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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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A FLIGHT INVESTIGATION OF THE REDUCTION OF AILERON OPERATING FORCE BY MEANS OF FIXED TABS AND DIFFERENTIAL LINKAGE, WITH NOTES ON LINKAGE DESIGN

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SUMMARY

Flight tests were made to demonstrate the practicability of employing fixed tabs in conjunction with a suitably designed differential linkage to reduce the force required to operate ailerons. The tests showed the system to be practicable with tabs of the inset type. The relative ineffectiveness of attached tabs for changing the aileron floating angle rendered them unsuitable. Experience gained in the investigation has indicated that the use of the system is limited to maximum deflections of one aileron relative to the other of less than 30° and that the differential linkage should always be designed on the basis of the highest probable floating angle.

INTRODUCTION

Experience with drooped ailerons has drawn attention to the marked effect upon the stick force that the differential linkage of the ailerons may exert. When such ailerons are adjusted to the high-lift position, the upward-moving aileron may have a fairly large hinge moment tending to rotate it upward throughout its range of deflection. Under certain conditions this assisting hinge moment, together with the relatively large mechanical advantage of this aileron with respect to the control stick as compared with that of the downward-moving aileron, may overbalance the effort on the stick required to rotate the downward-moving aileron downward, resulting in a reversal of the stick force.

Jones and Nerken (reference 1) suggested a method, for the case of the ordinary undrooped ailerons, of utilizing these characteristics of the differential linkage for the purpose of reducing the stick forces required for their operation. It was suggested that the ailerons be fitted with narrow-chord full-span tabs deflected downward several degrees so as to adjust upward the position for zero hinge moment (floating angle). The results of flight tests to determine the feasibility of this method of reducing aileron forces form the subject of the present paper.

The tests were made with a Fairchild 22 airplane. In the first series of tests, tabs were attached to the ailerons of a wing having a 2:1 taper. Difficulty experienced in obtaining satisfactory results with the attached tabs resulted in the second series of tests, which covered trials of inset tabs. The second series of tests was made with the standard wing for the Fairchild 22 with the ailerons modified to incorporate inset tabs. Three arrangements of the differential linkage were tried with these ailerons. The flight tests consisted primarily of pilots' observations of the relative control forces with the different arrangements. Measurements of the rolling motion were made with one linkage to determine the effect of tab setting on the aileron effectiveness.

AILERON AND TAB ARRANGEMENTS

The Fairchild 22 airplane used for the investigation is a small, high-wing, parasol monoplane that has been used by the Committee for the general investigation of lateral control and stability. The wing with which the airplane was equipped for the first series of tests is tapered 2:1 in plan form and thickness and is swept back so as to have a straight trailing edge. The airfoil section varies from an N.A.C.A. 2218 section at the wing root to an N.A.C.A. 2209 section at a station 15 feet from the root.

For lateral control, the wing is equipped with ailerons having a constant 12-inch chord, each aileron extending over approximately 80 percent of the wing semispan. The aileron mechanism has a nominal 2:1 differential and was used without modification in the present investigation. Data on the aileron deflections and the control-stick movement are shown in figures 1, 2, and 3. The significance of the broken line in figure 2 will be discussed later. The total deflection with these ailerons is somewhat greater than is conventional for the Fairchild 22 and, consequently, the aileron forces are greater. It was appreciated that the linkage would not fulfill the conditions required in order that the stick force be zero; but calculations indicated that, if the assumptions of reference 1 were correct, the stick force would be reduced to approximately one-half its original value for floating angles such as reference 2 had shown could be obtained.

The attached tabs used on the ailerons consisted of flat sheets of metal attached to the upper surface of the ailerons by self-tapping screws. (See fig. 4.) Two arrangements of the tabs were tried. The first set, which was considered the logical installation for the particular airplane used, extended along practically the entire straight portion of the aileron trailing edge (12 feet) and projected 1 inch back of the trailing edge of the ailerons, making the tab chord approximately 8 percent of the aileron chord. The second set of tabs had twice the chord of the first set but extended over only the outboard half of the aileron. This set of tabs was tried because it was thought that the effects of sideslip and rolling, which had not been treated in reference 1, would be more pronounced on tabs concentrated near the wing tip where ailerons are more usually located than in the position occupied by those on the Fairchild 22 airplane.

After the failure to obtain satisfactory results with the attached tabs and after some subsequent wind-tunnel tests to compare the action of attached tabs with that of inset tabs, tests were made with tabs of the inset type. The tapered wing not being well adapted to the installation of inset tabs, the tests were carried out with a standard Fairchild 22 wing. This wing had the same area and span as the tapered wing but was rectangular in plan form with semicircular tips. The ailerons on this wing had the same plan form as those for the tapered wing. (See fig. 5.)

The installation of the inset tabs required some modification of the wing. In order to avoid a major structural change, which would have been necessary to maintain the same chord, the installation for the tab was made by slightly thickening the aileron, particularly at the trailing edge, adding a tab conforming to the section, and building out the aileron to form a smooth plan form. This modification resulted in an aileron of slightly greater chord than the original one but provided the principal features of the inset type of tab. This tab (fig. 5) had a span of 10 feet 6-3/16 inches and a chord of 1-1/8 inches. The tab hinge consisted of a series of metal strips. After each adjustment of the tabs, the V-gaps at the hinge were faired over with fabric. The aileron hinges were sealed with fabric to prevent any air flow through them.

During the trial of the inset tabs, three differential linkages were investigated. The first linkage used was the standard one for the wing; it was used primarily for reference but showed the incidental improvement possible with tabs alone. The second linkage had extreme differential and was tried because it would show the greatest variation with floating angle, if any appreciable discrepancy remained between the flight and the wind-tunnel conditions such as had been experienced with the attached tabs. The third arrangement of the mechanism was obtained by trial and error and represented an attempt to obtain the optimum conditions. The deflections of the ailerons for the modified linkages are given in figures 6 to 11. The broken lines in figures 7 and 10 will be discussed later.

TESTS

The tests consisted primarily of observations by two pilots of the relative aileron force for the different linkage and tab arrangements. To obtain these observations, the pilots performed a series of what they considered representative maneuvers; the exact nature of the tests was left to their discretion. In particular, they observed the effects of sideslip and the forces required for small control deflections, where the differential mechanism has the least effect.

In order to determine the effect of tab setting on the aileron effectiveness, tests in which the rolling motion of the airplane was measured were made with the inset tabs and the standard mechanism for the Fairchild 22. These measurements were made in accordance with the usual practice regarding aileron effectiveness. (See reference 3.) The measurements consisted of recording the angular motion of the airplane following abrupt right-aileron movements at various speeds throughout the speed range with the tabs set in neutral, down 10°, and down 20°.

An attempt was made to obtain a record of the control forces required for different conditions with a control-force recorder supplemented by air-speed and control-position recorders. The correlation between the recorded forces and those estimated by the pilots was satisfactory in the case of the first series of tests and also for the original mechanism used in the second series, the forces being relatively large in both cases; but the correlation was unsatisfactory in the later tests, in which the forces were small. The very light forces required to overcome the aileron hinge moments were masked by the effect of the mass of the control-force recorder, and it was removed for the later tests.

RESULTS AND DISCUSSION

The results of the investigation with the attached tabs on the tapered wing were entirely negative. The control forces were not noticeably affected by any angular setting of either set of tabs up to 30°. Inasmuch as the flight tests had failed to confirm the prediction of decreased stick forces made in reference 1, it was believed advisable to subject the tabs to further wind-tunnel tests. In order to eliminate the possibility of an adverse scale effect that might have been present in the tests of reference 2, tests were made at large scale in the N.A.C.A. 7- by 10-foot wind tunnel. A model was constructed to obtain conditions similar to those tested in the first phase of the flight investigation. These tests showed, when compared with those of reference 2, the occurrence of some adverse scale effect, but the difference in the results was insufficient to account for the results of the flight tests. A large difference, however, was found to exist between the attached and the inset tabs, which indicated that the difficulty encountered in the flight tests was probably due to the use of attached tabs. The attached tabs were found to have little effect upon the aileron floating angle.

As a result of the first series of flight tests and the subsequent wind-tunnel tests, it was seen that high stick forces on the ailerons of existing airplanes could not readily be relieved merely by attaching simple flat-plate tabs to the trailing edge of existing ailerons. It was evident that effective reductions could be obtained only by modifying the ailerons so as to include tabs of the inset type.

The flight tests involving the use of inset tabs indicated the practicability of their use with a suitably designed differential mechanism. With the original linkage for the Fairchild 22, a reduction of aileron forces of the order of one-third was obtained with a 20° tab deflection as compared with the forces obtained with the tab neutral. The control had a reasonable "feel" and no noticeable peculiarities in the aileron action were observed in sideslip. The second linkage, which gave extreme differential, gave a variation in the control force that was not linear even with zero tab deflection, the force increasing more rapidly at large than at small stick deflections. The irregularity of the stick-force variation increased with tab deflection. With tab settings between 5° and 10° down, the aileron force became zero at small deflections but was only slightly reduced at large deflections.

With the final linkage, the stick-force variation was nearly linear with all tab settings. The force, however, was reduced by setting the tabs down. With the tab in neutral the stick force was of the order of 10 or 12 pounds but, with a 20° tab setting, the force for small deflections was less than the friction in the control system, so that the control would stay where placed for about one-quarter of the total travel. The most satisfactory conditions were obtained with the tab set at 15°. With this setting the magnitude of the forces was so small as to make estimation difficult. The forces were, at most, one-quarter of those for the original linkage with the tab set at zero. Despite these low forces, the control stick definitely tended to return to neutral.

The measurements of the rolling velocities, the data for which for the first linkage are given in figure 12, show that the tab setting has only a small effect on the rolling control. The measured differences in the maximum rolling velocities are almost within the precision of the measurements.

The results obtained in the second series of tests show that tabs of the inset type offer a practical method of controlling the floating angle of an aileron used with differential mechanism for reducing aileron control forces and that the tab has very little influence on the effectiveness of the ailerons. Experience with the second linkage, however, showed that reasonable care must be exercised in choosing a suitable differential mechanism.

LINKAGE DESIGN CONSIDERATIONS

The experience in the design of differential mechanisms gained during the investigation has indicated some general principles that should be appreciated before a design is attempted. These principles will be briefly outlined.

As has been shown in reference 1, the condition necessary in order that the work done in deflecting the ailerons, and consequently the control-stick force, be zero at every point may be expressed in terms of the upward deflection δ_u and the downward deflection δ_d of the two ailerons, and the upfloating angle δ_{uf} (angle for zero hinge moment), all taken as positive numbers, by the equation

$$\delta_d = \sqrt{(\delta_{uf} + \delta_u)^2 - 2\,\delta_u^2} - \delta_{uf} \qquad (1)$$

which may be written in the form

$$(\delta_u - \delta_{uf})^2 + (\delta_d + \delta_{uf})^2 - 2\delta_{uf}^2 = 0 \qquad (2)$$

This expression is the equation in δ_u and δ_d of a circle of radius $\sqrt{2}\ \delta_{uf}$ passing through the origin and with the center at the point $(\delta_{uf}, -\delta_{uf})$. The limit of this equation is reached when $d\delta_d/d\delta_u = -1$, at which point the down aileron has returned to zero and is moving upward at the same rate as the upgoing aileron. Inasmuch as the aileron control is proportional to the sum of the upward and downward deflections of the two ailerons, this limit represents the condition of maximum control. When this condition is reached

$$\delta_u + \delta_d = 2\ \delta_{uf} \qquad (3)$$

As the maximum upfloating angle of an aileron, even when equipped with inset tabs, is of the order of 20°, it follows that the maximum value of the sum of the upward and downward deflections of the two ailerons is limited to 40°.

From practical consideration, however, the maximum value of the sum of these deflections is appreciably less than the 40° indicated by the foregoing equations. For example, in order to meet the further condition that the rolling moment be proportional to the stick deflection, the sum of the upward and downward deflections of the two ailerons must also be proportional to the stick deflection. It can be shown that, in order to meet this requirement, the mechanical advantage of the ailerons over the control stick must be infinity when $d\delta_d/d\delta_u = -1$. Unless the design floating angle is attained, the control force will therefore be infinite at this point. As the aileron floating angle varies with angle of attack, the design floating angle can be attained at only one angle of attack and consequently, at all other angles, the stick force at full deflection will be infinite for an aileron system so designed. In addition to this consideration, when $d\delta_d/d\delta_u = -1$, δ_d is zero and δ_u is 40°; but the straight-line variations of aileron hinge moment with aileron deflection, assumed in reference 2, do not hold for aileron angles much greater than 20°. Both of these considerations lead to a practical limitation of δ_u to less than 20°. The sum of the upward and downward deflections of the two ailerons, if δ_u is limited to 20° and a maximum probable floating angle of 20° is assumed, will be 28.3°.

The attainment of zero stick force is, of course, not practicable or desirable. A more general work equation may be written for the case of a finite stick force by imposing the condition that the force be directly proportional to the stick deflection θ; that is,

$$\text{Stick force} = K\theta \tag{4}$$

where K is a constant depending on the particular design. It follows that the work done in deflecting the ailerons is then proportional to the square of the stick deflection, and a general expression for aileron deflection becomes

$$(\delta_u - \delta_{uf})^2 + (\delta_d + \delta_{uf})^2 - 2\delta_{uf}^2 = K\theta^2 \tag{5}$$

From the condition that the aileron effectiveness also be proportional to the stick deflection, the equation

$$\delta_u + \delta_d = C\theta \tag{6}$$

where C is a constant, is obtained. The angle θ may, therefore, be eliminated from (5), giving the expression

$$(\delta_u - \delta_{uf})^2 + (\delta_d + \delta_{uf})^2 - 2\delta_{uf}{}^2 = \frac{K}{C^2}(\delta_u + \delta_d)^2 \tag{7}$$

On the basis of equation (7), figure 13 has been prepared to show the differential ranges required for several floating angles to meet the conditions that both the stick force and the aileron effectiveness vary linearly with stick deflection. The sum of the aileron deflections $(\delta_u + \delta_d)$ at the maximum up-aileron deflection is the same (28.3°) for all the curves and is the value that corresponds to a maximum up-aileron deflection of 20°. The floating angle taken for zero stick force is 20°, which is considered the largest practicable value, and the corresponding differential motion is indicated by the solid curve. The dotted curves, which refer to the condition of finite stick force, show the differential arrangements that would be required for linear variation of stick force and aileron effectiveness with stick deflection for floating angles of 15°, 10°, and 5°. It will be noted from this figure that the curve for zero force with a floating angle of 20° reasonably well approximates those for linear force variation with floating angles of 15° and 10°.

Figure 14 has been prepared on the same basis as figure 13, with the exception that the zero-force curve was computed for a floating angle of 15° rather than 20°, that is, for a case requiring a more extreme differential movement than that of figure 13. From a comparison of the two figures, it will be seen that the 10° curve in figure 13 more closely approximates the zero-force curve than does the 10° curve in figure 14. Another point illustrated in figure 14 is that there is a minimum value of the floating angle below which it would be impossible to design a differential linkage to give maximum aileron effectiveness (maximum value of $\delta_u + \delta_d$) at maximum up-aileron displacement. This fact is shown by the curve giving the sum of δ_u and δ_d for the floating angle of 7.5°, which is plotted against δ_u in the figure. The curve reaches a maximum value approximately 1.5° before the maximum up-aileron deflection is reached.

Figure 15, which shows the variation of stick force with $\delta_u + \delta_d$, further illustrates the advantage of basing the differential design upon a relatively large floating angle. The curves were obtained by graphical differentiation of work curves given by equation (7). For each of the cases illustrated, it is assumed, for purposes of comparison and for a particular flight condition, that zero hinge moment corresponds to a floating angle of 10°. For the design based on zero force for a 20° floating angle, even when the floating angle attained is only 10°, the variation of stick force with aileron effectiveness is much more nearly linear than for the case of the differential based on zero force for a floating angle of 15°. It will also be noted that, in the case of $\delta_{uf} = 15°$, although the deviation of the actual from the design floating angle is only half as great as for $\delta_{uf} = 20°$, the stick force at full deflection is much greater. The general characteristic desired in a lateral-control system is that the stick force be small but finite and that it vary linearly with deflection and, since the floating angle is not constant but varies with the angle of attack of the wing section, it is obvious that the design should be based on the larger floating angle.

In view of the facts illustrated by figures 13, 14, and 15, it is believed that, for practical purposes, it would be satisfactory to design aileron mechanisms on the basis of the zero-force curves, using the largest floating angle likely to be attained. This conclusion suggests that a graphical method may be used to investigate proposed differential mechanisms in order to check the variation of control effectiveness with stick deflection. A plot of the sum of the upward and downward deflections of the two ailerons against stick deflection should be made as in figures 3, 8, and 11. The deflection of the up aileron should next be plotted against that of the down aileron as in figures 2, 7, and 10. With the first type of figure, the approach to proportionality of the control effectiveness with deflection will be shown by the approach of the curve to linearity. In the second curve, a line should be drawn through the origin with a slope of -1. With this line as the locus of centers, the largest circle passing through the origin that will not pass beyond the curve of aileron deflections should be drawn. For illustration, this construction has been made for the differential linkages shown in figures 2, 7, and 10, as indicated by the dotted curves. The abscissa of the center is the floating angle, and the circle is the curve for zero work (equation (2)) and zero stick force. When the differential is too extreme, a small-radius circle, as shown in figure 7, will be obtained. In any case, inspection will show how great are the variations from the desired condition and will indicate the necessary modifications.

CONCLUSIONS

1. Tabs of the inset type offer a practicable means of changing the floating angles of ailerons as required by the differential linkages employed for the reduction of the aileron operating force. Such tabs will not appreciably influence the aileron effectiveness.

2. Because of their widely different characteristics, attached tabs consisting of simple flat plates cannot be substituted for inset tabs for the purpose of reducing the stick forces by varying the floating angles.

3. The combined use of differential linkage and inset tabs for the reduction of aileron operating forces is limited by practical considerations to aileron systems for which the sum of the upward and downward deflections of the two ailerons is less than 30°.

4. In order to obtain the most nearly linear variations of stick force with deflection at all speeds, the differential linkage should be designed upon the basis of the maximum probable floating angle.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 12, 1938.

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2. Harris, Thomas A.: Reduction of Hinge Moments of Airplane Control Surfaces by Tabs. T.R. No. 528, N.A.C.A., 1935.

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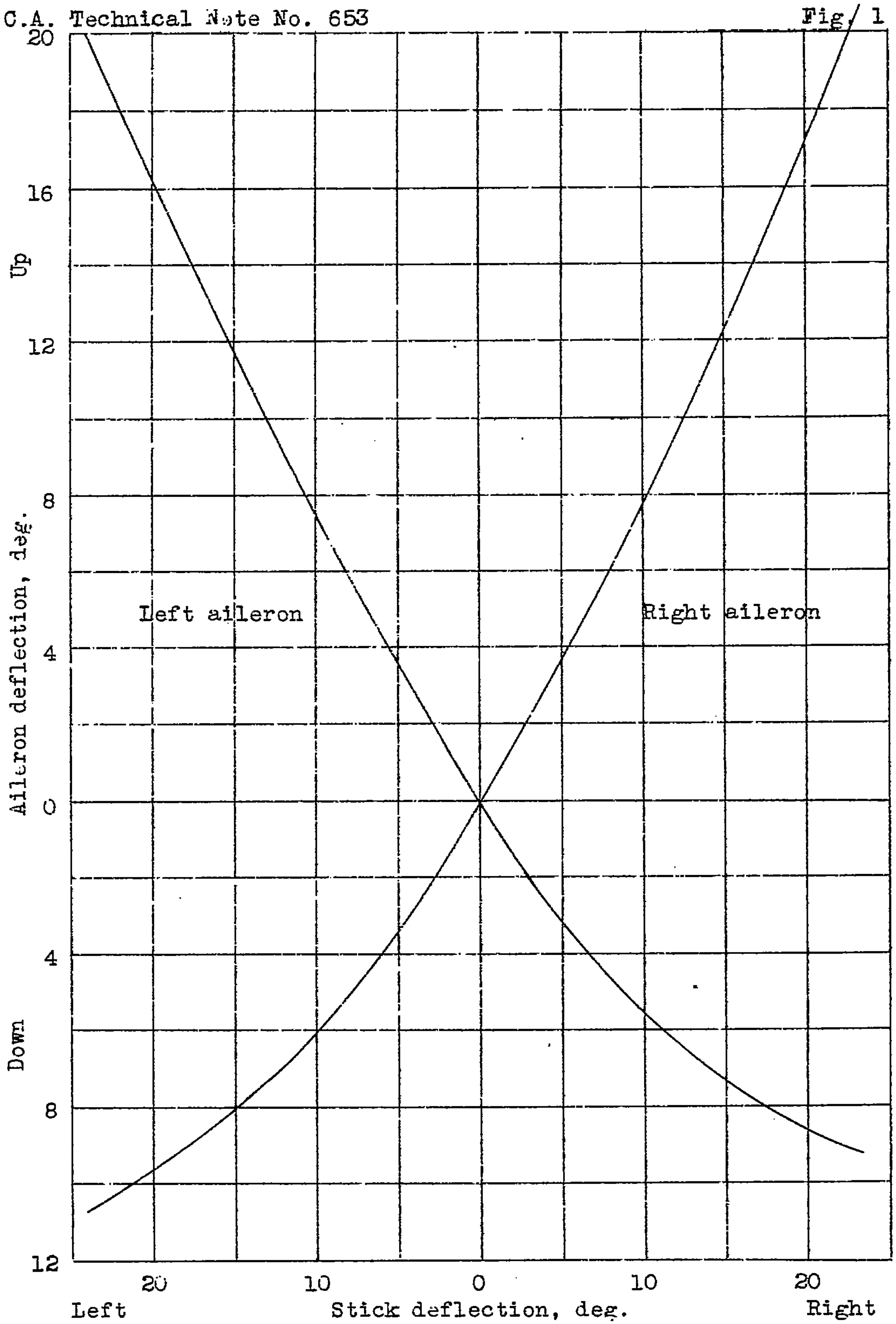

Figure 1.- Relation between deflection of control stick and ailerons on tapered wing.

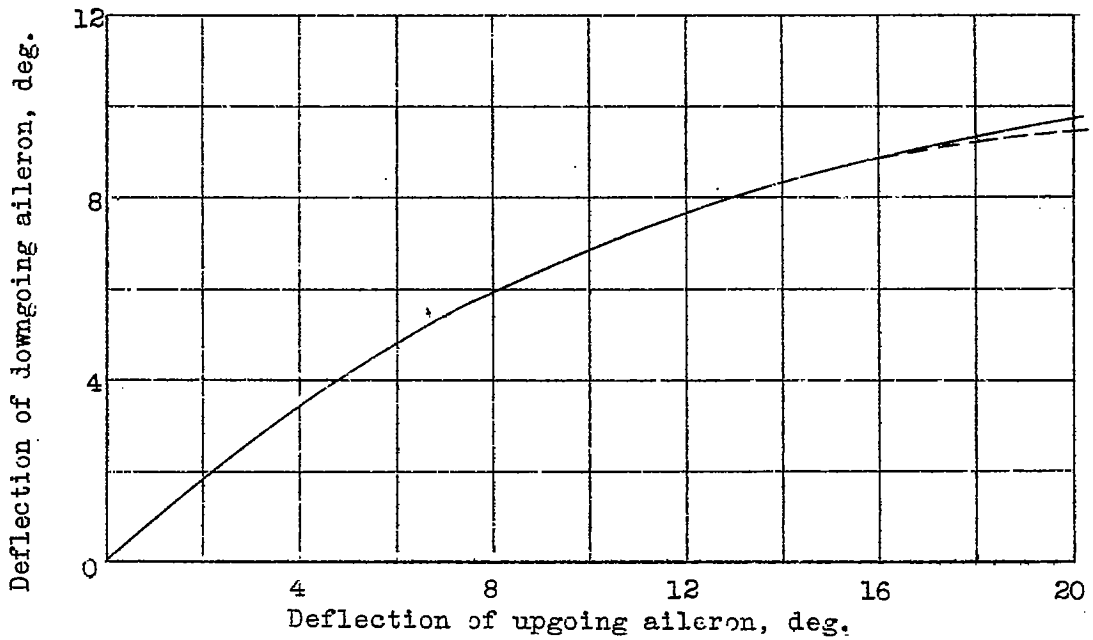

Figure 2.- Relation between deflections of ailerons on tapered wing.

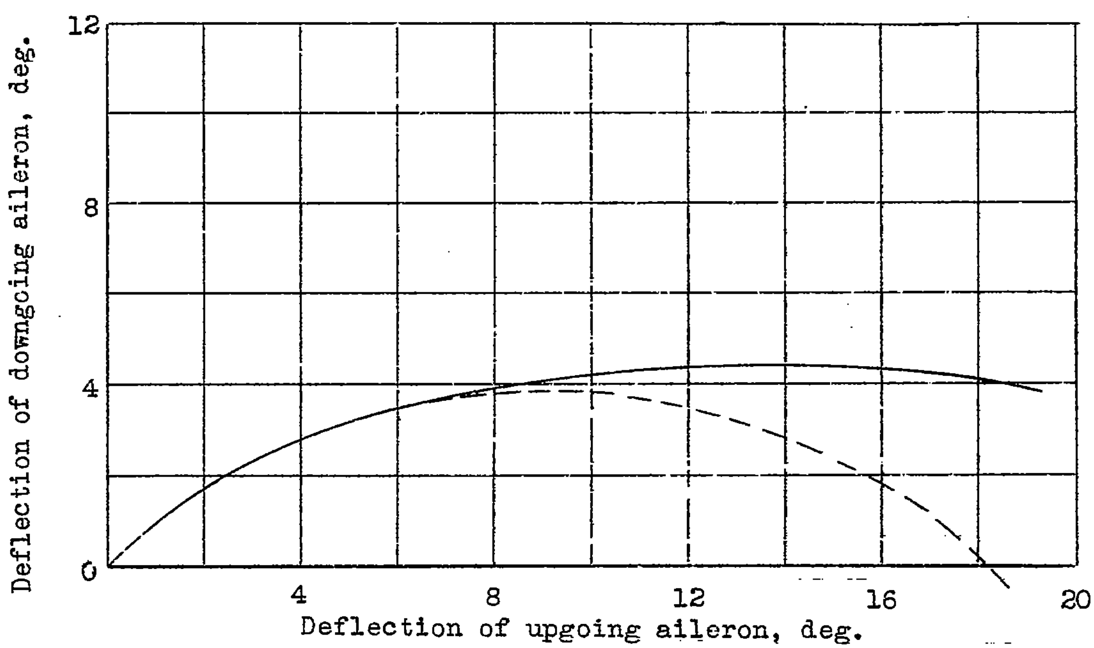

Figure 7.- Relation between deflections of ailerons on standard wing for first modified linkage.

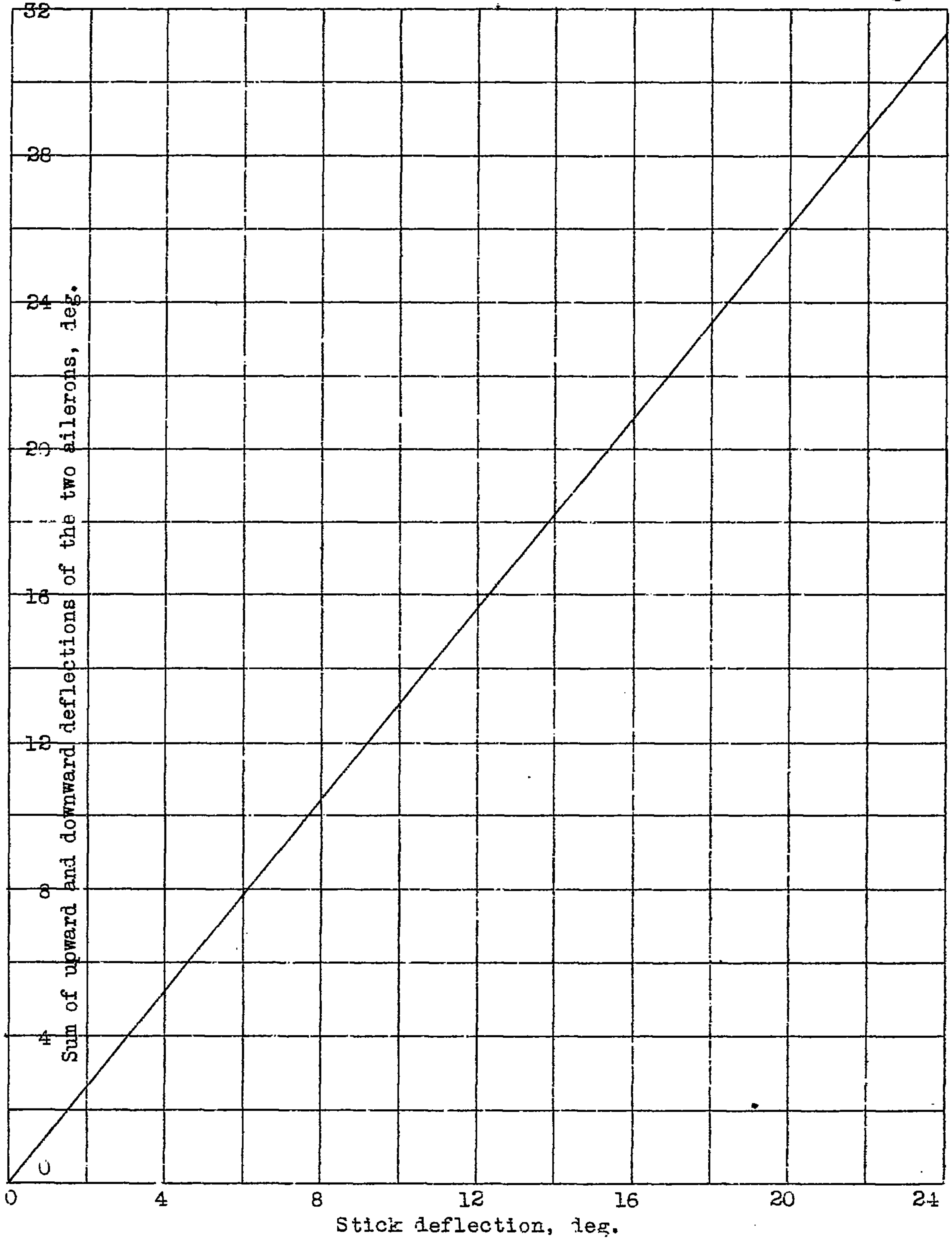

Figure 3.- Variation with control-stick position of the sum of the upward and downward deflections of the two ailerons on the tapered wing.

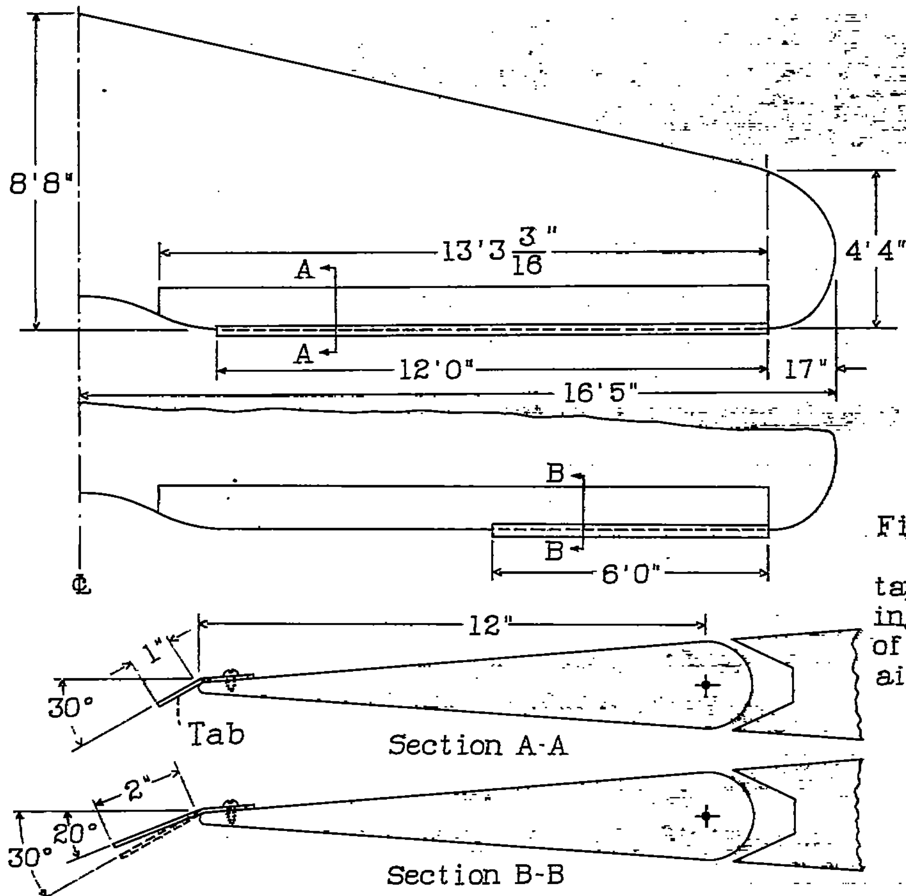

Figure 4.- Sketch of tapered wing showing installation of attached aileron tabs.

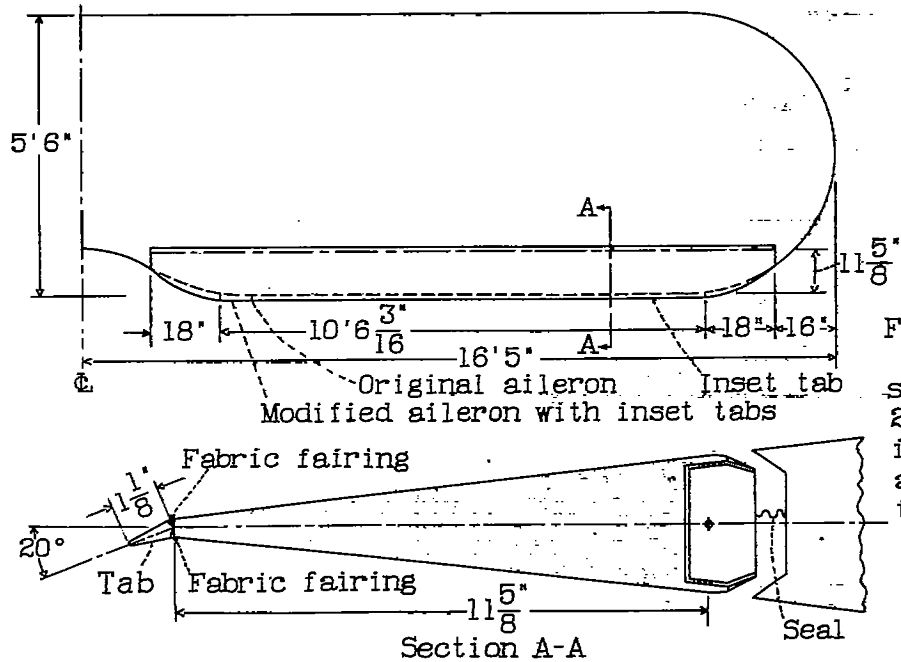

Figure 5.- Sketch of standard Fairchild 22 wing showing installation of aileron tabs of the inset type.

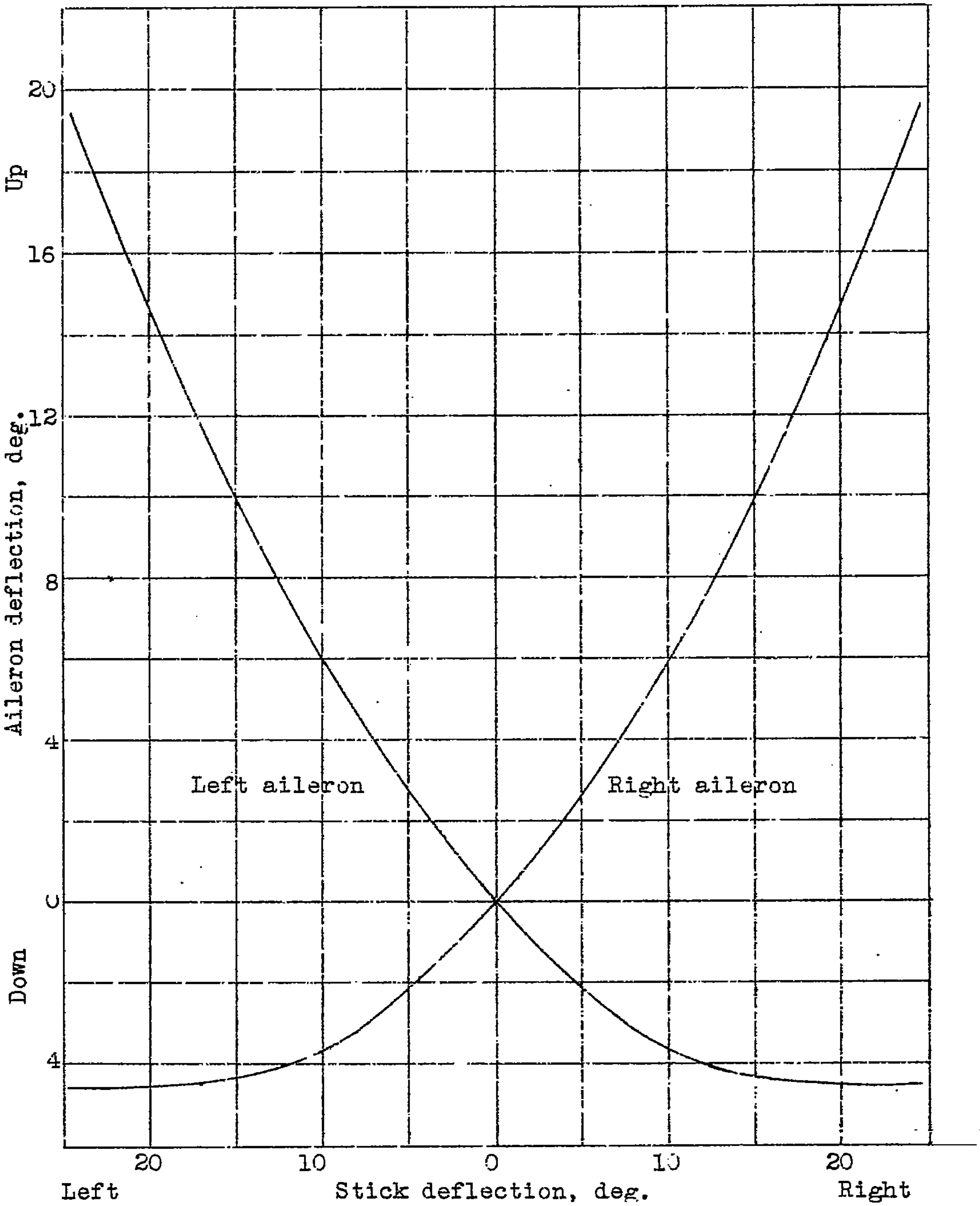

Figure 6.- Relation between deflections of control stick and ailerons on standard wing for first modified linkage.

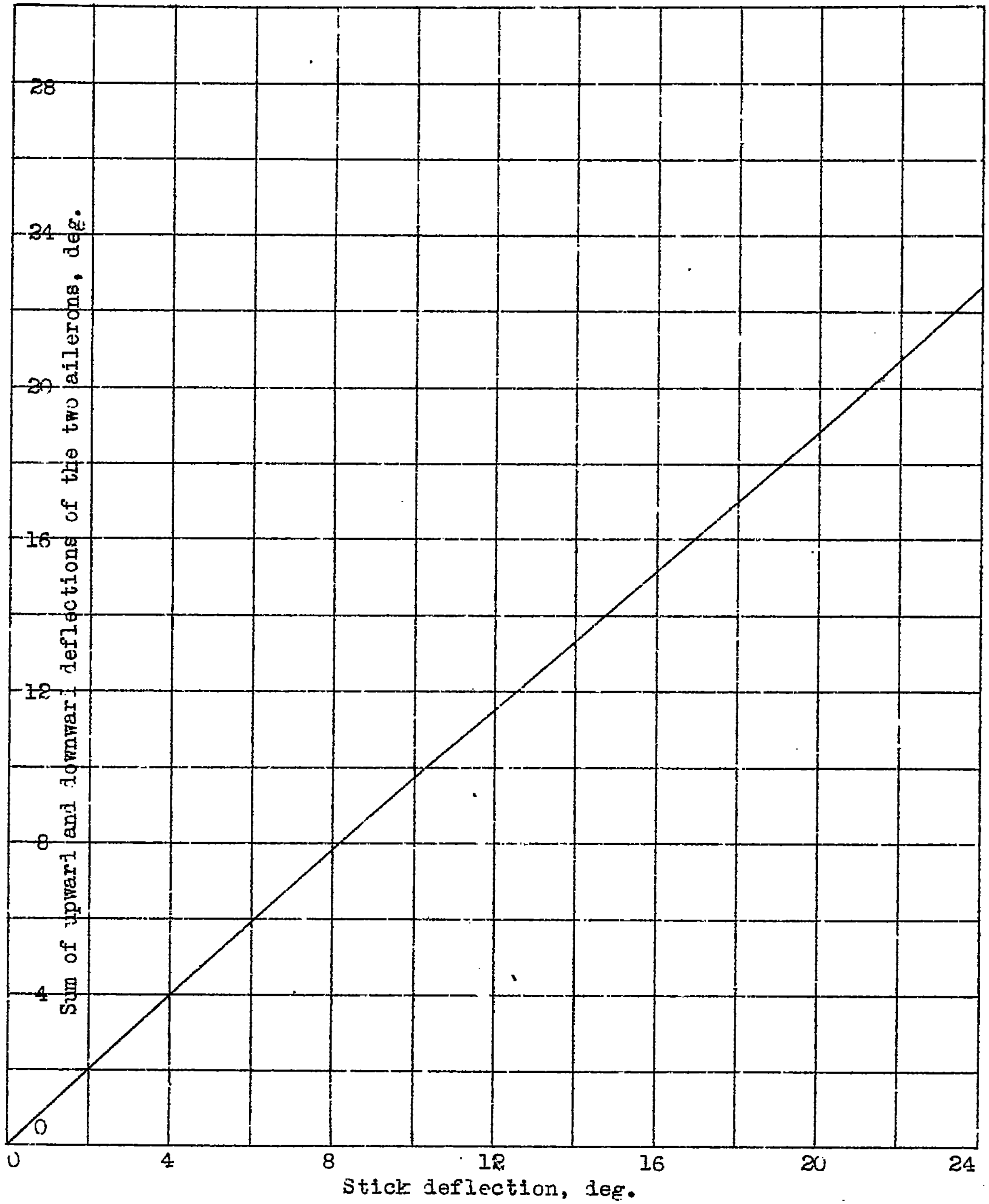

Figure 8.- Variation with stick position of the sum of the upward and downward deflections of the two ailerons on the standard wing for first modified linkage.

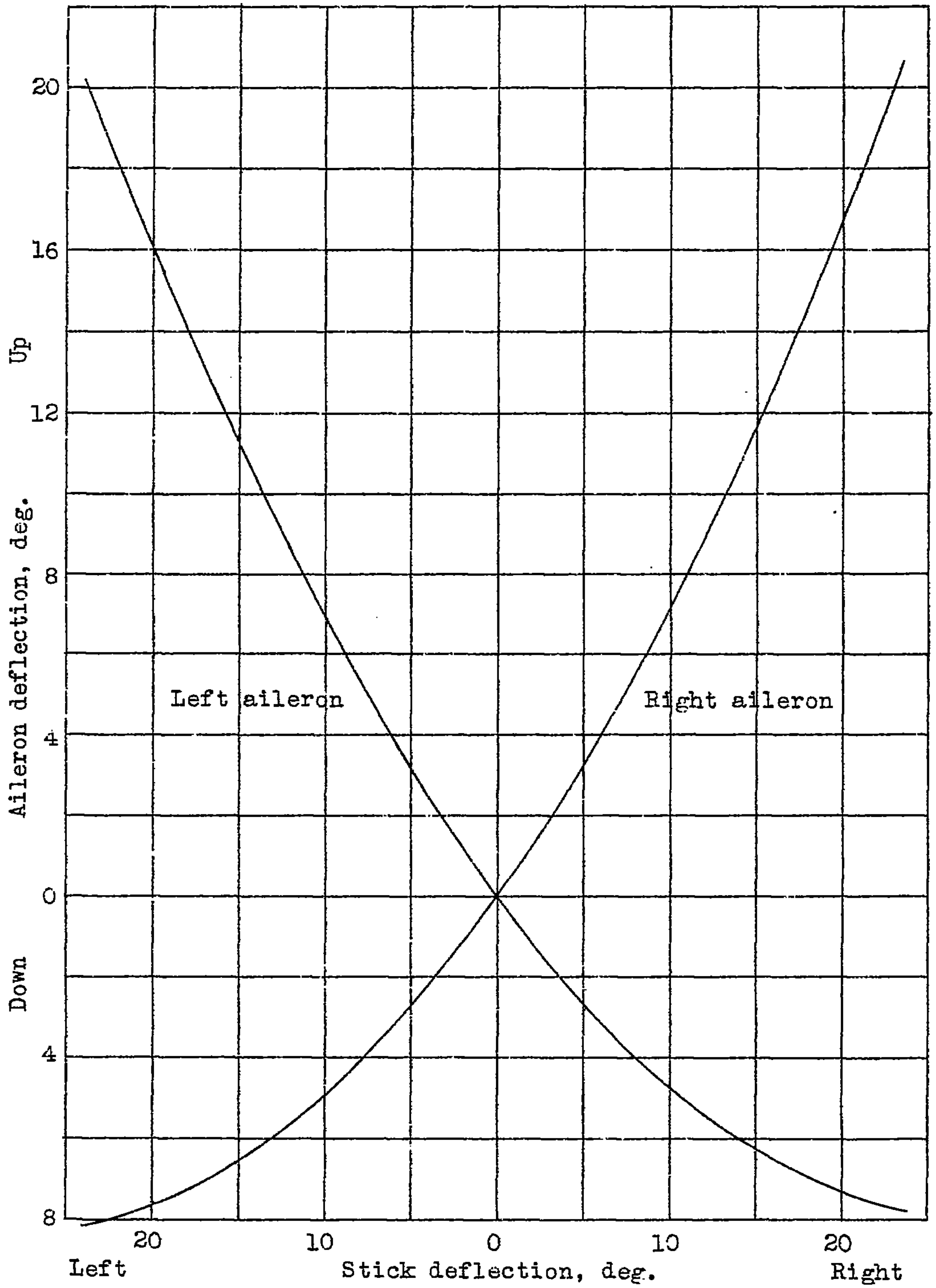

Figure 9.- Relation between deflections of control stick and ailerons on standard wing for final linkage.

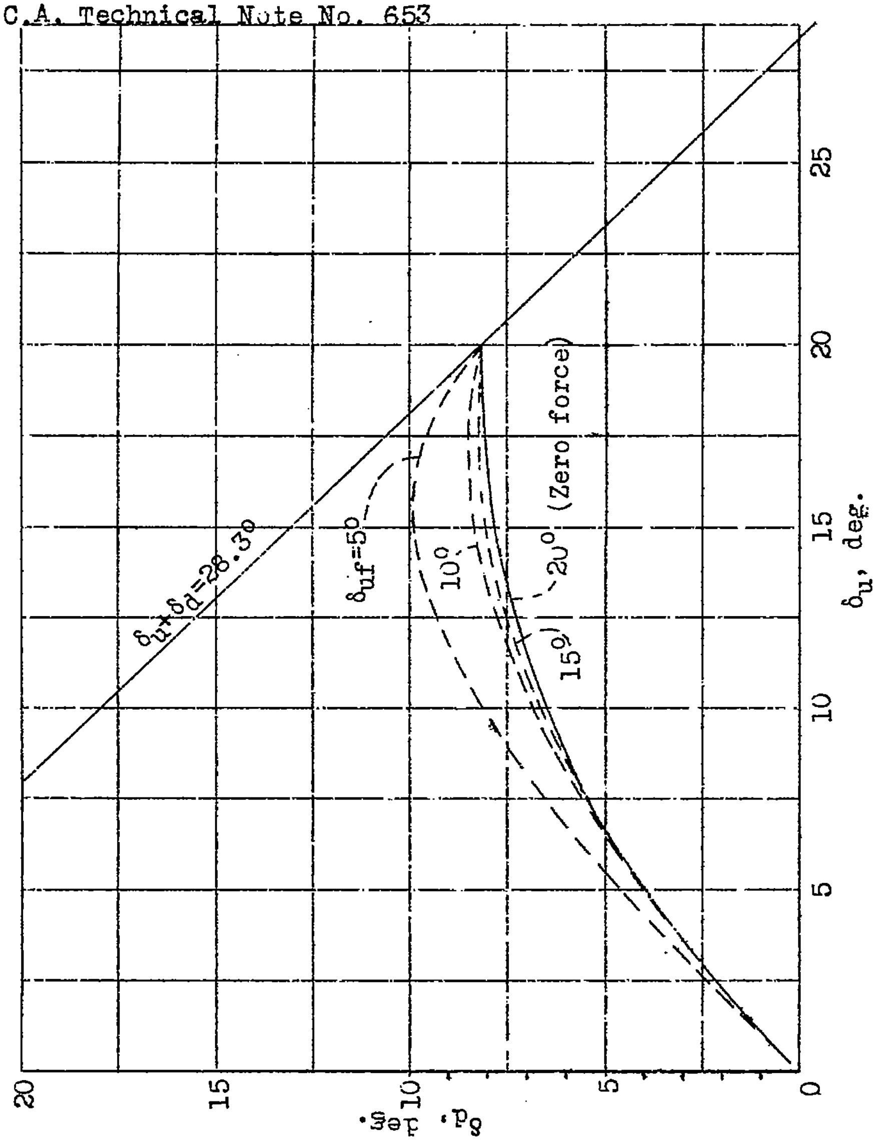

Figure 13.- Comparison of linkages for different floating angles for linear stick-force variation. The zero-force curve is computed for a floating angle of 20°.

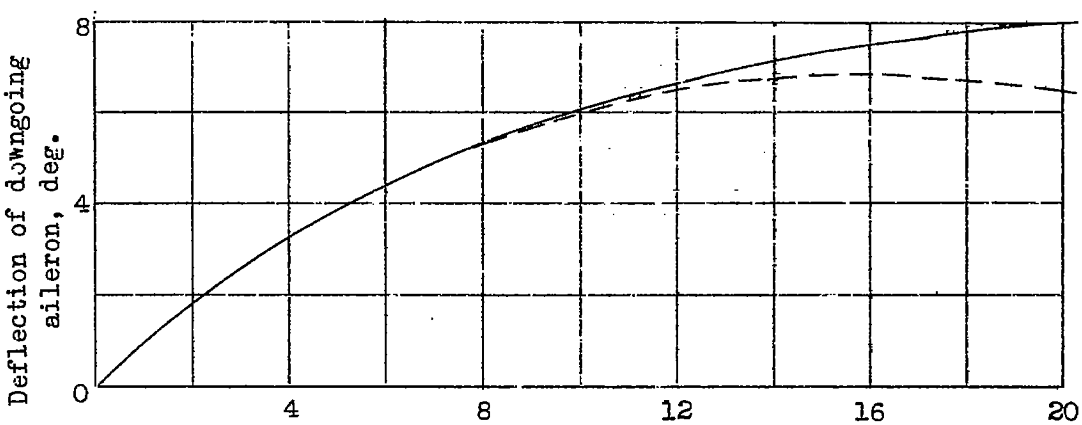

Figure 10.- Relation between deflection of ailerons on standard wing for final linkage.

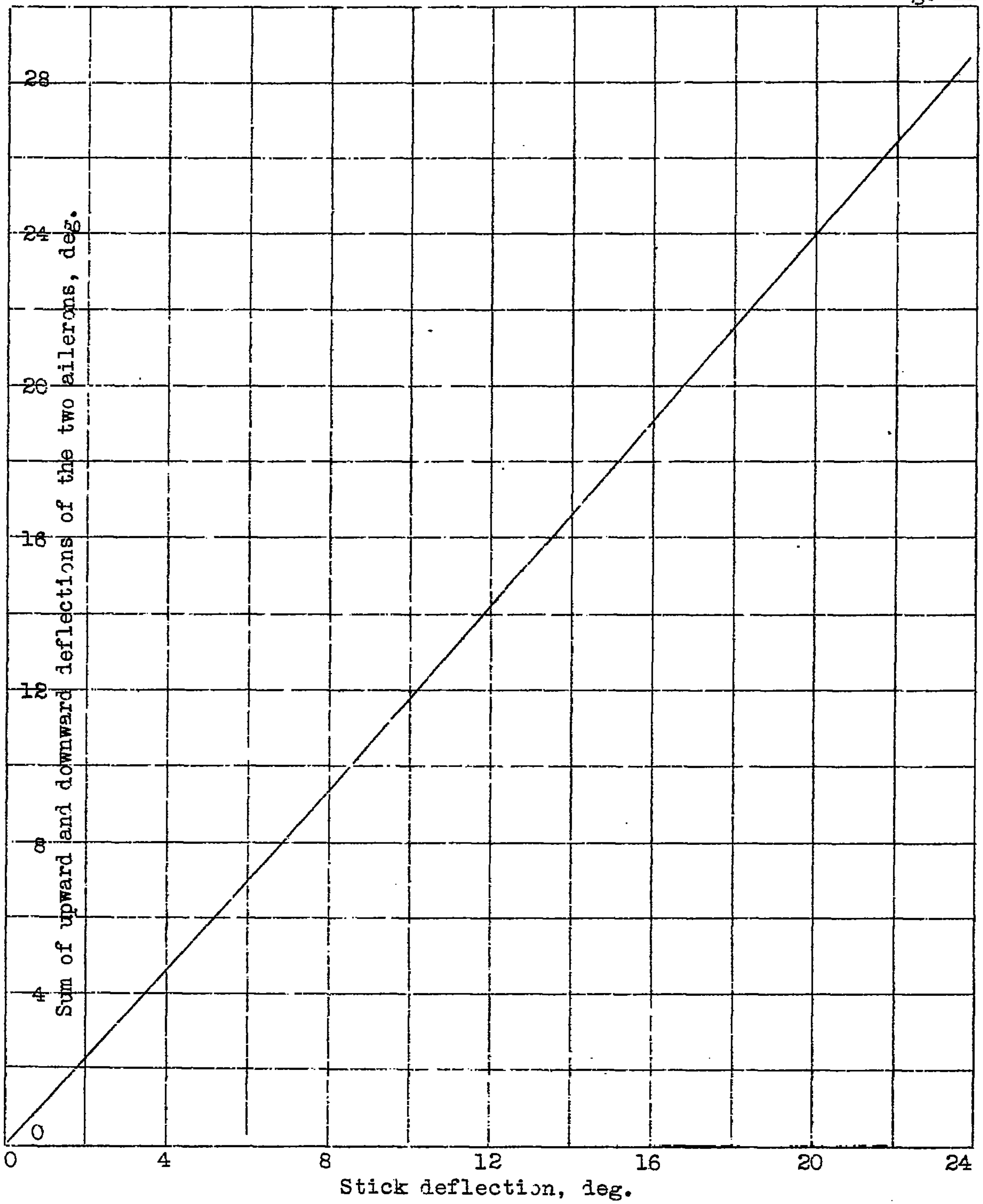

Figure 11.- Variation with stick position of the sum of the upward and downward deflections of the two ailerons on the standard wing for the final linkage.

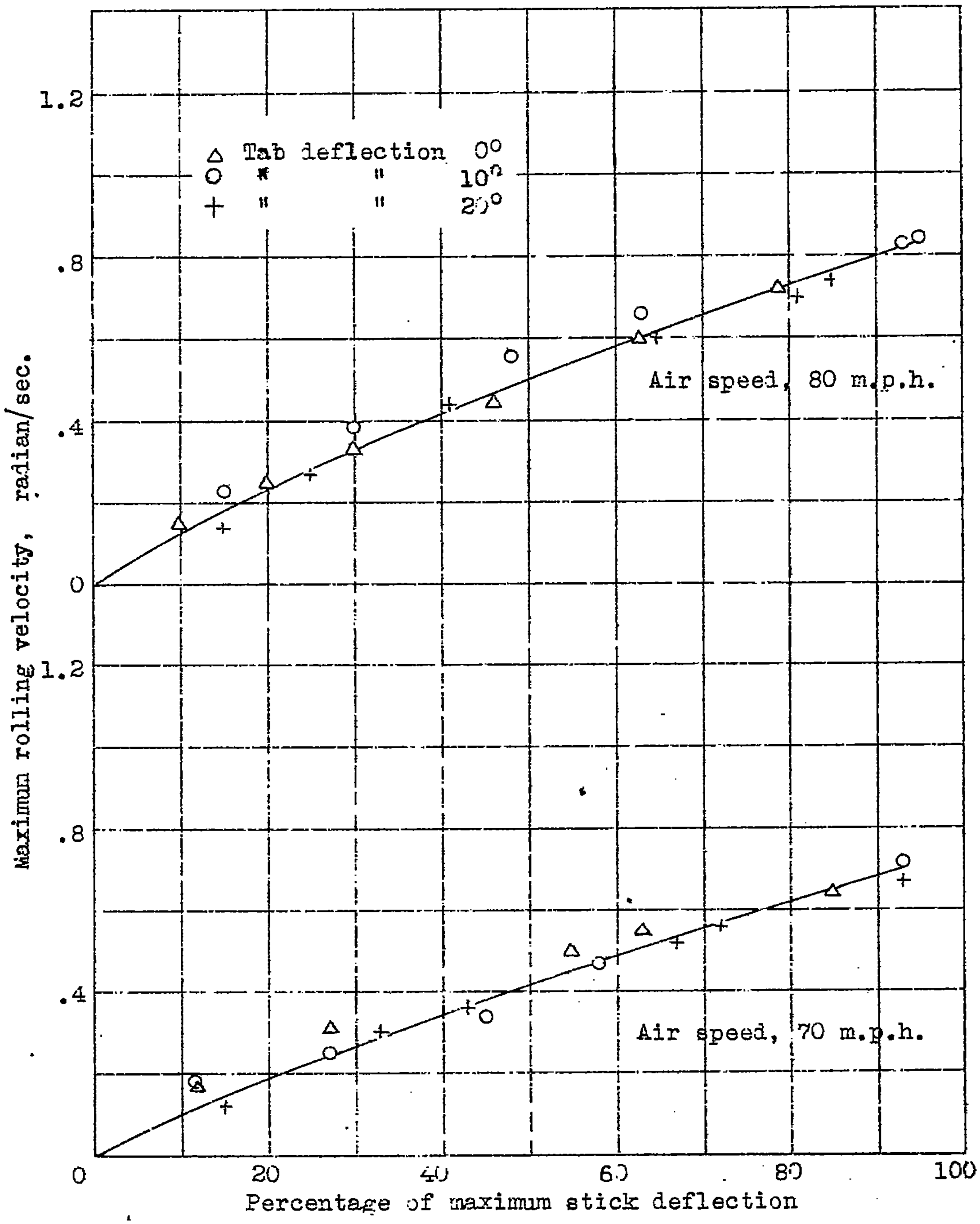

Figure 12.- Effect of tab deflection on maximum rolling velocity obtained with ailerons on standard wing with first modified linkage.

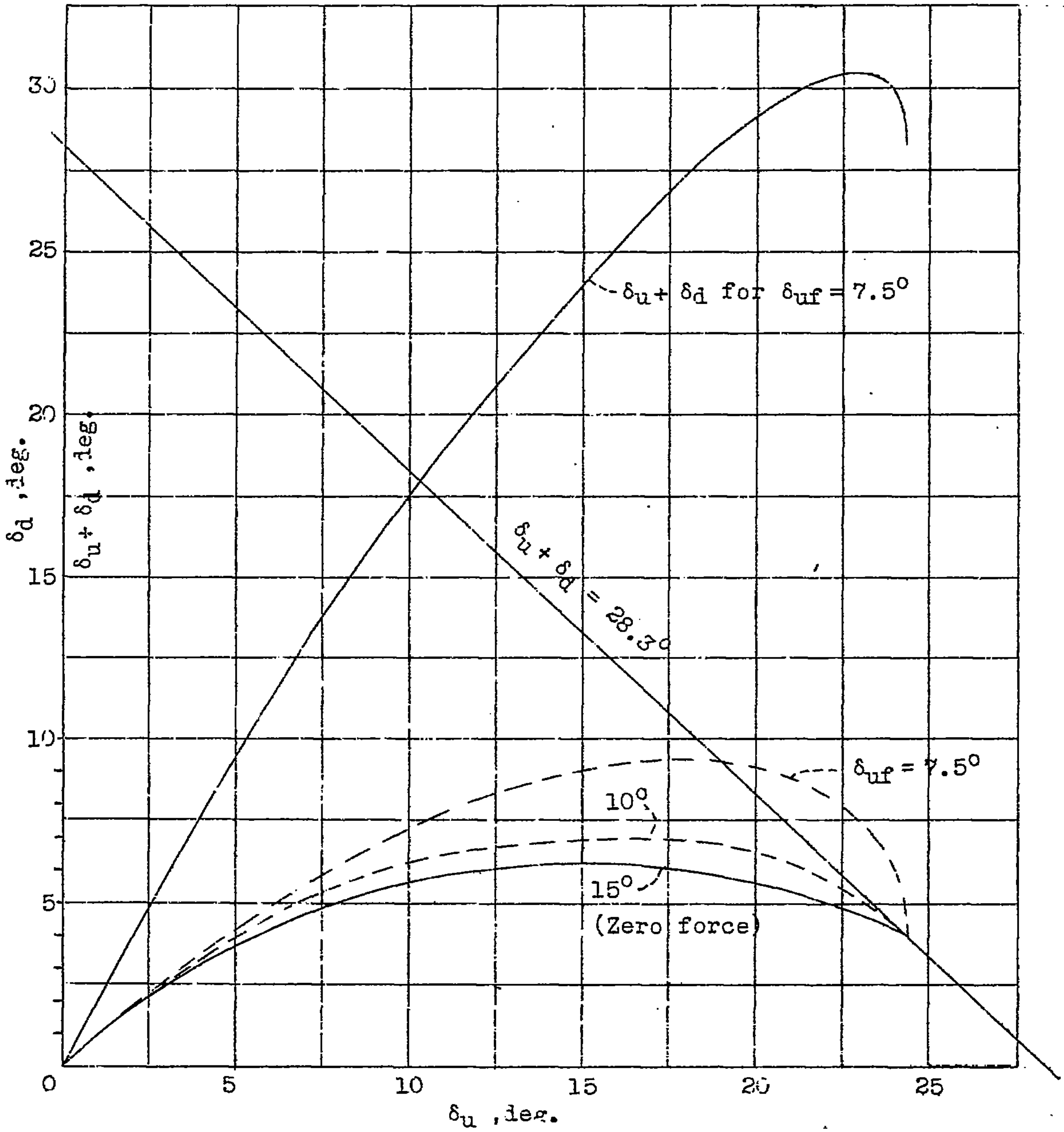

Figure 14.- Comparison of linkages for different floating angles for linear stick-force variation. The zero-force curve is computed for a floating angle of 15°.

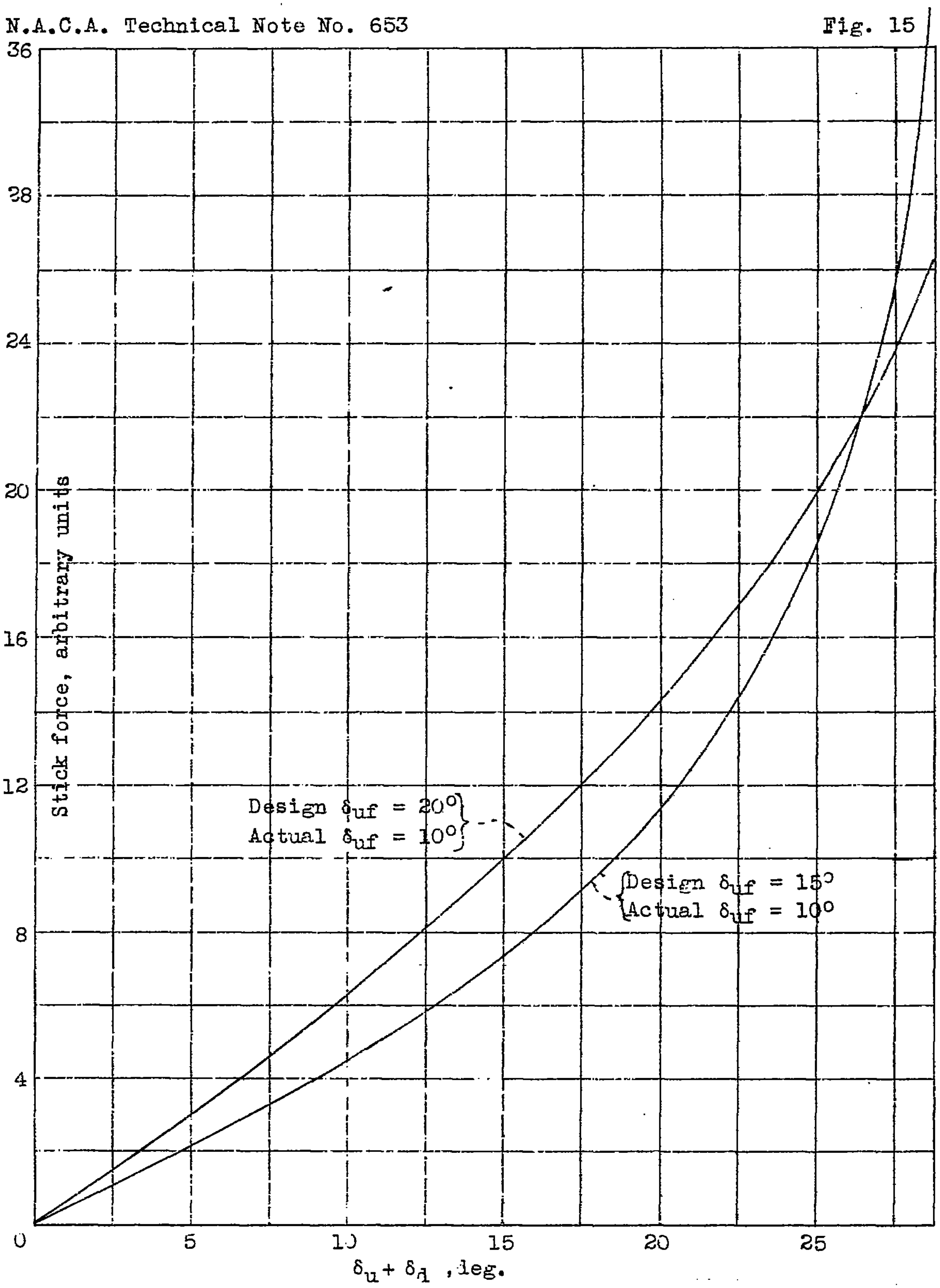

Figure 15.- The variation of stick force with the sum of the upward and downward deflections of the two ailerons.