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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 458

WIND-TUNNEL RESEARCH COMPARING LATERAL CONTROL DEVICES, PARTICULARLY AT HIGH ANGLES OF ATTACK

XI. VARIOUS FLOATING TIP AILERONS ON BOTH RECTANGULAR AND TAPERED WINGS

By Fred E. Weick and Thomas A. Harris
Langley Memorial Aeronautical Laboratory

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SUMMARY

This report covers the eleventh of a series of systematic tests being conducted by the National Advisory Committee for Aeronautics to compare different lateral control devices with particular reference to their effectiveness at high angles of attack. The present tests were made with six different forms of floating tip ailerons of symmetrical section. One form had a relatively narrow chord, 40 per cent that of the wing, and was tested in four different fore-and-aft locations on the tips of a rectangular wing. Three of the forms were multiple floating tip ailerons having three, four, and five narrow ailerons each, located one behind the other at the wing tips. The other two forms were included in the plan forms of wings with two different degrees of taper, 5:3 and 5:1. The tests showed the effect of the various ailerons on the general performance characteristics of the wing, and on the lateral controllability and stability characteristics. In addition, the hinge moments were measured for the most interesting cases. The results are compared with those for a rectangular wing with ordinary ailerons and also with those for a rectangular wing having full-chord floating tip ailerons.

Practically all the floating tip ailerons gave reasonably satisfactory rolling moments at all angles of attack and at the same time gave no adverse yawing moments of appreciable magnitude. The general performance characteristics with the floating tip ailerons, however, were relatively poor, especially the rate of climb. None of the floating tip ailerons entirely eliminated the autorotational moments at angles of attack above the stall but

all of them gave lower moments than a plain wing. Some of the floating ailerons fluttered if given sufficiently large deflection, but this could have been eliminated by moving the hinge axis of the ailerons forward. Considering all points including hinge moments, the floating tip ailerons on the wing with 5:1 taper are probably the best of those which were tested.

INTRODUCTION

A series of systematic wind-tunnel investigations, one of which is covered by this report, is being made by the National Advisory Committee for Aeronautics in order to compare various lateral control devices. These devices are given the same routine tests to show their relative merits in regard to lateral controllability and their effect on the lateral stability and on airplane performance. They are being tested first on rectangular Clark Y wings of aspect ratio 6, followed by wings with different plan forms, wings with high lift devices, and also wings with such variations as washout and sweepback, which affect lateral stability. The first report of this series (reference 1, Part I) deals with three sizes of ordinary ailerons, one of which is a medium-sized aileron taken from the average of a number of conventional airplanes and used as the standard of comparison throughout the entire investigation. Other work that has been done in this series is reported in reference 1, Parts II to X.

Under reference 1, Part IV, a preliminary investigation is reported of full-chord floating tip ailerons on rectangular wings. Floating tip ailerons having different airfoil sections were tested with different hinge-axis locations, with trailing-edge flaps on the ailerons, and with end plates between the wing and ailerons. With the best arrangements, satisfactory lateral control at the high angles of attack was obtained and the maximum autorotational moments were lower than those for a plain wing, but the maximum lift coefficients were low and the performance characteristics in climb were poor.

The present report is on a continuation of the floating tip aileron investigation, involving tests of both single and multiple floating tip ailerons of reduced chord on rectangular wings and also of floating tip ailerons which were included in the plan forms of two tapered wings, one having a medium degree of taper, 5:3, and one having an extreme degree of taper, 5:1. Some of these arrangements, it was believed, might improve the maximum lift coefficients and the performance in climb over those obtained with the full-chord floating tip ailerons on rectangular wings. In addition, from the results of tests reported in reference 2, it seemed possible that the multiple tip ailerons might give improved damping in roll at angles of attack above the stall.

APPARATUS

Wind tunnel.- All the present tests were made in the N.A.C.A. 7 by 10 foot open-jet wind tunnel. In this tunnel the model is supported in such a manner that the forces and moments at the quarter-chord point of the mid section of the model are measured directly in coefficient form. For autorotation tests, the standard force-test tripod is replaced by a special mounting that permits the model to rotate about the longitudinal wind axis passing through the midspan quarter-chord point. This apparatus is mounted on the balance, and the rolling-moment coefficient can be read directly during the forced-rotation tests. A complete description of the above equipment is given in reference 3.

Models.- The dimensions of the various floating tip ailerons are given in Figures 1 to 6. All the ailerons were designed to give approximately the same rolling control at 10° angle of attack as the ordinary ailerons on the standard wing. In each case the over-all span of the model was 60 inches, the main wing had the Clark Y airfoil section, and the ailerons had the symmetrical N.A.C.A. 0010 section. Except in the cases of the multiple tip ailerons with three and four sections, the aspect ratio, including the area of the ailerons, was in each case 6. All the ailerons were hinged about an axis 18 per cent of their chord back of the leading edge, a position which was thought, on the basis of the tests on the full-chord floating tip ailerons of Part IV, would probably be the most satisfactory. In the present tests some of the tip ailerons fluttered when given sufficiently high deflections. The previous tests on floating tip ailerons show, however, that flutter may be avoided by locating the aileron axis slightly farther forward. All the single ailerons were equipped with trailing-edge flaps covering 20 per cent of the chord which could be set to control the floating angle. The right and left ailerons were rigidly connected by means of a shaft through the wing model. The tapered wings required two shafts having angles with respect to each other and connected at the center by means of two universal joints. In all cases the shaft was supported as freely as possible in plain bearings in the wing.

The four axis positions of the single narrow-chord ailerons are shown in Figure 1. In one position the leading edge of the aileron was even with that of the wing, in another the trailing edges were even; the other two positions were intermediate. With the multiple tip ailerons (figs. 2, 3, and 4) the leading edge of the forward section was in each case even with the leading edge of the wing and the trailing edge of the rear section was even with the trailing edge of the wing. No flaps were used on these ailerons because they were constructed after the results of the tests on the single narrow-chord ailerons had indicated that the flaps would not be necessary. The various sections of each multiple tip aileron were connected by a linkage system which kept them parallel to each other at all angles of deflection. This linkage system had considerably more friction than the shaft supporting the single ailerons.

The main wing portion of each model was constructed of laminated mahogany within ±0.005 inch of the specified dimensions. The ailerons were statically balanced about their hinge axes, the rear portion being made of white pine and the front portion brass. The accuracy of their construction was slightly less than that of the main wing.

TESTS AND RESULTS

The tests were conducted in accordance with the standard procedure, and at the dynamic pressure and Reynolds Number employed throughout the entire series of investigations on lateral control. (Reference 1.) The dynamic pressure was 16.37 pounds per square foot, corresponding to an air speed of 80 miles per hour at standard density, and the Reynolds Number was 609,000, based on the average chord.

The regular force tests were made at a sufficient number of angles of attack to determine the maximum lift coefficient, the minimum drag coefficient, and the drag coefficient at $C_L = 0.70$, which is used to give a rate-of-climb criterion. Free-autorotation tests were made to determine the angle of attack above which autorotation was self-starting with all controls neutral. Forced-rotation tests were also made in which the rolling moment while rolling was measured at the rotational velocity corresponding to $\frac{p'b}{2V} = 0.05$, where p' is the rate of rotation about the wind axis, b is the span, and V is the air velocity. The value 0.05 represents the highest rate likely to be obtained in gusty air. The forced-rotation tests were made at angles of yaw of both 0° and -20°.

Preliminary tests to find the best flap settings.- Inasmuch as in the tests of the full-chord floating tip ailerons of Part IV the highest values of the speed-range ratio $C_{L_{max}}/C_{D_{min}}$ were obtained with aileron flaps set up 2°, flaps were provided for the present ailerons also, the multiple tip ailerons excepted. With each of the wings having single ailerons, tests were made in which the ailerons were set neutral (both ailerons at the same angle) and allowed to float with the flaps deflected various amounts. The deflections giving the highest values of the ratio $C_{L_{max}}/C_{D_{min}}$ were 0° with the narrow-chord ailerons, 0.5° on the wing with 5:3 taper, and 0° on the wing with 5:1 taper. These results indicate that 0° is probably the best setting and that the 0.5° setting on the wing with 5:3 taper probably corrects for a slight dissymmetry of the ailerons. The remainder of the tests were all made with the flaps set at the above angles.

Tests to determine suitable maximum aileron deflection.- Tests were made on all the ailerons at an angle of attack of 10° with the ailerons deflected various amounts to determine the deflection necessary to give the same control at this angle of attack as the standard conventional ailerons. This amount of control has been assumed as a satisfactory value when given in terms of the lateral control criterion RC, which is explained later in this report. Had sufficiently accurate data been available upon which to base the design of the floating tip ailerons, the assumed satisfactory rolling moments would have been just below the maximum moments given by the ailerons with any deflection. With some of these ailerons, however, substantially greater moments could be obtained with higher deflections and the tests were extended to determine the maximum rolling moment which could be obtained with any deflection. In some cases the maximum usable deflection was limited by the fact that the ailerons fluttered when the deflection was increased beyond a certain point. The question of this flutter and its relation to the test results is discussed more fully in the next section.

The first tests were made with the single narrow-chord ailerons at each of the four longitudinal locations and the results are given in Figure 7. The aileron deflections necessary to produce the assumed satisfactory control moment at the 10° angle of attack were $\pm 8^{\circ}$ (16° difference between ailerons), $\pm 9^{\circ}$, $\pm 9^{\circ}$, and $\pm 9.5^{\circ}$ for the four locations taken respectively from front to rear. In the forward location these ailerons fluttered when given a deflection greater than $\pm 12^{\circ}$, but no flutter occurred with any of the deflections tried at any of the other three locations.

The results of the tests of the multiple tip ailerons are shown in Figure 8. Neither the 5-section ailerons nor the 3-section ailerons gave entirely satisfactory values at the 10° angle of attack. The maximum deflections chosen were $\pm 24^{\circ}$ for the 5-section ailerons and $\pm 21^{\circ}$ for the 3-section ailerons. With the 4-section ailerons the rolling moment continued to increase with deflection up to $\pm 30^{\circ}$, which gave satisfactory control and was chosen as the maximum.

The results for the floating tip ailerons on both tapered wings at an angle of attack of 10° are given in Figure 9. The deflections required for the assumed satisfactory control were $\pm 15^{\circ}$ for the ailerons on the wings with 5:3 taper and $\pm 10.75^{\circ}$ for the ailerons on the wing with 5:1 taper. These ailerons fluttered when deflected above $\pm 16^{\circ}$ on the wing with 5:3 taper and $\pm 14^{\circ}$ on the wing with 5:1 taper. If the ailerons had not fluttered it would have been possible to obtain slightly greater rolling moments but it is not believed that the increase would have been greater than 5 or 10 per cent.

The deflections that gave the assumed satisfactory rolling moment at the 10° angle of attack are assumed as the maximum deflection giving the best comparison between these ailerons and ailerons of other forms. Inasmuch as the final complete tests showed that with these deflections the floating tip ailerons would not give satisfactory moments at the higher angles of attack, the results are also compared for the deflections giving the maximum rolling moments, which in some cases were the maximum deflections that could be used without flutter.

Aileron flutter.- The single narrow-chord ailerons at the forward location and the ailerons on both tapered wings fluttered at all angles of attack with zero yaw if given sufficient deflection, and they also fluttered with smaller deflections if yawed sufficiently. This condition of flutter need not give rise to serious difficulty, however, for, according to the tests on the full-chord floating tip ailerons of Part IV, the flutter can be eliminated by moving the axis ahead slightly. Inasmuch as the test results would not be greatly different if the axes were moved farther ahead, it was not thought necessary to repeat the tests with the more favorable locations. The hinge moments would, of course, be slightly higher. The effect of yaw on flutter is illustrated by the following case: The ailerons on the wing with 5:3 taper would not flutter at any angle of yaw with deflections of less than $\pm 11^\circ$, but with a deflection of $\pm 12^\circ$ flutter occurred at angles of attack from 16.5° to 22° with 9° of yaw or more, and with a deflection of $\pm 16^\circ$ flutter occurred at angles of attack from 14.5° to 22° with 5° of yaw or more.

Final tests.- Force tests at both 0° and -20° yaw were made with the single narrow-chord ailerons set neutral and deflected various amounts, at each of the four axis locations. The results of these tests are given in Tables I and II as absolute coefficients of lift and drag and of rolling and yawing moments:

$$C_L = \frac{\text{lift}}{q\ S}$$

$$C_D = \frac{\text{drag}}{q\ S}$$

$$C_l' = \frac{\text{rolling moment}}{q\ b\ S}$$

$$C_n' = \frac{\text{yawing moment}}{q\ b\ S}$$

where S is the total wing area, including the area of the ailerons, b is the over-all span, and q is the dynamic pressure. The coefficients as given above are obtained directly from the balance and refer to the wind (or tunnel) axes. In special cases in the discussion where the moments are used with reference to the body axes the coefficients are not primed. Thus, the symbols for the rolling and yawing moment coefficients about the body axes are, respectively, C_l and C_n.

The rolling and yawing moments at 0° yaw with ailerons deflected are the moments due to ailerons alone. At 20° yaw with the ailerons neutral the moments as tabulated are due to yaw alone, but those with the ailerons deflected have been corrected so that they represent only the effect of the ailerons. The floating angles of the right ailerons with respect to the chord of the model, designated δ_{AF}, are also included in these tables.

Rotation tests at both 0° and 20° yaw were made with the ailerons floating neutral at each axis location. The first of these were free-autorotation tests at 0° yaw to find the angle of attack below which it would not rotate. Next forced-rotation tests were made at both 0° and 20° yaw in which the rolling moment while rolling was measured at the rotational speed corresponding to $\frac{p'b}{2V} = 0.05$, the highest rate likely to be caused by gusty air. The results are given in Table III in terms of a coefficient representing the rolling moment due to rolling, or if yawed due to rolling and yaw,

$$C_\lambda = \frac{\lambda}{q\ b\ S}$$

where λ is the rolling moment measured while the wing is rolling and the other factors have the usual significance.

Similar results are given for the wings with multiple tip ailerons and tapered ailerons in Tables IV to XII.

Hinge-moment tests were made for the single narrow-chord ailerons at the forward location, for the ailerons on both tapered wings, and for the full-chord ailerons of Part IV with the 15 per cent and 20 per cent axis locations. The results of all these tests are given in Table XIII.

<u>Accuracy</u>.- The accuracy of the results given in this report is the same as that obtained in Part I. (Reference 1.) It is considered satisfactory at all angles of

attack except in the burbled region between 20° and 25°. In this region the rolling and yawing moments are relatively unreliable owing to the critical and often unsymmetrical condition of the burbled air flow around the wing. On some occasions two values were measured at the same angle of attack, in which case both are recorded in the tables.

DISCUSSION IN TERMS OF CRITERIONS

For a comparison of the different aileron effects, the results of the tests are discussed in terms of criterions which are explained in detail in reference 1 and briefly in the following paragraphs. By use of these criterions a comparison of the effect of the different ailerons on the general performance, the lateral controllability, and the lateral stability may be easily made. The results of the above tests in terms of the criterions are given in Table XIV. The criterions for the following aileron arrangements are included in the table for comparison: the wing with the 25 per cent chord by 40 per cent semispan ordinary ailerons, which is used as the standard; one of the best full-chord floating tip ailerons on a rectangular wing from Part IV, this aileron having a symmetrical section with the aileron flaps up 2° and a maximum aileron deflection of ±20°.

General Performance

(Controls Neutral)

Wing area required for desired landing speed.- The criterion $C_{L_{max}}$ is used to indicate the wing area required for a given landing speed, or conversely, for the minimum landing speed obtainable with a given wing area. The coefficient as used herein is based on the entire wing area, including the ailerons. The use of this area in calculating the coefficients was considered a fair basis for comparing floating tip ailerons with ordinary ailerons as the floating ailerons represent additional structural weight and span.

A comparison of the maximum lift coefficient obtained with the various floating tip ailerons with the maximum lift coefficient obtained with ordinary ailerons on the standard wing shows that the value is less in every case with the floating ailerons. The greatest reduction, about 22 per cent, occurred with the single narrow-chord aileron in any of the fore-and-aft locations. With the multiple tip ailerons having five sections, the reduction was 18 per cent, with four sections 16 per cent, and with three sections 12 per cent. The rectangular wing with full-chord floating tip ailerons and the wing with 5:3 taper also showed a reduction of about 12 per cent, but with the wing having 5:1 taper the reduction was only 7 per cent, which was about 4 per cent higher than the maximum lift with the full-chord tip ailerons.

Speed range.- The ratio $C_{L_{max}}/C_{D_{min}}$ is taken as a criterion for speed range. The value of this ratio for the wings with the single narrow-chord ailerons, the wing with 5:3 taper, and the wings with multiple tip ailerons was about 20 to 25 per cent lower than the standard wing and about 5 to 15 per cent lower than the wing with the full-chord floating tip ailerons. The value for the wing with 5:1 taper, however, was practically as high as that for the standard wing and about 14 per cent higher than for the wing with the full-chord tip ailerons.

Rate of climb.- In order to establish a suitable criterion for the effect of the wing and the lateral control devices on the rate of climb of an airplane, the performance curves of a number of types and sizes of airplanes were calculated, and the relation of the maximum rate of climb to the lift and drag curves was studied. This investigation showed that the L/D at $C_L = 0.70$ gave a consistently reliable figure of merit for this purpose. The value of this criterion is substantially lower for the wings with any of the floating tip ailerons of the present tests than for the standard wing, the loss ranging from a minimum of 20 per cent for the wing with 5:3 taper and the wing with the three-section multiple tip to a maximum of 45 per cent for the wing with a narrow-chord aileron in the forward position. Likewise, the values of this criterion for any of the wings for this series are from 4 to 34 per cent lower than that for the wing with the full-chord floating tip ailerons.

In the above discussion the ailerons have been considered a part of the wing proper as previously explained. If, however, the ailerons were assumed to be solely control devices added to the standard wing of aspect ratio 6, the relative values of the criterions would be considerably different. The maximum lift in every case would then be approximately the same as that for the standard wing and the speed-range ratio and the rate-of-climb criterion would be only slightly lower than for the standard wing, the decrease being the result of the additional parasite drag of the tip ailerons. If the tip ailerons were considered in this way, however, the additional weight and the additional span, the latter requiring greater space for housing purposes, would be separate disadvantages not included in the criterion.

Lateral Controllability

(Maximum Assumed Control Deflection)

Rolling criterion.- The rolling criterion upon which the control effectiveness of each of the aileron arrangements is judged is a figure of merit that is designed to be proportional to the initial acceleration of the wing tip, following a deflection of the aileron from neutral, regardless of the air speed or, within reasonable limits, of the plan form of the wing. Expressed in coefficient form this rolling criterion is

$$RC = \frac{C_l \; S \; b^2}{12 \; C_L \; I_x}$$

where C_l is the coefficient of rolling moment due to the ailerons with respect to the body axis (which axis for the wing alone is taken as the midspan chord line) and I_x is the area moment of inertia about the midspan chord line. A more detailed discussion of RC and the assumptions upon which it is based is given in reference 1, Part I.

The numerical value of this criterion that is assumed to represent satisfactory control conditions is approximately 0.075, the value given by the standard ailerons with an assumed maximum deflection of ±25° at an angle of attack of 10°. None of the lower of the assumed maximum deflections gave satisfactory control at all angles of attack (particularly at angles of attack in the neighborhood of 20°), but satisfactory control was approached by all of the single ailerons with the maximum usable deflections. Values of the criterions are given for both deflections in Table XIV.

At $\alpha = 0^\circ$ all the ailerons tested gave substantially greater values of RC than that considered necessary.

At $\alpha = 10^\circ$ all the ailerons gave approximately satisfactory values of RC, except for the multiple tip ailerons with five and with three sections. The single ailerons with the higher of the two assumed maximum deflections all gave somewhat greater than the assumed necessary value of RC at the 10° angle of attack.

At $\alpha = 20^\circ$, which is just above the stall, all the floating tip ailerons were found to be better than the standard ordinary ailerons. For the single ailerons with the lower of the two assumed maximum deflections which gave just satisfactory control at an angle of attack of 10°, and also for the multiple tip ailerons, however, the values of RC were not in any case satisfactory at the 20° angle of attack. The largest, which was about 80 per cent of the satisfactory value, was obtained on the wing with 5:3 taper. With the higher of the assumed maximum deflections, satisfactory values of RC were obtained at the 20° angle of attack with the single narrow-chord ailerons in the foremost location, and 86 per cent of the satisfactory value with the wing having 5:3 taper. If the aileron hinge axis were moved ahead somewhat to permit greater deflections without flutter, it is possible that satisfactory control moments at the 20° angle of attack could be obtained also with the ailerons on the wing with the 5:1 taper.

At $\alpha = 30^\circ$, which is well above the range of angles ordinarily obtainable in steady stalled flight, all the floating tip ailerons tested gave reasonably satisfactory values of RC. Ordinary ailerons fail almost completely at this angle of attack.

Lateral control with sideslip.- If a wing is yawed 20°, a rolling moment that tends to raise the forward tip is set up with a magnitude that is greater at very high angles of attack than the available rolling moment due to conventional ailerons. The limiting angle of attack at which the ailerons can balance the rolling moment due to 20° yaw represents the greatest angle of attack that can be held in an average sideslip. This angle is tabulated for all the ailerons as a criterion of control with sideslip.

The values in Table XIV show that all the single floating tip ailerons tested gave control against 20° sideslip up to angles of attack from 17° to 20°, the 20° value being the same as that for the standard ailerons. The multiple tip ailerons with three and four sections also gave control to about the same angle of attack as the standard ailerons, but the five-section multiple tip aileron maintained control up to an angle of attack of 23°.

Yawing moment due to ailerons.- The amount and even the direction of the yawing moment which is desirable from ailerons does not seem to have been definitely determined up to the present time. It was thought in the past, particularly with reference to acrobatic flying and probably with reference to most ordinary maneuvers, that to the pilot the maneuvers would seem as if they occurred about the airplane, or body, axes. For a maneuverable or acrobatic airplane it was therefore thought that complete independense of the three aerodynamic controls about the body axes would probably be a desirable feature. Recent flight tests made in a control investigation that is still under way, however, indicate that the yawing action of the ailerons as observed by the pilot is that which would be expected from the yawing moments occurring about the wind axes, not those about the body axes. It is hoped that the present flight investigation, in which some of the interesting ailerons and spoilers developed in the present series of wind-tunnel tests on lateral control devices are being tested in regard to their operation in flight, will give sufficient information on yawing moments to settle in large measure the question of the amount of yawing moment desirable for various flying conditions. At the present time no final conclusions have been reached. The indication is, however, that zero or very small yawing moments about the wind axes are desirable for acrobatic flying and possibly for flying in general, but yawing moments of such a sense that they tend to retard the low wing in a turn definitely improve the lateral control at angles of attack above the stall. Until more definite conclusions are reached, the yawing-moment coefficient in the criterion table will be, as in the previous reports of this series, given with respect to the body axes. In all the reports including the present, however, the yawing-moment coefficients with respect to the wind axes are given in the detailed tables of measured data.

For all the floating tip ailerons the yawing-moment coefficients about the wind axes were very close to zero at all angles of attack. In terms of the body axes the yawing moments were, of course, the same at the zero angle of attack, but at the high angles of attack they became very large in the so-called favorable sense.

Lateral Stability

(Controls Neutral)

Angle of attack above which autorotation is self-starting.- This criterion is a measure of the range of angles of attack above which autorotation will start from an initial condition of practically zero rate of rotation. In general, the angle of attack at which autorotation is self-starting was found to be about the same for the wings with floating tip ailerons as for the standard wing with ordinary ailerons. It was, however, slightly higher for the wing with the single narrow-chord floating tip ailerons in both the front and rear positions.

Stability against rolling caused by gusts.- Test flights have shown that in severe gusts a rolling velocity such that $\frac{p'b}{2V} = 0.05$ may be obtained. Consequently, the rolling moment of a wing due to rolling at this value of $\frac{p'b}{2V}$ gives a measure of one factor affecting lateral stability characteristics in rough air. In the present case, the angle at which this rolling moment becomes zero is used as a more severe criterion than the previously mentioned angle at which autorotation is self-starting, to indicate the practical upper limit of the useful angle-of-attack range. As in the case of the angle of attack above which autorotation was self-starting, the angle of instability while rotating with $\frac{p'b}{2V} = 0.05$ was approximately the same for all the wings with floating tip ailerons as for the plain wing with standard ailerons. With 20° yaw the wings with narrow-chord ailerons and multiple tip ailerons, like the standard wing, had an angle of attack for initial instability about 7° lower than with 0° yaw. For the wing with 5:3 taper this difference was only 4° and for the wing with 5:1 taper the angle for initial instability was actually 1° higher with 20° yaw than with 0° yaw.

The above criterion shows the critical range below which the stability is such that any rolling is damped out, and above which instability exists. The last criterion, maximum C_λ, indicates the degree of this instability. All the rotation tests showed somewhat unsymmetrical conditions in the two directions of rotation, and the maximum value of C_λ found with any angle of attack in either direction of rotation is used as the criterion. At 0° yaw the wing with the single narrow-chord floating tip ailerons in any of the fore-and-aft locations showed a much weaker tendency to autorotate than the standard wing with the plain ailerons or the rectangular wing with full-chord floating tip ailerons. The wing with 5:3 taper showed about the same autorotational tendency as that with the single narrow-chord ailerons but the one with 5:1 taper and the one with the four-section multiple tip ailerons showed much stronger autorotational tendencies, although definitely below that for the plain wing.

The maximum autorotational moment with 20° yaw is of importance only in the condition in which the airplane is skidded and the forward wing tip is rolled upward or the rear tip downward by means of a gust. This autorotational moment, which is large with the plain standard wing, was substantially smaller with all the floating tip ailerons.

Control Force Required

The control-force criterion, with which the various lateral control devices are compared in regard to the control-stick force required to attain the assumed maximum deflections, is based on a control-stick movement of ±25° and is independent of air speed. The criterion is

$$CF = \frac{F\,l}{q\ c\ S\ C_L} = \frac{C_H}{C_L}\left(\frac{\delta_A}{25}\right)$$

where F is the force applied at end of control lever of length l and $\delta_A/25$ is the gear ratio between the aileron and the control lever.

The control force required for the full-chord tip ailerons hinged at the 15 per cent axis location was about three times as great as that required for the standard ordinary ailerons. It may be seen from Table XIII that the hinge moments are from 25 to 50 per cent greater for the 15 per cent axis location than for the 20 per cent.

The control force for the single narrow-chord tip ailerons with the larger of the two maximum deflections assumed was found to be only about one-half as great as that for the standard ailerons. The hinge moments were tested for the forward location only but it is likely that the values for the other locations would not be greatly different. The hinge moments for the multiple tip ailerons were not measured, but on the assumption that the hinge moments are approximately proportional to the square of the aileron chord, they should be somewhat lower than those for the single narrow-chord ailerons.

The control force required for the floating ailerons on the 5:3 tapered wing was found to be approximately the same as for the standard ordinary ailerons. It would probably not be prohibitive even if the axis were moved ahead to the 15 per cent location definitely to avoid flutter. Very low control forces were found for the ailerons on the wing with 5:1 taper, the values being about the same as those for ordinary type ailerons with very narrow chord, such as the 15 per cent chord ailerons of Part I.

CONCLUSIONS

1. The values of the maximum lift coefficient and the speed-range ratio $C_{L_{max}}/C_{D_{min}}$ obtained with the floating tip ailerons on the wing with 5:1 taper were definitely higher than the values for the best full-chord floating tip ailerons on a rectangular wing and nearly as high as the values for the standard rectangular wing with plain ailerons. The values for the multiple floating tip ailerons were lower and those for the single narrow-chord floating tip ailerons were substantially lower than the values for the full-chord floating tip ailerons on the rectangular wing.

2. The values of the rate-of-climb criterion for all the floating tip ailerons of the present tests were lower than for the full-chord floating tip ailerons on a rectangular wing, which in turn is substantially lower than the value for a plain wing with ordinary ailerons.

3. With the higher of the two maximum deflections the floating tip ailerons on the wing with 5:3 taper and also the single narrow-chord ailerons in the foremost location gave approximately satisfactory values of RC at

all angles of attack. Values of RC of fair magnitude were given at all angles of attack by all the floating tip ailerons with all the maximum deflections assumed.

4. None of the floating tip ailerons gave adverse yawing moments of appreciable magnitude but all gave large favorable values about the body axes at the high angles of attack. The yawing moments about the wind axes were close to zero throughout.

5. The maximum instability in rolling at angles of attack above the stall was not as great for any of the wings with floating tip ailerons as for the standard wing with ordinary ailerons. None of the ailerons tested, however, entirely eliminated the autorotational moments.

6. Some of the floating ailerons of the present tests fluttered if given a sufficiently large deflection, but reasonably satisfactory control could in all cases be obtained with smaller deflections with which no flutter occurred. Previous tests indicate that the flutter could in all cases be eliminated by moving the hinge axis of the ailerons forward a slight amount.

7. The control force required for the full-chord floating tip ailerons on rectangular wings is so large that ailerons of this nature are probably not practicable. That required for the floating tip ailerons on the wing with 5:3 taper was about the same as for the standard ordinary ailerons, but that required for the aileron on the wing with 5:1 taper and for the single narrow-chord tip ailerons was much lower.

8. Considering all points, the best floating tip ailerons tested are probably those on the wing with 5:1 taper and these could probably be improved somewhat by moving the hinge axis forward 1 or 2 per cent of the chord from the present 18 per cent location.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 3, 1933.

REFERENCES

1. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack.

I. Ordinary Ailerons on Rectangular Wings. T.R. No. 419, N.A.C.A., 1932, by Fred E. Weick and Carl J. Wenzinger.

II. Slotted Ailerons and Frise Ailerons. T.R. No. 422, N.A.C.A., 1932, by Fred E. Weick and Richard W. Noyes.

III. Ordinary Ailerons Rigged Up 10° When Neutral. T.R. No. 423, N.A.C.A., 1932, by Fred E. Weick and Carl J. Wenzinger.

IV. Floating Tip Ailerons on Rectangular Wings. T.R. No. 424, N.A.C.A., 1932, by Fred E. Weick and Thomas A. Harris.

V. Spoilers and Ailerons on Rectangular Wings. T.R. No. 439, N.A.C.A., 1932, by Fred E. Weick and Joseph A. Shortal.

VI. Skewed Ailerons on Rectangular Wings. T.R. No. 444, N.A.C.A., 1932, by Fred E. Weick and Thomas A. Harris.

VII. Handley Page Tip and Full-Span Slots with Ailerons and Spoilers. T.N. No. 443, N.A.C.A., 1933, by Fred E. Weick and Carl J. Wenzinger.

VIII. Straight and Skewed Ailerons on Wings with Rounded Tips. T.N. No. 445, N.A.C.A., 1933, by Fred E. Weick and Joseph A. Shortal.

IX. Tapered Wings with Ordinary Ailerons. T.N. No. 449, N.A.C.A., 1933, by Fred E. Weick and Carl J. Wenzinger.

X. Various Control Devices on a Wing with a Fixed Auxiliary Airfoil. T.N. No. 451, N.A.C.A., 1933, by Fred E. Weick and Richard W. Noyes.

2. Schmidt, Wilhelm: Development of a Non-Autorotative Airplane Capable of Steep Landing. T.M. No. 650, N.A.C.A., 1931.

3. Harris, Thomas A.: The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 412, N.A.C.A., 1931.

TABLE I

FORCE TESTS. 12.5 BY 40 INCH CLARK Y WING
WITH SYMMETRICAL FLOATING TIP AILERONS 5 INCH c BY 10 INCH b
AILERON AXIS 18 PER CENT OF AILERON CHORD FROM LEADING EDGE. FLAPS 0°
R.N. = 609,000 Velocity = 80 m.p.h. Yaw = 0°

a. Axis in wing 7.2 per cent chord from leading edge

δ_A Up | δ_A Dn Difference	α	-5°	-4°	-3°	0°	5°	10°	14°	15°	16°	17°	18°	20°	22°	25°	30°	40°	50°	60°
		Ailerons floating, neutral																	
0°	C_L	0.052	0.095	0.140	0.245	0.466	0.718	0.908	0.950	0.987	0.978	0.940	0.910	0.872	0.725	0.665	0.595	0.554	0.474
0°	C_D	.017	.016	.016	.020	.043	.085	.124	.136	.147	.167	.191	.211	.239	.333	.413	.544	.697	.832
0°	δ_{AF}	9°	7.5°	5.5°	-1°	-10.5°	-16.5°	-20.5°	-21.5°	-23°	-22.5°	-23.5°	-25°	-26°	-26.5°	-33.5°	-45.5°	-56°	-65°
		Up-and-down																	
8°	C_l'				.022		.021	.021		.020		.020	.020	.020	.025	.031	.013		
8°	C_n'				0		.001	.002		.002		.002	.002	.001	.003	-.004	-.003		
8°	δ_{AF}				-4.5°		-19.5°	-23°		-25°		-26.5°	-27.5°	-28.5°	-30°	-37°	-47.5°		
16°	C_l'				.042		.040	.039		.036		.038	.039	.038	.045	.045	.026		
16°	C_n'				0		.002	.003		.003		.004	.003	.003	.004	-.003	-.002		
16°	δ_{AF}				-7°		-21°	-26°		-28°		-30°	-32°	-32°	-34°	-41°	-50°		
24°	C_l'				.057		.055	.054		.053		.053	.054	.054	.064	.057	.037		
24°	C_n'				.001		.002	.004		.004		.004	.004	.004	.003	-.003	-.003		
24°	δ_{AF}				-13°		-24°	-29°		-31°		-33°	-35°	-37°	-40°	-45°	-54°		
b. Axis in wing 27.2 per cent chord from leading edge																			
		Ailerons floating, neutral																	
0°	C_L	-.013	0.053	0.110	0.258	0.482	0.742	0.930	0.965	1.002	0.968	0.940	0.900	0.857	0.698	0.675	0.586	0.548	0.565
0°	C_D	.017	.016	.016	.020	.044	.083	.124	.134	.147	.165	.180	.210	.237	.333	.431	.549	.701	.843
0°	δ_{AF}	4°	3°	3°	0°	-10°	-17°	-21°	-22°	-23°	-24°	-25°	-27°	-29°	-31°	-37°	-46°	-56°	-66°
		Up-and-down																	
8°	C_l'				.022		.021	.020		.020		.019	.019	.018	{.024 .028	{.031 .027	.012		
8°	C_n'				0		.001	.001		.001		.002	.002	.002	.005	0	-.002		
8°	δ_{AF}				-4°		-18°	-23°		-24°		-27°	-29°	-30°	-32°	-40°	-46°		
16°	C_l'				.039		.037	.037		.036		.036	.036	.034	{.040 .043	{.034 .039	.024		
16°	C_n'				.002		.001	.002		.002		.003	.003	.003	.005	0	-.003		
16°	δ_{AF}				-11°		-21°	-25°		-28°		-30°	-32°	-34°	-37°	-42°	-49°		
24°	C_l'				.057		.053	.053		.052		.052	.052	.050	{.055 .059	.055	.035		
24°	C_n'				.001		.002	.004		.005		.005	.005	.004	.005	-.002	-.004		
24°	δ_{AF}				-13°		-26°	-31°		-33°		[a]-35°	[a]-37°	[a]-39°	-41°	-46°	-55°		
		[a]Ailerons fluttered slightly																	
c. Axis in wing 47.2 per cent chord from leading edge																			
		Ailerons floating, neutral																	
0°	C_L	-.031	0.035	0.080	0.216	0.479	0.741	0.926	0.963	0.997	0.966	0.945	0.900	0.842	0.680	0.633	0.577	0.525	0.435
0°	C_D	.017	.016	.017	.022	.044	.083	.136	.140	.150	.167	.182	.212	.240	.343	.430	.549	.701	.844
0°	δ_{AF}	2°	2°	1°	-4°	-11°	-18°	-22°	-25°	-26°	-27°	-28°	-30°	-32°	-35°	-43°	-46°	-57°	-67°
		Up-and-down																	
8°	C_l'				.022		.020	.019		.019		.018	.019	.018	{.023 .029	{.024 .026	.012		
8°	C_n'				0		.001	.002		.002		.002	.002	.002	.005	0	-.002		
8°	δ_{AF}				-4°		-20°	-24°		-26°		-28°	-30°	-32°	-35°	-44°	-43°		
16°	C_l'				.039		.037	.037		.036		.035	.035	.034	{.036 .041	{.037 .038	.024		
16°	C_n'				.002		.002	.003		.004		.004	.004	.004	.006	.001	-.003		
16°	δ_{AF}				-12°		-23°	-27°		-31°		-33°	-35°	-37°	-40°	-45°	-54°		
24°	C_l'				.054		.051	.049		.048		.047	.048	.046	{.055 .052	.049	.034		
24°	C_n'				.001		.004	.005		.005		.005	.005	.005	.007	.001	-.003		
24°	δ_{AF}				-13°		-26°	-32°		-34°		-36°	-38°	-40°	-43°	-48°	-53°		
d. Axis in wing 67.2 per cent chord from leading edge																			
		Ailerons floating, neutral																	
0°	C_L	-.032	0.032	0.095	0.255	0.497	0.755	0.930	0.970	0.994	0.960	0.944	0.893	0.845	0.670	0.626	0.583	0.517	0.410
0°	C_D	.017	.016	.016	.021	.044	.083	.124	.136	.148	.167	.183	.216	.241	.341	.432	.552	.700	.842
0°	δ_{AF}	0.5°	0.5°	0.5°	-2.5°	-12°	-18.5°	-23.5°	-25°	-26.5°	-28°	-29°	-31°	-33°	-36.5°	-42°	-50°	-59.5°	-72°
		Up-and-down																	
8°	C_l'				.020		.020	.019		.019		.019	.020	.018	{.019 .025	{.020 .023	.011		
8°	C_n'				0		.002	.002		.002		.002	.002	.003	.006	0	-.001		
8°	δ_{AF}				-5°		-20°	-26°		-29°		-31°	-33°	-35°	-38°	-43°	-43°		
16°	C_l'				.037		.037	.037		.035		.035	.035	.034	{.033 .039	.033	.023		
16°	C_n'				0		.002	.003		.003		.003	.003	.004	.008	.001	-.002		
16°	δ_{AF}				-8°		-24°	-30°		-32°		-34°	-36°	-38°	-41°	-46°	-48°		
24°	C_l'				.051		.046	.048		.045		.046	.044	.044	{.043 .053	{.047 .043	.033		
24°	C_n'				0		.002	.003		.002		.003	.004	.004	.008	0	-.003		
24°	δ_{AF}				-15°		-28°	-34°		-36°		-38°	-40°	-42°	-44°	-48°	-52°		

TABLE II

FORCE TESTS. 12.5 BY 40 INCH CLARK Y WING
WITH SYMMETRICAL FLOATING TIP AILERONS 5 INCH c BY 10 INCH b
AILERON AXIS 18 PER CENT OF AILERON CHORD FROM LEADING EDGE. FLAPS 0°
R.N. = 609,000 Velocity = 80 m.p.h. Yaw = -20°

	α	-5°	-3°	0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
a. Axis in wing 7.2 per cent chord from leading edge																
δ_A up | δ_A dn Difference	Ailerons floating, neutral															
0°	C_L	0.023	0.108	0.225	0.437	0.653	0.828	0.905	0.970	1.036	1.035	0.800	0.740	0.655	0.584	0.492
0°	C_D	.019	.018	.021	.041	.076	.112	.132	.155	.187	.242	.358	.439	.552	.677	.802
0°	C_l'	.003	.001	-.003	-.008	-.014	-.019	-.023	-.029	-.037	-.053	-.063	-.048	-.026	-.020	.018
0°	C_n'	.002	.001	.002	.003	.005	.007	.009	.012	.013	.013	.019	.022	.019	.020	.021
0°	δ_{AF}	8°	5°	-1°	-8.5°	-16°	-20°	-22°	-23.5°	-25.5°	-27.5°	-31°	-35.5°	-45.5°	-56.5°	-66.5°
	Up-and-down															
16°	C_l'			.029		.032	.032	.032	.031	.030	.025	.019	.026	.020		
16°	C_n'			.002		.003	.003	.003	.004	.003	.002	0	0	0		
16°	δ_{AF}			-10°		-22°	-26°	-28°	-29°	-31°	-31°	-33°	-40°	-50°		
24°	C_l'			.040		.046	.045	.045	.043	.042	.037	.029	.035	.029		
24°	C_n'			.001		.004	.004	.004	.005	.006	.004	-.001	-.001	0		
24°	δ_{AF}			-13°		-25°	-29°	-31°	-35°	-35°	-37°	-37°	-42°	-53°		
b. Axis in wing 27.2 per cent chord from leading edge																
	Ailerons floating, neutral															
0°	C_L	0.022	0.127	0.240	0.458	0.676	0.838	0.915	0.980	1.039	1.030	0.812	0.730	0.636	0.583	0.471
0°	C_D	.019	.018	.021	.040	.076	.111	.132	.156	.191	.245	.362	.439	.557	.694	.824
0°	C_l'	.003	.002	-.001	-.007	-.013	-.019	-.023	-.028	-.036	-.055	-.063	-.043	-.022	-.018	-.017
0°	C_n'	.002	.002	.002	.003	.005	.008	.010	.012	.013	.012	.018	.023	.020	.021	.022
0°	δ_{AF}	9°	7°	1°	-6°	-14°	-19°	-22°	-24°	-26°	-28°	-32°	-38°	-49°	-59°	-69°
	Up-and-down															
16°	C_l'			.028		.029	.029	.029	.028	.025	.023	{.020, .018}	{.014, .017}	.012		
16°	C_n'			.002		.001	.002	.002	.003	.003	.002	.002	.001	0		
16°	δ_{AF}			-10°		-20°	-24°	-27°	-29°	-31°	-32°	-34°	-39°	-49°		
24°	C_l'			.044		.044	.043	.042	.041	.039	.036	.031	{.023, .026}	.021		
24°	C_n'			0		.003	.005	.005	.006	.006	.004	.002	.001	0		
24°	δ_{AF}			-12°		-26°	-31°	-34°	-35°	-37°	-37°	-37°	-42°	-52°		
c. Axis in wing 47.2 per cent chord from leading edge																
	Ailerons floating, neutral															
0°	C_L	-0.004	0.098	0.206	0.448	0.679	0.845	0.918	0.977	1.032	1.028	0.797	0.710	0.622	0.557	0.465
0°	C_D	.019	.019	.023	.041	.076	.111	.133	.154	.189	.246	.359	.443	.562	.692	.822
0°	C_l'	.002	0	-.002	-.009	-.015	-.021	-.025	-.030	-.038	-.063	-.063	-.042	-.021	-.018	{-.015, -.018}
0°	C_n'	.002	.002	.002	.003	.005	.007	.010	.012	.014	.013	.021	.025	.021	.021	.022
0°	δ_{AF}	6°	4°	1°	-8°	-14°	-18°	-22°	-24°	-27°	-29°	-32°	-41°	-51°	-59°	-69°
	Up-and-down															
16°	C_l'			.029		.030	.030	.029	.028	.016	.029	.019	.014	.008		
16°	C_n'			.001		.002	.002	.002	.002	.002	.002	.001	-.001	-.002		
16°	δ_{AF}			-9°		-21°	-25°	-28°	-30°	-32°	-34°	-35°	-40°	-48°		
24°	C_l'			.042		.044	.043	.041	.042	.038	.040	.028	.022	.014		
24°	C_n'			0		.003	.005	.005	.005	.004	.004	.002	0	-.003		
24°	δ_{AF}			-12°		-25°	-31°	-33°	-35°	-37°	-37°	-38°	-43°	-60°		
d. Axis in wing 67.2 per cent chord from leading edge																
	Ailerons floating, neutral															
0°	C_L	-0.017	0.108	0.237	0.478	0.705	0.854	0.930	0.988	1.033	1.020	0.783	0.710	0.613	0.545	0.448
0°	C_D	.019	.018	.021	.040	.073	.108	.131	.153	.188	.244	.363	.447	.570	.695	.820
0°	C_l'	.001	-.002	-.005	-.011	-.017	-.021	-.025	-.032	-.039	-.055	{-.062, -.063}	{-.039, -.041}	-.019	-.017	-.015
0°	C_n'	.002	.002	.002	.003	.005	.008	.010	.012	.014	.013	.021	.025	.022	.021	.022
0°	δ_{AF}	5°	3°	0°	-5°	-12°	-17°	-19°	-22°	-25°	-28°	-34°	-42°	-52°	-60°	-69°
	Up-and-down															
16°	C_l'			.028		.028	.027	.027	.026	.022	.019	{.015, .017}	{.010, .012}	.003		
16°	C_n'			0		.002	.002	.003	.003	.003	.002	.002	-.001	-.002		
16°	δ_{AF}			-7°		-21°	-25°	-27°	-30°	-31°	-33°	-36°	-41°	-46°		
24°	C_l'			.042		.043	.041	.041	.040	.035	.030	{.024, .025}	{.015, .017}	.009		
24°	C_n'			0		.003	.004	.005	.005	.005	.003	.001	-.002	-.004		
24°	δ_{AF}			-12°		-26°	-30°	-32°	-35°	-37°	-39°	-39°	-41°	-47°		

TABLE III

ROTATION TESTS. 12.5 BY 40 INCH CLARK Y WING
WITH SYMMETRICAL FLOATING TIP AILERONS 5 INCH c BY 10 INCH b
AILERON AXIS 18 PER CENT AILERON CHORD FROM LEADING EDGE. FLAPS 0°

C_λ is given for forced rotation at $\frac{p'b}{2V} = 0.05$ (+) aiding rotation, (-) damping rotation

R.N. = 609,000 Velocity = 80 m.p.h.

a. Axis in wing 7.2 per cent chord from leading edge

	α	0°	10°	14°	16°	18°	19°	20°	21°	22°	24°	25°	28°	30°	37°	40°
		Ailerons floating, neutral - Yaw = 0°														
(+) Rotation	C_λ	-0.018	-0.020	-0.019	-0.015	-0.005	-0.003	-0.005	-0.004	0.004	-0.004	0.005	0.006	0.001	-0.009	-0.010
(-) Rotation	C_λ	-.017	-.017	-.017	-.015	-.004	-.006	-.005	-.006	.003	-.020	-.021	-.020	-.009	-.008	-.008
		Ailerons floating, neutral - Yaw = -20°														
(+) Rotation	C_λ	-.017	-.025	-.028	-.033	-.039		-.049		-.055		-.050		-.031		-.019
(-) Rotation	C_λ	-.015	-.007	-.002	.001	.006		.014		.038		.036		.020		.004

b. Axis in wing 27.2 per cent chord from leading edge

	α	0°	10°	14°	16°	18°	20°	21°	22°	23°	24°	25°	28°	30°	35°	40°
		Ailerons floating, neutral - Yaw = 0°														
(+) Rotation	C_λ	-0.020	-0.021	-0.020	-0.015	-0.006	-0.005	0.002	0.006	0.002	-0.004	0.005	0.006	0.002	-0.006	-0.009
(-) Rotation	C_λ	-.017	-.017	-.016	-.012	-.005	-.005	0	.005	{0 -.012	-.020	-.022	-.015	-.008	-.009	-.008
		Ailerons floating, neutral - Yaw = -20°														
(+) Rotation	C_λ	-.017	-.025	-.028	-.030	-.036	-.046		-.058			-.055		-.035		-.014
(-) Rotation	C_λ	-.017	-.008	-.004	-.001	.003	.013		.037			.037		.023		.001

c. Axis in wing 47.2 per cent chord from leading edge

	α	0°	10°	14°	15°	16°	18°	20°	21°	22°	23°	25°	27°	30°	40°	
		Ailerons floating, neutral - Yaw = 0°														
(+) Rotation	C_λ	-0.017	-0.018		-0.015			-0.010	0.008	0.010	0.006	0.009	0.008	0.003	-0.007	
(-) Rotation	C_λ	-.018	-.017		-.016			-.008	-.006	.004	-.003	-.023	-.023	-.009	-.002	
		Ailerons floating, neutral - Yaw = -20°														
(+) Rotation	C_λ	-.018	-.027	-.031		-.035	-.041	-.053		-.059		-.050	-.042	-.030	-.014	
(-) Rotation	C_λ	-.014	-.005	-.001		.003	.007	.018		.042		.036	.028	.020	.002	

d. Axis in wing 67.2 per cent chord from leading edge

	α	0°	10°	14°	16°	18°	19°	20°	21°	22°	23°	24°	25°	27°	30°	40°
		Ailerons floating, neutral - Yaw = 0°														
(+) Rotation	C_λ	-0.019	-0.019	-0.018	-0.013	-0.004	-0.002	-0.003	-0.002	0.010	0.006	0.001	0.009	0.010	0.004	-0.007
(-) Rotation	C_λ	-.017	-.017	-.016	-.014	-.006	-.004	-.005	-.004	.003	-.021	-.014	-.023	-.022	-.008	-.006
		Ailerons floating, neutral - Yaw = -20°														
(+) Rotation	C_λ	-.021	-.025	-.029	-.034	-.041		-.049		-.056			-.048	-.041	-.027	-.008
(-) Rotation	C_λ	-.009	-.003	.002	.006	.010		.021		.043			.037	.029	.018	-.001

TABLE IV

FORCE TESTS. WING WITH MULTIPLE TIP FLOATING AILERONS
R.N. = 609,000 Velocity = 80 m.p.h. Yaw = 0°

a. Five tips each end of wing

α		-3°	0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A		Ailerons floating, neutral													
0°	C_L	0.071	0.231	0.527	0.812	0.986	1.045	1.013	0.986	0.903	0.610	0.623	0.622	0.591	0.504
0°	C_D	.018	.022	.043	.075	.107	.127	.161	.190	.222	.328	.399	.538	.687	.797
0°	δ_{AF}	-5°	-11°	-18.5°	-24°	-27.5°	-30.5°	-32°	-35°	-37°	-37°	-39°	-41.5°	-49.5°	-55°
		Up-and-down													
± 8°	C_l'		.035		.030				.033			.036	.034		
± 8°	C_n'		0		.004				.005			.001	-.003		
± 8°	δ_{AF}		-10°		-29°				-41°			-47.5°	-53.5°		
±16°	C_l'		.038		.052				.055			.061	.056		
±16°	C_n'		.001		.009				.010			0	-.008		
±16°	δ_{AF}		-20°		-40°				-48.5°			-56°	-62°		
±24°	C_l'		.038		.058	.062	.064	.065	.068	.066	.068	.070	.068		
±24°	C_n'		.003		.007	.010	.010	.009	.010	.008	0	-.002	-.011		
±24°	δ_{AF}		-31°		-45°	-52°	-52.5°	-54°	-56°	-57°	-60°	-64.5°	-70.5°		

b. Four tips each end of wing

α		-3°	0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A		Ailerons floating, neutral													
0°	C_L	0.104	0.293	0.567	0.833	1.020	1.069	1.052	1.019	0.954	0.623	0.647	0.649	0.621	0.525
0°	C_D	.017	.020	.042	.076	.111	.132	.166	.200	.233	.338	.411	.561	.714	.827
0°	δ_{AF}	1°	-2°	-13°	-22°	-25°	-26.5°	-31.5°	-32°	-34.5°	-35°	-36.5°	-40°	-47.5°	-57°
		Up-and-down													
±10°	C_l'		.030		.036				.032			.042	.036		
±10°	C_n'		.002		.005				.008			.002	-.003		
±10°	δ_{AF}		-15°		-29°				-40°			-47°	-54°		
±20°	C_l'		.043		.056				.052			.067	.058		
±20°	C_n'		.003		.004				.012			.002	-.003		
±20°	δ_{AF}		-30°		-39°				-50°			-59°	-66°		
±30°	C_l'		.037		.062	.061	.058	.057	.048	.050	.055	.072	.067		
±30°	C_n'		.006		.003	.001	.006	.004	.003	.003	-.005	-.001	-.007		
±30°	δ_{AF}		-46°		-47°	-50°	-52°	-53°	-54°	-56°	-57°	-66°	-75°		

c. Three tips each end of wing

α		-4°	0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_{AF}		Ailerons floating, neutral													
0°	C_L	0.070	0.300	0.607	0.887	1.063	1.121	1.097	1.058	0.990	0.665	0.674	0.662	0.617	0.529
0°	C_D	.017	.022	.045	.082	.121	.142	.179	.215	.249	.353	.436	.599	.752	.899
0°	δ_{AF}	-3°	-5°	-13°	-21°	-28°	-30°	-32°	-35°	-37°	-36.5°	-38.5°	-47°	-52°	-59.5°
		Up-and-down													
± 7°	C_l'		.024		.026				.025			.027	.024		
± 7°	C_n'		0		0				.004			0	-.004		
± 7°	δ_{AF}		-8°		-23°				-39°			-42.5°	-52°		
±14°	C_l'		.039		.039				.040			.044	.039		
±14°	C_n'		.002		.001				.005			0	-.005		
±14°	δ_{AF}		-20°		-31°				-44°			-50°	-58°		
±21°	C_l'		.040		.046	.047	.046	.046	.046	.045	.046	.048	.046		
±21°	C_n'		.005		-.002	0	.001	.002	.003	.004	-.002	-.004	-.010		
±21°	δ_{AF}		-33°		-35°	-41°	-44°	-47°	-49°	-51°	-52°	-54°	-61°		

TABLE V

FORCE TESTS. WING WITH MULTIPLE TIP FLOATING AILERONS

R.N. = 609,000 Velocity = 80 m.p.h. Yaw = -20°

a. Five tips each end of wing

α		-5°	-4°	0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A		Aileron floating, neutral														
0°	C_L		-0.011	0.210	0.469	0.721	0.880	0.955	0.993	1.000	0.985	0.721	0.658	0.634	0.597	0.526
0°	C_D		.030	.022	.039	.067	.095	.113	.133	.168	.215	.347	.420	.547	.692	.820
0°	C_l'		-.004	-.006	-.008	-.011	-.018	-.023	-.033	-.046	-.065	-.073	-.056	-.035	-.033	-.033
0°	C_n'		.001	.001	.002	.004	.007	.006	.010	.012	.014	.026	.031	.028	.032	.033
0°	δ_{AF}		-4.5°	-7°	-14°	-20°	-24.5°	-26°	-28.5°	-32°	-35.5°	-36°	-42.5°	-48.5°	-53.5°	-56.5°
		Up-and-down														
±24°	C_l'			.039		.056	.056	.055	.054	.061	.060	.060	.058	.040		
±24°	C_n'			-.003		.007	.001	.001	0	.004	.003	.006	.001	-.006		
±24°	δ_{AF}			-20.5°		-43°	-42.5°	-47°	-49°	-50.5°	-52.5°	-58.5°	-60.5°	-67.5°		

b. Four tips each end of wing

α		-5°		0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A		Ailerons floating, neutral														
0°	C_L	-0.083		0.233	0.503	0.744	0.907	0.975	1.016	1.034	1.036	0.752	0.701	0.651	0.615	0.556
0°	C_D	.024		.022	.039	.069	.099	.118	.136	.175	.222	.360	.439	.568	.728	.849
0°	C_l'	-.004		-.005	-.008	-.011	-.017	-.021	-.033	-.045	-.064	-.075	-.055	-.032	-.031	-.032
0°	C_n'	.001		0	.002	.005	.006	.010	.011	.013	.015	.026	.031	.027	.030	.034
0°	δ_{AF}	-3.5°		-4.5°	-10.5°	-20°	-25.5°	-26.5°	-28.5°	-32.5°	-35°	-39°	-43.5°	-50.5°	-56°	-55.5°
		Up-and-down														
±30°	C_l'			.049		.064	.064	.062	.064	.062	.058	.050	.051	.044		
±30°	C_n'			.010		.006	.002	-.002	-.003	-.003	-.003	-.002	-.004	-.008		
±30°	δ_{AF}			-40°		-44°	-44°	-45°	-46°	-47°	-49°	-52°	-56°	-67°		

c. Three tips each end of wing

α		-5°		0°	5°	10°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A		Ailerons floating, neutral														
0°	C_L	0.009		0.263	0.537	0.786	0.954	1.017	1.058	1.078	1.076	0.797	0.739	0.680	0.636	0.563
0°	C_D	.020		.022	.041	.073	.103	.124	.145	.183	.233	.374	.453	.590	.758	.895
0°	C_l'	-.004		-.007	-.008	-.015	-.019	-.026	-.036	-.052	-.069	-.060	-.060	-.036	-.032	-.033
0°	C_n'	.001		.002	.003	.005	.008	.010	.013	.014	.015	.028	.035	.030	.034	.036
0°	δ_{AF}	3.5°		-3°	-12.5°	-19.5°	-25°	-26°	-29°	-32°	-35°	-36°	-44°	-50°	-57°	-59°
		Up-and-down														
±21°	C_l'			.455		.435	.042	.046	.046	.048	.045	.042	.038	.028		
±21°	C_n'			.005		-.005	-.006	-.006	-.004	-.002	-.002	-.001	-.004	-.004		
±21°	δ_{AF}			-29°		-29°	-35°	-38°	-40°	-42°	-45°	-48°	-50°	-56°		

TABLE VI

ROTATION TESTS. WING WITH MULTIPLE TIP FLOATING AILERONS

C_λ is given for forced rotation at $\frac{p'b}{2V} = 0.05$ (+) aiding rotation, (−) damping rotation

R.N. = 609,000 Velocity = 80 m.p.h.

a. Five tips each end of wing

α		0°	10°	14°	16°	18°	20°	21°	22°	23°	24°	25°	26°	30°	40°
Ailerons floating, neutral Yaw = 0°															
(+) Rotation	C_λ	-0.013	-0.017	-0.013	-0.013	-0.004	0.001	0.017	0.009		-0.002			-0.006	-0.006
(−) Rotation	C_λ	-.018	-.020	-.019	-.017	-.012	{-.006, .010	.003	-.002		-.007			-.006	-.007
Ailerons floating, neutral Yaw = -20°															
(+) Rotation	C_λ	-.016	-.032	-.036	-.042	-.052	-.062		-.062	-0.063	-.061		-0.056	-.050	-.036
(−) Rotation	C_λ	-.015	-.004	.002	.007	.017	.034		.055	.055	.055		.052	.038	.023

b. Four tips each end of wing

α		0°	10°	14°	16°	18°	20°	21°	22°	23°	24°	25°	26°	30°	40°
Ailerons floating, neutral Yaw = 0°															
(+) Rotation	C_λ	-0.018	-0.019	-0.021	-0.017	-0.008	0.021	0.029	0.032	0		-.005		-0.007	-0.007
(−) Rotation	C_λ	-.017	-.015	-.012	-.012	-.005	{-.026, .013	.007	{.002, -.036	-.003		-.003		-.004	-.004
Ailerons floating, neutral Yaw = -20°															
(+) Rotation	C_λ	-.022	-.034	-.038	-.045	-.055	-.068		-.069	-.068	-.066	-.063		-.053	-.039
(−) Rotation	C_λ	-.009	0	.007	.011	.022	.036		.060	.060	.059	.059		.043	.029

c. Three tips each end of wing

α		0°	10°	14°	16°	18°	20°	21°	22°	23°	24°	25°	26°	30°	40°
Ailerons floating, neutral Yaw = 0°															
(+) Rotation	C_λ	-0.019	-0.018	-0.016	-0.013	-0.005	0.017	0.014	0.006		-0.007			-0.005	-0.006
(−) Rotation	C_λ	-.020	-.022	-.020	-.017	-.012	{-.008, .006	.004	-.001		-.002			-.007	-.007
Ailerons floating, neutral Yaw = -20°															
(+) Rotation	C_λ	-.022	-.032	-.039	-.045	-.054	-.065		-.068	-0.070	-.068			-.054	-.038
(−) Rotation	C_λ	-.013	-.002	.005	.012	.020	.035		.059	.061	.060			.045	.026

TABLE VII

FORCE TESTS. 5:3 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b
WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 22.5 PER CENT b/2
AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE. FLAPS 0.5° UP
R.N. = 609,000 Velocity = 80 m.p.h. Yaw = 0°

α		-5°	-3°	0°	5°	10°	12°	14°	15°	16°	17°	18°	20°	22°	25°	30°	40°	50°	60°
δ_A up δ_A dn Difference		Ailerons floating, neutral																	
0°	C_L	0.094	0.195	0.244	0.570	0.886	0.991		1.114	1.120	1.075	1.063	0.951	0.876	0.660	0.555	0.643	0.600	0.518
0°	C_D	.020	.019	.021	.043	.075	.092		.117	.131	.149	.166	.193	.220	.333	.401	.556	.712	.848
0°	δ_{AF}	14°	10°	-6°	-10°	-12.5°	-13.5°		-16°	-17°	-17°	-17.5°	-18°	-19°	-22°	-27°	[a]-36°	[a]-42°	[a]-53°
		Up-and-down																	
12°	C_l'			.027		.036	.036	.036		.027		.033	.022	.024	.023	.022	.015		
12°	C_n'			.001		.001	.001	.001		.001		0	-.001	-.003	-.003	-.004	-.005		
12°	δ_{AF}			-7°		-19°	-22°	-24°		-24°		-24°	-24°	-25°	-25°	-34°	-44°		
24°	C_l'			.050		.049	.050	.049		.048		.045 / .053	.043	.044	.044	.039	.028		
24°	C_n'			0		.003	.003	.003		.003		.002	0	-.003	-.005	-.006	-.007		
24°	δ_{AF}			-12°		-25°	-27°	-29°		-31°		-32°	-33°	-34°	-39°	-43°	-52°		
32°	C_l'			.064		.063	.062	.060		.059		.054	.066	.051	.056	.051	.037		
32°	C_n'			-.001		.002	.002	.003		.003		.002	-.001	-.002	-.005	-.006	-.007		
32°	δ_{AF}			-15°		-27°	-30°	-32°		-34°		-36°	-37°	-40°	-42°	-46°	-53°		

[a]Ailerons fluttered slightly

TABLE VIII

FORCE TESTS. 5:3 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b
WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 22.5 PER CENT b/2.
AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE. FLAPS 0.5° UP
R.N. = 609,000 Velocity = 80 m.p.h. Yaw = -20°

α		-5°	-3°	0°	5°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°		
δ_A up δ_A dn Difference		Ailerons floating, neutral																	
0°	C_L	0.053	0.095	0.237	0.512	0.780	0.869	.950	1.005	1.045	1.045	0.790	0.724	0.710	0.650	0.602	0.506		
0°	C_D	.018	.016	.021	.040	.070	.084	.099	.116	.141	.185	.298	.338	.412	.547	.697	.737		
0°	C_l'	.007	.002	.001	-.002	-.004	-.006	-.009	-.016	-.028	-.053	-.058	-.054	-.040	-.017	-.014	-.013		
0°	C_n'	.001	.001	.003	.003	.004	.004	.006	.008	.009	.011	.015	.021	.024	.022	.026	.028		
0°	δ_{AF}	11°	2°	-4°	-9°	-14°	-16°	-17°	-19°	-20°	-22°	-25°	-28°	[a]-34°	[a]-46°	[a]-54°	[a]-60°		
		Up-and-down																	
24°	C_l'			.042		.041	.039	b	b	.034	.041	.030	.037	.017	.014				
24°	C_n'			-.001		0	-.001	b	b	-.001	-.003	0	-.003	-.001	-.004				
24°	δ_{AF}			-11°		-22°	-25°	b	b	-31°	-31°	-32°	-35°	-39°	-48°				
32°	C_l'			.052		b	b	b	b	.048	.049	.034	.035	.023	.016				
32°	C_n'			-.003		b	b	b	b	0	-.003	-.005	-.005	-.003	-.006				
32°	δ_{AF}			-14°		b	b	b	b	-34°	-35°	-36°	-37°	-38°	-48°				

[a]Ailerons fluttered slightly
[b]Ailerons fluttered violently; impossible to read balances.

TABLE IX

ROTATION TESTS. 5:3 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b
WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 22.5 PER CENT b/2
AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE

C_λ is given for forced rotation at $\frac{p'b}{2V} = 0.05$ (+) aiding rotation, (-) damping rotation

R.N. = 609,000 Velocity = 80 m.p.h.

α		0°	12°	14°	15°	16°	17°	18°	19°	20°	21°	22°	23°	25°	30°	35°	40°	
		Ailerons floating, neutral Yaw = 0°																
(+) Rotation	C_λ	-0.021	-0.018		-0.005	0.003	0.009	0.009	0.008	0.031 / .007		0.006	-0.004	-0.011	-0.008		-0.007	
(-) Rotation	C_λ	-0.018	-.016		-.010	-.002	.002	.003	.002	.003		.001	-.004	-.006	-.006		-.005	
		Ailerons floating, neutral Yaw = -20°																
(+) Rotation	C_λ	-.026	-.033	-.036		-.045		-.059	-.066	-.041	-.046		-.058	-.055	-.036	-.032	-.027	
(-) Rotation	C_λ	-.011	-.001	.006		.014		.029	.039	.055	.054		.047	.042	.034	.016	.013	

TABLE X

FORCE TESTS. 5:1 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b
WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 28.33 PER CENT b/2
AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE. FLAPS 0°

R.N. = 609,000 Velocity = 80 m.p.h. Yaw = 0°

	α	-5°	-4°	-3°	0°	5°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°	
δ_A up δ_A dn Difference		Ailerons floating, neutral																	
0°	C_L	-0.018	0.047	0.086	0.238	0.526	0.815	0.925	1.028	1.120	1.183	1.067	0.958	0.723	0.665	0.618	0.584	.502	
0°	C_D	.016	.015	.016	.020	.041	.077	.094	.114	.133	.154	.192	.215	.348	.408	.537	.690	.822	
0°	δ_{AF}	4°	3°	2°	-4°	-9°	-14°	-16°	-18°	-20°	-20°	-22°	-24°	-27°	-33°	-42°	-52°	-62°	
		Up-and-down																	
10°	C_l'				.022		.022	.021	.021	.020	.019	.020	.023 / .015	.029 / .007	.016	.012			
10°	C_n'				.001		0	0	0	0	.001	.001	-.001	-.004	-.003	-.002			
10°	δ_{AF}				-10°		-17°	-18°	-20°	-21°	-23°	-26°	-28°	-31°	-36°	-46°			
20°	C_l'				.040		.039	.039	.038	.037	.035	.036	.032	.031	.034	.034			
20°	C_n'				.003		.002	.002	.002	.002	.002	.001	0	.001	-.002	-.002			
20°	δ_{AF}				-15°		-23°	-25°	-26°	-26°	-29°	-31°	-33°	-37°	-42°	-51°			
28°	C_l'				.054		.053	.053	.049	.048	.047	.051 / .040	.045	.043 / .015	.043	.033			
28°	C_n'				.001		.004	.004	.004	.004	.004	.003	.001	-.003	-.003	-.002			
28°	δ_{AF}				-15°		-28°	-30°	-33°	-35°	-37°	-39°	-39°	-41°	-46°	-55°			

TABLE XI

FORCE TESTS. 5:1 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 28.33 PER CENT b/2 AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE. FLAPS 0°

R.N. = 609,000 Velocity = 80 m.p.h. Yaw = -20°

δ_A up | δ_A dn Difference	α	-5°	-3°	0°	5°	10°	12°	14°	16°	18°	20°	22°	25°	30°	40°	50°	60°
	Ailerons floating, neutral																
0°	C_L	-0.021	0.076	0.214	0.464	0.715	0.819	0.905	0.990	1.066	1.116	1.088	1.048	0.883	0.621	0.566	0.482
0°	C_D	.017	.016	.021	.039	.070	.085	.101	.122	.142	.175	.253	.339	.400	.534	.682	.814
0°	C_l'	-.002	.003	-.006	-.011	-.017	-.019	-.021	-.025	-.028	-.037	-.061	-.064	-.035	-.026	-.023	-.022
0°	C_n'	.002	.002	.002	.002	.004	.005	.006	.008	.010	.010	.004	.011	.018	.019	.022	.025
0°	δ_{AF}	4°	-2°	-3°	-8°	-13°	-15°	-15.5°	-17.5°	-20°	-23°	-26°	-27°	-32°	-44°	-55°	-64°
	Up-and-down																
20°	C_l'			.031		.031	.031	.030	.030	.029	.019	.027	.026	.024	.017		
20°	C_n'			.001		.002	.002	.002	.003	.002	.002	.004	.003	.002	.001		
20°	δ_{AF}			-10°		-21°	-23°	-25°	-27°	-29°	-31°	-35°	-35°	-41°	-49°		
28°	C_l'			.043		.043	.043	.043	a	a	.030	.034	.035	.032	.024		
28°	C_n'			.003		.003	.003	.004	a	a	.003	.006	.002	.002	0		
28°	δ_{AF}			-15°		-26°	-29°	-31°	a	a	-37°	-38°	-39°	-44°	-54°		

[a]Ailerons fluttered violently; impossible to read balances.

TABLE XII

ROTATION TESTS. 5:1 TAPERED WING 10 INCH AVERAGE c BY 60 INCH b WITH CLARK Y MAIN PROFILE AND SYMMETRICAL FLOATING TIP AILERONS 28.33 PER CENT b/2 AXIS 18 PER CENT OF SECTION CHORDS FROM LEADING EDGE. FLAPS 0°

C_λ is given for forced rotation at $\frac{p'b}{2V} = 0.05$ (+) aiding rotation (-) damping rotation

R.N. = 609,000 Velocity = 80 m.p.h.

	α	0°	12°	16°	17°	18°	19°	20°	21°	22°	23°	24°	25°	28°	30°	40°	
Ailerons floating, neutral Yaw = 0°																	
(+) Rotation	C_λ	-0.018	-0.017	-0.004	0.005	0.011	0.027	0.026	0.023		0.019		0.004	0.001	-0.004	-0.008	
(-) Rotation	C_λ	-.014	-.012	-.005	.003	.008	.008	.006	.005		-.003		.005	.005	-.003	-.004	
Ailerons floating, neutral Yaw = -20°																	
(+) Rotation	C_λ	-.018	-.018	-.019	-.020	-.023		-.030	-.036	-.006	-.024	-.001	-.004		-.020	-.011	
(-) Rotation	C_λ	-.011	-.010	-.006	-.003	.006		.019	.025	.032	.039	.004	.004		.006	-.001	

TABLE XIII

HINGE MOMENTS COEFFICIENTS (C_H)
CLARK Y WINGS WITH N.A.C.A. 0010 FLOATING TIP AILERONS

α	0°	10°	20°	30°
δ_{AF}	a. Tip ailerons 100 per cent c by 20 per cent b/2 Flaps 0°. No end plates			
15 per cent axis				
±10°	0.0068	0.0108	0.0096	0.0077
±20°	.0173	.0236	.0250	.0196
20 per cent axis				
±10°	.0036	.0070	.0064	.0054
±20°	.0115	.0189	.0199	.0136
b. Narrow chord tip ailerons. Aileron axis 18 per cent chord from L.E. of aileron and 7.2 per cent chord from L.E. of wing				
± 4°	.0013	.0014	.0020	.0012
± 8°	.0026	.0030	.0031	.0023
±12°	.0030	.0042	.0047	.0036
c. 5:3 Tapered wing. Aileron axis 18 per cent c from L.E.				
± 6°	.0010	.0030	.0043	.0036
±12°	.0036	.0068	.0083	.0072
±16°	.0059	.0099	.0121	.0106
d. 5:1 Tapered wing. Aileron axis 18 per cent c from L.E.				
± 5°	.0014	.0020	.0020	.0014
±10°	.0028	.0037	.0037	.0029
±14°	.0035	.0050	.0061	.0041

TABLE XIV

CRITERIONS SHOWING RELATIVE MERITS OF AILERONS

SUBJECT	CRITERION	Plain ailerons 25 per cent c by 40 per cent b/2 (assumed standard size)	Symmetrical floating tip ailerons 100 per cent c by 20 per cent b/2. Flaps 3° up. No end plates.	Narrow chord symmetrical floating tip ailerons 40 per cent of basic wing chord 33.33 per cent b/2. Flaps 0°. No end plates. Aileron axis 18 per cent of aileron c from leading edge.								Wing with multiple tip floating ailerons			5:3 tapered wing with tapered symmetrical floating tip ailerons 100 per cent c by 22.5 per cent b/2. Flaps 0.5° up. No end plates. 18 per cent axis		5:1 tapered wing with tapered symmetrical floating tip ailerons 100 per cent c by 28.33 per cent b/2. Flaps 0°. No end plates. 18 per cent axis	
				Axis 7.2 per cent of basic wing c from leading edge		Axis 27.2 per cent of basic wing c from leading edge		Axis 47.2 per cent of basic wing c from leading edge		Axis 67.2 per cent of basic wing c from leading edge		5 tips each end of wing	4 tips each end of wing	3 tips each end of wing				
		Standard $\delta = 25°$ up $25°$ dn	Floating 40° difference 15 per cent axis	Floating 16° difference	Floating 24° difference	Floating 18° difference	Floating 24° difference	Floating 18° difference	Floating 24° difference	Floating 19° difference	Floating 24° difference	Floating 48° difference	Floating 60° difference	Floating 42° difference	Floating 30 difference	Floating 32 difference	Floating 21.5 difference	Floating 28 difference
Wing area or minimum speed	$C_{L_{max}}$ ($\delta_A = 0°$)	1.270	1.115	0.987	0.987	1.002	1.002	0.997	0.997	0.994	0.994	1.045	1.069	1.121	1.120	1.120	1.183	1.183
Speed range	$\frac{C_{L_{max}}}{C_{D_{min}}}$ ($\delta_A = 0°$)	79.4	68.0	62.3	62.3	62.2	62.2	61.2	61.2	60.6	60.6	56.1	64.5	64.5	62.2	63.3	77.8	77.8
Rate of climb	L/D at $C_L = 0.70$ ($\delta_A = 0°$)	15.9	13.3	8.7	8.7	8.9	8.9	9.2	9.2	9.5	9.5	11.1	11.8	12.7	12.7	12.7	11.4	11.4
Lateral controllability	RC $\alpha = 0°$	.204	.269	.338	.323	.334	.306	.278	.346	.234	.278	.162	.141	.094	.282	.298	.271	.343
	RC $\alpha = 10°$	.075	.082	.075	.104	.075	.097	.075	.093	.075	.087	.069	.090	.064	.075	.080	.075	.085
	RC $\alpha = 20°$	.038	.063	.053	.074	.065	.072	.063	.066	.065	.063	.061	.048	.049	[a].060 .068	[a].064 .075	.061	[a].062 .066
	RC $\alpha = 30°$	.017	.092	.084	.105	[a].065 .076	.095	[a].075 .077	.092	[a].071 .077	[a].090 .083	.100	.106	.061	.077	.081	.072	.081
Lateral control with sideslip	Maximum α at which ailerons will balance C_l' due to 20° yaw	20°	20°	19°	21°	18°	20°	18°	20°	18°	19°	23°	21°	20°	20°	20°	18°	20°
Yawing moments due to ailerons (+) favorable (–) unfavorable	C_n' $\alpha = 0°$	– −.007	–	–	.001 –	.008 –	[b].002	.008 –	.001 [b].002	–	–	.003 –	.006 –	.005 –	[c].001 –	[c].001 −.001	.003 –	[d].001 .003
	C_n' $\alpha = 10°$	– −.004	.004 –	.009 –	.012 –	.008 –	.012 –	.010 –	.013 –	.009 –	.010 –	[e].018 –	.014 –	[g].008 –	.013 –	.013 –	.009 –	.013 –
	C_n' $\alpha = 20°$	– −.010	.027 –	.016 –	.022 –	.017 –	.022 –	.017 –	.031 –	.017 –	.019 –	.032 –	[f].030 –	.019 –	.030 –	.022 –	.014 –	[a].016 .020
	C_n' $\alpha = 30°$	– −.008	.027 –	.030 –	.026 –	[a].019 .021	.026 –	[a].021 .023	.026 –	[a].019 .021	[a].022 .023	.034 –	[f].036 –	[g].022 –	.019 –	.020 –	.015 –	.019 –
Lateral stability ($\delta_A = 0°$)	α for initial instability in rolling	18°	19°	22°	22°	[h]19°	[h]19°	[i]19°	[i]19°	21°	21°	20°	19°	20°	17°	17°	17°	17°
	α for initial instability at p'b/2V = 0.05, Yaw = 0°	17°	18°	23°	22°	21°	21°	20°	20°	21°	21°	20°	19°	19°	16°	16°	18°	16°
	α for initial instability at p'b/2V = 0.05, Yaw = 20°	10°	10°	15°	15°	16°	16°	14°	14°	12°	12°	13°	10°	11°	12°	12°	17°	17°
	Maximum unstable C_λ at p'b/2V = 0.05, Yaw = 0°	.048	.018	.010	.010	.010	.010	.010	.010	.012	.012	.017	.032	.017	.010	.010	.027	.027
	Maximum unstable C_λ at p'b/2V = 0.05, Yaw = 20°	.093	.062	.068	.038	.037	.037	.042	.042	.043	.043	.065	.060	.061	.055	.055	.059	.039
Controllability / Control force required	CF $\alpha = 0°$	.017	[j].058	.003	.008										.013	.016	.005	.008
	CF $\alpha = 10°$	.008	[j].022	.001	.003										.008	.007	.002	.003
	CF $\alpha = 20°$	.008	[j].019	.001	.002										.007	.009	.002	.003
	CF $\alpha = 30°$	.007	[j].094	.001	.003										.009	.010	.002	.003

[a]Unsymmetrical stalling of the wing made it possible to obtain two balance readings. The lower is used in the discussion.

[b,c,d,e,f,g]Where the maximum yawing moment occurred below maximum deflection the letters indicate the deflection of the up aileron as follows: b = 8°, c = 8°, d = 10°, e = 16°, f = 20°, g = 14°

[h]Rotation in positive direction only at $\alpha = 19°$. No rotation in either direction at $\alpha = 20°$ to 22°. Rotation self-starting in both directions at $\alpha = 23°$.

[i]Rotation in positive direction only at $\alpha = 19°$. No rotation in either direction at $\alpha = 20°$. Rotation self-starting in both directions at $\alpha = 21°$.

[j]These values of CF are for ailerons with flaps 0° but it is believed that flaps deflected will not appreciably affect the hinge moments.

Note. x indicates axis locations.

a, 0.9"
b, 3.4"

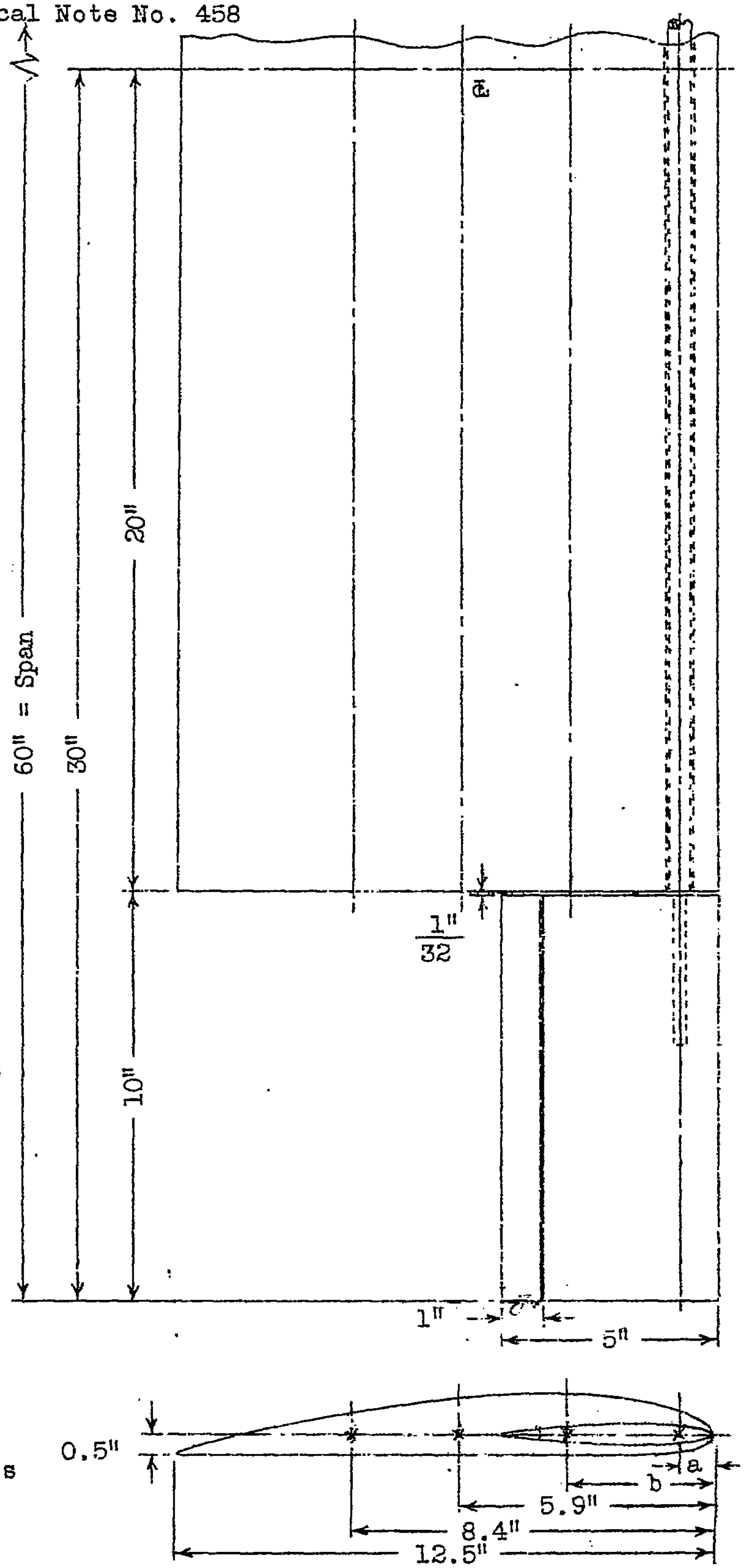
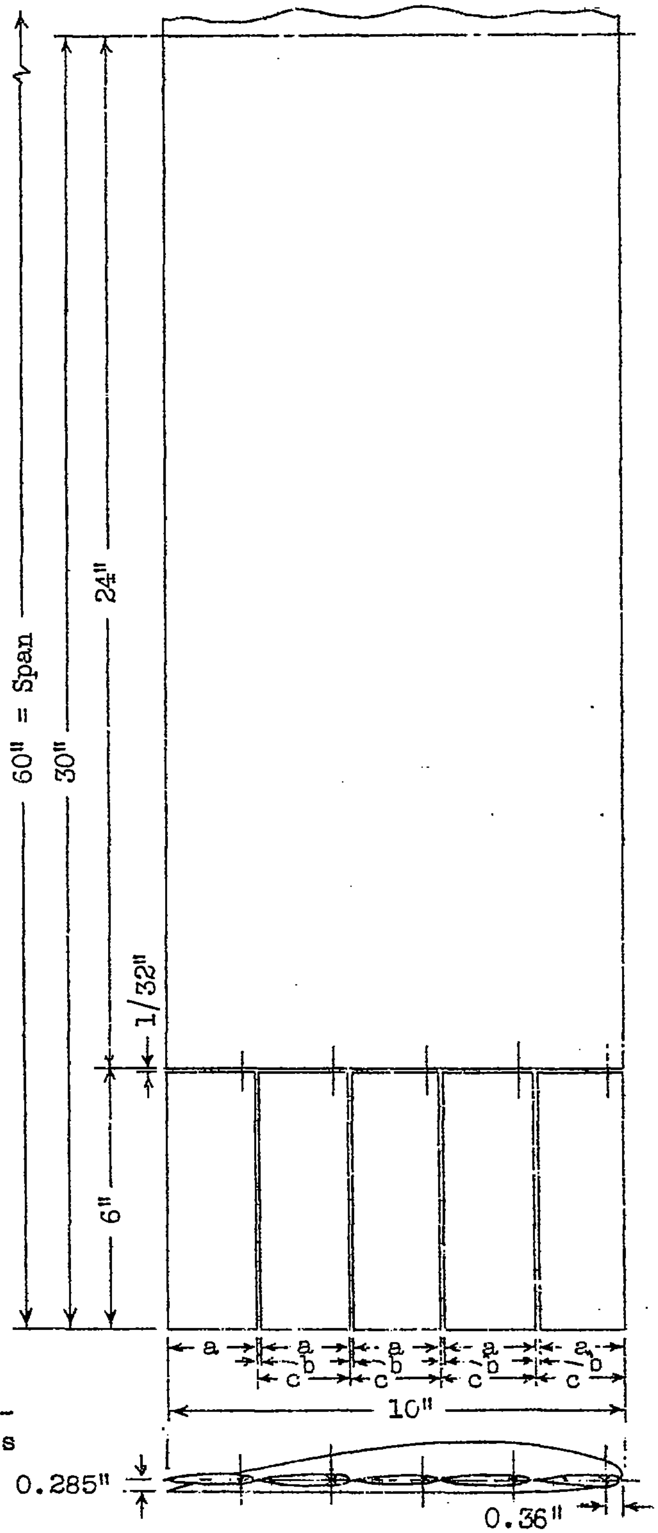


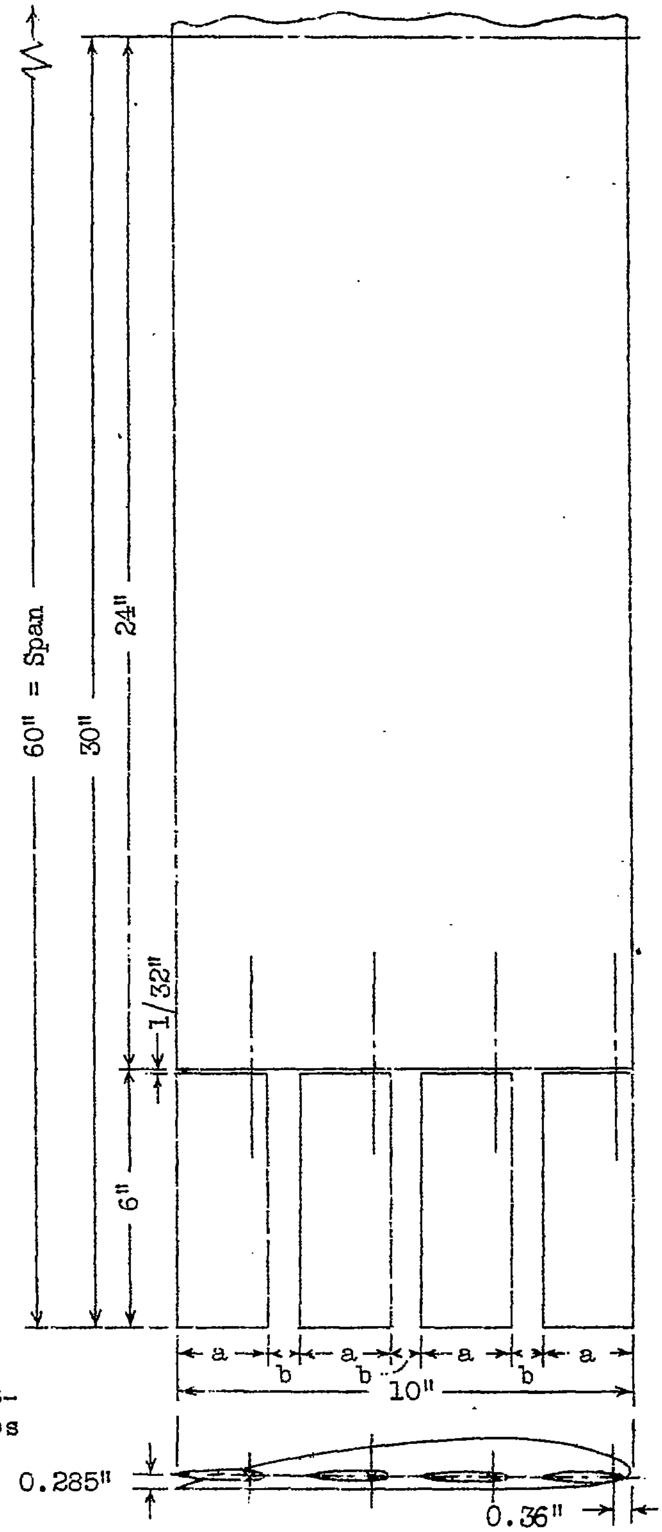
Figure 1. Narrow-chord floating tip ailerons - four axis locations.



Note. x indicates aileron axis locations.

a, 1.990"
b, .010"
c, 2"

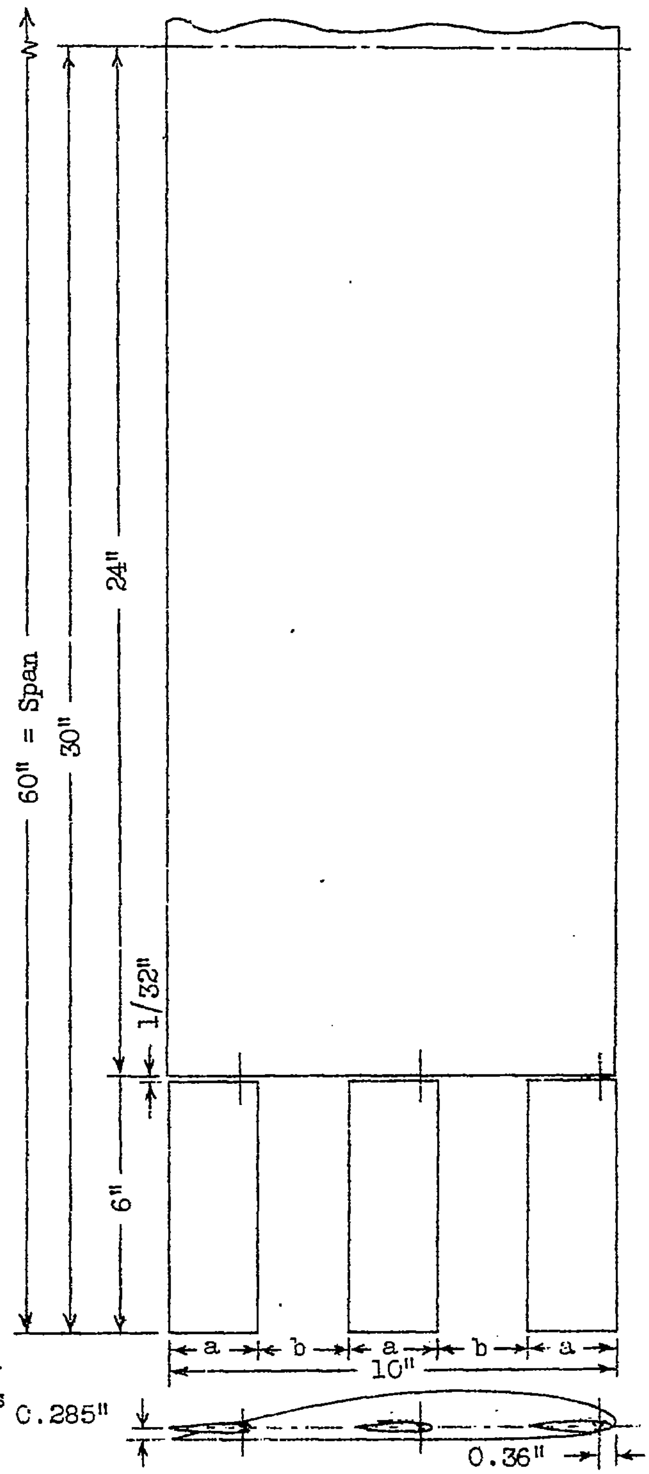
Figure 2. Multiple tip floating ailerons. 5 tips each end.



Note. x indicates aileron axis locations.

a, 1.99"
b, C.671"

Figure 3. Multiple tip floating ailerons. 4 tips each end.



Note. x indicates aileron axis locations.

a, 1.990"
b, 2.015"

Figure 4. Multiple tip floating ailerons. 3 tips each end.

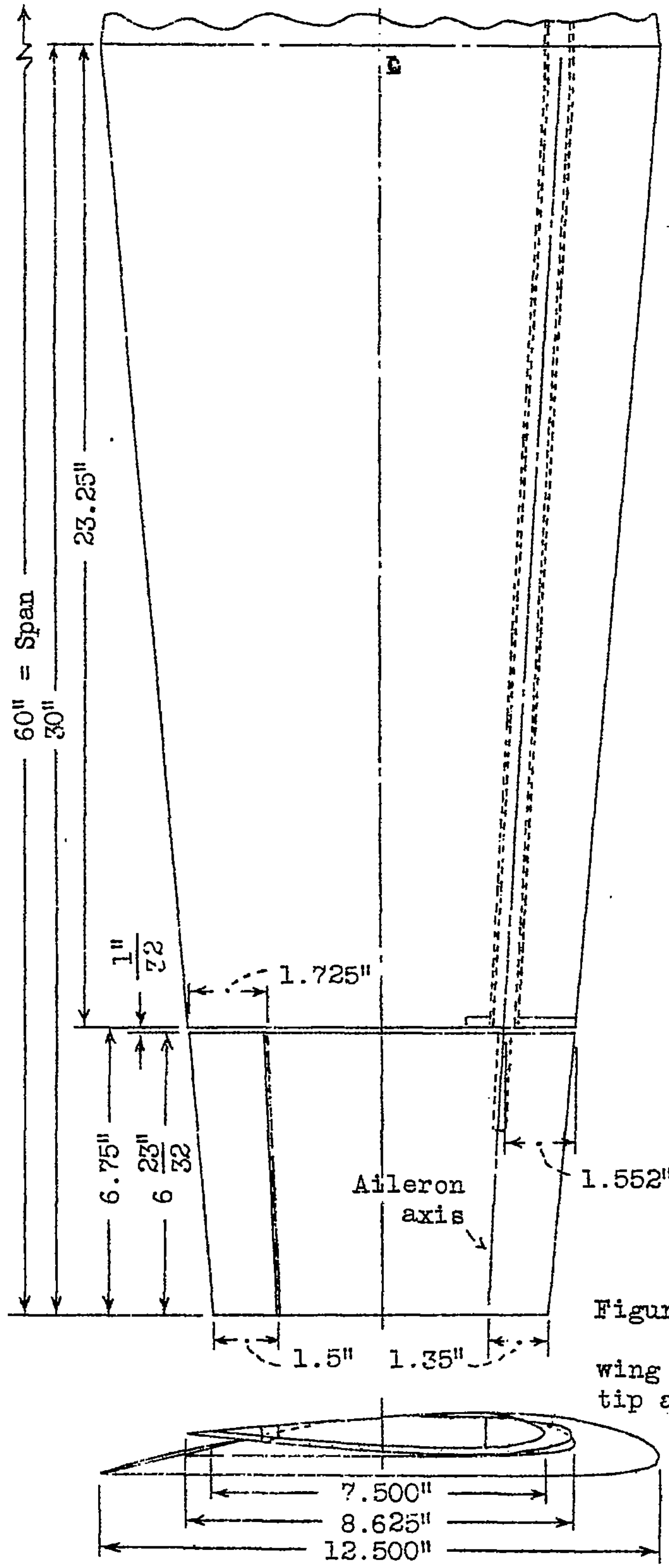


Figure 5. The 5:3 tapered wing with floating tip ailerons.

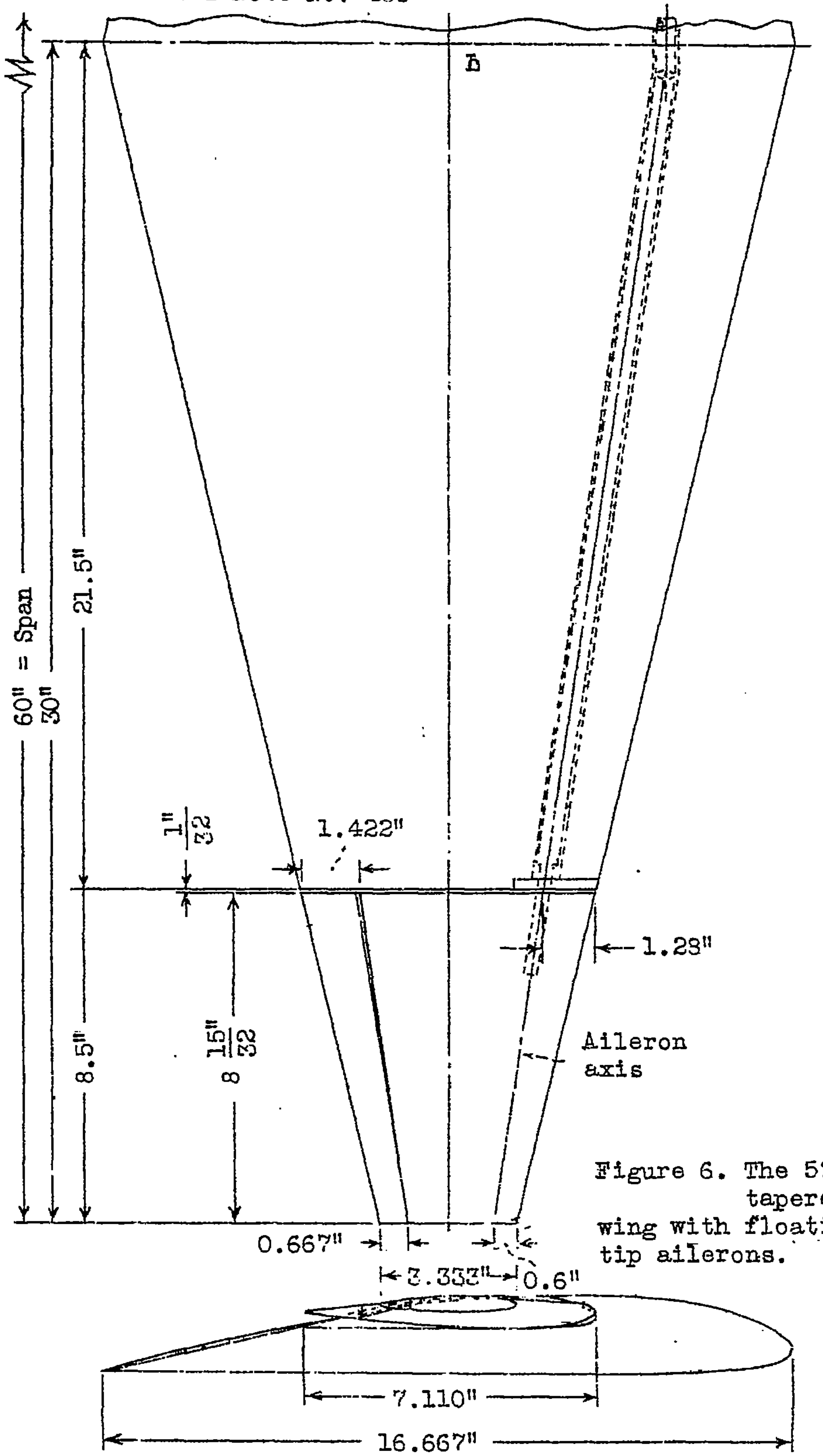


Figure 6. The 5:1 tapered wing with floating tip ailerons.

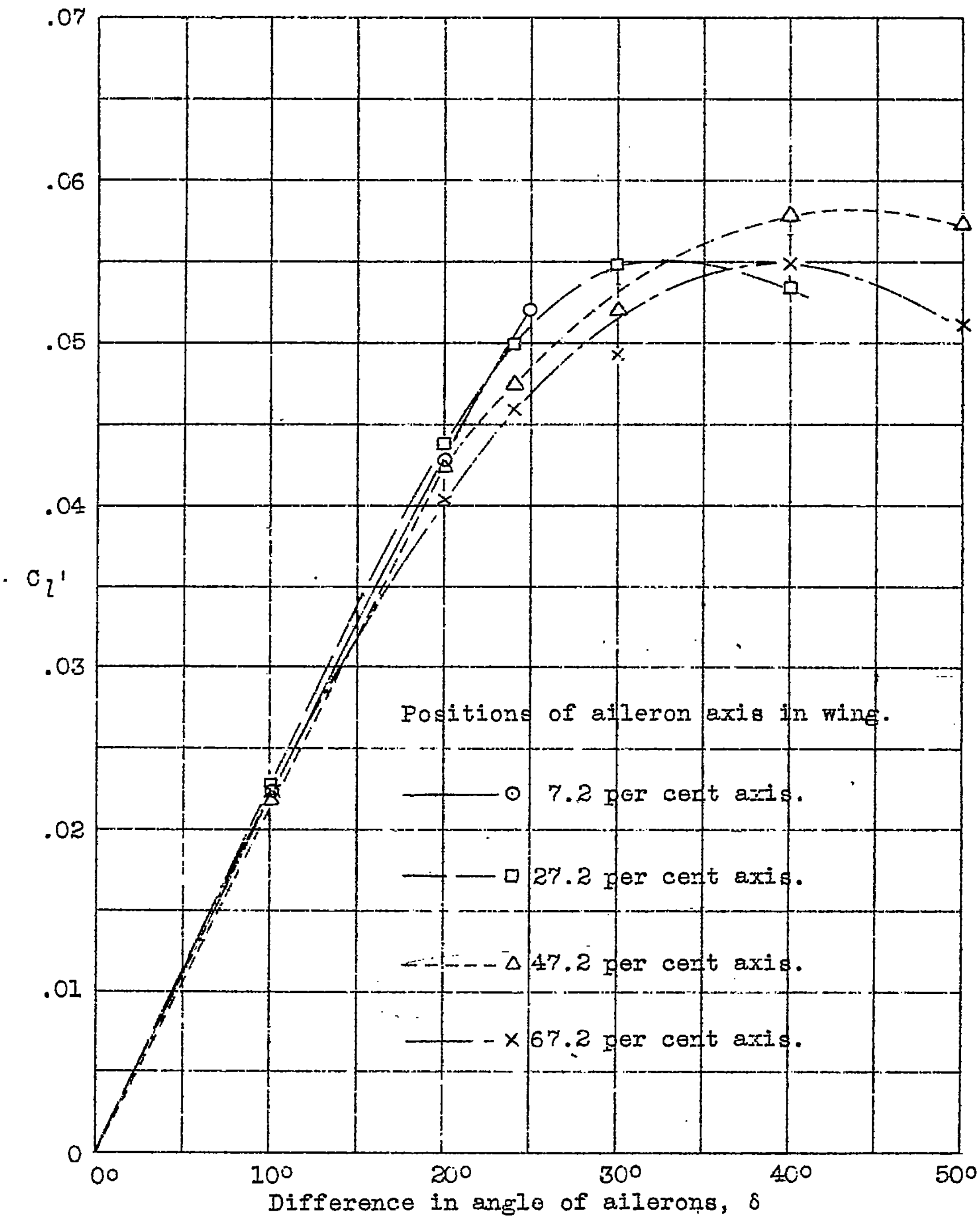


Figure 7. Variation of rolling moment coefficient with aileron deflection for the narrow-chord tip ailerons, $\alpha = 10^{\circ}$

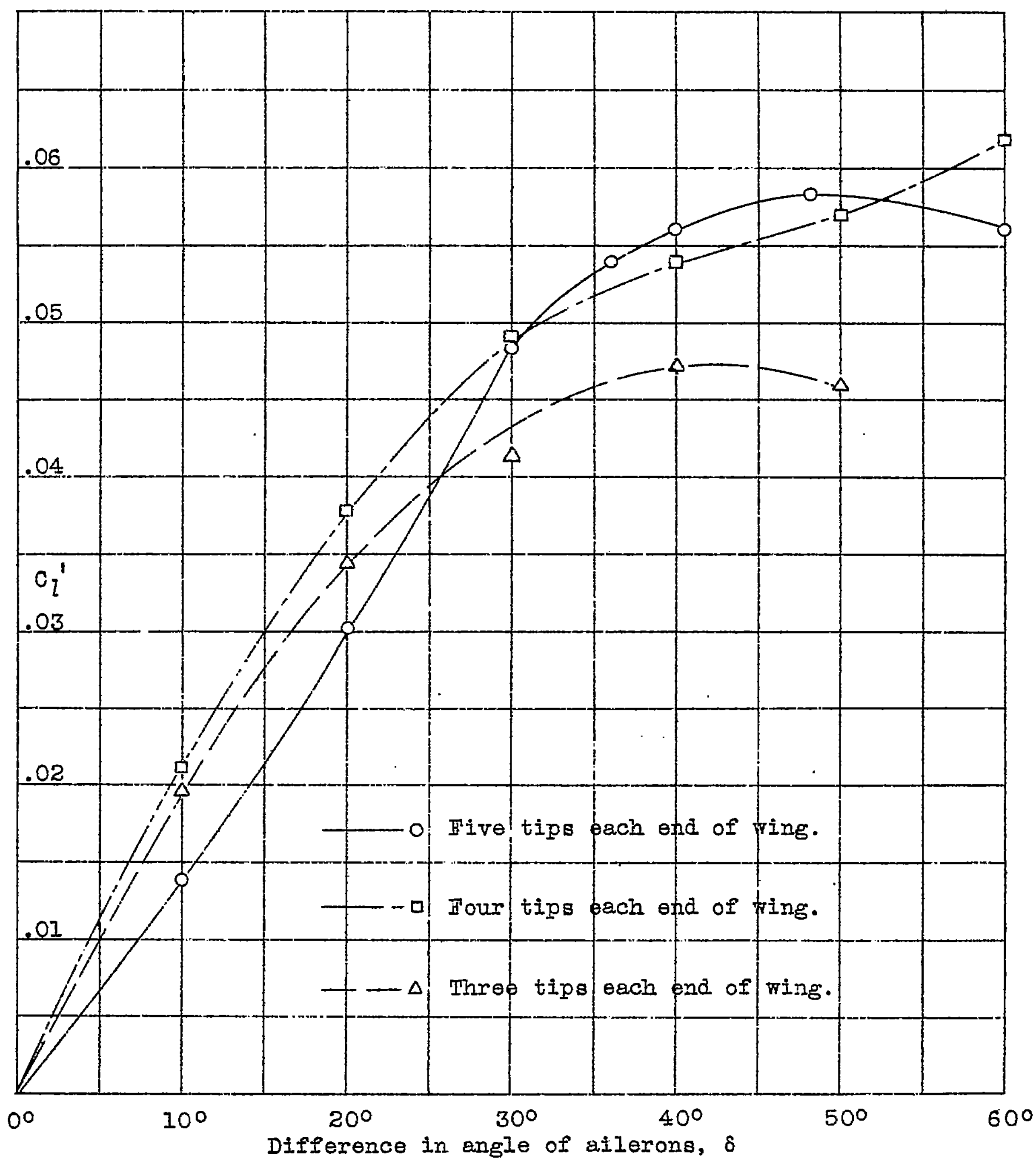


Figure 8. Variation of rolling moment coefficient with aileron deflection for the multiple tip ailerons, $\alpha = 10°$

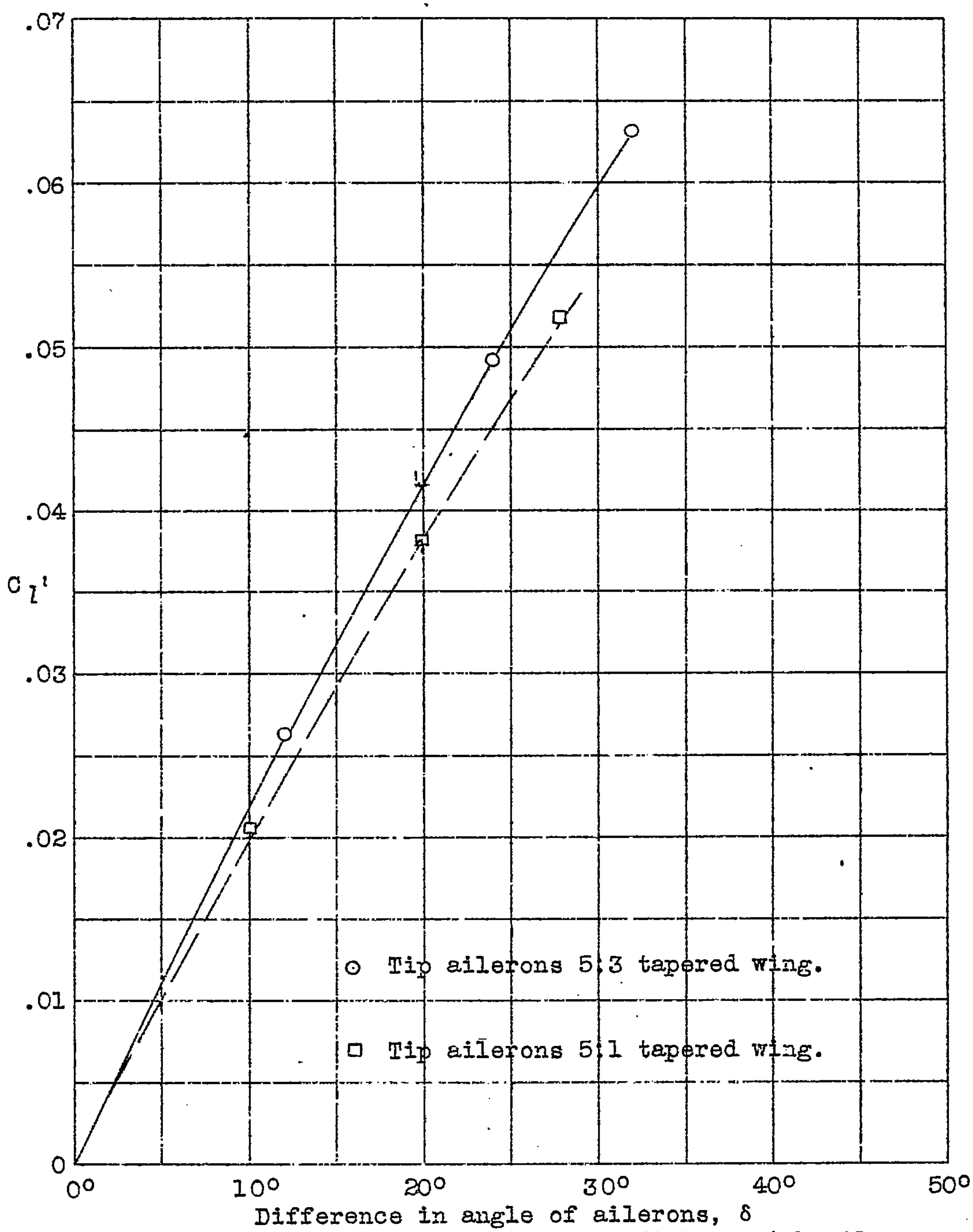


Figure 9. Variation of rolling moment coefficient with aileron deflection for the tip ailerons on the tapered wings, $\alpha = 10°$