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Special Report #159

WIND-TUNNEL INVESTIGATION OF THE LIFT CHARACTERISTICS OF AN NACA 27-212 AIRFOIL EQUIPPED WITH TWO TYPES OF FLAP

By Robert S. Swanson and Marvin J. Schuldenfrei
Langley Memorial Aeronautical Laboratory

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SUMMARY

An investigation has been made in the NACA 7- by 10-foot wind tunnel of a large chord NACA 27-212 airfoil with a 20-percent-chord split flap and with two arrangements of a 25.66-percent-chord slotted flap to determine the section lift characteristics as affected by flap deflection for the split flap and as affected by flap deflection, flap position, and slot shape for the slotted flap. For the two arrangements of the slotted flap, the flap positions for maximum section lift are given. Comparable data on the NACA 23012 airfoil equipped with similar flaps are also given.

On the basis of maximum section lift coefficient, the slotted flap with an easy slot entry was slightly better than either the split flap or the slotted flap with a sharp slot entry. With both types of flap the decrease in the angle of attack, for maximum section lift coefficient, with flap deflection is large for the NACA 27-212 airfoil as compared with the NACA 23012 airfoil. Also with both flaps, the maximum section lift coefficient obtained with flaps is much lower for the NACA 27-212 airfoil than for the NACA 23012 airfoil.

INTRODUCTION

The National Advisory Committee for Aeronautics has been conducting an extensive investigation of wing-flap combinations to furnish information applicable to the aerodynamic and the structural design of high-lift devices for improving the safety and the performance of airplanes. For take-off and initial climb a wing-flap combination capable of producing moderately high lift with low drag is desirable, but for landing a device producing high lift with a variable drag is probably preferable. Other important features are: no increase in drag with the flap neutral; small change in pitching moment with flap deflection; low operation forces; and freedom from possible icing hazards.

The investigation up to the present time has been on conventional airfoils of various thicknesses from 12 to 30 percent. (See references 1 to 6.) From these tests it was found that for a moderately thick airfoil very little improvement in the wing-flap combination was obtained if the split-flap chord was greater than 20 percent (reference 1) and the slotted-flap chord was greater than 25 percent (references 2 to 6).

Although the split flap cannot meet some of the requirements, its simplicity makes it one of the most widely used types of flap. The slotted flaps are apparently capable of meeting more of the specifications than any other type of flap tested by the NACA.

The present paper gives the results of an investigation of the lift characteristics of a laminar-flow airfoil (NACA 27-212), equipped with a 20-percent-chord split flap and with two arrangements of a 25.66-percent-chord slotted flap.

MODELS

Plain Airfoil

The basic airfoil was built of laminated mahogany to the NACA 27-212 profile and has a chord of 3 feet and a span of 7 feet; the ordinates for the section are given in table I. The trailing-edge portion of the airfoil is easily removable so that the model can be quickly altered for tests of various flap arrangements.

Airfoil with Split Flap

The simple split flap used was a 20-percent-chord flap built of straight plywood and did not conform to the airfoil profile. The flap was arranged for setting at deflections from 0° to 75° in 15° increments. The flap deflection δ_f is measured along the arc between the trailing edge of the airfoil and the trailing edge of the flap, as shown in figure 1.

Slotted-Flap Arrangements and Slot Shapes

The flap and the slot shapes were built of laminated mahogany. The slotted flap used in the present investigation was made comparable with flap 1 of reference 2 and had a 25.66-percent chord. The flap is designated flap 1, and the ordinates are given in table II.

The slot shapes were made comparable with the slot shapes of reference 4. The sharp-entry slot is designated shape a and the easy-entry slot, shape b (fig. 2). The pieces forming the slot shapes were bolted to the main airfoil in place of the plain trailing edge, and the flaps were mounted on the airfoil by means of special hinges that permitted a wide variation in the location of the flap with respect to the slot lip.

TESTS

The models were mounted in the closed test section of the NACA 7- by 10-foot wind tunnel (references 2 and 7) so that they completely spanned the jet except for small clearances at each end. The main airfoil was rigidly attached to the balance frame by torque tubes, which extended through the upper and the lower boundaries of the tunnel. The angle of attack of the model was set from outside the tunnel by rotating the torque tubes with a calibrated drive. Since approximately two-dimensional flow is obtained with this type of installation, the section characteristics of the model under test can be determined.

All of the tests, except those performed to determine the effect of scale, were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour under standard atmospheric conditions and to an average test Reynolds number of about 2,190,000. Because of the wind-tunnel turbulence, the effective Reynolds number was approximately 3,500,000. For all tests the Reynolds number is based on the chord of the airfoil with the flap retracted and on a turbulence factor of 1.6 for the tunnel.

Plain Airfoil

The lift of the plain airfoil was measured over the complete angle-of-attack range from -6° to the stall.

Tests were also made to determine the effect of scale on the maximum lift coefficient over the range available in the NACA 7- by 10-foot wind tunnel.

Airfoil with Split Flap

The airfoil with the split flap was tested at flap deflections from 0° to 75° in 15° increments. As in tests of the plain airfoil, the lift was measured over the complete angle-of-attack range from -6° to the stall. The effect of scale on maximum lift coefficient was determined for the 60° flap deflection.

Airfoil with Slotted Flaps

The airfoil with the slotted flap was tested with both slot shapes over a large range of flap positions at deflections from 0° to 60° in 10° increments. The lift was measured throughout the complete angle-of-attack range from -6° to the stall for all low flap deflections and at selected optimum points for high flap deflections. Tests were made to determine the effect of scale on the maximum lift coefficient for the slotted flap with the easy entry (slot 1-b) when deflected 40° and located at the optimum position for maximum lift.

RESULTS AND DISCUSSION

The test results are given in standard section nondimensional coefficient form corrected as explained in reference 2.

c_l section lift coefficient (l/qc)

where

l section lift

q dynamic pressure $(1/2\ \rho V^2)$

c chord of basic airfoil with flap fully retracted.

and

α_o angle of attack for infinite aspect ratio

δ_f flap deflection

The various measurements made in the tests are believed to be accurate within the following limits:

$c_{l_{max}}$ - - - - - - - - - - - - - - ± 0.03

α_o - - - - - - - - - - - - - - - ±0.1°

δ_f - - - - - - - - - - - - - - - ±0.2°

Flap position - - - - - - - - - - ±0.001 c

Plain Airfoil

The section lift characteristics of the plain NACA 27-212 airfoil from the tests in the turbulent 7- by 10-foot tunnel are given in figure 3. The section lift characteristics of a plain airfoil when determined in the more turbulent variable-density tunnel (reference 8) showed a maximum lift coefficient of about 0.2 less than that obtained in the 7- by 10-foot wind tunnel at the same effective Reynolds number. The angle of attack for a given lift coefficient is approximately 1/2° less for the model of the NACA 27-212 airfoil installed in the variable-density tunnel and tested under three-dimensional flow conditions but corrected to two-dimensional flow conditions.

Airfoil with Split Flap

The section lift characteristics of the airfoil equipped with a split flap are given for each flap deflection in figure 4. The maximum section lift coefficient determined in the variable-density tunnel (reference 8) for an NACA 27-213 airfoil with a split flap deflected 60° was about 0.17 less than that obtained in the 7- by 10-foot wind tunnel at the same effective Reynolds number. The angle of attack for a given lift coefficient is approximately 1° less for the model tested in the variable-density tunnel.

The decrease in the angle of attack, for the maximum section lift coefficient, with flap deflection is large compared with that of the NACA 23012 airfoil (reference 1) and may be of importance in the case of stalling with partial-span flaps.

Airfoil with Slotted Flap

<u>Determination of optimum positions for maximum lift.</u>- The data presented in this section are the results of the maximum-lift investigation of both slot shapes in which the flap, at a given deflection, was located at various points over a considerable area with respect to the slot lip of the main airfoil. The data are presented as contours of the position of the nose point of the flap relative to the slot lip for a given lift coefficient. The nose point of the flap is defined as the point of tangency of a line drawn perpendicular to the airfoil chord and tangent to the leading-edge arc of the flap when neutral, as shown in figure 2.

The complete maximum-lift data for slotted flaps 1-a and 1-b deflected 10°, 20°, 30°, 40°, 50°, and 60° are given in figures 5 and 6. An inspection of these figures shows that the contours closed only for the 40° flap deflection for flap 1-a (sharp entry) and for the 20°, 40°, and 60° flap deflections for flap 1-b (easy entry). For the small deflections, the position for maximum lift coefficient is not very critical and only a sufficient number of positions were taken to cover any practical path along which the flap is likely to be operated. As for the split flap, the decrease in angle of attack for maximum section lift coefficient with flap deflection is large compared with that of the NACA 23012 airfoil.

It may also be noted that the optimum gap between the airfoil and the flap tends, in general, to decrease as the flap deflection increases.

From these contours, it should be possible for the designer to choose the best path for the flap to follow from a consideration of maximum lift coefficient alone. If, because of structural considerations, it is impossible to use the best aerodynamic path, the loss caused by using a compromise path can be readily evaluated.

<u>Section lift characteristics of selected optimum arrangements.</u>- The section lift characteristics of selected optimum arrangements of slotted flaps 1-a and 1-b are given

in figures 7 and 8. The optimum arrangements were chosen from considerations of maximum lift coefficient alone. Additional data are included for arrangements that are aerodynamically less desirable in order to allow for deviations in the flap path to simplify the construction. A table included in each figure shows the nose position of the flap for the various deflections, and these positions are plotted on the diagram. The path hereinafter referred to as the "selected optimum path" is shown by the broken line through the points and is an assumed compromise between aerodynamic and structural considerations. The lift characteristics shown in these figures are typical; complete data for other positions of the various flaps at the several flap deflections are available upon request.

A comparison of the two slotted-flap arrangements and the split flap, as lift-increasing devices on an NACA 27-212 airfoil, is shown in figure 9, where increments of maximum lift coefficients with respect to the plain airfoil are plotted against flap deflection. The slotted flaps are moved along the selected optimum path. Note that there is only a small gain in the maximum lift coefficient with deflections greater than 40°.

Although slotted flap 1-b is the better flap for all flap deflections, the split flap is almost as satisfactory as a lift-increasing device and is mechanically simpler to construct and operate. For this reason the split flap seems to be the best compromise from the standpoint of structural and of lift-increasing considerations.

Effect of Scale on the Maximum Lift Coefficient

The effect of scale on the maximum lift coefficient of the plain airfoil, of the airfoil with split flap deflected 60°, and of the airfoil with slotted flap 1-b located at its optimum position for 40° deflection is shown in figure 10 along with some results from the variable-density tunnel (reference 8). The difference between the results of the two tunnels at the same effective Reynolds number is unexplained but has been previously noted for other airfoils.

Inspection of the curves shows that the increment of maximum section lift coefficient is not constant with the effective Reynolds number but decreases slightly as the Reynolds number increases. The break in the curve for the plain airfoil at the effective Reynolds number

2,630,000 is apparently due to a change in air flow in the maximum lift region, which allows the airfoil to go to a higher angle of attack without stalling at the higher Reynolds numbers.

Comparison with the NACA 23012 Airfoil

Figure 11 shows that a much higher maximum section lift coefficient is obtainable with the NACA 23012 airfoil (references 1 and 2) equipped with split and slotted flaps than with the NACA 27-212 airfoil equipped with similar flaps. It must be remembered, however, that the maximum lift is but one of the several factors involved in the final selection of an airfoil for a given airplane.

CONCLUDING REMARKS

On the basis of maximum section lift coefficient, the slotted flap with an easy slot entry was slightly better than either the split flap or the slotted flap with a sharp slot entry. For both types of flap the decrease in angle of attack for maximum section lift with flap deflection is large on the NACA 27-212 airfoil as compared with the NACA 23012 airfoil. In addition, the maximum section lift obtained with flaps on the NACA 27-212 airfoil is much lower than that obtained with flaps on the NACA 23012 airfoil.

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

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TABLE I

Ordinates for NACA 27-212 Airfoil
(Stations and ordinates in percent of airfoil chord)

insert Reference - SR159

Station	Upper surface	Lower surface
0	0	0
1.25	1.45	-1.10
2.5	2.02	-1.51
5.0	2.86	-2.05
7.5	3.50	-2.42
10	4.01	-2.72
15	4.85	-3.21
20	5.50	-3.58
25	6.02	-3.88
30	6.47	-4.12
35	6.82	-4.32
40	7.08	-4.47
45	7.24	-4.57
50	7.35	-4.61
55	7.35	-4.64
60	7.26	-4.60
65	7.04	-4.47
70	6.72	-4.25
75	6.20	-3.98
80	5.48	-3.52
85	4.39	-2.83
90	3.00	-1.94
95	1.46	- .95
97.5	.70	- .45
100	.08	- .08

L.E. radius: 0.70. Slope of radius through end of chord: 0.12.

TABLE II

Ordinates for Slotted Flap 1
(Stations and ordinates in percent of airfoil chord)

Station	Upper surface	Lower surface
0	-1.24	-1.24
.67	.76	-2.50
1.39	1.79	-3.06
2.78	3.01	-3.58
4.17	3.83	-3.64
5.67	4.44	-3.52
6.95	4.76	-3.39
8.33	4.82	-3.22
10.67	4.39	-2.83
15.67	3.00	-1.94
20.67	1.46	- .95
23.17	.70	- .45
25.66	.08	- .08

Center of L.E. arc

2.92	-1.24	

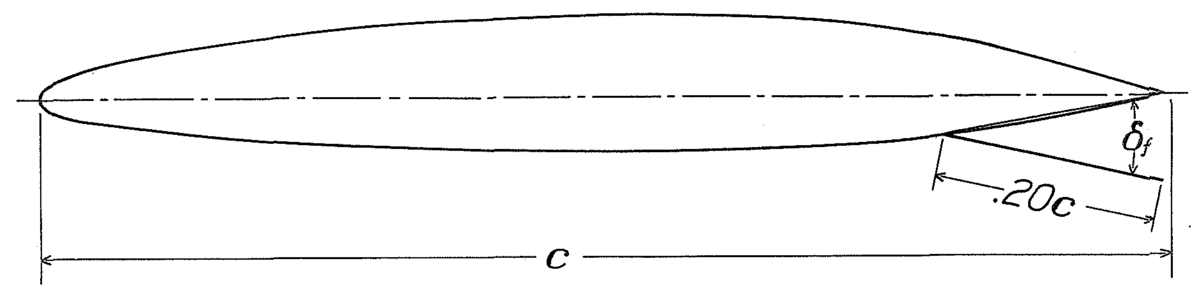


Figure 1.- Section of NACA 27-212 airfoil with split flap.

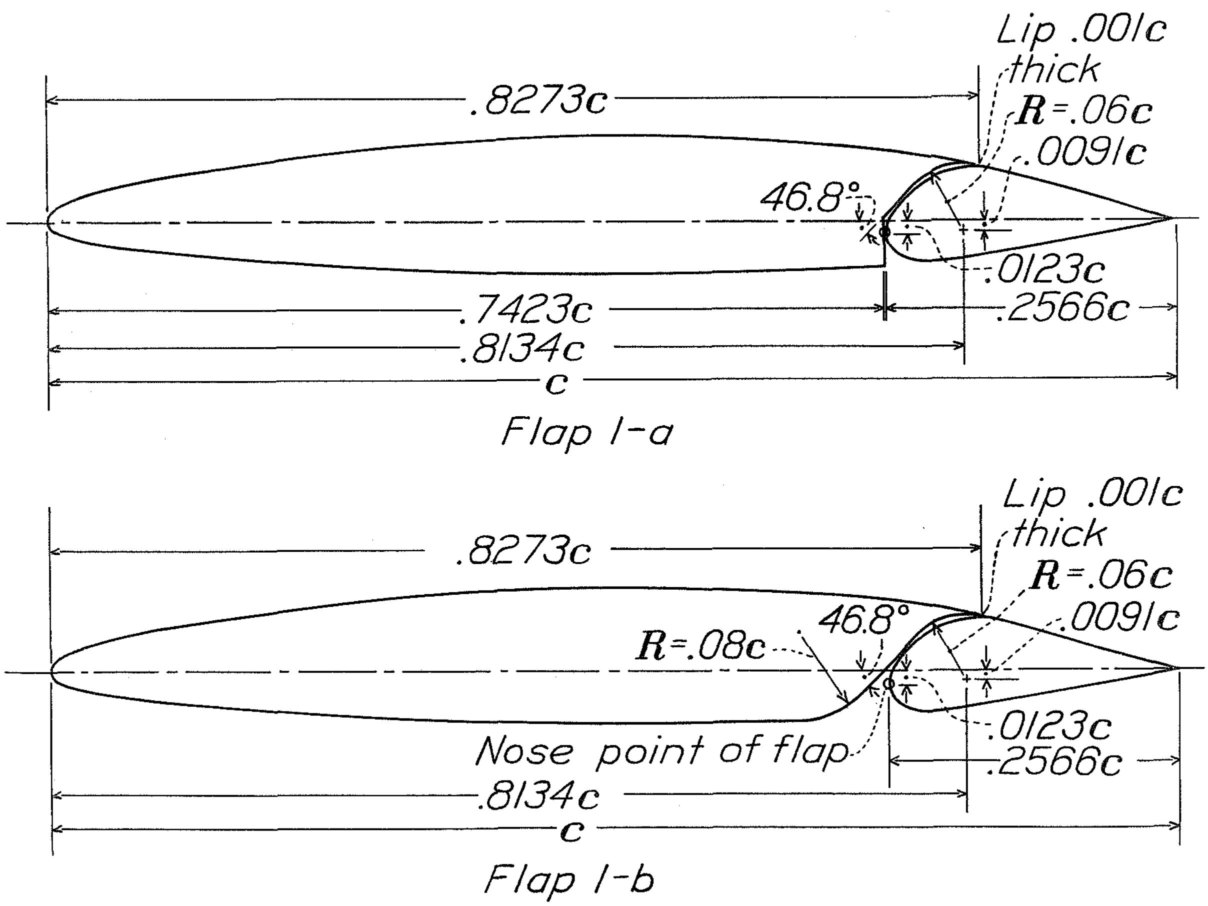
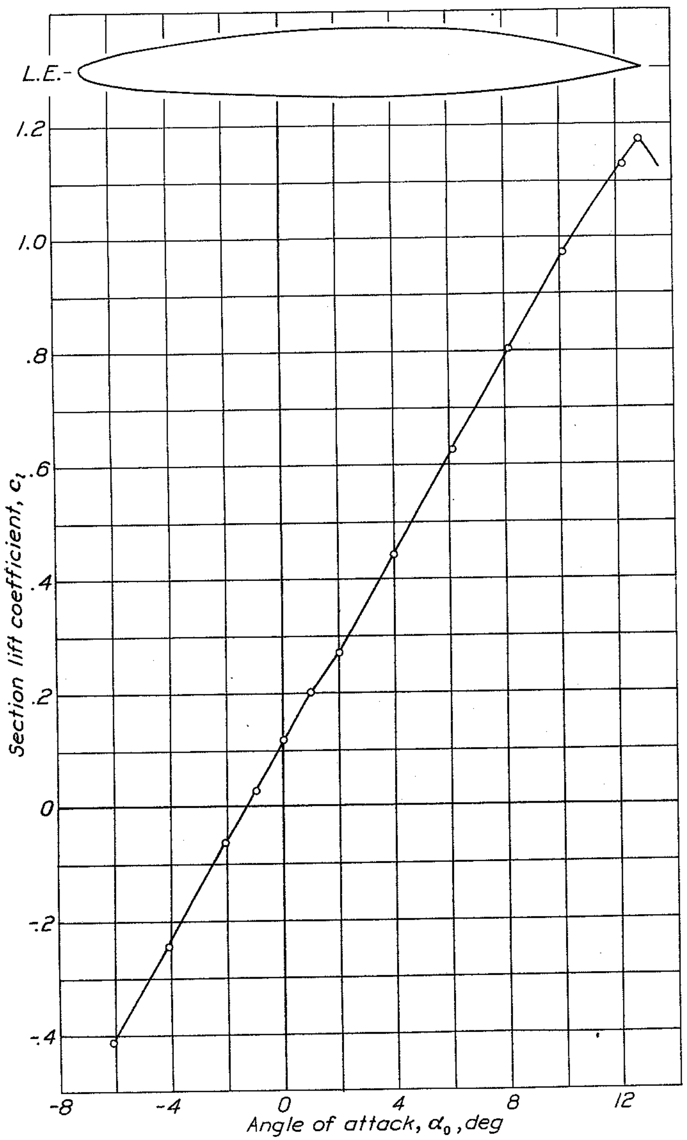


Figure 2.- Sections of NACA 27-212 airfoil with two arrangements of slotted flap 1.



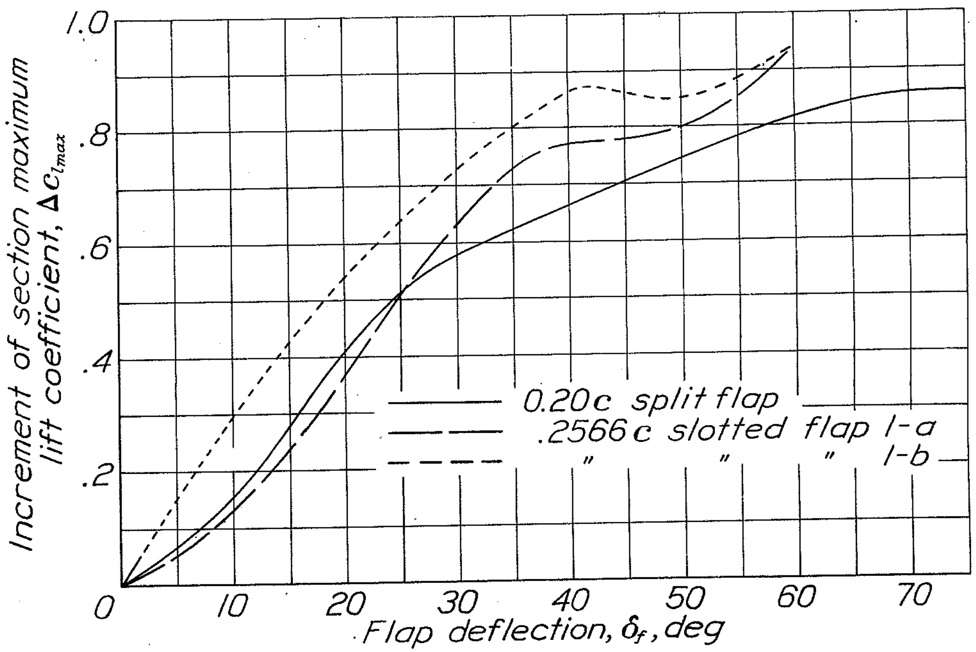


Figure 9.- Comparison of increments of section maximum lift coefficients for 0.20c split flap and 0.2566c slotted flaps 1-a and 1-b when moved and deflected along the selected optimum paths. NACA 27-212 airfoil.

Figure 3.- Section lift characteristics of the NACA 27-212 plain airfoil.

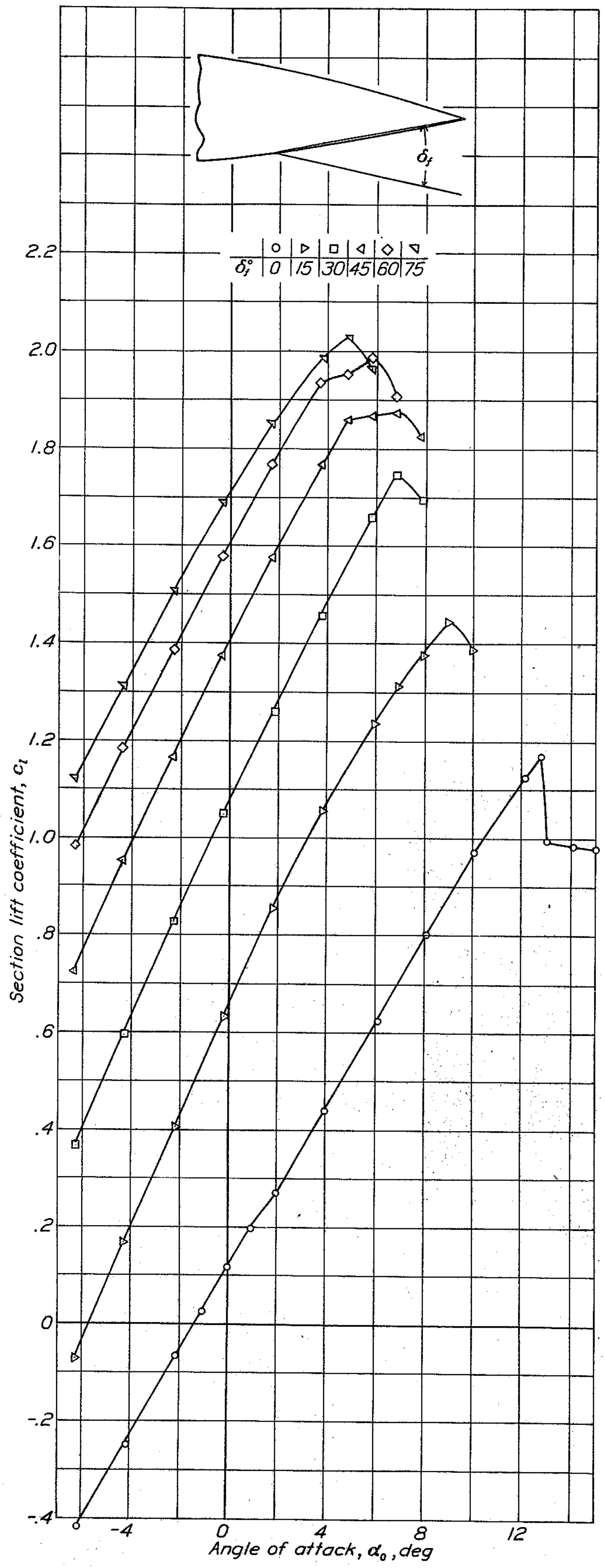
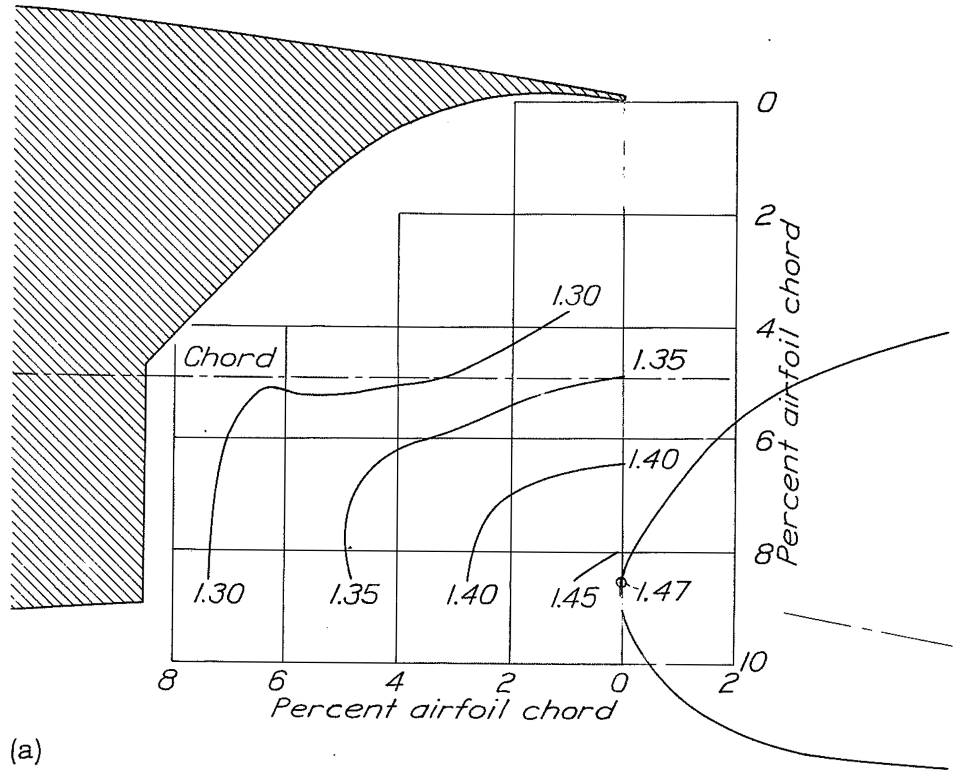
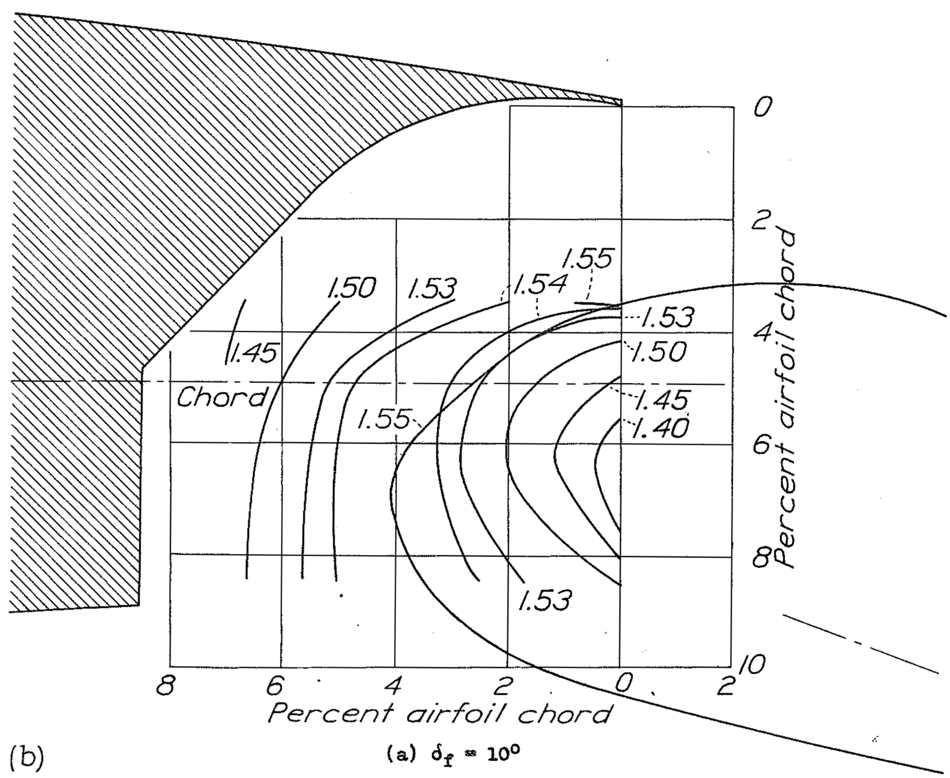


Figure 4.- Section lift characteristics of the NACA 27-212 airfoil with a 0.20c split flap.



(a)

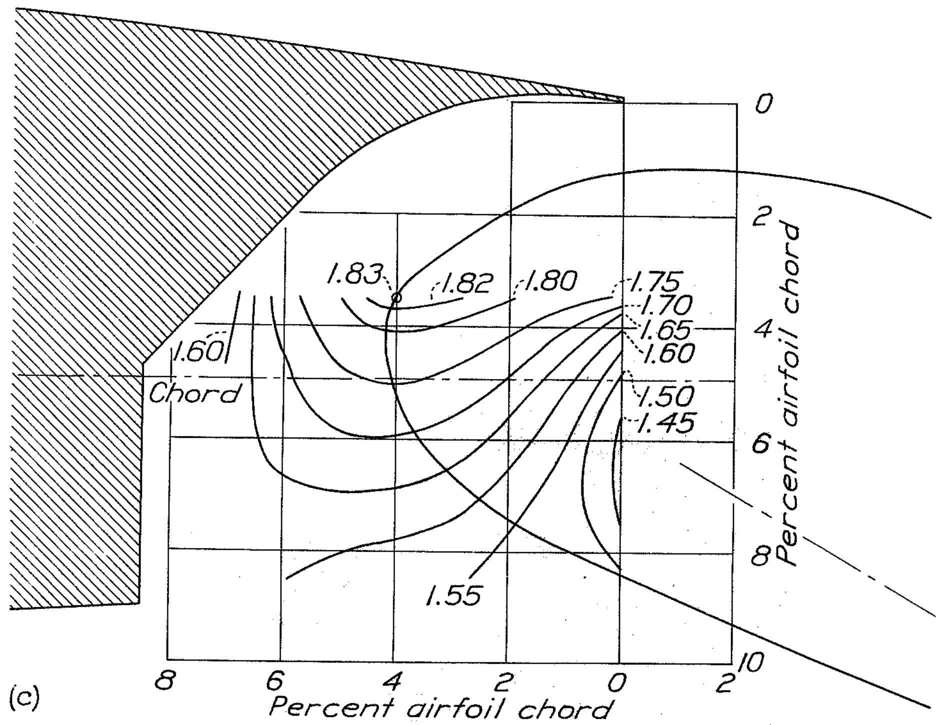


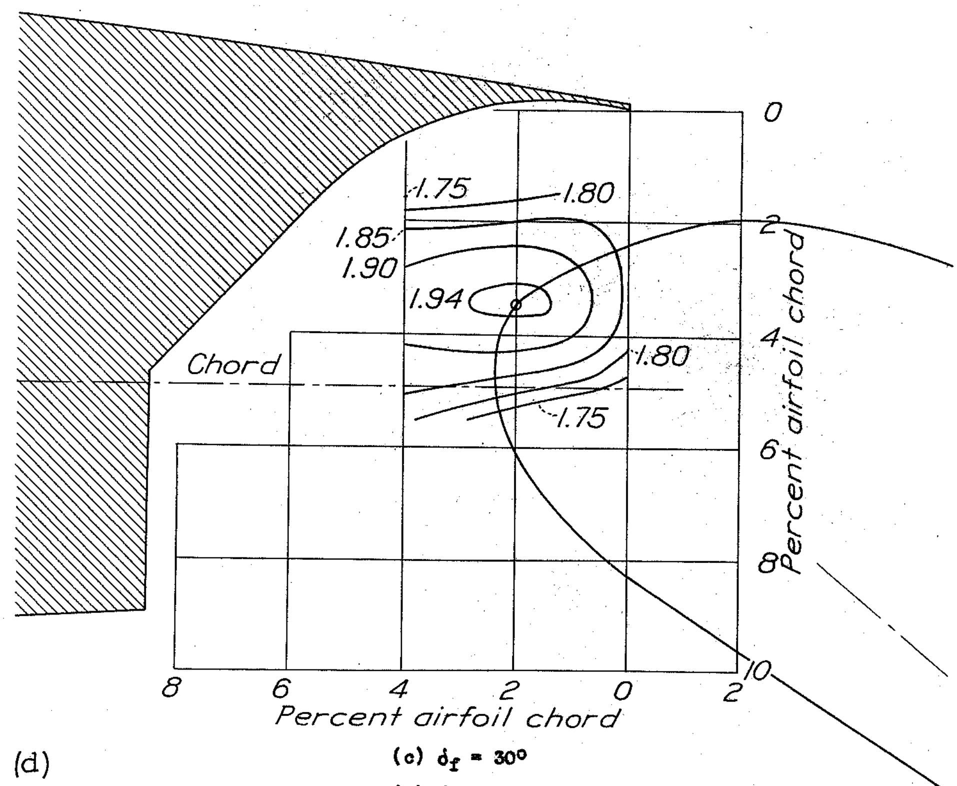
(b)

(a) $\delta_f = 10^\circ$

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

Figure 5 a to f.- Contours of flap location for $c_{l_{max}}$. Slotted flap 1-a.

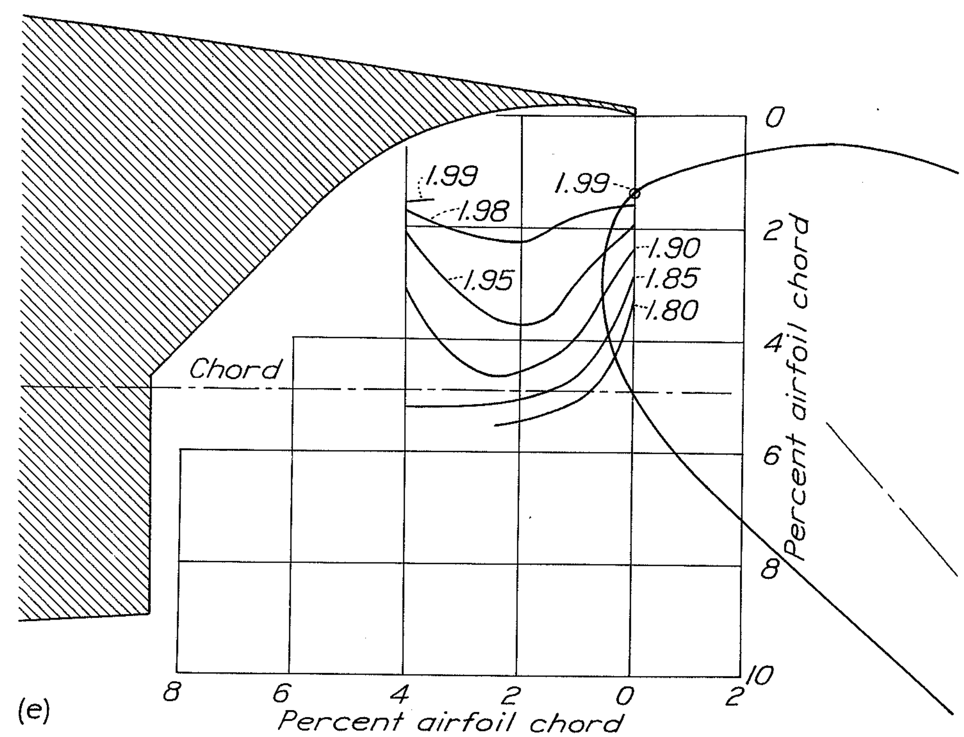


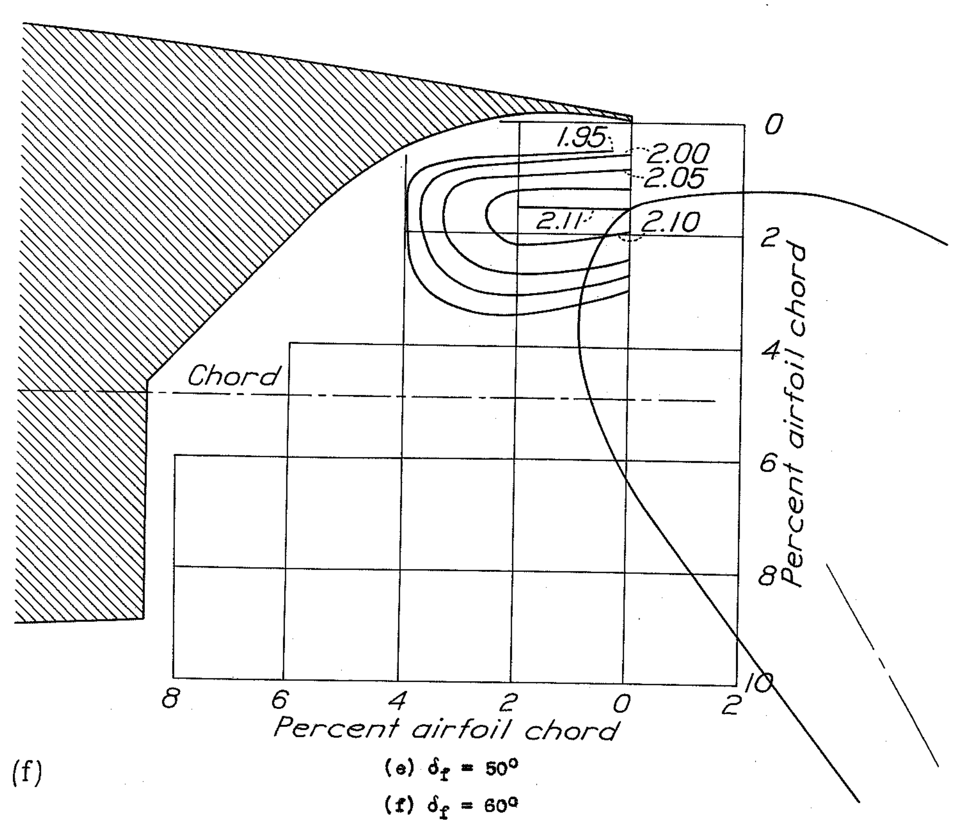


(c) $\delta_f = 30°$

(d) $\delta_f = 40°$

Figure 5 c,d.

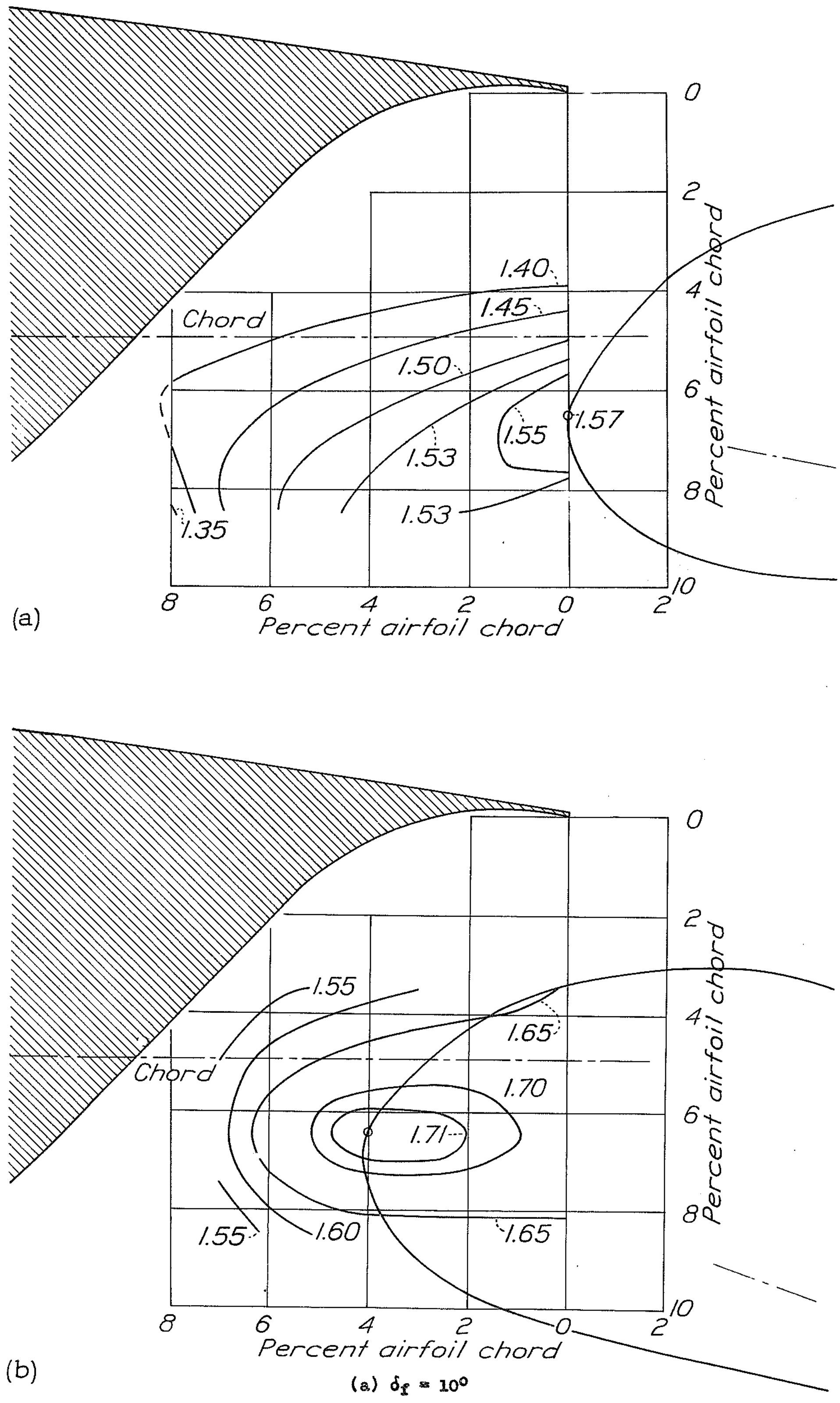




(e) $\delta_f = 50^\circ$

(f) $\delta_f = 60^\circ$

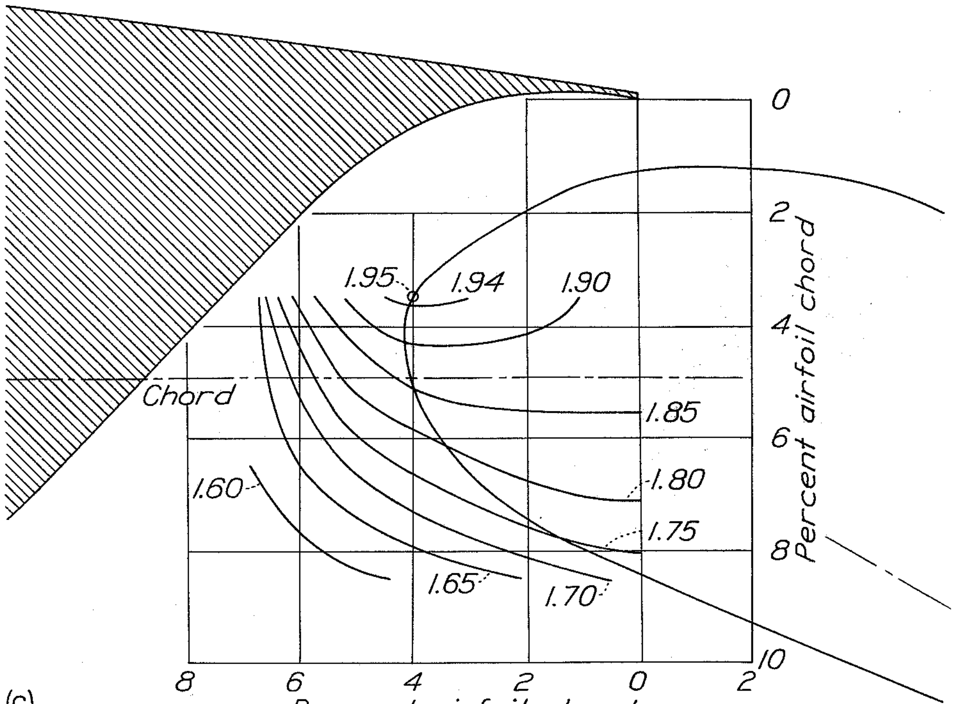
Figure 5 e,f.



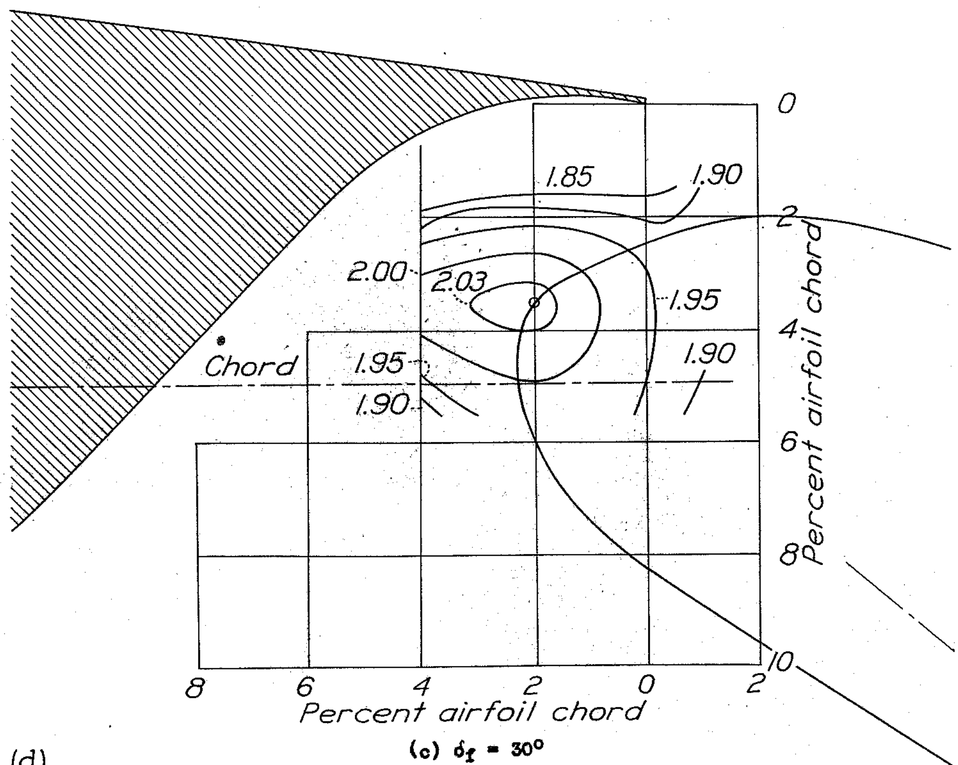
(a) $\delta_f = 10°$

(b) $\delta_f = 20°$

Figure 6 a to f.- Contours of flap location for $c_{l_{max}}$. Slotted flap 1-b.



(c)

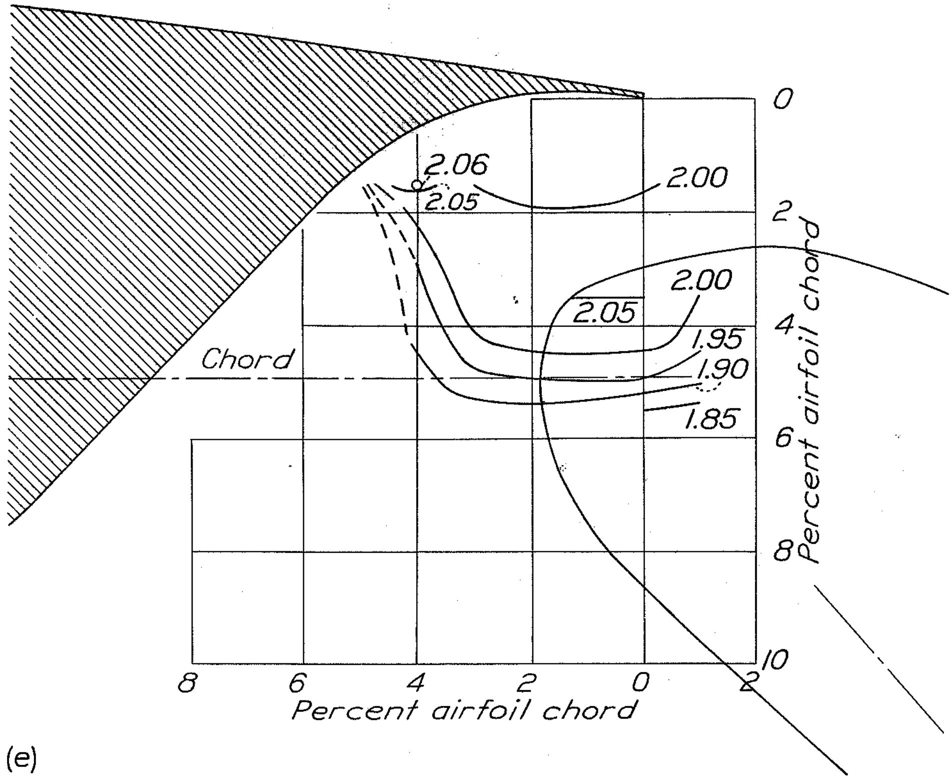


(d)

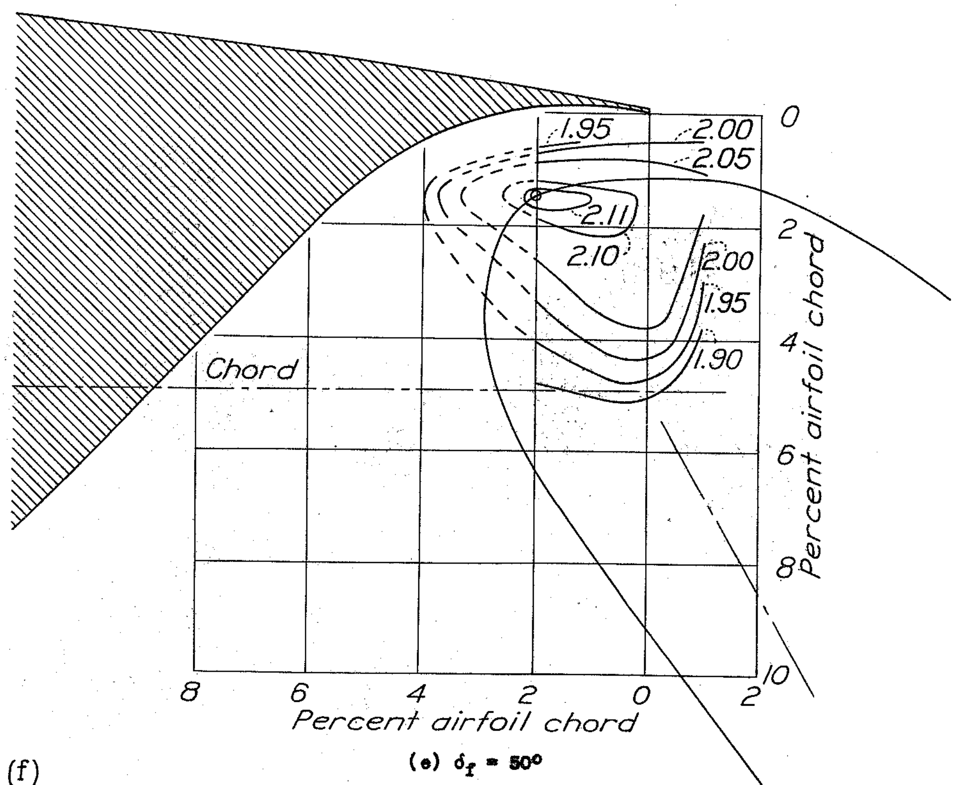
(c) $\delta_f = 30^\circ$

(d) $\delta_f = 40^\circ$

Figure 6 c,d.



(e)



(f)

(e) $\delta_f = 50°$

(f) $\delta_f = 60°$

Figure 6 e,f.

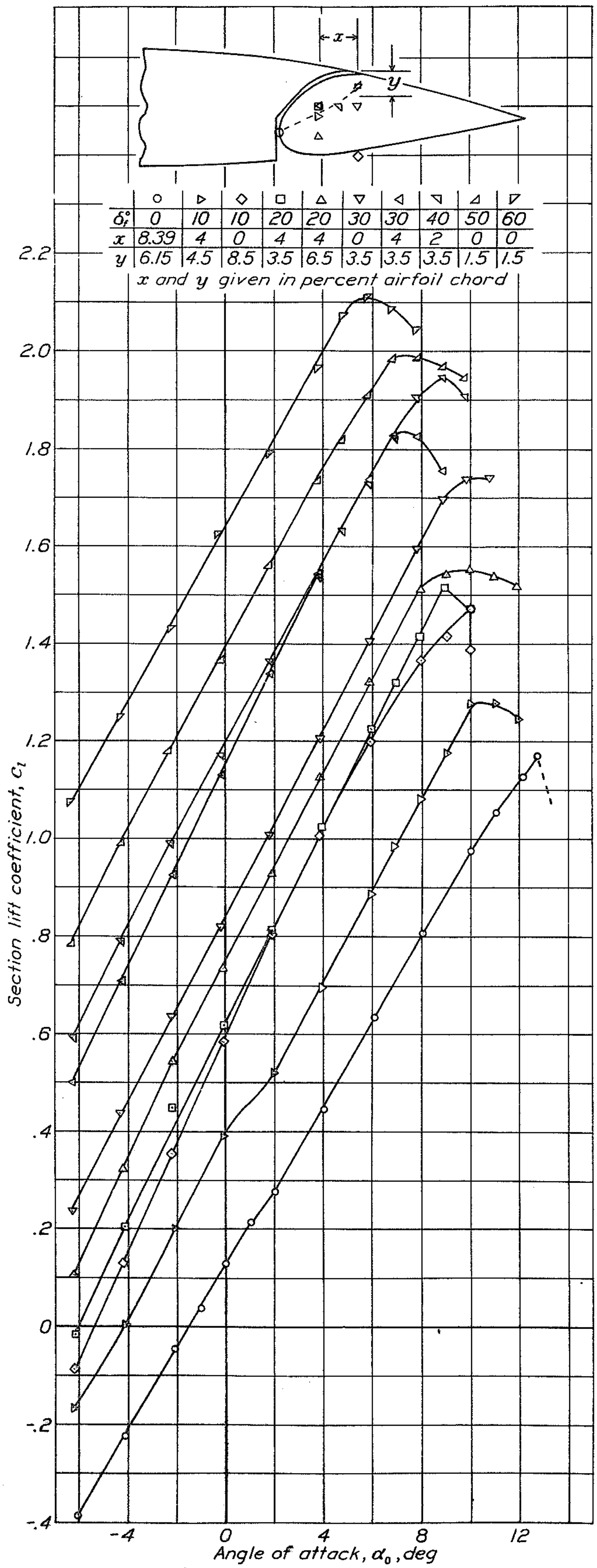


Figure 7.- Section lift characteristics of the NACA 27-212 airfoil with 0.2566c slotted flap 1-a at selected positions.

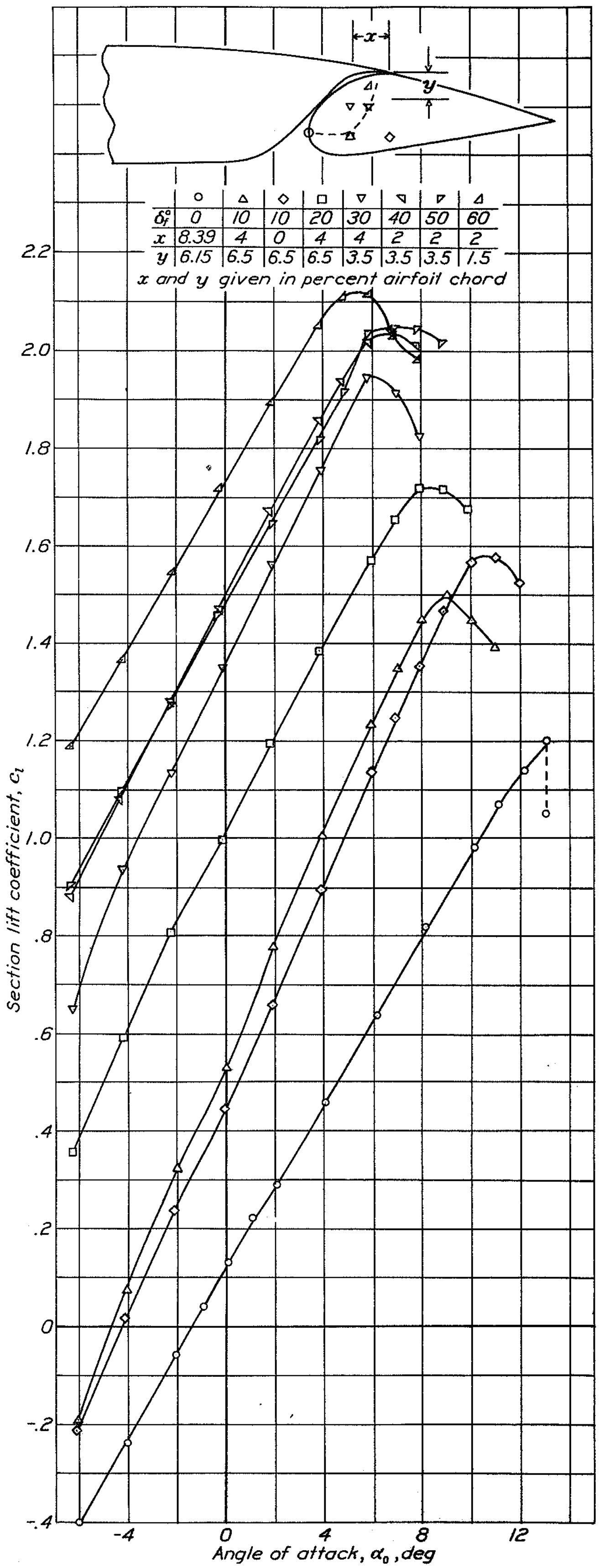


Figure 8.- Section lift characteristics of the NACA 27-212 airfoil with 0.2566c slotted flap 1-b at selected positions.

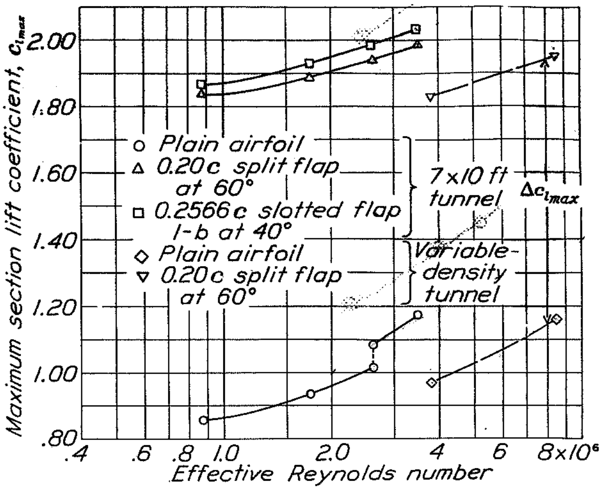


Figure 10.- Scale effect on maximum lift coefficient of NACA 27-212 airfoil with .20c split flap and 0.2566c slotted flap 1-b at optimum location.

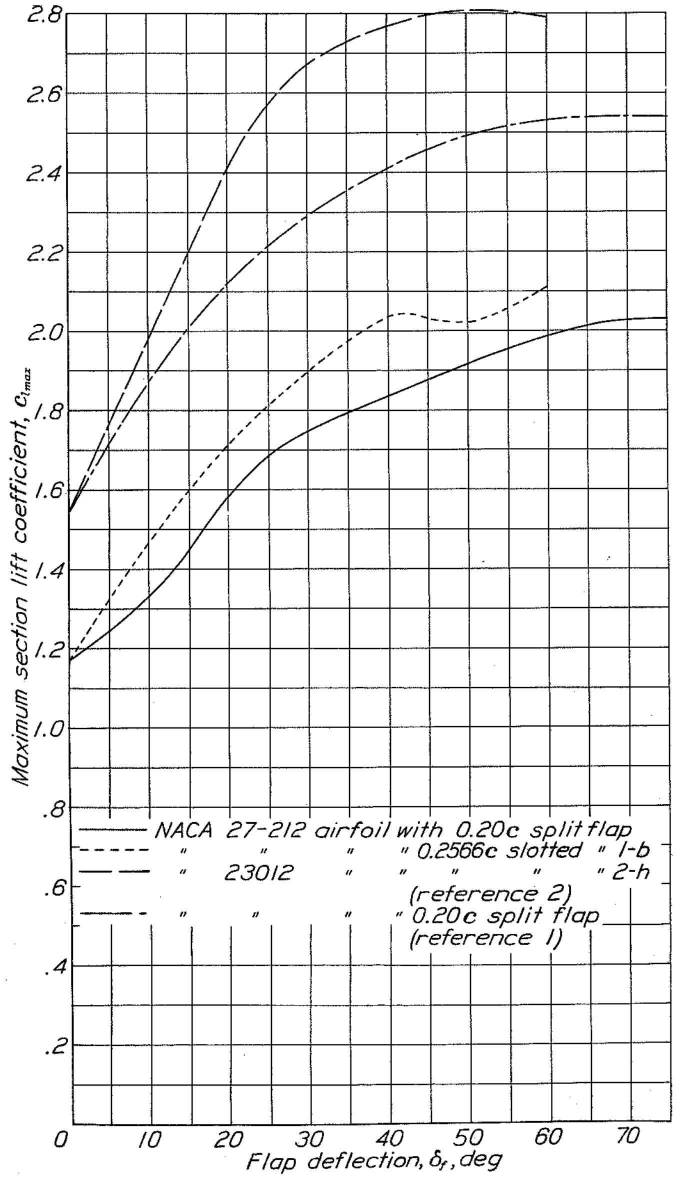


Figure 11.- Comparison of slotted and split flaps on NACA 27-212 and 23012 airfoils.