COLLECTION OF TEST DATA FOR LATERAL CONTROL WITH FULL-SPAN FLAPS

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FOR REFERENCE

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Washington
April 1948
A collection of the available test data on lateral control with full-span flaps is presented. Lateral-control effectiveness and hinge-moment data obtained from two-dimensional, three-dimensional, and flight tests are presented in the form of figures and the data include the characteristics of spoiler devices and ailerons with retractable flaps. The basic data presented on the various flap and aileron combinations should facilitate the design of full-span-flap lateral-control arrangements. A discussion is given of the characteristics of the lateral-control devices considered and of the application of the data to specific airplane design.

INTRODUCTION

One of the problems arising from the increased speed and wing loading of modern airplanes is the difficulty of obtaining high lift for landing and take-off without impairing lateral control. If conventional aileron arrangements are used to satisfy the lateral-control requirements, the flap span is necessarily limited and the problem of obtaining the lift required for take-off or landing becomes quite important. When full-span flaps are used to obtain the desired lift coefficient for the airplane, the designer is faced with the problem of including and properly locating a lateral-control device on the airplane which will be effective in all flight configurations and have characteristics that will not be deleterious or objectionable.

The purpose of the present paper is to give the most pertinent part of the experimental data on the characteristics of lateral-control devices for use with full-span or almost full-span flaps. The data are, necessarily, greatly condensed and some data have been given in a form different from the original source. Additional information on any particular model may be obtained from the references. (See references 1 to 25 and table 1.)

Data on conventional balanced ailerons have been reported previously in reference 26, and a collection of fairly large-chord control-surface data has been given in reference 27.
CLASSIFICATION OF DATA

The data are divided into sections as follows:

A Slot-lip and flap-trailing-edge ailerons
B Spoiler-type ailerons other than slot-lip ailerons
C Ailerons with retractable flaps

The lateral-control arrangements for which data are presented may be considered to consist essentially of only two types — ailerons located at the wing trailing edge (conventional ailerons) and devices located forward of the trailing edge (commonly referred to as "spoiler ailerons") — but the division of the data into the three aforementioned groups has been made for convenience of presentation and is purely arbitrary.

In almost all instances, the aileron designation given to the lateral-control device in the reference paper has been used herein. The flap-trailing-edge ailerons of group A therefore are usually termed plain ailerons (regardless of balance) in the figures and in the text. The designation conventional, ordinary, or standard aileron employed in the figures of groups B and C and in the text refers to the more conventional arrangements in use today of an aileron on the wing trailing edge. This aileron usually spans the outboard part of the wing.

Much of the data presented in group C was obtained on models equipped with duplex flap arrangements (two separate flaps) and since the outboard flap of such arrangements would usually retract into the airfoil contour ahead of the aileron for the flaps-up configuration, the data are representative of retractable-flap aileron arrangements and may be applied in the design of such arrangements.

SYMBOLS

$C_L$  lift coefficient
$Cm_{c/4}$  pitching-moment coefficient about quarter chord of wing
$\Delta Cm_{c/h}$  increment of pitching-moment coefficient about quarter chord of wing
$\Delta C_D$  increment of drag coefficient
$C_{l''}$  rolling-moment coefficient about axis in plane of symmetry of complete model or airplane, referred to wind axes
$C_n'$ yawing-moment coefficient about axis in plane of symmetry of complete model or airplane, referred to wind axes

$C_h$ hinge-moment coefficient

\[ C_h = \frac{H}{q_o b_e \bar{a}^2} \] for plain and slot-lip ailerons and plate spoilers

\[ C_h = \frac{H}{q_o M} \] for plug ailerons where $M$ is area moment of top edge about hinge line

\[ C_h = \frac{H}{q_o R_m t b_s} \] for retractable ailerons

where

- $R_m$ mean radius of retractable aileron, feet
- $t$ thickness of retractable aileron, feet
- $b_s$ span of retractable aileron, feet

$C_{lp}$ rate of change of rolling-moment coefficient $C_n'$ with helix angle $\rho b/2V$

$c_l$ section lift coefficient

$\Delta c_l$ increment of section lift coefficient

$\Delta c_d$ increment of section profile-drag coefficient

$c_{mc/4}$ section pitching-moment coefficient about quarter chord of airfoil

$C_h$ section hinge-moment coefficient

\[ C_h = \frac{b_s}{q_o \bar{a}^2} \] for plain and slot-lip ailerons

\[ C_h = \frac{h}{q_o R_m t} \] for retractable ailerons

$P$ pressure coefficient \( \frac{p_1 - p_2}{q_o} \)

$(v/V)^2$ pressure coefficient \( 1 - P \)
wing chord; also used with subscripts to denote components of wing

c
chord of a control surface rearward of the hinge axis

\bar{c}
wing span; also used with subscripts to denote components of wing

b
angle of attack, degrees

\alpha
section angle of attack, degrees

\alpha_0
effective change in angle of attack, degrees

\Delta \alpha
deflection, degrees

\delta
angle of roll, degrees

\phi
aileron effectiveness factor, effective change in angle of attack of wing-aileron section per unit aileron deflection \( \Delta \alpha/\Delta \delta \)

k
aspect ratio

A
ratio of tip chord to root chord

\lambda
distance from plane of symmetry to inboard end of flap or lateral-control device, feet

\gamma_1
distance from plane of symmetry to outboard end of flap or lateral-control device, feet

\gamma_0
free-stream dynamic pressure, pounds per square foot

q
static pressure at a point on the airfoil, pounds per square foot

P_l
free-stream static pressure, pounds per square foot

P_o
ttrue airspeed, feet per second

V
service indicated airspeed, miles per hour

V_{ig}
local velocity, feet per second

v
rolling angular velocity, radians per second

p
yawing angular velocity, radians per second

r
\pi b/2V
helix angle generated by wing tip in a roll, radians
H hinge moment of a control surface about hinge axis, foot pounds
h section hinge moment of a control surface, foot pounds
F_s stick force, pounds
F_w wheel force, pounds
M Mach number
R Reynolds number
x/c distance from leading edge of wing to protruding edge of flat-plate spoiler-type ailerons or to chordwise position of emergence from wing of retractable and plug ailerons

Subscripts:
a aileron
f flap
f_1 inboard flap
f_2 outboard flap
w wing
sl slot lip
sp spoiler
p plain, plug, or plate
s stick
max maximum

Supplementary information and the test conditions for models and airplanes are given in Table I. This table also gives published references and serves as an index to the results presented, because the model or airplane designation is given in the first column of the table and in the upper right-hand corner of each page of model drawings or test results.
CORRECTIONS

The larger part of the data was plotted as taken from the source and the plotting scale for the data is necessarily nonuniform. The data obtained on models A-V and A-VI, B-VII, B-VIII, B-IX, B-XI, and B-XII, and C-III were corrected for jet-boundary effects according to the methods outlined in reference 28 and were plotted as corrected. A reduction of approximately 10 percent in the rolling-moment coefficients of model B-XV was estimated but not applied. Corrections to the data of model C-IV and C-V are unknown because of the uncertainty of end-plate effects. It is not known whether corrections were made to the data of model B-X. Some of the hinge-moment data was given in inch-pounds in the references but was reduced to coefficient form for the present paper.

DISCUSSION

All the lateral-control arrangements for which data are presented herein consist of either a conventional flap-type aileron, some device of the spoiler type, or a combination of both. (See table I and figs. A1 to A33, B1 to B133, and C1 to C49.) The characteristics of flap-type ailerons with flaps retracted, such as the flap-trailing-edge (plain) ailerons of group A and the ailerons of group C, were identical with the aileron characteristics of conventional arrangements and have been summarized previously (references 26 and 29). With full-span flaps deflected the characteristics of these ailerons differed from the characteristics of the ailerons in the flap-retracted condition and are discussed herein in the sections entitled "Slot-Lip and Flap-Trailing-Edge Ailerons" and "Ailerons with Retractable-Type Flaps".

Lateral-control devices located forward of the wing trailing edge are generally termed "spoilers" or "spoiler ailerons". There are four main types of spoiler ailerons — the retractable aileron, which consists of a circular-arc spoiler that usually emerges only from the upper surface of the wing; the plug aileron, which fits into a slot in the wing when in the neutral position and leaves this slot open when deflected upward; the hinged-flap-type spoiler aileron or upper-surface aileron, which lies along and forms part of the wing contour when in the neutral position; and the slot-lip aileron, which also lies along and forms part of the wing contour when in the neutral position and which has a fixed wing slot behind it.

Almost all spoiler-type devices have certain common characteristics that are dependent on the wing, aileron, and flap configuration. When spoilers were located near the wing leading edge, their effectiveness was roughly proportional to the lift coefficient; large rolling moments were provided at large angles of attack. As these devices were moved toward the wing trailing edge, the effectiveness became more nearly
independent of lift coefficient (remained almost constant or increased slightly at small angles of attack and decreased at large angles of attack) and became more nearly linear with respect to spoiler projection (figs. A7 to A10, A26, A27, and B18 to B20 and references 2, 8, and 30). Data obtained from both wind-tunnel and flight tests at low values of Mach and Reynolds numbers indicated that small spoiler deflections or projections (of the order of 0.01c or less) generally had little or no effect in producing roll when the wing was not slotted in the spoiler vicinity (figs. A12, B12 to B14, B32 to B39, B44 to B50, B95, B117, B118, and B123). Slotting the wing from the lower to the upper surfaces to the rear of the spoiler improved the rolling effectiveness, particularly at large angles of attack (figs. B44 to B47 and B95 and reference 10), and the linearity with respect to projection (fig. B95) with flaps retracted or deflected. Spoiler controls, especially those located far forward on the wing, were quite effective in the low-speed-flight range near and slightly beyond the stall, because of their pronounced effect in reducing lift or reducing the effective angle of attack over the wing section affected by their action.

Tests of spoiler ailerons at various chordwise locations indicated a perceptible time lag in the rolling response for forward spoiler locations and this time lag decreased as the spoiler was moved rearward. Slotting the wing behind the spoiler further reduced the lag in the response of the airplane to control deflection. At spoiler locations to the rear of about 0.60c, this time lag becomes imperceptible to pilots and hence unobjectionable at low and moderate values of Mach and Reynolds numbers (figs. B27, B28, B60, B82, B100, B112, B113, and B114, and references 2, 9, 14, 16, and 30). (The first part of the curve of the time-response figs. B27 and B28 is indicative of the lag whereas the last part of the curve is indicative of the steady state of roll.) In high-speed flight, time lag may not be noticeable for forward spoiler locations and the use of forward locations would provide increased aileron effectiveness; however, the possibility exists for reversal of effectiveness for small spoiler projections.

Spoilers provide less pitching moment than conventional ailerons (figs. B7, B10, B14, B19, B20, and B69 and reference 31) and hence would be expected to produce lower wing stresses and to have higher reversal speeds. In addition, spoilers provide favorable yawing moments over most of the flight range, except possibly at high angles of attack or lift, where the adverse yaw produced is less than that obtained with conventional ailerons.

The hinge-moment characteristics of spoilers are very unusual over the spoiler deflection range and require special treatment to provide acceptable control forces.

Since spoiler control is obtained through a loss of lift on one wing whereas almost no effect is produced on the other wing, some difficulty may be encountered in raising a wing that had dropped.
This problem is not serious, however, since the axis of rotation with spoiler control is seldom farther outboard than \(0.20\frac{b}{2}\) from the plane of symmetry.

**Slot-Lip and Flap-Trailing-Edge Ailerons**

The test conditions and the results of tests conducted on models and airplanes equipped with slot-lip and flap-trailing-edge ailerons and full-span flaps are given in table I-A and in figures A1 to A33. Data obtained in two-dimensional wind-tunnel tests are shown in figures A1 to A5, three-dimensional wind-tunnel test data are shown in figures A6 to A25, and flight data are presented in figures A26 to A33.

**Slot-lip ailerons**—Both wind-tunnel and flight tests of slot-lip ailerons at various chordwise positions have indicated that the most satisfactory position of the slot-lip aileron, from both aerodynamic and structural considerations, is between 0.7c and 0.8c. When slot-lip ailerons are used in conjunction with a slotted flap, a convenient arrangement having satisfactory characteristics consists of a slot-lip aileron located on the lip of the wing slot, ahead of the flap. Because of the physical impossibility of obtaining positive aileron deflections in this position with the flaps retracted, a high differential stick linkage (probably a cam) would be required in the control system.

Wind-tunnel and flight data also indicate that the effectiveness of slot-lip ailerons (figs. A1 to A33) increases with slotted-flap deflection and that these ailerons are very effective at large flap deflections; however, the ailerons are not very effective in the flaps-up condition. The data generally indicate a sharp increase in aileron effectiveness for small and moderate aileron deflections (flaps deflected) with a decreasing increment in effectiveness at larger deflections.

The hinge moments produced by slot-lip ailerons indicate an opening tendency of the aileron near neutral which, coupled with the large differential required, may cause overbalance of the controls. In the flight tests of slot-lip ailerons on a fighter-type airplane (figs. A28 to A33 and reference 5), a spring was introduced into the lateral-control system to counteract the overbalancing tendency of the ailerons. In general, if such adverse hinge-moment effects are encountered, balancing of the control surface or modification of the control linkage probably would result in satisfactory slot-lip-aileron control forces in all flight conditions. If slot-lip ailerons are used on extremely large airplanes, some aerodynamic balance would be required to reduce the large hinge moments at the large aileron deflections.

**Flap-trailing-edge ailerons**—When flap-trailing-edge (plain) ailerons were tested in the presence of full-span slotted flaps, the ailerons were necessarily only about 0.10c because of structural
considerations and had large spans in order to provide adequate effectiveness (figs. A1 to A33). In the flap-retracted position, the aileron is a narrow-chord long-span aileron. (See reference 26.) In flap-down operation, the aileron effectiveness decreased in the positive aileron-deflection range and generally increased slightly in the negative aileron-deflection range as the flap deflection increased (figs. A3, A5, A14, and A21). A change in the control linkage to provide a greater negative and smaller positive aileron deflection, and probably a greater total aileron deflection, therefore would be desirable to provide adequate lateral control for flap-down operation, if equal up and down deflections were used with flaps up.

The plain ailerons, flaps down, have about the same value for the rate of change of hinge-moment coefficient with aileron deflection as the ailerons with flaps retracted. Plain ailerons also have an upfloating tendency at aileron neutral, flaps deflected. This upfloating tendency, coupled with the differential required for good control, will help to reduce the stick forces but may cause overbalance if the differential for flaps down is too severe. The adverse yawing moments produced by aileron deflection, flaps deflected, were larger than those produced by other lateral controls.

**Slot-lip and flap-trailing-edge aileron combination.**— The characteristics exhibited by slot-lip and plain ailerons when each is used alone indicate that a lateral-control system consisting of both types of aileron—that is, plain ailerons for flaps-up operation, slot-lip ailerons for flaps-down operation—combines the best qualities of each type. This arrangement requires a mechanism that provides for changing from plain-aileron to slot-lip-aileron operation while extending the flap. Flight tests of such an installation on a fighter-type airplane indicated the adequacy of control provided by this arrangement, particularly in the low-speed range (figs. A28 to A33), and also indicated that some balancing of the ailerons is necessary to provide satisfactory stick-force characteristics over the complete flight range.

**Spoiler-Type Ailerons Other Than Slot-lip Ailerons**

Supplementary information and some of the results of various investigations on models equipped with spoiler-type ailerons are given in table I-1 and in figures B1 to B133, respectively. Two-dimensional wind-tunnel test data, three-dimensional wind-tunnel test data, and flight data are presented in figures B1 to B14, B15 to B78, and B79 to B133, respectively. Because data were not obtained at small aileron projections in the investigations of models B-II and B-VI, the curves for \( \Delta C_L \) and \( C_L \), respectively, of these models have been fared with dashed lines for these small projections to indicate the probable variations of \( \Delta C_L \) and \( C_L \) with projection. These data have been fared thus on the basis of data obtained at small projections in other investigations of similar lateral-control devices.
The spoiler-aileron usually projects above one wing and remains within the airfoil contour or projects slightly below the lower contour on the other wing when the control stick is displaced laterally. When spoilers and conventional ailerons are compared, the fact that the spoiler effectiveness on one wing is comparable to the aileron effectiveness on both wings should therefore be considered. For a given rolling performance the span of the spoiler must therefore be larger than that of a conventional aileron.

Although, as previously indicated, spoiler projections of the order of 0.01c or less produced little or no rolling moment at low Reynolds and Mach numbers, the effectiveness of spoiler controls located at approximately 0.6c or 0.7c usually increased rapidly for projections between 0.02c and 0.07c and increased less rapidly for larger projections. Spoiler data obtained on a low-drag wing at low lift coefficients indicated that an increased rolling moment was provided over the entire projection range and small spoiler projections became more effective as the Mach number increased until shock was obtained (figs. B68 and B69 and reference 13).

Retractable ailerons and hinged-plate-type spoiler ailerons located to the rear of approximately 0.5c were quite effective in the low angle-of-attack range, flaps up, but their effectiveness generally decreased at large angles of attack, probably as a result of flow separation ahead of the spoilers (fig. B11). As previously indicated, slotting the wing behind the spoilers (thus changing the retractable aileron to a plug-type aileron or ventilating the hinged-flap spoiler) improved the effectiveness in the high angle-of-attack range with flaps up (figs. B44 to B47 and B95 and reference 10). Spoiler ailerons generally were more effective with flaps down than in the flap-retracted condition and exhibited a greater effectiveness with slotted flaps than with split flaps (figs. B48 and B49).

The hinge-moment characteristics of spoiler-aileron generally tend to be somewhat erratic and quite unusual; that is, appreciable moments are provided by the plug-type and hinged-plate-type spoiler ailerons (figs. B30, B76, and B101) and little or no moments are provided by a thin retractable aileron hinged at the center of the spoiler arc (figs. B14, B130, B131, and B133 and references 15 and 16). An appreciable amount of control over the hinge moments, to provide acceptable control forces, can be obtained, however, by such spoiler modifications as varying the thickness of the retractable aileron or installing a plate (hinged or stationary) on top of and normal to the spoiler arc (figs. B33 and B44 to B50), venting or beveling the spoiler (figs. B12 to B14, B57 to B59, and B96), and providing other aero-dynamic balance (figs. B110 and B118). With either the hinged plate, the plug, or the thick retractable spoiler ailerons, opening moments were encountered near neutral—they are generally balanced in the negative pressure existing over the upper surface of the wing (figs. B65 and B66). This condition might be corrected by slotting, venting, or otherwise modifying the spoiler. Control "feel" of the type normally associated
Ailerons with Retractable-Type Flaps

The results of tests and the test conditions of models and airplanes with ailerons in the presence of retractable-type flaps are given in figures C1 to C49 and in table I-C. Three-dimensional wind-tunnel data are presented in figures C1 to C46 and flight data are presented in figures C47 to C49.

When ailerons in the presence of retractable-type flaps were used with duplex flap arrangements, the aileron characteristics obtained with the partial-span inboard flap deflected indicate a slight increase in rolling effectiveness for negative aileron deflections compared with that obtained with flap retracted and an increase in the variation of hinge-moment coefficient with aileron deflection (figs. C8, C9, C11, and C24). Because of the low speed in this attitude, the stick forces should not be critical.

The characteristics of ailerons in the presence of flaps spanning the same part of the wing as the ailerons are affected by the positions and deflections of these flaps and also by the contour of the flap. Wind-tunnel investigations indicated that deflecting a plain split flap in front of an aileron had a blanketing effect on the aileron and resulted in a decrease in rolling effectiveness as well as a decrease in the adverse yaw and the hinge moments (figs. C3 to C11 and C30 to C34). Various tests of balanced split or retractable-type flaps ahead of ailerons showed that this loss in rolling effectiveness decreased when the flap was moved downward away from the wing contour, and also rearward, so as to avoid complete blanketing of the aileron (figs. C15, C22 to C29, and C47 to C49). In general, however, the rolling effectiveness obtained with the outboard flap deflected and located forward of the aileron hinge line was less than that obtained with the flap retracted (figs. C23 and C27).

Locating the flap to the rear of the aileron hinge line and several percent chord below the wing contour increased the effectiveness above that obtained in the flap retracted condition; and the effectiveness of the upgoing aileron was particularly good when the flap was located near and slightly below the aileron trailing edge (figs. C1, C2, and C22 to C29). When the flap is located rearward of the aileron hinge line and in close proximity to the aileron, the positive aileron deflections should be restricted because of the deleterious effects (sudden loss in effectiveness and reversal of hinge-moment slope) obtained. (See reference 22.) This decreased deflection is compensated for in part by the increased effectiveness of the upgoing aileron (figs. C24 and C29 and reference 22). When the flap was moved rearward
and deflected, the lift characteristics improved considerably (references 21 and 22), particularly when the configuration of model C-VIII had the flap at the wing trailing edge. An indication of the flap loads on the outboard flap at various flap positions and deflections and at various aileron deflections is given in the pressure-distribution data obtained on model C-V (figs. C16 to C18).

When the flap was located and deflected forward of the aileron hinge and partlyblanketed the aileron, the aileron hinge moments indicated a down-floating tendency (figs. C6 to C11, C15, and C21), and this down-floating tendency decreased and became an up-floating tendency as the flap moved rearward (fig. C24 and references 21 and 22). The hinge-moment-coefficient deflection slope generally increased negatively with increased aileron effectiveness, flaps down, and particularly for positive aileron deflections.

The adverse yawing effect usually produced by conventional aileron arrangements was also evident when a flap was employed over the same span as the aileron. This adverse yaw was appreciable when the flap was located near the wing trailing edge and at high values of wing lift coefficient (figs. C24 and C29).

Application of Data to Specific Airplane Design

The data presented herein have not been correlated to provide design charts for full-span flap-ailerons installations, as they are intended primarily for illustrating the effects of full-span flaps on various lateral-control devices. Design charts for conventional ailerons, such as the plain ailerons of group A and the ailerons of group C, have been presented in references 29 and 32 to 35, and it is expected that full-span flaps would not prevent use of the charts in aileron design except for aileron effectiveness with flap deflected. When flaps are deflected, experimental data should be used.

Although no design charts have been presented specifically for spoiler-type controls, it is expected and unpublished data indicate that about the same relation exists for the effectiveness of spoiler-type controls as for conventional ailerons with respect to spanwise location of the control device. The values of aileron effectiveness at various spanwise locations given in references 32 and 34 are therefore considered to hold for spoiler ailerons.

In order to find the rolling moment produced by a control, the effective change in the angle of attack produced by a given control deflection (or projection for spoilers) must also be known. Conventional aileron design utilizes the aileron-effectiveness factor $k$ (or $\Delta\alpha/\Delta\delta$) multiplied by the control deflection $\delta$ to obtain the angle-of-attack change, but spoiler design cannot employ this simple method because spoiler effectiveness is a complex function of spoiler projection and angle of attack. A chart of effective change in angle
of attack $\Delta \alpha$ (or $k_6$) produced by various spoiler projections should therefore be utilized to obtain $\Delta \alpha$ and provide the rolling moment obtainable with the given control as shown in the following equation

$$\frac{C_L}{\Delta \alpha} = C_l$$

where 114.6 $\frac{C_L}{\Delta \alpha}$ equals the expression $C_{18}/k$ used in references 32 and 34. This procedure will ultimately give the rolling effectiveness $\frac{p_b}{2V}$ of the control by the relation

$$\frac{p_b}{2V} = \frac{C_l}{C_{18}}.$$

The value of $C_{18}$ employed is the same as that for an aileron spanning the same part of the wing as the spoiler in question, since $C_{18}$ is expected to be the same for spoilers and ailerons. In order to obtain the aforementioned values of $\Delta \alpha$ (or $k_6$) for a given spoiler-type control, the spoiler geometry, the chordwise location of the spoiler, and the wing profile must be considered as these all affect the values of $\Delta \alpha$.

With regard to spoiler-control stick forces, a number of general facts are known and have been discussed about the hinge moments of slot-lip, flat-plate, plug-type, and retractable-arc-type spoilers and the methods of balancing these control surfaces. Although no design charts exist for balancing these controls, the available spoiler data are considered fairly adequate for preliminary design and indicate possible modifications to obtain acceptable control forces.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 22, 1947
REFERENCES


Table I.- Supplementary Information Regarding Tests of Models and Airplanes Having Full-Span Flaps
A-Slot-Lip and Flap-Trailing-Edge Ailerons

<table>
<thead>
<tr>
<th>Model or Airplane Designation</th>
<th>Plane form of surface</th>
<th>Typical aileron section</th>
<th>Airfoil section</th>
<th>A</th>
<th>Airfoil location and chord</th>
<th>Flap location and chord</th>
<th>Type of test</th>
<th>Air flow characteristics</th>
<th>Published reference</th>
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<td>A-I</td>
<td></td>
<td>NACA 23012</td>
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<td>0.10</td>
<td>0.10</td>
<td></td>
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<td>0.10</td>
<td></td>
<td>Two dimensional</td>
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<td>Clark Y</td>
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<td>0.63</td>
<td>1.00</td>
<td>0.727</td>
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Table I.- Supplementary Information Regarding Tests of Models and Airplanes Having Full-Span Flaps—Continued

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Figure A7.- Effect of slot-tip-aileron deflection on the section aerodynamic characteristics of an NACA 23012 airfoil equipped with a full-span slotted flap.

(a) $\varphi = 0^\circ$

(b) $\varphi = 20^\circ$

Figure A7.- Continued.
Figure A2. Effect of plain aileron deflection on the section aerodynamic characteristics of an NACA 23012 airfoil equipped with a full-span slotted flap.
(a) \( \alpha_0 = 30^\circ \)

Figure A3.- Continued.

(b) \( \alpha_0 = 45^\circ \)

Figure A3.- Concluded.
Figure A4. - Plan form and sections of an NACA 66,2-015, $\alpha = 0.6$ airfoil with a slotted and plain flap as tested in Langley two-dimensional low-turbulence tunnel.

Figure A5. - Effect of plain flap deflection on the lift characteristics of an NACA 66,2-015, $\alpha = 0.6$ airfoil with 0.3c slotted and 0.1c plain flap.
Figure A5. - Continued.
Figure A5. - Plan form and sections of the Clark Y wing tested with slot-lip ailerons and full-span split flaps in the Langley 7'-by 10'-foot tunnel.
Figure A7.- Rolling-moment and yawing-moment coefficients of the Clark Y wing due to six-in ailerons at 45°.

(a) $\delta_x = 0^\circ$.

(b) $\delta_x = 60^\circ$.

Figure A7.- Concluded.
Figure AB.-- Rolling-moment and yawing-moment coefficients of the Clark Y wing due to slot-tip ailerons at 0.30c.
Figure A9. Rolling- and yawing-moment coefficients of the Clark Y wing due to side-tip ailerons at 0.55c.
Figure A10. Rolling- and yawing-moment coefficients of the Clark Y wing due to slot-tip ailerons at 0.55c with a special slot.
Figure A11.- Plan view and section of the 10" by 30-inch NACA 8010 wing tested with a full-span slotted flap and a slot-tip aileron in the Langley 7' by 10-foot tunnel.
Figure A12.- Rolling-, yawing-, and hinge-moment characteristics of the 10- by 60-inch wing equipped with full-span slotted flaps and a slot-tip aileron.
Figure A13: Diagram of test setup and a section of the 4- by 8-foot NACA 23012 semispan wing tested with a 0.150-in full-span slotted flap and 0.125 by 0.375 in/8 slot-lip and plain ailerons in the Langley 7- by 10-foot tunnel.

Figure A14: Effect of plan-ailerons deflection on the aerodynamic characteristics of the 4- by 8-foot NACA 23012 semispan wing equipped with a 0.350-in full-span slotted flap and 0.125 by 0.375 in/8 slot-lip and plain ailerons. $C_{L}$ vs $\delta_{a}$.
Figure A34. - Continued.
Figure A15.- Effect of slot-tip-aileron deflection on the aerodynamic characteristics of the 4-by-5-foot NACA 2303 semi-span wing equipped with a 0.2366c full-span slotted flap and 0.13c by 0.27 by 3 slot-tip and plain ailerons. $\delta_{y,0} = 0^\circ$. 

(a) $\delta_{y,0} = 0^\circ$. 

(b) $\delta_{y,20^\circ}$.
\( \delta_f = 50^{\circ} \); flap nose located 0.0025c ahead of lip and 0.015c below lip.

*Figure A15. Continued.*
Figure A.15. Plan form and sections of the 4- by 8-foot NACA 23012 semispan wing equipped with 0.39 b/2 modified split flap outboard and a 0.63 b/2 Fowler flap inboard with 0.37 b/2 sealed slot-tip and plain aileron. Tested in the Langley 7- by 10-foot wind tunnel.

Figure A.17. Effect of sealed-plain-aileron deflection on the aerodynamic characteristics of the NACA 23012 wing.
(b) $\alpha_1, 40^\circ; \delta_a, 0^\circ$.

Figure A17.- Continued.

(c) $\alpha_1, 40^\circ; \delta_a, 25^\circ$.

Figure A17.- Concluded.
Figure A18a: Effect of sealed slot-lip-aileror deflection on the aerodynamic characteristics of the NACA 23015 wing.

Figure A18b: Concluded.
Figure A20. - Sectional view of the wing showing the slotted flap and plain and slot-tip ailerons.

Figure A21. - Effect of plain aileron deflection on the yawing- and rolling-moment coefficients of the model of a fighter-type airplane. \( \theta_{a1} \), \( \theta_{a2} \) (right), \( \theta_{a1} \) (left).
Figure A21. - Continued.
Figure A23.— Effect of total aileron deflection on rolling-moment coefficients of the 1/8-scale model of a fighter-type airplane. $C_{\alpha}$, $\alpha$ (deg); $C_{t}$ for aileron-stick differential.)
Figure A34.- Variation of stick position with slot-tip aileron deflection for the Fairchild 22 airplane.

Figure A33.- Plan form of semispan wing and profile of wing sections of the Fairchild 22 airplane tested with slot-tip ailerons and full-span split flaps in the Langley full-scale tunnel and in flight.

Figure A35.- Increase in drag due to slot-tip ailerons on the Fairchild 22 airplane in the Langley full-scale tunnel. Airspeed, 98 miles per hour.
Figure 403.- Variation of maximum rolling angular velocity with aileron deflection for a 600 ft./sec. run on the Fairchild 22 airplane in flight.

(a) Slot-up ailerons at 0.30c.

(b) Slot-up ailerons at 0.45c.
Figure A38. Plan form and section of the wing of a fighter-type airplane tested in flight at Langley with full-span slotted flaps, internally balanced trailing-edge ailerons, and slot-tip ailerons.

Figure A39. Relation between trailing-edge and slot-tip-ailerone deflections and stick position. Stick length, 19.0 inches.
Figure A31. - Variation of wing-tip helix angle (ph/IV) with aileron deflection. Internally-balanced flap trailing-edge ailerons deflected; slot-tip ailerons neutral; level-flight power.

Figure A32. - Variation of aileron deflection, effectiveness, and stick force with airspeed for full stick throw or 35-pound stick force. Internally balanced flap trailing-edge ailerons deflected; slot-tip ailerons neutral; level-flight power.
Figure A33. - Variation of wing-tip helix angle (phi/CV) and stick force with deflection of upper slot-tip aileron; flap trailing-edge aileron neutral; level-flight power.

(a) Flap selector setting, 20°.

(b) Flap selector setting, 30°.

Figure A33. - Continued.
(c) Flap selector setting, 45°.

Figure A33—Continued.

(d) Flap selector setting, 50°.

Figure A33—Concluded.
Figure B1. Plan form and section of the Clark Y airfoil tested in the Langley 7-by 10-foot tunnel.

Figure B2. Section of unbalanced upper-surface aileron and unbalanced split flap and section of balanced upper-surface aileron and balanced split flap with A, aileron axes; and C, flap axes tested.
Figure 93a. Characteristics of the unbalanced upper-surface aileron on the Clark Y airfoil.

Figure 93b. Continued.
Figure 14A - Characteristics of the balanced upper-surface aileron at station A12 on the Clark Y airfoil.

(a) Flap neutral.

(b) Flap down 60° at station A12.

Figure 14B - Concluded.
Figure 65. Characteristics of the balanced upper-surface aileron at axis A-B on the Clark Y airfoil.

(a) Flap neutral.

(b) Flap down 75° at axis FB.

Figure 66. Concluded.
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Figure B7.- Section pitching-moment characteristics of the NACA 23012 airfoil due to various aileron projections.

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Figure 18d. Continued.
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Figure B14a. Continued.

Figure B14b. Continued.

(b) $\alpha_p: \omega^\circ$.

(c) $\alpha_p: \omega^\circ$.

Figure B14c. Continued.
(a) 0.25c flap and aileron.

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Figure B15.—Plan form and sections of the 13- by 60-inch Clark Y wing with upper-surface ailerons and full-span split flaps. Tested in the Langley 7- by 10-foot wind tunnel.

(b) 0.15c flap and aileron.

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Figure B15.—Concluded.
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(b) Upper spoiler projection.

Figure 334. - Continued.

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(a) Lower spoiler projection.

(c) Upper and lower spoiler projection.

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(Wing restrained in roll by means of a spring.)
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(b) $\alpha = 0^\circ$.

Figure B11.- Concluded.
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Figure 353.- Aileron characteristics of a retractable aileron on a Clark Y-15 wing with a 0.26c full-span split flap.

(a) Flap removed.

(b) $\theta = 0^\circ$.

Figure 353.- Concluded.
Figure 354. - Concluded
Figure B35. - Allercon characteristics of a 0.10c deflector hinged at 0.50c on an NACA 23012 wing with a 0.3060c full-span slotted flap.

Figure B35.- Continued.
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Figure IXb.- Concluded.
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(a) $C_D = 0.6$

(b) $C_D = 4.0$

Figure 137. - Concluded.
Figure 8.4a. - Aileron characteristics of a 0.12c deflector hinged at 0.30c and a retractable aileron on an NACA 23015 wing with a 0.256c full-span slotted flap, projection ratio of aileron to deflector, 1:1.

Figure 8.4b. - Concluded.
Figure 532. - Alleran characteristic of a 0.30c spoiler and a 0.25c deflector with a slit on an NACA 3015 wing with a 0.665c full-span slotted flap, spoiler slotted at 0.25c, deflector slotted at 0.40c; projection ratio of spoiler to deflector, 1/1.

(a) $\alpha = 0^\circ$.

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(a) Flap up: \( n = 0 \); \( c_{L} = 0.17 \).

Figure 94.- Concluded.
Figure B45. - Aileron characteristics of a 0.37 b/s plug-type aileron on an NACA 3313 wing with a 0.2656c full-span slotted flap. Width of spoiler face, 0.035c.

(a) Flap neutral; \( \alpha = 0 \); \( C_L = 0.77 \).

(b) Flap deflected 40\(^\circ\); \( \alpha = 13.2^\circ \); \( C_L = 2.36 \).

Figure B45. - Concluded.
Figure 147.- Aileron characteristics of a 0.37 b/s plug-type aileron on an NACA 23012 wing with a 0.250c full-span slotted flap. Width of slotted face, 0.060c.

(a) Flap neutral; a, 0.00; C_{L} = 0.77.

(b) Flap deflected 45°; a, 13.5°; C_{L} = 2.36.

Figure 147.- Concluded.
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(a) Flap neutral.

(b) Flap deflected 40°.

Figure 150.- Continued.
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(b) Flap deflected 20°.
Figure 155.- Continued.

(c) Flap deflected 40°.
Figure 156.- Concluded.
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(a) α = 0°; C_{L} = 1.20.

(b) α = 14.1°; C_{L} = 2.31.

Figure 386.- Concluded.
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Figure 257.- Concluded.
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Figure 38b. Concluded.
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- Figure 31(b). - Continued.
Figure 8o: Rolling, yawing, and hinge-moment coefficients due to aileron deflection at various plate angles for the tapered-wing model with a full-span flap and plug aileron; $\alpha = 0\deg$.

(a) $\alpha = 0\deg$; $C_L = 0.10$.

(b) $\alpha = 13\deg$; $C_L = 1.05$.

Figure B90: Concluded.
Figure 21. - Rolling-, yawing-, and hinge-moment coefficients due to aileron deflection at various \( \alpha \) and \( \delta \) for the tapered-wing model with a full-span flap and plug aileron; \( \delta_p \), 0°.
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(a) $\alpha = -90^\circ$

(b) $\alpha = -40^\circ$

Figure 66b. - Continued.
\( \alpha \) (deg)  
- Outside plug  
- Inside plug  
- Between plug and plate 1

\( \alpha \) (deg)  
- Outside plug  
- Inside plug  
- Between plug and plate 1

Figure 1965: Continued.
Figure 104. - Pressure distribution on plug aileron b on the tapered-wing model with a full-span slotted flaps at $\alpha = 30^\circ$.

(a) $\alpha = 30^\circ$.

(b) $\alpha = 60^\circ$.
\[ \alpha \text{ (deg)} \]

- Outside plug
- Inside plug
- Between plug and plate 1

\[ \alpha \text{ (deg)} \]

- 0.8
- 14.1

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Figure 106C - Cont'd.
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Figure 107.- Concluded.
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(a) $\alpha_1 = 0$°

(b) $\alpha_1 = 30.5$°
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--- Force required to slowly increase aileron angle
-Approximate mean force required to deflect aileron

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Wing area, $S$, sq ft
Aspect ratio, $A$
Taper ratio, $\lambda$
Wing section, root
Wing section, tip

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Figure B101.— Continued.
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(a) Flaps up.

Figure B305.- Concluded.

(b) Flaps down.

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(a) Rated power.

(b) Power off.

Figure B115a. - Concluded.
(a) Rated power.

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(b) Power off.

Figure B117.- Concluded.
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(b) Flaps down, 122 miles per hour.

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(a) Revised ailerons I

(b) Revised ailerons II
(a) Revised ailerons I.
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(b) Revised ailerons II.
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(a) Revised ailerons I.
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(b) Revised ailerons II.
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(Spoilers and ailerons deflected.)

Figure B127. Concluded.

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Figure B117: Variation of left aileron hinge moment with aileron angle. Climb condition (power on, flaps up).

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Figure B122: Variation of right spoiler hinge moment with spoiler angle. Wave-off condition (power on, flaps down).

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Figure C3, Continued.

Figure C3, Concluded.
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Figure C4. - The 5:1 tapered NACA 23012 wing with a 0.15c by 0.60 h/2 plain aileron and full-span 0.10c split flaps at 0.25c. Tested in the Langley 7- by 10-foot tunnel.
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(a) Flap neutral.

(b) Flap deflection, 60°.

Figure C5. - Concluded.
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(a) Flap neutral.

(b) Flap 60°.
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Figure C6. Continued.
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retractable plain split flap (f2).

Figure C9 - Continued.
(c) $\delta_{a_1} = 40^\circ$; $\delta_{a_2} = 0^\circ$.

Figure C9.- Continued.

(d) $\delta_{a_1} = 40^\circ$; $\delta_{a_2} = 60^\circ$.

Figure C9.- Concluded.
Figure C10. - Concluded.

(a) $\delta_1 = 40^\circ$; $\delta_3 = 60^\circ$.

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Model C-II
(a) $\delta_{A_x}, 0^\circ; \delta_{A_y}, 0^\circ$.

Figure C11.- Aerodynamic characteristics of a 0.15c by 0.37 b/l sealed aileron with 0.25c, balance on an NACA 2315 wing with a 0.33c by 0.33 b/l inboard Fowler flap ($\delta_f$) and a 0.23c by 0.37 b/l outboard retractable balanced split flap ($\delta_g$).

(b) $\delta_{A_x}, 40^\circ; \delta_{A_y}, 0^\circ$.

Figure C11.- Continued.
Figure C11 - Continued.
Figure C12. Plan form of semispan rectangular wing model equipped with duplex flaps. Model tested in Ames 7 by 10-foot tunnel.

Figure C13. Cut-away view of the 0.30c by 0.665 h/2 inboard Fowler flap on the rectangular wing model.

Figure C14. Cut-away view of the 0.15c by 0.411 h/2 outboard sealed-gap ailerons and retractable balanced split flap on the rectangular wing model.
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b) Inboard Fowler flap 45°; outboard flap retracted.
(c) Inboard Fowler flap 40°; outboard flap 40° with a gap of 0.04c at hinge line.

Figure C15.- Continued.

(d) Inboard Fowler flap 40°; outboard flap 40° with a gap of 0.07c at hinge line.

Figure C15.- Concluded.
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Figure C18.- Variation of chordwise pressure coefficient with percent flap chord over the outboard balanced split flap on the rectangular wing model. \( \alpha = 15^\circ \).
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Figure 35b. - Continued.
(c) $\alpha_1$, $\alpha_2$, $\alpha_3$ at position 5 with 0.006c gap.
Figure C24.- Continued.

(d) $\alpha_1$, $\alpha_2$, $\alpha_3$ at position 7 with 0.006c gap.
Figure C24.- Concluded.
The form of the 34-scale model of a tapered semispan wing tested with a full-span flaps and a full-span aileron in the Langley 7- by 10-foot tunnel.

Figure C58. - Sections of the wing showing the 0.0365 aileron with 0.250 in. internal balance and the retractable flap.
Figure C87. - Values of rolling-moment coefficient due to aileron deflections of \( \pm 15^\circ \) at various flap-open positions and flap deflections. Tapered wing model with a full-span flap and a full-span aileron with \( 0.30 \alpha_0 \) internal balance.
(a) Flap retracted. Figure C.1B.- Rolling-, yawing-, and hinge-moment coefficients of the tapered wing model with a full-span flap and a full-span aileron with 0.50 of internal balance. (See fig. C.3 for flap-nose position.)

(b) Flap-nose position, $F = 8$; $e_{y} = 15^\circ$. Figure C.2B.- Continued.
Figure C39. Rolling-, yawing-, and hinge-moment coefficients of the tapered wing model with a full-span flap and a full-span aileron with 0.56c₀ internal balance. Flap-nose position L = L; \( \delta_{fl} = 30^\circ \). (See fig. C27 for flap-nose position.)
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Figure CM.— Variation of rolling-, yawing-, and hinge-moment coefficients with right aileron deflection on the model of a fighter-type airplane.
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Figure C36. - Typical section through the outboard flap and aileron on the wing of the model of a bomber-type airplane.
Figure C37 - Effect of right aileron deflection on the rolling and yawing moment characteristics of the model of a bomber-type airplane landing position. $\alpha$, $\Psi$, $\phi = 0$.

(a) $\delta_3 = 40^\circ$.

(b) $\delta_3 = 45^\circ$; $\delta_2 = 40^\circ$.

Figure C37. - Concluded.
### Fowler-type flap

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<tr>
<td>0.92900095</td>
<td>0.90502540172</td>
</tr>
</tbody>
</table>

X, Y, and C_\text{f} are given in percent of c, wing chord at mean station of flap.

(a) Cross section of the Fowler-type flap.

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### Cross section and dimensions of sealed aileron and balanced split flap

- Hinge line
- Chord line
- 0° Position
- 5° Position

C_g = 0.30 c
C_g = 0.152 c
C_g = 0.04 c
C_g = 0.02 c
C_g = 0.08 c
C_g = 0.07 c

(b) Cross section and dimensions of sealed aileron and balanced split flap.

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Figure C26.- Typical cross sections of the wing showing the Fowler-type flap and the sealed aileron with a balanced split-flap on the 1/8-scale model.
Figure 24: Variation of the rolling and yawing-moment coefficients with aileron deflection on the half-scale model.

Figure 24a: continued.
Figure C41. - Plan form of the semi-span wing of a 1/6-scale model of a torpedo-bomber-type airplane tested in the Langley 7- by 10-foot tunnel.

Figure C42. - Sections of the wing at the aileron section, showing the aileron and the outboard flap in the extended position.
(a) $\alpha$, 0°; $\delta_a$, 0°.

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The data on rolling-, yawing-, and hinge-moment coefficients with right aileron, 60°, 45°, and 30°
$
\frac{1}{2}$-scale model airplane.

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Figure C1b - Concluded.
Figure C4A.- Plan form of the \( \frac{1}{3} \)-scale model of the torpedo bomber-type airplane tested in the Langley 10-foot tunnel.

Figure C4B.- Aileron sections of the \( \frac{1}{3} \)-scale model.
Figure C36.—Concluded.
Figure C47.—Plan form of the semispan wing of a personal-type airplane with fixed and balanced split flaps as tested in flight at Langley.

(a) Aileron alone (flap retracted).

(c) Flap fully extended, 0.02\(c\) gap.

(b) Flap partially retracted.

(d) Flap fully extended, 0.04\(c\) gap.

Figure C48.—Sections of internally balanced aileron and balanced split-flap arrangement as tested on a personal-type airplane.
Figure C49.- Variation of helix angle \( \phi \) with change in deflection for a personal-type airplane.