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WIND-TUNNEL INVESTIGATION OF AN NACA LOW-DRAG TAPERED WING WITH STRAIGHT TRAILING EDGE AND SIMPLE SPLIT FLAPS

By Thomas C. Muse and Robert H. Neely
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SUMMARY

An investigation was conducted in the NACA 19-foot pressure wind tunnel of a tapered wing with straight trailing edge having NACA 66 series low-drag airfoil sections and equipped with full-span and partial-span simple split flaps. The airfoil sections used were the NACA 66,2-116 at the root and the 66,2-216 at the tip. The primary purpose of the investigation was to determine the effect of the split flaps on the aerodynamic characteristics of the tapered wing. Complete lift, drag, and pitching-moment coefficients were determined for the plain wing and for each flap arrangement through a Reynolds number range of 2,600,000 to 4,600,000.

The results of this investigation indicate that values of maximum lift coefficient comparable to values obtained on tapered wings with conventional sections and similar flap installations can be obtained from wings with the NACA low-drag sections. The increment of maximum lift due to the split flap was found to vary somewhat with Reynolds number over the range investigated. The $C_{L_{max}}$ of the wing alone is 1.49 at a Reynolds number of 4,600,000; whereas with the partial-span simple split flap it is 2.22 and with the full-span arrangement, 2.80.

Observations of wool tufts on the wing indicate that the addition of split flaps did not appreciably alter the pattern of the stall; even though the stall did occur more abruptly than with the wing alone.

INTRODUCTION

The NACA is undertaking an extensive investigation in the 19-foot pressure tunnel to determine the effect of various high-lift devices on the aerodynamic characteristics of representative wings having NACA low-drag airfoil sections. This investigation is to include tests of wings of different plan form equipped with various types of trailing-edge flaps; the effects of a fuselage will be included after the wing-alone tests. Table I gives an outline of the models to be tested in the program. The aerodynamic characteristics of a rectangular NACA 66,2-216 wing with full-span and partial-span split flaps of various chords were presented in a previous report (reference 1), the first of the series.

The present paper constitutes the second part of the series. In it are presented the results of wind-tunnel tests of full-span and of partial-span simple split flaps on a tapered wing with straight trailing edge, constructed to NACA low-drag airfoil sections.

.65 washin going from 66,2-116 to 66,2-216 at tip

MODELS

Plain Wing

The plain wing, or basic model, (fig 1) was constructed of laminated mahogany to NACA low-drag airfoil sections. These sections are the 66,2-116 (table II) for the root and the 66,2-216 (table III) for the construction tip. The wing plan form consists of a square center section and tapered outboard sections with elliptical tips. The trailing edge is a straight-line continuation of the square center section; whereas the leading edge is swept back at an angle of 12.5°. The wing has a geometric twist, or washout, of 1.5° between the outboard edge of the center section and the extreme wing tip. ~~This angle, which corresponds to an aerodynamic twist of approximately 2.5°, was used to give improved stalling characteristics.~~

1.5 washout - .65 washin = .85 washout net 3-3-42

While no dihedral is used, a small dihedral effect is obtained by having the wing upper surface between the 40-percent-chord point of the root section and the 50-percent-chord point of the construction tip lie in a horizontal plane. In as much as the span, aspect ratio, and area are 15 feet, 7.0, and 32.14 square feet, respectively, or identical with those of the rectangular wing described in reference 1, a fair comparison of the relative merits of the two wings can be made. An "aerodynamically smooth" surface was obtained by spraying the wing with a number of coats of lacquer and then rubbing until smooth with No. 500 watercloth.

Flaps

The flaps were of the simple split type with a chord 20 percent of the wing section chord. These flaps were made of 1/16-inch galvanized sheet steel curved to approximate the contour of the flap portion of the wing lower surface. The desired deflections were obtained by inserting appropriately shaped wooden blocks between the wing lower surface and the flap. For the partial-span condition the flaps extended over 53 percent of the wing span. (See fig. 1.) This span was determined as the distance between the inboard ends of 0.37 b/2 ailerons, should they be used. The full-span arrangement extended along 90 percent of the entire wing span.

TESTS

The tests were conducted in the NACA 19-foot pressure wind tunnel at an absolute pressure of 35 pounds per square inch with the model mounted on the standard wing supports. (See fig. 2.)

Since the aerodynamic characteristics of the plain wing are the basis for comparing the merits of the various high-lift devices, a set of complete polar runs was made for this condition. For these runs the angle of attack was varied from -4° through the stall for dynamic pressures of 20, 40, and 70 pounds per square foot, corresponding to test Reynolds numbers of about 2,600,000; 3,700,000; and 4,600,000; respectively. Simultaneous measurements of lift and drag were recorded by a six-component electrical recording balance.

For the partial-span-flap arrangement complete polar runs were made for flap deflections of 15°, 30°, 45°, and 60° at dynamic pressures of 20, 40, and 70 pounds per square foot. Complete polar runs were made with the full-span-flap installation at the same dynamic pressures as for the partial-span arrangement but only for the 60° deflection.

In order to provide a basis for a comparison of the aerodynamic characteristics obtained in these tests with section characteristics obtained in other two-dimensional-flow tests, momentum surveys for the plain-wing condition were made in the wing wake at dynamic pressures of 40 and

70 pounds per square foot. Measurements were made at approximately 6-inch intervals along the span except near the tips, where a closer spacing was used. The surveys were made at an angle of attack of 1°, which previously had been found to give the minimum drag.

In order to study the wing stalling characteristics, wool tufts were fastened with cellulose tape to the wing upper surface at the 20-, 30-, 40-, 60-, 70-, 80-, and 90-percent-chord points. These tufts were arranged in parallel rows spaced approximately 7 inches apart along the wing span. Slightly closer spacing was used near the tips. Sketches were made from visual observations of the behavior of the tufts at various angles of attack through the stall for the plain wing and also for the wing with partial-span flap deflected 60°. The tuft observations were made at a dynamic pressure of 70 pounds per square foot.

RESULTS AND DISCUSSION

Coefficients

The data presented in this report are given in standard nondimensional coefficient form corrected for the effect of model support tare and interference and for jet-boundary effects.

The coefficients and symbols used herein are defined as follows:

C_L lift coefficient (L/qS)

C_D drag coefficient (D/qS)

$C_{m_{\frac{c_s}{4}}}$ pitching-moment coefficient about the quarter-chord point of the plain wing root section $(M/qS\bar{c})$

C_{D_0} wing profile-drag coefficient

c_{d_0} section profile-drag coefficient (d_0/qc)

where

q dynamic pressure in the undisturbed air stream $(1/2\ \rho V^2)$

S wing area (32.14 sq ft)

$\bar{c}$ mean wing chord S/b (2.14 ft)

c_s root section wing chord

c section chord

b wing span (15 ft)

ρ mass density of air, slugs per cubic foot

and

δ_f flap deflection measured between the lower surface of the wing and the flap

α angle of attack of root chord corrected for jet-boundary interference

R test Reynolds number based on mean wing chord $(\rho V \bar{c}/\mu)$

μ coefficient of viscosity

Precision

The accidental experimental errors as determined from repeat tests are believed to be within the following limits:

α	$\pm 0.10^\circ$
$C_{L_{max}}$	± 0.03
$C_{m_{\frac{c_s}{4}}}$	± 0.01
$C_{D_{(C_L=0)}}$	± 0.0003
$C_{D_{(C_L=1)}}$	± 0.0006
$C_{D_{(C_L=2)}}$	± 0.002

$C_{d_{o}(c_l=0)}$ wake	± 0.0002
δ_f	$\pm 0.5^{\circ}$
Flap position	$\pm 0.002c$

The coefficients given are corrected for the effect of model support tare and interference as determined for the plain wing. No additional tare tests were made for the flap installations, as the tare increment is believed to be small.

Plain Wing

The aerodynamic characteristics of the plain wing as determined in these tests are given in figure 3 as the zero-flap-deflection condition. Examination of the lift curves reveals that the slope $dC_L/d\alpha$ is constant up to the point where $C_L = 0.5$; from this point the slope gradually decreases up to the stall. Of significance is the absence of any irregularity around $C_L = 0.3$ as shown by the rectangular wing tests reported in reference 1. Further comparison with the rectangular wing shows that the tapered wing has a greater slope of the lift curve and a higher angle of stall, resulting in an increase of $C_{L_{max}}$.

See Notes In Low Drag Airfoil Book

The pitching-moment coefficient was computed about the quarter-chord point of the root section in the interest of simplicity since the aerodynamic center varies somewhat with C_L and R. The moment coefficient curves have a negative slope and exhibit little scale effect.

The section profile-drag coefficients determined by the momentum-loss method are shown in figure 4 for two values of Reynolds number. The minimum wing profile-drag coefficient $C_{D_{o_{min}}}$ obtained by this method at a Reynolds number of 3,750,000 is 0.0038, which is in good agreement with the value of 0.0041 obtained by the force measurements.

Wing with Flaps

The aerodynamic characteristics of the wing with flaps are plotted against angle of attack in figure 3.

The slopes of the lift curves, in general, appear to be consistent and uniform almost to the stall. The peaks of the curves, however, show wide variation, ranging from sharp breaks to almost flat-top curves. At present no complete explanation of the differences is available. The curves do indicate a pronounced increase in the angle of stall with increase of Reynolds number.

As was true for the plain wing, the pitching-moment coefficients about the quarter-chord point of the root section have a negative slope $-\frac{dC_{m_{\frac{c_s}{4}}}}{d\alpha}$ when plotted against angle of attack. Little variation with Reynolds number is indicated, however. On the other hand, a large increase, negatively, is shown by the pitching-moment coefficients as the flap deflections are increased.

The variation of $C_{L_{max}}$ with Reynolds number is given in figure 5 for both the wing alone and the wing with flaps. These curves show some scale effect for both conditions and an increase of $C_{L_{max}}$ over similar installations on the rectangular wing described in reference 1. The increment of maximum lift coefficient $\Delta C_{L_{max}}$ occasioned by the use of the flaps indicates a change with Reynolds number as shown by figure 6. This result is somewhat different from that obtained with the rectangular wing mentioned previously where little change was noted.

The variation of $\Delta C_{L_{max}}$ with flap deflection is given in figure 7. At the maximum deflection tested (60°), the curve is still increasing somewhat; however, it is beginning to level off, indicating that higher deflections would give only a small increase in the maximum lift coefficient.

Stalling Characteristics

The stall diagrams for the plain wing and for the wing with partial-span split flap deflected 60° are given in figures 8 and 9. These diagrams show that the stall begins on the rear portion of the wing directly behind the wing supports from whence it spreads forward and outward with increase of angle of attack. The addition of the flap delays the beginning of the stall somewhat, but complete stall develops more rapidly and occurs at a lower angle of attack than with the plain wing. As was true of the rectangular low-drag wing described in reference 1, the addition of the flap induces an appreciable inflow over that portion of the wing normally occupied by the ailerons. It may be noted that the right side of the wing appears to stall first, but this may be due to a slight asymmetry of the wing rather than something of an aerodynamic nature. Moreover, since the investigation was conducted in a closed-throat wind tunnel, the results should be somewhat conservative compared with those in free air.

CONCLUSIONS

1. The addition of a simple split flap to a tapered wing having NACA low-drag sections gives aerodynamic characteristics that compare favorably with those obtained with similar installations on wings having conventional sections.

2. The increment of maximum lift coefficient due to the split flap on the wing tested was found to vary somewhat with Reynolds number. The minimum effect occurs with the smallest flap deflection and increases as the deflection increases.

3. The $C_{L_{max}}$ of the wing alone is 1.49 at a Reynolds number of 4,600,000; whereas with the partial-span split-flap arrangement the value is 2.22 and with the full-span arrangement, 2.80.

4. The plain wing appears to have favorable stalling characteristics that are not appreciably altered by the addition of a split flap, even though complete stall occurs earlier with the flap.

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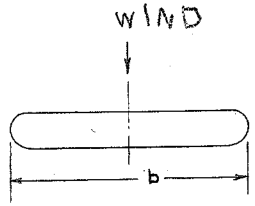
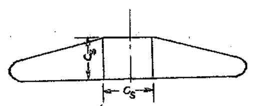
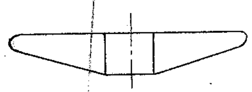
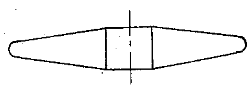
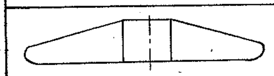
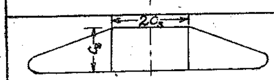
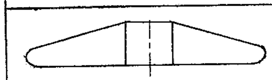
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCE

1. Muse, Thomas C., and Neely, Robert H.: Wind-Tunnel Investigation of an NACA 66,2-216 Low-Drag Wing with Split Flaps of Various Sizes. NACA A.C.R. Sept. 1941.

TABLE I.- WING MODELS AND SUMMARY OF TEST RESULTS FOR HIGH-LIFT DEVICE AND STALLING INVESTIGATION IN THE NACA 19-FOOT PRESSURE TUNNEL.

Model	Wing	NACA airfoil section		Geometric twist (deg)	High-lift device	δ_f (deg)	Aerodynamic characteristics											
		Root	Tip				$C_{L_{max}}$		$\Delta C_{L_{max}}$		$\alpha_{C_{L_{max}}}$ (deg)		C_{D_o} wake	$C_{m_{c/4}}$				Reynolds number
														$C_L = 0.1$		$C_{L_{max}}$		
							Partial (a)	Full (b)	Partial	Full	Partial	Full		Partial	Full	Partial	Full	
	O(NACA)	66,2-216	66,2-216	0	- - - - - - - - -	- -	1.40	- -	- - -	- - -	20.6	- -	0.0038	-0.005	- - -	0.030	- - -	4.6×10^6
					0.10c split flap	60	1.84	2.15	0.44	0.75	20.0	18.0	- - -	- - -	- - -	-.085	-0.160	4.6
					.20c split flap	60	2.07	2.53	.67	1.13	17.8	18.4	- - -	- - -	- - -	-.140	-.225	4.6
					.30c split flap	60	2.07	2.52	.67	1.12	16.8	17.2	- - -	- - -	- - -	-.150	-.270	4.6
	I(NACA)	66,2-116	66,2-216	$-1\frac{1}{2}$	- - - - - - - -	- -	1.49	- -	- - -	- -	22.2	- -	0.0040	-0.030	- - -	-0.210	- - -	4.6
					0.20c split flap	60	2.22	2.80	0.73	1.31	21.2	21.4	- -	- -	- -	-.460	-0.650	4.6
					.30c Fowler flap	30	2.73	3.57	1.32	2.10	22.2	24.5	-	-	-	-.525	-1.260	3.6
					.25c slotted flap	50	2.42	2.97	.93	1.48	22.0	21.5	-	-	-	-.540	-.815	4.9
					.20c plain flap	50	2.11	2.43	.62	.94	21.0	20.6	-	-	-	-.440	-.550	4.7
	II(NACA)	66,2-116	66,2-216	$-1\frac{1}{2}$	- - - - - - - -	- - -												
					0.20c split flap													
					.30c Fowler flap													
					.25c slotted flap													
					.20c plain flap													
	II(Navy)	23015	23009	0	- - - - - - - -	- - -												
					Maxwell slot													
					Split flap													
					Slotted flap													
	III(Navy)	23015	23009	0	- - - - - - -	- - -	1.62											4.6
					0.20c split flap	60	2.26	2.65	.64	1.03								4.6
	VI(Navy)	23015	23009	0	- - - - - - - -	- - -												
					0.20c split flap													
	VII(Navy)	4416.5R	4409R	-3	- - - - - - - -	- - -												
					0.20c split flap													

[a] Partial-span flap extends over 0.53b.
[b] Full-span flap extends over 0.90b.

= [66(215)-116 (a=.6)]
see CMR L4K21 (CR 2/18/45)

TABLE II.- ORDINATES FOR NACA 66,2-116 AIRFOIL SECTION
[Stations and ordinates in percent of wing chord]

SR 212

a=.6 as near as I can check RBE 1/6/43

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.435	1.214	.565	-1.150
.678	1.462	.822	-1.370
1.170	1.823	1.330	-1.683
2.408	2.498	2.592	-2.254
4.897	3.498	5.103	-3.082
7.392	4.286	7.608	-3.726
9.890	4.969	10.110	-4.281
14.894	6.054	15.106	-5.154
19.903	6.895	20.097	-5.827
24.916	7.554	25.084	-6.346
29.931	8.052	30.069	-6.738
34.949	8.401	35.051	-7.009
39.968	8.633	40.032	-7.185
44.989	8.734	45.011	-7.260
50.011	8.694	49.989	-7.220
55.037	8.502	54.963	-7.058
60.070	8.113	59.930	-6.737
65.096	7.459	64.904	-6.203
70.099	6.519	69.901	-5.419
75.091	5.429	74.909	-4.503
80.074	4.218	79.926	-3.478
85.053	2.995	84.947	-2.451
90.030	1.763	89.970	-1.411
95.011	.679	94.989	-.515
100.000	0	100.000	0

TABLE III.- ORDINATES FOR NACA 66,2-216 AIRFOIL SECTION
[Stations and ordinates in percent of wing chord]

SR-212

a=.6 as near as I can check RBE 1/6/43 ✓ see also ACR 4H15

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.371	1.242	.629	-1.112
.607	1.501	.893	-1.319
1.091	1.886	1.409	-1.608
2.317	2.615	2.683	-2.127
4.794	3.701	5.206	-2.869
7.284	4.563	7.716	-3.441
9.781	5.308	10.219	-3.934
14.788	6.500	15.212	-4.702
19.806	7.428	20.194	-5.290
24.832	8.155	25.168	-5.741
29.862	8.708	30.138	-6.080
34.897	9.098	35.103	-6.312
39.936	9.356	40.064	-6.462
44.978	9.471	45.022	-6.523
50.023	9.431	49.977	-6.483
55.073	9.224	54.927	-6.336
60.141	8.800	59.859	-6.048
65.191	8.084	64.809	-5.574
70.198	7.068	69.802	-4.866
75.181	5.889	74.819	-4.037
80.149	4.585	79.852	-3.107
85.106	3.265	84.894	-2.177
90.061	1.937	89.939	-1.235
95.021	.762	94.979	-.432
100.000	0	100.000	0

THESE ORDINATES ARE NOT OBTAINED BY APPLYING THE 66,2-016 ORDINATES TO THE 6021 MEAN LINE BUT TO SOME OTHER MEANLINE.

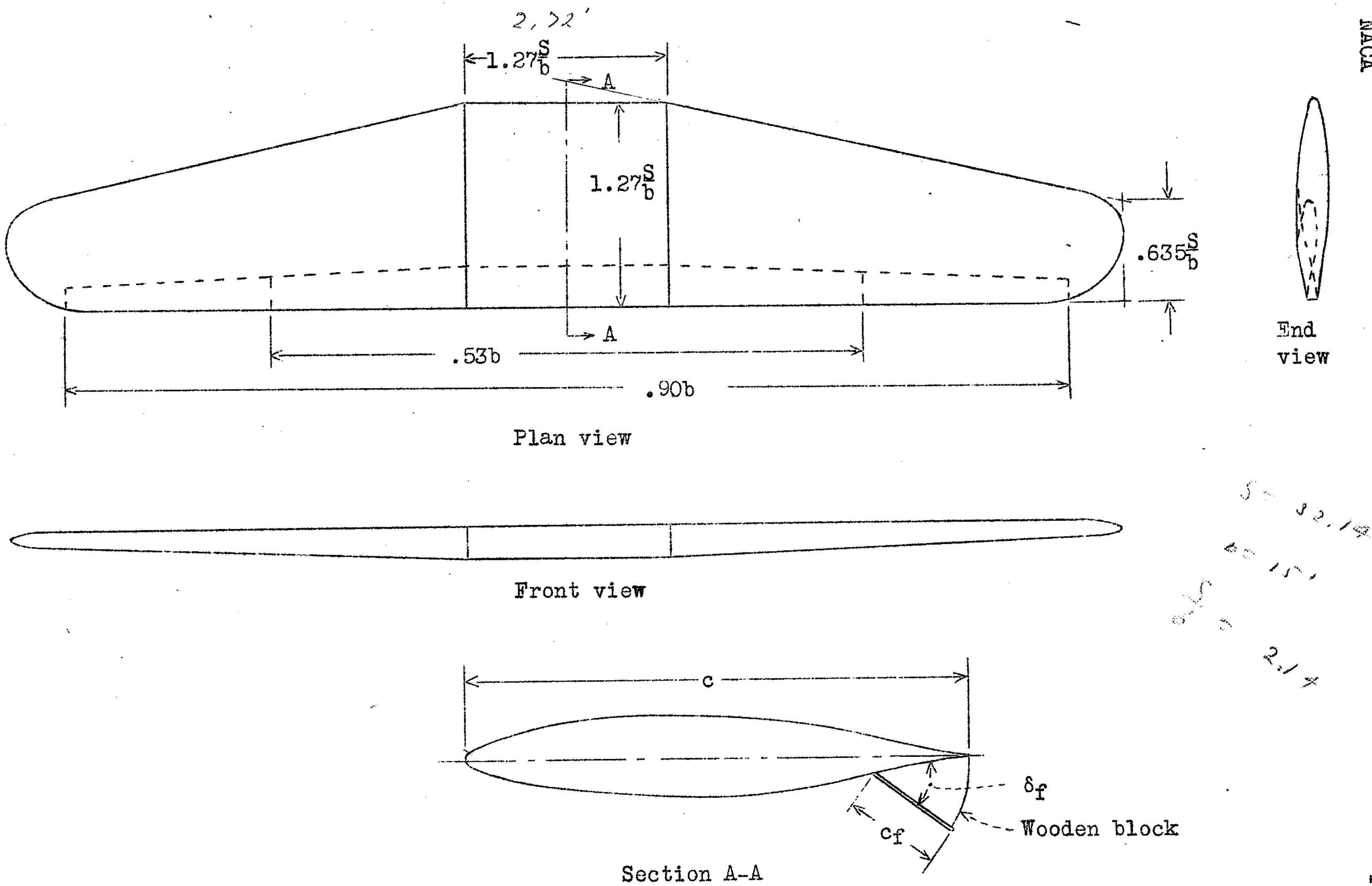


Figure 1.- The NACA 66 series low-drag tapered wing.

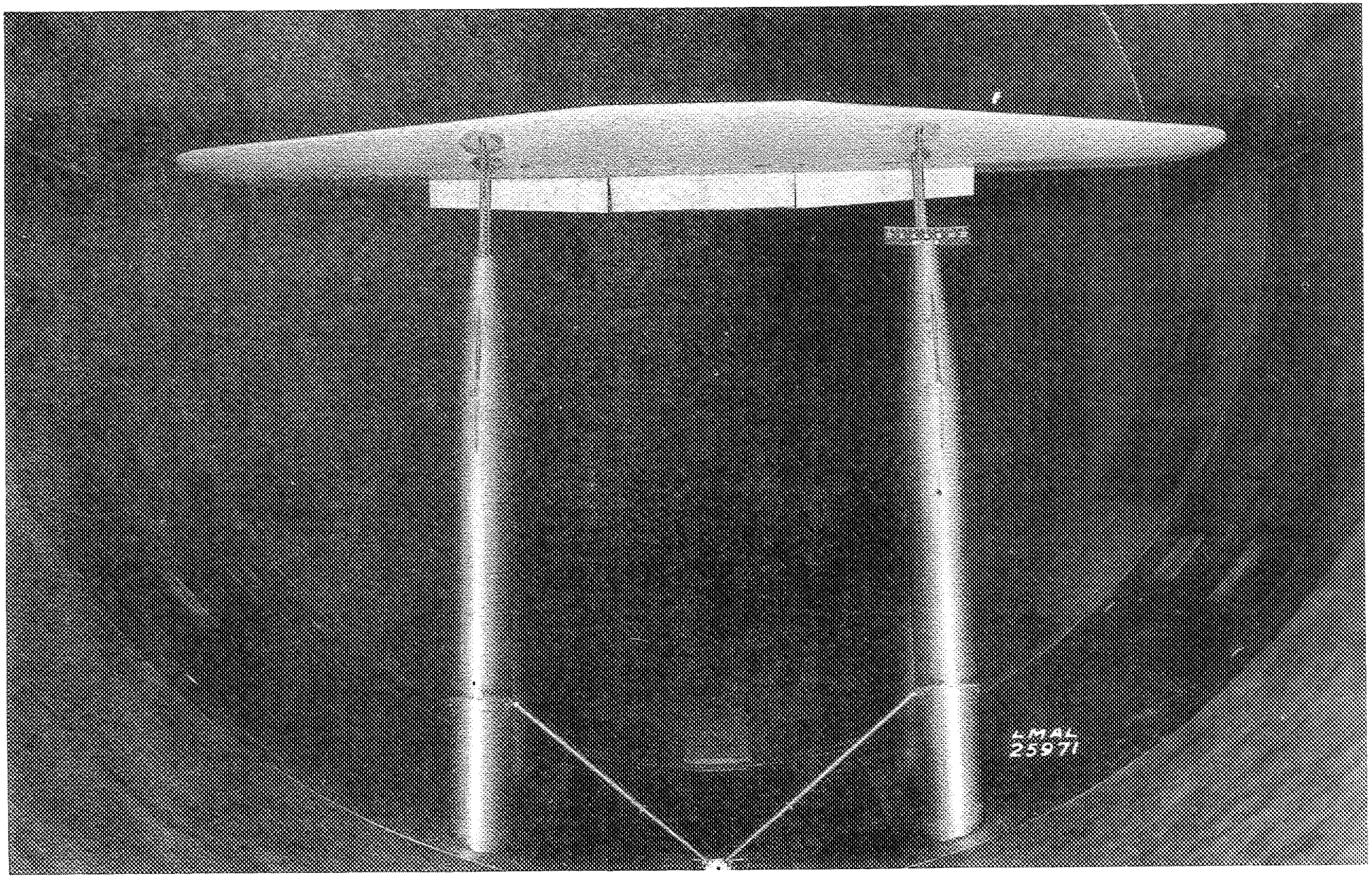
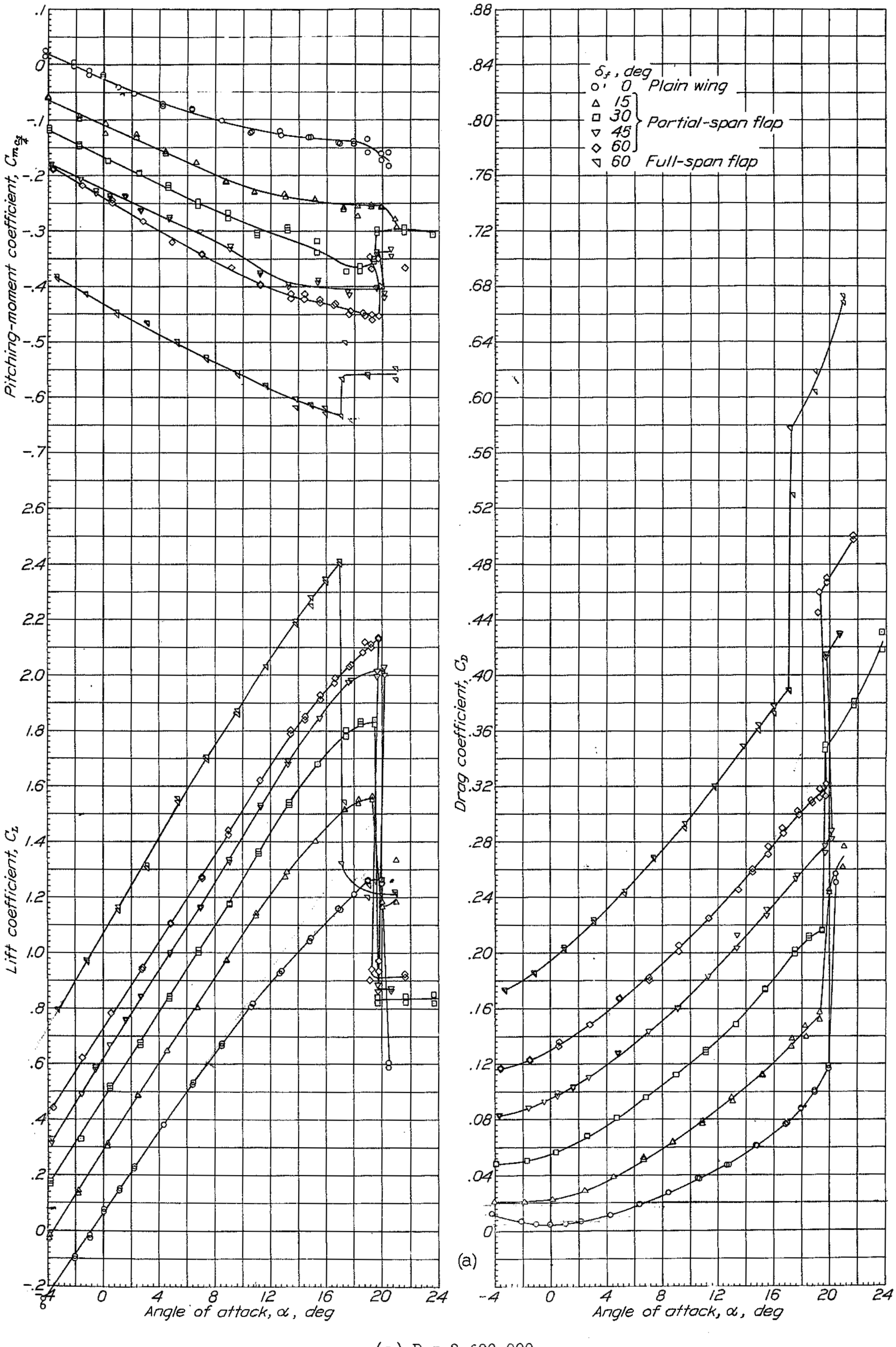
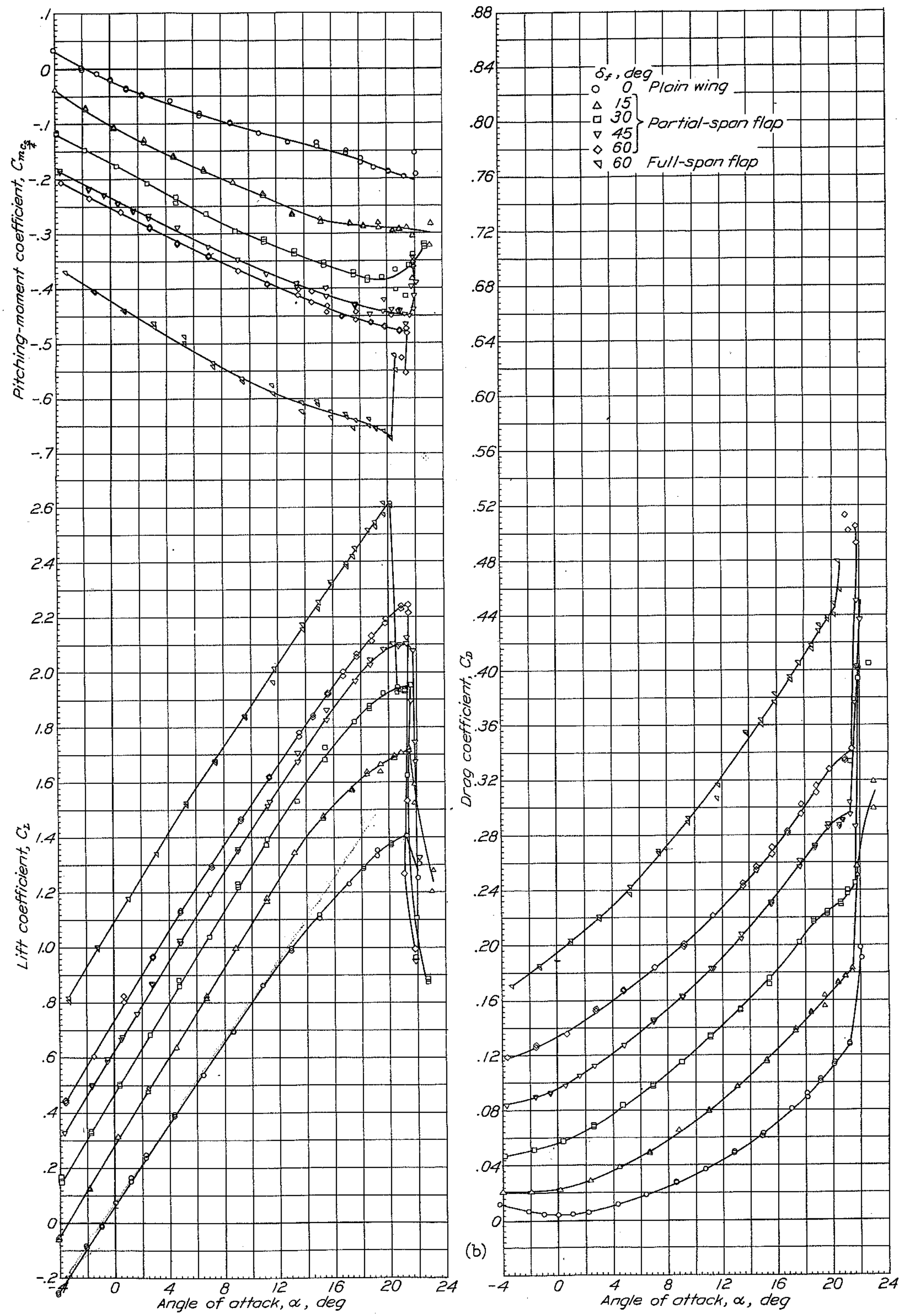


Figure 2.- The NACA 66 series low-drag tapered wing with split flaps on the standard wing supports in the 19-foot pressure tunnel.



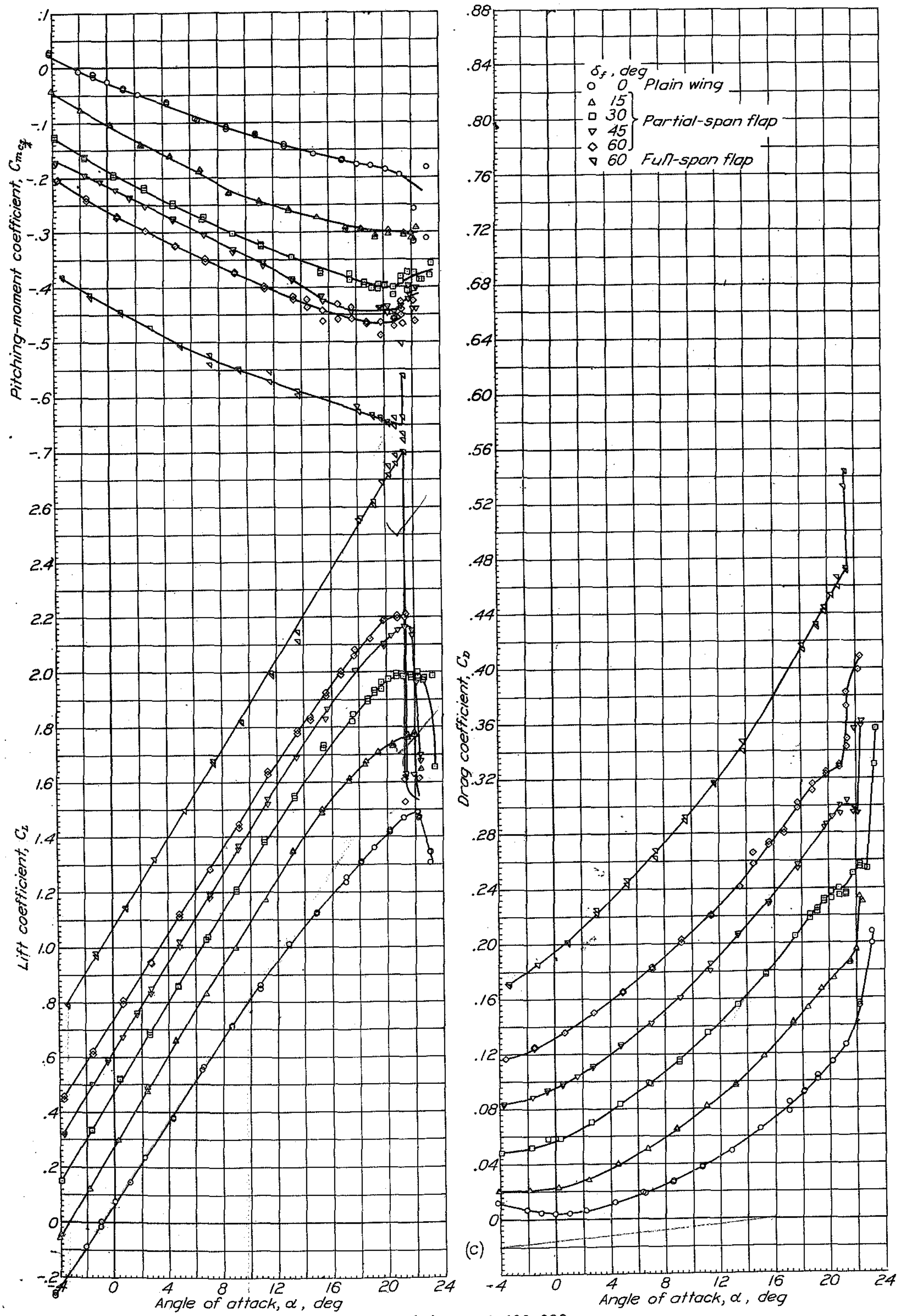
(a) R = 2,600,000.

Figure 3(a to c).- Aerodynamic characteristics of an NACA 66 series low-drag tapered wing with 0.20c split flap.



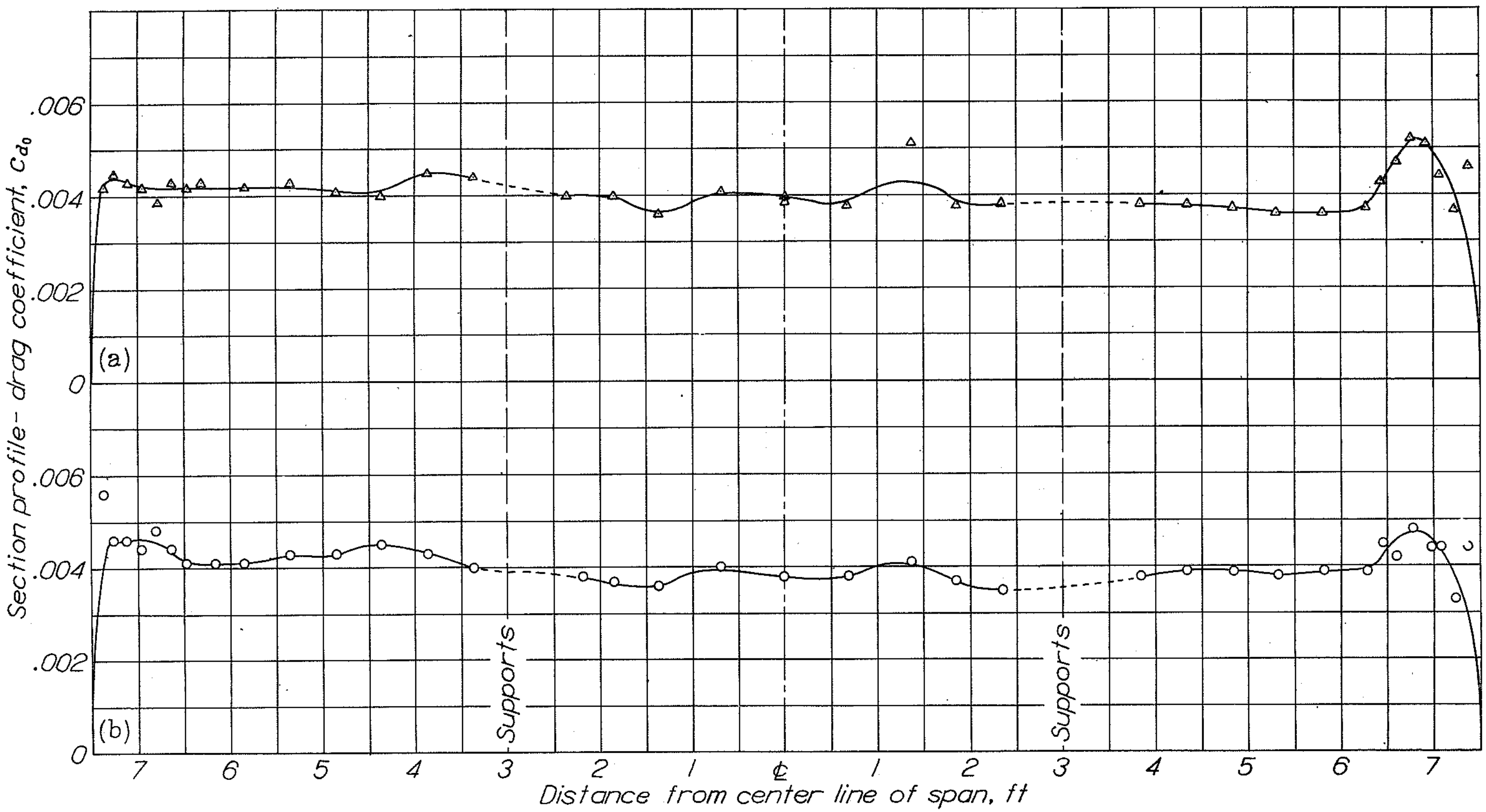
(b) R = 3,700,000.

Figure 3(b).



(c) R = 4,600,000

Figure 3c.



(a) R = 4,750,000. (b) R = 3,750,000.

Figure 4.- The variation of section profile-drag coefficient along the span of an NACA 66 series low-drag tapered wing.

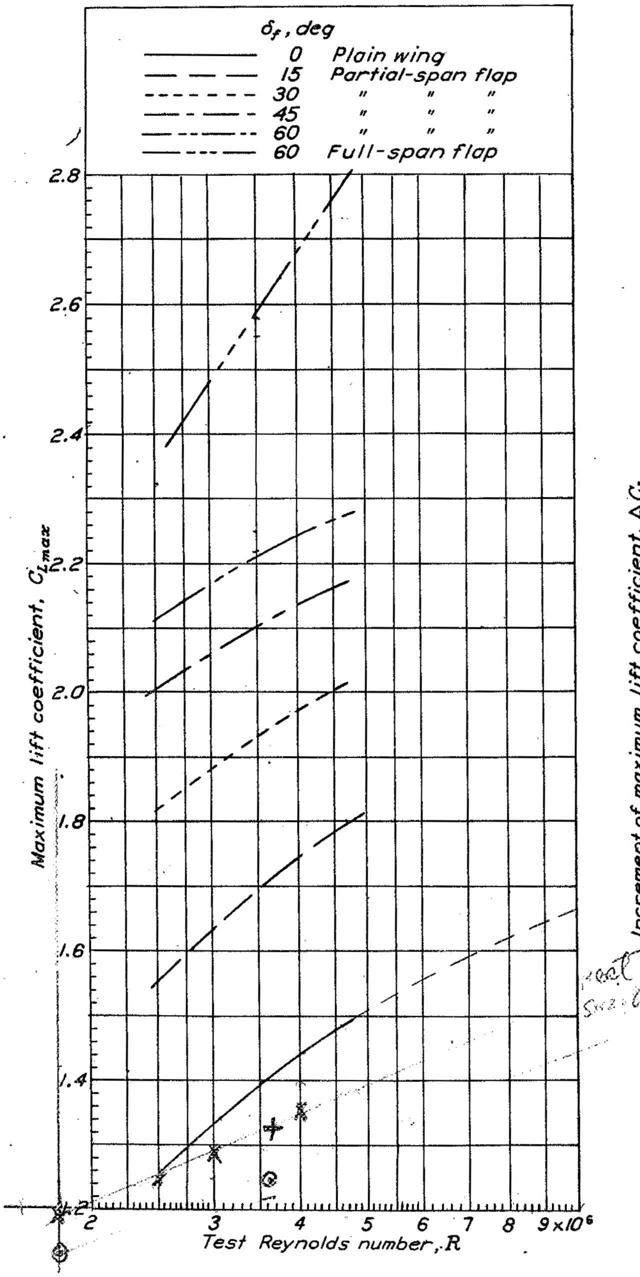


Figure 5.- Variation of maximum lift coefficient with Reynolds number of an NACA 66 series low-drag tapered wing with a 0.20c split flap.

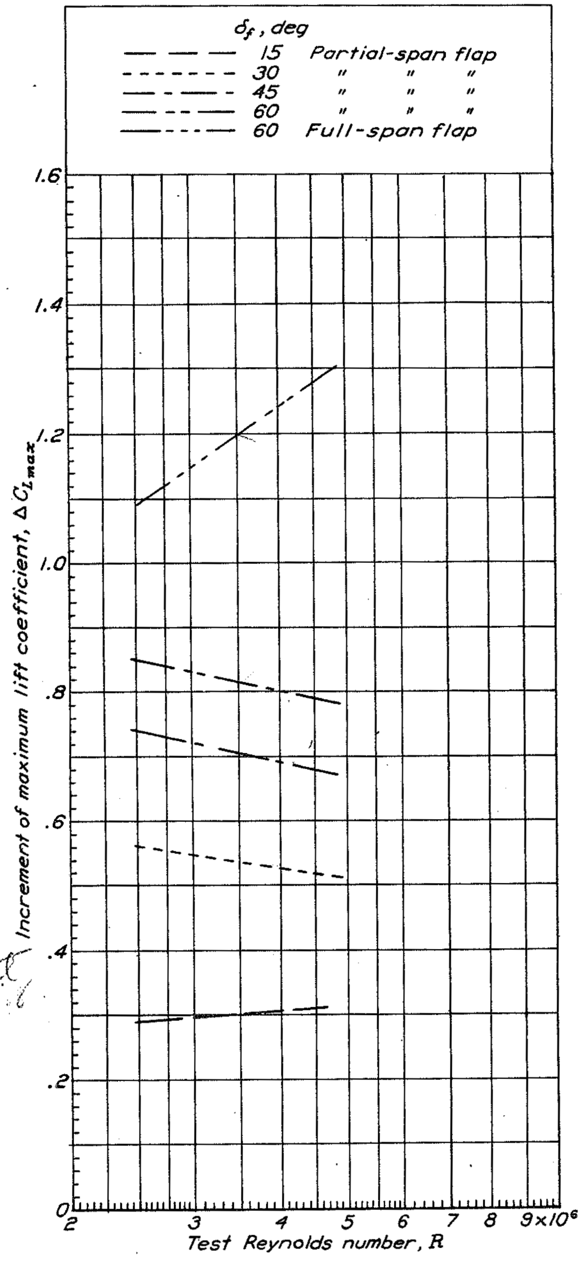


Figure 6.- Variation of increment of maximum lift coefficient with Reynolds number of an NACA 66 series low-drag tapered wing with 0.20c split flaps.

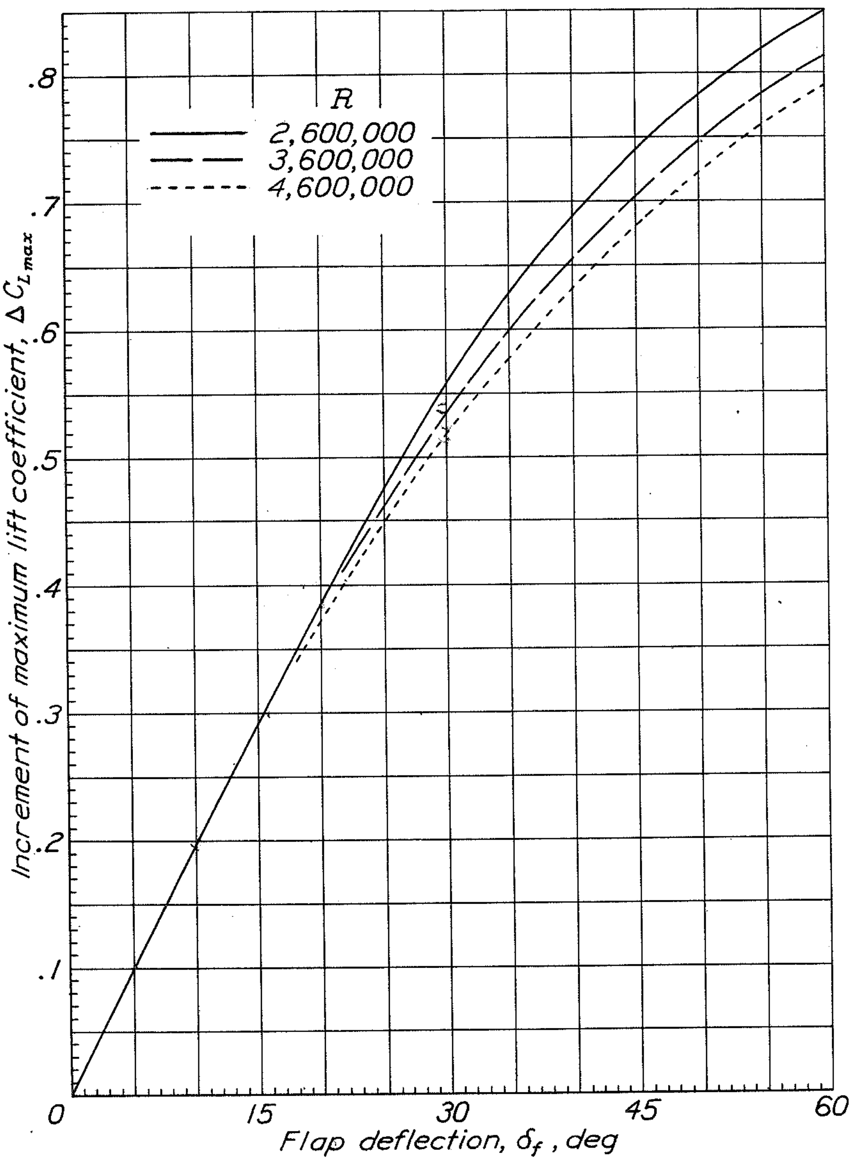


Figure 7.- Effect of flap deflection on the increment of maximum lift coefficient for a 0.20c partial-span split flap on an NACA 66 series low-drag tapered wing.

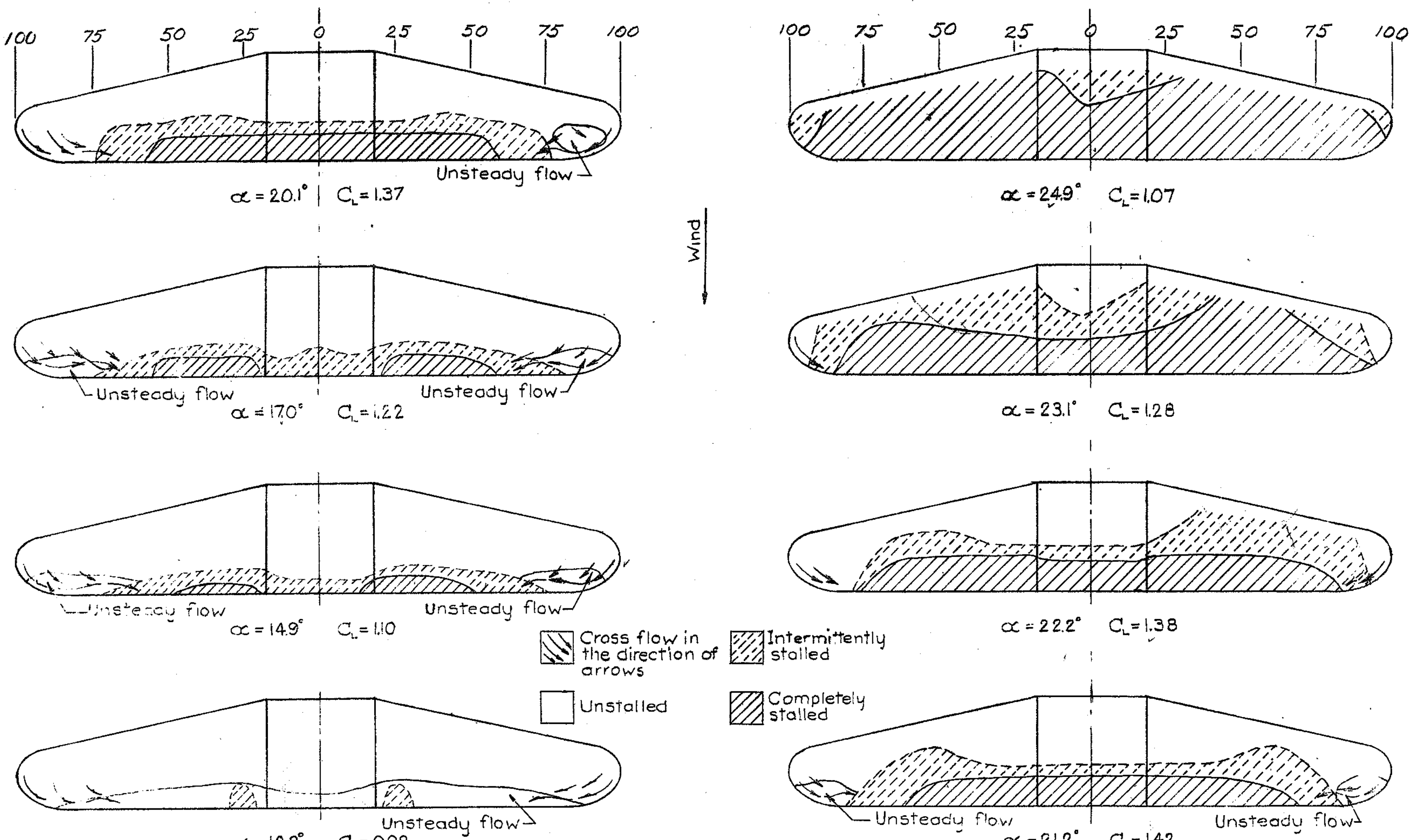


Figure 8.–Stall diagrams of an NACA low-drag tapered wing; δ_f, 0°; R = 4,600,000

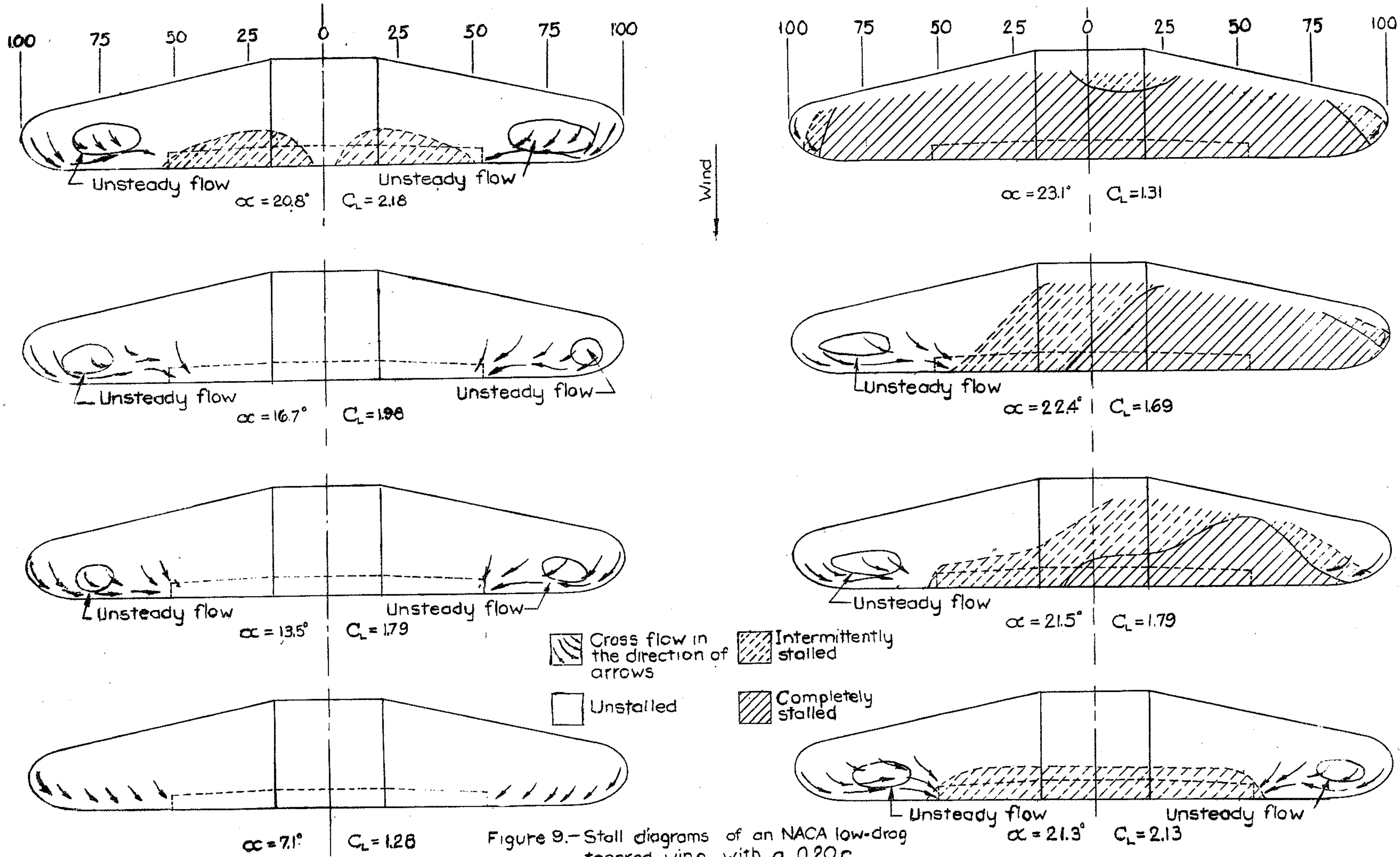


Figure 9.- Stall diagrams of an NACA low-drag tapered wing with a 0.20c partial-span split flap; δ_f, 60°; R, 4,600,000