L-272

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

December 1943 as
Advance Restricted Report 3L07

FLIGHT TESTS OF F2A-2 AIRPLANE WITH FULL-SPAN SLOTTED FLAPS AND TRAILING-EDGE AND SLOT-LIP AILERONS

By Joseph W. Wetmore and Richard H. Sawyer

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

FLIGHT TESTS OF F2A-2 AIRPLANE WITH FULL-SPAN SLOTTED FLAPS AND TRAILING-EDGE AND SLOT-LIP AILERONS

By Joseph W. Wetmore and Richard H. Sawyer

SUMMARY

Flight tests were made of a Navy F2A-2 airplane specially equipped with full-span NACA slotted flaps and with two sets of lateral controls: internally balanced, sealed ailerons on the flap trailing edge for use with flaps up and slot-lip ailerons, immediately forward of the flaps, for use with flaps down. The tests, made with various flap positions ranging from neutral to 50°, included determination of effectiveness and stick forces of the two aileron systems, power-off maximum lift coefficients, and static longitudinal stability.

The effectiveness of the trailing-edge ailerons was somewhat low, primarily because of lack of rigidity in the control system; the stick forces were fairly large, probably as a result of leakage through the aileron seal. The slot-lip ailerons were very effective, particularly at large flap deflections; with a slight modification of the control linkage, the stick-force characteristics would probably be satisfactory for all conditions under which these ailerons would be used. The highest maximum lift coefficient, which occurred at a flap deflection of about 40°, was 2.43. With the center of gravity at 30.4 percent of the mean aerodynamic chord and with engine idling, the airplane had positive static longitudinal stability for all conditions tested; with level-flight power, the stability decreased with increasing flap deflection and the airplane became unstable for flap deflections of 40° and 50° at service indicated airspeeds below 100 miles per hour.

INTRODUCTION

The results of wind-tunnel tests, constituting a part of the program of research by the National Advisory

Committee for Aeronautics on lateral-control devices for use with full-span flaps, indicated that a double system consisting of plain trailing-edge ailerons for the flaps-up condition and slot-lip ailerons for the flaps-down condition would provide satisfactory control for an airplane having full-span NACA slotted flaps (reference 1). An F2A-2 airplane was therefore equipped with these devices and flight tests were conducted.

The results of the first series of flight tests, designed to indicate the fundamental characteristics of the full-span slotted flaps and lateral-control systems, are presented herein. These results include the effectiveness and stick-force characteristics of the two aileron systems, the maximum lift coefficients obtainable with the full-span slotted flaps with engine idling, and the static longitudinal stability for one center-of-gravity position, both with engine idling and with level-flight power. The tests in most cases covered flap deflections ranging from neutral to 50° by 10° intervals.

AIRPLANE

A Navy F2A-2 airplane, fitted with a special wing incorporating full-span NACA slotted flaps and both internally balanced, trailing-edge ailerons and slot-lip ailerons, was used for the tests. Several views of the airplane are given in figures 1 to 4 and a sketch showing the plan-view arrangement of the devices in the wing is given in figure 5.

The design of the slotted flaps is based on NACA slotted flap 2-h, described in reference 2. The flaps move rearward as deflected and follow a path approximating the optimum path defined in reference 2. (See fig. 6.) Power for operating the flaps is generated by a hydraulic motor and transmitted to the flaps through a torsion shaft and screw jacks. An electrical selector and limit switches provide nominal flap deflections of 0°, 10°, 20°, 30°, 40°, and 50°. The relation between actual flap deflections and nominal flap deflections is shown in figure 7.

The trailing-edge ailerons are of narrow chord and large span and constitute the trailing-edge portions of the flaps. The ailerons are of the sealed, internally

balanced type, as shown in figure 8. They have an equal up-and-down motion and are operated through push-pull rod systems contained within the flaps. These ailerons continue in operation as the flaps are deflected from neutral to about 18°, where an automatic change-over device locks the ailerons in neutral position with respect to the flaps and engages the slot-lip ailerons.

The slot-lip ailerons are essentially upper-surface spoilers, which in the neutral position form the lip of the flap slot, as shown in figure 8. These ailerons are in operation for all flap deflections from 18° to full down and are locked in neutral for smaller flap deflections. The slot-lip ailerons are actuated through a push-pull rod system. Springs are incorporated in the control system to prevent overbalance of the control forces due to the combination of the strong upfloating tendency of the ailerons and their extreme differential motion.

A new horizontal tail of greater area and aspect ratio than the original F2A-2 tail was used to ensure longitudinal trim and stability with the full-span flaps.

Pertinent airplane specifications and dimensions follow:

Wing:

Span	35 ft
Area (including 30.8 sq ft of fuselage)	208.9 sq ft

Wing flaps (NACA slotted type):

Total area	44.8 sq ft
Flap semispan	14 ft $4\frac{29}{32}$ in.
Travel	50°
Chord (25 percent of mean wing chord)	19.047 in.

Trailing-edge ailerons:

Span (each)	9 ft $10\frac{1}{4}$ in.
Chord (10 percent mean wing chord)	7 in.
Area (rearward of hinge line, each)	5.6 sq ft
Travel	17.6° up, 17.6° down
Balance area (each)	1.76 sq ft

Slot-lip ailerons:

Span (each)	6 ft $10\frac{9}{32}$ in.
Chord (10 percent of mean wing chord)	7 in.
Area (rearward of hinge line, each)	4.0 sq ft
Travel	46° up, 9° down

Stabilizer:

(a) New

Area (including 4.86 sq ft of fuselage)	30.2 sq ft
Incidence to thrust axis	15'

(b) Original

Area (including 4.86 sq ft of fuselage)	22.6 sq ft
Incidence to thrust axis	15'

Elevators:

(a) New

Span	14 ft $9\frac{3}{4}$ in.
Area	18.8 sq ft
Travel	28° up, 20° down
Trim-tab area	0.59 sq ft

(b) Original

Span	12 ft $6\frac{1}{4}$ in.
Area	16.9 sq ft
Travel	28° up, 20° down
Trim-tab area	1.0 sq ft

Vertical fin:

Area	10.3 sq ft
Offset	0°

Rudder:

Vertical span	5 ft $10\frac{3}{8}$ in.
Area (rearward of hinge)	8.9 sq ft
Travel	30° left, 30° right
Trim-tab area	0.45 sq ft

Distance from elevator hinge line to leading edge of wing at center line of fuselage . . . . 18 ft $4\frac{1}{4}$ in.

Distance from rudder hinge line to leading edge of wing at center line of fuselage . . . . 17 ft $3\frac{1}{4}$ in.

Normal gross weight (original wing and tail) . . 5311 lb
Weight as flown for tests . . . . . 5765 lb
Normal center-of-gravity position (original wing and tail) . . . . . 25 percent M.A.C.
Center of gravity as flown (wheels down) . . . . . 30.4 percent M.A.C.
Engine . . . . . Wright R-1820-40
Engine rating . . . . . 900 hp at 2300 rpm at 14,000 ft
Gear ratio 3:2
Propeller . . . . . Curtiss electric (with cuffs)
  Diameter . . . . . 10 ft 3 in.
  Number of blades . . . . . Three

The relations between control-stick position and the deflections of the trailing-edge ailerons, the slot-lip ailerons, and the elevator are shown in figures 9 to 11.

INSTRUMENT INSTALLATION

The following NACA photographically recording instruments were installed in the airplane:

Item measured	NACA instrument
Time	$\frac{1}{2}$-second chronometric timer
Airspeed	Airspeed recorder
Positions of control stick and rudder pedals	Three-element control-position recorder
Positions of right ailerons	Electrical control-position recorders
Rolling velocity	Angular-velocity recorder
Yawing velocity	Angular-velocity recorder
Normal, longitudinal, and lateral acceleration	Recording three-component accelerometer
Angle of yaw	Recording yaw vane
Aileron and elevator stick forces	Stick-force recorder

All the recording instruments were synchronized by the timer. The airspeed recorder was connected to a swiveling static head, free to rotate in both pitch and yaw, and to a shielded total-head tube, both of which were mounted on a boom extending 1 chord ahead of the right wing tip. The yaw vane was mounted on a similar boom on the left wing tip. The three-element control-position recorder was situated in the cockpit near the base of the stick. The electrical control-position recorders were mounted on the upper surface of the right wing, each forward of the aileron to which it was connected. The angular-velocity recorders and the three-component accelerometer were placed as near the center line and the center of gravity of the airplane as feasible. The original stick was replaced by a stick incorporating the stick-force recorder.

TESTS

The aileron tests consisted in making abrupt aileron rolls, during which the positions of the ailerons and stick, the airspeed, the stick force, the yaw angle, and the rolling and yawing angular velocities were recorded. The control stick was abruptly moved either to the right or to the left from its neutral position and held in its deflected position until maximum rolling velocity was attained. The rudder was held in neutral throughout the maneuver. Both full and partial control-stick deflections were made by using a chain fixed to the top of the control stick and to the side of the fuselage as a stop. These abrupt aileron rolls were recorded at various airspeeds throughout a considerable speed range for all flap settings, generally in level flight; a few tests were taken with engine idling for the flaps-neutral condition (trailing-edge ailerons). The pilot observed free-air temperature and pressure altitude to permit determination of true airspeed from the recorded impact pressure. The maximum rolling velocity and true airspeed were used to determine the helix angle generated by the wing tips as a measure of aileron effectiveness. The stick-force values used were the values obtained at the time that maximum rolling velocity occurred. The lag of the ailerons was defined as the time between the start of the movement of the ailerons and the beginning of rolling motion.

The records of yaw angle and yawing angular velocity were not evaluated except in a few cases for which it was desired to compare the motion of the airplane obtained with the slot-lip ailerons, flaps down, with the motion obtained with the trailing-edge ailerons, flaps up.

For the determination of maximum lift coefficients and stalling characteristics, stalls with engine idling were made for all flap settings from neutral to full down. For each flap setting the airplane was tested with extended and retracted positions of the landing gear and open and closed positions of the cockpit hood. The stalls were approached as steadily and gradually as was practicable to avoid dynamic effects. Records were taken of impact pressure, position of the controls, and motion of the airplane throughout the approach and stall. In order to correct the recorded stalling speeds for position error, the test airspeed installation was calibrated by flying alongside another airplane for which the airspeed calibration was known and taking records simultaneously in both airplanes. The calibration was made with engine idling at several airspeeds close to and including the stalling speed with all flap settings.

The position of the elevators and the airspeed, read from the initial, steady-flight part of the aileron-roll records, provided the information required for the determination of control-fixed, static longitudinal stability in the level-flight power condition. Similar information for the engine-idling condition was obtained from the airspeed calibration and stall test records. Some of these series of tests were made with fixed elevator trim-tab setting in order that an indication of control-free longitudinal stability might be obtained from the stick-force measurements.

All tests were made at relatively low altitudes, that is, between 5000 and 10,000 feet.

As used in this report, values of service indicated airspeed V_{is} were determined from the relation $V_{is} = 45.1\ f_o\sqrt{q_c}$, where f_o is compressibility factor for standard sea-level conditions and q_c is impact pressure in inches of water as measured with the test airspeed installation. Unless otherwise stated, V_{is} is not corrected for error due to position of airspeed head.

RESULTS AND DISCUSSION

Aileron Characteristics

Trailing-edge ailerons.- In accordance with present NACA practice (reference 3), the effectiveness of the ailerons in producing roll is considered as defined by the helix angle generated by the wing tips as a result of abrupt aileron displacement; the value of the helix angle in radians is given by the computation of $pb/2V$, where

p rolling angular velocity

b wing span

V true airspeed

The effectiveness of the trailing-edge ailerons is given in figure 12 as a plot of $pb/2V$ against right aileron deflection for service indicated airspeeds V_{is} ranging from 90 to 229 miles per hour with flaps neutral and from 85 to 149 miles per hour with a flap selector setting of 10°. The aileron effectiveness is shown to vary practically linearly with aileron angle and, for a given aileron angle, to be essentially independent of airspeed and flap deflection within the ranges tested. The maximum values of $pb/2V$ attained, however, were in all cases less than 0.07, which is suggested in reference 3 to be the minimum satisfactory value.

The low effectiveness of the trailing-edge ailerons can be attributed, in a large measure, to the excessive elasticity in the aileron control system, which reduced the aileron-deflection range attainable in flight to considerably less than the design range of ±17.5° even at the lower speeds. For example, the maximum aileron deflection obtained with full stick deflection was about 16° at a service indicated airspeed of 90 miles per hour and about 12° at 216 miles per hour; the corresponding values of $pb/2V$ were about 0.065 and 0.050, respectively. The elasticity in the aileron control system is indicated in figure 13, which shows the relation between stick force and deflection of the aileron due to elastic deformation of the control system under load. For a stick force of only 30 pounds, the deflection was reduced by 5.5°, or more than 30 percent. Tests on the ground, whereby the positions of various elements of the control system were

measured with and without a load on the ailerons, indicated that the greater part of the reduction in aileron travel results from torsional deflection of a pair of torque tubes in the system.

The force characteristics of the trailing-edge ailerons for the flap-neutral condition are presented in figure 14 as effective hinge-moment coefficient plotted against right aileron deflection. The effective hinge-moment coefficient C_{h_e} is defined as the average hinge-moment coefficient of the upgoing and downgoing ailerons including the effects of steady rolling and is obtained from the relation

$$C_{h_e} = \frac{F_s l_s}{S_a \bar{c}_a q \frac{d\delta_a}{d\delta_s}}$$

where

F_s stick force, pounds

l_s length of stick from grip to pivot, feet

S_a total area of both ailerons back of hinge axis, square feet

$\bar{c}_a$ mean aileron chord, feet

q dynamic pressure, pounds per square foot

$\frac{d\delta_a}{d\delta_s}$ rate of change of aileron deflection with angular stick displacement, with no load on ailerons

In using this relation, it was assumed that the mechanical advantage of the control system was not materially changed by the elasticity in the system. For the present case, the relation reduces to

$$C_{h_e} = 0.322 \frac{F_s}{q}$$

With the exception of the points obtained at an airspeed of 90 miles per hour, the variation of C_{h_e} with aileron angle for all airspeeds tested is defined reasonably well by a single straight line. The displacement from this line of the points for V_{is} = 90 miles per hour is

probably due, to a large extent, to the effects of friction and weight moments in the control system, which are largely obscured at the higher speeds by the greater aerodynamic forces.

The variation with service indicated airspeed of aileron deflection, effectiveness, and stick force for full control-stick deflection derived from the faired curves of figures 12 to 14 is plotted in figure 15. At speeds for which the stick force with full control-stick deflection exceeds 30 pounds, values corresponding to a 30-pound stick force are also given. At V_{is} = 200 miles per hour, the value of $pb/2V$ attainable is shown to be only about 0.052. The corresponding stick force is 28 pounds.

Extrapolation of the data of figures 12 and 14 indicates that, if the ailerons could be deflected sufficiently to produce a $pb/2V$ of 0.07, the stick force required would be about 45 pounds at V_{is} = 200 miles per hour (80 percent of maximum level-flight speed), or 50 percent in excess of the value considered satisfactory in reference 3. From the flight tests of reference 4 with internally balanced and sealed ailerons having twice the ratio of aileron chord to wing chord of the present aileron, hinge-moment coefficients only half as great as those of figure 14 were obtained. Calculations of the hinge-moment coefficients of the two sets of ailerons, based on the results of numerous wind-tunnel tests of sealed ailerons and flaps of various chords, indicate that the present ailerons should have somewhat lower hinge-moment coefficients than the ailerons of reference 4. The fact that the seals in the ailerons of reference 4 were continuous over the entire span of the ailerons, whereas the seals in the present ailerons are broken at each of four hinge brackets, may account for a considerable part of the apparent discrepancy because it has been found that small leaks through the seal of internally balanced control surfaces cause a marked reduction in the effectiveness of the balance.

The pilot's opinion of the trailing-edge ailerons is in agreement with the measured results in that he considered the rolling action rather weak and the stick forces heavy at the higher speeds.

From the foregoing considerations, it appears possible that increasing the torsional stiffness of the

torque tubes in the aileron control system, increasing the no-load deflection range of the ailerons to about ±20° to allow for the residual elasticity in the control system, and more effectively sealing the ailerons might make the aileron characteristics satisfactory.

Slot-lip ailerons.- The variation in pb/2V and stick force with deflection of the upgoing slot-lip ailerons at various values of service indicated airspeed is given for nominal flap settings of 20°, 30°, 40°, and 50° in figures 16 to 19. For all flap settings, the rate of change of pb/2V with aileron deflection decreases with increasing aileron deflection until at 40° to 45° the slope becomes so shallow as to indicate that little gain in effectiveness could be realized by going to greater deflections. The aileron effectiveness for a given deflection appears to be practically unaffected by variation in airspeed but increases progressively with increase in flap setting. For a nominal flap setting of 20°, an upward deflection of the slot-lip ailerons of about 30° is required to give a pb/2V of 0.07; whereas, for a nominal flap setting of 50°, an aileron deflection of between 9° and 12° is sufficient to give the same effectiveness. The maximum values of pb/2V attained with approximately full deflection of the ailerons average (from rolls in both directions) about 0.085 and about 0.130 with the 20° and 50° nominal flap settings, respectively.

Two curves of stick force are given for each value of service indicated airspeed in figures 16 to 19, one defining the variation in measured stick force with deflection of the slot-lip aileron and the other defining the corresponding variation in aerodynamic stick force (measured stick force less stick force due to springs in control system). The aerodynamic stick forces in all cases are stable for small aileron deflections; that is, the aerodynamic forces would return the controls to neutral from small displacements. As the aileron deflection is increased farther, however, it is shown that, without the springs, the stick forces would reverse at low airspeeds for all flap deflections tested. This overbalancing tendency increases with flap deflection; with a nominal flap setting of 20°, reversal of the aerodynamic stick force would occur only at V_{is} less than 79 miles per hour whereas, with the 50° nominal flap setting, the reversal would occur at airspeeds at least as

great as 119 miles per hour. The springs in the control system prevent actual reversal of the stick forces, at least for all the conditions tested.

With a flap selector setting of 20°, the stick forces increase very rapidly with airspeed as a result of the combined effects of increasing dynamic pressure and decreasing upfloating tendency of the ailerons. The aerodynamic stick force corresponding to a 30° deflection of the upgoing aileron ($pb/2V = 0.07$) is between 1 and 5 pounds at 79 miles per hour and about 25 pounds at 119 miles per hour; the springs increase the forces to about 14 pounds at the lower speed and to between 35 and 40 pounds at the higher speed.

The relation between aileron deflection and stick deflection for the slot-lip ailerons was practically the same in flight as on the ground, which indicates that there is no appreciable elastic deformation in the control system of these ailerons under load.

Time histories of the rolling and yawing motion of the airplane resulting from abrupt application of the slot-lip ailerons with a flap selector setting of 40° are compared in figure 20 with those for a similar maneuver performed with the trailing-edge ailerons, flaps neutral. The comparison indicates that the lag in rolling response following control displacement is not materially greater with the slot-lip ailerons than with the trailing-edge ailerons. The rolling angular velocity for the trailing-edge ailerons reaches a maximum value 1 second after the start of the control movement and thereafter decreases slowly. With the slot-lip ailerons, however, the rolling angular velocity continues to increase slightly after 1 second. This difference may indicate a reduction in dihedral effect due to the flaps but does not appear to be sufficiently great to cause particular difficulty in handling the airplane. The adverse yaw resulting from aileron application, as indicated by the time histories of yawing angular velocity, is shown to be small in both cases. The angle of sideslip developed in a given time following the application of the controls is practically the same for both conditions.

In the opinion of the pilot, the rolling effectiveness of the slot-lip ailerons is adequate for all conditions and he was not aware of any lag in the response to

control manipulation. The fact that the variation of stick force with control displacement is not uniform was not considered a serious defect, so long as the control forces did not actually reverse. With the 20° flap selector setting the stick forces were considered to be too great even at fairly moderate speeds. The abruptness with which the change-over from one aileron system to the other occurs apparently caused the pilot no concern.

Inasmuch as the upward slot-lip-aileron deflection required to give a $pb/2V$ of 0.07 with the 20° flap selector setting is only 30° (fig. 16) and at greater flap selector settings is less than 30° (figs. 17 to 19), the heavy stick forces for the 20° setting could be materially reduced by decreasing the upward travel of the ailerons from 46° to 30° and thereby increasing the mechanical advantage of the control system. Computations of stick forces were therefore made for both the original linkage system and an assumed modified system by use of hinge-moment-coefficient data obtained on similar ailerons by the Douglas Aircraft Co., Inc. The assumed modification to the linkage system consisted in reducing the length of the primary bell cranks in the fuselage, which transmit the stick motion to the push-pull rods between the fuselage and the ailerons. The modified linkage system gives the same down travel as the original system - that is, 9° - but reduces the up travel to 30°.

The variation of stick forces with up-aileron deflection computed for the original and modified control systems for a service indicated airspeed of 119 miles per hour with the 20° flap selector setting and for a service indicated airspeed of 84 miles per hour with the 50° flap selector setting is shown in figure 21. The computed results for the 20° flap selector setting with the original linkage agree fairly closely with the experimental data of figure 16; both computed and experimental data give a 40-pound stick force at an upward aileron deflection of 30°. The computed results for the modified control system for the same condition indicate a reduction of the stick force to 25 pounds; similarly, the stick force less spring force is reduced from 29 to 19 pounds for the 30° upward aileron deflection. The computed stick forces for the 50° nominal flap setting, for which the overbalancing tendency is greatest, indicate that the modified linkage

will slightly reduce the stick forces for this condition but that the spring force will still prevent overbalance at speeds at least as low as 84 miles per hour.

Maximum Lift Coefficients and Stalling Characteristics

The maximum lift coefficients obtained with the full-span slotted flaps are plotted against flap deflection in figure 22. The results of several tests covering the conditions of landing gear extended and retracted and cockpit hood open and closed are given for each flap deflection; although there is some variation in the values obtained from the different tests, the variation does not appear to be related to the position of the landing gear or hood. There is a possibility of some error in estimating the weight of the airplane for individual tests, which may contribute to this variation; it is unlikely, however, that the error from this source in the average value of maximum lift coefficient for a given flap position exceeds 1 or 2 percent. The maximum lift coefficient attainable under the basic condition of the tests - throttle closed, engine idling - is shown to occur at a flap deflection of 40° and to have an average value of about 2.43, which represents an increment of 0.88 over the average flaps-neutral maximum lift coefficient of 1.55.

Wind-tunnel tests (unpublished) of a 1/8-scale model of the F2A-2 airplane with full-span slotted flaps, propeller windmilling, gave an increment of about 1.00 (corrected to trimmed conditions) with a 40° flap deflection. It is pointed out that, in the flight tests, the Reynolds number was lower with flaps down than with flaps up. This fact explains a somewhat smaller increment of maximum lift than was obtained in the wind-tunnel tests, for which the Reynolds number was the same in both conditions. There are also other factors, such as propeller effects and the effect, in flight, caused by the varying angle of attack, that introduce some uncertainty in the comparison of maximum lift coefficients from flight and wind-tunnel tests. The effect of varying angle of attack was investigated in wind-tunnel tests reported in reference 5 and it was found that a relatively small rate of increase of angle of attack gave an appreciable increase in the maximum lift coefficient. The results of the present tests indicated that, in general, the rate of increase in angle of attack at the stall was greater

with flaps down than with flaps up. With a given flap setting, the rate of change of angle of attack varied rather widely between different tests - from 0.12° to 0.45° per second with flap neutral and from 0.25° to 1.00° per second with a flap selector setting of 40° - but there was no indication of a consistent variation of maximum lift coefficient with rate of change of angle of attack.

The presence of extreme elasticity in the control system of the trailing-edge ailerons introduced the possibility that the ailerons might float up considerably with the flaps deflected and reduce the maximum lift coefficients attainable. The position of the ailerons was therefore measured with several flap deflections and the results are presented in figure 23. These results indicate that the deflection of the ailerons at the stalling speed does not exceed $2\frac{1}{2}^{\circ}$ for nominal flap deflections up to 40° and therefore probably has no material effect on the maximum lift coefficients.

Pilot's observations indicate that with engine idling the stalling characteristics of the airplane with flaps up are better than average for a fighter type. In this condition tail buffeting provides a definite warning of stall, the roll-off at the stall is relatively mild, and the airplane readily recovers with normal manipulation of the controls. The stalling characteristics become progressively worse, however, with increasing flap deflection. There is little or no warning; the rate of roll-off at the stall increases; and, with the larger flap deflections, the airplane assumes a very steep nose-down attitude with the result that there is a relatively large loss of altitude before recovery can be effected.

Longitudinal Stability and Control

The fixed-control, static longitudinal-stability characteristics of the airplane with the center of gravity at 30.4 percent M.A.C. are indicated in figure 24 for all flap settings by plots of elevator deflection required for trim against service indicated airspeed. With engine idling, the airplane is stable with all flap settings. With level-flight power, the stability is considerably less than for the engine-idling condition but remains positive for flap selector settings up to and including 30°. With nominal flap settings of 40° and 50°, the

airplane becomes unstable with level-flight power when the service indicated airspeed is decreased to less than about 100 miles per hour.

The elevator deflection required to stall the airplane with engine idling increases a relatively small amount as the flap is deflected and in no case exceeds about 14°.

Some elevator stick-force data are included in figure 24 as an indication of the control-free stability characteristics. With flaps neutral for both engine-idling and level-flight power conditions, the stick force changes from a pull to a push force as the airspeed is increased through the trim speed, which indicates positive control-free stability. No data are available for the smaller flap deflections but, with a flap selector setting of 40°, it is shown that the airplane is unstable with controls free for the level-flight power condition, probably at all speeds below about 100 miles per hour. The curve of stick force for level-flight power for the 50° nominal flap setting indicates control-free instability at all speeds up to at least 130 miles per hour. The stick-force curve given for the engine-idling condition with the 50° nominal flap setting does not include a trimmed condition within the speed range covered and therefore does not show directly whether the airplane is stable or unstable for these conditions. If it can be assumed, however, that the change in stick force due to a change in trim-tab setting is proportional to the square of the velocity, then the shape of this curve indicates positive control-free stability.

The elevator trim-force change due to power is also shown in figure 24 for the neutral position and the nominal 50° position of the flaps. With the flaps up, the trim-force change in going from engine-idling to level-flight power is from 2 to 3 pounds in the speed range tested. With the flap selector setting of 50°, the trim-force change between engine-idling and level-flight power conditions is between 8 and 11 pounds.

The change in elevator stick force required to maintain trim with fixed tabs when the flaps are deflected is shown in figure 25 for V_{is} = 94 miles per hour with engine idling and with power for level flight, flaps up. The maximum trim-force change with flap

position occurs at a deflection of about 40° and, for the speed represented, amounts to 8 pounds with engine idling and to 6 pounds with power for level flight, flaps up.

CONCLUDING REMARKS

The principal results of the flight tests of a Navy F2A-2 airplane, equipped with full-span NACA slotted flaps and with a double system of internally balanced, trailing-edge ailerons and slot-lip ailerons, are summarized as follows:

Trailing-edge-aileron characteristics:

1. The effectiveness of the trailing-edge-aileron installation was unsatisfactory; with full stick travel, the maximum values of wing-tip helix angle obtained were 0.065 at a service indicated airspeed of 90 miles per hour and 0.050 at 216 miles per hour.

2. The low effectiveness of these ailerons is attributed to the extreme elastic deformation in the control system under load.

3. The stick forces were excessive at high speeds. It was estimated that at a service indicated airspeed of 200 miles per hour (80 percent of maximum level-flight speed), if the effectiveness were not limited by deformation of the control system under load, the stick force required to give a value of wing-tip helix angle of 0.07 would be about 45 pounds.

4. A reduction in the effect of the internal balance caused by gaps in the aileron seals at the hinge brackets may be responsible for the high stick forces.

5. Increasing the torsional stiffness of the torque tubes in the aileron control system, increasing the no-load deflection range of the ailerons to about ±20°, and more effectively sealing the ailerons might make the aileron characteristics satisfactory.

Slot-lip-aileron characteristics:

1. The effectiveness of the slot-lip ailerons was adequate for all conditions tested; the maximum

values of wing-tip helix angle obtained increased progressively with flap deflection from 0.085 at a flap selector setting of 20° to 0.130 at a flap selector setting of 50°.

2. Springs were required in the control system of the slot-lip ailerons to prevent overbalance of the stick forces at low speeds, particularly with the larger flap deflections.

3. The variation of stick force with control deflection was not uniform but the pilot did not consider this characteristic a serious defect so long as the force always tends to return the stick to neutral.

4. With the 20° nominal flap setting, the stick forces (including spring force) became too heavy at moderate speeds; for example, at a service indicated airspeed of 119 miles per hour, the force required to give a value of wing-tip helix angle of 0.07 was between 35 and 40 pounds. It is indicated from calculation, however, that the stick forces for this condition could be materially reduced (from 40 to 25 lb at 119 mph) by modifying the control linkage system to reduce the full-deflection up-aileron travel from 46° to 30°, which is sufficient to give a wing-tip helix angle of at least 0.07 with all flap settings involving use of the slot-lip ailerons.

5. The lag in the response of the rolling motion to control application did not appear to be materially greater for the slot-lip ailerons than for the trailing-edge ailerons and was not noticeable to the pilot.

Maximum lift coefficients and stalling characteristics:

1. The highest value of maximum lift coefficient obtained with engine idling was 2.43; this value represents an increase of 0.88 over the value obtained with flaps neutral.

2. The highest value of maximum lift coefficient occurred at a flap deflection of 40°.

3. The stalling characteristics of the airplane were good with the flaps up but became progressively worse as the flaps were deflected.

Longitudinal stability and control (center of gravity at 30.4 percent M.A.C.):

1. With engine idling, the airplane had positive static stability with controls fixed, for all flap positions.

2. With level-flight power the stability was considerably reduced but remained positive for all flap selector settings up to and including 30°; with 40° and 50° nominal flap settings, the airplane was unstable at service indicated airspeeds below about 100 miles per hour.

3. The elevator deflection required to stall the airplane with engine idling increased a relatively small amount when the flap was deflected and in no case exceeded 14°.

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

REFERENCES

1. Rogallo, Francis M., and Spano, Bartholomew S.: Wind-Tunnel Investigation of a Plain and a Slot-Lip Aileron on a Wing with a Full-Span Slotted Flap. NACA ACR, April 1941.

2. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. Rep. No. 664, NACA, 1939.

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

4. Williams, W. C., and Kleckner, H. F.: A Flight Investigation of Internally Balanced Sealed Ailerons. NACA ARR, Dec. 1941.

5. Silverstein, Abe, Katzoff, S., and Hootman, James A.: Comparative Flight and Full-Scale Wind-Tunnel Measurements of the Maximum Lift of an Airplane. Rep. No. 618, NACA, 1938.

Figure 1.- Three-quarter front view of F2A-2 airplane with full-span slotted flap retracted.

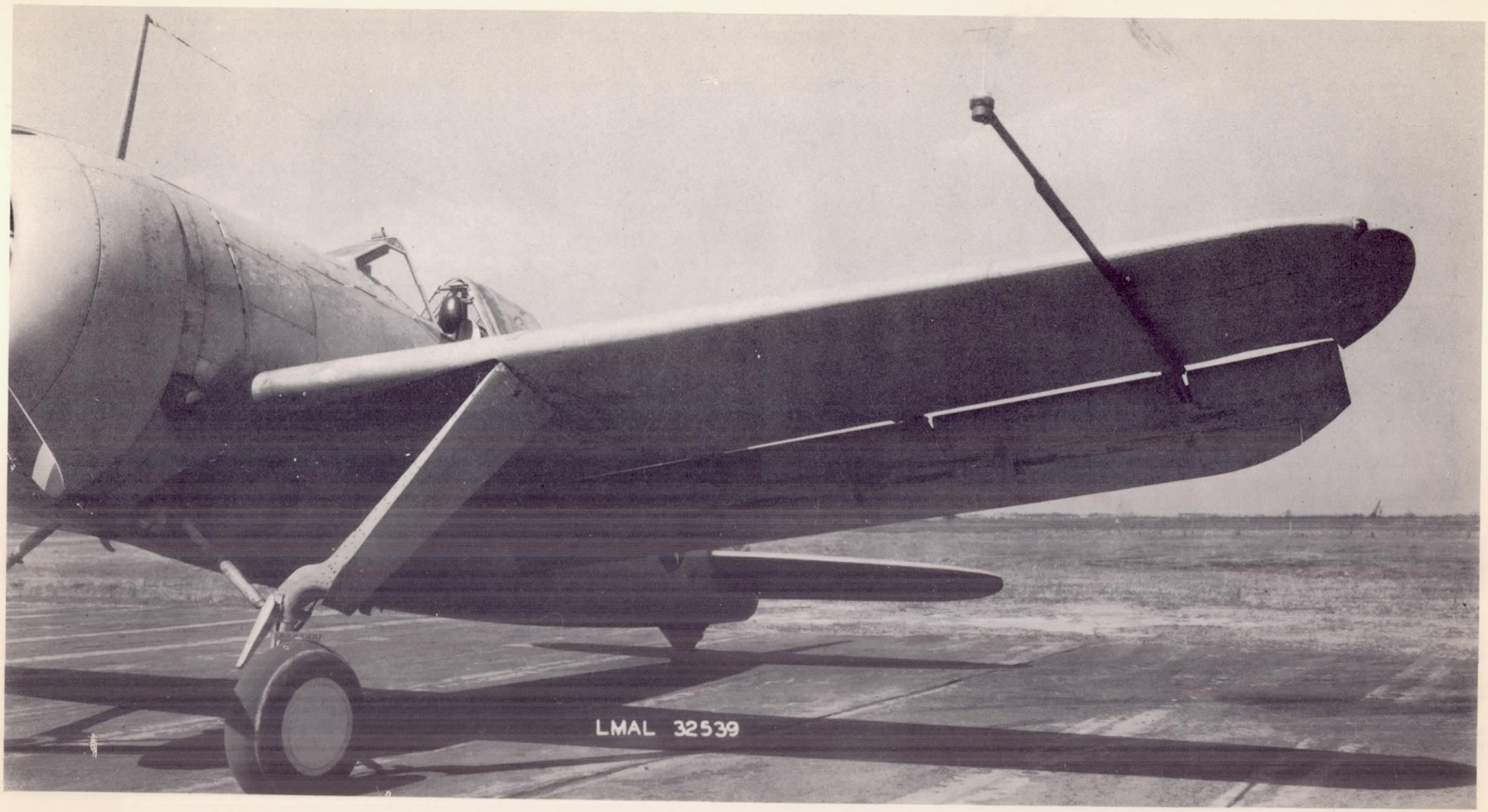


Figure 2.- Three-quarter front view of left wing of F2A-2 airplane with full-span slotted flap. Nominal flap setting, 50°.

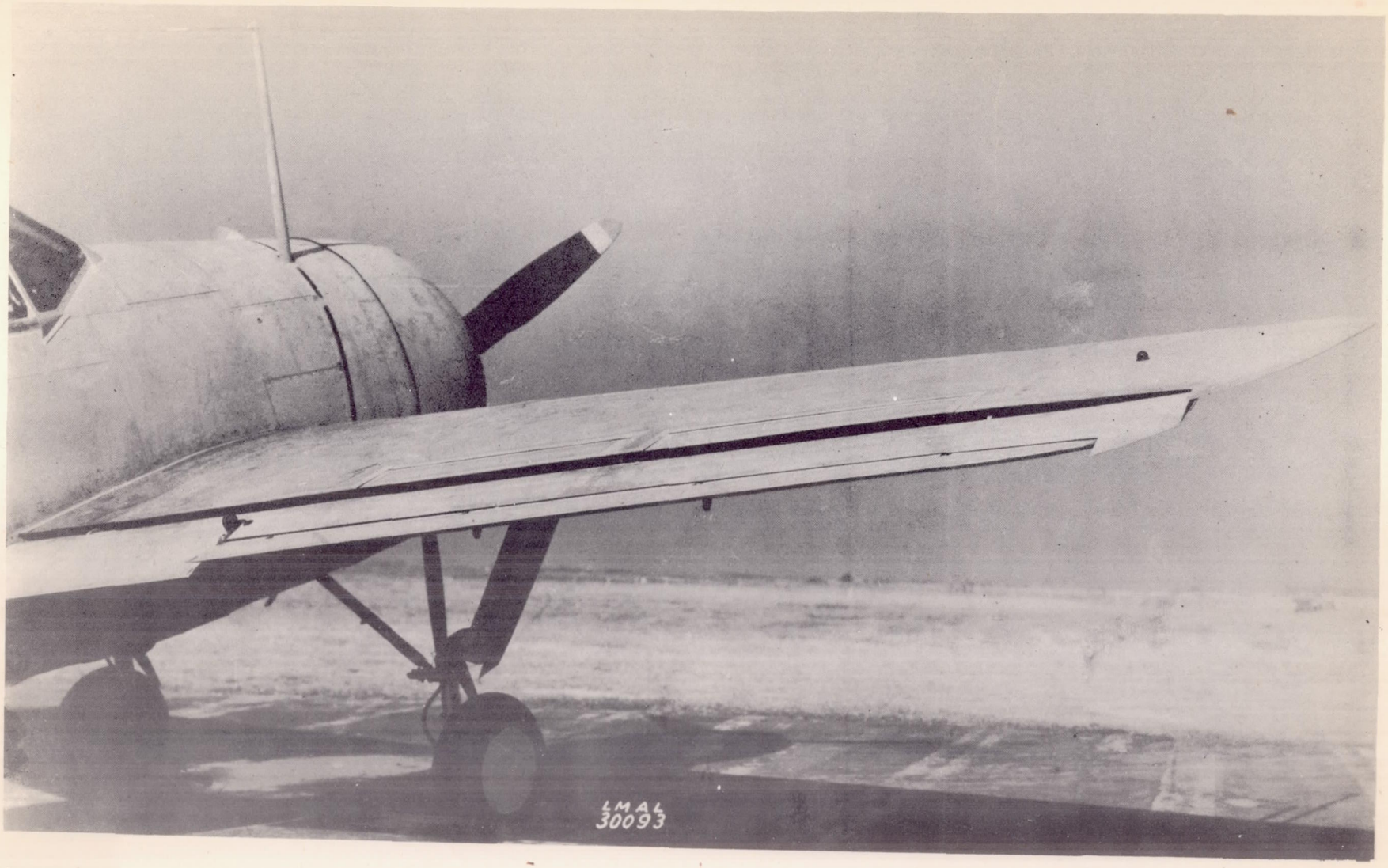


Figure 3.- Three-quarter rear view of the right wing of the F2A-2 airplane with full-span slotted flap. Nominal flap setting, 10°; trailing-edge ailerons deflected upward.

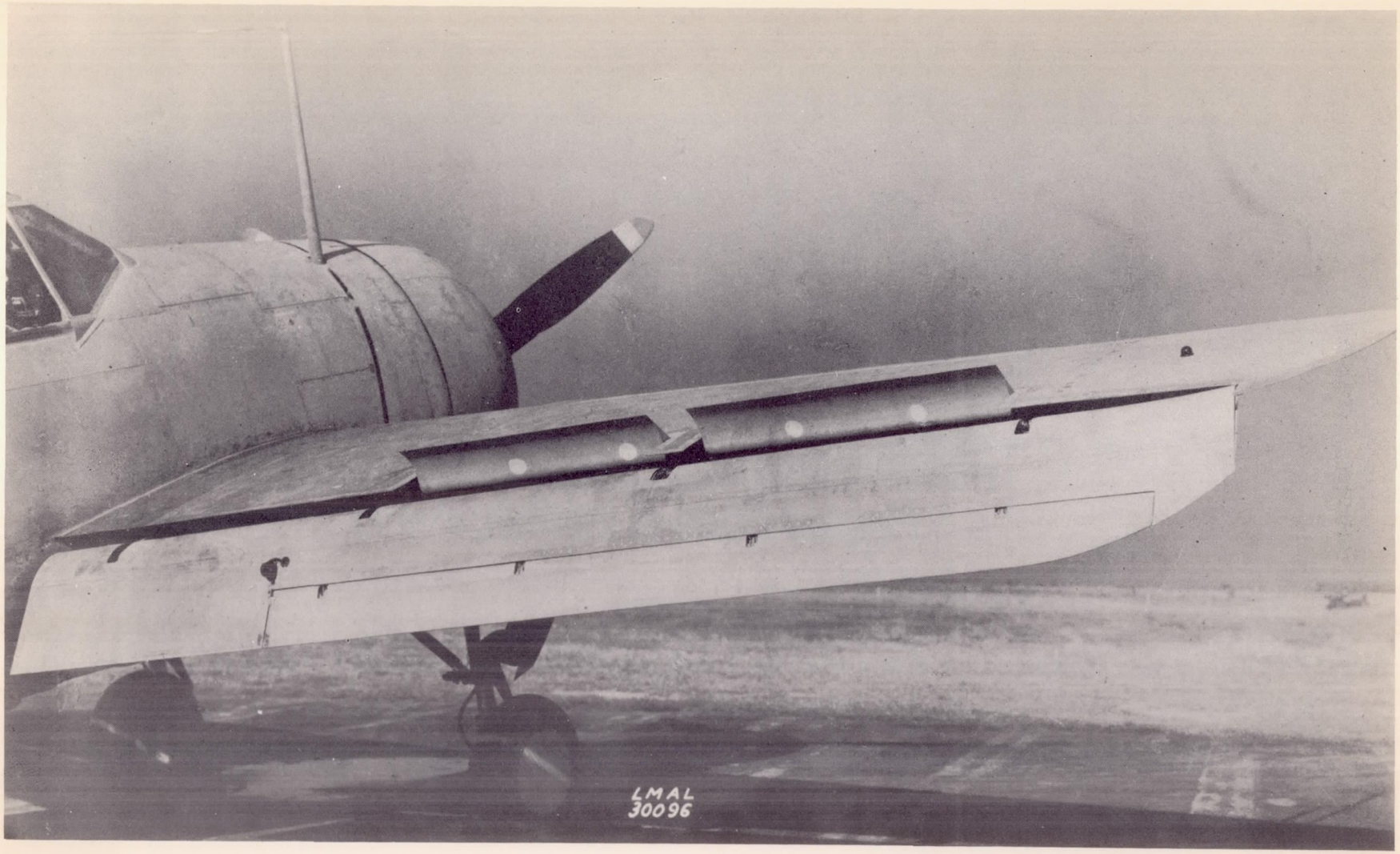


Figure 4.- Three-quarter rear view of the right wing of the F2A-2 airplane with full-span slotted flap. Nominal flap setting, 50°; slot-lip aileron deflected upward.

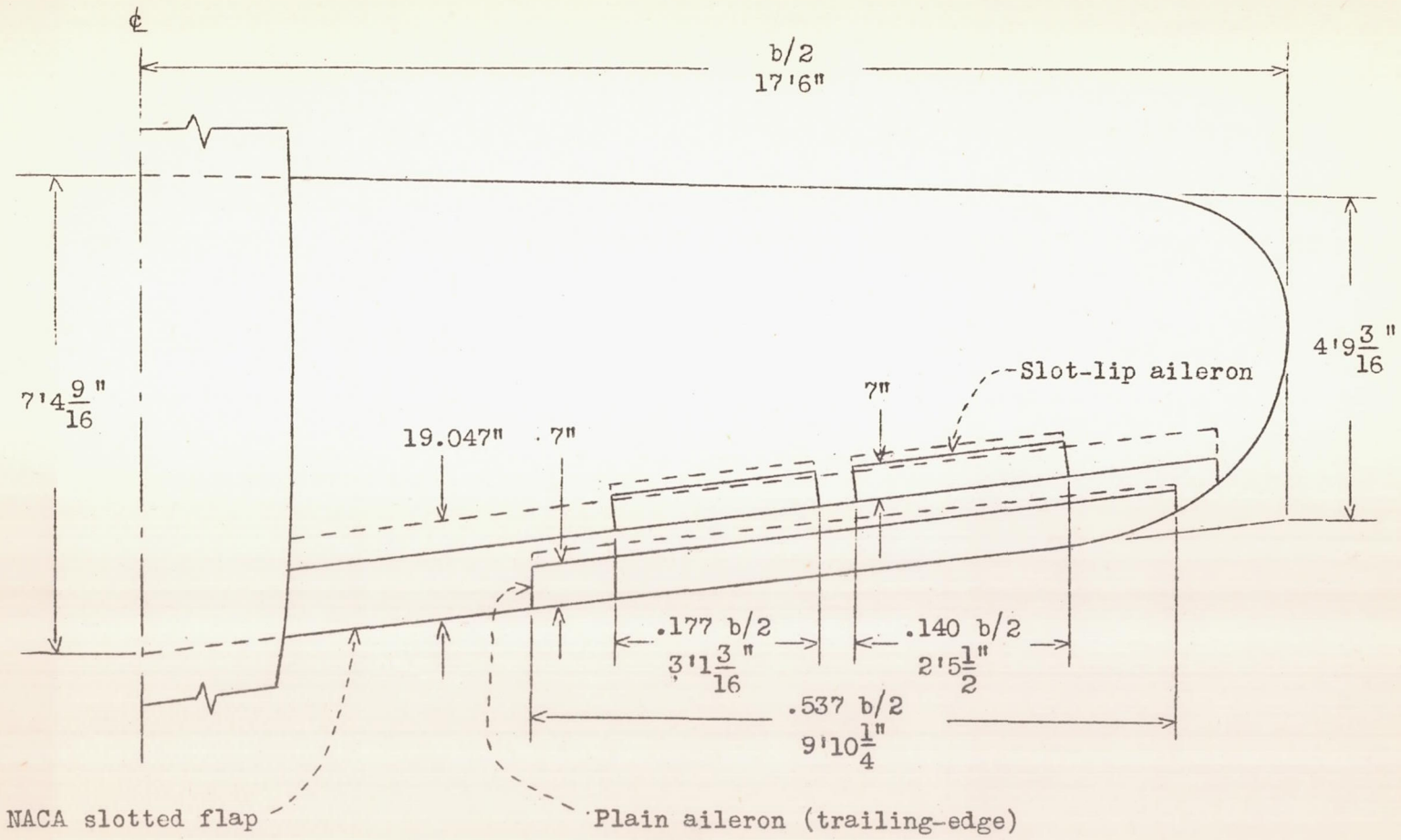
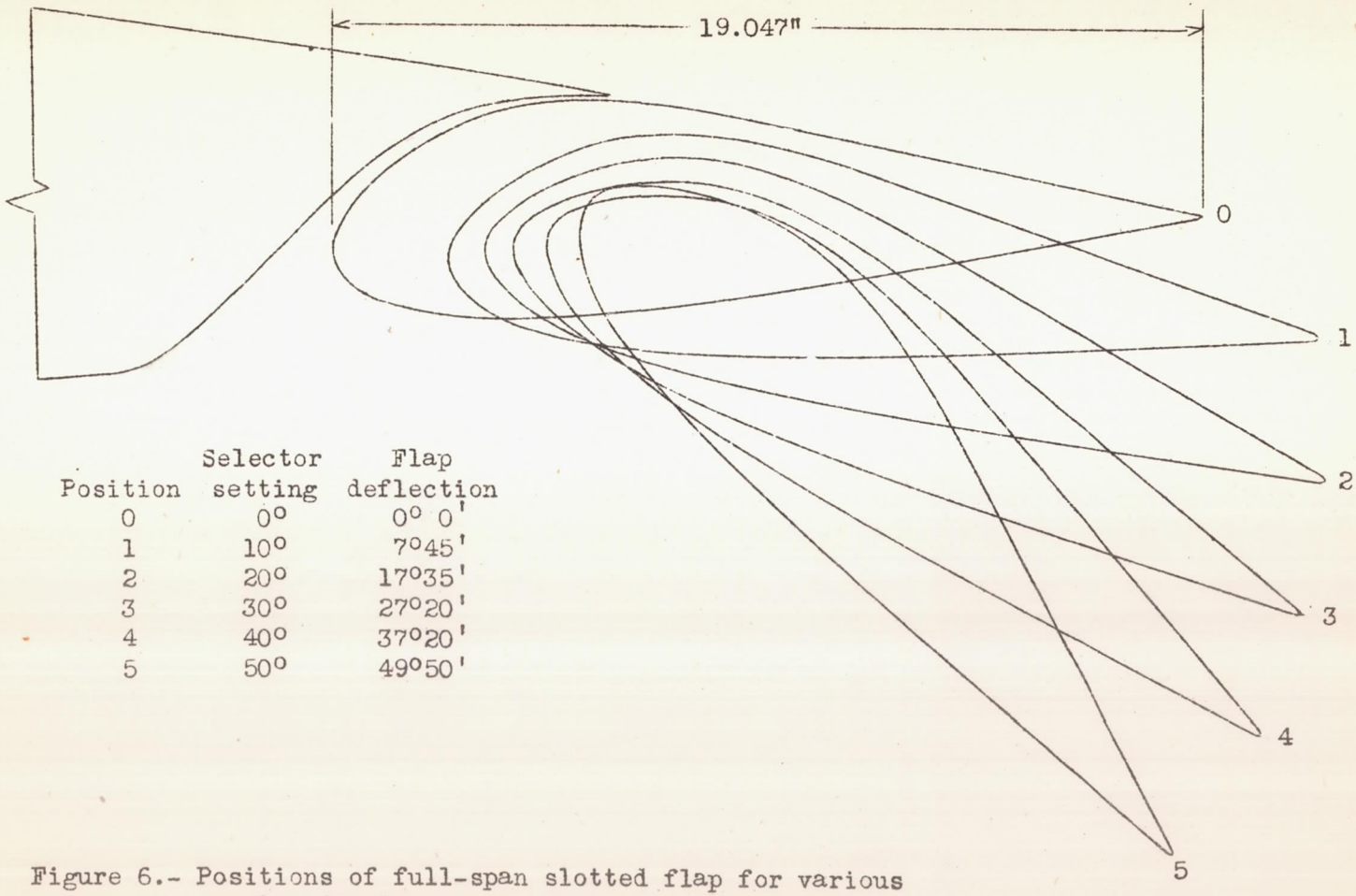


Figure 5.- Sketch of plan form of F2A-2 wing with full-span slotted flaps, internally balanced, trailing-edge ailerons, and slot-lip ailerons.



Position	Selector setting	Flap deflection
0	0°	0° 0'
1	10°	7°45'
2	20°	17°35'
3	30°	27°20'
4	40°	37°20'
5	50°	49°50'

Figure 6.- Positions of full-span slotted flap for various angular displacements, as measured at spanwise station 32 percent of semispan from center line. F2A-2 airplane.

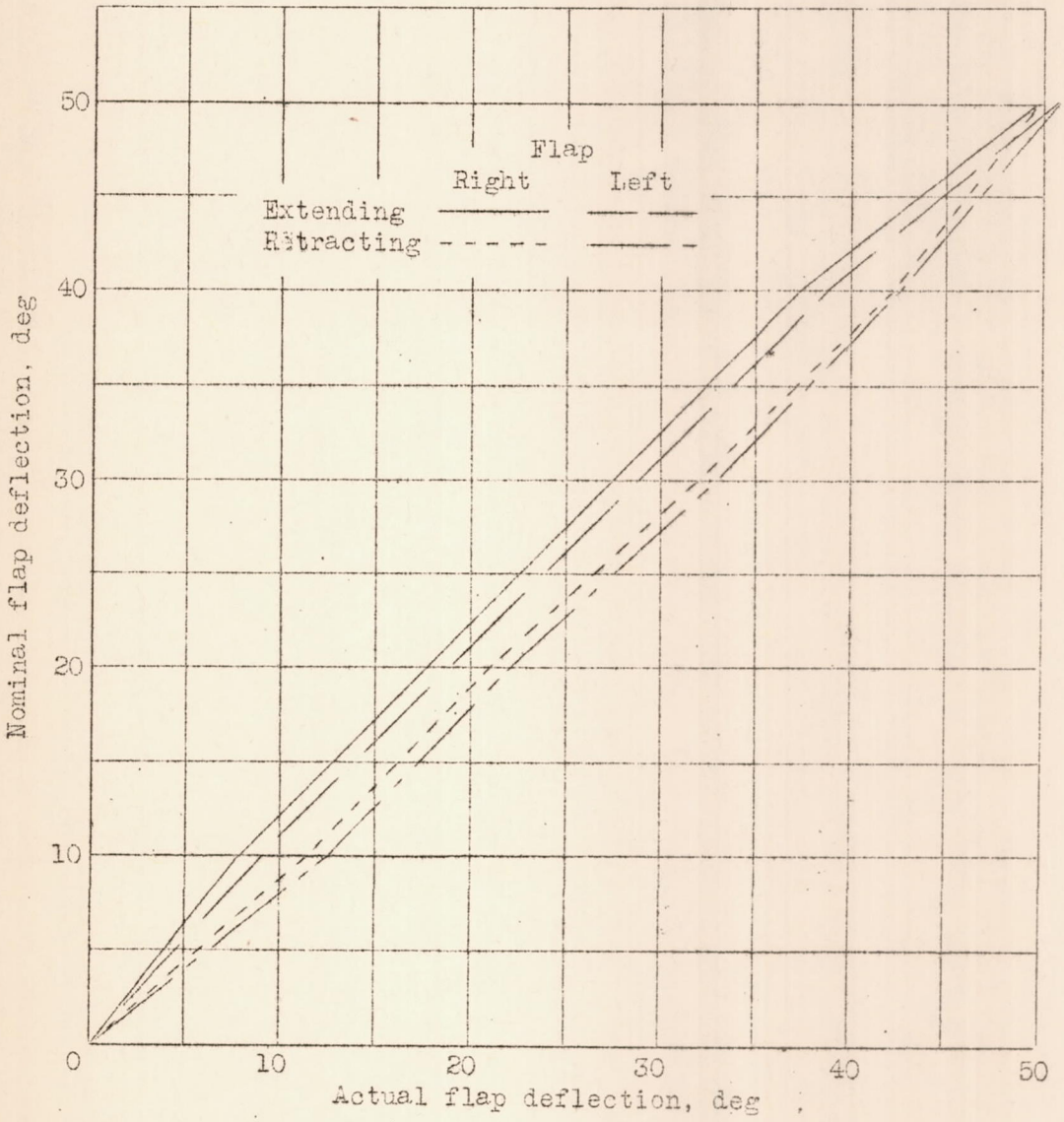


Figure 7.- Relation between nominal deflections and actual deflections of full-span slotted flaps with no load on flaps; F2A-2 airplane.

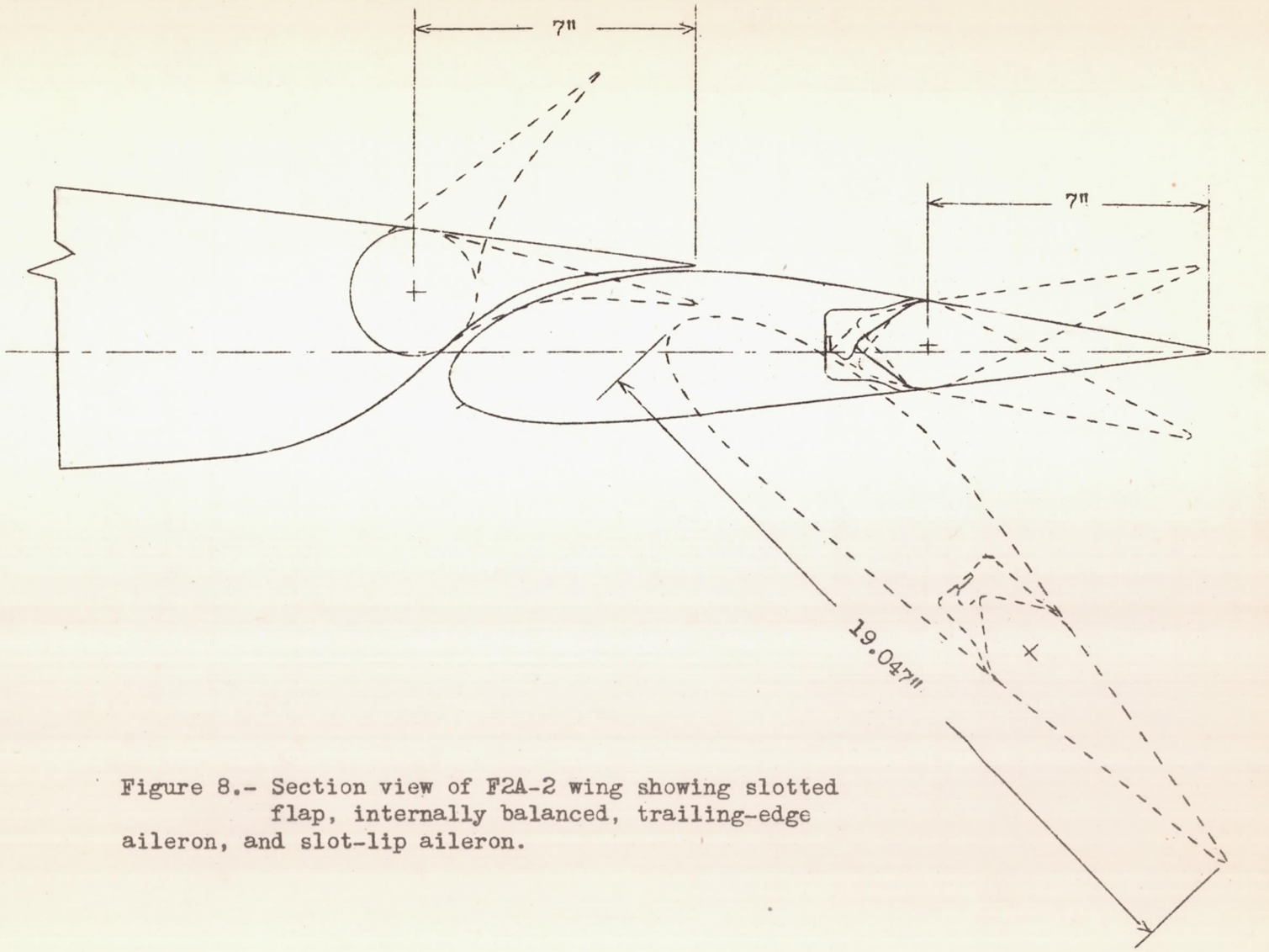


Figure 8.- Section view of F2A-2 wing showing slotted flap, internally balanced, trailing-edge aileron, and slot-lip aileron.

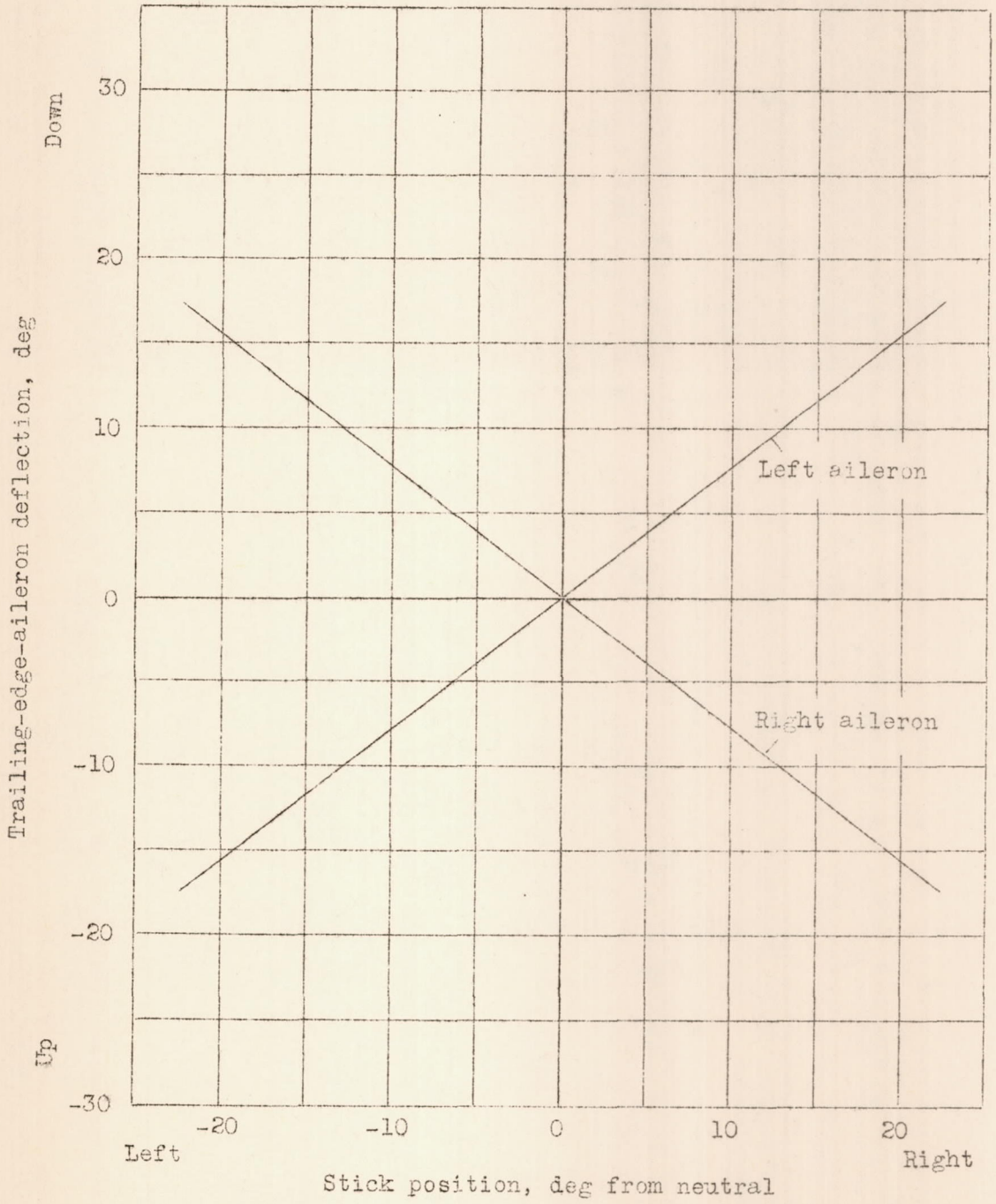


Figure 9.- Relation between trailing-edge-aileron deflections and stick position with no load on system and flap selector settings of 0° or 10°. Stick length, 19.0 inches; F2A-2 airplane.

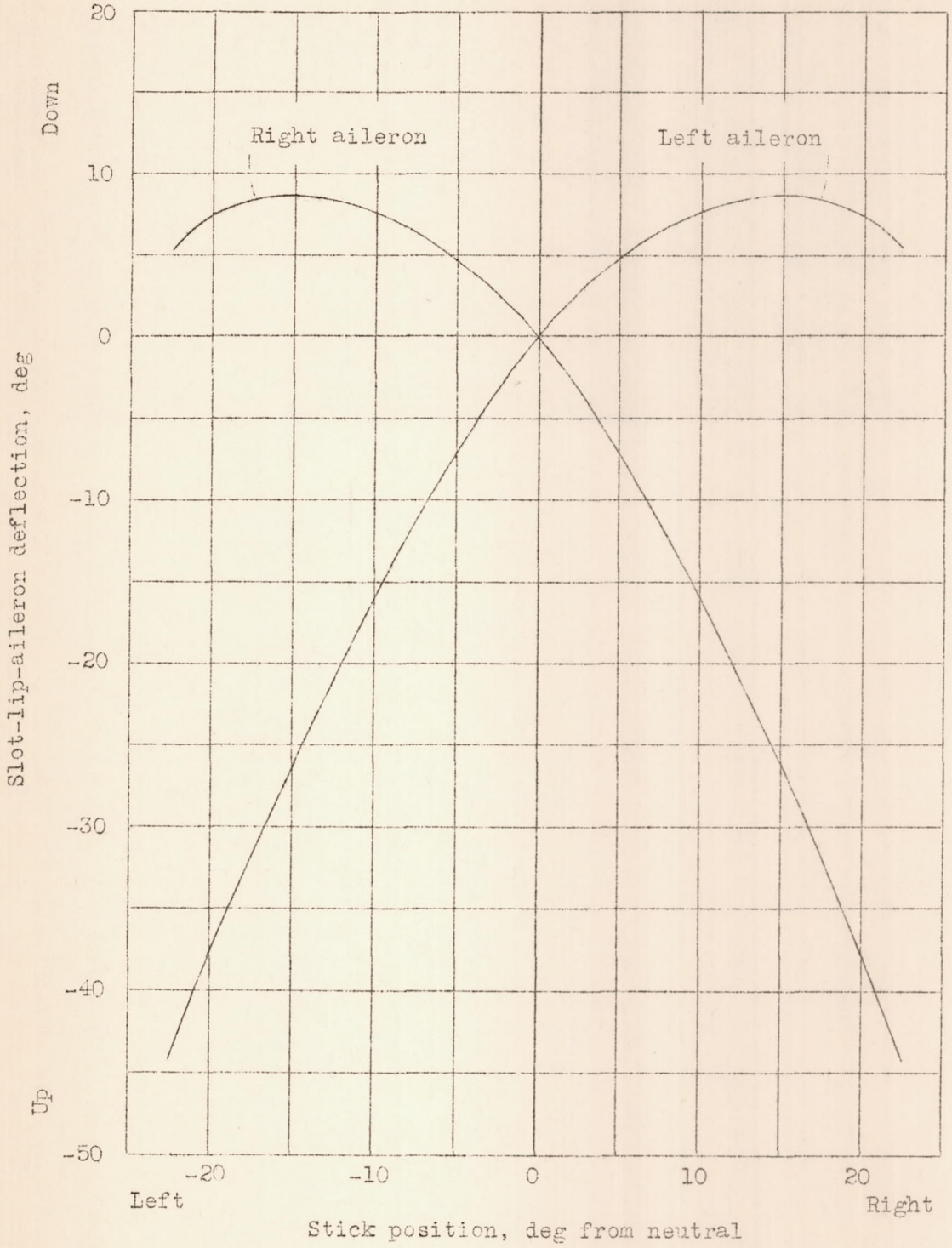


Figure 10.- Relation between slot-lip-aileron deflection and stick position with no load on system and flap selector settings of 20°, 30°, 40°, or 50°. Stick length, 19.0 inches; F2A-2 airplane.

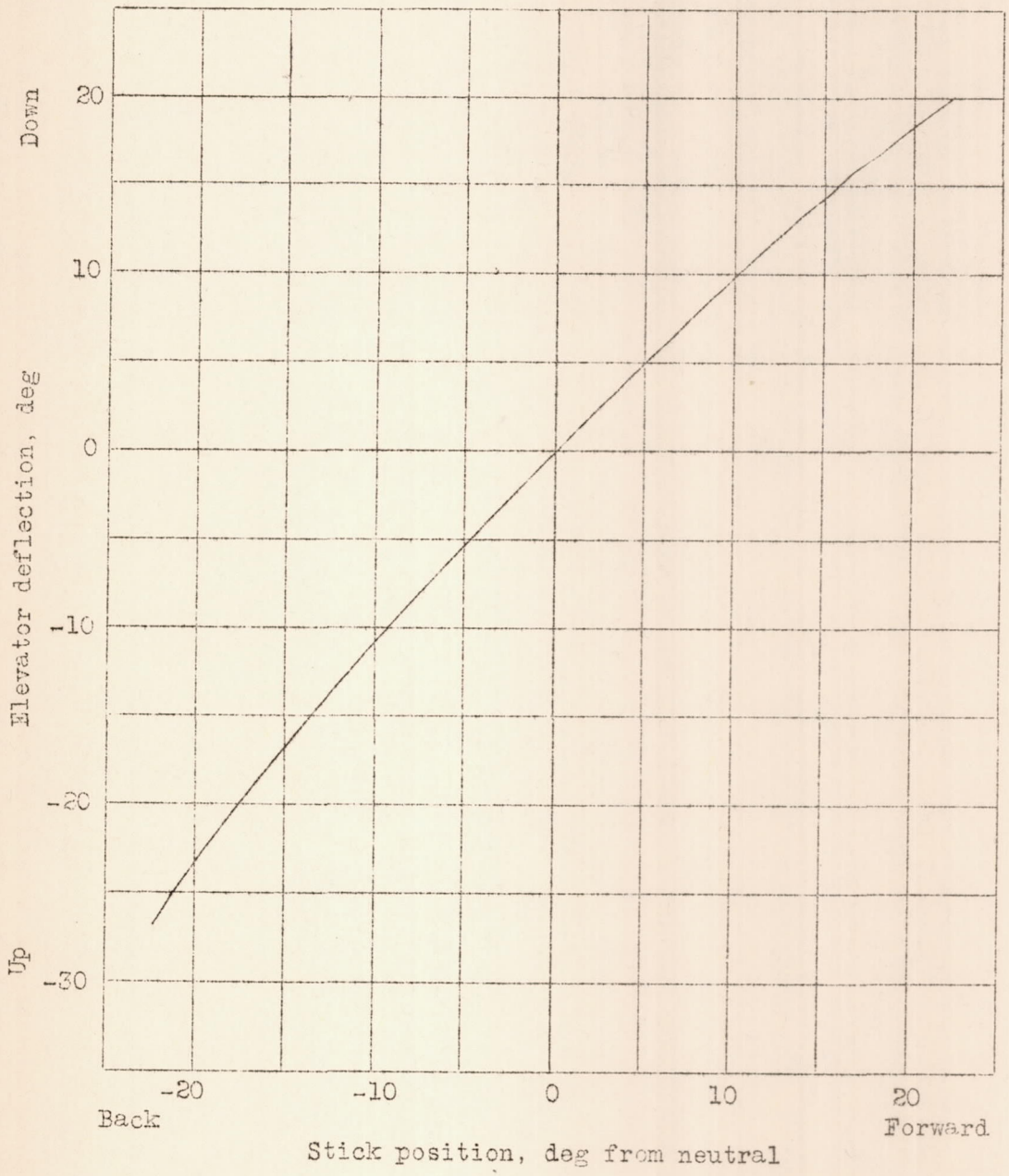


Figure 11.- Relation between elevator deflection and stick position with no load on system and flaps up or down. Stick length, 19.0 inches; F2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

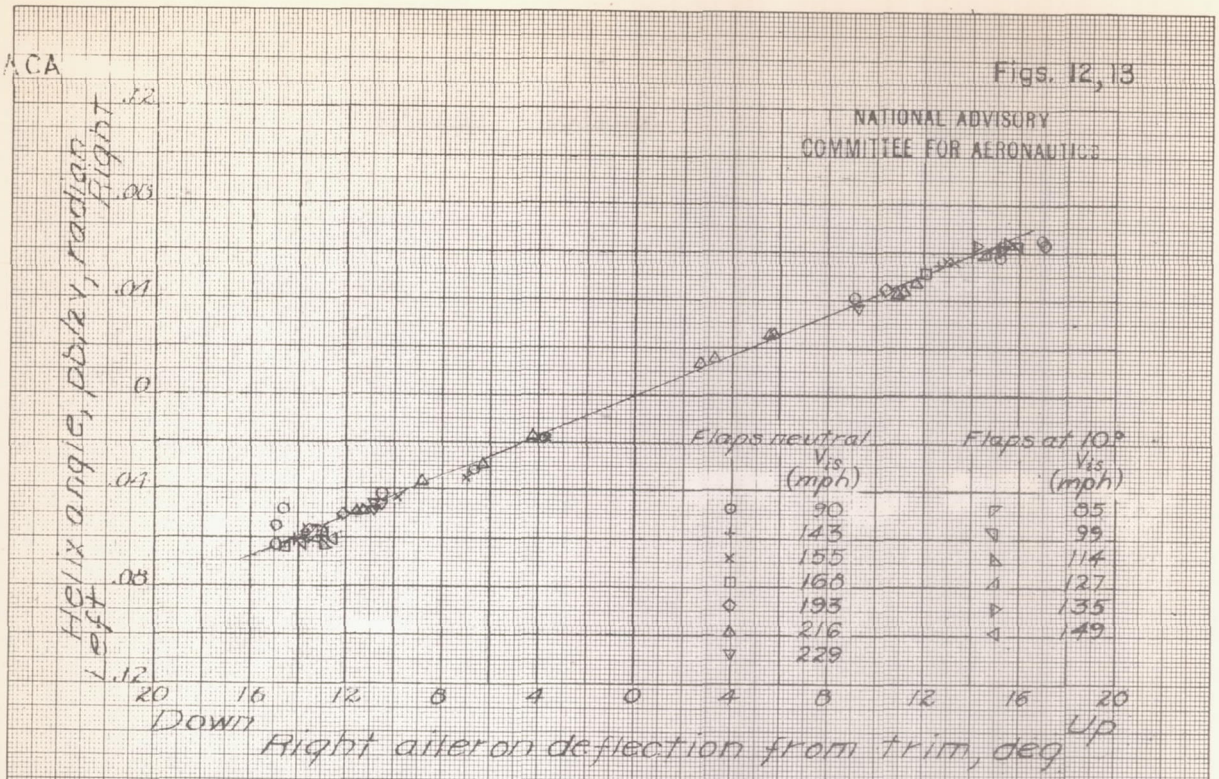


Figure 12.- Variation of wing-tip helix angle pb/2V with aileron deflection. Internally balanced, trailing-edge ailerons; level-flight power; F2A-2 airplane.

(1 block = 10 divisions on 1/40" Engr. scale)

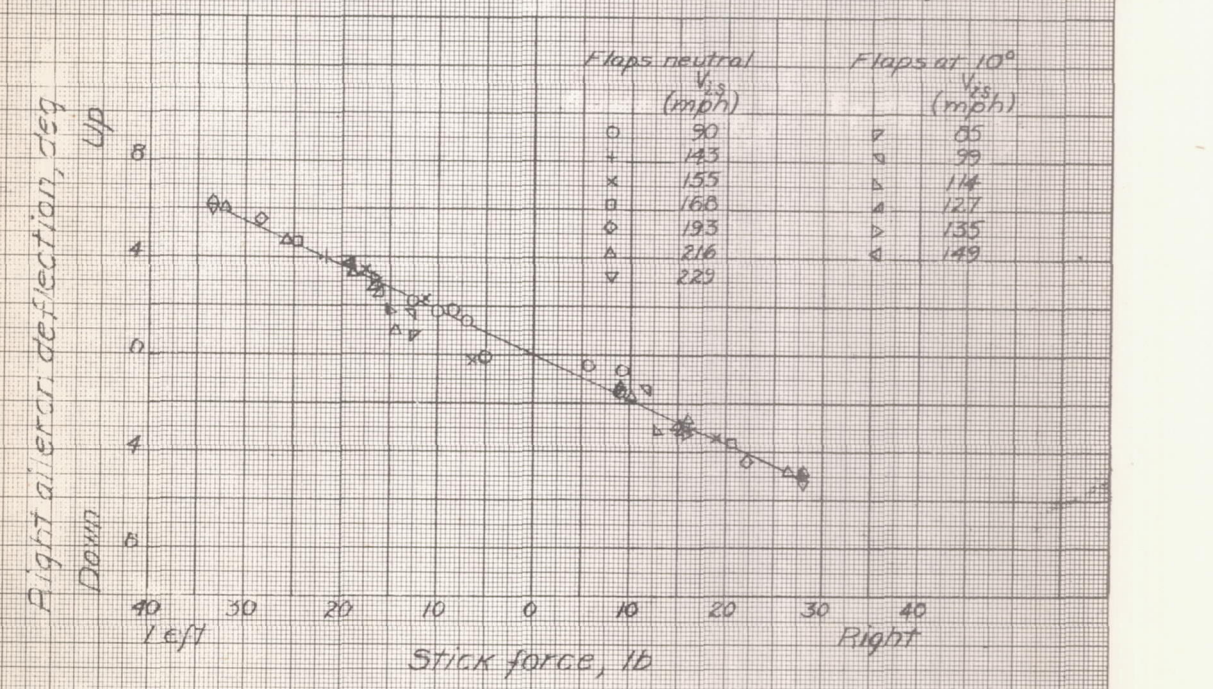


Figure 13.- Relation between stick force and deflection of aileron due to elastic deformation of control system under load. Internally balanced, trailing-edge ailerons; level-flight power; F2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

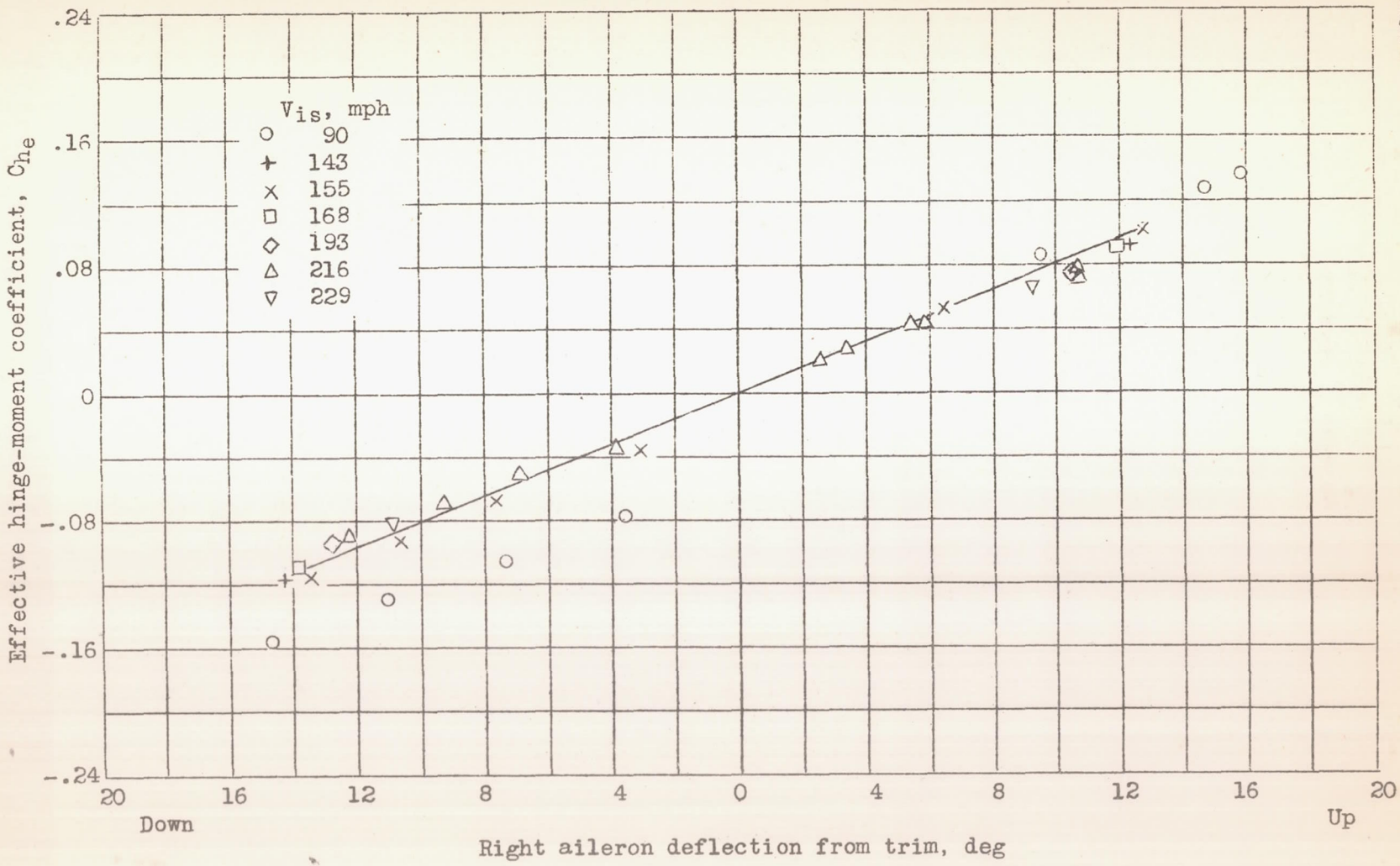


Figure 14.- Variation of effective hinge-moment coefficient with aileron deflection. Internally balanced, trailing-edge ailerons; level-flight power; F2A-2 airplane.

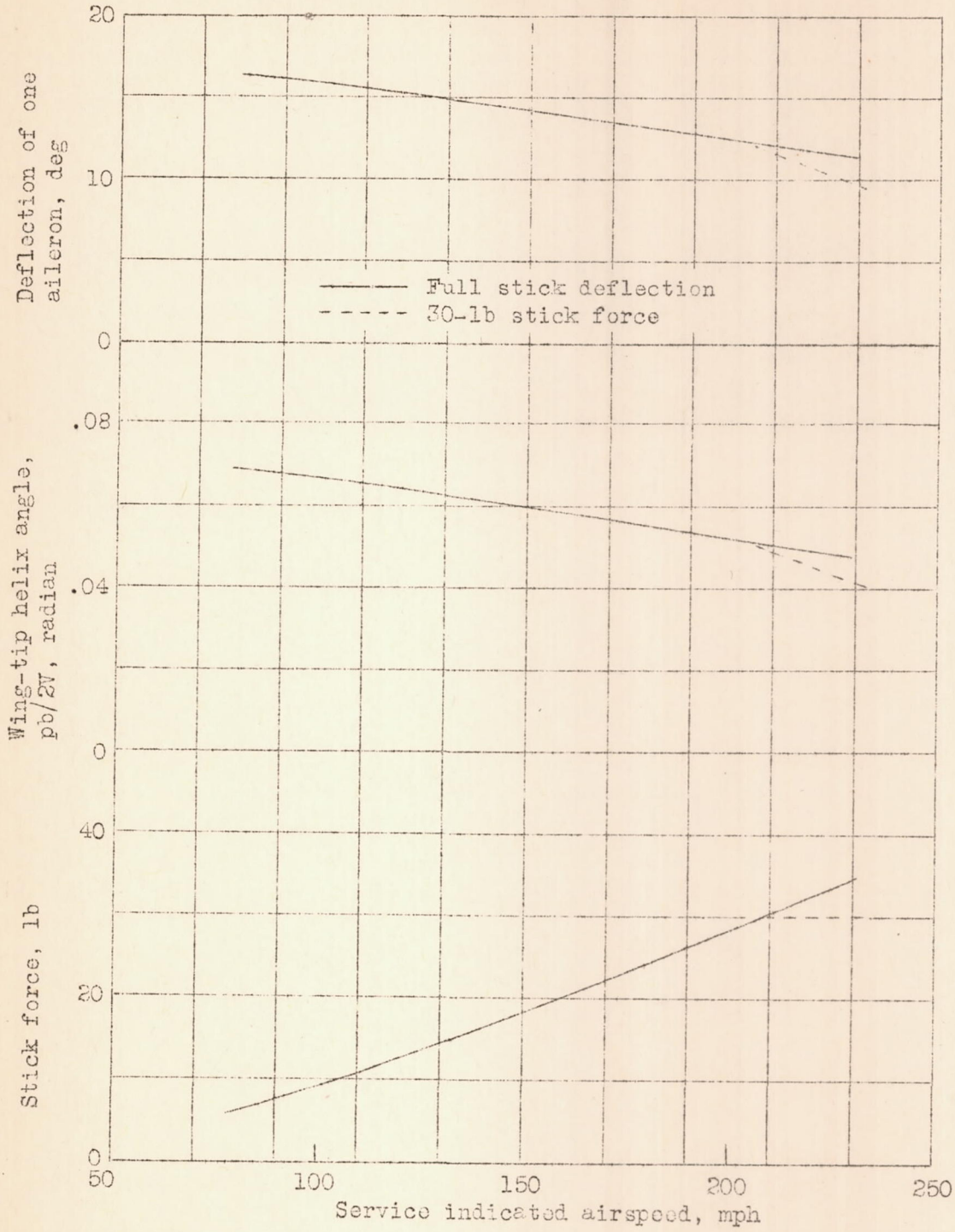


Figure 15.- Variation of aileron deflection, effectiveness, and stick force with airspeed for full stick throw or 30-lb stick force. Internally balanced, trailing-edge ailerons; level-flight power; F2A-2 airplane.

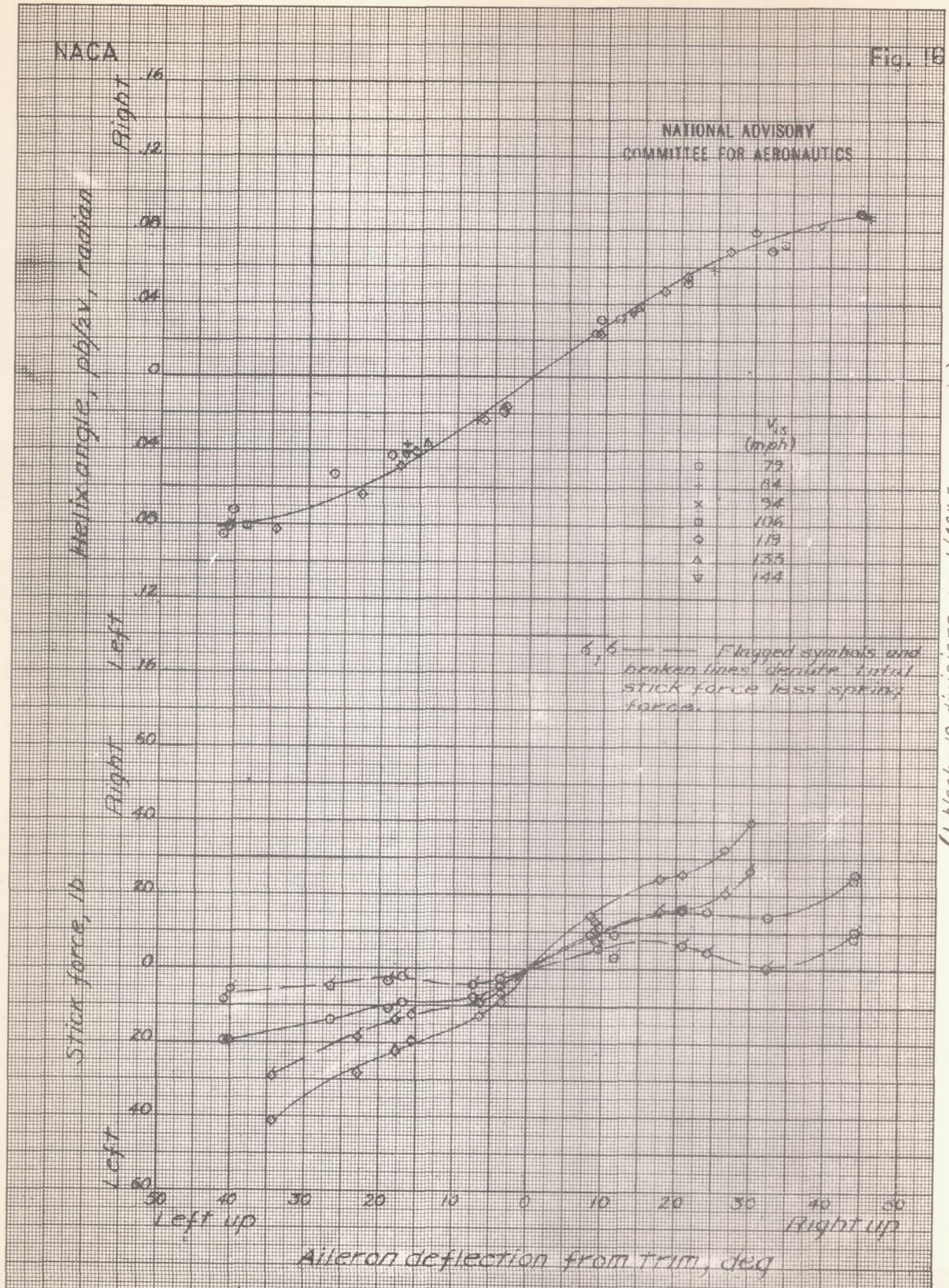


Figure 16.- Variation of wing-tip helix angle pb/2V and stick force with deflection of up-going aileron. Slot-lip ailerons; flap selector setting, 20°; level-flight power; P2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

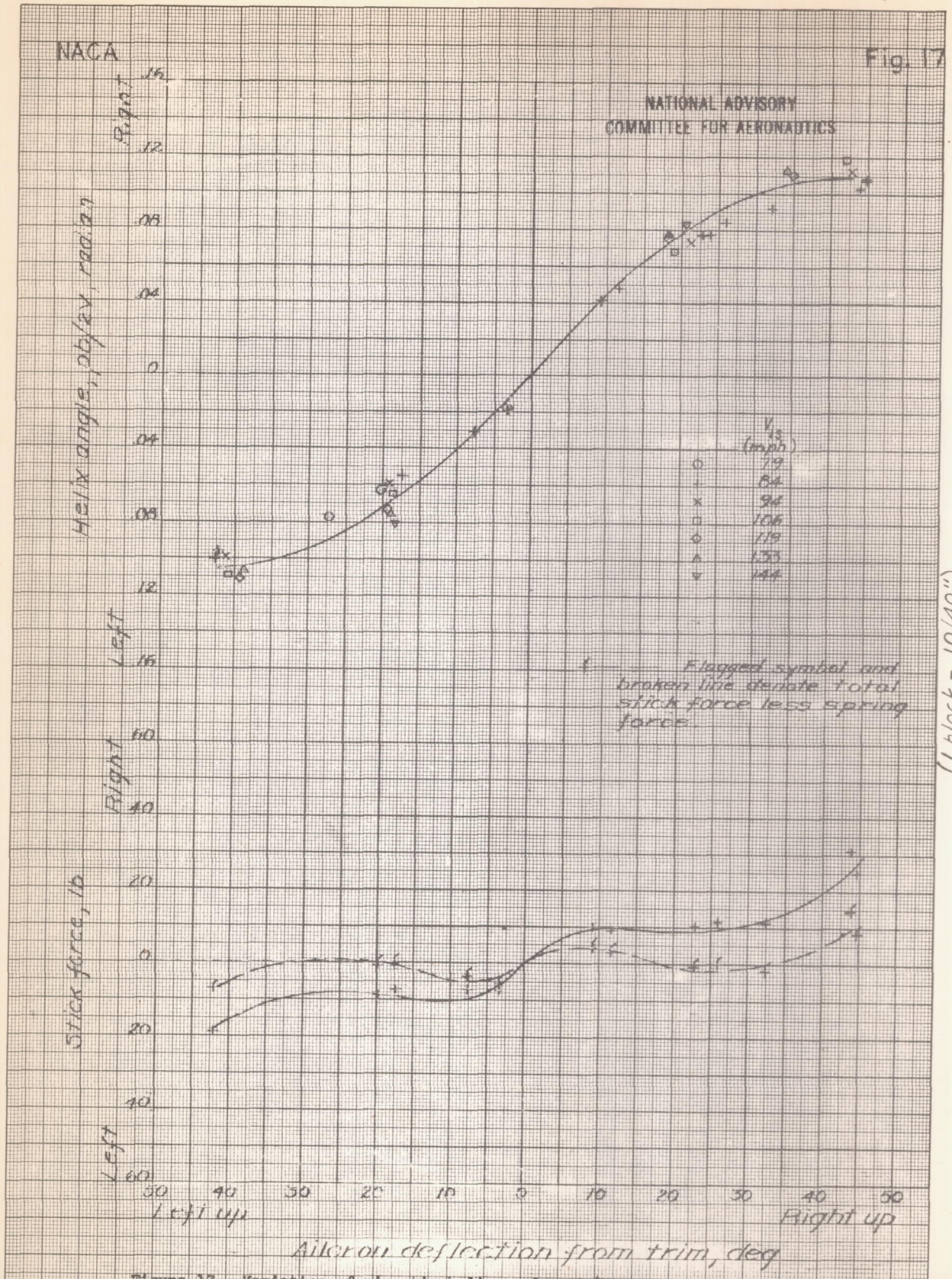


Figure 17.- Variation of wing-tip helix angle pb/2V and stick force with deflection of up-going aileron. Slot-lip ailerons; flap selector setting 30°; level-flight power; F2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

L-272

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

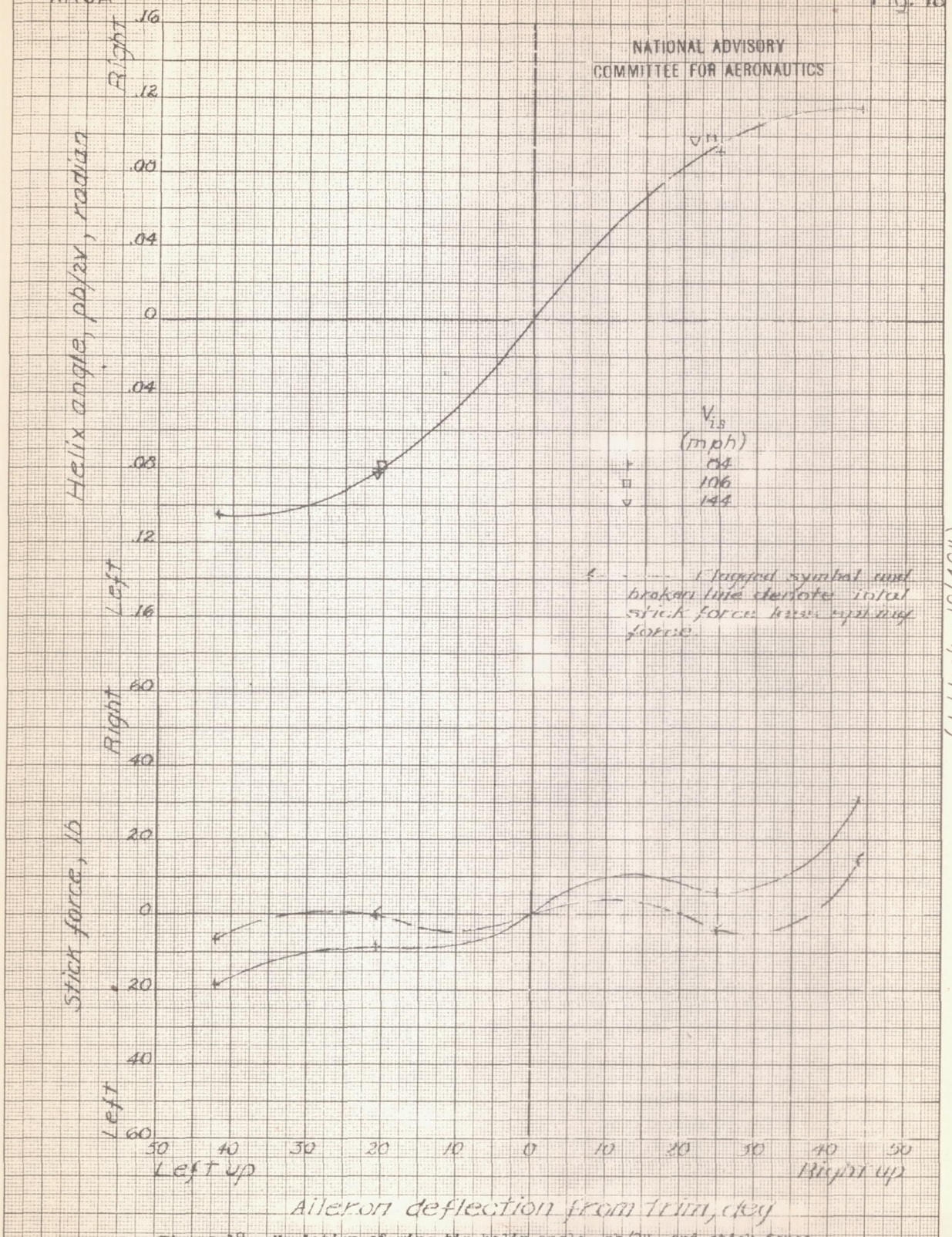
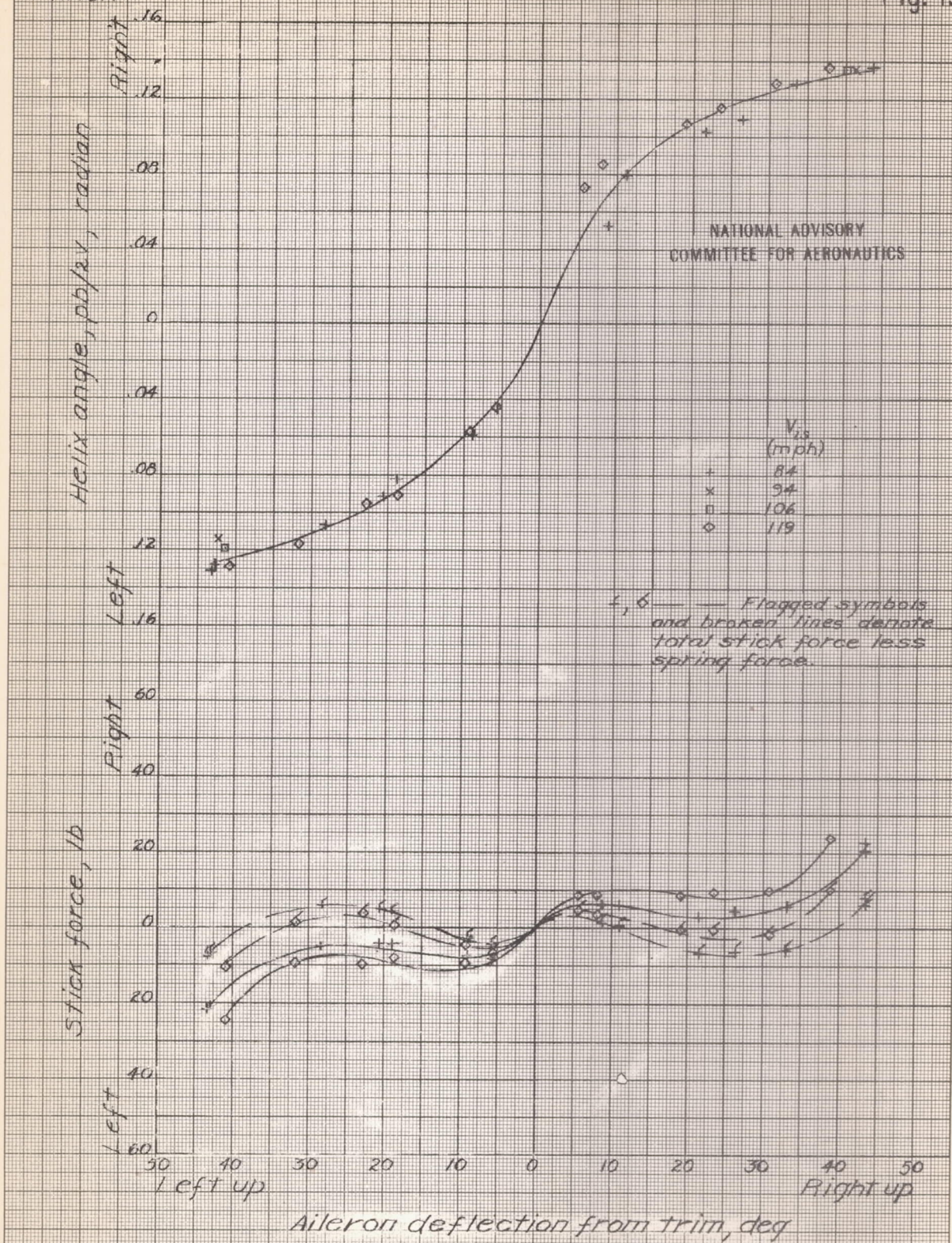


Figure 18.- Variation of wing-tip helix angle pb/2V and stick force with deflection of up-going aileron. Slot-lip ailerons; flap selector setting, 40°; level-flight power; P2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

L-272



(1 block = 10/40")

Figure 19.- Variation of wing-tip helix angle pb/2V and stick force with deflection of up-going aileron. Slot-lip ailerons; flap selector setting, 50°; level-flight power; F2A-2 airplane.

NATIONAL ADVISORY
COMMITTEE FOR AERONA

L-272

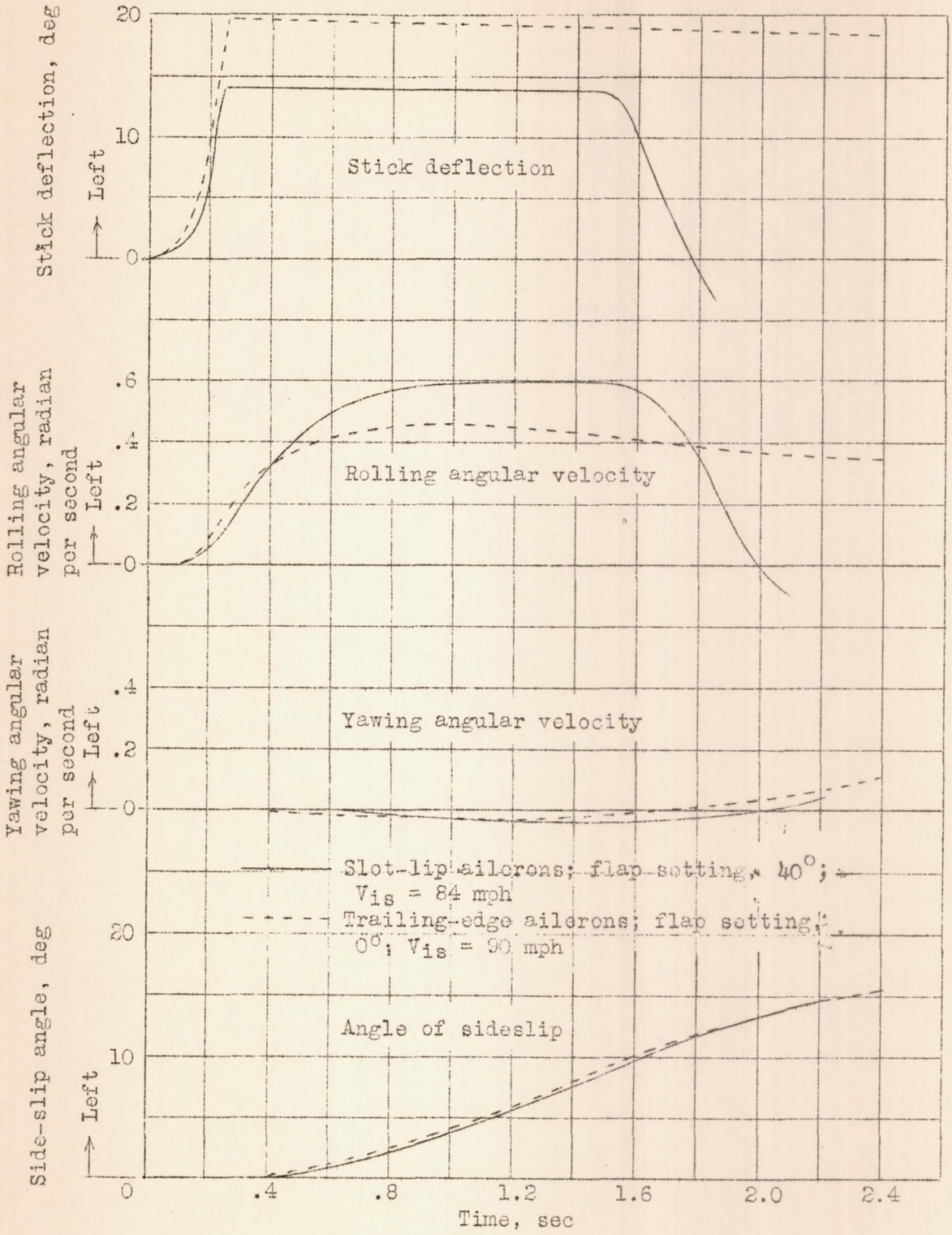


Figure 20.- Comparison of motion of F2A-2 airplane resulting from abrupt application of slot-lip ailerons and of trailing-edge ailerons. Level-flight power.

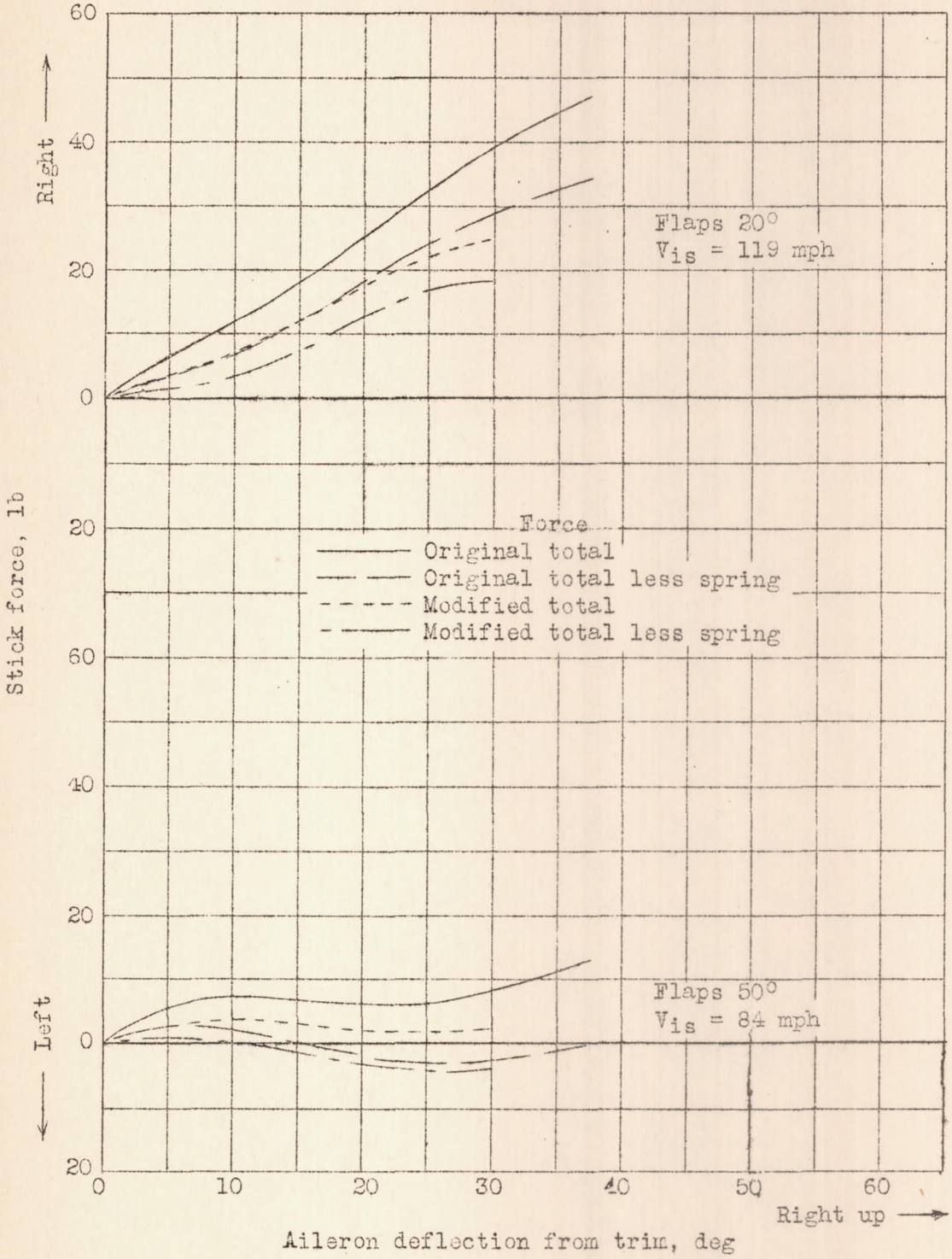


Figure 21.- Computed variation of stick force with up-deflection of right aileron for original and assumed modified control systems. Slot-lip ailerons; nominal flap settings of 20° and 50°; F2A-2 airplane.

L-272

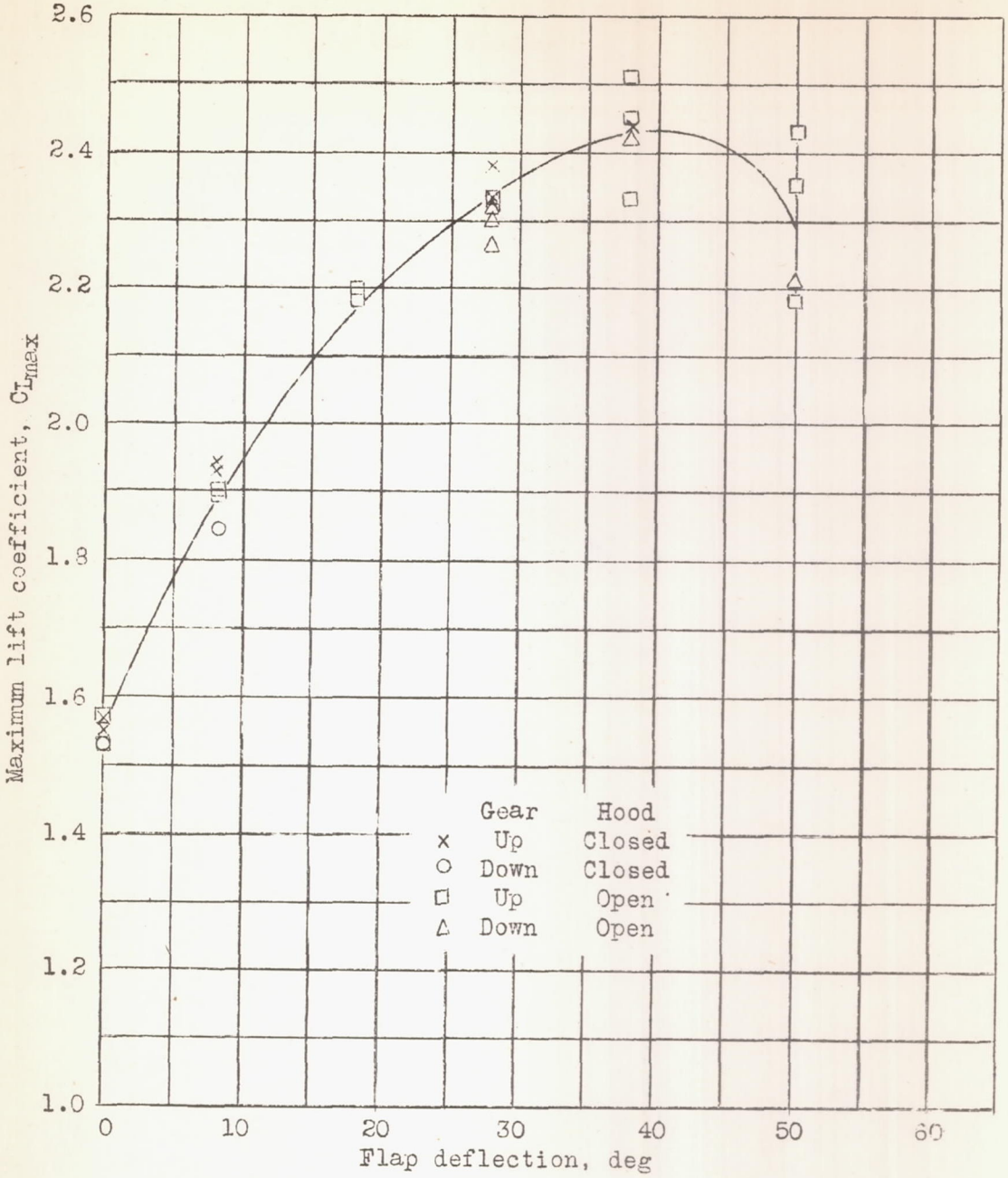


Figure 22.- Variation of maximum lift coefficient with deflection of full-span slotted flaps. Engine idling; F2A-2 airplane.

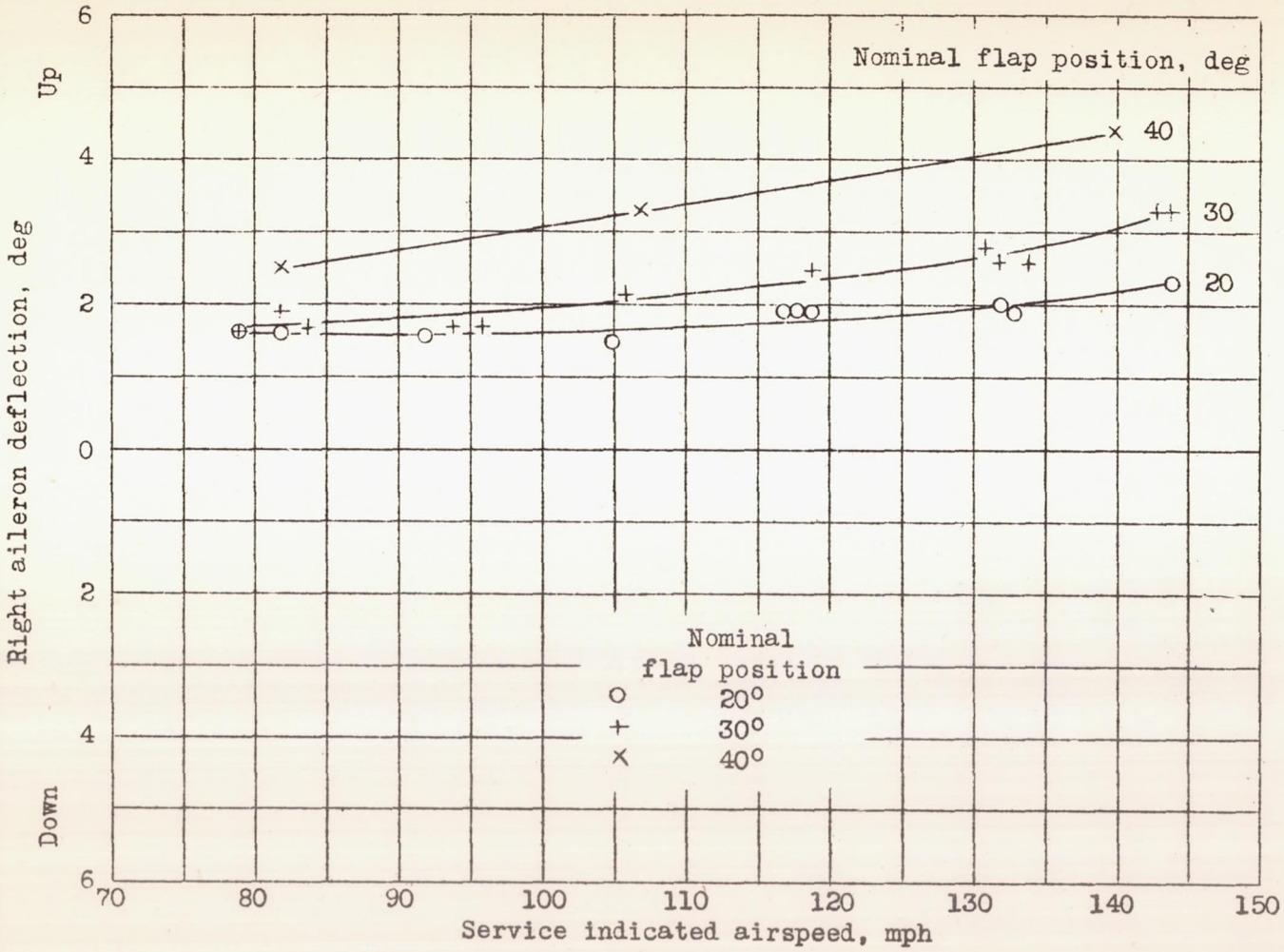
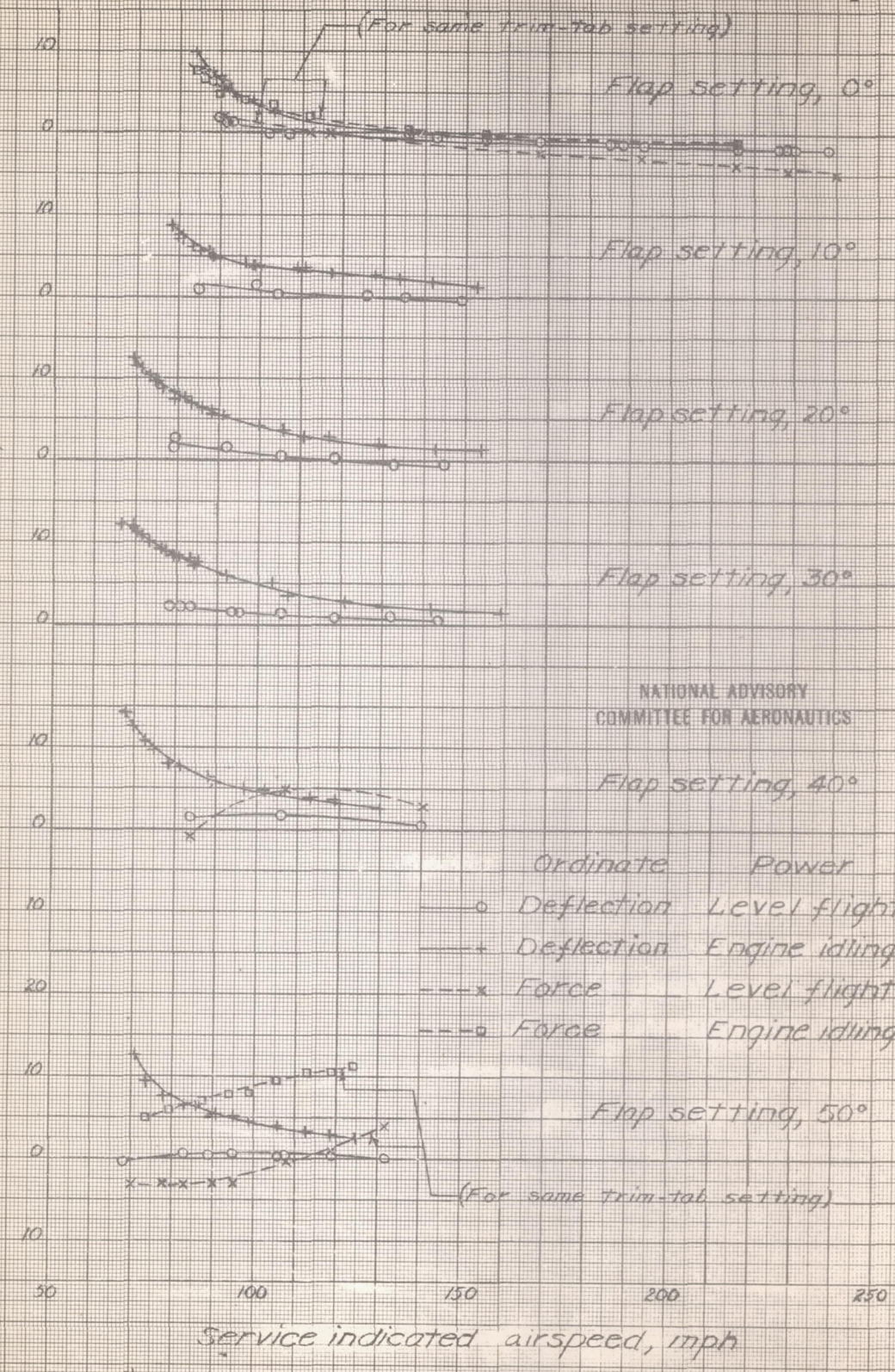


Figure 23.- Up-floating angle of trailing-edge ailerons in locked condition with flaps down. Measured on right aileron; level-flight power; F2A-2 airplane.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(1 block = 10/40")

Figure 24.- Variation of elevator deflection and stick force with service indicated airspeed. Steady flight; c.g. at 30.4 percent M.A.C.; landing gear up; F2A-2 airplane.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

L-372

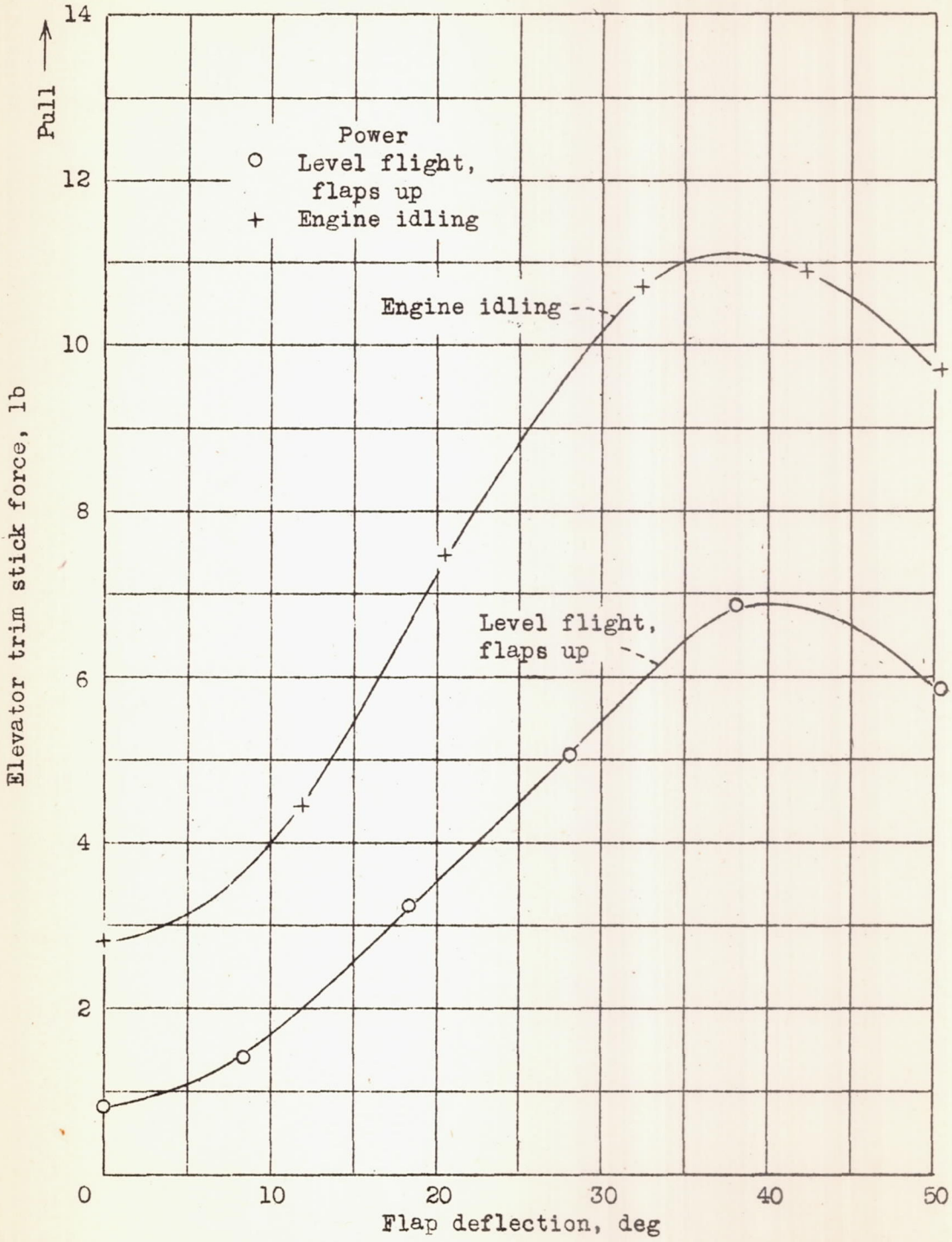


Figure 25.- Variation of elevator stick force required for trim with deflection of full-span slotted flap. Steady flight; service indicated airspeed, 94 mph; c.g. at 30.4 percent M.A.C.; landing gear up; F2A-2 airplane.