TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 499

EFFECT OF RETRACTABLE-SPOILER LOCATION ON ROLLING- AND YAWING-MOMENT COEFFICIENTS

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Washington
July 1934

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SUMMARY

In this report are presented the results of wind-tunnel tests of retractable spoilers on the upper surface of a Clark Y wing, which have been made as part of an investigation of lateral control devices being conducted by the National Advisory Committee for Aeronautics. Spoilers with chords up to 15.0 percent of the wing chord were tested in several locations on a plain rectangular wing and in two locations on the same wing equipped with a 20.0 percent chord split flap down 60°.

Charts are given for four representative angles of attack from which values of rolling- and yawing-moment coefficients may be obtained for spoilers up to 15.0 percent chord located on the upper surface of a Clark Y wing.

The tests showed that at low angles of attack practically the same rolling moments can be obtained with a given spoiler at any location back of 30.0 percent of the wing chord, while at high angles of attack there is a definite advantage in locating the spoiler at least as far forward as 30.0 percent of the chord. The yawing moments accompanying a given rolling moment increase positively as the spoiler location is moved forward from the trailing edge of the wing. It is concluded that the 30.0 percent chord location is probably the optimum provided that instantaneous response of the airplane to a control movement can be obtained.

INTRODUCTION

The National Advisory Committee for Aeronautics has undertaken an investigation of the effectiveness of various lateral control devices, particularly at high angles of attack (reference 1). As a part of the investigation a hinged-plate spoiler located 20 percent of the wing chord (c) from the leading edge was tested in the wind tunnel (reference 2) and in flight (reference 3). The flight test showed that this type of spoiler had the objectionable characteristic of delayed response of the airplane to a movement of the spoiler. In an effort to overcome this lag, a retractable spoiler consisting of a curved plate hinged at the center of curvature was tested which presented a sharp-edged projection to the air flow well forward on the wing (15.0 percent c location) and which, it was hoped, would give instantaneous response. Flight tests with this device, however, showed longer lag than with the hinged-plate spoiler. Since ordinary ailerons have no noticeable lag, it was believed that moving the location of the spoiler rearward along the wing chord might materially reduce the lag. With this idea in mind, the present investigation was made to determine the effect on the rolling and yawing moments of moving the spoiler rearward. The retractable type of spoiler was used because it may be arranged to transmit no appreciable aerodynamic moment to the control stick. Since the retractable spoiler could be used with full-span flap, the tests were repeated with a split flap deflected and with the spoiler in two different locations.

The tests were made in the same tunnel and under the same conditions of test as those in the regular lateral control series.

APPARATUS

Wind tunnel.- The N.A.C.A. 7 by 10 foot wind tunnel, which is being used throughout the entire investigation, has an open jet and a single closed return passage. The tunnel, together with the regular balance and associated apparatus, is described in detail in reference 4.

Models.- The wing models used in the present investigation were ones that had been previously used in an investigation of ordinary ailerons and were constructed of laminated mahogany to within ±0.005 inch of the specified Clark Y ordinates. Both wings were rectangular in plan form with a chord of 10 inches and a span of 60 inches (aspect ratio 6). A 20 percent c split flap was made of thin steel plate and screwed to the lower surface of one of the wings. The spoilers were also made of steel plate formed with the proper radius and screwed to the upper surface of the wing. Figure 1 shows the locations of the deflected split flap and of all the spoilers tested. The radius of curvature, or length of control arm, was 17.0 percent c for all the spoilers except the most forward one for which the radius was limited to 12.8 percent c by structural considerations. The axes of rotation for the spoilers were selected so that the spoiler could be retracted into the wing on the arc of a circle.

TESTS AND RESULTS

All the tests were made at a dynamic pressure of 16.37 pounds per square foot, corresponding to an air speed of 80 miles per hour in standard air, which makes the Reynolds Number 609,000 based on the 10-inch chord.

The regular force tests were made at angles of attack from 0° to 40° at zero yaw.

Coefficients.- The results are given in the form of absolute coefficients of lift and drag and of rolling, yawing, and pitching moments.

$$C_L = \frac{\text{lift}}{qS}$$

$$C_D = \frac{\text{drag}}{qS}$$

$$C_l' = \frac{\text{rolling moment}}{qbS}$$

$$C_n' = \frac{\text{yawing moment}}{qbS}$$

$$C_{m_{c/4}}' = \frac{\text{pitching moment}}{qcS}$$

where S is the total area, b is the wing span, c is the wing chord, and q is the dynamic pressure. The coefficients as given are not corrected for tunnel-wall effect. They are obtained directly from the balance and refer to the wind axes.

Preliminary tests with a spoiler in the most forward location.- The first of the series of retractable spoilers tested was arranged so that the spoiler emerged from the upper surface of the wing 15.0 percent c from the leading edge, as shown in figure 1. The hinge axis of the spoiler was located on the center of curvature of the spoiler so that when the spoiler was deflected the entire surface moved on the same arc. In the wind-tunnel tests, spoilers of different chords were used corresponding to different deflections of the control. The spoiler tested at the above location was 40.0 percent b/2 long and was located 10.0 percent b/2 inboard from the end of the wing. Chordwise slots were cut through the spoiler at intervals corresponding to the rib spacing on the full-scale airplane on which a similar spoiler was to be tested later. The results of these tests are given in table I and plotted against spoiler chord in figure 2(a). One test was made with the fully deflected spoiler before the slots were cut, to determine the effect of the slots. The results of this test are also given in table I, and showed that the slots had no noticeable effect on the moment coefficients. A noteworthy characteristic of the rolling-moment coefficients obtained with this first uniform-chord spoiler is that, at 16° and 20° angles of attack (fig. 2(a)), approximately three fifths of the maximum rolling moment was obtained with only one fifth of the maximum deflection. In order to obtain a better graduation of rolling action with the same total spoiler deflection three different shapes of spoilers having the same radii were tested. These spoilers, together with a cross-plot of the results obtained with them, are shown in figures 2(b), 2(c), and 2(d). The spoiler shown in figure 2(d) gave the best results.

In order to measure the control force required for this type of spoiler an installation was made in a half-span wing of 33-inch chord and the hinge moments on the retractable spoiler were measured. Within the accuracy of the measurements the control force (aerodynamic moment) was zero.

Tests of retractable spoilers back of the maximum ordinate.- In a later series of tests a 15.0 percent c uniform-chord spoiler, 50.0 percent b/2 long, extending to the wing tip, was tested located successively at the 30.0, 45.0, 60.0, 83.3, and 95.0 percent c stations. This spoiler was then cut down to 10.0 and 5.0 percent c to simulate retraction into the wing and the tests were repeated. A 20.0 percent c split flap was then attached to the lower surface and the 5.0 and 15.0 percent c spoilers were tested at the 30.0 and 83.3 percent c stations. The rolling- and yawing-moment coefficients obtained are given in table II and the pitching-moment coefficients are given in table III.

Charts have been prepared from the test data of rolling- and yawing-moment coefficients with no flap in figures 3 and 4. The lines on the charts represent equal values of rolling- or yawing-moment coefficients. The results of the tests with the spoiler at the 15.0 percent c station, which spoiler was four fifths the length of the others, have been corrected to the longer length so that the values on the chart are directly comparable. The charts have been prepared for four representative angles of attack: $\alpha = 0^\circ$ represents the normal high-speed attitude; $\alpha = 10^\circ$ represents about the highest angle of attack at which ordinary ailerons give good control; $\alpha = 15^\circ$ represents the angle of maximum lift, landing condition; and $\alpha = 20^\circ$ is well above the stall on a Clark Y wing and represents probably the most unsteady condition.

DISCUSSION

Rolling moment.- With the flap neutral, the rolling moments are given on the charts in figure 3 for the four representative angles of attack. The shortest chord spoiler that will give the desired rolling moment is probably the most desirable. At 0° angle of attack a location near mid chord is apparently the best, although the variation from the 30.0 percent c station back to the 95.0 percent c station is not great. With a spoiler ahead of the 30.0 percent c station, however, the rolling moments are definitely low. At 10° angle of attack, the effect of location becomes more noticeable, the rolling moment obtained with a 15.0 percent c spoiler at the 95.0 percent c station being equaled at the 30.0 percent c station by a spoiler only one fourth as high. At the stall (15° angle of attack), the moments at the rear positions continue to decrease while the moments at the forward locations reach their highest values. At 20° angle of attack the forward positions are still good, while the rear positions are definitely bad. The disadvantage of a uniform-chord spoiler at the most forward location is shown at angles of attack of 15° and 20°, where a small percentage of the maximum deflection gives a large percentage of the total rolling moment.

With the flap down, the spoilers were tested in only two locations, 30.0 percent c and 83.3 percent c. The results given in table II, show that at 0° angle of attack, the rolling moments obtained at the rear location were slightly higher than those obtained at the forward location. At the 10° and 15° angles of attack, however, the forward location gave definitely better results. At the 20° angle of attack a spoiler in either location was ineffective in producing a rolling moment of any consequence.

Yawing moments.- With the flap neutral the charts in figure 4 show that at 0° angle of attack, the yawing moment with all the spoilers tested is positive, the forward locations giving slightly higher values. As the angle of attack is increased the yawing moments become negative for the rearmost position, the line of zero moment moving forward as the angle is further increased until at 20° angle of attack, even the spoiler at the 30.0 percent c location gives negative moments at low deflections. With the most forward location (15.0 percent c) the yawing moments have high positive values even at 20° angle of attack.

With the flap down, the yawing-moment coefficients were about the same as those obtained with the flap neutral except that at the rear positions they became negative at a lower angle of attack.

Rolling criterion (RC').- When the angle of attack is increased or the split flap is deflected at angles of attack below the stall, an increase in lift coefficient is obtained that allows a lower flight-path velocity. This reduced velocity for a given rolling-moment coefficient means lower actual rolling moments and resulting accelerations in roll. The effect of angle of attack and particularly the effect of split flaps upon the rolling accelerations experienced in flight with a given control deflection are shown by a rolling criterion RC', which is proportional to the tangential acceleration of the wing tip. This RC' is the same as the RC discussed in detail in reference 1 except that it refers to motion about the wind axis instead of about the body axis. For a rectangular wing it is equal to the rolling-moment coefficient divided by the lift coefficient. Values of RC' have been computed for a 15.0 percent c by 50.0 percent b/2 retractable spoiler located at two different positions, 30.0 percent c and 83.3 percent c, both with and without a split flap. (See fig. 5.) In flight tests of one particular airplane (reference 5), a value of RC' of at least 0.045 was found to be desirable. The spoiler at the 30.0 percent c location gives values of RC' greater than 0.045 at all lift coefficients up to the maximum with or without a split flap in operation. With the spoiler at the 83.3 percent c location, the values of RC' fall below 0.045 at the upper end of the range of lift coefficients obtained with or without a split flap.

<u>Pitching-moment coefficients.</u>- The pitching-moment coefficients about the quarter-chord point of the wing are given in table III for the more recent tests with the spoilers located back of the maximum ordinate on a wing with and without a split flap. Either with or without the flap in use, deflecting a retractable spoiler located near the trailing edge of the wing produces an appreciable stalling moment which for a sustained spoiler deflection must be balanced by a tail movement if a change in angle of attack is to be avoided. Moving the spoiler location forward from the trailing edge reduces this stalling moment until at the 30.0 percent c location, no change in pitching-moment coefficient accompanies the spoiler deflection.

<u>Practical application.</u>- The results given herein are concerned with rolling and yawing moments as affected by spoiler location without reference to lag in the response of the airplane. Lag, of course, stands as a serious drawback in the application of this type of lateral control to airplanes and at the present time it is the subject of an investigation. On the basis of results obtained to date in the lag investigation, it may be stated that the lag decreases progressively as the spoiler location is moved toward the trailing edge, a practical value being reached at about the 80.0 percent c location. Furthermore, some promising results have been obtained in an effort to eliminate the lag in the region of the optimum location (30.0 percent c) as determined in this report. The results of the investigation of lag will be the subject of a subsequent report. At the present time, however, the practical application of spoilers, unless used in combination with ailerons, seems to be limited to locations near the trailing edge of the wing.

CONCLUSIONS

1. A retractable spoiler 15.0 percent c by 50.0 percent b/2 located 30.0 percent c back of the leading edge of the wing will give reasonably satisfactory values of a rolling criterion with or without a split flap, throughout the normal flight range, accompanied by positive yawing moments and no appreciable aerodynamic hinge moments. This location is probably the optimum, provided that instantaneous response of the airplane to the movement of the spoiler can be obtained.

2. Moving the location of a spoiler rearward from the 30.0 percent c station reduces the rolling-moment coefficients at high angles of attack, and reduces the ratio of yawing moment to rolling moment.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 22, 1934.

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TABLE I. FORCE TESTS. 10 by 60 Inch Clark Y Wing with a Retractable Spoiler 15 percent c from L.E. of Wing[1)] on the Upper Surface
R.N. = 609,000. Air speed = 80 m.p.h. Yaw = 0°

α, deg.		0	10	14	16	18	20	22	25	30	40
Spoiler retracted											
	C_L C_D	0.375 .021	1.075 .089	1.253 .131	1.272 .162	1.220 .200	1.172 .244	1.100 .356	0.822 .416	0.860 .546	0.803 .713
Spoiler chord, percent c	Spoiler deflected										
1.1	C_l' C_n'	0.003 .001	0.011 .002	0.028 .007	0.033 .007	0.023 .005	0.018 .003	0.017 .001	-0.003 - .002	-0.001 - .001	0.001 0
2.2	C_l' C_n'	.004 .003	.030 .009	.052 .009	.058 .008	.048 .005	.044 .002	.039 0	- .005 .001	0 .002	0 0
3.4	C_l' C_n'	.006 .006	.041 .010	.054 .010	.059 .009	.051 .006	.049 .004	.044 .001	- .005 0	- .001 .001	0 0
5.6	C_l' C_n'	.017 .010	.055 .012	.063 .013	.064 .012	.053 .009	.049 .008	.049 .006	- .001 - .001	- .006 .001	- .001 0
7.7	C_l' C_n'	.023 .012	.064 .014	.073 .015	.074 .014	.061 .012	.056 .011	.054 .008	.009 - .001	- .003 - .001	0 0
10.0	C_l' C_n'	.025 .012	.069 .015	.080 .016	.083 .016	.071 .014	.066 .012	.062 .009	.017 .003	.005 .002	-.001 0
With no chordwise saw cuts											
10.0	C_l' C_n'	0.026 .012	0.069 .016	0.081 .016	0.083 .016	0.072 .014	0.067 .012	0.061 .009	0.018 .003	0.004 .002	-0.002 - .001

1) This spoiler was 40 percent b/2 and inset 10 percent b/2 from the end of the wing. The chord was varied. Chordwise saw cuts 1/16 inch were made every 2 inches on the 12-inch spoiler except for the test noted.

TABLE II. FORCE TESTS
10 by 60 inch Clark Y Wing with a 20 percent Split Flap and Retractable Spoilers
50 percent of the Semispan with Several Chords at Different Locations on the Upper Surface
R.N. = 609,000. Air speed = 80 m.p.h. Yaw = 0°

α, deg.			-10	-5	-4	-3	0	5	10	14	15	16	18	20	22	25	30	40
Spoiler retracted - Flap neutral																		
		C_L	-0.327	.013	.084	.154	0.367	0.730	1.067	1.248	1.268	1.265	1.258	1.178	1.100	0.892	0.863	0.783
		C_D	.032	.017	.0163	.017	.022	.048	.091	.132	.146	.165	.200	.242	.283	.392	.548	.703
Spoiler chord, per cent c	Chordwise location per cent c	Spoiler deflected - Flap neutral																
15.0	30.0	C_l'					0.060		0.087		0.094		0.086	0.072	0.066	0.013	0.007	0
		C_n'					.024		.023		.021		.017	.015	.011	.004	.002	-.001
15.0	60.0	C_l'					.069		.081		.076		.066	.047	.037	0	.005	0
		C_n'					.020		.012		.008		.003	0	-.002	.003	-.002	-.001
15.0	83.3	C_l'					.065		.064		.054		.043	.025	.023	0	.002	0
		C_n'					.017		.006		.002		-.001	-.002	-.001	0	-.001	-.001
15.0	95.0	C_l'					.061		.051		.040		.031	.013	.016	-.003	.002	0
		C_n'					.008		0		-.002		-.003	-.003	-.002	0	-.001	0
10.0	30.0	C_l'					.048		.078		.085		.080	.066	.053	.003	.001	0
		C_n'					.017		.016		.015		.010	.006	.005	.001	.001	0
10.0	60.0	C_l'					.055		.061		.056		.049	.029	.027	.002	.003	0
		C_n'					.013		.007		.003		0	-.002	-.003	0	-.002	0
10.0	83.3	C_l'					.050		.046		.035		.030	.012	.015	0	.002	.001
		C_n'					.010		.002		0		-.002	-.002	-.002	-.005	-.001	-.001
10.0	95.0	C_l'					.044		.035		.024		.018	.007	.006	.001	.001	0
		C_n'					.003		-.002		-.003		-.003	-.003	-.002	0	-.004	-.001
5.0	30.0	C_l'					.028		.058		.063		.063	.046	.037	.001	.002	0
		C_n'					.011		.010		.008		.003	0	-.003	-.006	-.001	-.001
5.0	60.0	C_l'					.037		.039		.033		.029	.019	.014	.002	.003	0
		C_n'					.007		.002		0		-.002	-.003	-.003	-.001	-.001	-.001
5.0	83.3	C_l'					.031		.025		.019		.015	.009	.006	0	.003	0
		C_n'					.003		-.001		-.002		-.002	-.001	-.002	0	-.001	-.001
5.0	95.0	C_l'					.025		.018		.011		.006	.004	.003	.001	.003	.001
		C_n'					.001		-.002		-.002		-.002	-.002	-.002	0	-.001	-.001
Spoiler retracted - Flap down 60°																		
		C_L	0.500	.897			1.258	1.588	1.900	2.140	2.190		1.410	1.190	1.115	1.080	0.950	0.800
		C_D	.180	.221			.271	.338	.417	.483	.493		.593	.699	.734	.779	.844	.998
Spoiler deflected - Flap down 60°																		
15.0	30.0	C_l'					0.065		0.104		0.128		0.071	0.015	0.012	0.010	0	0
		C_n'					.033		.019		.015		.017	.013	.005	.001	0	.001
15.0	83.3	C_l'					.078		.074	0.069	.053		.026	.002	.007	.003	.001	0
		C_n'					.010		-.001	-.002	-.001		0	0	-.003	-.002	-.002	-.001
5.0	30.0	C_l'					.033		.074	.088	.065		.035	0	.002	.002	-.001	0
		C_n'					.010		.005	0	.001		.001	0	-.002	-.001	-.001	-.001
5.0	83.3	C_l'					.038		.034		.032		.007	.002	-.002	.001	0	0
		C_n'					-.001		-.006		-.008		-.002	-.001	-.001	0	-.001	-.002

TABLE III. PITCHING-MOMENT COEFFICIENTS (QUARTER-CHORD POINT)
10 by 60 Inch Clark Y Wing with a 20 percent c Split Flap and 50 percent Semispan Retractable Spoilers of Various Chords in Several Locations on the Upper Surface
R.N. = 609,000. Air speed = 80 m.p.h. Yaw = 0°

α, deg.		-5	0	10	15	18	20	23	25	30	40
Spoiler retracted - Flap neutral											
		-0.079	-0.074	-0.072	-0.067	-0.083	-0.106	-0.119	-0.142	-0.167	-0.191
Spoiler chord, percent c	Chordwise location percent c	Spoiler deflected - Flap neutral									
15.0	30.0		-0.075	-0.070	-0.068	-0.091	-0.107	-0.124	-0.139	-0.165	-0.195
15.0	60.0		- .054	- .050	- .052	- .072	- .088	- .106	- .136	- .172	- .190
15.0	83.3		- .025	- .027	- .034	- .059	- .076	- .095	- .133	- .169	- .193
15.0	95.0		- .006	- .013	- .024	- .050	- .070	- .090	- .136	- .178	- .192
10.0	30.0		- .081	- .073	- .070	- .086	- .102	- .115	- .136	- .161	- .192
10.0	60.0		- .056	- .054	- .054	- .071	- .089	- .105	- .134	- .167	- .192
10.0	83.3		- .039	- .041	- .045	- .063	- .081	- .104	- .143	- .169	- .192
10.0	95.0		- .030	- .033	- .042	- .065	- .085	- .108	- .139	- .171	- .193
5.0	30.0		- .086	- .076	- .075	- .085	- .102	- .112	- .143	- .170	- .192
5.0	60.0		- .066	- .063	- .063	- .078	- .098	- .112	- .138	- .166	- .190
5.0	83.3		- .052	- .053	- .055	- .071	- .096	- .116	- .140	- .168	- .194
5.0	95.0		- .050	- .051	- .055	- .075	- .096	- .114	- .140	- .169	- .192
Spoiler retracted - Flap down 60°											
		-0.261	-0.268	-0.280	-0.293	-0.252	-0.300	-0.294	-0.287	-0.286	-0.286
Spoiler deflected - Flap down 60°											
15.0	30.0		-0.263	-0.263	-0.264	-0.267	-0.273	-0.282	-0.282	-0.280	-0.283
15.0	83.3		- .208	- .228	- .222	- .232	- .273	- .285	- .284	- .282	- .283
5.0	30.0		- .278	- .271	- .254	- .259	- .280	- .288	- .285	- .283	- .283
5.0	83.3		- .240	- .255	- .266	- .247	- .280	- .288	- .288	- .281	- .283

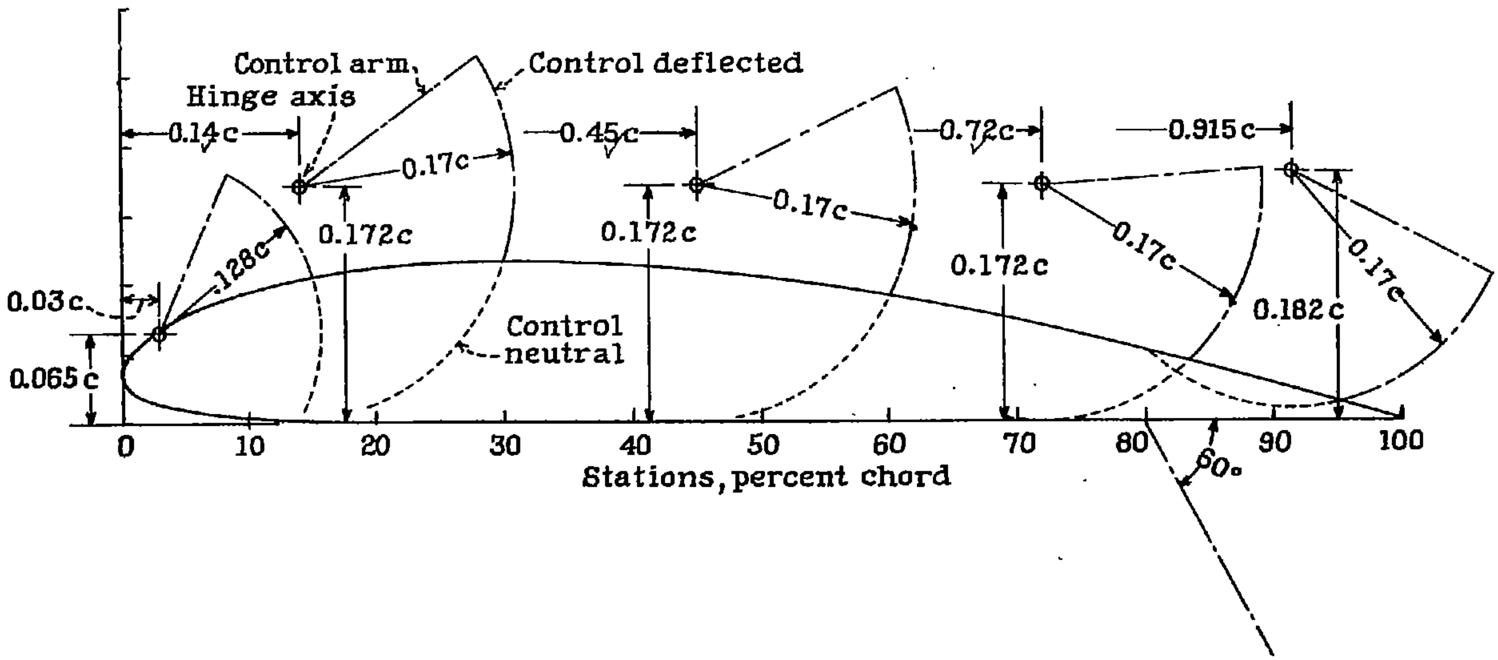

Figure 1.- Section of Clark Y wing showing locations of retractable spoilers and a 20 percent c split flap.

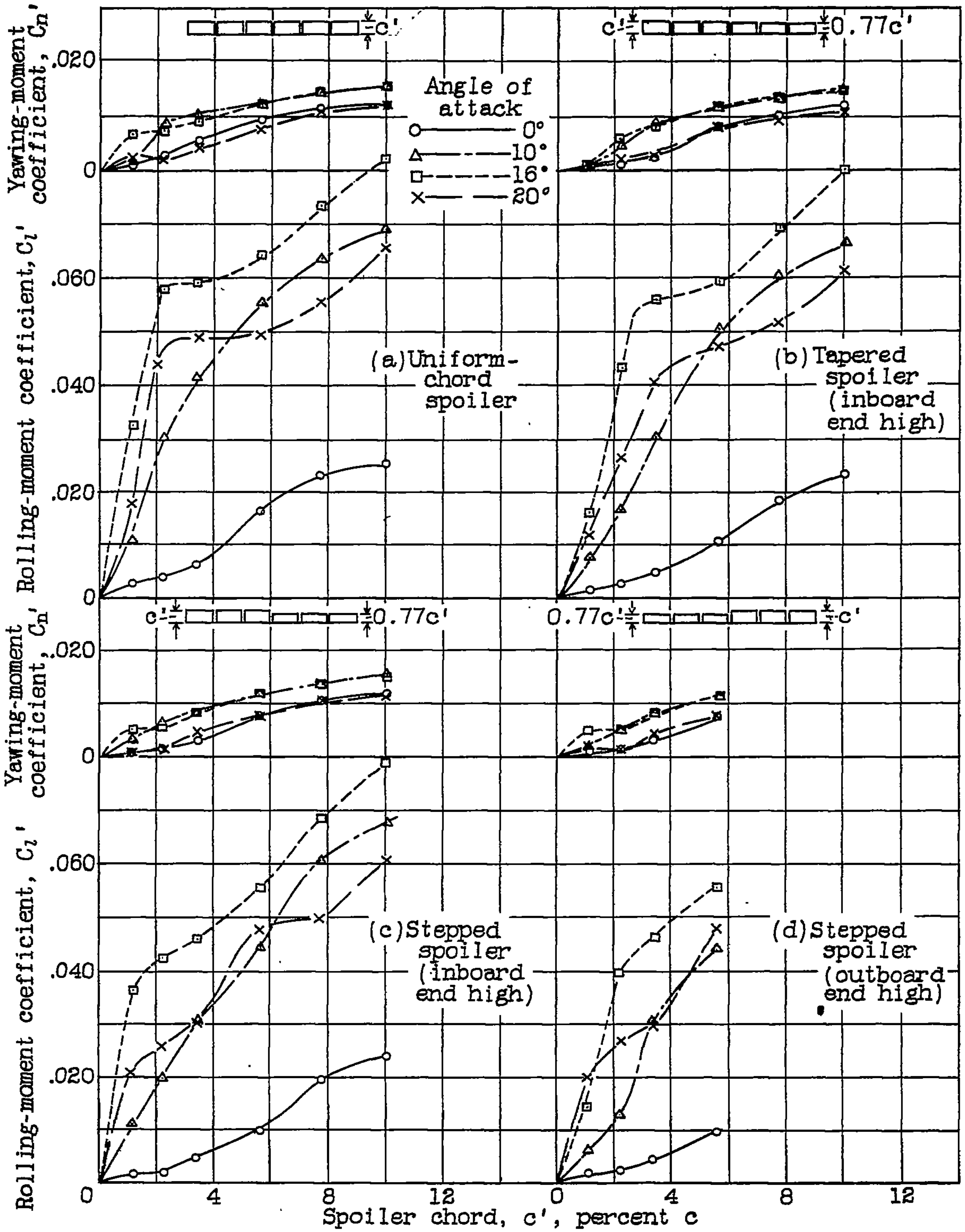

Figure 2(a,b,c,d).-Rolling-and yawing-moment coefficients due to a 40 percent semispan retractable spoiler at 15 percent c location.

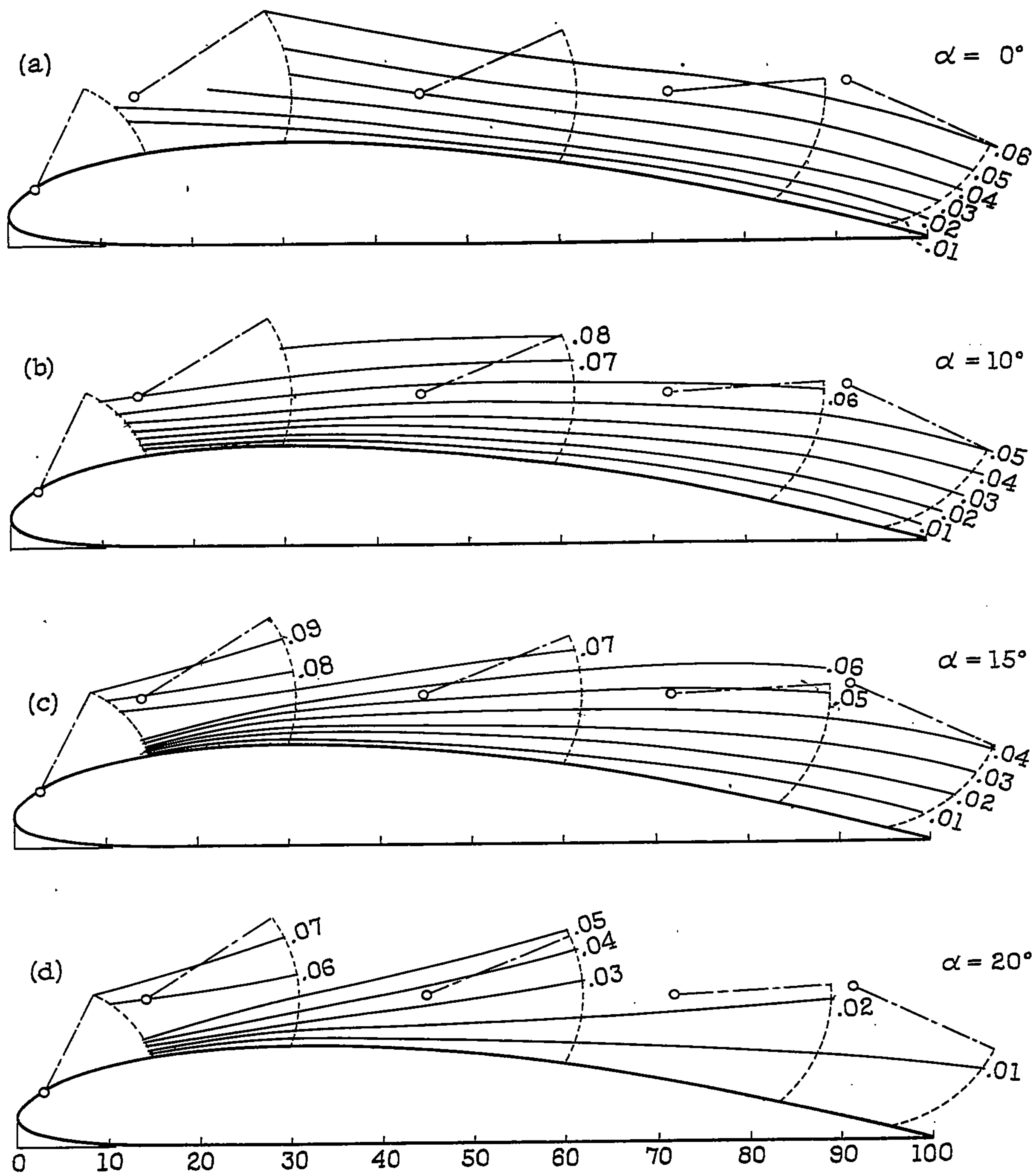

Figure 3(a,b,c,d).- Lines of equal rolling-moment coefficients due to a 50 percent semispan retractable spoiler at various locations on a Clark Y wing.

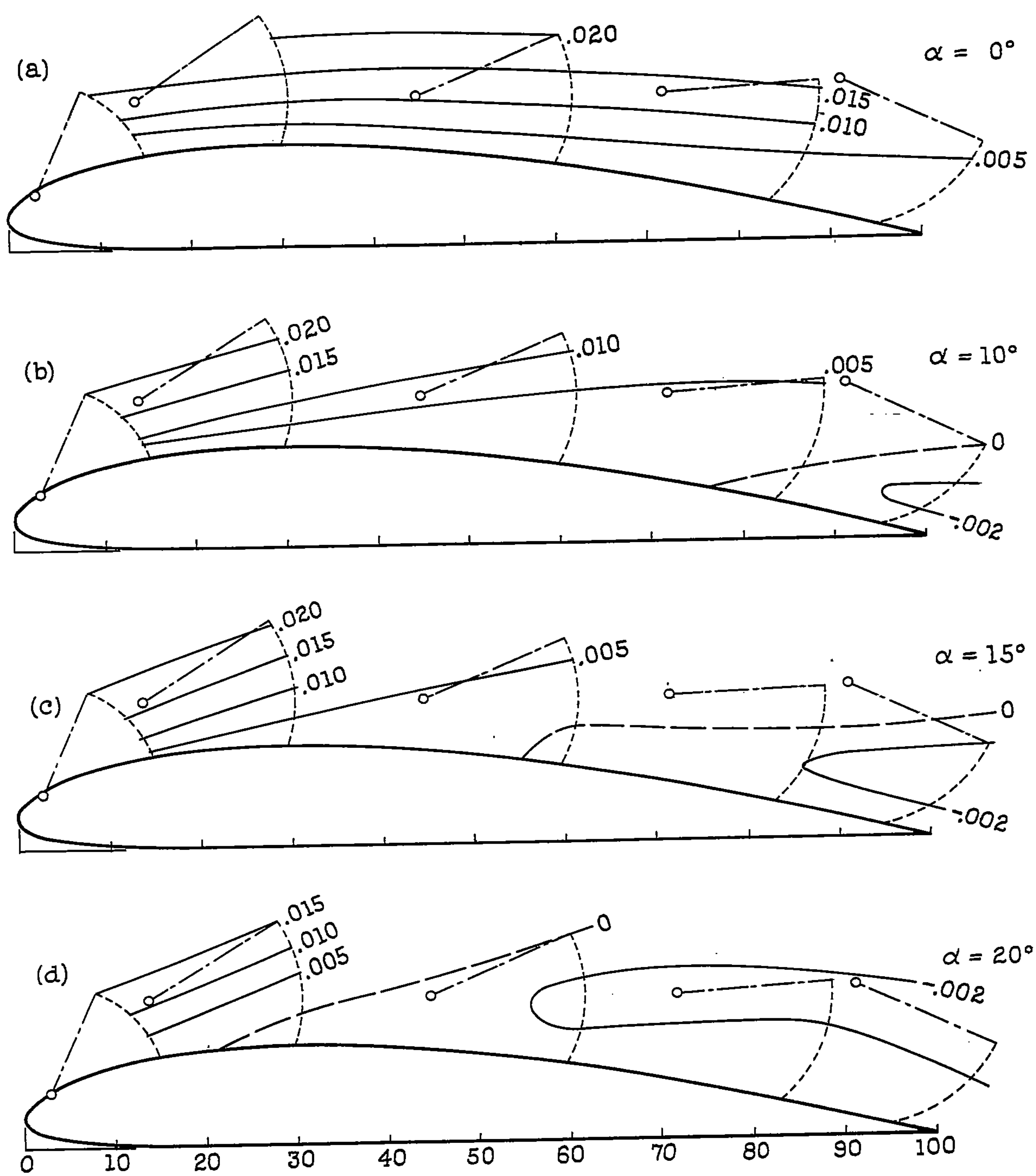

Figure 4(a,b,c,d). - Lines of equal yawing-moment coefficients due to a 50 percent semispan retractable spoiler at various locations on a Clark Y wing.

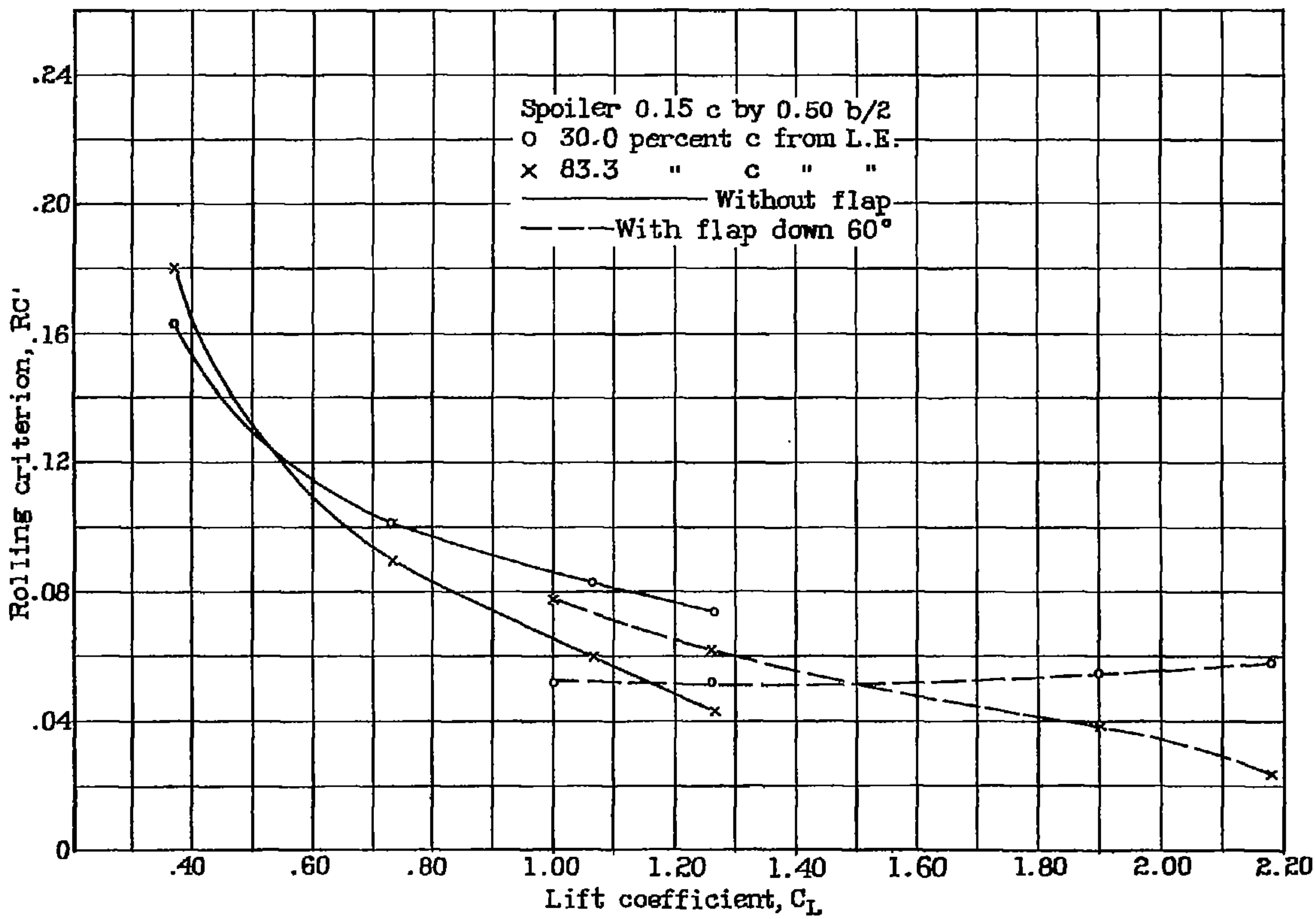

Figure 5.- Effect of spoiler location on rolling criterion with and without a 20 percent c split flap.