NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1085

FLIGHT TESTS OF EXPERIMENTAL BEVELED-TRAILING-EDGE FRISE AILERONS ON A FIGHTER AIRPLANE

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SUMMARY

Flight measurements have been made to determine the characteristics of a pair of experimental ailerons designed to provide a close degree of balance and to maintain a linear variation of aileron effectiveness with aileron angle through a large deflection range. The ailerons, which were tested on a production fighter airplane, incorporated an upswept Frise nose and a beveled trailing edge. These ailerons were designed for application to an experimental fighter airplane, which was to employ wings similar to those of the test airplane as outer panels added to a rectangular center section. Individual aileron hinge moments, aileron rolling effectiveness pb/2V, and stick-force characteristics were measured in abrupt aileron rolls over an equivalent-airspeed range from approximately 109 to 276 miles per hour.

The results of the tests indicated that the variation of rolling moment with aileron deflection was linear for a deflection range from $-24\frac{1}{2}^\circ$ to 22°. A deflection range of $\pm 24^\circ$ would give a value of pb/2V of 0.137 for the test airplane, or 0.098 for the experimental fighter airplane. With a rigid control system, a range of aileron deflection of $\pm 24^\circ$ could be reached with a 32-pound stick force at 202 miles per hour. Data are presented that show the critical importance of the effects of control-system elasticity in determining the stick forces. The calculations indicated that overbalance encountered on the test airplane was due to control-system stretch and that, with the control system of the experimental fighter airplane, the aileron stick forces would be unsatisfactory at a speed of 300 miles per hour or more. The data presented also show that exceptional care must be exercised in the construction of closely balanced Frise ailerons

because small protuberances on the leading edge of the balance may cause overbalance or premature stalling of the balance on the up-deflected aileron. Calculations were also made to show the increase in aileron effectiveness available if the aileron span were extended.

INTRODUCTION

A pair of Frise ailerons was designed by the Langley Memorial Aeronautical Laboratory of the NACA to provide a close degree of balance and to maintain a linear variation of aileron effectiveness with aileron angle through a large deflection range. These ailerons were intended for application to an experimental fighter airplane. The wings of this experimental airplane consist of a 12.5-foot-span rectangular center section with the wings of an existing production fighter airplane as the outer panels. Flight tests of these ailerons were conducted on the production airplane . A sketch showing the wing plan form of the experimental fighter airplane as compared with the wing plan form of the test airplane is shown as figure 1 and detail dimensions of the test-airplane wing are shown in figure 2. It was estimated that this increase in wing span of the experimental airplane would decrease the aileron effectiveness $pb/2V$ to 71 percent of that available with the test airplane.

An attempt was first made to increase the rolling effectiveness of the ailerons without modifying the outer wing panel or the aileron support bracket so as to have a value of $pb/2V$ of 0.07 on the experimental fighter airplane with a 50-pound stick force at 292 miles per hour. Modifications to the wing were allowed later, however, and calculations were made to show the effects of replacing the rounded wing tip by a square tip and of extending the aileron outboard approximately 18 inches without increasing the wing span.

Consideration of methods available to improve the aileron rolling effectiveness without modifying the outer wing panel indicated that the most expedient means was to increase the aileron-deflection range from the range of -18° to 10°, used on the test fighter airplane, to a range of approximately $\pm 25^{\circ}$, the deflection required to obtain the desired effectiveness when a linear variation of $pb/2V$ with aileron angle is assumed throughout the deflection range. Increasing the deflection range, however, was not merely a mechanical problem because the existing Frise aileron was effective to an up deflection of 18° only, at which deflection the balance stalled. Furthermore, the increase in maximum speed at which full deflection was required on the experimental fighter airplane, together with the decrease in stick-to-aileron mechanical advantage, would cause forces at full deflection to exceed the specified stick-force limits by 300 to 400 percent if the existing ailerons were used.

In an attempt to obtain satisfactory control forces and a linear variation of effectiveness for a deflection range of ±25°, the original Frise aileron was modified to incorporate an upswept balance with nose of relatively large leading-edge radius and to have a trailing-edge bevel of 25°. The results of flight tests of these ailerons together with calculated effects of control-system stretch and extended aileron span are presented herein.

SYMBOLS

$pb/2V$ — helix angle described by wing tip during roll, radians

p — rolling angular velocity, radians per second

b — wing span, feet

V — true airspeed, feet per second

C_h — aileron hinge-moment coefficient $\left(H/qS_a\bar{c}_a\right)$

H — aileron hinge moment (positive moment tends to rotate trailing edge downward), pound-feet

q — dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

ρ — mass density of air

S_a — aileron area back of hinge line, square feet

c_a — local aileron chord

$\bar{c}_a$	root-mean-square chord of aileron area back of hinge line, feet
V_e	equivalent airspeed $\left(\sqrt{\frac{2q}{\rho_0}}\right)$
ρ_0	standard sea-level mass density of air
C_{h_α}	rate of change of aileron hinge-moment coefficient with angle of attack at constant aileron angle
C_{h_δ}	rate of change of aileron hinge-moment coefficient with aileron angle at constant angle of attack
δ_a	aileron angle with respect to wing chord line, positive when trailing edge is down, degrees
$\delta_{a_{up}}$	aileron angle of up-deflected aileron
$\delta_{a_{down}}$	aileron angle of down-deflected aileron
F_{up}	stick force required by up-deflected aileron
F_{down}	stick force required by down-deflected aileron

AIRPLANE AND INSTRUMENTATION

Description of Airplane

The test airplane was flown at an average gross weight of 7870 pounds with the center of gravity at approximately 28 percent mean aerodynamic chord when the wheels were retracted. Two photographs of the test airplane equipped with its original ailerons are shown as figure 3. A section view showing the experimental aileron-wing profile is presented as figure 4, and the experimental aileron contours are shown in figure 5. These experimental ailerons were of all-metal construction and were built by the manufacturer of the experimental fighter airplane according to contours recommended by the staff of the Langley Laboratory. Detail specifications for the recommended contours are given in figure 5(a). The aileron contours shown in figure 5(b) were obtained by means of plaster casts and therefore include local surface details; however, the larger deviations from the design contour, such as those at the leading-edge lower surface and at the trailing edge, were apparent throughout the aileron span. For the contour at the center hinge the design layout was measured parallel to the airplane thrust axis, whereas all the other aileron contours were laid out and measured perpendicular to the hinge line. Both ailerons were equipped with trimming tabs that were adjustable only on the ground. The chordwise and spanwise gaps between the tabs and ailerons were sealed by doped fabric. Except for a few preliminary tests, the aileron-nose gap was sealed by flexible aircraft fabric secured to the wing by a metal strip and sheet-metal screws and cemented to the lower surface of the aileron. The method of installing this seal is illustrated in figure 6, and two photographs of the seal installation are shown as figure 7. For the first series of tests, referred to as the "small-deflection tests," this seal was made partly airtight by one coat of dope, but in later tests the seal was made more nearly airtight by an application of rubber cement. Pertinent dimensions of the test airplane and experimental ailerons are as follows:

Wing area, square feet	236
Wing span, feet	37.3
Wing aspect ratio	5.95
Wing taper ratio	2.32
Aileron area back of hinge line, square feet (per aileron)	7.04
Aileron-balance area, square feet (per aileron)	1.82
Root-mean-square chord of area back of hinge line, feet	1.03
Control-stick length, feet	1.76
Tab area, square feet	0.63
Aileron location (inboard end), percent wing semispan	54.00
Aileron location (outboard end), percent wing semispan	91.00

Description of Instrumentation

Instrumentation for the tests included the following standard NACA recording instruments synchronized by an NACA chronometric timer: airspeed recorder, roll turnmeter, aileron-position recorder, three-component accelerometer, stick-force recorder, and recording galvanometer (aileron hinge-moment recorder). In addition to the recording instruments the airplane was equipped with a sensitive indicating airspeed meter, an indicating altimeter, and an indicating free-air thermometer (resistance-bulb type).

The airspeed recorder and indicator were connected to the test-airplane airspeed head. In order to avoid possible detrimental effects on the aileron characteristics due to the disturbed flow caused by a boom, the usual experimental airspeed installation consisting of a static-pressure tube mounted on a boom ahead of the wing was not used. The airspeed installation was calibrated for position error and the thermometer, for compressibility effects.

Aileron hinge moments were measured by cable-tension recorders calibrated in terms of aileron hinge moments. The cable-tension-recorder unit, shown in a three-view drawing (fig. 8) and in a photograph (fig. 9), consisted essentially of a C-shape spring unit with electric strain gages mounted on the stressed shank so as to measure cable tension as a function of strain in the shank. A sufficiently large number of strain gages were mounted on the unit to make possible direct measurements of the current changes with a recording galvanometer and no intermediate amplifier. The cable-tension recorders were calibrated in terms of aileron hinge moments for various aileron angles. The aileron angles were measured at the inboard end of the aileron and are therefore independent of stretch in the aileron control system. Twisting of the aileron under load is neglected, however.

TESTS AND PROCEDURE

All flights were made with the landing gear and flaps retracted at the power required for level flight or at rated power for speeds exceeding maximum level-flight speed. An average pressure altitude of 10,000 feet was maintained throughout the tests. Aileron rolling effectiveness, stick forces, and hinge-moment characteristics were measured in abrupt aileron rolls with the rudder and elevator controls held fixed in the trim position in accordance with standard NACA procedure. Whenever possible the aileron characteristics at each of the test speeds were measured by repeated flights in order to provide an adequate check on the results. The check calibrations and repeated tests indicated that the measurements were within the following limits of accuracy:

Rolling angular velocity, radians per second . . .	±0.03
Aileron angle, degrees	±0.2
Aileron hinge moment, pound-feet	±3
Equivalent airspeed, miles per hour	±1
Stick force, pounds	±1

The accuracy of the aileron hinge moments is based on a comparison between measured stick forces and stick forces calculated from measured aileron hinge moments; consequently the percentage of the error due to each aileron is not determined. The scatter in hinge-moment and stick-force data is attributed to the friction in the control system, which in flight is apparently less than static friction because of relief due to continuous vibration of the airplane.

Because of interference between the wing and aileron-control crank, the ailerons when first fitted were restricted to a deflection range of approximately ±14°. Initial tests were made with this deflection range because of a desire to obtain even a limited amount of data as soon as possible. Later the aileron structure was changed to permit a deflection range of 22° to $-24\frac{1}{2}°$. Inasmuch as a large structural change would have been required to obtain the projected deflection range of ±25°, no further modifications were attempted.

Small-Deflection Tests

For the small-deflection tests the control system of the test airplane was modified to provide a deflection range of approximately ±14°. Data were obtained for the aileron operating as a normal Frise aileron with unsealed aileron-nose gap and for the aileron operating with the gap closed by a flexible seal. In the tests with the aileron-nose gap unsealed, the ailerons were rigged neutral on the ground with a cable tension of 90 pounds; but with the aileron-nose gap sealed, the cable tension was increased to 100 pounds. For the tests in which the aileron-nose gap was sealed, the fabric seal was made partly airtight by the application of one coat of airplane dope. The trimming tabs were set at

0° deflection with both chordwise and spanwise tab gaps sealed by doped fabric.

Large-Deflection Tests

With the reworked control mechanism the aileron-deflection range was from 22° to $-24\frac{1}{2}°$ with the airplane on the ground without load. The aileron-nose gap was sealed by fabric impregnated with rubber cement and the ailerons were rigged neutral on the ground with a cable tension of 100 pounds. For these tests the trimming tabs on both ailerons were deflected downward 5°. Both chordwise and spanwise tab gaps were sealed.

RESULTS AND DISCUSSION

Small-Deflection Tests

The relationship between aileron angle and stick deflection is shown in figure 10, and the stick forces due to friction in the aileron control system as measured on the ground without aileron load are shown in figure 11. The seal was very flexible and therefore had negligible effect on the friction. The relation between stick deflection and aileron deflection was the same for the small-deflection tests as for the large-deflection tests (1° aileron deflection per degree stick travel in the linear range). The maximum stick deflection was therefore limited in the small-deflection tests, as shown in figure 10.

Data from the tests with the aileron-nose gaps unsealed at speeds of 148, 198, and 247 miles per hour are presented in figures 12 to 15. The data shown in figure 12 are not entirely satisfactory in that the pilot failed to hold the stick fixed during some full-deflection rolls when the forces exhibited an overbalancing tendency. These data are included herein, nevertheless, because these were the only measurements of effectiveness made with the aileron-nose gaps unsealed and are sufficiently accurate to show the principal characteristics of the ailerons with the gaps unsealed. In the cases in which the ailerons were not held steady the maximum and minimum values of aileron angle were plotted and connected by a straight line. For two left rolls (figs. 12 and 14), indicated with question marks, the maximum rolling velocity was not clearly reached before the end of the records and the accuracy of the data is therefore questioned.

The hinge-moment coefficients for each of the ailerons with aileron-nose gap unsealed, as measured during the condition of steady maximum rolling velocity attained with any particular aileron angle, are presented in figures 13 and 14. The aileron trim angles (aileron angles in steady flight with wings level) indicated in these figures show clearly that the ailerons floated down and that the downward deflections increased as the speed was increased. This "effective droop" increased the slope of the stick-force curves (fig. 12) through zero and thereby made the overbalance at high deflections more apparent. Another factor contributing to this undesirable stick-force gradient and to overbalance was the unequal travel of the upgoing and downgoing ailerons. In left rolls at 198 miles per hour, for example, the changes in the aileron angle from trim as shown in figures 13 and 14 are as follows:

Increment of aileron angle (deg)	
Left aileron	Right aileron
-2.0	2.4
-3.7	4.0
-5.2	5.2
-7.7	6.9
-10.0	7.9
-14.1	9.2

For approximately equal increments of stick deflection the increments of the downgoing-aileron angle decrease as the deflection increases, whereas the increments of the upgoing-aileron angle increase. When a hinge-moment curve of the type shown in figures 13 and 14 is obtained with the aileron effectively drooped in the trim position, the hinge moments at the small stick deflections are larger than those at the large stick deflections and, at large stick deflections, the overbalancing tendency of the upgoing aileron exceeds the restoring tendency of the downgoing aileron. If the control system were rigid, both the undesirable droop and unequal aileron travel would be eliminated.

The variation of hinge-moment coefficient with angle of attack was obtained by calculating angle of attack with an estimated lift-curve slope of 0.074 per degree. The data of figures 13 and 14 for 0° aileron angle show a $C_{h_{\alpha}}$ of -0.0005 for the left aileron and of essentially zero for the right aileron. For the right aileron, then, $C_{h_{\delta}}$ may be measured directly from the slope of the curve and, for the range of ±2°, is -0.0018; however, the variation of hinge moment with aileron angle is nonlinear at the higher aileron angles and $C_{h_{\delta}}$ therefore varies throughout the deflection range. The comparison in figure 15 between aileron control forces measured at the stick and control forces calculated from the measured hinge moments shows no consistent deviation.

The aileron stick force and rolling effectiveness measured over the small deflection range with the aileron-nose gaps sealed at speeds of 147, 198, 248, and 276 miles per hour are presented in figure 16. The extremely small forces at speeds up to 248 miles per hour indicate the large degree of balance attained with these ailerons. Although only three test points are available for either the left or right roll at 276 miles per hour, the points are faired by a dashed line to approximate the pilot's opinion of the stick-force variation. The tendency toward an unstable force gradient at 198 and 248 miles per hour, particularly for left rolls, and toward overbalance at 276 miles per hour is attributable to the elasticity of the control system. The trim angles with the aileron-nose gaps sealed, indicated in the hinge-moment-coefficient curves of figures 17 and 18, show an appreciable decrease in the tendency of the ailerons to droop as the speed was increased, as compared with the tests with the gaps unsealed. This reduction in droop is due partly to the increased cable tension but largely to the 50-percent reduction, caused by sealing the ailerons, in hinge moment at 0° aileron deflection. The seal did not appreciably alter the floating angle of the aileron (angle for zero hinge moment). The effectiveness of the sealed ailerons was approximately the same as that of the unsealed ailerons.

In figure 19, stick forces calculated from hinge moments are again compared with forces measured at the stick, but this figure is not directly comparable to figure 15 because the force scales have been expanded in order to show the distribution of points.

Large-Deflection Tests

With the reworked aileron control mechanism, a deflection range of 22° to $-24\frac{1}{2}°$ was available on the ground without aileron load. The variation of aileron angle with stick deflection without load is shown in figure 20 and the stick forces due to friction are shown in figure 21.

The stick-force and aileron-effectiveness characteristics measured over the full deflection range at speeds of 109, 150, and 202 miles per hour are presented in figures 22 to 24 and the hinge-moment characteristics, in figure 25. The stick-force gradient with aileron deflection decreased as the speed was increased in contrast to the usual increase in stick-force gradient with increase in speed. In order to show the cause of this unusual trend, stick forces attainable with a control system assumed to be rigid are shown in figures 22 to 24. These forces with a rigid control system were calculated for an assumed range of aileron deflection of ±24° and with the assumption that both ailerons had hinge-moment characteristics as measured for the right aileron. From these calculated results it appears that at 202 miles per hour the stick forces would have no tendency to overbalance and a 32-pound stick force would be required for full deflection. Because no tests were made at speeds higher than 202 miles per hour, the force required to deflect the ailerons on the experimental fighter airplane at 292 miles per hour cannot be determined exactly. It was believed that the stick forces would not greatly exceed the required value of 50 pounds, however. The effect of elasticity of the control system of the experimental fighter airplane on the control forces will be discussed in the section on the effect of stretch on stick forces.

At 202 miles per hour the maximum measured value of pb/2V for the test airplane was 0.110 (corresponding to 0.078 for the experimental fighter airplane). With a rigid control system giving a range of total aileron angle of 48°, pb/2V could be increased to 0.137 (corresponding to 0.098 for the experimental fighter airplane). A further consideration is that if the lower value of pb/2V were acceptable, a considerable reduction in stick forces (from the rigid-system stick forces) could be attained by the use of a specially designed differential aileron linkage. The low value of pb/2V attained with the test airplane was due to the control-system elasticity, because only 16° of down aileron travel was reached with full stick deflection at 202 miles per hour.

The data of figures 22 and 23 show a decrease of approximately 6 percent in aileron effectiveness as given by the value of pb/2V per degree aileron angle when the speed was decreased from 150 to 109 miles per hour. This reduction in effectiveness at low speeds is due partly to the effect of sideslip, which was appreciable in these tests because of the low directional stability of the test airplane. The sideslip angle measured at maximum rolling velocity (full aileron deflection) averaged approximately 8° at 109 miles per hour, $6\frac{1}{2}^{\circ}$ at 150 miles per hour, and $2\frac{1}{2}^{\circ}$ at 202 miles per hour. Data for the left rolls of flight 21 (fig. 23) were neglected in fairing the curves because the seal in the aileron-nose gap was improperly installed and therefore affected the aileron effectiveness adversely. The improper seal attachment formed four bumps on the lower leading edge of the aileron, each of which was approximately 3 inches long and 3/32 inch high. The bumps were partly removed before flight 22 with the result that this flight showed the increase in hinge moment to occur at a higher up deflection. The very critical effect of small changes in nose-balance contour on the hinge moments, stick forces, and aileron effectiveness of a highly balanced Frise aileron is shown by the marked change that occurred between flights 21 and 22 (fig. 23) for the up-deflection range of the left aileron.

At 202 miles per hour (fig. 25) the right aileron stalled abruptly at an aileron angle between -23° and -24° with an accompanying oscillation, which indicated that a sudden breakdown of flow over the nose balance had occurred. Although no hinge-moment data are available, deflections of more than -24° were recorded for the left aileron without an aileron oscillation or decrease in rolling effectiveness, which indicated that no breakdown of flow over the leading edge had occurred. Some roughness was still present at the leading edge of the left aileron during flights 22 and 23 and may have been sufficient to cause the flow over the nose balance to break down gradually rather than abruptly. This gradual breakdown caused the smooth but rapid increase in hinge moments indicated at high up deflections of the left aileron.

For the large-deflection tests the tabs were deflected downward 5° with the spanwise and chordwise gaps sealed by doped fabric. This tab setting was used to reduce the positive hinge moment at 0° aileron angle, that is, to reduce the down-floating tendency. A comparison of the hinge-moment curves in figure 25 with the corresponding curves of figures 17 and 18 indicates that the tab was equally effective in changing the hinge moment at any angle in the aileron-deflection range. An inspection of these data also suggests the possibility of using a linked tab that always moves upward to reduce the hinge moments throughout the deflection range and thereby to alleviate the effects of the elastic control system. Such a tab arrangement should be so linked that the tab deflects downward 5° when the aileron is neutral and moves upward at an increasing rate as the aileron moves upward (approximately sinusoidal motion), with the result that the tab is neutral at full up-aileron deflection and maintains a small positive hinge moment for the upgoing aileron. The tab on the downgoing aileron should likewise move upward and a careful choice of linkage would permit the tab to move upward more than 5° for full down-aileron deflection. In order to obtain this tab motion, a link extending from a horn on the upper surface of the tab to a fixed pivot point between the hinge lines of the tab and aileron may be employed. The fixed pivot point would be very near a line joining the hinge axes of the tab and aileron when the aileron is neutral.

The large-deflection tests were terminated at the relatively low speed of 202 miles per hour because both the test data and calculations indicated that the elastic control system would cause dangerous overbalance at high speeds.

Effect of Stretch on Stick Forces

The preceding discussion has shown that elasticity in the control system adversely affects the aileron control forces by increasing the stick-force gradient through the small deflection range and causing overbalance at large deflections. In order to provide a high degree of balance with Frise ailerons, the upgoing aileron must be overbalanced for part of the deflection range. If the control system is flexible, the upgoing aileron reaches up deflections that are larger for a given stick deflection than those corresponding to a rigid-control system; the downgoing aileron, however, reaches smaller down deflections. The relation between the hinge moments of the upgoing and downgoing ailerons is therefore not that required to produce the desired degree of balance; in fact, violent overbalancing or "snatch" of the ailerons appears at high speeds.

In order to show more clearly the effect of control-system stretch, stick forces were calculated for a speed range of 250 to 400 miles per hour for control systems assumed to stretch 0.058° and 0.040° per pound-foot of aileron hinge moment. These particular values of control-system rigidity were chosen because 0.058° per pound-foot was reported to be the rigidity of the control system of the experimental fighter airplane and 0.040°, which would indicate the effect of increasing the control-system rigidity, has been attained in control systems of push-pull tube type on other airplanes (unpublished data). The test-airplane control system stretched 0.087° per pound-foot of aileron hinge moment. In these calculations the ailerons were assumed to have hinge-moment characteristics as shown for 202 miles per hour in figure 25 and to operate on a linear aileron-stick linkage with a deflection range of ±24° without load.

The aileron characteristics for the control system with 0.058° of stretch per foot pound of hinge moment are summarized in figure 26 and individual effects contributed by the upgoing and downgoing ailerons are shown in figures 27 to 30. The calculations are limited to the stick-deflection range in which a tendency for force reversal is apparent, but they show clearly that this control system will not permit satisfactory stick-force gradients at a speed of 300 miles per hour or more and that excessive aileron deflection at high speeds may result from the application of light stick forces.

The calculated forces with the rigidity of the control system increased to 0.040° per pound-foot of hinge moment are summarized in figure 31 and show an appreciable improvement over the forces attainable with the more elastic system. The individual contributions of each aileron are not presented for the more rigid system because the results are very similar to those shown in figures 27 to 30.

Analysis of Extended-Span Ailerons

Originally an attempt was made to increase the rolling effectiveness of the ailerons without modifying the outer wing panel. When it appeared that changes in the outer panel would be allowed, an analysis was made to determine the effects of extending the aileron span. The results of these calculations are summarized in figure 32. The data presented show the inboard extension of the aileron span required to obtain values of $pb/2V$ of 0.09 and 0.10 for two outboard wing-panel configurations. The two panels considered are the test panel and the test panel modified by a square tip with the aileron extended outboard to the end of this new tip. The square tip adds approximately 18 inches to the aileron span without increasing the span of the wing panel as tested.

The required aileron extensions were calculated on the basis of data presented in reference 1 with an aileron effectiveness factor k of 0.41, which was determined from flight tests of the original ailerons on the test airplane (unpublished data) at an equivalent airspeed of 250 miles per hour. The curves of figure 32, therefore, incorporate the losses in aileron rolling effectiveness due to wing twist of the test airplane at this speed. The effect of tip shape on the damping moment due to rolling is neglected, but conservative estimates based on the increase in moment of the wing area indicate that the damping coefficient of the rectangular tip may be 3 percent higher than that of the rounded tip. This error, which would tend to reduce the rolling velocities shown for the square-tip wing, is within the accuracy of the results of these tests.

The data of figure 32 indicate that by replacing the rounded tip by a square tip and extending the aileron outboard (approximately 18 in. available) the rolling effectiveness can be increased 20 percent without any inboard extension of the aileron.

CONCLUSIONS

A pair of closely balanced experimental Frise ailerons with beveled trailing edges was tested in flight. These ailerons were designed for application to an experimental fighter airplane, which incorporated the wings of a production fighter airplane as outer panels added to a rectangular center section. The flight tests were conducted with the production fighter airplane. The following conclusions were drawn from the results obtained:

1. The experimental ailerons provided linear variation of rolling moment with deflections from $-24\frac{1}{2}^{\circ}$ to 22°. With a total aileron-deflection range of 48°, values of aileron effectiveness of 0.137 on the test airplane and 0.098 on the experimental fighter airplane would be available.

2. The calculations indicated that the ailerons provide a sufficient degree of balance to obtain a range of aileron deflection of $\pm 24^{\circ}$ with a stick force of 32 pounds at 202 miles per hour, the highest test speed, when a rigid control system is used.

3. With the test-airplane control system the stick-force gradient was heavy at small deflections and the ailerons were overbalanced at large deflections because of the adverse effects of control-system elasticity.

4. The calculations indicated that, with a control-system flexibility equal to that of the system of the experimental fighter airplane, the aileron stick forces would be unsatisfactory at a speed of 300 miles per hour or more.

5. Exceptional care must be exercised in the construction of highly balanced Frise ailerons because

small protuberances on the leading edge of the balance area may cause overbalance or premature stalling of the balance on the up-deflected aileron.

6. The calculations indicated that extending the aileron 18 inches on the outboard end would increase the aileron rolling effectiveness 20 percent.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., March 28, 1946

REFERENCE

1. Gilruth, R. R., and Turner, W. N.: Lateral Control Required for Satisfactory Flying Qualities Based on Flight Tests of Numerous Airplanes. NACA Rep. No. 715, 1941.

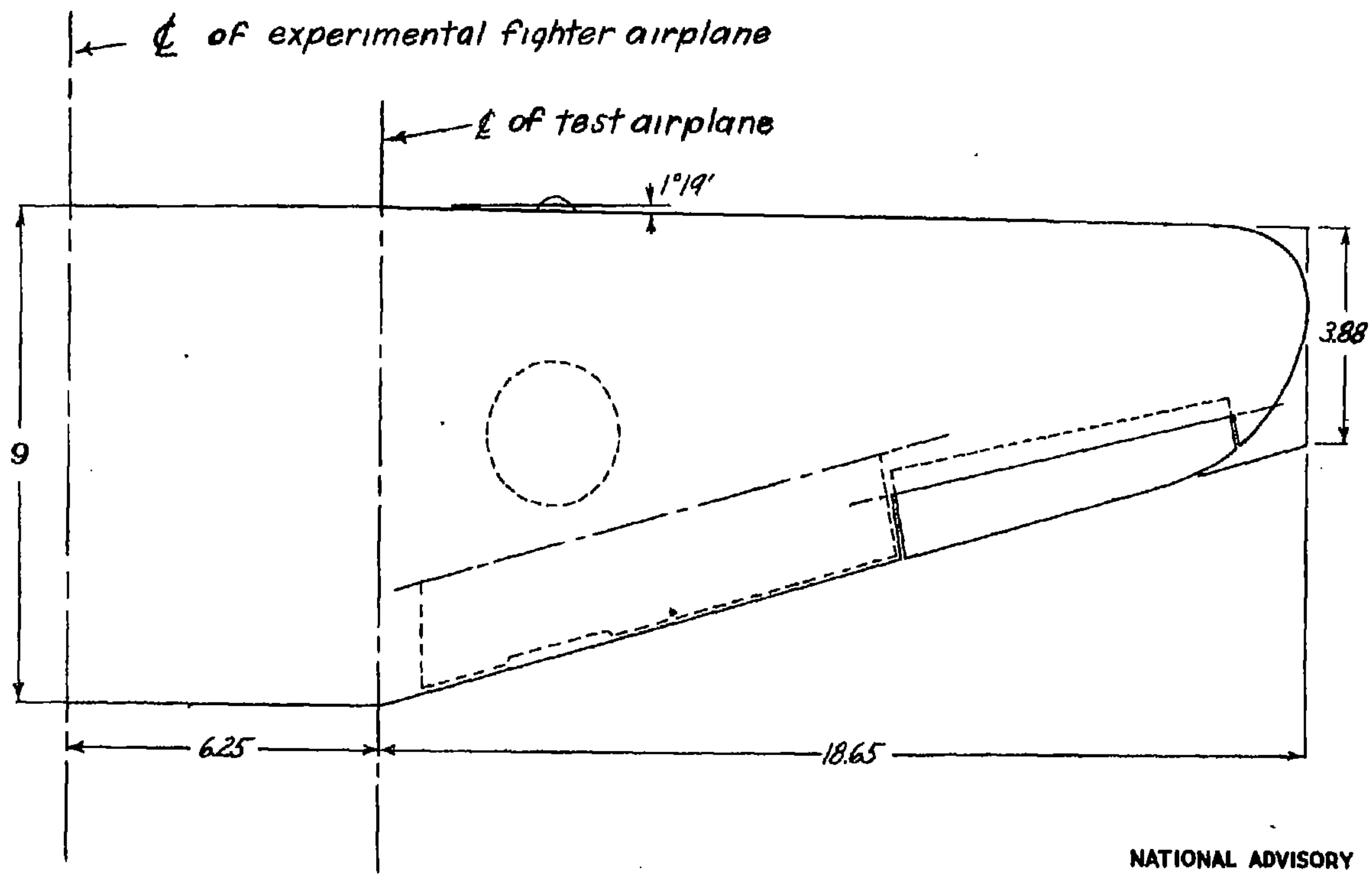

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Figure 1.- Wing plan form of experimental fighter airplane in relation to wing plan form of test airplane. (All dimensions in feet.)

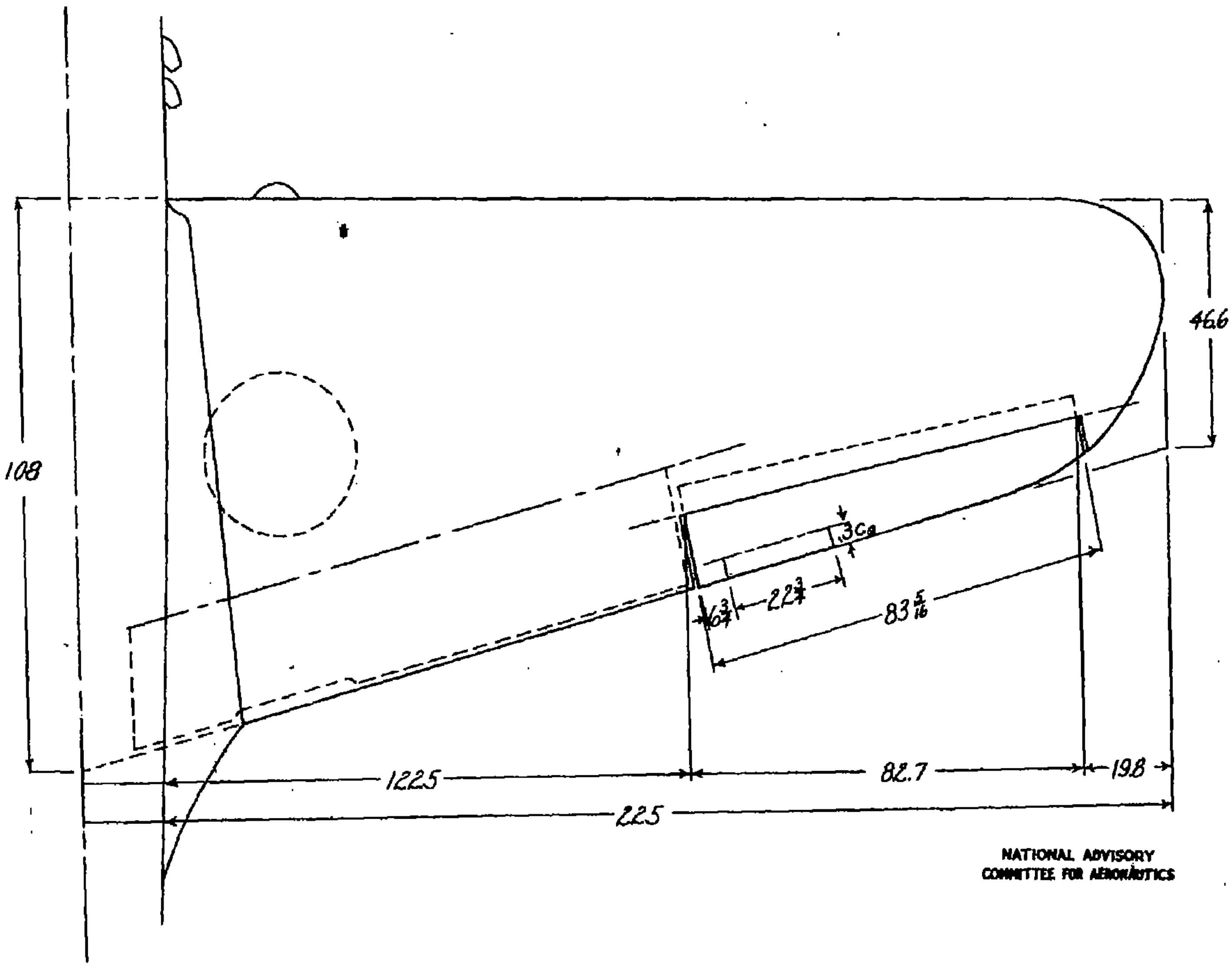
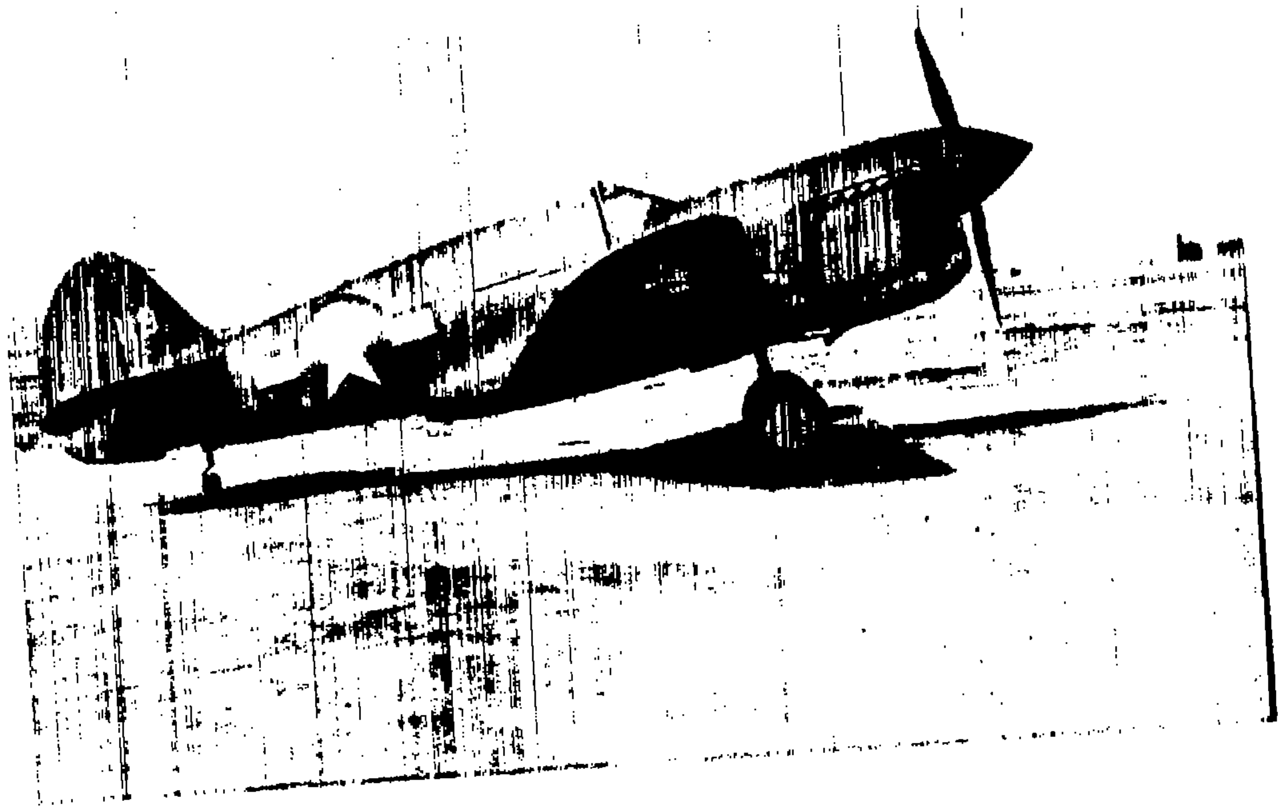
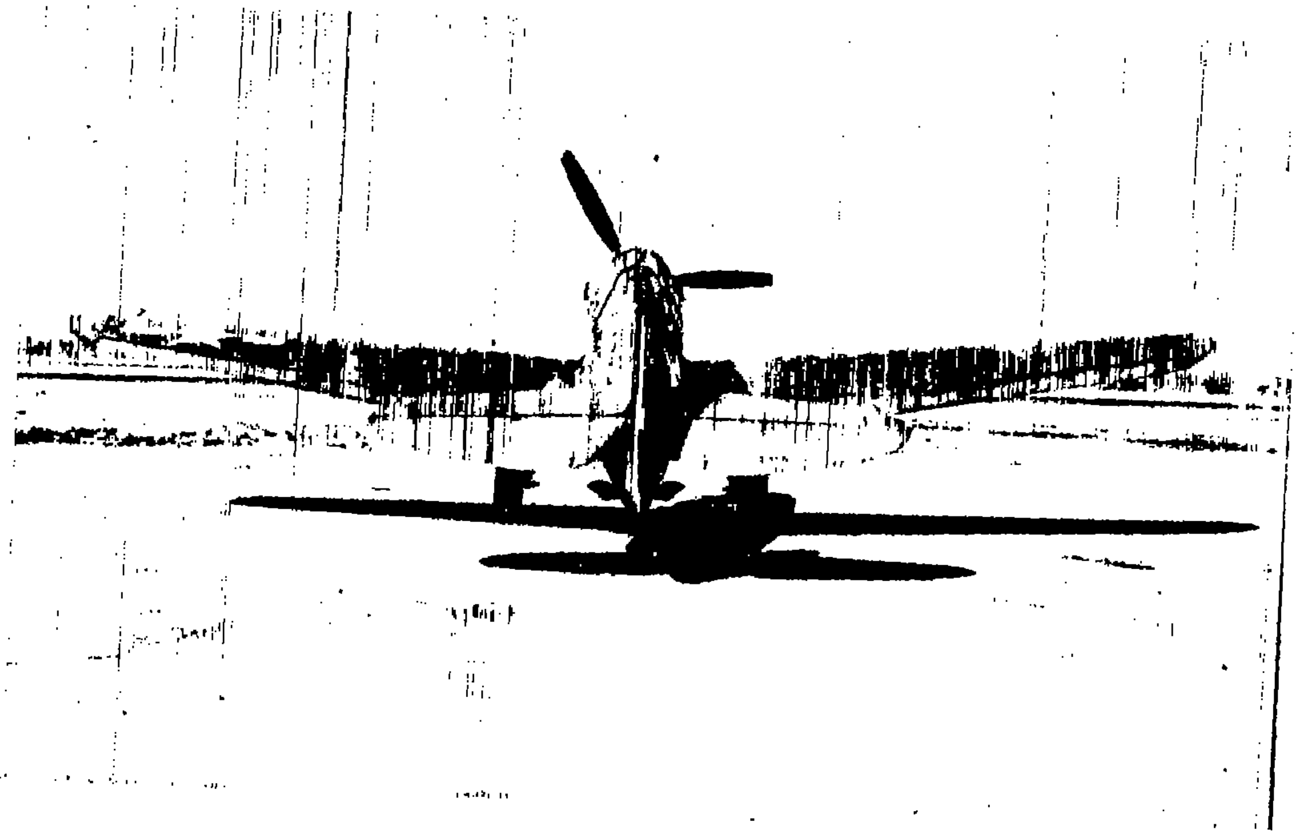


Figure 2.- Test-airplane wing with experimental aileron. (All dimensions in inches.)



(a) Side view.

Figure 3.- Test airplane.



(b) Rear view.

Figure 3.- Concluded.

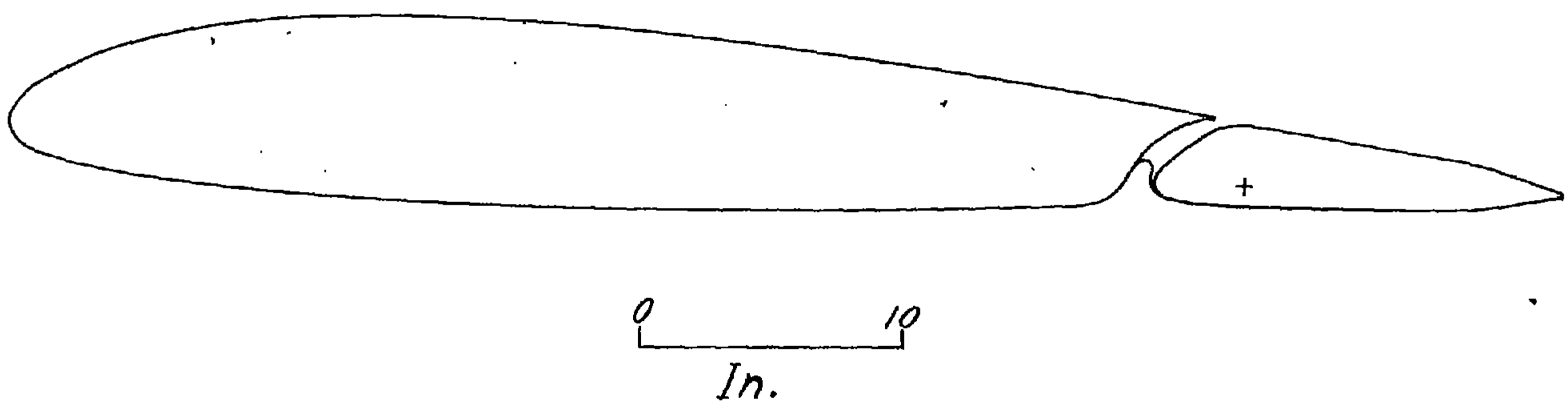


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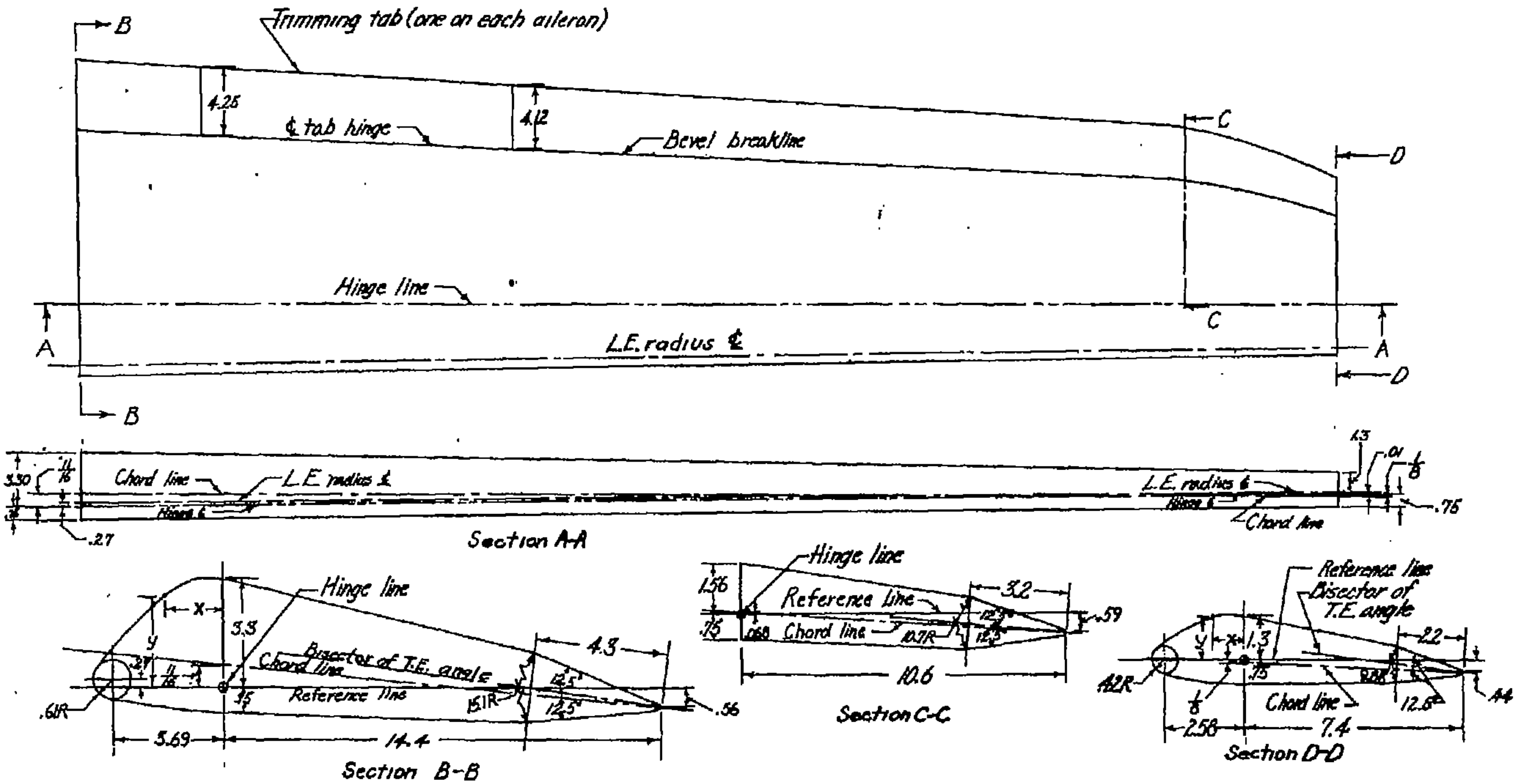
Figure 4.- Aileron-wing profile measured parallel to the thrust axis at the aileron center hinge.



Ordinates of L. E. contour at section B-B							
X	0.5	1.0	1.5	2.0	2.5	3.0	3.5
Y (upper)	3.31	3.24	3.05	2.73	2.32	1.87	1.37
Y (lower)	0.72	0.68	0.63	0.57	0.51	0.44	0.37

Ordinates of L. E. contour at section D-D					
X	0.5	1.0	1.5	2.0	2.5
Y (upper)	2.35	1.27	1.09	0.86	0.66
Y (lower)	0.73	0.69	0.63	0.57	0.46

(a) Specifications for experimental aileron contours. (All dimensions in inches.)

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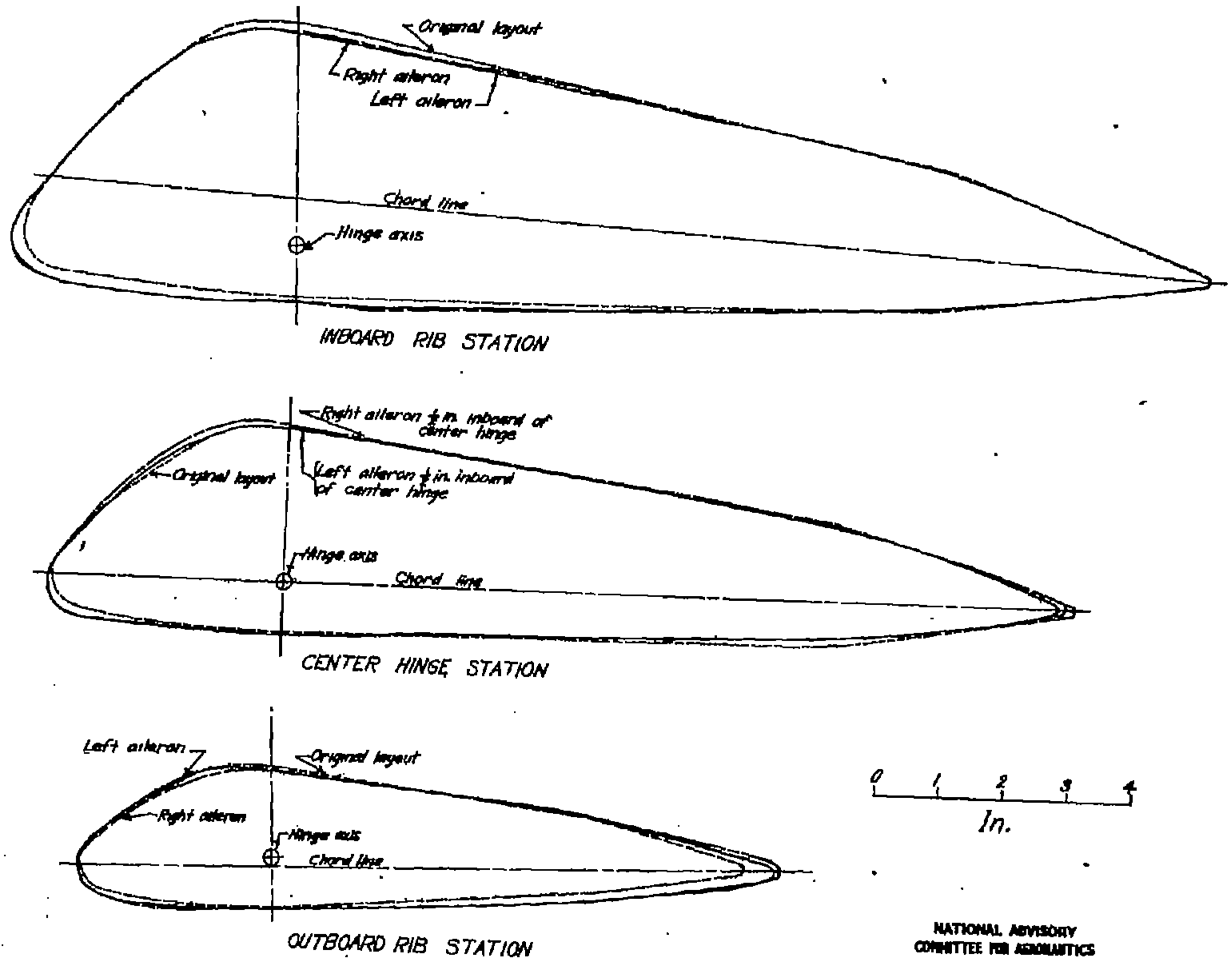
Figure 5.- Details of aileron contours.



(b) Comparison of measured aileron contours with original layout.

Figure 5.- Concluded.

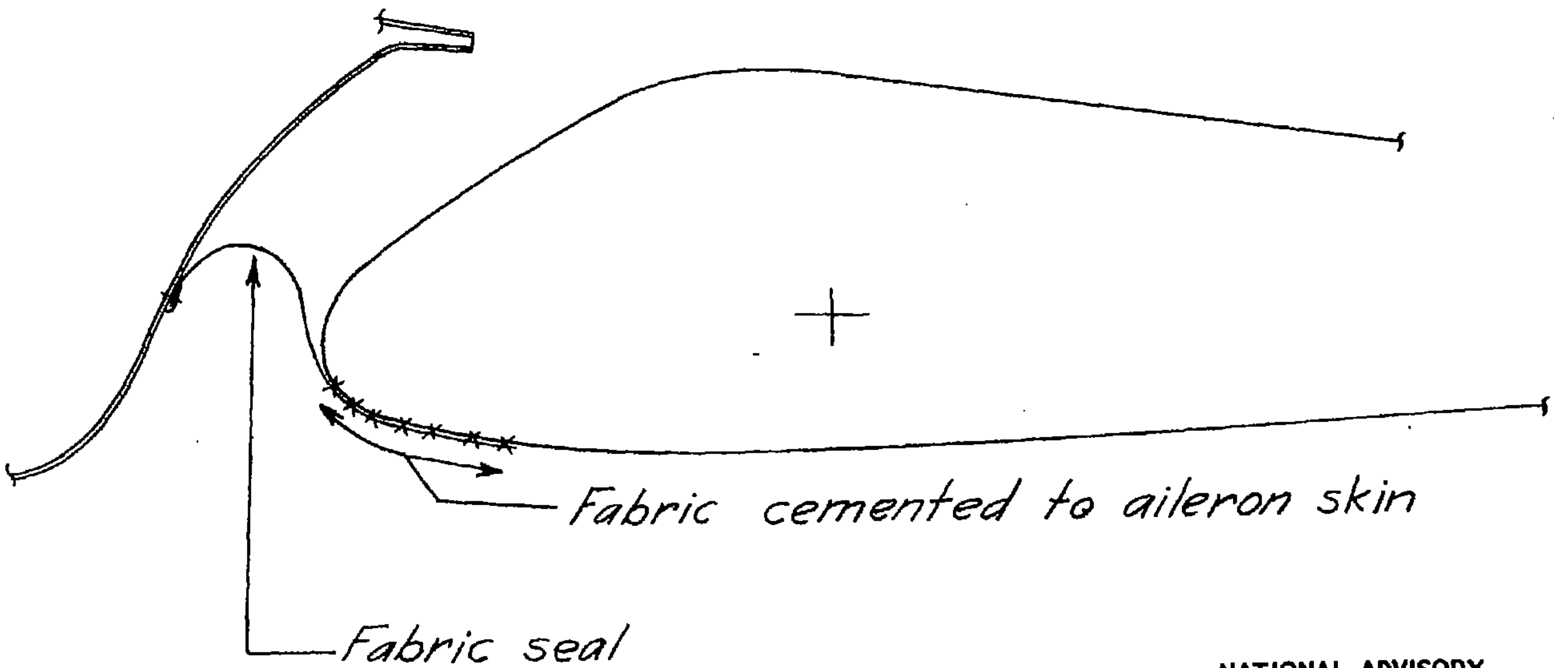


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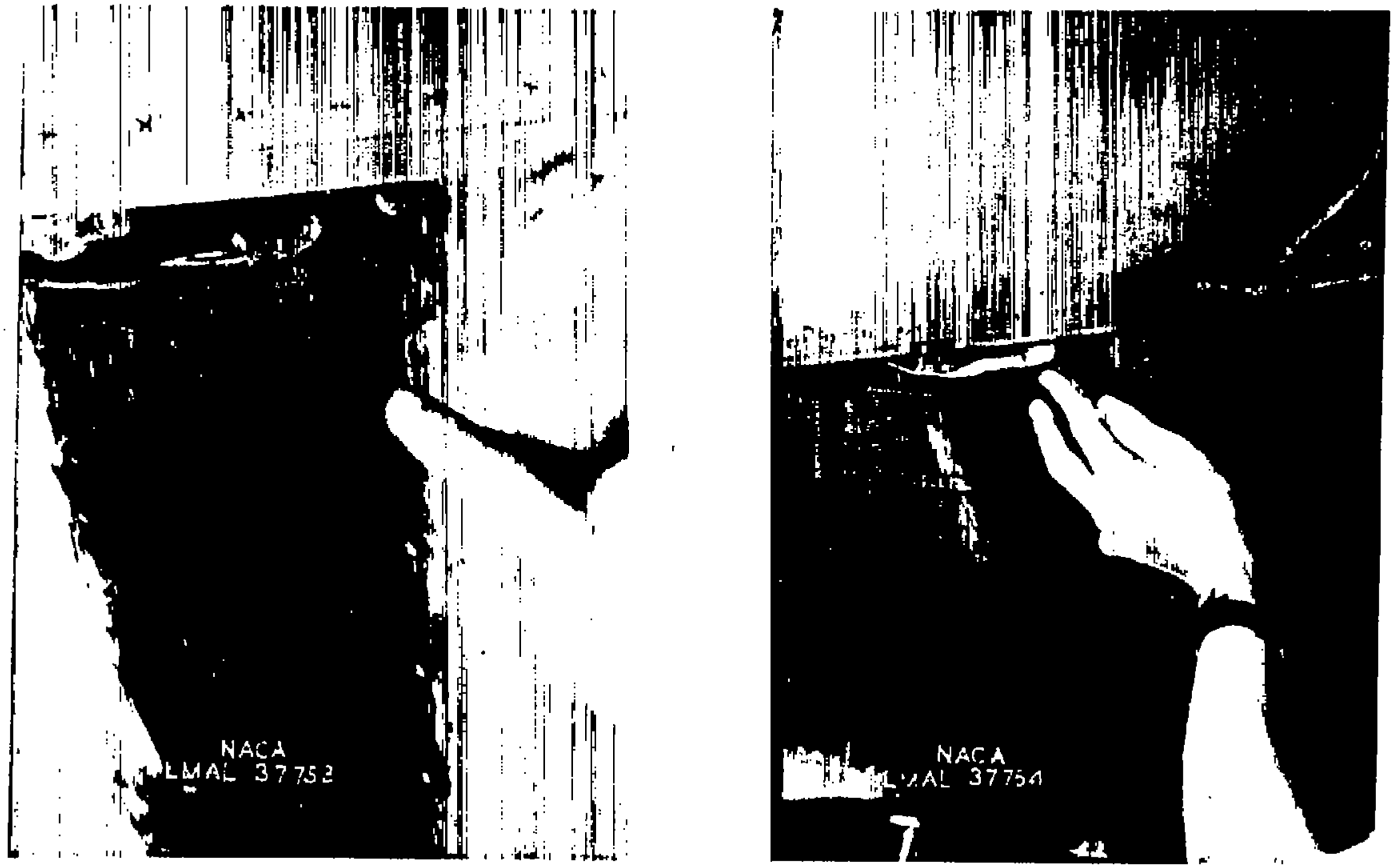
Figure 6.- Typical section through aileron gap showing method of installing seal.



a) Seal in place.

(b) Seal pulled away from wing.

Figure 7.- Method of installing flexible seal over aileron-nose gap at outboard end of aileron.

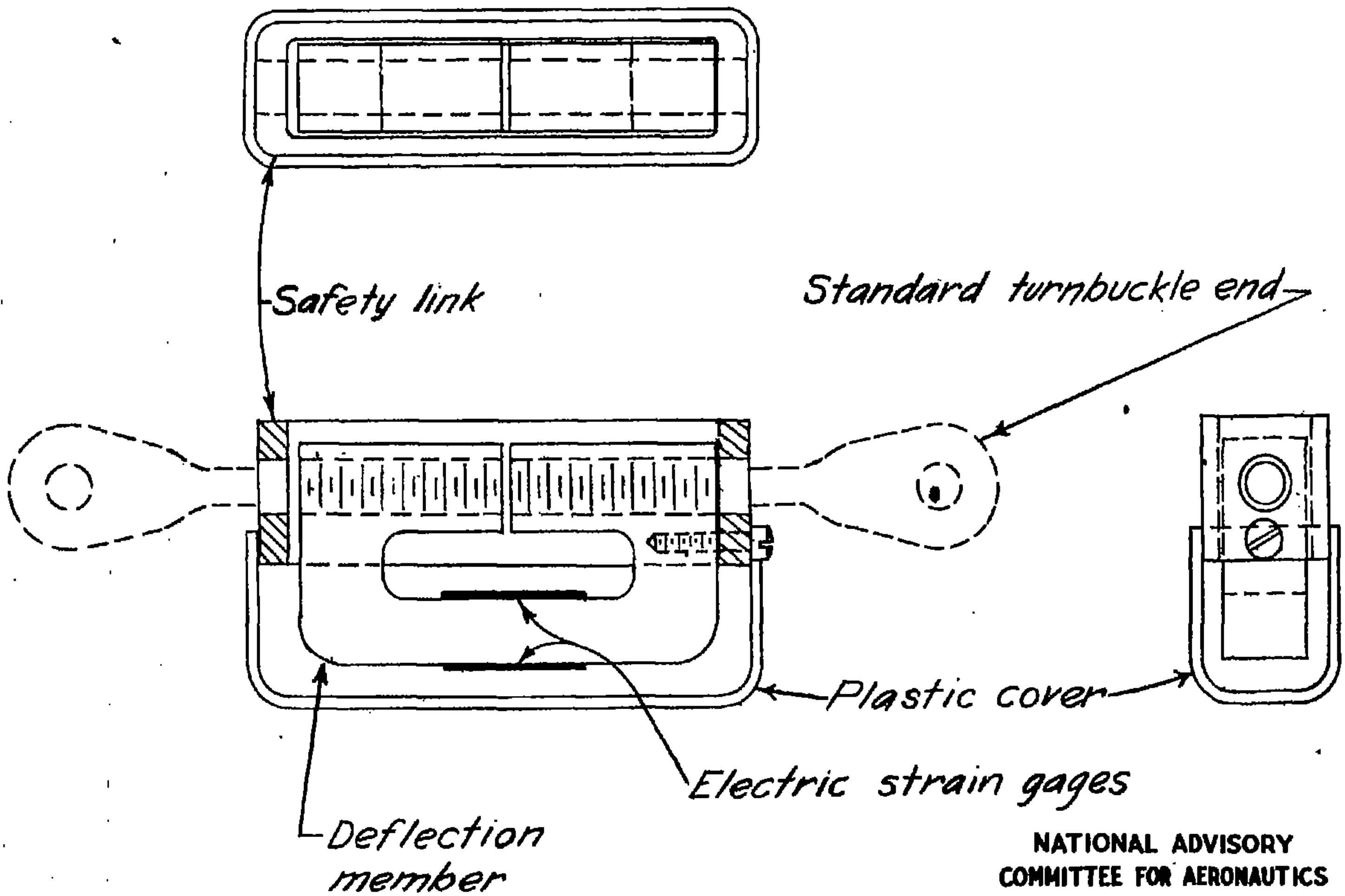
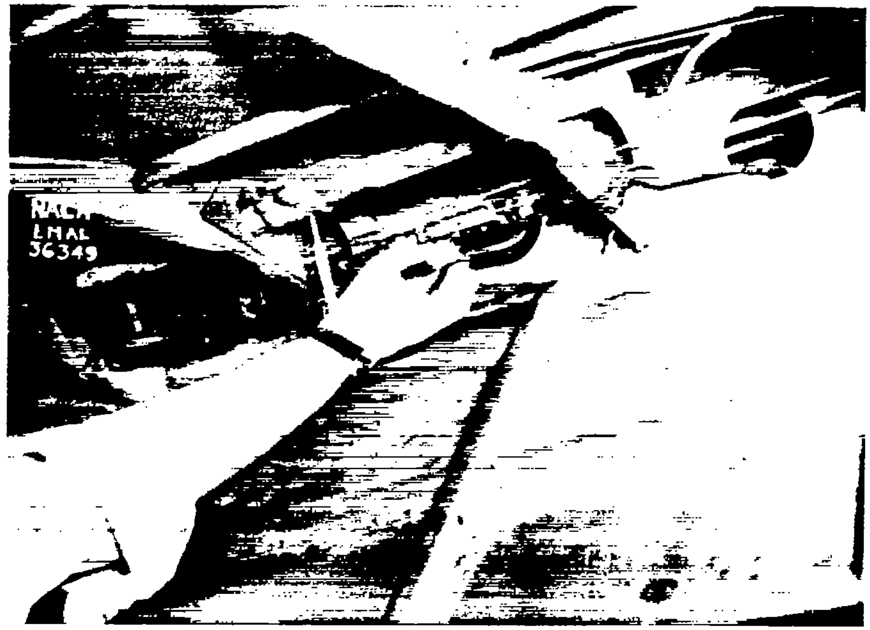


Figure 8.- Three-view drawing of cable-tension-recorder unit.



(a) Top view.

(b) Side view.

Figure 9.- Cable-tension-recorder unit used to measure aileron hinge moments.

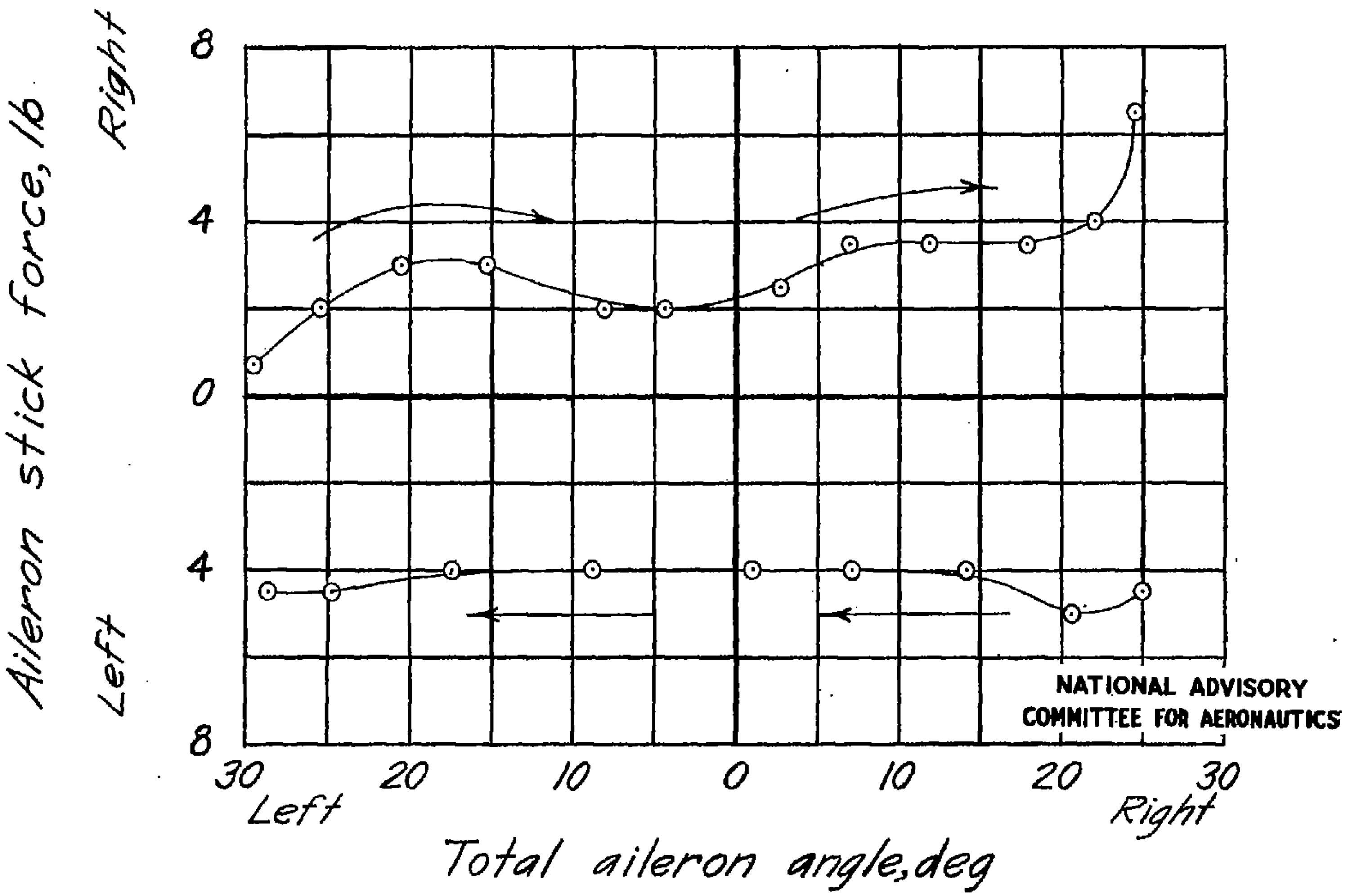


Figure 11.- Stick forces due to friction in aileron control system as measured on the ground without aileron load. Small-deflection tests; aileron-nose gap unsealed.

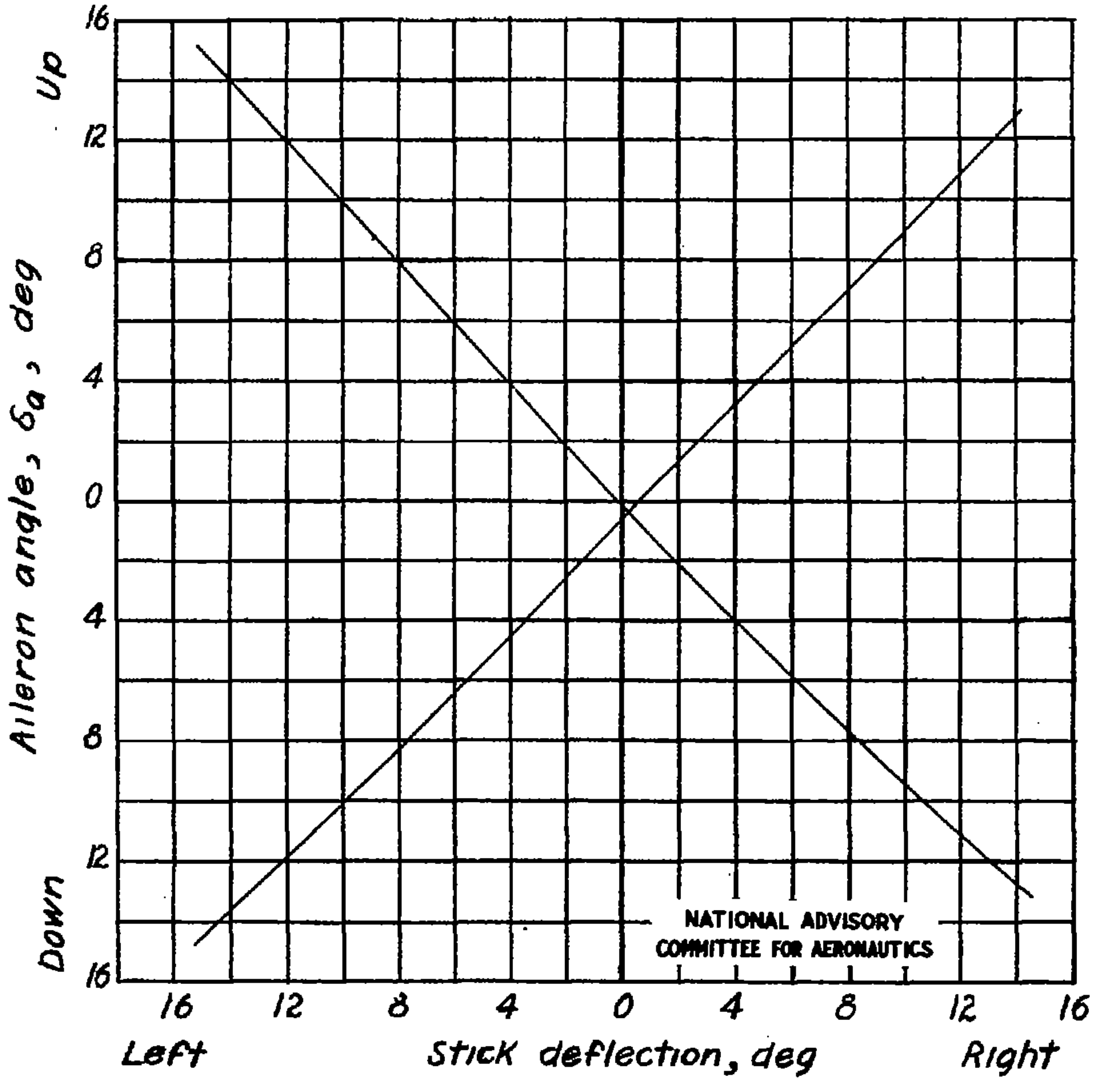


Figure 10.- Variation of aileron angle with stick deflection on test airplane, as measured on the ground without aileron load. Small-deflection tests.

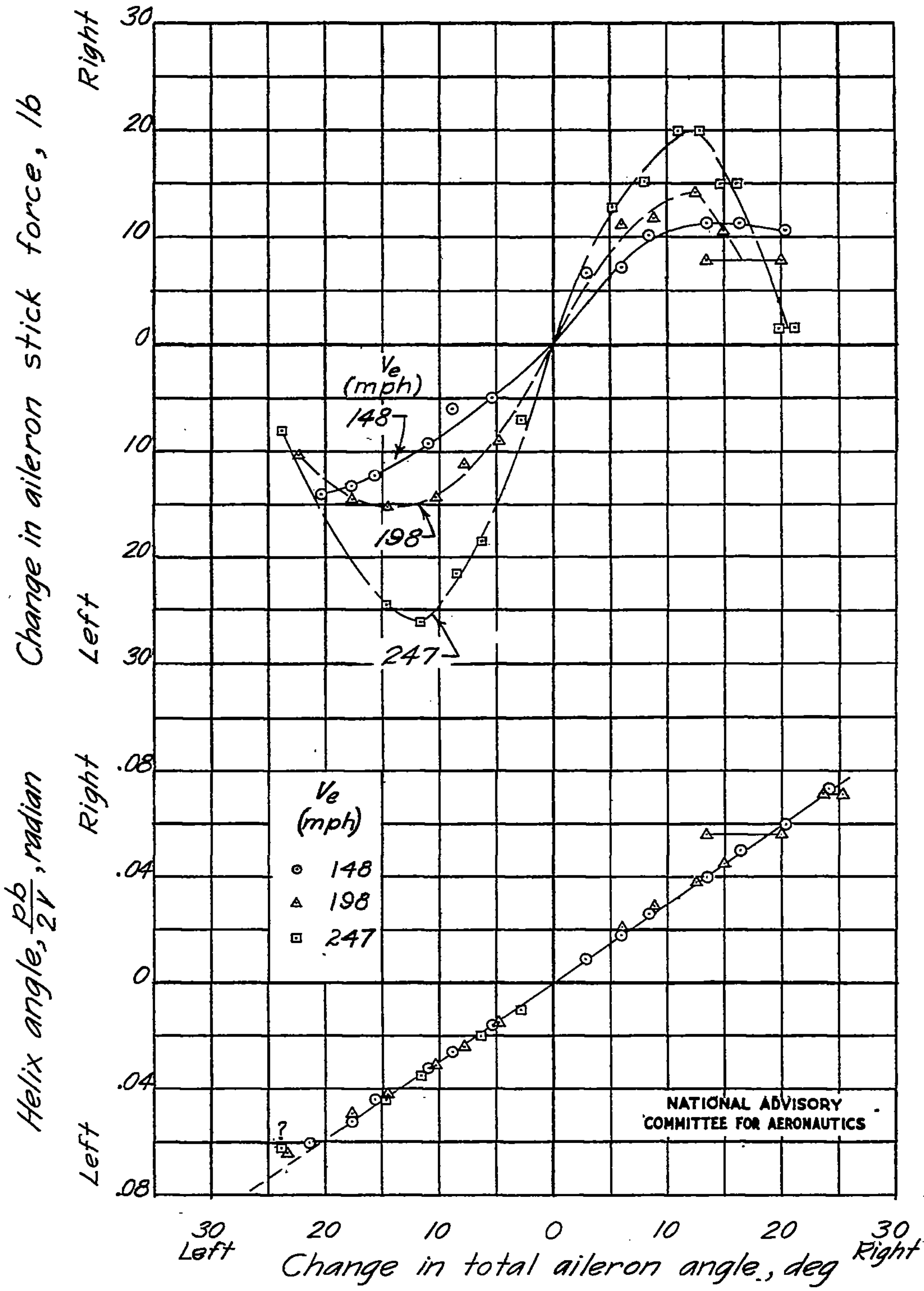


Figure 12.- Variation of helix angle pb/2V and stick force with aileron angle. Small-deflection tests; aileron-nose gap unsealed; trimming tabs sealed at 0° deflection.

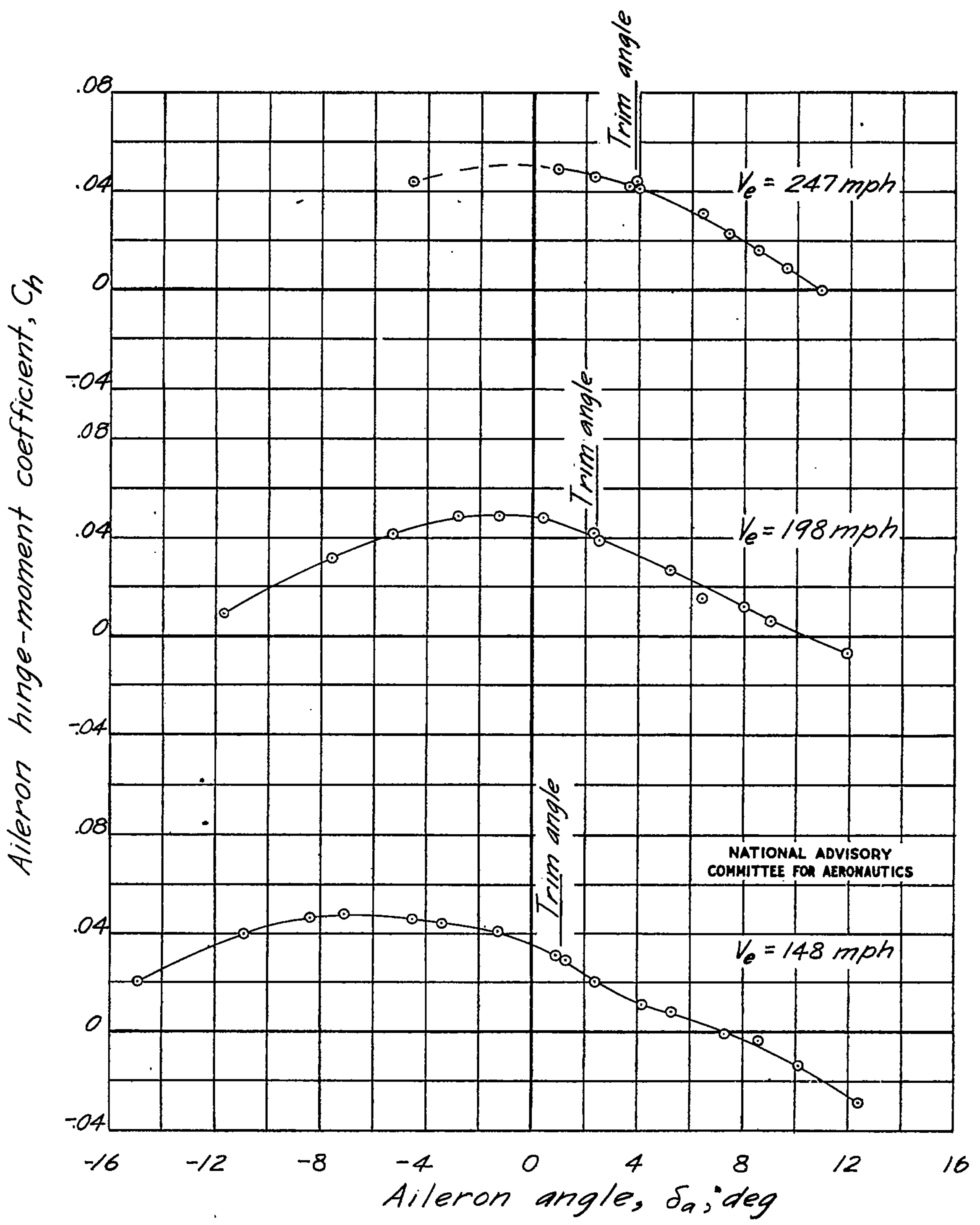


Figure 13.- Variation of hinge-moment coefficient of left aileron with aileron angle measured during condition of steady rolling velocity. Small-deflection tests; aileron-nose gap unsealed; trimming tabs sealed at 0° deflection.

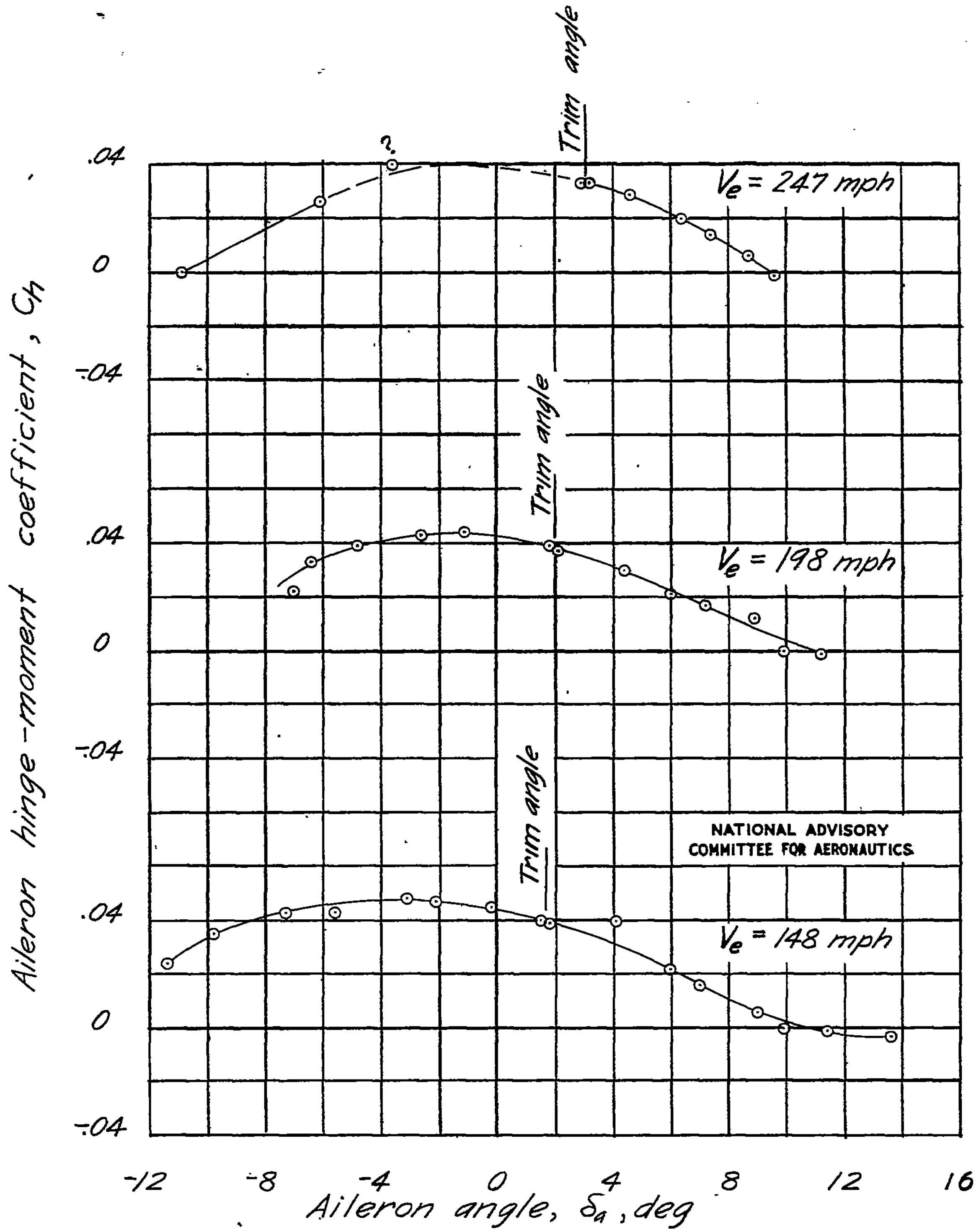


Figure 14.- Variation of hinge-moment coefficient of right aileron with aileron angle measured during condition of steady rolling velocity. Small-deflection tests; aileron-nose gap unsealed; trimming tabs sealed at 0° deflection.

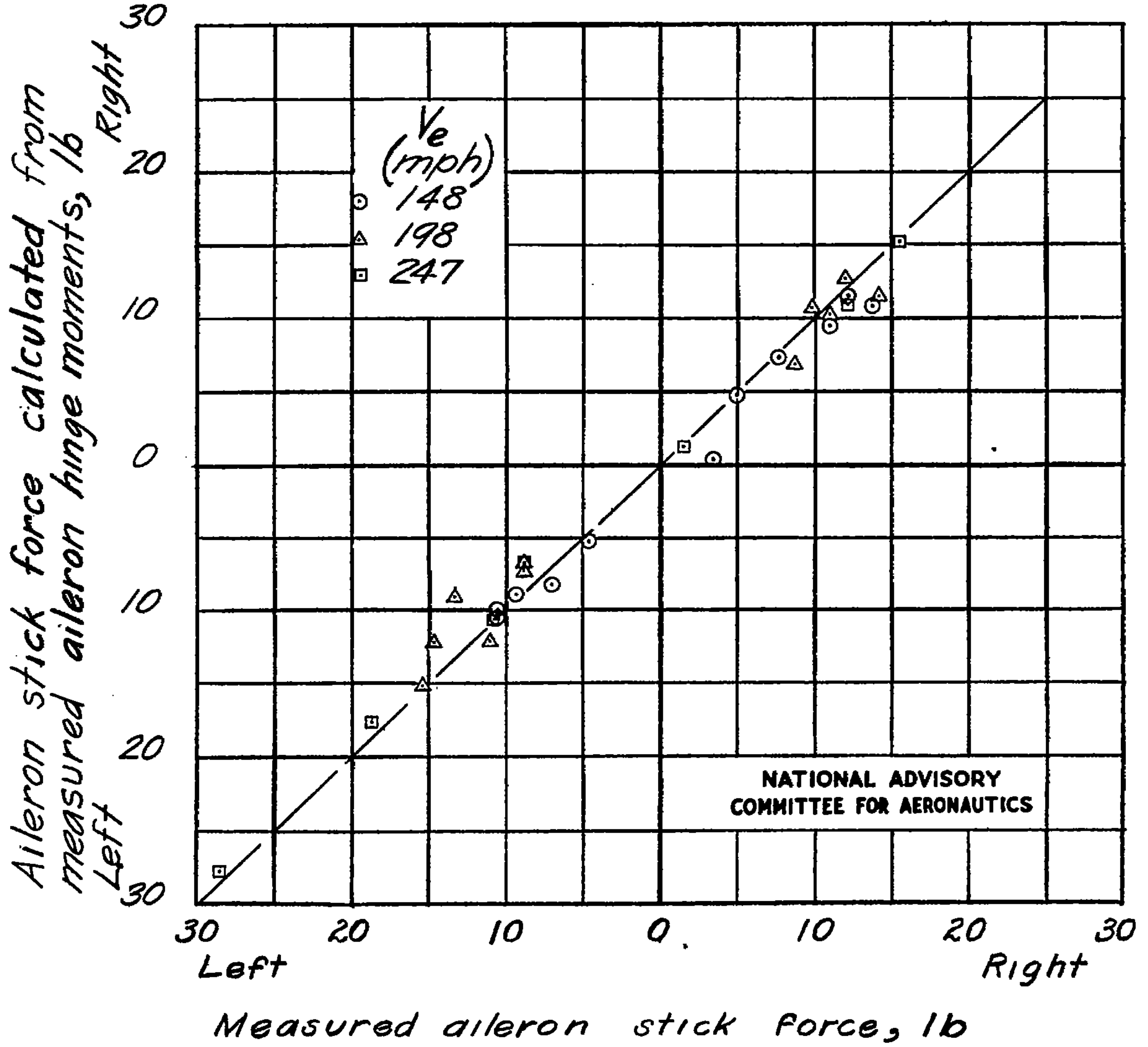


Figure 15.- Comparison of aileron stick forces measured at control stick and forces calculated from measured values of individual aileron hinge moments. Small-deflection tests; aileron-nose gap unsealed.

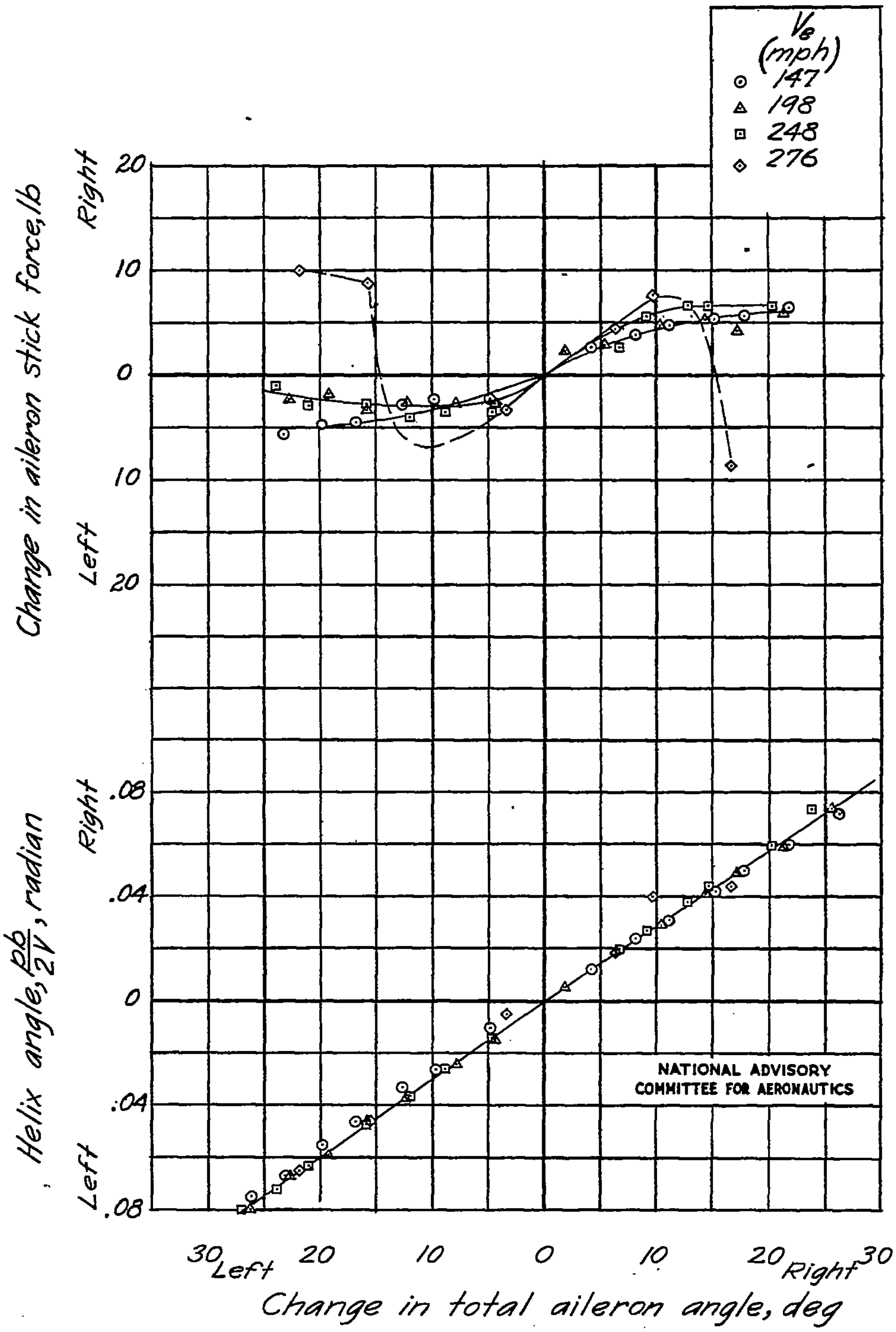


Figure 16.- Variation of helix angle pb/2V and stick force with aileron angle. Small-deflection tests; aileron-nose gap sealed; trimming tabs sealed at 0° deflection.

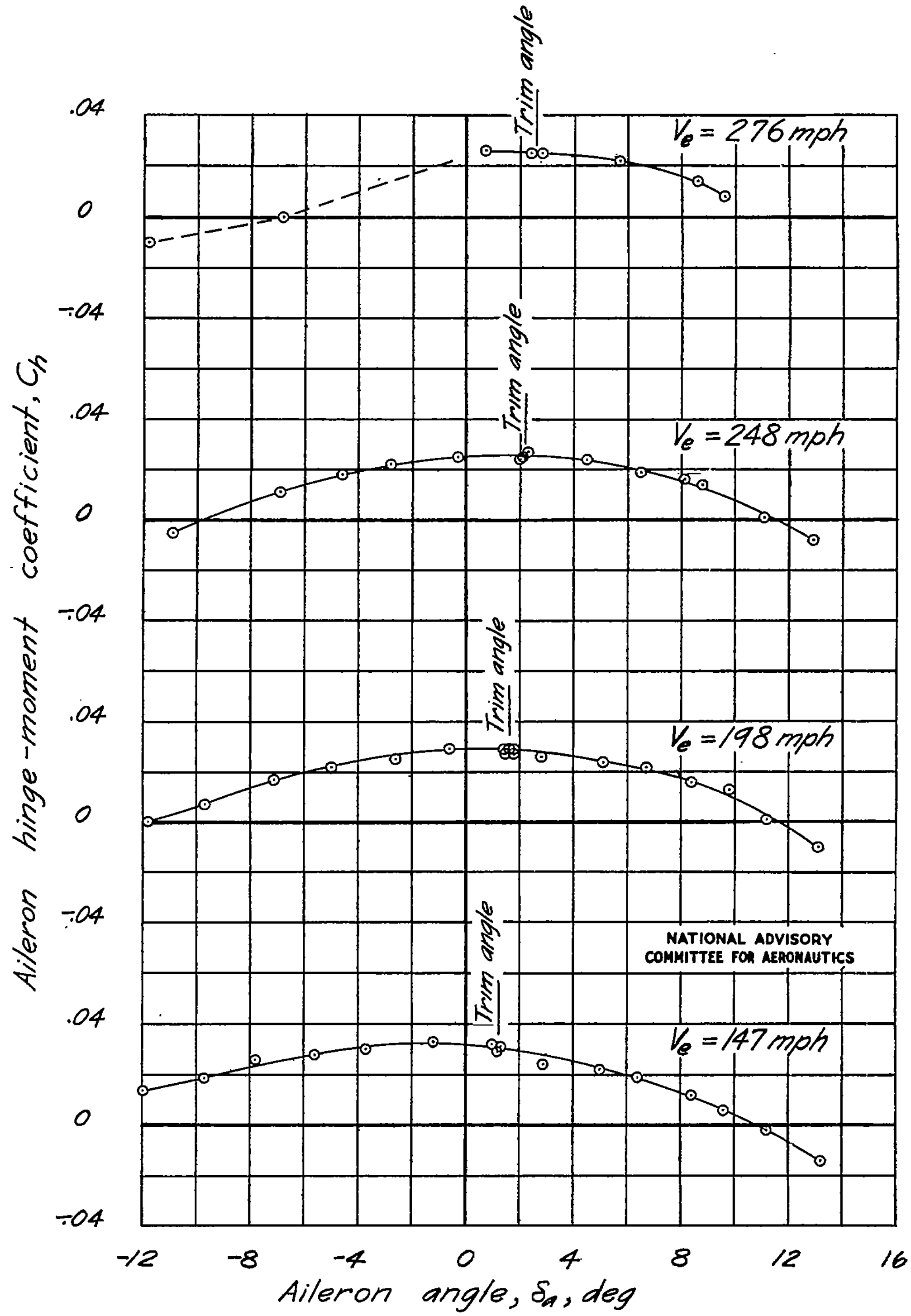


Figure 17.- Variation of hinge-moment coefficient of left aileron with aileron angle measured during condition of steady rolling velocity. Small-deflection tests; aileron-nose gap sealed; trimming tabs sealed at 0° deflection.

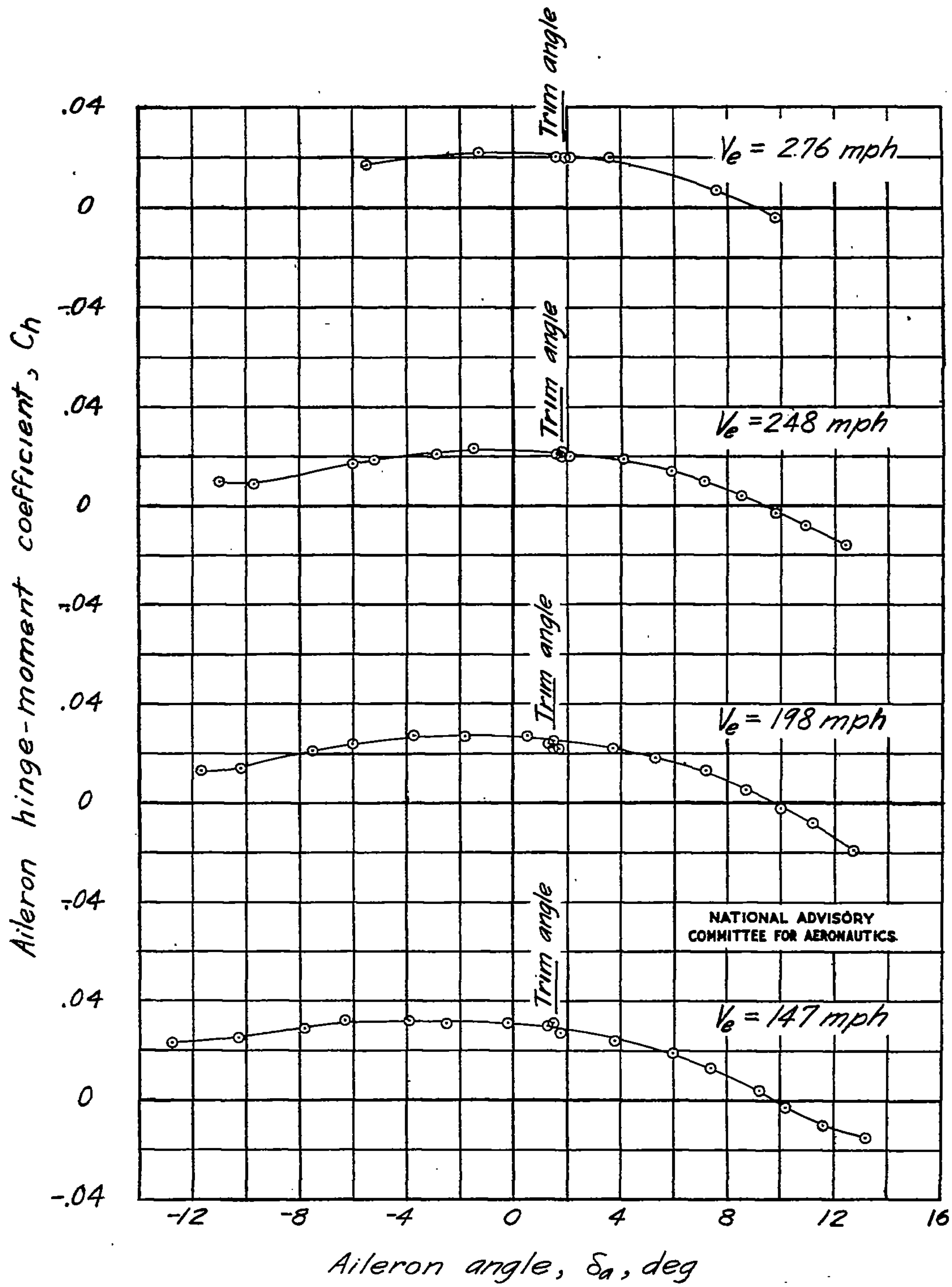


Figure 18.- Variation of hinge-moment coefficient of right aileron with aileron angle measured during condition of steady rolling velocity. Small-deflection tests; aileron-nose gap sealed; trimming tabs sealed at 0° deflection.

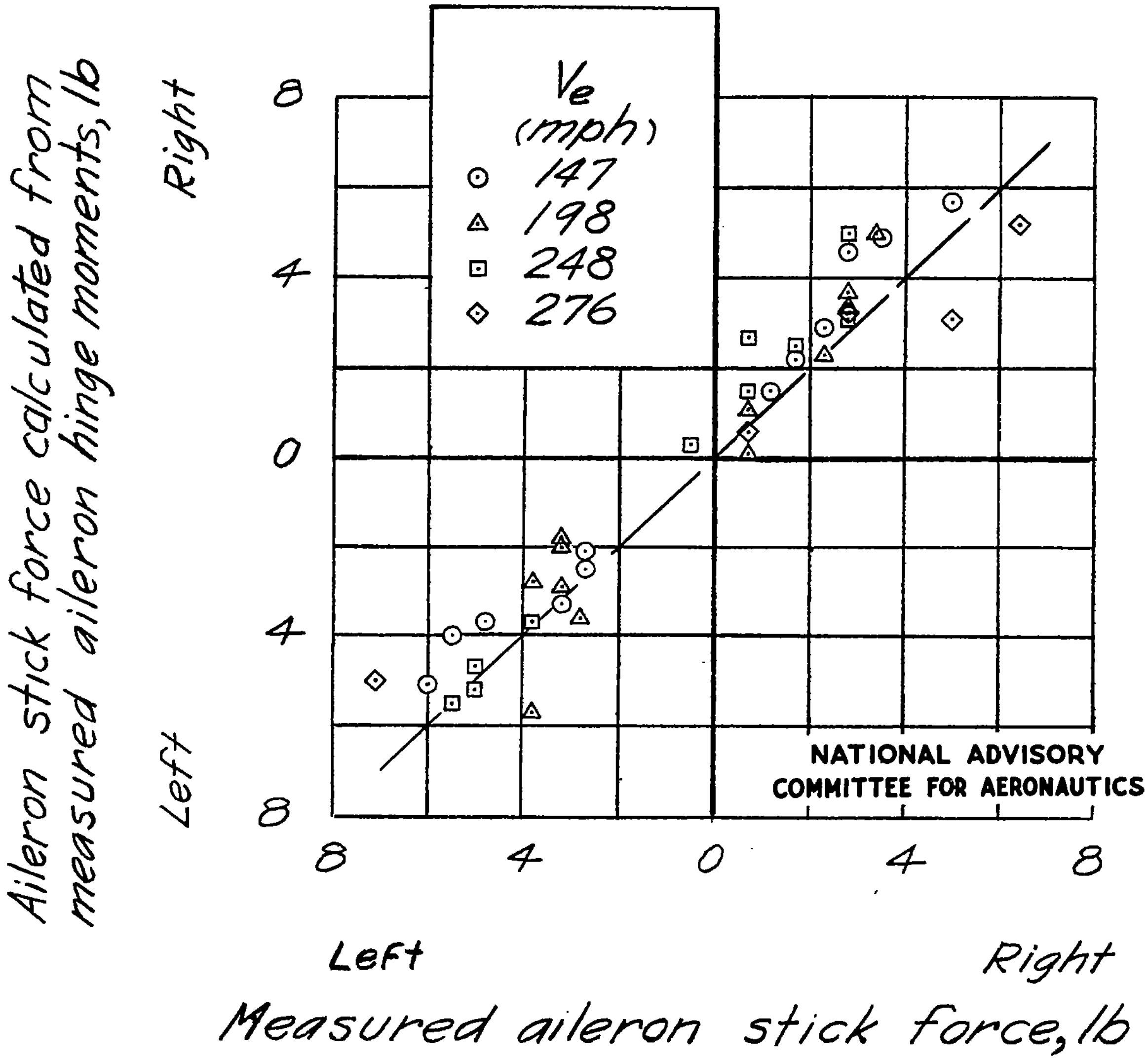


Figure 19.- Comparison of aileron stick forces measured at control stick and forces calculated from measured values of individual aileron hinge moments. Small-deflection tests; aileron-nose gap sealed.

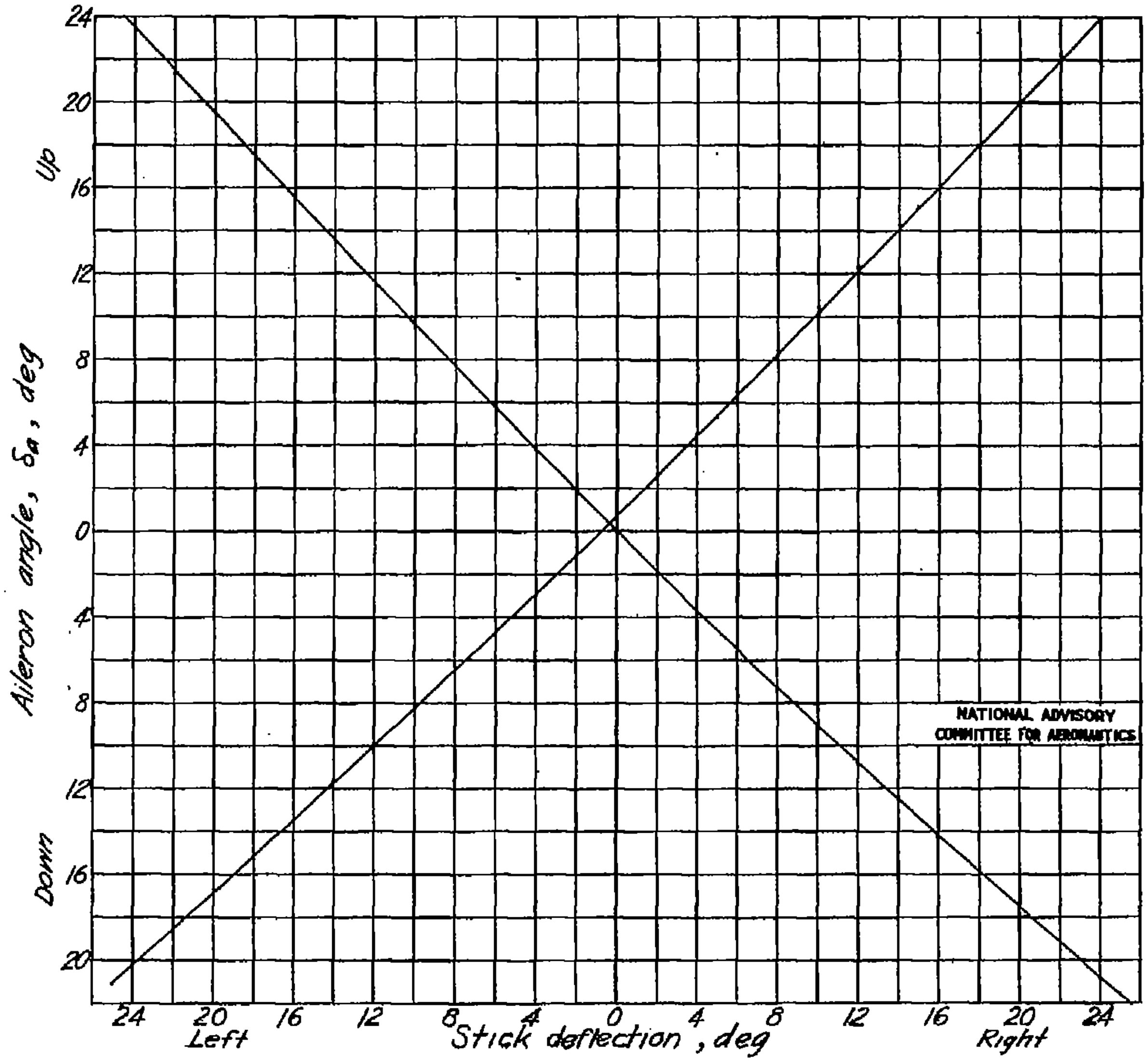


Figure 20.- Variation of aileron angle with stick deflection on test airplane, as measured on the ground without aileron load. Large-deflection tests.

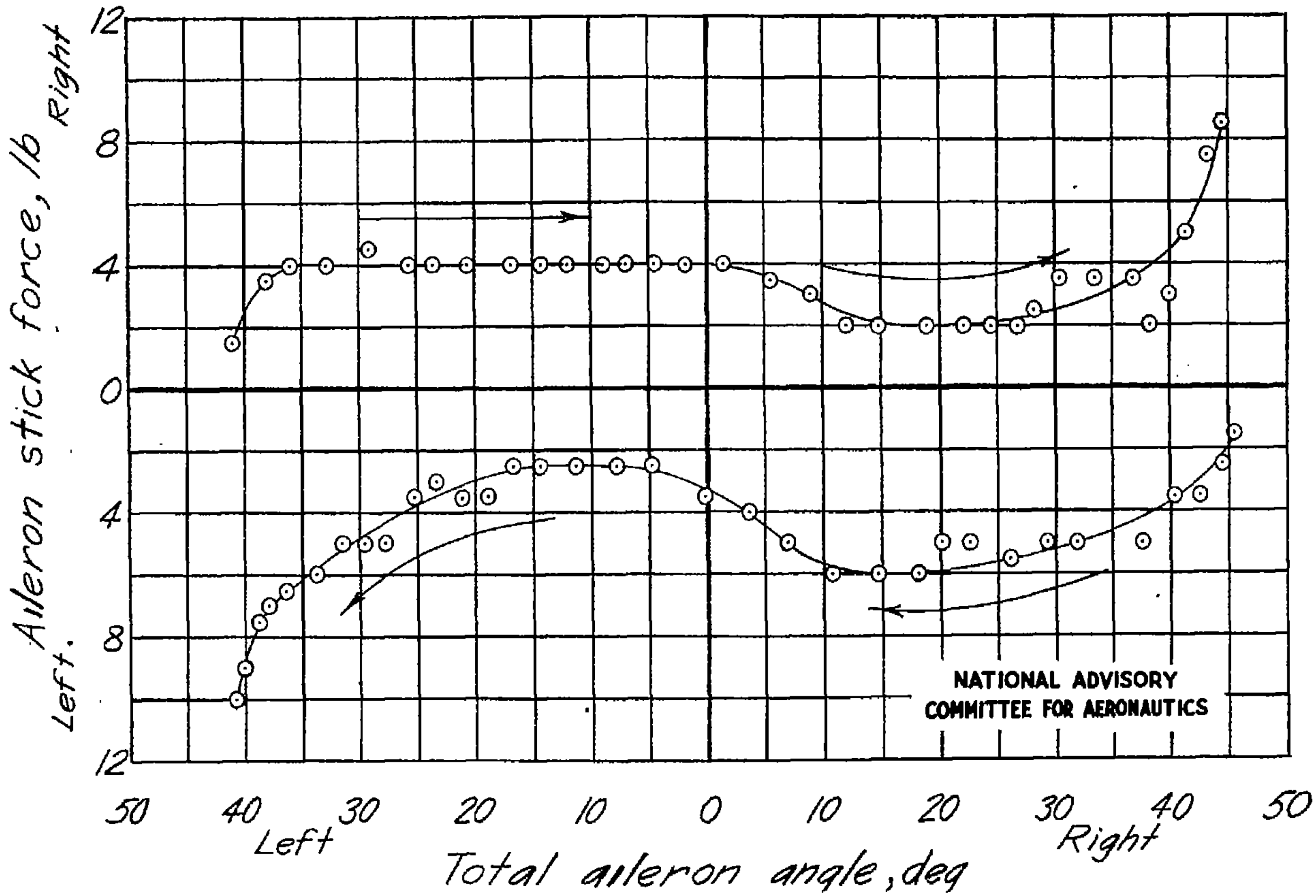


Figure 21.- Stick forces due to friction in aileron control system, as measured on the ground without aileron load. Large-deflection tests; rubberized seal in aileron-nose gap.

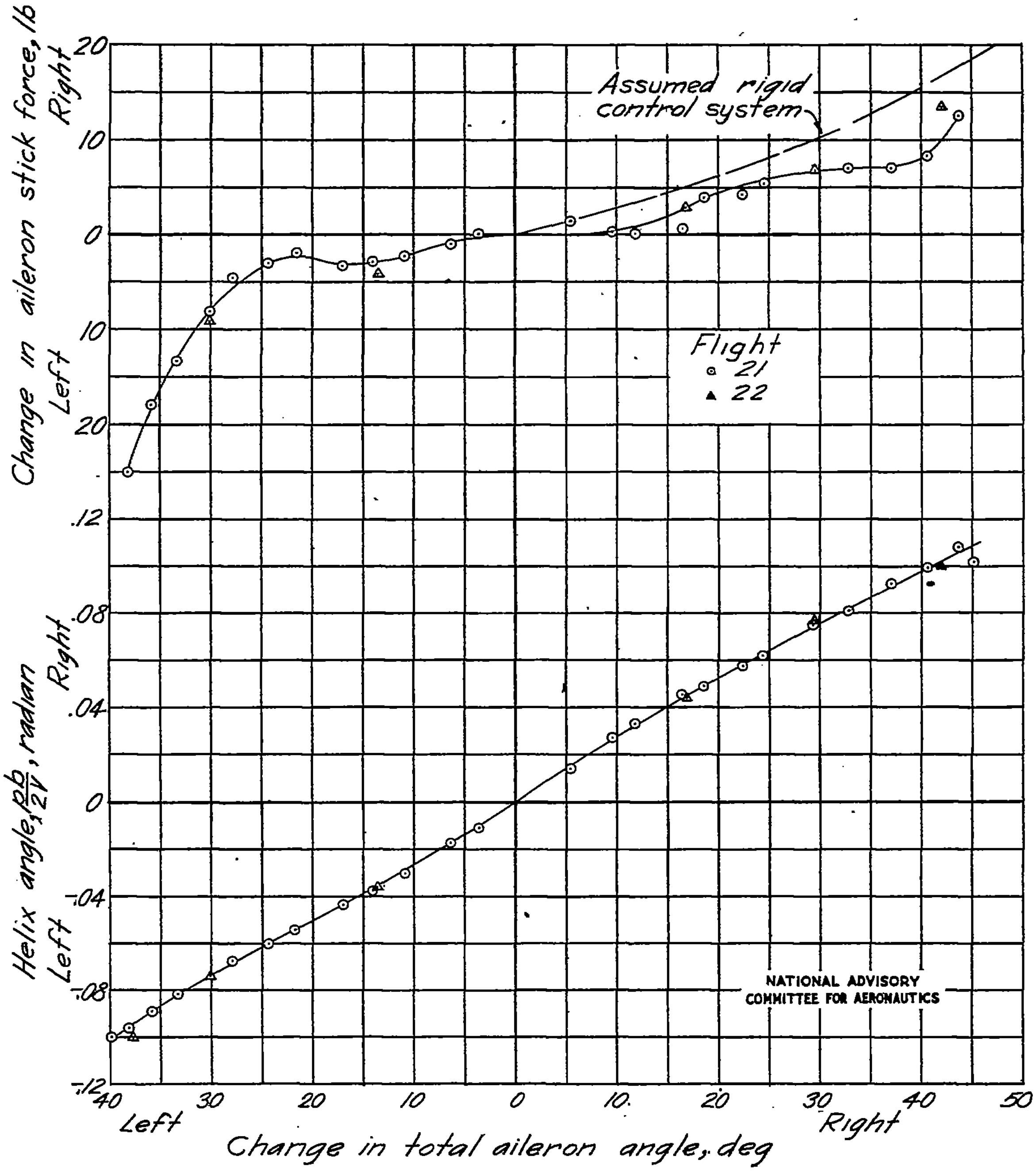


Figure 22.- Variation of helix angle pb/2V and stick force with aileron angle. Large-deflection tests; rubberized seal in aileron-nose gap; V_e = 109 miles per hour; trimming tabs sealed at 5° down deflection.

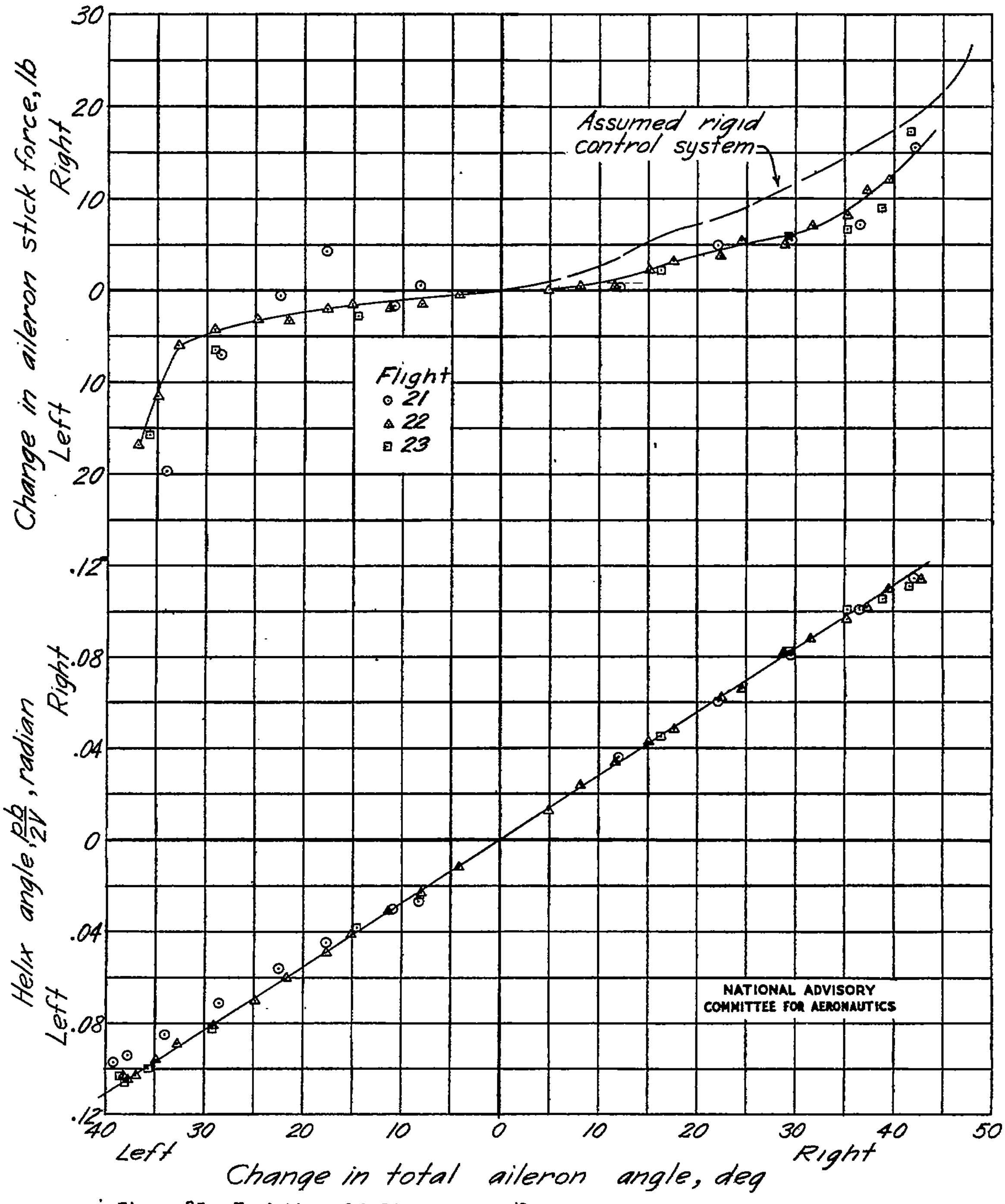


Figure 23.- Variation of helix angle pb/2V and stick force with aileron angle. Large-deflection tests; rubberized seal in aileron-nose gap; V_e = 150 miles per hour; trimming tabs sealed at 5° down deflection.

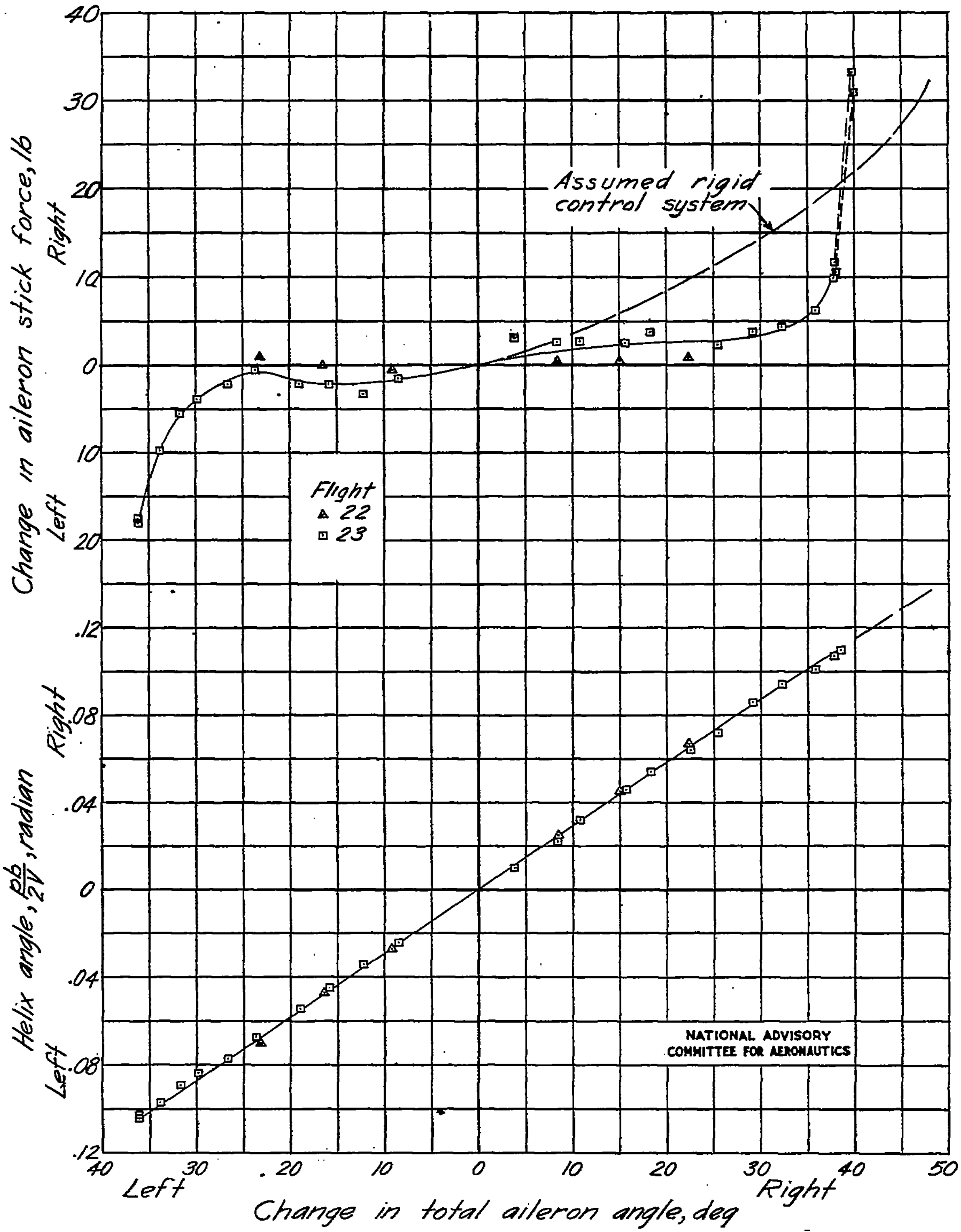


Figure 24.- Variation of helix angle pb/2V and stick force with aileron angle. Large-deflection tests; rubberized seal in aileron-nose gap; V_e = 202 miles per hour; trimming tabs sealed at 5° down deflection.

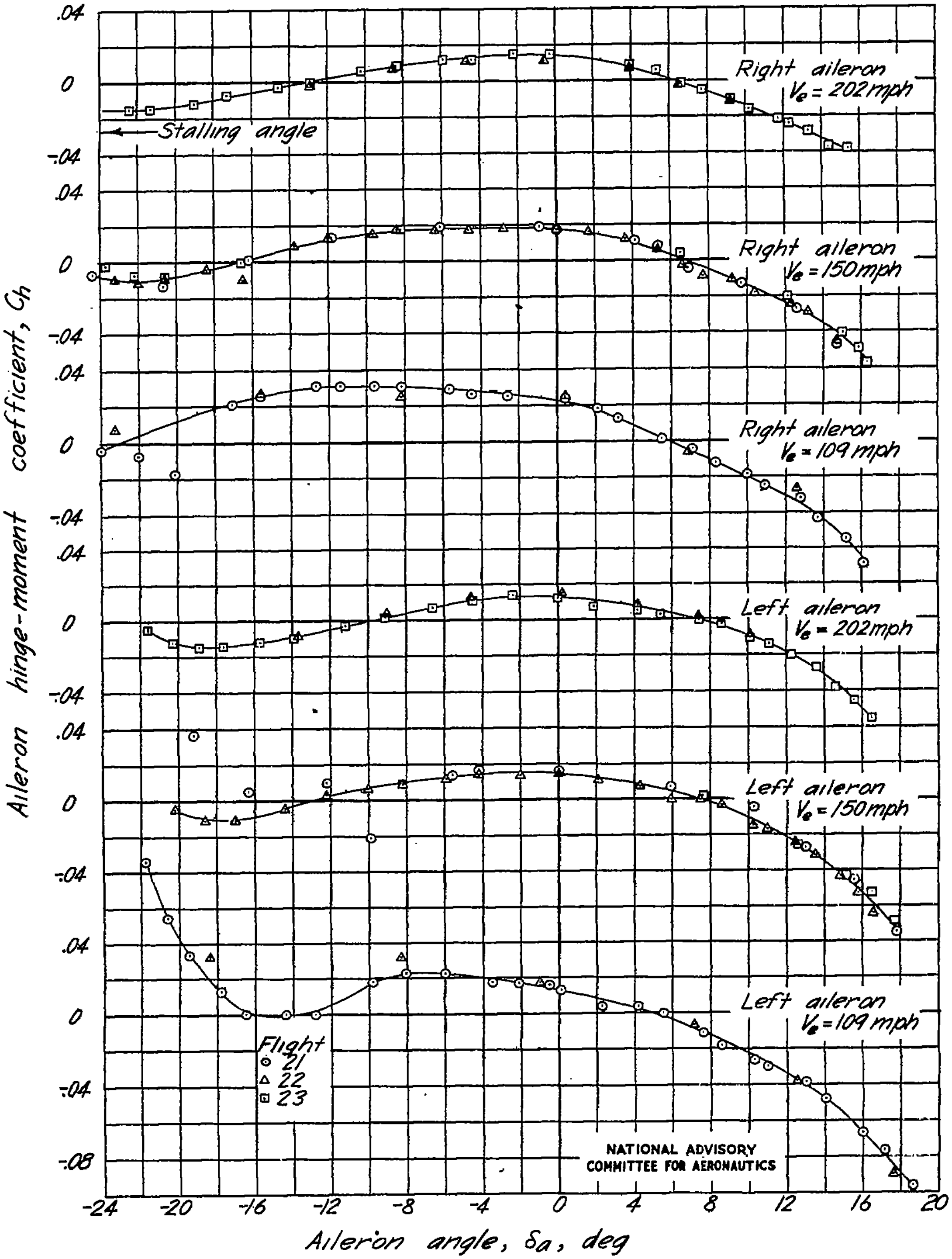


Figure 25.- Variation of hinge-moment coefficient with aileron angle measured during condition of steady rolling velocity. Large-deflection tests; rubberized seal in aileron-nose gap; trimming tabs sealed at 5° down deflection.

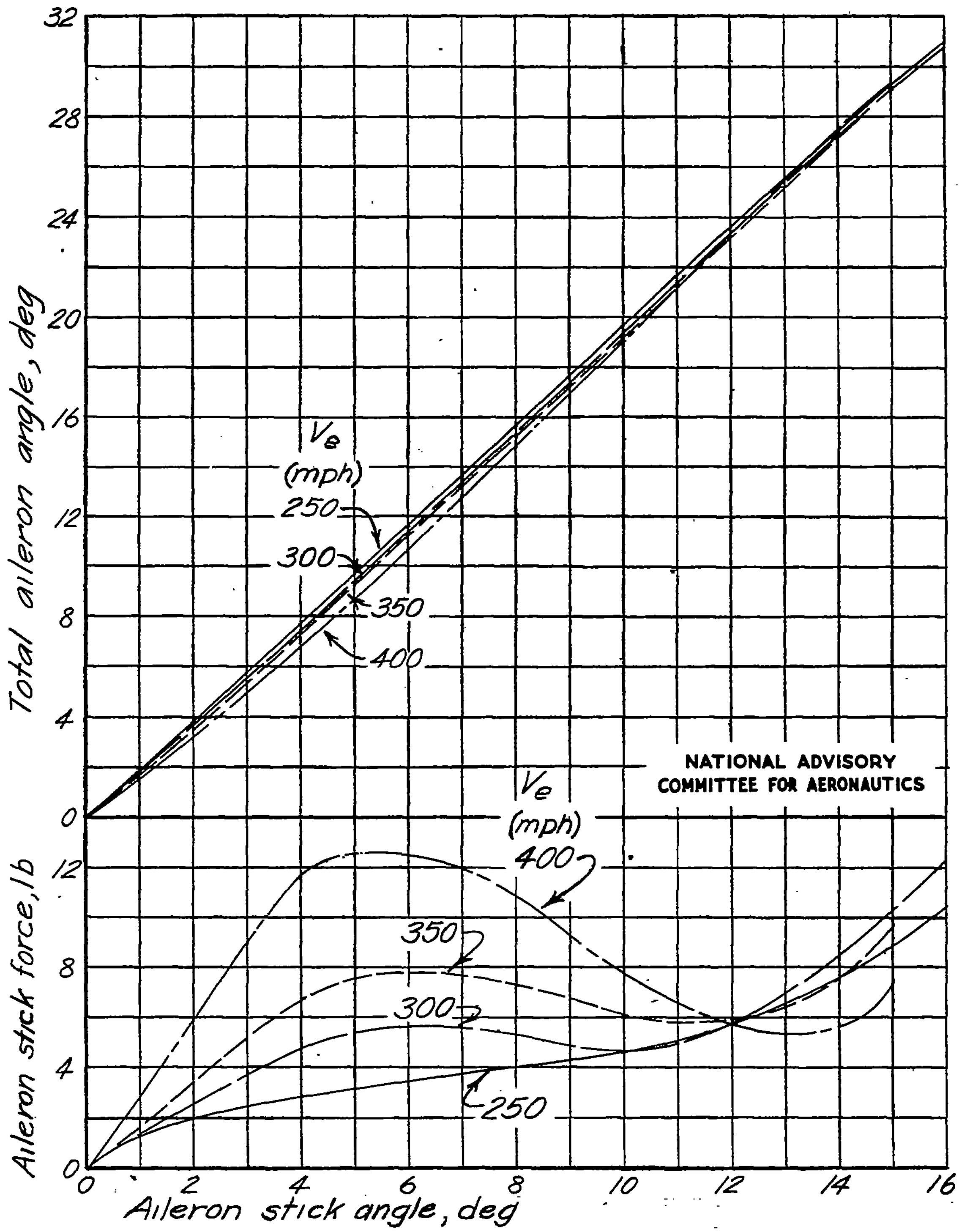


Figure 26.- Summary of effects of stretch on aileron characteristics for aileron control system of experimental fighter airplane. Stretch, 0.058° per pound-foot of hinge moment; V_e = 250 to 400 miles per hour.

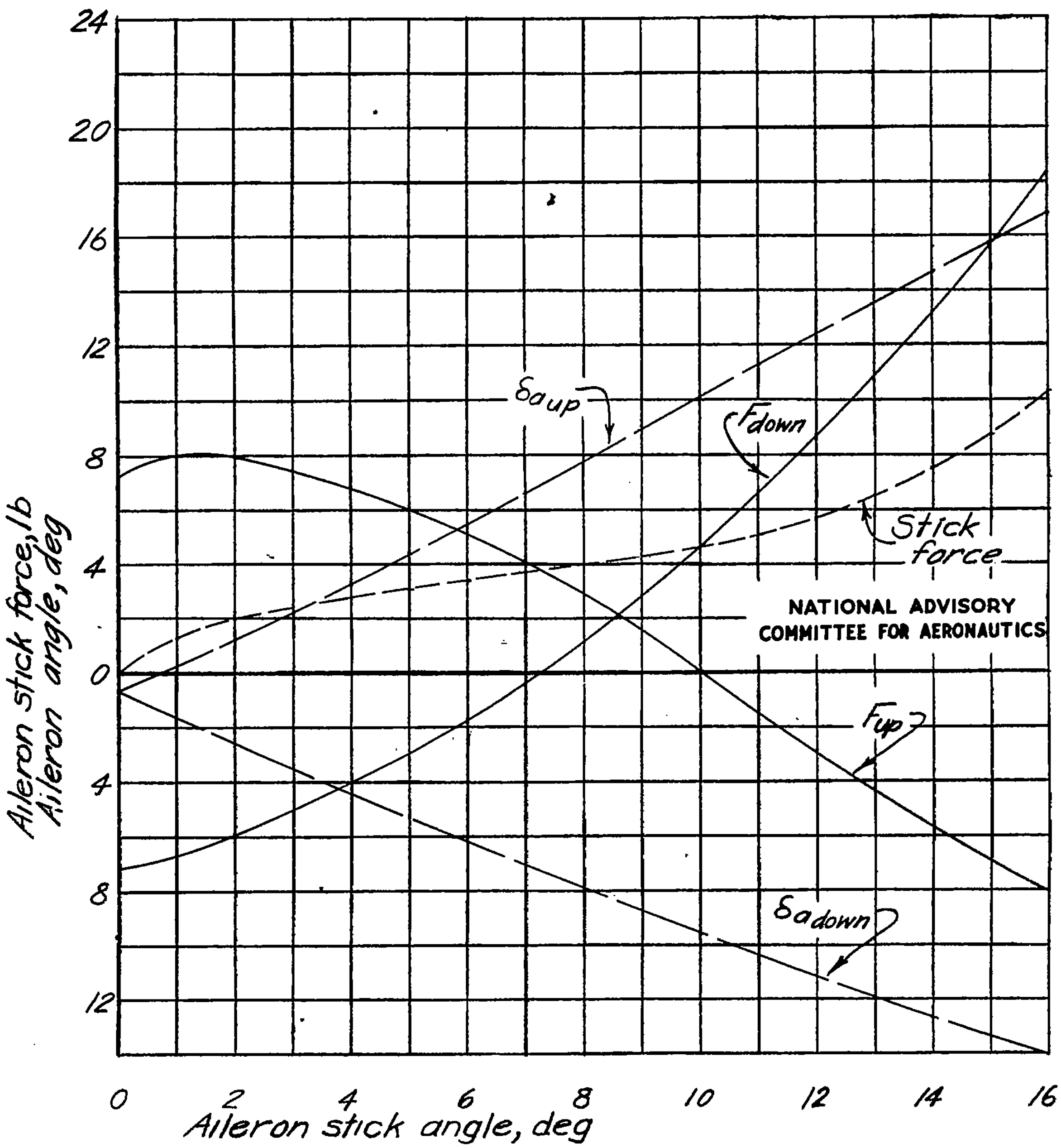


Figure 27.- Effects of stretch on individual aileron characteristics for aileron control system of experimental fighter airplane. Stretch, 0.058° per pound-foot of hinge moment; V_e = 250 miles per hour.

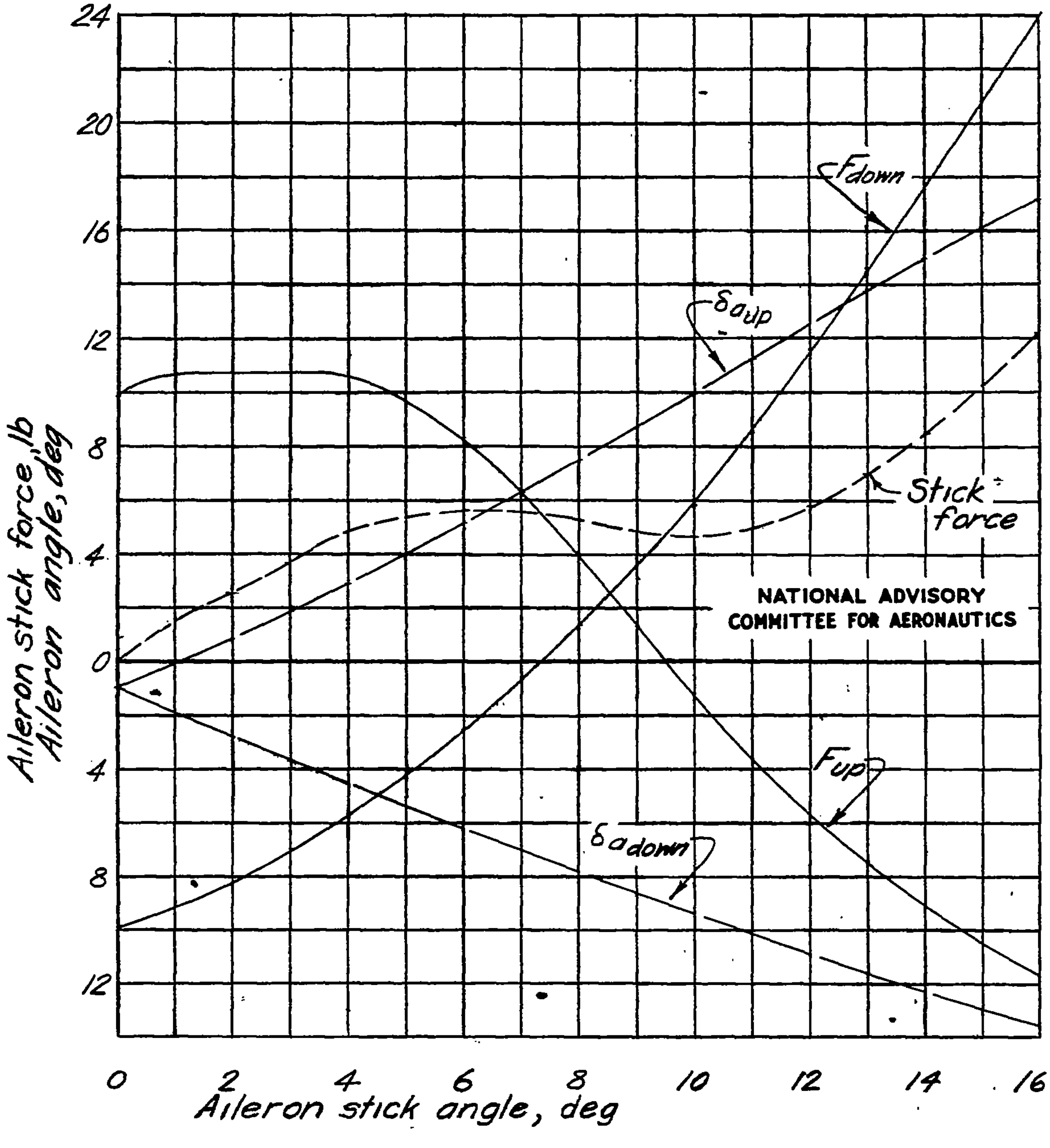


Figure 28.- Effects of stretch on individual aileron characteristics for aileron control system of experimental fighter airplane. Stretch, 0.058° per pound-foot of hinge moment; V_e = 300 miles per hour.

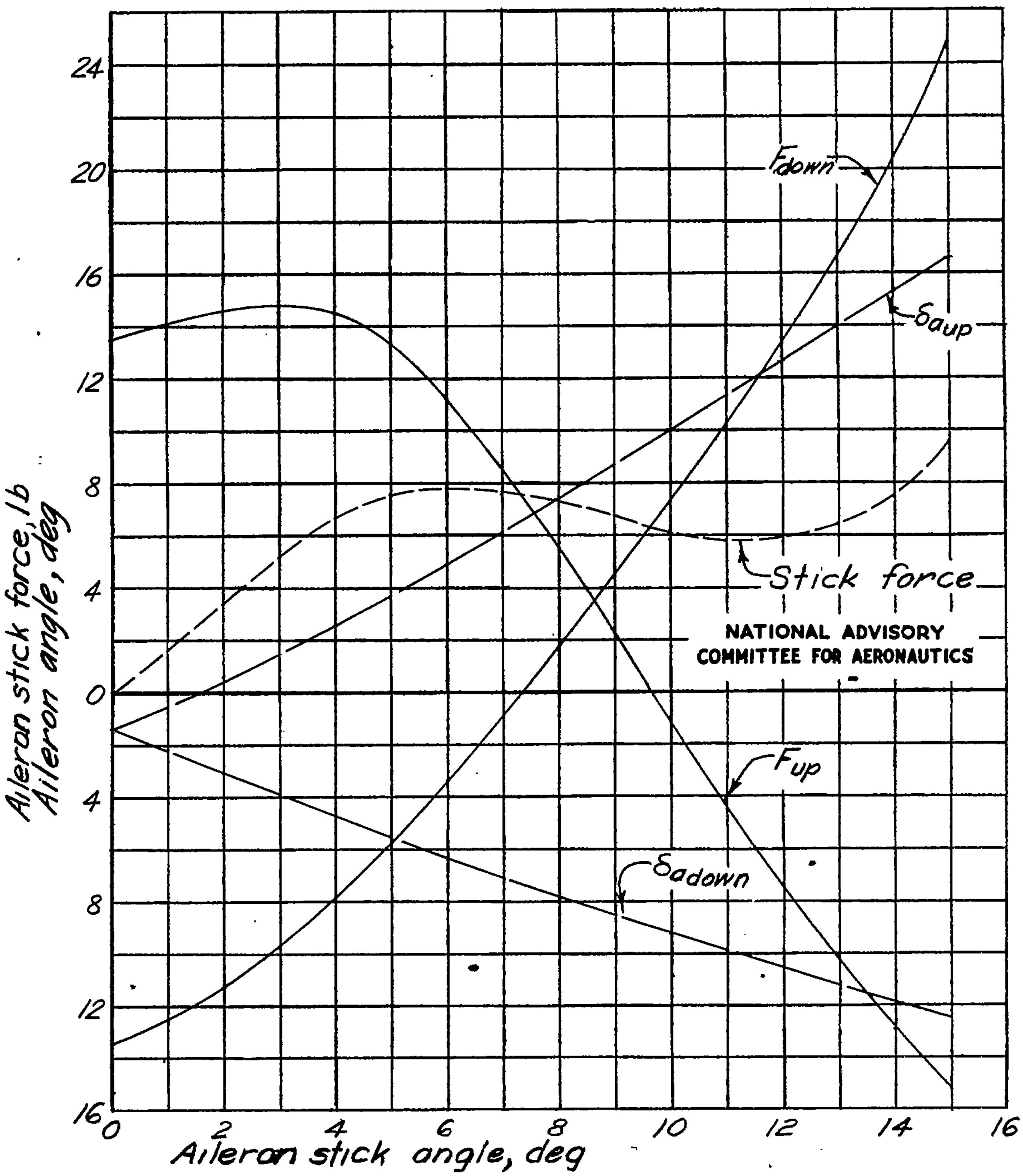


Figure 29.- Effects of stretch on individual aileron characteristics for aileron control system of experimental fighter airplane. Stretch, 0.058° per pound-foot of hinge moment; V_e = 350 miles per hour.

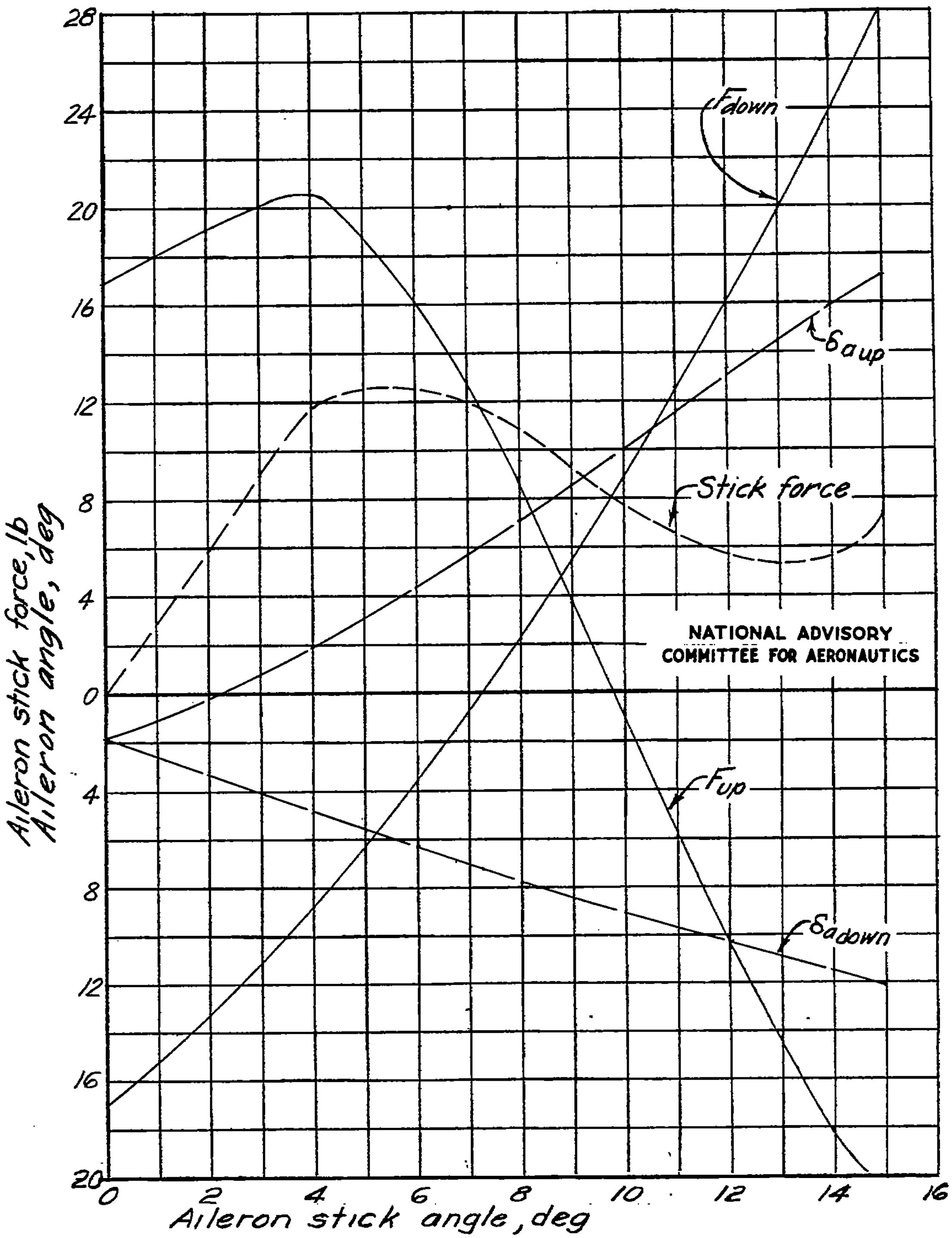


Figure 30.- Effects of stretch on individual aileron characteristics for aileron control system of experimental fighter airplane. Stretch, 0.058° per pound-foot of hinge moment; V_e = 400 miles per hour.

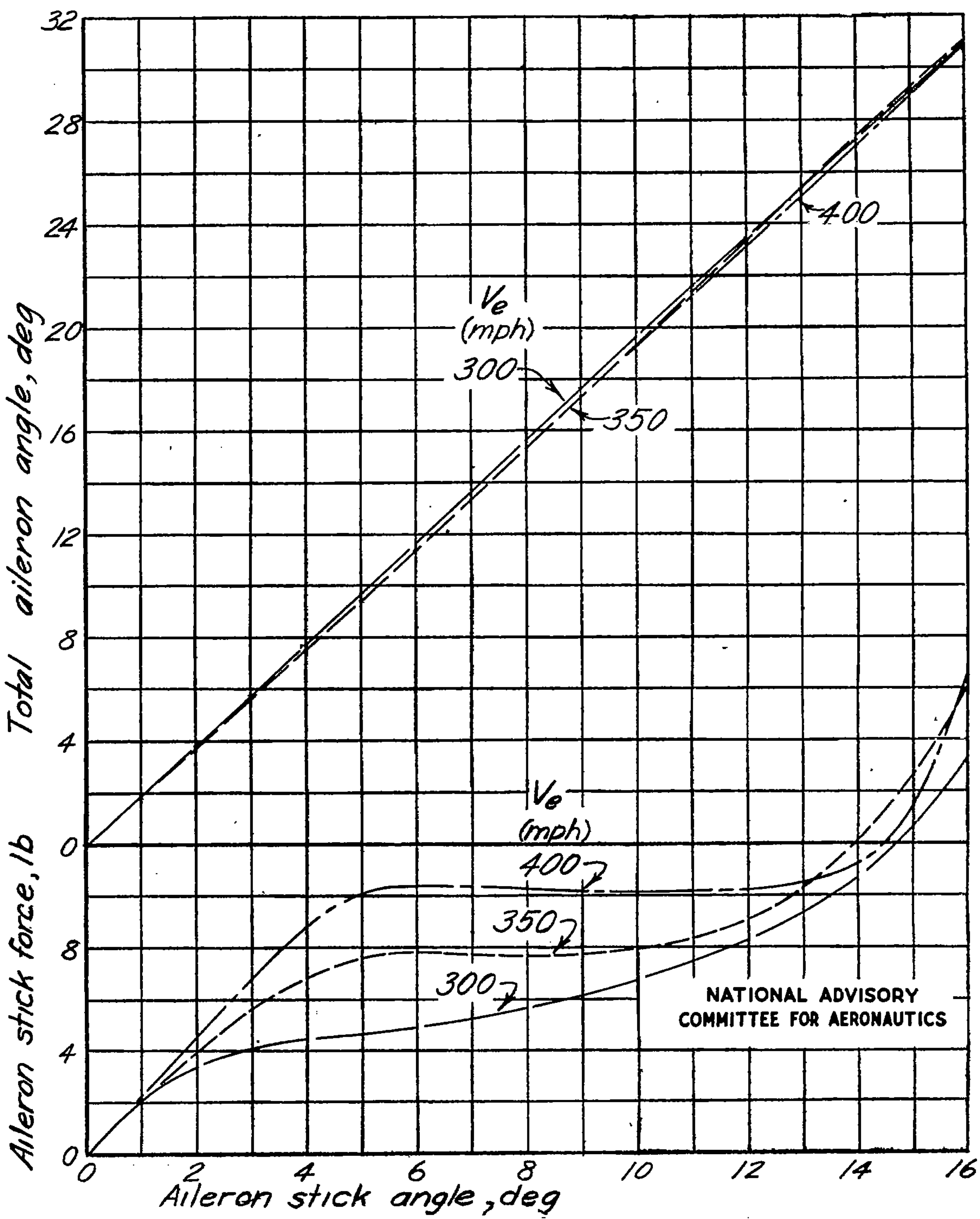


Figure 31.- Summary of effects of stretch on aileron characteristics for aileron control system more rigid than that of experimental fighter airplane. Stretch, 0.040° per pound-foot of hinge moment; V_e = 300 to 400 miles per hour.

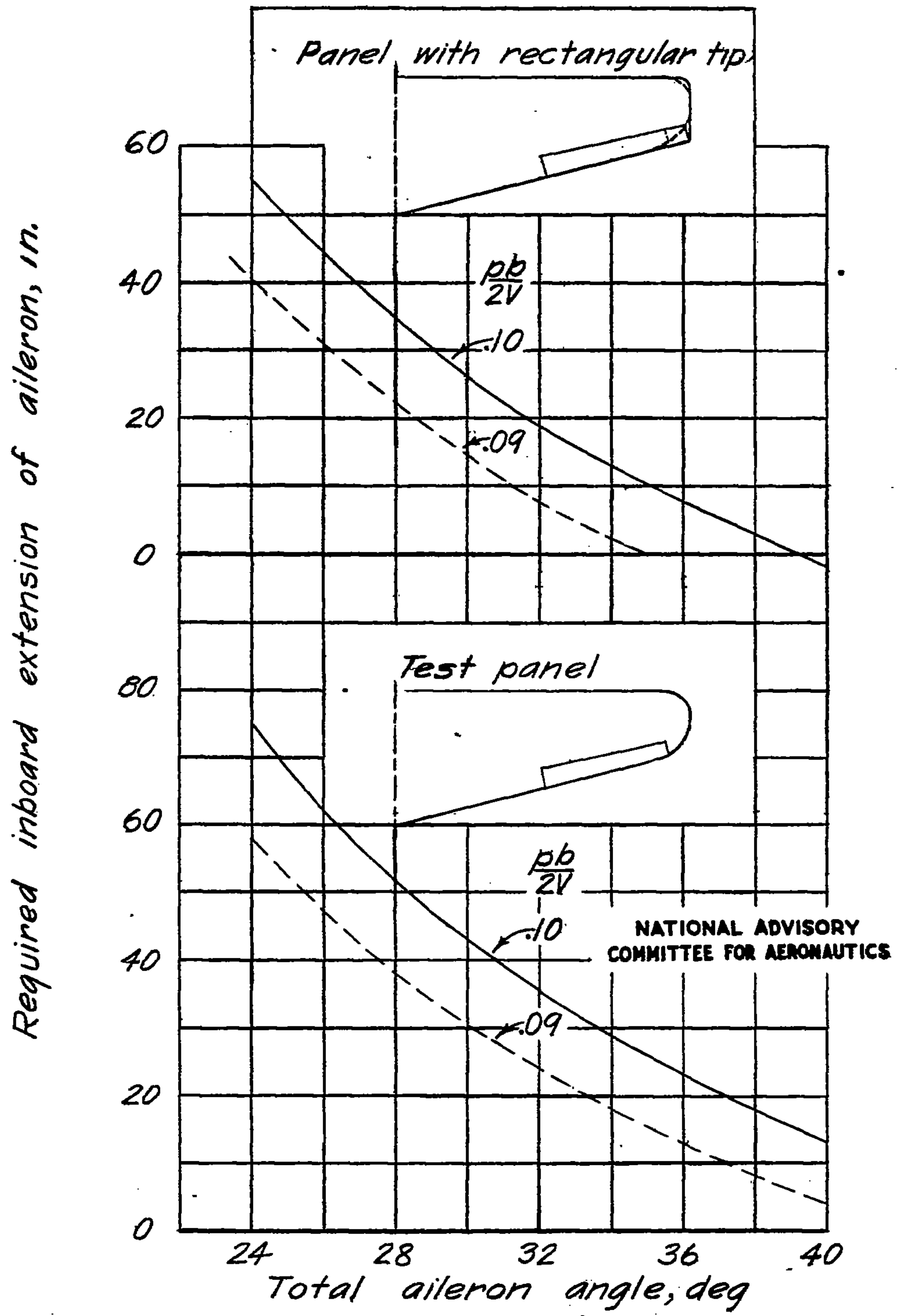


Figure 32.- Calculated inboard extension of aileron required to obtain an aileron effectiveness pb/2V of 0.10 and 0.09 with experimental fighter airplane.