REPORT No. 661

TESTS IN THE VARIABLE-DENSITY WIND TUNNEL OF THE N. A. C. A. 23012 AIRFOIL WITH PLAIN AND SPLIT FLAPS

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SUMMARY

Section characteristics for use in wing design are presented for the N. A. C. A. 23012 airfoil with plain and split flaps of 20 percent wing chord at a value of the effective Reynolds Number of about 8,000,000. The flap deflections covered a range from 60° upward to 75° downward for the plain flap and from neutral to 90° downward for the split flap. The split flap was aerodynamically superior to the plain flap in producing high maximum lift coefficients and in having lower profile-drag coefficients at high lift coefficients.

INTRODUCTION

The prevailing method of modifying the aerodynamic characteristics of airplane wings so that higher lift coefficients can be obtained is to equip the wings with trailing-edge flaps. For the design of such wings, airfoil section data at the proper values of the Reynolds Number are needed for the various sections used along the span with and without flap deflection. The purpose of this report is to present some additional section characteristics for such use.

The investigation comprised tests of the N. A. C. A. 23012 airfoil equipped with plain and split flaps of 20 percent chord. The ranges of flap settings were very comprehensive. The angle-of-attack range extended from below zero lift to beyond maximum lift for all conditions and was extended through negative maximum lift for most of the settings of the plain flap. All tests were made in the N. A. C. A. variable-density tunnel at a high value of the Reynolds Number. Maximum lift coefficients were also obtained for all combinations at a lower value of the Reynolds Number.

APPARATUS AND TESTS

The N. A. C. A. variable-density tunnel, in which these tests were made, is described in reference 1, and the N. A. C. A. 23012 airfoil section is described in reference 2. The two aluminum-alloy models were made as described in reference 1, except that they were anodically treated to provide hard smooth surfaces that could be more easily maintained during the course of the tests than the usual polished metallic surfaces.

The model that was used for the tests of the plain flap was provided with a brass flap hinged at five points along the span at the station 80 percent of the chord midway between the upper and the lower surfaces. After the flap had been set at the required deflection for each test, the gap between the flap and the wing was filled with plaster of paris, which was then painted and rubbed to produce a smooth, fair surface of the proper contour.

The other model was used for the tests of the split flap. A 0.20*c* split flap was made of brass for each flap deflection tested and was fastened to the lower surface of the model with screws. For flap deflections up to 20°, the flap was made as a solid triangular prism. For flap deflections of 30° and more, the flap was made of two brass strips, each 1 inch by 30 inches, joined at one pair of long edges and kept apart at the proper angle by eight triangular stiffeners equally spaced along the span. In either case, the flap trailing edge was a sharp acute angle.

Standard force tests were made of each combination at a value of the effective Reynolds Number of approximately 8,000,000; the maximum lift coefficient was also determined at an effective Reynolds Number of about 3,800,000. The flap settings covered a range from 60° upward to 75° downward for the plain flap and from 0° to 90° downward for the split flap. The range of angle of attack for all combinations extended from below zero lift to above maximum lift and, for the plain-flap combinations, extended through negative maximum lift except for flap deflections between 20° upward and the neutral position.

PRECISION

The precision of the data obtained from force tests in the N. A. C. A. variable-density tunnel is discussed in considerable detail in references 3 and 4. It is believed that the results may be applied with normal engineering accuracy to free-flight conditions at the stated values of the effective Reynolds Number. It should be noted, however, that the data presented herein for the increments of maximum lift due to the flap are somewhat lower than those obtained in some other wind tunnels (references 5 and 6). The values of maximum lift coefficient contained in this report may be somewhat conservative.

RESULTS AND DISCUSSION

Presentation of results.—The results are presented in figures 1 to 9. Figures 1, 4, and 5 show lift curves for the rectangular wing of aspect ratio 6 at both values of the Reynolds Number. The other six figures show the section characteristics usually presented, which were derived as explained in reference 4 and which may be distinguished from the wing characteristics usually presented and from previously used profile characteristics by the lower-case symbols. Thus c_{d_0} represents the profile-drag coefficient for the airfoil section corrected from the older profile-drag coefficient C_{D_0} by applying corrections for tip effects, for variation of lift along the wing span, and for turbulence to correct to the effective Reynolds Number. The methods of correction are explained in reference 4 and the results so corrected are intended to represent the section data in the form required for application to wing-design problems.

Standard airfoil plots, of the form presented in reference 7, for each flap deflection tested are available upon request from the National Advisory Committee for Aeronautics.

The pitching-moment coefficients $c_{m_{(a.c.)_0}}$ for the flapped airfoils are computed about the aerodynamic center of the unflapped airfoil. Table I presents important section characteristics and also certain derived wing characteristics. The characteristics of the wing with flap neutral are obtained from tests of a plain airfoil.

Maximum-lift coefficients.—The increment of maximum-lift coefficient due to the flap is plotted against flap deflection for both the plain and the split flaps in figure 10. This maximum-lift increment has been plotted instead of the more usual maximum lift coefficient because it has been shown (references 4 and 5) to be nearly independent of Reynolds Number. The maximum-lift increment for the split flap increases more rapidly with flap deflection and reaches an appreciably higher value than that for the plain flap.

The maximum-lift increments obtained from these tests are appreciably lower than those obtained from tests in the N. A. C. A. 7- by 10-foot tunnel (reference 5). German tests (reference 6) of the N. A. C. A. 23012 airfoil with and without a 0.20c split flap deflected 60° were made over a range of Reynolds Numbers. At the lower end of the scale range, the results agree with those obtained in the N. A. C. A. 7- by 10-foot tunnel but, at the higher end, the increment of maximum lift lies about midway between that obtained in the N. A. C. A. variable-density tunnel and in the 7- by 10-foot tunnel. Results obtained in the N. A. C. A. variable-density tunnel for the N. A. C. A. 23021 airfoil with a 0.20c split flap deflected 75° agree, however, with results obtained for a similar model in the N. A. C. A. 7- by 10-foot tunnel (reference 5).

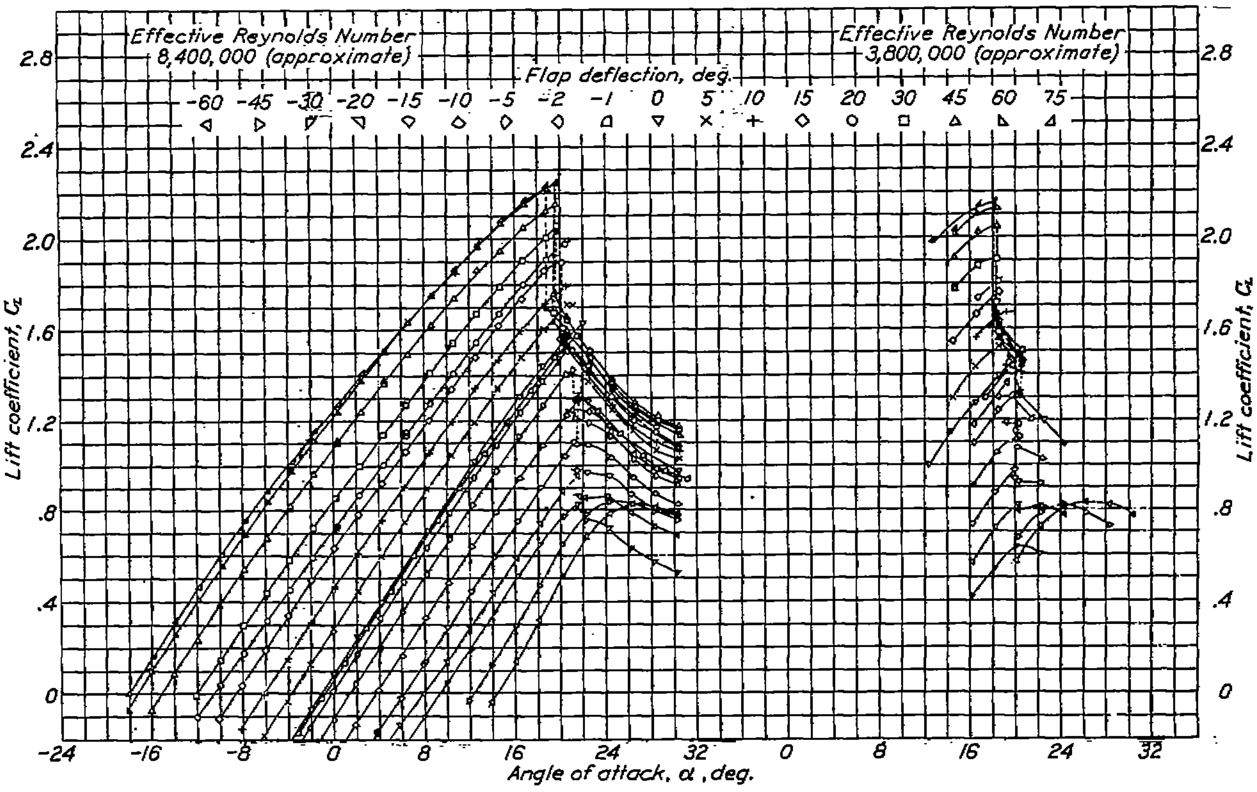

FIGURE 1.—Lift for the N. A. C. A. 23012 rectangular wing of aspect ratio 6 with 0.20c full-span plain flap.

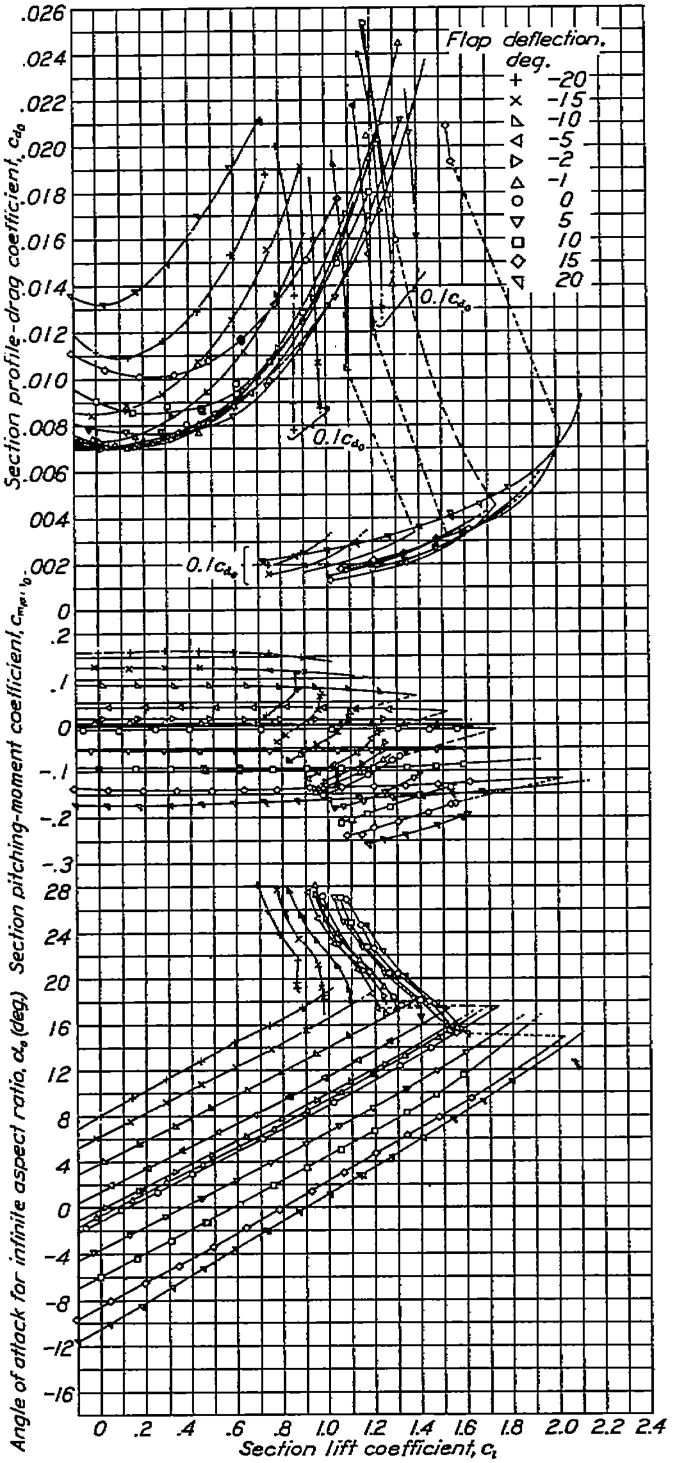

FIGURE 2.—Section characteristics for the N. A. C. A. 23012 airfoil with 0.20c plain flap. Small flap deflections.

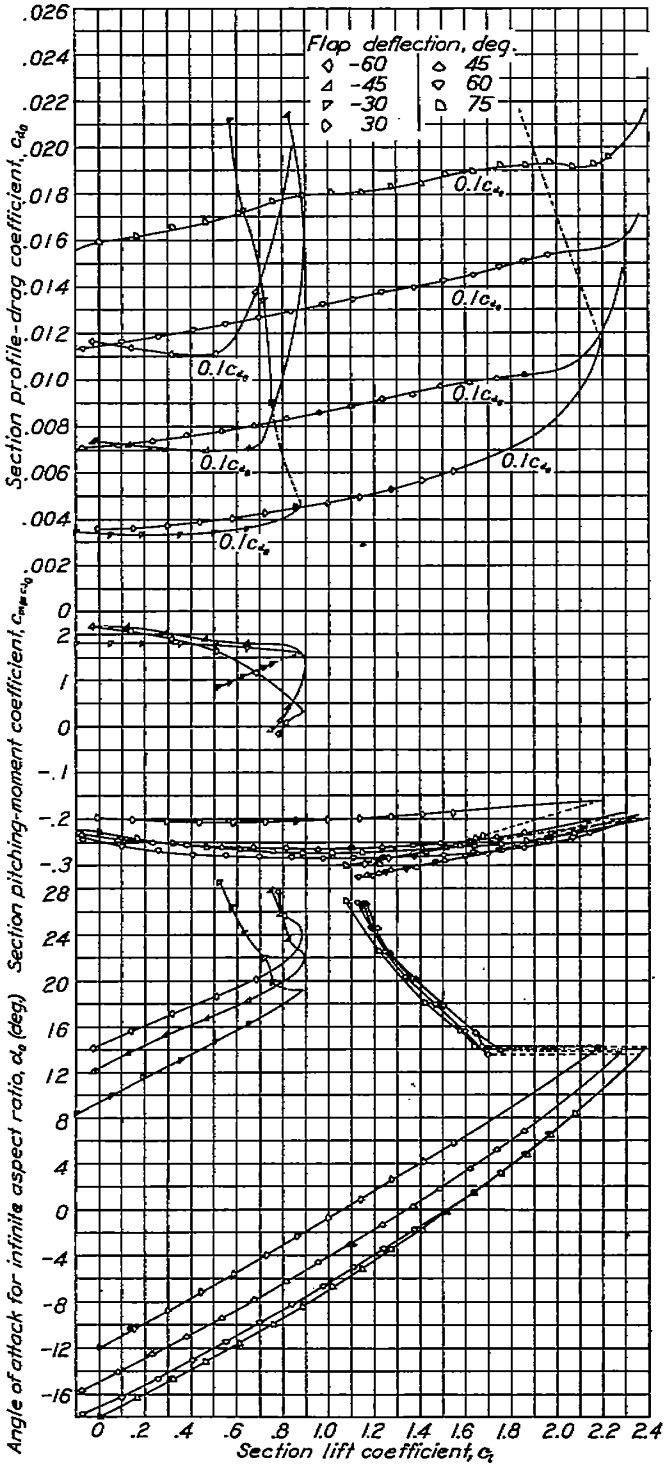

FIGURE 3.—Section characteristics for the N. A. C. A. 23012 airfoil with 0.20c plain flap. Large flap deflections.

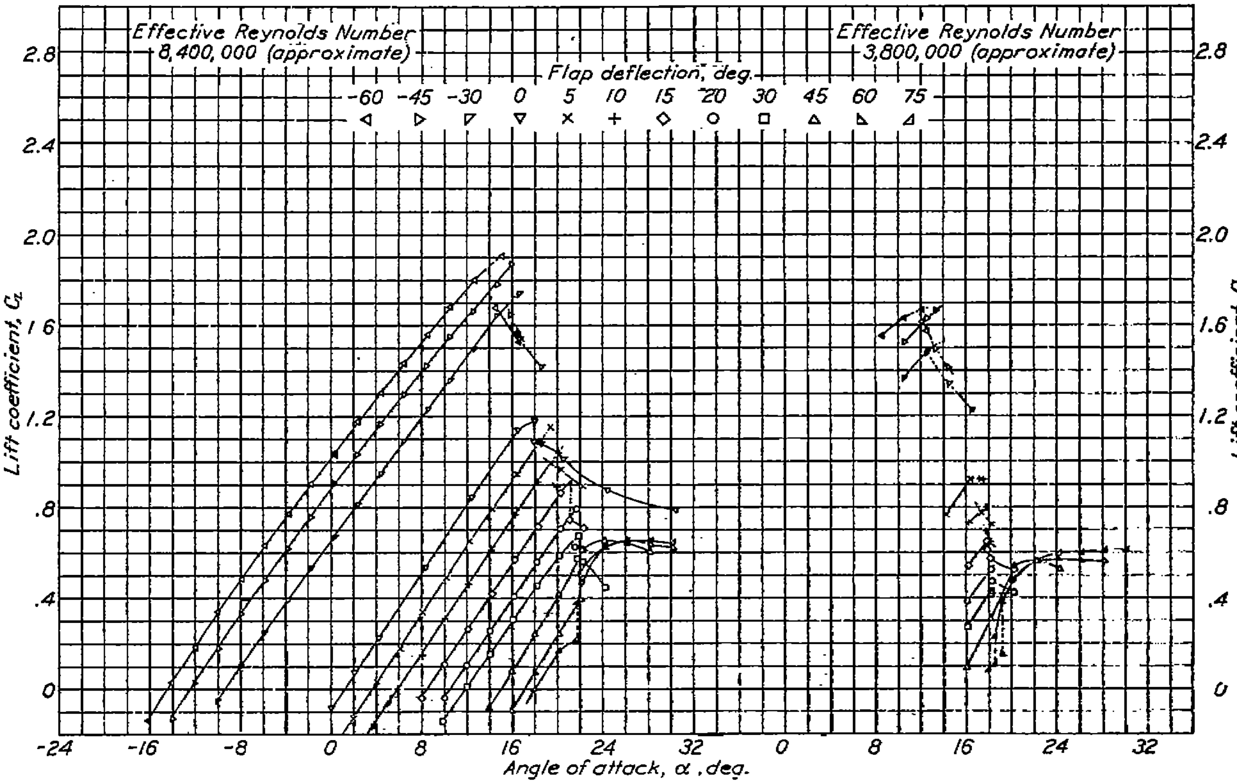

FIGURE 4.—Lift for the N. A. C. A. 23012 rectangular wing of aspect ratio 6 (inverted) with 0.20c full-span plain flap.

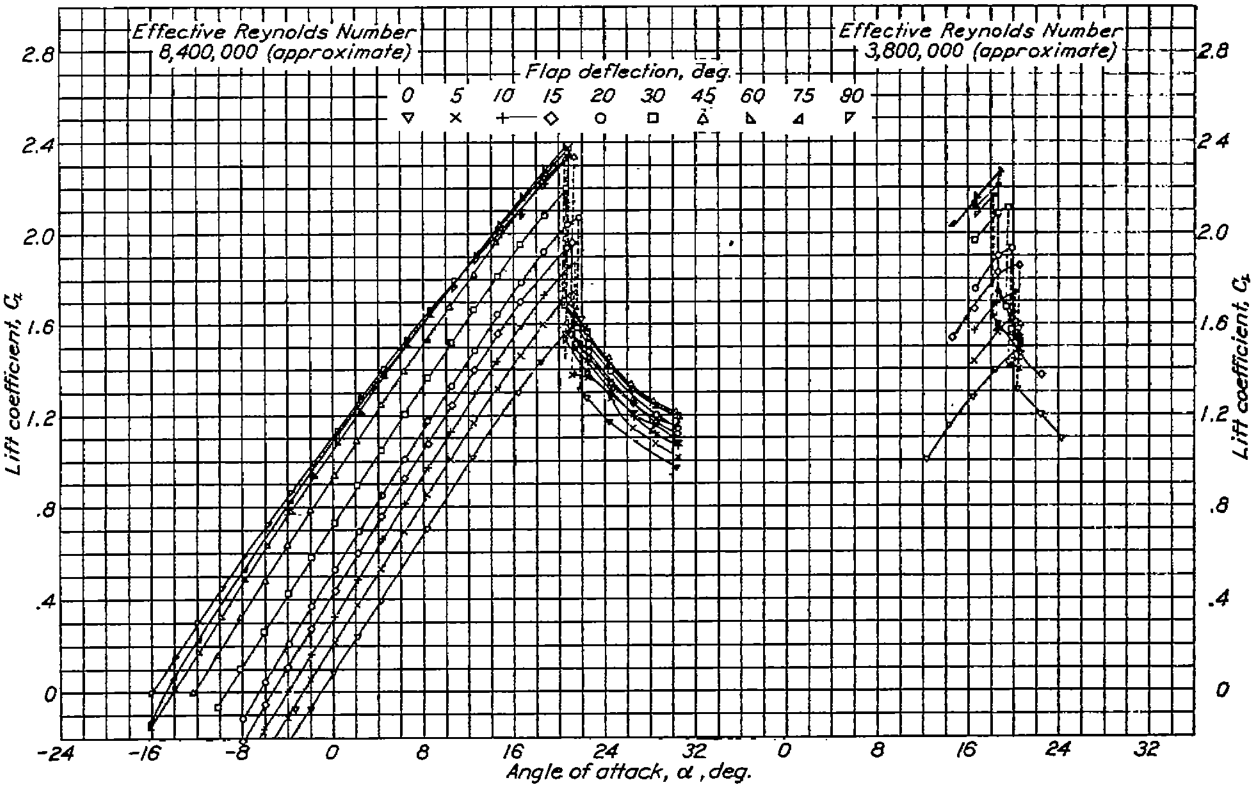

FIGURE 5.—Lift for the N. A. C. A. 23012 rectangular wing of aspect ratio 6 with 0.20c full-span split flap.

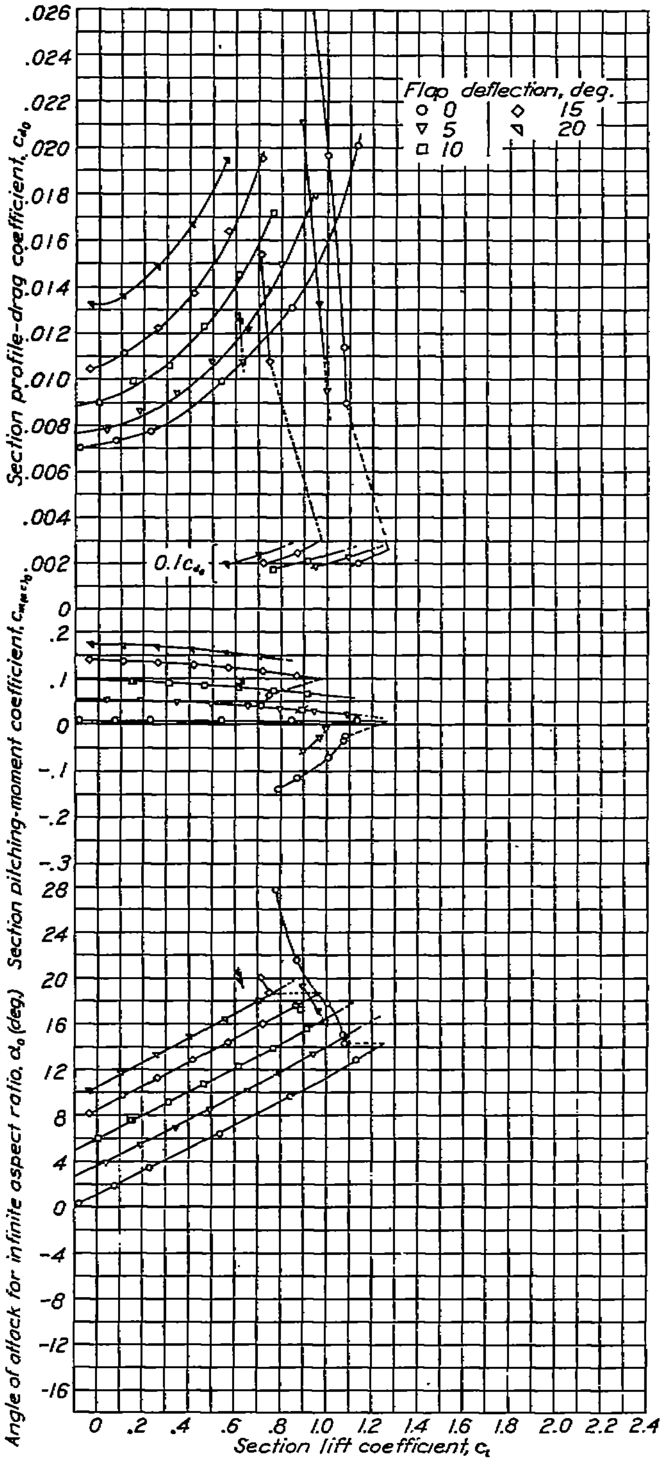

FIGURE 6.—Section characteristics for the N. A. C. A. 23012 airfoil (inverted) with 0.20c plain flap. Small flap deflections.

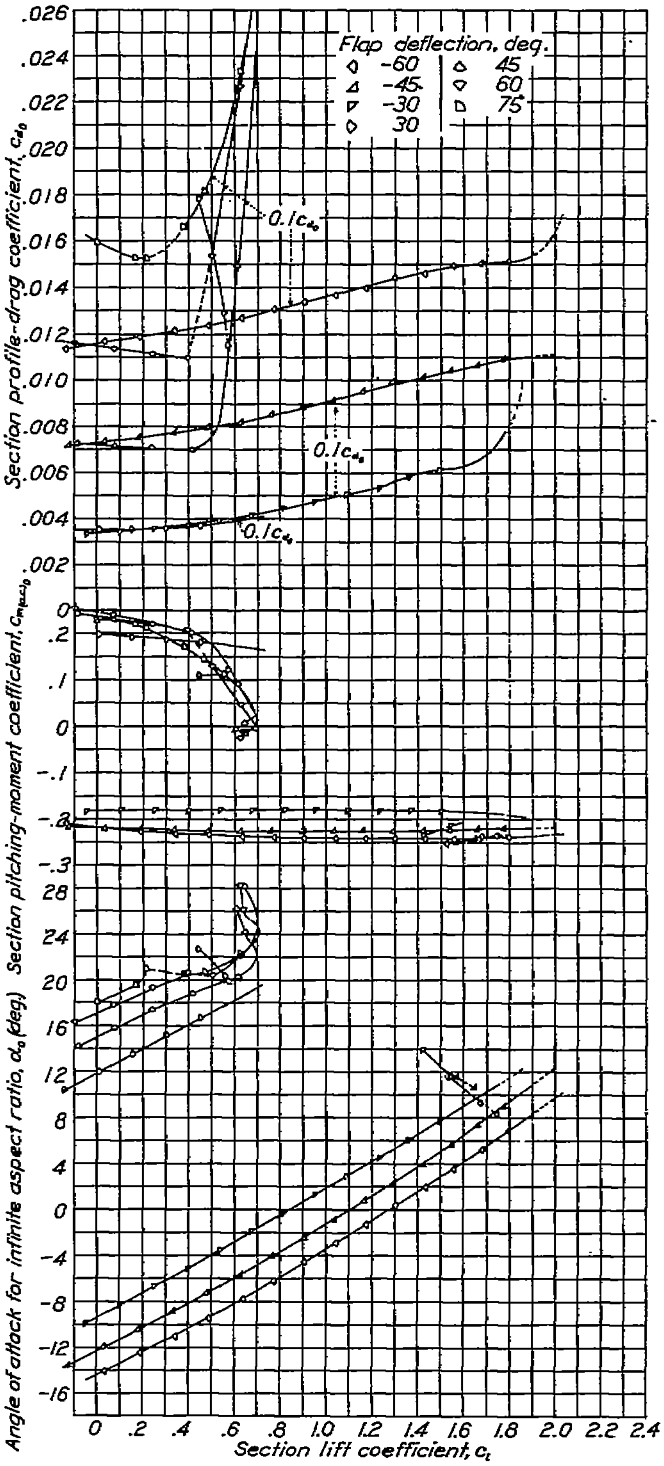

FIGURE 7.—Section characteristics for the N. A. C. A. 23012 airfoil (inverted) with 0.20c plain flap. Large flap deflections.

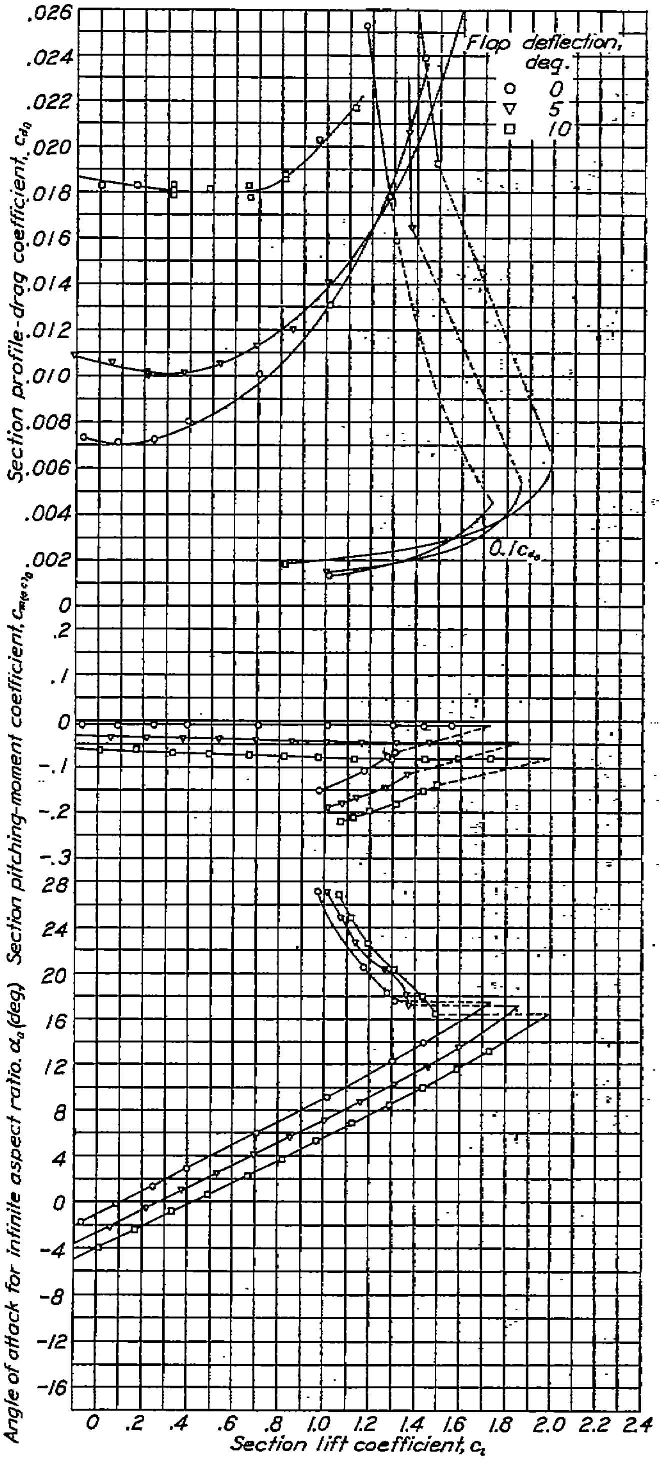

FIGURE 8.—Section characteristics for the N. A. C. A. 23012 airfoil with 0.20c split flap. Small flap deflections.

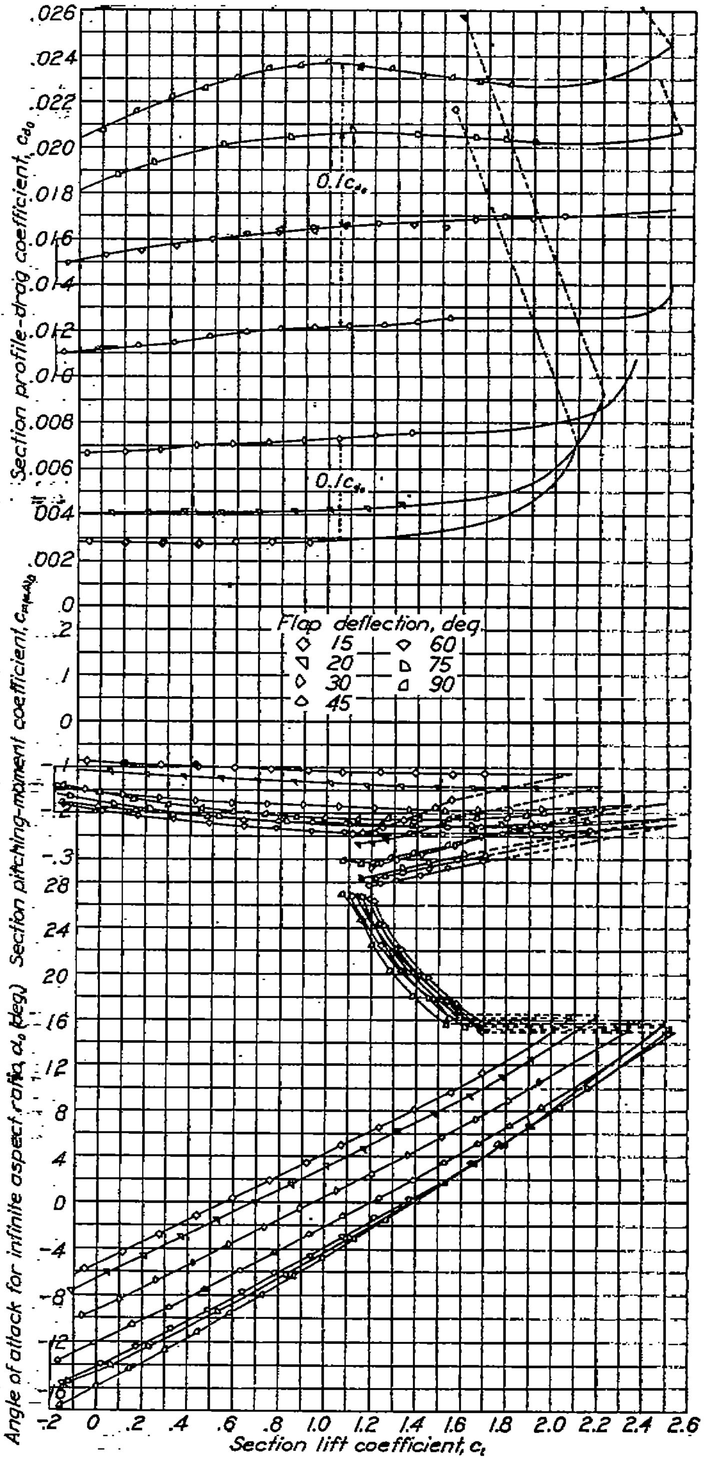

FIGURE 9.—Section characteristics for the N. A. C. A. 23012 airfoil with 0.20c split flap. Large flap deflections.

Similarly, results obtained in the N. A. C. A. variable-density tunnel for the N. A. C. A. 23009 airfoil with a 0.20*c* split flap deflected 60° (reference 7) agree with those obtained in Germany for a similar model (reference 6). Until more data have been obtained, the reason for the inconsistency in the results from tests of different airfoils in various wind tunnels must remain unexplained.

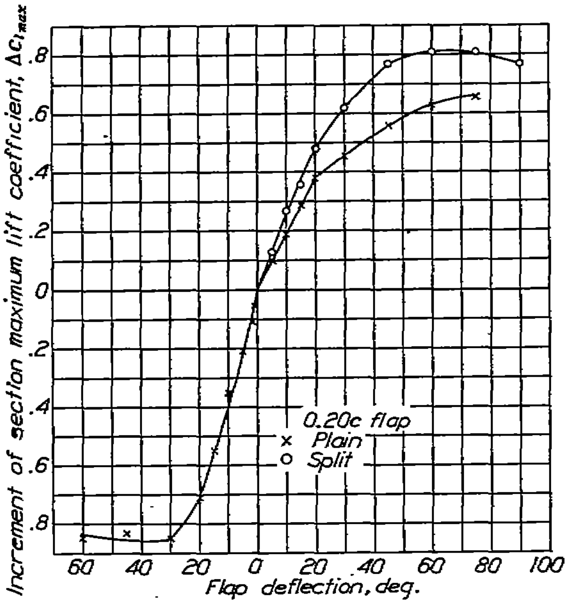

FIGURE 10.—Variation with flap deflection of the increment of section maximum lift coefficient caused by 0.20c plain and split flaps on the N. A. C. A. 23012 airfoil.

The N. A. C. A. 23012 airfoil with and without the flap shows a sudden large loss of lift as the angle of attack for maximum lift is exceeded, except for the cases where the plain flap is deflected in such a manner as greatly to reduce the value of the maximum lift. In general, the amount of lift lost at the peak increases as the maximum-lift increment due to the flap increases. Thus, the type of lift-curve peak is usually either type A or type C (table I), where the fluctuations of the type C peaks extend over a very narrow range of angle of attack and thus the lift-curve peak approximates type A.

Drag coefficients.—Profile-drag coefficients for the two combinations tested are plotted against lift coefficient in figure 11. These polar curves for the flap combinations are envelope curves of the series of polars obtained at the various flap-angle settings, thus giving at each lift coefficient the minimum profile-drag coefficient obtainable from the airfoil-flap combination. The profile-drag coefficient increases much more rapidly with lift coefficient for both the plain and the split flap than for a good slotted flap, such as slotted flap 2-h reported in reference 9. Neither flap can therefore be considered as suitable for improving take-off as the slotted flap.

Although the plain flap has comparatively low profile drag at small deflections and low lift coefficients, the drag even with low deflections increases more rapidly with lift coefficient than for the split flap; the split flap is slightly superior to the plain flap in producing high lift coefficients with lower profile-drag coefficients.

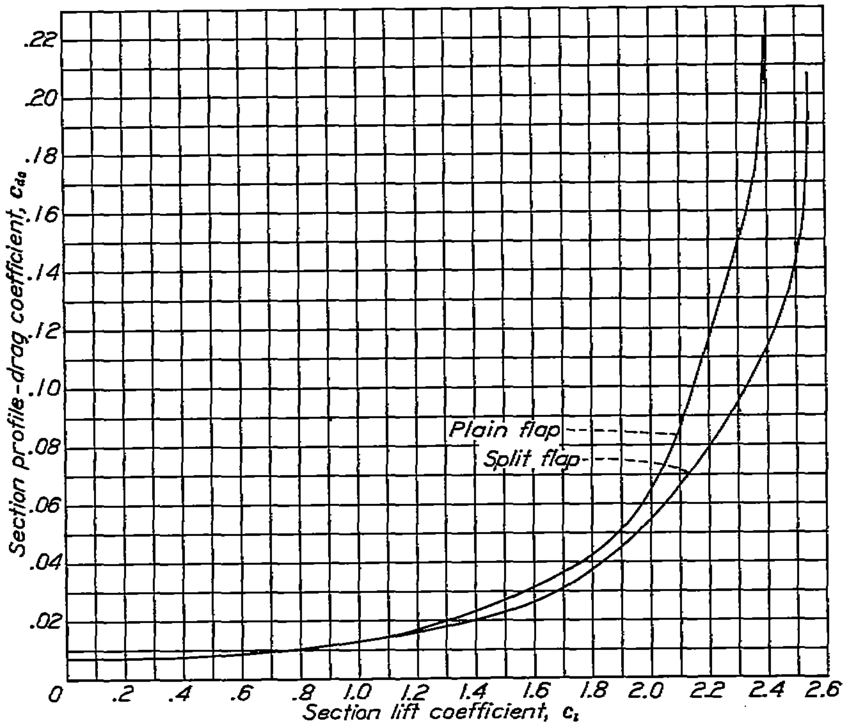

FIGURE 11.—Comparison of profile-drag envelope polars for the N. A. C. A. 23012 airfoil with 0.20c plain and split flaps.

Pitching-moment coefficients.—The pitching-moment coefficients for either flap are about equal for equal flap deflection but are lower for the split flap for flap deflections producing equal maximum lift coefficients. It should be pointed out that the values given in table I are average values of the pitching moment and that, in certain cases, the actual pitching moment at any lift coefficient varies considerably from the average.

CONCLUSIONS

As applied to the N. A. C. A. 23012 airfoil section, the split flap was superior to the plain flap in producing high maximum lift coefficients, in having slightly lower profile-drag coefficients at lift coefficients useful in take-off, and in having smaller pitching-moment coefficients for equal maximum lift coefficients. Both types were unsatisfactory in producing low profile-drag coefficients at lift coefficients useful in take-off as compared with low-drag slotted flaps.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *January 21, 1938.*

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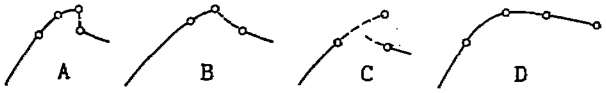
TABLE I.—CHARACTERISTICS OF N. A. C. A. 23012 AIRFOIL WITH 20-PERCENT-CHORD PLAIN AND SPLIT FLAPS

Airfoil	0.20c flap		Classification				Fundamental section characteristics									Derived and additional characteristics that may be used for structural design			
	Type	Deflection (deg.) (1)	Chord (2)	PD (3)	SE (4)	$C_{L_{max}}$ (5)	Effective Reynolds Number (millions) (6)	$c_{l_{max}}$ (7)	α_{l_0} (deg.) (8)	a_0 (per deg.) (7, 9)	$c_{l_{opt}}$ (7)	$c_{d_{0_{min}}}$ (7)	$c_{m_{(a.c.)_0}}$ (11)	a. c. (percent c from c/4) Ahead	a. c. (percent c from c/4) Above	$\frac{c_{l_{max}}}{c_{d_{0_{min}}}}$ (12)	c. p. at $c_{l_{max}}$ (percent c)	Wing characteristics $A=6$; round tips m_0 (per radian)	Wing characteristics $A=6$; round tips $C_{D_{min}}$
N. A. C. A. 23012	Plain	−60	A	------	------	D	8.3	0.88	14.4	0.119	0.4	0.110	------	------	------	126	23	4.95	0.114
23012 inv.	do	−60	A	------	------	C	8.4	2.04	−15.6	.081	------	------	------	------	------	291	36	3.68	------
23012	do	−45	A	------	------	D	8.4	.90	12.4	.109	.5	.069	------	------	------	128	18	4.63	.073
23012 inv.	do	−45	A	------	------	C	8.5	2.00	−13.8	.078	------	------	------	------	------	286	35	3.57	------
23012	do	−30	A	------	------	B	8.3	.88	9.4	.095	.2	.033	0.18	------	------	126	6	4.17	.034
23012 inv.	do	−30	A	------	------	C	8.4	1.87	−9.6	.086	------	------	−.18	------	------	267	34	3.86	------
23012	do	−20	A	------	D2	C	8.4	1.02	8.0	.092	.1	.0109	.16	------	------	146	10	4.07	.0110
23012	do	−15	A	------	D2	C	8.2	1.18	6.1	.095	0	.0085	.12	------	------	169	16	4.17	.0085
23012	do	−10	A	------	D2	A	8.5	1.38	3.8	.099	0	.0073	.08	------	------	197	20	4.31	.0073
23012	do	−5	A	------	D2	B	8.4	1.52	1.4	.100	0	.0071	.04	------	------	217	24	4.34	.0071
23012	do	−2	A	------	D2	C	8.3	1.62	−.2	.099	.05	.0071	.01	------	------	231	25	4.31	.0071
23012	do	−1	A	------	D2	C	8.4	1.68	−.7	.098	.15	.0070	0	------	------	240	26	4.28	.0072
23012	do	0	A	C12	D2	A	8.4	1.74	−1.2	.100	.08	.0070	−.008	1.2	7	249	25	4.34	.0071
23012 inv.	do	0	A	C12	------	A	8.0	1.26	1.1	.099	------	------	.008	1.3	4	180	24	4.31	------
23012	do	5	A	------	D2	C	8.4	1.83	−3.6	.097	.25	.0076	−.05	------	------	261	29	4.24	.0079
23012 inv.	do	5	A	------	------	C	8.5	1.23	3.6	.097	------	------	.04	------	------	176	20	4.24	------
23012	do	10	A	------	D2	C	8.3	1.92	−6.0	.094	.25	.0085	−.09	------	------	274	30	4.14	.0089
23012 inv.	do	10	A	------	------	C	8.4	1.11	6.0	.098	------	------	.09	------	------	159	16	4.28	------
23012	do	15	A	------	D2	A	8.3	2.02	−9.1	.087	.25	.0101	−.13	------	------	289	31	3.89	.0105
23012 inv.	do	15	A	------	------	A	8.4	.98	8.6	.096	------	------	.13	------	------	140	11	4.20	------
23012	do	20	A	------	D2	C	8.5	2.11	−10.5	.086	0	.0132	−.15	------	------	301	32	3.86	.0132
23012 inv.	do	20	A	------	------	C	8.6	.85	10.5	.094	------	------	.16	------	------	121	3	4.14	------
23012	do	30	A	------	D2	A	8.5	2.19	−12.3	.086	0	.035	−.19	------	------	313	34	3.86	.035
23012 inv.	do	30	A	------	------	C	8.6	.72	11.9	.094	------	------	------	------	------	103	−4	4.14	------
23012	do	45	A	------	D2	A	8.2	2.29	−15.6	.085	------	------	−.25	------	------	327	34	3.82	------
23012 inv.	do	45	A	------	------	D	8.3	.70	15.0	.111	.4	.070	------	------	------	100	18	4.70	.072
23012	do	60	A	------	D2	A	8.3	2.36	−17.9	.082	------	------	−.28	------	------	337	34	3.72	------
23012 inv.	do	60	A	------	------	D	8.4	.71	17.1	------	.4	.109	------	------	------	101	23	------	.114
23012	do	75	A	------	D2	A	8.4	2.39	−19.0	.078	------	------	−.26	------	------	341	34	3.57	------
23012 inv.	do	75	A	------	------	D	8.5	.70	18.0	------	.2	.152	------	------	------	100	27	------	.153
23012	Split	5	A	------	D2	A	8.4	1.86	−2.7	.102	.3	.0101	−.04	------	------	266	28	4.41	.0105
23012	do	10	A	------	D2	A	8.4	2.00	−4.0	.106	.5	.0180	−.08	------	------	286	30	4.54	.0185
23012	do	15	A	------	D2	A	8.3	2.09	−5.4	.104	.5	.028	−.10	------	------	299	31	4.47	.028
23012	do	20	A	------	D2	A	8.4	2.21	−6.6	.105	------	[10].042	−.18	------	------	316	32	4.51	------
23012	do	30	A	------	D2	A	8.4	2.35	−9.5	.090	------	[10].072	−.18	------	------	336	34	4.00	------
23012	do	45	A	------	D2	A	8.5	2.50	−12.5	.095	------	[10].12	−.22	------	------	357	34	4.18	------
23012	do	60	A	------	D2	A	8.4	2.54	−14.6	.091	------	[10].16	−.23	------	------	363	35	4.04	------
23012	do	75	A	------	D2	A	8.1	2.54	−15.6	.087	------	[10].20	−.27	------	------	363	34	3.89	------
23012	do	90	A	------	D2	A	8.4	2.50	−16.7	.082	------	[10].23	−.20	------	------	357	33	3.72	------

[1] When the airfoil is inverted, a minus deflection of the flap indicates that the flap is deflected downward.
[2] Type of chord of the airfoil with flap neutral. A refers to a chord defined as a line joining the extremities of the mean line.
[3] Type of pressure distribution. See reference 3.
[4] Type of scale effect on maximum lift. See reference 4.
[5] Type of lift-curve peak as shown in the sketches.



[6] Turbulence factor is 2.64.
[7] These data have been corrected for tip effect.
[8] Angle of zero lift obtained from linear lift curve approximating experimental lift curve.
[9] Slope obtained from linear lift curve approximating experimental lift curve.
[10] $c_{d_{0_{min}}}$ lay outside range of lift coefficients covered in these tests. Value of $c_{d_{0_{min}}}$ given applies approximately over entire useful range of lift coefficients.
[11] $c_{m_{(a.c.)_0}}$ is taken about the aerodynamic center of the airfoil without the flap and is the average value.
[12] Values of $c_{d_{0_{min}}}$ used in computing this ratio are takenf rom tests of the plain airfoil.