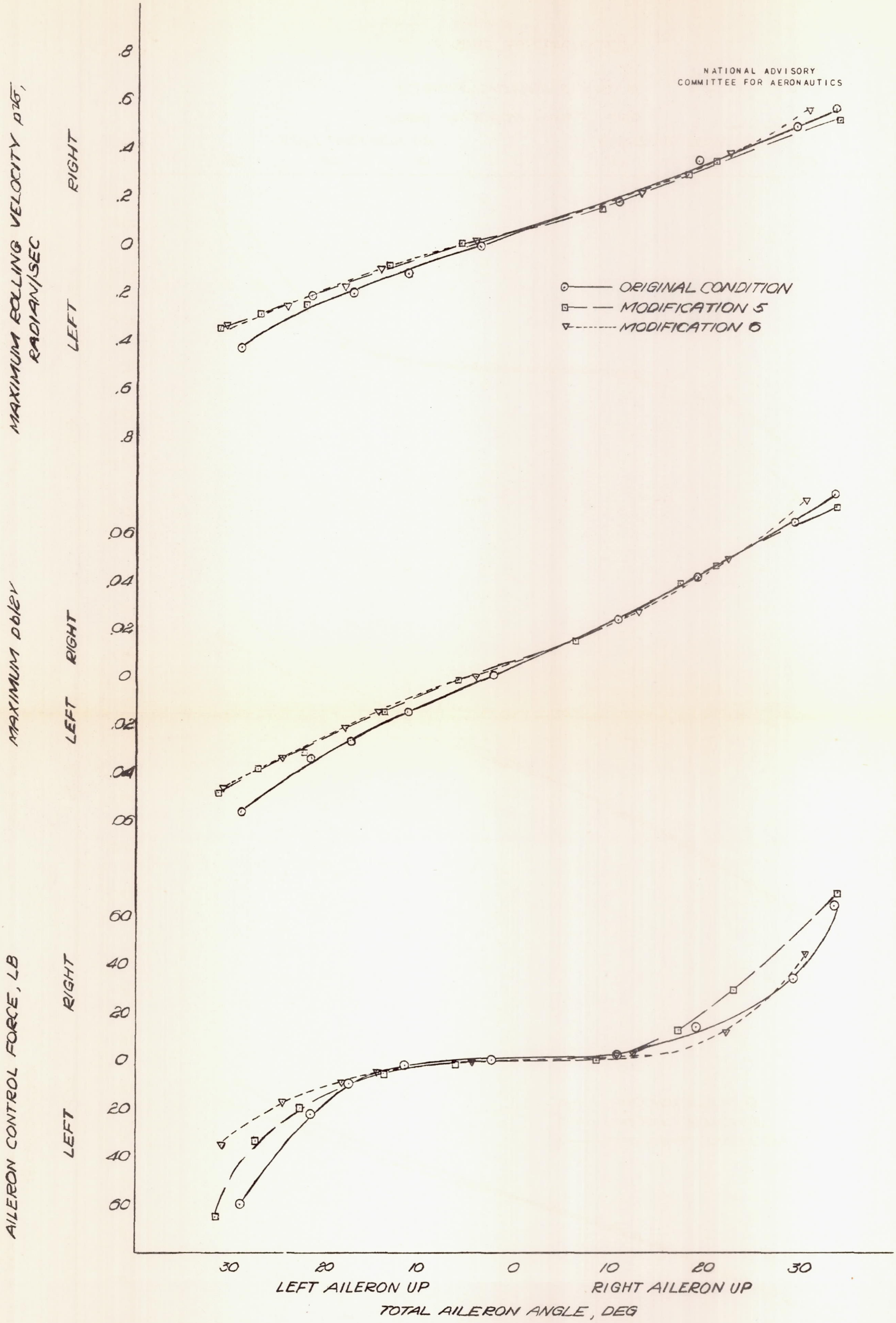
(a) MODIFICATIONS 1 AND 2

FIGURE 36. — AILERON CONTROL CHARACTERISTICS WITH MODIFIED AILERONS, RATED POWER, FLAPS UP, 92 MILES PER HOUR.



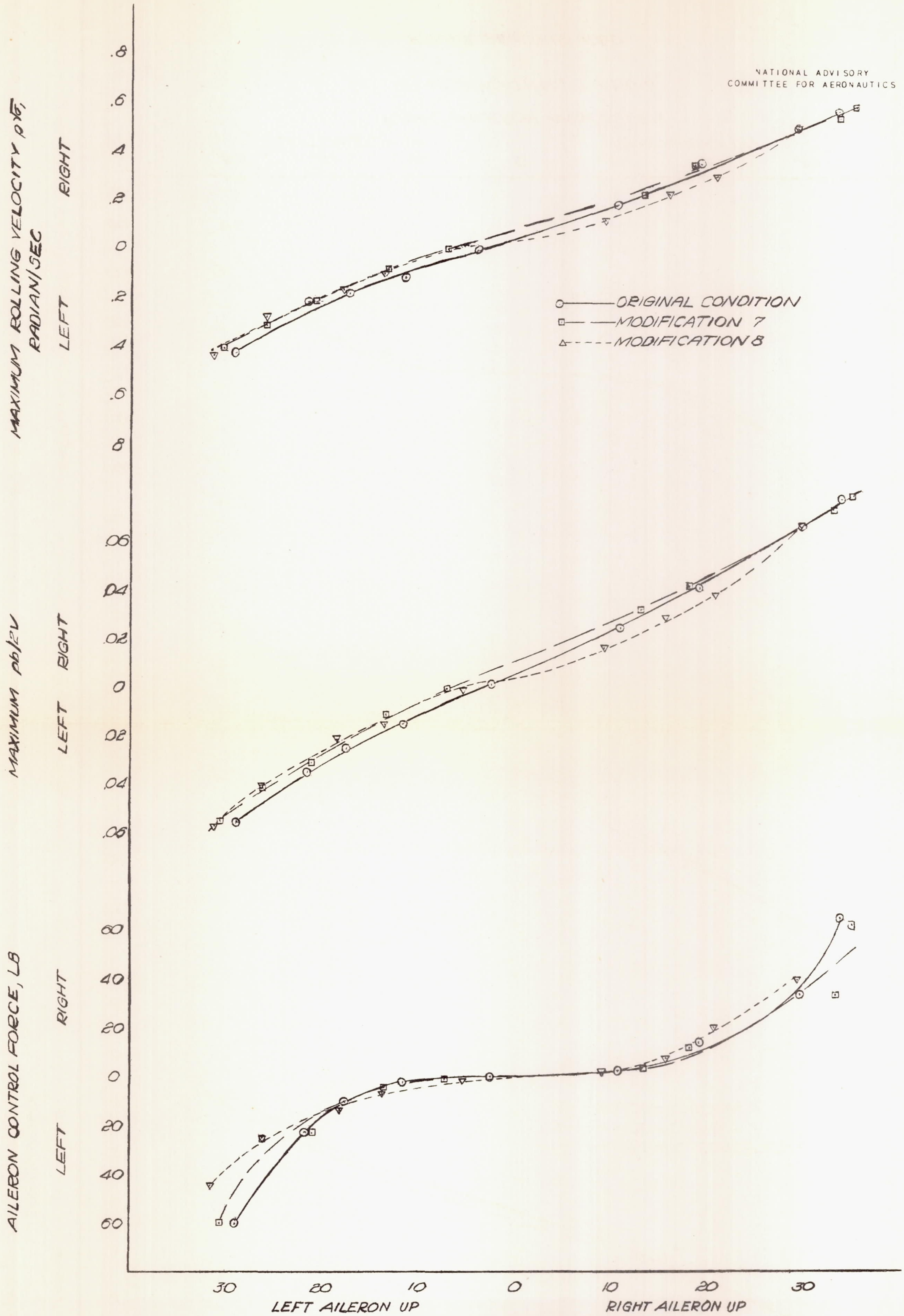
(b) MODIFICATIONS 3 AND 4

FIGURE 36.-CONTINUED



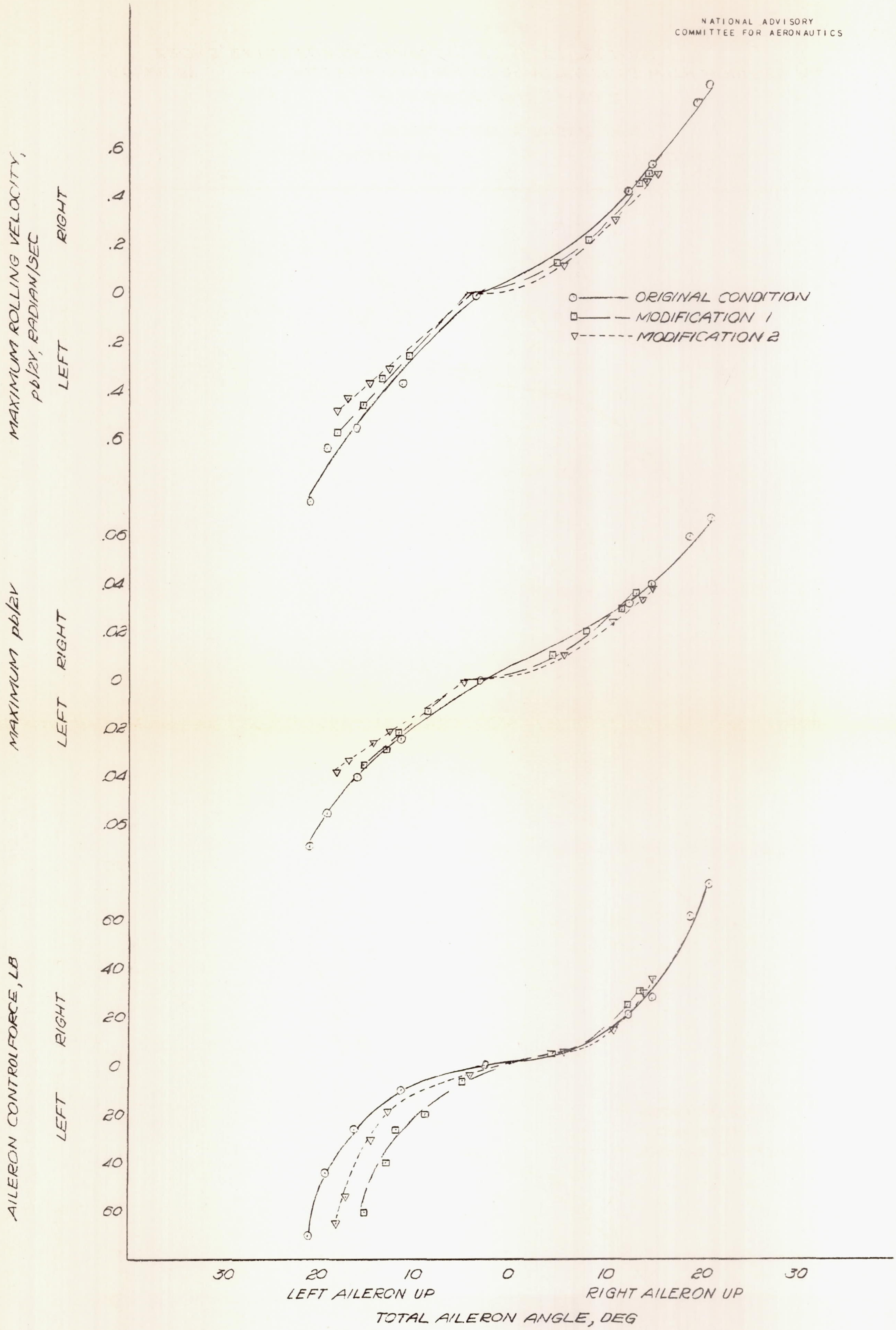
(c) MODIFICATIONS 5 AND 6

FIGURE 36-CONTINUED



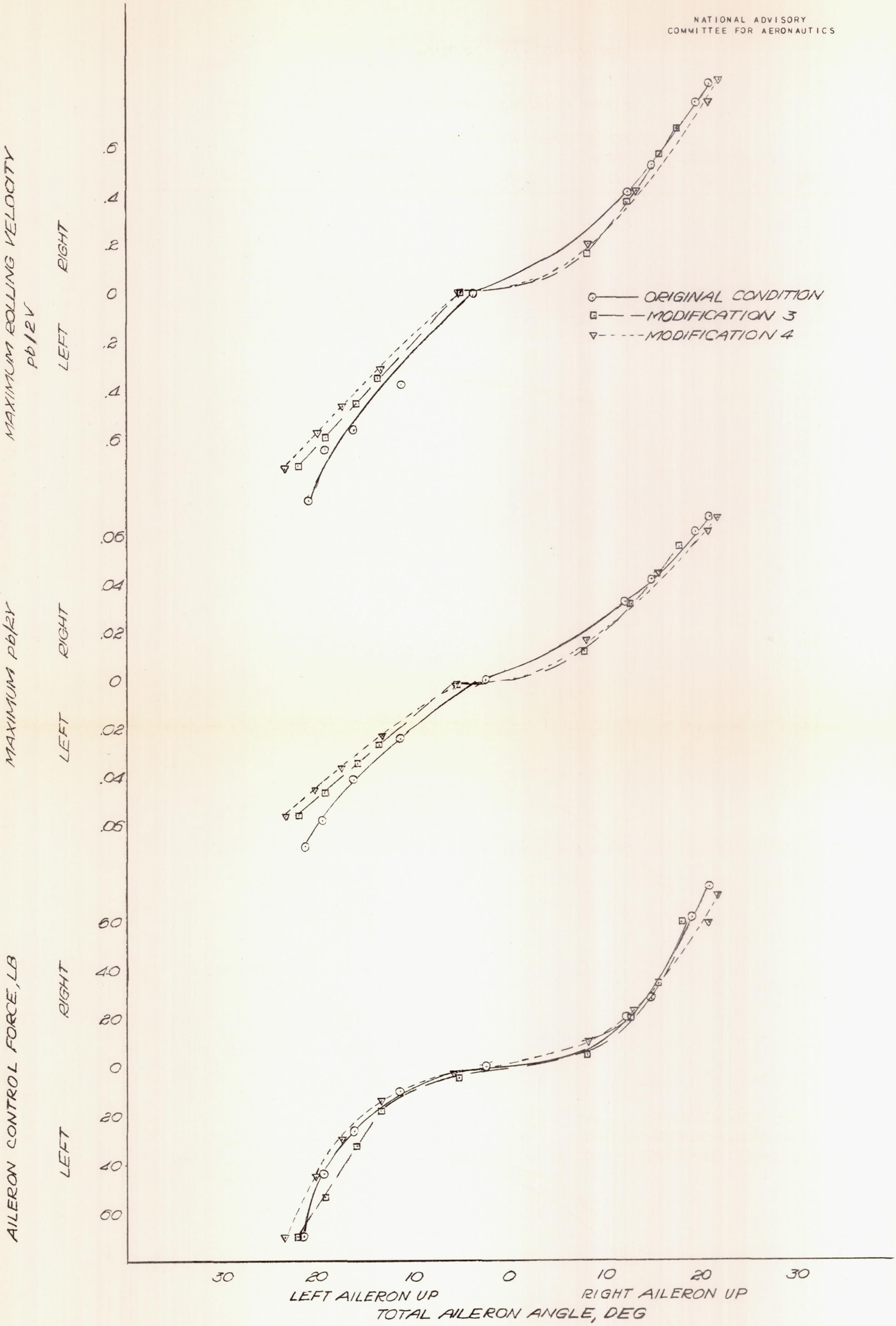
(d) MODIFICATIONS 7 AND 8

FIGURE 36.-CONCLUDED



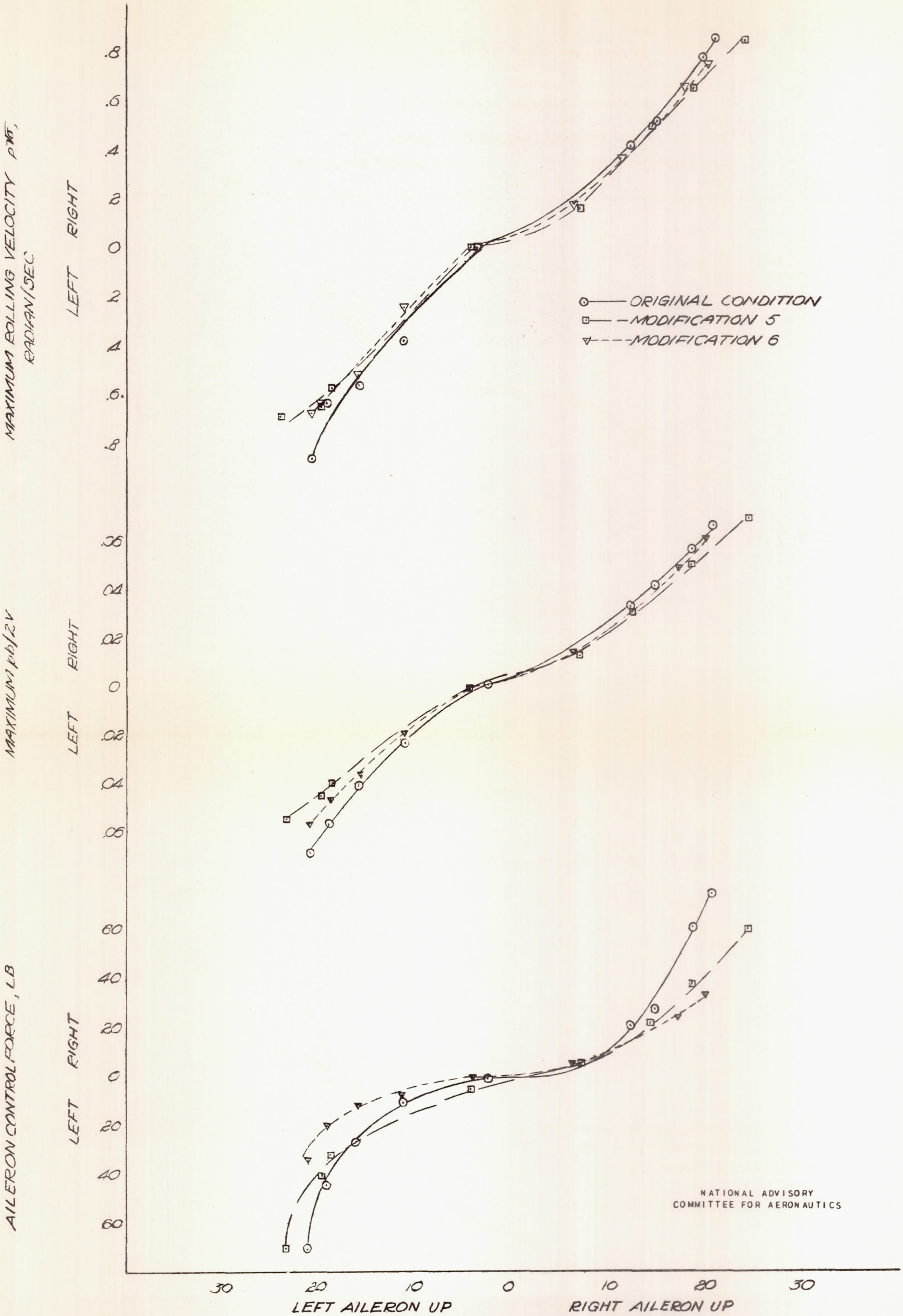
(a) MODIFICATIONS 1 AND 2

FIGURE 37. — AILERON CONTROL CHARACTERISTICS WITH MODIFIED AILERONS, RATED POWER, FLAPS UP, 155 MILES PER HOUR



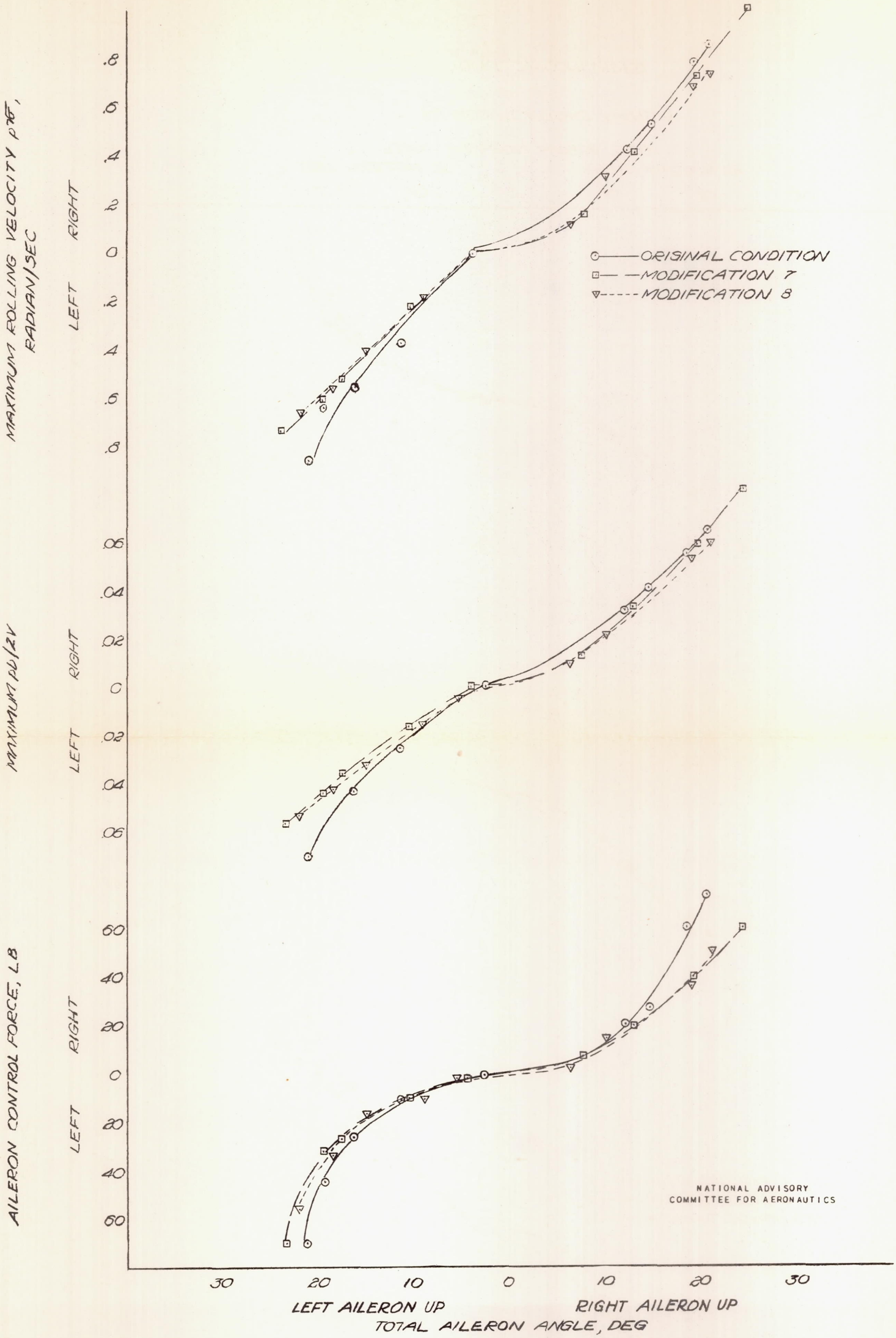
(b) MODIFICATIONS 3 AND 4.

FIGURE 37.-CONTINUED



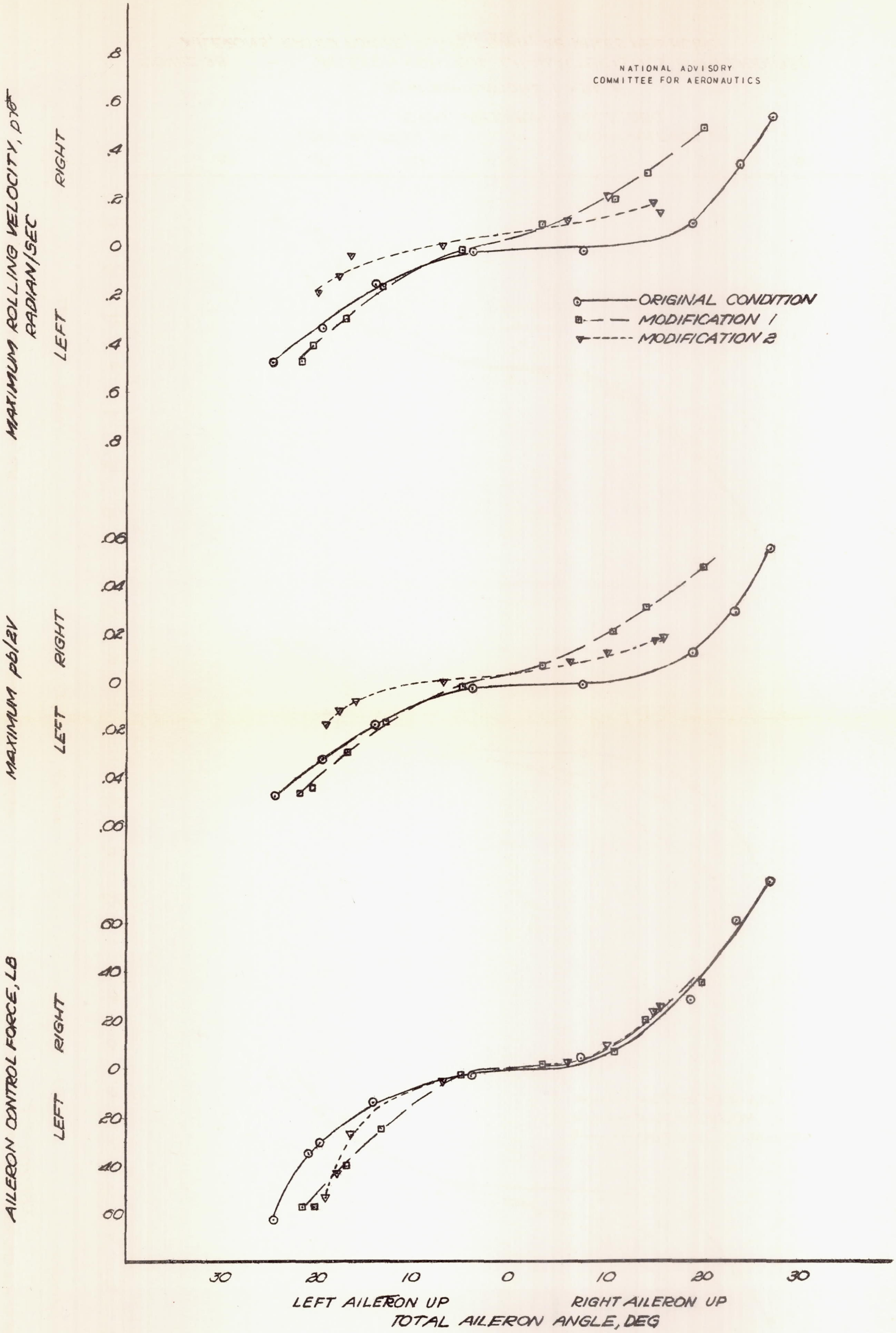
(c) MODIFICATIONS 5 AND 6

FIGURE 37.-CONTINUED



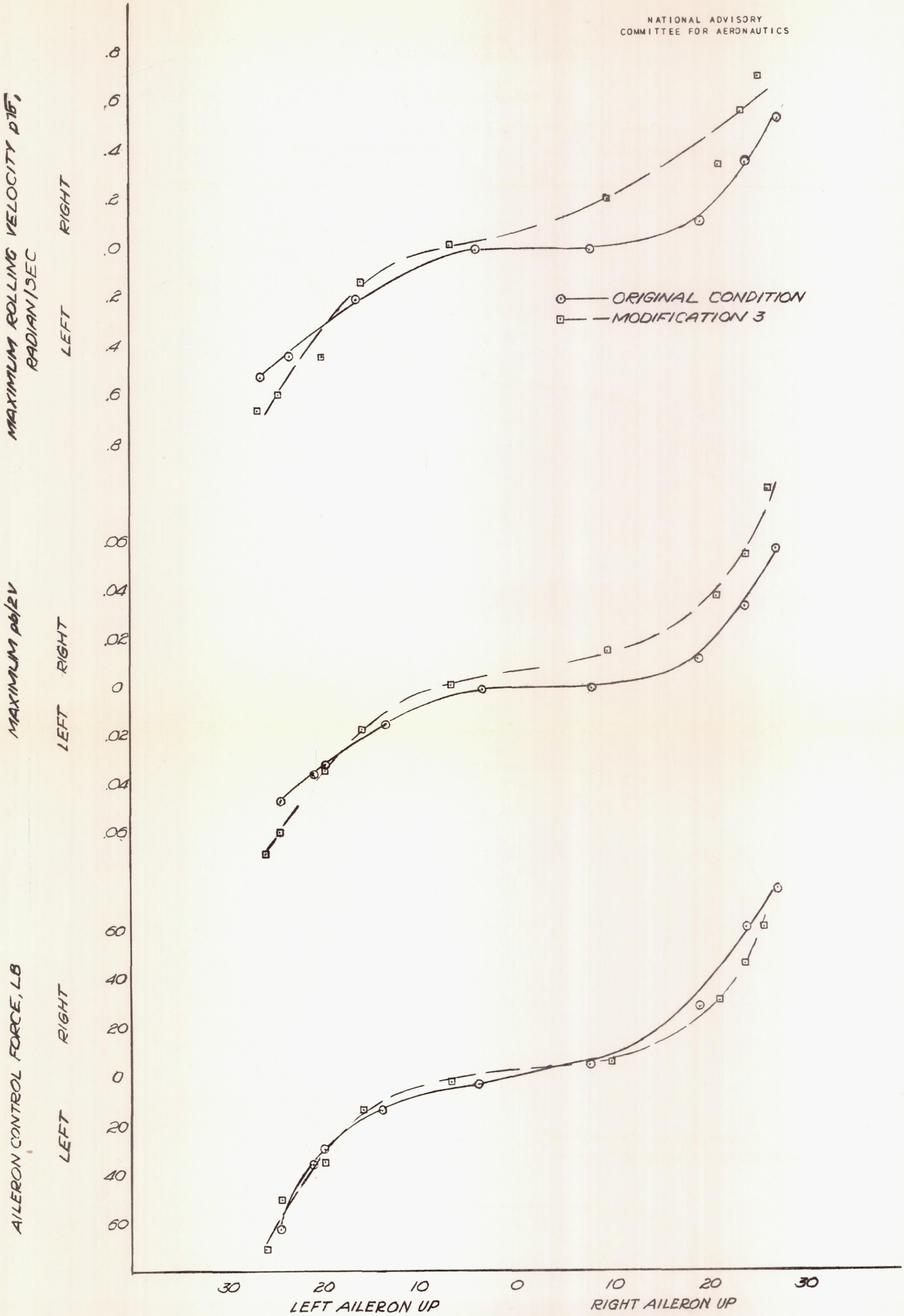
(d) MODIFICATIONS 7 AND 8

FIGURE 37.-CONCLUDED



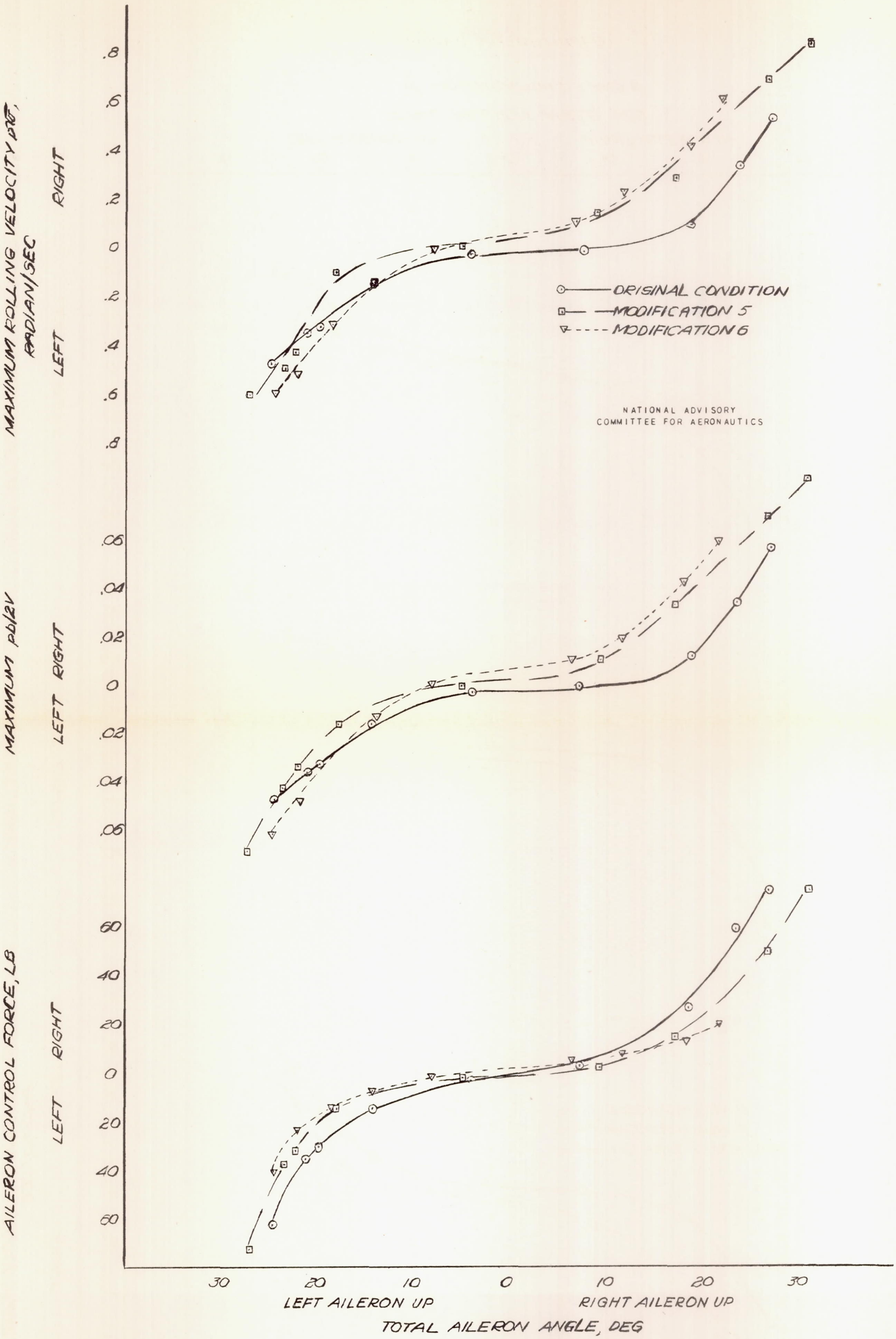
(a) MODIFICATIONS 1 AND 2

FIGURE 38. — AILERON CONTROL CHARACTERISTICS WITH MODIFIED AILERONS, RATED POWER, FLAPS DOWN, 122 MILES PER HOUR.



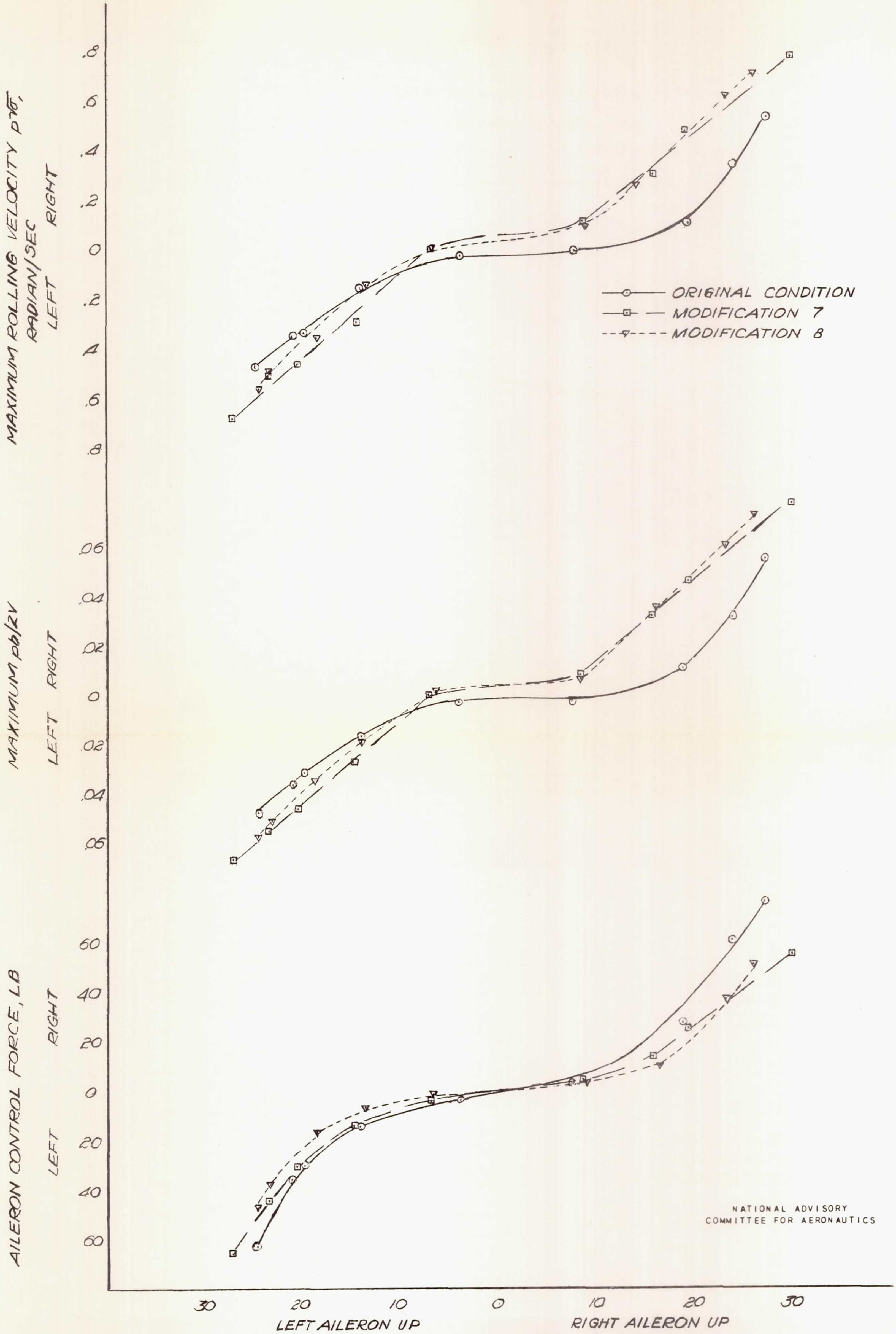
(b) MODIFICATION 3

FIGURE 38.-CONTINUED



(c) MODIFICATIONS 5 AND 6

FIGURE 38.-CONTINUED



(d) MODIFICATIONS 7 AND 8

FIGURE 38.-CONCLUDED

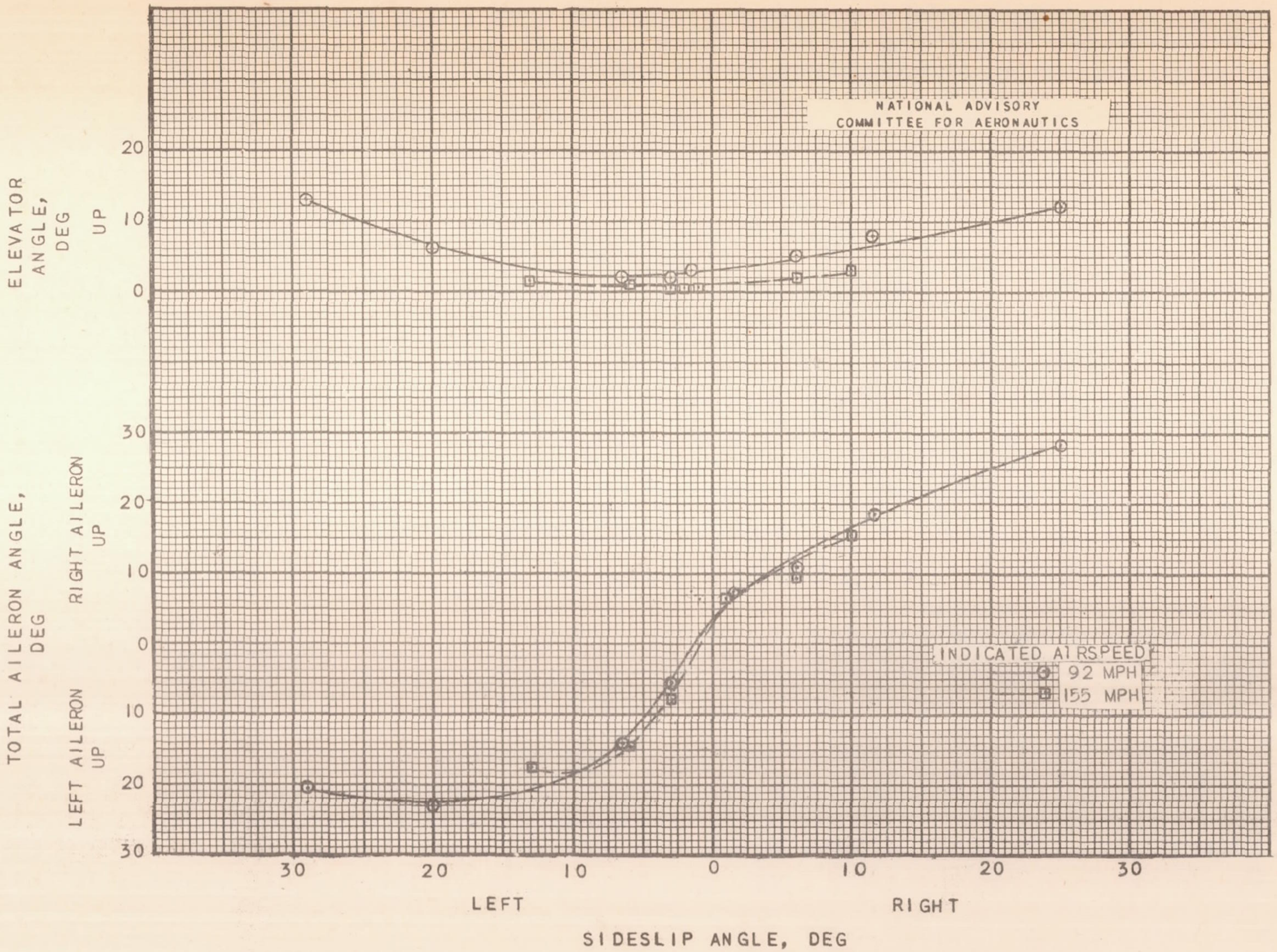


FIGURE 39. - CHARACTERISTICS IN STEADY SIDESLIPS, RATED POWER, FLAPS UP.

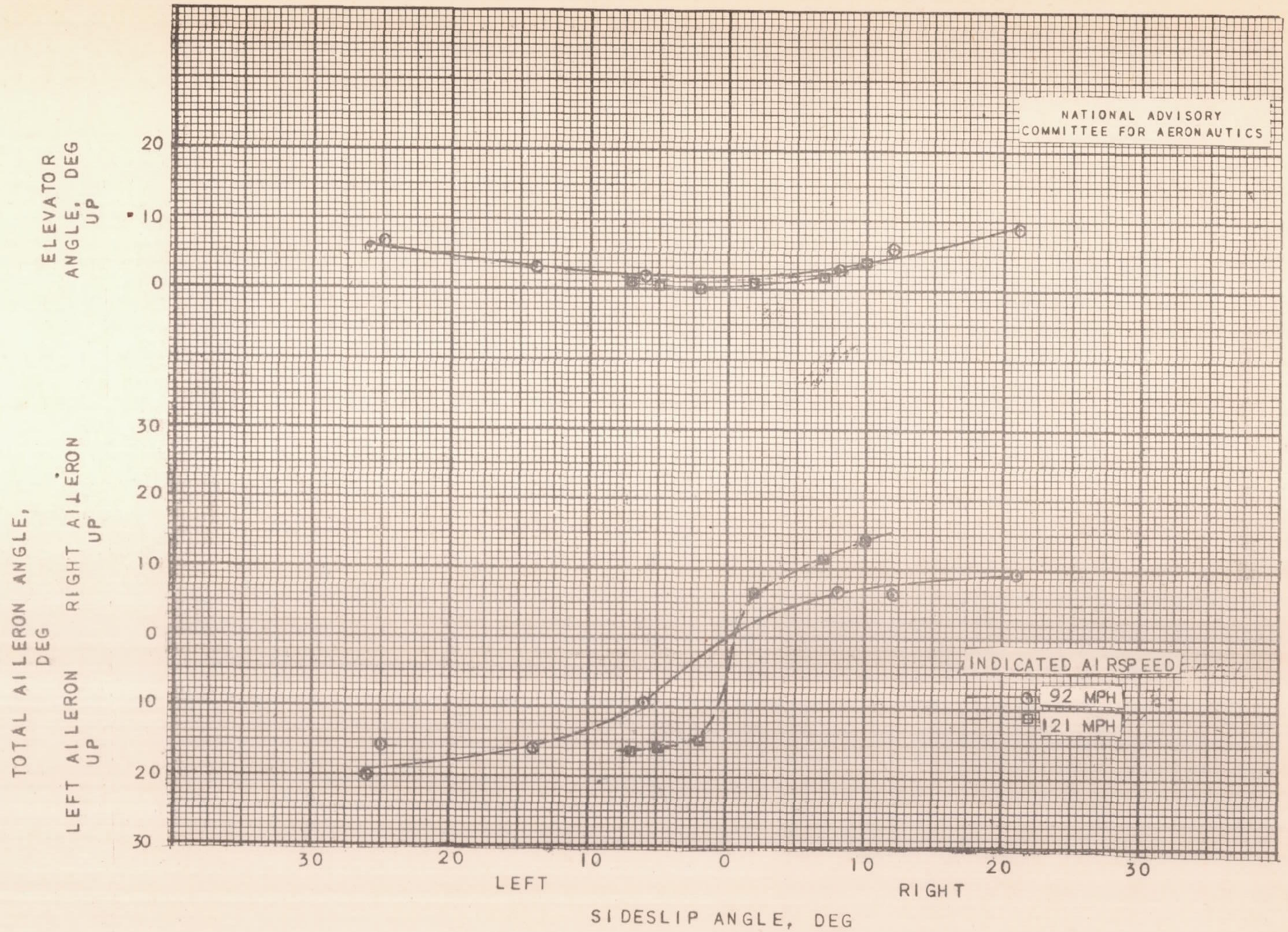


FIGURE 40. - CHARACTERISTICS IN STEADY SIDESLIPS, RATED POWER, FLAPS DOWN.

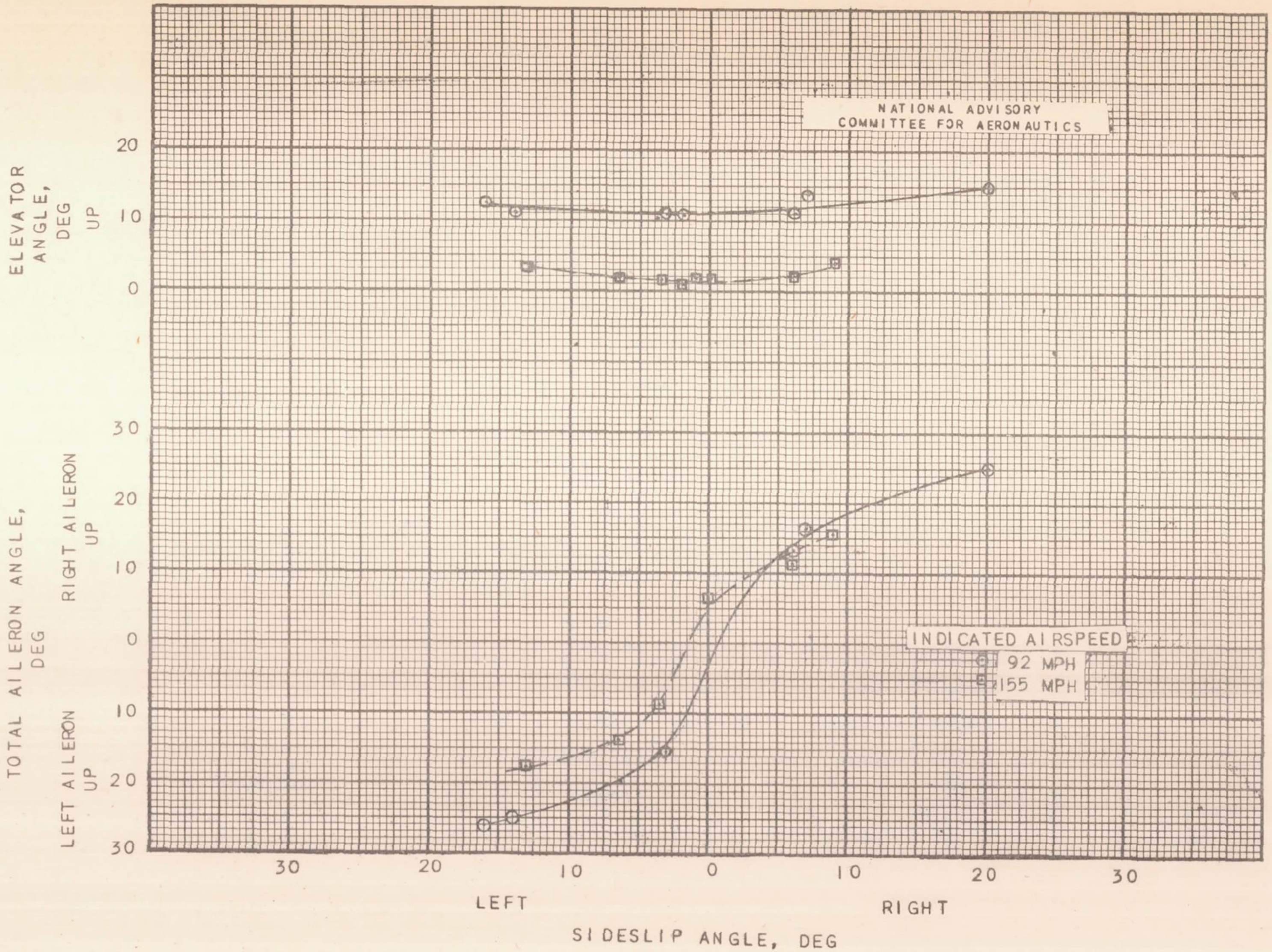


FIGURE 41. - CHARACTERISTICS IN STEADY SIDESLIPS, POWER OFF, FLAPS UP.

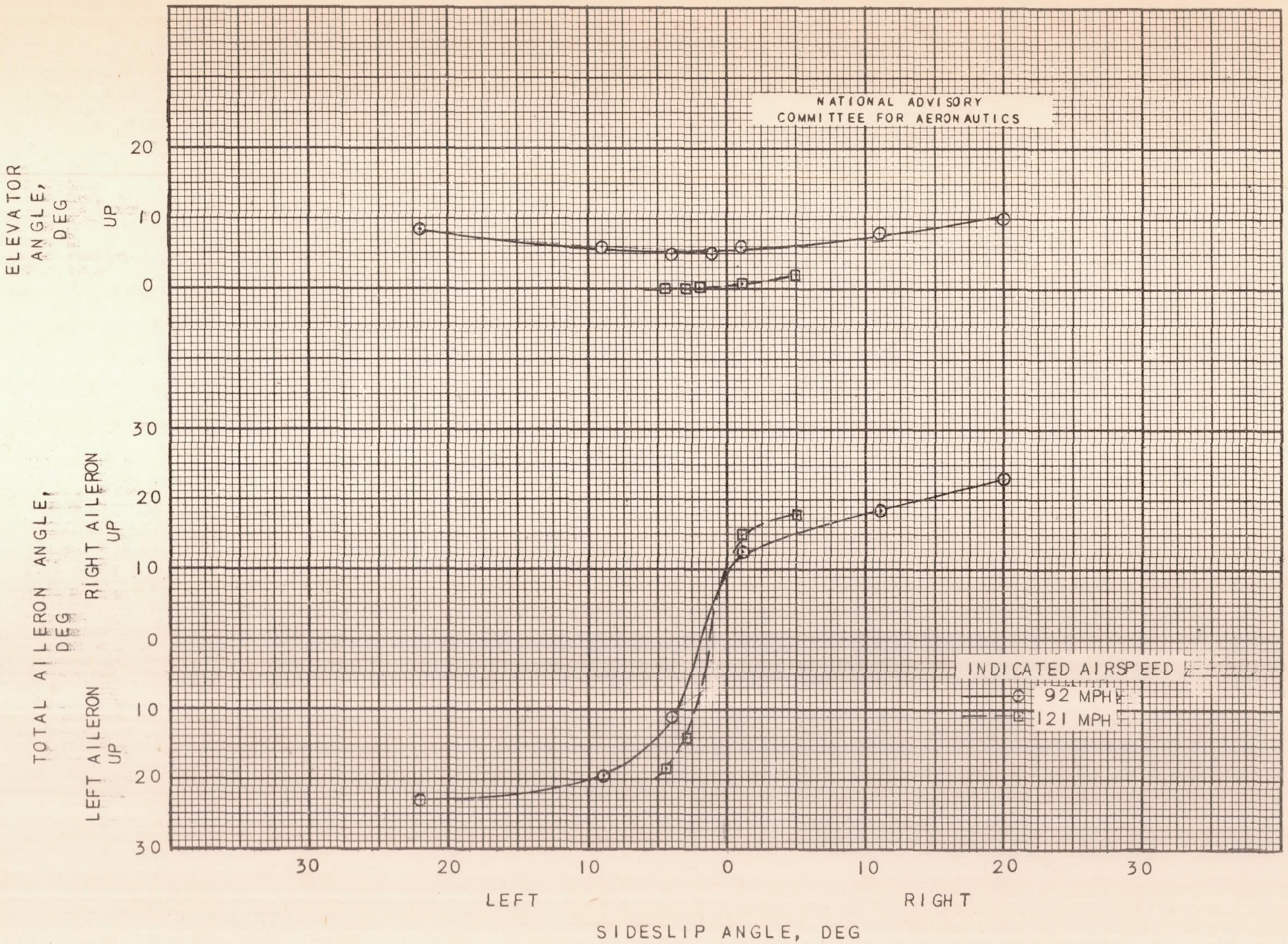


FIGURE 42. - CHARACTERISTICS IN STEADY SIDESLIPS, POWER OFF, FLAPS DOWN.

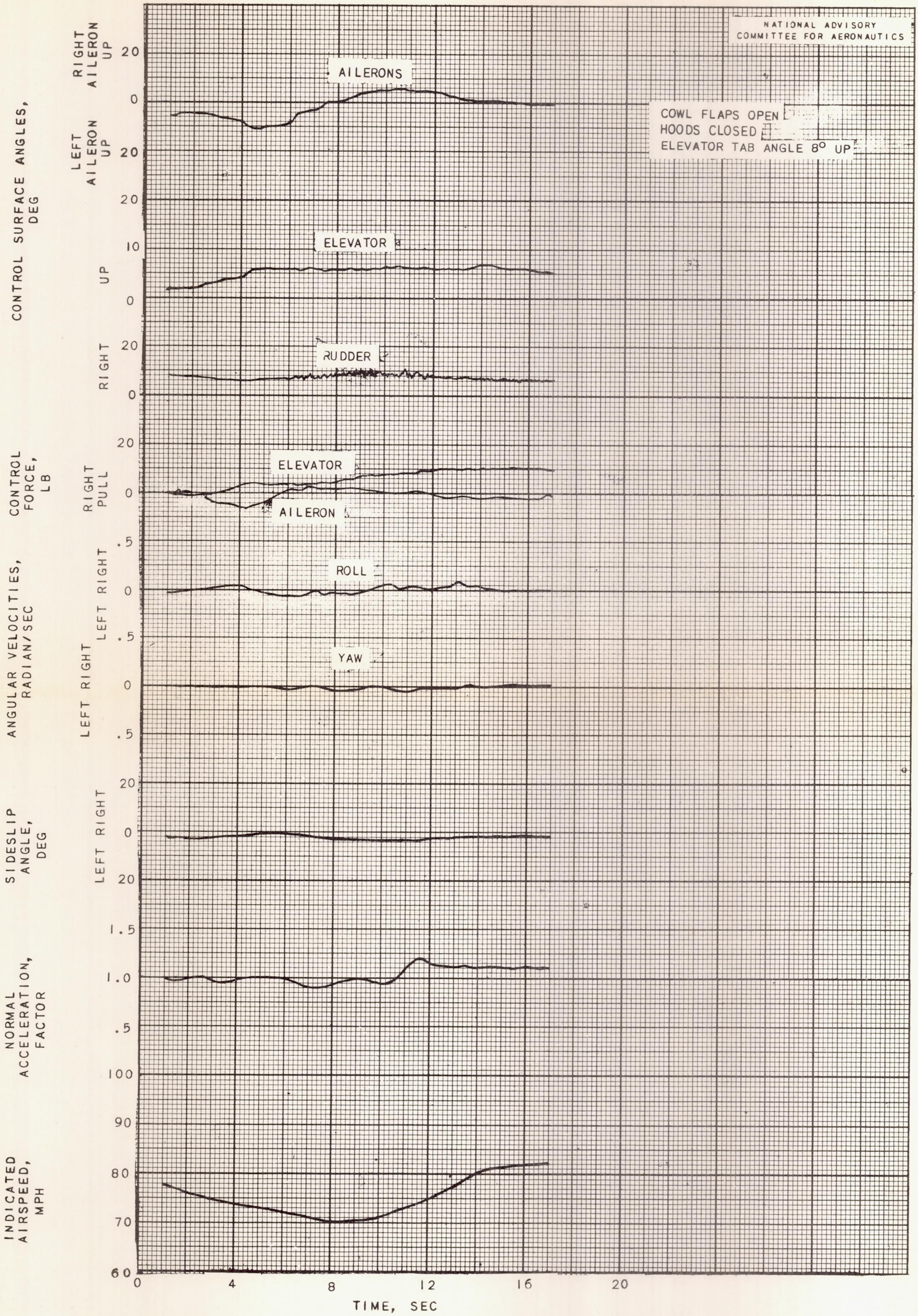


FIGURE 43. - TIME HISTORY OF A STALL, RATED POWER, FLAPS UP. STICK BACK AND HELD AT FIRST WARNING OF STALL; ATTEMPT MADE TO HOLD AILERON AND RUDDER FIXED.

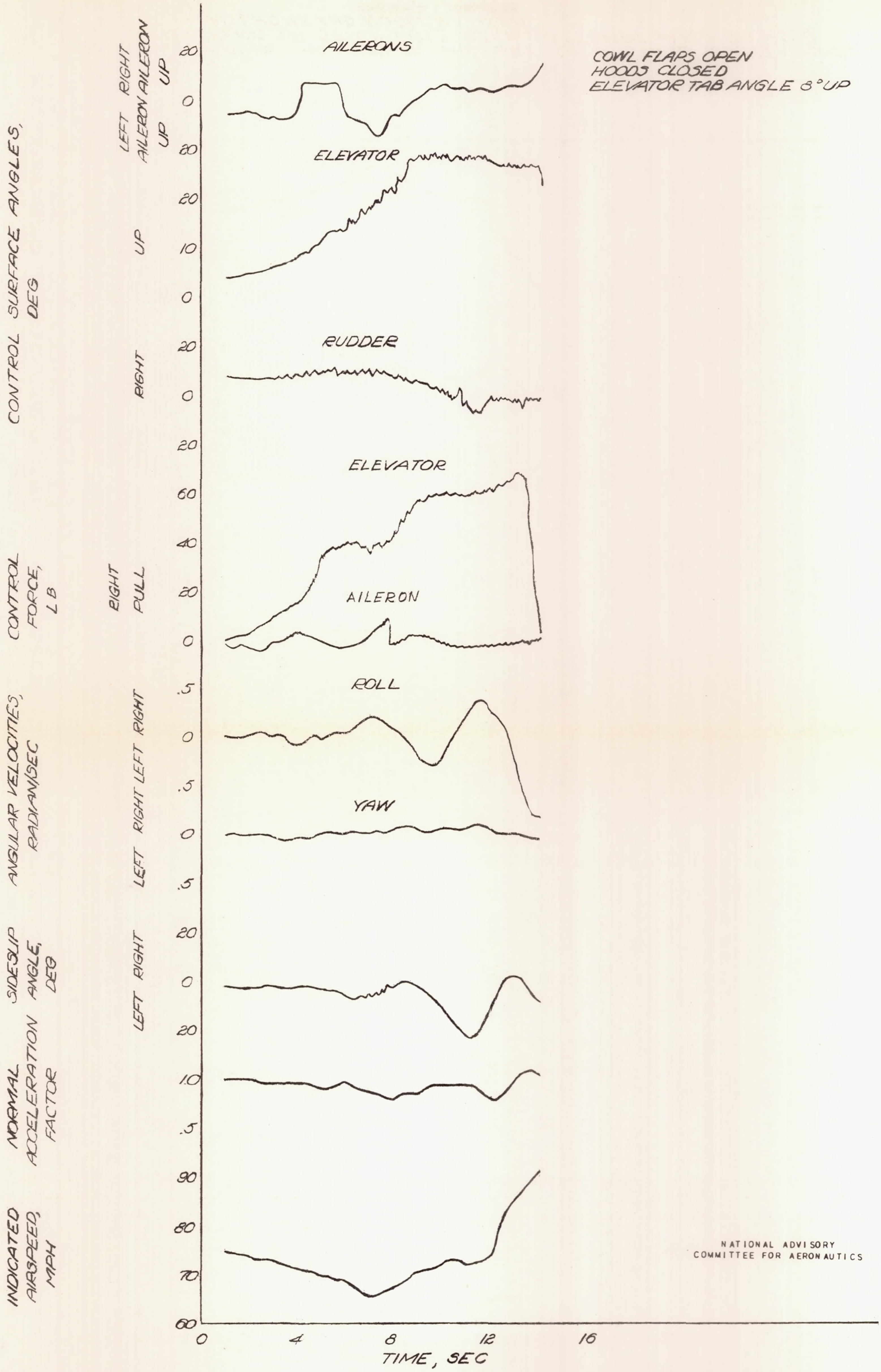


FIGURE 44 – TIME HISTORY OF A STALL RATED POWER, FLAPS UP STICK FULL BACK. ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

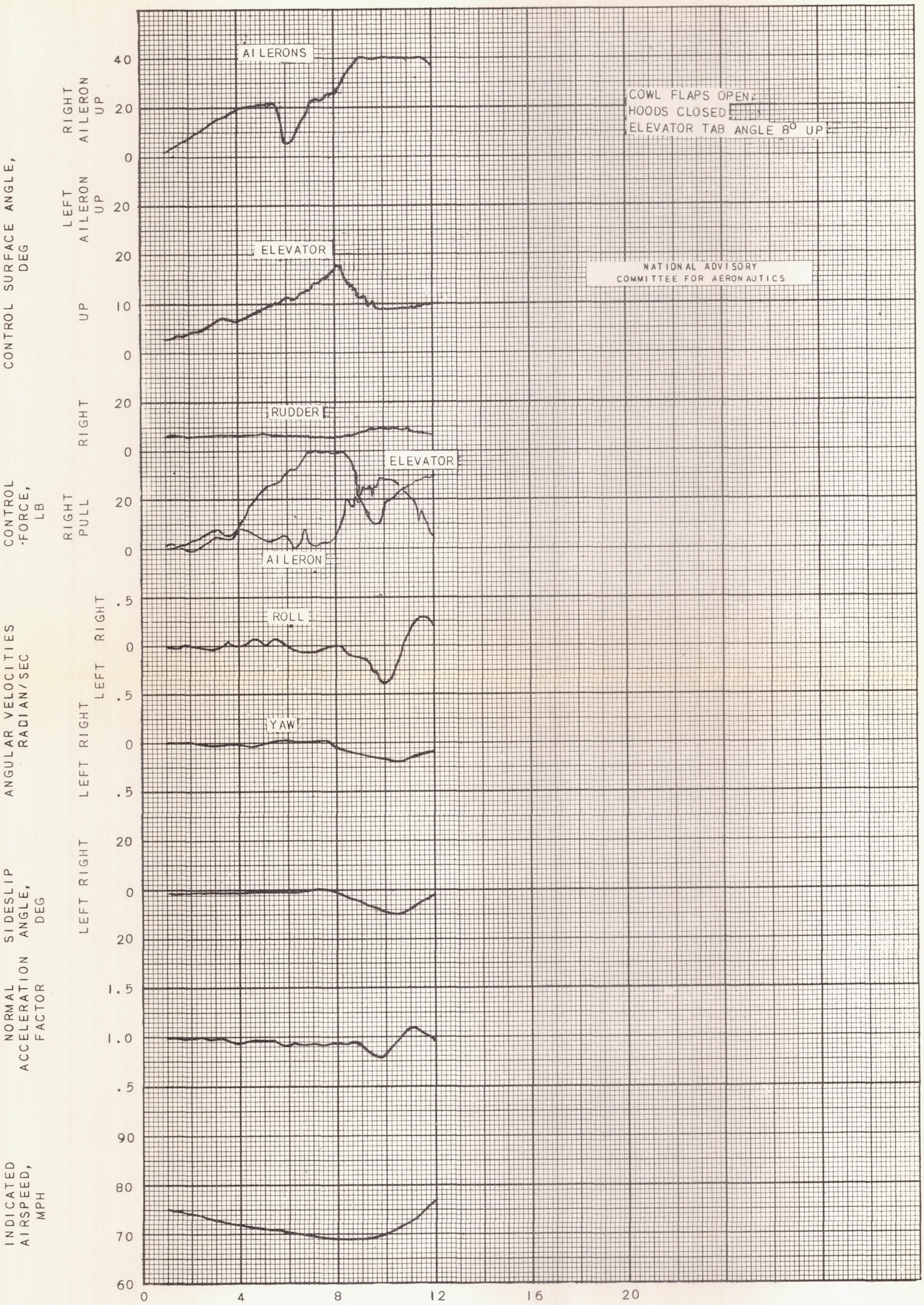


FIGURE 45. - TIME HISTORY OF A STALL, RATED POWER, FLAPS UP. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL.

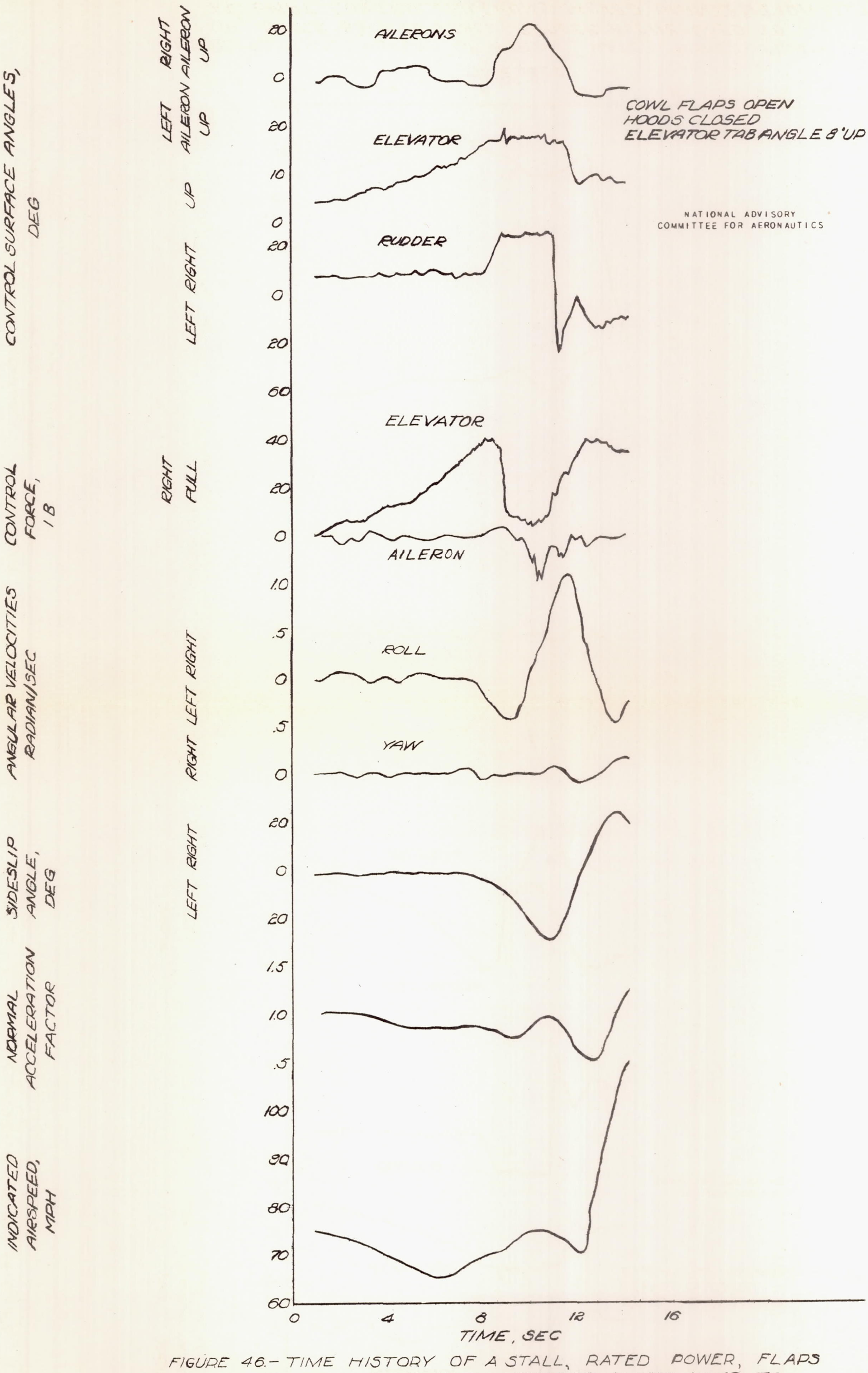


FIGURE 46.– TIME HISTORY OF A STALL, RATED POWER, FLAPS UP, STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL. AILERONS MOVED UNINTENTIONALLY.

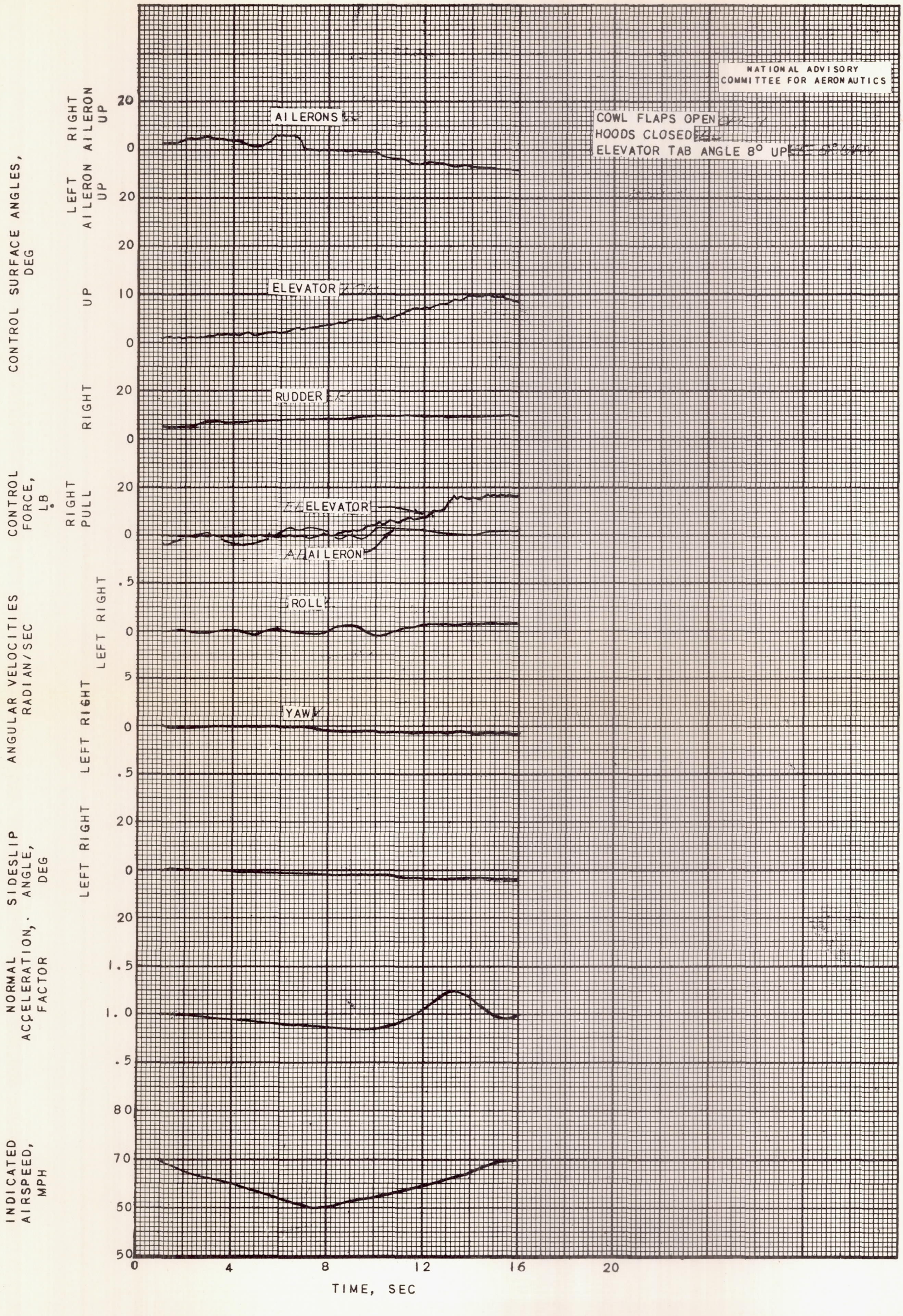


FIGURE 47. - TIME HISTORY OF A STALL, RATED POWER, FLAPS ONE-HALF DOWN. STICK BACK AND HELD AT FIRST WARNING OF STALL. ATTEMPT MADE TO HOLD AILERON AND RUDDER FIXED.

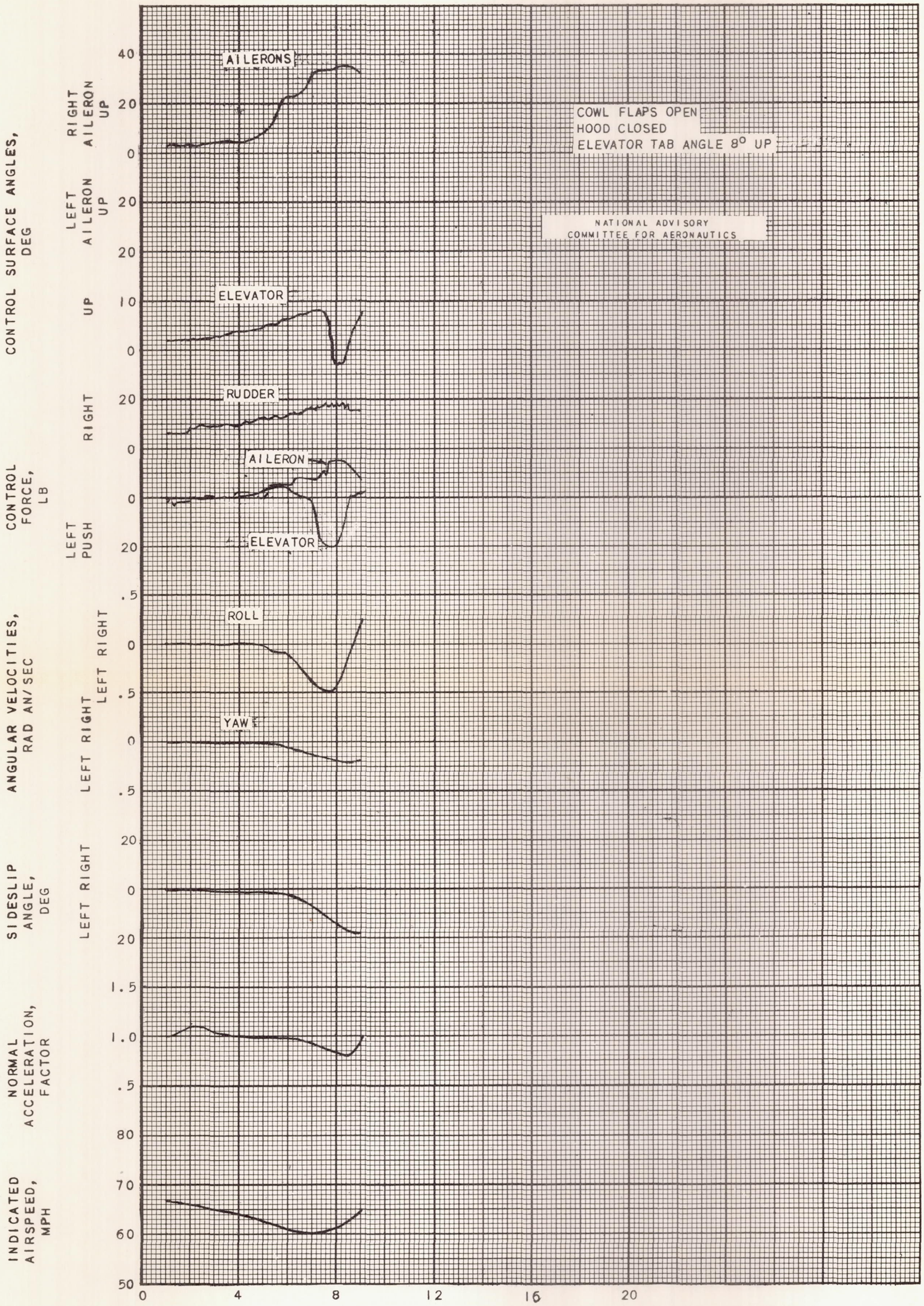


FIGURE 48. - TIME HISTORY OF A STALL, RATED POWER, FLAPS ONE-HALF DOWN. STICK FULL BACK; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

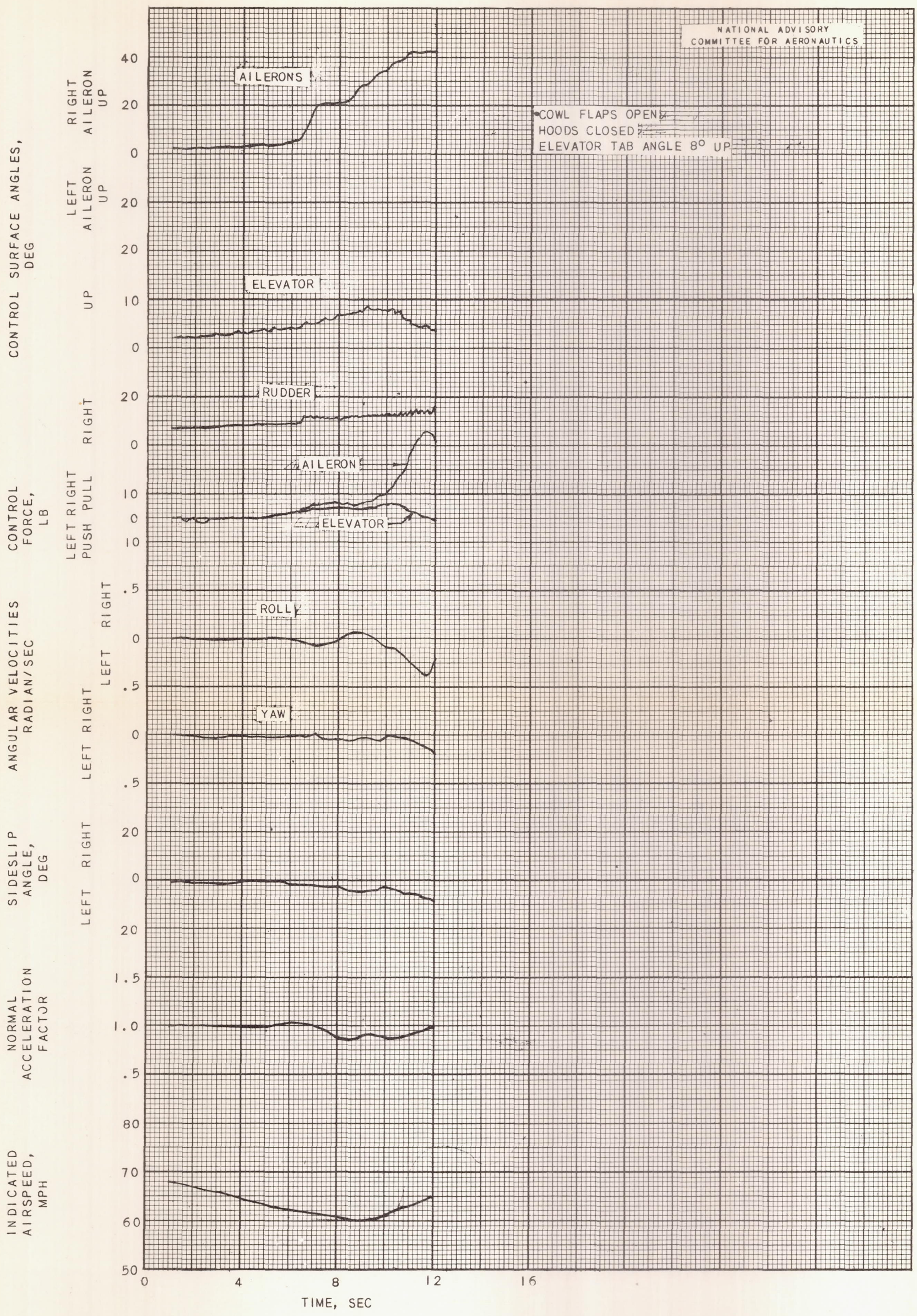


FIGURE 49. - TIME HISTORY OF A STALL, RATED POWER, FLAPS ONE-HALF DOWN. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL. RUDDER MOVED UNINTENTIONALLY.

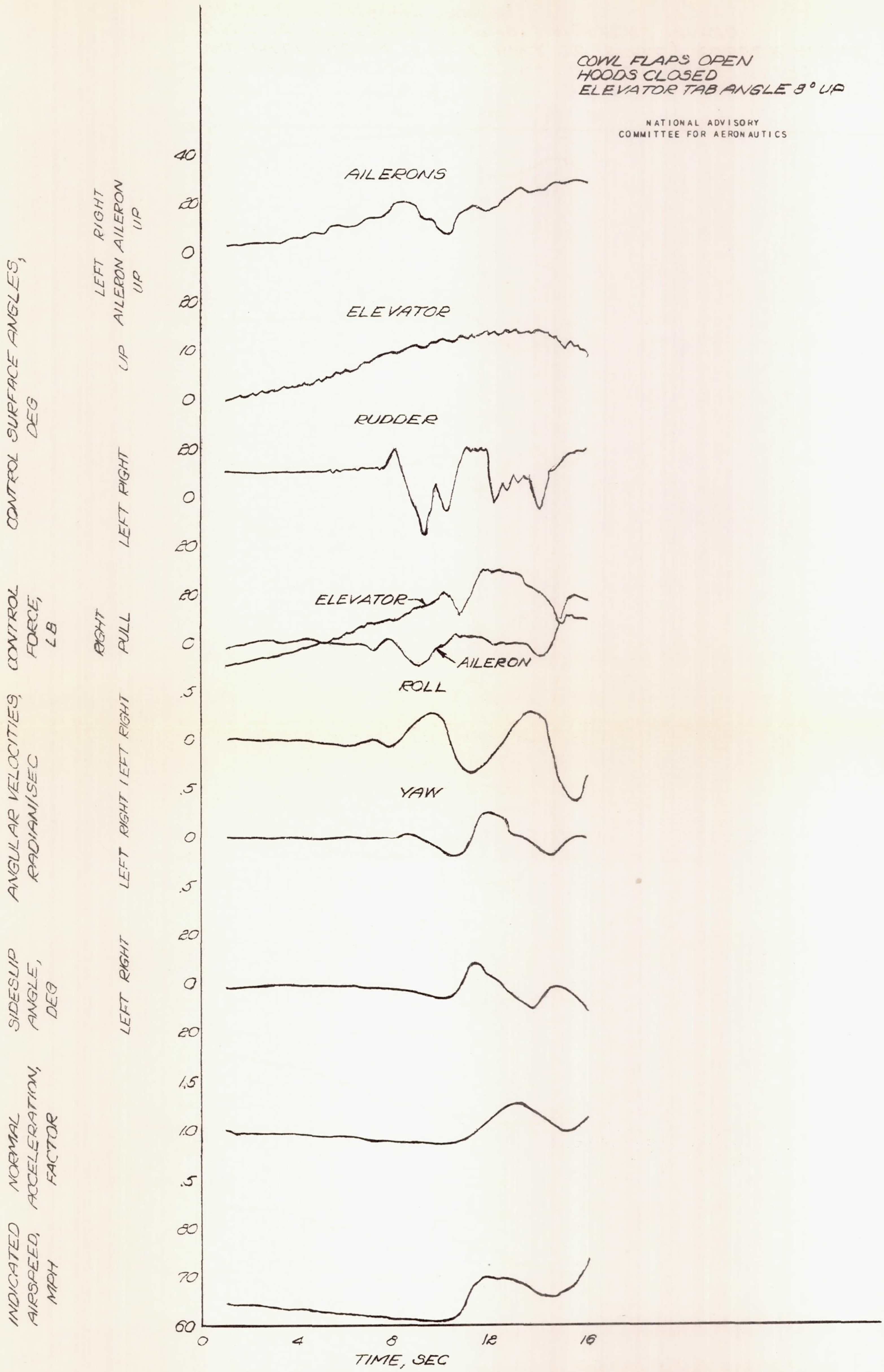


FIGURE 50.– TIME HISTORY OF A STALL, RATED POWER, FLAPS ONE-HALF DOWN. STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL. AILERONS MOVED UNINTENTIONALLY.

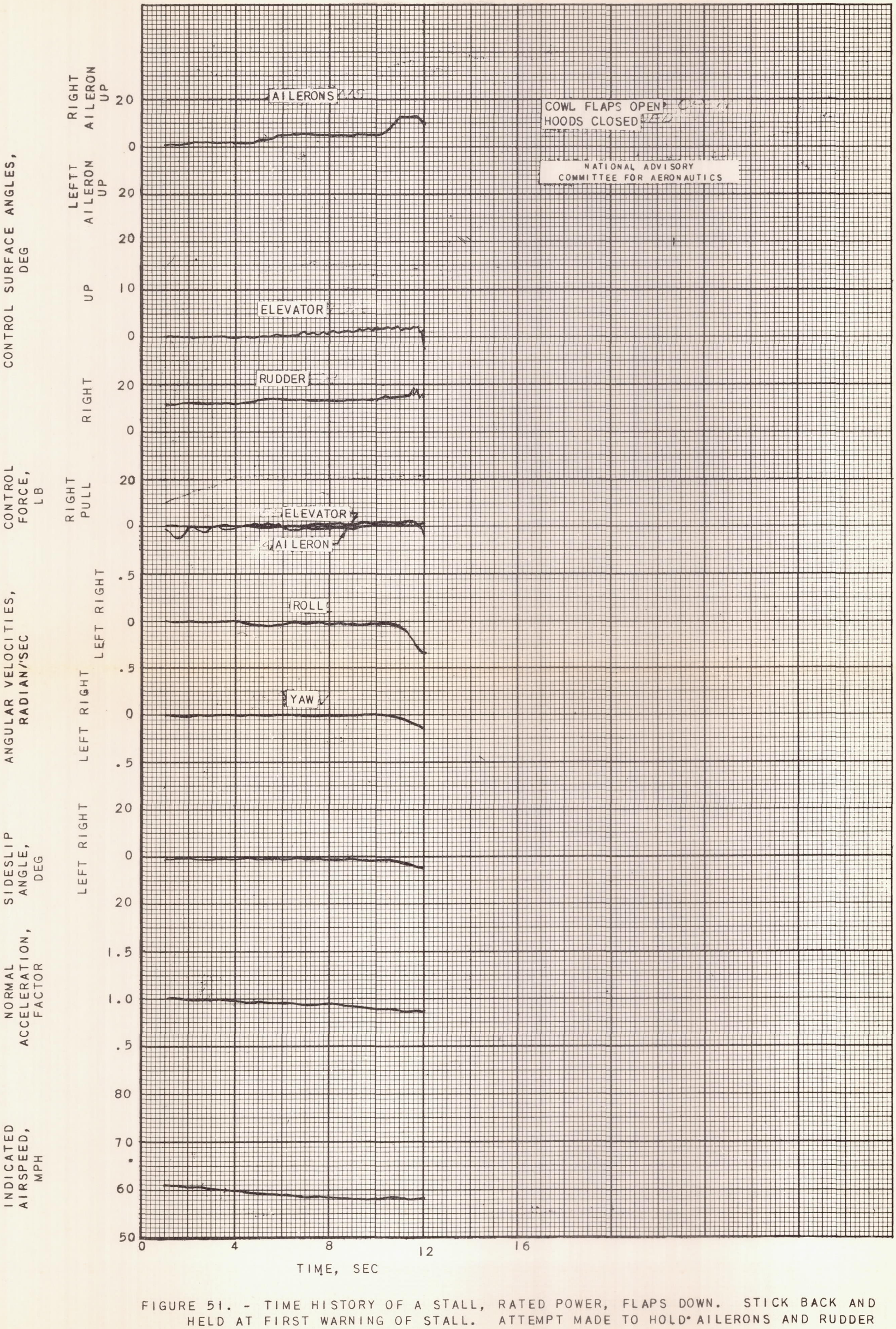


FIGURE 51. - TIME HISTORY OF A STALL, RATED POWER, FLAPS DOWN. STICK BACK AND HELD AT FIRST WARNING OF STALL. ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

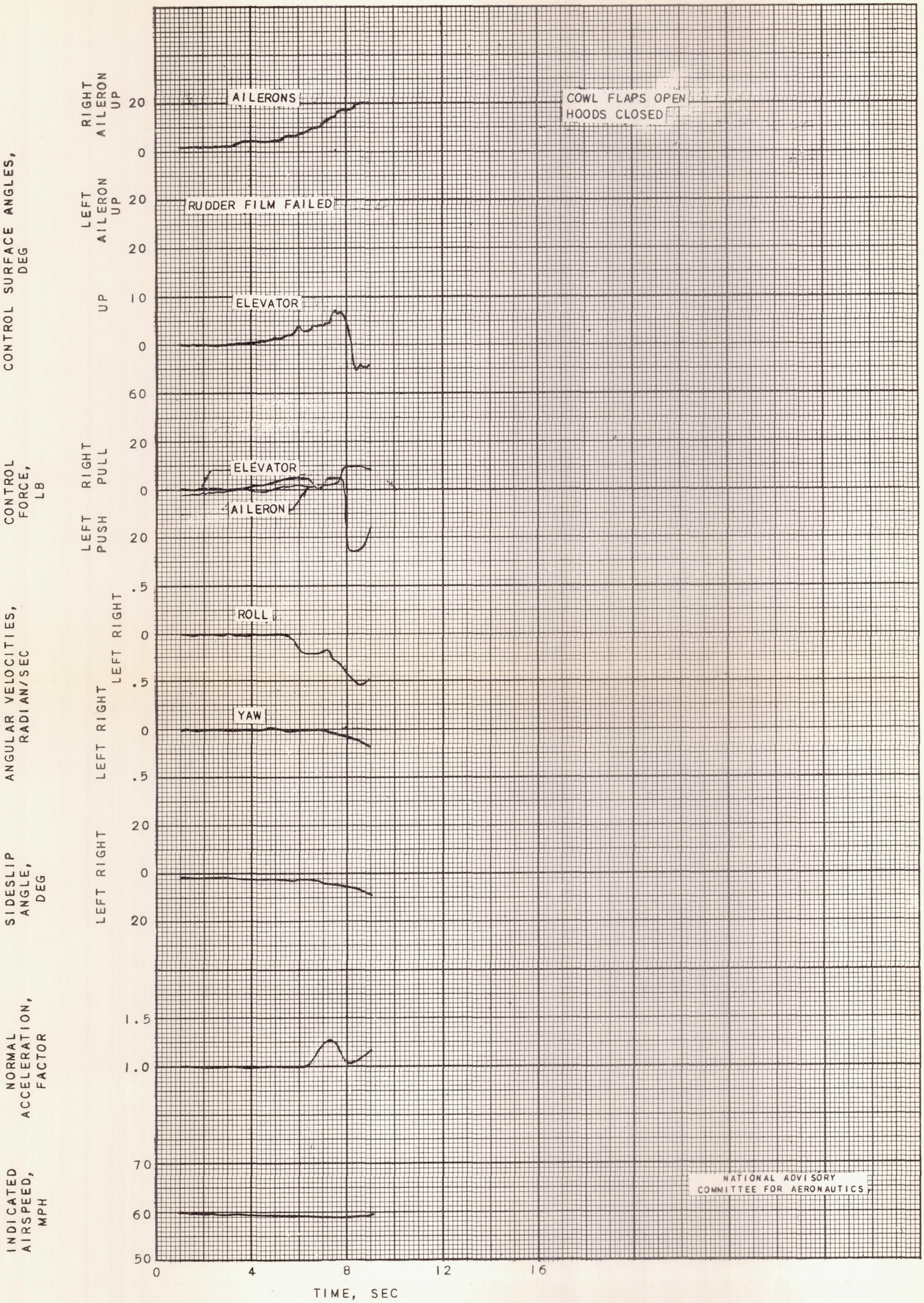


FIGURE 52. - TIME HISTORY OF A STALL, RATED POWER, FLAPS DOWN. STICK FULL BACK; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

FIGURE 53. - TIME HISTORY OF A STALL, RATED POWER, FLAPS DOWN. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL. RUDDER MOVED UNINTENTIONALLY.

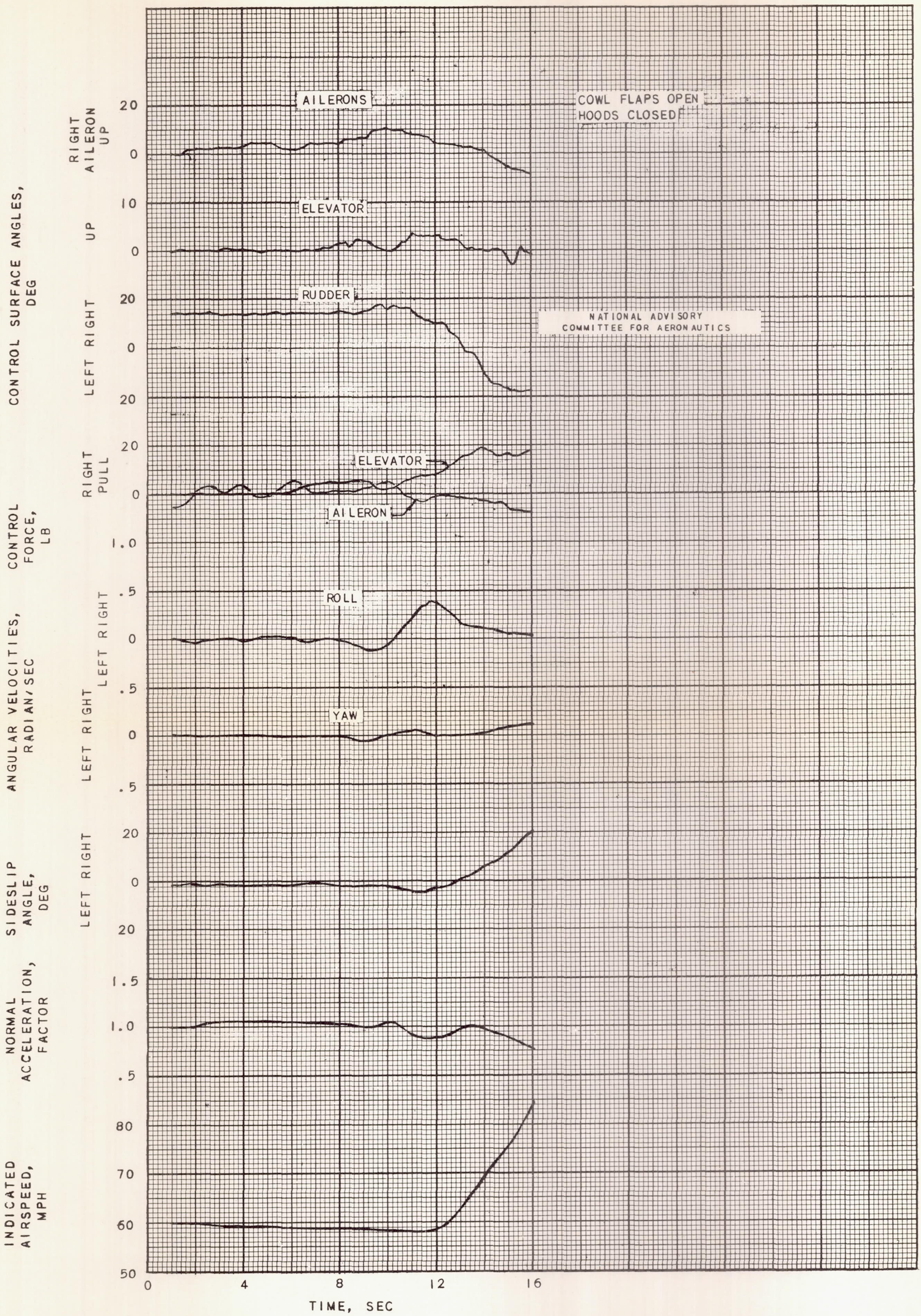


FIGURE 54. - TIME HISTORY OF A STALL, RATED POWER, FLAPS DOWN. STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL. AILERONS MOVED UNINTENTIONALLY.

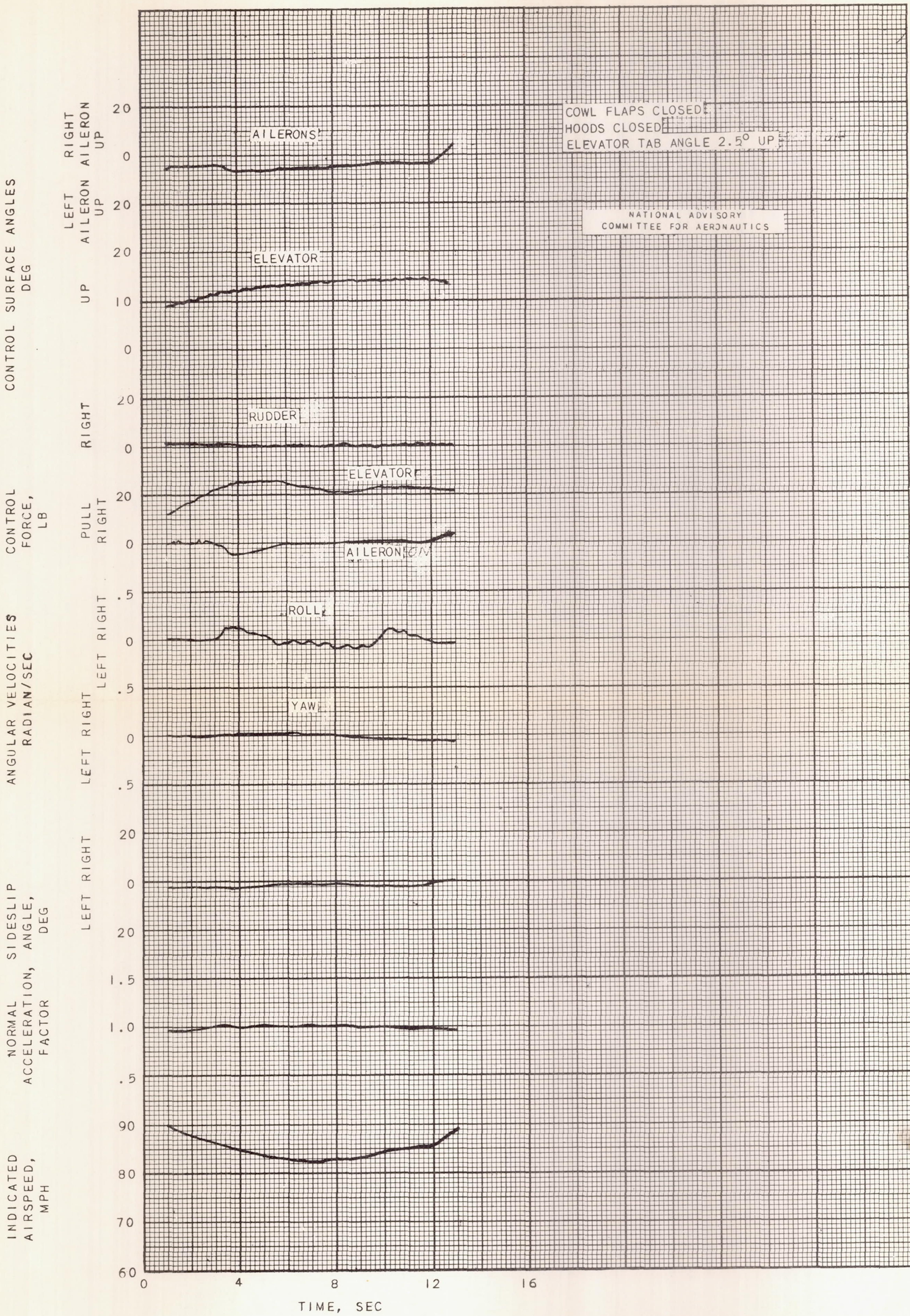


FIGURE 55. - TIME HISTORY OF A STALL, POWER OFF, FLAPS UP. STICK BACK AND HELD AT FIRST WARNING OF STALL; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

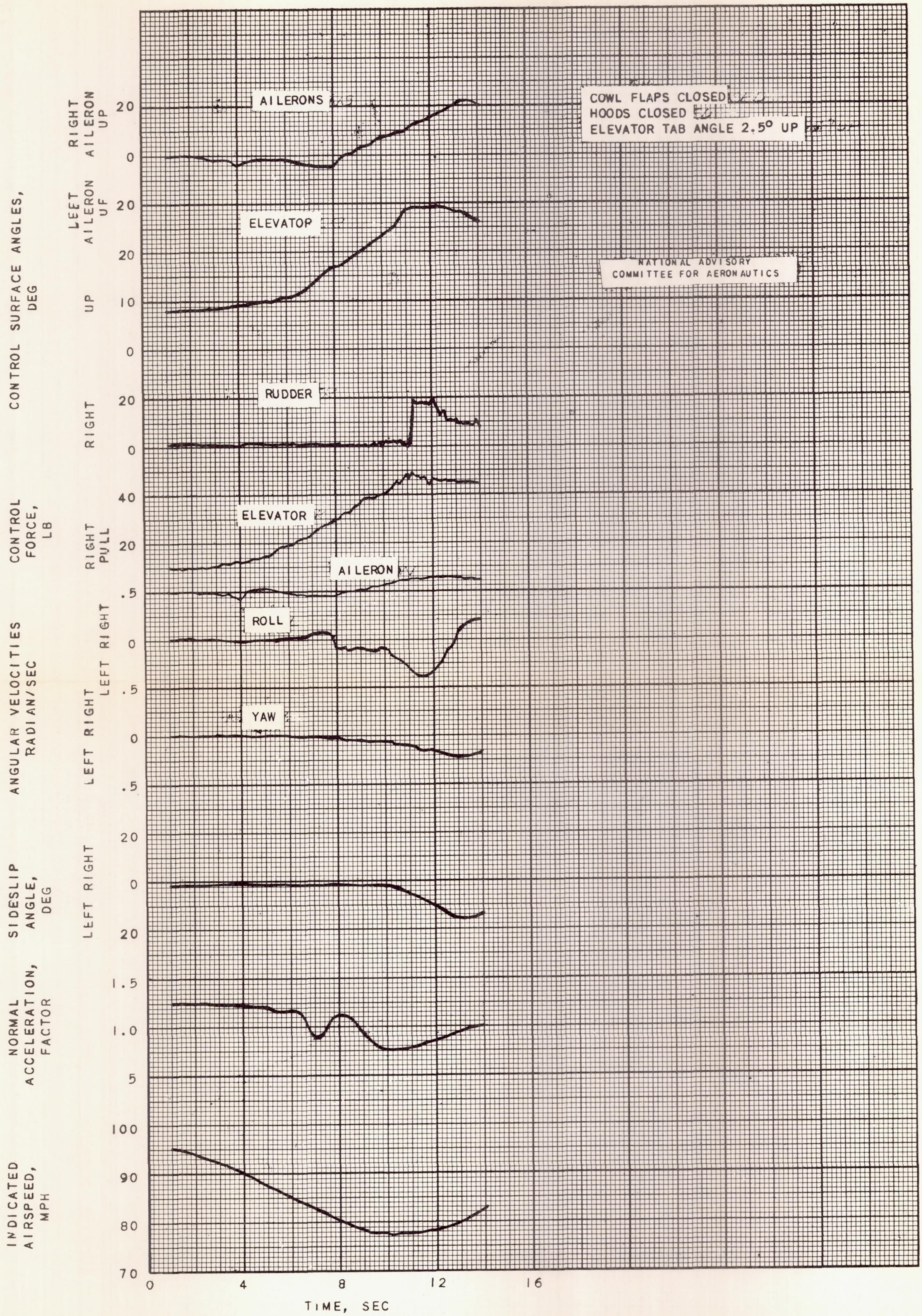


FIGURE 56. - TIME HISTORY OF A STALL, POWER OFF, FLAPS UP. STICK FULL BACK; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

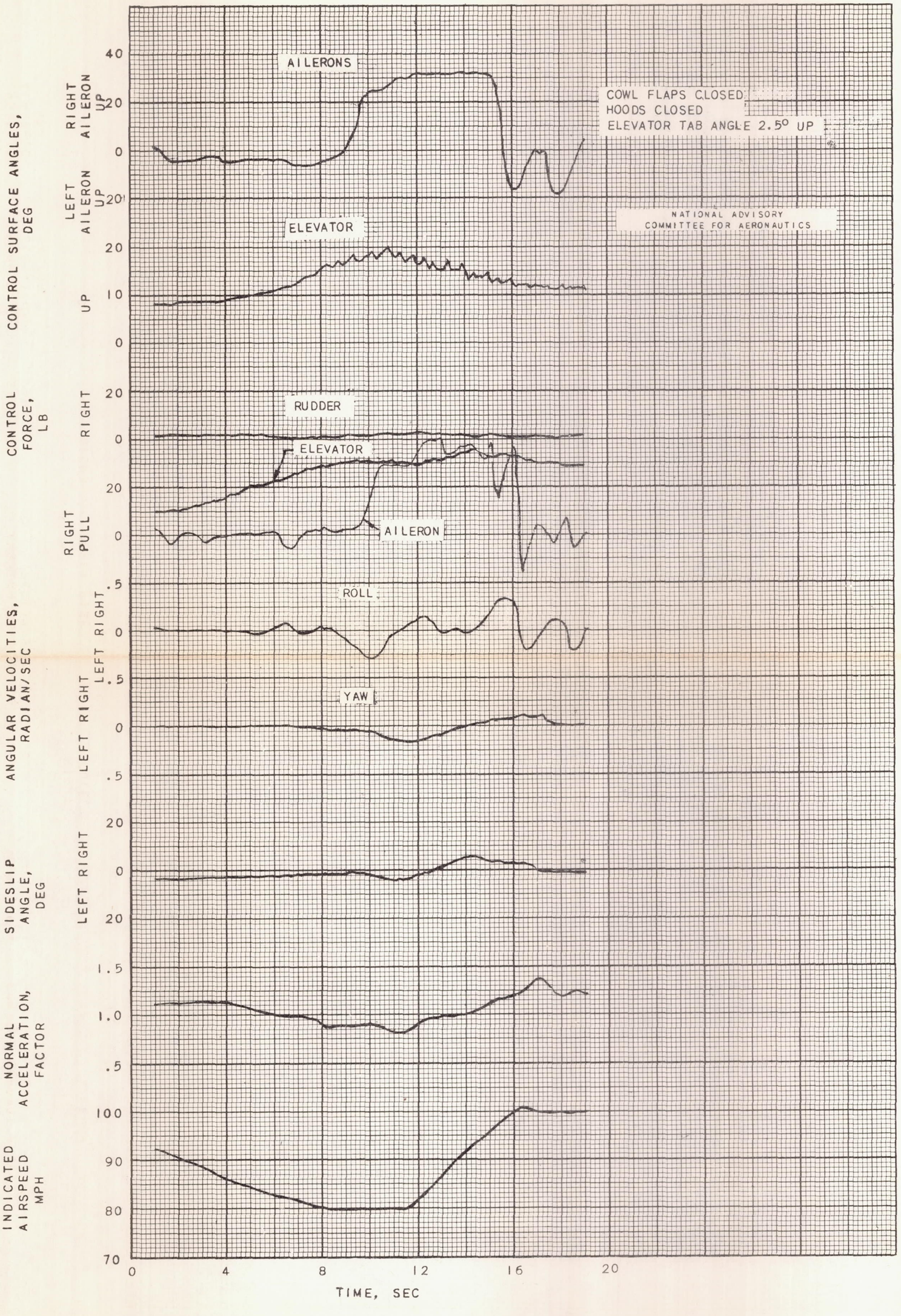


FIGURE 57. - TIME HISTORY OF A STALL, POWER OFF, FLAPS UP. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL.

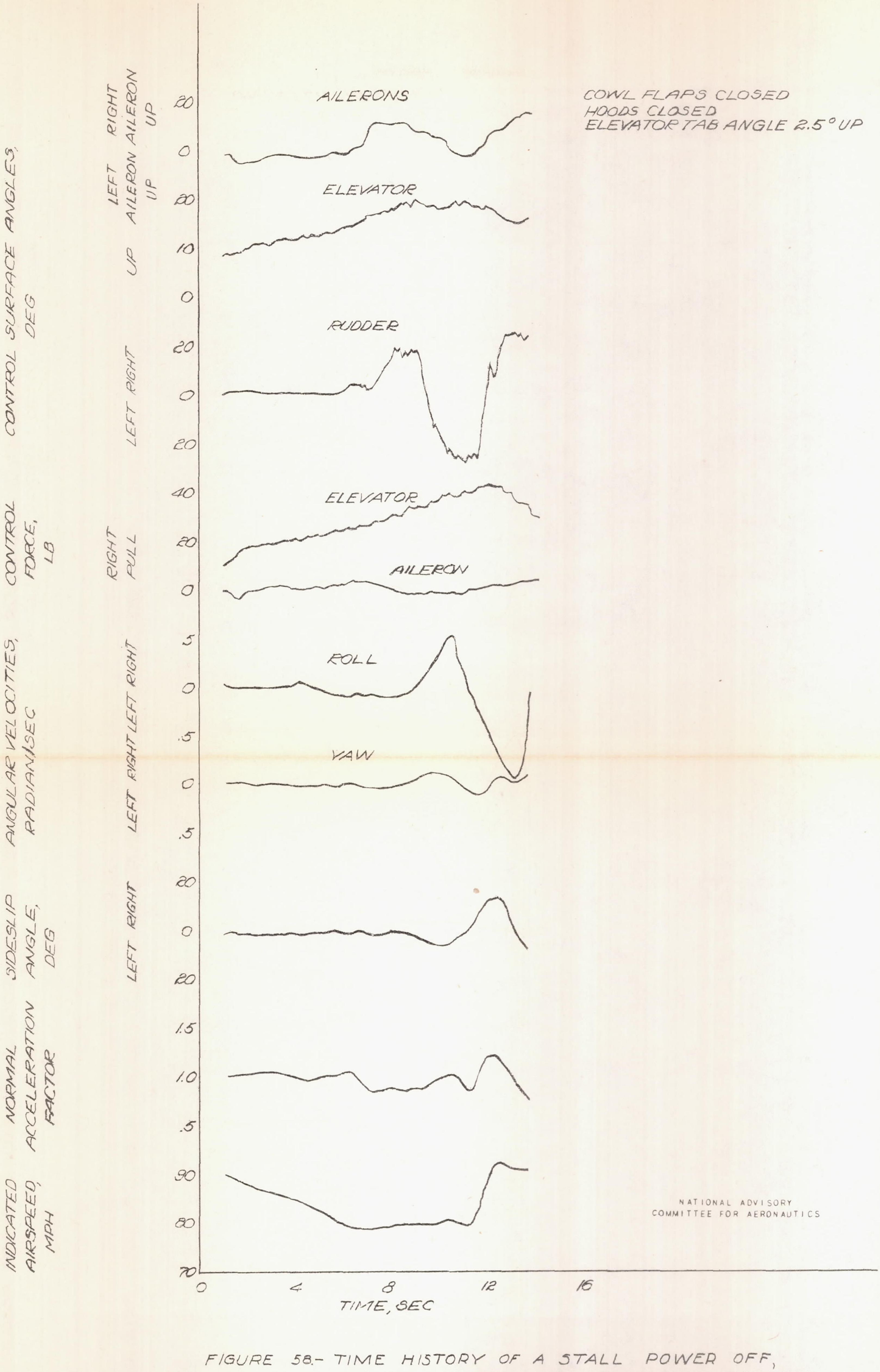


FIGURE 58.- TIME HISTORY OF A STALL POWER OFF, FLAPS UP. STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL. AILERONS MOVED UNINTENTIONALLY.

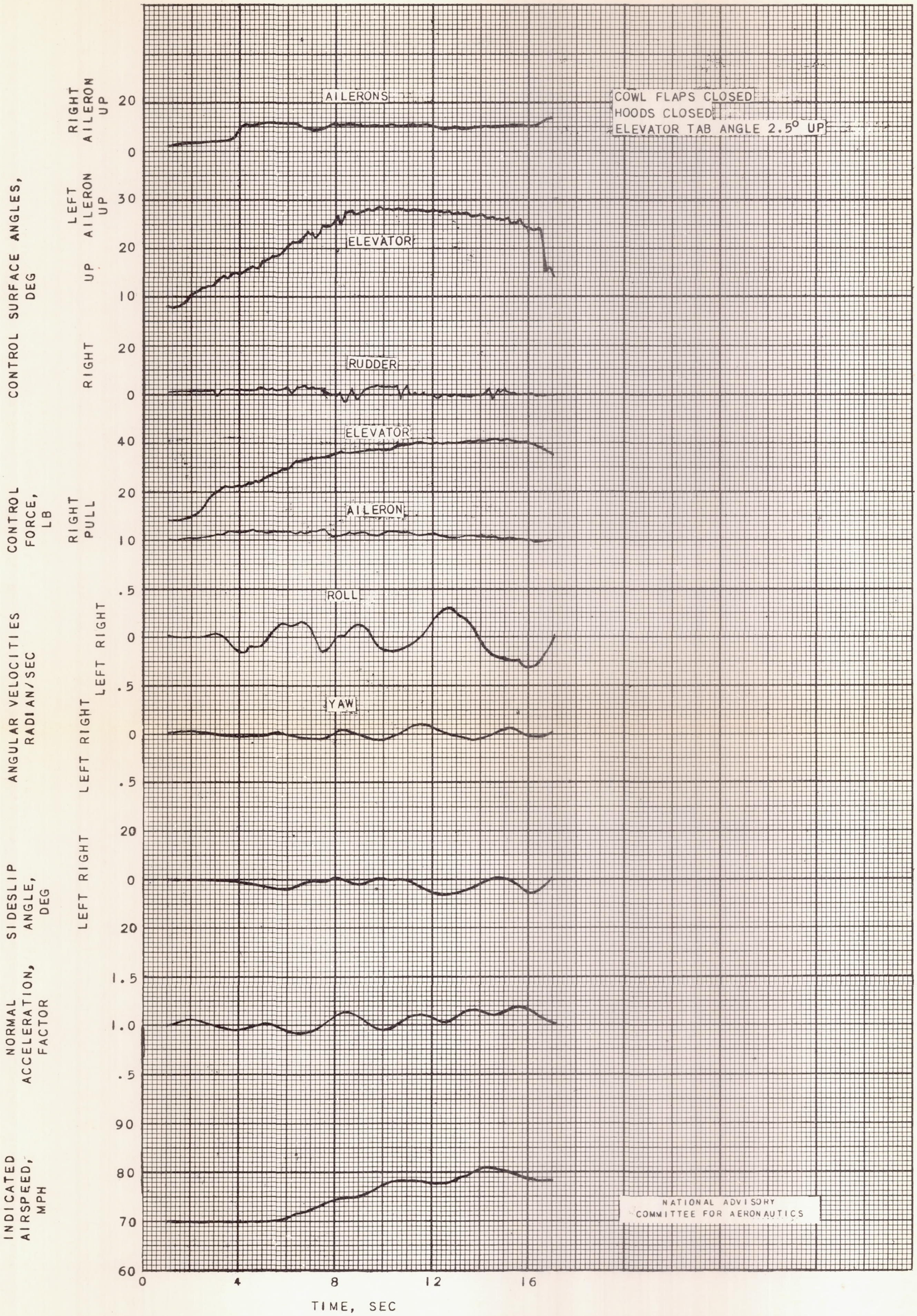


FIGURE 59. - TIME HISTORY OF A STALL, POWER OFF, FLAPS ONE-HALF DOWN. STICK BACK AND HELD WHEN STALL BECAME EVIDENT; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

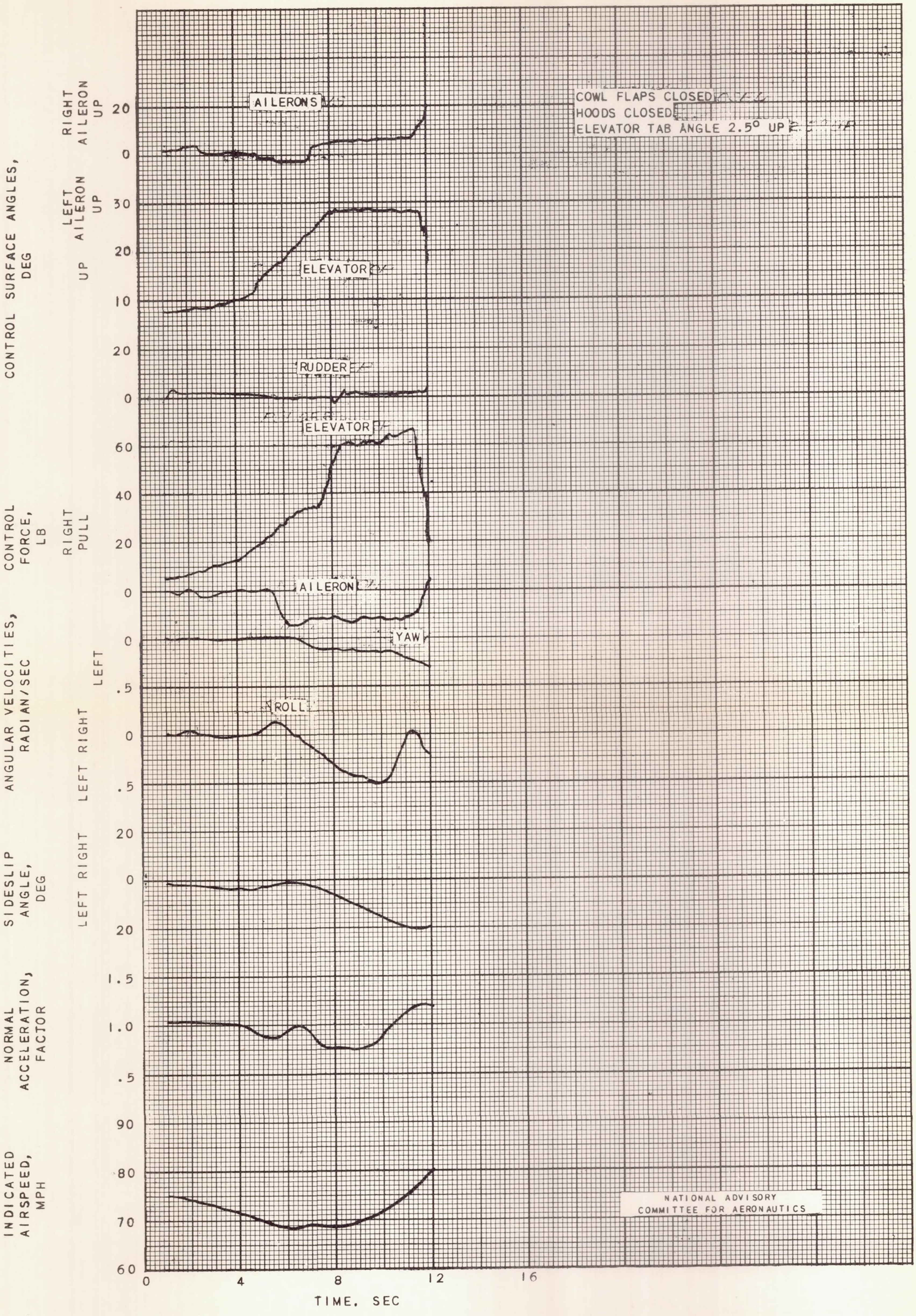


FIGURE 60. - TIME HISTORY OF A STALL, POWER OFF, FLAPS ONE-HALF DOWN. STICK FULL BACK; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

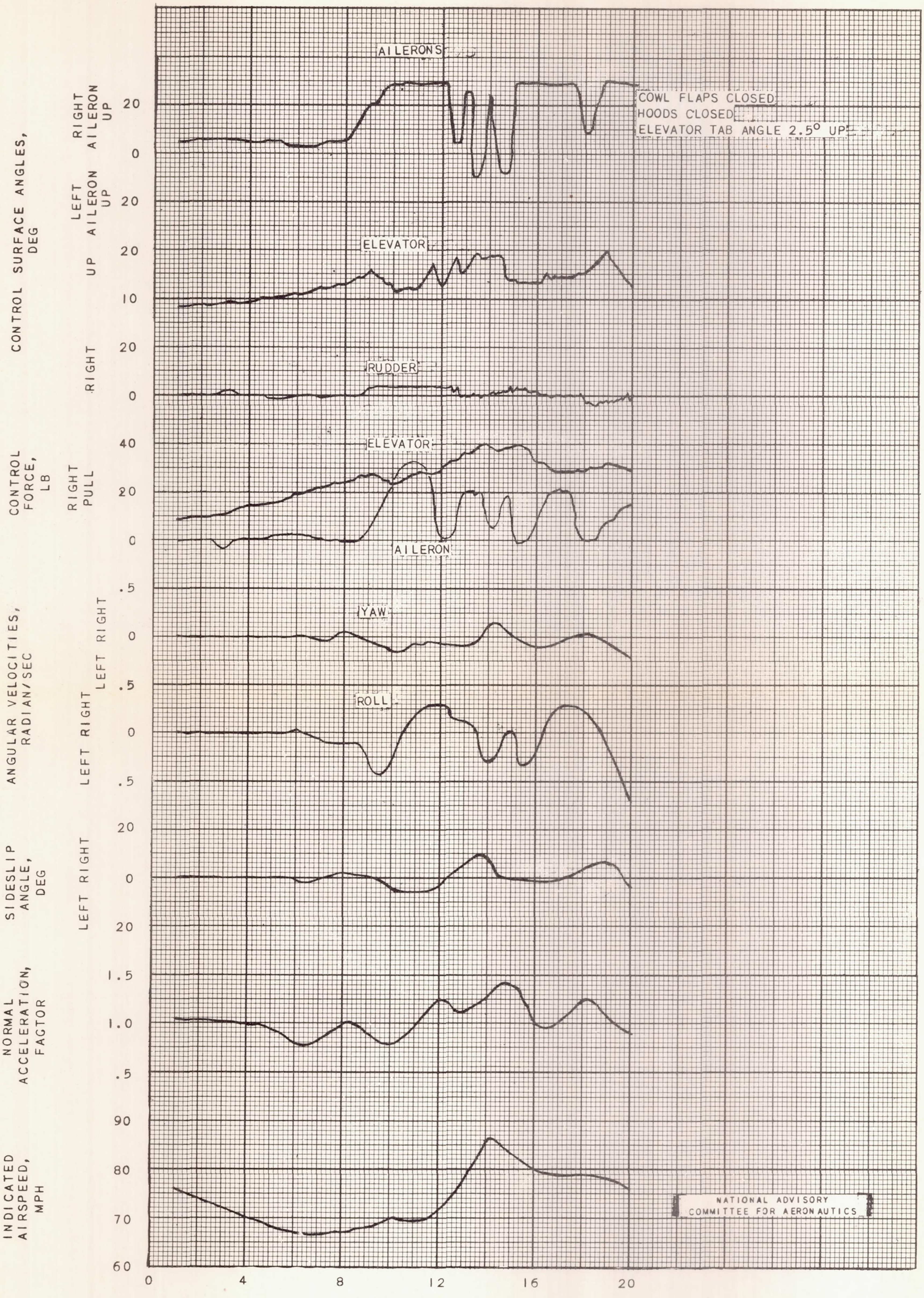


FIGURE 61. - TIME HISTORY OF A STALL, POWER OFF, FLAPS ONE-HALF DOWN. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL.

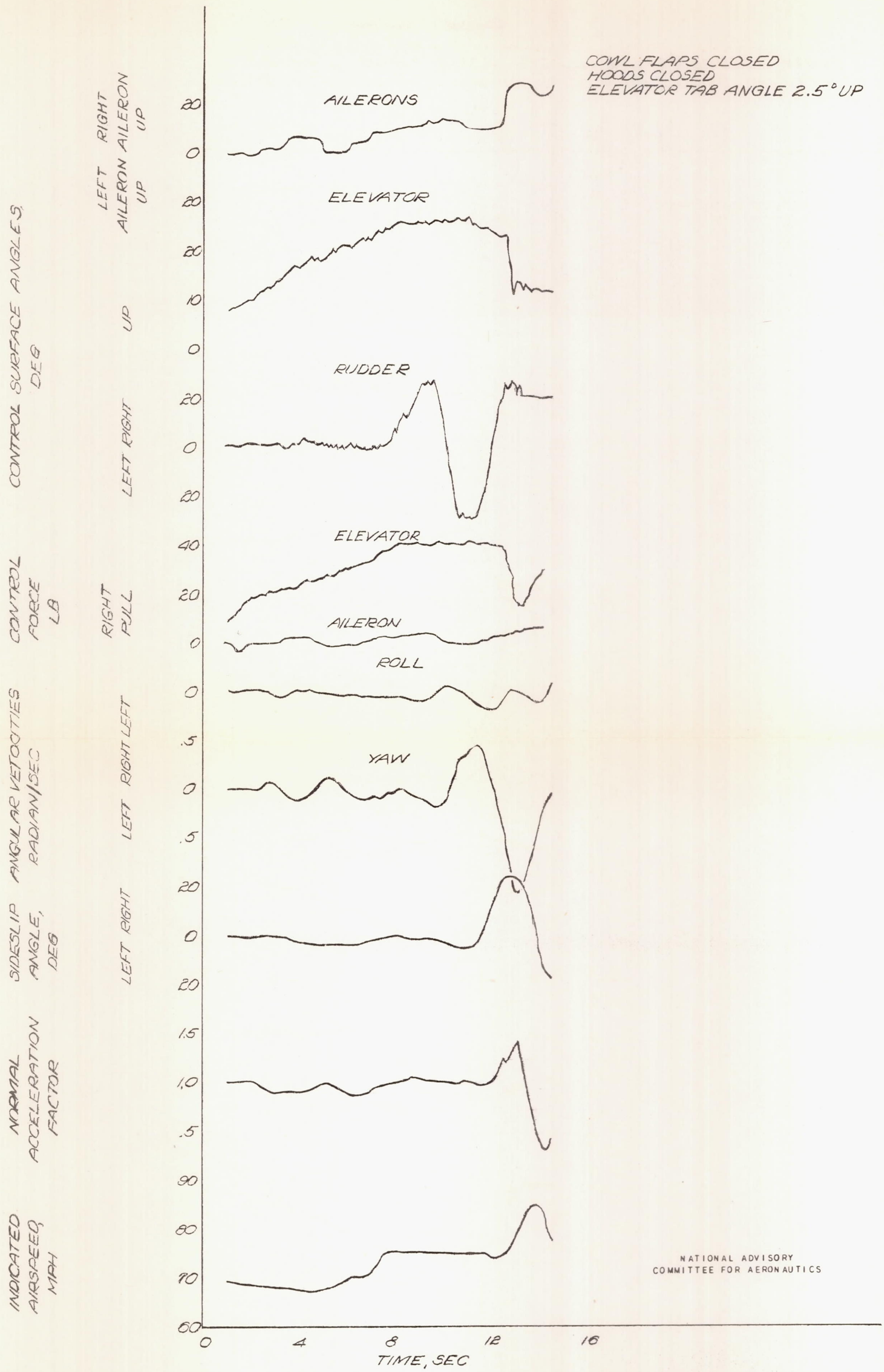


FIGURE 62.- TIME HISTORY OF A STALL, POWER OFF, FLAPS ONE-HALF DOWN. STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL. AILERONS MOVED UNINTENTIONALLY.

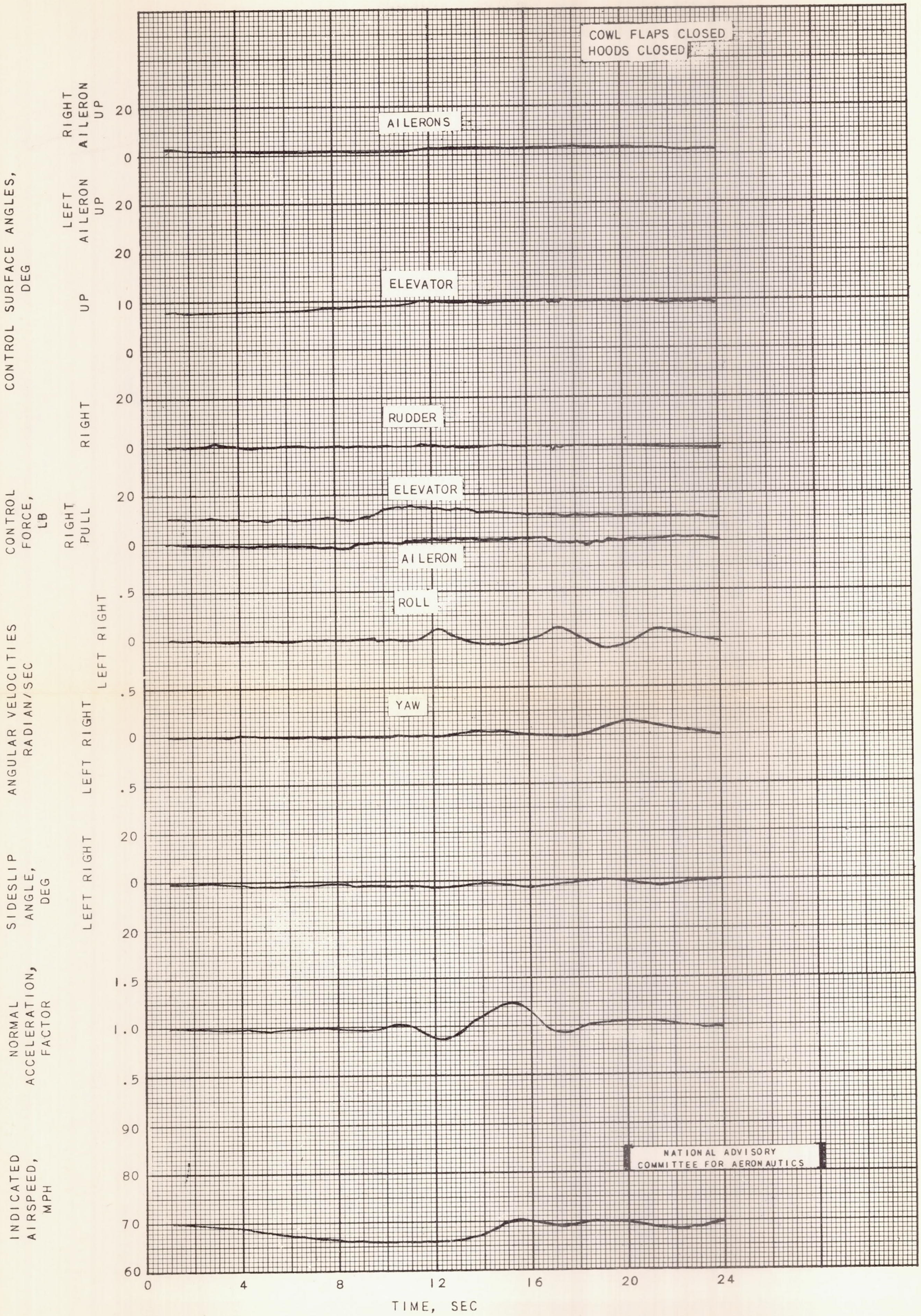


FIGURE 63. - TIME HISTORY OF A STALL, POWER OFF, FLAPS DOWN. STICK BACK AND HELD AT FIRST WARNING OF STALL. ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

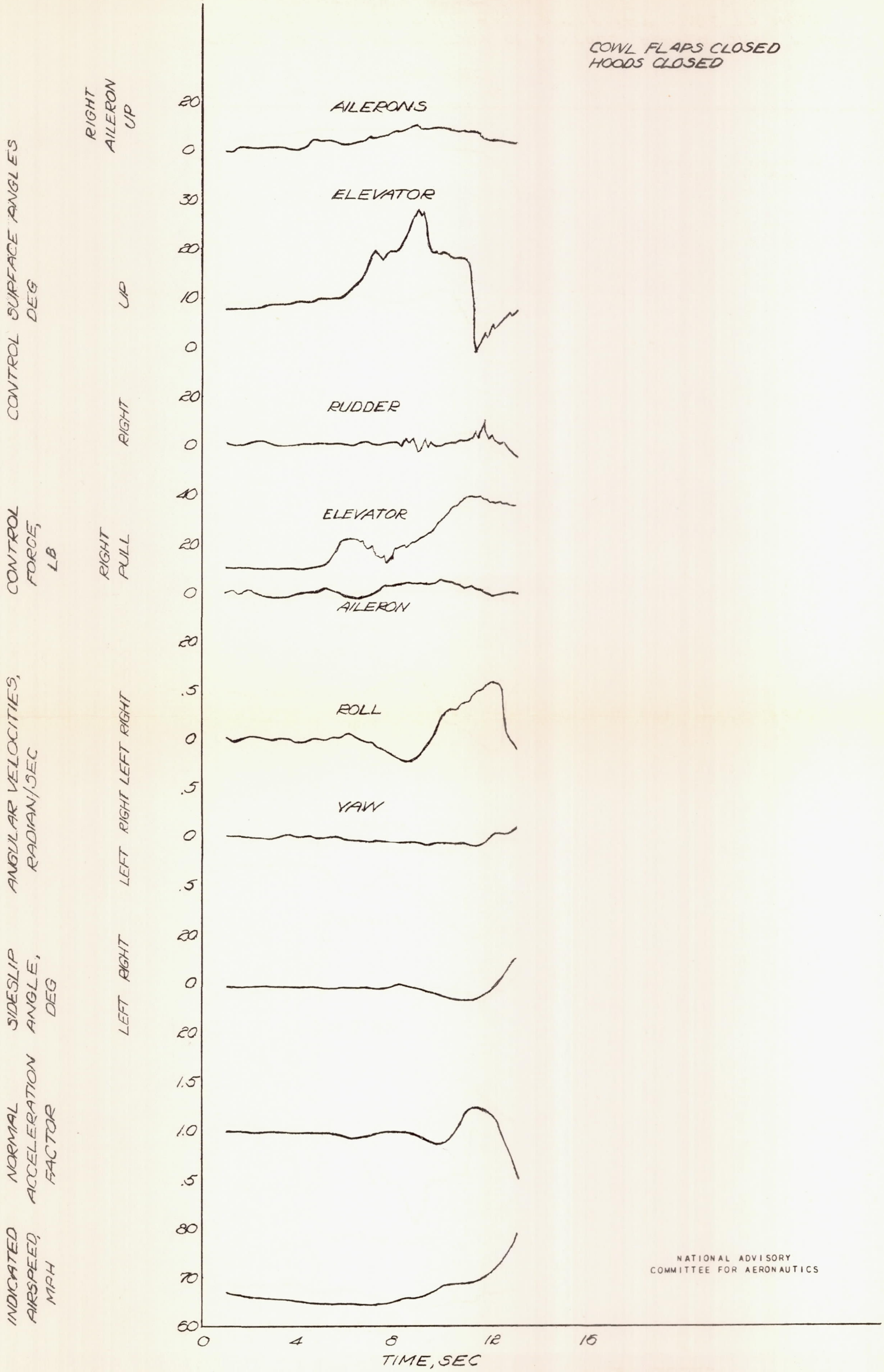


FIGURE 64.– TIME HISTORY OF A STALL POWER OFF, FLAPS DOWN. STICK FULL BACK; ATTEMPT MADE TO HOLD AILERONS AND RUDDER FIXED.

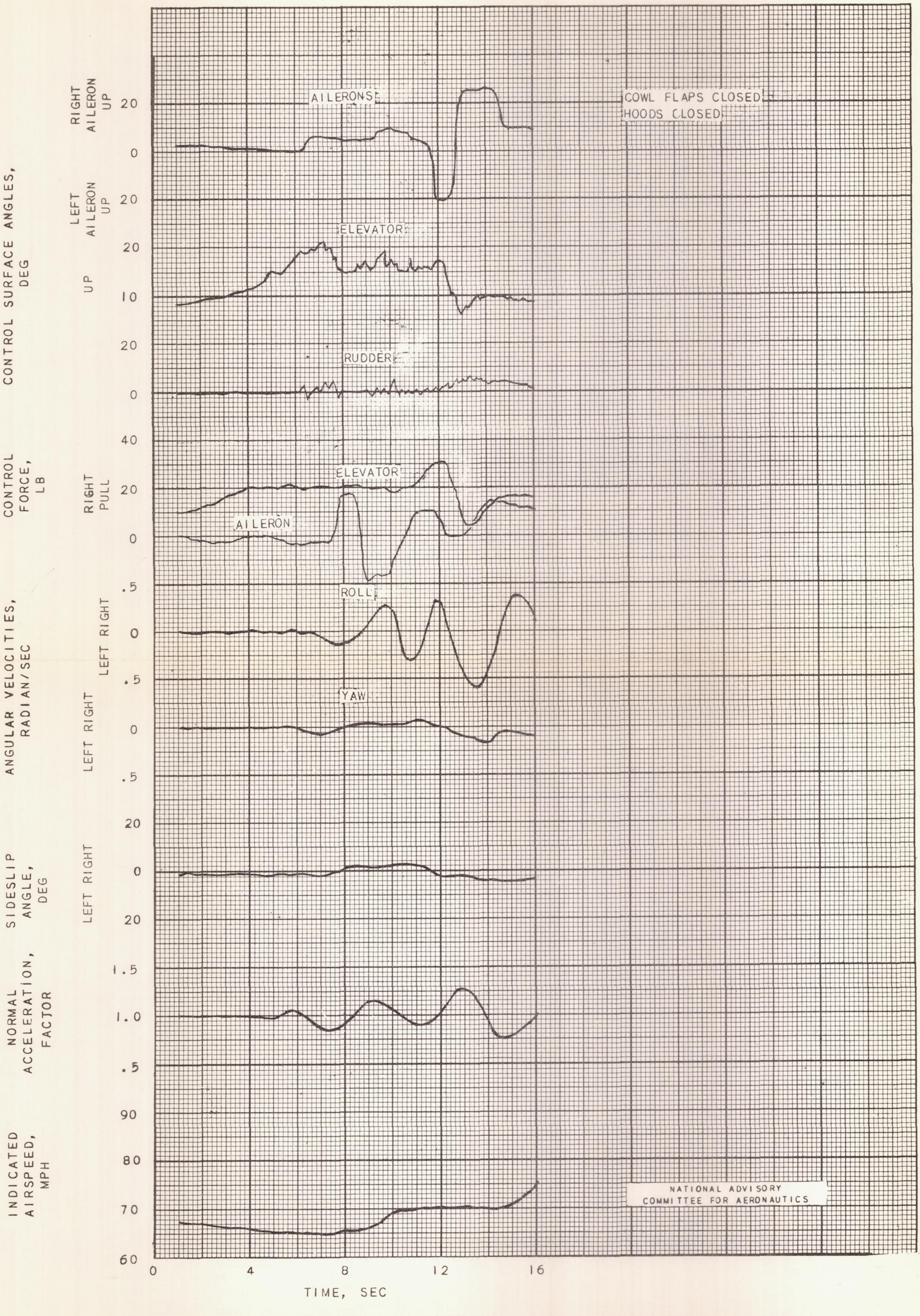


FIGURE 65 - TIME HISTORY OF A STALL POWER OFF, FLAPS DOWN. STICK BACK TO STALL; AILERONS ALONE USED TO ATTEMPT CONTROL.

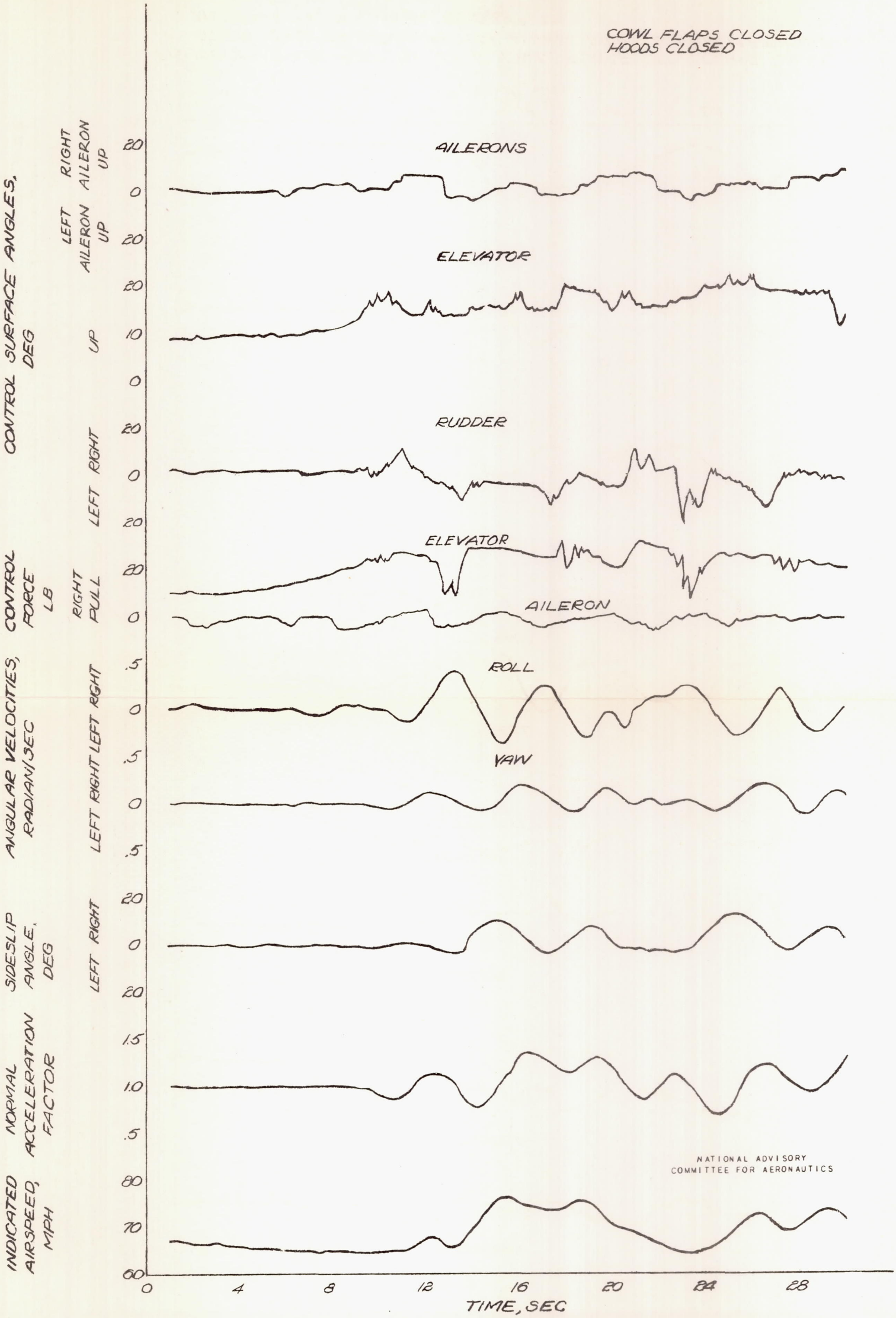


FIGURE 66.- TIME HISTORY OF A STALL, POWER OFF, FLAPS DOWN. STICK BACK TO STALL; RUDDER ALONE USED TO ATTEMPT CONTROL AILERONS MOVED UNINTENTIONALLY.