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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ORIGINALLY ISSUED

September 1942 as
Memorandum Report

FLIGHT MEASUREMENTS OF THE LATERAL CONTROL CHARACTERISTICS OF AN AIRPLANE EQUIPPED WITH A COMBINATION AILERON-SPOILER CONTROL SYSTEM

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WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

FLIGHT MEASUREMENTS OF THE LATERAL CONTROL CHARACTERISTICS OF AN AIRPLANE EQUIPPED WITH A COMBINATION AILERON-SPOILER CONTROL SYSTEM

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SUMMARY

Flight tests were conducted to measure the lateral-control characteristics of an airplane, equipped with a lateral-control system, in which as the flaps are lowered the ailerons droop and a gradual transition of lateral control from ailerons to spoilers takes place. The particular airplane used in these tests was also equipped with a Maxwell-type leading-edge slot. The tests showed satisfactory lateral control except that at full deflection of the controls the values of pb/2V were less than 0.07 for most settings of flap, slot, and power; that stick forces were higher than desirable in some conditions; and that a reduction of control force and effectiveness gradients occurred near neutral when spoilers alone were operative.

INTRODUCTION

Much study has been devoted to the attainment of satisfactory lateral control when full-span flaps are employed to increase the maximum lift. Quantitative information on the lateral-control characteristics of airplanes employing full-span flaps is therefore desirable. Flight tests have been conducted to measure the lateral-control characteristics of an airplane equipped with a lateral-control system in which, as the flaps are lowered, the ailerons droop and a gradual transition of lateral control from ailerons to spoilers takes place.

The particular airplane on which tests were run had also been modified to incorporate a Maxwell-type leading-edge slot, and lateral-control measurements with the slot in operation are also presented.

DESCRIPTION OF AIRPLANE

The airplane used in the tests was a two-place, single-engine, mid-wing, cantilever monoplane with fixed landing gear, and partial-span, spring-loaded, deflector-plate, slotted flaps operating in combination with drooped ailerons. When the ailerons droop, due to lowering of the flaps, there is a gradual transition from lateral control by ailerons to lateral control by spoilers. The particular airplane on which tests were carried out had also been modified to incorporate a Maxwell-type leading-edge slot. Figure 1 shows the airplane as instrumented for flight tests with the flaps up and slots closed. Figure 2 shows the airplane with the flaps and slots open and the right wing spoiler up. A plan-view drawing of the airplane is shown in figure 3, and in figures 4 and 5 are shown plan views and sectional views of the slots, flaps, and lateral control surfaces.

General specifications for the airplane are as follows:

Engine	R-985-50; 400 bhp at 2200 rpm at 5500 feet altitude
Propeller	Two-blade, direct-drive, constant-speed; 8 feet, 6 inches in diameter
Gross weight	4717 pounds
Wing	
Span	35 feet, 10-11/16 inches
Area (total, including fuselage and ailerons)	261.9 square feet
Dihedral	7°
Sweepback (leading edge)	0

Mean aerodynamic chord	89.5 inches
Incidence	3°
Aileron area (aft of hinge, total)	13.4 square feet
Stabilizer area (including 3.5 sq ft fuselage and 1.83 sq ft elevator balance	34.6 square feet
Elevator area, aft of hinge (including 1.78 sq ft of tabs)	24.0 square feet
Fin area (including 1.18 sq ft rudder balance)	10.5 square feet
Rudder, aft of hinge (including 0.35 sq ft tabs)	11.5 square feet
Control surface movements	
Rudder	25° either side
Rudder pedals (pilot)	3-11/16 inches forward, 3-5/8 inches aft
Elevators	30° up, 20° down
Elevator controls	7-1/4 inches forward, 10-7/8 inches aft
Ailerons (normal)	32° up, 20° down
Ailerons (drooped 29°)	0° up, 0° down
Right spoiler	53° up
Left spoiler	49° up
Aileron control	8 inches right, 8 inches left
Aileron droop control	22 maximum turns for 29° aileron droop
Elevator tabs	10-3/4° up, 15-3/4° down

Rudder tab . . . . 20° right, 20° left

Flaps . . . . 40° down

(Note: Flaps are spring loaded)

Tolerance on all angles . . . . ± 1°

Tolerance on all control movements . . . . . . ± 1/4 inch

The manner in which the maximum movements of the ailerons and spoilers are affected by change in flap setting is shown in figure 6. Inasmuch as the flap was spring loaded, it was free to move up from a full-down setting when air forces exceeded the spring loading. The movement of the flap in this manner, however, caused no change in the relative movements of the ailerons and spoilers, provided the setting of the lever controlling the no-load flap position remained fixed. The friction in the lateral control system in both loaded and unloaded conditions is shown in figures 7 to 10, inclusive, for flap positions of full up, one-third down, two-thirds down, and full down, respectively. It will be noted that the values of friction are indicated by the force required to move the controls in each direction, and that therefore the friction force is indicated by one-half the difference between the values of force shown.

INSTRUMENT INSTALLATION

Items Measured	Instrument
Time	NACA timer
Air speed	NACA airspeed control
Rolling velocity	NACA recording turnmeter
Manifold pressure	Standard airplane manifold pressure gauge
Rpm	Standard airplane tachometer
Free-air temperature	Standard airplane indicating thermometer

Aileron and spoiler angles	NACA control-position recorder
Stick position	NACA control-position recorder
Flap position	NACA control-position recorder
Sideslip angle	NACA yaw-angle recorder
Stick force	NACA stick-force recorder

The airspeed recorder was connected to a swiveling pitot-static head, which was free to rotate in pitch, located on a boom extending about a chord length ahead of the left wing tip. All recording instruments were synchronized by the timer, and the records were obtained photographically.

The aileron and spoiler control-position recorders were mounted at the control surfaces, and thus recorded accurate angles of these surfaces irrespective of the deflection in the control system. The stick-position recorder was mounted at the rear stick, near the control stops.

RESULTS AND DISCUSSION

The lateral control measurements are compared with the requirements for satisfactory lateral control set up in reference 1.

One requirement of reference 1 (II-B-1) specifies that, at any given speed, the maximum rolling velocity obtained by abrupt use of the ailerons should vary smoothly with the aileron deflection and should be approximately proportional to the aileron deflection. The ability of the lateral controls to meet this requirement is indicated by plotting the rolling velocity in abrupt rudder-fixed aileron rolls as a function of stick deflection for the following conditions:

Figure No.	Flap Position	Slot Position	Power
11	Full up	Closed	On and Off
12	Full up	Open	On and Off
13	One-third down	Closed	On and Off
14	One-third down	Open	On and Off
15	Two-thirds down	Closed	On and Off
16	Two-thirds down	Open	On and Off
17	Full down	Closed	On and Off
18	Full down	Open	On and Off

The requirement appears to be met for all conditions except the flap-full-down condition (lateral control entirely by spoilers). In this condition it will be noted from figures 17 and 18 that the movement of the stick when near its neutral position did not produce the same change in rolling velocity as when displaced from neutral. This condition was considered unsatisfactory by the pilots.

Another requirement of reference 1 (II-B-2) specifies that the variation of rolling acceleration with time following an abrupt control deflection should always be in the correct direction and should reach a maximum value not later than 0.2 second after the controls have reached their given deflection. The ability of the lateral controls to meet this requirement is indicated by the time histories of two typical abrupt, rudder-fixed, aileron rolls. In figure 19, control is obtained entirely by the ailerons, and in figure 20 control is obtained entirely by the spoilers. Figures 19 and 20 show that these requirements are met for control by either aileron or spoiler. It may be presumed that therefore this requirement is met for any combination of aileron and spoilers. The pilots noticed no adverse rolling acceleration or noticeable lag in any of the abrupt aileron rolls made.

The ability of the lateral controls to meet another requirement of reference 1 (II-B-3) is indicated in figures 21 through 28. This requirement specifies that the maximum rolling velocity obtained by the use of ailerons alone should be such that the helix angle generated by the wing tip $pb/2V$ is equal to or greater than 0.07 where p is the maximum rolling velocity in radians per second, b is the wing span, and V is the true airspeed in foot per second. It will be observed that the curves of figures 21 through 28 do not include test points for rolls of full stick deflection but that the curves are nevertheless extrapolated to full stick deflection. The extrapolation of the curve to full stick deflection with the control system under load is considered valid. The stick-position recorder was mounted in the control system near the control stops. Thus, the limiting values of stick movement recorded were the same under load as under no load. The range of angles over which the extrapolation is carried out is small. Rolls were not actually made at full stick deflection in order that the control forces which were also measured during the rolls might not include an indeterminate amount of force due to holding the control against the stop. The extent to which this requirement is met for full stick deflection at the least favorable speeds for various conditions is summarized in the following tabulation:

Figure number	Flap position	Slot position	Power	Speed mph	Max. pb/2V right roll	Max. pb/2V left roll
21	Up	Closed	Off	108	0.054	0.062
21	Up	Closed	On	78	.07	.06
22	Up	Open	Off	105	.047	.035
22	Up	Open	On	64	.03	.051
23	1/3 Down	Closed	Off	79	.066	.052
23	1/3 Down	Closed	On	121	.071	.068
24	1/3 Down	Open	Off	96	.046	.048
24	1/3 Down	Open	On	62	.057	.051
25	2/3 Down	Closed	Off	94	.015	.030
25	2/3 Down	Closed	On	64	.042	.050
26	2/3 Down	Open	Off	94	.042	.047
26	2/3 Down	Open	On	121	.065	.058
27	Down	Closed	Off	75	.055	.043
27	Down	Closed	On	103	.066	.070
28	Down	Open	Off	93	.080	.070
28	Down	Open	On	104	.073	.080

It will be noticed that the pb/2V requirements of reference 1 are not met. There is considerable variation in the maximum values of pb/2V for the various conditions. It appears that highest values of pb/2V are obtained in the flap-full-down condition with the flap-two-thirds-down condition giving the lowest values of pb/2V.

The extent to which deflection of the control system resulted in loss of possible rolling velocity is indicated by figures 29 through 36, in which the relation between recorded stick position and the aileron and spoiler positions when under load in actual flight are compared with the no-load relationship observed on the ground. It will be noted that the deflections of the ailerons and spoilers under load were relatively small, and are probably as small as ordinary structural design practice in lateral control systems will permit. With control by the aileron (flaps-up condition), figure 29 would indicate that probably not more than 10 percent of the possible rolling velocity is lost due to deflection of the control system. With control by the spoilers alone, figure 36 would indicate that probably not more than 15 percent of the possible rolling velocity is lost due to deflection under load.

In considering the loss of possible rolling velocity due to deflection in the control system, it should be appreciated that the position of the control stops are an important factor. If the control stops were at the control surfaces themselves, deflection of the control system would not prevent the attainment of maximum rolling velocity provided freedom of stick movement prevailed. In the test airplane, the deflection of the front stick with relation to the lateral control surfaces was much greater than is indicated in figures 29 through 36 as the stick-position recorder was mounted at the rear stick near which the lateral control tubes into the wings are attached. Thus, the deflections shown in figures 29 through 36 do not include the additional deflection between front and rear sticks. For record purposes to allow the front stick position to be determined if desired, figure 37 is included to show the deflection between front and rear stick positions when a force is applied at the front stick as indicated by the stick force and is resisted by weights placed on the right aileron.

Reference 1 further specifies (requirement II-B-4) that the variation of aileron control force with aileron deflection should be a smooth curve, and that the force should everywhere be great enough to return the control to trim position. The ability of the lateral controls to meet this requirement is indicated in figures 38 through 41. These figures show that this requirement is met, except perhaps in the flap-full-down position for which condition figure 41 shows a slight inflection in the force curves near the neutral position. This inflection was noticeable to the pilots in flight.

Another requirement of reference 1 (II-B-5) specifies that, at every speed below 80 percent of maximum level flight speed, it should be possible to obtain the specified value of pb/2V without exceeding ± 30 pounds applied at the grip of the stick. The ability of the lateral controls to meet this requirement is illustrated in figures 42 and 43. The maximum indicated airspeed in level flight is 169 miles per hour. Figures 42 and 43 show that this requirement is not met.

Figures 44 through 47 illustrate the ability of the lateral controls to meet a requirement of reference 1 (II-C) which specifies that, with rudder locked at 110 percent of the minimum speed, the sideslip developed as a result of full aileron deflection should not exceed 20°. The minimum speeds for the various conditions and the maximum angle of sideslip obtained are tabulated as follows:

Figure Number	Flap Position	Slot Position	Power	Minimum Speed *mph	Maximum Angle of Sideslip Degrees
44	Up	Closed	Off	70.5-77	14.5 at 88 mph
44	Up	Closed	On	--	9.5 at 78 mph
44	Up	Open	Off	79.0-82	15 at 93 mph
44	Up	Open	On	--	22 at 64 mph
45	1/3 Down	Closed	Off	--	19 at 79 mph
45	1/3 Down	Closed	On	--	17 at 70 mph
45	1/3 Down	Open	Off	--	15 at 88 mph
45	1/3 Down	Open	On	--	22 at 62 mph
46	2/3 Down	Closed	Off	--	10 at 81 mph
46	2/3 Down	Closed	On	--	16 at 64 mph
46	2/3 Down	Open	Off	--	10 at 81 mph
46	2/3 Down	Open	On	--	15.5 at 60 mph
47	Full Down	Closed	Off	60.5-62.5	11.5 at 75 mph
47	Full Down	Closed	On	49.0-50.0	14.5 at 68 mph
47	Full Down	Open	Off	63.5-65.0	11.5 at 78 mph
47	Full Down	Open	On	48.5-49.0	13 at 59 mph

* Minimum speed dependent upon cowl flap, and hood positions.

It will be observed from the tabulation that 20° of sideslip was exceeded in only one condition at which a value of 22° sideslip was obtained. It appears, however, that the speed at which this value was obtained was lower than 110 percent of the minimum speed, although this is not certain as the minimum speed was not obtained for the condition concerned. Because of the many varied values of minimum speed of this airplane, it is not possible to state definitely whether or not this requirement has been met for all conditions. In general, however, it appears that the requirement is met satisfactorily.

On the whole, the pilots regarded the lateral controls as unsatisfactory. With controls entirely by the ailerons (flaps up), control forces were too heavy and the controls seemed to provide insufficient rolling velocity. With control entirely by the spoilers (flaps down), control seemed uncertain. It is believed that this effect was caused by the nonlinear characteristics of the lateral control when near the neutral position as is shown by figures 17, 18, 27, 28, and 41. It was the impression of the pilots that as the stick was moved beyond a certain region near neutral the rolling velocity resulting would not tend to be the exact value desired by the pilot. Apparently, the nonlinear roll and force characteristics made smooth control difficult. It is not believed that figures 17, 18, 27, 28, and 41 show this characteristic to the extent that it is felt by the pilots, probably because an insufficient number of test points were obtained with controls near the neutral position. Control forces were most satisfactory when obtained by a combination of ailerons and spoilers in the flap-one-third-down position. However, in this condition as in other conditions the impression was gained that lateral control was insufficient.

CONCLUSIONS

1. The variation of maximum rolling velocity with lateral stick movement as obtained in abrupt rudder-locked rolls was satisfactorily smooth except when control was by spoiler alone.

2. There was no lag in the attainment of maximum rolling acceleration with any combination of ailerons and spoilers.

3. For full deflection of the controls, the values of pb/2V obtained were less than the required value of 0.07 for most conditions of flap, slot, and power.

4. The variation of lateral-control force with lateral stick movement was satisfactorily smooth except when control was by the spoilers alone.

5. The force was everywhere great enough to return the control to trim position.

6. It was not possible to obtain a value of pb/2V of 0.07 at every speed below 80 percent of maximum level-flight speed without exceeding 30 pounds applied at grip of the stick.

7. The sideslip developed as a result of full deflection, rudder-locked, aileron rolls did not exceed 20° at 110 percent of the minimum speed.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, California.

REFERENCE

1. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA ACR, April 1941.

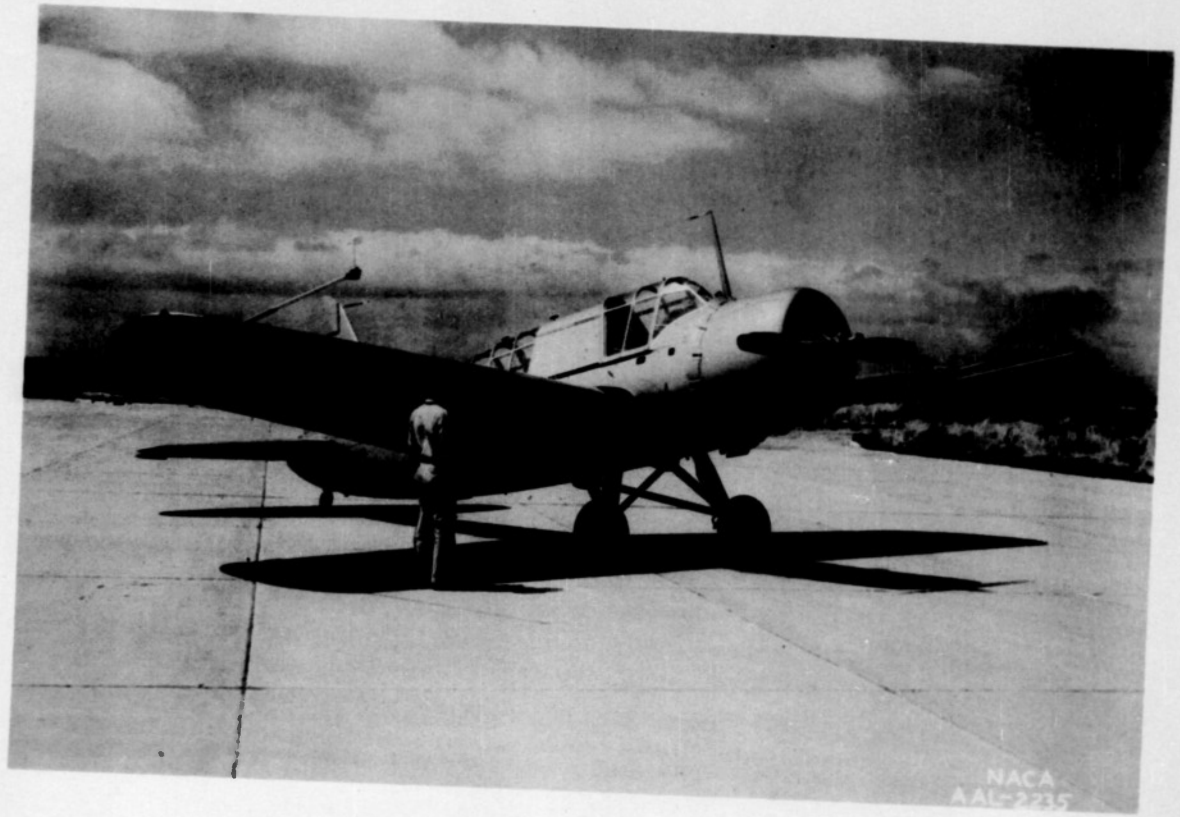

Figure 1.- Three-quarter front view of the test airplane as instrumented for flight.

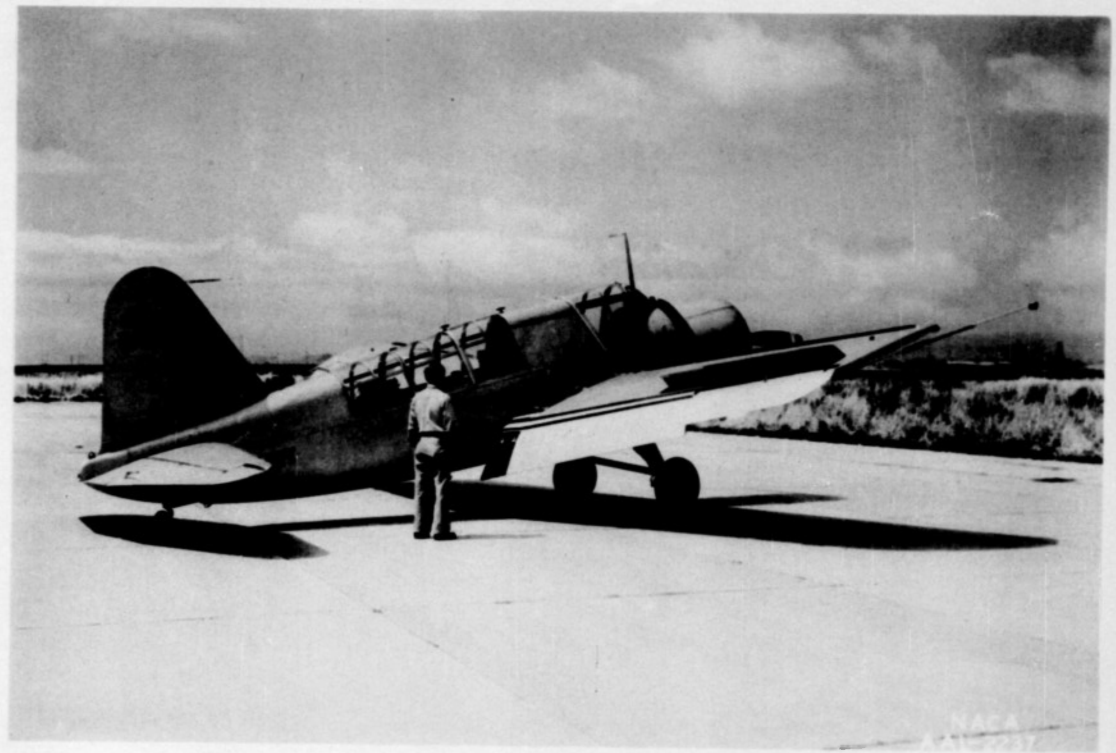

Figure 2.- Three-quarter rear view of the test airplane as instrumented for flight showing deflected flap, drooped aileron, deflected spoiler, and open slot.

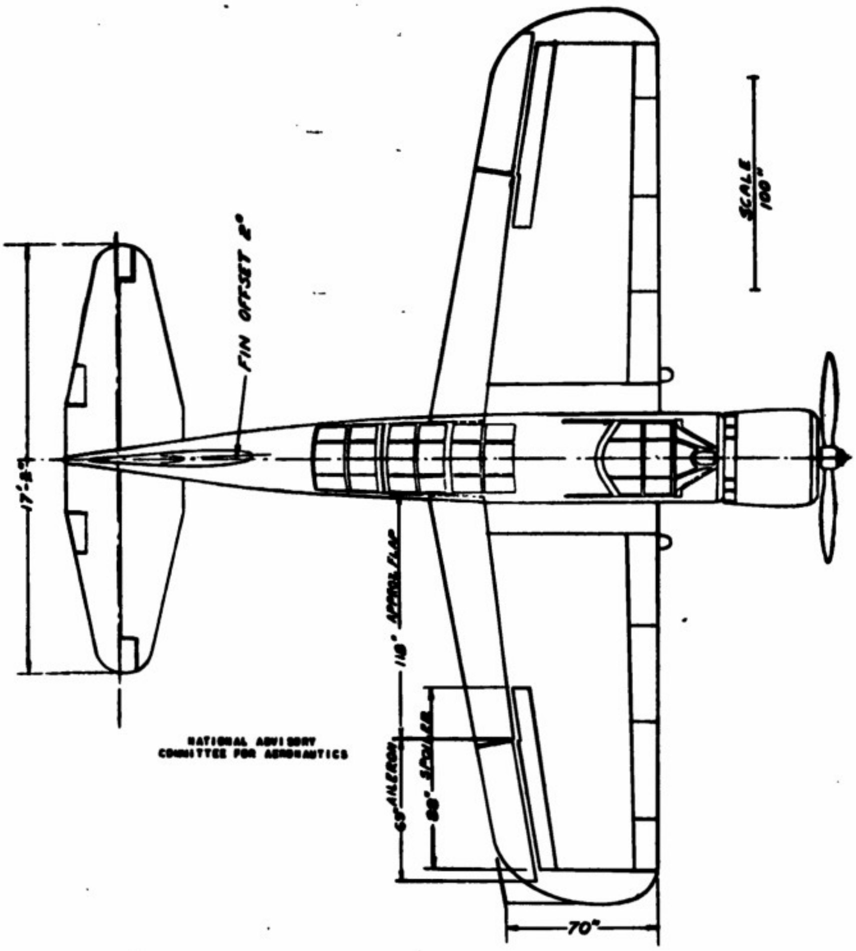

Figure 3.- Test airplane, plan view.

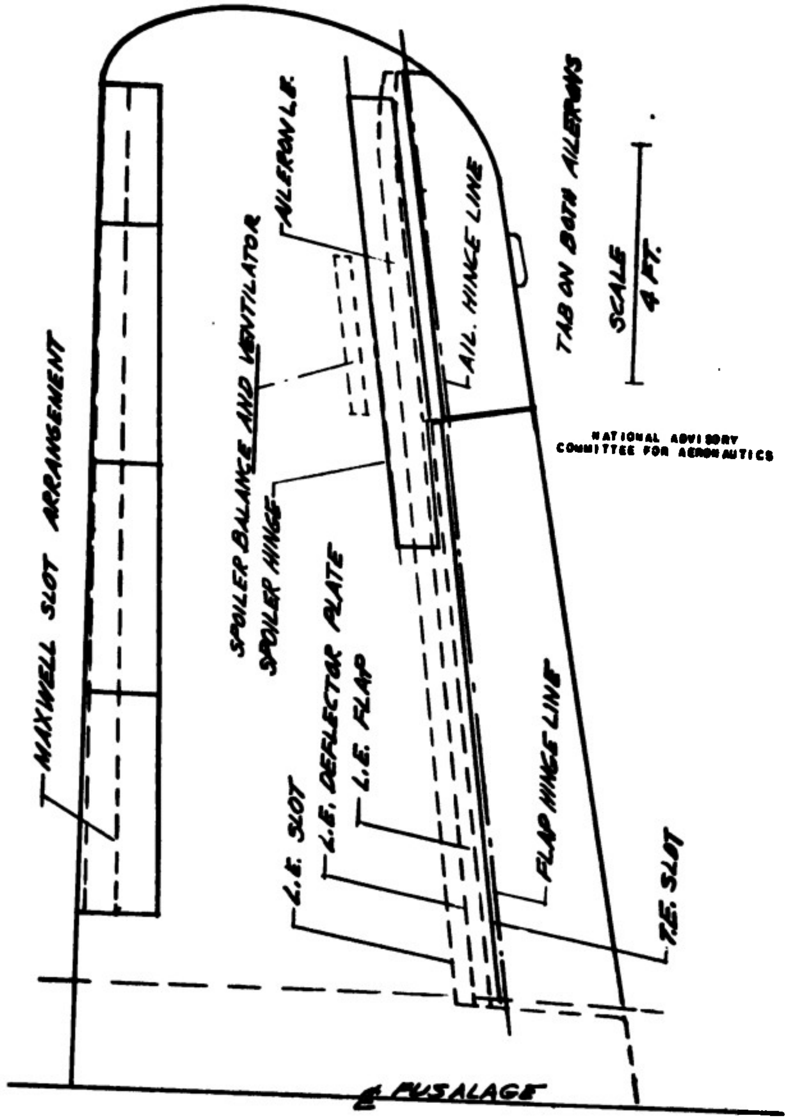

Figure 4.- Plan view drawing showing location and approximate dimensions of high-lift devices and lateral control.

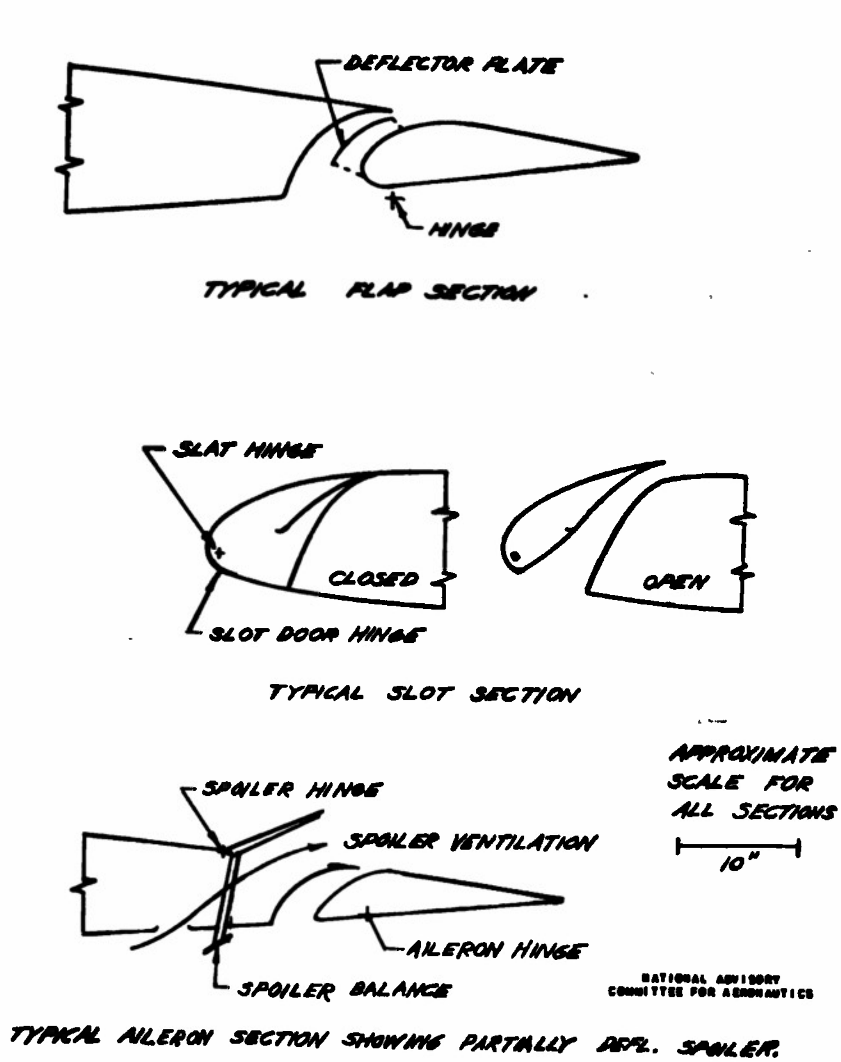

Figure 5.- Typical sections of high-lift devices and lateral controls.

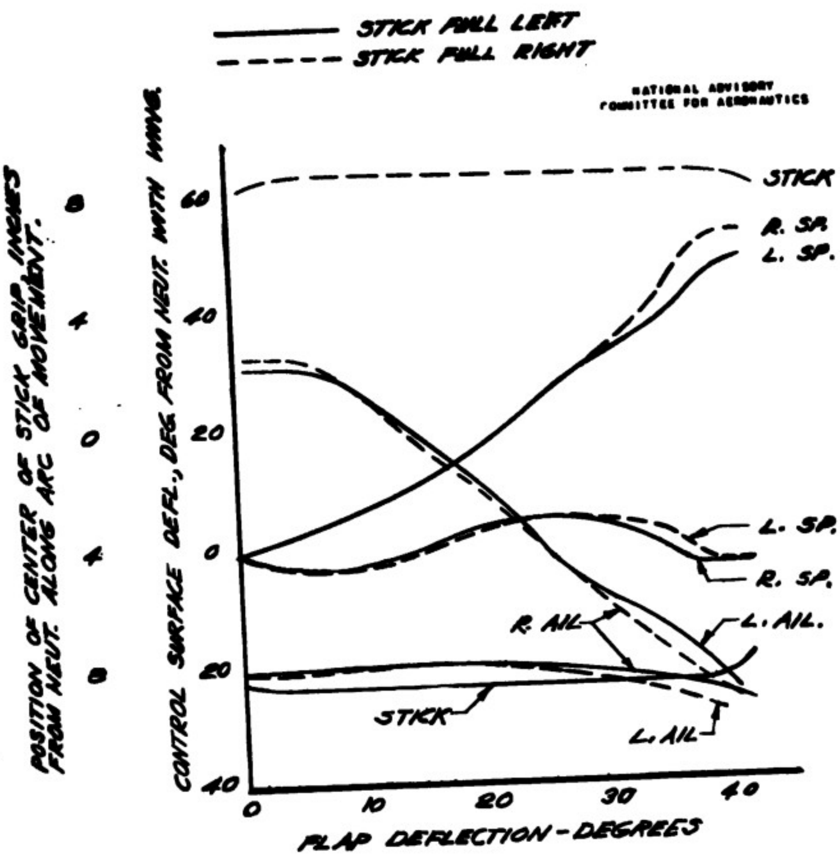

Figure 6.- Variation of maximum movements of ailerons and spoilers with change in flap position.

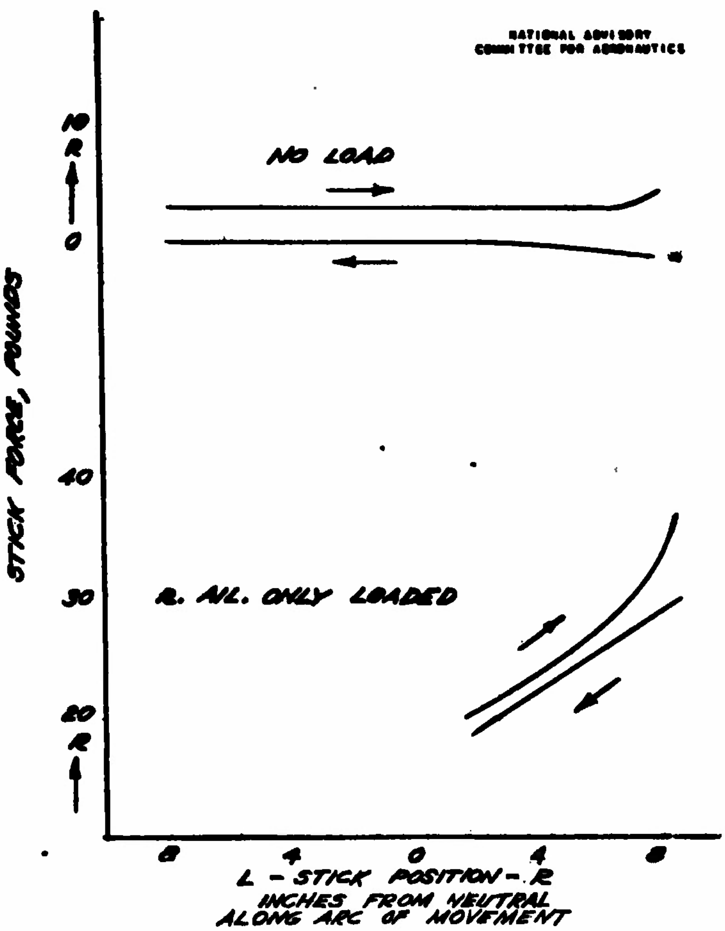

Figure 7.- Friction in the lateral control system, flaps up, as indicated by the stick force required to move the controls on the ground.

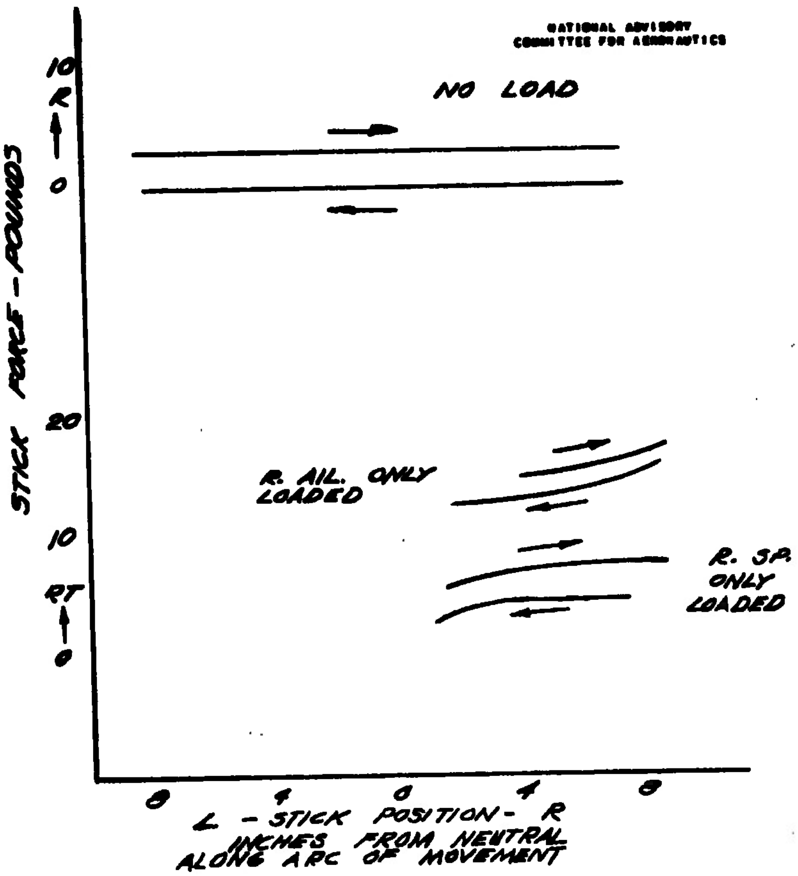

Figure 8.- Friction in the lateral control system, flaps one-third down, as indicated by the stick force required to move the controls on the ground.

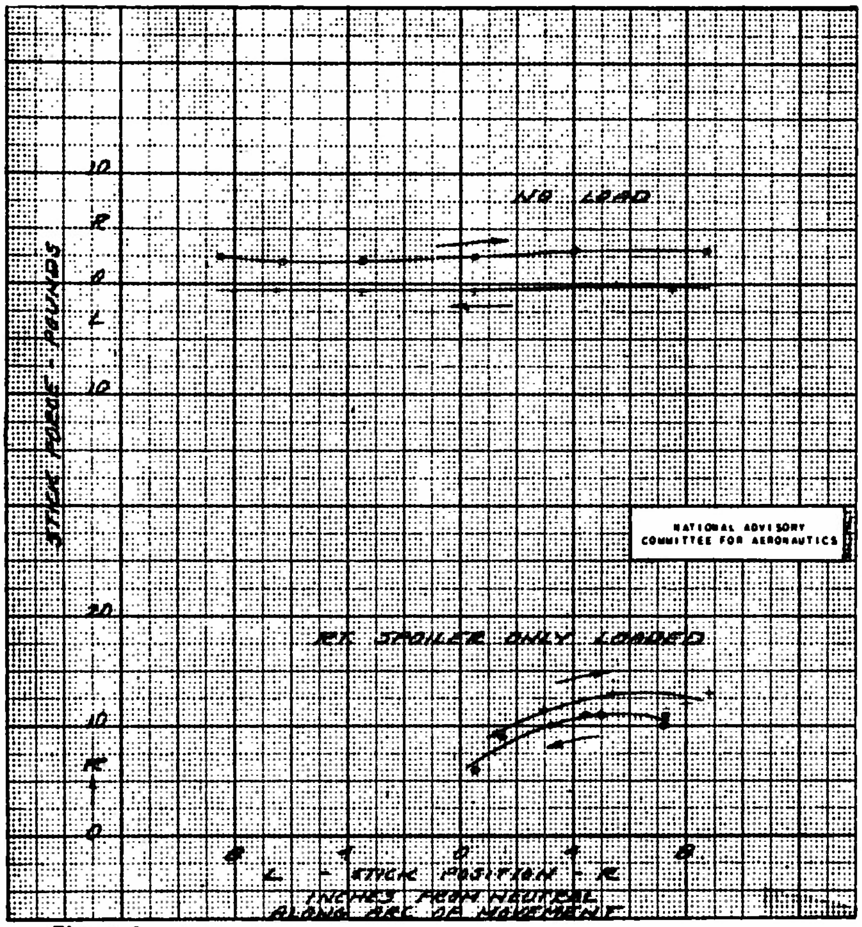

Figure 9.- Friction in the lateral control system, flaps two-thirds down, as indicated by the stick force required to move the controls on the ground.

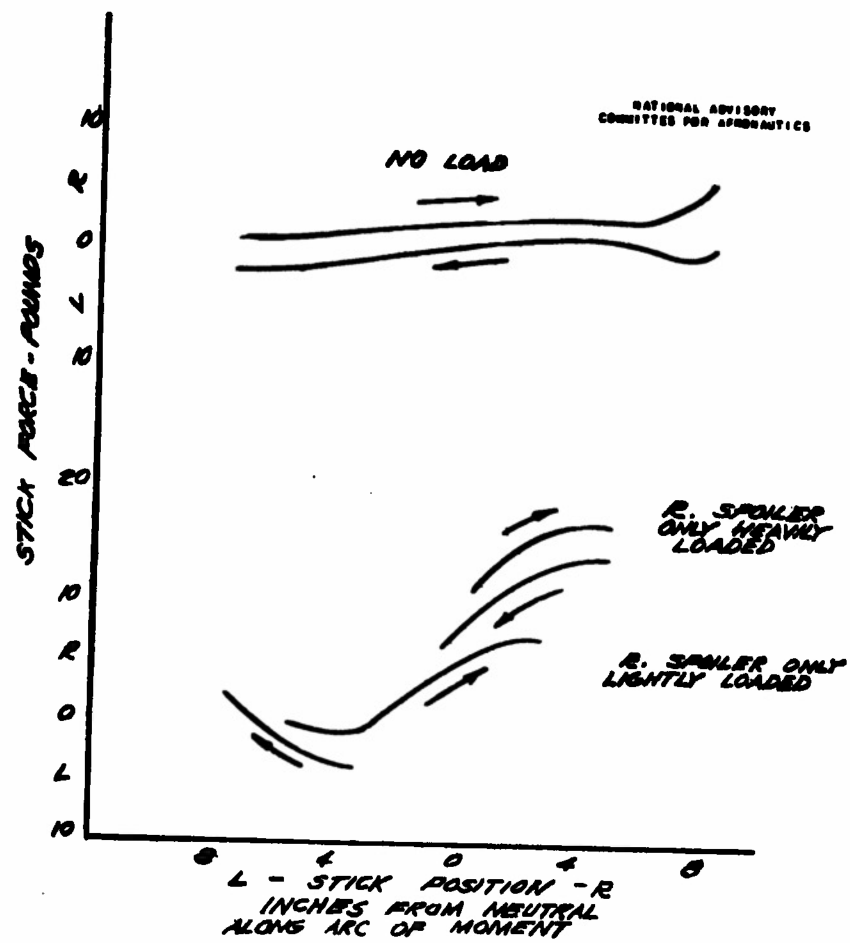

Figure 10.- Friction in the lateral control system, flaps full down, as indicated by the stick force required to move the controls on the ground.

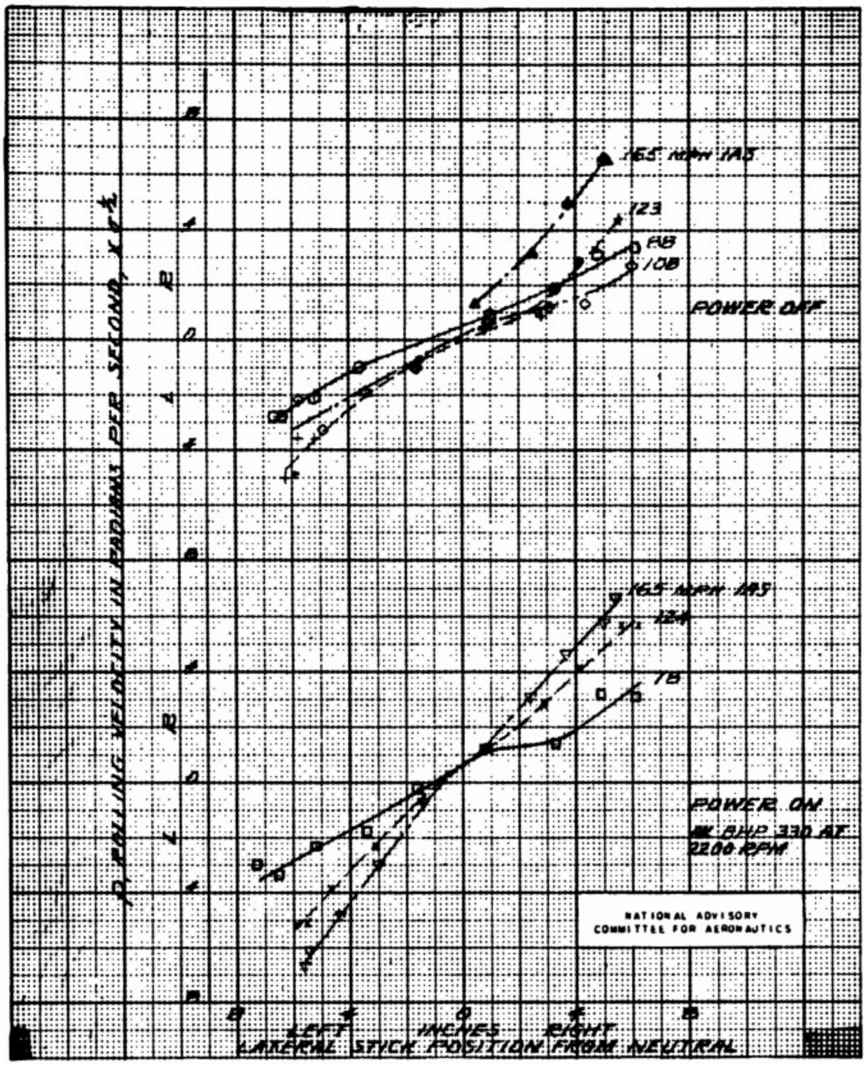

Figure 11.- Rolling velocity as a function of lateral stick position, flaps up, slots closed.

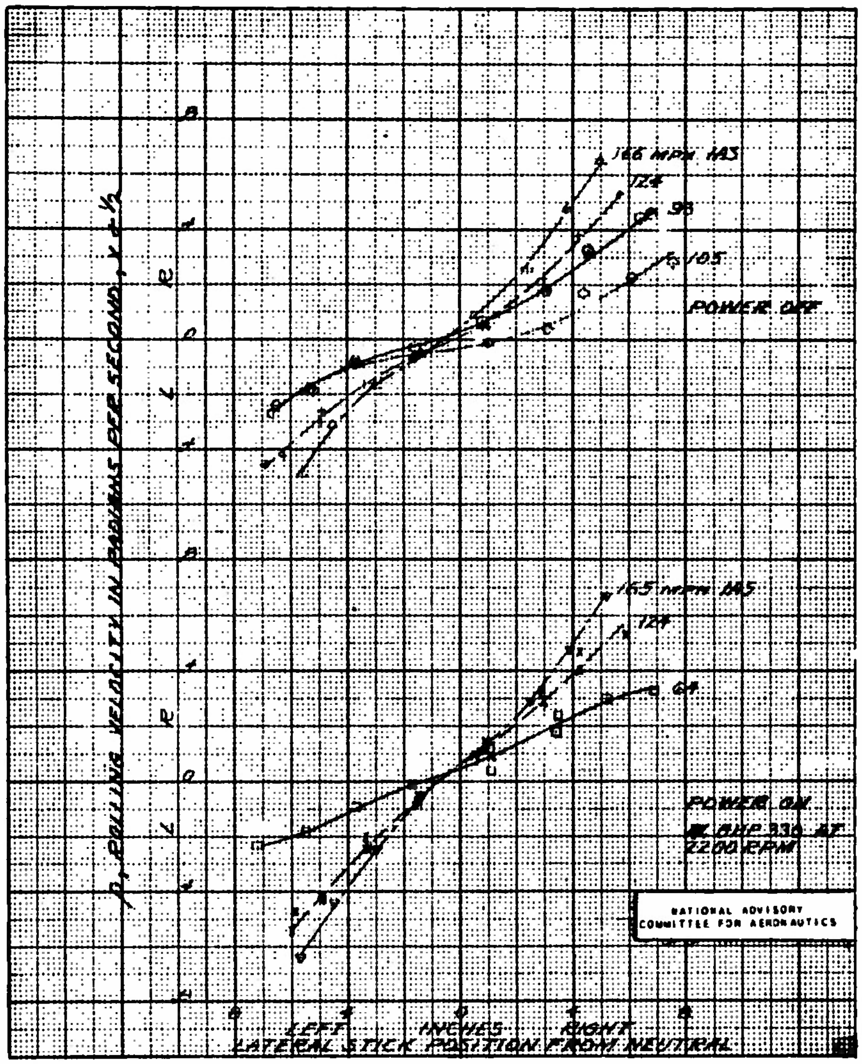

Figure 12.- Rolling velocity as a function of lateral stick position, flaps up, slots open.

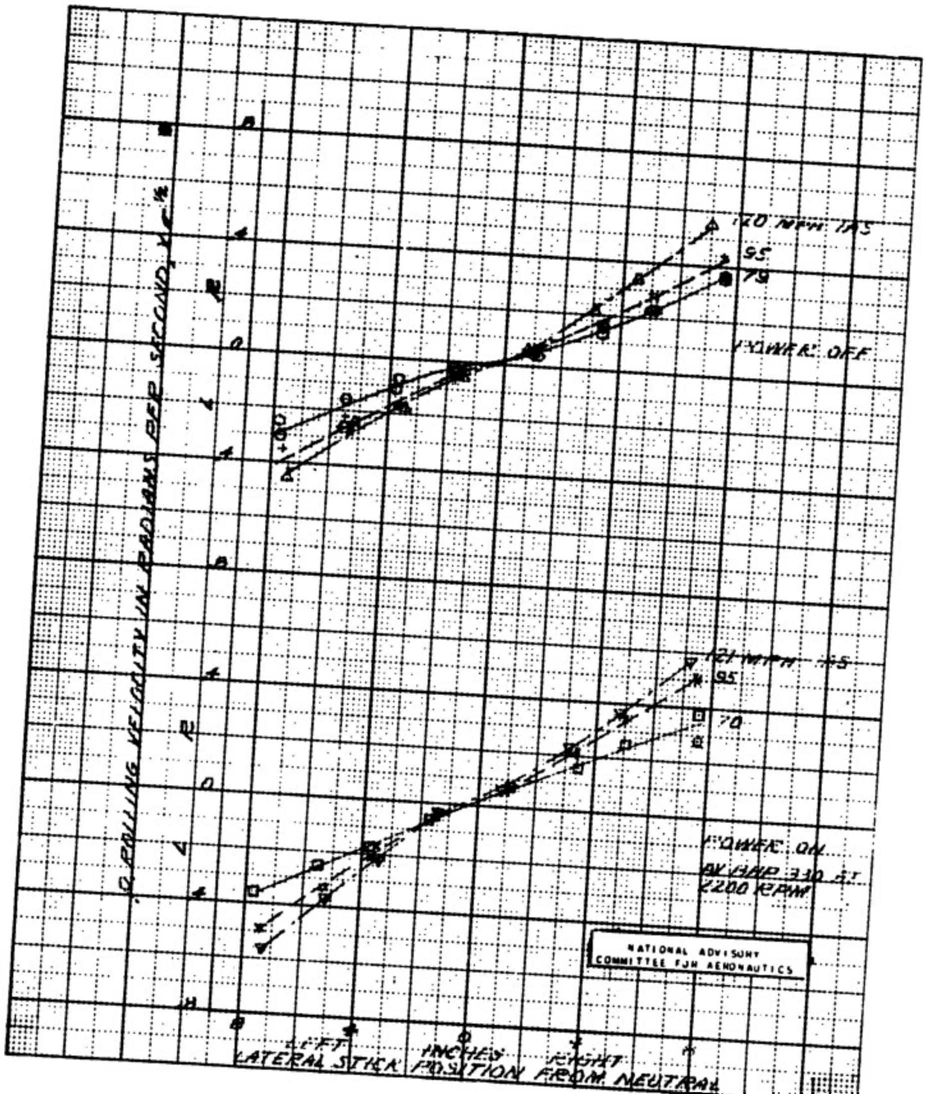

Figure 13.- Rolling velocity as a function of lateral stick position, flaps one-third down, slots closed.

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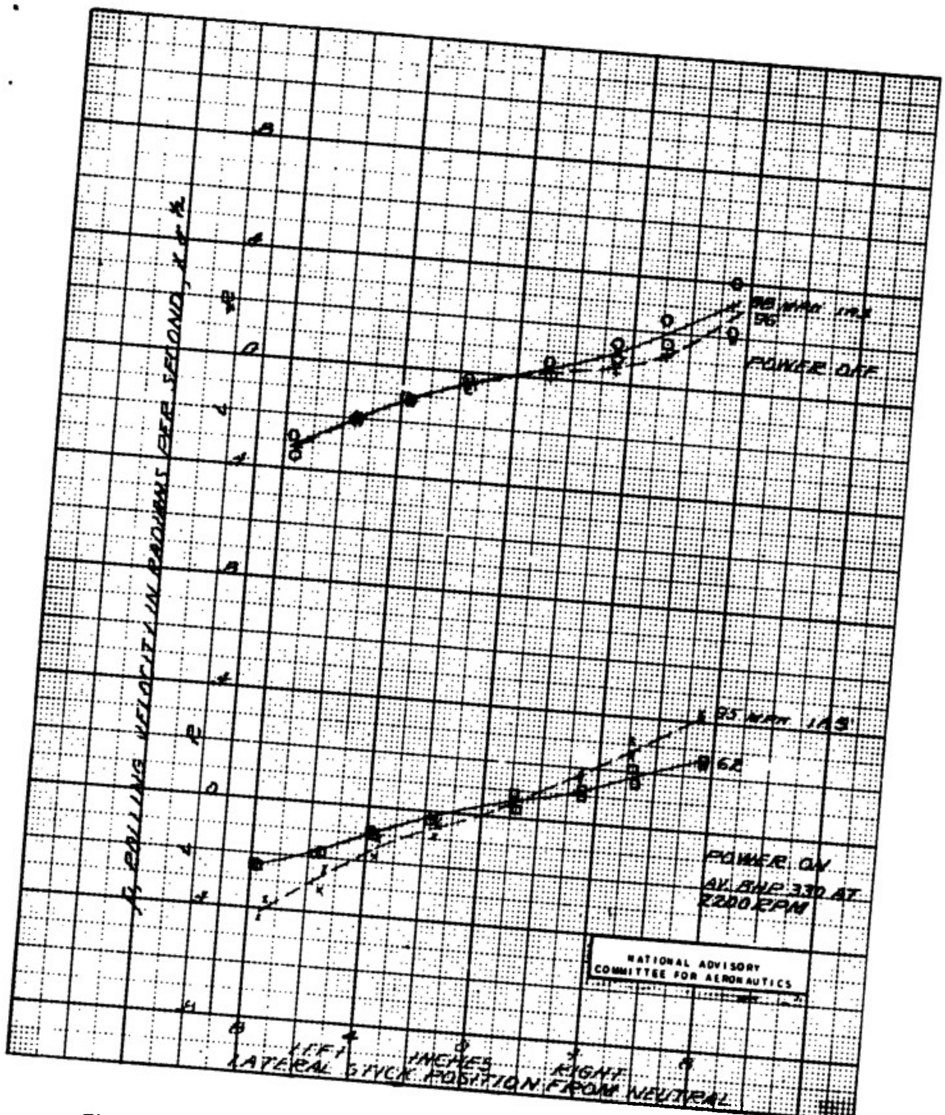

Figure 14.- Rolling velocity as a function of lateral stick position, flaps one-third down, slots open.

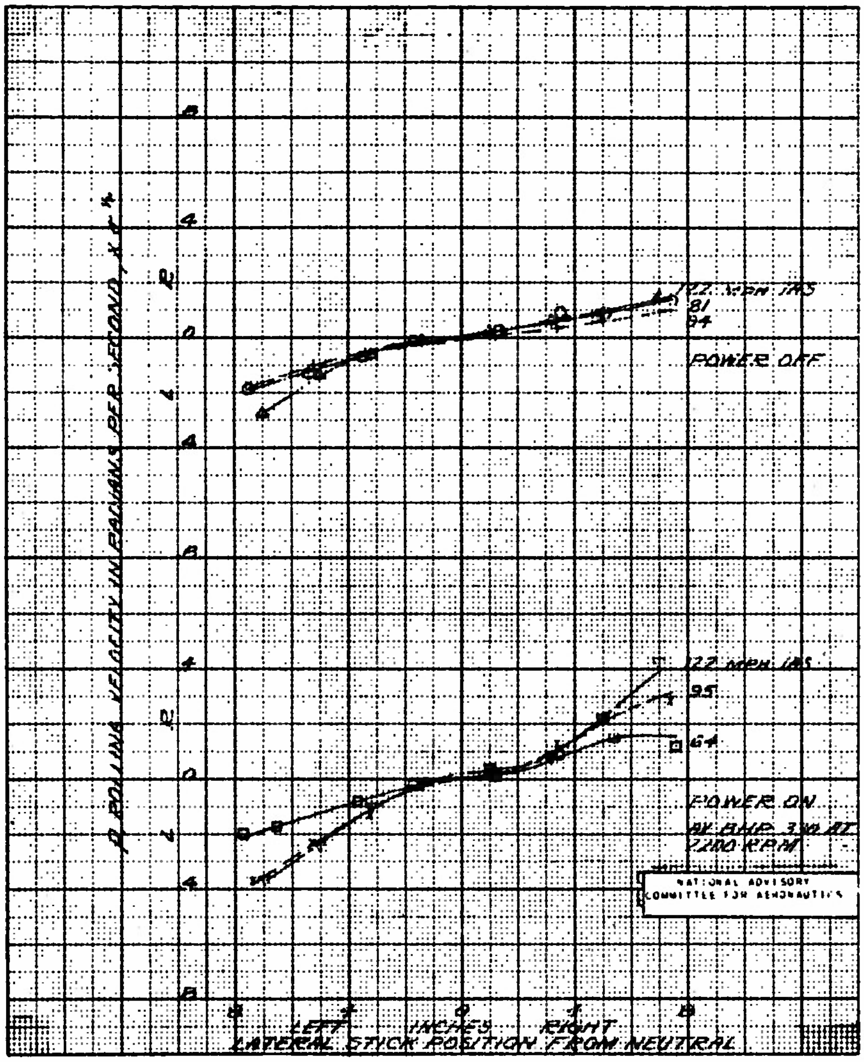

Figure 15.- Rolling velocity as a function of lateral stick position, flaps two-thirds down, slots closed.

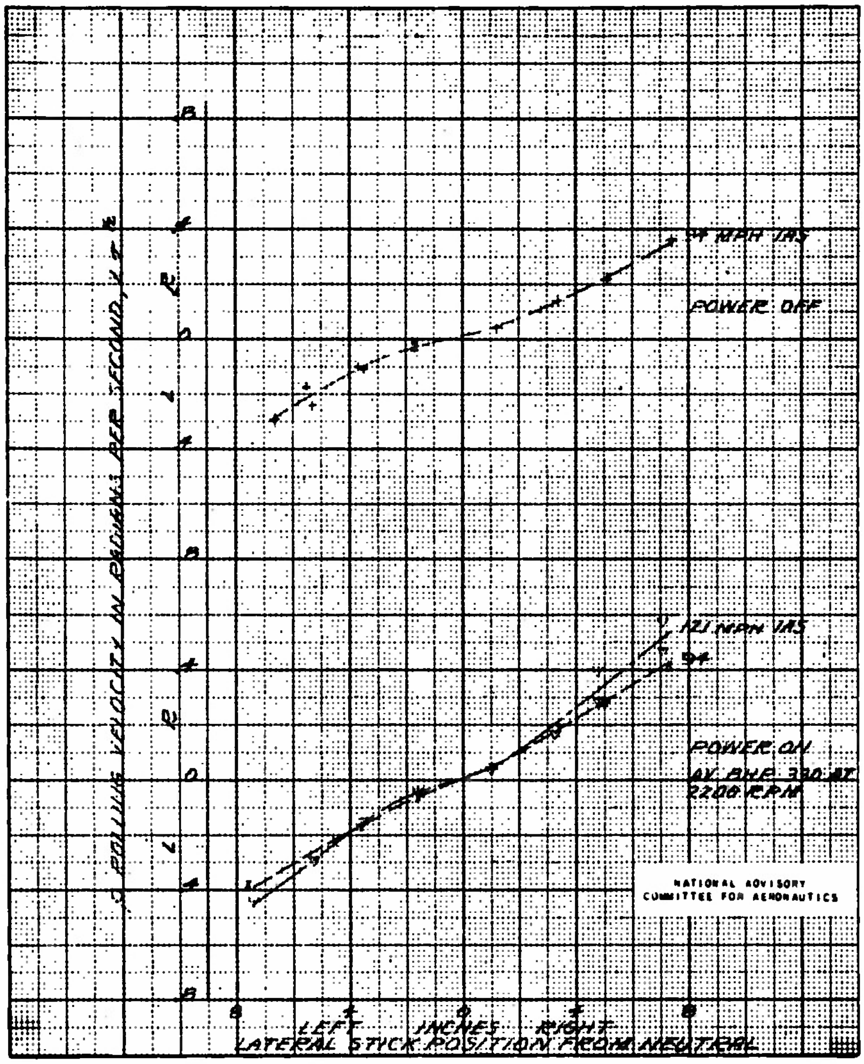

Figure 16.- Rolling velocity as a function of lateral stick position, flaps two-thirds down, slots open.

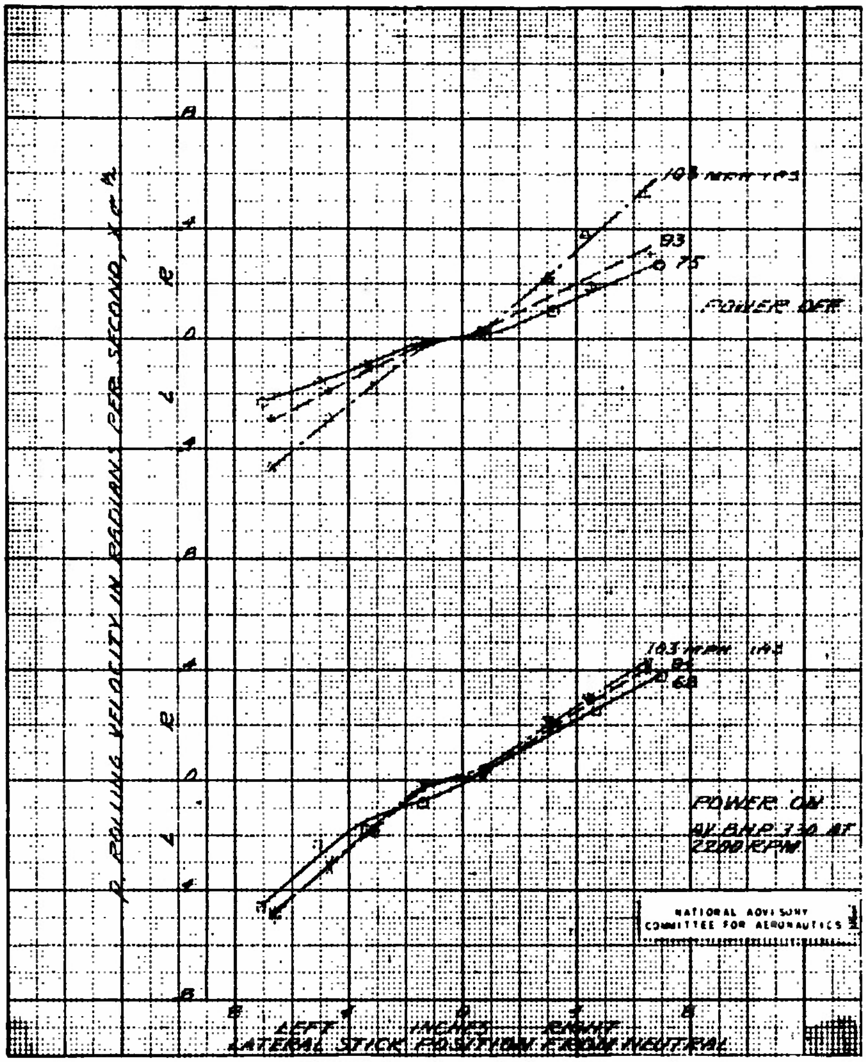

Figure 17.- Rolling velocity as a function of lateral stick position, flaps full down, slots closed.

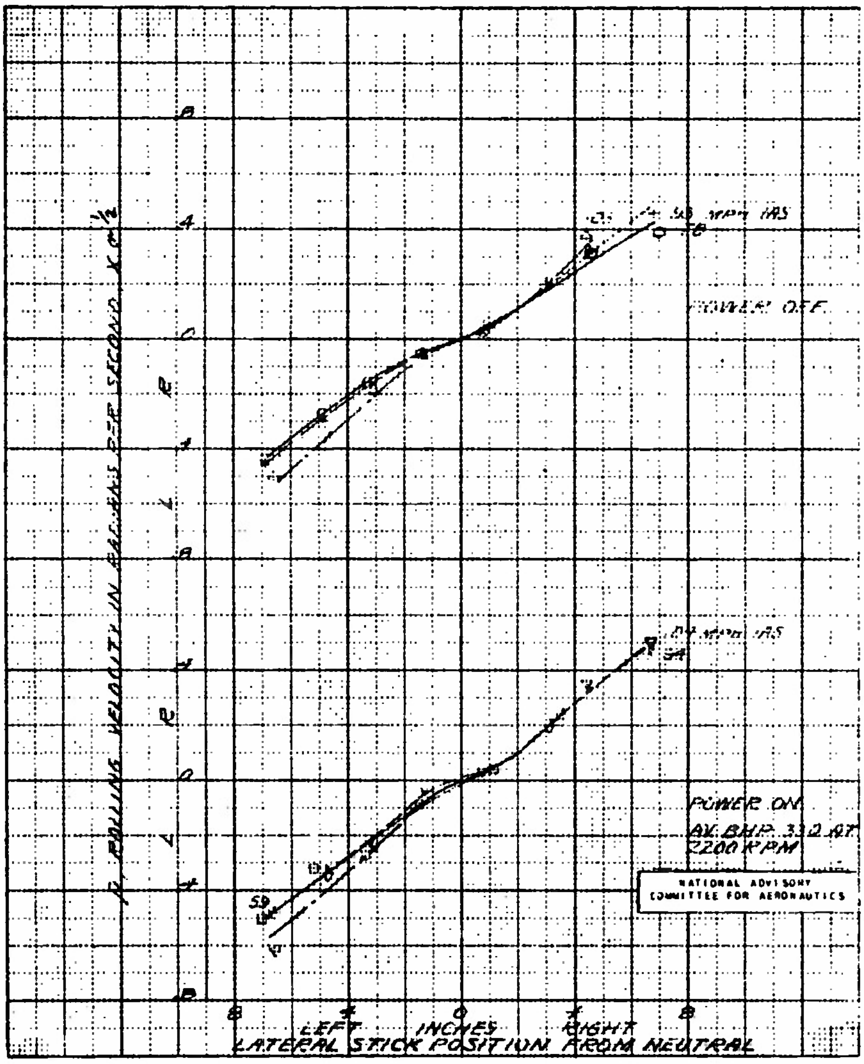

Figure 18.- Rolling velocity as a function of lateral stick position, flaps full down, slots open.

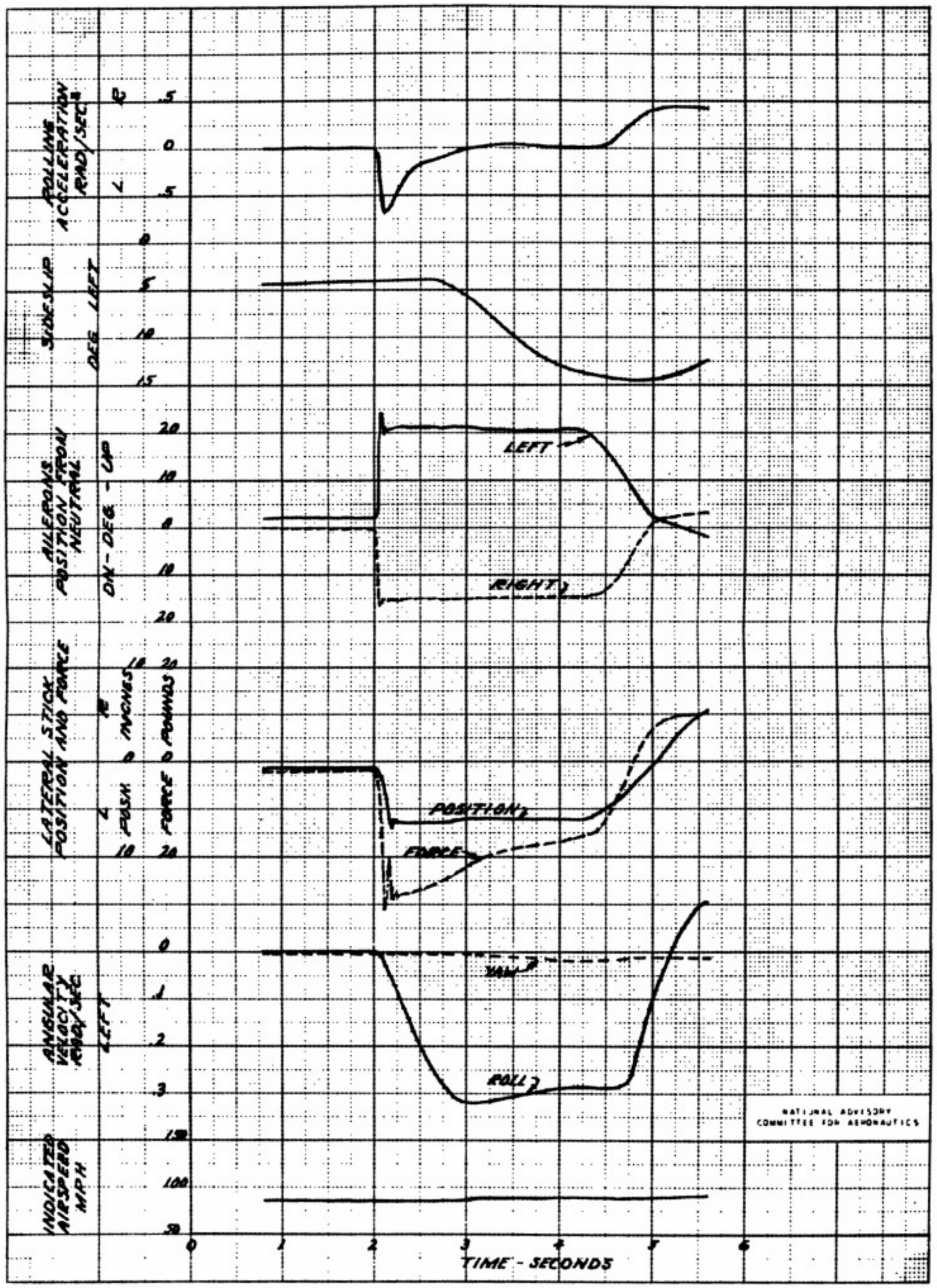

Figure 19.- Time history of an abrupt rudder locked aileron roll, flaps up, slots closed, power off.

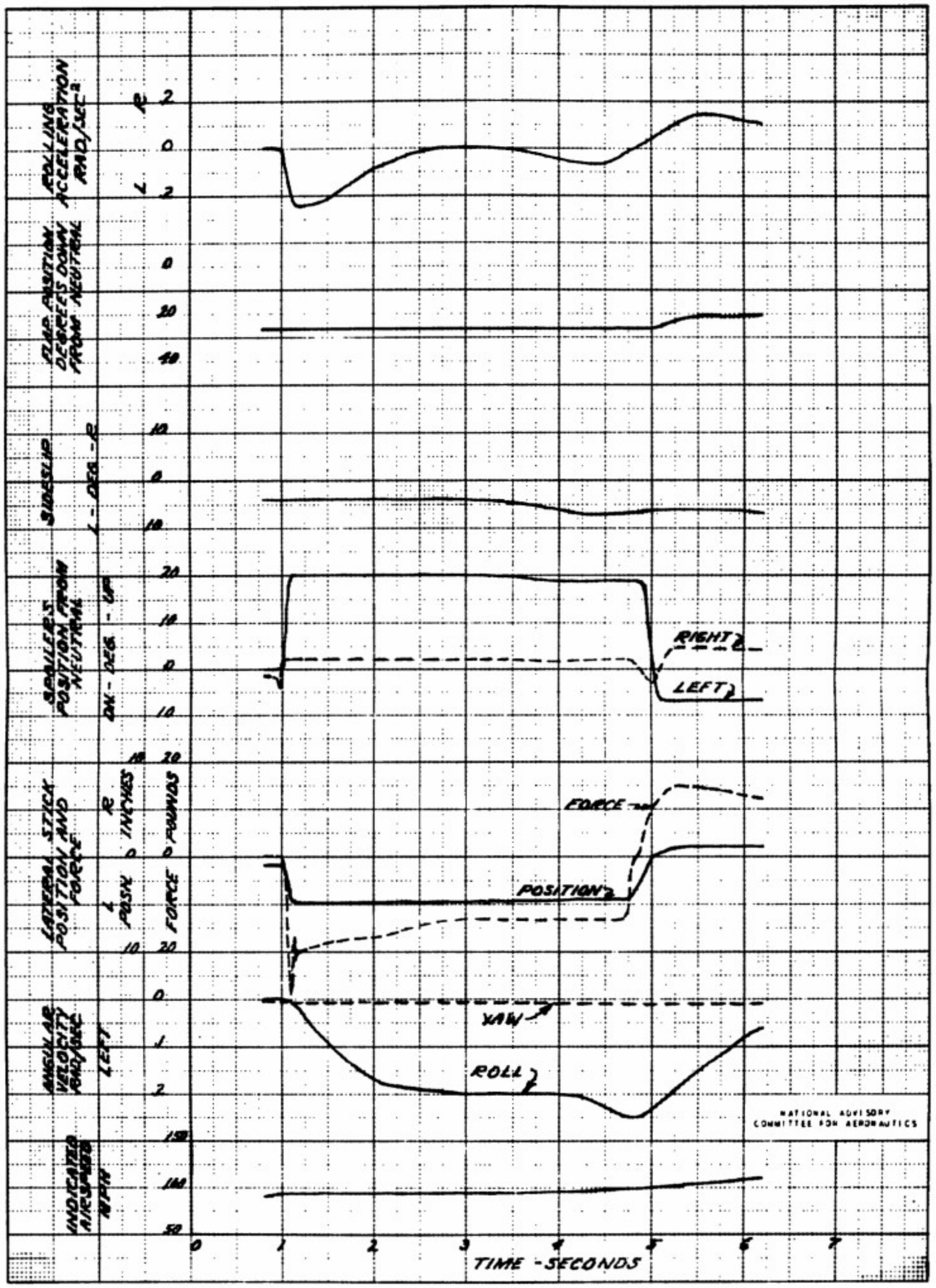

Figure 20.- Time history of an abrupt rudder locked roll by use of spoilers, flaps full down, slots closed, power off.

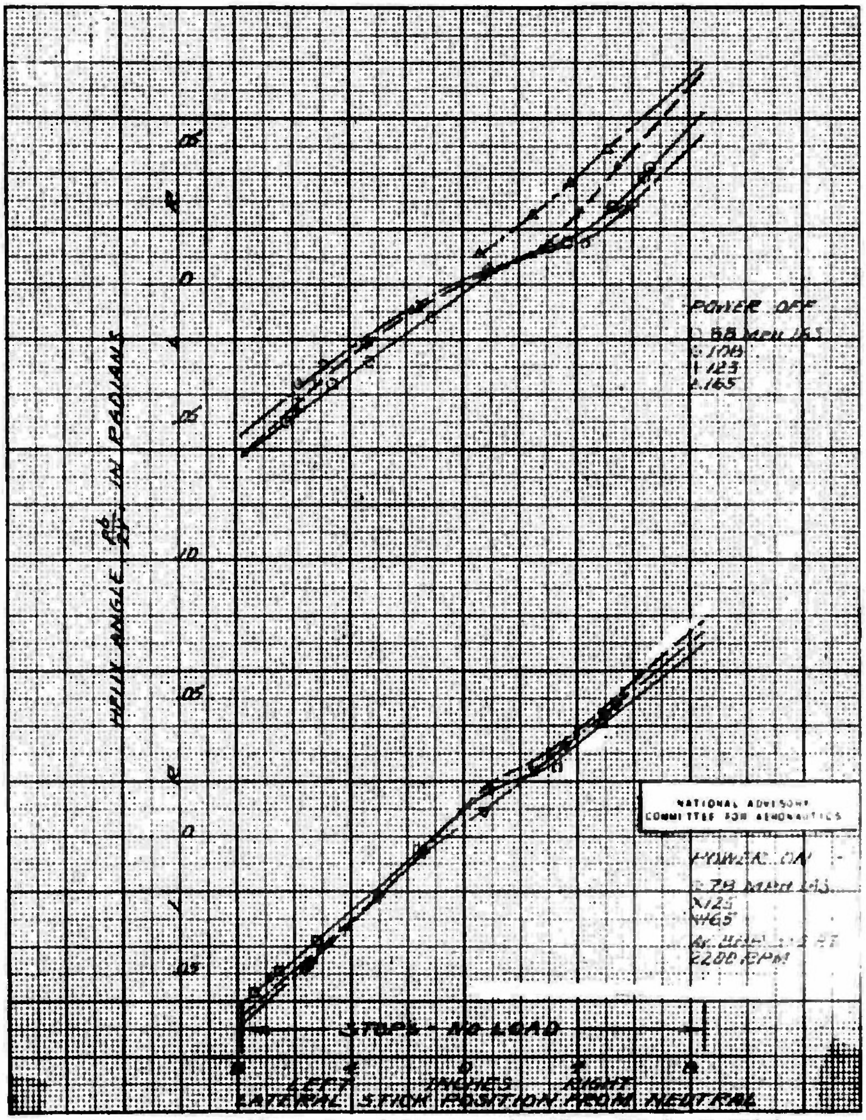

Figure 21.- Helix angle, pb/2V, as a function of lateral stick position, flaps up, slots closed.

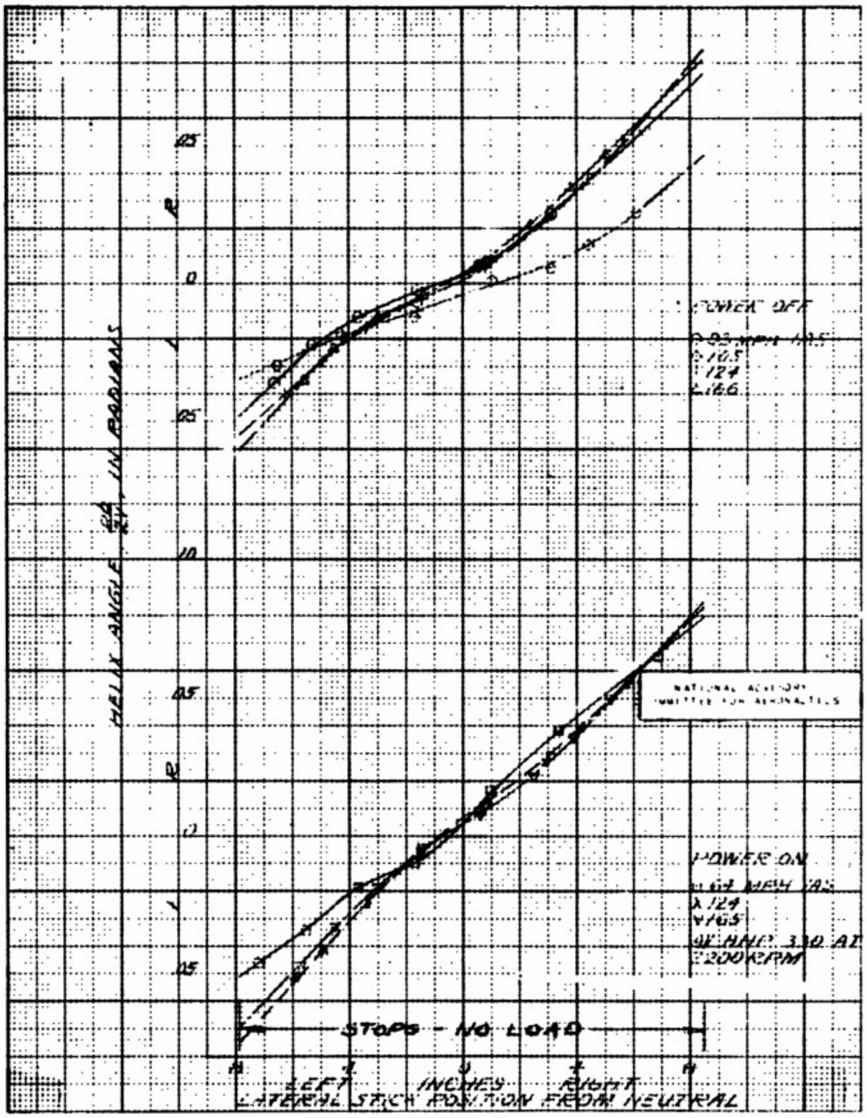

Figure 22.- Helix angle, pb/2V, as a function of lateral stick position, flaps up, slots open.

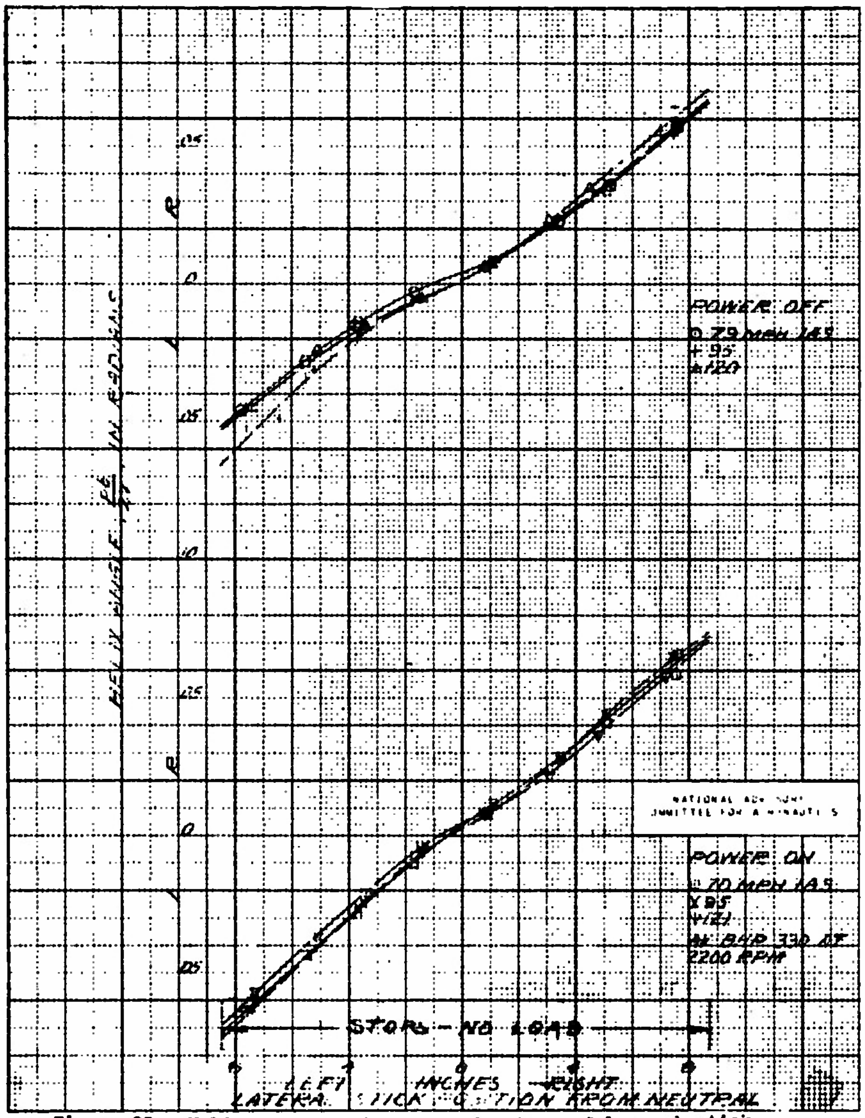

Figure 23.- Helix angle, pb/2V, as a function of lateral stick position, flaps one-third down, slots closed.

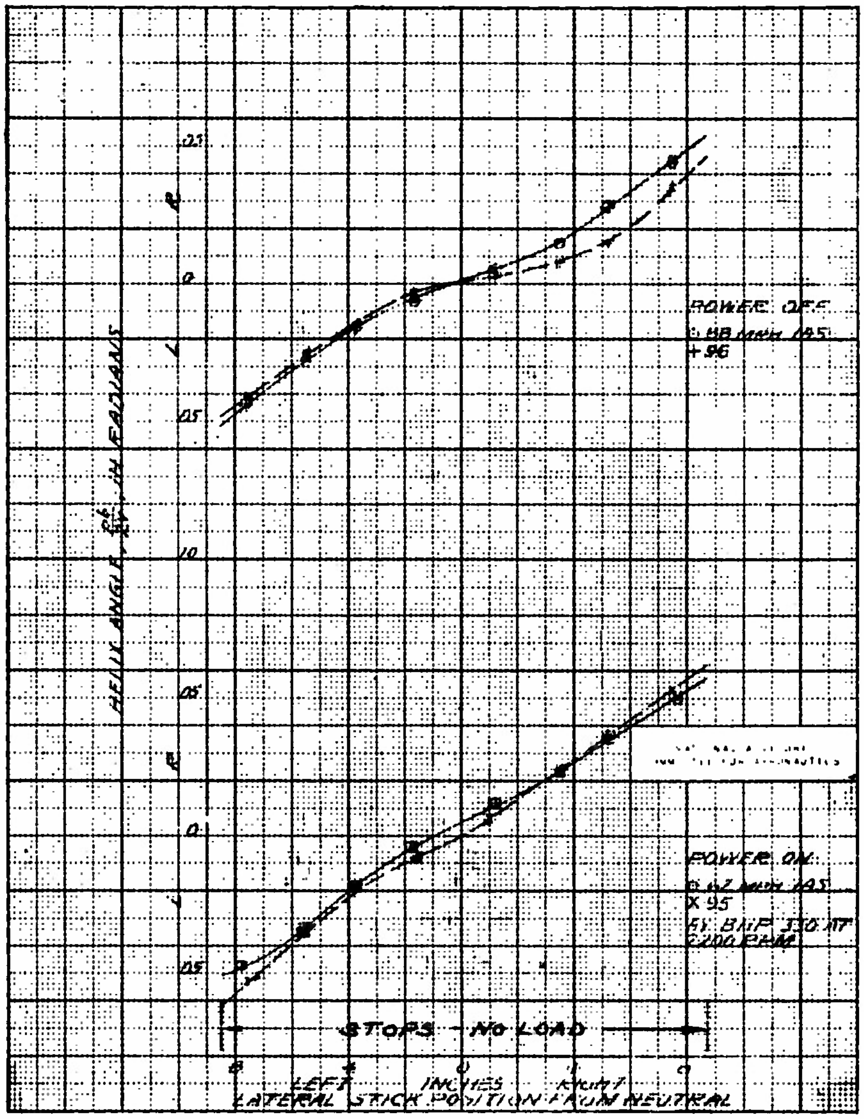

Figure 24.- Helix angle, pb/2V, as a function of lateral stick position, flaps one-third down, slots open.

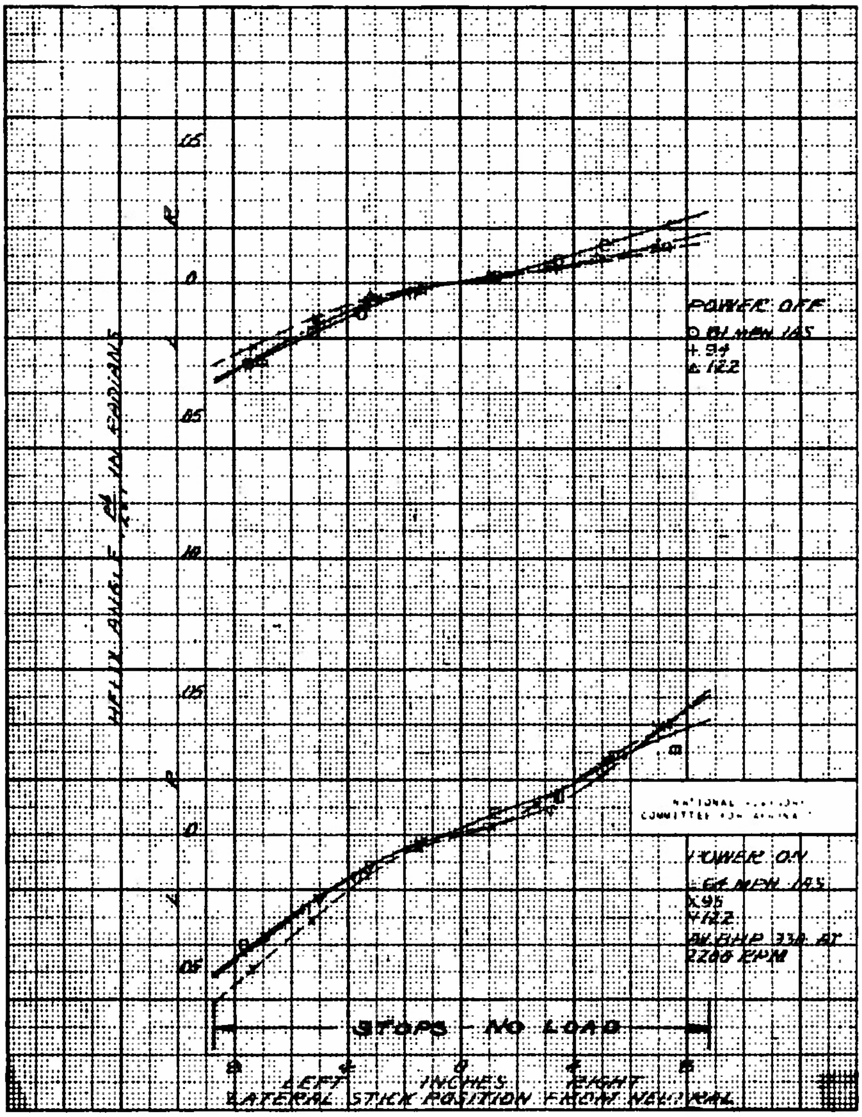

Figure 25.- Helix angle, pb/2V, as a function of lateral stick position, flaps two-thirds down, slots closed.

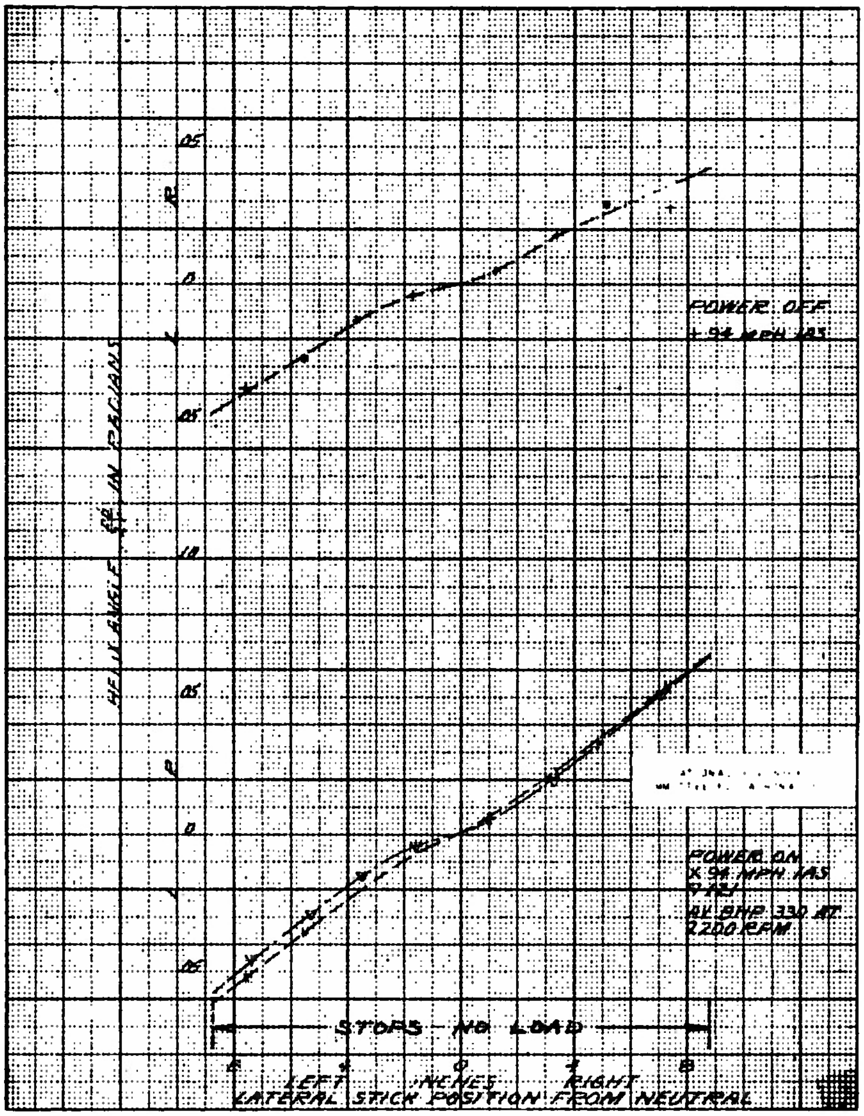

Figure 26.- Helix angle, pb/2V, as a function of lateral stick position, flaps two-thirds down, slots open.

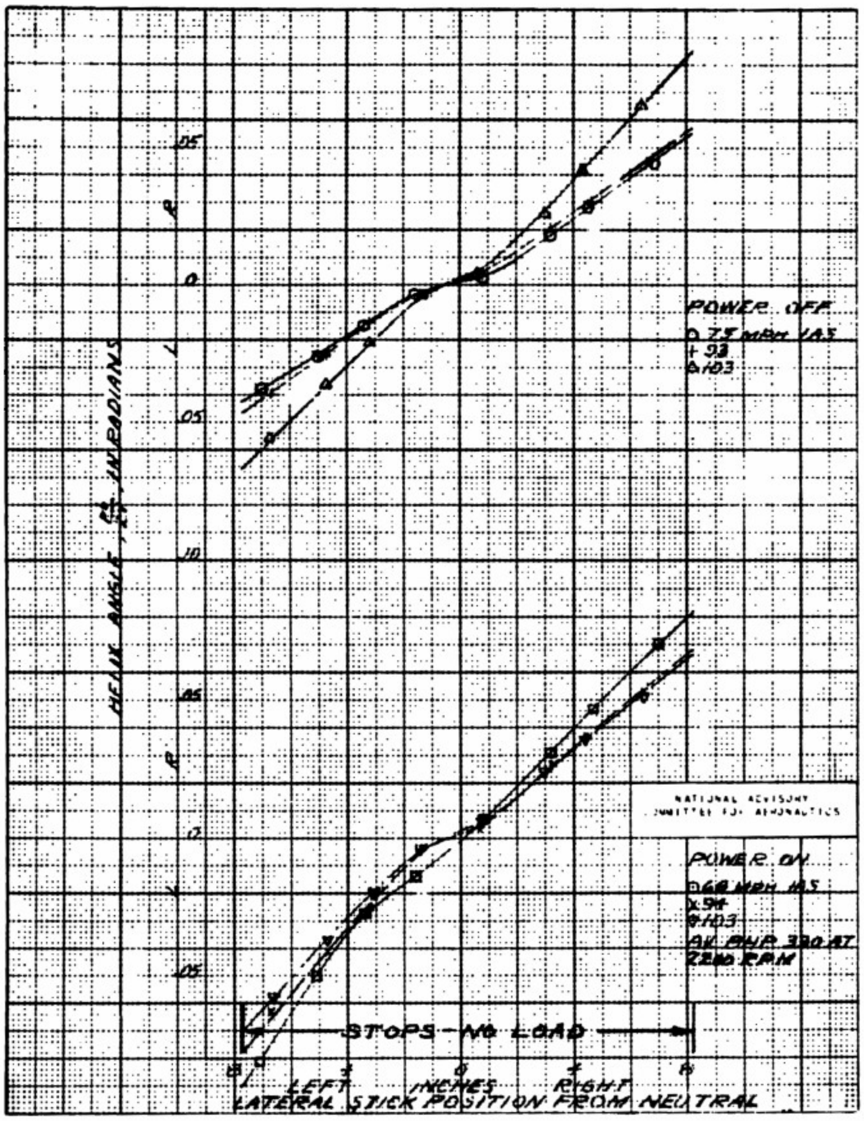

Figure 27.- Helix angle, pb/2V, as a function of lateral stick position, flaps full down, slots closed.

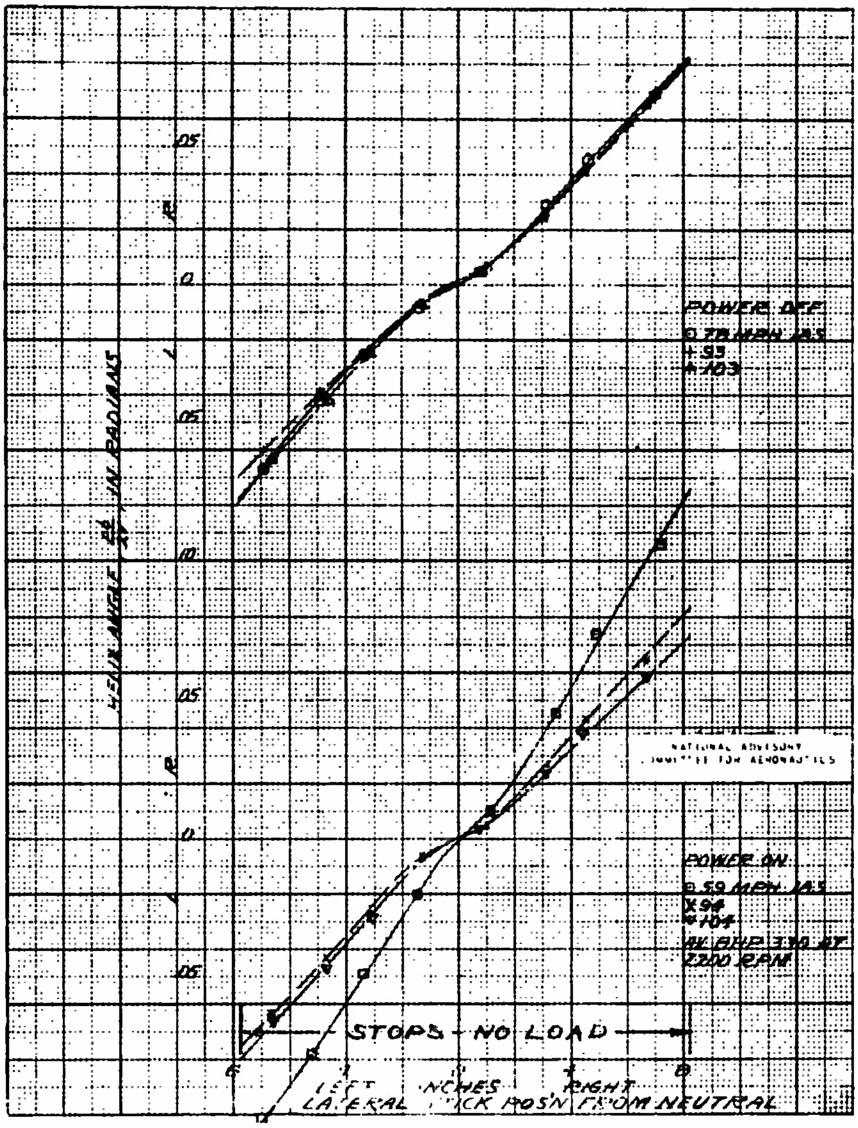

Figure 28.- Helix angle, pb/2V, as a function of lateral stick position, flaps full down, slots open.

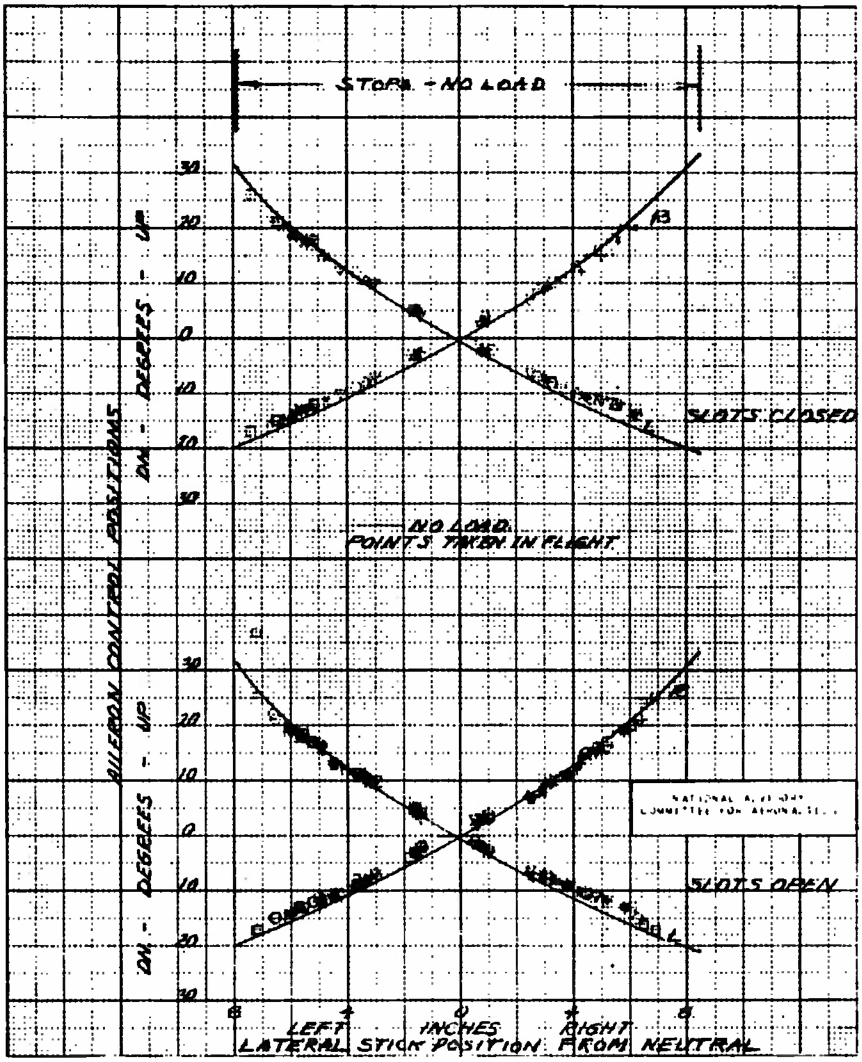

Figure 29.- Relation between aileron angle and lateral stick position when under no load and when in flight, flaps up.

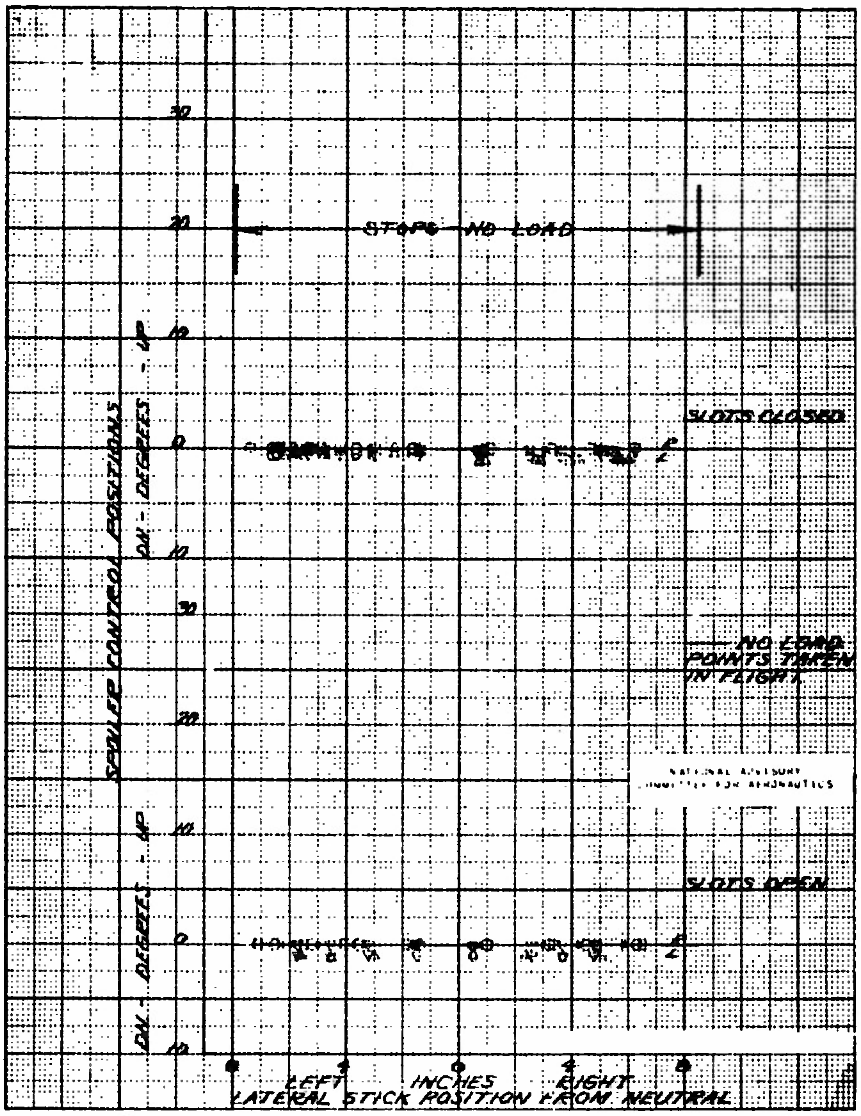

Figure 30.- Relation between spoiler angle and lateral stick position when under no load and when in flight, flaps up.

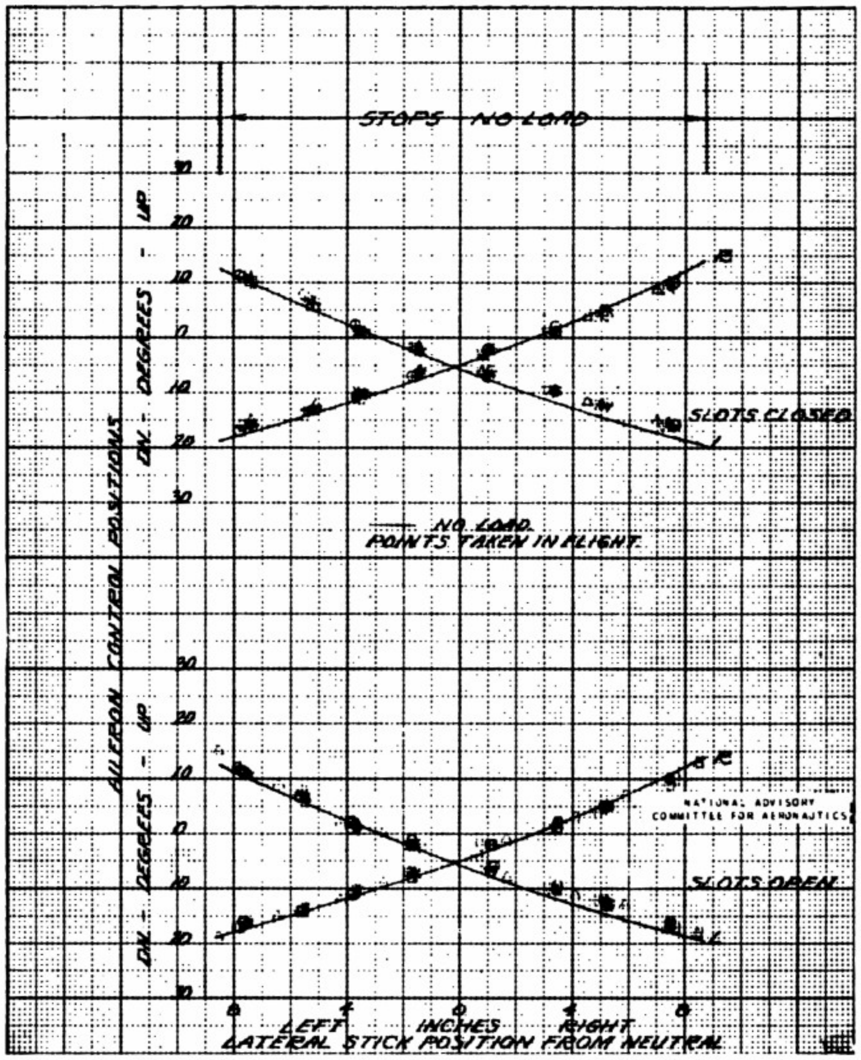

Figure 31.- Relation between aileron angle and lateral stick position when under no load and when in flight, flaps one-third down.

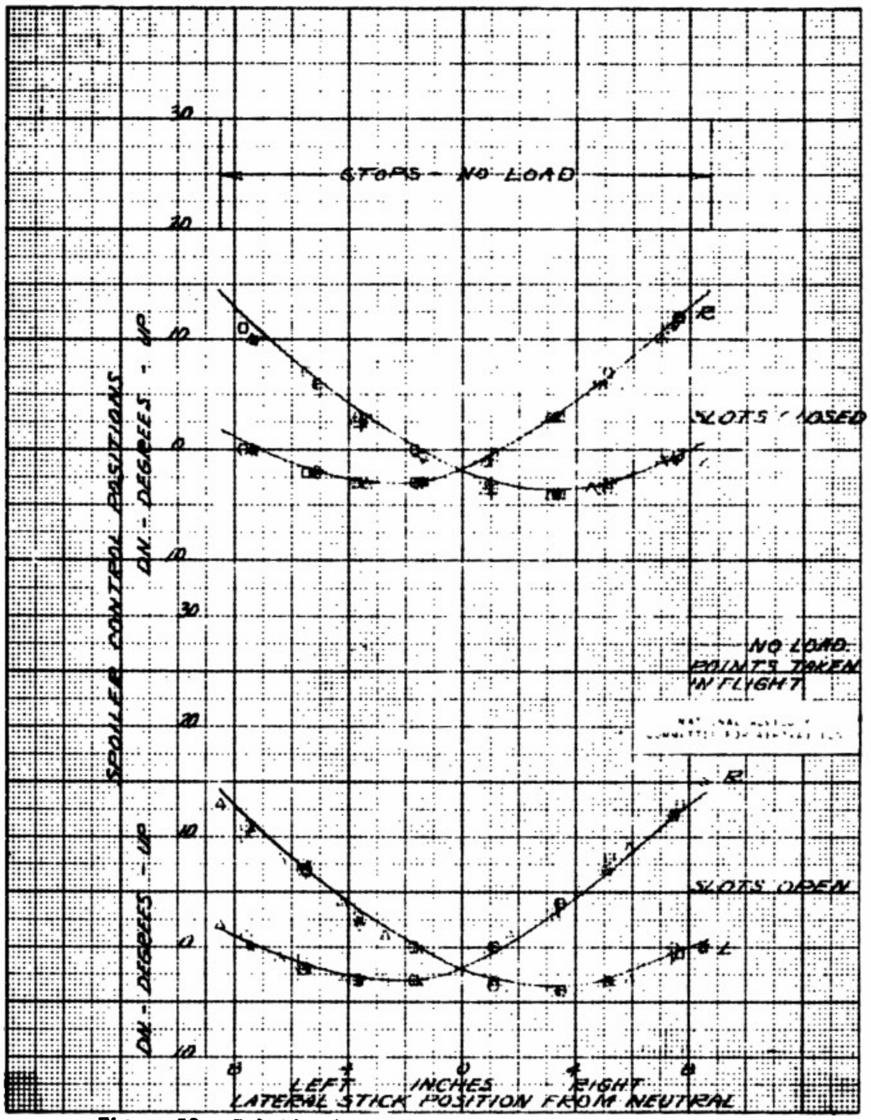

Figure 32.- Relation between spoiler angle and lateral stick position when under no load and when in flight, flaps one-third down.

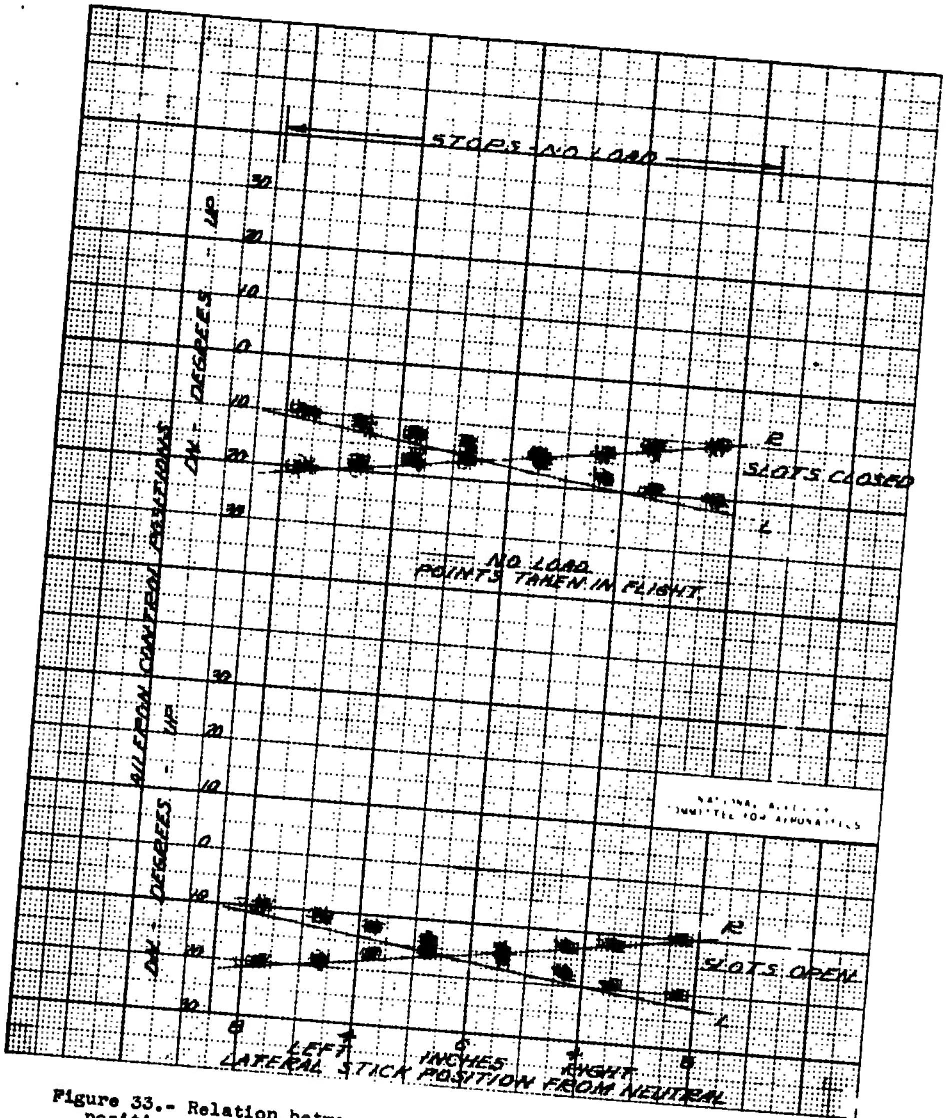

Figure 33.- Relation between aileron angle and lateral stick position when under no load and when in flight, flaps two-thirds down.

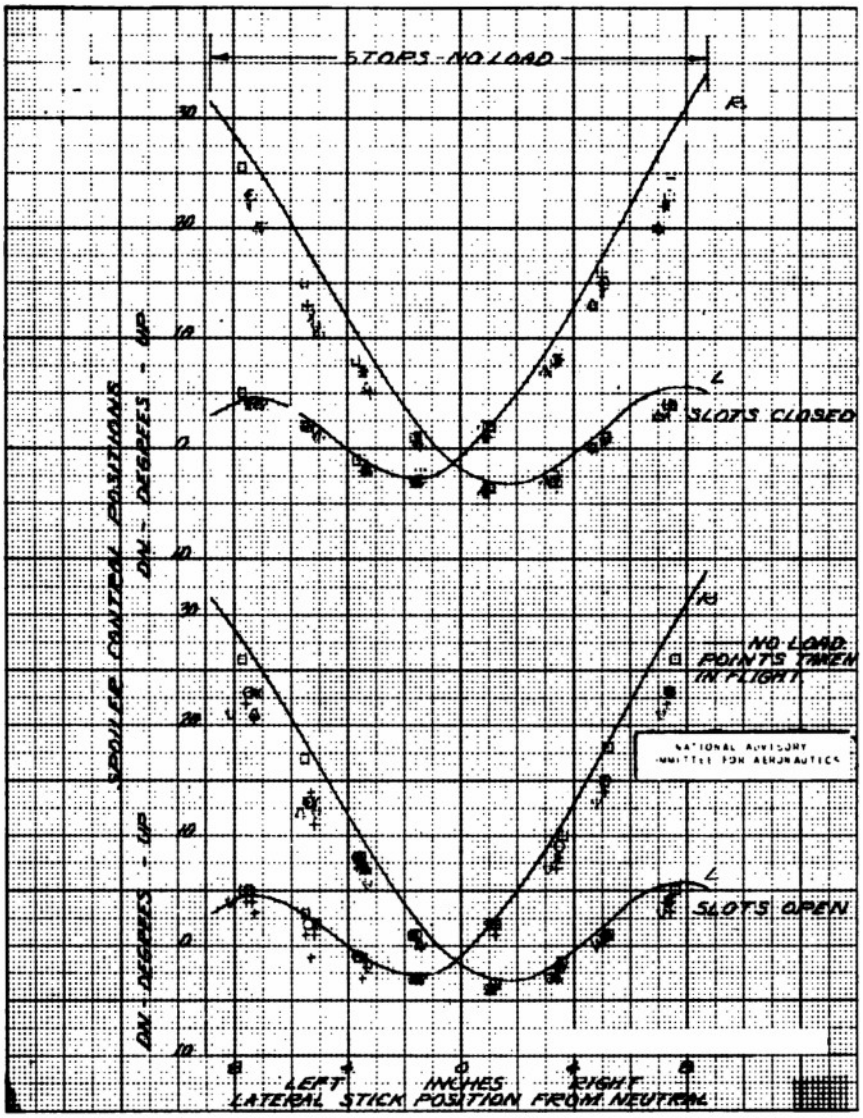

Figure 34.- Relation between spoiler angle and lateral stick position when under no load and when in flight, flaps two-thirds down.

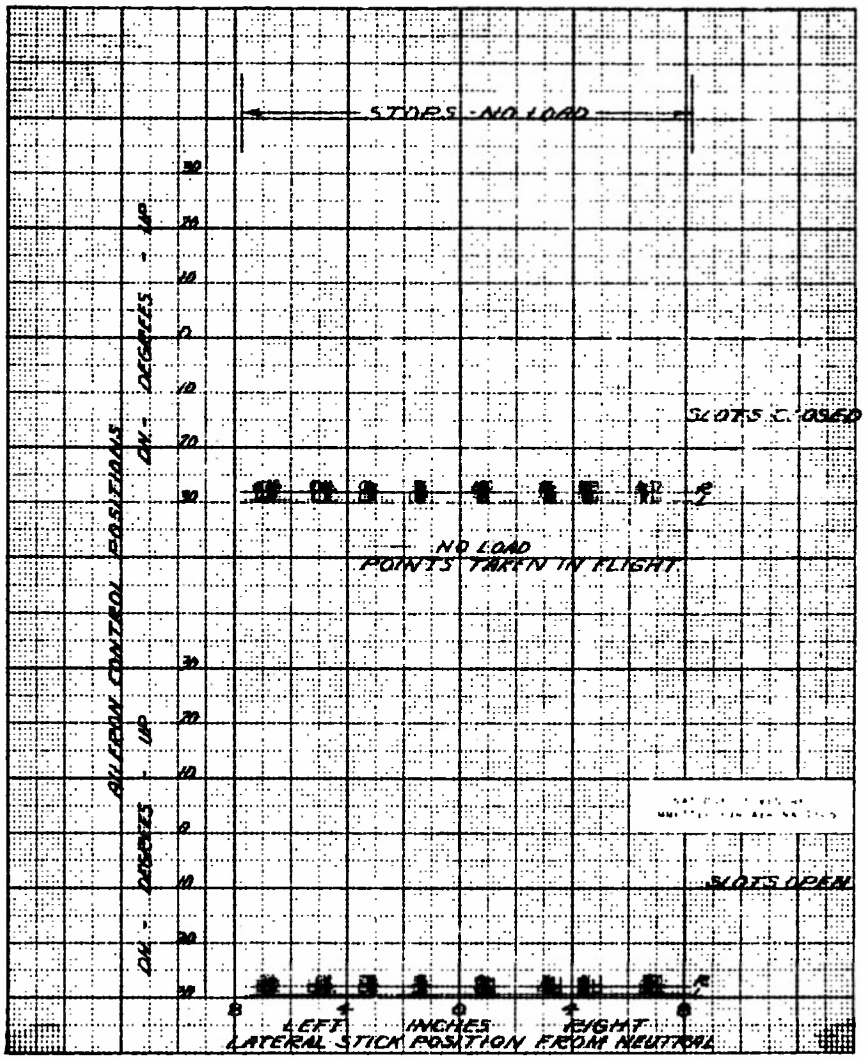

Figure 35.- Relation between aileron angle and lateral stick position when under no load and when in flight, flaps full down.

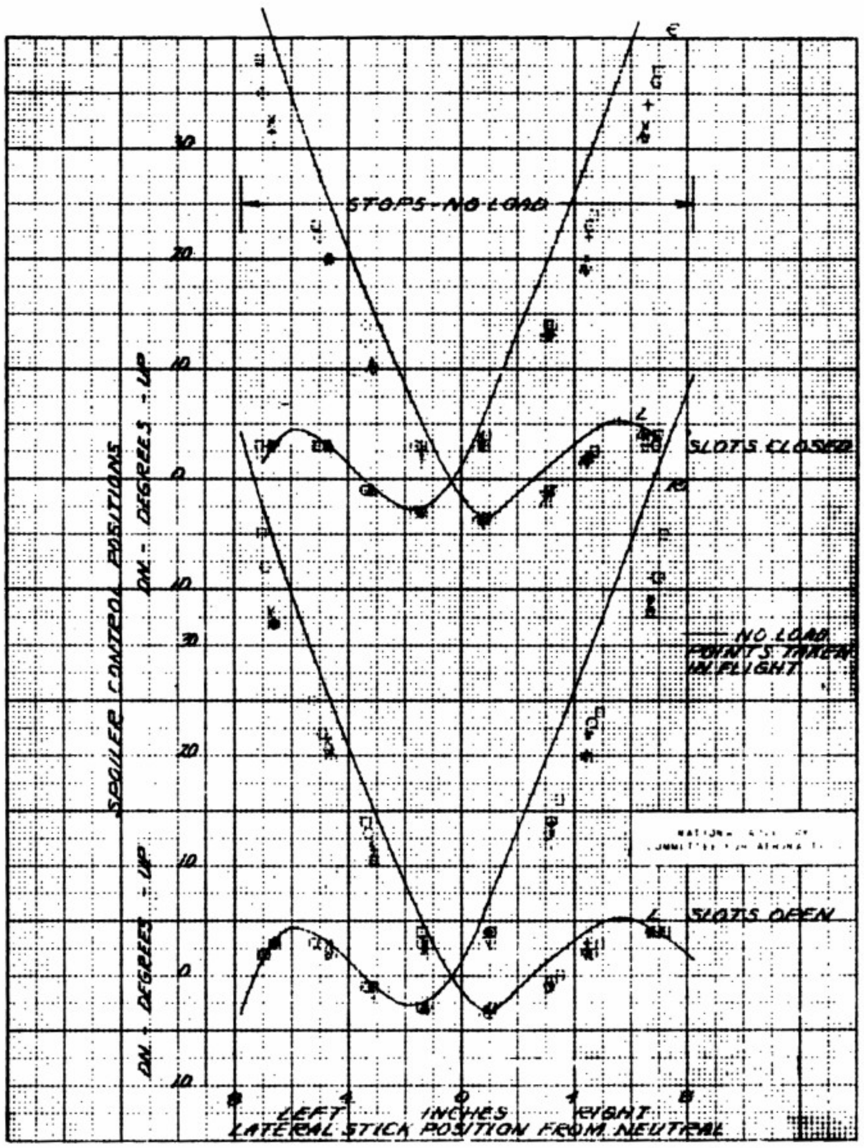

Figure 36.- Relation between spoiler control and lateral stick position when under no load and when in flight, flaps full down.

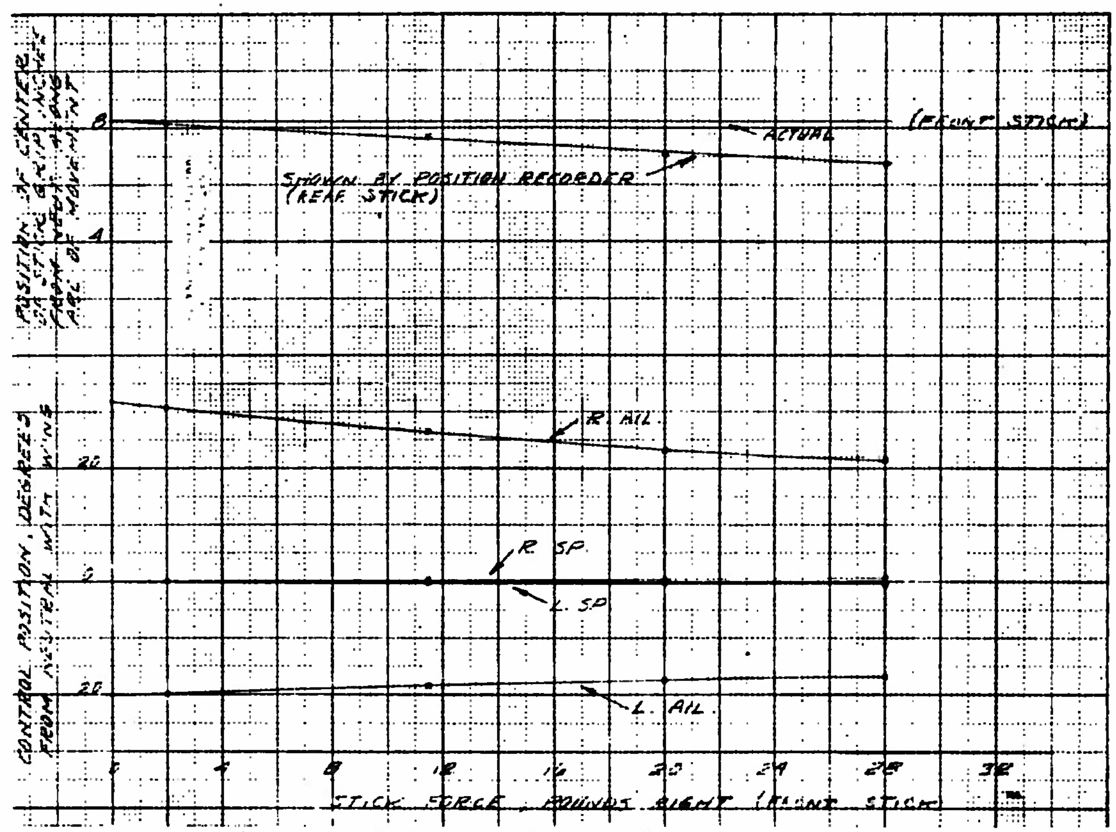

Figure 37. Variation of deflection of the control system with stick force when the right aileron only is loaded, and the front stick is held fixed, flaps up.

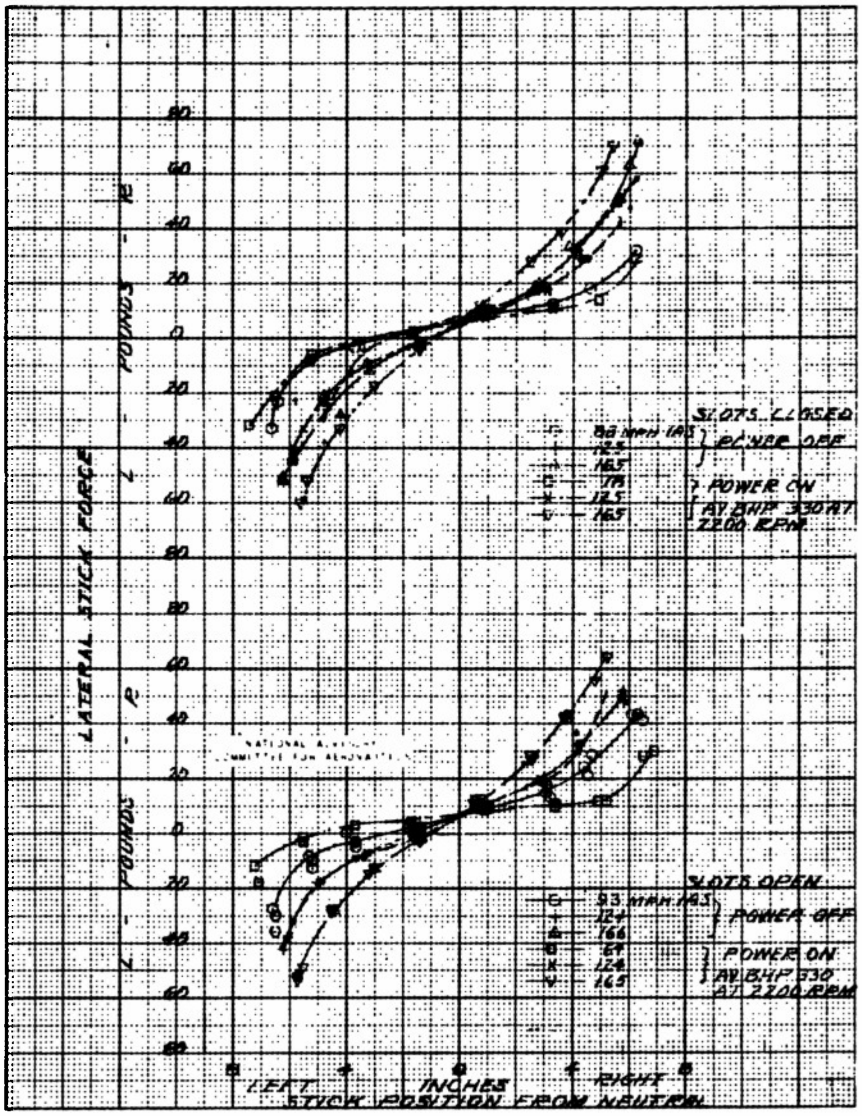

Figure 38.- Variation of aileron stick force with lateral stick position, flaps up.

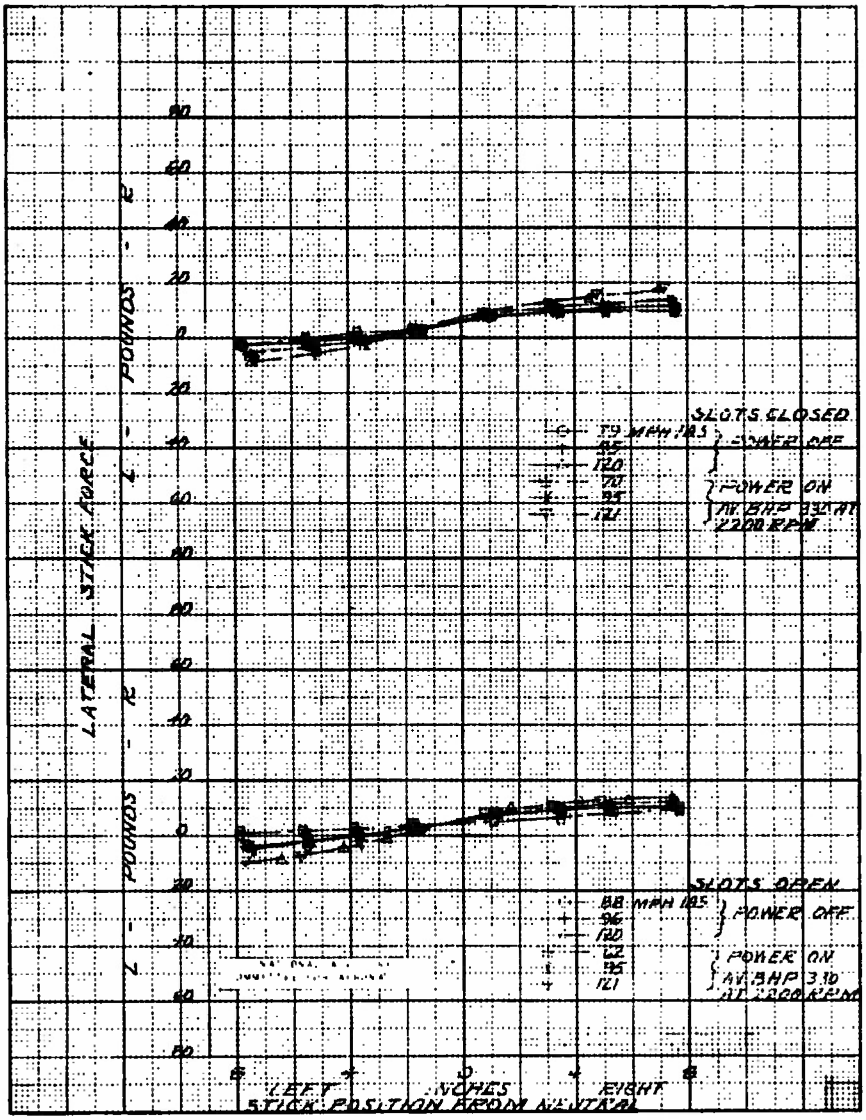

Figure 39.- Variation of aileron stick force with lateral stick position, flaps one-third down.

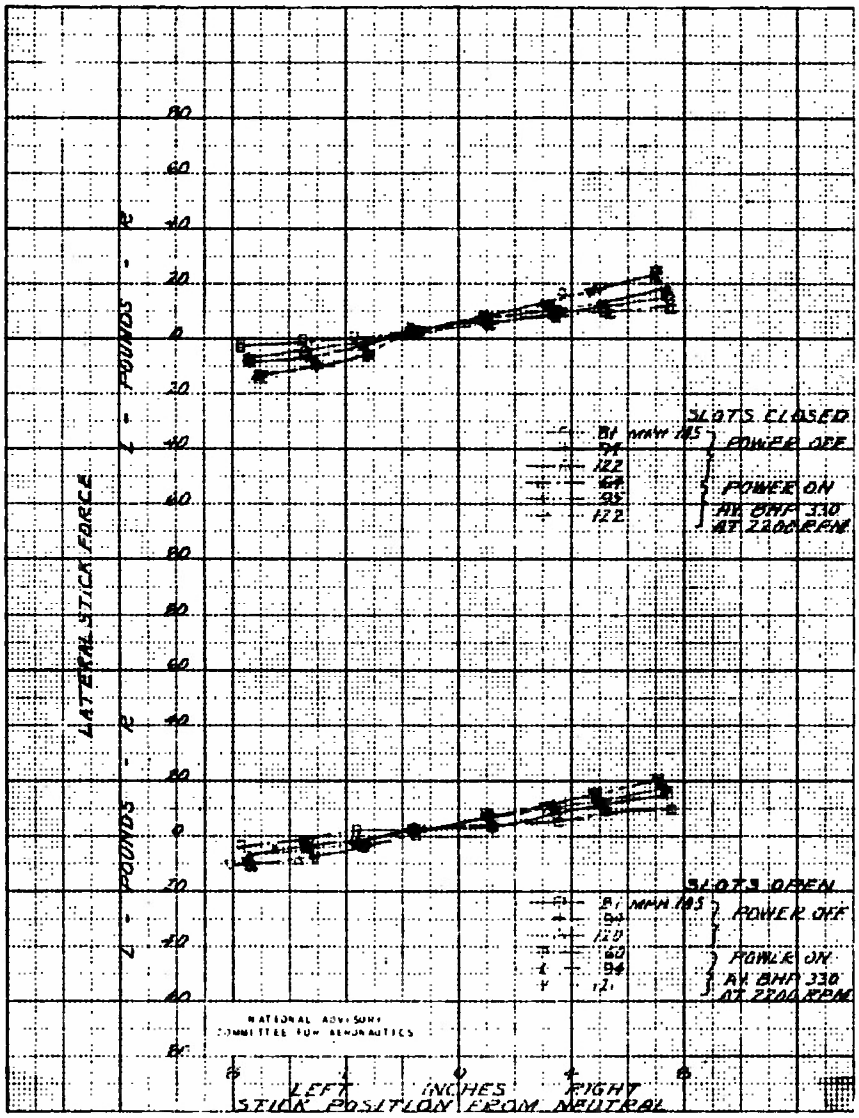

Figure 40.- Variation of aileron stick force with lateral stick position, flaps two-thirds down.

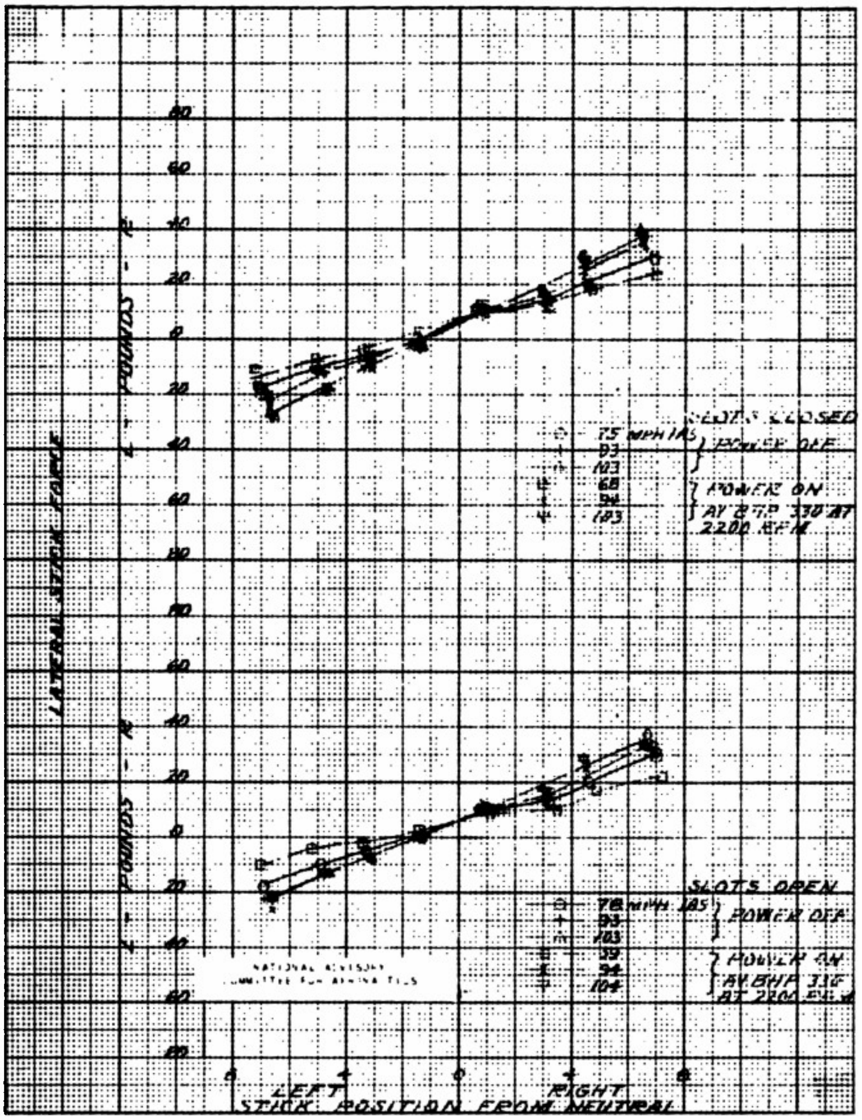

Figure 41.- Variation of aileron stick force with lateral stick position, flaps full down.

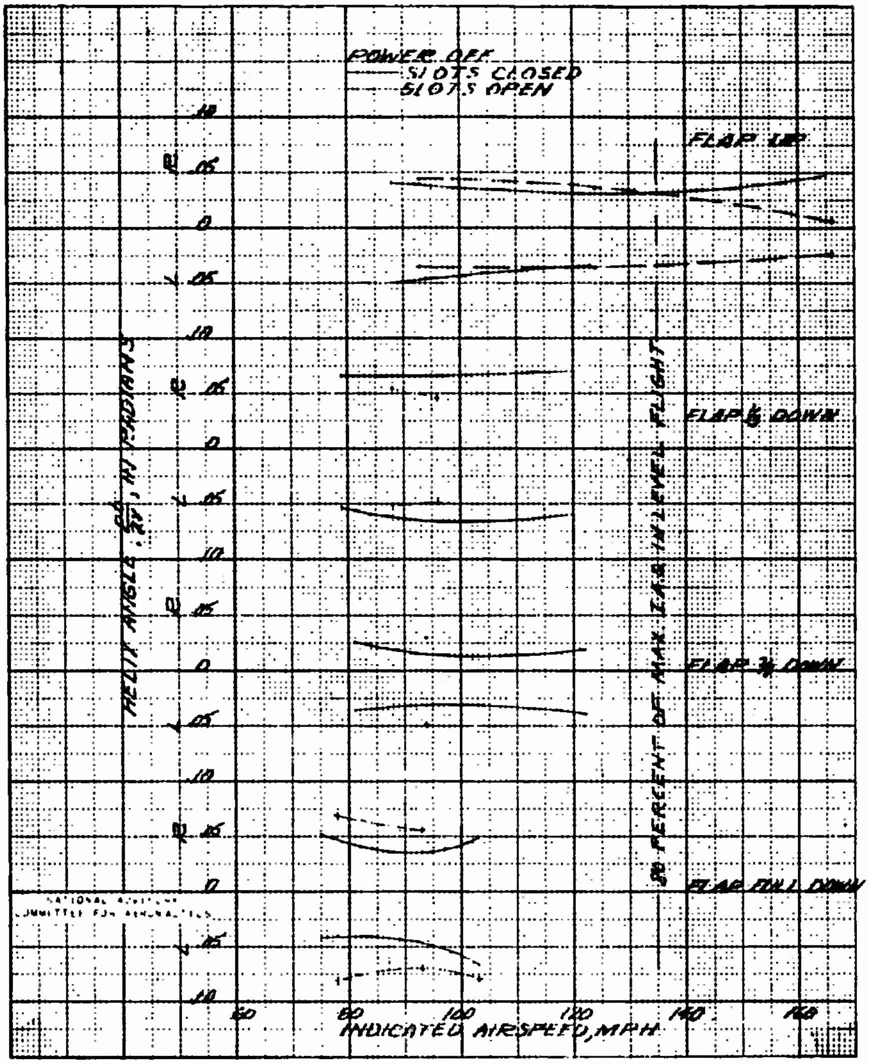

Figure 42.- Maximum helix angle, pb/2V, for lateral stick force of 30 pounds or less, all power-off conditions.

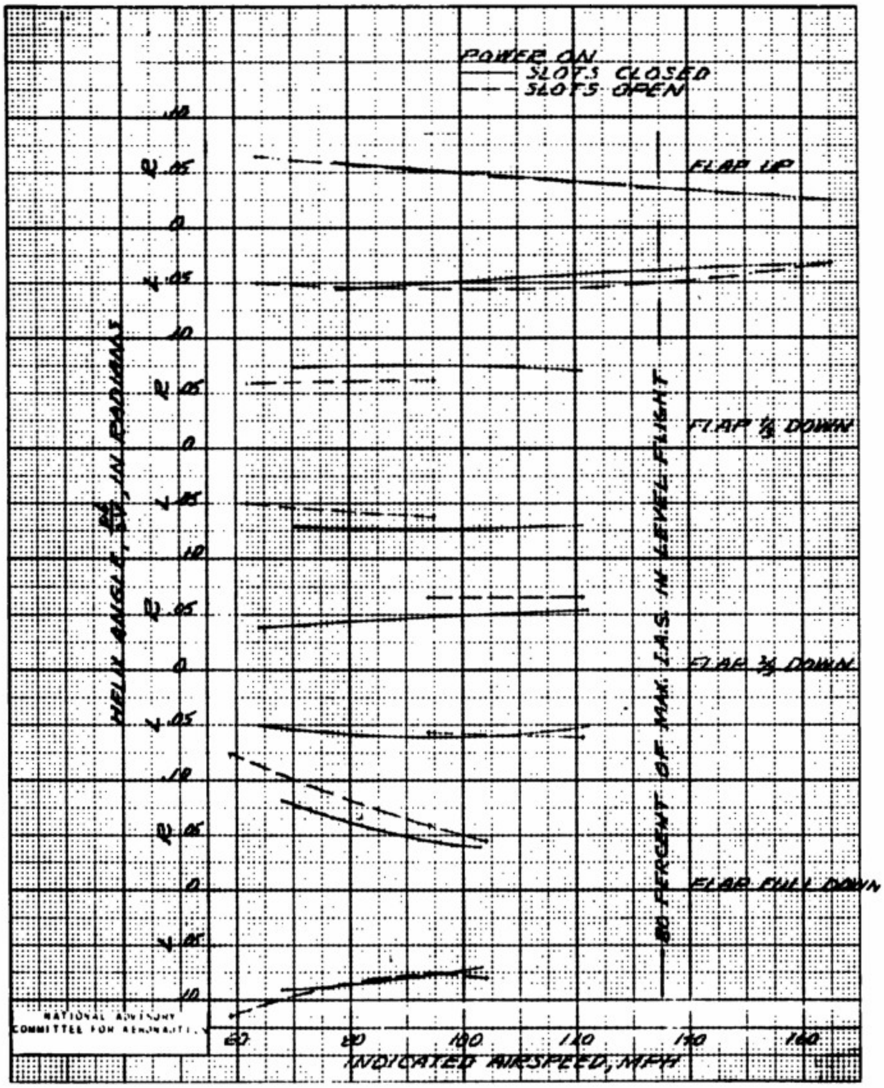

Figure 43.- Maximum helix angle, pb/2V, for lateral stick force of 30 pounds or less, all power-on conditions.

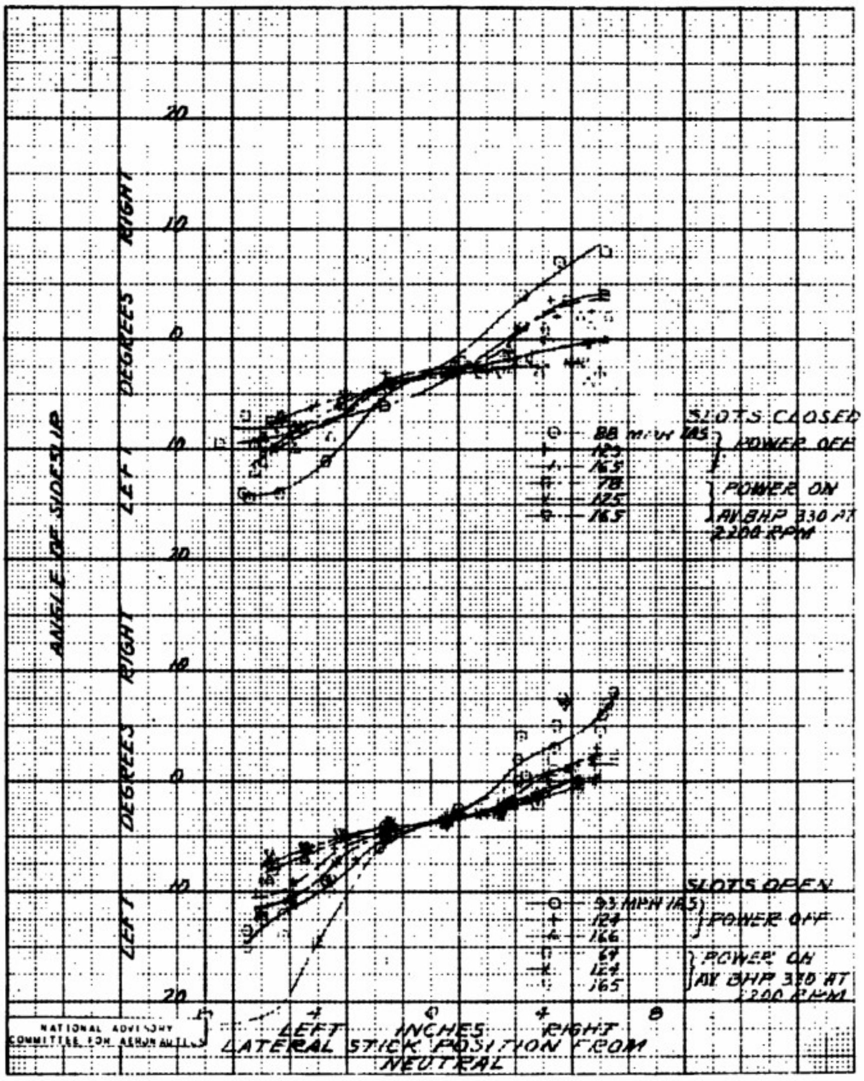

Figure 44.- The angles of sideslip developed as a result of lateral stick movement, flaps up.

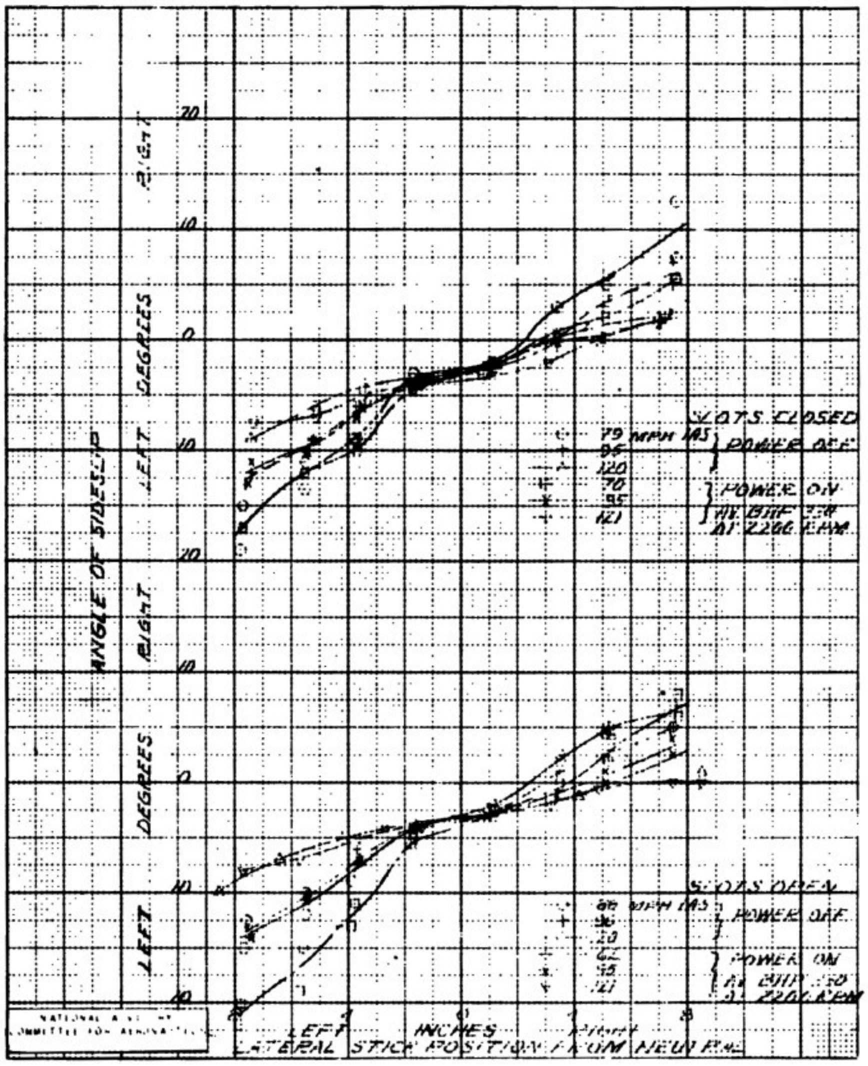

Figure 45.- The angles of sideslip developed as a result of lateral stick movement, flaps one-third down.

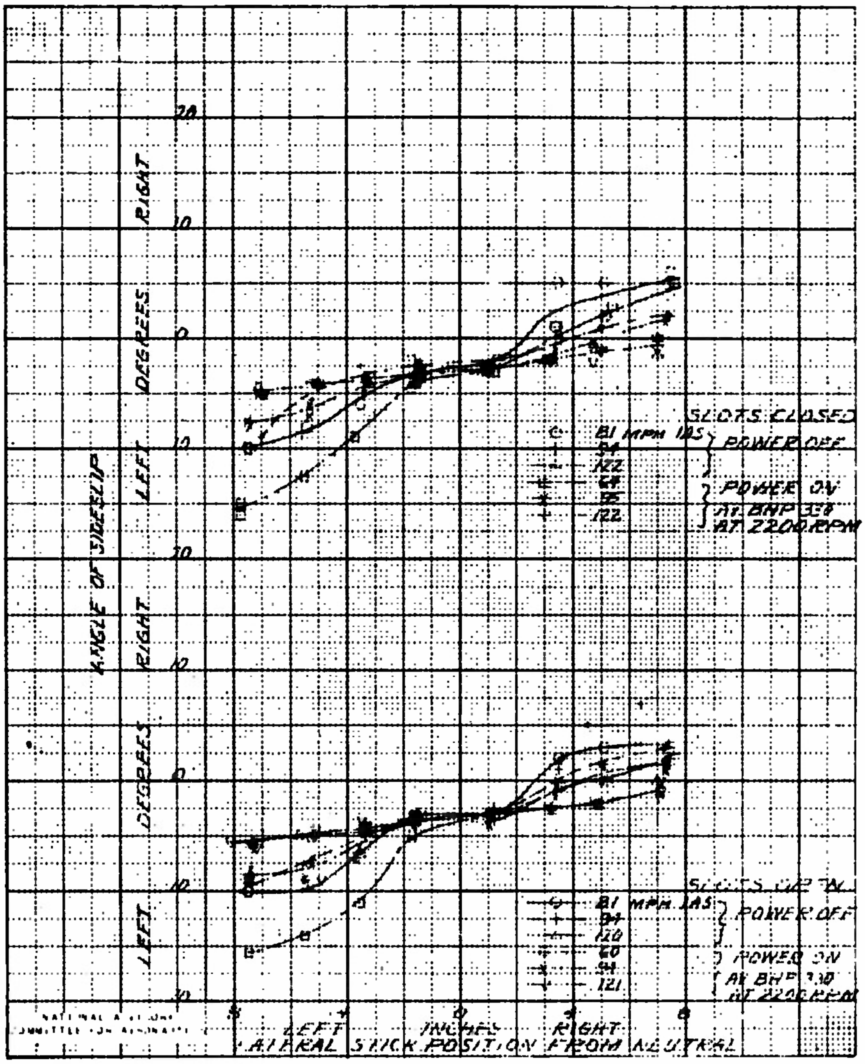

Figure 46.- The angles of sideslip developed as a result of lateral stick movement, flaps two-thirds down.

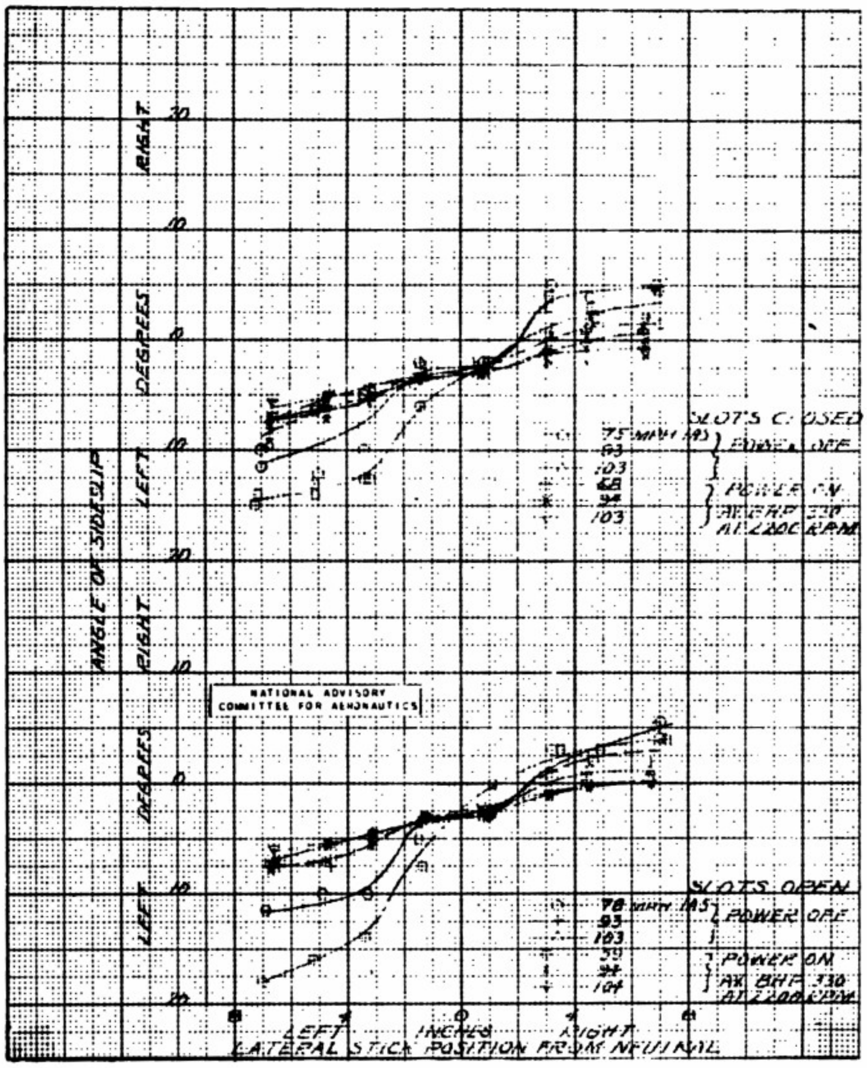

Figure 47.- The angles of sideslip developed as a result of lateral stick movement, flaps full down.

REEL – C

336

A.T.I.

9689

TITLE: Flight Measurements of the Lateral Control Characteristics of an Airplane Equipped with a Combination Aileron-Spoiler Control System	ATI- 9889
AUTHOR(S): Clousing, L. A.; McAvoy, W. H.	REVISION (None)
ORIGINATING AGENCY: National Advisory Committee for Aeronautics, Washington, D. C.	ORIG. AGENCY NO. MR-A-88
PUBLISHED BY: (Same)	PUBLISHING AGENCY NO.

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Sept '42	Unclass.	U. S.	Eng.	58	photos, graphs

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DIVISION: Aerodynamics (2)	SUBJECT HEADINGS: Airplanes - Lateral control (08470.5); Controls, Lateral - Aerodynamics (26500)
SECTION: Stability and Control (1)	
ATI SHEET NO.: R-2-1-42	

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AD-B805 605

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(23) * Aerodynamic Stability

Ailerons

Spoilers