N 62 65866
MR Aug. 1943

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

August 1943 as
Memorandum Report

FLIGHT MEASUREMENTS OF THE EFFECT OF VARIOUS AMOUNTS OF AILERON DROOP ON THE LOW-SPEED LATERAL-CONTROL CHARACTERISTICS OF AN OBSERVATION AIRPLANE

By William N. Turner and Betty Adams

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WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

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SUMMARY

Tests were made of the low-speed lateral-control characteristics of an observation airplane with ailerons and spoilers in combination, and with the spoilers disconnected and the ailerons used alone with various amounts of droop. It was found that in unstalled flight at low speeds and with flaps deflected, little or no aerodynamic benefit was derived by changing the lateral-control system from the aileron and spoiler combination to a normal aileron installation either with or without aileron droop. In stalled flight with power on and flaps down, control with ailerons alone improved as the aileron droop was decreased; with 0° aileron droop the control was better than that in the original condition in which ailerons and spoilers were used in combination. The highest maximum lift coefficients in any power condition were obtained with 15° aileron droop, the maximum aileron droop tested, followed in decreasing order by the original condition, the 10° droop condition, and the 0° droop condition.

INTRODUCTION

The spoilers used for lateral control of the test airplane had been reported to provide insufficient rolling moment to overcome the torque reaction when power was suddenly applied after the airplane had bounced to a high angle-of-attack attitude in rough-water landings.

The investigation reported herein was conducted to determine the lateral-control characteristics of the test airplane at low speeds in the original condition, supplemented by tests in which the spoilers were inoperative with the ailerons drooped varied amounts. The investigation included tests to determine the effectiveness of the lateral controls, the sideslipping characteristics, and the stalling and maximum lift characteristics of the airplane.

Additional information on the lateral-control, stability maximum lift, and high-speed characteristics of the test airplane has been reported in references 1 and 2.

DESCRIPTION OF THE AIRPLANE

The airplane used in the tests was a two-place, single-engine, midwing, cantilever monoplane with fixed landing gear, partial-span deflector-plate flaps, combination aileron-spoiler lateral control, and Maxwell leading-edge slots extending from the wing tip to within approximately 14 inches of the fuselage. (See figs. 1, 2, and 3.) The general specifications of the airplane are:

Wing

Area, including section projected through fuselage	261.9 square feet
Span	35.89 feet
Taper ratio	1.5:1
Section, root	NACA 23015
Section, tip	NACA 23009
Incidence	3°
Mean aerodynamic chord	89.5 inches
Dihedral, outer-panel chord line	7°

Ailerons

Type	Frise

Area aft of hinge linge, each. . . . . 6.7 square feet

Balance area, each . . . . 2.0 square feet

Span, each . . . . 31 percent semispan

Chord, average aft of hinge line . . . . 17.2 percent local wing chord

Droop . . . . 29^{o} at full flap deflection

Spoilers

Type . . . . Ventilated and paddle-balanced

Area, each . . . . 4.98 square feet

Span . . . . 41 percent semispan

Chord, average . . . . 10 percent local wing chord

Flaps

Type . . . . Slotted deflector-plate, spring-loaded to automatically decrease deflection at the higher loads

Area aft of hinge line, each . . . . 17.5 square feet

Span, each . . . . 51 percent semispan

Chord aft of hinge line, average . . . . 23 percent local wing chord

Slots

Type . . . . Maxwell

Span, each . . . . 69 percent semispan

Chord, average . . . . 15 percent local wing chord

Horizontal tail

Span . . . . 17.17 feet

Total area . . . . 58.6 square feet

Elevator area aft of hinge line . . . 24.0 square feet

Elevator balance area . . . . 1.83 square feet

Distance of elevator hinge line from wing leading edge . . . . 20.7 feet

Incidence . . . . 2°

Vertical tail

Span (height above fuselage) . . . . 5.25 feet

Total area . . . . 22.0 square feet

Rudder area aft of hinge line . . . . 11.5 square feet

Rudder balance area . . . . 1.18 square feet

Offset . . . . 2°, leading edge left

Distance of rudder hinge line from wing leading edge . . . . 19.0 feet

Design weight and balance:

Center of gravity most forward . . . . 25.4 percent mean aerodynamic chord

Weight, center of gravity most forward . . . . 3809.1 pounds

Center of gravity normal . . . . 29.1 percent mean aerodynamic chord

Weight, center of gravity normal . . . . 4717.0 pounds

Center of gravity most rearward . . . 30.6 percent mean aerodynamic chord

Weight, center of gravity most rearward . . . . 4723.5 pounds

Engine:

Type R-985-50

Rating, take-off . . . . 450 brake horsepower at 2300 rpm and 35.5 inches mercury at sea level

Rating, normal	400 brake horsepower at 2200 rpm at sea level and 5500 feet
Gear ratio	Direct drive
Carburetor	Automatic mixture control, type NA-R9C2
Fuel	92 octane
Maximum rpm limit	2860

Propeller

Type	Two-blade, constant-speed
Diameter	8.50 feet
Maximum blade-angle range	15°
Index setting	24° at 42-inch station
High pitch stop	22° at 42-inch station
Low pitch stop	9° at 42-inch station

Plan and section views of the lateral-control surfaces are shown in figures 4 and 5.

INSTRUMENT INSTALLATION

NACA instruments were used to record photographically as a function of time the following variables: airspeed, normal and longitudinal acceleration, rolling velocity, control position, stick force, angle of sideslip, and angle of bank.

Indicating service instruments with which the airplane was equipped were used in observing pressure altitude and free-air temperature.

An airspeed head, free to aline itself with the relative wind in pitch, but not in yaw, was mounted on a boom extending approximately one chord length ahead of the leading edge of the left wing near the tip. The installation was calibrated in straight flight with a trailing pitot-static airspeed head.

A yaw vane was mounted on a boom near the right wing tip approximately one chord length ahead of the leading edge.

A two-element control-position recorder was installed in the tail and attached directly to the elevator and rudder control surface torque tubes.

A two-element control-position recorder was installed in each wing and connected directly to each aileron and spoiler.

The lateral-control surface characteristics of the airplane may be seen in figures 6 to 16. Calibrations of the control surface deflections in terms of the cockpit control positions are shown in figures 6 to 11. It should be noted in figure 7 that the lateral stick travel is unsymmetrical with the airplane in the original condition with flaps two-thirds down. Inadvertent moving of a stop while rigging the airplane was responsible for this effect.

Friction in the lateral-control system is indicated by figures 13 to 16. The data were obtained by measuring the angle at the stick and the corresponding force as the stick was moved slowly throughout its maximum deflection range.

TESTS, RESULTS, AND DISCUSSION

Flight tests were made of the effectiveness of the lateral controls, the lateral control required to overcome the torque reaction, the sideslipping characteristics, and the stalling and maximum lift characteristics. The measurements were made with the airplane in the original condition and with the spoilers disconnected and ailerons drooped 15°, 10°, and 0°, with flaps two-thirds and full down.

In the original condition the lateral control is obtained by a combination of ailerons and spoilers. As the flaps are lowered a gradual transition occurs from aileron control alone to spoiler control alone and the droop of the ailerons increases from 0° with flaps full up to 29° with flaps full down.

In the other conditions the spoilers were inoperative, lateral control being obtained by means of the ailerons alone. The spoilers were disengaged by removing the telescoping shaft shown in figure 12 when the flaps were up. Deflection of the flap then had no effect on the mechanical linkage of the control system. The aileron droop was varied by changing the length of the aileron link shown in figure 12.

Throughout the flight program the following conditions were maintained: Maxwell slots closed, cowl flaps open, front hood open, rear hood closed, and propeller in low pitch. The average weight was 4,620 pounds with center of gravity at 26.4 percent of the mean aerodynamic chord.

Lateral-Control Characteristics in Straight Flight

In order to determine the amount of lateral control required to overcome the torque reaction, measurements of the angles of the lateral controls and the lateral stick forces required to hold the wings level were made as the speed was gradually decreased to the stall. The results are shown in figures 17 to 24. These data show that with power on or off only a small change in lateral-control angle or force was required to maintain the wings in a level attitude. As reliable measurements of the sideslip angles were not obtained for this group of tests, the rolling moment contributed by the difference in sideslip angles between the power-off and power-on conditions is not known. Observations of data taken when the power was suddenly applied near the power-off stalling speed, however, indicated that the sideslip angles involved had little effect on the control angles required.

In reference 2 it was shown that with power on, the test airplane would always stall first on the outboard sections of the wing causing an abrupt roll-off. The difficulty then in controlling the airplane in landing at high angles of attack with power on is not primarily that the lateral control is insufficient but that the stall pattern is poor. The solution to the problem would not be to provide more effective lateral controls, but to delay the stall on the outer wing panels to a higher angle of attack. One method of doing this, as shown in reference 2, would be to employ a partial-span leading-edge slot.

Dynamic Lateral-Control Characteristics

The lateral-control characteristics of the airplane were investigated at low speed by taking records in abrupt aileron rolls during which the pilot attempted to hold the rudder fixed. The pilot was requested to make these rolls at a velocity approximately five knots above the stalling speed. The results are presented in figures 25 to 80 and are summarized in table I.

The comparative rates of roll and corresponding stick forces for the four different basic conditions of lateral control varied considerably with power and flap position.

With the flaps full down, the highest rates of roll were obtained in the original condition. The stick forces in the original condition were high with power off and low with power on. With aileron control alone, no consistent variation of rolling velocity with angle of aileron droop was apparent. The stick forces were highest with 0° aileron droop, and decreased as the droop increased. The abrupt change in slope of the stick-force curve near maximum deflection with 0° droop is characteristic of Frise ailerons and may be attributed to loss of balance effect on the upgoing aileron due to stalling of the lower aileron surface. If a type of aileron less susceptible to local stalling had been used, it is probable that the stick forces at large aileron deflections with 0° droop would have been more comparable with those measured in the other droop conditions.

With flaps two-thirds down, the highest rate of roll was obtained with 10° aileron droop. With aileron control alone, the stick forces were again high with 0° droop, and decreased as the droop was increased. The lowest stick forces were obtained in the original condition, but the rate of roll was also lowest in this condition.

The maximum rate of roll in either flap condition was generally greater to the right with power off and greater to the left with power on.

The adverse yaw characteristics of the several control arrangements may be judged from the change in angle of sideslip measured in the rolls. Except with power off and flaps two-thirds down, the adverse sideslip at maximum rolling velocity was greatest in the original condition. The maximum sideslip reached in the rolls, however, was considerably less in the original condition than in the other conditions. With aileron control alone, the slip at maximum rolling velocity varied little with aileron droop, but the maximum slip reached was noticeably larger with 15° droop than with 10° or 0° droop. The curves of observed inadvertent movement of the rudder in aileron rolls are presented as a matter of interest, inasmuch as any movement of the rudder will affect the sideslip angles recorded. Any slope in the curves indicates that, on the average, the rudder was not held absolutely fixed during the roll.

With power off, the time histories of the aileron rolls with 15° aileron droop show that the rolling velocity decreased markedly after the initial maximum value was reached. As the angle of aileron droop was decreased, this effect became less pronounced. With 0° aileron droop, and in the original condition, the decrease in rolling velocity after the initial maximum value was reached was small or absent entirely.

With power on, instances in which the rolling velocity decreased after the initial maximum value was reached were rare, even though the sideslip angles attained were of the same order of magnitude as with power off. In fact, in all configurations with power on there was a tendency for the rolling velocity to increase as long as the ailerons were held deflected.

The rates of roll obtained in the original condition with flaps full down and power off are considerably higher than those obtained in the configuration of flaps full down, Maxwell slots closed, and power off reported in reference 1. It is noted in reference 1 that the data were not always consistent. It is believed that data represented herein are reasonably accurate.

Characteristics in Steady Sideslips

Data measured in steady sideslips are plotted in figures 81 to 88. Owing to difficulties with the recording mechanism, the true angle of sideslip may have differed several degrees from that shown. The slopes of the curves may, however, be considered correct. All tests were run at approximately five knots above the stalling speed of the particular configuration being tested.

The variation of cross-wind force with angle of sideslip was in the correct direction for any condition of flap, power, or aileron droop. This is shown by the fact that increasing right bank accompanied increasing right sideslip, and vice versa.

The variation of rolling moment (stick fixed) with angle of sideslip was stable with power off for all configurations, but unstable with power on for all configurations with flaps full down, and in the 10°-droop condition with flaps two-thirds down. This is shown by the slopes of the curves of aileron angle against sideslip.

The variation of rolling moment (stick free) with angle of sideslip was stable with power off and unstable with power on for all configurations. This is shown by the curves of lateral stick force against sideslip.

The variation of yawing moment with sideslip was stable for all configurations. This is shown by the curves of rudder angle against sideslip.

With full power on in all configurations, the left sideslip available with full right rudder was only about 5°. It was noted by the pilots that full right rudder was barely enough to prevent turning at the stall with this amount of power.

With 15° droop, flaps two-thirds down, power on, the pilot noted a rudder-force reversal with full left rudder. In all configurations with power off, angles of sideslip greater than those for which data are shown on the curves were difficult or impossible to hold steady. This condition was probably caused by partial stalling of the wings and/or vertical tail.

Stalling Characteristics

The ability to control the airplane at low speeds and in the stall was investigated in all configurations by slowly approaching the stall while rolling the airplane with the ailerons (or spoilers), and attempting control in the stall with the wing lateral controls alone. The results are presented in the form of time histories (figs. 89 to 104) and are summarized below:

Original condition.-

(a) Flaps full down (figs. 89 and 90)

The airplane was controllable in the stall with the stick full back and power off. With power on, control was sometimes possible for a short time in the stall.

(b) Flaps two-thirds down (figs. 91 and 92)
With power off, the airplane was controllable in the stall with the stick full back. With power on, the airplane was usually controllable immediately after the stall, but the amplitude of the lateral oscillations increased until the airplane finally rolled off.

Ailerons drooped 15°.-

(a) Flaps full down (figs. 93 and 94)
With power off, the airplane was controllable in the stall with the stick full back. With power on, the airplane was not controllable in the stall, sharp left roll-off occurring with full right aileron.

(b) Flaps two-thirds down (figs. 95 and 96)
With power off, the airplane was controllable in the stall. With power on, the airplane was controllable during the early part of the stall.

Ailerons drooped 10°.-

(a) Flaps full down (figs. 97 and 98)
With power off, the airplane was controllable in the stall with the stick full back. With power on, the airplane was not controllable in the stall, left roll-off occurring with nearly full right aileron.

(b) Flaps two-thirds down (figs. 99 and 100)
With power off, the airplane was controllable during the first part of the stall with the stick full back, but right roll-off finally occurred. With power on, the airplane was sometimes controllable for a short time in the stall, although nearly full aileron was required.

Ailerons drooped 0°.

(a) Flaps full down (figs. 101 and 102)

With power off, the airplane was controllable in the stall. With power on, the airplane would pitch down strongly at the stall. Initial rolling tendencies could be checked with the ailerons. Sufficient record was not available to judge the control in protracted stalls.

(b) Flaps two-thirds down (figs. 103 and 104)
With power off, the airplane was controllable in the stall with the stick full back. With power on, full aileron deflection controlled the stall with the stick well back.

General discussion of lateral control in the stall.- It is apparent from the foregoing that the airplane was controllable laterally with the ailerons alone (or ailerons and spoilers alone) with power off in all configurations. It should be noted that with a more rearward center-of-gravity location than was used in these tests, full up elevator might have produced a more complete and consequently a less controllable stall.

With power on, the controllability in the stall was poor with the ailerons drooped 15°, but improved gradually as the droop was decreased until, with 0° aileron droop, a fair amount of control was usually possible. In the original condition with power on, control was sometimes possible for a short time after the stall.

With power on, control in the stall was consistently better with flaps two-thirds down than with flaps full down.

Maximum Lift

Maximum lift coefficients were determined for all configurations from measurements taken in slow stall approaches. The lift coefficient is defined in this report as

$$C_L = \frac{W\ An}{qS}$$

where

W weight of airplane, pounds

A_n recorded normal acceleration (A_Z/g)

q dynamic pressure, pounds per square foot

S total wing area, square feet

The results are summarized in the following table:

Aileron Droop	Flap Setting	$C_{L_{max}}$ Power on	$C_{L_{max}}$ Power off
Original Condition	Full Down	2.46	1.85
Original Condition	2/3 Down	2.26	1.66
15°	Full Down	2.68	1.89
15°	2/3 Down	2.48	1.86
10°	Full Down	2.52	1.70
10°	2/3 Down	2.20	1.62
0°	Full Down	2.38	1.70
0°	2/3 Down	2.07	1.60

The lift coefficient shown for each condition is the average determined from the records of several stalls.

With power off, it is seen that the highest lift coefficients were obtained with the ailerons drooped 15°. The next highest lift coefficients were obtained in the original condition, while the 10° and 0° aileron droop conditions were lowest and had about the same values of maximum lift.

With power on, the highest values of maximum lift coefficient were again obtained with the ailerons drooped

15°. The original and 10° droop condition followed with about the same values of $C_{L_{max}}$, and the 0° droop condition was again lowest.

CONCLUSIONS

1. The results of this investigation show that in unstalled flight, little or no aerodynamic benefit is to be gained at low speeds with flaps deflected by changing the lateral-control system from spoiler control to aileron control either with or without initial aileron droop.

2. A poor stall pattern with power on, not insufficient lateral control per se, was the probable cause of the difficulty encountered in controlling the airplane when power was applied at high angles of attack in rough-water landings. Partial-span leading-edge slots are suggested as one means of delaying the stall on the outer wing panels to higher angles of attack.

3. In stalls, the airplane was controllable laterally with power off in all configurations. The 10° droop condition with flaps two-thirds down illustrated by figure 99 may seem to be an exception in that the final roll-off was not controllable. However, since control was maintained for 10 seconds after the stall, it is believed that this condition may be considered controllable. With power on, the controllability in the stall was poor with the ailerons drooped 15°, but improved gradually as the droop was decreased until, with 0° aileron droop, a fair amount of control was usually possible. In the original condition with power on, control was sometimes possible for a short time after the stall. With power on, control in the stall was consistently better with flaps two-thirds down than with flaps full down.

4. The highest values of the maximum lift coefficient in any power condition were obtained with the ailerons drooped 15°. The other conditions, in order of merit, were as follows: original condition, ailerons drooped 10°, and ailerons drooped 0°.

5. Characteristics in steady sideslips were satisfactory except as follows:

(a) Stick-fixed lateral instability was indicated with power on in all configurations with flaps full down and in the 10° droop condition with flaps two-thirds down.

(b) Stick-free lateral instability was indicated with power on in all conditions.

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REFERENCES

1. Clousing, Lawrence, and McAvoy, William H.: Flight Measurements of the Lateral Control Characteristics of a Vought-Sikorsky OS2U-2 Airplane (Navy No. 2189). NACA CMR, Sept. 1942.

2. Turner, William N., and Adams, Betty: Flight Tests of the Stability, Maximum Lift, and High Speed of a Navy OS2U-2 Airplane (No. 2189) Equipped with a Maxwell Slot. NACA CMR, Jan. 1943.

TABLE I.- DATA TAKEN IN AILERON ROLLS

Item		Flaps full down				Flaps two-thirds down			
		Original condition	15° Aileron droop	10° Aileron droop	0° Aileron droop	Original condition	15° Aileron droop	10° Aileron droop	0° Aileron droop
Power off									
Indicated stalling speed, miles per hour		60	59	63	62	63	59	63	64
Indicated airspeed at which the aileron rolls were made, miles per hour		71	67	71	69	68	70	70	70
$\left(\frac{pb}{2V}\right)_{max}$ at test speed		0.086L 0.089R	0.078L 0.075R	0.079L 0.089R	0.057L 0.089R	0.066L 0.057R	0.074L 0.081R	0.077L 0.087R	0.070L 0.079R
Stick force at $\left(\frac{pb}{2V}\right)_{max}$, pounds		50L* 35R*	22L 20R*	25L* 26R*	40L* 47R*	10L* 9R*	16L* 18R*	21L* 21R*	56L* 58R*
Change in recorded angle of sideslip, degrees	At maximum rolling velocity	9L 8R	5L 4R	4L 3R	5L 7R	7L 6R	5L 5R	4L 6R	6L 12R
	At maximum sideslip	17L 17R	25L 25R	23L 20R	17L 20R	20L 13R	27L 27R	--- 20R	21L 22R
Maximum total aileron (or spoiler) deflection, (From unloaded ground calibration)		Spoilers 53L 54R Ailerons --- ---	48L 50R	48L 51R	52L 54R	Spoilers 40L 25R Ailerons 16L 15R	48L 50R	48L 51R	52L 54R
400 bhp at 2200 rpm									
Indicated stalling speed, miles per hour		51	49	49	51	53	50	52	55
Indicated airspeed at which the aileron rolls were made, miles per hour		53	54	58	58	59	58	60	58
$\left(\frac{pb}{2V}\right)_{max}$ at test speed		0.105L 0.102R	0.081L 0.072R	0.093L 0.082R	0.089L 0.087R	0.077L 0.067R	0.085L 0.079R	0.081L 0.083R	0.084L 0.077R
Stick force at $\left(\frac{pb}{2V}\right)_{max}$, pounds		17L* 12R*	10L* 12R	14L* 18R*	33L* 41R*	10L* 6R*	8L* 14R*	13L* 16R*	30L* 30R*
Change in recorded angle of sideslip, degrees	At maximum rolling velocity	10L 9R	7L 4R	6L 4R	7L 6R	12L 7R	7L 4R	7L 8R	6L 8R
	At maximum sideslip	18L 13R	32L 20R	20L 16R	22L 16R	20L 11R	33L 15R	--- 18R	25L 16R
Maximum total aileron (or spoiler) deflection (From unloaded ground calibration)		Spoilers 53L 54R Ailerons --- ---	48L 50R	48L 51R	52L 54R	Spoilers 40L 25R Ailerons 16L 15R	48L 50R	48L 51R	52L 54R

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*Extrapolated stick forces.

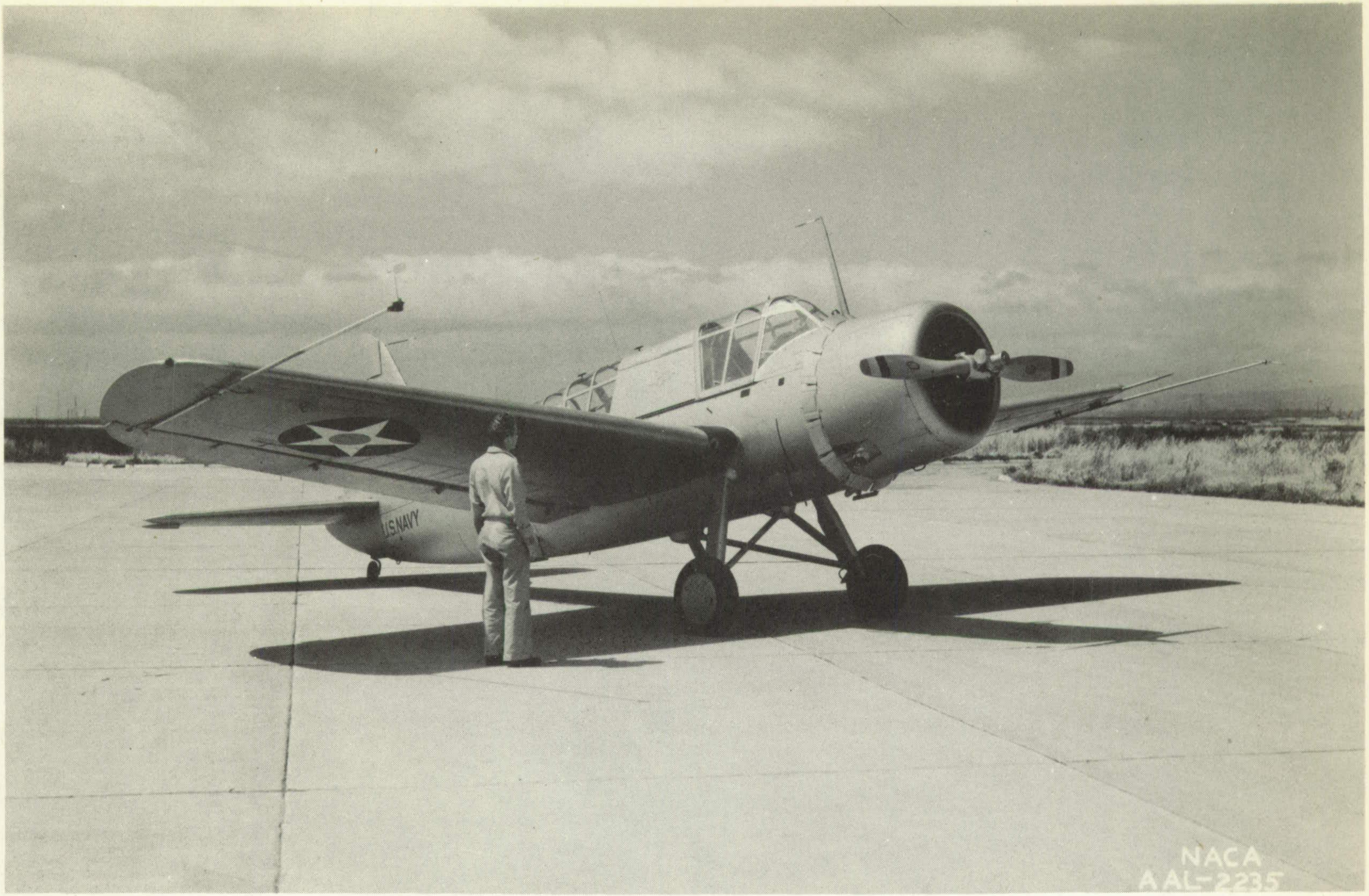


Figure 1.- Three-quarter front view of the test airplane as instrumented for flight.

Figure 2.- Three-quarter rear view of the test airplane as instrumented for flight showing deflected flap, drooped aileron, deflected spoiler, and open slot.

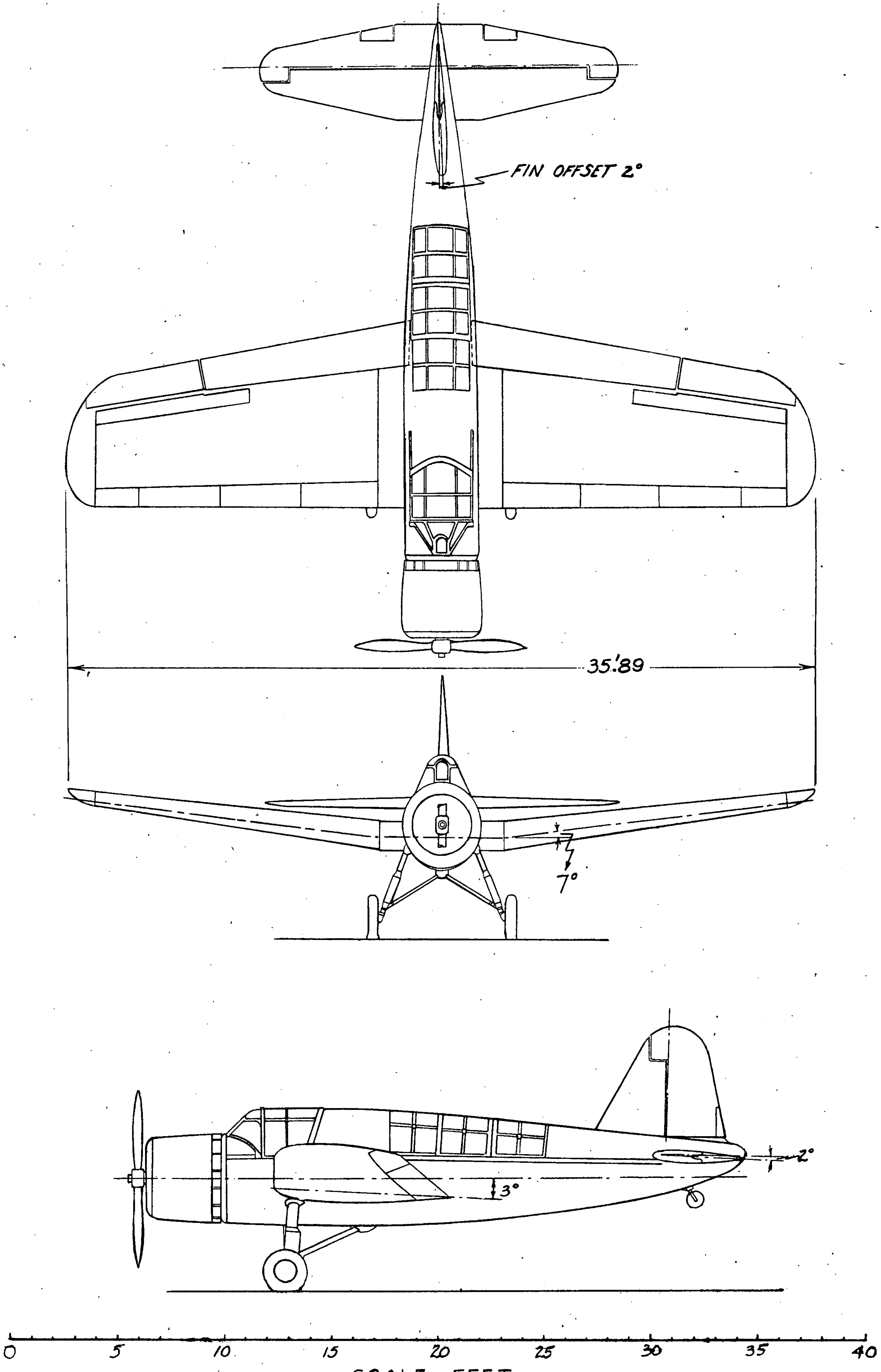


FIGURE 3. - THREE-VIEW DRAWING OF TEST AIRPLANE.

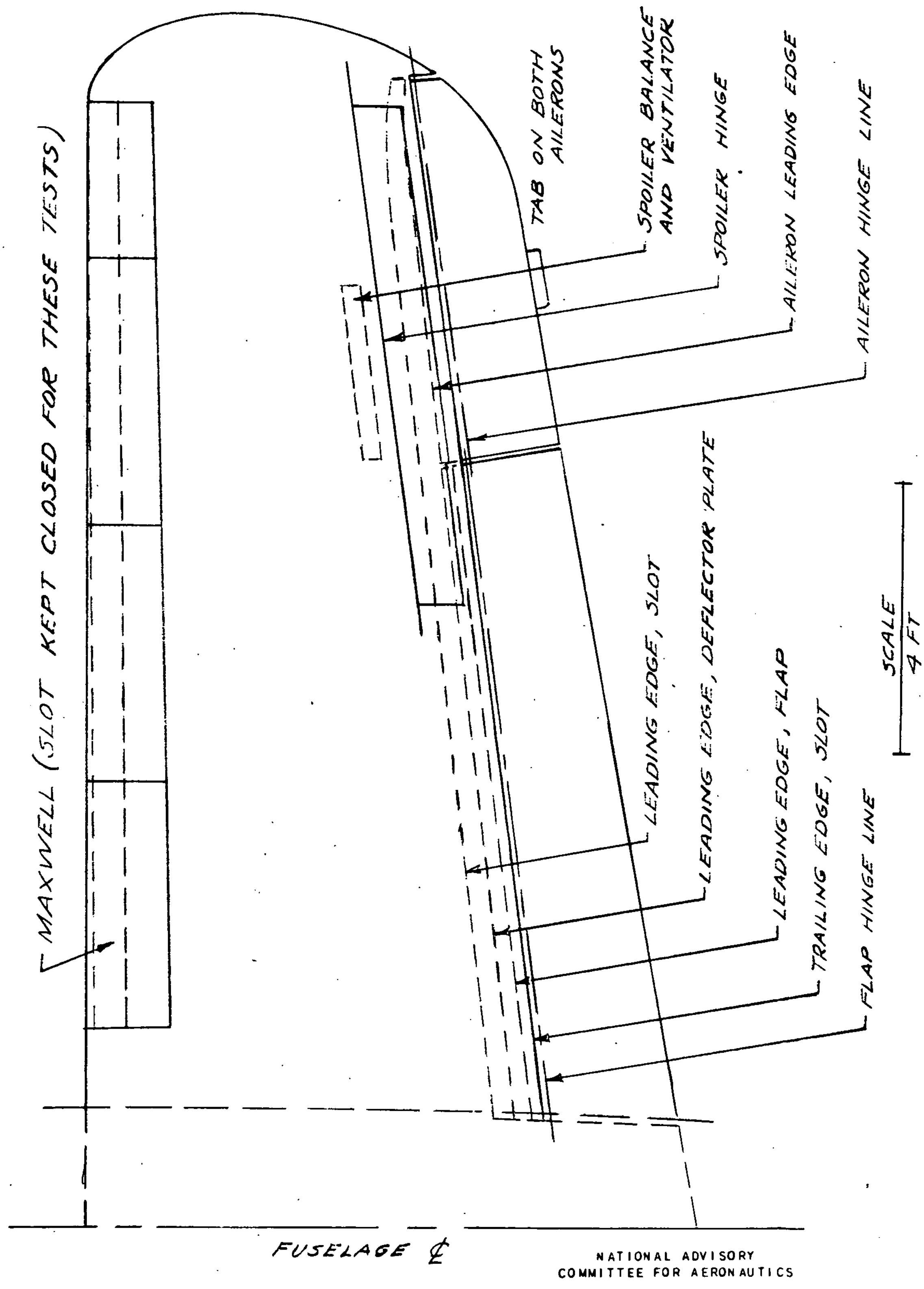
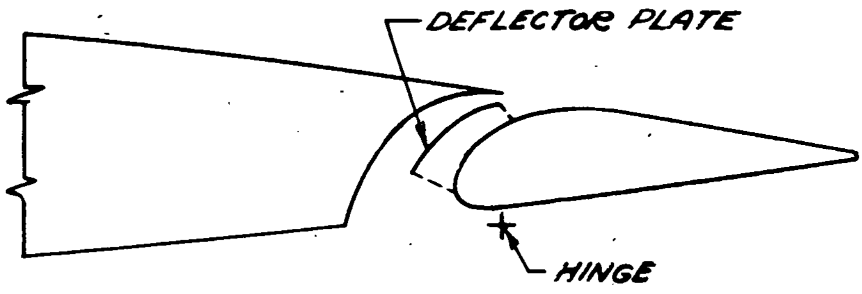
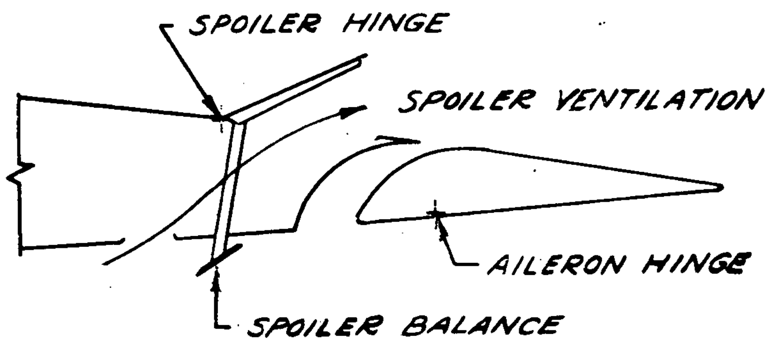


Figure 4.- Plan view showing high lift and lateral-control devices.



TYPICAL FLAP SECTION



TYPICAL AILERON SECTION SHOWING PARTIALLY DEFLECTED SPOILER

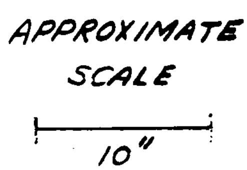


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FIGURE 5.- TYPICAL SECTIONS OF FLAP AND LATERAL CONTROLS.

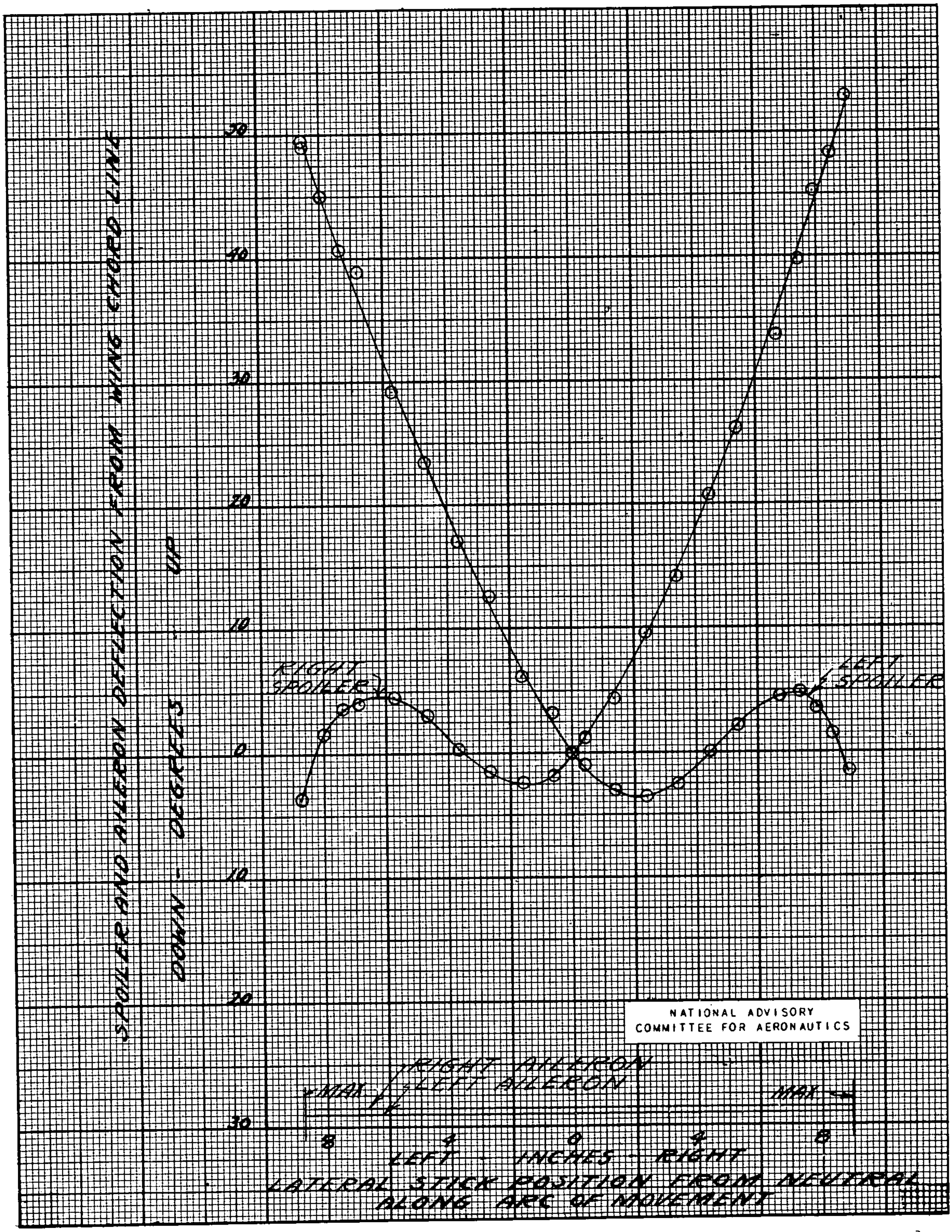

Figure 6.- Variation of aileron and spoiler angles with stick position as measured on the ground with no load on the surfaces. Flaps full down.

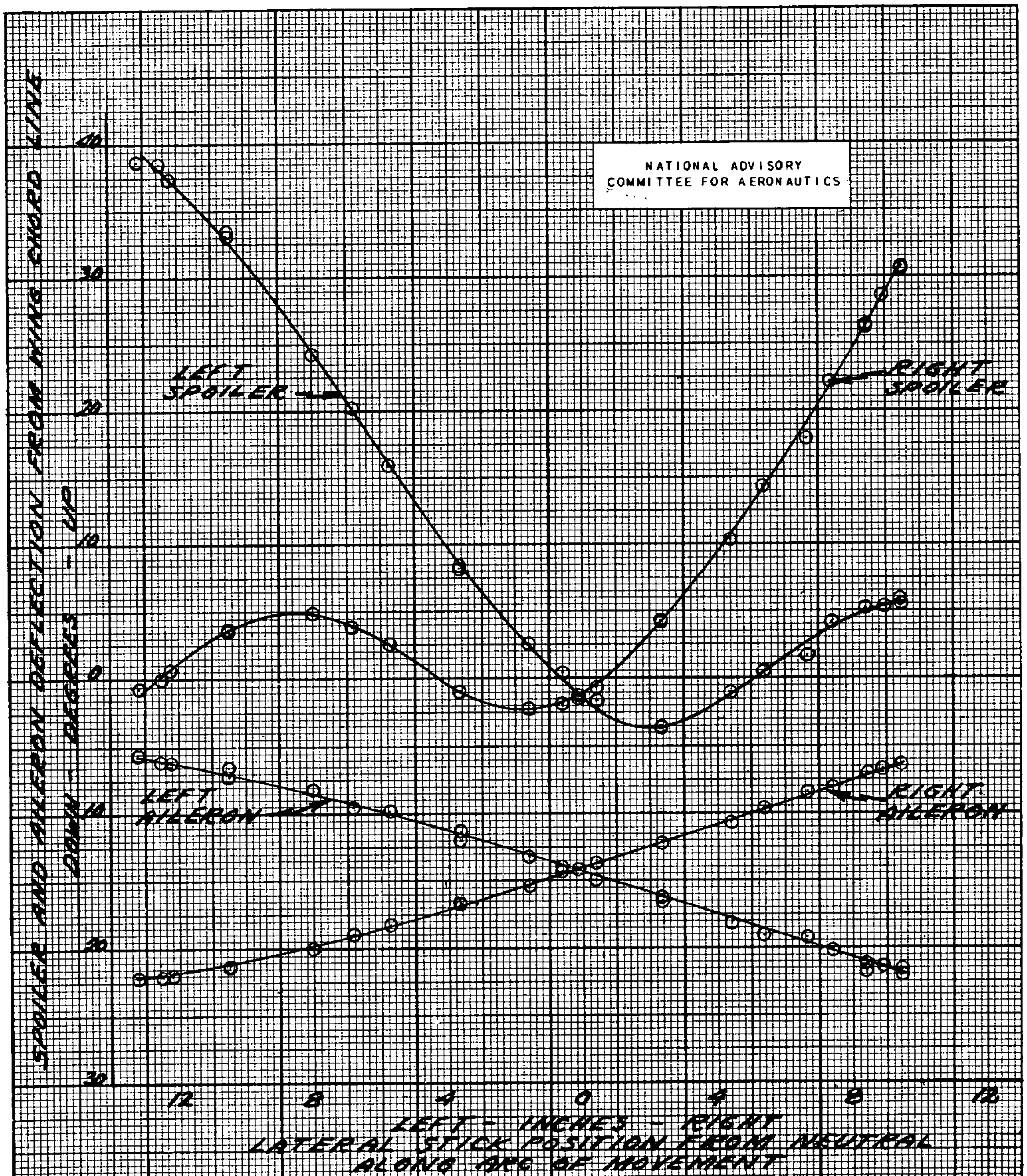

Figure 7.- Variation of aileron and spoiler angles with stick position as measured on the ground with no load on the surfaces. Flaps two-thirds down.

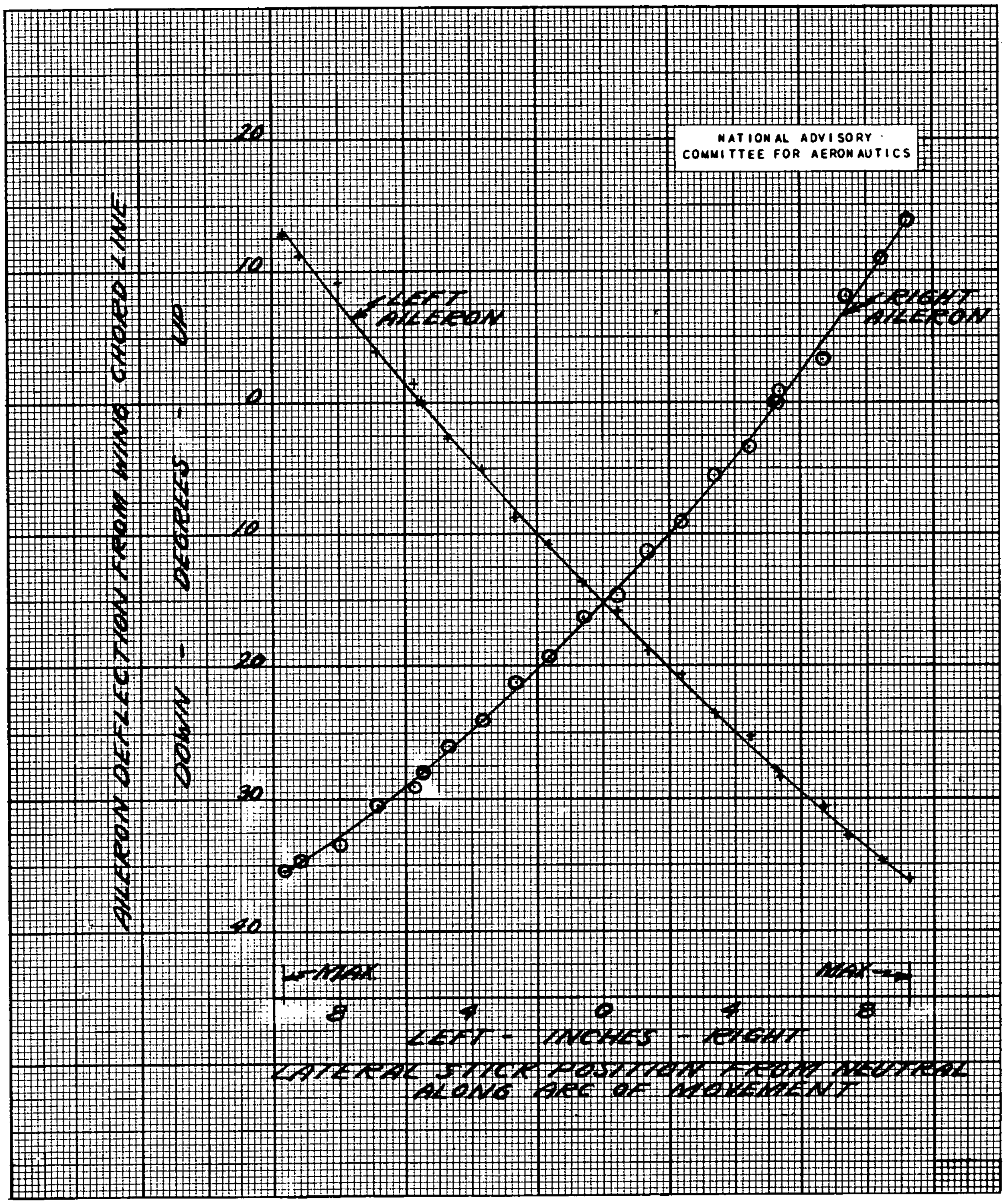

Figure 8.- Variation of aileron angle with stick position as measured on the ground with no load on the surfaces. 15° aileron droop.

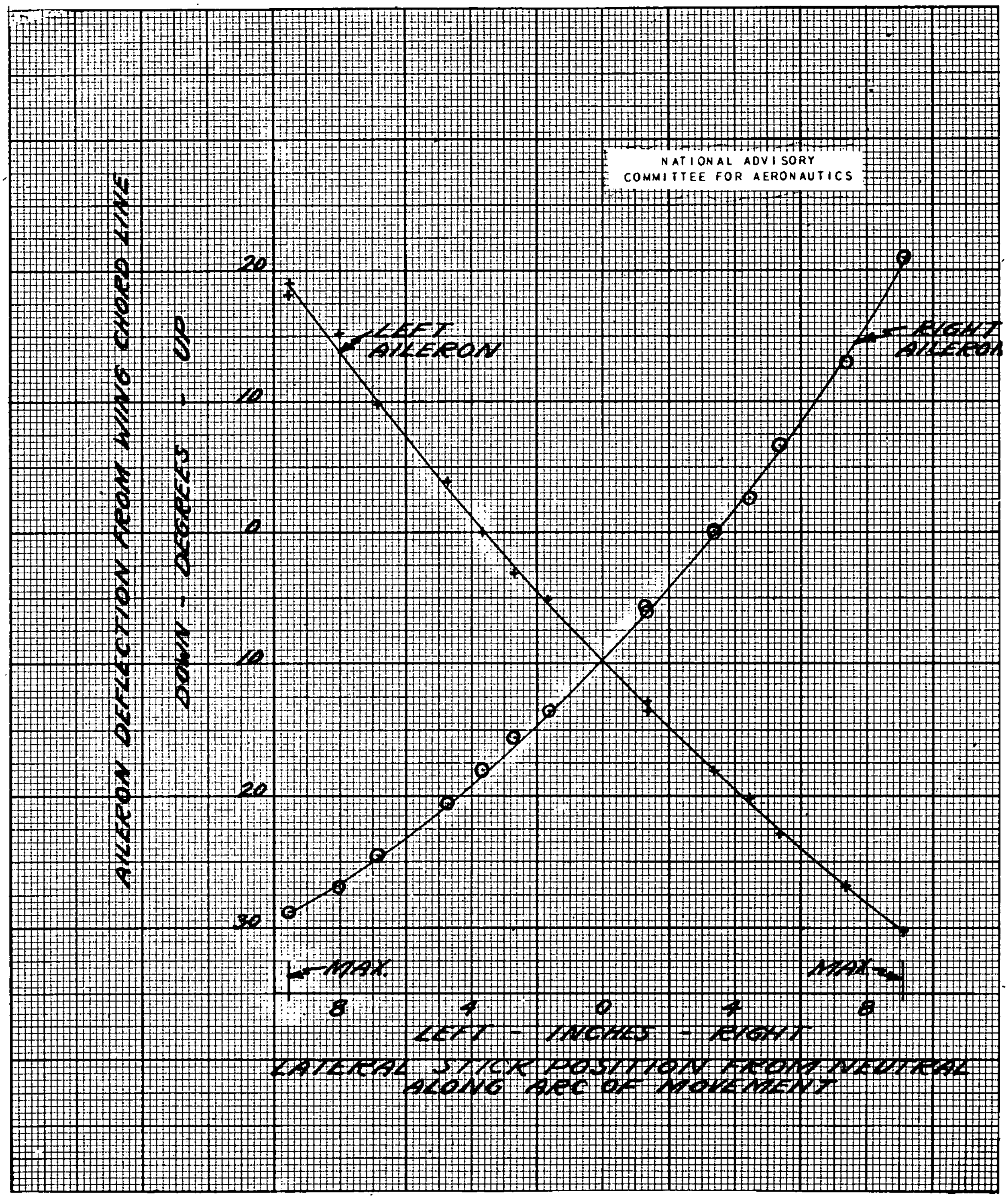

Figure 9.- Variation of aileron angle with stick position as measured on the ground with no load on the surfaces. 10° aileron droop.

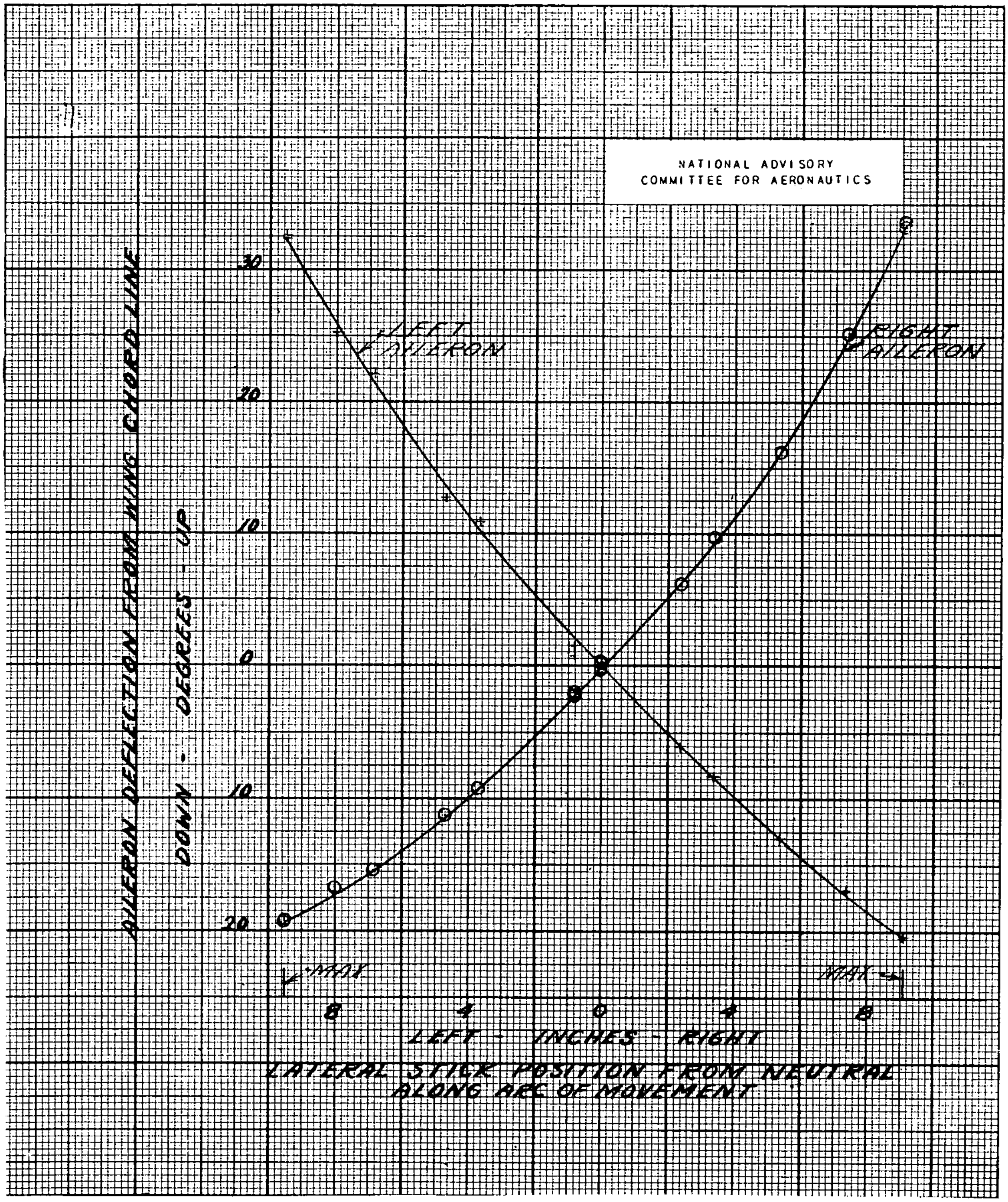

Figure 10.- Variation of aileron angle with stick position as measured on the ground with no load on the surfaces. 0° aileron droop.

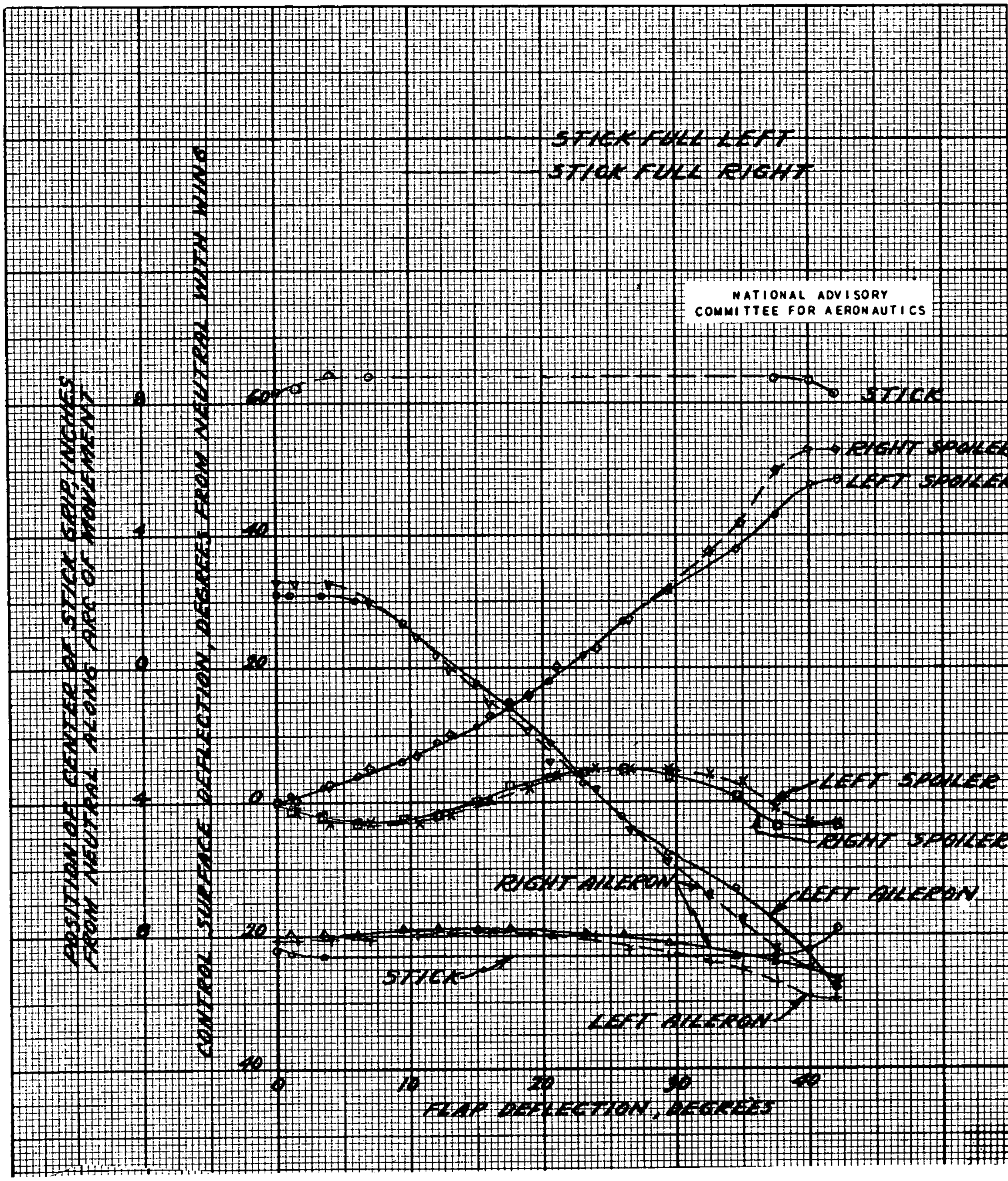

Figure 11.- Variation of maximum movements of ailerons and spoilers with change in flap position.

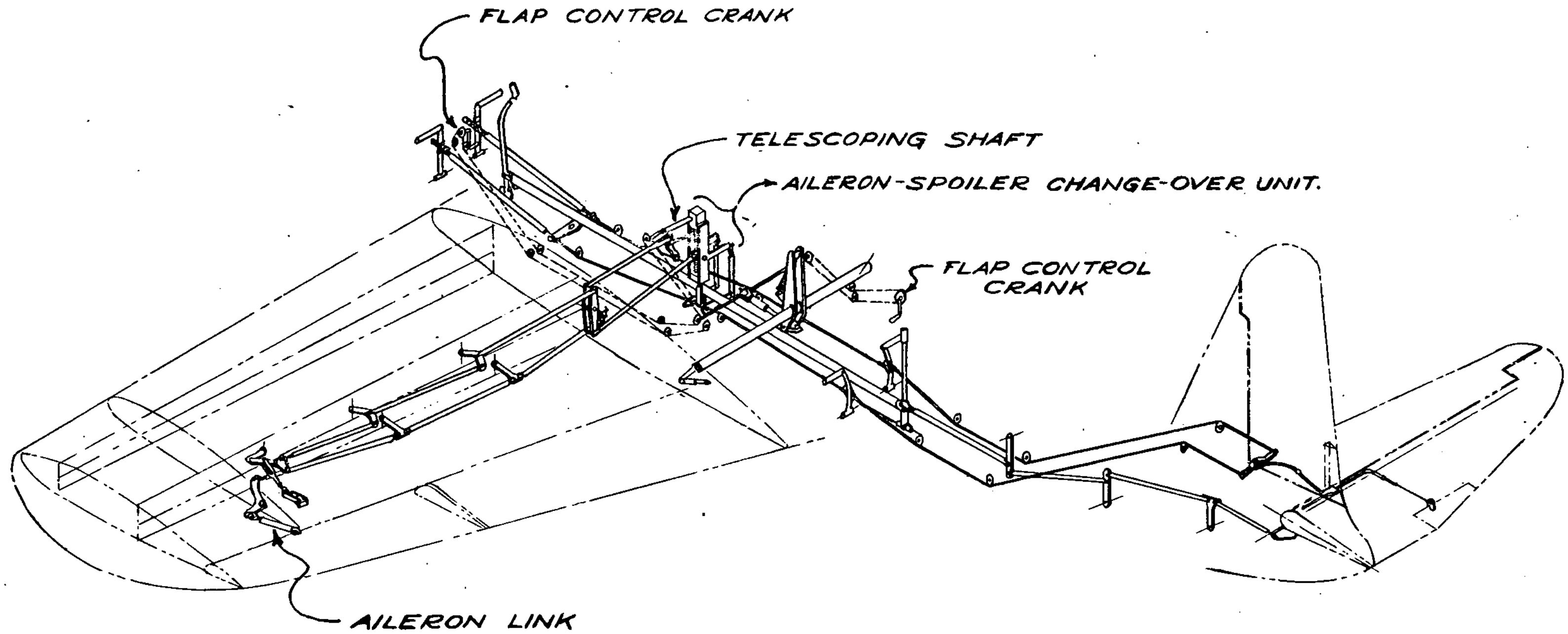

FIGURE 12.- LATERAL-CONTROL SYSTEM.

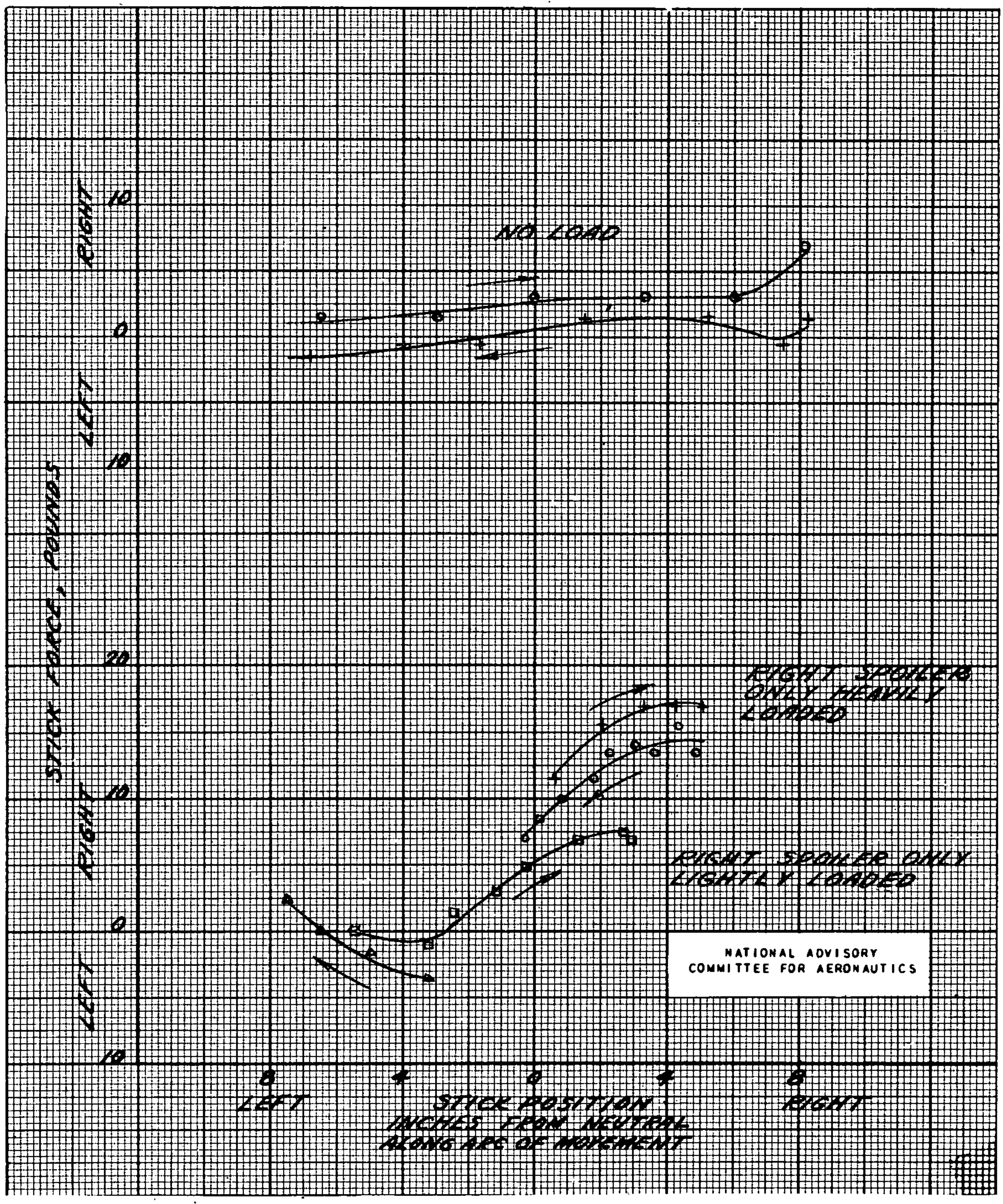

Figure 13.- Friction in the lateral-control system as indicated by the stick force required to move the controls on the ground. Flaps full down.

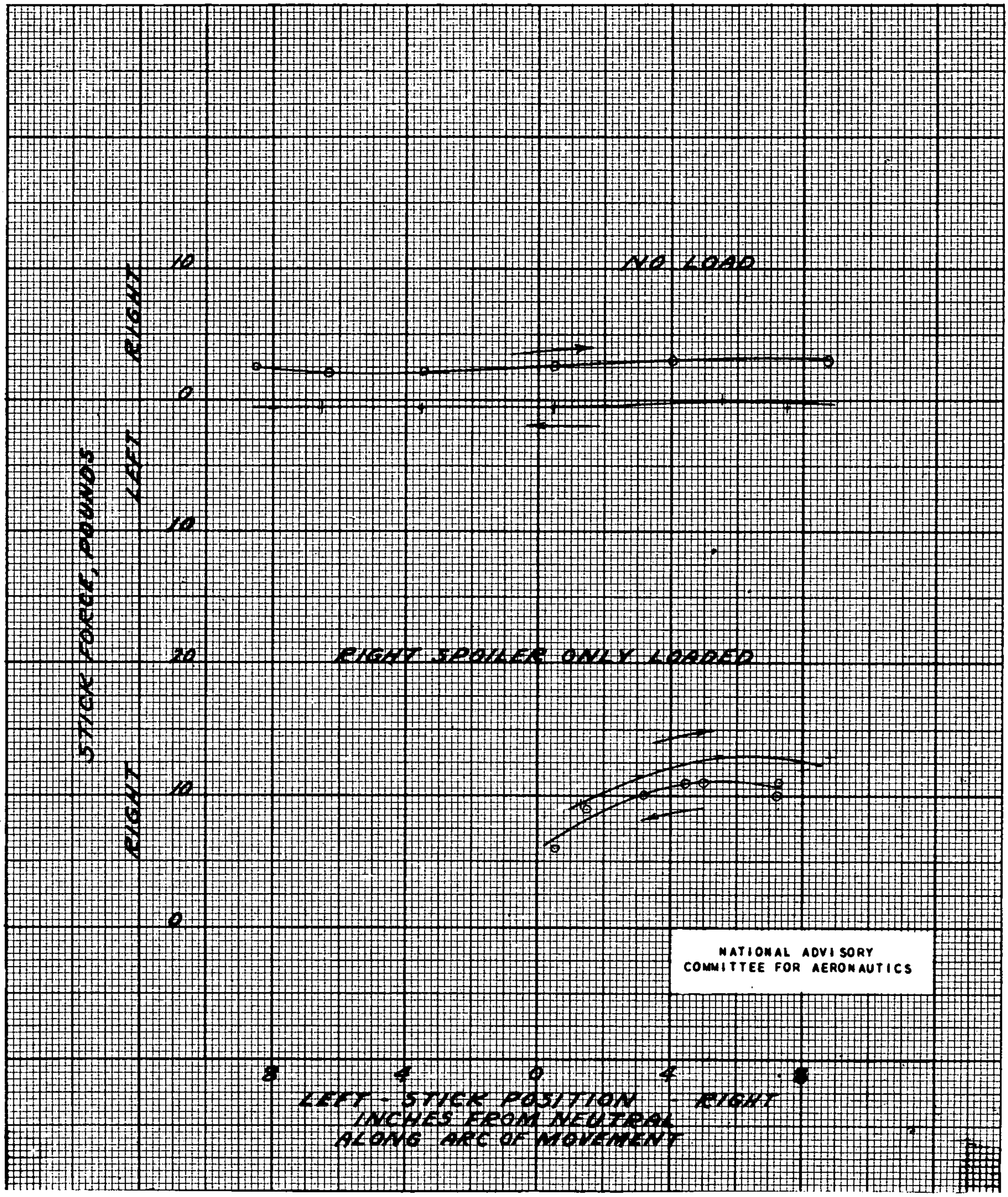

Figure 14.- Friction in the lateral-control system as indicated by the stick force required to move the controls on the ground. Flaps two-thirds down.

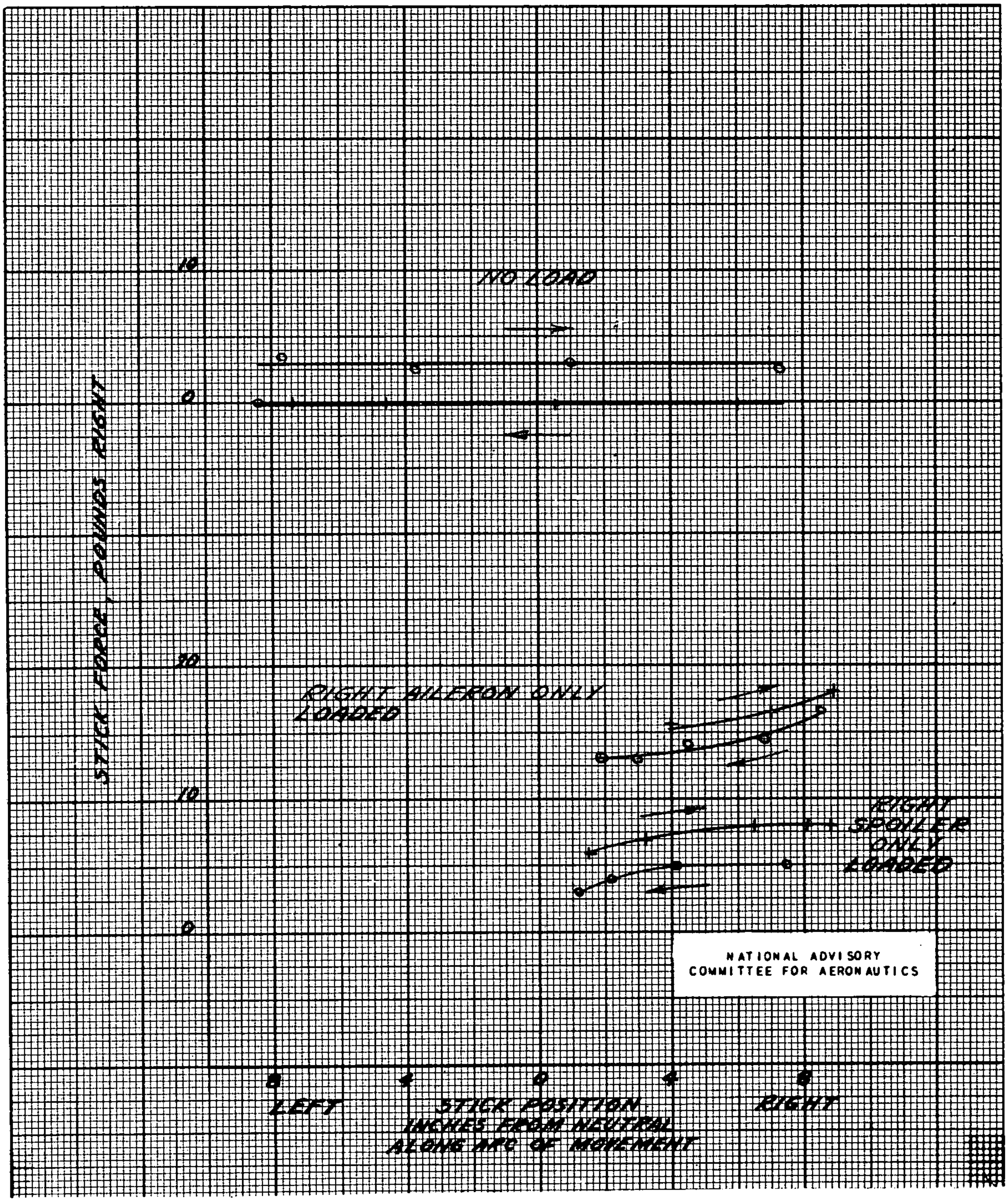

Figure 15.- Friction in the lateral-control system as indicated by the stick force required to move the controls on the ground. Flaps one-third down.

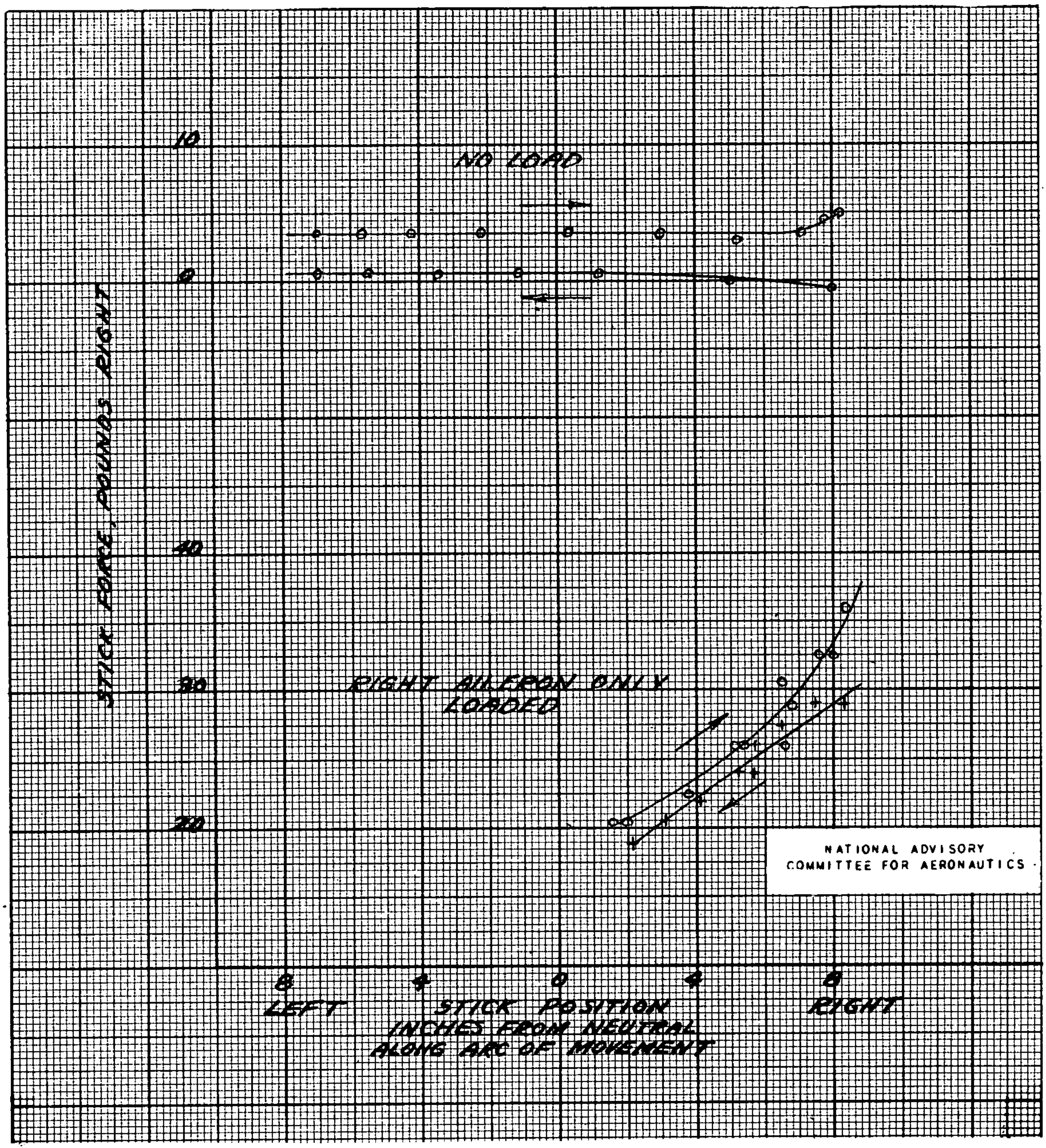

Figure 16.- Friction in the lateral-control system as indicated by the stick force required to move the controls on the ground. Flaps up.

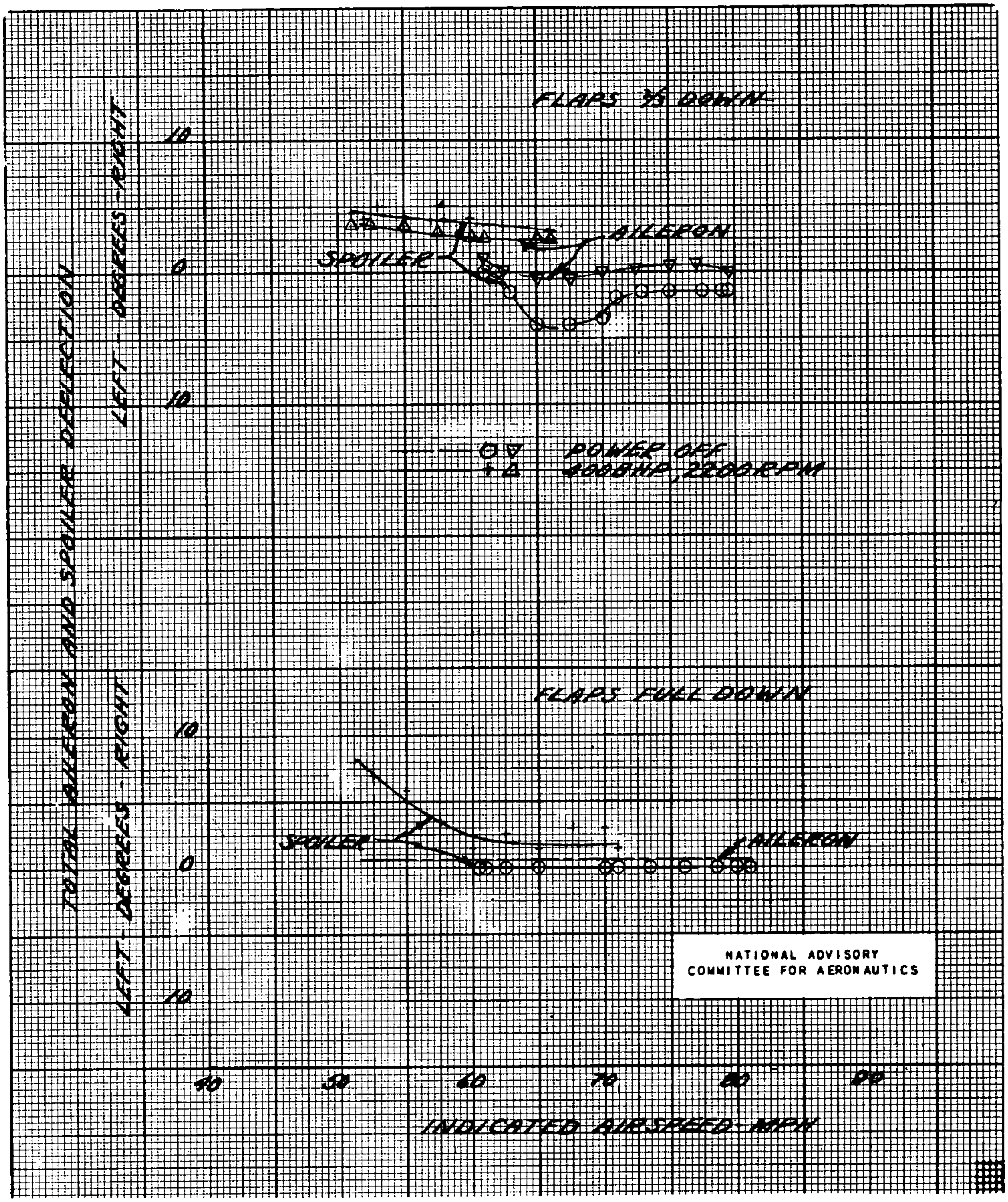

Figure 17.- Lateral-control deflection required to hold the wings level in straight flight at various airspeeds.

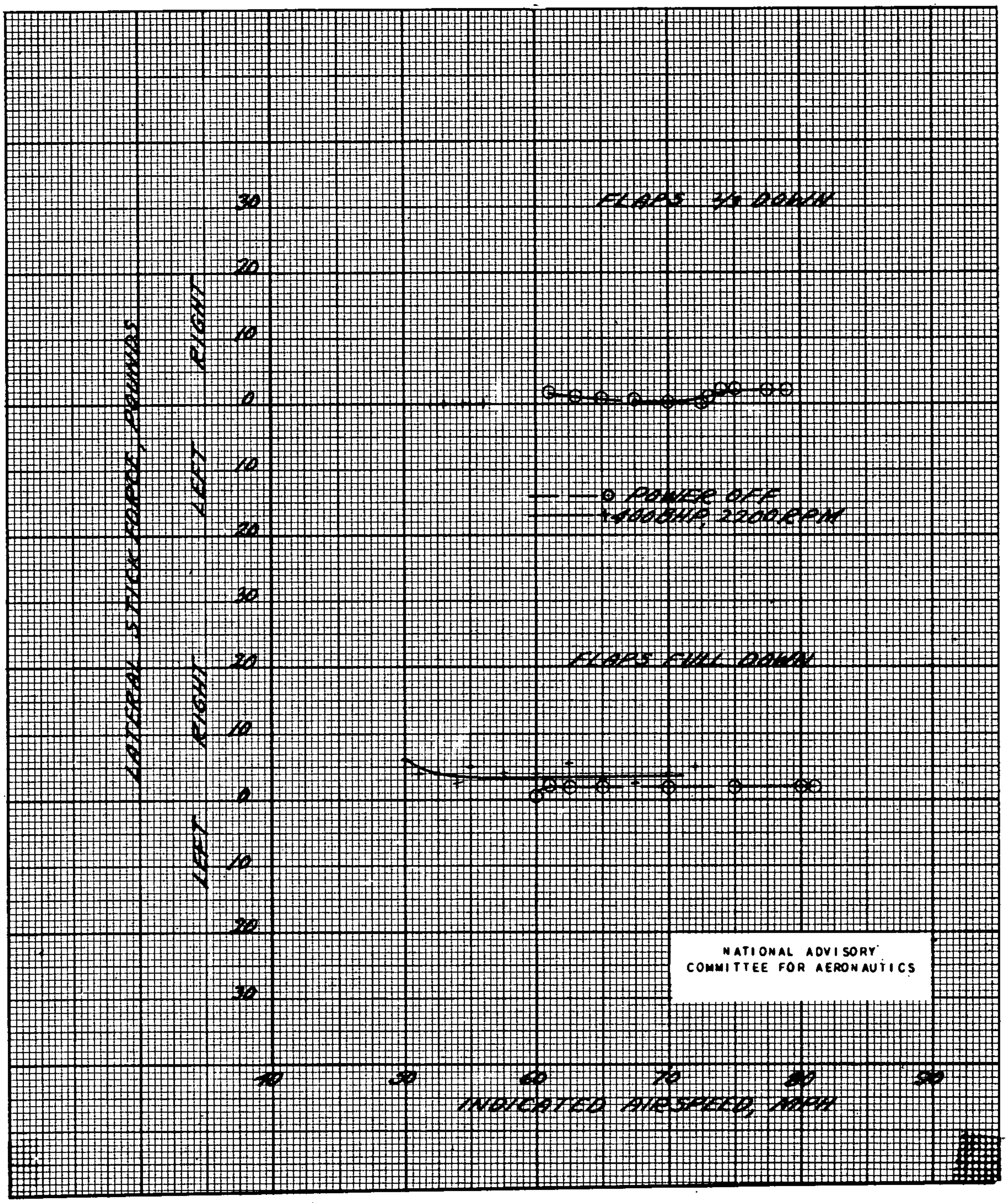

Figure 18.- Lateral-control force required to hold the wings level in straight flight at various airspeeds.

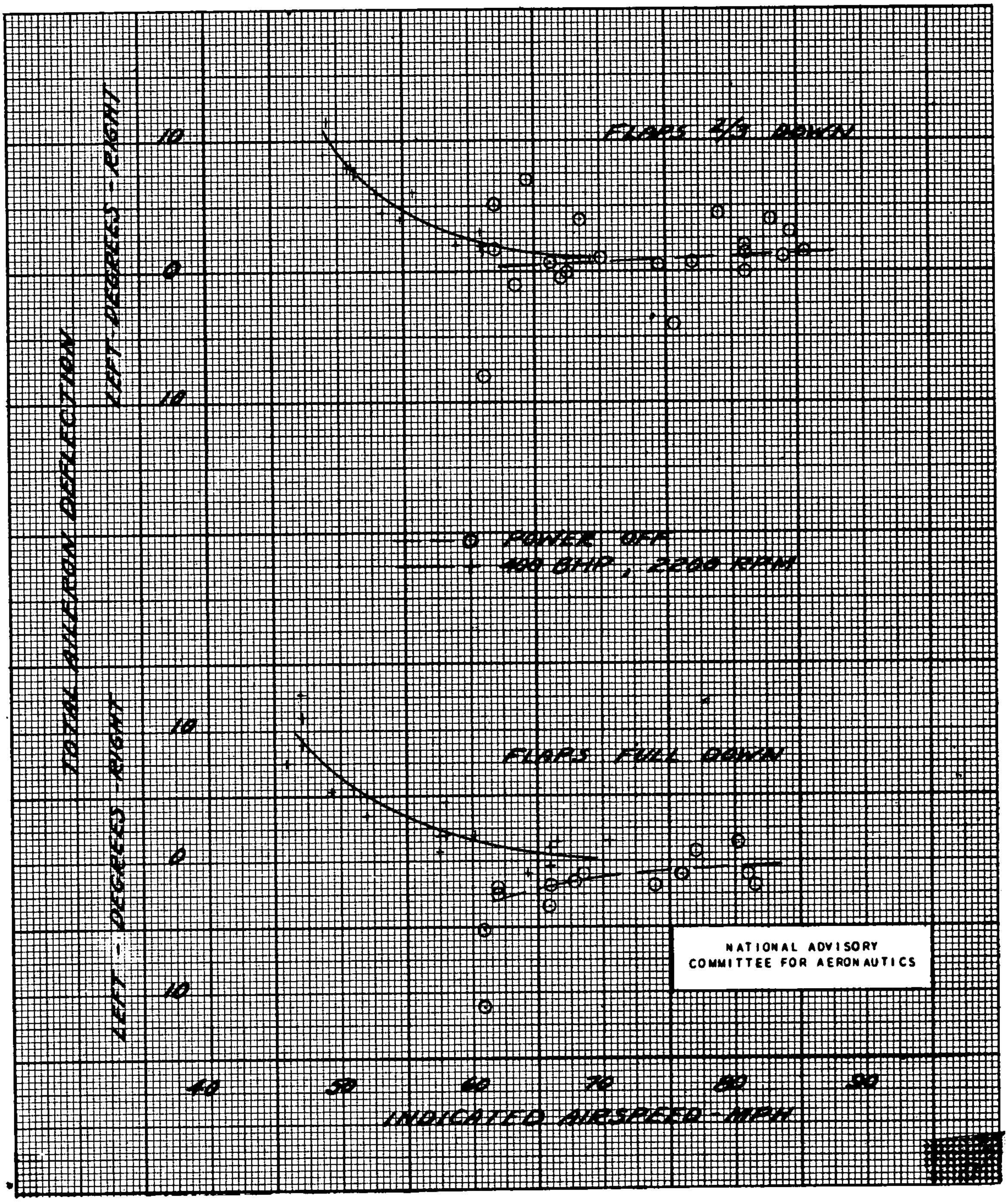

Figure 19.- Lateral-control deflection required to hold the wings level in straight flight at various airspeeds. 15° aileron droop.

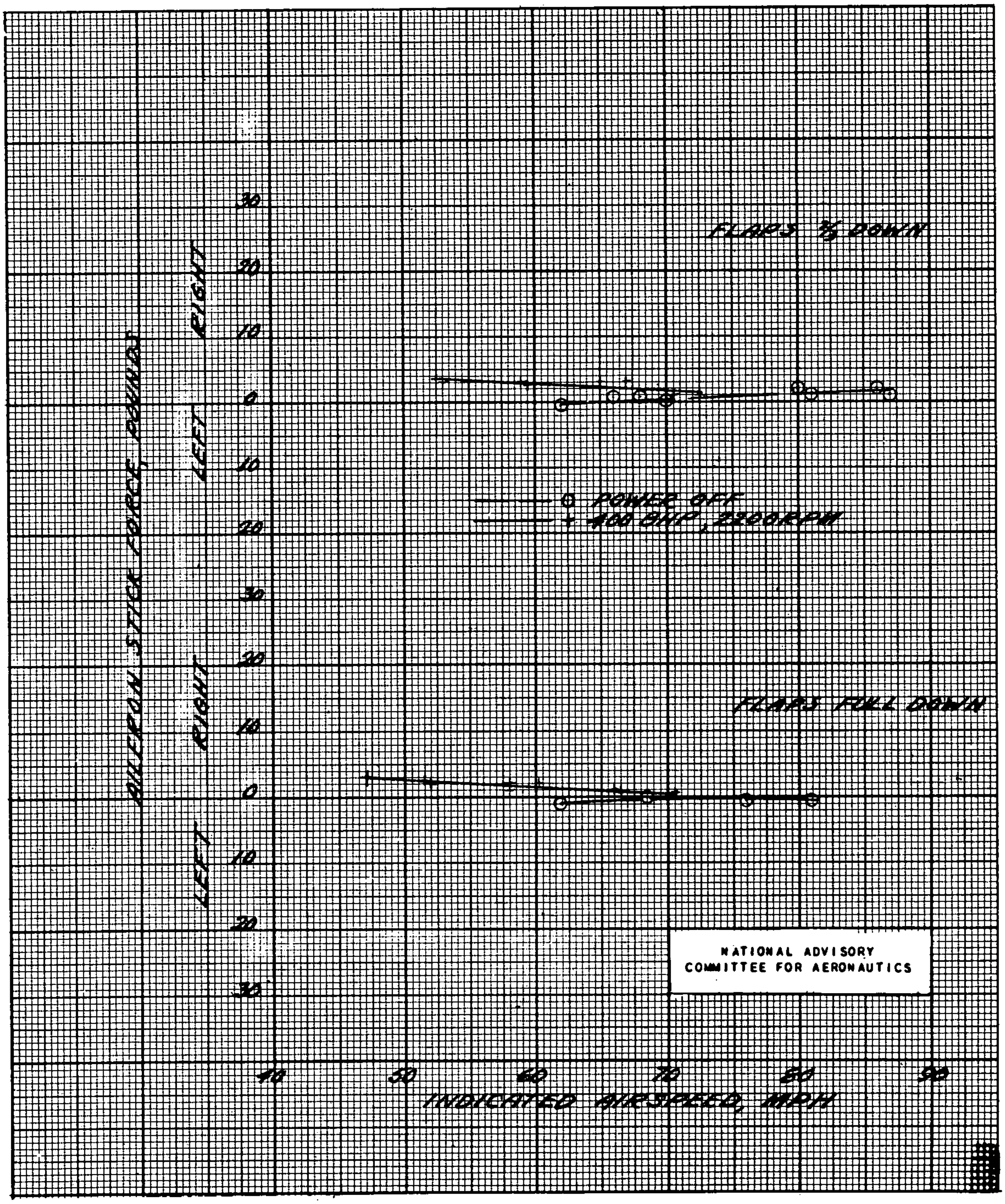

Figure 20.- Lateral-control force required to hold the wings level in straight flight at various airspeeds. 15° aileron droop.

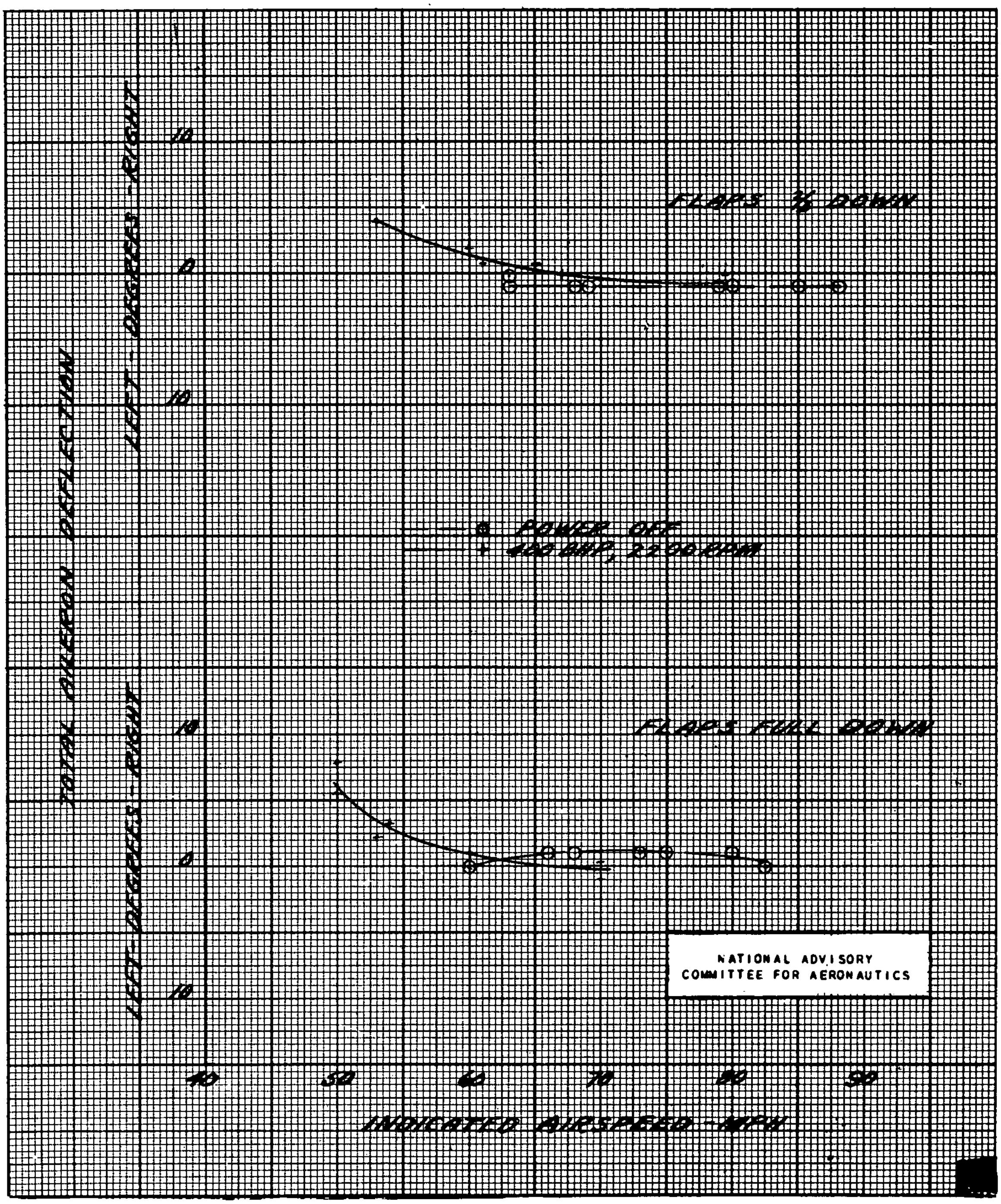

Figure 21.- Lateral-control deflection required to hold the wings level in straight flight at various airspeeds. 10° aileron droop.

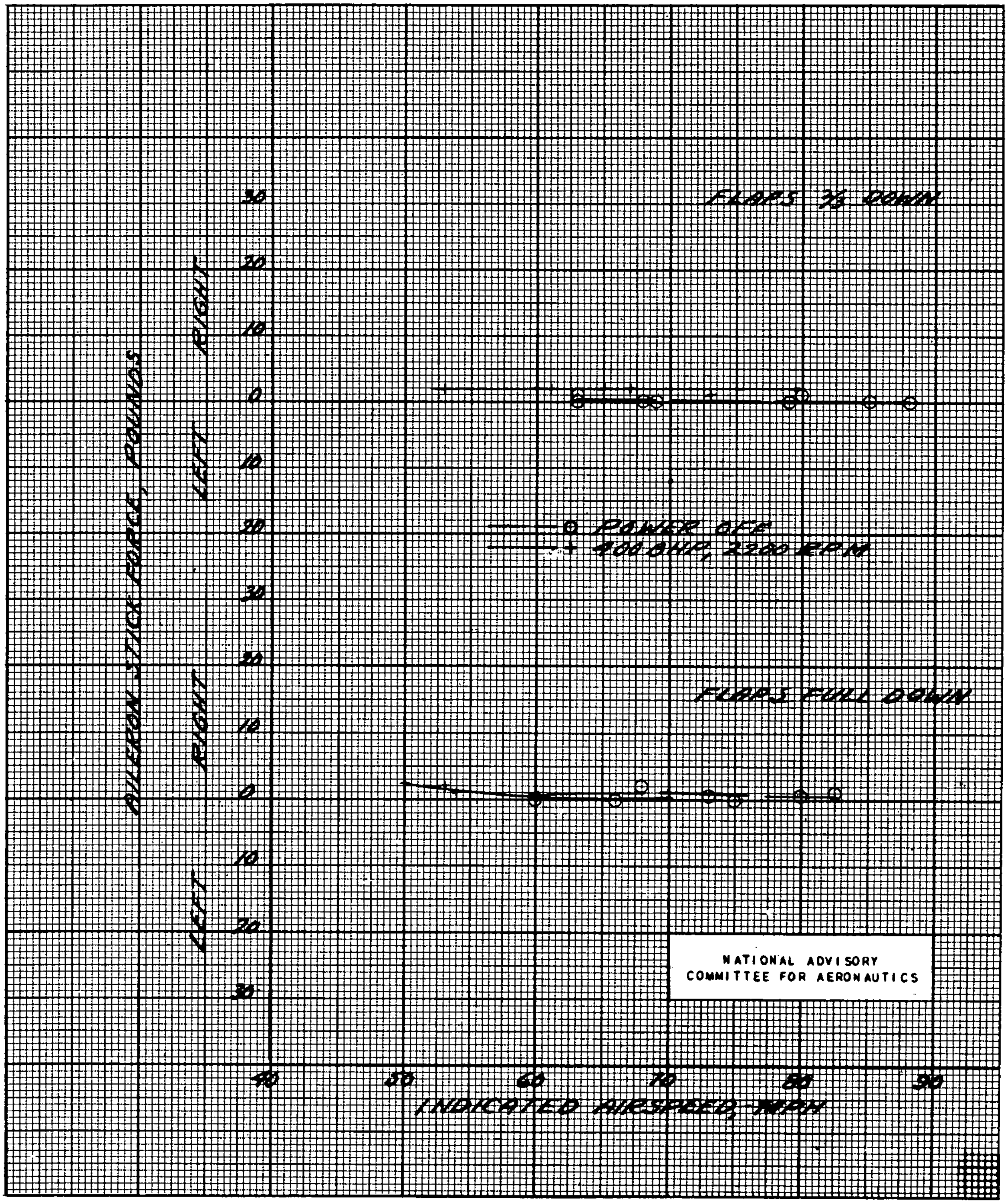

Figure 22.- Lateral-control force required to hold the wings level in straight flight at various airspeeds. 10° aileron droop.

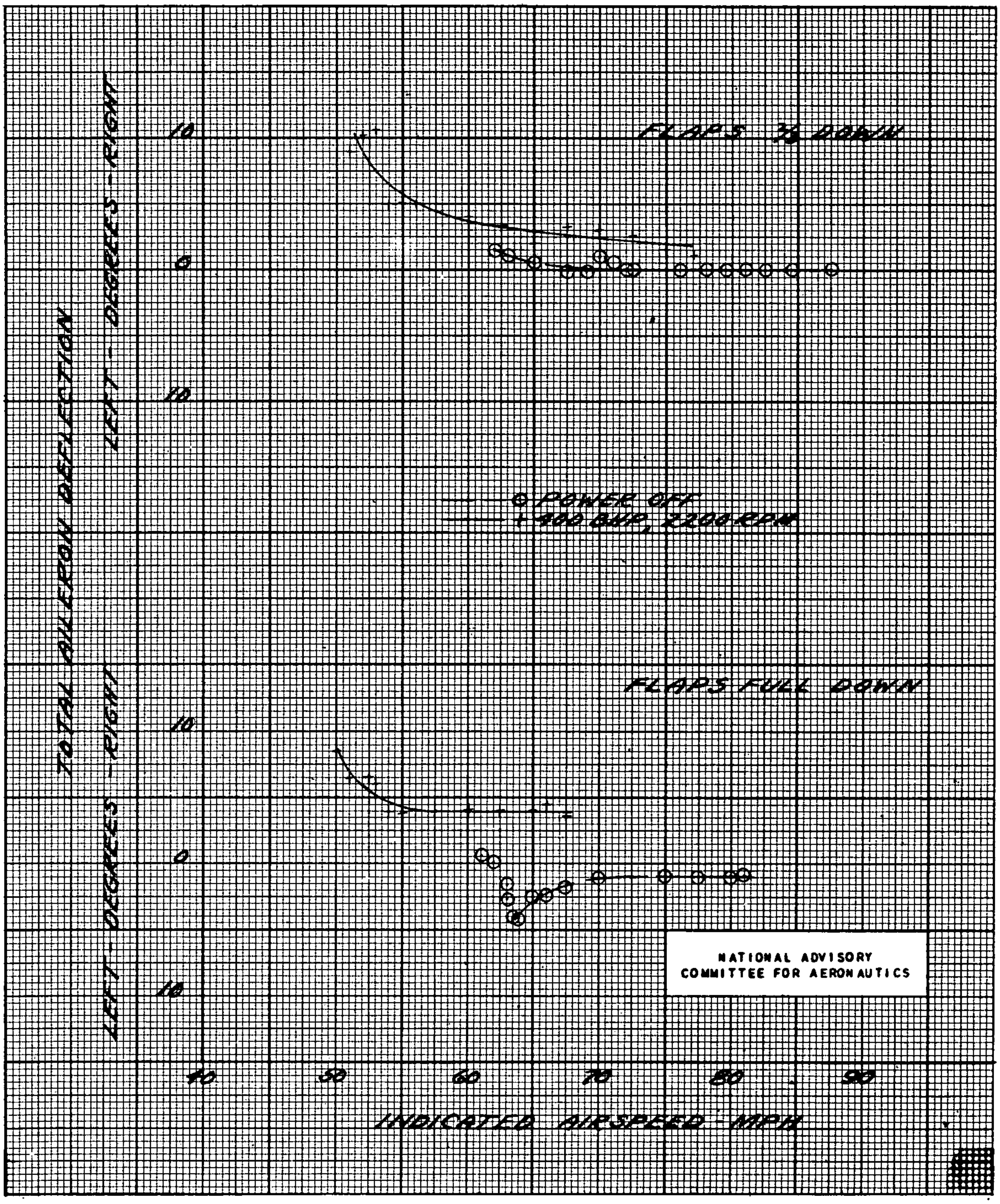

Figure 23.- Lateral-control deflection required to hold the wings level in straight flight at various airspeeds. 0° aileron droop.

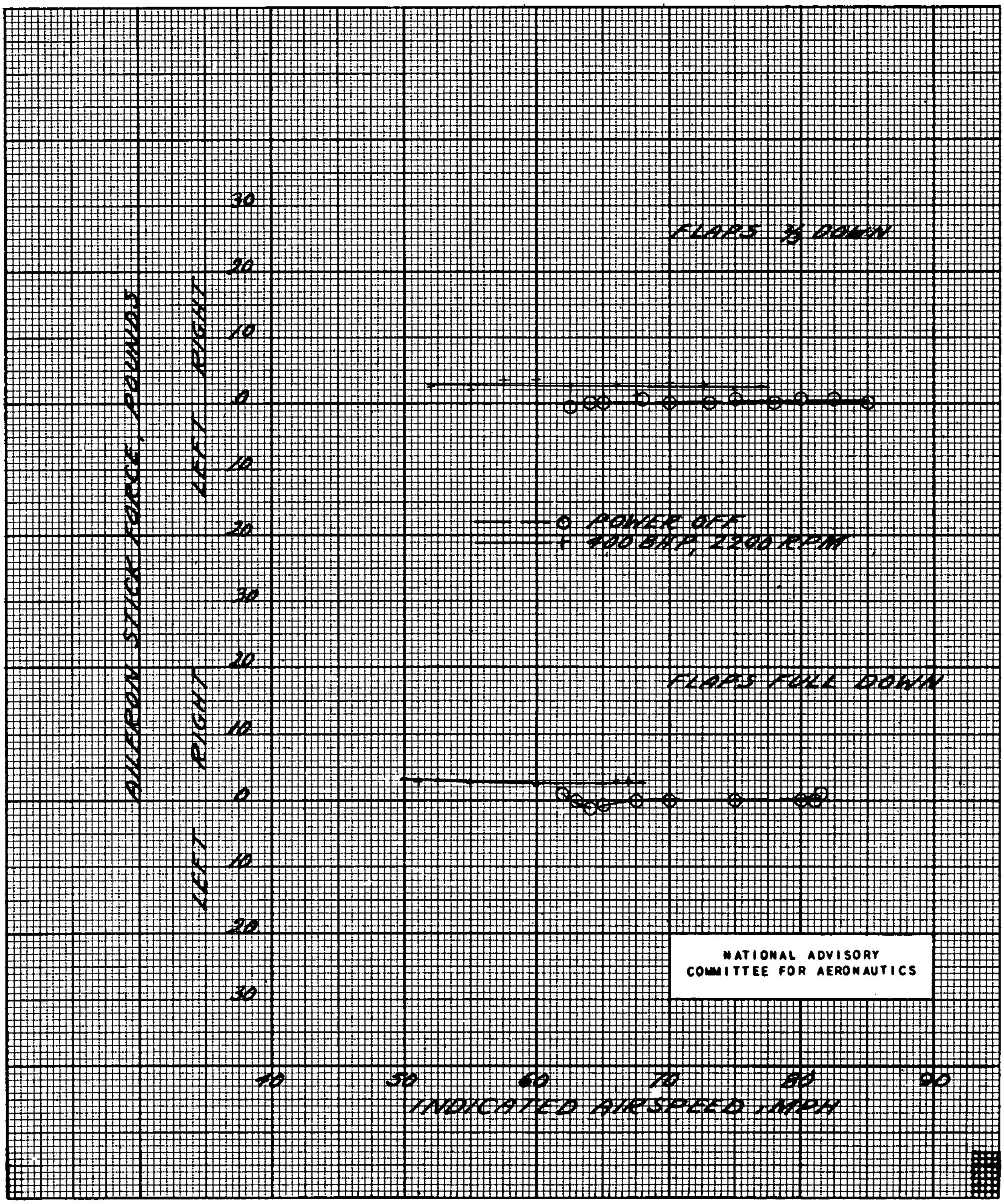

Figure 24.- Lateral-control force required to hold the wings level in straight flight at various airspeeds. 0° aileron droop.

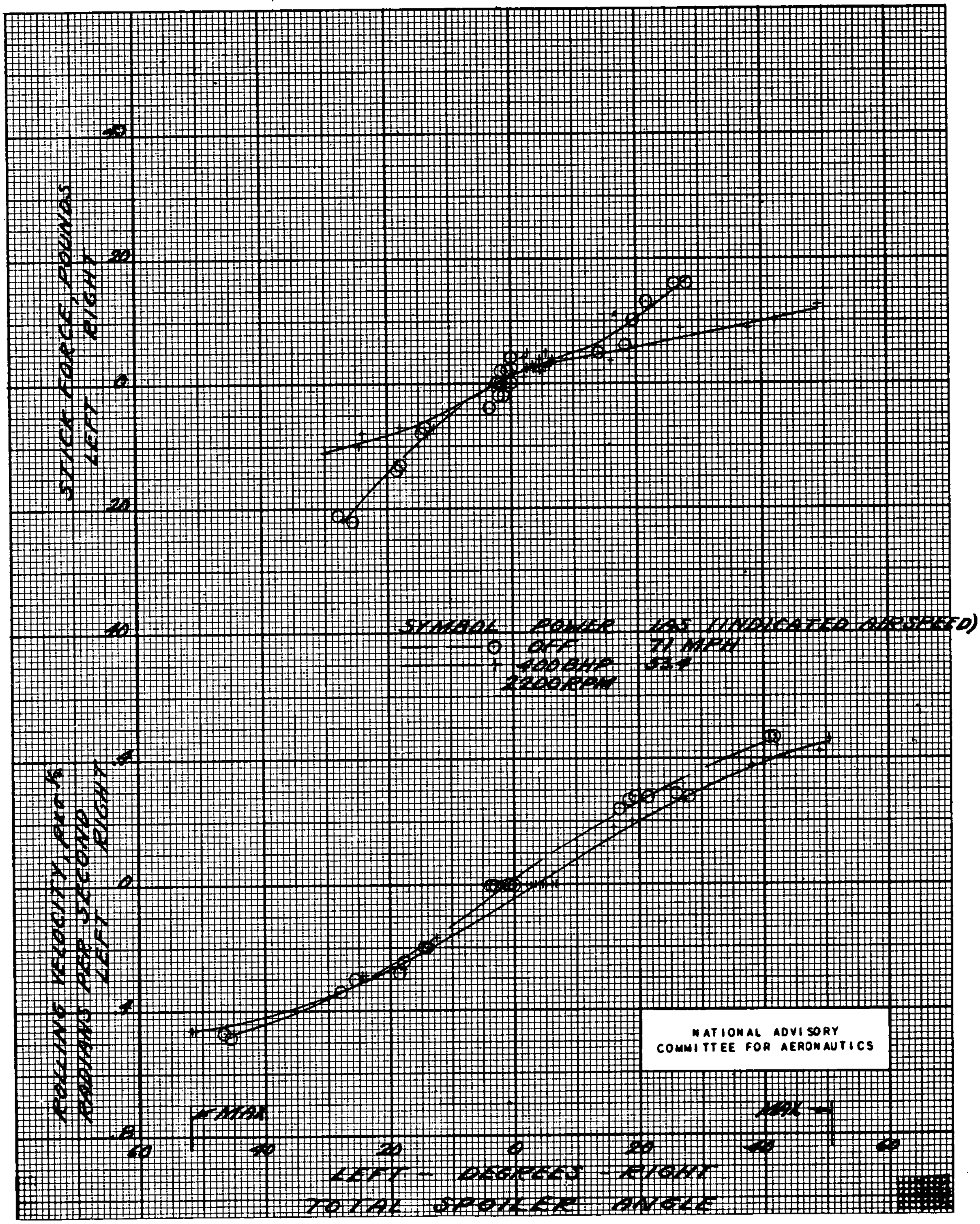

Figure 25.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. Flaps full down.

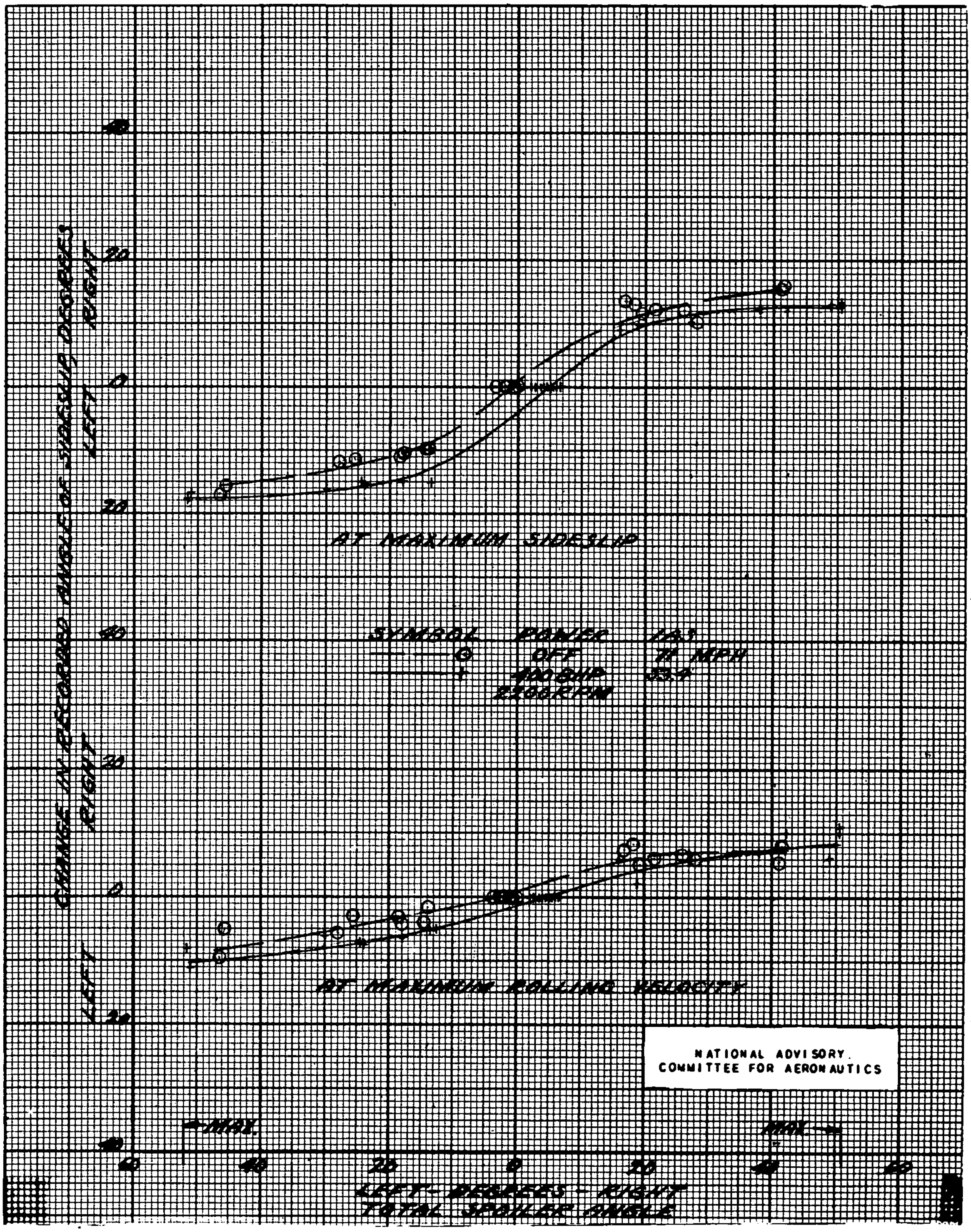

Figure 26.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. Flaps full down.

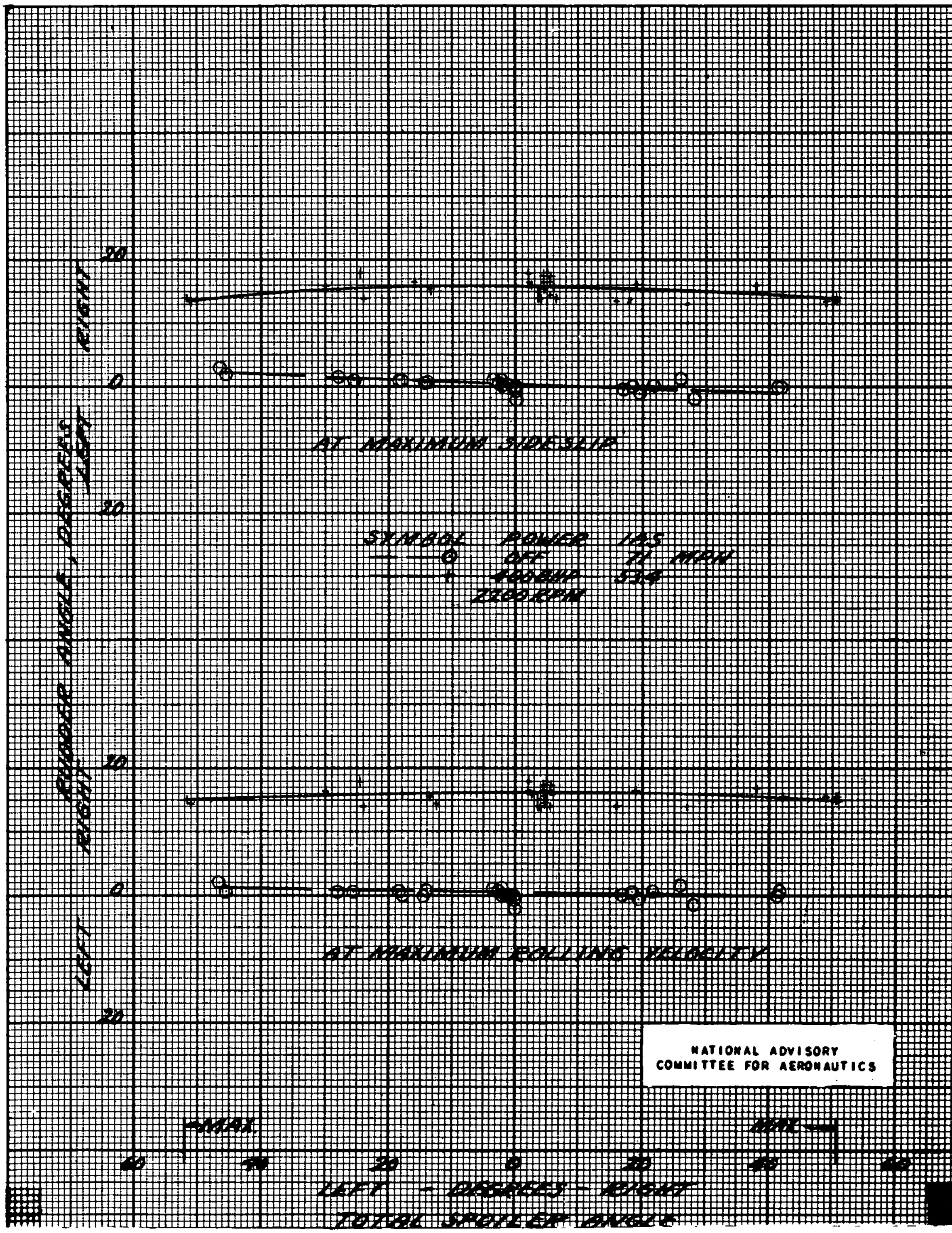

Figure 27.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. Flaps full down.

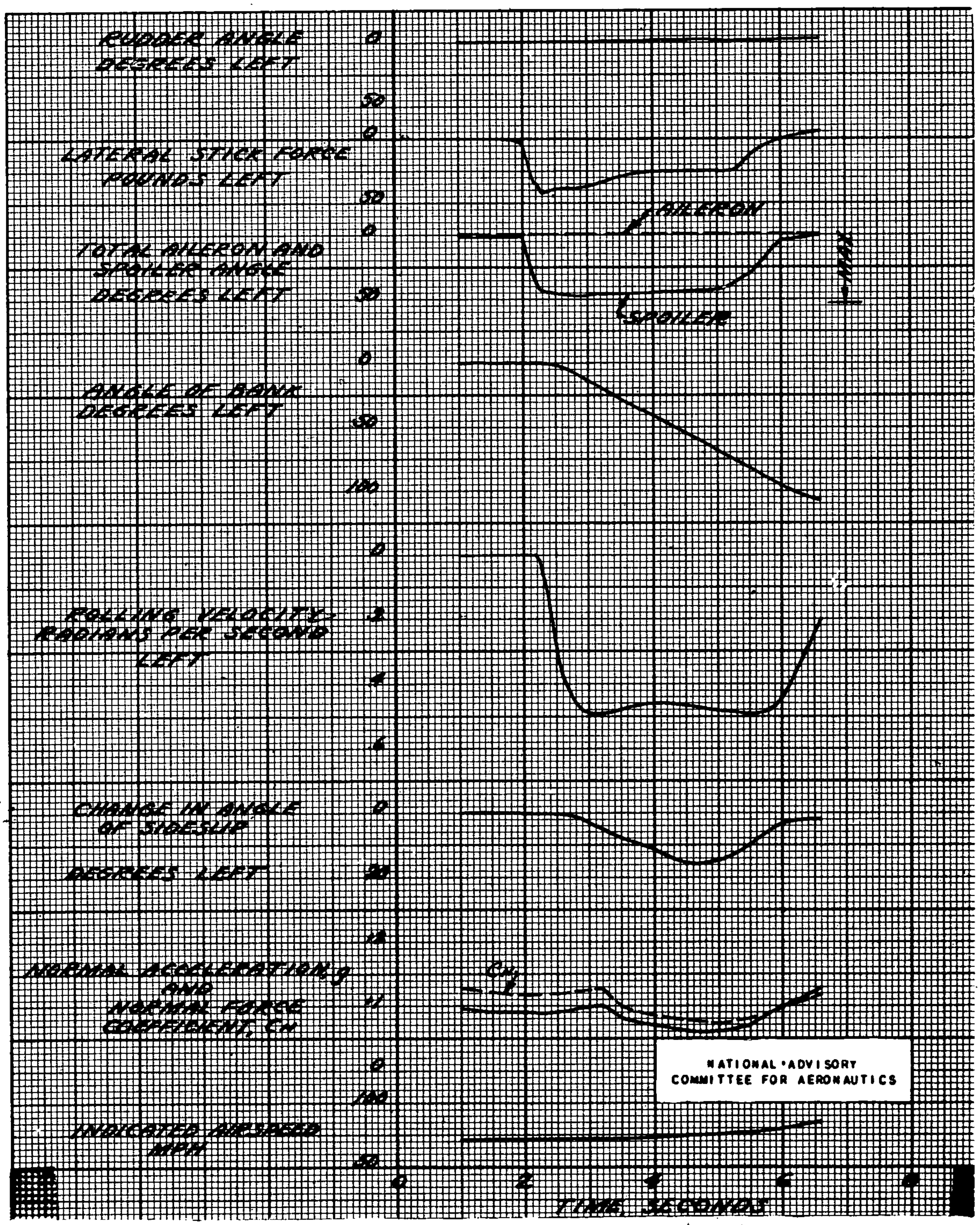

Figure 28.- Time history of a power off left aileron roll made with the rudder fixed in trim position. Flaps full down.

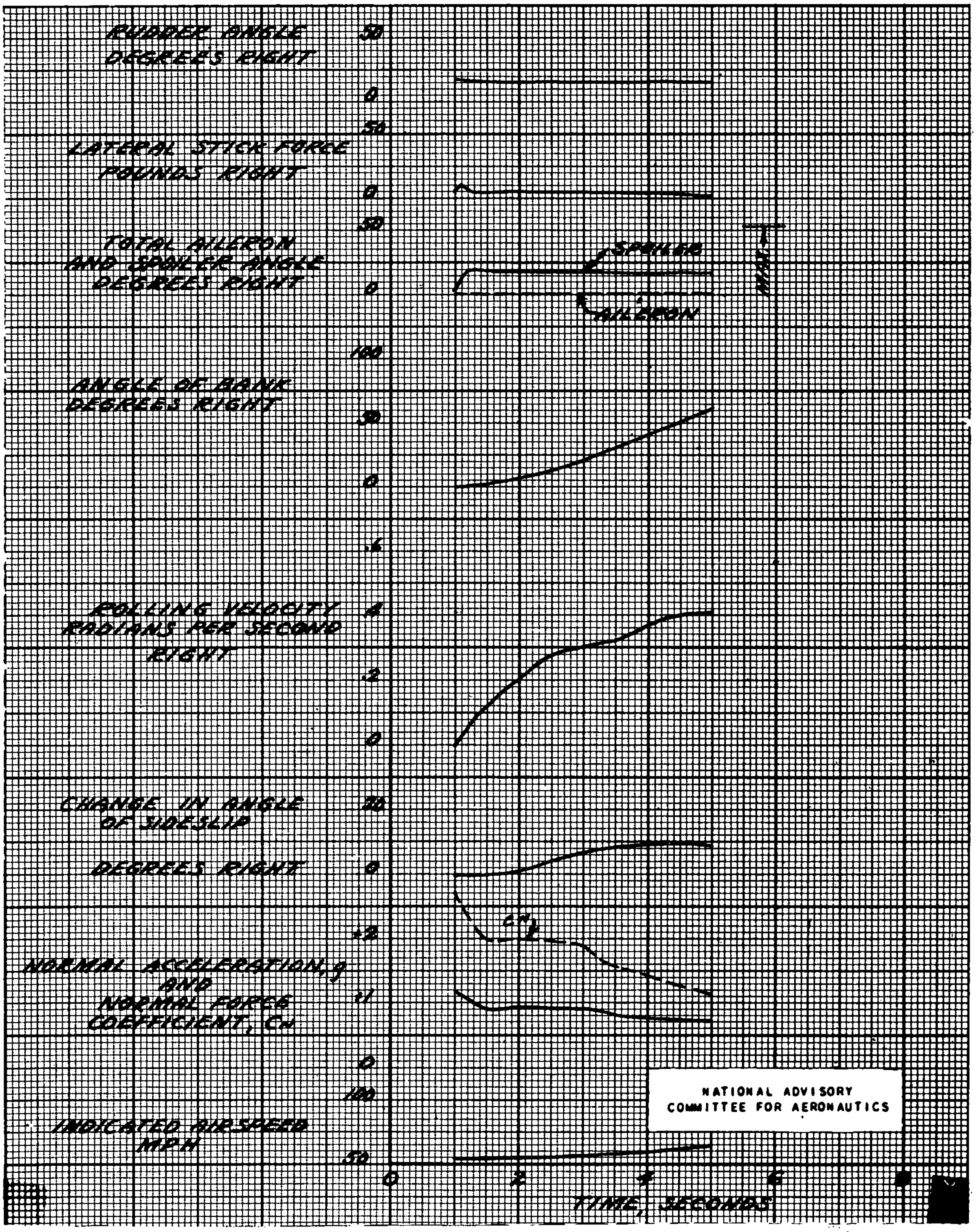

Figure 29.- Time history of a power off right aileron roll made with the rudder fixed in trim position. Flaps full down.

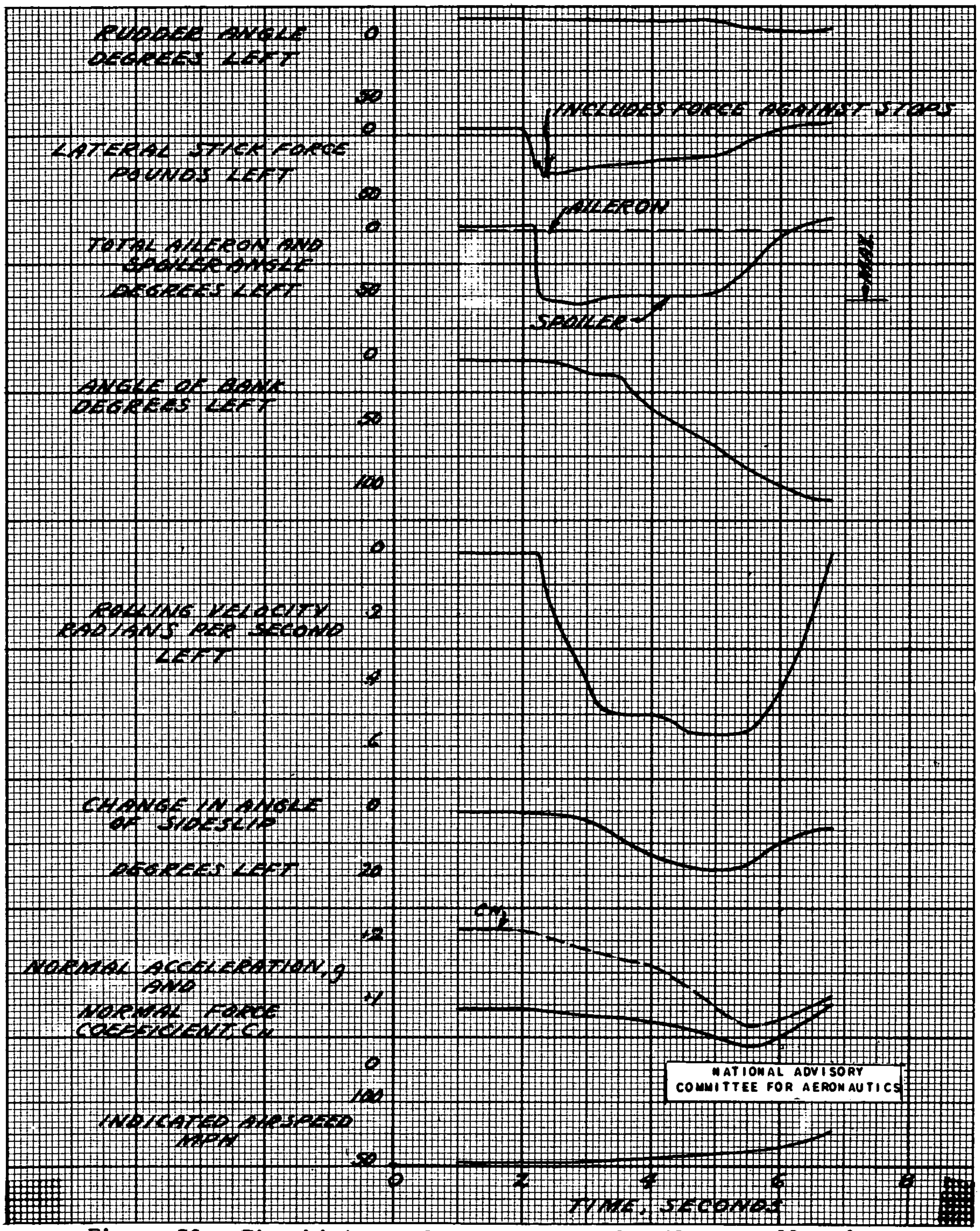

Figure 30.- Time history of a power on left aileron roll made with the rudder fixed in trim position. Flaps full down.

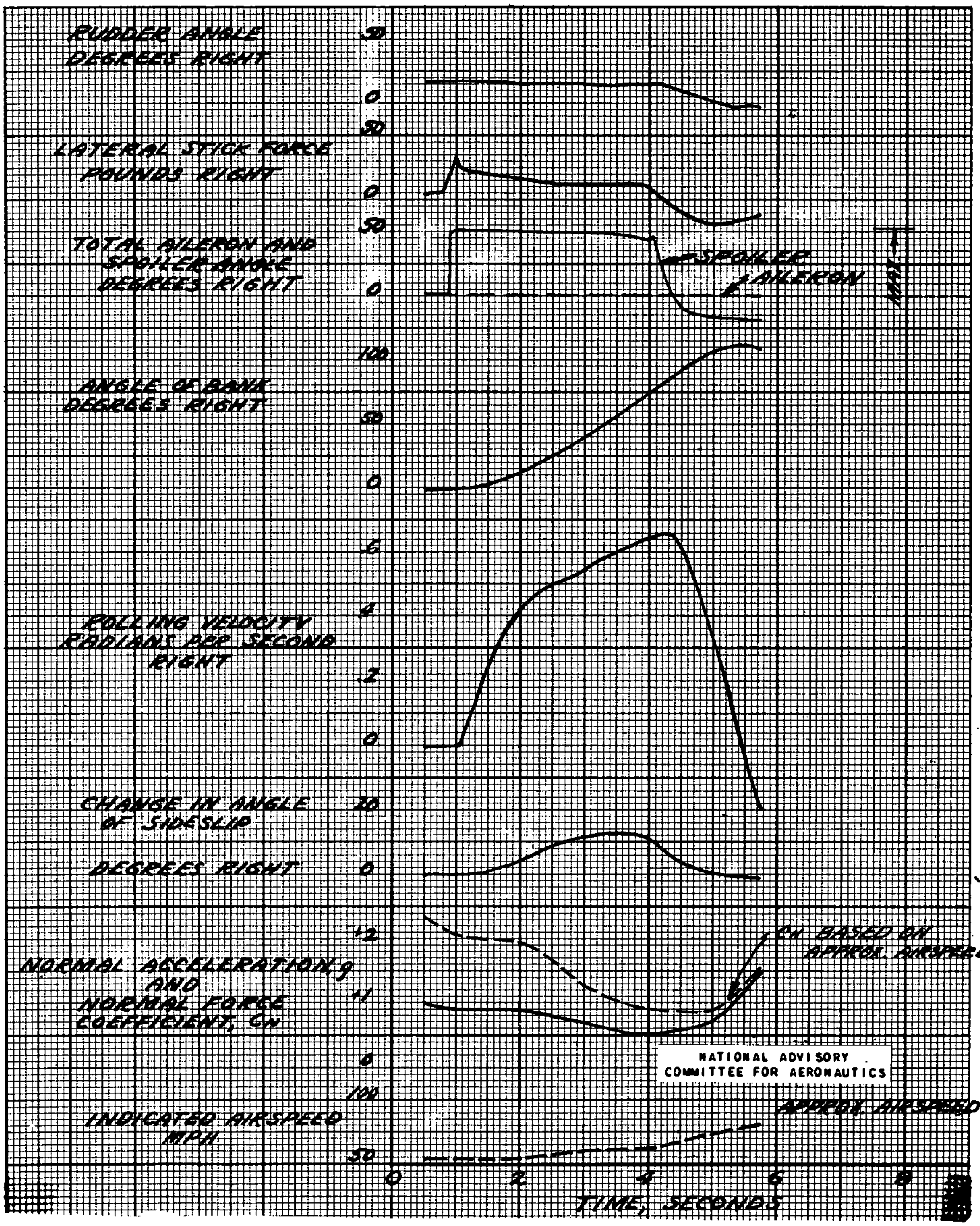

Figure 31.- Time history of a power on right aileron roll made with the rudder fixed in trim position. Flaps full down.

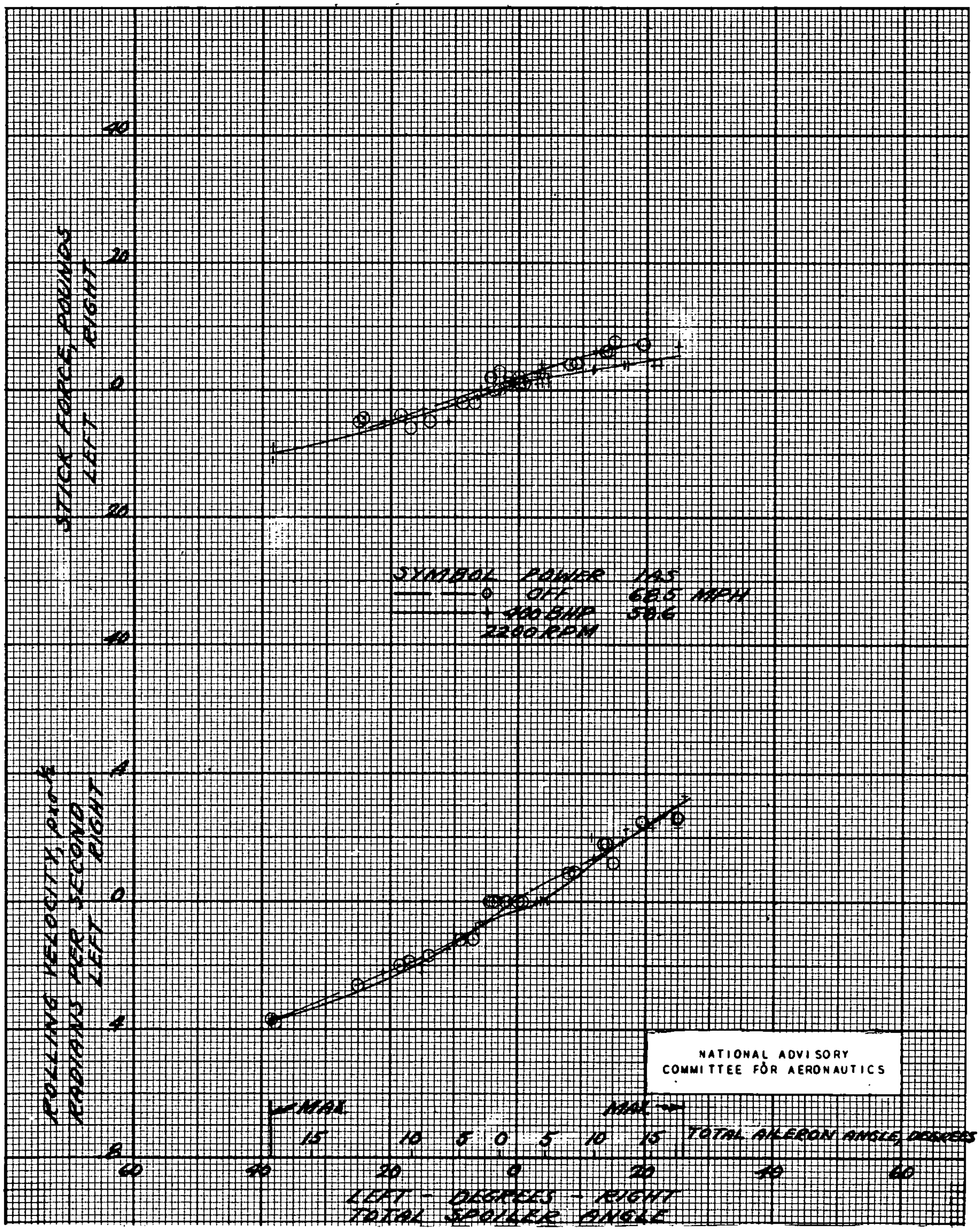

Figure 32.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. Flaps two-thirds down.

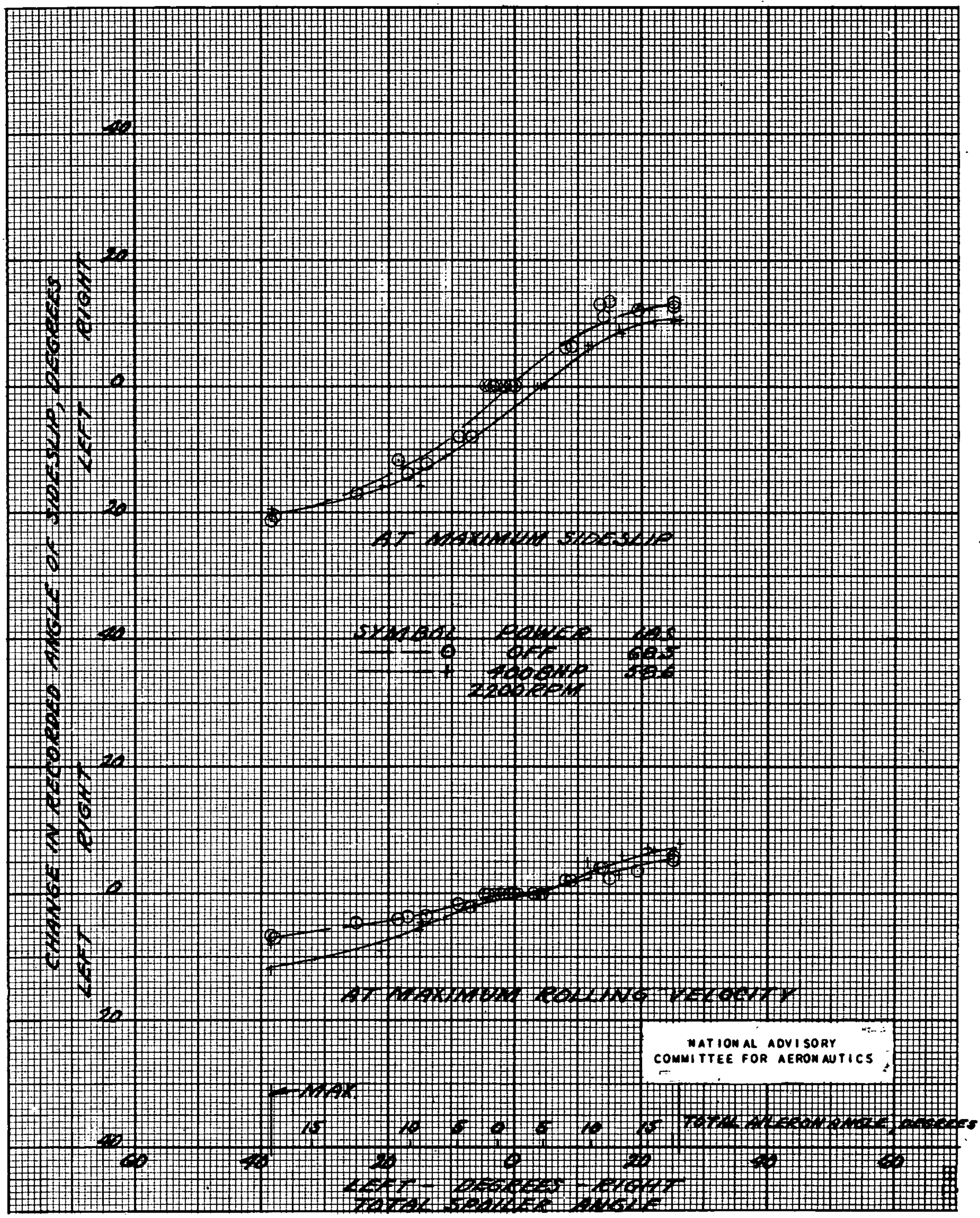

Figure 33.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. Flaps two-thirds down.

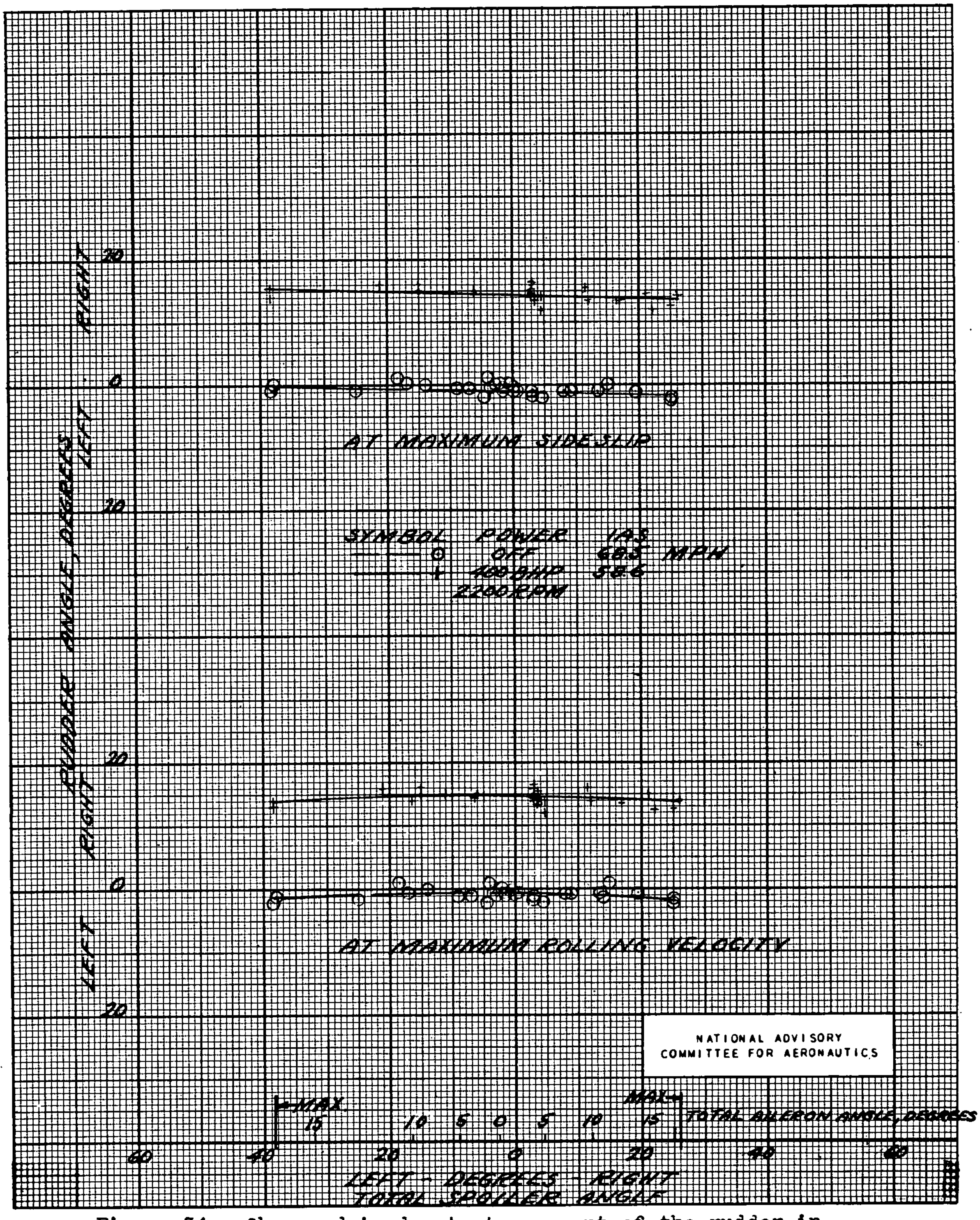

Figure 34.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. Flaps two-thirds down.

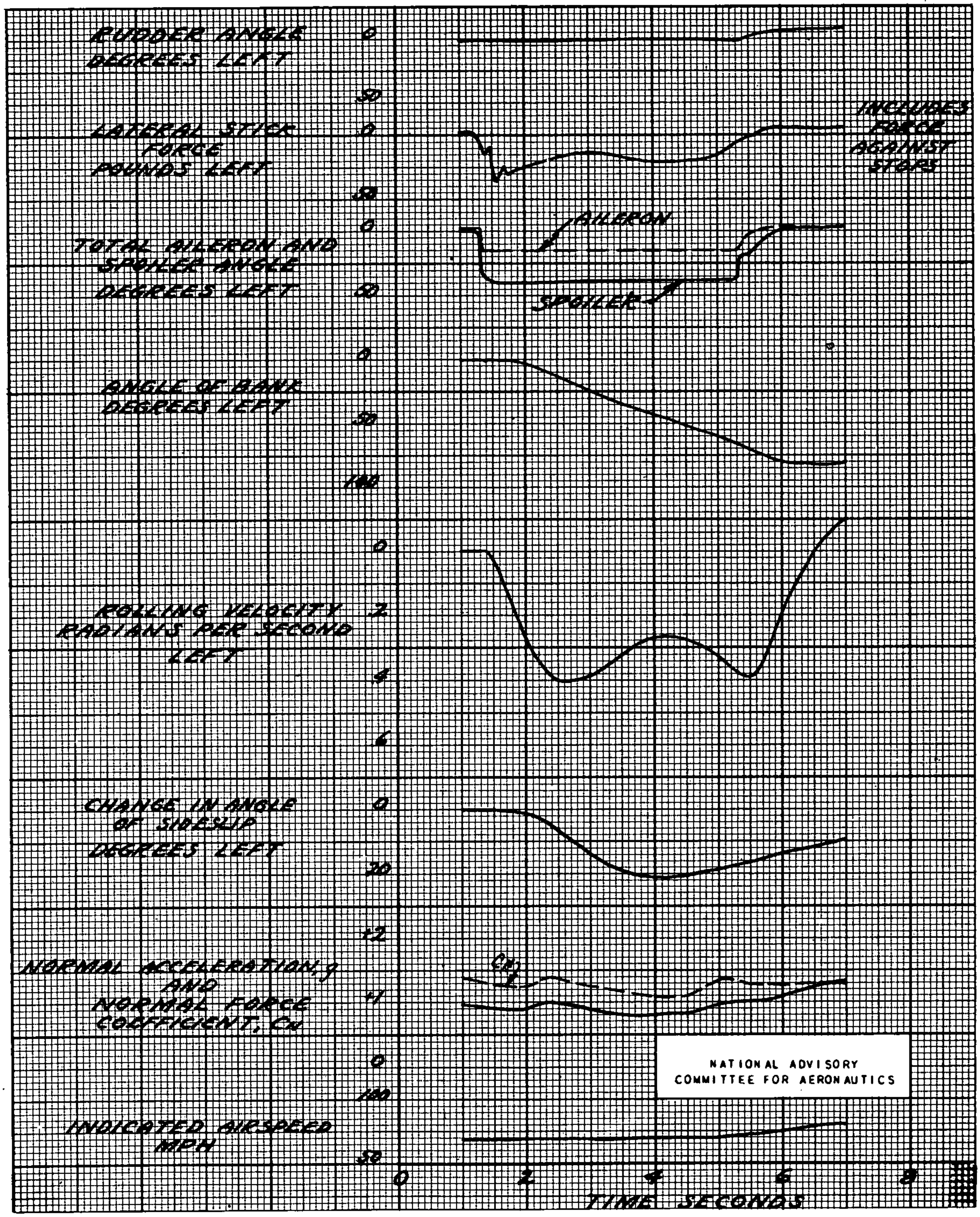

Figure 35.- Time history of a power off maximum deflection left aileron roll made with the rudder fixed in trim position. Flaps two-thirds down.

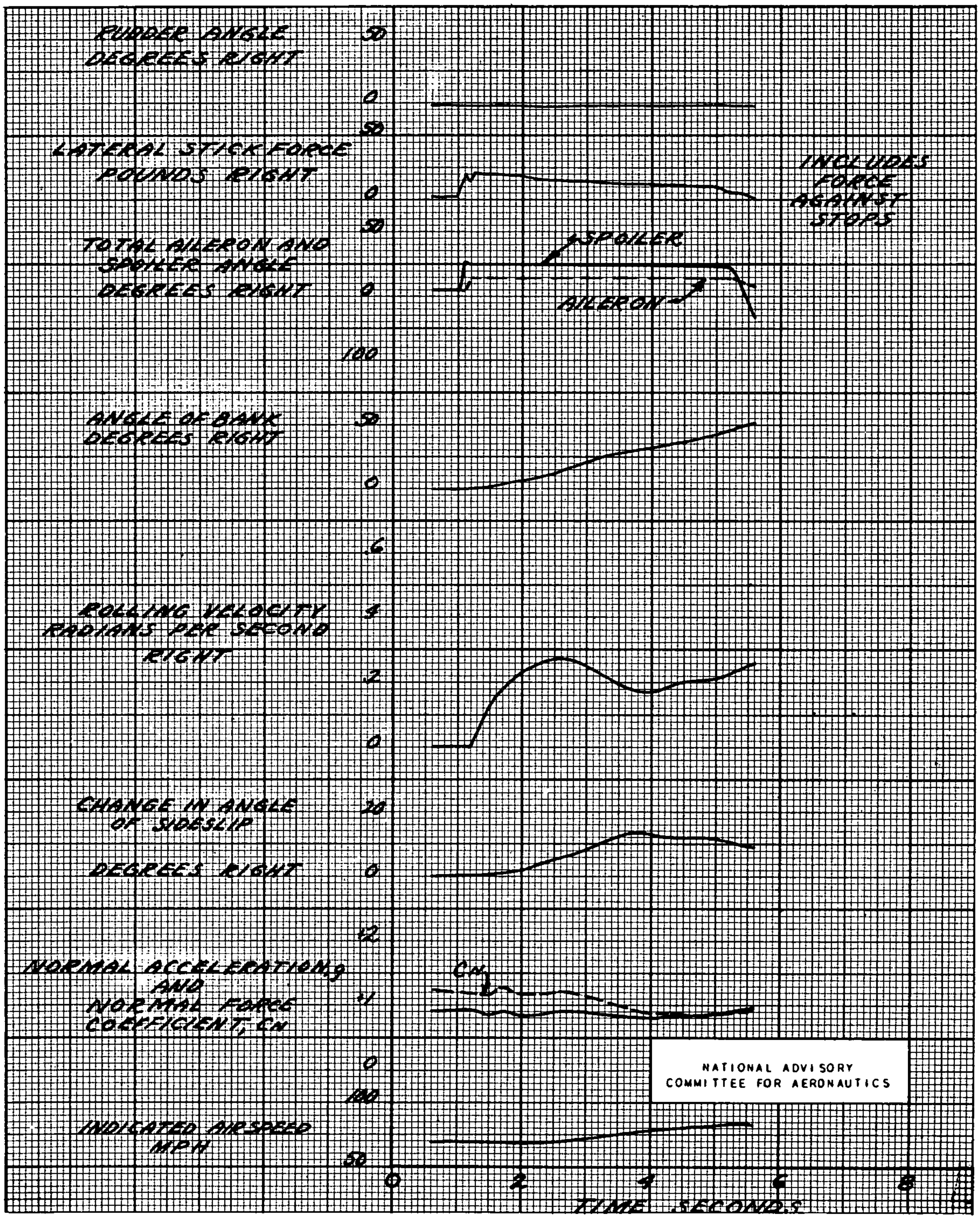

Figure 36.- Time history of a power off maximum deflection aileron roll made with the rudder fixed in trim position. Flaps two-thirds down.

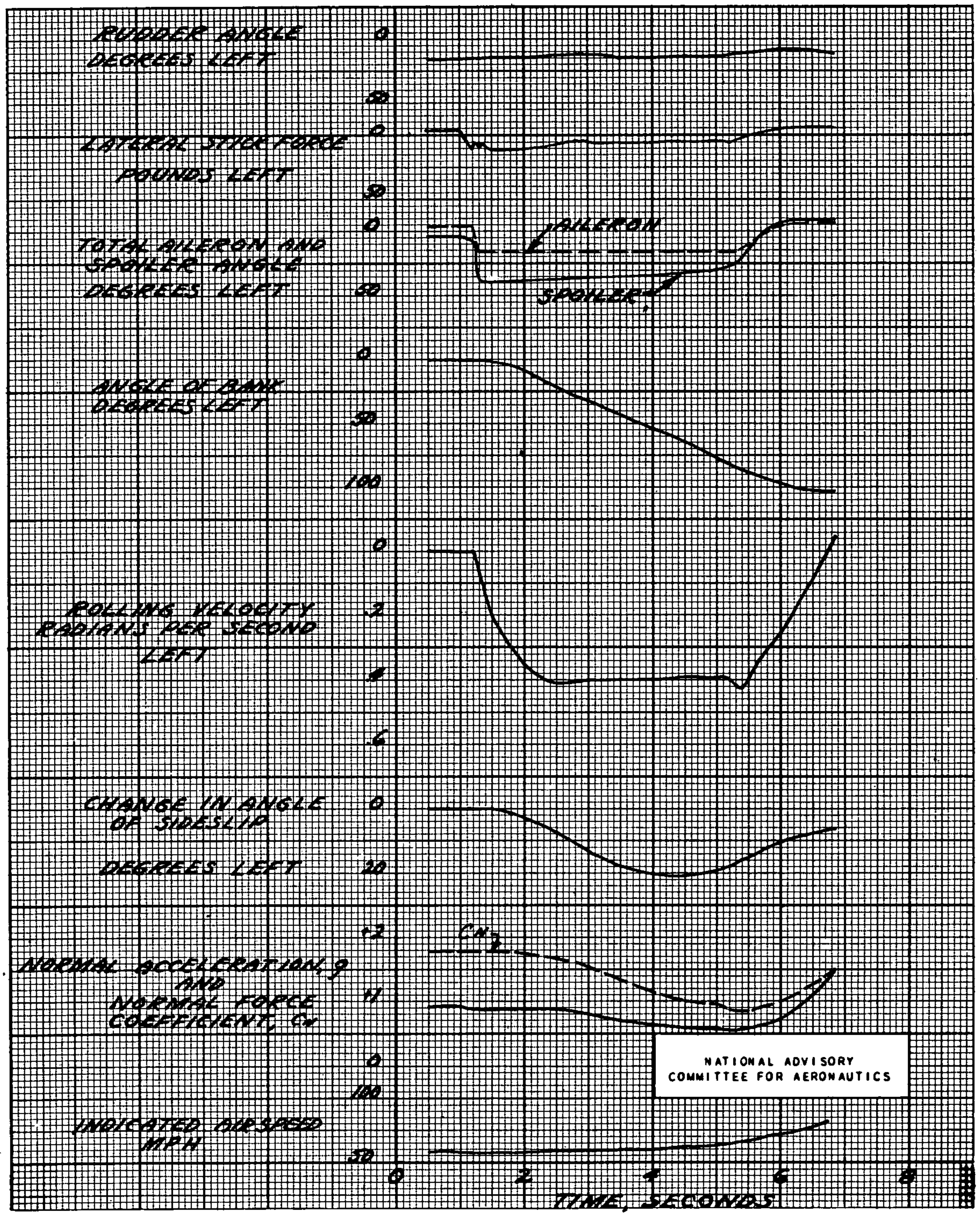

Figure 37.- Time history of a power on left aileron roll made with the rudder fixed in trim position. Flaps two-thirds down.

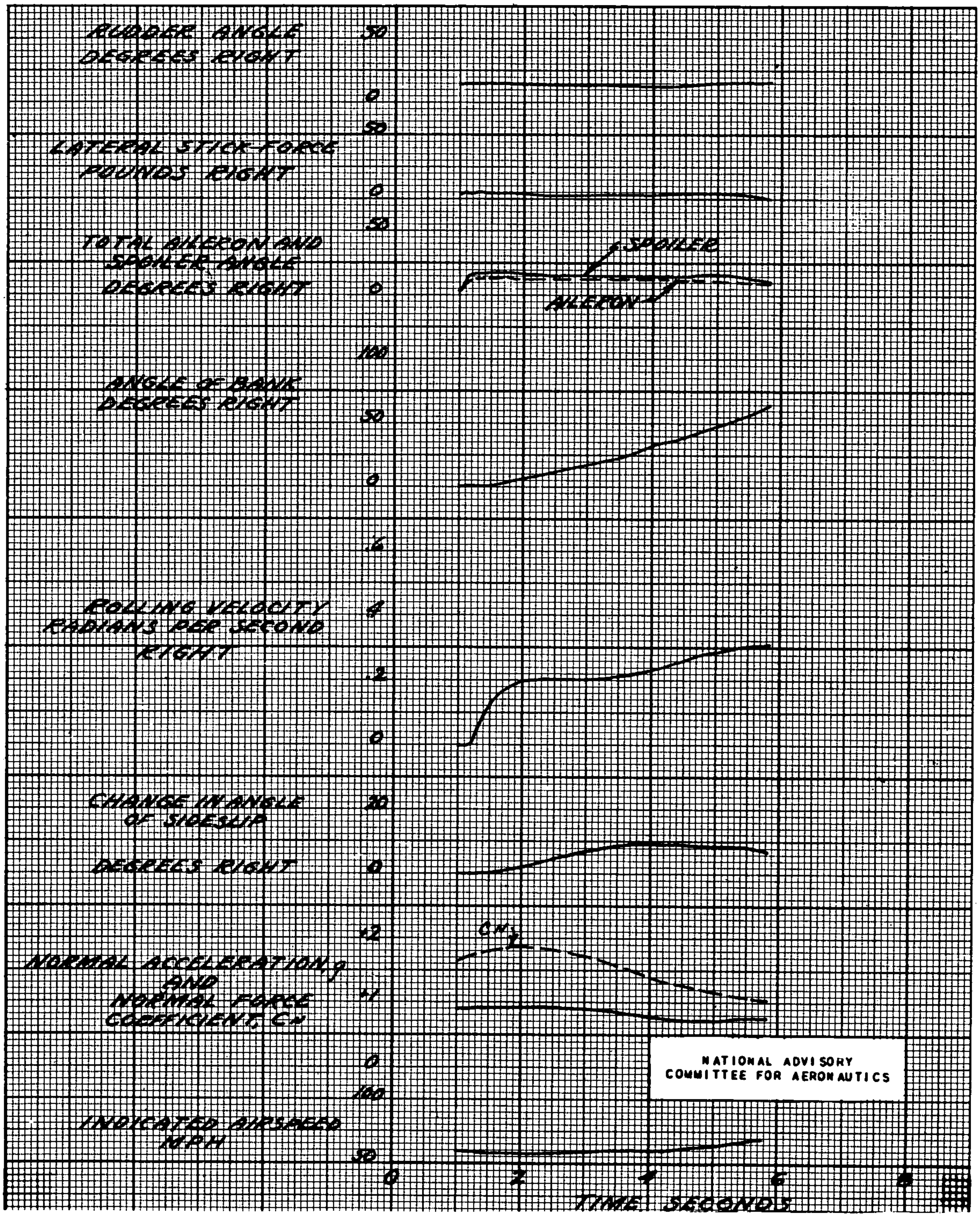

Figure 38.- Time history of a power on right aileron roll made with the rudder fixed in trim position. Flaps two-thirds down.

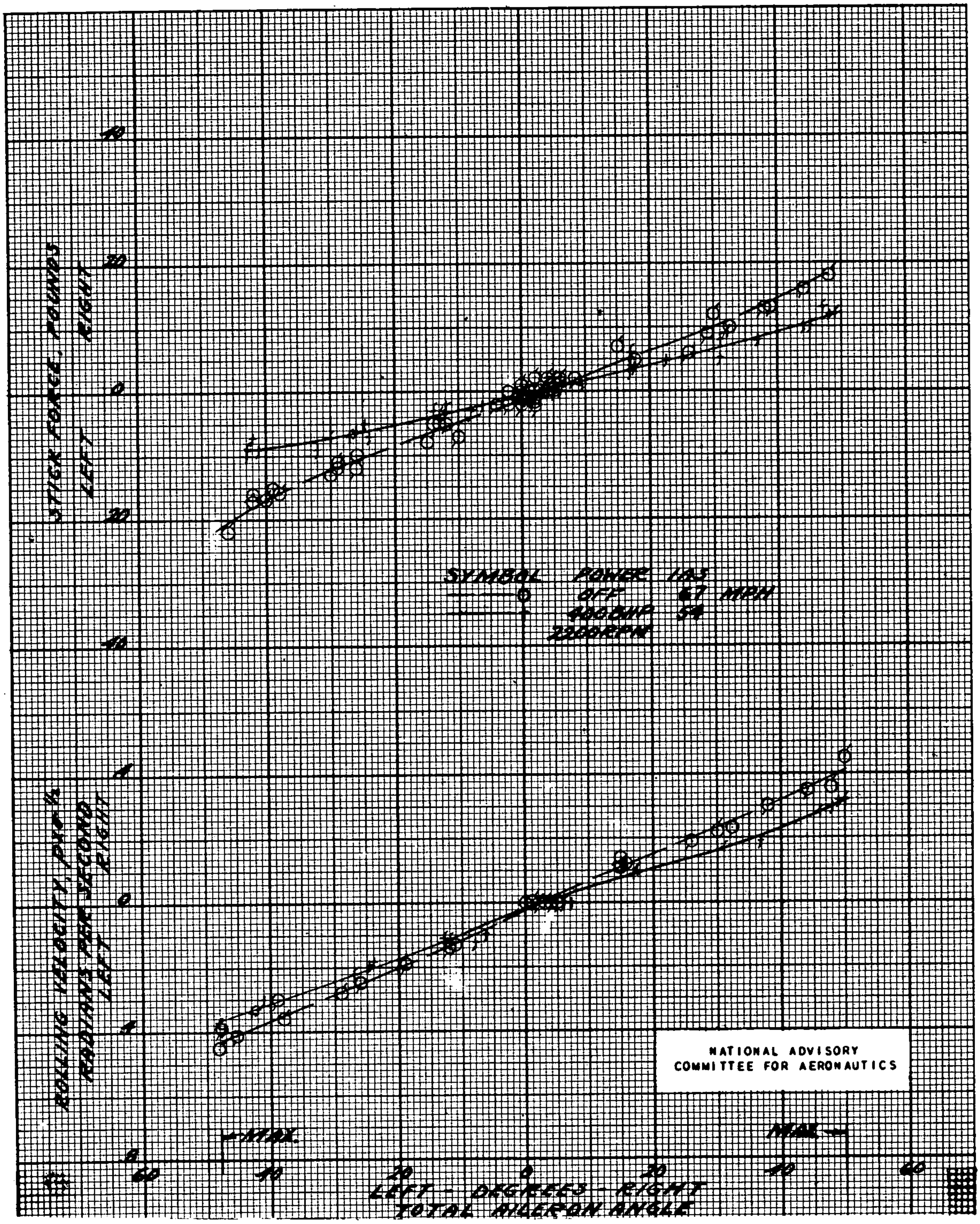

Figure 39.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 15° aileron droop and flaps full down.

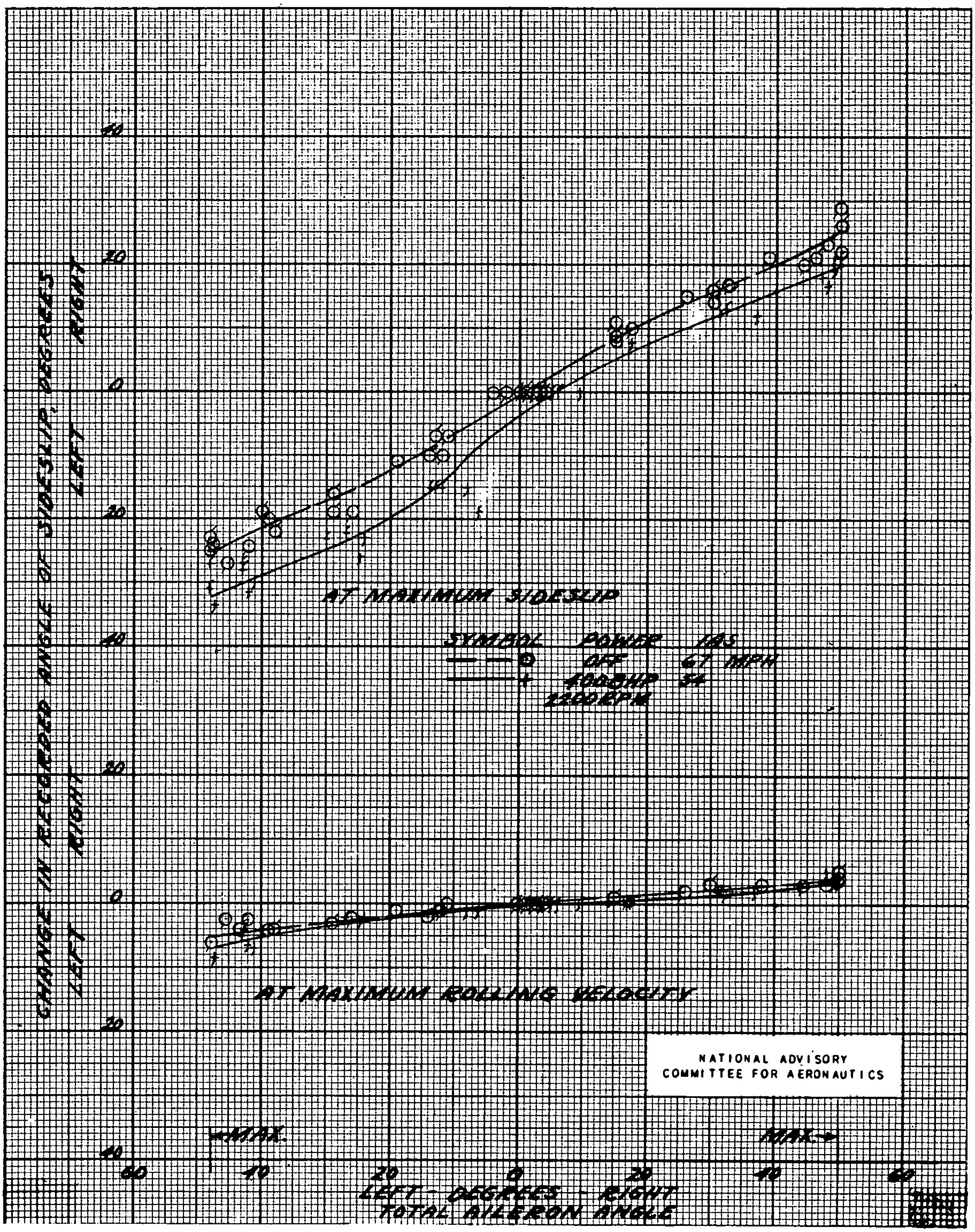

Figure 40.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 15° aileron droop and flaps full down.

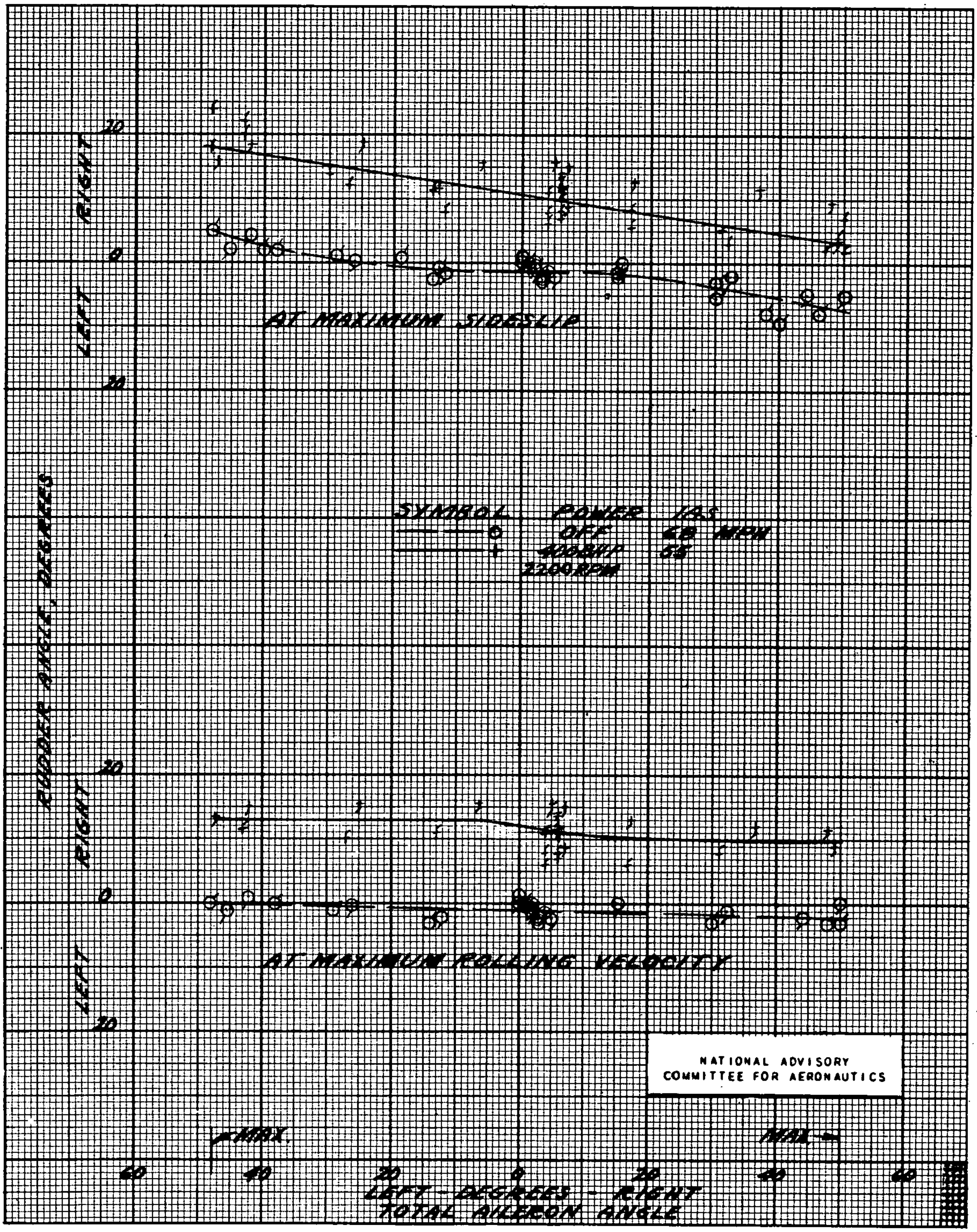

Figure 41.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 15° aileron droop and flaps full down.

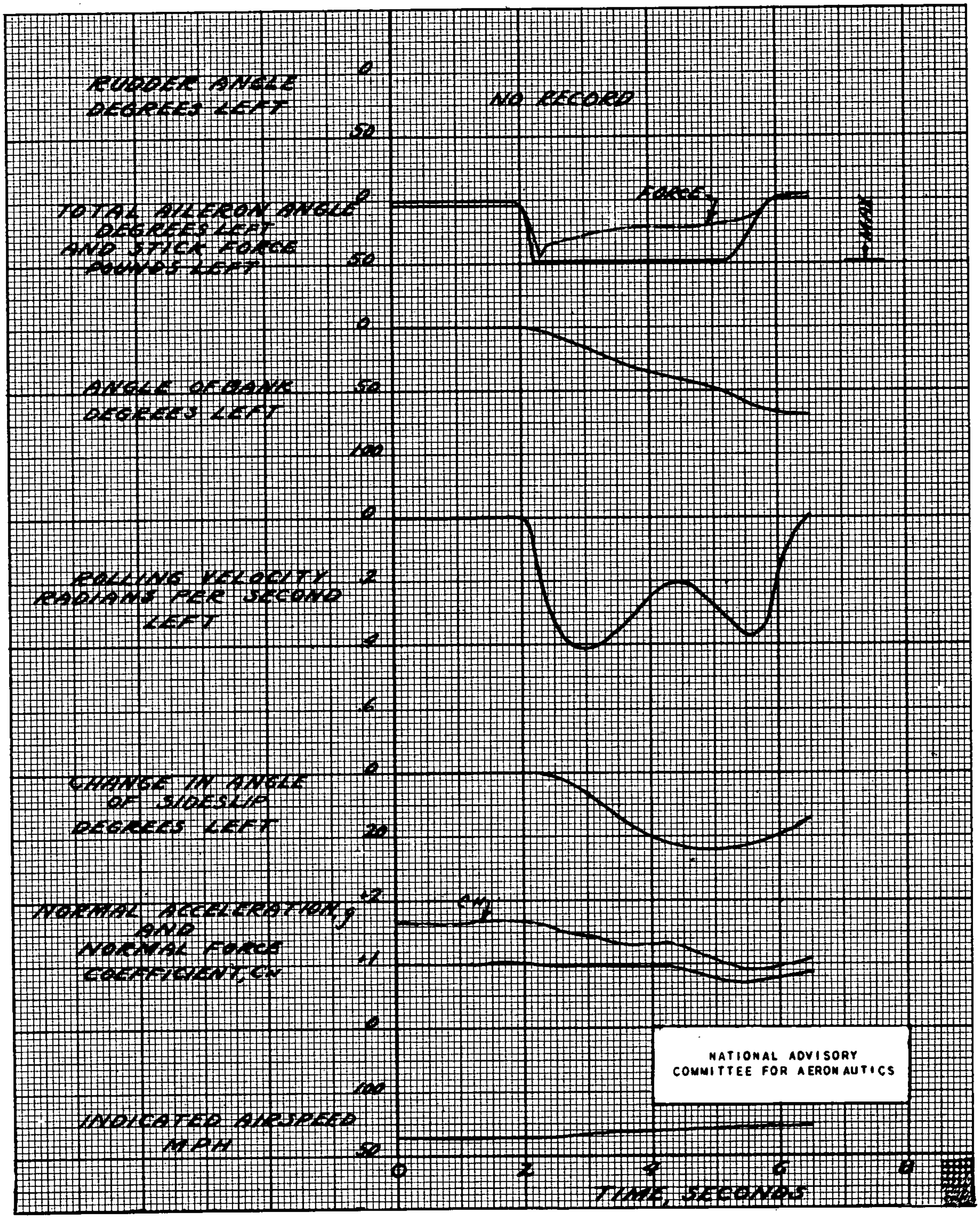

Figure 42.- Time history of a power off left aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps full down.

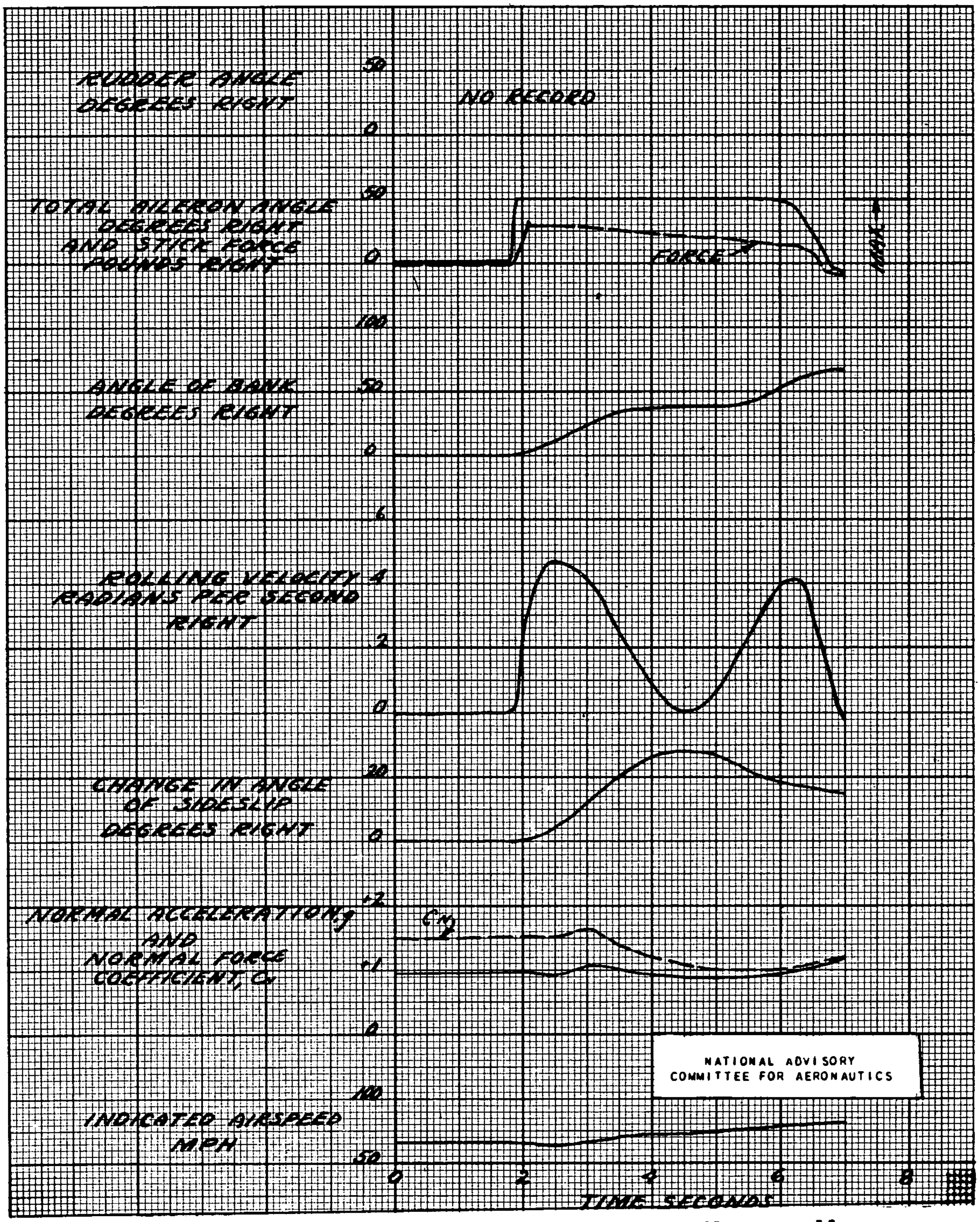

Figure 43.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps full down.

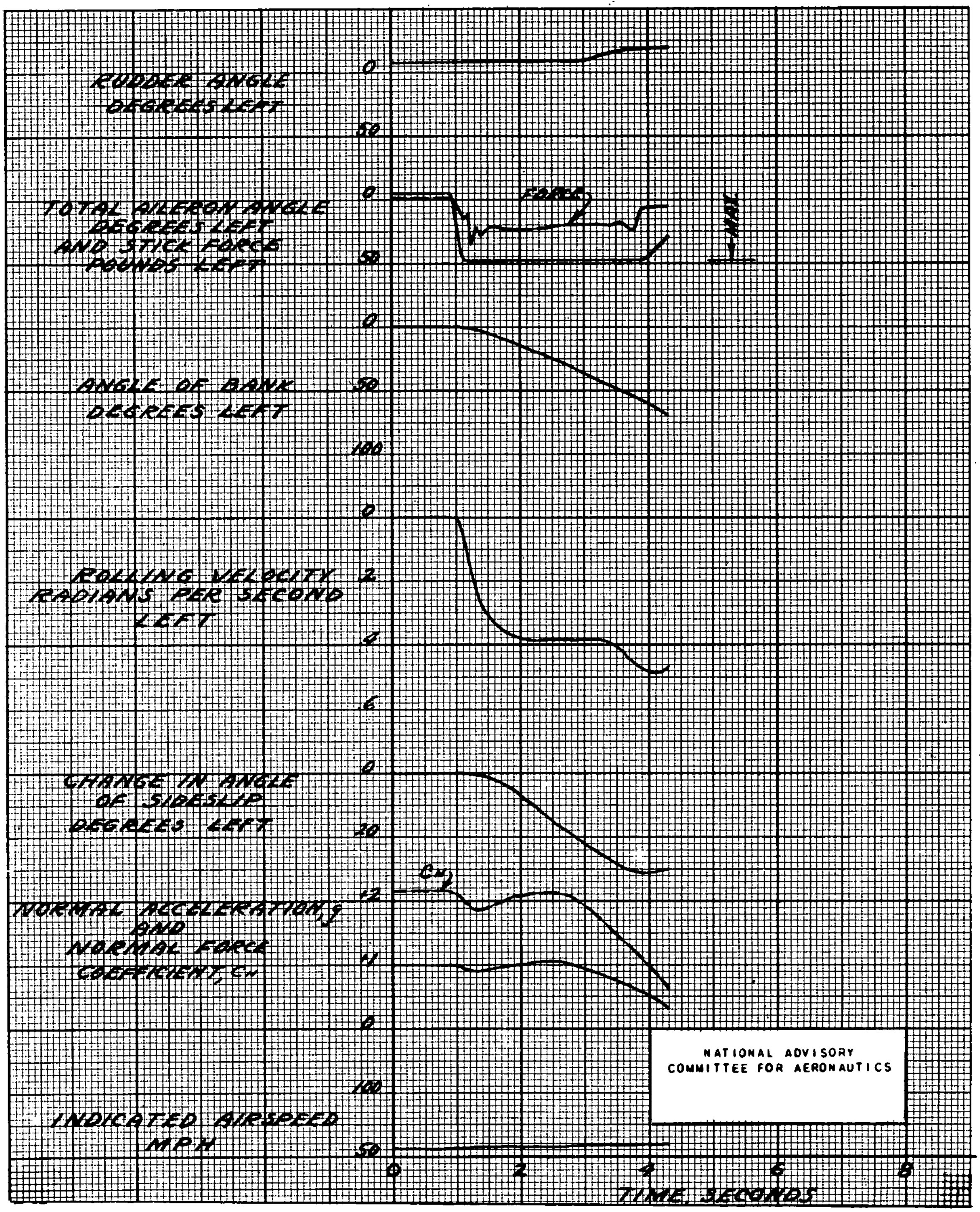

Figure 44.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps full down.

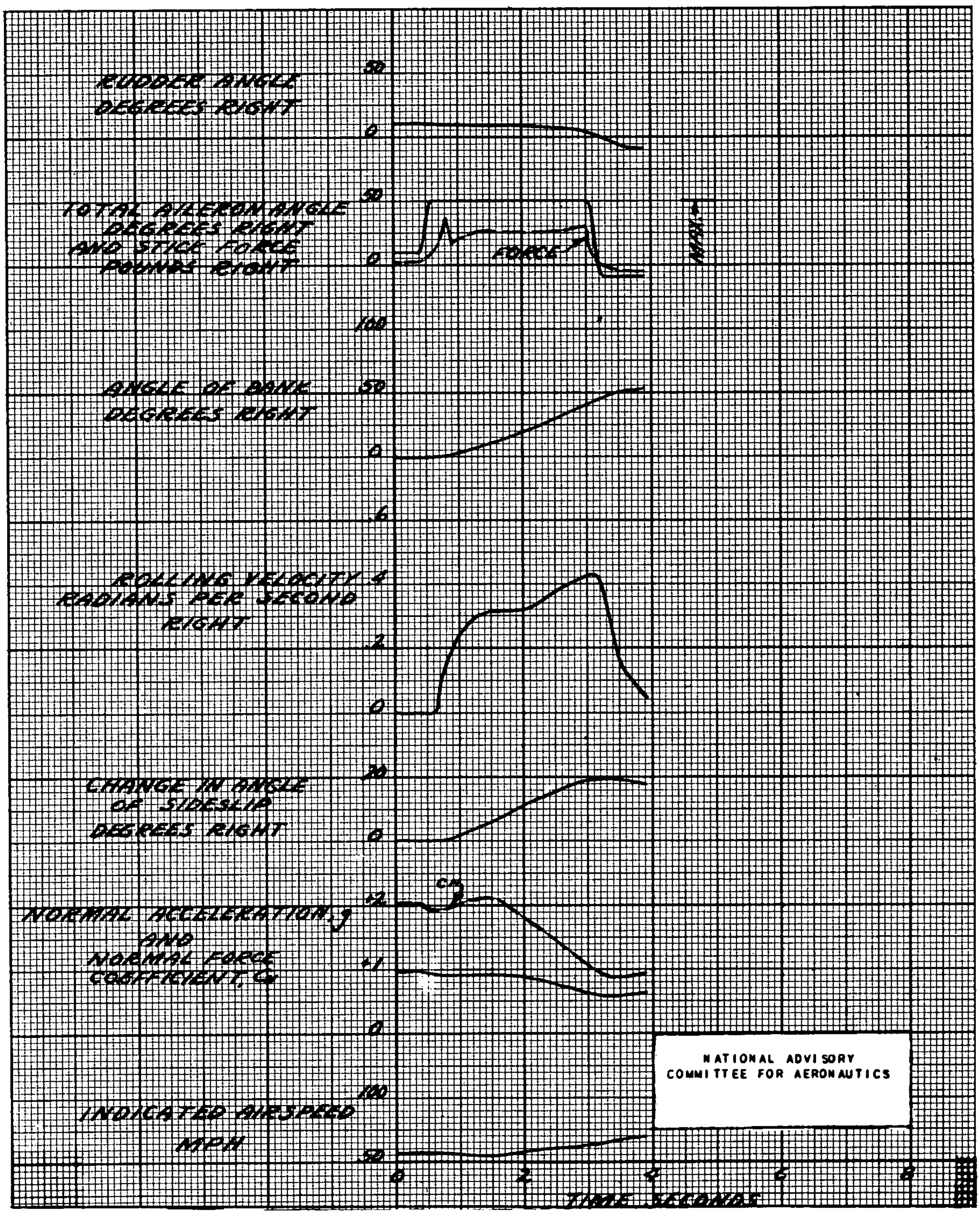

Figure 45.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps full down.

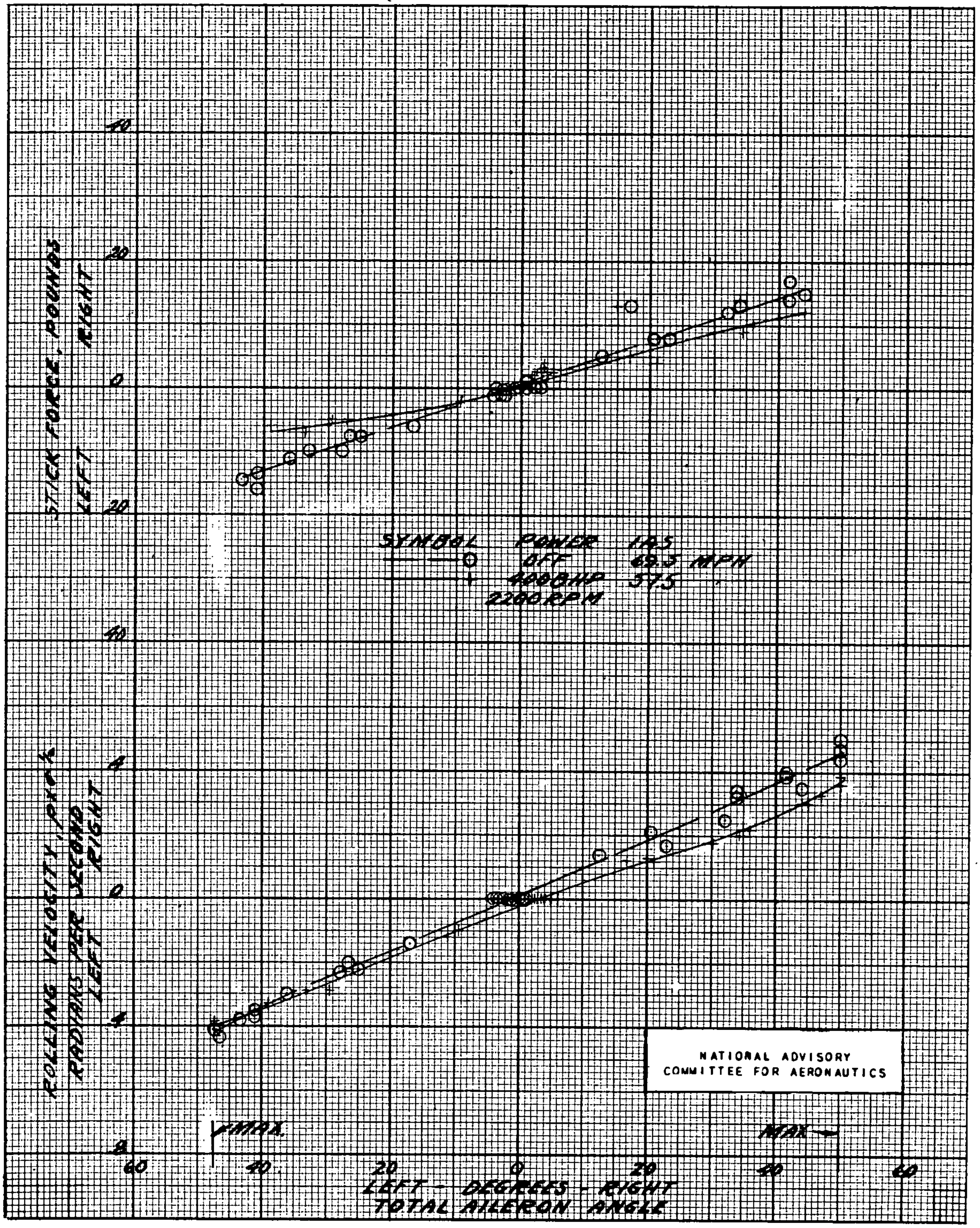

Figure 46.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

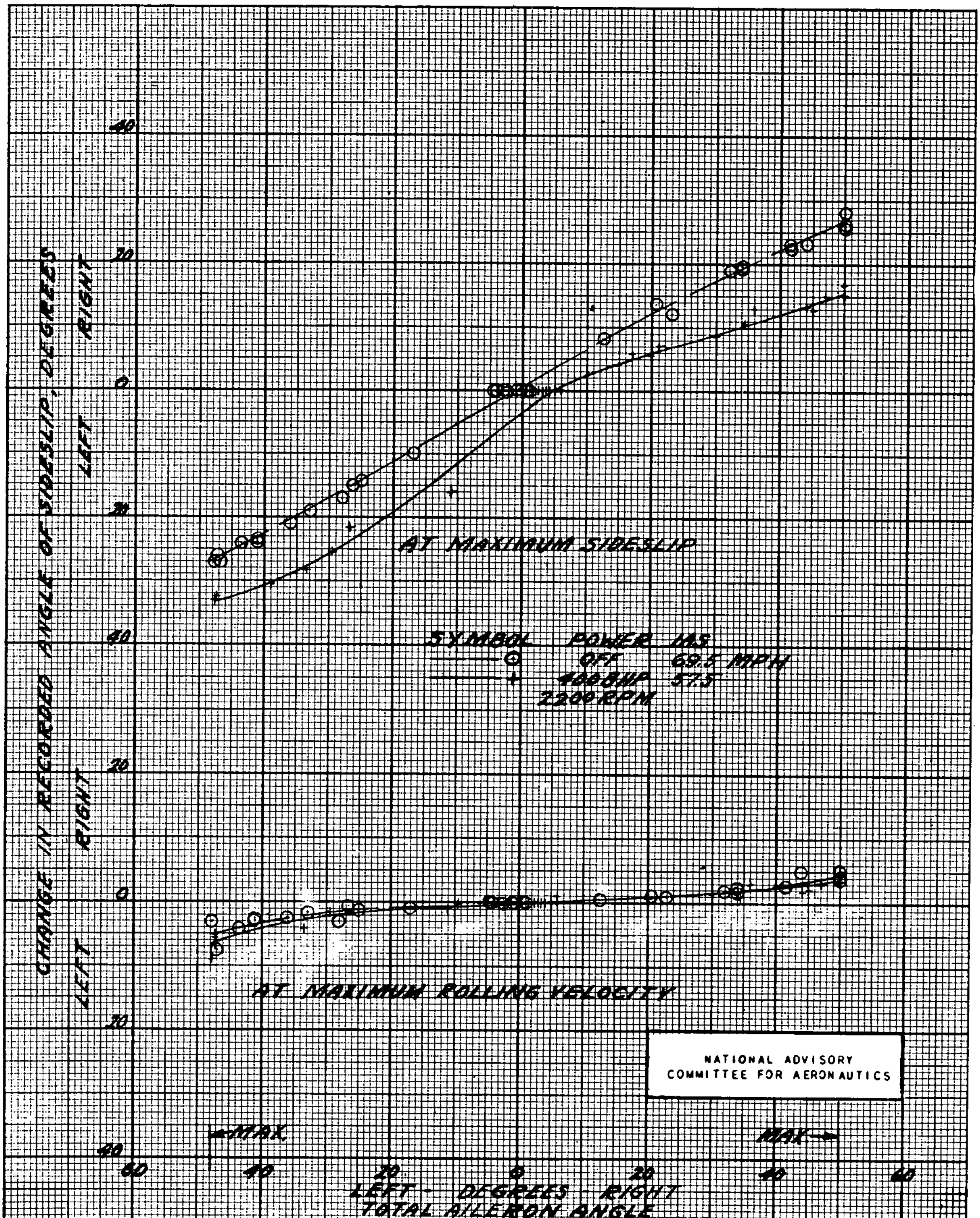

Figure 47.- Variation of angle of sideslip with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

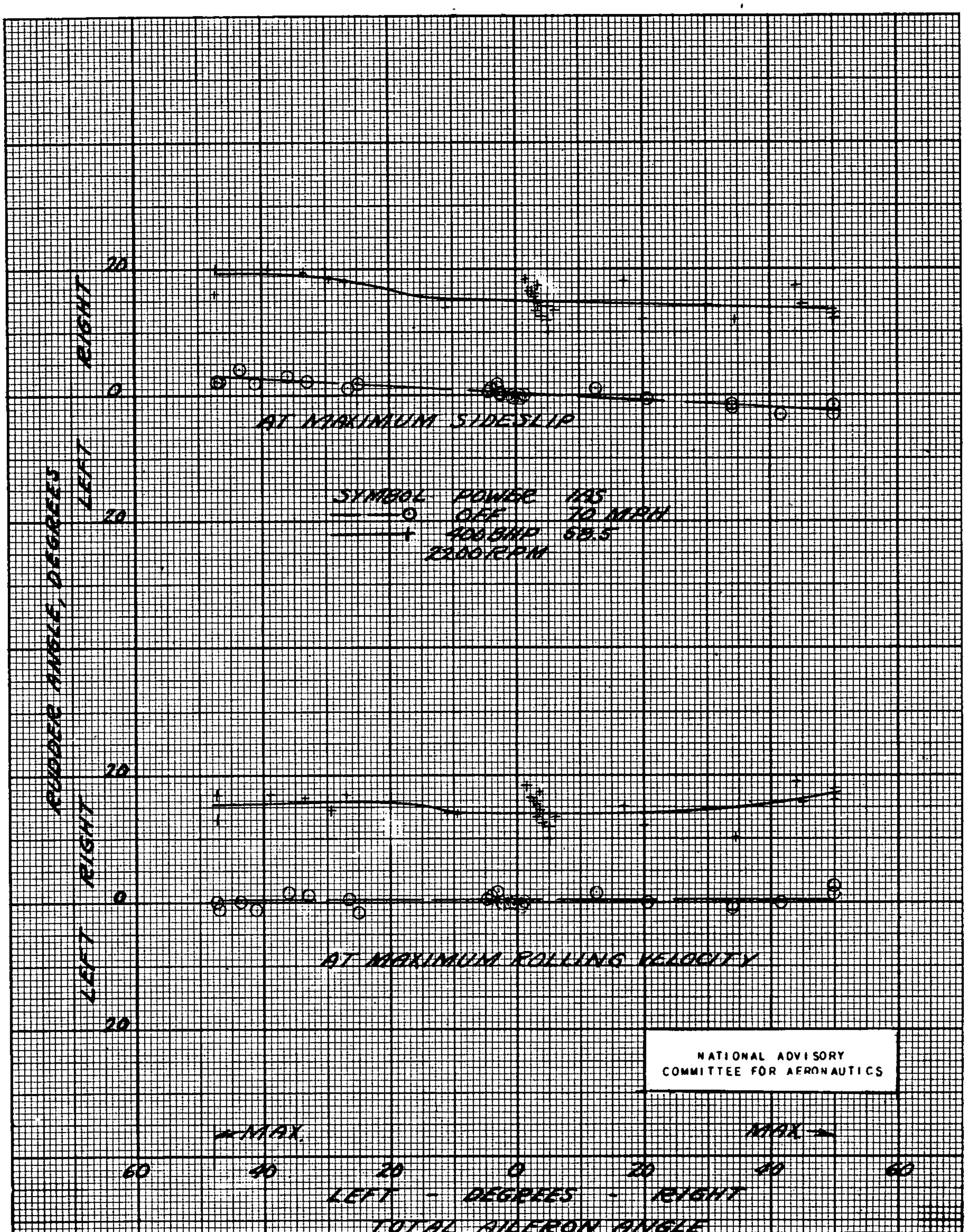

Figure 48.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

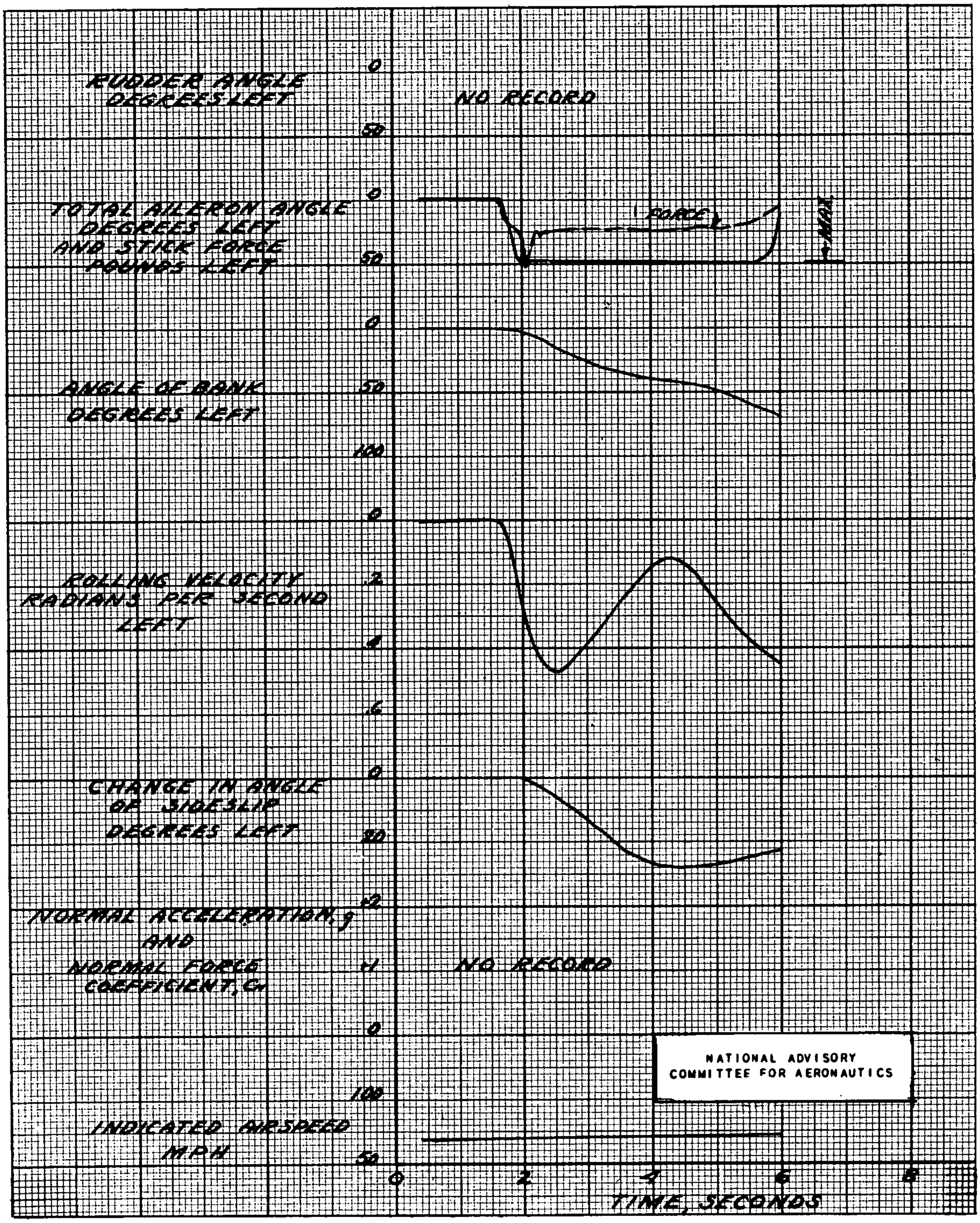

Figure 49.- Time history of a power off left aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

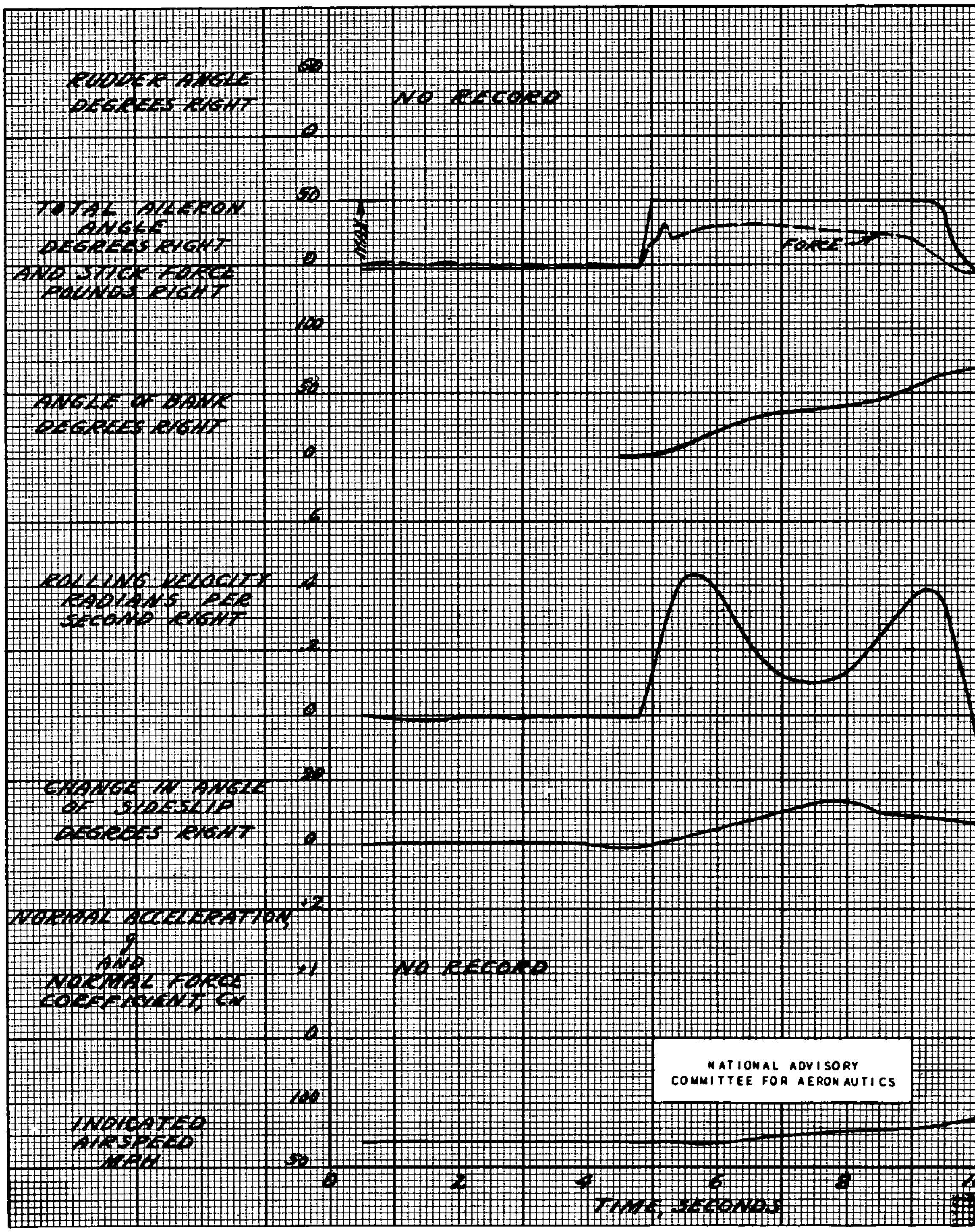

Figure 50.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

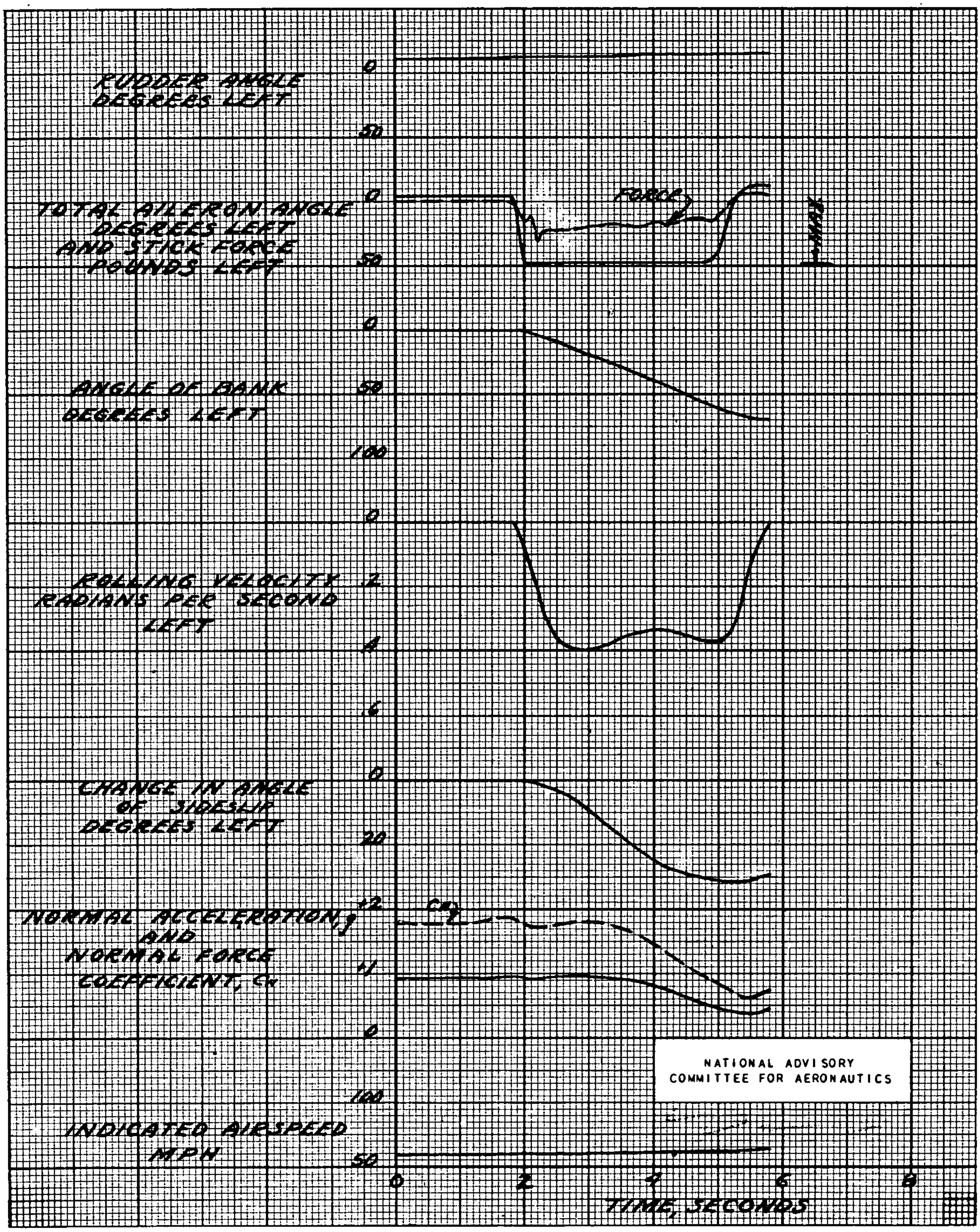

Figure 51.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

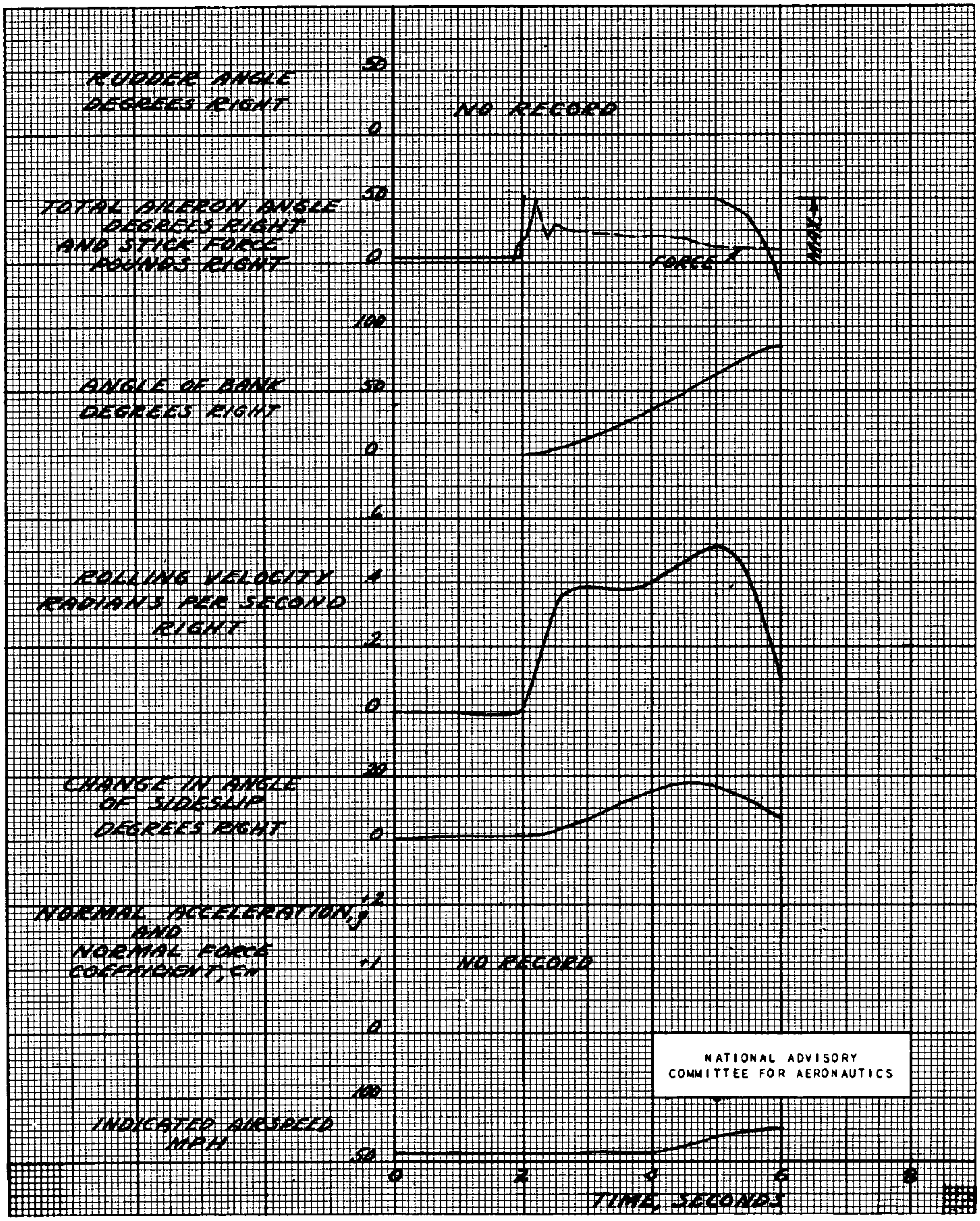

Figure 52.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 15° aileron droop and flaps two-thirds down.

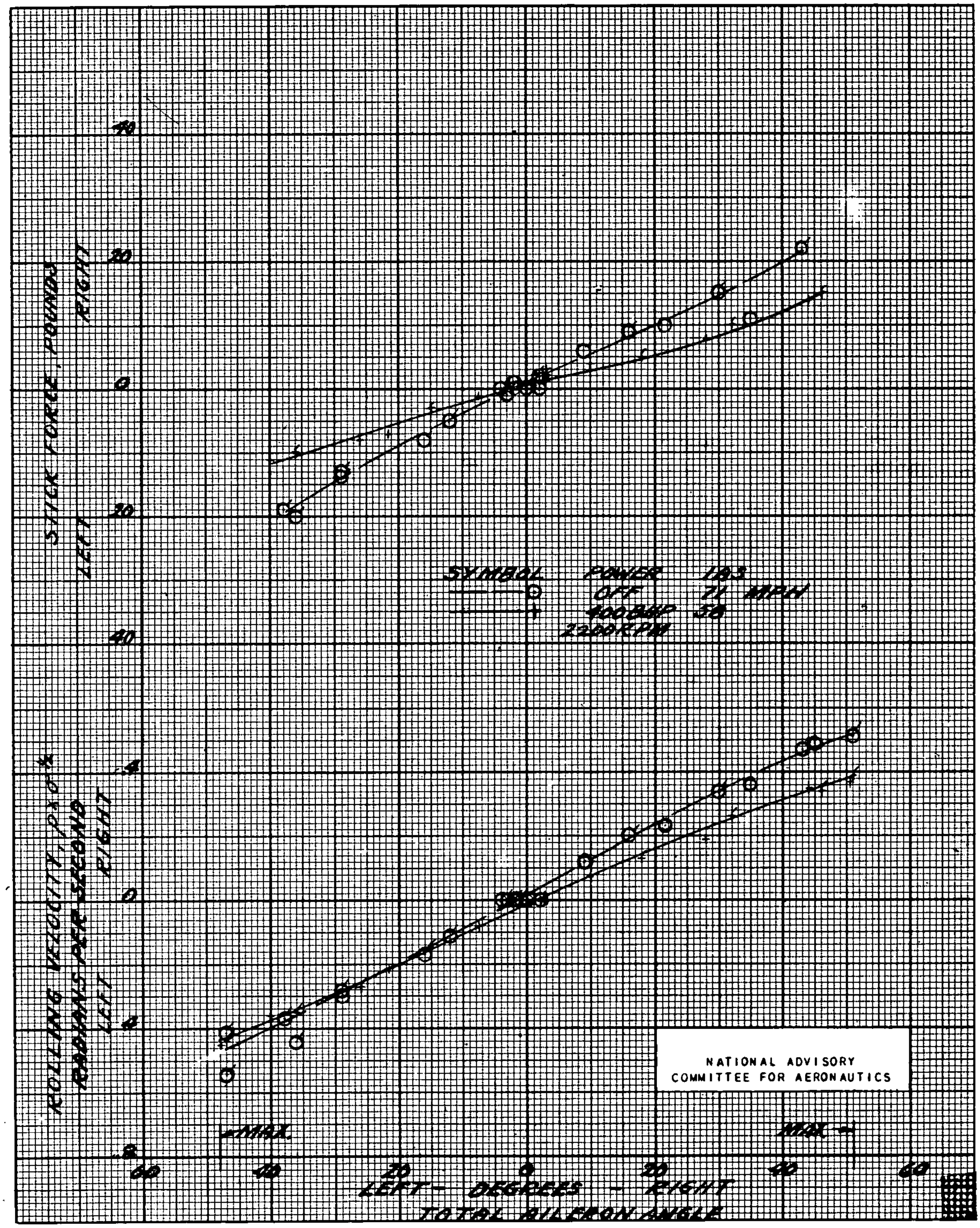

Figure 53.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 10° aileron droop and flaps full down.

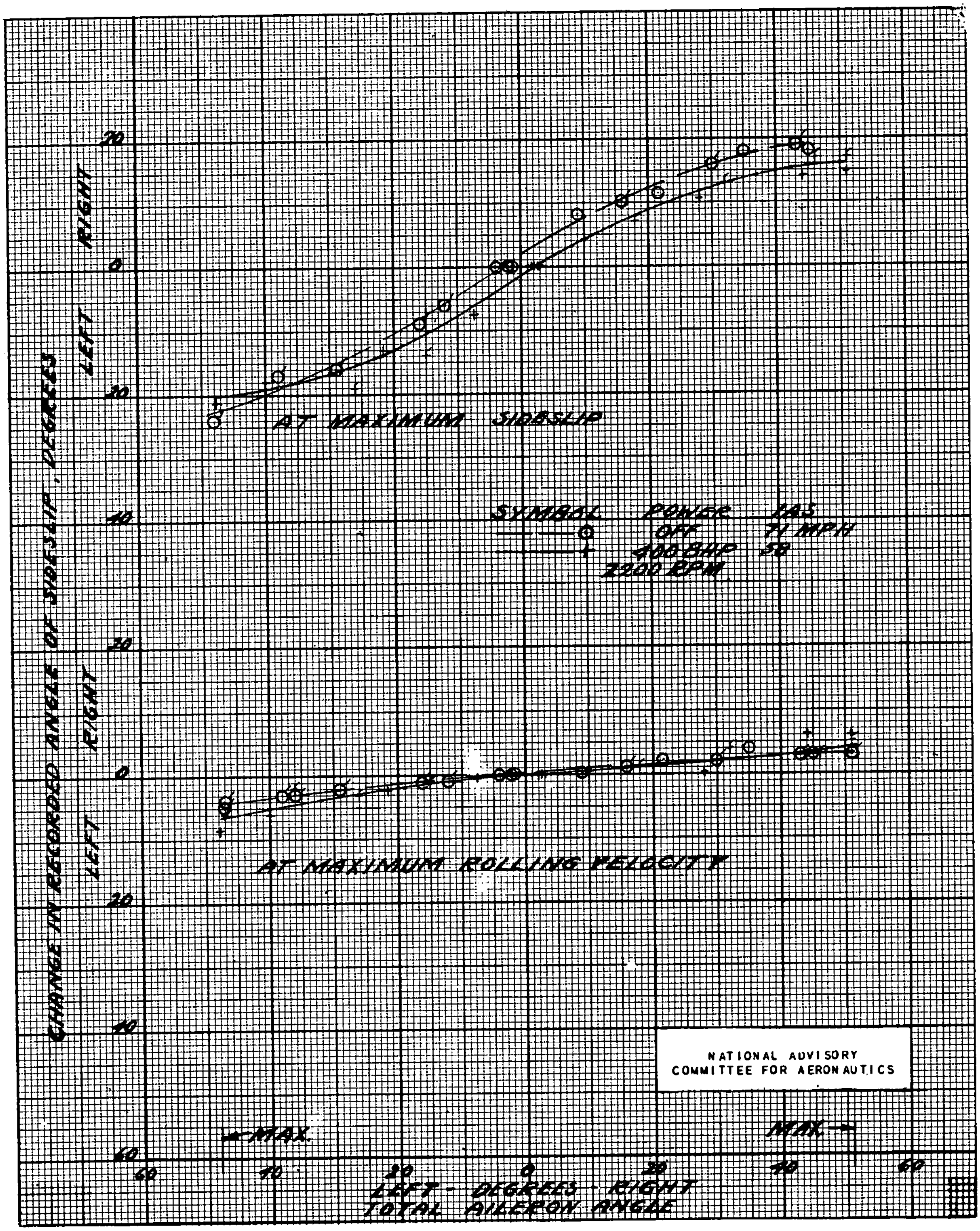

Figure 54.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 10° aileron droop and flaps full down.

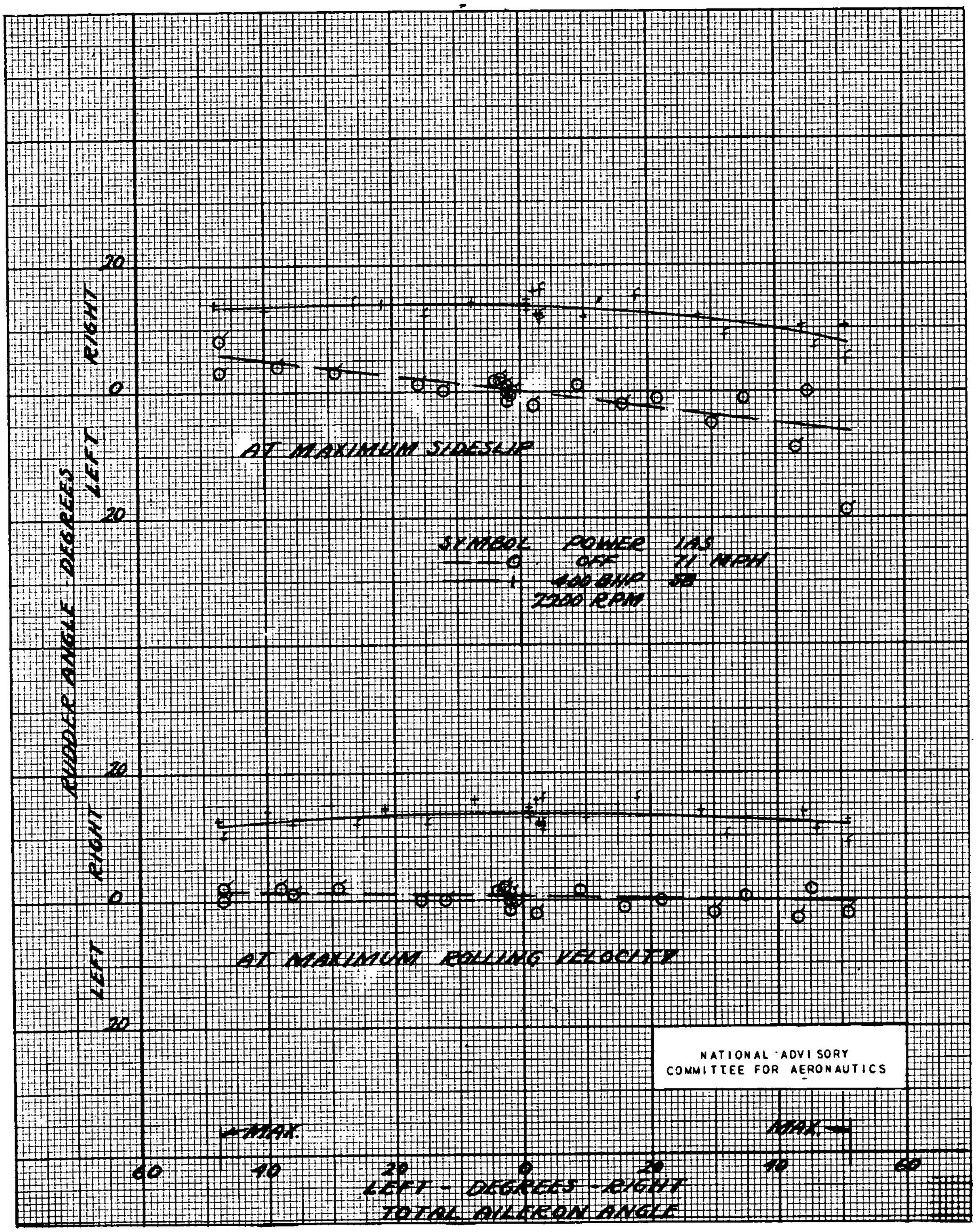

Figure 55.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 10° aileron droop and flaps full down.

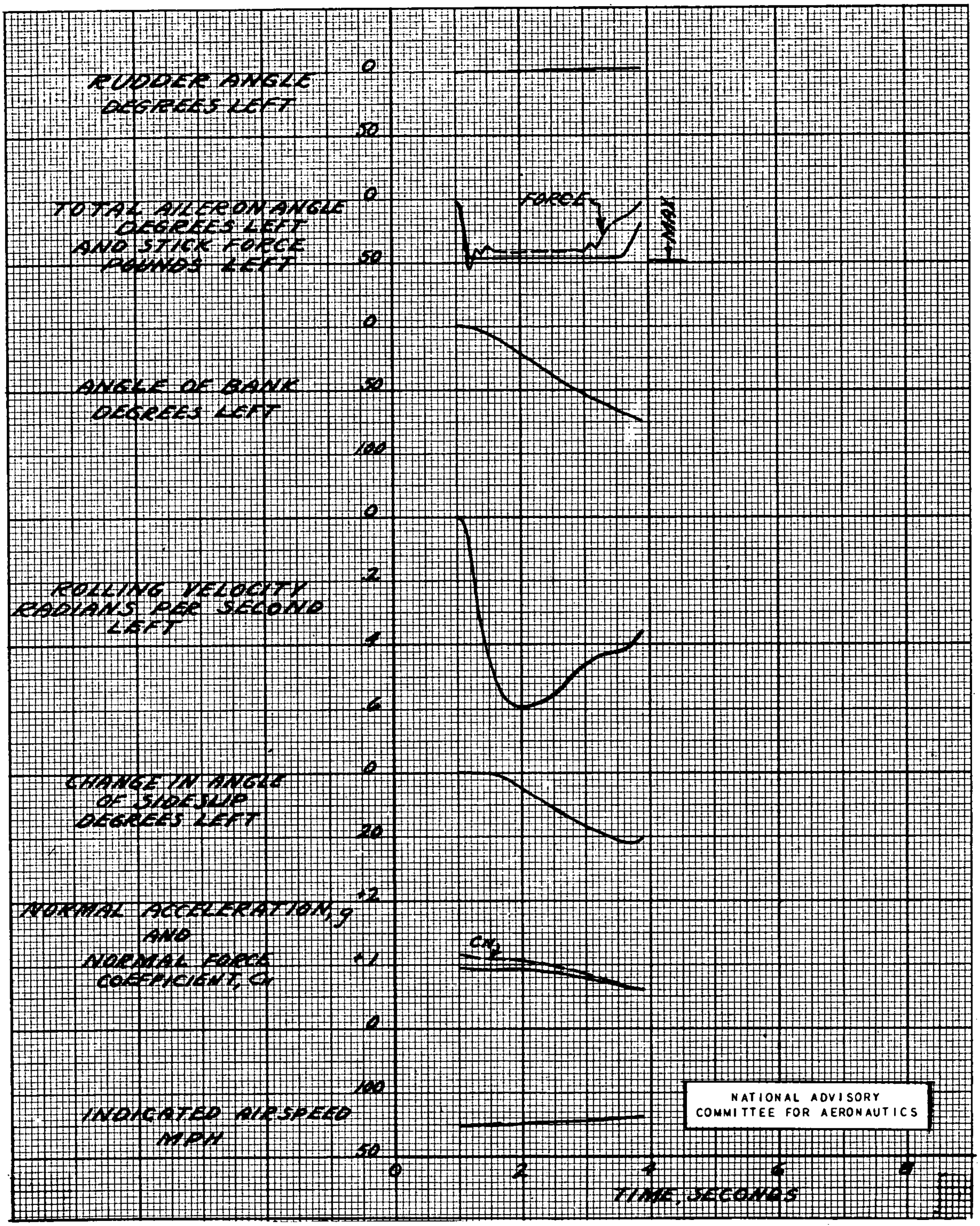

Figure 56.- Time history of a power off left aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps full down.

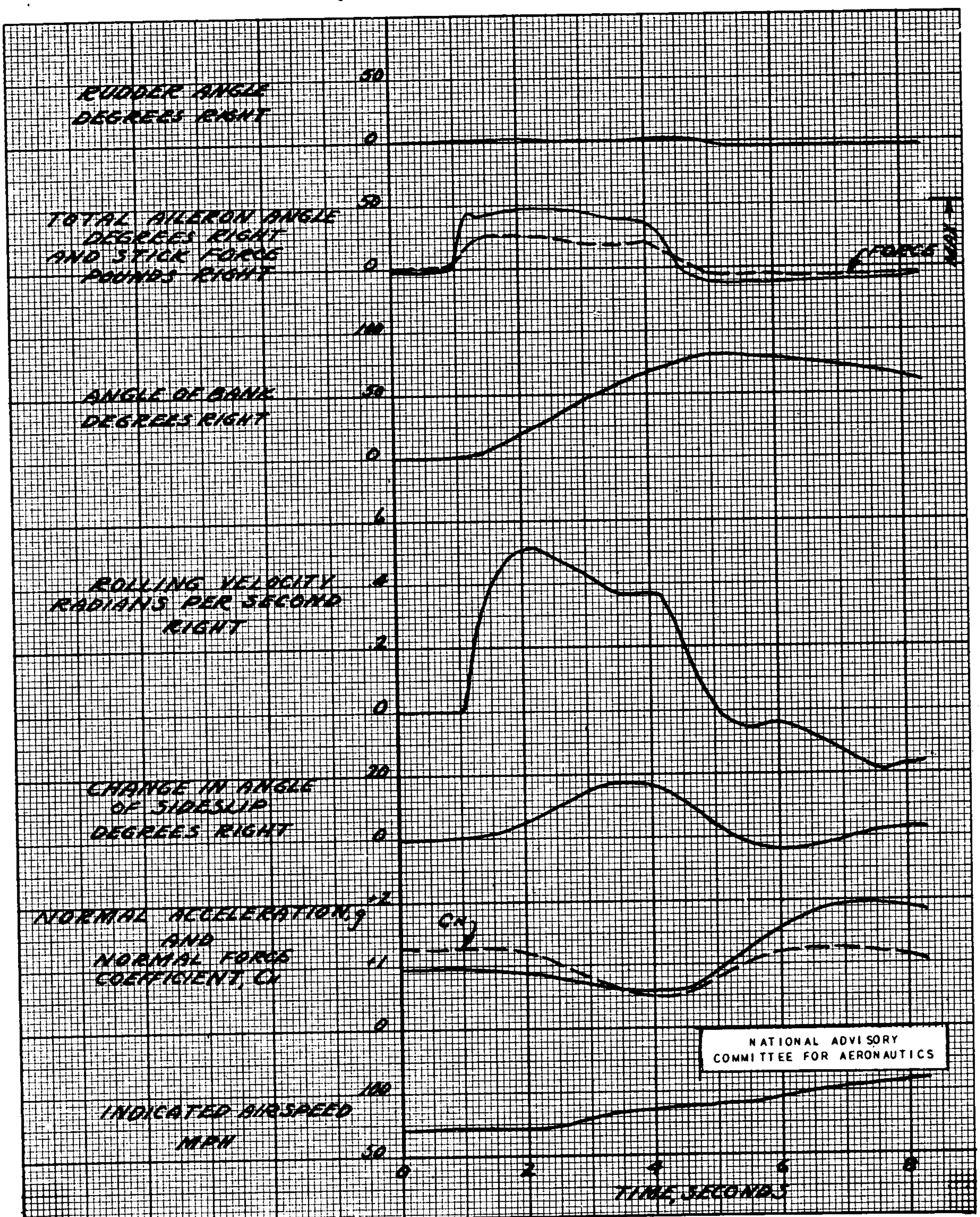

Figure 57.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps full down.

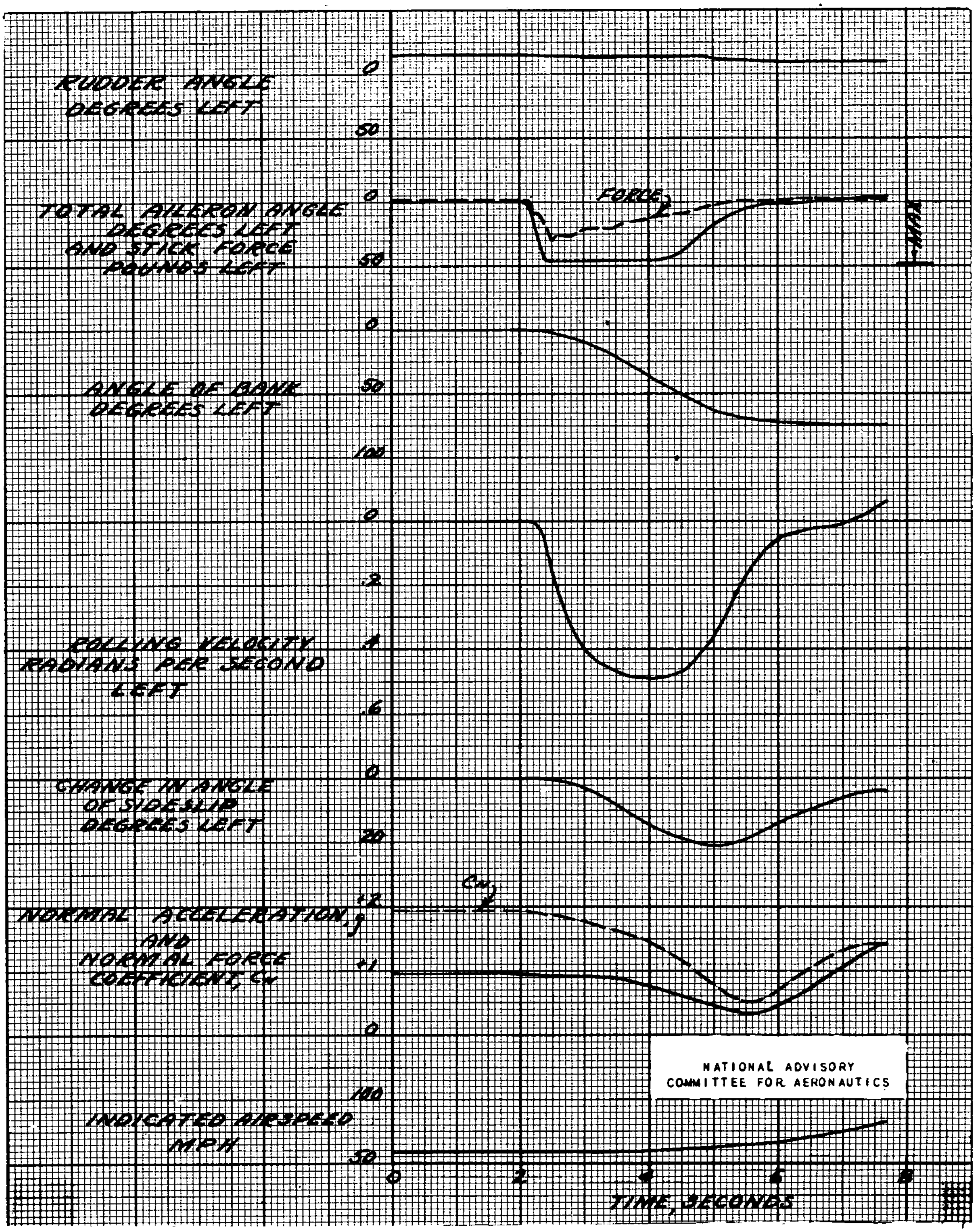

Figure 58.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps full down.

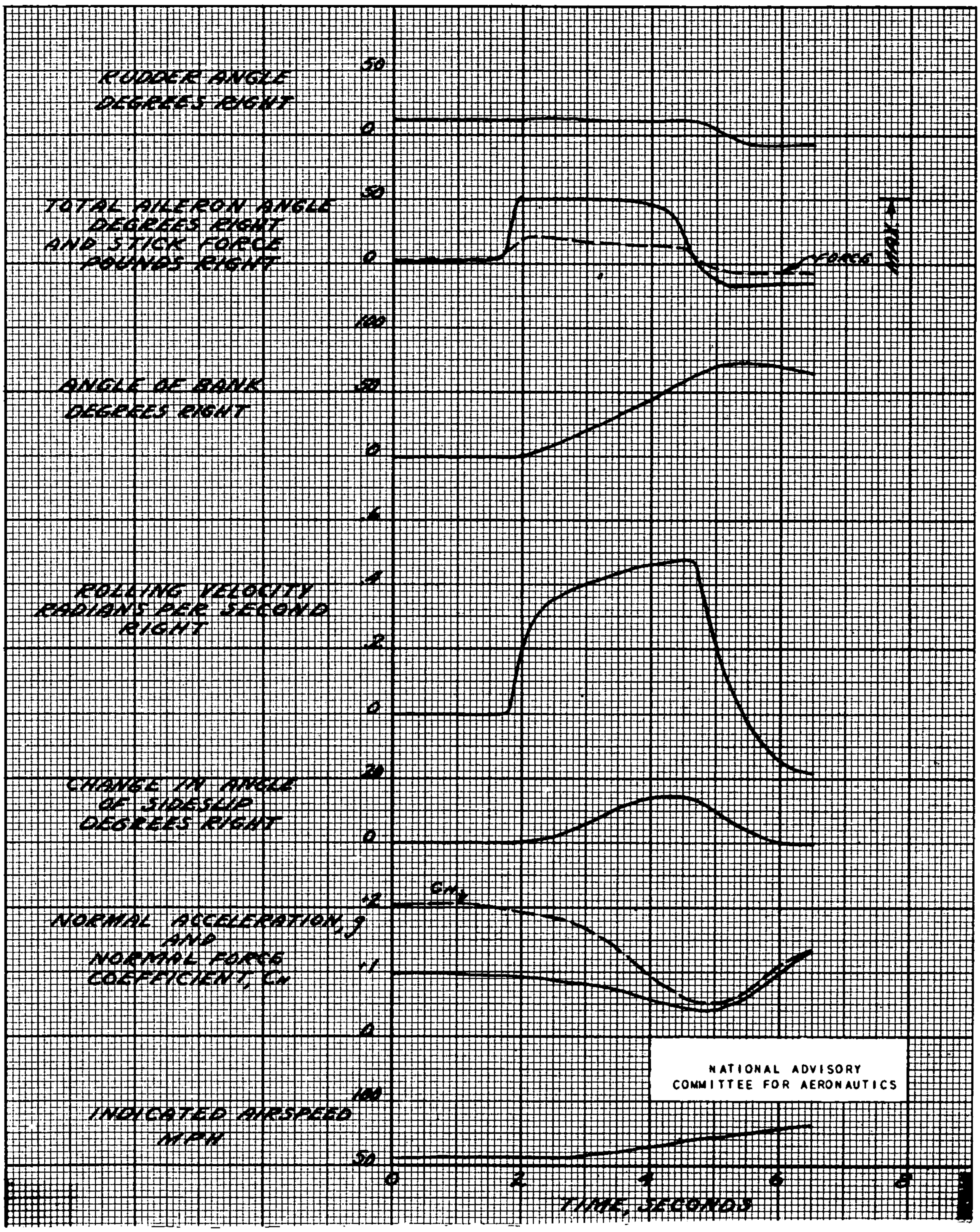

Figure 59.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps full down.

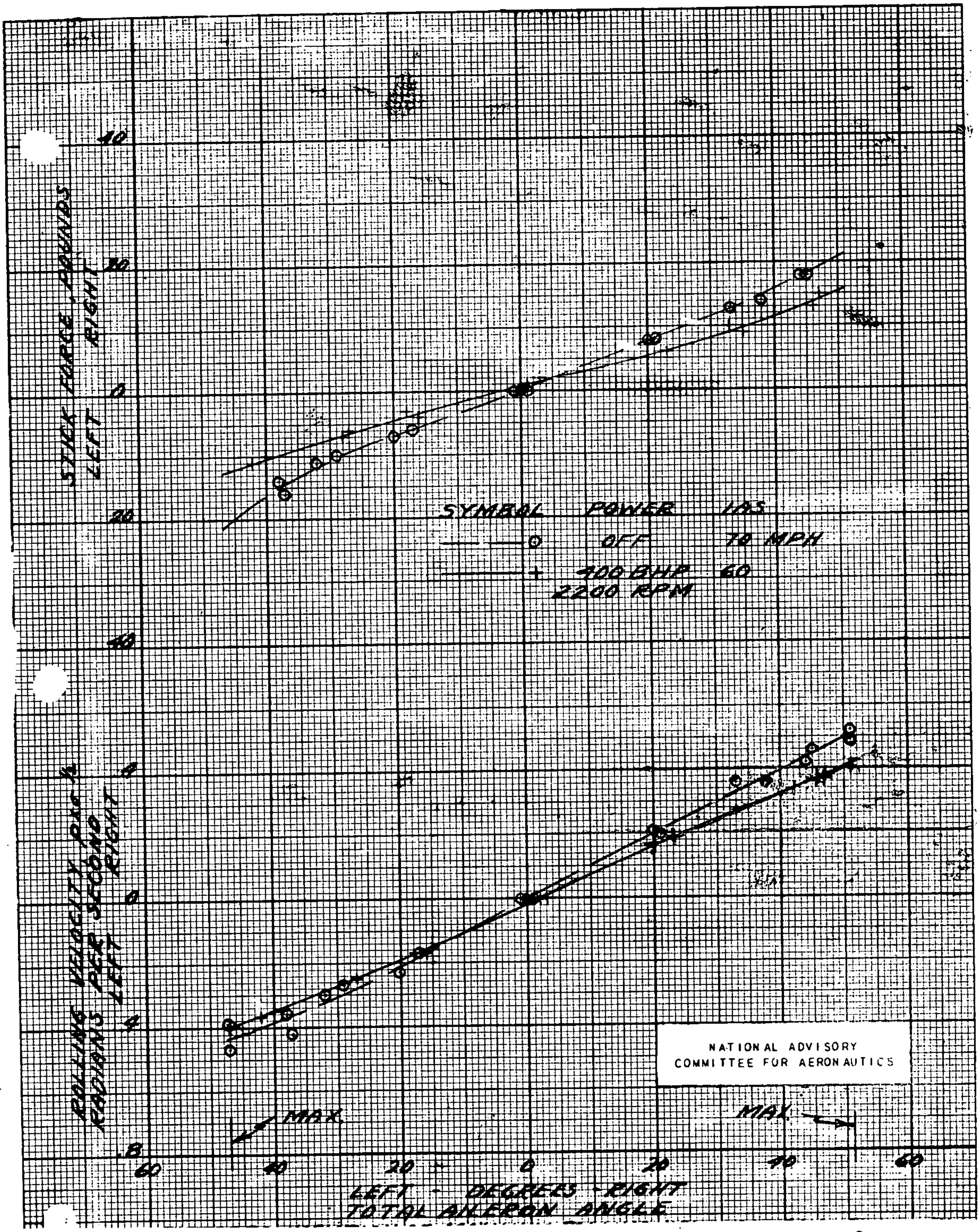

Figure 60.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

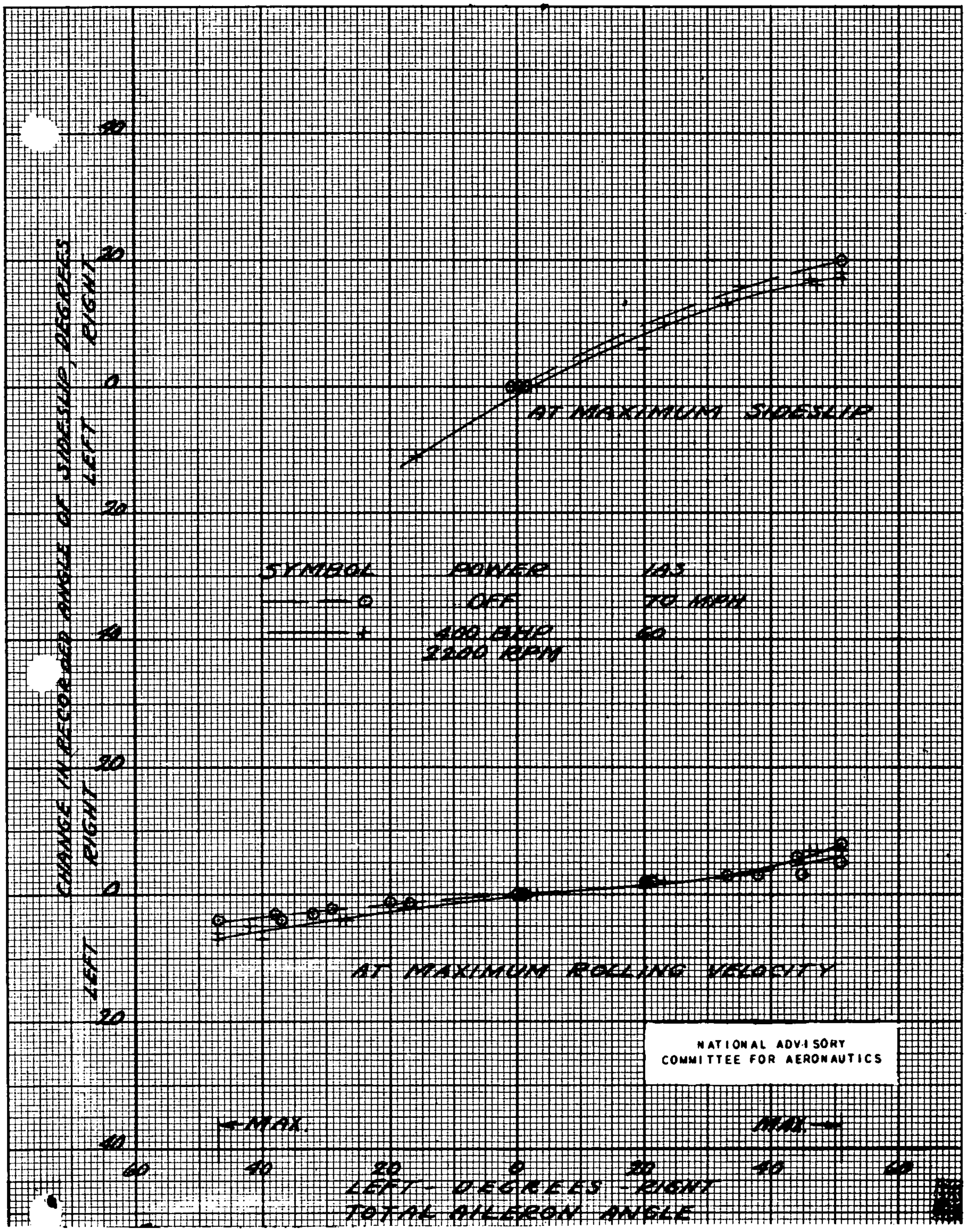

Figure 61.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

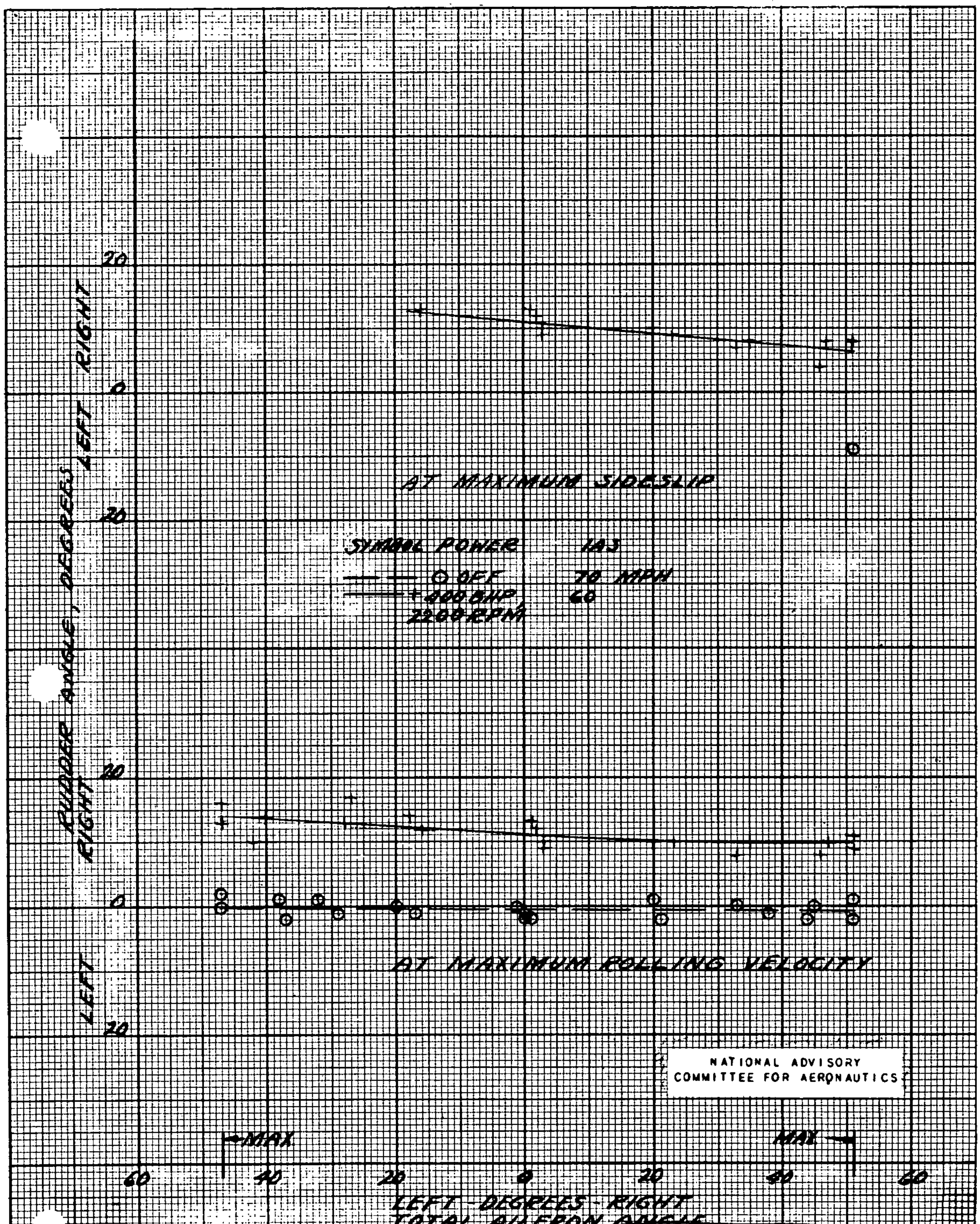

Figure 62.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

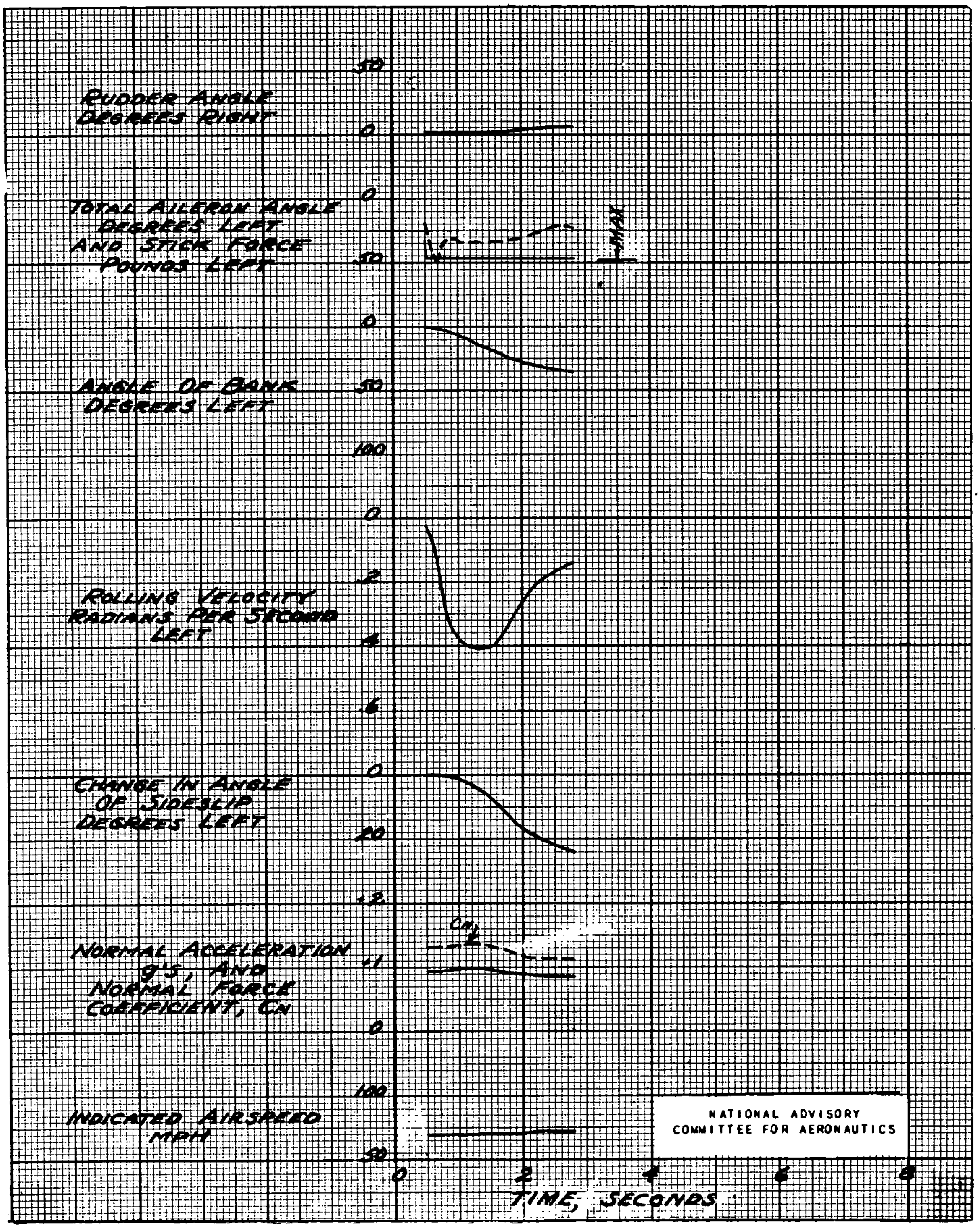

Figure 63. Time history of a power off left aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

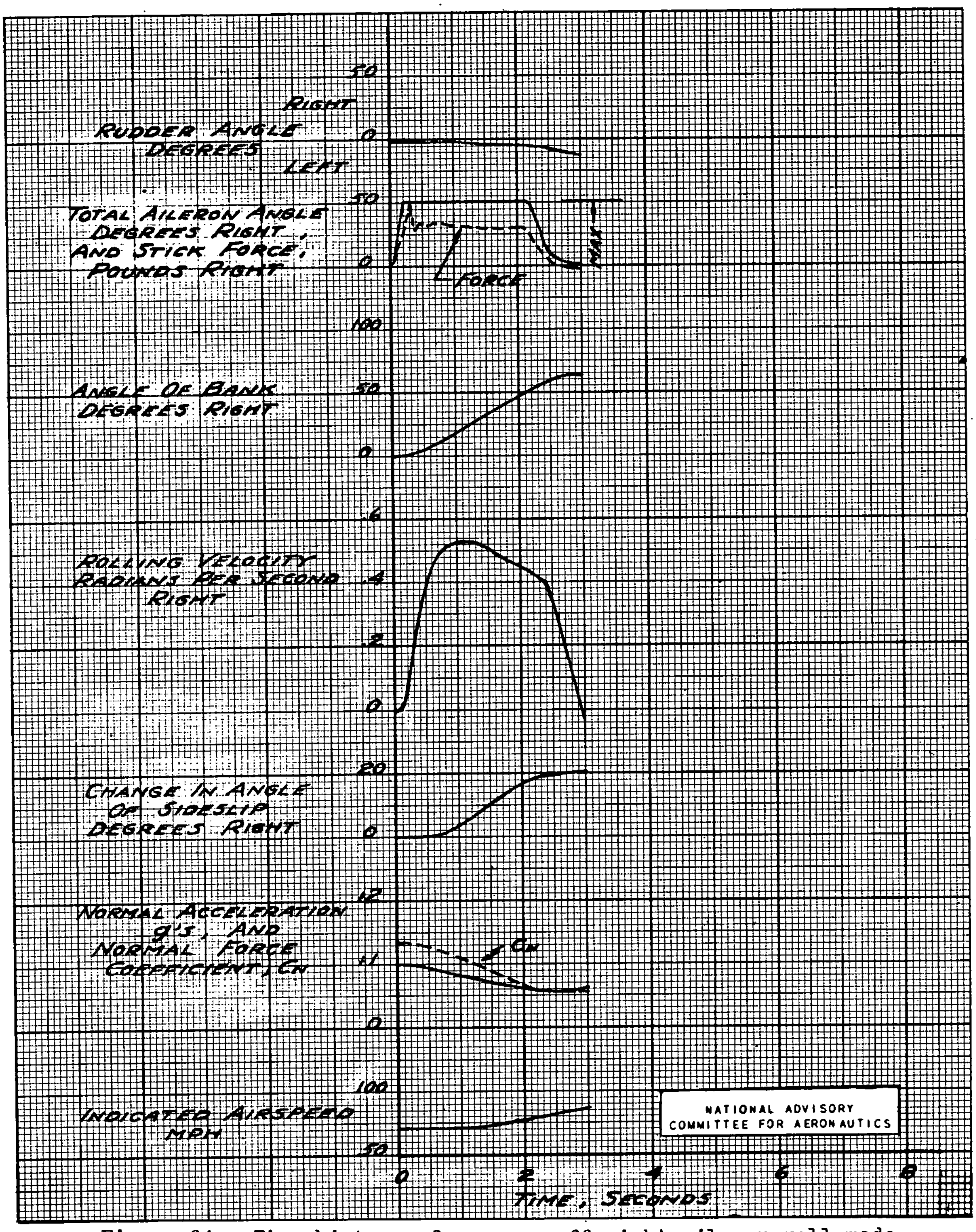

Figure 64.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds dow

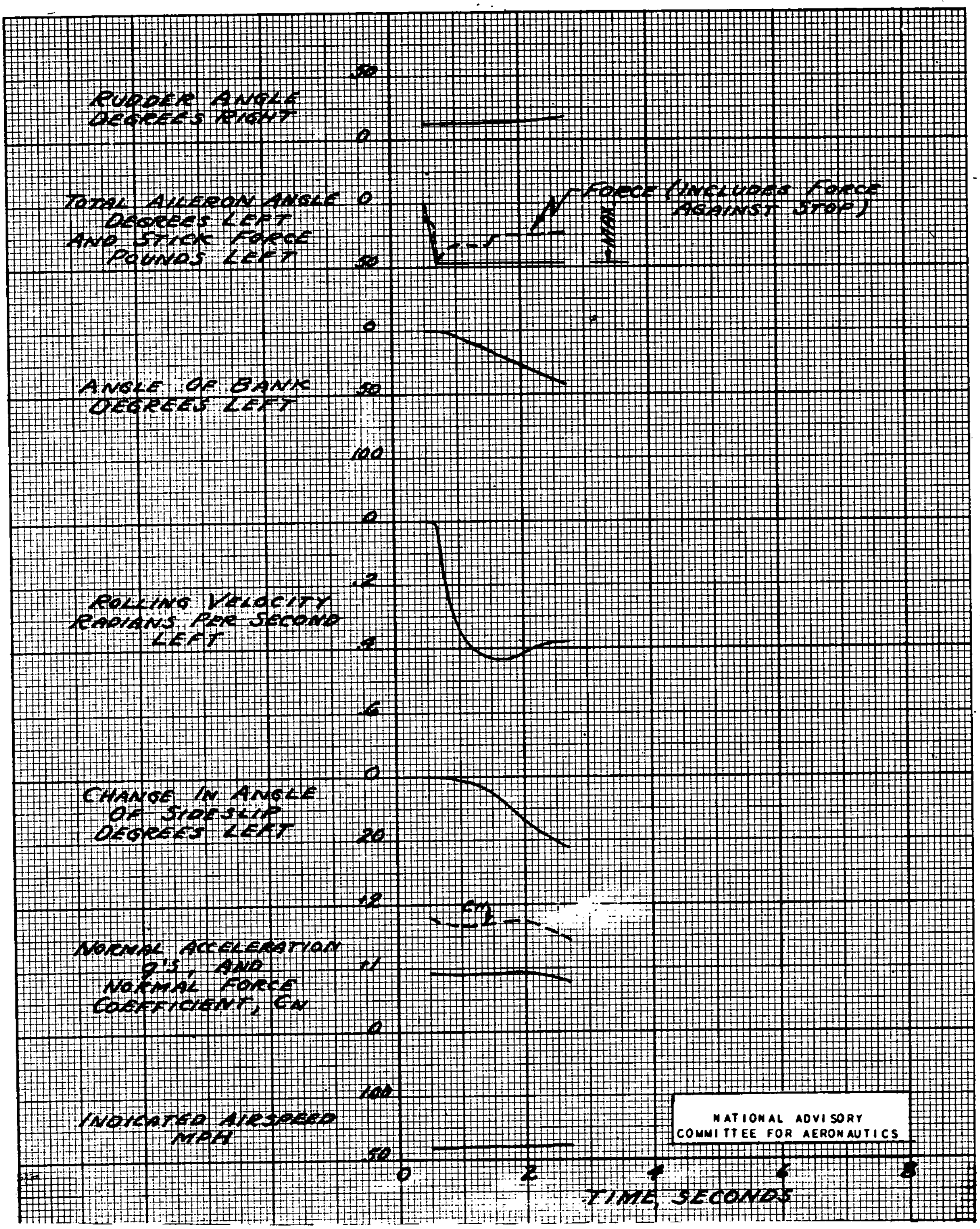

Figure 65.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

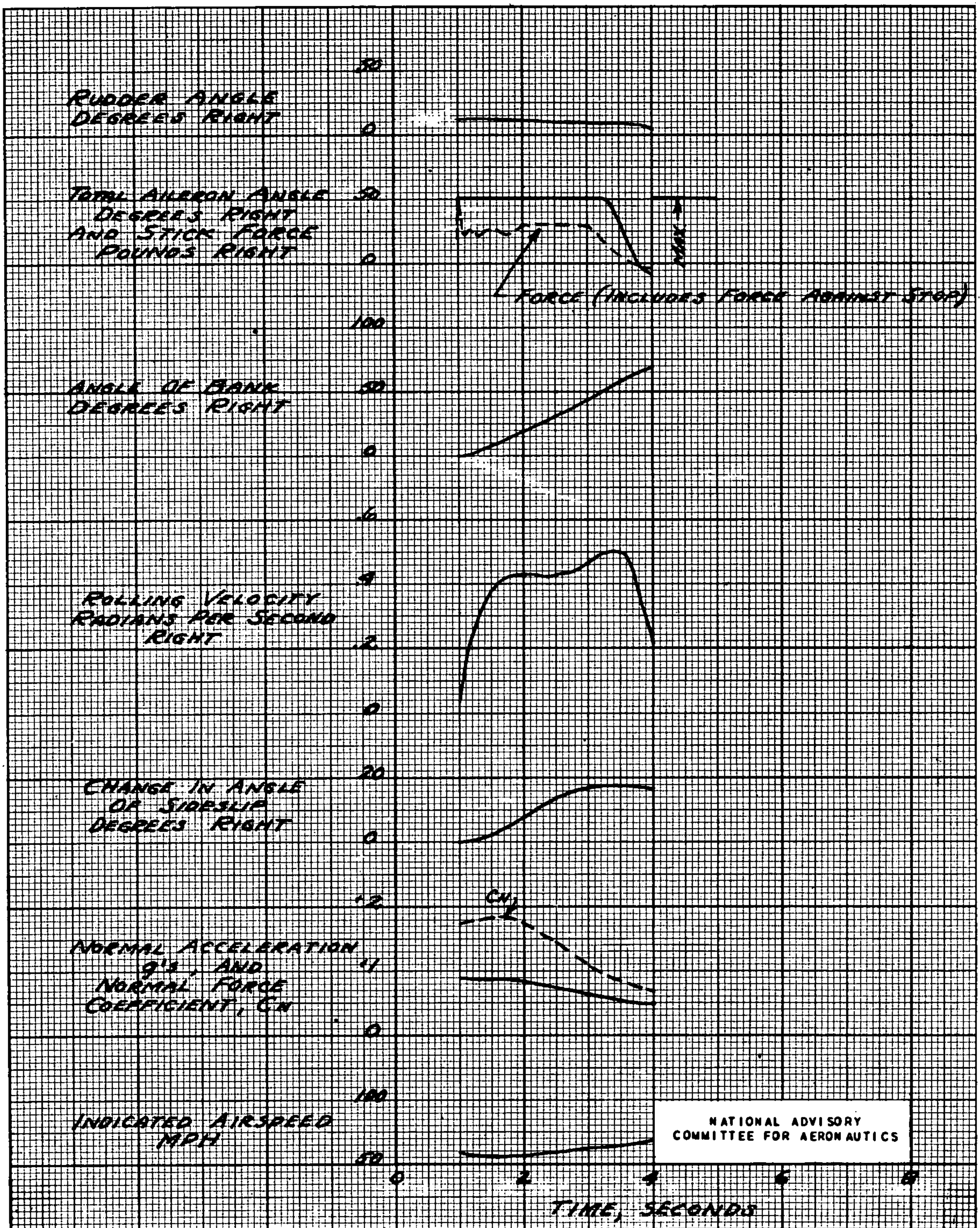

Figure 66.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 10° aileron droop and flaps two-thirds down.

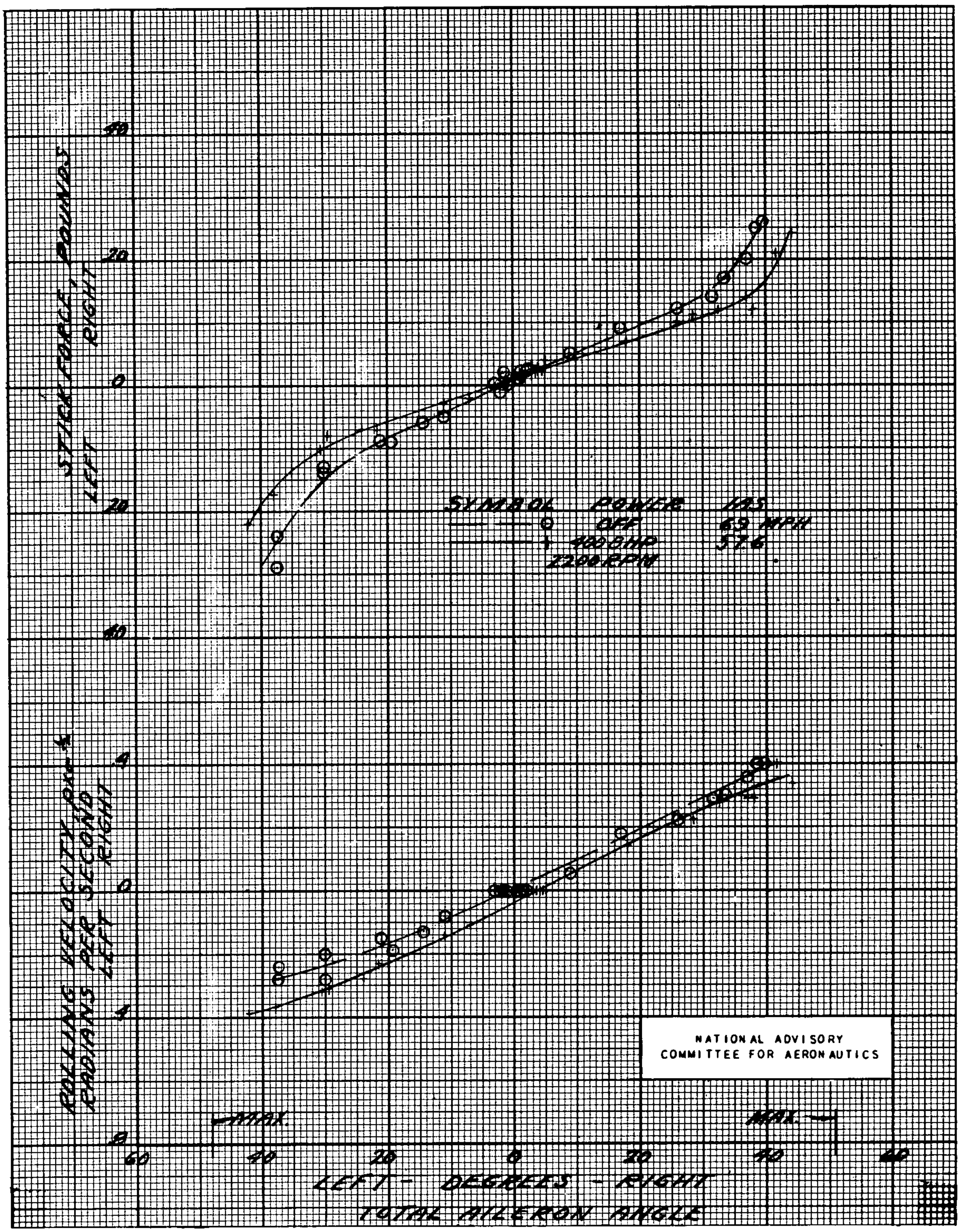

Figure 67.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 0° aileron droop and flaps full down.

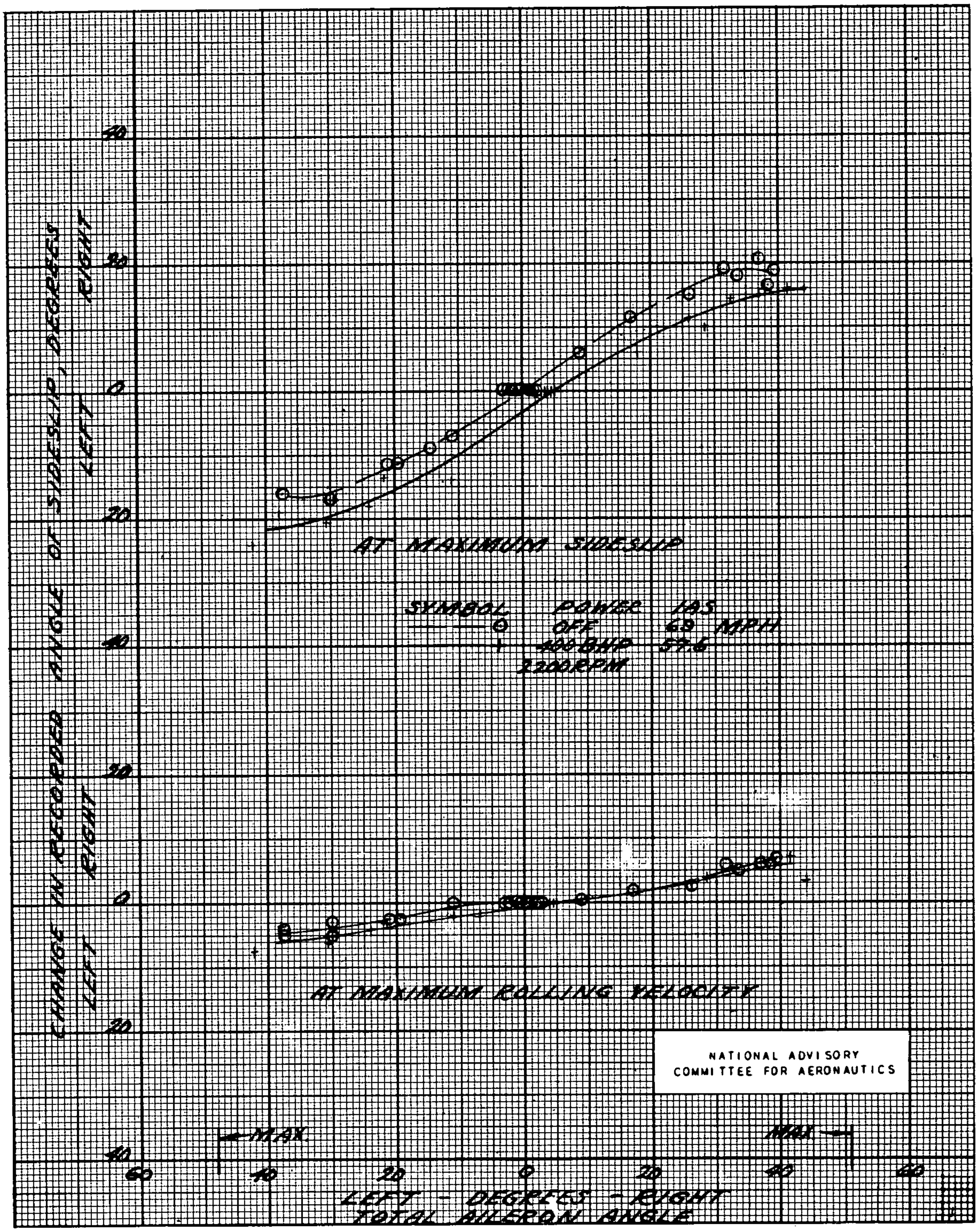

Figure 68.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 0° aileron droop and flaps full down.

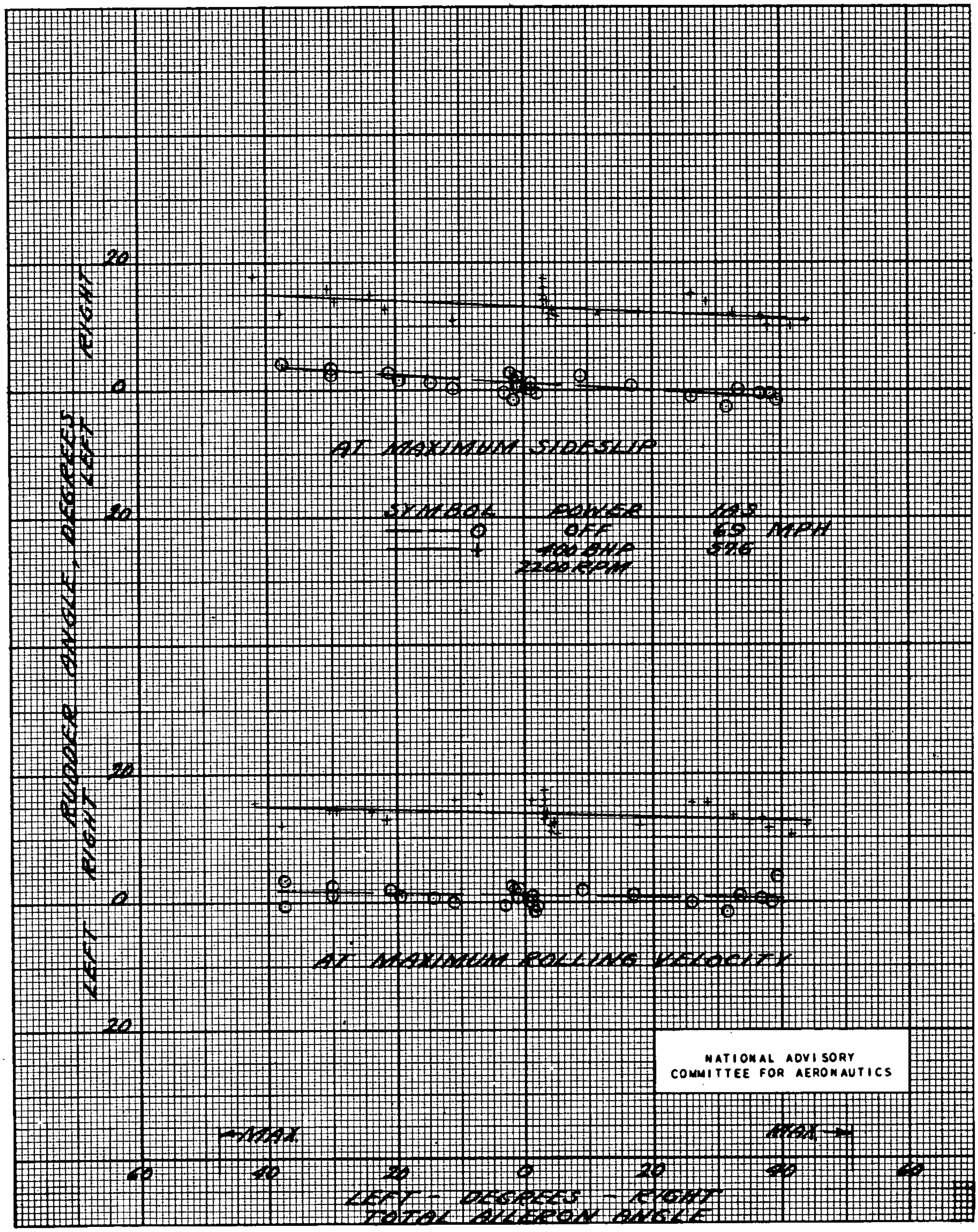

Figure 69.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 0° aileron droop and flaps full down.

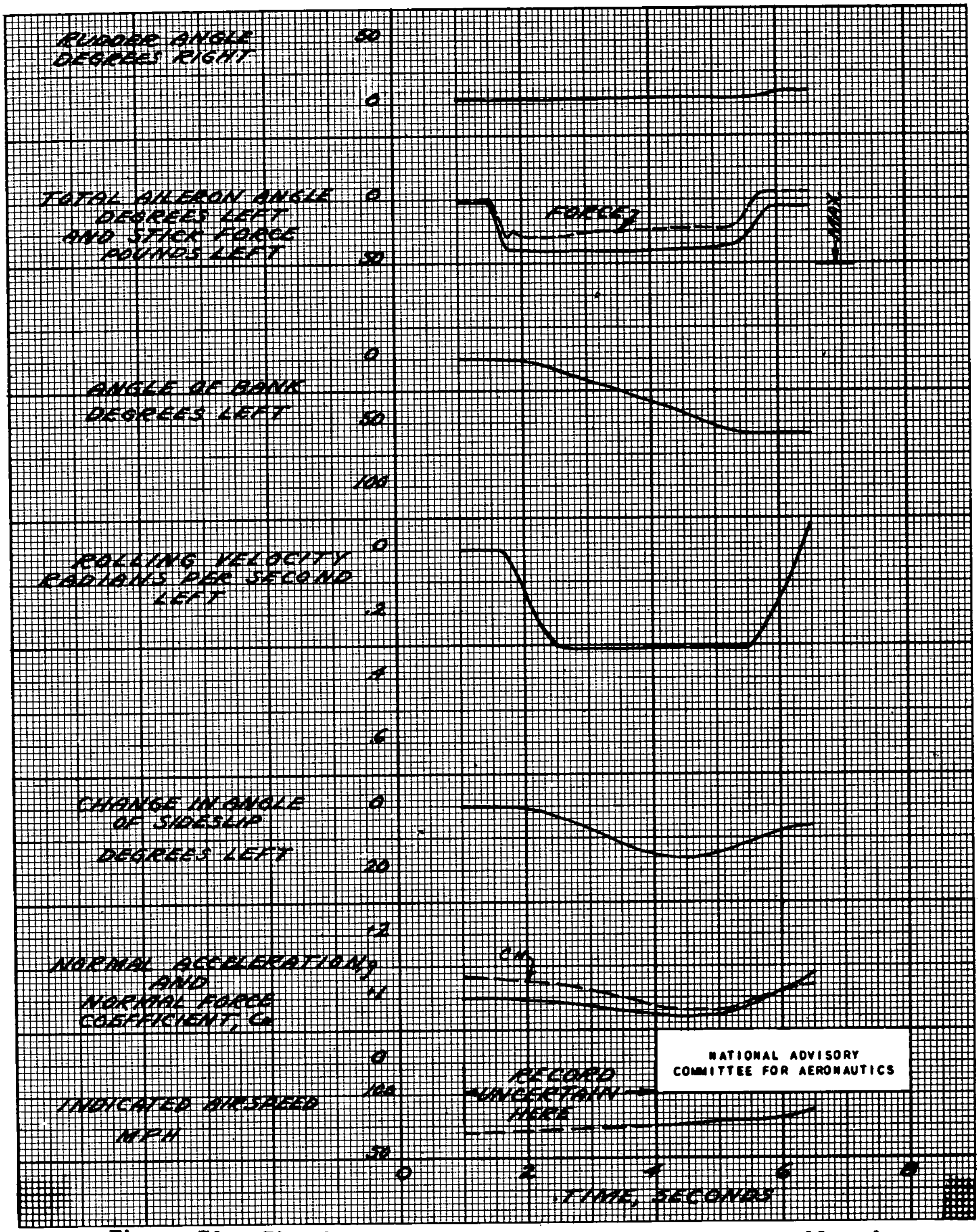

Figure 70.- Time history of a power off left aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps full down.

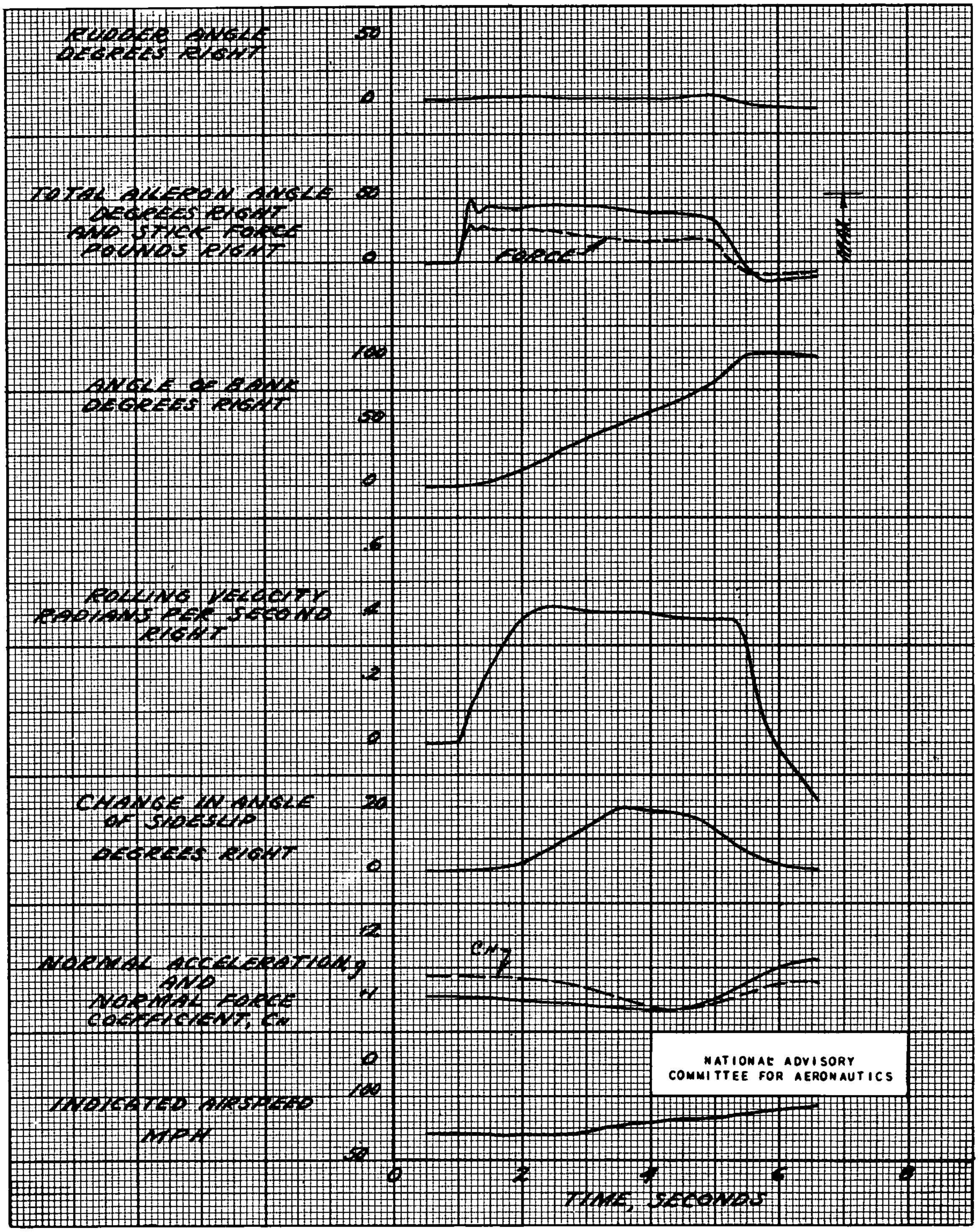

Figure 71.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps full down.

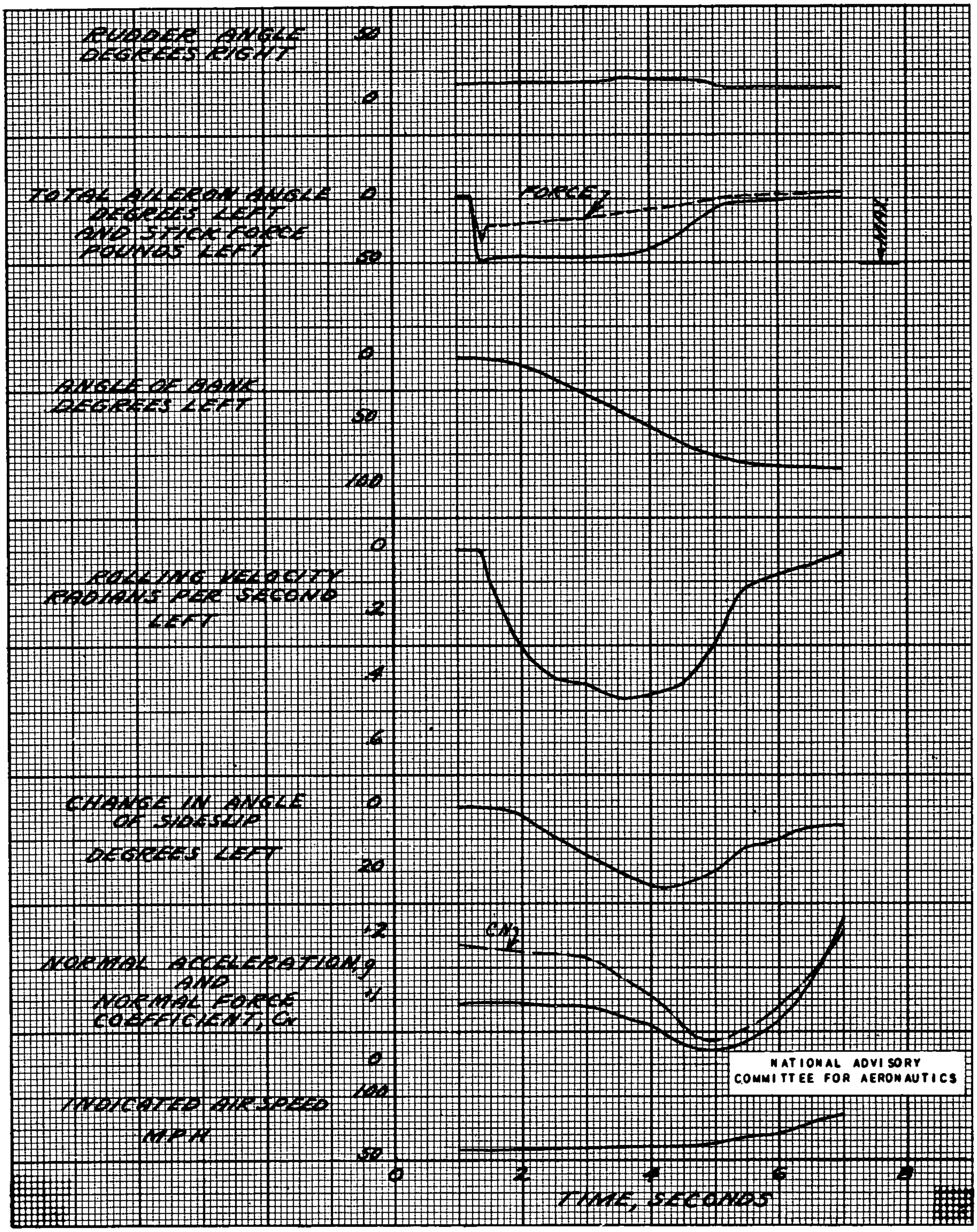

Figure 72.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps full down.

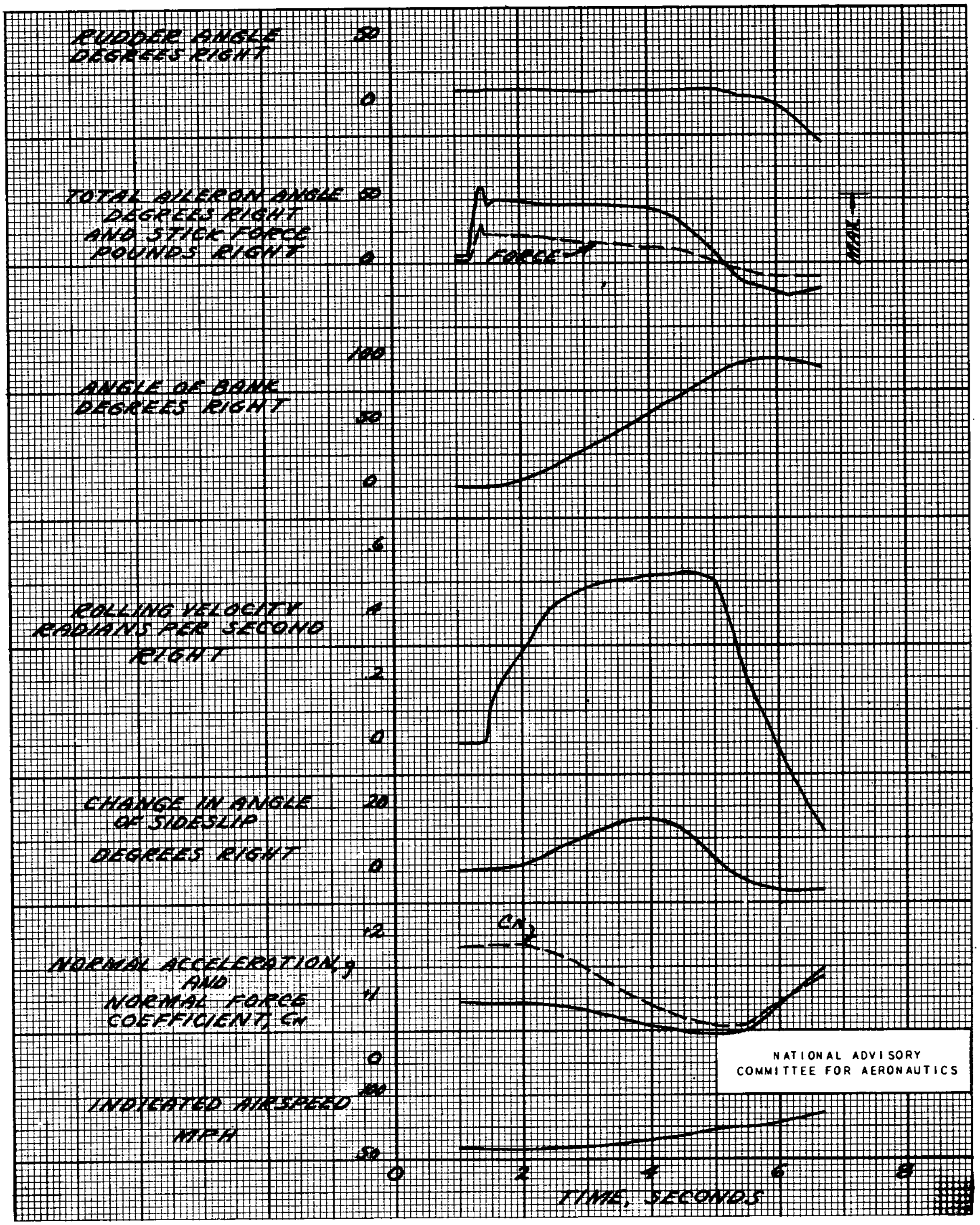

Figure 73.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps full down.

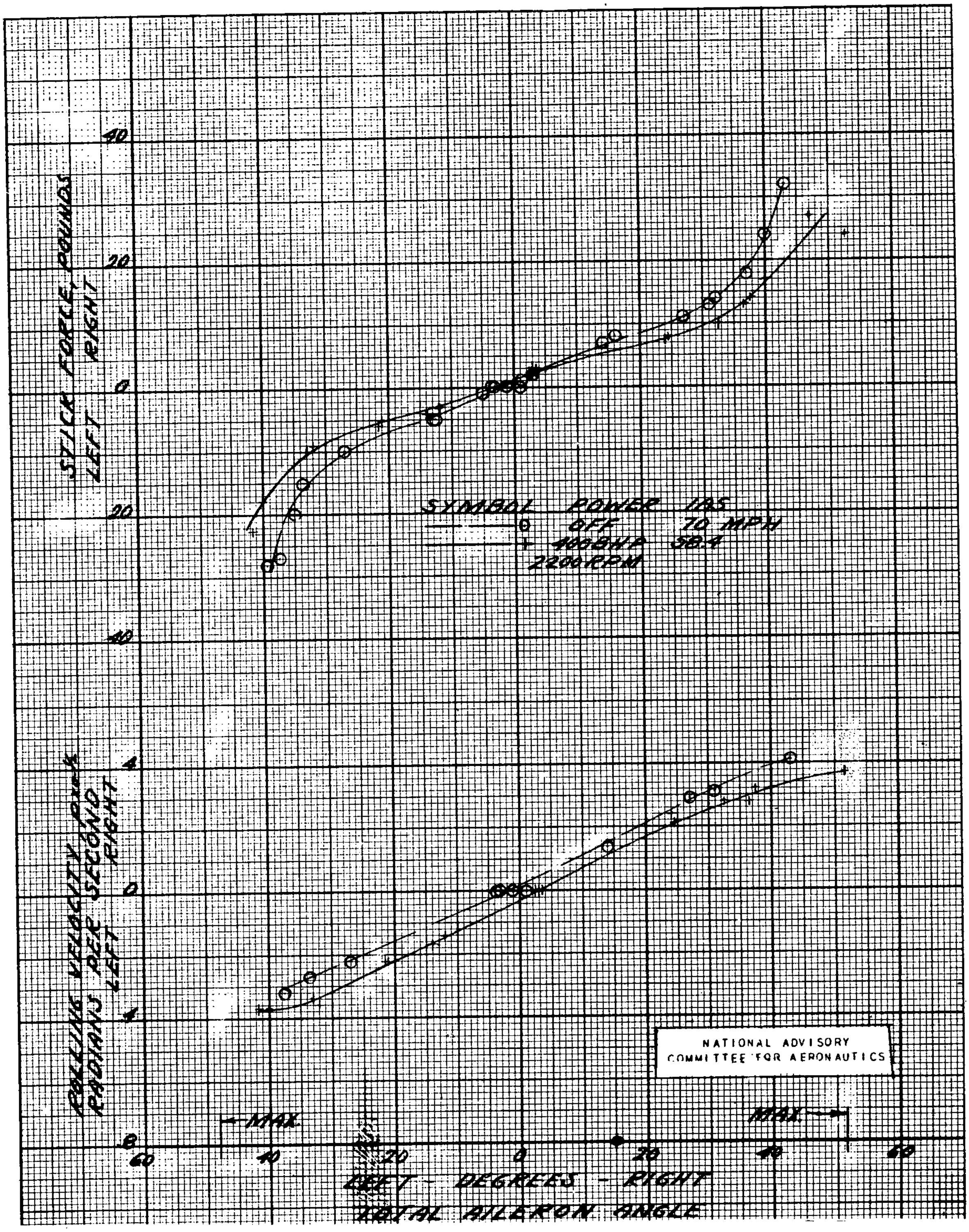

Figure 74.- Variation of maximum rolling velocity and stick force with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

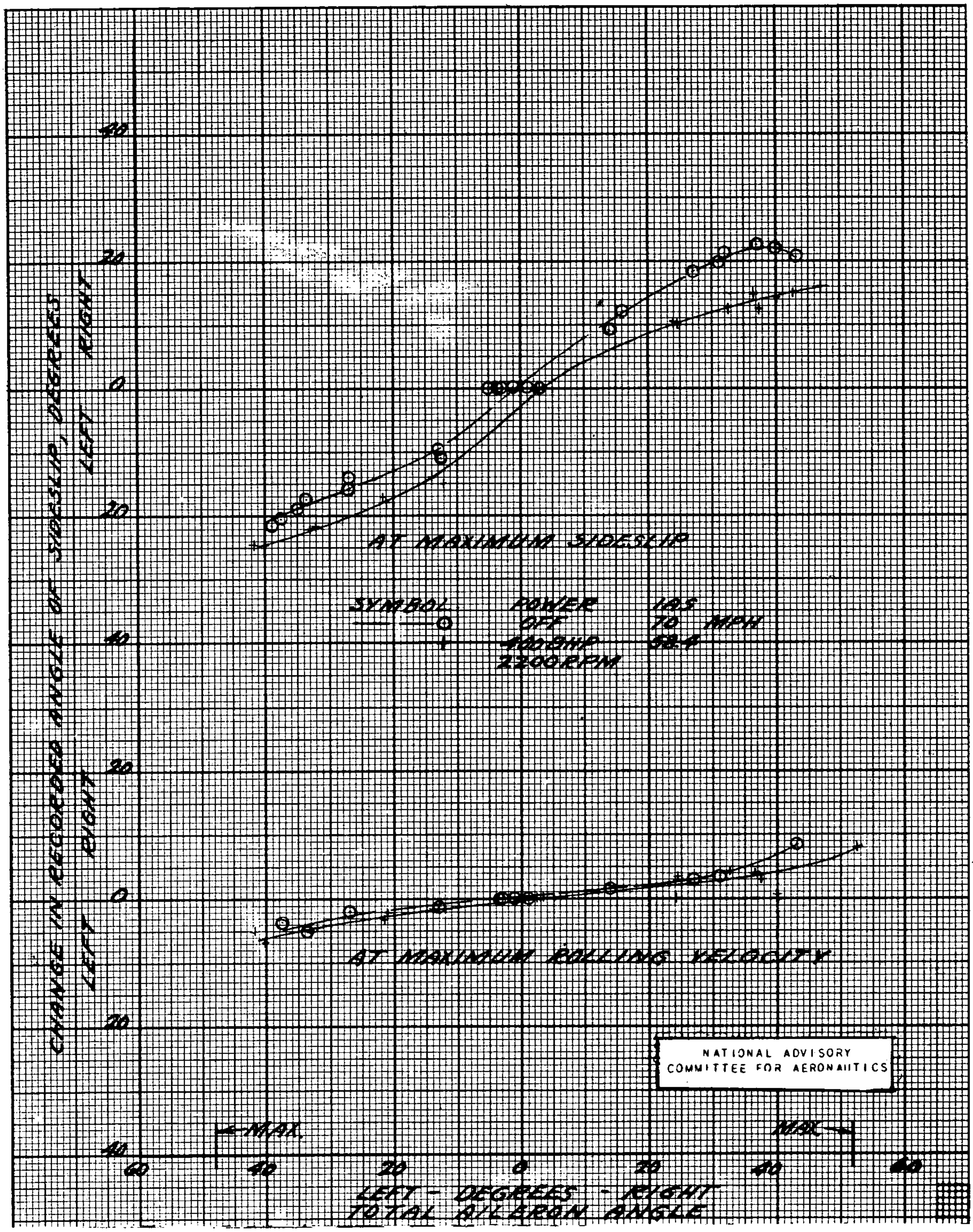

Figure 75.- Variation of sideslip angle with deflection of the lateral controls in abrupt aileron rolls with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

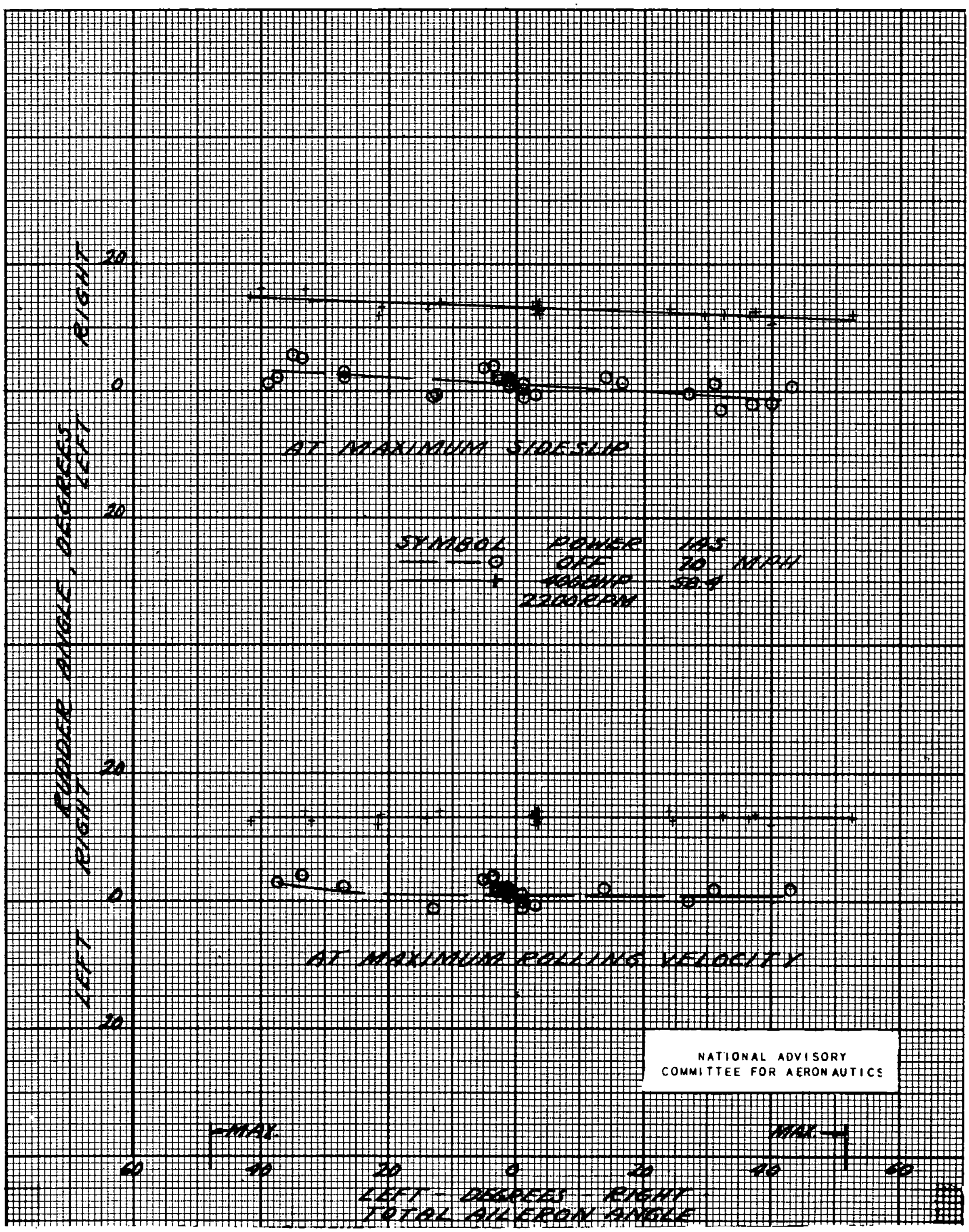

Figure 76.- Observed inadvertent movement of the rudder in aileron rolls in which it was attempted to hold the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

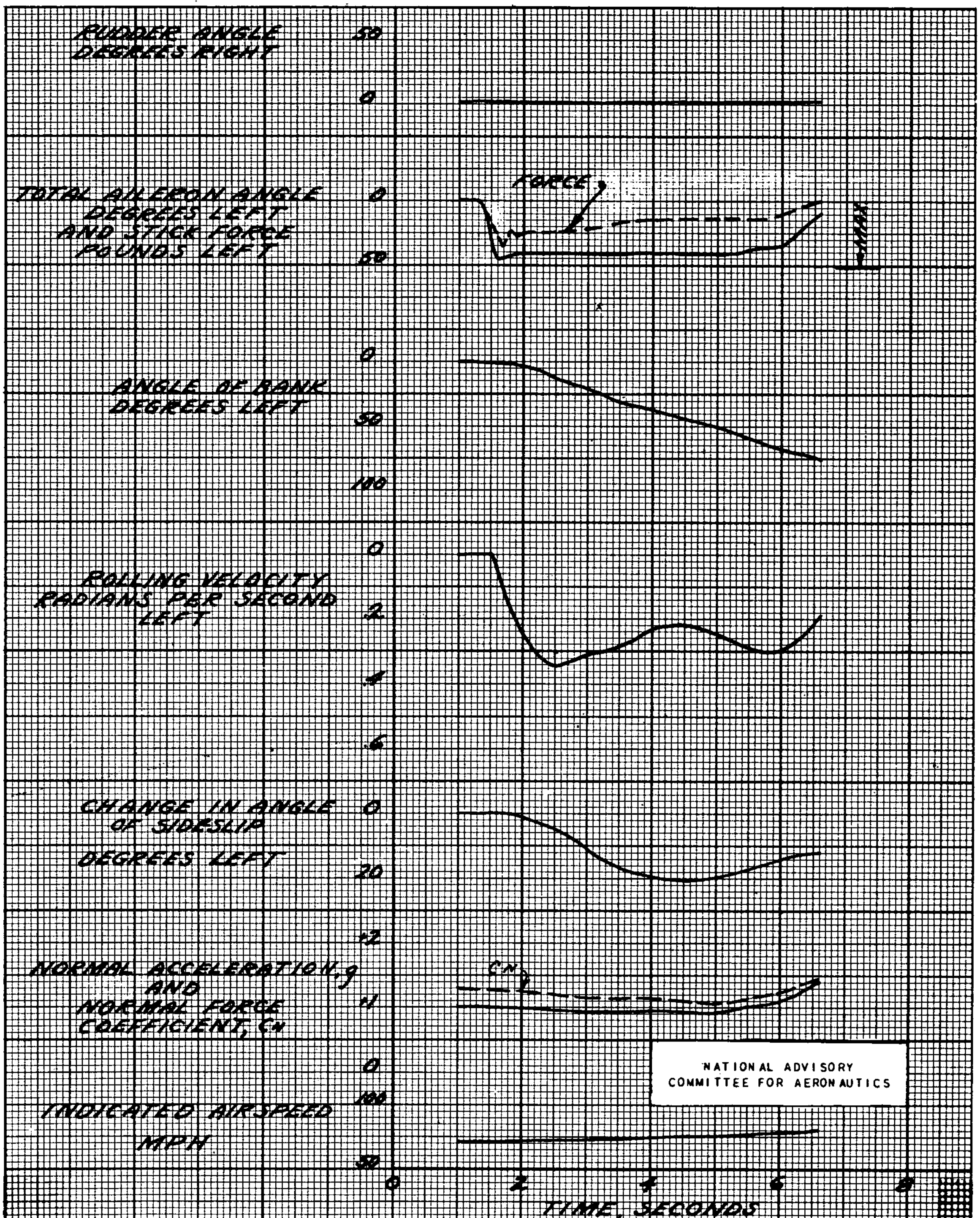

Figure 77.- Time history of a power off left aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

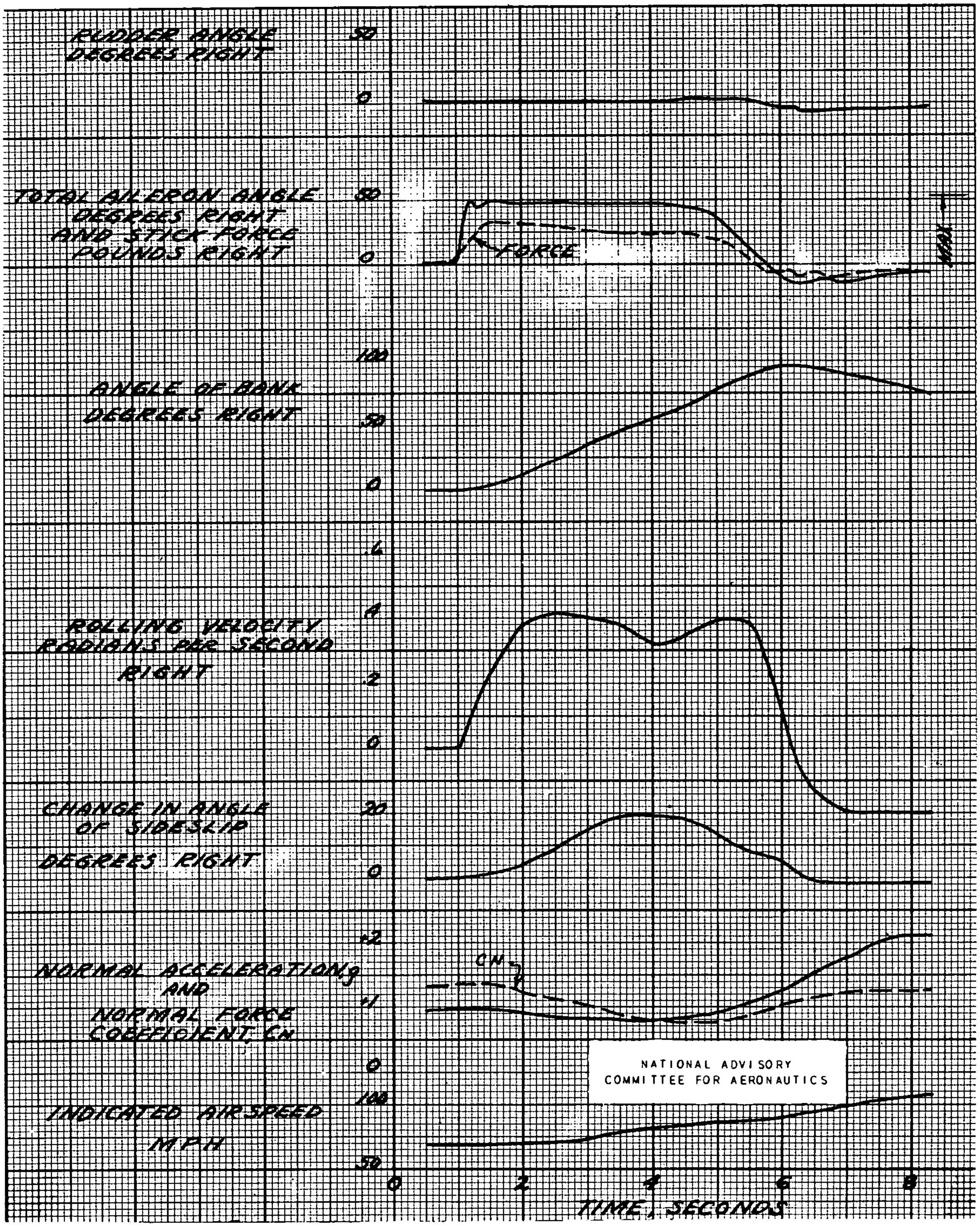

Figure 78.- Time history of a power off right aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

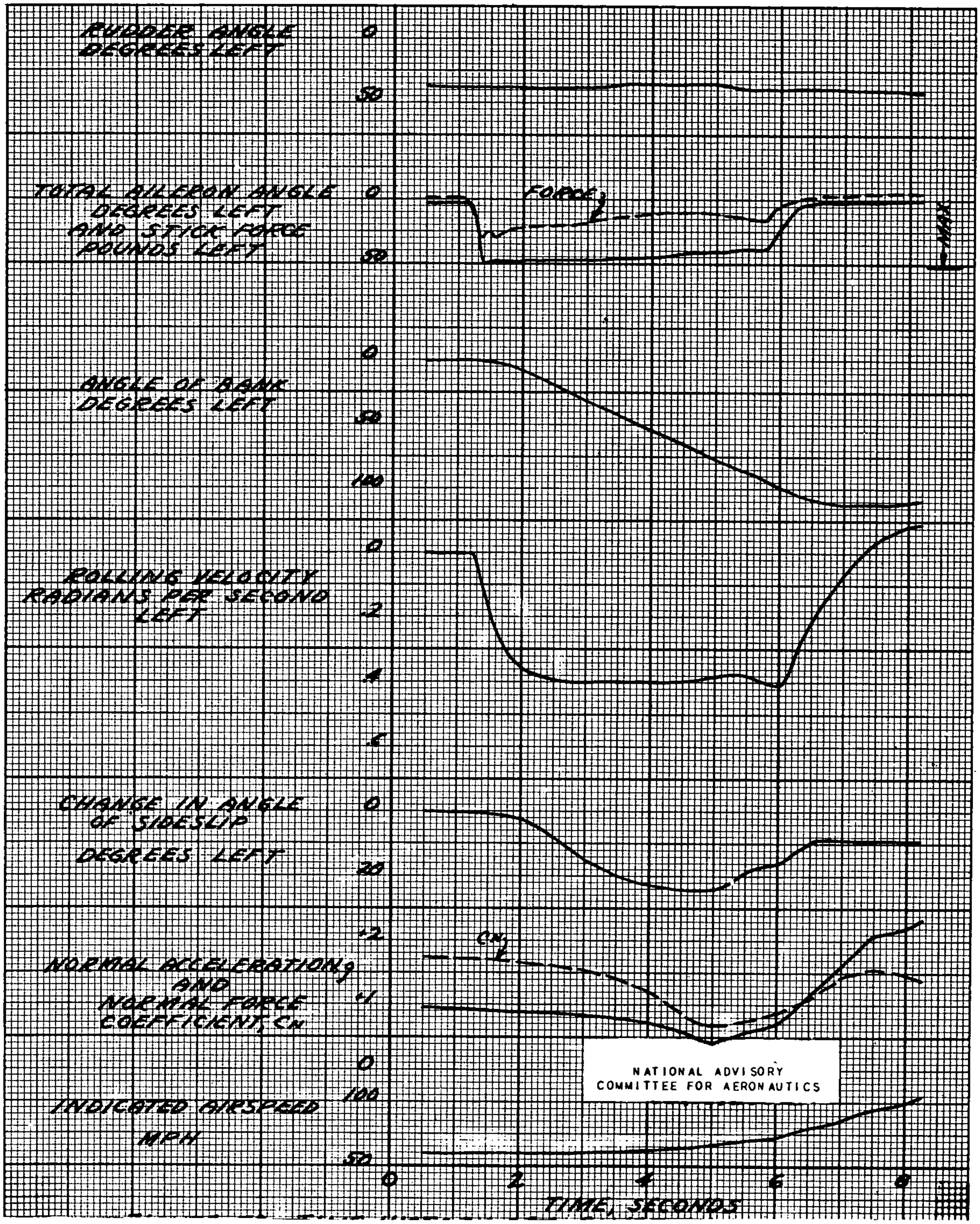

Figure 79.- Time history of a power on left aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

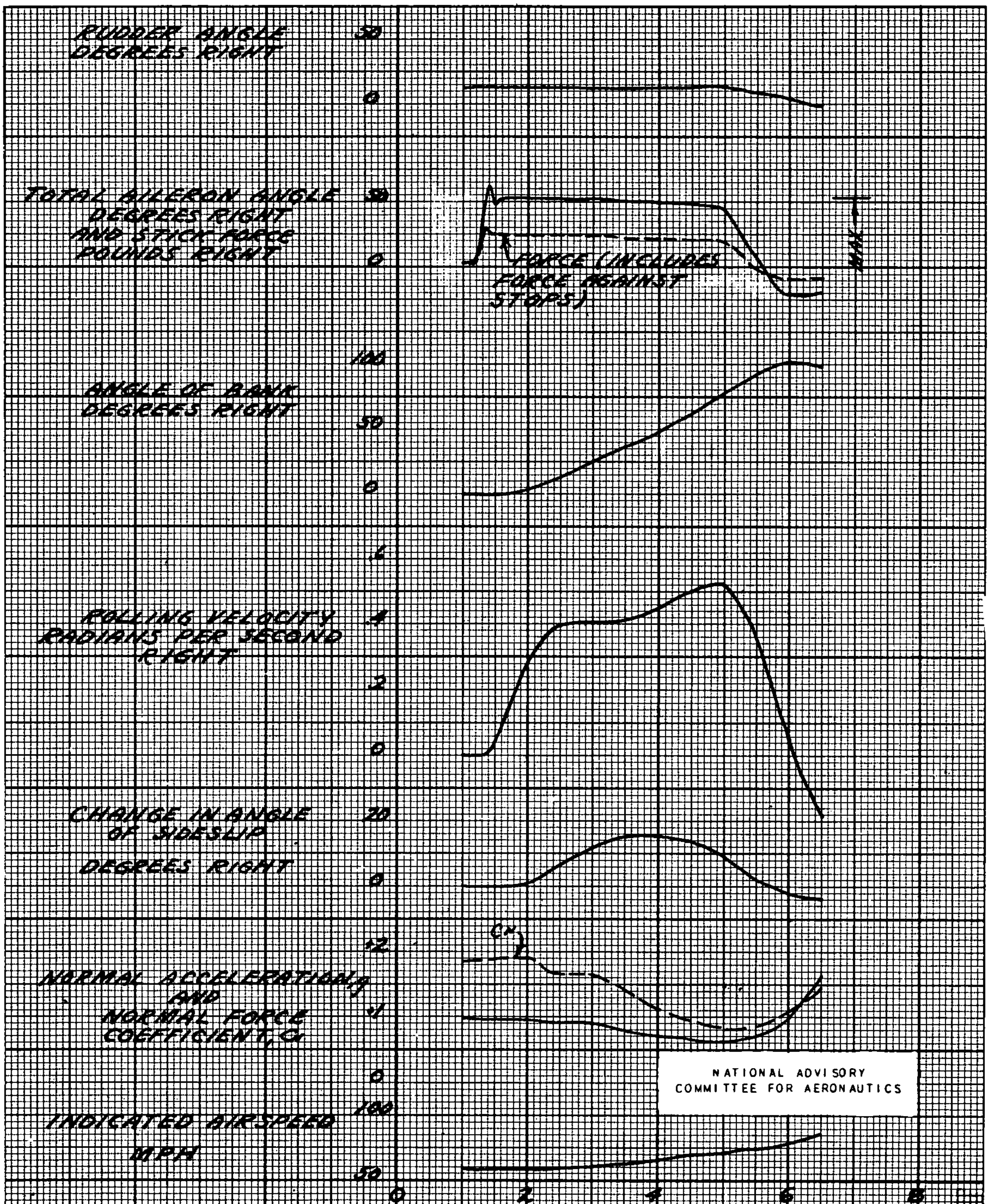

Figure 80.- Time history of a power on right aileron roll made with the rudder fixed in trim position. 0° aileron droop and flaps two-thirds down.

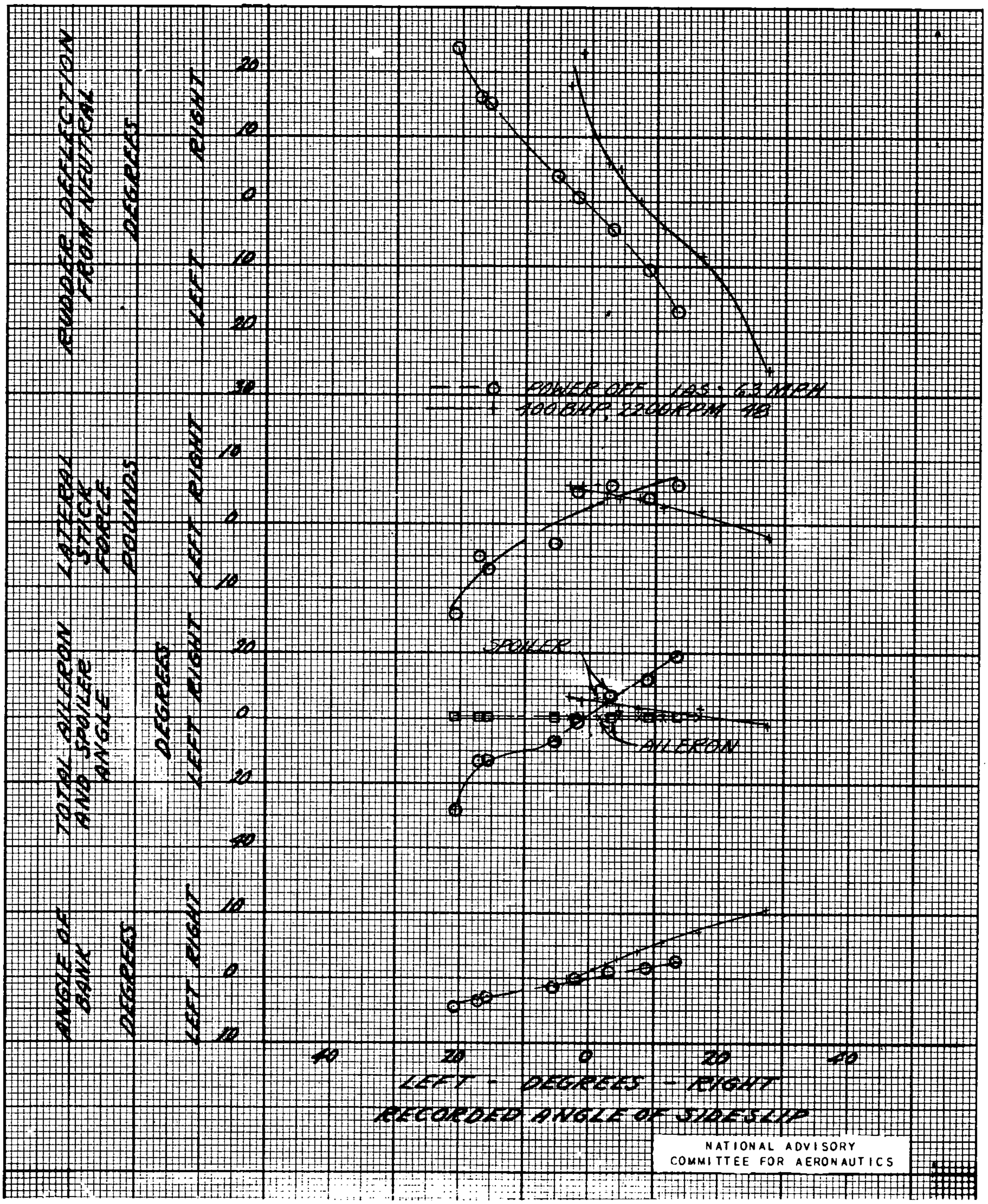

Figure 81.- Characteristics in steady sideslips. Flaps full down.

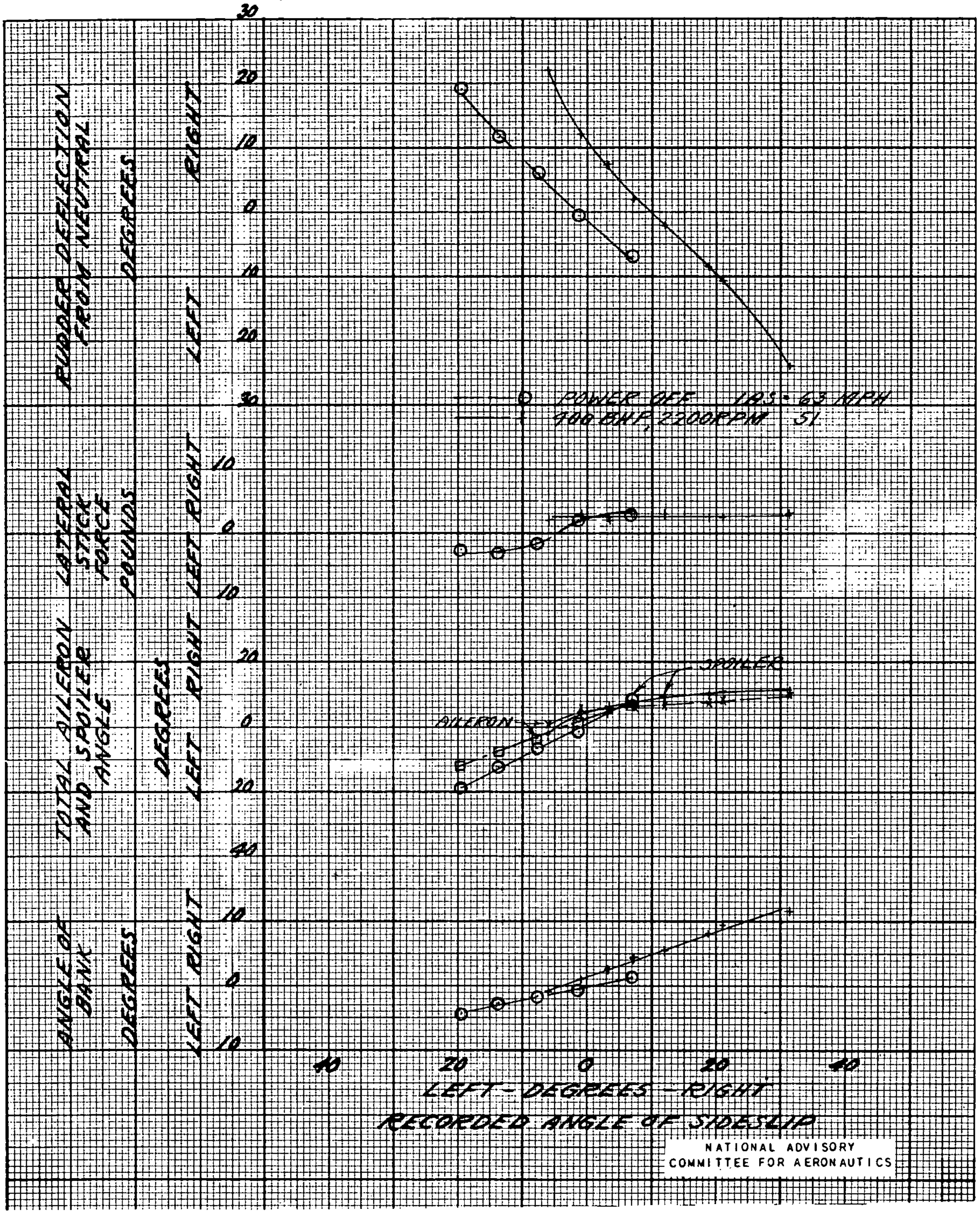

Figure 82.- Characteristics in steady sideslips. Flaps two-thirds down.

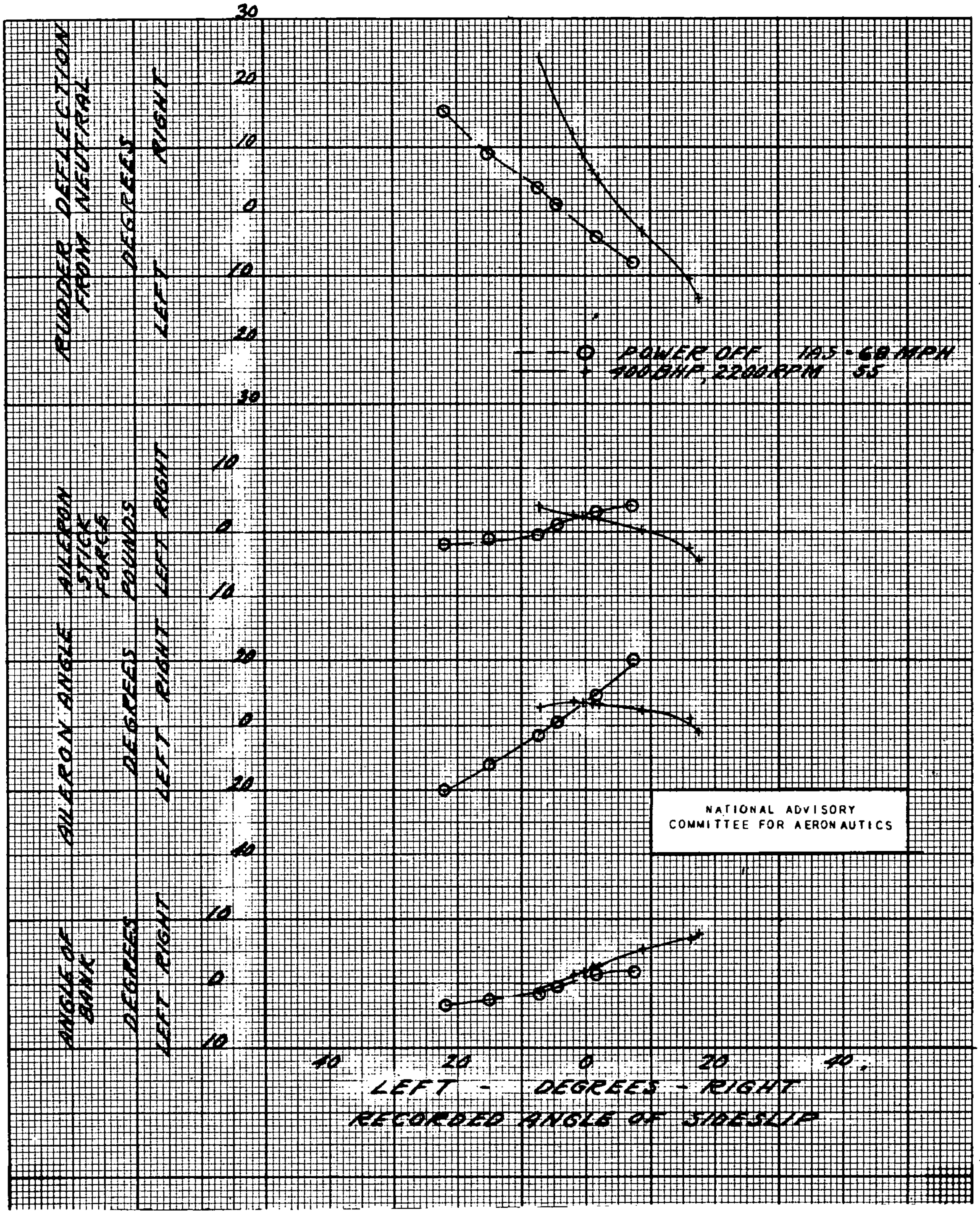

Figure 83.- Characteristics in steady sideslips. 15° aileron droop and flaps full down.

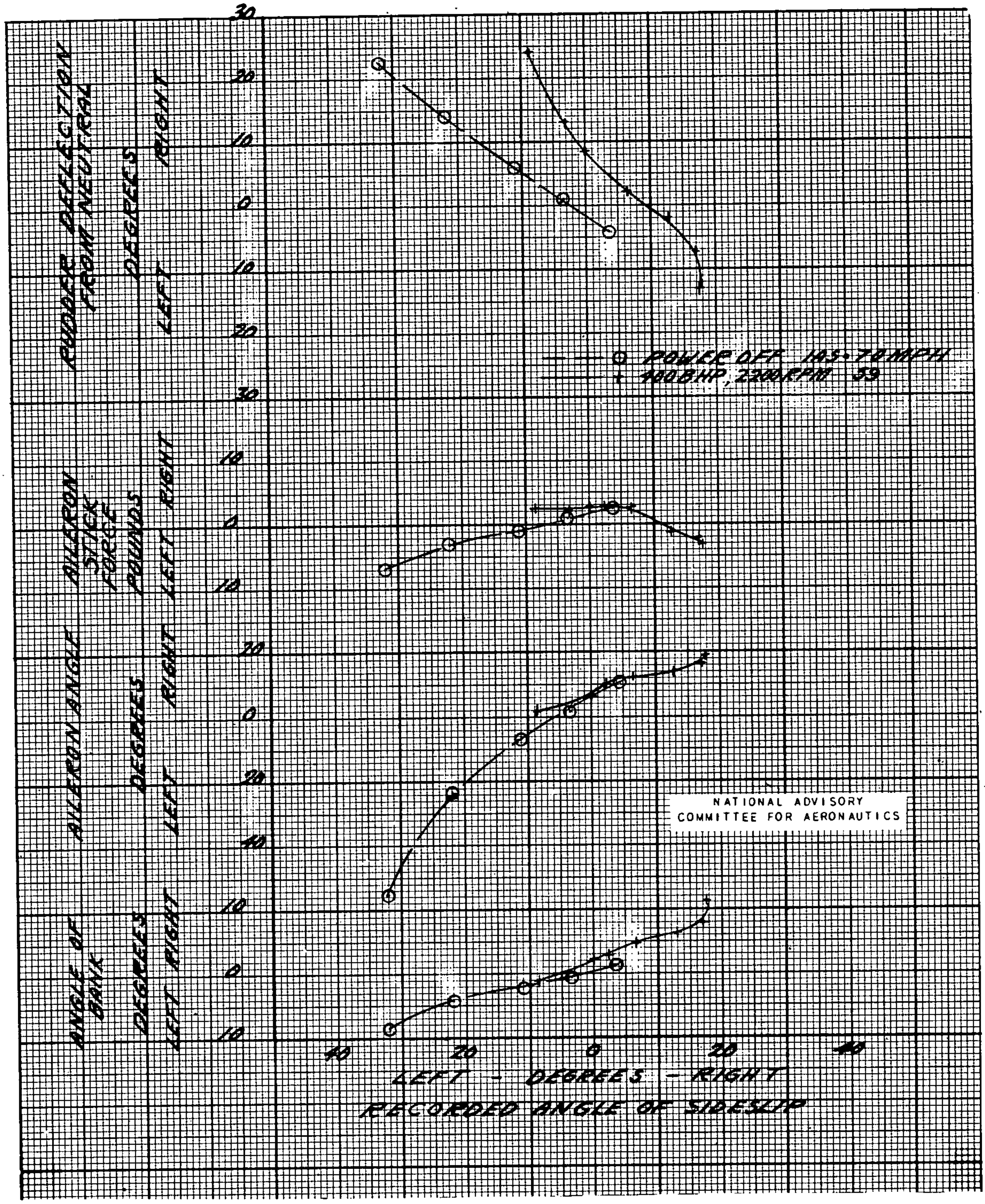

Figure 84.- Characteristics in steady sideslips. 15° aileron droop and flaps two-thirds down.

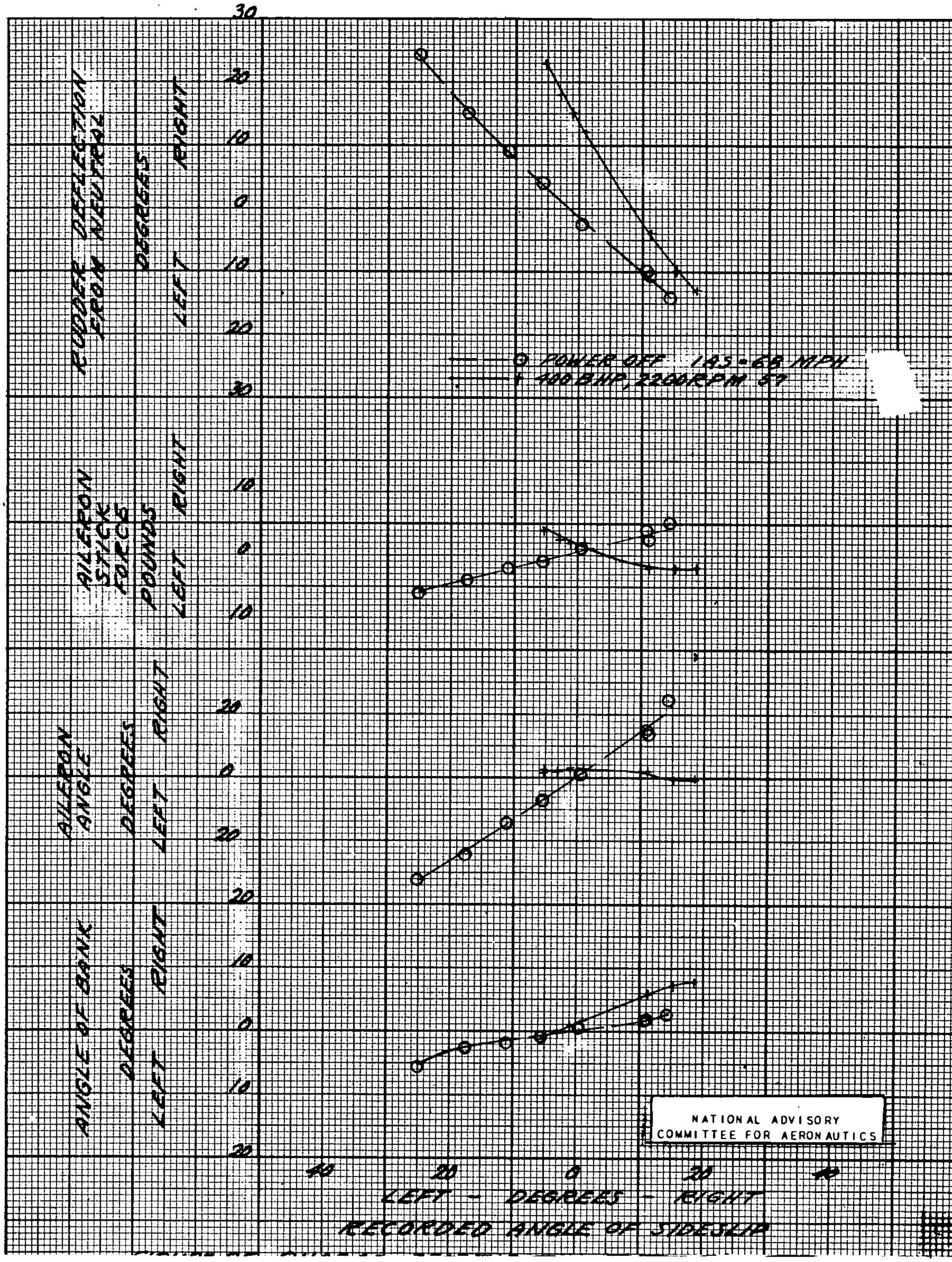

Figure 85.- Characteristics in steady sideslips. 10° aileron droop and flaps full down.

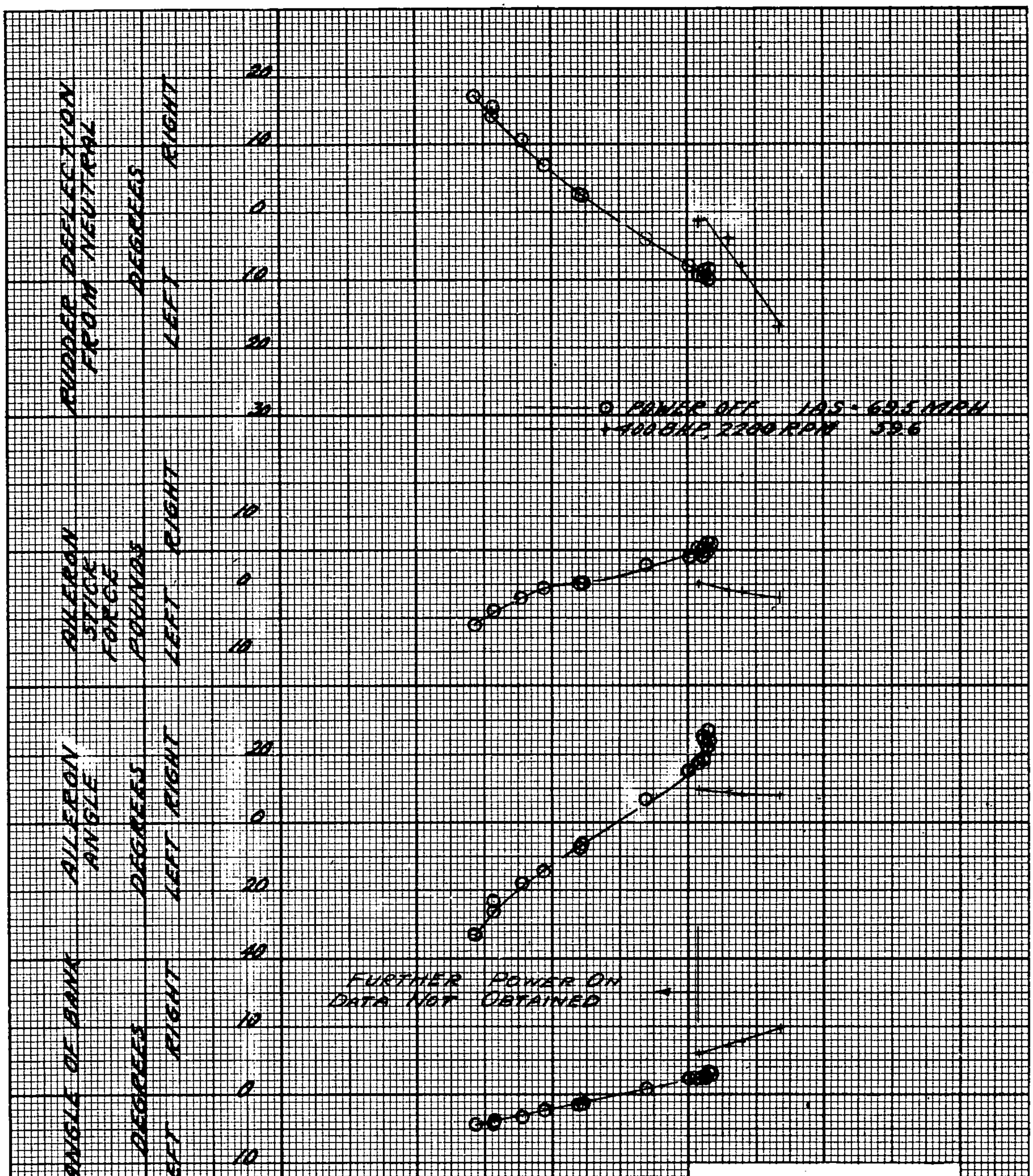

Figure 86.- Characteristics in steady sideslips. 10° aileron droop and flaps two-thirds down.

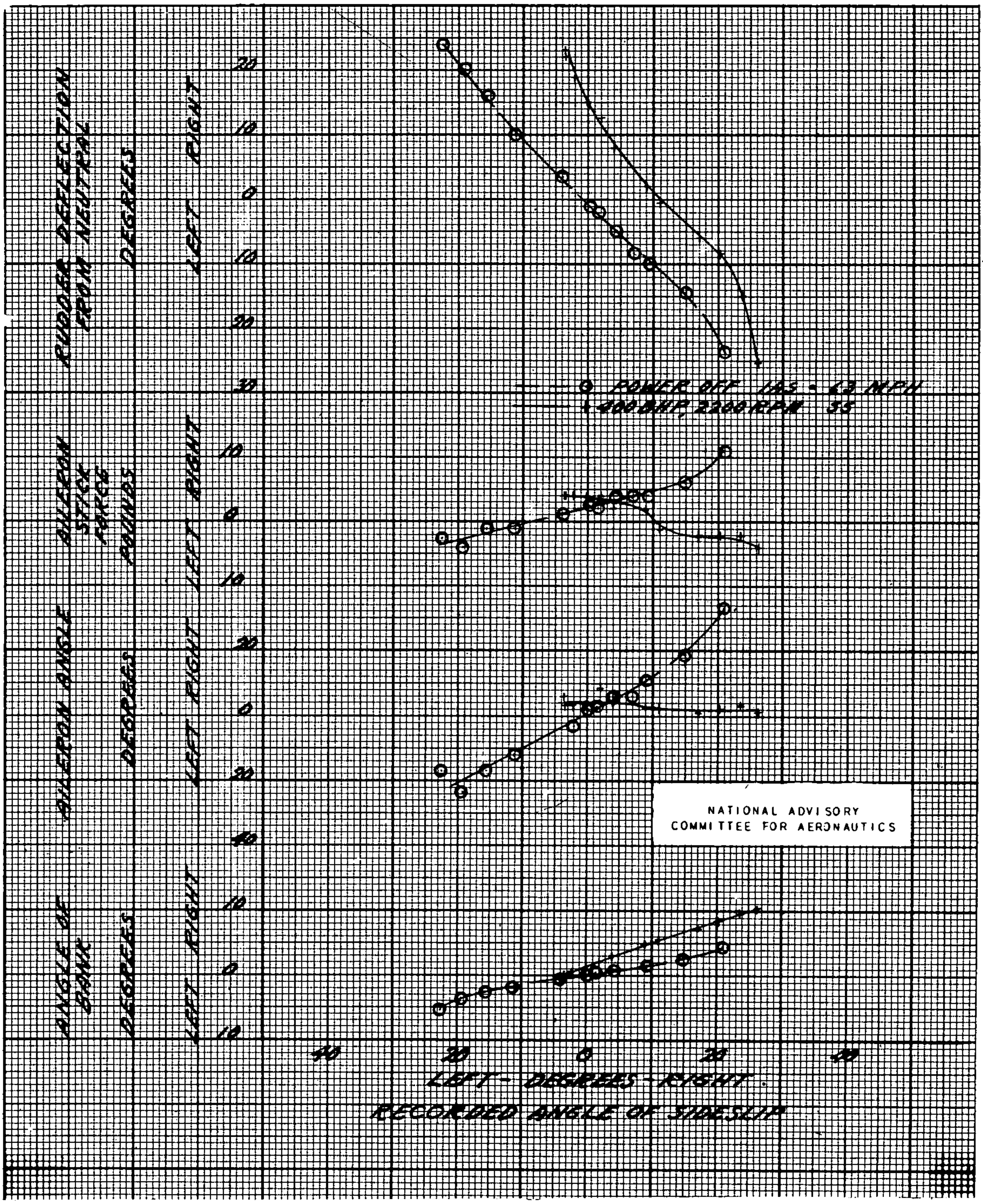

Figure 87.- Characteristics in steady sideslips. 0° aileron droop and flaps full down.

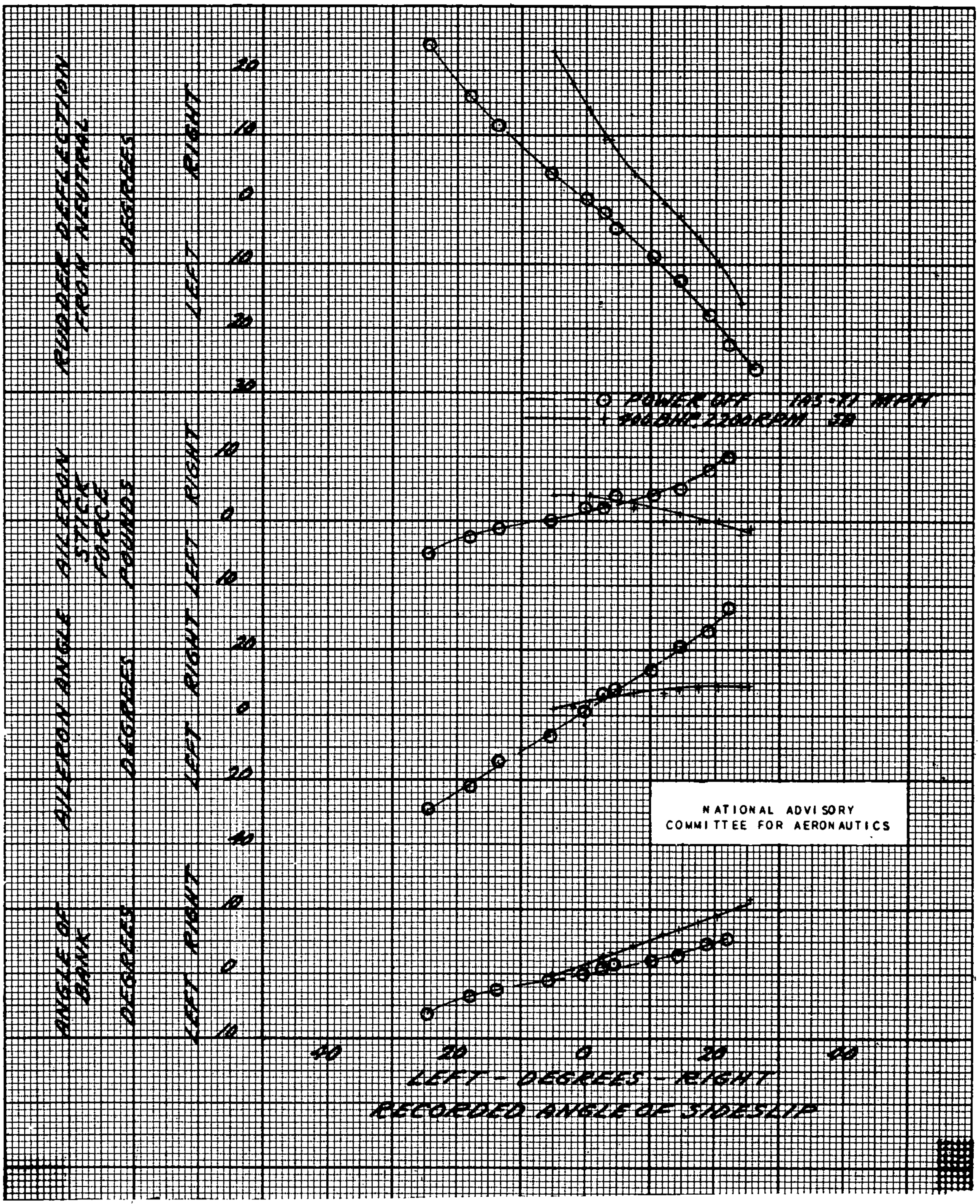

Figure 88.- Characteristics in steady sideslips. 0° aileron droop and flaps two-thirds down.

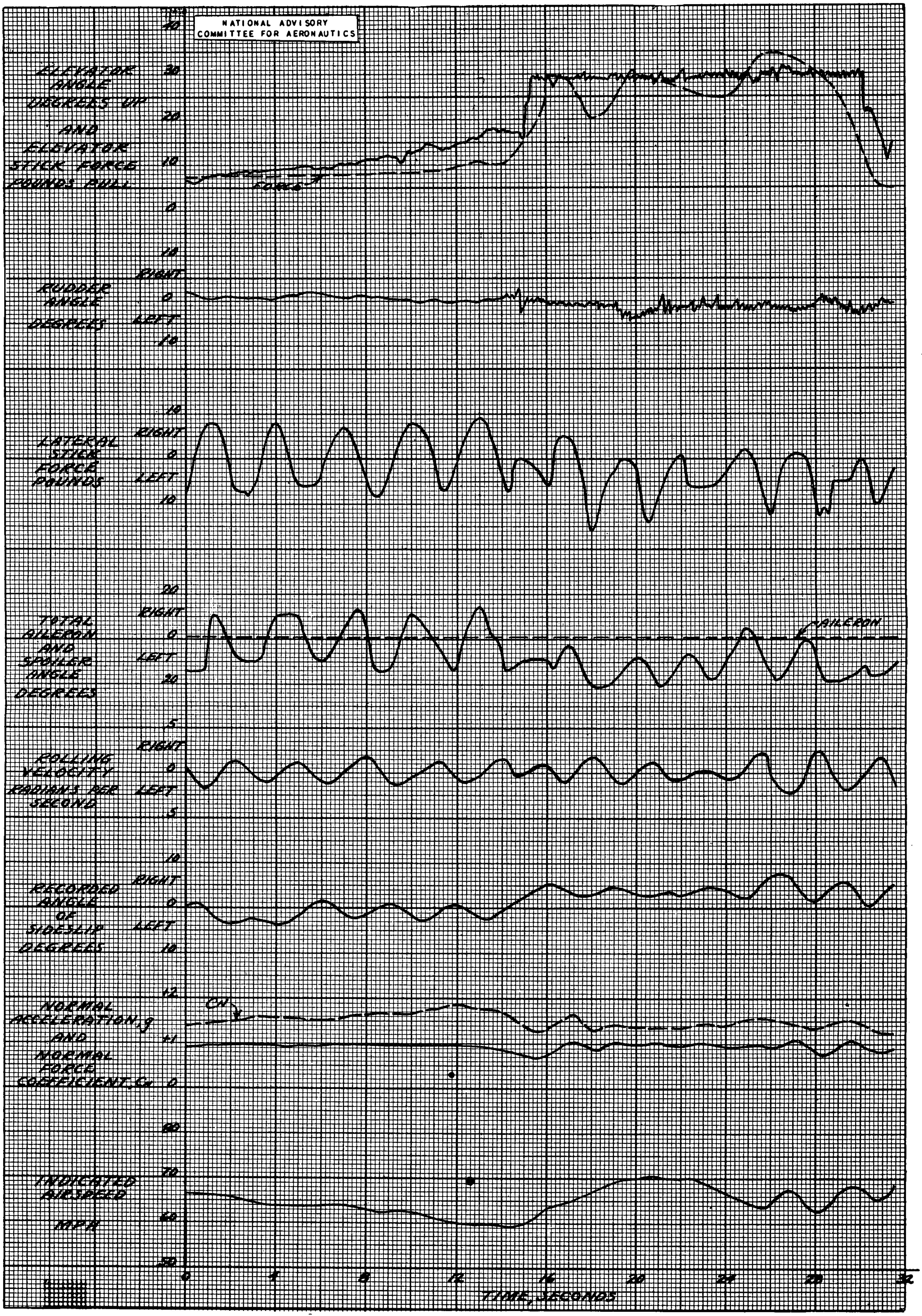

Figure 89.- Time history of a power off stall. Flaps full down.

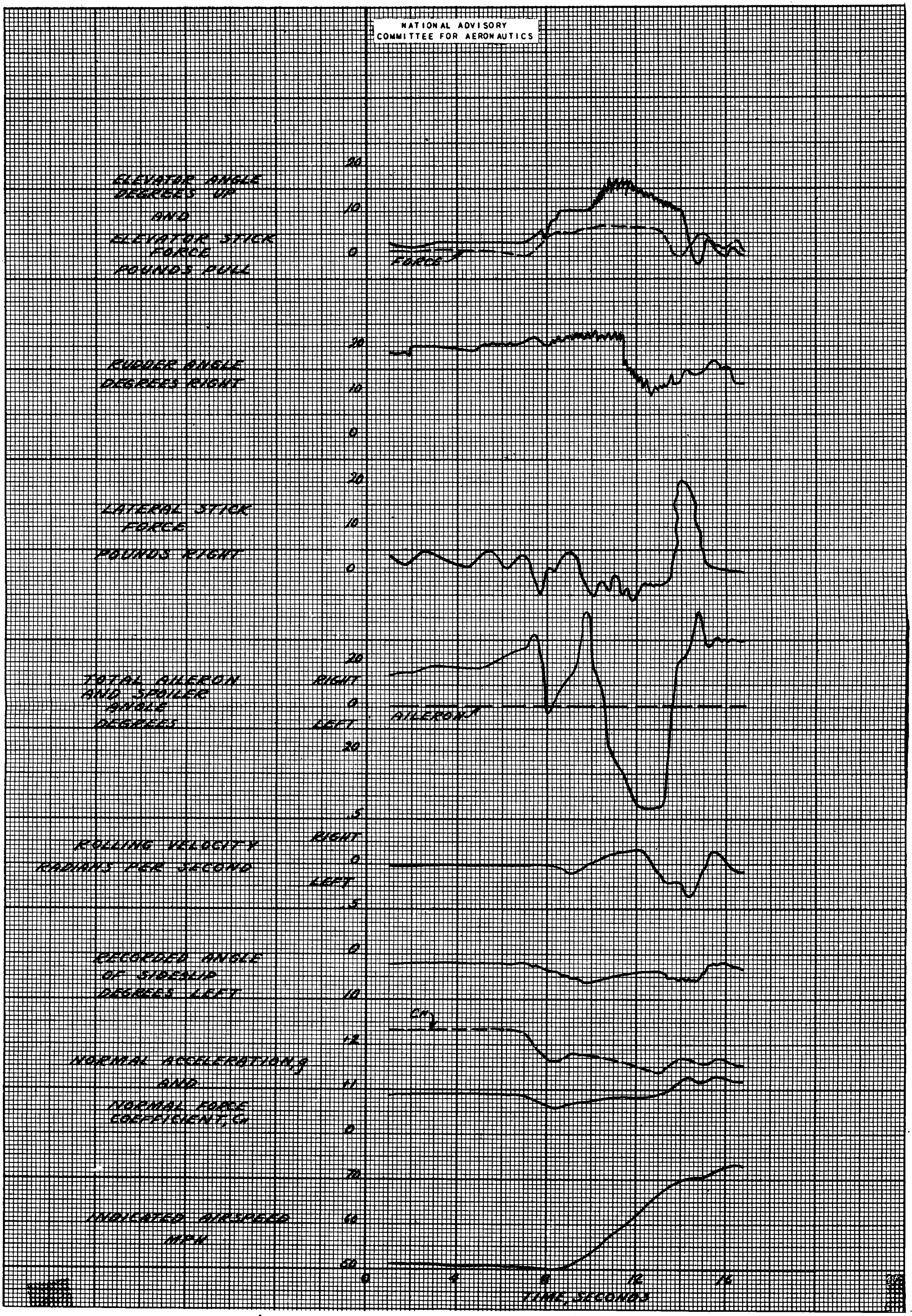

Figure 90.- Time history of a power on stall. Flaps full down.

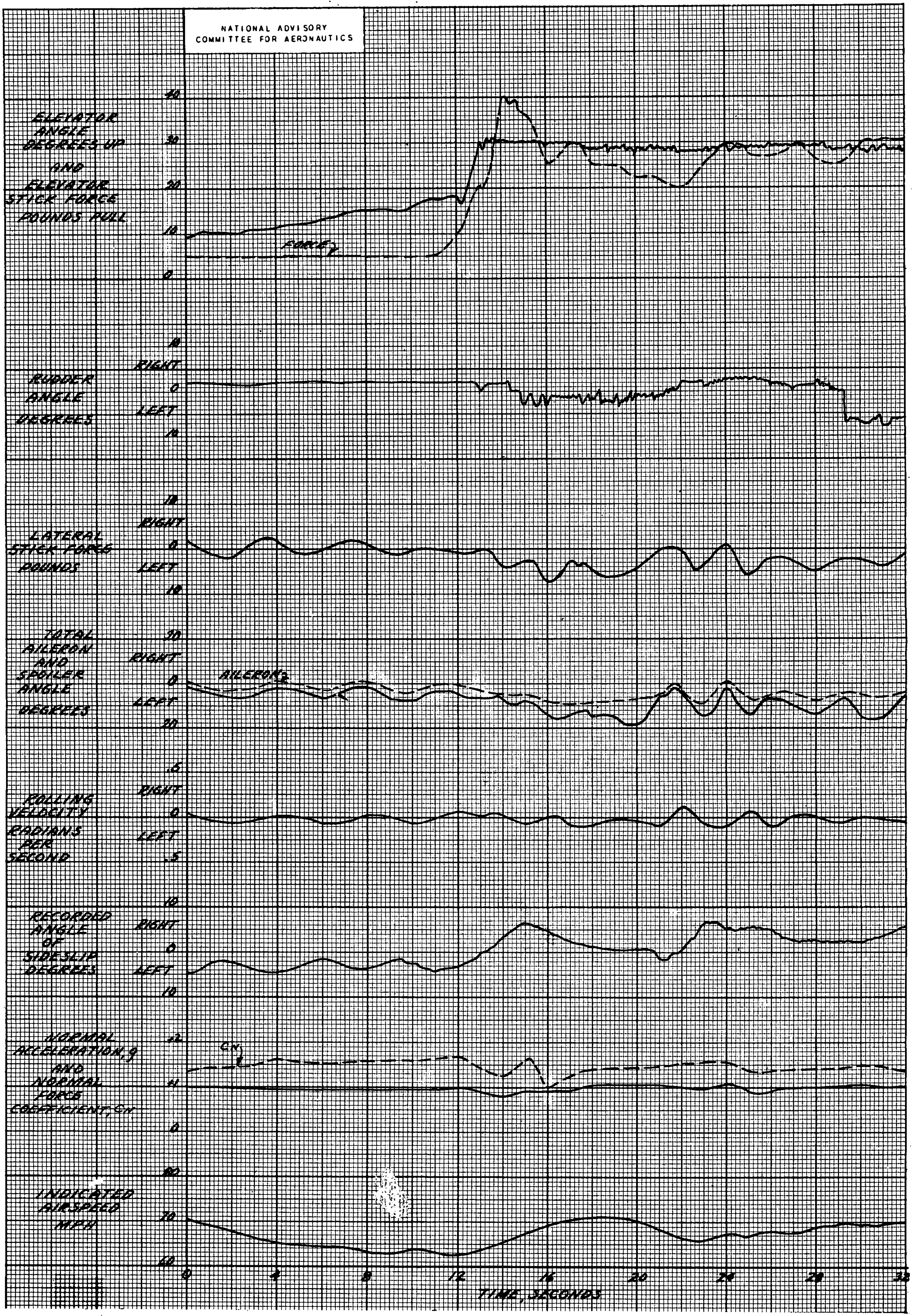

Figure 91.- Time history of a power off stall. Flaps two-thirds down.

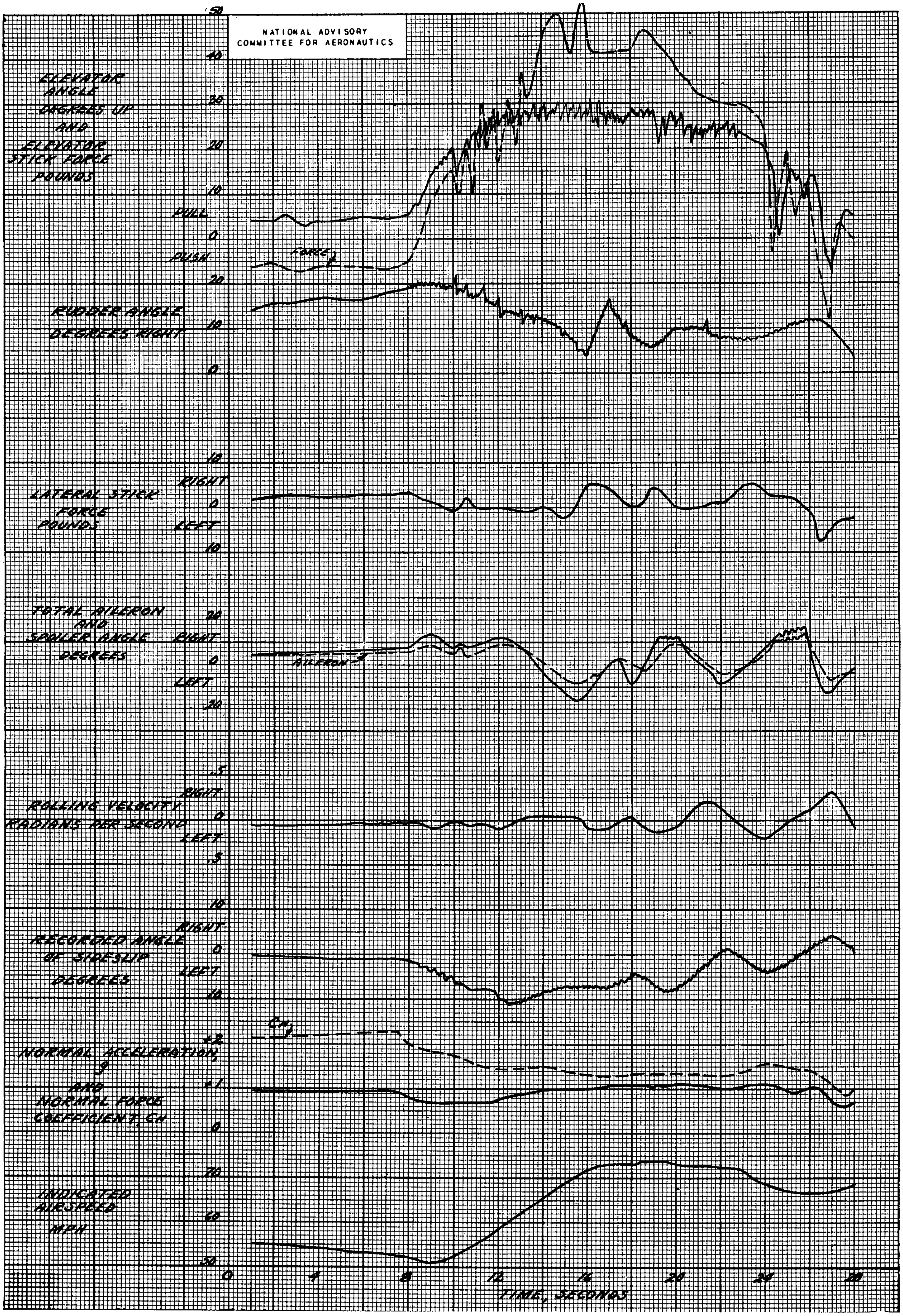

Figure 92.- Time history of a power on stall. Flaps two-thirds down.

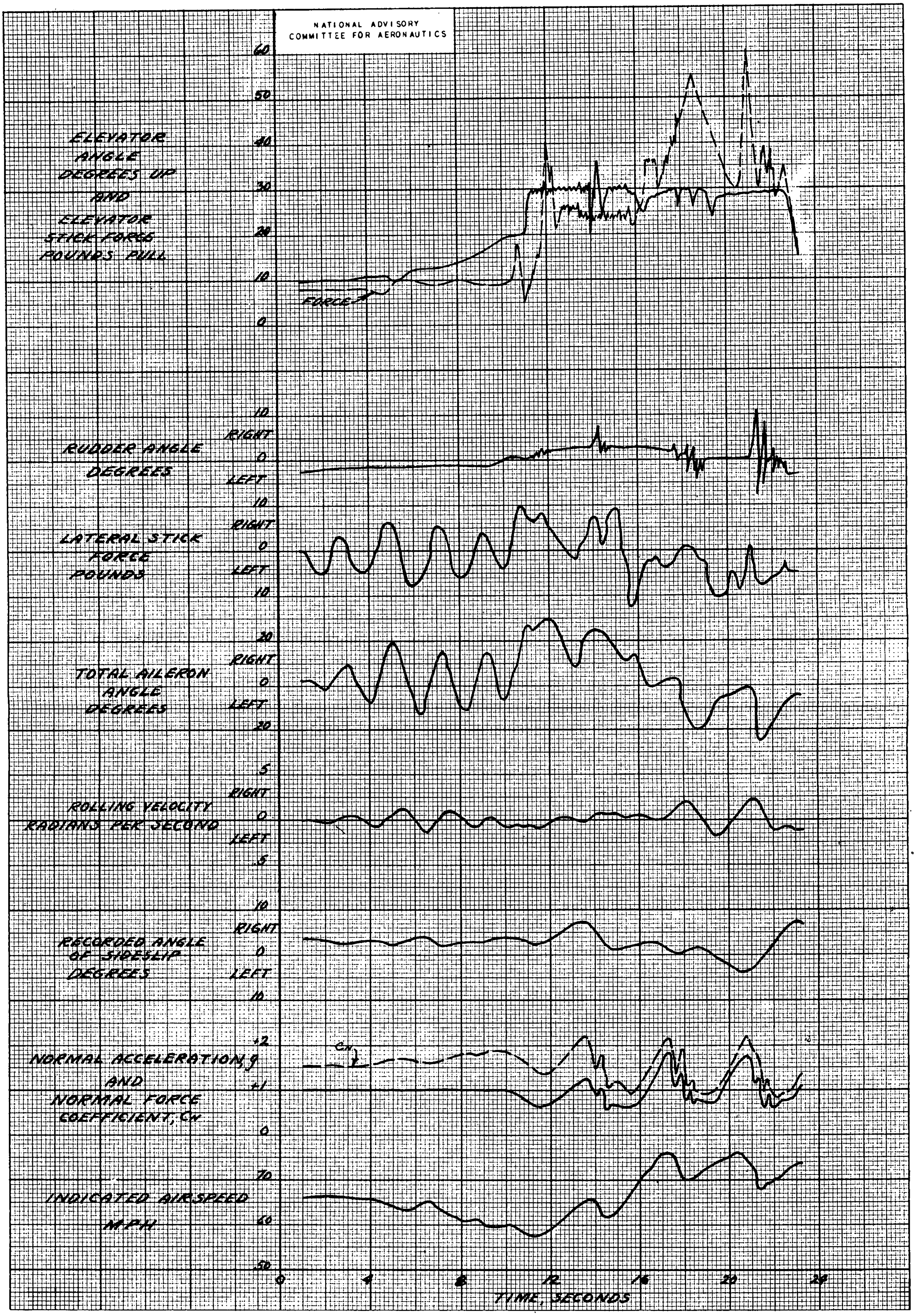

Figure 93.- Time history of a power off stall. 15° aileron droop and flaps full down.

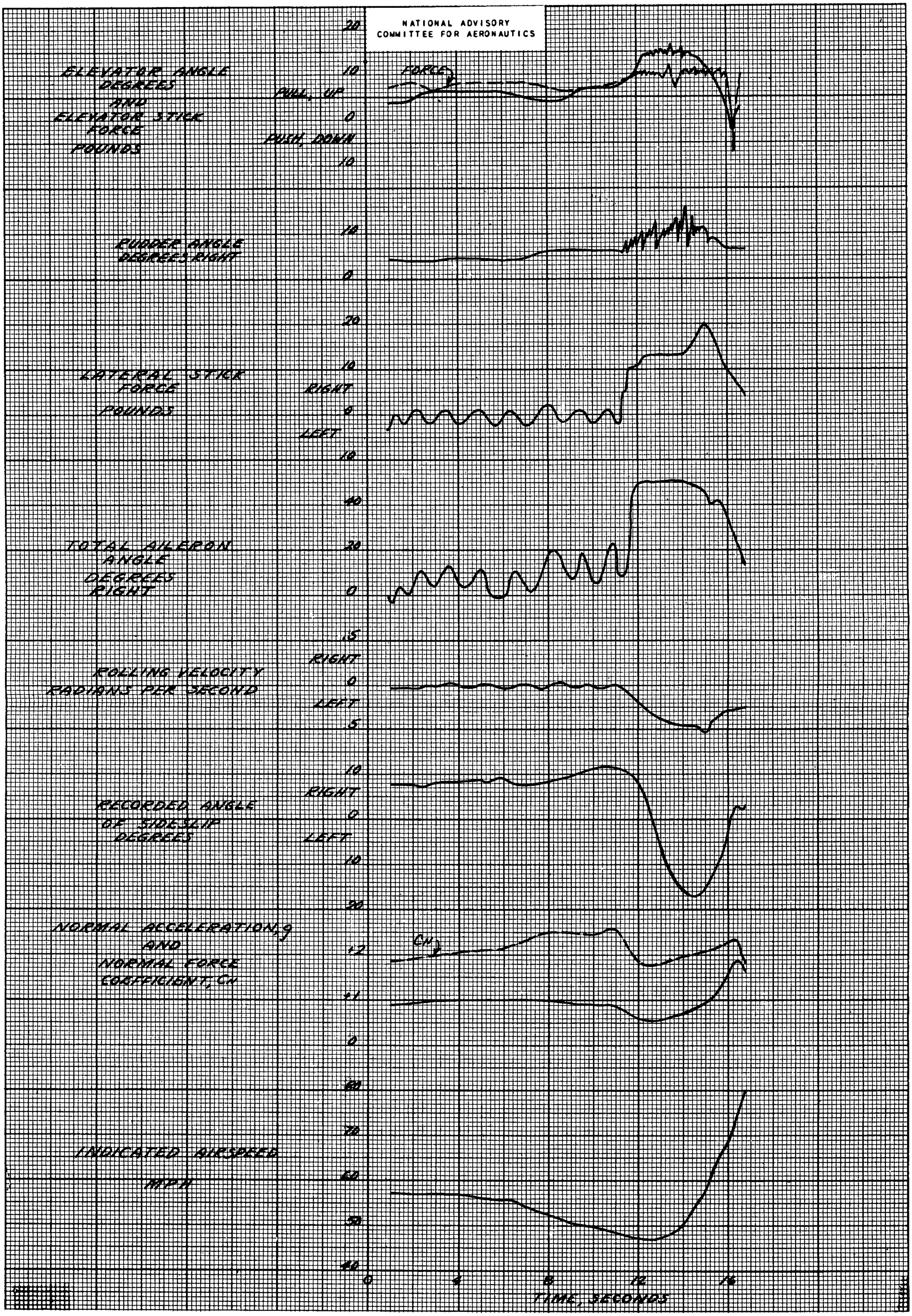

Figure 94.- Time history of a power on stall. 15° aileron droop and flaps full down.

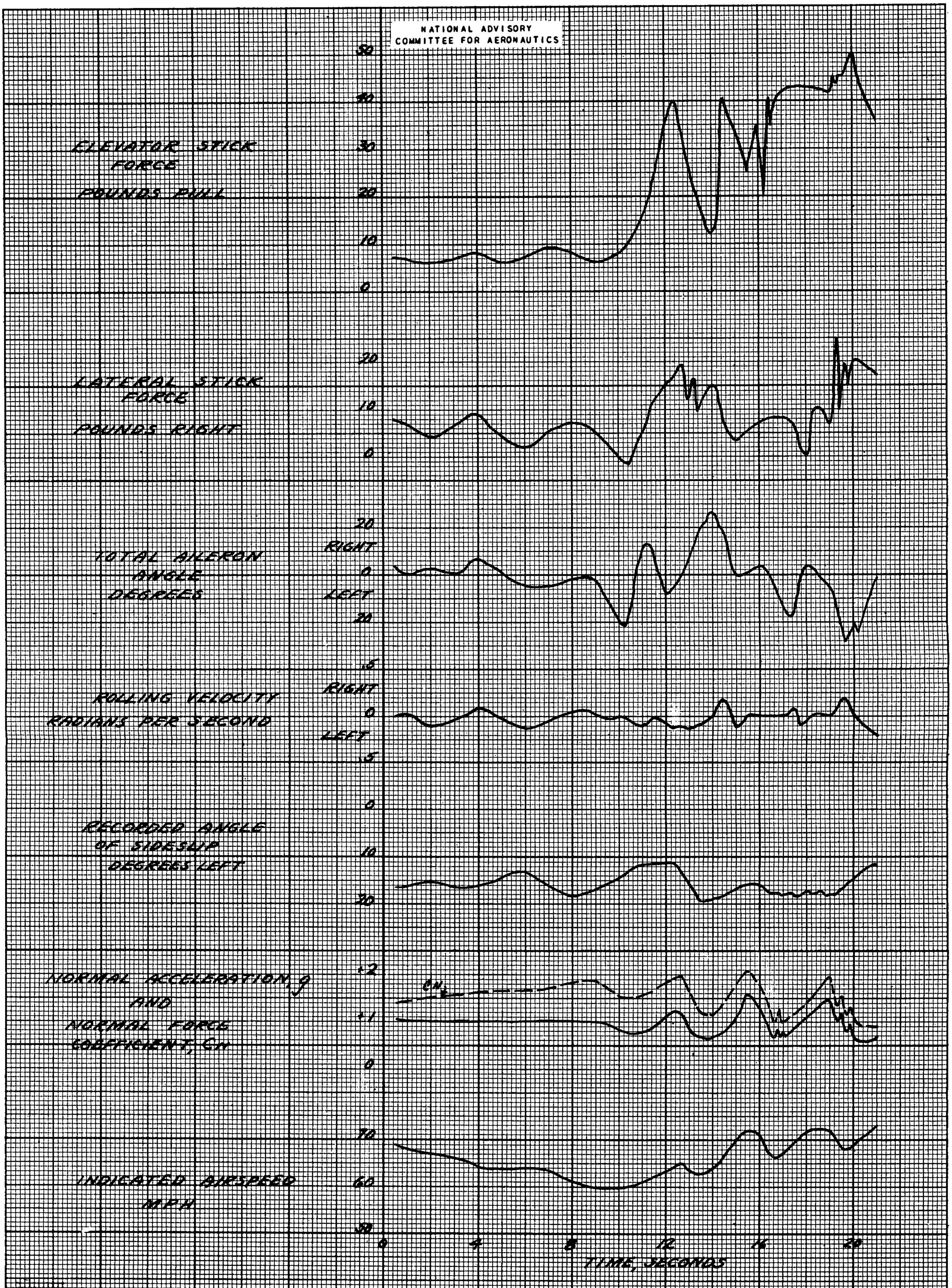

Figure 95.- Time history of a power off stall. 15° aileron droop and flaps two-thirds down.

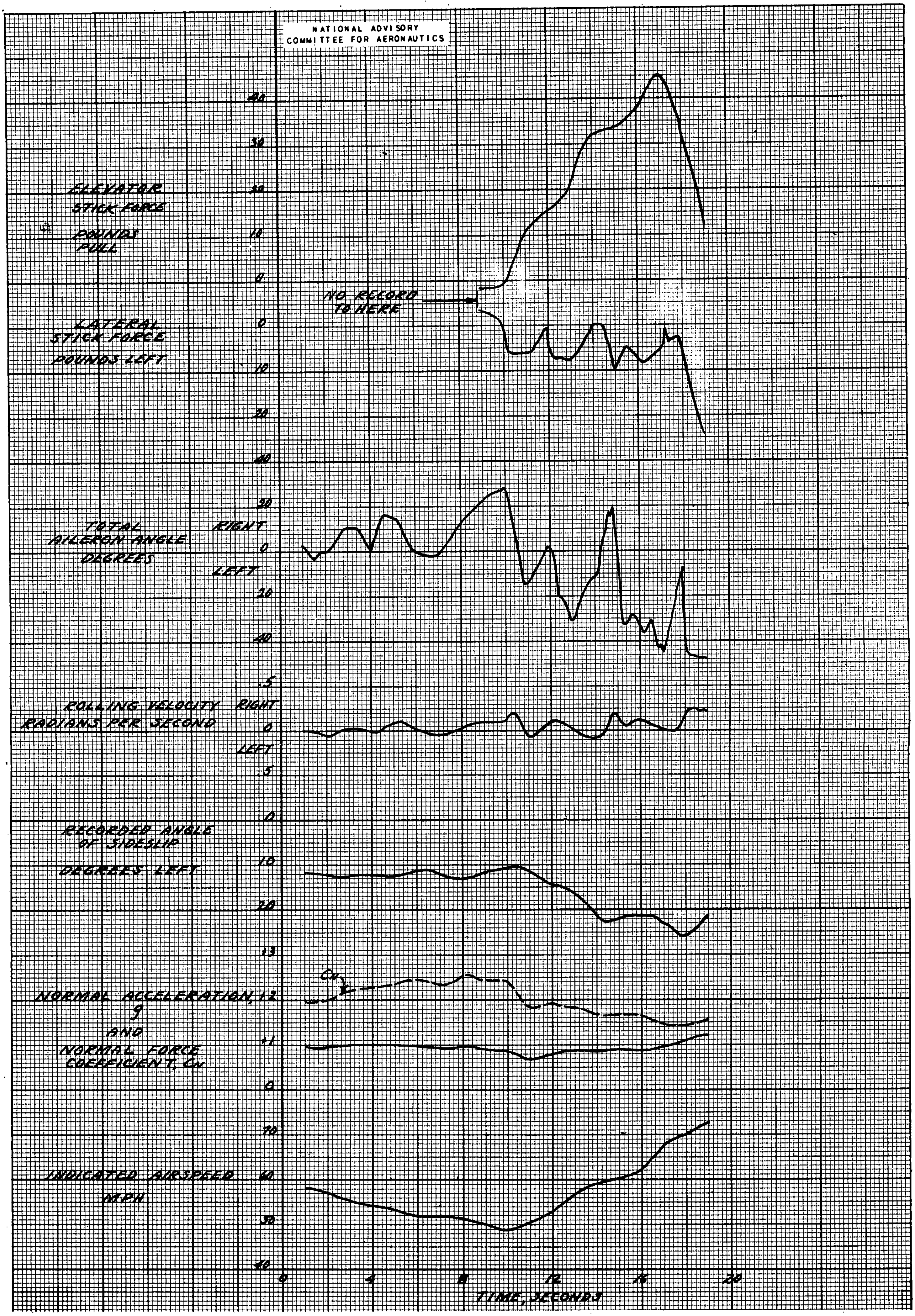

Figure 96.- Time history of a power on stall. 15° aileron droop and flaps two-thirds down.

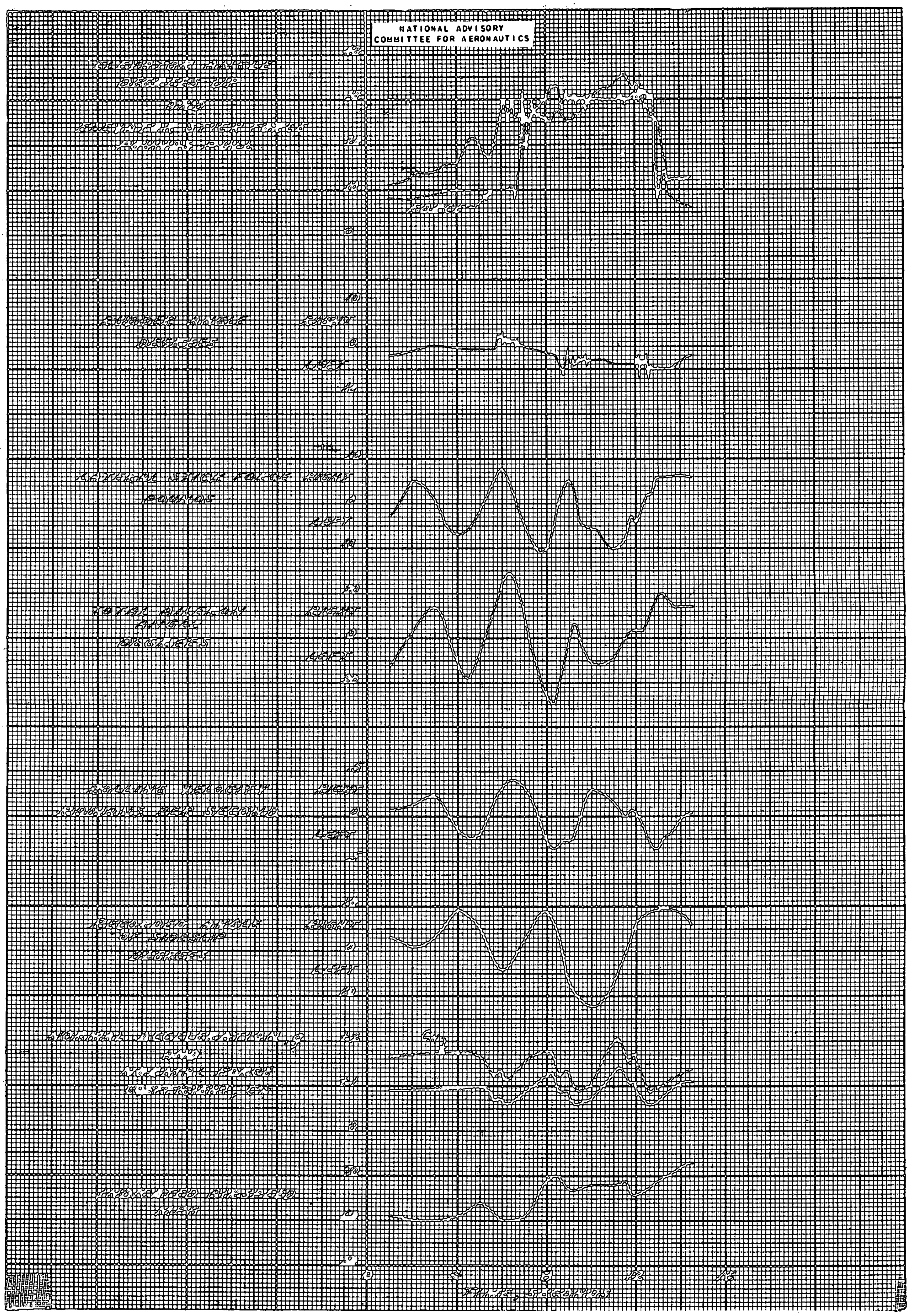

Figure 97.- Time history of a power off stall. 10° aileron droop and flaps full down.

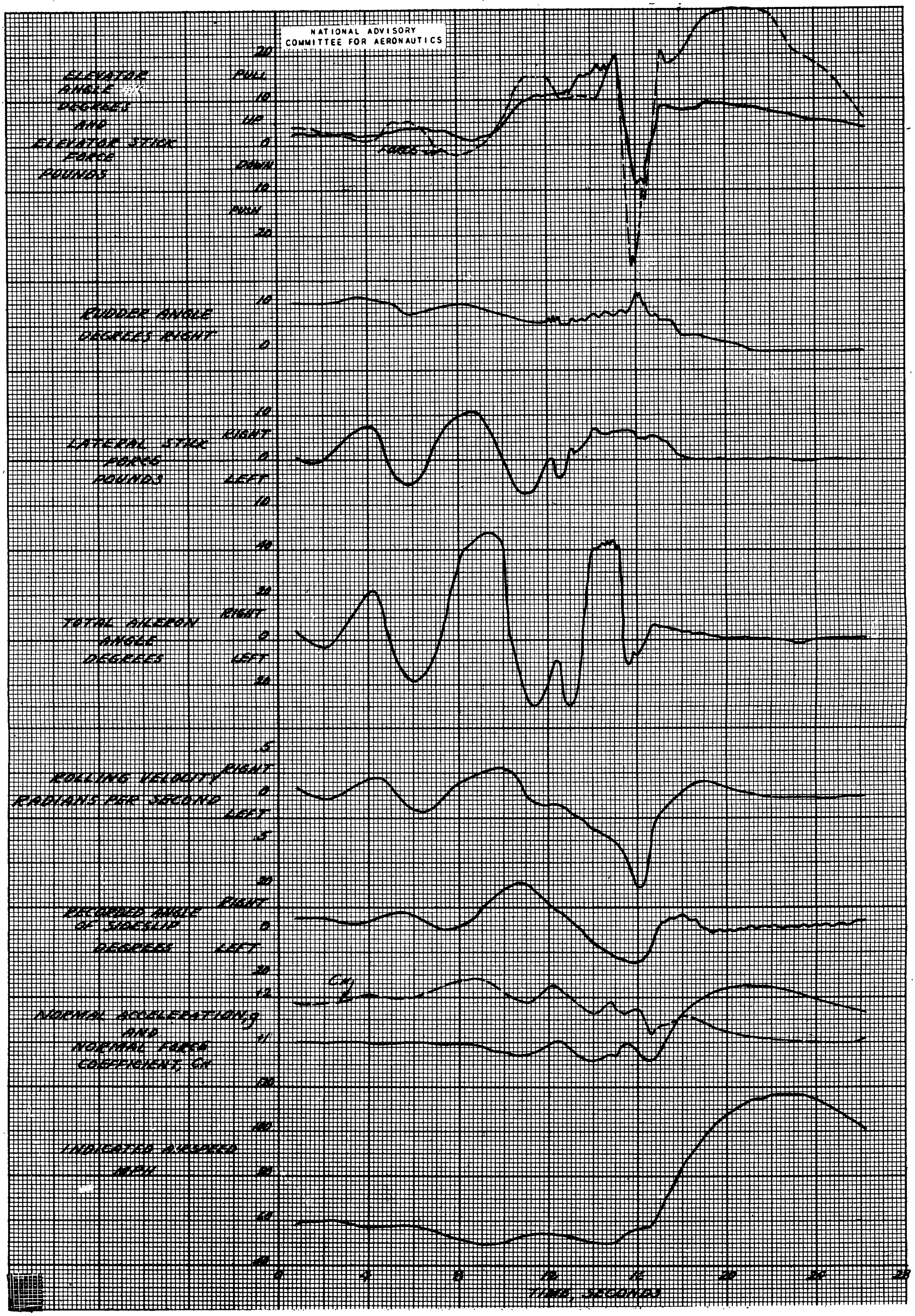

Figure 98.- Time history of a power on stall. 10° aileron droop and flaps full down.

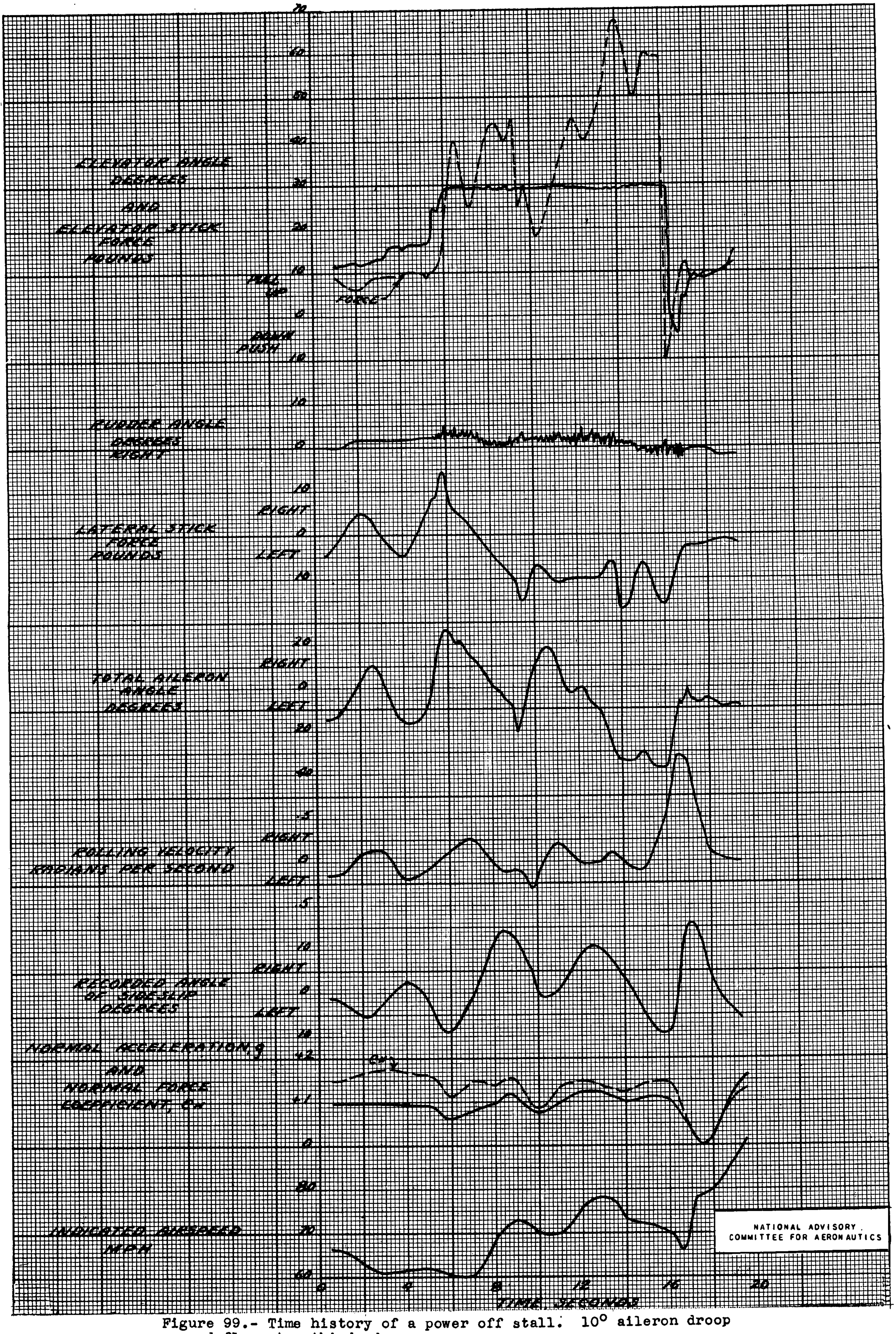

Figure 99.- Time history of a power off stall. 10° aileron droop and flaps two-thirds down.

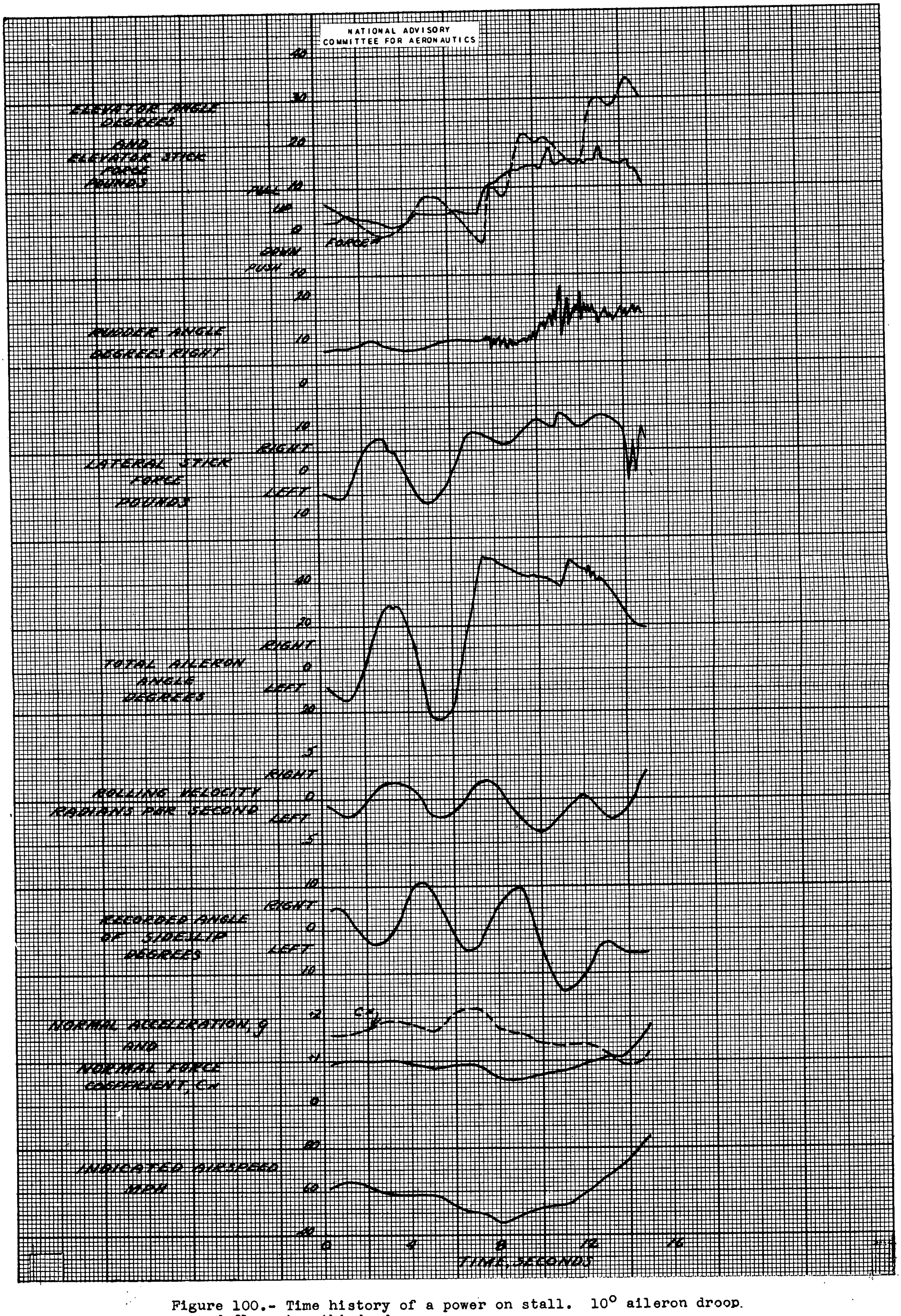

Figure 100.- Time history of a power on stall. 10° aileron droop and flaps two-thirds down.

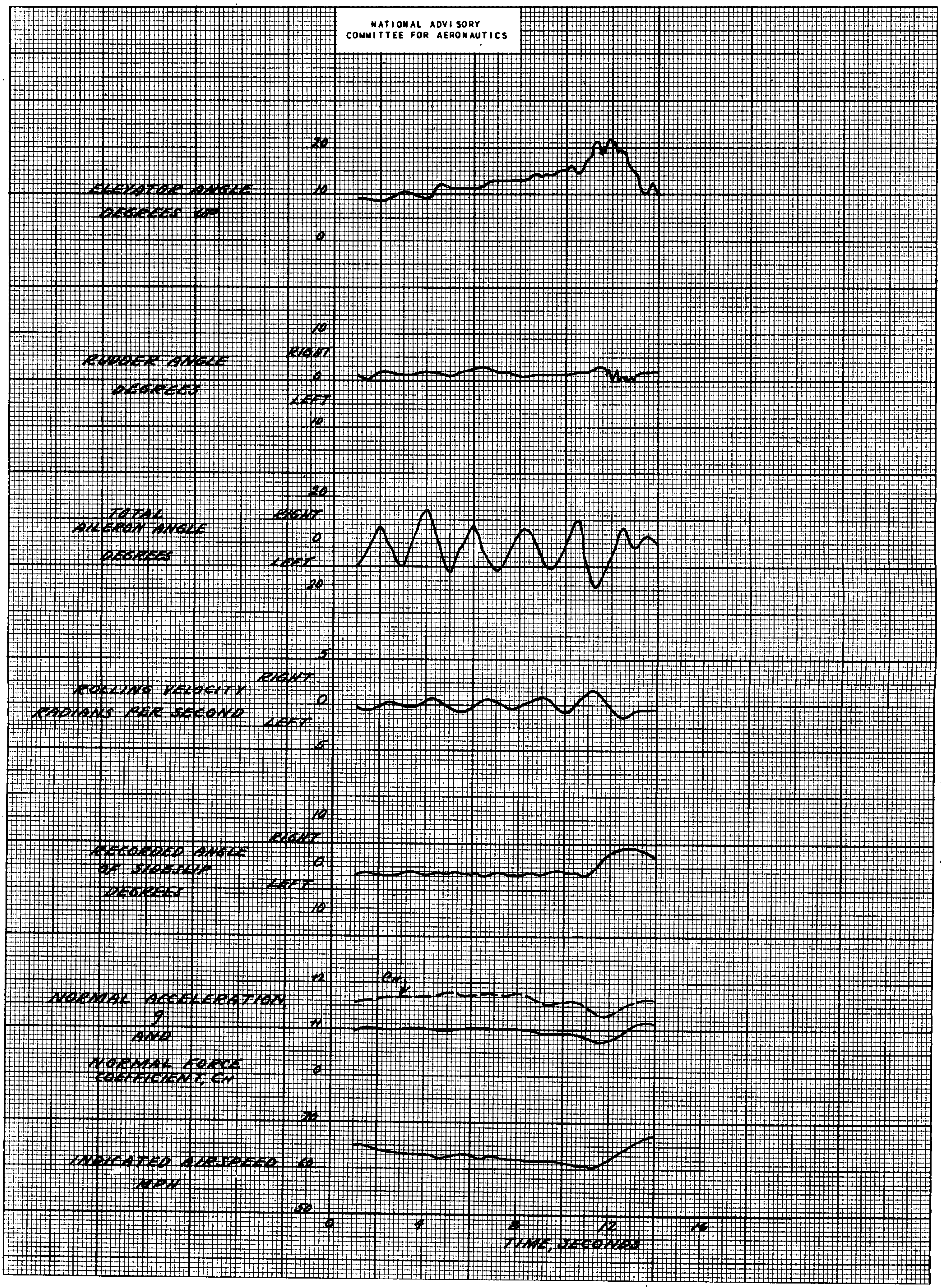

Figure 101.- Time history of a power off stall. 0° aileron droop and flaps full down.

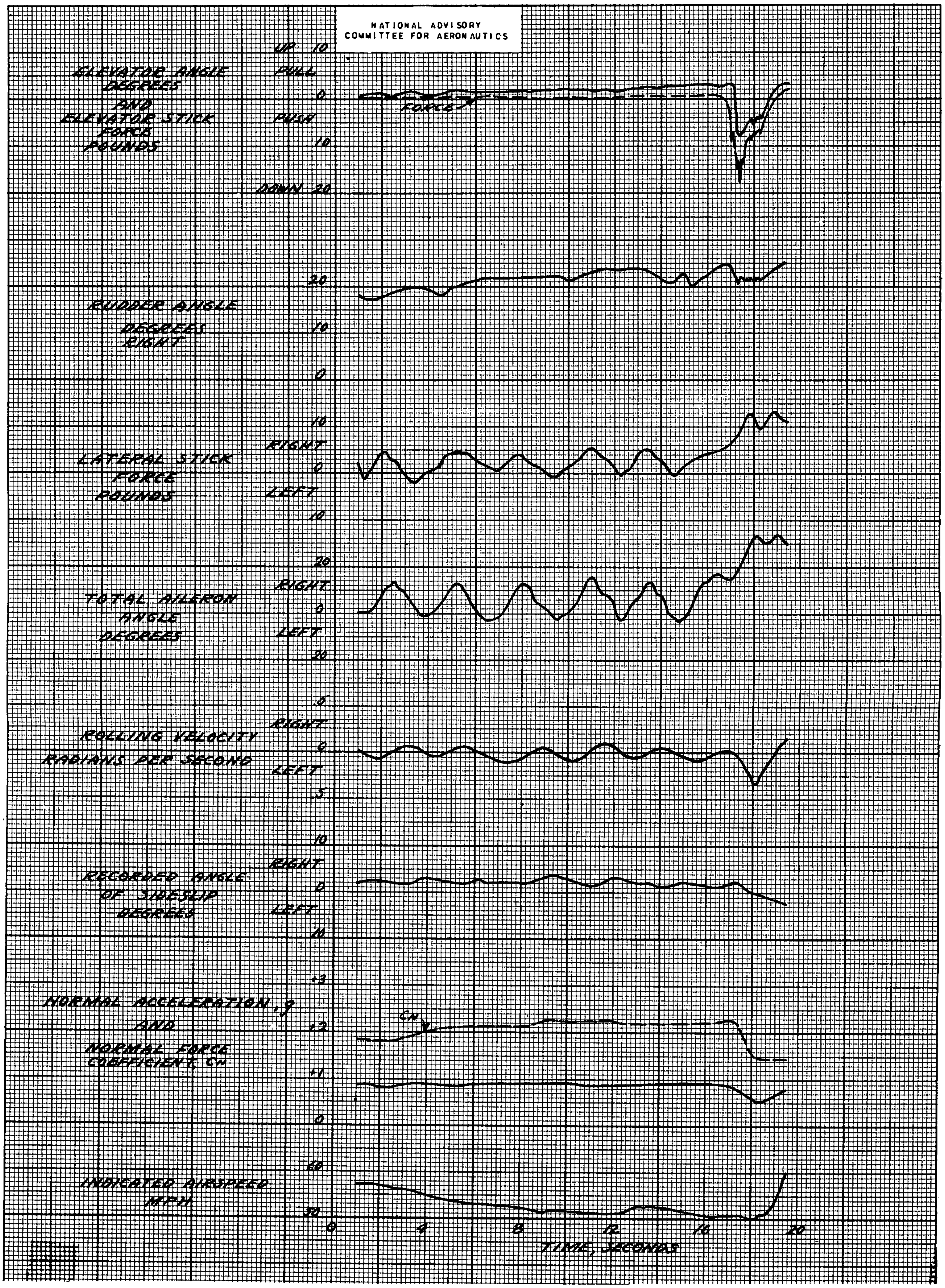

Figure 102.- Time history of a power on stall. 0° aileron droop and flaps full down.

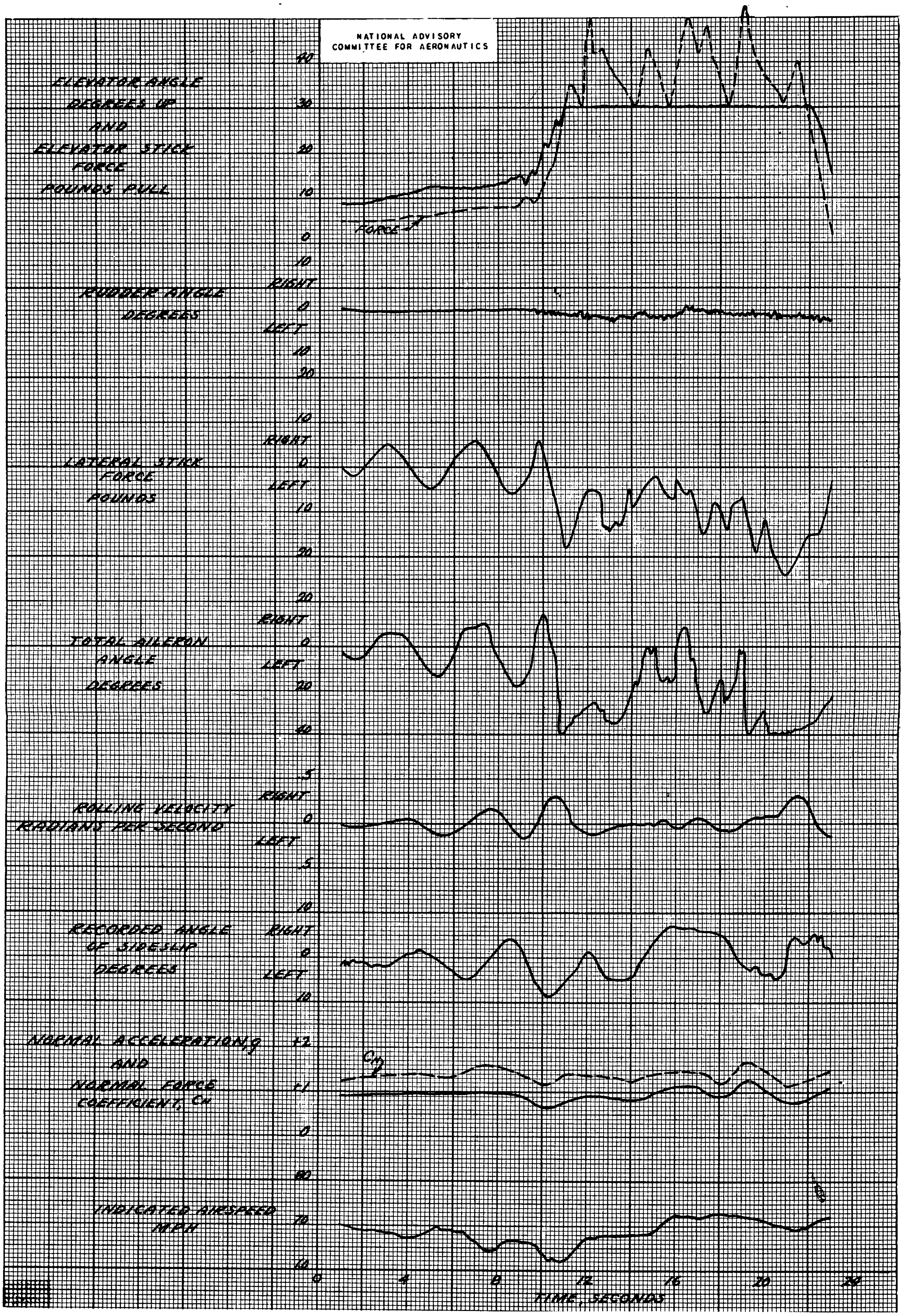

Figure 103.- Time history of a power off stall. 0° aileron droop and flaps two-thirds down.

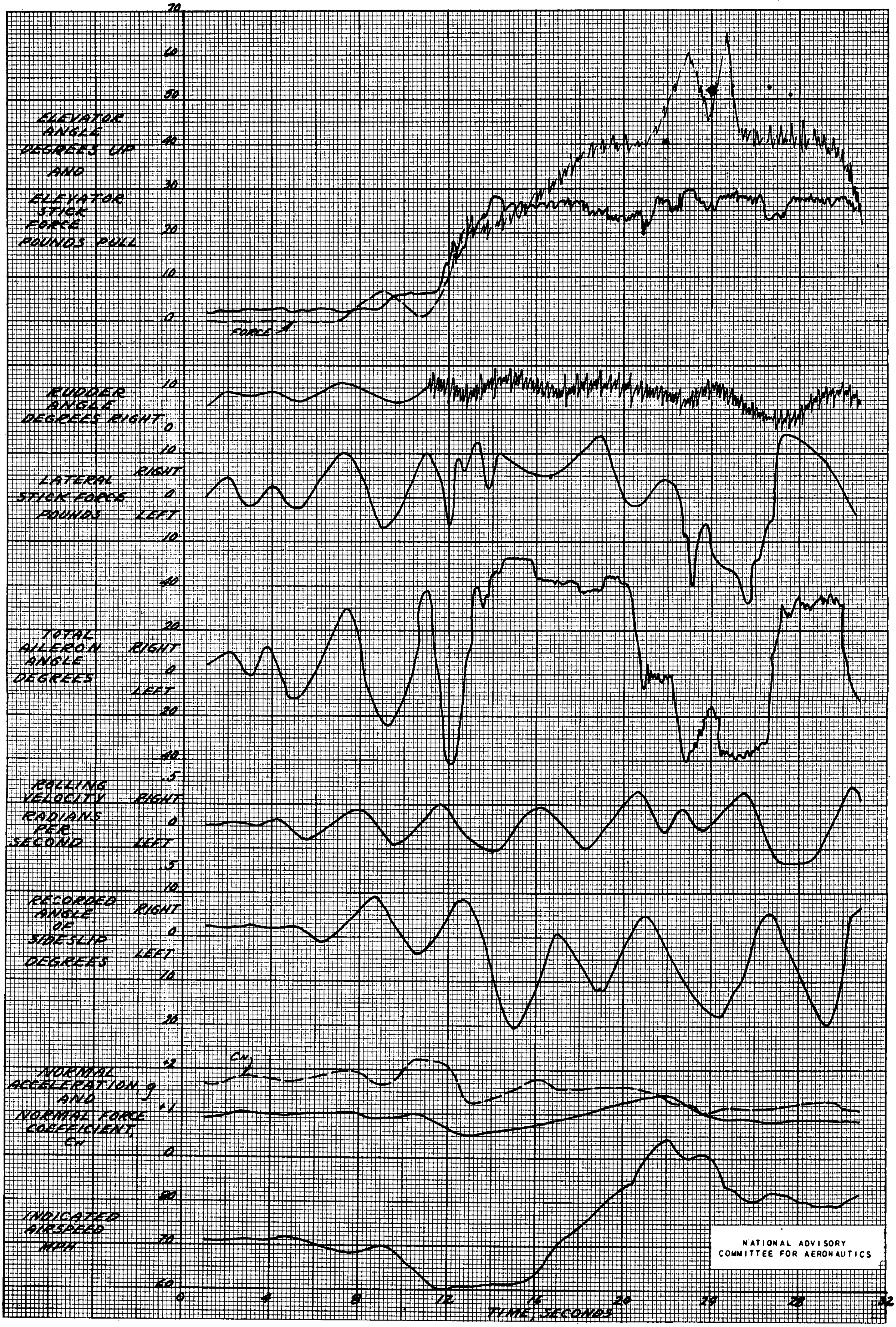

Figure 104.- Time history of a power on stall. 0° aileron droop and flaps two-thirds down.