CHAPTER 8
HIGH-LIFT DEVICES

8.1. Symbols.

\( C_D \)  drag coefficient
\( C_{D_{min}} \)  minimum lift coefficient
\( C_{L_{max}} \)  maximum lift coefficient
\( \Delta C_{L_{max}} \)  increment of maximum lift coefficient
\( C_N \)  normal-force coefficient
\( C_{N_f} \)  flap normal-force coefficient based on the area of the flap
\( C_Q \)  volume-flow coefficient, \( Q/VS \)
\( E \)  flap-chord ratio, \( c_f/c \)
\( G \)  moment arm, in terms of the chord, of the basic normal force about the quarter-chord point
\( M \)  Mach number
\( P_{05} \)  incremental additional load distribution associated with flap deflection
\( P_{03} \)  incremental basic load distribution associated with flap deflection
\( P_3 \)  incremental load distribution associated with flap deflection
\( Q \)  volume of flow through slot
\( R \)  Reynolds number, \( \rho V_c/\mu \)
\( S \)  wing area
\( V \)  velocity of the free stream
\( c \)  chord
\( c_d \)  section drag coefficient
\( c_f \)  flap chord
\( c_h \)  section flap hinge-moment coefficient, \( h/\sqrt{\rho V^2 c_f} \)
\( c_i \)  section lift coefficient
\( c_{i_f} \)  section flap lift coefficient, \( l_f/\sqrt{\rho V^2 c_f} \)
\( c_{t_{max}} \)  maximum section lift coefficient
\( \Delta c_{t_{max}} \)  increment of maximum section lift coefficient
\( c_m \)  section pitching-moment coefficient, \( m/\sqrt{\rho V^2 c^2} \)
\( c_{m_1} \)  section pitching-moment coefficient about the quarter-chord point
\( c_{m_1} \)  section pitching-moment coefficient about the quarter-chord point with flap neutral
\( c_{m_2} \)  section pitching-moment coefficient about the quarter-chord point with flap deflected
\( \Delta c_m \)  incremental section pitching-moment coefficient about the quarter-chord point
\( c_{n_1} \)  section normal-force coefficient with flap neutral
\( c_{n_2} \)  section normal-force coefficient with flap deflected
\( c_{n_3} \)  incremental additional normal-force coefficient associated with flap deflection
\( c_{n_5} \)  incremental basic normal-force coefficient associated with flap deflection
\( c_{n_7} \)  incremental flap normal-force coefficient
\( \Delta c_n \)  incremental section normal-force coefficient
\( (cp)_f \)  center of pressure of the load on a flap measured from the leading edge of the flap
\( h \)  section flap hinge-moment coefficient (positive in direction of positive flap deflection)
$l_f$ lift force acting on the flap per unit span

$m$ section pitching moment

$n_{f_{\perp}}$ incremental flap normal force per unit span

$q$ dynamic pressure, $\frac{1}{2} \rho V^2$

$r$ leading-edge radius

$t$ thickness of wing section

$v$ local velocity over the surface of a symmetrical section at zero lift

$\Delta \alpha_\delta$ increment of local velocity over the surface of a wing section associated with angle of attack

$x$ distance parallel to chord

$y$ distance normal to chord

$\alpha$ angle of attack

$\alpha_0$ section angle of attack

$\Delta \alpha_0$ increment of section angle of zero lift

$\gamma_{f_{\perp}}, \gamma_\delta$ ratios of the flap normal force to the section normal force for the incremental additional and the incremental basic normal forces

$\delta$ flap deflection

$\delta_{f_{\perp}}$ deflection of fore flap or vane

$\delta_f$, deflection of main flap of a double-slotted flap configuration

$\Delta \delta$ increment of flap deflection

$\rho$ mass density of air

$\tau$ turbulence factor, effective Reynolds number/test Reynolds number

$\tau_n, \tau_m$ see Eq. (8.8)

### 8.2. Introduction

The auxiliary devices discussed in this chapter are essentially movable elements that permit the pilot to change the geometry and aerodynamic characteristics of the wing sections to control the motion of the airplane or to improve the performance in some desired manner. The desire to improve performance by increasing the wing loading while maintaining acceptable landing and take-off speeds led to the development of retractable devices to improve the maximum lift coefficients of wings without changing the characteristics for the cruising and high-speed flight conditions. Some typical high-lift devices are illustrated in Fig. 95. The aerodynamic characteristics of some typical high-lift devices are presented and discussed in the following sections. Primary emphasis is given to the capabilities and relative merits
of the various devices. Numerous references to the literature are given to provide design information.

![Diagram of section flap effectiveness with flap chord ratio for true-airfoil-contour flaps without exposed overhang balance on a number of airfoil sections; gaps sealed; $c_1 = 0$.](image)

Fig. 96. Variation of section flap effectiveness with flap chord ratio for true-airfoil-contour flaps without exposed overhang balance on a number of airfoil sections; gaps sealed; $c_1 = 0$.

8.3. Plain Flaps. Plain trailing-edge flaps are formed by hinging the rearmost part of the wing section about a point within the contour. Downward deflections of the trailing edge are called "positive-flap deflections." Deflection of a plain flap with no gap effectively changes the camber of the wing section, and some of the resulting changes of the aerodynamic charac-
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Basic airfoil</th>
<th>Type of flap</th>
<th>Air-flow characteristics</th>
</tr>
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<td></td>
<td>NACA 0009</td>
<td>Plain</td>
<td>τ: 1.93, M: 0.08, R: ...</td>
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<td></td>
<td>NACA 66(2x15)-009</td>
<td>Plain, straight contour</td>
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</table>

(c) Supplementary information.

Fig. 96. (Concluded)

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characteristics may be calculated from the theory of thin wing sections (Chap. 4) if the flow does not separate from the surface. For most commonly used wing sections, this condition is satisfied reasonably well for flap deflections of not over 10 to 15 degrees. The theory permits calculation of the angle of zero lift, the pitching-moment coefficient, and the chordwise load distribution with reasonable accuracy. The flap loads and hinge moments may also be obtained, but the accuracy of these quantities is relatively poor because the effects of viscosity are particularly pronounced over the aft portion of the section. The effectiveness of the flap in increasing the maximum lift coefficient cannot be calculated.

Glauert\textsuperscript{36} calculated the effect of plain flaps in changing the angle of zero lift, the pitching moment, and the flap hinge moments. The calculated effect of flap deflection on the angle of zero lift is shown in Fig. 96, where the flap effectiveness \( \Delta \alpha_0 / \Delta \delta \) is plotted against the ratio of the flap chord to the section chord \( c_f / c \). Numerous experimental points are also shown for flap deflections of 0 to 10 degrees and 0 to 20 degrees. In general, the flap effectiveness is less than that indicated by the theory, and the discrepancy increases with increased flap deflection for small chord flaps. The calculated effectiveness of a plain flap in changing the section pitching-moment coefficient about the quarter-chord point \( d_{cm} / d \delta \) is shown in Fig. 97. The calculated values of the rate of change of hinge moment with lift coefficient \( dc_h / dc_l \) and the rate of change of hinge moment with flap deflection \( d_{ch} / d \delta \) are also shown in Fig. 97. For symmetrical wing sections, the theoretical pitching-moment and hinge-moment coefficients are

\[
c_m = \delta \left( \frac{d_{cm}}{d \delta} \right)
\]

\[
c_h = c_l \left( \frac{d_{ch}}{dc_l} \right) + \delta \left( \frac{d_{ch}}{d \delta} \right)
\]

The linearity of the theory of thin wing sections permits the application of the values obtained from Figs. 96 and 97 to cambered as well as symmetrical sections. In the case of cambered sections, these values are applied as increments to the corresponding values for the unflapped section.
Pinkerton calculated the flap loads that are presented in Fig. 98. The rate of change of the flap lift coefficient with the section lift coefficient $dc_{l_f}/dc_{l}$ and with flap deflection $dc_{l_f}/d\delta$ are plotted against the ratio of flap chord to section chord.

![Diagram of flap lift coefficient and deflection](image)

**Fig. 98.** Theoretical variation of flap lift coefficient with section lift coefficient and flap deflection.

The pressure distribution over a wing section with a deflected plain flap may be calculated by the wing-section theory of Chap. 3, but such calculations for a number of flap deflections would be unduly laborious. Some knowledge of the chordwise load distribution is given by the theory of thin wing sections. The change of load distribution caused by flap deflection can be resolved into two components, one of which is simply the additional load distribution associated with angle of attack. The other component is the difference between the load distribution on the original and deflected mean lines at their respective ideal angles of attack. These load distribu-
tions may be calculated by the theory of thin wing sections (Chap. 4) as explained by Allen,\(^6\) but the results are not very accurate. For example, the simple theory predicts infinite load concentrations at the leading edge and hinge location. The infinite load concentration at the leading edge may be avoided by use of the additional types of load distribution associated with angle of attack as obtained from thick-wing-section theory and presented in Appendix I. Allen\(^6\) obtained empirical load distributions analogous to those associated with changes of the camber that permit calculation of reasonable approximations to the load distributions of flapped wing sections. Allen's method is presented in Sec. 8.8. Once the load distribution is obtained, the pressure distribution may be calculated by the method of Sec. 4.5. Some typical pressure distributions for sections with plain flaps\(^6\) are presented in Fig. 99.

The lift, drag, and moment characteristics of a typical NACA 6-series wing section with a 0.20c plain flap\(^8\) are presented in Fig. 100 for several flap deflections up to 60 degrees. These and other data\(^4\) show that the angle of maximum lift coefficient with the flap deflected is generally somewhat less than for the plain wing section. Curves of the maximum lift coefficient plotted against flap deflection for two sections\(^5\) are presented in Fig. 101. Plain flaps of 0.20c appear to be capable of producing increments of the section maximum lift coefficient ranging up to about 1.0 and are more effective when applied to sections with small amounts of camber. Additional data on plain flaps are presented by Jacobs,\(^4\) Abbott,\(^2\) and Wenzinger.\(^148, 149, 156\)
Fig. 100. Aerodynamic characteristics of the NACA 66(215)-216 airfoil section with 0.20c sealed plain flap.
Fig. 100. (Concluded)
When the turbulent boundary layer over the aft portion of the wing section is thin and resistant to separation (as when extensive laminar flow is obtained), small deflections of a plain flap do not cause separation but shift the range of lift coefficients for which low drag is obtained.\textsuperscript{3} If the extent of laminar flow is not large or if the flap deflection is sufficiently large to be of interest as a high-lift device, the flow over the flap separates and large drag increments result. A typical variation of drag with lift coefficient for the NACA 23012 wing section with a 0.20c plain flap deflected the optimum amount at each lift coefficient\textsuperscript{2} is shown in Fig. 102.

8.4. Split Flaps. The split flap is one of the simplest of the high-lift devices. The usual split flap is formed by deflecting the aft portion of the lower surface about a hinge point on the surface at the forward edge of the deflected portion (see Fig. 95). One variation of the simple split flap has the hinge point located forward of the deflected portion of the surface in
such a manner as to leave a gap between the deflected flap and the wing surface. In another variation the leading edge of the flap is moved aft as the flap is deflected, either with or without a gap between the flap and the wing surface. Split flaps derive their effectiveness from the large increase of camber produced and, in the case of some of the variations, from the effective increase of wing area.

![Graph](image)

**Fig. 102.** Comparison of profile-drag envelope polars for the NACA 23012 airfoil with 0.20c plain and split flaps.

The lift and moment characteristics for typical NACA 6-series wing sections with 0.20c split flaps deflected 0, 40, 50, 60, and 70 degrees are presented in Figs. 103 and 104. Similar data for a flap deflection of 60 degrees are presented for most of the wing sections of Appendix IV. The lift-curve slope with split flaps is higher and the angle of maximum lift is somewhat lower than for the plain section. There appears to be a tendency for the lift-curve slope for large flap deflections to be less than that for moderate deflections.

Inspection of Figs. 103 and 104 shows that the split flap is more effective in increasing the maximum lift coefficient when applied to the thick than when applied to the thin wing sections. Figure 58 shows that the maximum lift coefficients of NACA 6-series wing sections with 0.20c split flaps deflected 60 degrees increase with thickness ratio up to ratios of at least 18 per cent. Figure 58 shows comparatively little variation of maximum lift coefficient for NACA four-digit wing sections with 0.20c split flaps for thickness ratios greater than 12 per cent, but the maximum lift coefficient
Fig. 103. Lift and moment characteristics of the NACA 66(215)-216 airfoil section with 0.20c split flap. $R_e \approx 6 \times 10^6$. 
Fig. 104. Lift and moment characteristics of the NACA 65P-212 airfoil section with 0.20c split flap. $R, 6 \times 10^6$. 
decreases for smaller thickness ratios. These results are in essential agreement with those\textsuperscript{154} of Fig. 105, which shows that, for the NACA 230-series sections, the maximum lift coefficient generally increases with thickness ratio for large-chord split flaps but decreases for small-chord flaps.

![Graph](image)

Fig. 105. Effect of airfoil thickness on maximum lift coefficient of NACA 230-series airfoils with and without split flaps.

The variation of the increment of maximum lift coefficient resulting from deflection of split flaps of 10, 20, 30, and 40 per cent chord\textsuperscript{154} is shown in Fig. 106. For wing sections of normal thickness ratios, substantially full benefit is obtained for flap deflections of 60 or 70 degrees. The effect of the chord of split flaps on the increment of maximum lift coefficient\textsuperscript{154} is shown in Fig. 107. For wings of normal thickness ratio, comparatively little benefit is obtained by increasing the flap chord to more than 20 or 25 per cent of the section chord, although large flap chords are more effective on thick than on thin sections.

Deflection of a split flap produces a bluff body, and large drag incre-
ments are to be expected. Figure 102 shows that the drag of the NACA 23012 section with a 0.20c split flap deflected the optimum amount at each lift coefficient is about the same or less than that for a plain flap.\(^2\)

The pressure distributions over wing sections with highly deflected split flaps are similar to those for plain flaps (Fig. 99). The pressure distributions with deflected split flaps may be predicted by the semiempirical method of Allen.\(^6\)

\[
\text{(a) NACA 23012 AIRFOIL} \quad \text{(b) NACA 23021 AIRFOIL} \quad \text{(c) NACA 23030 AIRFOIL}
\]

Fig. 106. Effect of split-flap deflection on increment of maximum lift coefficient for various airfoils and flaps.

Data required for the structural design of split flaps are given by Wenzinger and Rogallo.\(^{156}\) The normal force coefficients and centers of pressure for a 0.20c split flap at various deflections are shown in Fig. 108. The data of Wenzinger and Rogallo show that the chordwise position of the forward edge of the flap has only a small effect on the flap loads.

The effect of a gap between the wing surface and a split flap with a nominal chord of 0.20c hinged at 0.80c from the leading edge of the section\(^{156}\) is shown in Fig. 109. The data show that the loss of maximum lift coefficient associated with the gap is considerably greater than that caused by removing the same area from the trailing edge of the flap.

Figure 110 summarizes the effect\(^{144}\) on maximum lift coefficient of moving a 0.20c split flap toward the trailing edge from its normal position. These data show that the percentage increment of maximum lift coefficient obtained by moving the split flap to the rear is about the same as the percentage increase of wing area measured as projected onto the original
chord line. Similar results have been obtained\(^{144}\) for 0.30\(c\) and 0.40\(c\) split flaps.

8.5. Slotted Flaps. \(a.\) *Description of Slotted Flaps.* Slotted flaps provide one or more slots between the main portion of the wing section and the

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**Fig. 107.** Effect of chord of split flap on increment of maximum lift coefficient for three airfoil thicknesses.

deflected flap; and they derive their effectiveness from increasing the camber and, in some cases, from increasing the effective chord of the section. The slots duct high-energy air from the lower surface to the upper surface and direct this air in such a manner as to delay separation of the flow over the flap by providing boundary-layer control.

The numerous types of slotted flap are classified by their geometry. Several types are shown in Fig. 111. The primary classification is the number of slots. The single-slotted flap is the simplest and most generally
used type. Double-slotted flaps have been used to some extent, and multiple-slotted or venetian-blind flaps have been investigated. An important consideration in the design of slotted flaps, especially of the single-

![Diagram]

**Fig. 108.** Normal force coefficients and centers of pressure of a 0.20c split flap at 0.80c on a NACA 2212 wing.

...slotted type, is the extent to which the flap moves aft as it is deflected. The movement of the flap may vary from a simple rotation about a fixed point to a combined rotation and translation that moves the leading edge of the flap to the vicinity of the normal trailing-edge position. Rearward movement of the flap requires an extension of the upper surface over some or all of the flap in the retracted position. This extension of the upper surface serves to direct the flow of air through the slot in the proper direc-
tion and is called the "lip." The external-airfoil flap (Fig. 111) may be considered as a special case of the single-slotted flap with the distinguishing feature that it does not retract within the section.

The flow about a wing section with a deflected slotted flap is very complicated, and no adequate theory has been developed to predict the aerodynamic characteristics. Consequently the information required for

![Diagram of wing sections](image)

**Fig. 109.** (c) Details of split flaps with gaps tested on Clark Y wing.

design is obtained entirely by empirical methods. Although many experimental data have been accumulated, the large number of configurations possible and the sensitivity of the characteristics to small changes in the slot configuration make the design problem a difficult one.

b. **Single-slotted Flaps.** One important parameter in the design of single-slotted flaps is the chordwise position of the lip. Although completely comparable data are not available for configurations with varied positions of the lip, the maximum lift coefficients appear to increase as the lip position approaches the trailing edge for wing sections of moderate thickness. This effect is shown in Fig. 112, where increments of maximum lift coefficient are presented for the NACA 23012 section with single-slotted flaps having lips located at 0.827c, 0.900c, and 1.000c. The con-
figuration with the lip located at 0.827c is not exactly comparable with the others because the chord of this flap is 0.2566c as compared with 0.30c for the others. It is apparent, nevertheless, that the increment of the maximum lift coefficient is considerably higher for the configuration having the lip at the normal trailing-edge position than for those with a more forward lip location. It is uncertain whether any of the difference between the

![Graph](image)

**Fig. 109.** (Concluded) (b) Effect on $C_{L_{\text{max}}}$ and on $C_D$ at $C_{L_{\text{max}}}$ of reducing the chord of a 0.20c split flap. $\delta = 60$ degrees.

other two configurations should be attributed to the difference in lip position. Envelope polars for these flaps are presented\textsuperscript{19} in Fig. 113.

When the lip is located at or near the normal trailing-edge position, the thickness of the flap is necessarily less than that for a more forward location of the lip\textsuperscript{20} (Fig. 114a). In the case of thin wing sections, especially of the NACA 6-series type, the flap thickness may become too small with a rearward location of the lip to permit favorable slot configurations. Under such conditions, the favorable effect on the maximum lift coefficient of moving the lip toward the normal trailing-edge position may not be realized. Cahill\textsuperscript{20} shows (Fig. 114b) that the maximum lift coefficients for
Fig. 110. Contours of $C_{L\text{max}}$ for various positions of trailing edge of 20 per cent flap.

Fig. 111. Several types of slotted flaps.
Fig. 112. Comparison of increments of section maximum lift coefficient for three flaps on a NACA 23012 airfoil.
the NACA 65-210 section are essentially the same for lip positions of 0.84c, 0.90c, and 0.975c. The structural difficulties presented by a long thin lip extension and the mechanism necessary for the corresponding large rearward movement of the flap are such as to discourage the use of rearward locations of the lip unless such configurations result in substantial improvement of the maximum lift coefficient.

![Graph showing lift coefficients](image)

*Fig. 113. Envelope polar curves for three slotted flaps on a NACA 23012 wing section.*

The effect of flap chord on the increment of maximum lift\(^{39, 153}\) is indicated by Fig. 115. The data presented for the 0.2566c and 0.40c flaps are reasonably comparable in that the shapes of the slots are generally similar. Figure 115 shows that larger increments of maximum lift coefficient are obtained with the larger chord flap, but the increased effectiveness is small compared with the increase of flap chord. The slightly higher maximum lift coefficients obtainable with large chord flaps do not appear to justify the structural difficulties encountered with such flaps, and flap chords in excess of 0.25c to 0.30c are seldom used.

The maximum lift coefficients obtained\(^{39, 96, 153}\) with various arrangements of slotted flap on NACA 23012, 23021, and 23030 wing sections are plotted in Fig. 116. The flap chord was 25.66 per cent of the section chord in all cases. These data indicate little variation of the maximum lift coefficient with thickness ratio from 12 to 30 per cent for this type of wing section. A few data\(^{8, 50}\) are also shown in Fig. 116 for comparable slotted flaps on NACA 6-series wing sections. In this case, the flap chords are 25 or 30 per cent of the section chord. These limited data indicate that, for the NACA 6-series sections, the maximum lift coefficients obtainable with
Fig. 114. Variation of maximum section lift coefficient with Reynolds number for several slotted flaps on the NACA 66-210 wing section.
Fig. 115. Effect of flap chord on increments of section maximum lift coefficient for the NACA 23012 wing section.

Fig. 116. Maximum lift coefficients for various arrangements of slotted flaps.
slotted flaps on 10 per cent thick sections are appreciably less than those obtainable with thicker sections.

The effects on the maximum lift coefficient of some variations of shape of the slot are illustrated in Fig. 117. In configurations 1-a and 1-c, the slot is only slowly converging, if at all, at the end of the lip, and these configurations have the lowest maximum lift coefficients of the 1-series configurations. A short extension of the lip as in configuration 1-b, which makes the slot definitely convergent and directs the air downward toward the flap surface, is effective in increasing the maximum lift coefficient. It may be concluded from these and other data that the slot should be definitely convergent in the vicinity of the lip and shaped to direct the air downward toward the flap. The effects of changing the radius of curvature at the entry to the slot from the lower surface are shown by configurations 1-b and 1-c of Fig. 117 for a flap having a comparatively small rearward displacement when deflected. Decreasing the radius of curvature from about 0.08c to 0.04c did not produce a significant difference in the maximum
lift coefficient. Other data indicate that this radius of curvature is of little importance when the flap is displaced rearward enough to produce a large area for the entry of air into the slot.

It is difficult to draw general conclusions about the proper shape of a slotted flap. Figure 117 shows that the highest maximum lift coefficients were obtained with flap 2, which is shaped more like a good wing section than flaps 1 or 3. The difference between the maximum lift coefficients produced by flaps 1 and 2 is small and may be caused by the difference in slot shape and lip extension rather than by the difference in flap shape.

![Diagram](image)

**Fig. 118.** Contours of flap location for $c_{l_{\text{max}}}$. Slotted flap 2-$h$, $\delta_f = 50$ degrees on NACA 23012 wing section.

Flap 3, however, appears to be too blunt with a too small radius of curvature on the upper surface aft of the lip in the deflected position.

Typical contours$^{155}$ of the maximum lift obtainable with various flap positions at one flap deflection are shown in Fig. 118. In general, the optimum flap position for good flaps at large deflections appears to be that which produces a slot opening of the order of 0.01c or slightly more and which locates the foremost point of the flap about 0.01c forward of the lip. The maximum lift coefficient, however, is frequently sensitive to the flap position, and the optimum position is best determined by test.

A complete set of section characteristics$^{155}$ for a typical single-slotted flap configuration is shown in Fig. 119. This figure illustrates the characteristic ability of slotted flaps to produce high lift coefficients with comparatively small profile drag coefficients.

The increment of moment coefficient associated with the use of single-slotted flaps$^{32}$ is illustrated by Fig. 120. This figure shows the ratio of the increment of the section pitching-moment coefficient to the increment of the section lift coefficient at an angle of attack of 0 degree for three wing sections and several flaps. The moment coefficients used in this case are
Path of flap nose for various flap deflections. Distances measured from lower edge of lip in per cent airfoil chord c.

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<th>y</th>
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<td>20</td>
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<td>3.45</td>
<td>60</td>
<td>0.12</td>
<td>1.48</td>
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<tr>
<td>30</td>
<td>2.63</td>
<td>3.37</td>
<td></td>
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</tbody>
</table>

Fig. 119. Section aerodynamic characteristics of NACA 23012 airfoil with slotted flap 2-4.
based on the total chord with the flap deflected. The ratio plotted appears to be fairly constant at values between about $-0.17$ and $-0.21$, instead of varying with flap-chord ratio as in the case of plain flaps at small deflections.

The normal-force coefficient, pitching-moment coefficient, and center of pressure for the flap of the configuration of Fig. 119 (configuration 2-$h$ of reference 153) are shown in Fig. 121. All the coefficients are based on the flap chord. The pitching moments are taken about the quarter-chord point of the flap, and the center of pressure is given in per cent of the flap chord from the leading edge of the flap. These data are useful in determining the loads on the flap and the flap linkages, and they show that the normal force coefficients on the flap are less than those for the wing section.

c. External-airfoil Flaps. The external-airfoil flap investigated by Wragg,\textsuperscript{196,197} Platt,\textsuperscript{83,84,85} and Wenzinger\textsuperscript{181} may be considered as a special case of the single-slotted flap in which the flap does not retract within the wing section. The maximum lift coefficients obtained at an effective Reynolds number of 8 million for a NACA 23012 wing section with a 0.20$c$ external-airfoil flap of the same section are shown plotted against flap deflection in Fig. 122. These maximum lift coefficients are based on the combined areas of the wing and flap. The values presented were obtained from tests of a
Fig. 121. Section characteristics of the flap alone of the NACA 23012 airfoil with a 0.266c slotted flap.
finite span model and were only partly corrected to section data. The corresponding section maximum lift coefficients are judged to be about 4 per cent higher than those presented. If these maximum lift coefficients were based on the chord of the wing section, as is customary for other types of flap, the resulting values would be about the same as those for single-slotted flaps. Although the external-airfoil flap appeared\textsuperscript{83, 85} to offer some advantages as a full-span flap, it has not been used extensively because of its failure to show definite advantages over retractable flaps and because its use would probably aggravate the icing hazard.

\textit{d. Double-slotted flaps.} Double-slotted flaps\textsuperscript{8} (Fig. 123) produce substantial increments of maximum lift coefficient over that obtainable with single-slotted flaps. The fore flap or vane of the double-slotted flap assists in turning the air downward over the main flap, thus delaying the stall of the flap to higher deflections. It has frequently been found possible to develop flap-vane combinations that can be retracted into the wing section without relative motion between the vane and the flap. Such an arrangement is desirable because the linkage system is much less complicated than when relative motion is required between the flap and vane.
Investigations by Harris,40 Purser,91 and Fischel92 of approximately 0.30c and 0.40c double-slotted flaps on the NACA 23021 and 23012 wing sections indicated maximum lift coefficients of the order of 3.3 and 3.5 for the two sizes of flap. Typical results for the NACA 23012 section are shown in Figs. 124 and 125. The fore flap and the main flap did not deflect together as a unit for these configurations. Aerodynamic characteristics9 are presented in Fig. 126 for the NACA 653-118 section with the 0.309c double-slotted flap shown in Fig. 123. For this configuration, the vane and flap moved together as a unit up to deflections of 45 degrees. At higher angles, the flap rotated about a pivot and the vane remained fixed.

The variation of maximum lift obtained for thin NACA 64-series sections21 with approximately 0.30c double-slotted flaps is shown in Fig. 127. The type of flap used for these tests is illustrated in Fig. 128. The flap and vane deflected as a unit. These data (Fig. 127) show that the maximum lift coefficient decreases rapidly as the thickness ratio of the wing section is decreased to values below 10 or 12 per cent. The maximum lift coefficient obtained for the NACA 1410 wing section21 is also plotted to indicate the effect of type of section. The maximum lift coefficient obtained for the NACA 653-118 wing section with a flap deflection of 45 degrees (Fig. 126) is also plotted to indicate the effect of larger thickness ratios. The NACA 653-118 data are not exactly comparable, but the indicated gradual rise of the maximum lift coefficient as the thickness ratio is increased to 18 per cent is believed to be representative.

The effect of the design position of minimum pressure on the maximum lift coefficients obtained with double-slotted flaps on 10 per cent thick NACA 6-series wing sections21 is shown in Fig. 129. The type of flap used
Fig. 124. Aerodynamic section characteristics of the NACA 23012 airfoil with a 0.30° double-slotted flap. \( \delta_f = 25 \) degrees; \( x_1 = 0.41; y_1 = 1.72 \). (Values of \( x_1, y_1, x_2, \) and \( y_2 \) are given in per cent of airfoil chord.)
Fig. 125. Aerodynamic characteristics of the NACA 23012 airfoil section with 40-per cent-chord double-slotted flap. \( \delta_1 = 30 \) degrees; \( x_1 = 1.50; y_1 = 3.50 \). (Values of \( x_1, y_1, x_2, \) and \( y_2 \) are given in per cent of airfoil chord.)
was similar to that shown in Fig. 128. These data show that the highest maximum lift coefficient was obtained for the NACA 64-series sections and that the maximum lift coefficient decreases rapidly as the minimum-pressure

![Graph](image)

**Fig. 126.** NACA 65s-118 airfoil section with 0.309c double-slotted flap.

position moves farther aft. It is thought that the rather large variations shown in Fig. 129 are associated with the fact that the thickness ratio of the sections was in a critical range, as indicated by Fig. 127.

Load data for typical double-slotted flaps are given by Cahill. These data show that a disproportionately large part of the load is carried by the vane. Normal-force coefficients for the vane based on the vane chord and the dynamic pressure of the free stream reached a value in excess of 5.0.
Fig. 126. (Concluded)
Fig. 127. Effect of thickness ratio and type of wing section on maximum lift with double-slotted flaps.

(a) AIRFOIL WITH FLAP

(b) VARIABLES USED TO DEFINE FLAP CONFIGURATIONS

Fig. 128. Typical airfoil and flap configuration.
Fig. 129. Variation of maximum section lift coefficient with position of minimum pressure for some NACA 6-series wing sections of 10 per cent thickness and a design lift coefficient of 0.2. $R_e, 6 \times 10^6$.

Fig. 130. Examples of fixed and retractable slats.
8.6. Leading-edge High-lift Devices. \textit{a. Slats.} Leading-edge slats are airfoils mounted ahead of the leading edge of the wing in such an attitude as to assist in turning the air around the leading edge at high angles of attack and thus delay leading-edge stalling. They may be either fixed in position or retractable (Fig. 130). The fixed leading-edge slat consisting of an auxiliary airfoil mounted ahead of the wing leading edge has been investigated in detail by Weick and Sanders.\textsuperscript{146} This investigation showed that leading-edge slats of this type with chords varying from 7.5 to 25 percent of the wing chord and with various sections all produced substantially the same maximum lift coefficient when located in the optimum position for the ratio
\[
\frac{C_{L_{\max}}^2}{C_{D_{\min}}}
\]
The value of this maximum lift coefficient was about 1.64 for the rather low Reynolds numbers of the tests. It is doubtful whether such configurations would experience much beneficial scale effect.

The effectiveness of the retractable leading-edge slat\textsuperscript{197} shown in Fig. 130 in increasing the maximum lift coefficient and the angle of attack for maximum lift is shown in Figs. 131 and 132. These data, which were obtained on a NACA 23012 wing section, indicate an increment of about 0.5 for the maximum lift coefficient and about 8 degrees for the angle of attack for maximum lift. The increment of maximum lift decreased to about one-half of its value for the unflapped section when either a split or slotted flap was deflected to optimum deflections despite readjustment of the slat to optimum positions with flap deflected. Weick and Platt\textsuperscript{136} obtained considerably larger increments of maximum lift coefficient with a special retractable slat (Fig. 133) having a shape providing a rounded entrance into the slot. The increments of maximum lift coefficient with
this configuration were 0.81 for the unflapped section and 0.45 with a
deflected slotted flap.

b. Slots. Slots to permit the passage of high-energy air from the lower
surface to control the boundary layer on the upper surface are common
features of many high-lift devices. The most common application is the
slotted flap. When the slot is located near the leading edge, the con-
figuration differs only in detail from the leading-edge slat. Additional
slots may be introduced at various chordwise stations. Weick and Shortal\textsuperscript{197}
made a systematic study of slots on a Clark Y airfoil. The results of
this investigation are summarized in Fig. 134. For the unflapped section,
the most effective position for a single slot is near the leading edge, and
the effectiveness decreases as the slot is moved aft. Multiple slots are
relatively ineffective on the plain airfoil unless they include a slot near the

![Fig. 133. Special retractable slat on Clark Y wing section.](image)

leading edge, in which case a total of three slots, all located well forward,
is optimum. For the flapped section, the slot located near the leading edge
was effective. A single or double slot at the flap changed the type of flap
from plain to slotted with a corresponding increase of the maximum lift
coefficient. Load data for the leading-edge slot are given by Harris and
Lowry.\textsuperscript{41} These data show resultant-force coefficients as large as about
7.5 for that portion of the wing section ahead of a slot near the leading edge.

If slots are considered as a fixed high-lift device, the profile drag in the
high-speed flight attitude is an important characteristic. Figure 134 shows
that any of the slots investigated cause large increments in the minimum
profile drag. This increment increases with the number of slots and de-
creases with rearward movement of the slots. Attempts have been made
to maintain low drags with slots open by locating the slots so that there
would be no flow through them in the high-speed condition.\textsuperscript{198} Such con-
figurations have failed to improve the ratio of maximum lift to minimum
drag over that for the plain wing section.

c. Leading-edge Flaps. A leading-edge flap may be formed by bending
down the forward portion of the wing section in a manner similar to that
in which the trailing edge is deflected in the case of plain flaps. Other
types of leading-edge flap are formed by extending a surface downward
and forward from the vicinity of the leading edge. As shown in Fig. 135,
such flaps may extend smoothly from the upper surface near the leading
edge, may be hinged at the center of the leading-edge radius, or may be
hinged on the lower surface somewhat aft of the leading edge. Although
<table>
<thead>
<tr>
<th>Slot combination</th>
<th>$C_L^\text{max}$</th>
<th>$C_D^\text{min}$</th>
<th>$\frac{C_L^\text{max}}{C_D^\text{min}}$</th>
<th>$\alpha_{C_L^\text{max}}$ degrees</th>
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<td></td>
<td>1.662</td>
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<td>64.4</td>
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(a) Multiple fixed slots.

Fig. 134. Aerodynamic characteristics of a Clark Y wing with slots and flaps.
<table>
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<tr>
<th>Slot combination</th>
<th>$C_{L_{\text{max}}}$</th>
<th>$C_{D_{\text{min}}}$</th>
<th>$\frac{C_{L_{\text{max}}}}{C_{D_{\text{min}}}}$</th>
<th>$\alpha_{C_{L_{\text{max}}}}$ degrees</th>
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<td>1.950</td>
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<td>0.0340</td>
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<td>1.770</td>
<td>0.0164</td>
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<td>2.185</td>
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<td>2.261</td>
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<td>2.320</td>
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<td>2.535</td>
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<td>2.600</td>
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<td>2.035</td>
<td>0.0298</td>
<td></td>
<td>68.3</td>
<td>21</td>
</tr>
</tbody>
</table>

* $C_{D_{\text{min}}}$ with flap neutral.

(b) Multiple fixed slots and a slotted flap deflected 45 degrees.

Fig. 134. (Concluded)
none of these devices is as powerful as trailing-edge flaps, they may be used full span without mechanical interference with lateral-control devices and they are effective when combined with trailing-edge high-lift devices. Leading-edge flaps reduce the severity of the pressure peak ordinarily associated with high angles of attack and thereby delay separa-

![Diagram](image)

(a) DROOPED LEADING EDGE

(b) UPPER SURFACE LEADING EDGE FLAP

(c) LOWER SURFACE LEADING EDGE FLAP

(d) FLAP HINGED ABOUT LEADING EDGE RADIUS

*Fig. 135. Various types of leading-edge flaps.*

...tion. Leading-edge flaps received little consideration until German investigators became interested in them during the Second World War.

Krueger, Lemme, and Koster showed increments of the maximum lift coefficient of as much as 0.7. These increments were, however, applied to maximum lift coefficients for the plain wings of the order of 0.72. These low maximum lift coefficients resulted from the small leading-edge radii of the wing sections usually used for these investigations and the very low Reynolds numbers of the tests. These investigations indicated that the effectiveness of leading-edge flaps increased with decreasing leading-edge radius. Typical results are shown in Fig. 136. The incre-
The increment of maximum lift coefficient, $\Delta C_{l_{\text{max}}}$, is plotted against the leading-edge radius parameter $(r/c)/(t/c)^2$ where $r$ is the leading-edge radius. The value of this parameter for NACA four- and five-digit wing sections is 1.1.

Fullmer\textsuperscript{32} investigated two types of leading-edge flap on the NACA 641-012 section at a Reynolds number of 6 million. The chord of the flap was 10 per cent of the section chord, and the configurations corresponded to $b$ and $c$ of Fig. 135. The increments of maximum lift coefficient and of the angle of attack for maximum lift are shown in Fig. 137. The leading-edge radius parameter for the NACA 641-012 section is 0.72. The maximum increments of Fig. 137 are shown plotted on Fig. 136 for comparison with the German results. The maximum lift coefficient of the plain wing section for these tests was 1.42.

8.7. Boundary-layer Control. The idea of removing the low-energy air of the boundary layer, or of adding kinetic energy to the boundary layer, as a means for increasing the maximum lift has been obvious since the basic mechanism for separation was first understood.\textsuperscript{87} The kinetic energy of the layers of air close to the surface may be increased by removing low-energy air through suction slots or a porous surface. Another common method is to blow high-energy air through backward-directed slots. The
air handled through either the suction or blowing slots may be carried through the interior of the wing and the necessary energy supplied by a blower. Alternately, the pressure difference required may be obtained from the variation of pressure about the wing section itself. This method

![Diagram](image)

**Fig. 137.** Variation of the increment of maximum section lift coefficient and the increment of section angle of attack for maximum section lift coefficient with leading-edge flap deflection. NACA 641-012 airfoil section with leading- and trailing-edge split flaps. \( R, 6.0 \times 10^6 \).

has been used successfully only in the case of blowing slots on the upper surface using air taken from the lower surface. Examples of such arrangements are the previously discussed slotted flaps, slots, and leading-edge slats.

It is obvious that, if boundary-layer control is applied at sufficiently close intervals along the upper surface of a wing section, separation can be avoided up to very high values of the lift coefficient. The increments of maximum lift coefficient are obtained as an extension of the lift curve to
HIGH LIFT DEVICES. To increase the speed range of airplanes, three general methods may be employed: (1) Flaps, either at leading or trailing edge. (2) Slots, either fixed or variable, located along the chord. (3) Boundary layer control either by applying suction, or expelling air rearwardly; or any combination of these methods. The advent of the jet engine, with its large quantities of compressed air, has made the third method a distinct possibility. Some experimental work has been done in this direction.

The general effect of moving trailing-edge flaps downward is to increase the concavity of the lower surface of the section and thus to increase the lift. Using trailing-edge flaps whose chord is approximately 20 to 25% of the chord of the basic airfoil, monoplane airfoils show an increase in maximum lift of about 40% with a flap setting of 45 to 60 degrees. In practice, however, the maximum flap travel usually is limited to about 30 degrees, under which conditions from 50 to 70% of the maximum possible increase in lift may be realized.

The general effect of a trailing edge flap on the lift and drag is shown in Fig. 14. Flaps may be either simple, the whole trailing-edge section of the wing being pulled down as a unit, or split, the lower part of the trailing edge being depressed while the upper part is left rigid and the form of the upper surface of the wing remains undisturbed. The split type is more efficient, but the difference is not great. A nose flap has been proposed for airplanes designed for high speeds approaching $M = 1$. It is referred to, in common parlance, as the “droop snoot.”

Fixed or variable leading-edge slots commonly are used only in that portion of the wing ahead of the ailerons. A variation of this is a slot immediately in front of the aileron for improving lateral control. The effect of the slot is to prevent “burbling” and thus maintain smooth airflow, with consequent increase in lift, at very large angles of attack. The fixed slot is preferred. Some of the combinations that have been tried, with their representative aerodynamic characteristics are shown in Fig. 15.

Another promising method is control of the boundary layer to reduce drag and delay burble, and thereby increase the maximum lift coefficient obtainable by sucking in the air along the airfoil surface. Similar advantages may be obtained by expelling air more or less tangentially (and rearwardly) to the airfoil surface. Neither approach has yet achieved a practical or economical means of controlling the boundary layer.
WING FLAPS AND THEIR MECHANISMS

Part 1

From outside an aircraft you really can’t tell whether its flaps are operated manually or electrically. Another thing you can’t see is that the only internal difference between electrically operated flaps and manually operated flaps is not their mechanical linkage but their power source.

Electrically operated flaps are powered by a geared electric motor while manually operated flaps are powered by a hand operated lever. Essentially, this constitutes the only difference between the two systems.

Manual Flaps vs Electric Flaps

Maybe the best thing to be said for an electrically operated flap system is that it can give you an infinite variety of flap settings whereas a manual deployment system is usually limited to two or three basic settings. I must add also that electrically operated flaps lend an air of elegance to any aircraft interior by eliminating an obtrusive ever-present flap lever.

That just about exhausts all the advantages an electrical flap system has over a manual one. Some folks say that a retractable landing gear installation messing with the manual flap lever occurs at a critical time during the approach and landing. I do not concur as it takes just about as much time to deploy electrically operated flaps. Actually, deploying flaps electrically could demand more of your attention and time than doing it manually. This is especially true if your flaps are controlled through a momentary contact switch and not by means of a flap lever backed by limit switches. This is so because you would have to hold a toggle switch until the flap reached the degree of deployment you want.

Manually operated flaps, on the other hand, deploy instantly and in the exact degree to which the flap lever is moved. The position of the flap lever shows you, without having to look for an indicator, how much of the flaps are deployed. Immediately after landing, the flaps can be pulled up quickly to “kill” off lift during roll-out... electrically operated flaps just aren’t as fast.

Another advantage a manual flap lever offers is important fringe benefit. If you have an electrically operated landing gear you are more likely to inadvertently pull up the gear (after landing) by flipping what you think is the electric flap switch. It is most unlikely any pilot would mistake a flap handle for a gear switch.

One negative aspect of a manual flap installation in a two seat side-by-side aircraft would be the location of the flap handle between the pilot and passenger. That long slotted opening required for the flap handle’s movement (travel) makes a drafty inlet for cold air in the winter time. This opening is difficult to seal or weather strip because the handle requires quite a few degrees of travel. But even with this slight inconvenience.

25 MARCH 1982
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A manual flap system must be considered as the more efficient of the two systems. A manual flap installation will always be lighter and much less expensive to build than an electric flap system. It is also a maintenance-free installation that will weigh 4 to 5 pounds less than an electrically operated one.

If you must have flaps, a manual system is the one . . . it will never blow a fuse or burn out a motor.

Flaps in General

Occasionally wing flaps as designed and installed turn out to be marginally effective. Often because the total flap area is too small due to structural limitations. Both the flap design and the degree of down-travel obtained influence their effectiveness. For example, a spin-type flap is nowhere near as efficient as the Fowler type which, in effect, increases the total wing area when deployed.

In general, a flap activation system should work smoothly and without undue sluggishness or binding throughout its entire range of travel. The flaps should stay in whatever position you place them. In an installation where the flaps are divided, you must be assured that both sides come down and go up together. It makes for uncomfortable control conditions to have it otherwise.

Although other control surfaces, such as the rudder, elevator and ailerons, generally are mounted on three hinges, flaps seem to do well enough on only two hinges.

The flap horn connection for deploying the flaps should be located, ideally, at or near the mid-point of the flap surface. In a low wing installation, however, it is usually more expedient and simpler to install the flap horn at the inboard end of the flap. This arrangement may

unfortunately, subject the flap structure to considerable stress during flap deployment. At higher airspeeds the twisting force on the flap can become excessive and cause structural damage unless the structure is ruggedly built and the maximum 'flaps down' speed is limited (planned).

The power required to operate flaps (electrical or manual) is transmitted through mechanical linkage to the flaps. In a typical low wing installation this is accomplished quite directly through a series of push-pull tubes, bell cranks and possibly a torque tube. In a high wing aircraft the system most generally employed operates through a series of pulleys and cables in addition to a few strategically located bell cranks.

A cable operated system usually requires two cables although it is possible to rig the system so that a single cable can be used. A strategically installed spring pulls them back to a full up position. This is a less positive system than a two cable installation but it is often easier to install.

Electric Flaps in Particular

For flap motors, a number of builders have been adapting automotive electric motors originally intended to operate car seats and windows. These units will work. They are quite heavy but are geared to provide the torque needed to operate a flap system, however, all the external parts should be replaced with durable pieces made of aluminum wherever possible to reduce the weight of the assembly.

By far, it is best to use a standard flap motor and jack screw (transmission) assembly from some aircraft. These units can be purchased through an aircraft dealer or more economically acquired from an aircraft salvage operation.

When buying a second hand flap motor assembly, check to see that the motor runs. The obvious check is that if the motor works the unit will be operational in other respects. If possible, try to obtain a flap motor assembly with a jack screw (transmission unit) that has a freewheeling provision at each end of travel. Otherwise, you will have to install limit switches at each end of travel to keep your system from self-destructing on an electric motor is out of control. But even if the unit does have a free-wheeling provision at the extreme ends of flap travel, the motor shouldn't be allowed to endlessly spin at the extremes of flap movement. I recommend that you install limit switches just to be sure.

There are only two wires coming out of a typical flap motor. In order to reverse its direction in operation, the
connections to the motor from the battery need to be switched. In effect, the motor circuit must be reversed by switching the wire connections to obtain first a down movement for the flaps, and then later an upward retrac-
tion. You can accomplish this without changing wire connec-
tions by using a double pole double throw (DPDT) switch that automatically returns to its spring loaded center OFF position. Wiring of this switch is illustrated in
Figure 3.
In wiring your electric flaps, provide a quick disconnect
connection fairly close to the flap motor so that everything
can be unplugged and the motor assembly removed for repair or replacement should the need arise.

An electric flap installation requires some sort of indicator to show the position of the flaps. This may tax your ingenuity but you can do it by connecting a wire indicator to some moving part of the flap linkage (in the cockpit area) and calibrating it to provide the relative relationship between full down and up positions. Builders with an electrical background can undoubtedly devise some sort of electric indicator. An indicator unit salvaged from some sophisticated store bought airplane could also provide the visual indicator you need.

During the time you are working to install the electric flap motor and adjusting the mechanism, it will be necessary to operate with in order to adjust the flap travel. If you don't have a 12 volt battery, you could use a battery charger plugged into a wall socket as a source of 12 volt DC power to operate your flap motor. Simply connect the battery charger leads to the motor through the switch you intend to install in the aircraft. You can then operate the switch as you would in the aircraft. The only trouble with this convenient set-up is that you'll be tempted to waste a lot of valuable building time playing with the flaps.

The typical stock flap motor and jack-screw assembly can deploy full flaps in about 10 to 12 seconds. This is far slower than what can be done with manual flaps. Still, sometimes this is to your advantage in faster aircraft (keeps you from sitting altitude when you really intend to go the other way). Electrically operated flaps, you will notice, tend to come up at a slightly faster rate than they do going down due to the assistance received from the alipstream.

Flap Adjustment and Operation

After your installation is completed be sure to check
that you are getting the full flap deployment you want, usually 40° to 45°. This can be done by using an indicator
motor, which you can make, or check the flap angle with
a level-protractor from a combination square set. Center
the bubble in the level with the flaps in their full up position by laying the protractor or clinometer on top of the flap. Depress the flaps and check the angle reading. If you are using a manual system, check your detent positions for a partial and half flap setting. Manual systems ordinarily don't have more than two alternate flap positions, say 10° and 25° of flaps.

It is said that a -5° to a -10° flap setting reduces drag and yields a worthwhile increase in cruise speed. In anticipation of this benefit a number of builders are rigging their flaps so as to obtain a negative or minus flap setting in flight, however, sometimes the wing fairing as an installation on a low wing aircraft in particular prevents experimenting with this idea.

Not much can go wrong with an electrical flap system
and even less with a manual system. If electric flaps fail to
operate, the motor is probably bad and will have to be
replaced. If this should develop you might suddenly
become more receptive to the idea of switching to a manual
flap system . . . after you find out what a new motor costs.

Something To Think About . . .

1. It is far easier to build an airplane without flaps
   than with flaps . . . cheaper and quicker, too.

2. You must have flaps, a manual control flap system
   is the most efficient.

3. Electrically operated flaps are hard to justify but
   the urge to install the system is overwhelming.

There you have it. These different choices. Actually, if
you would consider hydraulically operated flaps, you'd
have another choice . . . another decision to make. Well,
that's the beauty of our homebuilt movement. As long as
we don't violate any of the three basic laws - aerodynamic,
mechanical, governmental, you can generally get results
that are individually satisfying. More next month.

28 MARCH 1982
HEAVY AIRCRAFT, and fast homebuilt with small wing areas, appear to benefit the most from the increase in lift and drag usually attributed to flaps. Sometimes, however, a reduction in landing speed realized from the increased lift/drag may not be as noteworthy as is an improved control feel and attitude change obtained whenever the flaps are deployed (as for an approach to landing).

Characteristically, the deployment of flaps causes the nose of the aircraft to pitch down. This attitude change is beneficial as it permits a steeper approach with a better over-the-nose visibility. Usually, however, the amount of pitch-down is excessive and it becomes necessary to hold considerable back pressure or to trim some of it out. This distraction generally takes place when you happen to be most interested in where the airplane is going to touch down... and how.

There is no reason to put up with such an old-fashioned flap system. A simple little spring-loaded trite tab connected directly to your flap bellcrank by piano wire can eliminate this inconvenience and add a touch of luxury to your airplane. It will automatically add the necessary trim adjustment needed without demanding any attention or effort on your part. See Figure 4 (Detail F) for one variation of this clever automatic flap trim device.

While we’re on the subject of controls, flap controls specifically, let’s also consider, briefly, why various controls operate in the manner that they do.

Traditionally, aircraft engine and flight controls are installed so that they operate in the proper, that is, the instinctive and natural, direction. For example, when the throttle is pulled forward, we expect to get, and do get, an increase in power. Can you imagine the panicky situation that could be created in an emergency go-around if the throttle were to be hooked up to operate opposite to the standard direction?
Theoretically, in an emergency situation all engine and systems controls "go forward"—that is, propeller high rpm, the mixture control (full rich), etc. But what about the flaps? What is the proper instinctive direction of operation for flap control? For electrically operated flaps the answer is easy; for manually operated flaps, not so easy.

Electric flaps are deployed when the flap switch is flipped DOWN and retracted when the switch is flipped UP.

Manual flap handles are mounted in a number of ways and locations so their operation is far from being standardized. Almost standardized, but not quite.

The direction of operation of a floor mounted flap handle is very obvious in a typical side-by-side two-seat aircraft. The flap handle is positioned so that it will not be in the way most of the time. This means that it will probably be installed so that when the flaps are not in use the handle will be flush or parallel to the floor or console. This also means that the flap handle must be raised (pulled up) to lower the flaps. Maybe it doesn't sound logical but it is the most common and natural manual installation you can make. See Figures 1, 2, and 4 (Details E and F).

In a high wing aircraft with a manual flap handle installed overhead, the obvious movement would be to pull the handle down to deploy flaps.

In a single seat aircraft, the flap handle would probably be mounted on the right hand side along the cockpit wall. Whether the flap handle should move forward or aft for flap deployment becomes an optional decision that only you, the builder, can make.

If your flap handle is floor-mounted, the recommendation would be to have it operate as in a side-by-side installation. That is, the flap handle would be pulled up and back for flaps. However, here again, there is no standardized direction of movement for such a flap handle. In essence, it can be made to operate in the direction that you, the builder, deems most logical. Of course, you would place the direction of operation on the flap handle or someplace adjacent to it.
A Few Comments About Flaps

Sometimes we see an airplane parked with its flaps down and we wonder whether the pilot forgot to retract them after landing or whether he really wants them down. Nothing with flaps down is considered to be as bad for the flaps as it is for the pilot's image. The reason, of course, is because debris harmful to the propeller is kicked up by the prop blast and wheels. Most pilots, therefore, retract their flaps as soon as the aircraft is on the ground and under control (note I said retract the flaps, not the G-E-A-R). Low winged aircraft with flaps running all the way to the sides of the fuselage seem to be a mute invitation for uninformed folks to use them as a step. Understandably, this may be looked upon by the owner as an unprovoked act of aggression and the offender could find himself bodily yanked off by a hot sweaty hand affixed to his collar.

Unless your flaps are built with a safety lock specifically devised for this purpose, they should be placarded with large letters warning that the flap is a NO STEP. However, warning sign or no warning sign, experienced aircraft owners of low wing aircraft attending fly-ins often make it a point to park their airplanes with flaps down. This precaution makes it virtually impossible for anyone but a mountain goat to step on them inadvertently or through deliberate ignorance. It is well for all builders to remember that flaps are designed to handle air loads and they are not structurally suited to take much ground abuse from anybody.

Flap Mechanisms in High Wingers

Installing a flap system in a high wing aircraft can be surprisingly complex. This applies equally to a system that is manually operated as it does to an electrical installation.

If you intend to use a cable operated system you may learn that you will have to capture the pulley market because anywhere from 12 to 16 of them will be needed ... large expensive ones at that. To make a cable operated flap system work smoothly its pulleys should be at least 3.5" in diameter wherever the 1/8" control cable must change direction 90° or more. The pulleys used most frequently are the commercially available AN210-44 although, some builders are also using the smaller (2.0" diameter) AN210-3A pulleys. If you should use the smaller pulley, more frequent inspections of the cables, wherever they pass over pulleys, are in order. It is at these points that cables will be under the greatest wear conditions due to friction within the cables. In addition, you will need at least 4 turnbuckles large enough to develop the full strength of the 1/8" flap control cables. Add in all of the necessary brackets and pulley guards and the cable operated flap system all of a sudden doesn't seem as attractive as it first appeared.

An alternative flap system that can be used in some high wing aircraft relies largely on the use of push-pull tubes. This is a non-positive type of installation, simpler and less expensive to install. Of course, the design of the aircraft usually dictates the type of installation that you can most easily make.

The flap systems in low wing aircraft are, ordinarily, the easiest to make and to install. This can also be said of those rare biplanes where the flaps would be fitted to the lower wings ... but who wants flaps on an old timey design?
About Those Flap Mechanisms...

After you have examined a few different flap installations one thing becomes apparent, just about all of them can be made to operate electrically or manually. The linkage and mechanism between the flaps and the actuating assembly is almost always identical. That is to say, a torque tube is generally installed across the fuselage serving as the basic element in most flap systems.

The linkage from the torque tube to the flap actuator is where the greatest number of variations are seen. The torque tube is typically suspended or pivoted at each end. Somewhere about its center is where horns or bellcranks of differing sizes and shapes are welded. I say welded because almost all torque tubes are about 1-1/4" or larger in diameter and are of a rather thin wall...about .030" (0130 steel tubing). Horns or lugs welded to the torque tube should be of the dual design spaced so that a rod end bearing on the end of a push rod can be slipped between them to provide a low friction pivot.

If the distance from the torque tube to the cockpit actuating unit is fairly long, you might consider using 1/8" control cables instead of heavy, more expensive, push-pull tubes or rods. Some flap installations work quite well having but a single cable for pulling the flaps down. A short spring-loaded cable returns the flaps to their retracted position. I guess a single cable installation would be the lightest possible to build and to install.

Perhaps as important as anything else is the need to consider the mechanical advantage gained by varying the lengths or combination of lengths for the walking beams, bellcranks, lugs and horns. Unfortunately, what you gain in mechanical advantage (leverage), you lose in the amount of travel at the other end of the linkages. So, although you might rig the flap actuating handle or motor so that it is only lightly loaded when deploying flaps, you might find that your flaps aren't dropping down fast a few degrees instead of the desired 40° of travel.

Anyway, working out the amount of flap travel obtained by varying the dimensions for the various horns, walking beams and torque tube bellcranks can be as interesting and as challenging as tangleing with the best video game around.

You can test out your ideas with a full scale mock-up of the linkage. Use cardboard, wood, welding rods and anything else you have on hand and see for yourself.

All things considered, the fewer the number of parts in a flap system the better. Not only is this true of the mechanical efficiency resulting but also in the savings realized in time and money.

A rarity among homebuilts...slotted flaps. The smooth curvature over the top of the wing with its fully deployed flaps conveys an air of aerodynamic efficiency. The airplane is an advanced T-65 series prototype.
METHOD AND MECHANISM FOR CHANGING THE WING PLAN
GEOMETRY OF AIRPLANES IN FLIGHT
(A DESIGN STUDY)

I SELDOM HEAR of homebuilt aircraft activities in
South America so I was pleasantly surprised when I re-
cently received a letter from Brazil describing a beauti-
ful sleek all-metal homebuilt and an invention for a
high lift device.
I knew there were EAA members in South America
because I do get occasional letters and book orders
from there, primarily from Argentina and Venezuela
as well as Brazil.
I knew too, Brazil was developing a pretty good
aeronautical base and is internationally known for
turning out some excellent aircraft designs. As a mat-
ter of fact, during its rebuild from a basketcase condi-
tion, my current Eversuda's English- built Rolls Royce
0-200 engine was fitted with new pistons from Brazil.
But allow me to report on another element of avia-
tion in Brazil— one of greater interest to me. It has
to do with a homebuilder, an EAA member. His letter
follows.

Belo Horizonte, 13 de abril de 1981

Mr. Antoni Bingelis
8509 Greenlint Lane
Austin, TX 78759

(Pardon My Accent)
Dear Bingelis,
I am an EAA membership No. 79160 since 1972 and
of course I read your articles every month. Through
them I learned how much N.A.A. studies the stall/ship
that frequently causes mortal accidents.
Of course stall-ship is a very complex problem, but
I hope to give some help to this subject and at the same
time to pay back all the help that the EAA gave me
through past nine years by SPORT AVIATION.

I invented a high lift device called "METHOD AND
MECHANISM FOR CHANGING THE WING PLAN
GEOMETRY OF AIRPLANES IN FLIGHT."
It has a patent pending in Brazil, U.S., Canada,
England, West Germany, Italy, Japan and France.

Of course, I would like to explore it on a commer-
cial level but for this it is necessary to make public
the device.
I think it would be a very good idea to permit any
EAA member to use it free in his own plane, of course
without commercial exploitation. I would give an of-
ficial permission to use it for each interested person.
This device, beyond its principal finality, if used
in asymmetry form and automatically moved by aer-
dynamic forces in front of a stall-spin, probably will
give lift to the stalled wing to recover or avoid the
spin. This dangerous test, of course, would be better
made by N.A.A.

The idea of this high lift device came when I was
in the final part of building my plane ESQUILO-180,
very similar to the Italian Falco but mine is all metal
and more slender.

I annexed its specifications and some photo for you
to know that here in Brazil also there are friends that
think and work like you in U.S. (in little scale and
with more difficulty, of course). If you consider that it is a good idea to permit some
EAA membership to use the device, I would like to
have you help in publishing it in SPORT AVIATION
in your articles.

Sincerely yours,
Mauricio Impezezieri P. Moura
P.S. My address is: B. Mangabeira 546 Apt. 301, 30000
B. Horizonte - Brazil
This pivoted leading-edge slat, when swung forward, increases the wing area in the outer portion of the wing and at the same time changes the angle of attack. The resultant boost claimed are reduced approach and landing speeds as well as better control.

The system can be made to be automatically actuated at pre-selected speeds to obtain a simultaneous or optional change in the wing camber, an increased wing tip chord and the formation of an adjustable slot in the leading edge of the wing.

The means and mechanism for doing all this to the wing consists of a lengthwise slat, nested along the outer third of the wing’s leading edge. This slat is pivotally mounted at its inboard end and is contoured to match the shape of the wing leading-edge.

Actuation of the slat is mechanically through a drive system made up of an electric motor and the components illustrated in Figures 1 through 5.

The key element in the device is the slat guide rail (see Figure 5). This guide rail may have a straight line path or may be provided with a curved path to effect the desired change in the airflow inboard for the wing and the degree of lifting to be imparted to the slat.

These sliding operations are collectively expected to result, in the proper positioning of the slat with respect to the wing and thereby improve aircraft stability at low speeds on take-off and when landing.

As Maurice puts it: “All kinds of sweepback wing designs usually have considerable geometric torsion (twist) from the root to the tip, to make it possible for the stall to progress from the root to tip. But what is good for landing isn’t good to run. I know you have one brilliant staff and they, of course, realize this, but I am presenting one solution.”
FIGURE 3. ACTUATING SYSTEM DRIVES SLAT FORWARD

FIGURE 4. SLAT PIVOT POINT MECHANISM
"The device, when opened, provides as much geometric tension as you need. (When the wing is in cruise configuration it does not need geometric tension, or at least it is very much reduced.)

"Of course, you will get less drag and more speed, putting all sections of the wing near the same better point of polar curve of the wing."

As stated earlier, the idea is untested and should be regarded simply as a design study at this point. Mauricio pointed out that he did not have time and enough money to use his device on the Esquila-180 because it was already finished. However, as soon as possible after the end of the test flight he intends to install it in "gloves form" as an add-on modification.

If you are interested in experimenting with the device contact Mauricio directly... [rest of text not legible]

Many new ideas, designs and inventions have emerged from the fertile minds of the EAA membership and these ideas are not unique to the U.S. members only. Often one idea leads to another and we all benefit from it. In looking back through the prolific presentations of material that the EAA makes available to its members through the pages of SPORT AVIATION, it is no wonder at all.
Falco has simple, plain-type flaps that are actuated by an electrically driven wormgear. Flap setting is 15° for takeoff, 20° for landing.

A view of the variable geometry laminar wing design. The wing, stabilator and building top are all preformed polyester. The flap setting can be varied from -10 to +80 degrees. The result is a speed range from 18 mph at +12 degree flaps to a top speed of 230 mph at 20,000 feet. Cruise speed is 185 mph at 9000 feet with +10 degree flaps. Trim tabs are electrically operated from the cockpit.
SPOILERS: AN EMERGING TREND IN HOMEBUILT DESIGN

By Peter Abbott III
going back to early work in the 1930s, under the old NACA banner.

An outstanding example of use of spoilers for roll-control was on NASA's "ALTIT" (Advanced Technology Light Twin) program, but this use as a substitute for ailerons came about almost coincidentally. ALTIT adopted the spoiler roll-control system simply because they had also employed a nearly full-span Fowler flap for improved low-speed performance, and so were to half-span spoilers for lateral control. In May 1975, John W. Paulson, Jr., of NASA/Langley Research Center, published a paper on that work that attracted the interest of Percival H. Spencer, of Spencer Air Car fame. Spencer was developing the Volpar-Spencer Hydro-Glider, Drag-N-Hy, and immediately saw merit in the NASA study.

As stated above, the NASA research was conducted to prove in a wind tunnel whether theoretical applications of spoilers to the GA(IV)-1 wing would really work as well as predicted in a three-dimensional format.

Paulson wrote: "The development of new, thick, high-lift airfoil sections has had a profound effect on the General Aviation community because these sections offer the possibility of improved performance on several new light aircraft designs.

"These airfoils provide higher maximum lift coefficients than the conventional 64-sections airfoils used on many General Aviation aircraft. This increase in maximum lift coefficient allows the use of a smaller, more highly loaded wing with less wetted area. "These developments can increase cruise performance and improve ride quality. The increased thickness of these airfoils also provides the opportunity for wing structural weight savings. "With an appropriate high-lift device such as a full-span Fowler flap, further reduction in wing area may be achieved, and the desirable low-landing speeds of typical light aircraft can be maintained. "Full-span flaps, however, generally preclude the use of conventional ailerons, and an alternate method of lateral control is needed. One such method would use partial span spoilers also known as 'slot-tip' airfoils. "Several airplanes which use Fowler flaps with the advanced airfoils are already at the design stage or early flight-test stage of development. "Some of these airplanes use the 17 percent thick section airfoil, one of particular interest being the ALTIT, whose spoilers are vented when the flaps are extended and unvented when the flaps are retracted."

Before NASA's ALTIT flew, there were some sticky problems that appeared in two-dimensional research into the spoiler/flap combination, dating back to 1941 wind tunnel data studied by Francis M. Kogallo, inventor of the popular hang glider wing-sail that bears his name.

These data indicated that the spoilers had a region of very low effectiveness when the deflection was less than 10 or 15 degrees. Control reversal also appeared under certain conditions, if a small left spoiler deflection was used in...
Spoilers were first used in homebuilts on the Volpar-Spencer Drag-N-Fly, initially on both top and bottom wings.

Upper-wing spoilers were eliminated on the Drag-N-Fly as unnecessary, since the lower spoilers gave a fast response.

an effort to produce a roll to the left, the result instead was a roll to the right.

Further to explore this anomaly, Paulson's work in the Langley V/STOL tunnel was launched, using a rectangular wing with Fowler flap and spoilers. Static forces and moments were obtained for the wing with various flap deflections and positions, spoiler deflections, spoiler cross-section geometries, and vent-lip geometries.

In general, Paulson found, the three-dimensional data concurred with the two-dimensional data. Regions of decreased spoiler effectiveness were found to be limited to spoiler deflections of less than 10 - 15 degrees, and were most prominent at the highest flap deflections.

Other conclusions arrived at included:

- The spoilers generally showed acceptable lateral-control characteristics except for some regions of low effectiveness at small spoiler deflections.
- The spoiler effectiveness was increased when the flap deflection was increased.
- The spoiler effectiveness was increased when the angle of attack was increased and the flaps were deflected.
- The spoiler effectiveness was
P.H. Spencer celebrated his birthday flight-testing Drag-N-Fly with spoilers on all four wing surfaces.

Olympic seaplane of 1940 introduced spoilers to glider pilots for better glide path control when used together.

Here designer P.H. Spencer corrects for roll by applying left up spoilers on both top and bottom wings.
affected by vent-lip geometry, and the blunt vent lip gave the highest rolling moment.

* The Fowler flaps, as expected, significantly increased maximum lift coefficient, up to 96 per cent at maximum flap deflection.

Thus proven viable in wind-tunnel research, the use of full-span Fowler flaps for better glide-path control combined with spoilers for roll control already has made its appearance in the commercial aviation marketplace. Robertson Aircraft Corp. adapted the NASA spoiler research program to their own studies and fitted the devices to Piper Seneca and Cherokee Six aircraft with notable results in improved V/STOL performance. They have appeared on the Helio Courier, the American Jet Hustler, the Mitsubishi MU-2, and in the homebuilt field, briefly on Burt Rutan's VariEze.

Initially Rutan had designed VariEze with only differential elevon controls for roll moment input, on the canard surface, but poor workmanship in a number of VariEze homebuilts resulted in serious yaw problems, due apparently to partial stalling of the down-moving elevon.

To improve roll control, wingroot spoilers were tried, but Rutan reported VariEze still had a sluggish feel in roll and also had some coupling (pitch inputs when roll was commanded), particularly at forward CG. The spoilers were abandoned, and Rutan issued a mandatory A.D. notice to all VariEze builders to install conventional ailerons, which gave the fine little ship the roll rate of a Yankee.

More enthusiastic were the Mitsubishi people, whose MU-2 project was the first business aircraft to go to spoilers for roll control, permitting also full-span Fowlers for improved slow-flight and short-field capability. They heralded the redesigned craft simply as "The Spoiler."

Specifically, the Mitsubishi MU-2L has a wing area of 178 sq.ft. and a NACA 64A415 airfoil, a high-speed wing that is loaded to 65 lbs/sq.ft., higher even than the Citation, Lear 24, or Rockwell Sabre 60, resulting in a more solid ride in turbulence.

Japanese engineers designed the new MU-2 wing developed a small...
a spoiler that resides at about two-thirds chord position and extends along most of the wing's span. Pilots claim the spoilers are fully effective in roll control, particularly at low airspeeds, where it counts most. The NASA spoiler design, says the firm, eliminates the requirement for boost controls at high airspeed as well as eliminating the adverse yaw problem common to ailerons. The full-span Fowlers are double-slotted, with a chord ratio of 37 per cent.

With this background, it's apparent there is much to be said for installing spoilers on your homebuilt, with one caution: According to EAA's expert, Designee Program Advisor Tony Binggeli, "The sophisticated use of spoilers requires a relatively complex mechanism. It would therefore be unlikely that greater use of spoilers will be forthcoming unless someone designs the ultimate installation which would provide for a simple mechanical mining system of control which permits a selective balance deployment of the spoilers for both roll control and for glide-path control functions."

There's the challenge. A whole new world of flight performance awaits the homebuilder who can successfully come up with a way to combine full-span flaps and spoilers to maximize his short field capabilities without sacrificing roll control, in a simple, direct manner.

NASA diagram shows mechanism of spoiler differential actuating system, position of spoiler in relation to full-span flaps.

American Jet's Hustler, which first flew in January this year, adopted spoilers in place of ailerons to make room for flaps.
Mooney's Cruise Missile

At a press conference during this year's Reading Air Show, spokesmen for Mooney Aircraft Corporation announced a commitment to proceed with development of a pressurized, single-engine aircraft. For at least the past 15 months, Roy Lopresti, vice president of research and development, has been rumored to be working on such a project.

Dubbed the MX for Mooney Experimental (not for an uncontinental ballistic missile), the formal model designation is M-30. The major design objectives have been defined as:

- 10,000 feet cabin at 25,000 feet (4.7 pounds per square inch pressurization)
- Cruise speed at 15 percent power of from 213 to 290 knots
- Top speed of from 343 to 260 knots
- Stall speed of 52 to 66 knots indicated airspeed
- Range of 996 nm at 75-percent power and 1,226 at 65 percent

A cabin mock-up has been constructed, and the new high-technology high-aspect ratio airstall, which features Fowler flaps extending 90 percent of the wingspan and spoilers for roll control, has been undergoing wind tunnel testing. Supplemental roll control will be provided by small ailerons.

Lopresti anticipates that the combination will result in a ratio between top and stall speeds of 6.1 and points out that 3.5:1 is standard for propeller-driven aircraft.

The aircraft has been designed from scratch (it does not look like other Mooney designs and has a swept tail) and consideration has been given to redundancy for the electrical and air-driven flight instrument systems. Provision for radar and tachos systems also has been incorporated in the study phase.

Entry to the six-place cabin is via an air-stair door in the left rear of the fuselage. An Avco Lycoming 530-540 series engine rated at 350 hp has been chosen to power the M-30, and fuel capacity is planned to be 1790 gallons usable.

Work has been started on a first aircraft. The company plans to start the flight-test program in 1962, and the target production date is 1965. —EDT

Sensors and Fowler flaps are displayed during wind tunnel testing of the Mooney M-30's airstall. Small ailerons will be mounted to improve roll response at low airspeeds.

A cabin mock-up of Mooney's six-place, pressurized M-30 sports an air-stair door and a swept tail. The 350-hp, 230-knot single is scheduled to go into production in 1965.
(Drawing by Bill Durand)
The spoiler nests neatly in a cavity just ahead of the rear spar and full span flap.

(Drawing by Bill Durand)
Spoiler control can be very, very simple as seen in this schematic diagram of the Mk. V's system.
<table>
<thead>
<tr>
<th>Plain basic airfoil</th>
<th>Angle of attack</th>
<th>Lift coefficient</th>
<th>Max. lift coefficient</th>
<th>Sp. range ratio</th>
<th>Percent improvement in lift</th>
<th>Overplain airfoil</th>
<th>Percent improvement in speed-range ratio</th>
<th>Report</th>
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</thead>
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<tr>
<td>Simple flap</td>
<td>45° 30%</td>
<td>1.950</td>
<td>128.2</td>
<td>4.0</td>
<td>12° 51%</td>
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<td>None</td>
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<tr>
<td>Slotted flap</td>
<td>45° 30%</td>
<td>1.980</td>
<td>120.5</td>
<td>4.0</td>
<td>12° 53%</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Double slot and flap</td>
<td>45° 30%</td>
<td>2.442</td>
<td>117.5</td>
<td>4.0</td>
<td>16° 19%</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Fixed slot, cut in basic airfoil</td>
<td></td>
<td>1.772</td>
<td>73.8</td>
<td>5.3</td>
<td>24° 37%</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>N.A.C.A. fixed auxiliary airfoil, ahead of basic airfoil</td>
<td></td>
<td>0° 14.5%</td>
<td>1.705</td>
<td>104.5</td>
<td>3.5 Approx.</td>
<td>24° 32%</td>
<td>None</td>
<td>23%</td>
</tr>
<tr>
<td>N.A.C.A. optimum fixed slot</td>
<td></td>
<td>0° 14.5%</td>
<td>1.648</td>
<td>76.4</td>
<td>24° 27%</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Handley-Page type automatic slot</td>
<td></td>
<td>0° 14.5%</td>
<td>1.632</td>
<td>114.2</td>
<td>28° 20%</td>
<td>None</td>
<td>None</td>
<td>34.3%</td>
</tr>
<tr>
<td>Front slot and simple flap</td>
<td>45° 30%</td>
<td>2.182</td>
<td>91.0</td>
<td>3.8</td>
<td>19° 10%</td>
<td>12%</td>
<td>None</td>
<td>7%</td>
</tr>
<tr>
<td>Front slot and slotted flap</td>
<td>45° 30%</td>
<td>2.261</td>
<td>93.2</td>
<td>3.8</td>
<td>19° 75%</td>
<td>16%</td>
<td>None</td>
<td>10%</td>
</tr>
<tr>
<td>Triple slot and flap</td>
<td>45° 30%</td>
<td>2.600</td>
<td>87.3</td>
<td>3.8</td>
<td>20° 101%</td>
<td>33%</td>
<td>None</td>
<td>3%</td>
</tr>
<tr>
<td>Split flap, rotated down, no backward movement</td>
<td>50° 30%</td>
<td>2.16</td>
<td>138.5</td>
<td>4.3</td>
<td>14° 70%</td>
<td>10.7%</td>
<td>63%</td>
<td>11%</td>
</tr>
<tr>
<td>Split flap, trailing edge moved vertically downward (lap)</td>
<td>60° 30%</td>
<td>2.35</td>
<td>150.8</td>
<td>3.7 Approx.</td>
<td>13° 85%</td>
<td>20.5%</td>
<td>77%</td>
<td>17.5%</td>
</tr>
<tr>
<td>Split flap, hinge point moved back to 90% of chord</td>
<td>54° 40%</td>
<td>2.222</td>
<td>142.2</td>
<td>3.8</td>
<td>13° 75%</td>
<td>10.7%</td>
<td>63%</td>
<td>11%</td>
</tr>
<tr>
<td>Hall wing, front slot closed</td>
<td>48° 34%</td>
<td>2.08</td>
<td>138.8</td>
<td>3.6</td>
<td>13° 64%</td>
<td>6.7%</td>
<td>63%</td>
<td>8.1%</td>
</tr>
<tr>
<td>Fowler wing projected (area increased approx. 31% over basic airfoil)</td>
<td>40° 40%</td>
<td>2.422</td>
<td>155.3</td>
<td>4.25</td>
<td>15° 90%</td>
<td>24.3%</td>
<td>83%</td>
<td>21.2%</td>
</tr>
<tr>
<td>Fowler wing with N.A.C.A. 22 slot and round nose of basic airfoil</td>
<td>Slot 14.5% Flap 40%</td>
<td>2.49</td>
<td>137 199</td>
<td>3.76</td>
<td>21° to 25°</td>
<td>96%</td>
<td>25.1%</td>
<td>7%</td>
</tr>
<tr>
<td>N.A.C.A. 22 slot on plain wing with rounded nose</td>
<td>Slot 14.5%</td>
<td>1.78</td>
<td>97.7</td>
<td>4.8</td>
<td>30° 40%</td>
<td>None</td>
<td>None</td>
<td>13%</td>
</tr>
</tbody>
</table>

Notes.—1. In comparing properties of modified sections with the plain basic section, the coefficients used in each case were obtained under similar test conditions. Drag coefficients were taken with slot closed (if movable) and with flap neutral.
2. A low value of L/D at maximum lift indicates a steep glide angle and consequently a short landing.
3. An L/D of 8 corresponds to a gliding angle of approximately 7 degrees, and a value of 3.5 means about 15 degrees. (T.R. 428.)
4. Based on total wing area; lift increasing device extended and projected on original chord line. Actually this area is necessary structural area and forms the basis for the comparison with the simple flap.
5. With slot and flap retracted the airfoil is not perfect, having a drag coefficient of 0.0182 compared with 0.0150 for the plain airfoil.
6. Based on contracted area.

Fig. 15. Characteristics of high lift devices applied to the Clark Y wing. (The Reynolds' number for all tests is 600,000, which corresponds to about one-third that for an ordinary small airplane at landing speed.)
<table>
<thead>
<tr>
<th>Slot combination</th>
<th>$C_{L_{\text{max}}}$</th>
<th>$C_{D_{\text{min}}}$</th>
<th>$\frac{C_{L_{\text{max}}}}{C_{D_{\text{min}}}}$</th>
<th>$\alpha_{C_{L_{\text{max}}}}$ degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.291</td>
<td>0.0152</td>
<td></td>
<td>85.0</td>
<td>15</td>
</tr>
<tr>
<td>1.772</td>
<td>0.0240</td>
<td></td>
<td>73.8</td>
<td>24</td>
</tr>
<tr>
<td>1.596</td>
<td>0.0199</td>
<td></td>
<td>80.3</td>
<td>21</td>
</tr>
<tr>
<td>1.548</td>
<td>0.0188</td>
<td></td>
<td>82.3</td>
<td>19</td>
</tr>
<tr>
<td>1.440</td>
<td>0.0164</td>
<td></td>
<td>87.8</td>
<td>17</td>
</tr>
<tr>
<td>1.902</td>
<td>0.0278</td>
<td></td>
<td>68.3</td>
<td>24</td>
</tr>
<tr>
<td>1.881</td>
<td>0.0270</td>
<td></td>
<td>69.7</td>
<td>24</td>
</tr>
<tr>
<td>1.813</td>
<td>0.0243</td>
<td></td>
<td>74.6</td>
<td>23</td>
</tr>
<tr>
<td>1.930</td>
<td>0.0340</td>
<td></td>
<td>56.8</td>
<td>25</td>
</tr>
<tr>
<td>1.885</td>
<td>0.0319</td>
<td></td>
<td>59.2</td>
<td>24</td>
</tr>
<tr>
<td>1.885</td>
<td>0.0363</td>
<td></td>
<td>51.9</td>
<td>25</td>
</tr>
<tr>
<td>1.850</td>
<td>0.0298</td>
<td></td>
<td>62.1</td>
<td>24</td>
</tr>
<tr>
<td>1.692</td>
<td>0.0228</td>
<td></td>
<td>74.2</td>
<td>22</td>
</tr>
<tr>
<td>1.672</td>
<td>0.0214</td>
<td></td>
<td>78.2</td>
<td>22</td>
</tr>
<tr>
<td>1.510</td>
<td>0.0208</td>
<td></td>
<td>72.6</td>
<td>19</td>
</tr>
<tr>
<td>1.662</td>
<td>0.0258</td>
<td></td>
<td>64.4</td>
<td>22</td>
</tr>
</tbody>
</table>

(a) Multiple fixed slots.

Aerodynamic characteristics of a Clark Y wing with slots and flaps.
<table>
<thead>
<tr>
<th>Slot combination</th>
<th>$C_{L_{\text{max}}}$</th>
<th>$C_{D_{\text{min}}}$</th>
<th>$\frac{C_{L_{\text{max}}}}{C_{D_{\text{min}}}}$</th>
<th>$\alpha C_{L_{\text{max}}}$ degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.950</td>
<td>0.0152</td>
<td>128.2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>2.182</td>
<td>0.0240</td>
<td>91.0</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>2.235</td>
<td>0.0278</td>
<td>80.3</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>2.200</td>
<td>0.0340</td>
<td>64.7</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>2.210</td>
<td>0.0270</td>
<td>81.8</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>1.980</td>
<td>0.0164</td>
<td>120.5</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1.770</td>
<td>0.0164</td>
<td>108.0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2.442</td>
<td>0.0208</td>
<td>117.5</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>2.500</td>
<td>0.0258</td>
<td>96.8</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2.185</td>
<td>0.0214</td>
<td>102.0</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2.261</td>
<td>0.0243</td>
<td>93.2</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>2.320</td>
<td>0.0319</td>
<td>72.7</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>2.535</td>
<td>0.0363</td>
<td>69.8</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>2.600</td>
<td>0.0298</td>
<td>87.3</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>2.035</td>
<td>0.0298</td>
<td>68.3</td>
<td>21</td>
</tr>
</tbody>
</table>

* $C_{D_{\text{min}}}$ with flap neutral.

(b) Multiple fixed slots and a slotted flap deflected 45 degrees.