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WIND-TUNNEL DEVELOPMENT OF A PLUG-TYPE SPOILER-SLOT AILERON FOR A WING WITH A FULL-SPAN SLOTTED FLAP AND A DISCUSSION OF ITS APPLICATION

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NACA

WASHINGTON

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AILERON FOR A WING WITH A FULL-SPAN SLOTTED FLAP

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SUMMARY

An investigation was made in the NACA 7- by 10-foot wind tunnel of several arrangements of a plug-type, spoiler-slot aileron on an NACA 23012 airfoil with a full-span slotted flap. One arrangement was also tested on a wing with a full-span split flap. The plug-type aileron is essentially a tapered plug that fits into a slot through the wing so as to conform to the original external wing contour when in the neutral position. When deflected, the plug projects from the upper surface of the wing as a spoiler, at the same time leaving a slot through the wing behind the spoiler. The static rolling, yawing, and hinge moments were determined and are presented for several angles of attack and flap deflections.

The results indicated that a plug-type, spoiler-slot aileron probably has negligible drag in the neutral position and will provide satisfactory lateral control for airplanes equipped with full-span slotted flaps. The aileron when located as tested was unsatisfactory for use on a wing with a full-span split flap but may be satisfactory if uprigged about 10° when the flap is deflected or if located nearer the trailing edge.

The application of this aileron to a pursuit-type airplane is considered and the resultant characteristics are estimated. Flight tests of the device on an airplane with a full-span slotted flap are recommended.

INTRODUCTION

The NACA has recently undertaken an extensive investigation for the purpose of developing lateral-control devices primarily for use with full-span trailing-edge high-lift devices. In the present investigation a spoiler-slot aileron has been developed for use on a wing with a full-span slotted flap. Several different basic shapes of the aileron were tested at a single angle of attack of an airfoil with a flap neutral and deflected 40°; and some arrangements of the device were tested at several angles of attack with the flap neutral and deflected 20°, 30°, and 40°. Static rolling, yawing, and hinge moments were determined. Lag tests were not considered necessary because previous tests of similar devices (reference 1) indicated that the lag will probably be acceptable when the devices are located relatively near the trailing edge of the airfoil.

APPARATUS AND METHODS

All tests were made in the NACA 7- by 10-foot closed-throat wind tunnel (see references 1 and 2) at an air speed of about 40 miles per hour, corresponding to an effective Reynolds number of approximately two millions. The test set-up is shown schematically in figure 1. The aileron was installed in the outer 0.37 b/2 of a 4- by 8-foot NACA 23012 airfoil with a 0.2566c full-span slotted flap. The slotted-flap installation was the installation designated 2-h in reference 2 and the flap was operated along the recommended optimum path. One aileron arrangement was tested with a 0.20c full-span split flap deflected 60°. The airfoil was suspended horizontally in the wind tunnel with the inboard end attached to the tunnel wall so as to simulate the semispan of a 16-foot wing. The attachment at the tunnel wall restrained the airfoil in pitch but not in roll or yaw. The forces necessary to restrain the outboard end of the airfoil were determined by means of the regular balance system. The lift of the airfoil with the aileron neutral was computed from the vertical outboard reaction and the assumption that the lateral center of pressure of the semispan was 0.45 b/2 from the plane of symmetry. The rolling moment was computed from the difference between the vertical reactions at the outboard end of the airfoil with the aileron neutral and deflected; the yawing moment was determined similarly from the horizontal reactions.

The aileron was manually operated by means of a crank outside the tunnel wall near the inboard end of the model. The aileron hinge moments were determined by means of a calibrated torque rod connecting the aileron and the crank.

The plug-type aileron is essentially a tapered plug that fits into a slot through the wing so as to conform to the original external wing contour when in the neutral position. When deflected, the plug projects from the upper surface of the wing as a spoiler, at the same time leaving a slot through the wing behind the spoiler. The two aileron arrangements most completely tested are shown in figure 2. Sketches of other arrangements, which were preliminary steps in the development of those shown in figure 2, are given in the figures that present the test results.

RESULTS AND DISCUSSION

In the presentation of results, the following symbols are used:

C_L lift coefficient (L/qS)

C_l' rolling-moment coefficient (L'/qbS)

C_n' yawing-moment coefficient (N'/qbS)

δ_s stick deflection

δ_a aileron deflection

F_s stick force in pounds

H_a aileron hinge moment, inch-pounds at 40 miles per hour

c airfoil chord

L twice the lift on the half-span model

S twice the area of the half-span model

b twice the span of the half-span model

L' rolling moment about wind axis

N' yawing moment about wind axis

q dynamic pressure of air stream

α uncorrected angle of attack

A positive value of L' or C_l' corresponds to a decrease in lift on the model and a positive value of N' or C_n' corresponds to an increase in drag on the model. A downward deflection of the ailerons is considered positive, as is the case of conventional ailerons. Twice the actual lift, area, and span of the model were used in the reduction of results because the model represents half of a complete wing, as previously stated. No corrections have been made for the effect of the tunnel walls although it is believed the corrections may be rather large for this set-up.

The results of preliminary tests in which the basic shape of the plug-type spoiler-slot aileron was varied over a fairly wide range, including spoilers without slots (retractable ailerons), are presented in figures 3 to 6. These tests were made with the airfoil set at 8° angle of attack and with the flap neutral and deflected 40°.

An opening in the lower surface of the airfoil without a slot completely through the airfoil (a condition true at aileron deflections below 54° for the device of fig. 3) had little effect on the rolling- and yawing-moment coefficients. (See fig. 3.) At aileron deflections above 54°, where a slot was actually opened through the airfoil, an increase in rolling-moment coefficient was noted. The rolling-moment characteristics of the devices shown in figure 3 are considered unsatisfactory because of ineffectiveness at low aileron deflections, particularly with the slotted flap deflected. The hinge-moment characteristics are unstable and therefore considered unsatisfactory.

A slot open through the airfoil at all negative (up) deflections of the aileron caused a marked increase in the rolling-moment coefficient, as shown in figures 4, 5, and 6, especially at low aileron deflections where the spoiler alone is shown to be ineffective. In a previous investigation of such spoilers (reference 3) this region of ineffectiveness was not detected because the low deflection range was not investigated. In figures 5 and 6 a variation of slot width from 0.030c to 0.015c was effected by a removal of the rear half of the plug and a lengthening of the lower rear lip of the slot so that in all cases the slot was closed when the aileron was neutral or deflected downward. The rolling- and the yawing-moment characteristics of these spoiler-slot combinations were considered generally satisfactory but their hinge-moment characteristics near the neutral position were not. The narrowest basic shape (see fig. 4) was chosen for further development because it had the lowest hinge moments and its rolling- and yawing-moment characteristics were considered as satisfactory as those of the thicker ailerons.

Some detailed aileron alterations that were made solely to improve the hinge-moment characteristics are shown in figure 2. One of the most important alterations, two forms of which are shown in figure 3, was to provide air vents in the spoiler with inlet openings that projected below the lower surface of the airfoil when the aileron was deflected positively. The purpose of these vents was to increase negatively the hinge moments of the aileron when at positive deflections by increasing the pressure in the chamber behind the spoiler. In order to illustrate the effectiveness of the vents in the range between $\delta_a = 5^\circ$ and $\delta_a = 15^\circ$, (in which range the modifications to the top of the plug had negligible effect, as shown in fig. 7) the hinge-moment curves of figure 4 may be compared with those of figure 8.

The plates on the upper surface of the spoiler on arrangements A and B (see fig. 3) were tilted and bent, respectively, so that the trailing edge projected slightly above the airfoil contour when the aileron was neutral. This modification, which increased the hinge moments positively at negative (up) deflections as shown in figure 7, could easily be made as an adjustment in a practical installation. If the plate were hinged and its angle varied by means of a suitable linkage the hinge-moment characteristics could be further modified.

The slots or gap G through the top of the spoiler (fig. 7(a)) were provided to eliminate the bump in the hinge-moment curve at very small negative deflections. If the slots are made appreciably larger than those shown in figure 2, however, they will decrease the effectiveness of the aileron at low deflections.

In order to determine the effect of more quickly exposing the vent when the aileron is deflected downward, the plate P (fig. 7(b)) was removed. Although removing this plate was considered beneficial to the hinge-moment characteristics, it was thought best to leave the plate in place to avoid increasing the drag of the airfoil with the aileron neutral.

Rolling-, yawing-, and hinge-moment characteristics of the aileron arrangements shown in figure 2 are presented in figures 8 and 9. In general, the characteristics of these arrangements of the plug-type spoiler-slot aileron were similar and were considered satisfactory at all angles of attack and flap deflections tested, although the rolling-moment coefficient obtained on the plain airfoil at $C_L = -0.8$ was small and the corresponding hinge-moment curve indicated that the system would be overbalanced. It should be noted also that when the flap was deflected 40° and the angle of attack was -6°, the rolling-moment coefficient was slightly negative for small aileron deflections. This characteristic is thought to be acceptable because it did not occur at other flap deflections or angles of attack.

Measurements showed that the increment of drag due to these spoiler-slot ailerons when in the neutral position was very small, as would be expected, because they entail little departure from the original contour of the airfoil.

The aerodynamic characteristics of ailerons of the type discussed in this paper are very largely dependent upon their chordwise location and upon the type of trailing-edge high-lift device employed. Movement of the aileron forward in the wing is thought to be detrimental, whereas a rearward movement may be beneficial. Arrangement A (see fig. 2(a)) in its present location, (rear edge located at 0.67c) was considered unsatisfactory when used in combination with a 0.20c full-span split flap deflected 60° (see fig. 10) because of ineffectiveness at low deflections, but it might have been satisfactory if it had been located farther rearward, as is possible with such a flap installation. In this connection, it is well to note that a retractable aileron located at 0.077c (0.10c behind arrangement A) has been tested in flight (see reference 4) on a wing with a full-span split flap and was considered satisfactory by the test pilots. Even in the position tested the plug-type, spoiler-slot aileron would be considered satisfactory on a wing with a full-span split flap if the ailerons were uprigged about 10° when the flap was deflected.

APPLICATION

In order to give some indication of the stick-force characteristics of the plug-type spoiler-slot aileron on an actual airplane installation, an aileron control system was designed and its characteristics were estimated for a typical pursuit airplane. (These computations can also be directly compared with the computations of the characteristics of other lateral-control devices for use on the same wing with full-span flaps, as given in references 5 and 6.) The general arrangement of the wing is shown in figure 11. A full-span slotted flap of 0.20c is indicated although the flap on the wind-tunnel model was about 0.25c. It was assumed that aileron characteristics at a given flap deflection and lift coefficient are independent of flap chord over the range of flap chords from 0.20c to 0.30c. Each aileron has a span of 115 inches or 0.514 b/2, as shown in figure 11. Cross sections at the inboard and the outboard ends of the ailerons are shown in figure 12; notice the alternate suggestions for plug construction. In either design the rear openings of the vents should be within the wing contour with the aileron full down and the upper plate should be free to be bent up. A schematic diagram of the aileron operating linkage is shown in figure 13; the angular deflections and the mechanical advantages of the ailerons relative to the stick are shown in figure 14.

The computed aerodynamic characteristics of the aileron system (see fig. 15) are based on the simple but approximately correct assumption that the rolling- and the yawing-moment coefficients due to the ailerons vary directly with the aileron span, in percent of wing semispan, and with the distance from the aileron axis to the downstream edge of the top face, a distance approximately proportional to the projection at any given aileron deflection, in percentage of the wing chord at the aileron. The section hinge moment was assumed to vary directly with the width of the top face and with the distance from the aileron axis to the downstream edge of the top face; this variation was indicated by an analysis of the hinge-moment data of figures 4, 5, and 6. The aileron-control characteristics presented cover the range of lift coefficients estimated for the wing in the tunnel. (See Apparatus and Methods for lift-coefficient estimation.) This lift range was probably greater than could be realized on the airplane, even if the chord of the slotted flap were increased to 0.25c.

The aileron-control characteristics given in figure 15 may be directly compared with those given in references 5 and 6 because the same airplane was assumed in the three sets of computations. Although the maximum stick deflection in degrees was slightly altered, the stick travel in inches was the same. At a lift coefficient of 0.17 with the slotted flap neutral, the stick forces on the spoiler-slot aileron were estimated to be less than those of the 0.10c plain aileron for rolling-moment coefficients, C_l', less than 0.022; at higher values of C_l' the spoiler-slot aileron has the higher stick forces. The stick forces due to the spoiler-slot aileron appear to be no higher than for systems with plain ailerons of about 0.15c (see reference 6) and these forces may be further reduced by a decrease in the width of the plug; it may be recalled that one of the objections to a thin-plate retractable aileron wasthe almost complete absence of aerodynamic hinge moment. (See reference 4.) It should be pointed out, however, that as the spoiler-slot aileron thickness is reduced, the slot width is reduced and the device becomes more nearly a retractable aileron, a device that wind-tunnel tests have shown to be ineffective at low aileron deflections. Thickness variations over the range of the present tests (see figs. 4, 5, and 6) did not show any reduction of aileron effectiveness with plug thickness (or slot width) at low deflections. If the device is to be applied to very large or very fast airplanes, additional tests should be made on ailerons designed to give small stick forces.

Except for the somewhat high stick forces at high speed, the spoiler-slot aileron appears to be aerodynamically as good or better than any of the plain and the slot-lip aileron combinations discussed in reference 5. Mechanically, the spoiler-slot aileron allows an aileron linkage system far simpler than any discussed in reference 5. The structural design may present some problems not encountered in the design of conventional trailing-edge devices, but the difficulties do not appear to be serious.

Because the plug-type aileron must displace some air from the slot in moving downward from neutral, its action is similar to that of a viscous damper or dashpot. Therefore, it may be inherently free of aileron flutter. Until flight tests show it to be unnecessary, however, mass balancing is recommended.

The danger of icing of the spoiler-slot aileron has been voiced as an objection. If the device proves to be otherwise acceptable, however, it is felt that it may be made reasonably free of any icing hazard by the application of heat or of de-icing fluid or by making some of the aileron parts of flexible material so that the ice will be broken off by contact.

CONCLUDING REMARKS

The results of this investigation indicate that a spoiler-slot aileron will provide satisfactory lateral control on airplanes equipped with full-span slotted flaps. Because the aileron requires no large slots or openings in the wing when it is in the neutral position, it should be acceptable for use on modern high-performance airplanes. The spoiler-slot aileron located as tested was considered unsatisfactory for use on a wing with a full-span split flap unless the aileron is uprigged when the flap is deflected, but it may be satisfactory when located nearer the trailing edge. Flight tests of the device on an airplane with a full-span slotted flap are recommended.

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1. Wenzinger, Carl J., and Rogallo, Francis M.: Wind-Tunnel Investigation of Spoiler, Deflector, and Slot Lateral-Control Devices on Wings with Full-Span Split and Slotted Flaps. Rep. No. 706, NACA, 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. Wenzinger, Carl J., and Bamber, Millard J.: Wind-Tunnel Tests of Three Lateral-Control Devices in Combination with a Full-Span Slotted Flap on an N.A.C.A. 23012 Airfoil. T.N. No. 659, NACA, 1938.

4. Soulé, H. A., and McAvoy, W. H.: Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps. Rep. No. 517, NACA, 1935.

5. 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.

6. Harris, Thomas A., and Purser, Paul E.: Wind-Tunnel Investigation of Plain Ailerons for a Wing with a Full-Span Flap Consisting of an Inboard Fowler and an Outboard Retractable Split Flap. NACA ACR, March 1941.

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1. Wenzinger Carl J., and Rogallo, Francis M.: Wind-Tunnel Investigation of Spoiler, Deflector, and Slot Lateral-Control Devices on Wings with Full-Span Split and Slotted Flaps. Rep. No. 706, NACA, 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. Wenzinger, Carl J., and Bamber, Millard J.: Wind-Tunnel Tests of Three Latoral-Control Devices in Combination with a Full-Span Slotted Flap on an N.A.C.A. 23012 Airfoil. T.N. No. 659, NACA, 1938.
4. Soulé, H. A., and McAvoy, W. H.: Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps. Rep. No. 517, NACA, 1935.
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6. Harris, Thomas A., and Purser, Paul E.: Wind-Tunnel Investigation of Plain Ailerons for a Wing with a Full-Span Flap Consisting of an Inboard Fowler and an Outboard Retractable Split Flap. NACA ACR, March 1941.

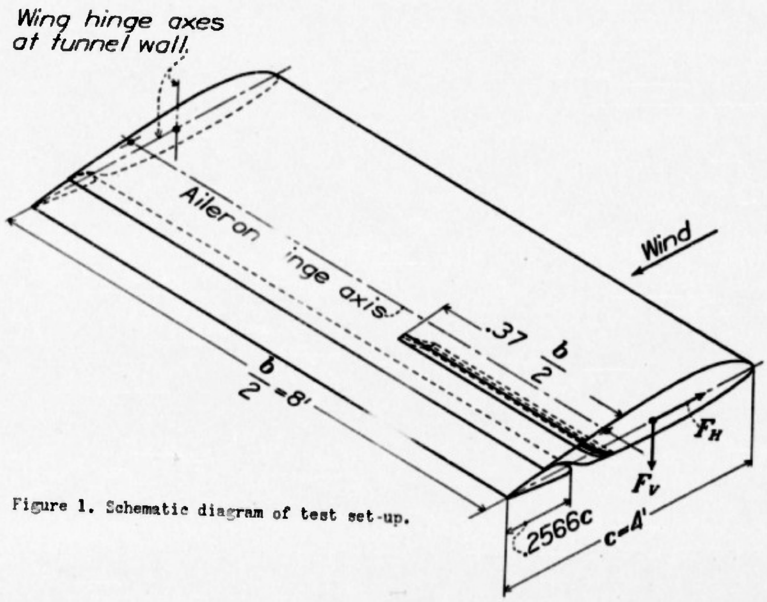

Figure 1. Schematic diagram of test set-up.

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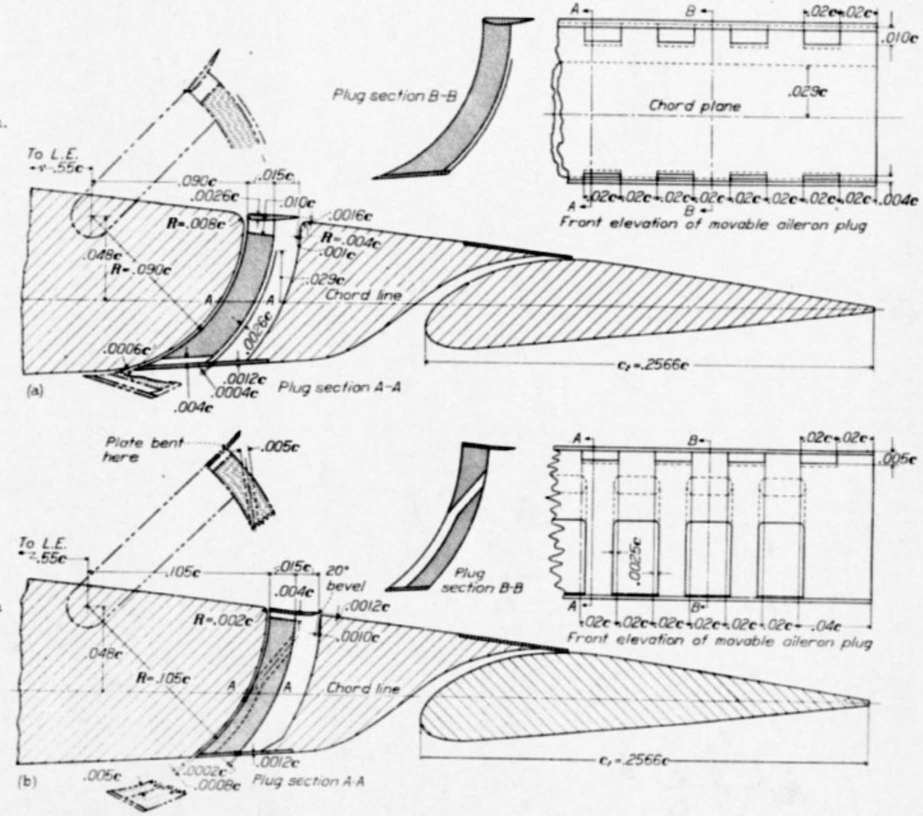
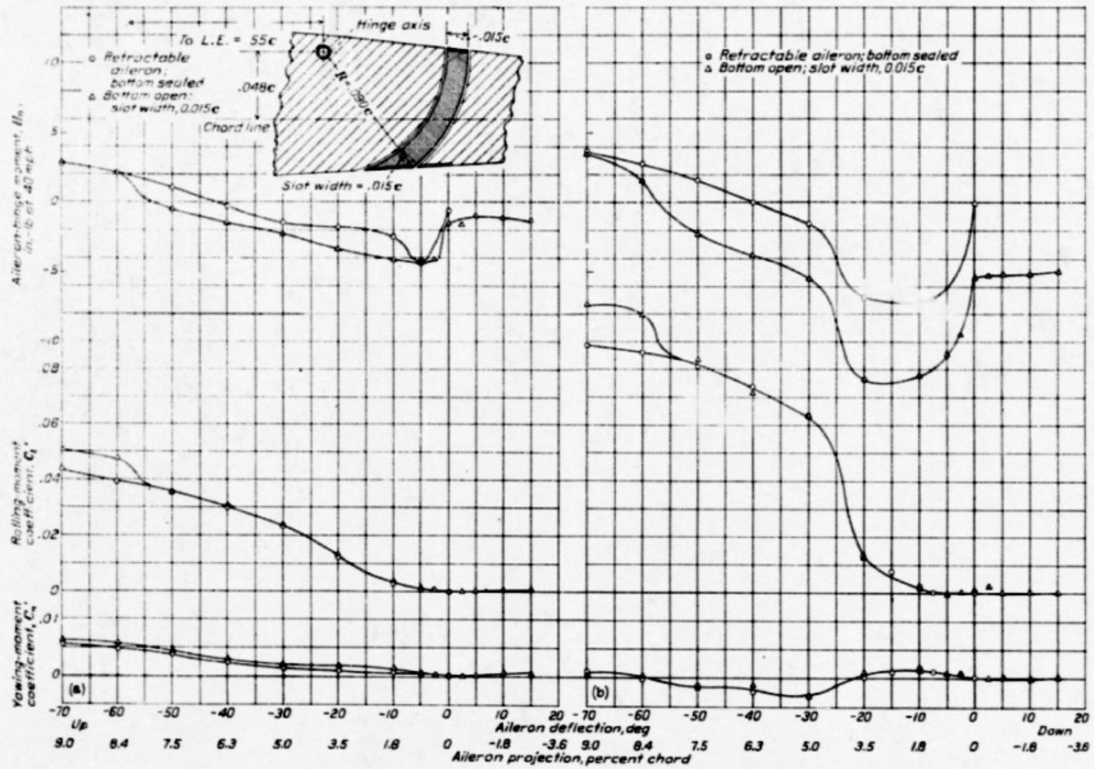


(a) Arrangement A.

(b) Arrangement B.

Figure 2.- A 0.37 b/2 spoiler-slot aileron on an 8-foot semispan NACA 23012 wing with a 0.2566c full-span slotted flap.



Flap neutral; C_L, 0.80.

Flap deflected 40°; C_L, 2.45.

Figure 3a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap, α, 8°. Width of spoiler face, 0.015c.

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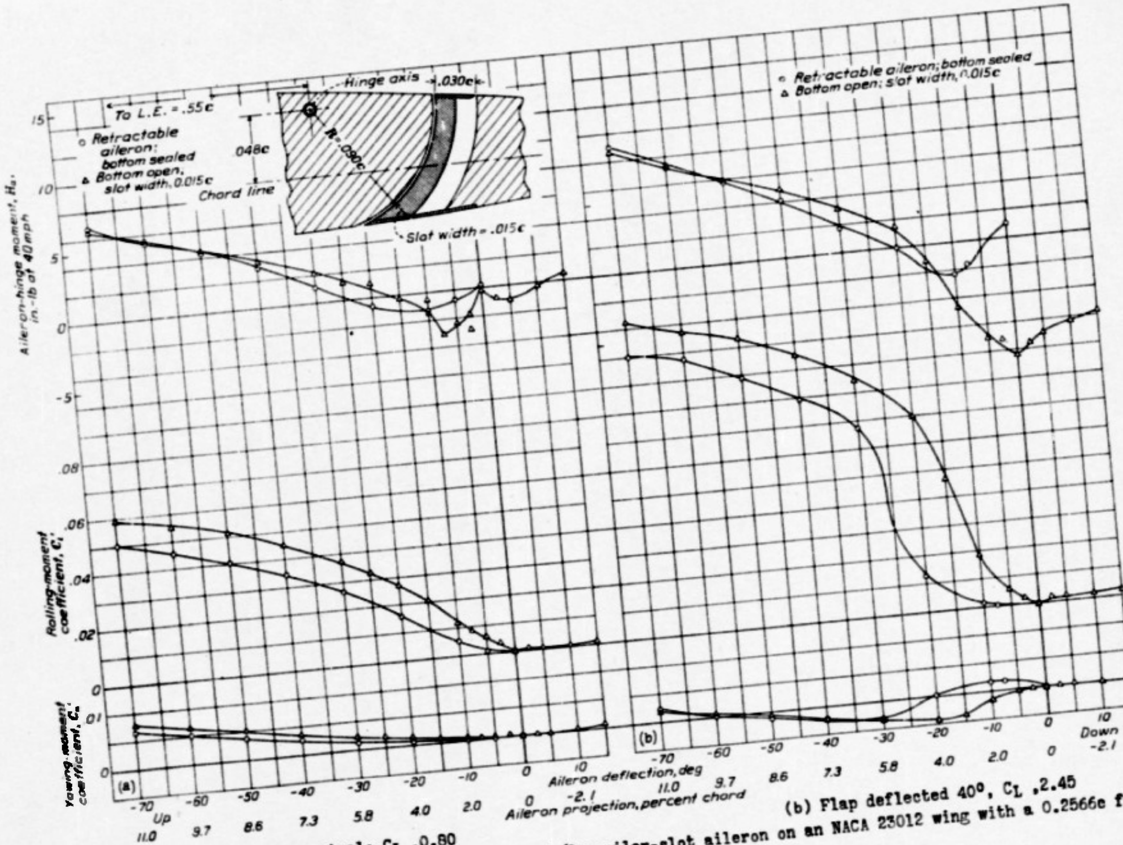

(a) Flap neutral; C_L ,0.80

(b) Flap deflected 40°, C_L ,2.45

Figure 4a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap, α , 8°. Width of spoiler face, 0.030c.

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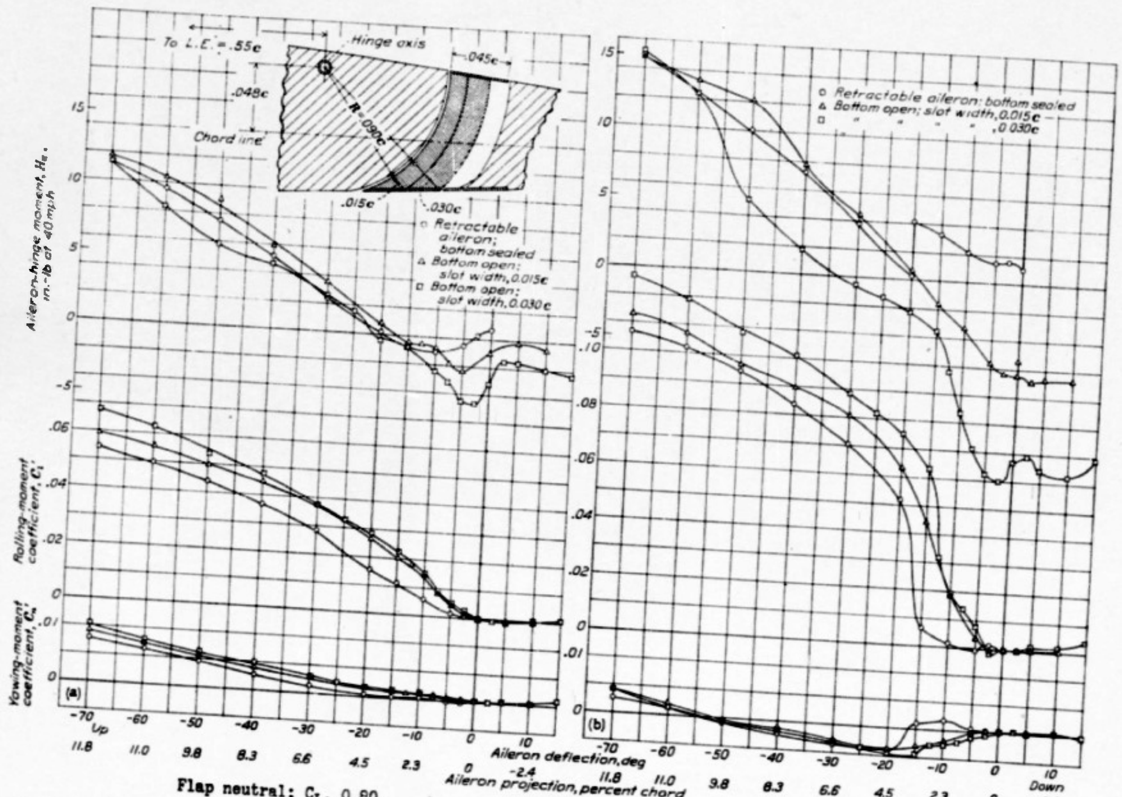
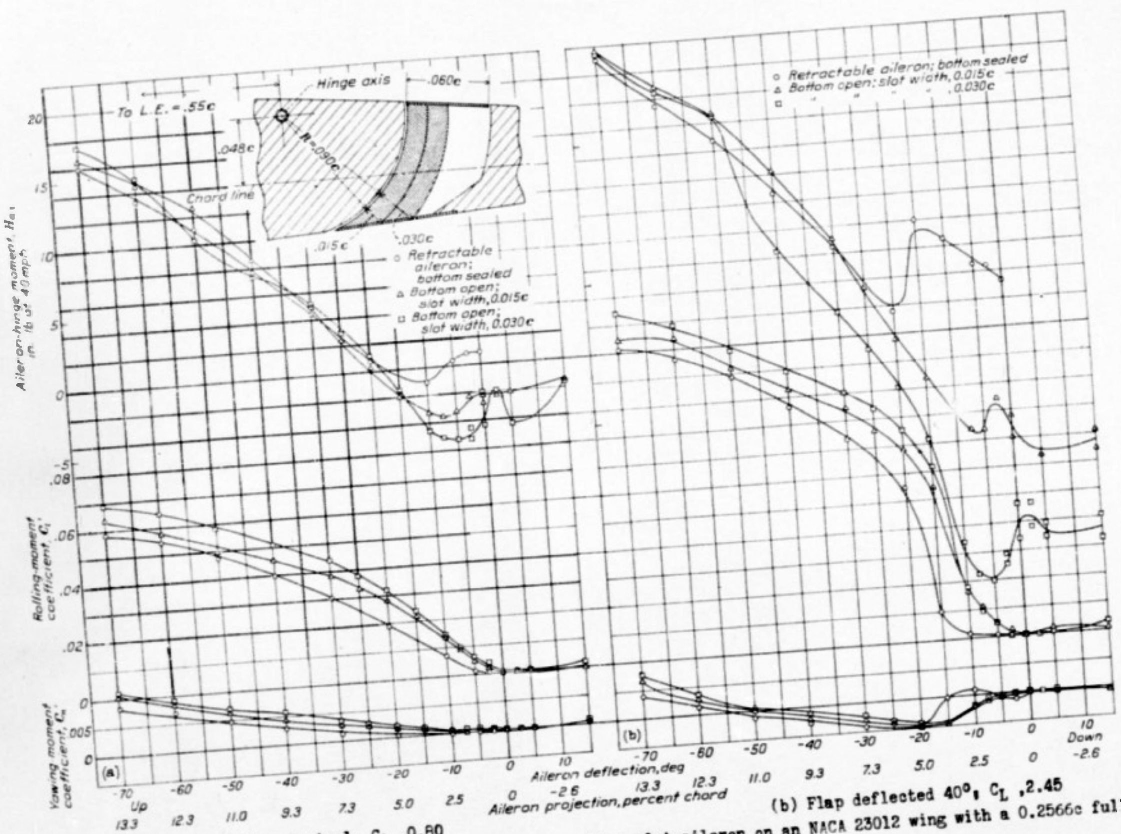


Flap neutral; C_L, 0.80.

Flap deflected 40°; C_L, 2.45.

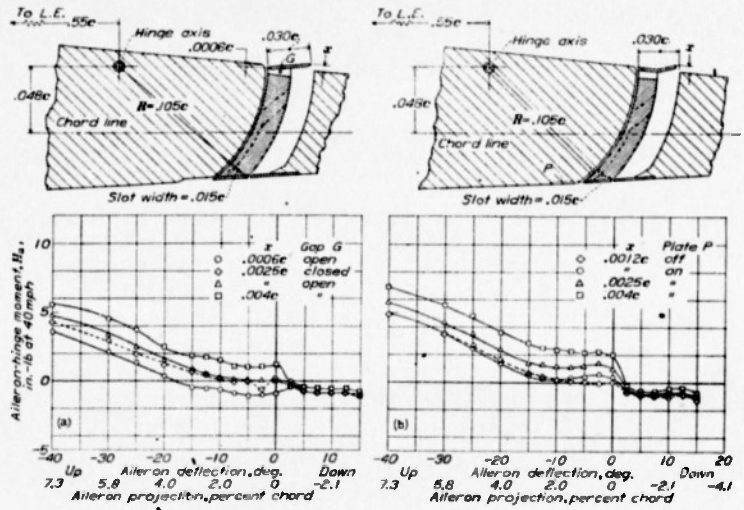
Figure 5a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap, α ,8°. Width of spoiler face, 0.045c.



(a) Flap neutral, C_L, 0.80

(b) Flap deflected 40°, C_L, 2.45

Figure 6a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap, α, 8°. Width of spoiler face 0.060c.



(a) Plate tilted (b) Plate bent at center

Figure 7.- The effect on the hinge-moment characteristics of tilting or bending the upper surface plate of an 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap. Arrangement B, α ,1°, C_L ,0.15. Flap neutral.

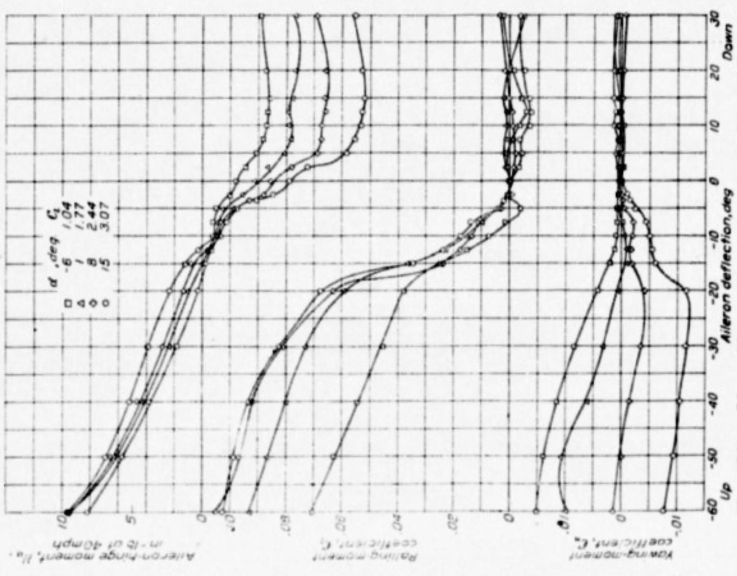
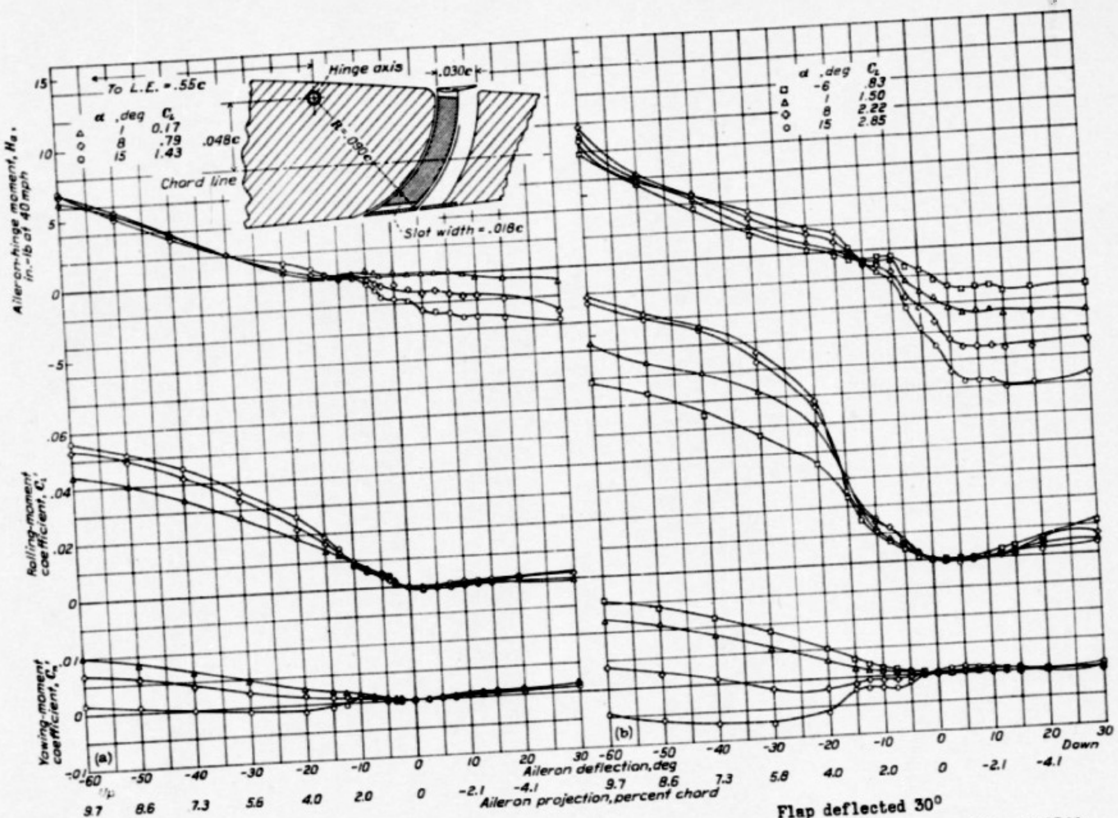


Figure 8c.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap deflected 40°. Arrangement A.



Flap neutral

Flap deflected 30°

Figure 8a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap. Arrangement A.

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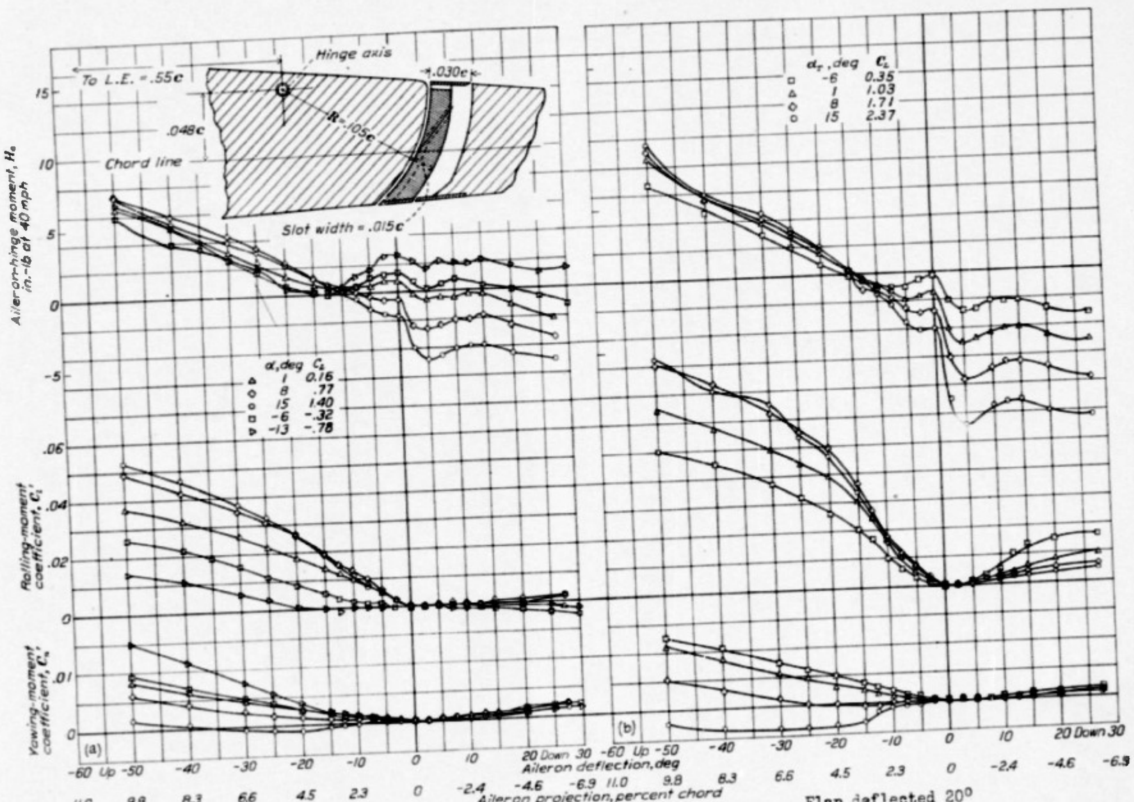

Figure 9a,b.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap. Arrangement B.

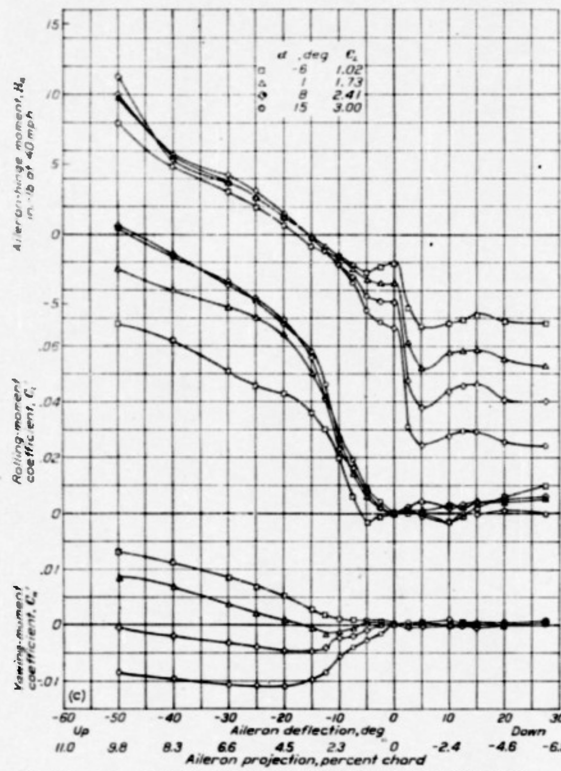

Figure 9c.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.2566c full-span slotted flap deflected 40°. Arrangement B.

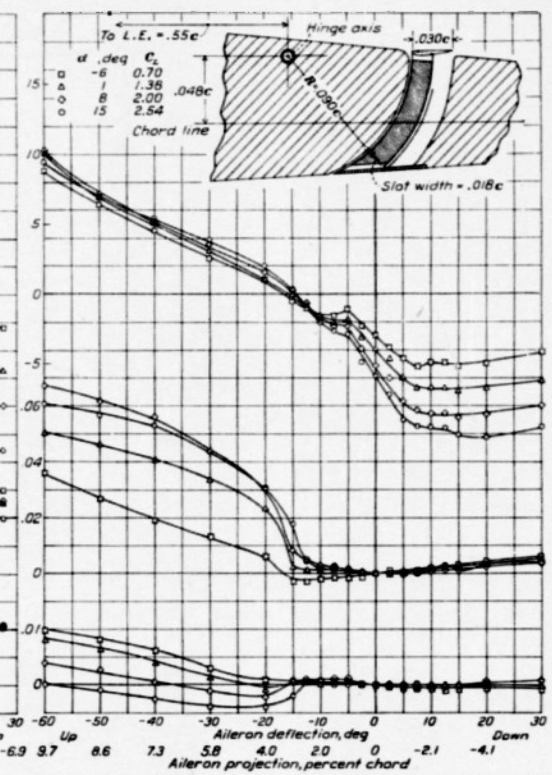

Figure 10.- Aerodynamic characteristics of a 0.37 b/2 spoiler-slot aileron on an NACA 23012 wing with a 0.20c full-span split flap deflected 60°. Arrangement A.

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Fig. 11

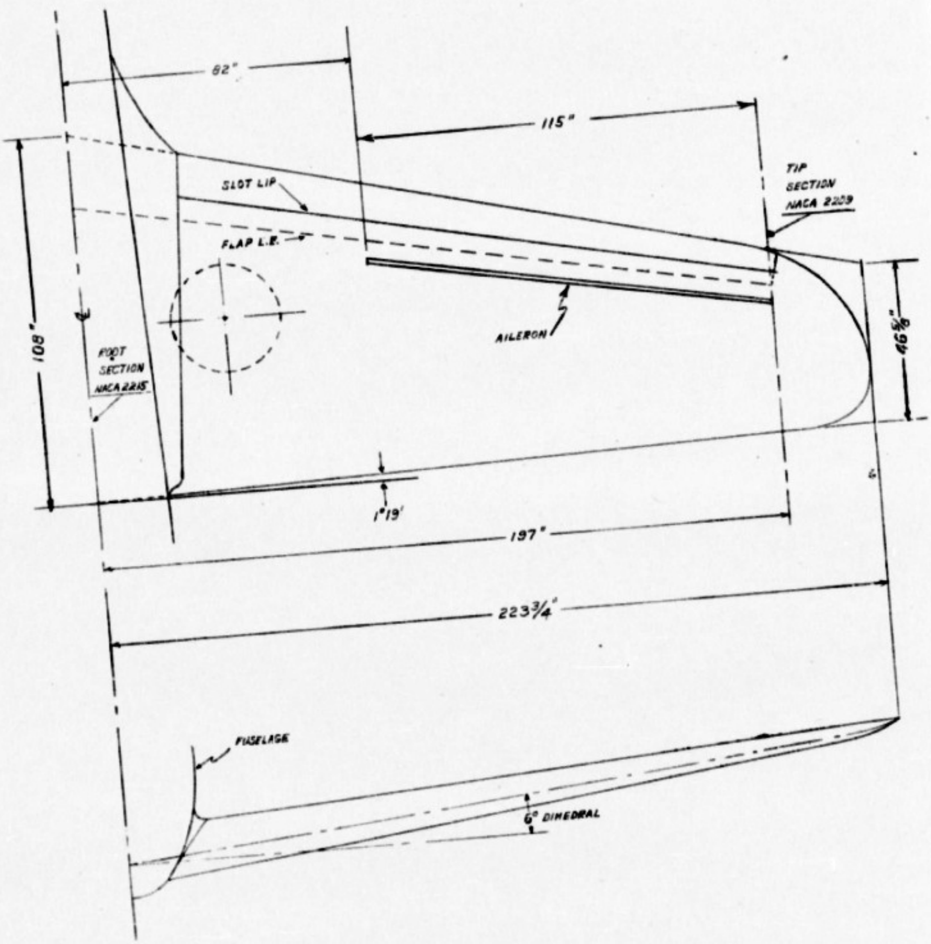

Figure 11.- Wing arrangement of the spoiler-slot aileron control system for a pursuit-type airplane.

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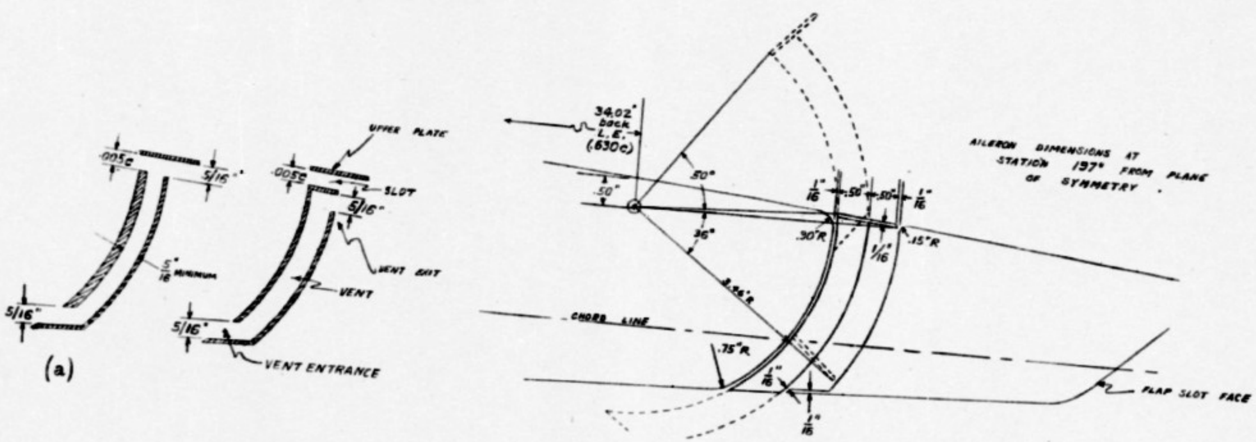

Figure 12(a-b).- Cross sections of the spoiler-slot aileron control system for a pursuit-type airplane.

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NACA FIG 12b

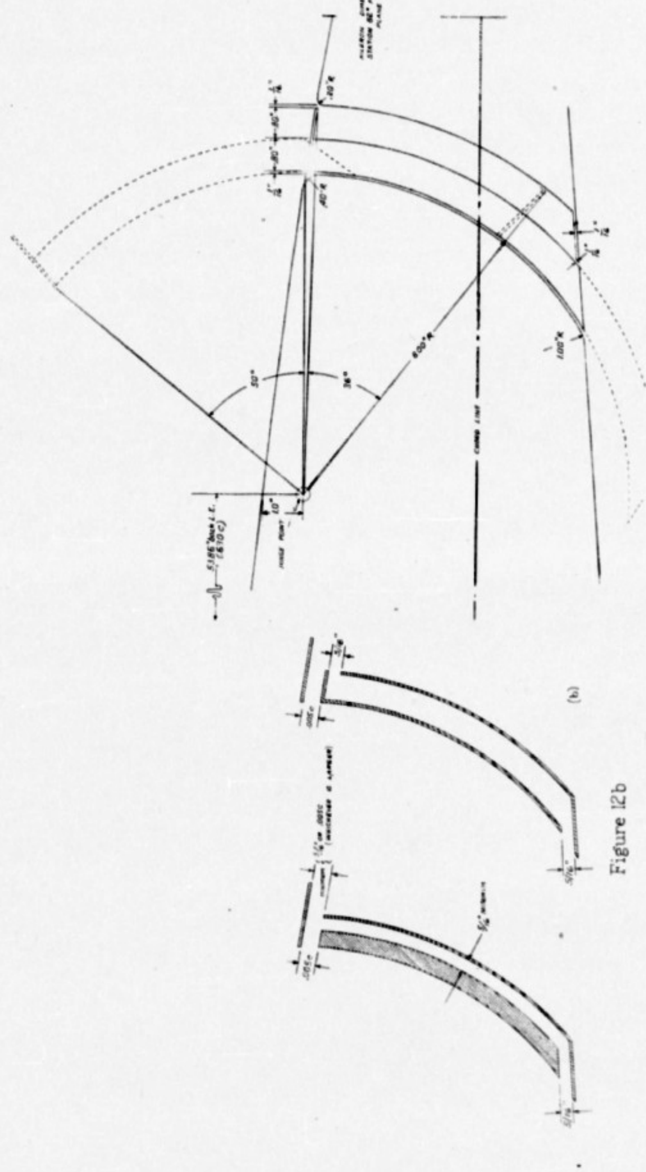

Figure 12b

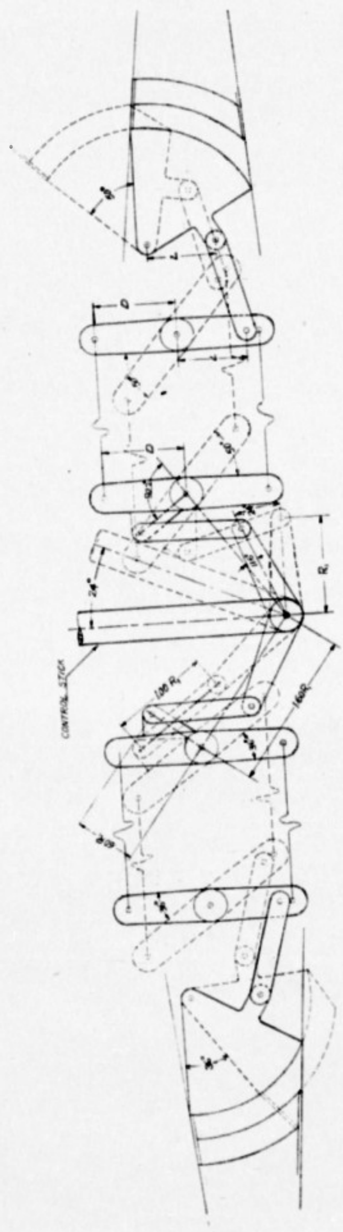

Figure 13.- Schematic diagram of spoiler-slot aileron control system for pursuit-type airplane.

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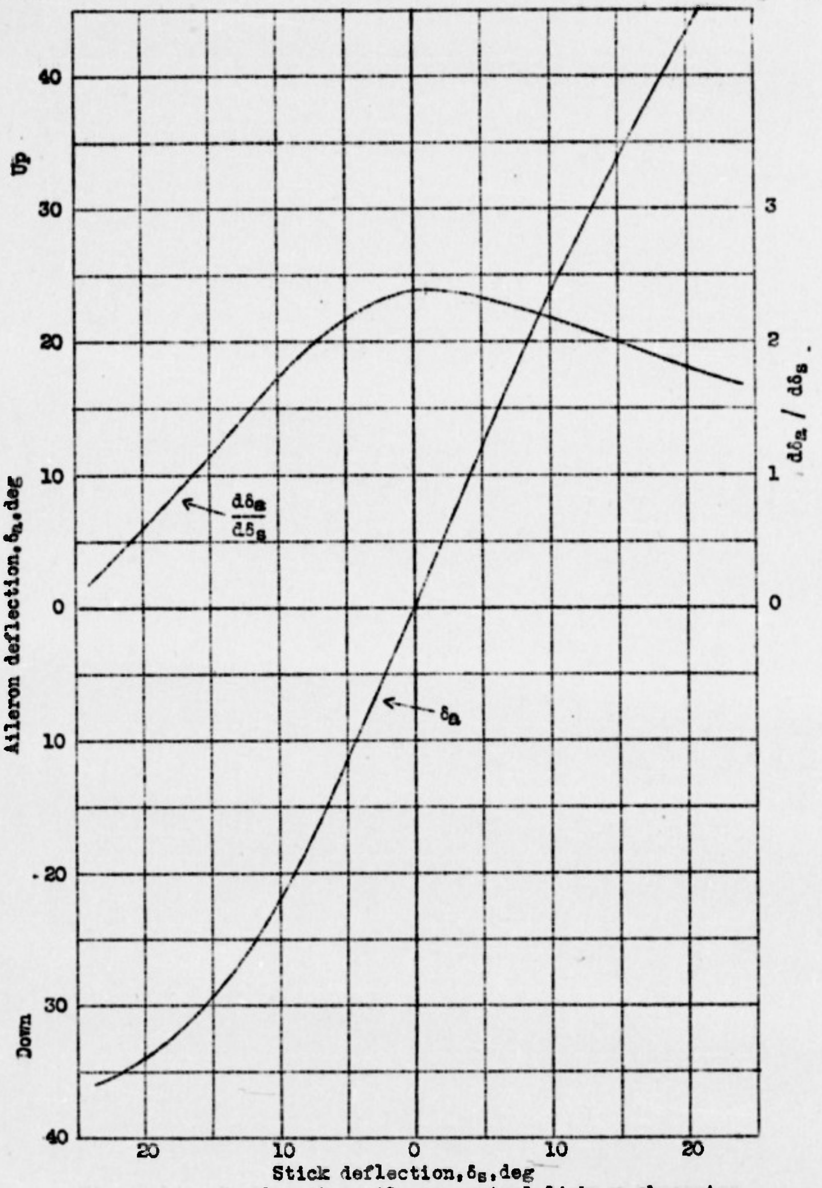
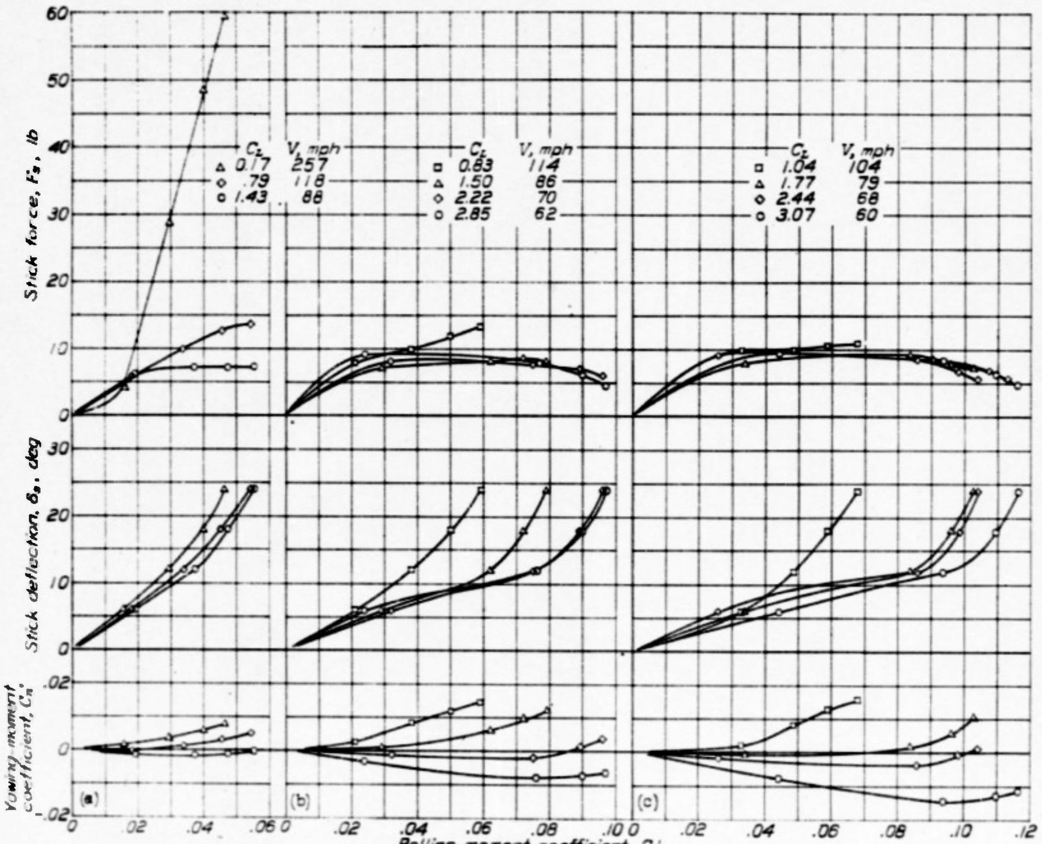


Figure 14.- Spoiler-slot aileron-control linkage characteristics for a pursuit-type airplane. Effective stick length, 21 inches; maximum stick deflection $\pm 24^{\circ}$.



(a) Flap neutral (b) Slotted flap extended 30° (c) Slotted flap extended 40°

Figure 15.- Estimated lateral-control characteristics of spoiler-slot ailerons on a pursuit-type airplane.

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TSDIN FORM 68 (13 MAR 47)

AUTHOR(S)		ATI- 6382
Rogallo, Francis Swanson, Robert	DIVISION: Aerodynamics (2) (1-(9) SECTION: Control Surfaces (3) (2) (6-7) CROSS REFERENCES: Ailerons, Spoiler -Slot - Aerodynamics (03242); Flaps, Slotted (37466); Control Lateral - Flap effectiveness (25489)	ORIG. AGENCY NUMBER ARR-L-420 REVISION

AMER. TITLE: Wind-tunnel development of a plug-type spoiler-slot aileron for a wing with a full-span slotted flap and a discussion of its application

FORG'N. TITLE: Slotted Flaps, Spoilers & Ailerons

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U.S.	Eng.		Unclass.	Nov'41	25	15	diagrs, graphs

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