TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 415

PRELIMINARY INVESTIGATION OF ROLLING MOMENTS OBTAINED WITH SPOILERS ON BOTH SLOTTED AND PLAIN WINGS

By Fred E. Weick and Carl J. Wenzinger
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SUMMARY

A wind-tunnel study has been made to determine the possibility of developing spoilers suitable for providing the lateral control for airplanes in place of the usual ailerons. The first tests were made on a model wing with a fixed tip slot, but when it was found that the effectiveness of the spoilers did not depend to any great extent on the slot, tests were made on a plain wing also. In both cases certain spoiler positions were found which were free from the usual adverse rolling moments with small deflections. Five different forms of spoiler were tested, the best ones being simple plates, either straight or slightly curved to fit the contour of the airfoil when not deflected. Sufficient rolling moment can probably be obtained from spoilers of reasonable size to provide satisfactory lateral control for certain types of airplanes.

INTRODUCTION

Improved lateral control at high angles of attack has been obtained by the combined use of Handley Page automatic wing-tip slots, interceptors, and ailerons. The tip slots and interceptors operate, however, only at the high angles of attack, where the interceptor destroys the slot effect on the side of the downgoing wing.

It appeared likely that spoilers could be used on a wing in connection with recently developed fixed tip slots (reference 1) to give the desired lateral control without the use of ailerons, by spoiling not only the slot effect but also a considerable portion of the lift at the low angles of attack where the slot effect is small.

As previously tested on plain wings, the spoiler consisted of a small flap projecting from the upper surface at or near the leading edge. With the spoiler erect, the flow over the upper surface breaks down so that the lift is decreased and the drag is increased on that side, thereby giving a rolling moment together with a favorable yawing moment. Some of the early tests showed that the wing profile affected the spoiler characteristics only slightly and that a greater effect was obtained with the spoiler on the upper surface a small distance back from, rather than exactly at, the leading edge of the wing. (Reference 2.) At high angles of attack and large spoiler deflections it was possible to obtain rolling moments as great as those of average ordinary ailerons by the use of the correct spoiler properly located. However, it was found in references 3 and 4 that at low angles of attack and small spoiler deflections the lift was increased, thereby giving a rolling moment in the wrong direction but changing to one in the right direction with further spoiler deflection. Because of this unfavorable rolling moment at the low deflections, the spoiler was rejected as a complete means for obtaining lateral control without the use of ailerons.

The present investigation was made to determine the possibility of developing a spoiler giving rolling moments in the desired direction at all deflections and angles of attack, and also giving reasonably large rolling moments at the low as well as the high angles of attack. A systematic series of tests has been made which is thought to cover the main factors affecting the spoiler characteristics within the probable range of practical application. The first tests were made on a wing model having the Clark Y over-all profile with a low-drag fixed tip slot. After it had been found that the best spoiler location was well back of the slot, additional tests were made with spoilers on a plain wing.

APPARATUS AND METHODS

The tests were made in the vertical wind tunnel of the National Advisory Committee for Aeronautics, which has a 5-foot diameter open jet. (Reference 5.) They were made at the same Reynolds Number as that of a series of controllability and stability tests being made in the 7 by 10 foot tunnel, which will include further tests with the best spoiler developed. Both tunnels have the same normal air speed and so the chords of the wing models were made the same, 10 inches.

Models. - Because of the small diameter of the air stream in the vertical tunnel, a full-span wing of 10-inch chord and aspect ratio 6 could not be tested, and consequently a half-span model and "reflection plane" were used. The wing model, having a Clark Y over-all profile, had been made for previous tests and was arranged so as to obtain the effect of cutting a full-span slot through the normal plain wing. The main portion of the wing was made of laminated mahogany. An auxiliary airfoil forming the nose was made of aluminum alloy. The auxiliary airfoil was supported on the main wing at each end by a thin metal plate. In addition, a small support fastened to the wooden and metal parts at midspan prevented any appreciable deflection of the nose airfoil under the applied air loads. The ordinates of the wooden section were held accurate to within ±0.01 inch and those of the metal portion to within ±0.003 inch of the specified ordinates.

The best low-drag fixed slot arrangement obtained in a previous investigation (reference 1) was used in these tests. Although the wing was originally provided with a full-span slot, for the present tests the slot was filled with Plasticine and the Clark Y section maintained except for the portion within 40 per cent of the semispan from the tip. The different spoilers were made of steel 1/32-inch thick, also 40 per cent of the semispan in length, and were fastened firmly to the upper surface of the wing.

Balances. - The drag forces were transmitted from the wing model to a platform balance above the tunnel by two fine wires which passed through tubes. The lift forces were transmitted by a system of bell cranks and rigid rods to two platform balances mounted on the tunnel test floor. A detailed description of the arrangement may be found in reference 6.

The lift of the wing was given by the sum of the two lift-balance readings. Rolling moments were obtained by taking the differences between the products of each balance reading and the appropriate moment arms. The rolling moments due to the spoiler were computed by subtracting the rolling moments due to the wing alone from those due to the wing with spoiler, at corresponding angles of attack.

Tests. - The tests were made first on the wing with only the fixed tip slot. Then the wing with the slot was tested with the different spoilers to obtain the effect of each spoiler. Finally the slot was filled entirely with Plasticine (forming a plain Clark Y wing) and this wing was tested alone and with the best form of spoiler developed.

The angle-of-attack range extended from about -4° to $+40^{\circ}$. 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 at standard atmospheric conditions. The Reynolds Number, based on the above test conditions and wing chord of 10 inches, was 609,000, which is about one-third of that for an ordinary small airplane while landing.

~~Accuracy~~. - The lift balances were sensitive to within ± 0.06 pound, and the drag balance was sensitive to within ± 0.03 pound. The angle-of-attack setting was accurate to $\pm 0.1^{\circ}$, and the dynamic pressure was maintained constant to within ± 0.5 per cent. A comparison of the results of check tests showed the maximum variation between values of the rolling moments to be about ± 4 per cent; the variation between the lift and drag values amounted to about ± 1 per cent.

DEVELOPMENT OF SUITABLE SPOILER

Clark Y Wing with Fixed Tip Slot

Two main types of spoilers were investigated. The first was a flat rectangular plate arranged to be protruded or retracted through a slot in the upper surface of the wing (See fig. 1.) The second type was a curved rectangular plate hinged about an axis on the wing upper surface. It was flush with the surface when in the zero, or closed, position. (See fig. 4.) All spoilers were tested at a series of different positions back of the tip slot.

Flat spoiler - effect of height. - The first series of tests was made with spoiler heights of 1, 2, 3, 5, 7, and 9 per cent of the wing chord. The spoiler was located just behind the slot at the 14 per cent chord station, and was set at 90° to the upper surface. (Fig. 1.)

At low angles of attack and small heights this type of spoiler gives a rolling moment in the wrong direction.

(Fig. 1.) The rolling moments at higher angles of attack first increase and then decrease again almost to zero with increasing spoiler height until the slot has been closed off. A further slight increase in the spoiler height then causes a sudden large increase in rolling moment, after which a gradual increase continues throughout the range tested.

The operation of this type of spoiler is unsatisfactory at this location because of the unfavorable rolling moments at low angles of attack and low heights of projection, and because of the erratic effects produced at the higher angles of attack as the spoiler height just closes the slot gap.

Flat spoiler - effect of location. - The next step with the flat spoiler projecting through the upper surface of the wing was an attempt to overcome the objectionable feature of the adverse rolling moments for small spoiler heights and low angles of attack. Heights of 1, 2, and 3 per cent of the wing chord were tested at locations 14, 17, 20, 23, and 26 per cent chord from the leading edge, with the spoiler in each case at 90° to the wing chord line.

The results of this series of tests are shown in Figure 2. As the spoiler location is moved back the adverse rolling moments gradually become less and they disappear entirely at the 26 per cent chord station. In addition, the erratic increase of rolling moment with spoiler height which occurred with the spoiler close behind the slot, was not present with the other rear spoiler positions. At the stalling angle the rolling moments obtained with a spoiler height of only 3 per cent of the chord were of the order of those obtained with average ailerons, but at the low angles of attack corresponding to high-speed flight the rolling moments with the spoiler were much less. Inasmuch as the rolling moments at the high angles of attack had dropped off somewhat as the spoiler was moved back to the 26 per cent station, no attempt was made to place it any farther back.

Plain curved spoiler - effect of location. - It seemed likely, from the standpoint of simplicity and ease of installation, that a spoiler rotatable about its forward edge and curved to fit flush with the surface of the wing in the closed position, would be the most satisfactory type to use. The next tests were therefore made with spoilers of this type, rotatable about axes in the wing upper surface.

The first curved spoiler investigated, shaped to fit the wing upper surface, was a plain plate having a width of 7 per cent of the wing chord and the same span as the slot. This spoiler was first tested with small deflections of 7.5° and 15° at locations 14, 17, 20, 23, 26, and 29 per cent of the chord on the upper surface, in order to investigate possible locations giving no adverse rolling moments.

As in the case of the flat spoiler with small heights, the curved spoiler gave adverse rolling moments at small deflections and low angles of attack for locations close to the slot. Likewise, as the spoiler location was moved back, the adverse rolling moments gradually decreased and disappeared at the same location, 26 per cent of the chord. (Fig. 3.) The spoiler was also tested at the 29 per cent station, and gave larger favorable rolling moments at the low angles of attack but smaller rolling moments at the high angles of attack than when located at the 26 per cent station.

Plain curved spoiler - effect of deflection. - The effect of full spoiler deflection was next investigated at two locations. The plain curved spoiler was tested at the 14 and at the 26 per cent chord locations for deflections of 7.5°, 15°, 22.5°, 30°, 37.5°, 45°, 60°, 75°, and 90° to the upper surface. The results of the tests at the 14 per cent station (fig. 4-A) for the low angles of attack show the unfavorable rolling moments at small deflections, (up to 20°) with very small favorable rolling moments at the larger deflections up to the limits tested. At the large angles of attack the rolling moments increase rapidly for spoiler deflections up to 30°, but there is no appreciable increase in rolling moment between 30° and 90° so that full spoiler effect is obtained with relatively small deflection at this location.

There are no appreciable adverse rolling moments at the 26 per cent location, and although the rolling moments in general increase at a fairly rapid rate up to 20° deflection, the increase with deflections from 20° to 90° is still considerable. (See fig. 4-B.) The maximum rolling moments obtained at the 26 per cent location are also somewhat greater than those at the 14 per cent location, particularly for the low angles of attack. The coefficients of rolling moment are plotted against angle of attack in Figure 5.

Curved spoiler with hinge axis ahead of forward edge. - From the foregoing results it is obvious that better control might be obtained with the spoiler if the flow over the wing upper surface could be destroyed further at the low angles of attack and small spoiler deflections. A few different types of spoilers were therefore tested at the best location - 26 per cent of the chord. The first of these, the plain curved spoiler 7 per cent of the chord in width, was cut out along the bottom 33 per cent of its width, so that the new spoiler no longer rotated about the forward edge but about an axis located in front of it. (Fig. 6.) A gap was then formed between the bottom of the spoiler and the wing upper surface as soon as the spoiler was deflected from its closed position, the purpose of the gap being to spoil the lift immediately and produce a larger favorable rolling moment. The results of these tests for small spoiler deflections (7.5° and 15°) and low angles of attack gave favorable rolling moments, but smaller in magnitude than those of the plain curved spoiler.

As the gap was thought to be too large, another curved spoiler was tested having a smaller gap between the bottom of the spoiler and the wing. (Fig. 7.) This spoiler had the same over-all width from the axis, 7 per cent of the chord, but was cut out only for the bottom 10 per cent of its width. The bottom of the spoiler was beveled to a sharp edge because of the small gap formed between wing and spoiler when deflected. The results of the tests with this spoiler showed favorable rolling moments of approximately the same magnitude at the small deflections and low angles of attack, as the moments obtained with the foregoing spoiler.

These two series of tests indicated that hinging the spoiler about an axis in front of its forward edge was not the proper course to follow in order to obtain improved operation.

Comb-type spoiler. - The next step was a change in the top of the spoiler to obtain an increased effect at low angles of attack and small spoiler deflections. A plain curved spoiler, 7 per cent of the chord in width, was provided with slots parallel to its chord, 0.025 inch wide and spaced the same distance apart along the whole length of the spoiler. (Fig. 8.) The slots extended through the outer one-third of the spoiler width. It seemed possible that this design would give increased spoiling effect with large rolling moments for the small deflections. However, the results of the test on this new spoiler showed adverse rolling moments at the small deflections and low angles of attack, which made it unsuitable for use. None of the special types of spoiler was as satisfactory as the plain type, the best developed thus far.

Plain Clark Y Wing

As the plain curved spoiler had shown favorable characteristics in connection with the wing having a fixed tip slot, but seemed to have no direct connection with the slot, a series of tests was also made to determine its suitability for use with a plain wing. The tip slot was filled with Plasticine and the wing model then became the plain Clark Y. The spoiler was tested with small deflections at several locations on the upper surface of the wing, and for the full range of deflections at the best location.

Plain curved spoiler - effect of location. - The locations tested were 26, 23, 20, and 17 per cent of the wing chord from the leading edge. The rolling moments obtained at the 26 per cent location were very small compared with those for the slotted wing, and a considerable adverse moment was found at 20° angle of attack. (See fig. 9.) As the spoiler location was moved forward, the favorable rolling moments increased up to the 20 per cent location, after which they decreased again. The 20 per cent location was therefore taken as the best for the plain wing, and the spoiler was tested there with deflections up to 90°.

Plain curved spoiler - effect of deflection. - The rolling moments produced by the spoiler on the plain wing (figs. 10 and 11) were similar to those of the slotted wing, but not quite so great. Even with the best location there is a very slight adverse rolling moment at an angle of attack of 20°, but it is so small that it would probably not be noticeable in flight. In addition, the change in rolling moment with increased spoiler deflection is not quite so gradual as with the slotted wing.

The plain wing with a spoiler of the size tested would probably have a fair amount of lateral control up to and somewhat beyond the stall for a transport-type airplane, but it would not have sufficient control for a highly maneuverable acrobatic airplane. The yawing moments with the spoiler as indicated by drag measurements, which are not included in the report, are favorable, however, and since the hinge moments would probably be extremely low it was decided to test spoilers of larger size as being of possible interest.

Plain curved spoiler 10 per cent of wing chord. - The width of the spoiler was increased to 10 per cent of the wing chord, the length remaining 40 per cent of the semispan. Tests were made at two spoiler deflections, 5° and 60°. The single 5° deflection was considered sufficient to show the adverse rolling moments which might occur at the low angles of attack, and the 60° deflection was assumed as a typical maximum value inasmuch as the previous tests showed very little increase in rolling moment with higher angles. Figure 12 shows that all three locations tested gave adverse rolling moments at an angle of attack of 0°. None, however, had adverse values sufficiently large to be of any importance except at angles of attack above 23°, and therefore above the range which can be maintained in gliding flight with ordinary conventional airplanes. The rolling moments obtained with a deflection of 60° are given in Figure 13. At an angle of attack of 0° the spoiler having a 10 per cent width gave rolling moments about 50 per cent greater than the spoiler having a 7 per cent width, but at the stall and above the increase was only 12 per cent.

Computations indicated that a spoiler having a width of 10 per cent of the wing chord and a length 60 per cent of the semispan should give sufficient rolling moment for reasonably satisfactory lateral control for an average airplane, and a final series of tests was made on a spoiler of that size with the 20 per cent hinge-axis location and a complete series of deflections up to 90°. The results of these tests are given in Figure 14. As was found with the smaller spoilers, relatively little improvement was obtained by increasing the deflection above 60°.

The rolling-moment coefficients obtained with the 60° deflections are compared with those obtained with an average pair of conventional ailerons in Figure 15. The average ailerons that were tested under reference 8 have a chord 25 per cent of the wing chord and a span 40 per cent of the wing semispan, one having an upward deflection of 25° and the other a downward deflection of 25°. At the low angles of attack where both forms of control give more than sufficient rolling moment, the ailerons give a greater amount than the spoilers, but at angles of attack between 10° and 25° where the ailerons give insufficient control the spoiler gives substantially higher values of rolling moment.

If, as seems likely, the hinge moments of these spoilers are relatively low and the yawing moments are in the favorable direction only, the spoilers might possibly provide a medium-strength lateral control superior in every way to that obtained with present conventional flap-type ailerons. For this reason it is planned to make further tests on the yawing moments and hinge moments. For more powerful controls at the higher angles of attack it is also planned to investigate the combined action of ailerons and spoilers of relatively small size.

CONCLUSIONS

1. No appreciable adverse rolling moments were obtained with any of the spoilers tested when they were located the proper distance back from the leading edge. This distance varied for the different arrangements tested.

2. The effects produced by the spoilers tested did not depend on the closing of the slot, for they gave approximately the same rolling moments on the plain wing as on the slotted wing.

3. The simple solid plate-type spoilers, both curved and flat, proved superior to the other types tested.

4. It is likely that sufficient rolling moment can be obtained from spoilers of reasonable size to provide satisfactory lateral control for certain types of airplanes.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 1, 1932.

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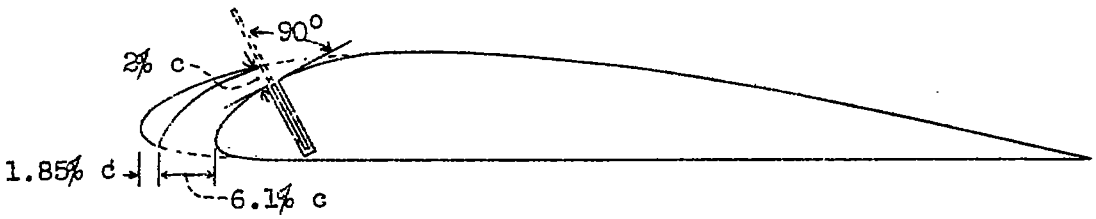


Clark Y wing with low-drag fixed tip slot 40 per cent of semispan. Plain flat spoiler.

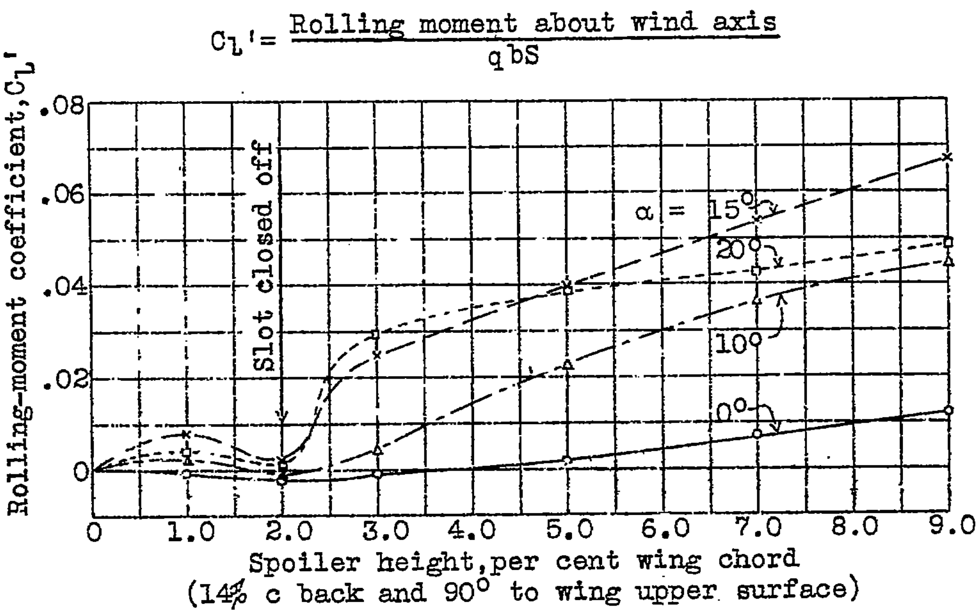


Fig.1 Effect of spoiler height on rolling-moment coefficient for location at back of slot.

Clark Y wing with low-drag fixed tip slot 40 per cent of semispan. Plain flat spoiler at 90° to wing chord.

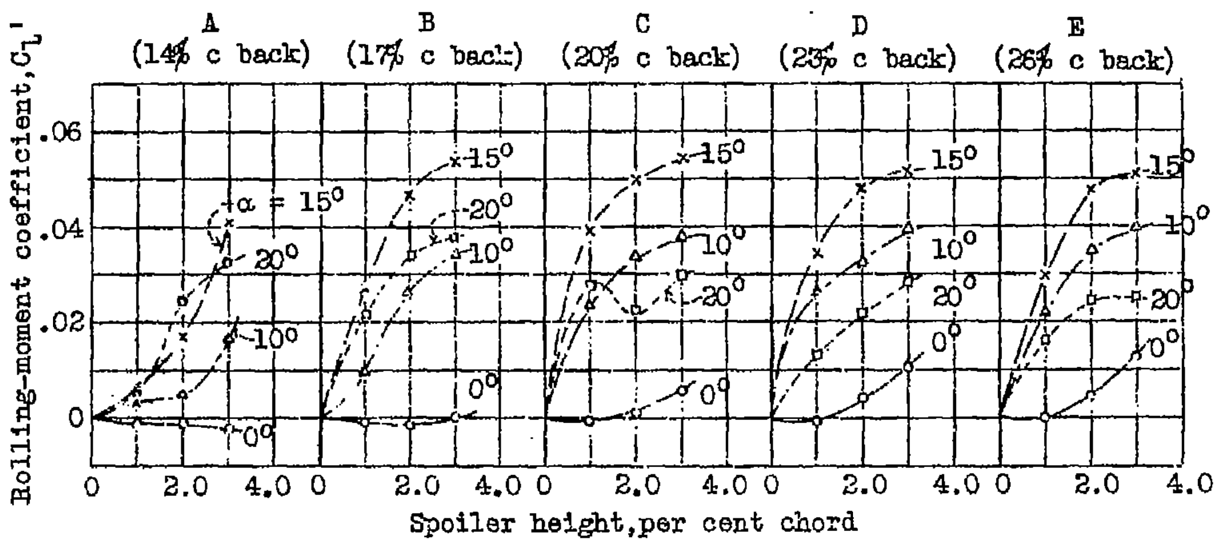
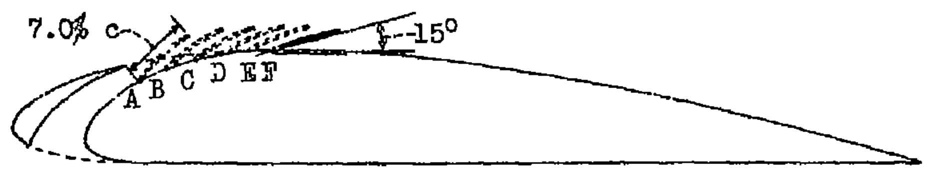


Fig.2 Effect of spoiler location on rolling-moment coefficient for small heights.



Clark Y wing with low-drag fixed tip slot 40 per cent of semispan. Curved plain spoiler at angles to upper surface of wing. 7 % c wide and 40% b/2 long.

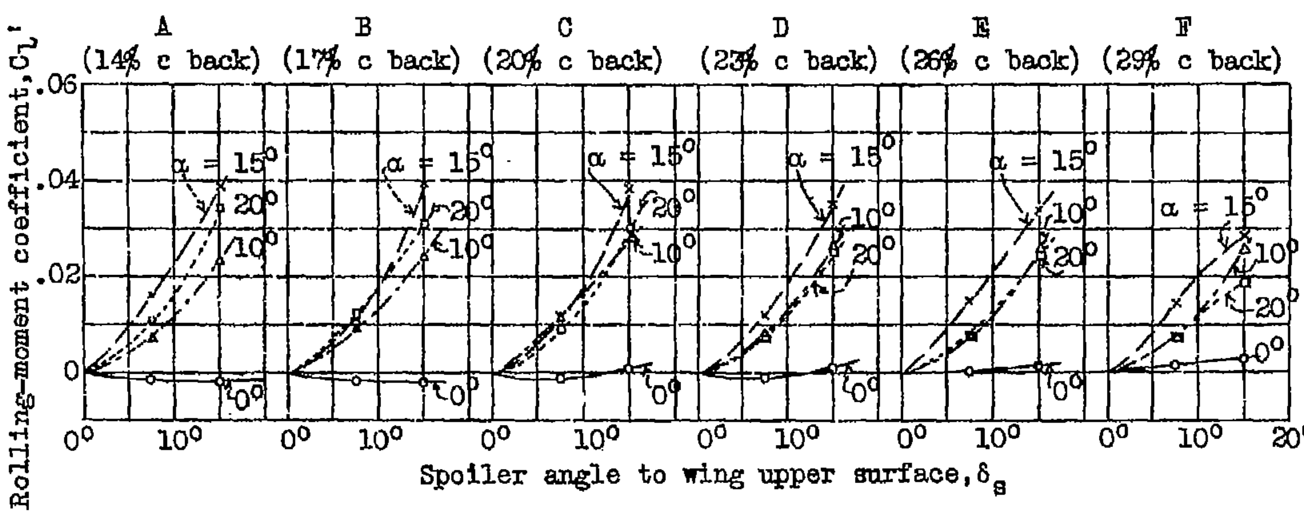
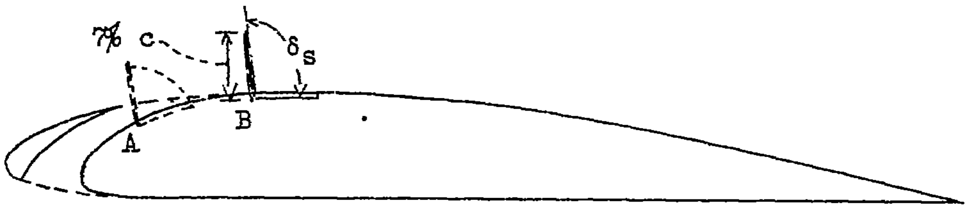
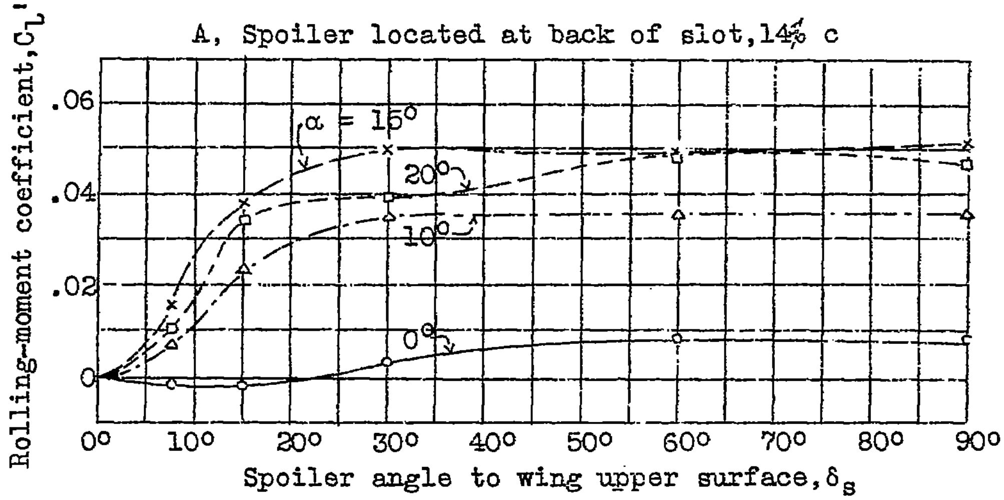


Fig.3 Effect of spoiler location on rolling-moment coefficient for small angular deflections.



Clark Y wing with low-drag fixed tip slot 40 per cent semispan. Plain curved spoiler 7% c wide and 40 per cent b/2 long.



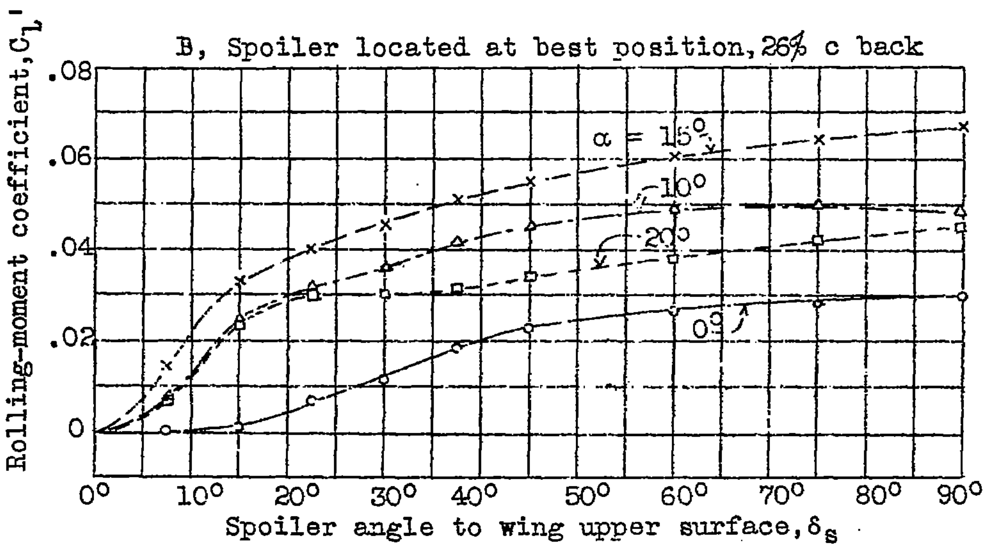
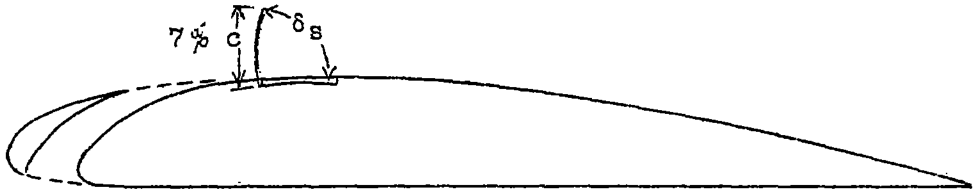


Fig. 4 Effect of spoiler deflection on rolling-moment coefficient for two locations back of slot.



Clark Y wing with low drag fixed tip slot 40 per cent semi-span long.

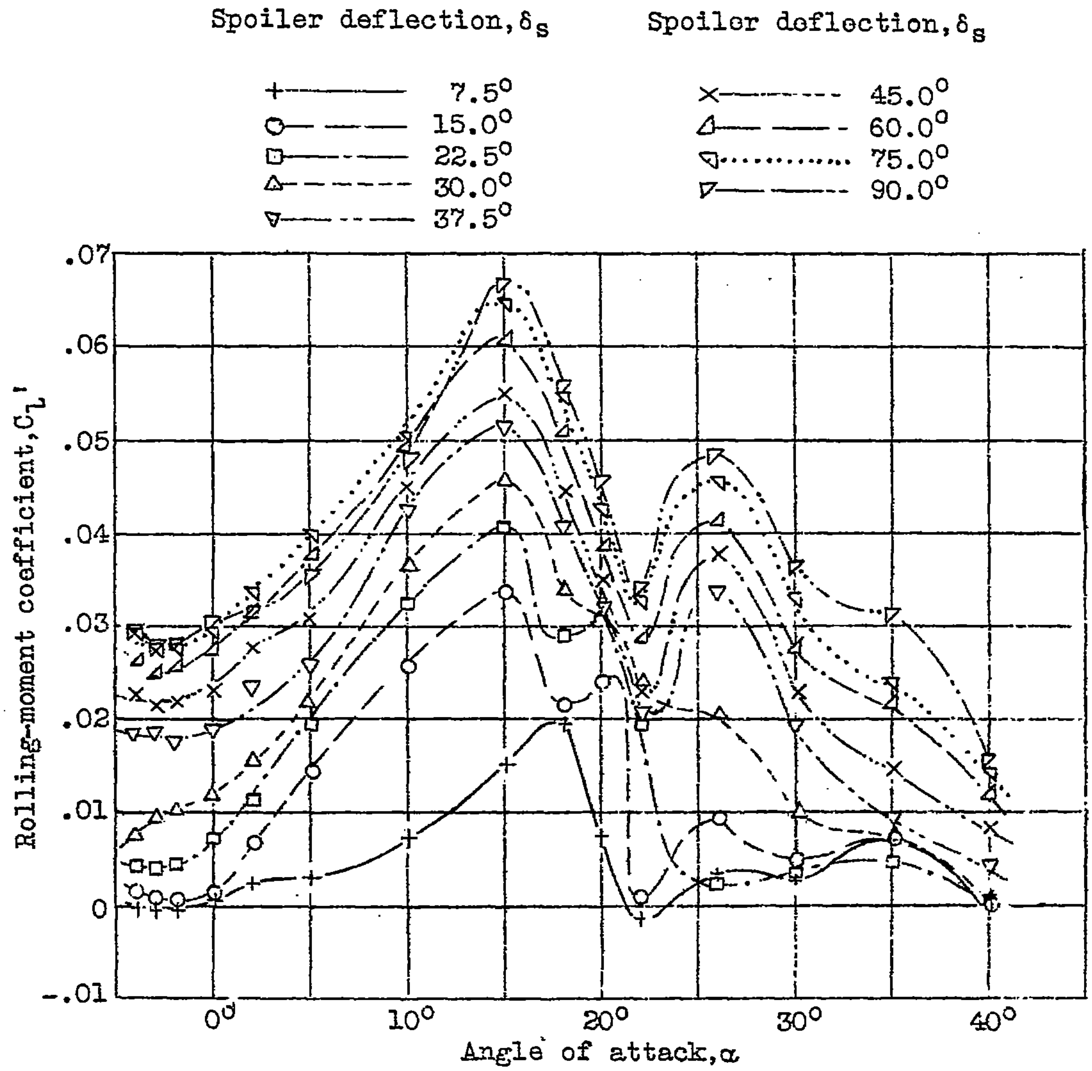


Fig.5 Rolling-moment coefficient versus angle of attack. Curved spoiler at 26 per cent location on slotted wing.

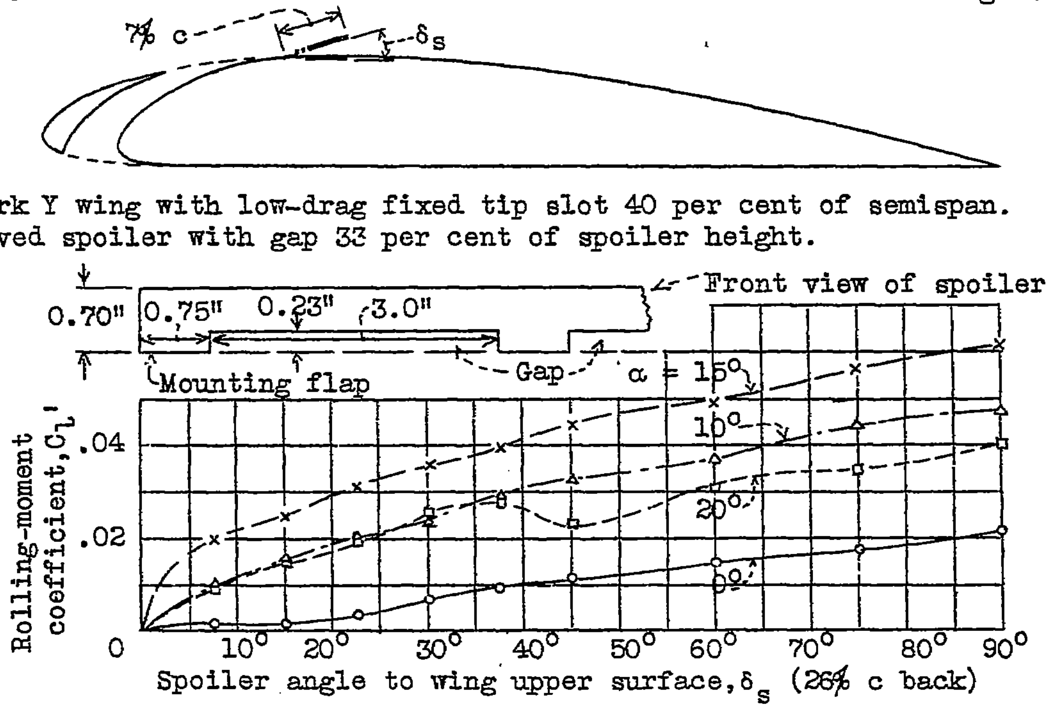


Fig.6 Spoiler with gap 33 percent of spoiler height on slotted wing.

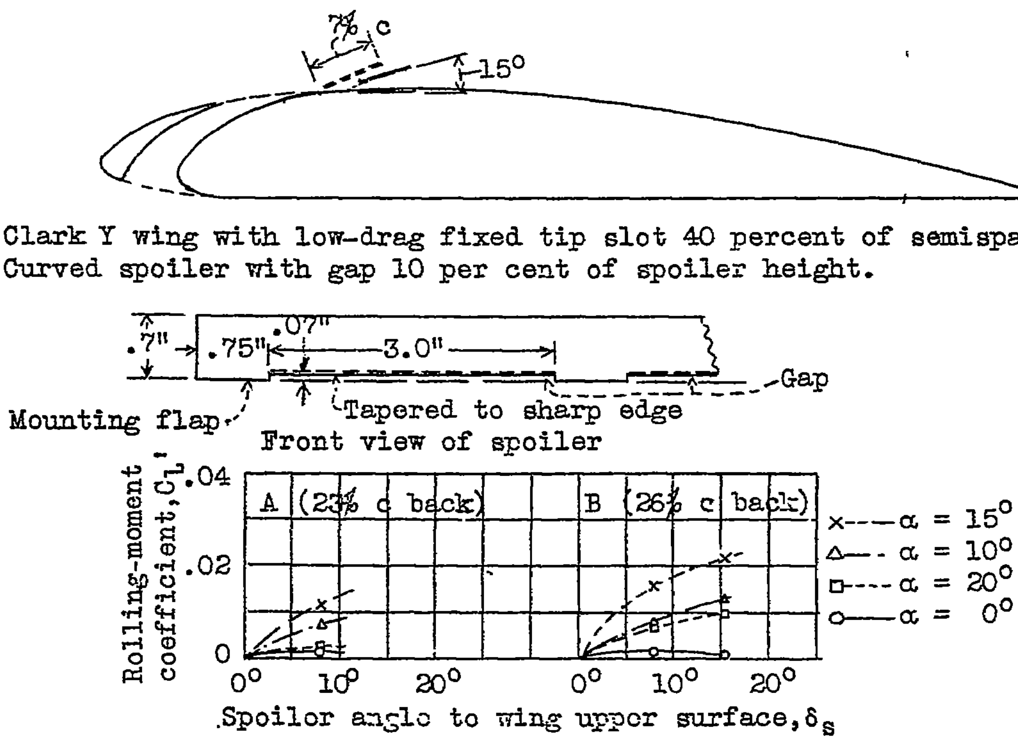
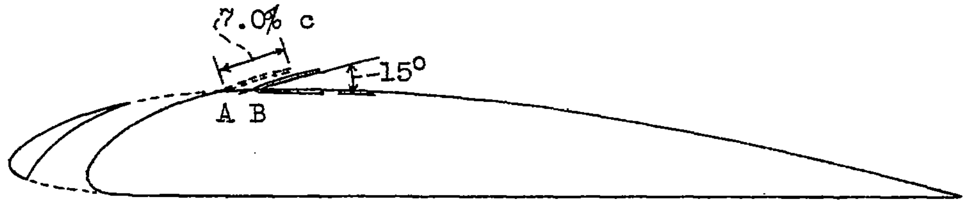
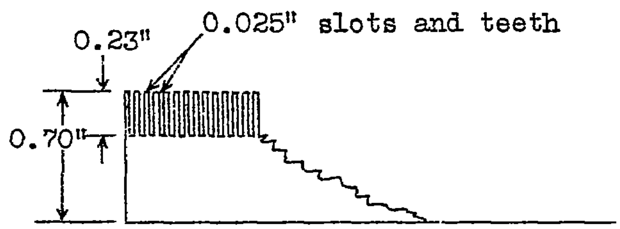


Fig.7 Spoiler with gap 10 per cent of spoiler height on slotted wing.



Clark Y wing with low-drag fixed tip slot 40 per cent of semispan.
Curved comb-type spoiler.



Front view of spoiler

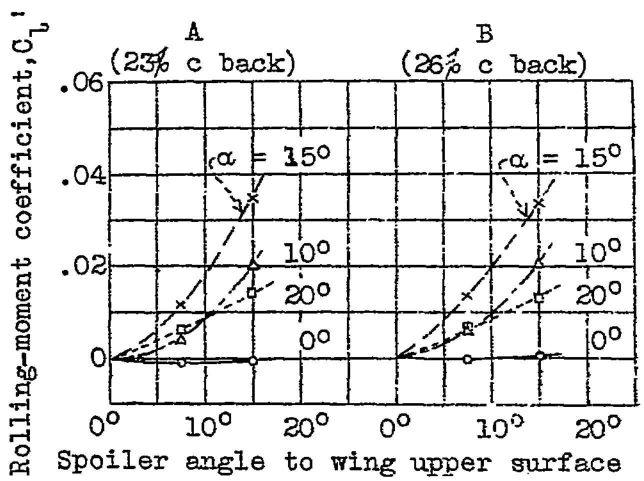
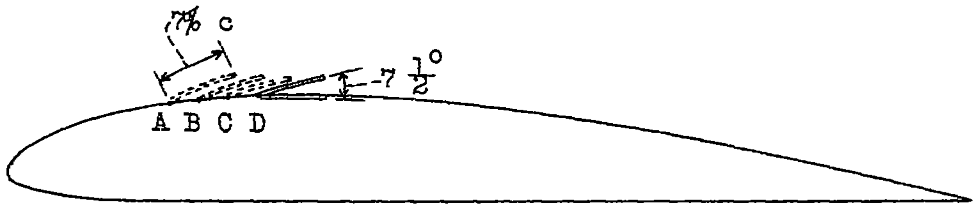


Fig.8 Comb-type spoiler on slotted wing.



Plain Clark Y wing. Curved plain spoiler 7% c wide and 40 per cent b/2 long at angles to upper surface.

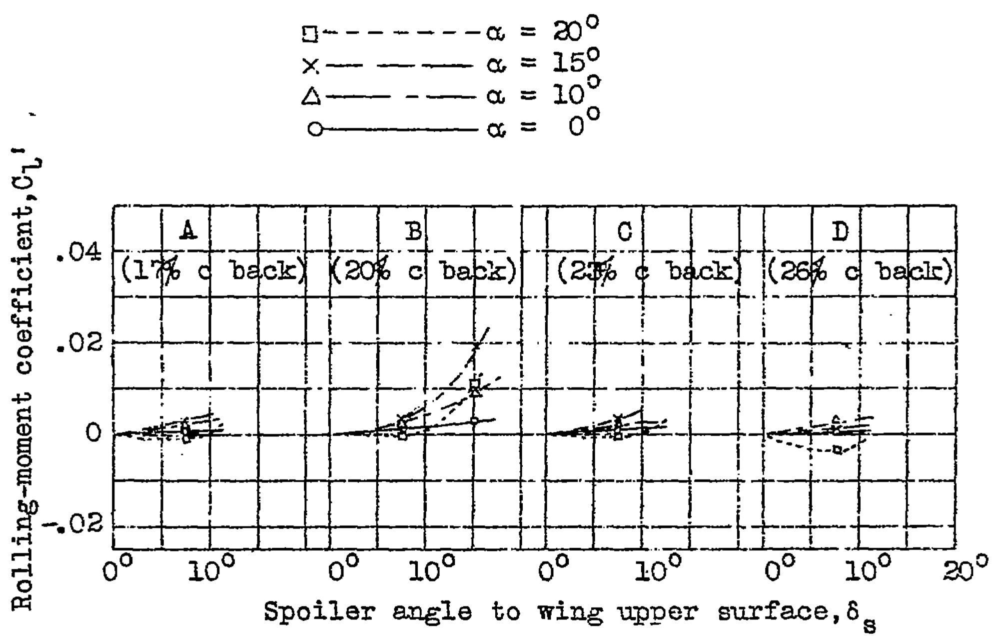


Fig.9 Effect of spoiler location on rolling-moment coefficient for small deflections. Plain wing.

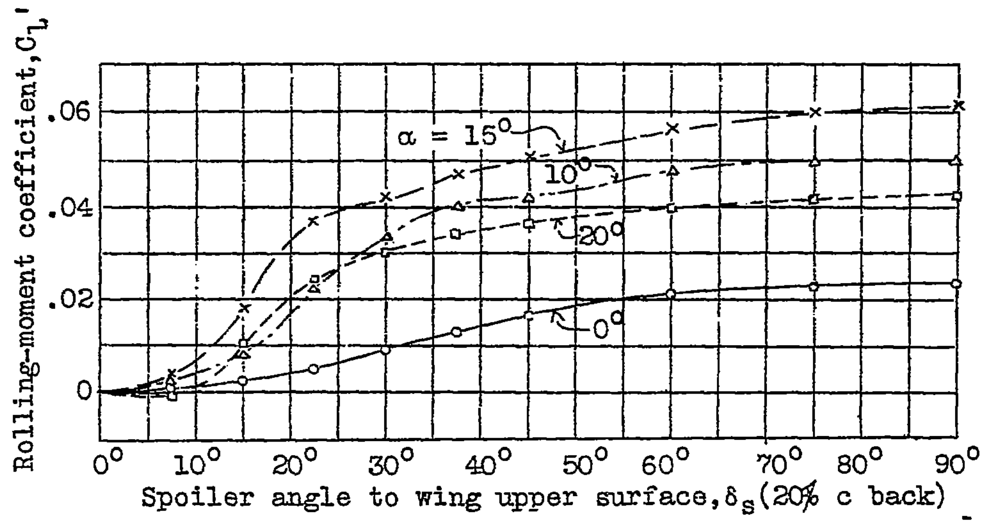


Fig.10 Effect of spoiler deflection on rolling-moment coefficient for 20 per cent location. 7 per cent c, spoiler on plain wing.

Plain Clark Y wing. Curved spoiler 7 per cent chord wide and 40 per cent semispan long.

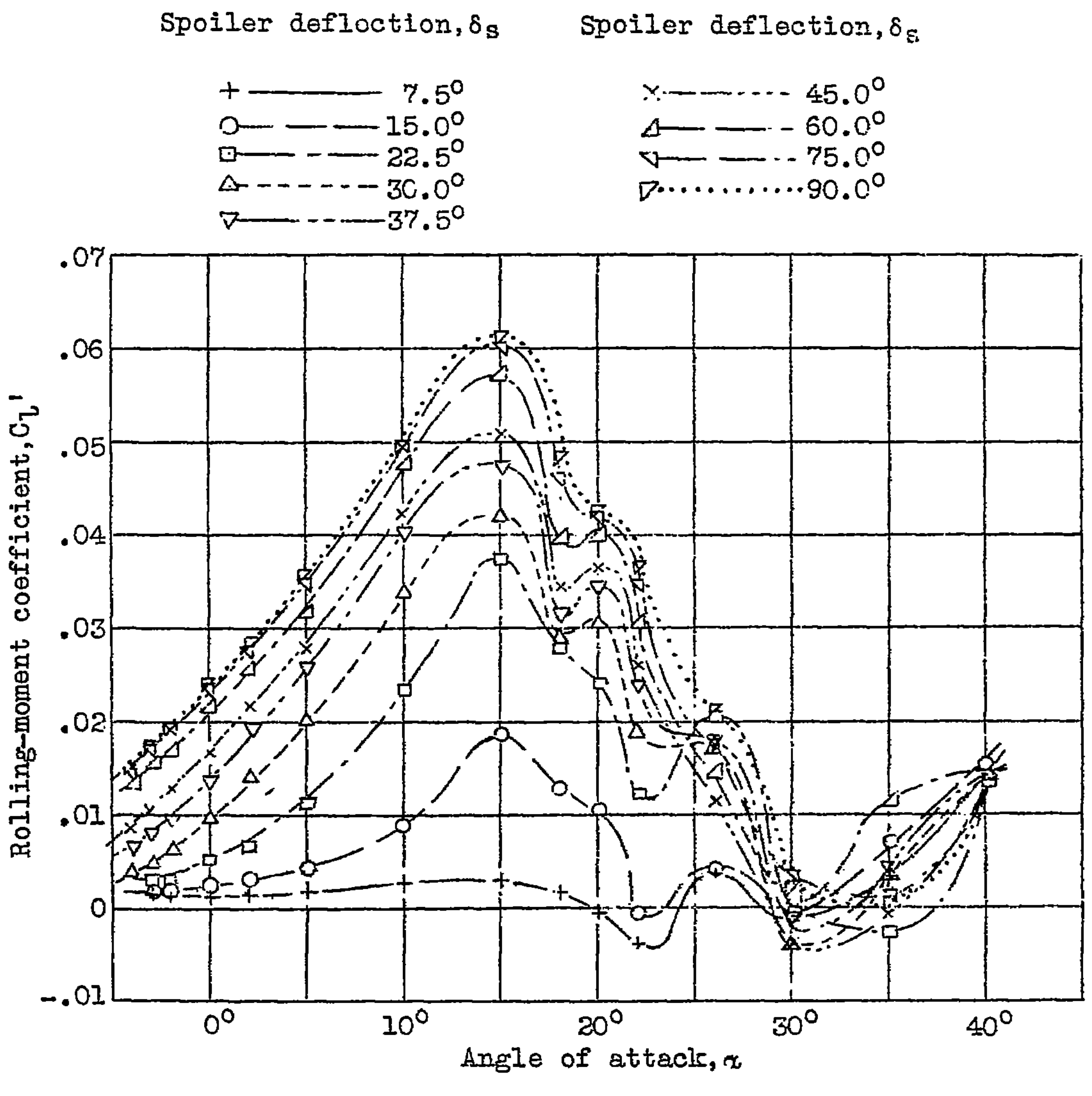


Fig.11 Rolling-moment coefficient versus angle of attack. 7 per cent c by 40 per cent b/2 curved spoiler at 20 per cent location on plain wing.

Plain Clark Y wing. Curved spoiler 10 per cent chord wide and 40 per cent semispan long, 5° deflection only.

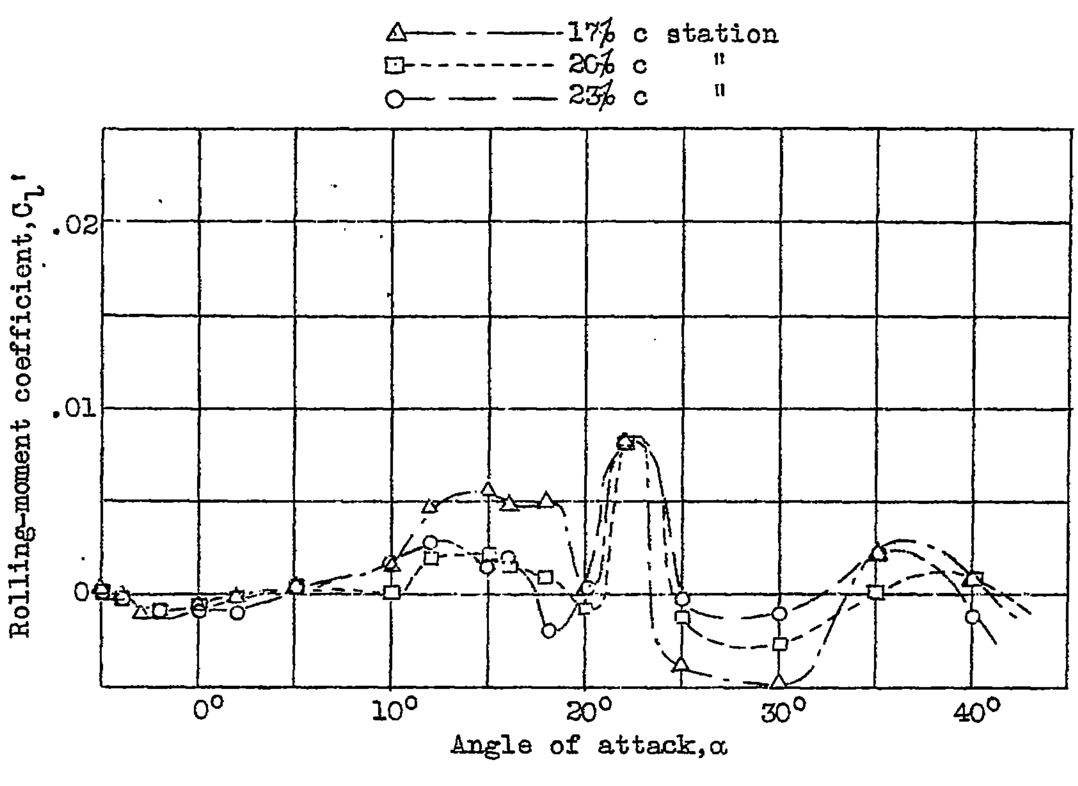


Fig.12 Effect of spoiler location on rolling-moment coefficient for small angular deflections. 10 per cent chord spoiler on plain wing.

Plain Clark Y wing. Curved spoiler 10 per cent chord wide and 40 per cent semispan long, 60° deflection only.

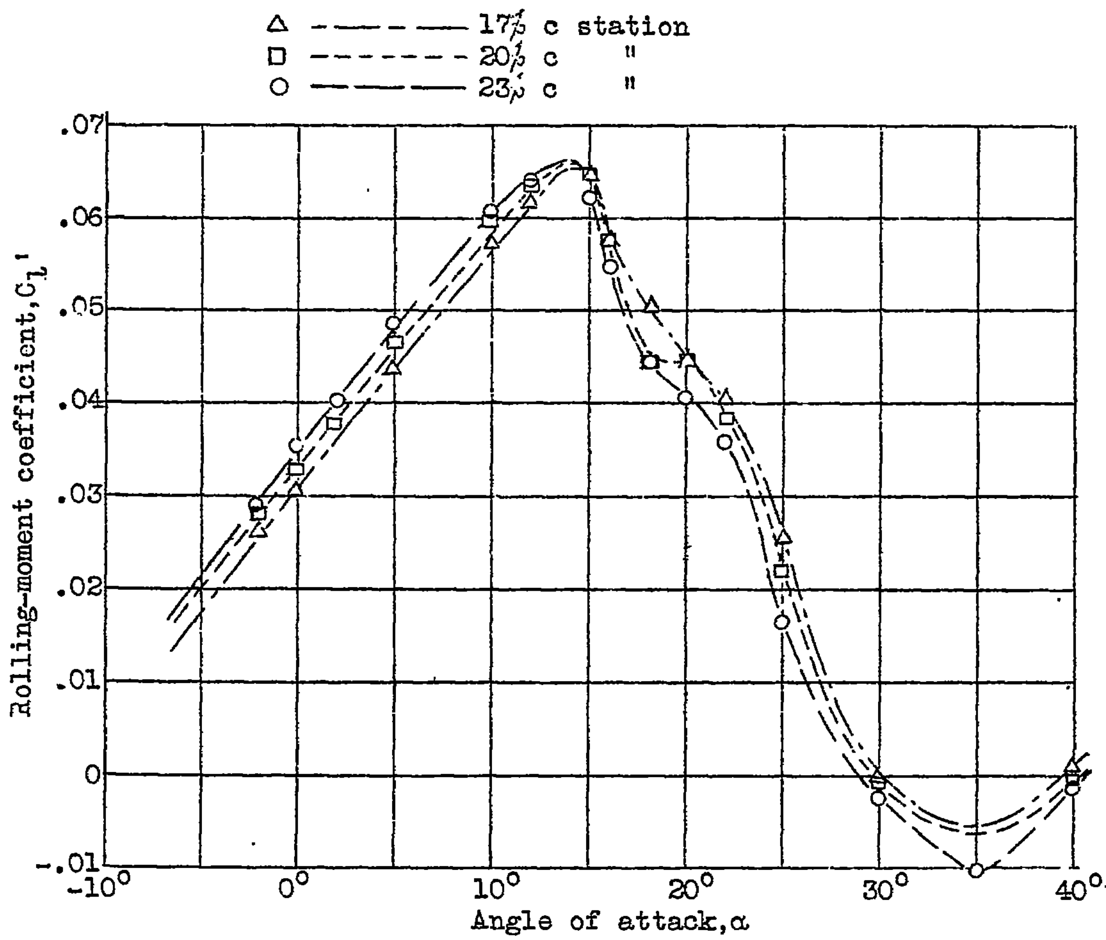
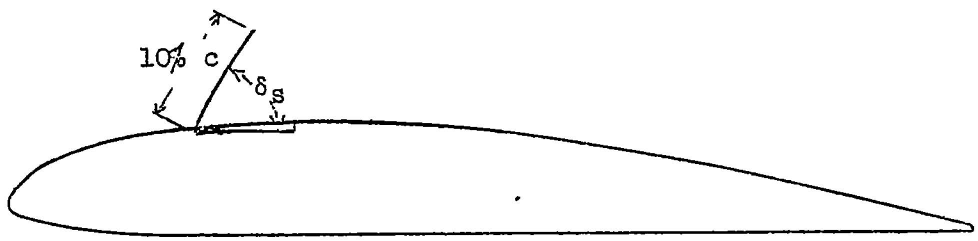


Fig.13 Effect of spoiler location on rolling-moment coefficient for large angular deflections. 10 per cent chord spoiler on plain wing.



Plain Clark Y wing. Curved spoiler 10 per cent chord wide and 60 per cent semispan long.

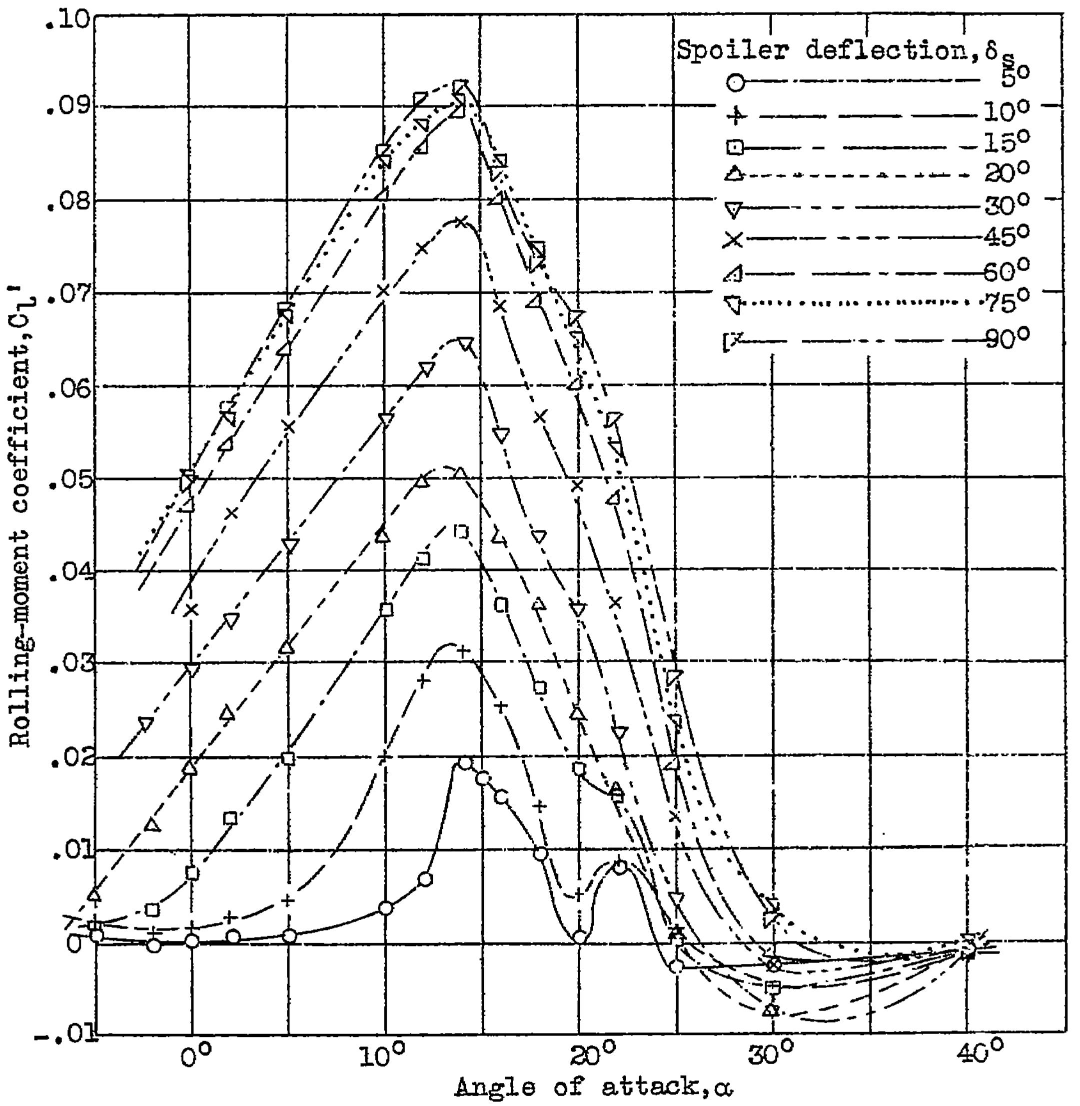
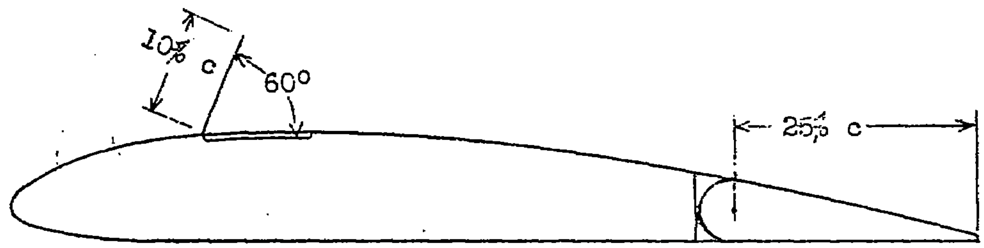


Fig.14 Rolling-moment coefficient versus angle of attack. 10 per cent c by 60 per cent b/2. Curved spoiler at 20 per cent location on plain wing.



Plain Clark Y wing. Spoilers and ailerons deflected individually.

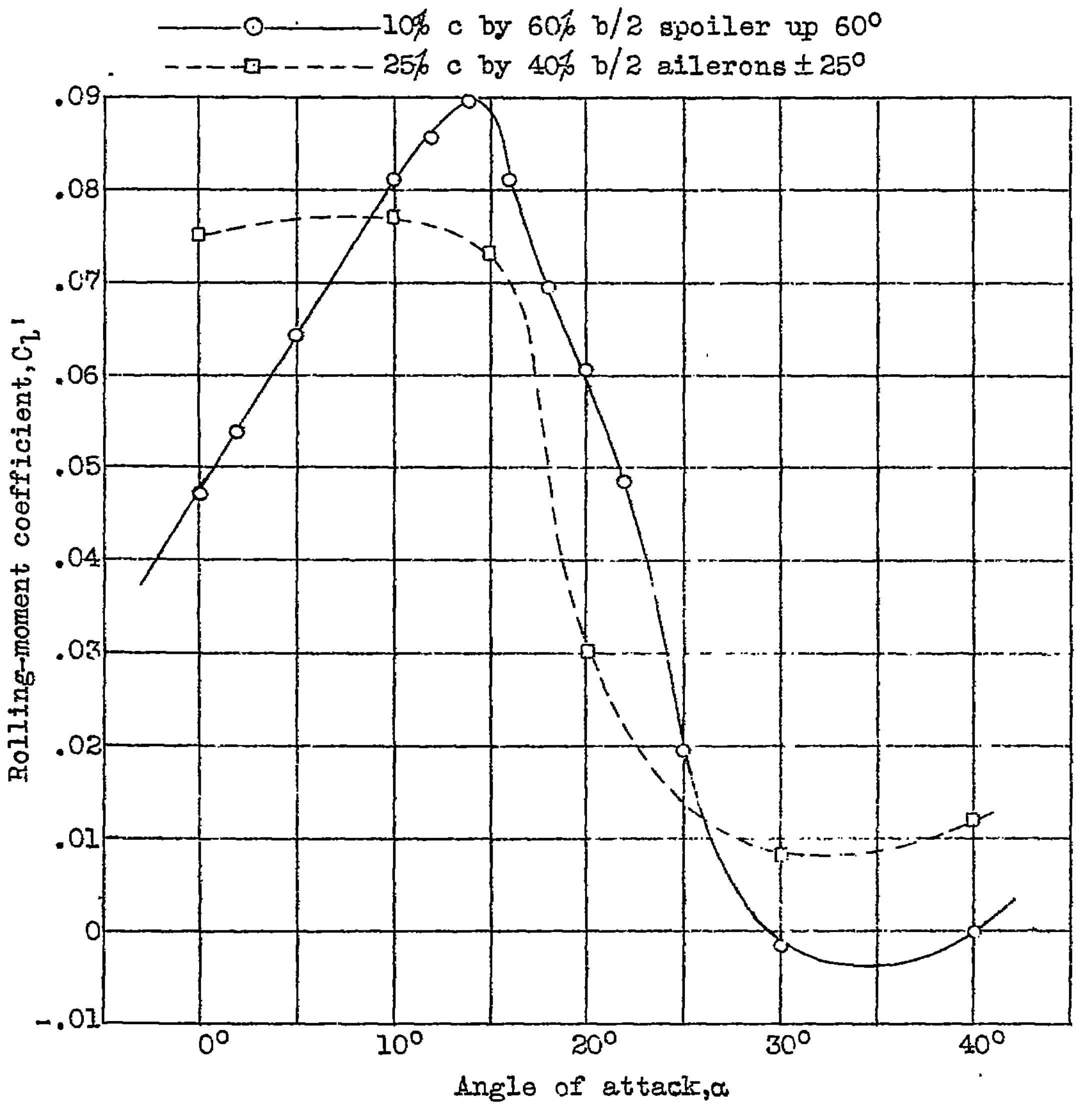


Fig.15 Comparison of spoiler with average ailerons. Plain wing.