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HIGH-SPEED WIND-TUNNEL INVESTIGATION OF AN NACA 65-210 SEMISPAN WING EQUIPPED WITH PLUG AND RETRACTABLE AILERONS AND A FULL-SPAN SLOTTED FLAP

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HIGH-SPEED WIND-TUNNEL INVESTIGATION OF AN NACA 65-210 SEMISPAN WING EQUIPPED WITH PLUG AND RETRACTABLE AILERONS AND A FULL-SPAN SLOTTED FLAP

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SUMMARY

A high-speed wind-tunnel investigation was made to determine the lateral-control characteristics of plug and retractable ailerons on a thin, low-drag, semispan wing equipped with a 25-percent-chord, full-span, slotted flap. The ailerons investigated covered 49 percent of the wing semispan, were located at the 70-percent-chord station, and were perforated and segmented. The investigation was performed through a Mach number range from 0.13 to 0.71. The Mach and Reynolds numbers were simultaneously varied during the investigation.

With flap retracted or deflected, the values of rolling-moment coefficient produced by projection of the basic plug or retractable ailerons generally increased with increase in the Mach and Reynolds numbers, particularly for small projections in the flap-retracted configuration. The rolling effectiveness of the basic plug aileron generally increased with increase in the angle of attack in both flap configurations; whereas the rolling effectiveness of the basic retractable aileron generally increased with increase in the angle of attack only at small projections in the flap-retracted configuration. Almost linear control effectiveness with aileron projection probably would be provided by both ailerons at all speeds in the flap-retracted configuration. Appreciably larger values of rolling-moment coefficient were produced at all projections of the basic plug and retractable ailerons with the full-span flap deflected than were produced with flap retracted, and large values of rolling-moment coefficient were produced by both ailerons above the flap-deflected stall angle. Inconsistent trends of reversed rolling effectiveness for small projections were exhibited by the retractable aileron with flap deflected.

Favorable values of yawing-moment coefficient that became more favorable with aileron projection, less favorable with increase in the angle of attack, and were essentially unaffected by increase in the Mach number were generally obtained with the basic plug and retractable ailerons below the wing stall angle.

The variation of hinge-moment coefficient with projection of either the basic plug or basic retractable aileron was generally irregular over the projection range and exhibited either small or inconsistent changes with increase in the Mach number. With flap retracted the curves of hinge-moment coefficient against aileron projection for the plug aileron were generally stable over the negative projection range and became more stable with increase in the angle of attack; whereas the corresponding data of the retractable aileron were generally unstable for small projections, stable for large projections, and were inconsistently affected by changes in the angle of attack. With the flap deflected, more negative values of hinge-moment coefficient were obtained at small projections of the basic plug aileron and more positive values of hinge-moment coefficient were obtained at large projections of the basic retractable aileron than were obtained with flap retracted.

Several modifications of the basic plug and basic retractable ailerons were investigated and were observed to have either a slight or a negligible effect on the aileron rolling-moment characteristics and a substantial effect on the hinge-moment characteristics. A means of altering, to some extent, the lateral-control characteristics of the aileron is thereby available.

INTRODUCTION

The necessity of providing sufficiently high lift for landing and take-off and adequate lateral control throughout the flight-speed range for the faster and more heavily loaded airplanes in use or in the design stage has presented a problem to airplane designers. If conventional wing-trailing-edge ailerons are used in conjunction with a partial-span flap, the problem of obtaining the lift necessitated by stalling-speed and take-off-distance requirements becomes serious, as does the lateral-control problem near the stall. As a solution to these problems, the use of spoiler-type lateral-control devices in conjunction with full-span slotted flaps has been proposed and has been the subject of a number of investigations by the National Advisory Committee for Aeronautics. (See references 1 to 8.) The results of these relatively low-speed investigations of wings having conventional airfoil sections indicated some of the merits of spoiler-type lateral-control devices, such as control at high angles of attack, favorable yawing moments, smaller wing twisting moments than ailerons and hence higher reversal speeds, small stick forces, and the increased effectiveness of these controls when full-span flaps are deflected, particularly when a plug aileron is used. In addition, one of the most apparent advantages possible with spoiler-type controls is the increased lift obtainable through use of a full-span flap. Moreover, an investigation performed on an unflapped wing having a high critical speed (reference 9) indicated an increase in effectiveness of the retractable aileron with an increase in speed until the critical Mach number was exceeded.

Because of the paucity of existing finite-span spoiler-control data on wings having high critical speeds, the subject investigation was performed in the Langley high-speed 7- by 10-foot tunnel to ascertain the lateral-control characteristics of a thin, low-drag, semispan wing equipped with a full-span slotted flap and either a plug aileron, a retractable aileron, or a modified plug or retractable aileron. The present investigation is an extension of the investigation reported in reference 10. Tests of the 0.492-semispan spoiler-type ailerons were performed through a projection range, with the full-span flap retracted or deflected, at various speeds up to a Mach number of 0.71. Wing lift, drag, and pitching-moment characteristics were determined only at a Mach number of 0.71 with the full-span flap retracted and at a Mach number of 0.13 with the flap deflected, since these characteristics had been determined at various speeds previously (reference 10).

SYMBOLS

The moments on the wing are presented about the wind axes. The X-axis is in the plane of symmetry of the model and is parallel to the tunnel free-stream air flow. The Z-axis is in the plane of symmetry of the model and is perpendicular to the X-axis. The Y-axis is mutually perpendicular to the X-axis and Z-axis. All three axes intersect at the intersection of the chord plane and the 35-percent-chord station at the root of the model.

The symbols used in the presentation of results are as follows:

C_L lift coefficient $\left(\frac{\text{Twice lift of semispan model}}{qS}\right)$

C_D drag coefficient $\left(\frac{D}{qS}\right)$

C_m pitching-moment coefficient $\left(\frac{\text{Twice pitching moment of semispan model about Y-axis}}{qS\bar{c}}\right)$

C_l rolling-moment coefficient $\left(\frac{L}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{N}{qSb}\right)$

C_h aileron hinge-moment coefficient $\left(\frac{H_a}{qM}\right.$ where M is area moment of aileron top edge about hinge line$\left.\right)$

$pb/2V$ wing-tip helix angle, radians

C_{l_p} damping coefficient; that is, rate of change of rolling-moment coefficient with wing-tip helix angle $\left(\frac{\partial C_l}{\partial \frac{pb}{2V}}\right)$

c local wing chord

$\bar{c}$ wing mean aerodynamic chord, 2.86 feet $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$

b twice span of semispan model, 16 feet

y lateral distance from plane of symmetry, feet

S twice area of semispan model, 44.42 square feet

D twice drag of semispan model, pounds

L rolling moment, resulting from aileron projection, about X-axis, foot-pounds

N yawing moment, resulting from aileron projection, about Z-axis, foot-pounds

H_a aileron hinge moment, positive when hinge moment tends to depress aileron, foot-pounds

q free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

V free-stream velocity, feet per second

ρ mass density of air, slugs per cubic foot

α angle of attack with respect to chord plane at root of model, degrees

M Mach number (V/a)

R Reynolds number

a speed of sound, feet per second

CORRECTIONS

With the exception of the aileron hinge-moment data, all the data presented are based on the dimensions of the complete wing.

The test data have been corrected for jet-boundary effects according to the methods outlined in reference 11. Compressibility effects on these jet-boundary corrections have been considered in correcting the test data. Blockage corrections were applied to the test data by the methods of reference 12.

MODEL AND APPARATUS

The right-semispan-wing model was mounted in an inverted position in the Langley high-speed 7- by 10-foot tunnel with its root section adjacent to one of the vertical walls of the tunnel, the vertical wall thereby serving as a reflection plane (figs. 1 and 2). The wing model was built to the plan-form dimensions shown in figure 3 and had an NACA 65-210 airfoil section (table I) from root to tip with neither twist nor dihedral. The model had an aspect ratio of 5.76 and a ratio of tip chord to root chord of 0.57. No transition strips were used on the wing and an attempt was made to keep the model surface smooth during the entire investigation.

The full-span, 0.25c, slotted flap was built to the section dimensions presented in table I and the plan-form dimensions given in figure 3 and is shown mounted on the wing in the tunnel test section in figures 1 and 2. The design dimensions for the flap as presented in table I agree with the dimensions for slotted flap 1 given in reference 13. The flap deflection (45°) and the normal flap position with respect to the upper-surface airfoil lip employed in the investigation reported in reference 10 were used for the flap-deflected configuration in the present investigation.

A more detailed description of the construction and mounting of the model is presented in reference 10. The model was modified in the interim between this investigation and that reported in reference 10 to accommodate the spoiler-type ailerons. The 0.492-semispan, spoiler-type, lateral-control device was built to the plan-form dimensions given in figure 3 and is shown mounted on the wing in figure 1. Section dimensions of the basic plug-aileron and retractable-aileron configurations tested are shown in figure 4. The ailerons were fabricated from sheet steel in segments which were perforated. The aileron perforations removed about 9 percent of the original aileron area. The aileron segments had actuating arms at each end of each segment as shown in figure 5. The aileron actuating arms were firmly attached to a steel shaft that was centered on the aileron hinge axis. This steel shaft extended outside the tunnel wall to a calibrated shaft-rotating mechanism and a calibrated, beam-type, strain-gage setup. The steel shaft was rotated by this mechanism in order to produce the various aileron projections employed in the investigation, and the aileron hinge moments were simultaneously obtained.

The various modified arrangements of the basic plug and retractable ailerons tested are shown in figure 6, and a sketch of each configuration tested is shown on each of the subsequent figures presenting lateral-control data.

The Langley high-speed 7- by 10-foot tunnel is a closed-throat single-return tunnel. The turbulence of the tunnel air stream has not been determined but is thought to be low because of the large tunnel-contraction ratio (14 to 1). This belief is substantiated by turbulence measurements made in the Langley 300 MPH 7- by 10-foot tunnel.

TESTS

Wing angle-of-attack tests with the flap retracted and deflected were performed at respective Mach numbers of 0.71 and 0.13, with corresponding Reynolds numbers of approximately 10.3×10^6 and 2.6×10^6 based on the mean aerodynamic chord of 2.86 feet.

Lateral-control tests were performed with the basic plug and retractable ailerons through the aileron projection range at various angles of attack and at Mach numbers from 0.13 to 0.71 with the full-span flap retracted or deflected. With the plug aileron, a projection range from about 2 percent chord to -8 percent chord was covered, and with the retractable aileron, a projection range from 0 percent chord to about -8 percent chord was covered in almost all the tests. Negative projections indicate that the ailerons were extended above the wing. In addition to the basic plug-aileron and retractable-aileron arrangements tested, several modifications of both ailerons (fig. 6) were investigated.

The variation of Reynolds number with Mach number for these tests is shown in figure 7. The Mach and Reynolds numbers were varied simultaneously during the investigation.

DISCUSSION

Wing Aerodynamic Characteristics

The aerodynamic characteristics of the wing in the flap-retracted condition at a Mach number of 0.71 and in the flap-deflected condition at a Mach number of 0.13 are shown in figures 8 and 9, respectively. For comparative purposes data obtained for the wing before the addition of the spoiler-type-aileron configuration (previously presented in reference 10) are also shown.

The effect of adding the plug aileron to the clean wing (reference 10) was to decrease the lift slightly in the flap-retracted configuration and to decrease the lift and increase the drag slightly throughout the angle-of-attack range, except at maximum lift, in the flap-deflected configuration.

In order to verify on a finite-span model the hysteresis effects (loss in lift at any angle of attack when the wing angle of attack is decreased from above the stall) sometimes encountered in two-dimensional flow on the curve of angle of attack against lift coefficient for the flap-deflected condition, the data presented in figure 9 were obtained by increasing the angle of attack above the stall and then decreasing it. The data (fig. 9) indicate that the hysteresis effects were generally small except for the maximum value of lift coefficient for which a reduction of about 0.1 occurred.

Lateral-Control Characteristics - Plug Aileron

Basic plug aileron.- The lateral-control characteristics of the basic plug aileron at various Mach numbers and angles of attack are presented in figures 10 and 11 for the flap-retracted condition and in figures 12 and 13 for the flap-deflected condition.

Increases in the Mach and Reynolds numbers in the flap-retracted or flap-deflected configurations generally resulted in relatively large increases in the aileron effectiveness (figs. 10, 12, and 14), except in the flap-retracted configuration where a slight reduction in effectiveness was noted as the Mach number increased from 0.27 to 0.41. This reduction is thought to result from changes in the wing pressure distribution in the vicinity of the wing plug slot as the Mach number increased, which effect in turn may have influenced the flow through the slot and thereby, the aileron effectiveness. This belief is based on unpublished pressure-distribution data obtained on a wing that was equipped with retractable ailerons at the same chordwise station as the present wing and employed the same airfoil section.

The data of figures 10 and 11 show that at small angles of attack and low Mach numbers in the flap-retracted condition the plug aileron was somewhat ineffective for small projections. This phenomenon has been observed with retractable-type ailerons on conventional wing sections, but was alleviated when a slot was added behind the aileron (references 4 and 5). The plug slot on the present wing model was therefore believed to be comparatively ineffective at these low angles of attack and Mach numbers because of the plug-slot narrowness and its probably weak "scoop effect" and also because of the small differences in pressure existing between the two wing surfaces in the vicinity of the plug slot when the flap was retracted (as is also shown in the previously mentioned unpublished pressure data). With the flap deflected, the pressure difference between the two wing surfaces near the plug slot was sufficient to cause the plug slot to increase the aileron effectiveness. The comparative ineffectiveness with flap retracted for small angles of attack and low Mach numbers just discussed is inconsequential, however, because an airplane having even moderate performance characteristics would not fly in this condition except in a dive. For flap-retracted level or maneuvering flight, computations made for airplane wing loadings of 20 and 60 pounds per square foot showed that the rolling effectiveness would vary almost linearly with aileron projection throughout the speed range and that the aileron effectiveness would increase with increase in speed.

Increase of the angle of attack below the stall angle in both flap configurations generally increased the aileron effectiveness over the negative-aileron-projection range for Mach numbers below 0.61. For positive aileron projections, small adverse rolling moments that became more adverse with increase in α were obtained with flap retracted, whereas angle-of-attack increase with flap deflected generally tended to produce more favorable rolling moments. Therefore, for an airplane utilizing a plug-aileron wing configuration similar to the configuration investigated, the effectiveness (as well as other characteristics) of the positive-projection range may limit the useable aileron projection in this range and thus affect the aileron control stick linkage.

The aileron effectiveness obtained with flap deflected was considerably larger at all projections than that obtained with flap retracted; the maximum values of C_l obtained with flap deflected were about 125 percent larger than the maximum values of C_l obtained with flap retracted. Moreover, the data of figures 12(e) and 13(a) indicate that the basic plug aileron was quite effective and provided large rolling moments above the flap-deflected stall angle.

A loss in aileron effectiveness usually occurred at Mach numbers below 0.61 for negative aileron projections above -7.3 percent chord. At this projection the aileron emerged from the wing, and at a projection of -8.33 percent chord, a gap of about 2 percent chord existed between the aileron and the wing upper surface. It is believed that at these large projections and at Mach numbers below 0.61, the aileron tends to act as a scoop over the wing upper surface and to effect a partial pressure recovery on the wing rearward of the aileron, the pressure recovery thereby causing a loss in effectiveness. In the plug-aileron investigation reported in reference 14, a similar effect was shown, but to a lesser degree, because the gap between aileron and wing was smaller than in the present investigation.

The values of yawing-moment coefficient obtained by projection of the plug aileron at angles of attack below the wing stall angle were generally favorable (that is, having the same sign as the values of C_l), particularly in the flap-retracted configuration. The values of C_n generally became more positive with increase in aileron projection, decreased with angle-of-attack increase, and were either slightly or inconsistently affected by changes in Mach number. The values of C_n generally were less favorable with the flap deflected than with the flap retracted.

The variation of hinge-moment coefficient with plug-aileron projection was irregular over the projection range, but was generally stable for negative projections. The curves of C_h against aileron projection became more stable with increase in the angle of attack and were only slightly or inconsistently affected by changes in the Mach number. Deflection of the flap resulted in a larger variation of C_h over the projection range and in more negative values of aileron hinge-moment coefficient compared to the flap-retracted data, except at large negative projections, where almost similar values were obtained in both flap conditions. These irregular hinge-moment variations could probably be alleviated somewhat by proper venting of the plug aileron (see references 5 and 6).

Plug aileron modified by removing the 0.01c top plate.- The characteristics of the plug aileron modified by replacing the 0.01c top plate with one as wide as the aileron body $\left(\frac{1}{8}\text{ inch}\right)$, and thereby leaving an enlarged slot in the wing upper surface behind the aileron, are shown in figures 15 to 19.

The rolling-effectiveness characteristics of this modified plug aileron were generally the same as those of the basic plug aileron, particularly as regards the increase in effectiveness with Mach number and flap deflection. (Compare figs. 15 to 19 with figs. 10 to 14.) With flap retracted, however, the modified plug aileron exhibited less rolling effectiveness at large angles of attack than the basic plug aileron and, at low projections, exhibited an ineffective region that became more adverse with increase in angle of attack and less adverse with increase in Mach number. With flap deflected, less positive values of C_l were sometimes obtained (at $M = 0.13$ and 0.19) with the modified plug aileron throughout the projection range than with the basic plug aileron. For both flap configurations, an increase in the angle of attack had an inconsistent effect on the rolling effectiveness. Because of the nature of these results, these phenomena are believed to be associated with the scale or Mach number of the tests and with the air leakage through the enlarged wing aileron slot with the aileron neutral. (Compare the values of lift coefficient in figs. 10 to 13 with figs. 15 to 18.)

The same effects and trends of the yawing-moment-coefficient curves previously discussed for the basic plug aileron generally were obtained with the modified plug aileron.

The dependence of aileron hinge moment on aileron top-edge area is illustrated by the similarity of the magnitude of the hinge-moment coefficients for the modified plug aileron and for the basic plug aileron at zero projection. The modified-plug-aileron data, however, usually exhibited less stability with negative aileron projection when the flap was retracted and more stability when the flap was deflected. The modified-plug-aileron data also exhibited a larger variation of C_h over the projection range than the basic-plug-aileron data, and the values of C_h for the modified plug generally became more negative with increase in α over most of the projection range. In all other respects, the values of C_h for the modified plug were affected by changes in Mach number, angle of attack, and flap deflection in the same manner as the values of C_h for the basic plug aileron previously discussed.

Plug aileron modified by enlarging the plug slot to the rear of the aileron on the wing lower surface.- The lateral-control characteristics produced by projection of the plug aileron modified by enlarging the plug slot to the rear of the basic plug aileron on the lower surface of the wing are shown in figures 20 and 21 for the flap-retracted and flap-deflected configurations, respectively. Comparison of these data with those given in figures 10 to 14 for the basic plug aileron indicates no important change in the basic-plug-aileron characteristics as a result of enlarging the plug slot on the wing lower surface. The enlarged slot on the wing lower surface behind the aileron did not produce the region of rolling ineffectiveness for small projections that was produced by the plug aileron with the 0.01c top plate removed and a large gap on the wing upper surface behind the aileron (compare fig. 20 with fig. 15). This fact appears to indicate some effect produced by the top plate in improving the effectiveness at small projections.

Other plug-aileron configurations.- The effects on the lateral-control characteristics of varying the size of the wing aileron slot ahead of the aileron or of sealing the aileron perforations are shown in figures 22 and 23. For purposes of comparison, the basic-plug-aileron data (unsealed aileron perforations and 0.002c slot ahead of aileron) have been included in these figures.

Sealing the aileron perforations had no notable effect on the basic-plug-aileron data other than producing more negative hinge-moment coefficients in the negative projection range with flap retracted and producing a small reduction in rolling effectiveness for large negative projections and more positive hinge-moment coefficients for small projections with flap deflected. This effect on the rolling effectiveness did not conform to the improved effectiveness previously noted when perforations were sealed (reference 15), but the aileron area removed by the perforations in the present investigation (about 9 percent of unperforated aileron area) was too small to produce any important changes in rolling moment.

Decreasing the size of the slot ahead of the aileron by installation of a wiper seal when the aileron perforations were sealed usually produced more negative rolling moments for positive projections and may have a slight measurable effect on the characteristics of wing-aileron installations employing positive and negative projections.

Increasing the slot ahead of the aileron to 0.004c resulted in a decrease in effectiveness for small negative projections, flap retracted, and a decrease in effectiveness for large projections, flap deflected. The effects on the hinge-moment characteristics of enlarging the slot ahead of the aileron were either inconsistent or small.

The plug-aileron modifications just discussed had no material effect in changing the yawing-moment characteristics of the basic plug aileron.

Lateral-Control Characteristics - Retractable Aileron

Basic retractable aileron.- Data obtained by projection of the basic retractable aileron at various angles of attack and Mach numbers are shown in figures 24 and 25 and figures 26 and 27 for the flap-retracted and flap-deflected configurations, respectively. It will be noted that no hinge-moment data are presented for zero aileron projection, because in this position the lower edge of the aileron is in contact with the seal covering the wing aileron slot on the wing lower surface.

The values of rolling-moment coefficient increased with aileron projection over most of the projection range, flap retracted or deflected (figs. 24 to 27), but showed inconsistent trends of reversed rolling effectiveness for small projections at various angles of attack and Mach numbers with flap deflected (fig. 26), a phenomenon usually exhibited by retractable ailerons in the flap-deflected configuration (reference 4). The rolling effectiveness produced by the retractable aileron generally increased with increase in the Mach and Reynolds numbers in both flap configurations, particularly for small projections in the flap-retracted configuration (figs. 24, 26, and 28).

With the flap retracted, small aileron projections were somewhat ineffective in producing roll at low angles of attack and low Mach numbers, but an increase in the angle of attack increased the effectiveness in this projection range. However, as previously discussed in the section dealing with the basic plug aileron, this ineffective region probably would not be encountered in flight by an airplane with even moderate performance characteristics. For such an airplane, flap-retracted flight would be at high speed and low angles of attack and vice versa; therefore, rolling effectiveness would vary almost linearly with aileron projection. In either flap configuration, an angle-of-attack increase had no consistent effect on rolling effectiveness at large projections. This lack of consistency is in contrast to the decrease in effectiveness exhibited by retractable ailerons on wings having conventional sections when the angle of attack was increased (references 1, 4, and 7).

With the full-span flap deflected, the values of C_l obtained were considerably larger than the values of C_l obtained with flap retracted; the maximum values of C_l obtained below the stall angle with flap deflected were approximately 100 percent larger than the flap-retracted values. (Compare fig. 24 with fig. 26.) In addition, the retractable aileron provided large values of rolling-moment coefficient above the flap-deflected stall angle (fig. 26(e)). These values of C_l obtained above the stall angle were larger than those obtained with flap retracted at any angle of attack.

At projections above approximately -7 percent chord, a drop in rolling effectiveness - previously noted and discussed for the basic plug aileron when the aileron projects above the wing surface so as to leave a gap between aileron and wing - was obtained with the basic retractable aileron. The data of figures 24 and 28 indicate how this drop in effectiveness decreased with increase in Mach number.

The values of the yawing-moment coefficient obtained with retractable-aileron projection generally had the same sign as the values of rolling-moment coefficient, at angles of attack below the stall angle, and hence were favorable, particularly in the flap-retracted configuration. These values of yawing-moment coefficient generally became more favorable with aileron projection and less favorable as the angle of attack increased (figs. 24 to 27). Mach number changes had no notable or consistent effect on the yawing-moment coefficients. Less favorable yawing characteristics generally were obtained with flap deflected than with flap retracted.

The curves of hinge-moment coefficient against aileron projection for the basic retractable aileron were unstable at small projections but became stable at large projections in either flap configuration. Increase in Mach and Reynolds numbers with flap deflected generally resulted in a small shift of the C_h-curves toward more negative values. Increase in the angle of attack in either flap condition produced no consistent change in the hinge-moment data. The values of C_h for small projections were quite similar in both flap configurations, but at large projections more positive values of C_h were obtained with flap deflected than with flap retracted.

Retractable aileron modified by enlarging the aileron slot behind the aileron on the wing upper surface.- The characteristics of the retractable aileron modified by enlarging the aileron slot behind the aileron from 0.002c to 0.008c are shown in figures 29 and 30. This modification to the retractable aileron produced no measurable or consistent change in the rolling-moment or yawing-moment characteristics of the basic retractable aileron discussed in the preceeding section (compare figs. 29 and 30 with figs. 24 to 27). The reversal in effectiveness produced by small aileron projections in the flap-deflected configuration for the basic retractable aileron is also shown for the modified aileron.

As a result of enlarging the wing slot behind the aileron, more positive values of hinge-moment coefficient and a more stable variation of C_h with projection for small projections were obtained. At large projections, the values of C_h were about the same as those obtained with the basic retractable aileron; therefore, the variation of C_h over the projection range was smaller for the modified retractable aileron. A larger variation of C_h over the projection range was obtained with flap deflected than with flap retracted.

Retractable aileron modified by installing an 0.01c top plate on the aileron.- The lateral-control characteristics exhibited by the retractable aileron modified by installing a 0.01c top plate on the aileron are shown in figures 31 and 32. A comparison of these figures with figures 24 to 27 shows that the modification of the basic retractable aileron had almost no effect on the yawing-moment characteristics. The modified retractable aileron generally produced slightly smaller values of C_l at values of M below 0.61 and slightly larger values of C_l at values of M above 0.61 than did the basic retractable aileron.

As was previously indicated for the plug-aileron configuration, the area of the aileron top edge affects the aileron hinge moments, especially near the aileron neutral position. This fact is corroborated by the similarity in the values of C_h obtained near zero projection for the modified and basic retractable ailerons. In addition, the curves of the hinge-moment coefficient against aileron projection for the modified aileron were stable over most of the projection range, had a smaller variation in the values of C_h over the projection range, and had smaller positive values of C_h at large projections than the basic retractable aileron. It is rather interesting to note that the values of C_h over the projection range for this modified retractable aileron are similar to those of the basic plug aileron in the flap-retracted configuration (compare fig. 31 with fig. 10(b)).

Comparison of Lateral-Control Characteristics of the Basic Plug and Retractable Ailerons

For purposes of direct comparison, some of the lateral-control data previously presented for both the basic plug and retractable ailerons have been replotted for similar test conditions in the same figure. (See figs. 33 and 34.) A more complete comparison of these data can be made with figures 10 to 14 and figures 24 to 28.

In general, the yawing-moment characteristics of both the plug and retractable ailerons were similar and exhibited the same trends with angle-of-attack change, flap deflection, and Mach number.

Both the retractable-aileron and the plug-aileron data exhibited general increases in rolling effectiveness with increase in the Mach number, but the retractable-aileron data did not exhibit the slight decrease in effectiveness produced by the plug aileron at low angles of attack when the Mach number was increased from 0.27 to 0.41. (See figs. 14 and 28.)

With the full-span flap retracted, the values of C_l obtained with the basic plug aileron generally were the same as those for the basic retractable aileron for small projections above the wing, but the retractable aileron produced slightly larger values of C_l for intermediate and large projections. This greater effectiveness exhibited by the retractable aileron compared to the plug aileron is in direct contrast to the results obtained from tests of plug and retractable ailerons on wings having conventional airfoil sections (references 4 and 5). However, the low-drag wing employed in the present investigation had its maximum thickness located farther downstream than the location of wing maximum thickness on the aforementioned conventional wings, and the wing plug slot on the wing investigated was fairly narrow with probably very little scoop effect. Unpublished pressure-distribution data obtained in a spoiler-type-aileron investigation of a wing employing an airfoil section similar to that of the present wing indicated the possibility of no flow or a downward flow of air through the wing slot when the plug aileron was projected in the flap-retracted configuration. This lack of or downward flow of air would tend to have either no effect on the plug-aileron rolling characteristics as compared to the retractable-aileron rolling characteristics or an effect such as to reduce the plug-aileron rolling effectiveness in the flap-retracted configuration. This reduction in rolling effectiveness of the plug aileron was apparently obtained in the present investigation, as shown by the data of figure 33. In the flap-deflected configuration, the pressure difference between the two wing surfaces in the vicinity of the wing plug slot is sufficient to induce a flow upward through the slot and thereby increase the effectiveness. It would seem, therefore, that in order to obtain the increased rolling effectiveness provided by a wing slot behind a spoiler-type aileron, the pressure distribution (and hence, location of wing maximum thickness) in the vicinity of the aileron and the design of the wing plug slot should be considered in the design of such configurations.

Increase in angle of attack below the stall angle generally increased the rolling effectiveness of the plug aileron but produced a negligible effect on rolling effectiveness of the retractable aileron. Deflecting the flap also had more effect in increasing the values of C_l for the plug aileron than for the retractable aileron. With the flap deflected, considerably larger values of C_l generally were obtained over the entire projection range for the plug aileron than for the retractable aileron, and the tendency toward reversal of effectiveness for small projections exhibited by the retractable-aileron data was not shown by the plug-aileron data.

Values of the helix angle $pb/2V$ generated by the wing tip in a roll were computed from the equation $\frac{pb}{2V} = \frac{C_l}{C_{l_p}}$, where C_{l_p} is the damping-in-roll coefficient, and indicated the effectiveness of the plug and retractable ailerons investigated, particularly with flap deflected. For example, at low speeds with flap retracted, which is perhaps the least effective flight range for the ailerons, the computed value of $pb/2V$ for maximum projection is about 0.08 or higher, based on a value of C_{l_p} (obtained from reference 16) of 0.40.

With the flap retracted, the values of C_h for both the retractable and plug ailerons were about the same near zero projection, and the variation of C_h with projection for the plug aileron generally was more stable over a greater part of the projection range than for the retractable aileron. With the flap deflected, the values of C_h near the aileron neutral position and for large projections were more negative for the plug aileron. Also, with flap deflected, the plug aileron had a larger variation of C_h over the projection range and had more stable curves of C_h against projection than the retractable aileron. In addition, the values of C_h for the plug aileron exhibited a larger change with flap deflection than did the values of C_h for the retractable aileron. With either aileron, changes in the Mach number had slight or negligible effects on C_h.

It should be borne in mind that the characteristics of the plug aileron and the retractable aileron may be changed somewhat by several modifications, as discussed previously and shown in figures 15 to 23 and 29 to 32 for the plug and retractable ailerons, respectively. The characteristics of the plug and retractable ailerons may also be changed by other modifications, as discussed in references 5, 6, and 17. These changes would be mainly in the hinge-moment characteristics and are considered somewhat secondary because the stick forces that would be provided on an airplane utilizing either of the spoiler-type devices investigated are rather low or may be masked by a booster system, a mechanical device providing "stick feel," or by a "feeler" aileron (reference 18). For example, the hinge moment provided on the model investigated herein at a dynamic pressure of 200 pounds per square foot (approx. 300 mph) and at a value of C_h of 1.0 was 4.8 foot-pounds and 2.0 foot-pounds for the basic plug and retractable ailerons, respectively. The characteristics of the positive-projection range for the plug aileron should be considered in the design of the control linkage and differential of the control system if a radical differential, such as would be required with the retractable aileron, is to be avoided.

Comparison of Lateral-Control Characteristics of the Plug and Retractable Ailerons with Those of a Sealed Plain Aileron

The variations of rolling-moment coefficient with Mach number for the basic plug and retractable ailerons investigated herein and for a sealed plain aileron previously investigated on the same wing (reference 10) are compared in figure 35. The sealed-plain-aileron data showed a general decrease in rolling effectiveness whereas the plug and retractable ailerons showed a general increase in effectiveness with increase in the Mach number. This effect is similar to that obtained in an almost similar investigation (reference 9) of a thicker semispan wing at Reynolds and Mach numbers (over the span of the ailerons tested) which were comparable to those existing herein.

Further comparisons of these data with the data of reference 10 indicate a slight loss in effectiveness of the sealed plain aileron as the angle of attack increased near the flap-retracted stall angle; whereas the plug aileron and retractable aileron of the present investigation gave an increased effectiveness and an inconsistent trend, respectively. Also, the spoiler-type ailerons produced extremely large values of C_l in the flap-deflected configuration and exhibited a large amount of effectiveness above the flap-deflected stall angle; whereas conventional-aileron effectiveness is known to receive no substantial boost as a result of flap deflection and to "washout" above the wing stall.

When comparing spoiler-type ailerons with conventional ailerons, it should be remembered that the spoiler-type aileron projects above one wing and remains within the wing contour or projects slightly below the lower contour on the other wing when the control stick is displaced laterally; therefore, the spoiler-type-aileron effectiveness on one wing is comparable to the conventional-aileron effectiveness on both wings. Moreover, spoiler-type ailerons permit use of full-span flaps to increase the wing lift, and the span of a spoiler-type aileron may be increased - to increase the aileron effectiveness - without adversely affecting the airplane lift characteristics; whereas conventional ailerons limit the flap span, and hence the airplane lift, and attempts to increase aileron control by increasing the aileron span would be detrimental to the performance of the airplane.

A comparison of the yawing-moment characteristics of the conventional aileron of reference 10 and the spoiler-type ailerons of the present investigation reveals the generally favorable yawing characteristics - such as to increase aileron effectiveness - of the plug and retractable ailerons and the unfavorable yawing characteristics of the conventional aileron.

The hinge-moment characteristics of the plug and retractable ailerons are somewhat irregular in comparison with the characteristics of the sealed plain aileron of reference 10. The plug and retractable ailerons, however, provided values of C_h that exhibited almost no Mach number effects and provided low hinge moments that could be masked or altered (as previously discussed) and permit large aileron projections, hence control, at high speed. The values of C_h for the sealed plain aileron increased with Mach number and the hinge moments probably would limit the aileron deflection, hence the control, at high speeds.

CONCLUSIONS

A high-speed wind-tunnel investigation was made to determine the lateral-control characteristics of plug and retractable ailerons on a thin, low-drag, semispan wing equipped with a 25-percent-chord, full-span, slotted flap. The ailerons investigated covered 49 percent of the wing semispan, were located at the 70-percent-chord station, and were perforated and segmented. The investigation was performed through a Mach number range from 0.13 to 0.71. The Mach and Reynolds numbers were simultaneously varied during the investigation. The results of the investigation led to the following conclusions:

1. With flap retracted or deflected, the values of rolling-moment coefficient produced by projection of the basic plug or retractable ailerons generally increased with increase in the Mach and Reynolds numbers, particularly for small projections in the flap-retracted configuration. The rolling effectiveness of the basic plug aileron generally increased with increase in the angle of attack in both flap configurations, whereas the rolling effectiveness of the basic retractable aileron generally increased with increase in the angle of attack only at small projections in the flap-retracted configuration. Almost linear control effectiveness with aileron projection probably would be provided in flight by both ailerons at all speeds in the flap-retracted configuration. Appreciably larger values of rolling-moment coefficient were produced at all projections of the basic plug and retractable ailerons with the full-span flap deflected than were produced with flap retracted, and large values of rolling-moment coefficient were produced by both ailerons above

the flap-deflected stall angle. Inconsistent trends of reversed rolling effectiveness for small projections were exhibited by the retractable aileron with flap deflected.

2. Favorable values of yawing-moment coefficient that became more favorable with aileron projection, less favorable with increase in the angle of attack, and were essentially unaffected by increase in the Mach number were generally obtained with the basic plug and retractable ailerons at angles of attack below the wing stall.

3. The variation of hinge-moment coefficient with projection of either the basic plug or retractable ailerons was generally irregular over the projection range and exhibited either small or inconsistent changes with increase in the Mach number. The curves of hinge-moment coefficient against aileron projection for the plug aileron with flap retracted were generally stable over the negative projection range and became more stable with increase in the angle of attack; whereas the corresponding data of the retractable aileron were generally unstable for small projections, stable for large projections, and were inconsistently affected by changes in the angle of attack. With the flap deflected, more negative values of hinge-moment coefficient were obtained at small projections of the basic plug aileron and more positive values of hinge-moment coefficient were obtained at large projections of the basic retractable aileron than were obtained with flap retracted.

4. Several modifications of the basic plug and basic retractable ailerons were investigated and were observed to have either a slight or a negligible effect on the aileron rolling-moment characteristics and a substantial effect on the hinge-moment characteristics. A means of altering, to some extent, the lateral-control characteristics of the aileron is thereby available.

5. A comparison of the characteristics of plug and retractable ailerons indicated similar yawing-moment characteristics for both ailerons, slightly larger values of rolling-moment coefficient for the retractable aileron with flap retracted at intermediate and large projections, and substantially larger values of rolling-moment coefficient for the plug aileron with flap deflected over the entire projection range. In addition, the tendency toward reversal of effectiveness for small projections with flap deflected which was exhibited by the retractable-aileron data was not shown by the plug-aileron data. The variation of hinge-moment coefficient with aileron projection generally was more stable over a greater part of the projection range for the plug aileron, and the values of hinge-moment coefficient of the plug aileron exhibited a larger change with flap deflection than did the values of hinge-moment coefficient of the retractable aileron.

6. A comparison of the data for plug and retractable ailerons with the data obtained with a sealed plain aileron on the same wing indicated the generally more beneficial effects obtained with the spoiler-type ailerons. Increase of rolling effectiveness with Mach number and flap

deflection, control above the flap-deflected wing stall angle, generally favorable yawing moments, and no appreciable effects of changes in Mach number on the hinge-moment characteristics were observed for the spoiler-type devices as contrasted to opposite trends shown or anticipated for the sealed plain aileron.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., April 7, 1948

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TABLE I.- ORDINATES FOR AIRFOIL AND FLAP

[All dimensions given in percent of wing chord]

NACA 65-210 airfoil

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.435	.819	.565	-.719
.678	.999	.822	-.859
1.169	1.273	1.331	-1.059
2.408	1.757	2.592	-1.385
4.898	2.491	5.102	-1.859
7.394	3.069	7.606	-2.221
9.894	3.555	10.106	-2.521
14.899	4.338	15.101	-2.992
19.909	4.938	20.091	-3.346
24.921	5.397	25.079	-3.607
29.936	5.732	30.064	-3.788
34.951	5.954	35.049	-3.894
39.968	6.067	40.032	-3.925
44.984	6.058	45.016	-3.868
50.000	5.918	50.000	-3.709
55.014	5.625	54.986	-3.435
60.027	5.217	59.973	-3.075
65.036	4.712	64.964	-2.652
70.043	4.128	69.957	-2.184
75.045	3.479	74.955	-1.689
80.044	2.783	79.956	-1.191
85.038	2.057	84.962	-.711
90.028	1.327	89.972	-.293
95.014	.622	94.986	.010
100.000	0	100.000	0

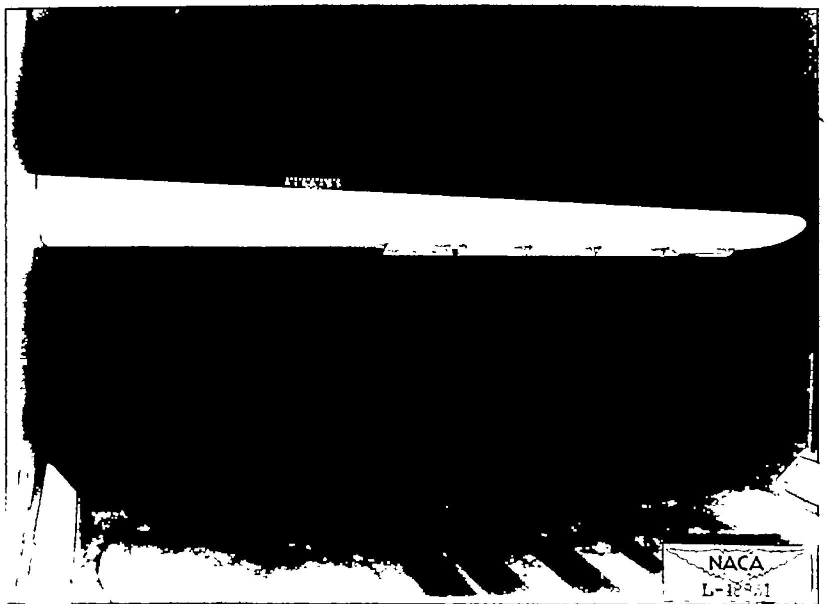
L.E. radius: 0.687
Slope of radius through L.E.: 0.084

Slotted flap

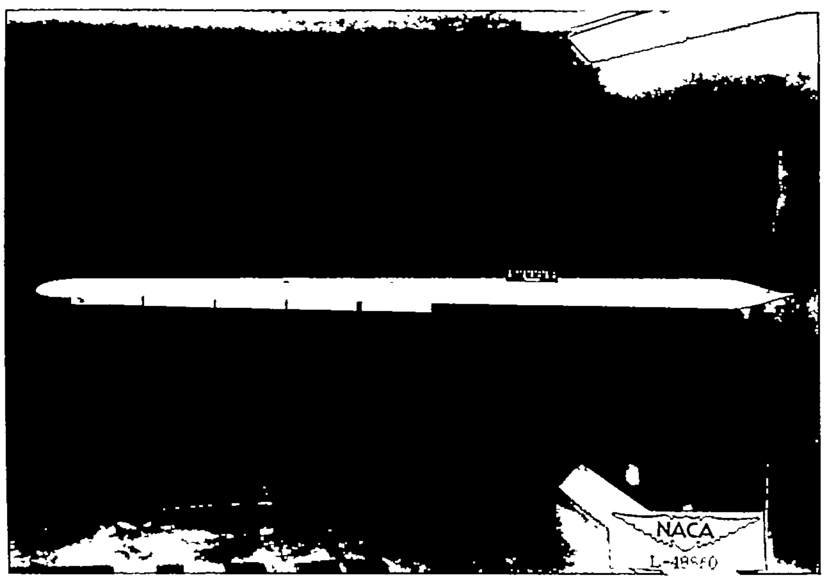
Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.28	.92	.28	-.41
.56	1.19	.56	-.62
1.12	1.56	1.12	-.88
1.69	1.80	1.69	-1.00
2.25	1.99	2.48	-1.03
3.38	2.22	4.98	-.83
4.50	2.33	7.48	-.63
5.61	2.38	9.98	-.44
7.00	2.40	12.48	-.27
9.00	2.35	14.98	-.12
11.00	2.16	17.48	.01
12.51	1.91	19.99	.10
15.01	1.50	22.49	.12
17.51	1.10	25.00	0
20.00	.71		
22.50	.34		
25.00	0		

L.E. radius: 0.80
Slope of radius through L.E.: 0.35

NACA



(a) Front view showing aileron projecting from upper surface of wing.



(b) Rear view showing aileron projecting from upper surface of wing.

Figure 1.- Reflection-plane model in inverted position with full-span flap retracted.

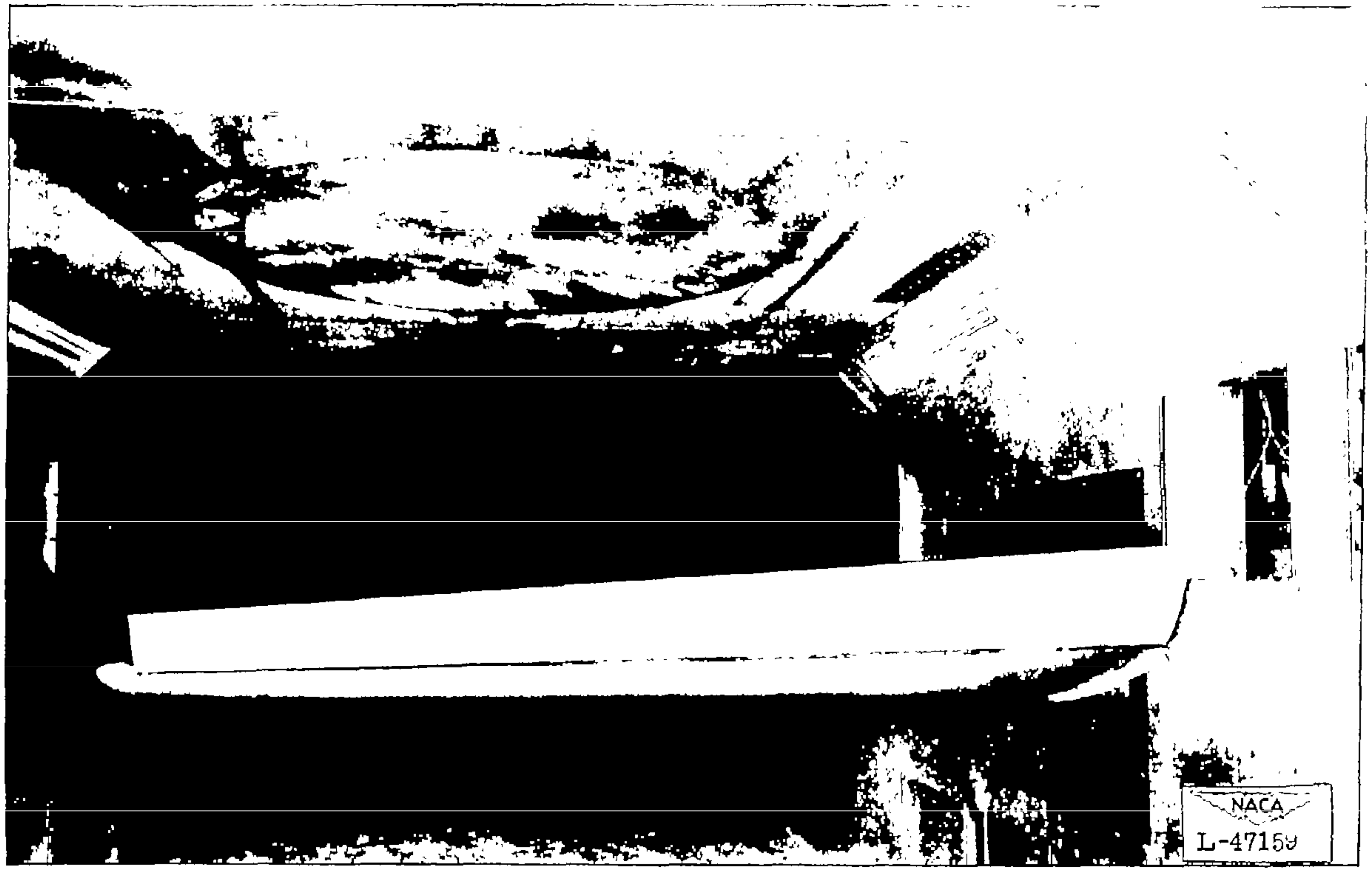


Figure 2.- Rear view of reflection-plane model in inverted position with full-span flap deflected.

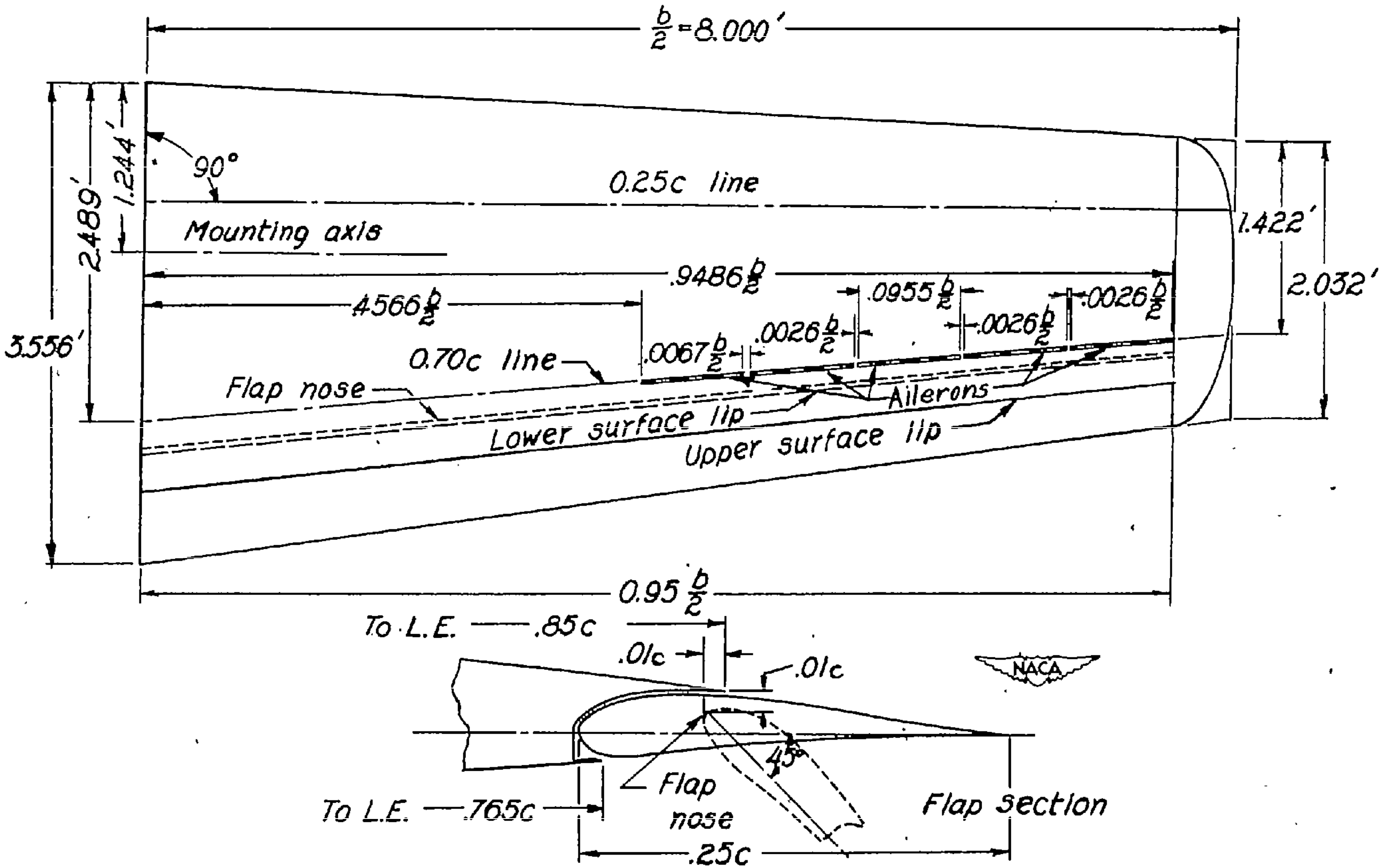
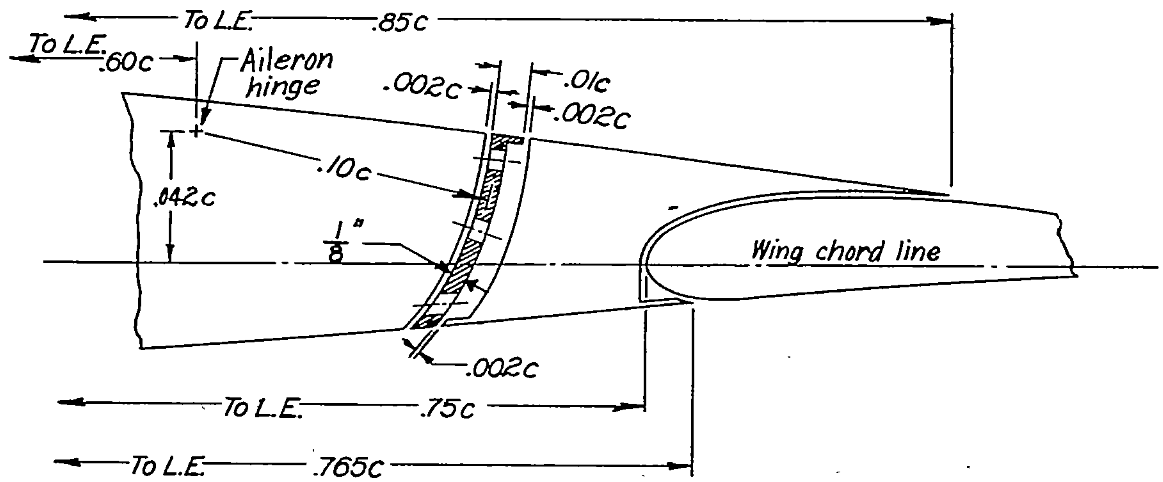
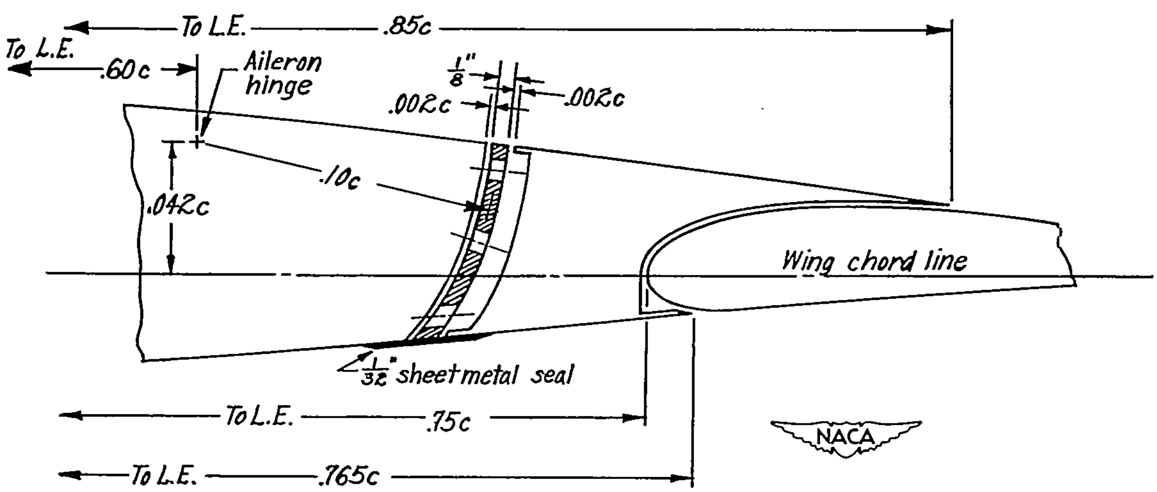


Figure 3.- Schematic drawing of right-semispan-wing model equipped with spoiler-type ailerons and full-span slotted flap.



(a) Basic plug-aileron arrangement.



(b) Basic retractable-aileron arrangement.

Figure 4.- Schematic drawing of basic plug-aileron and retractable-aileron arrangements tested on semispan wing.

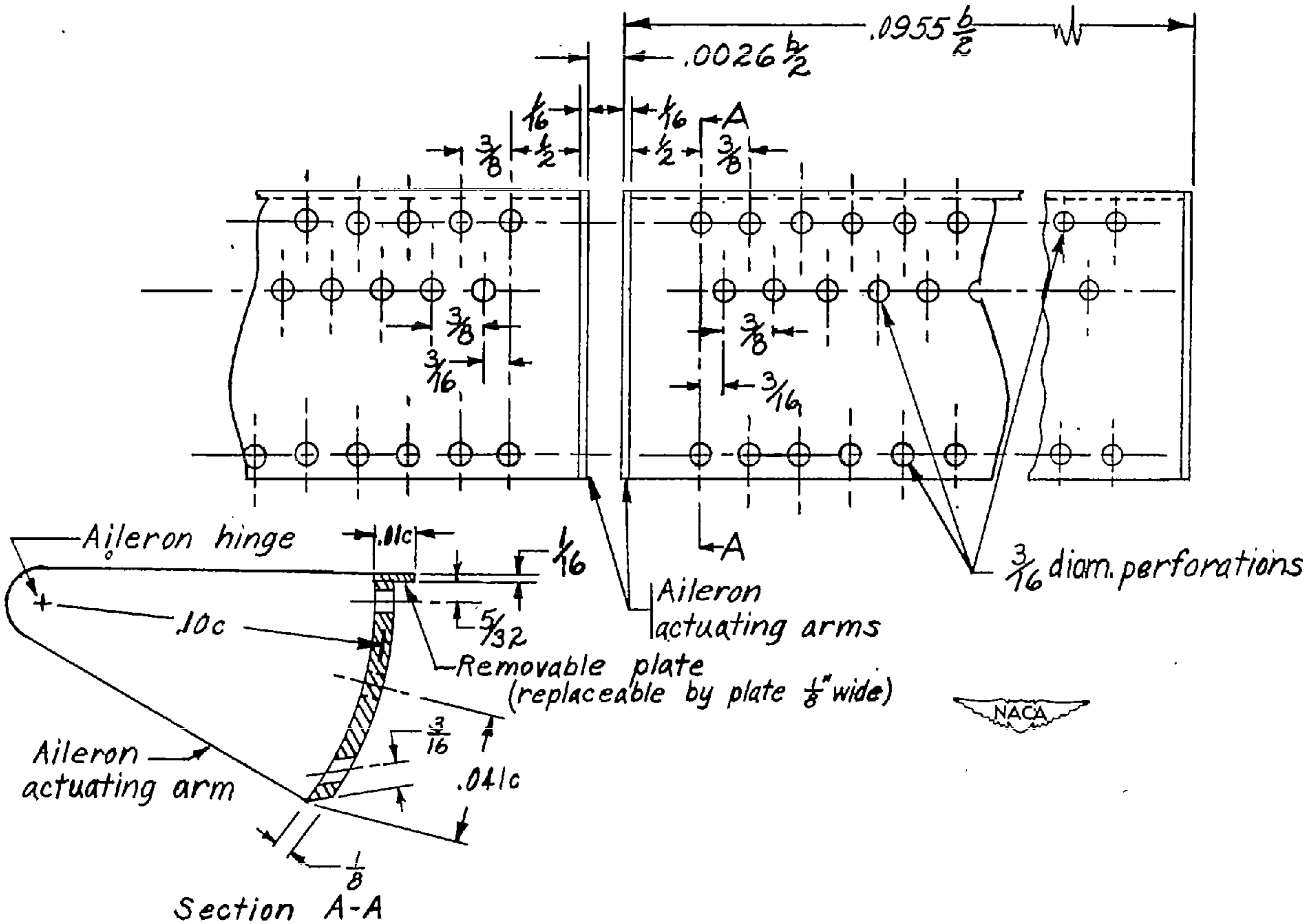
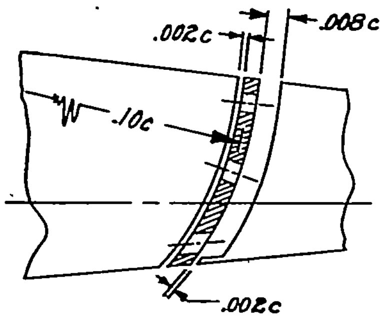
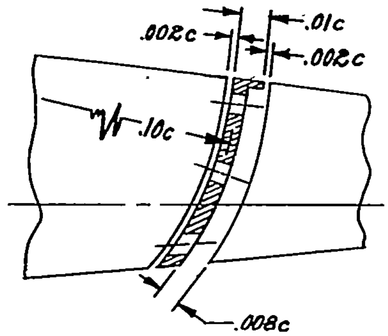


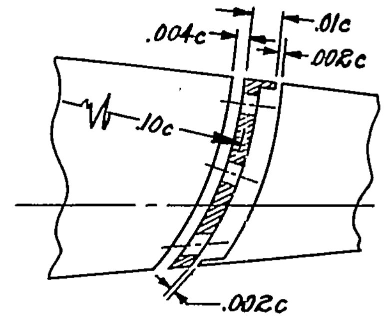
Figure 5.- Details of aileron and aileron actuating arms installed on semispan wing. (All dimensions are in inches except where otherwise noted.)



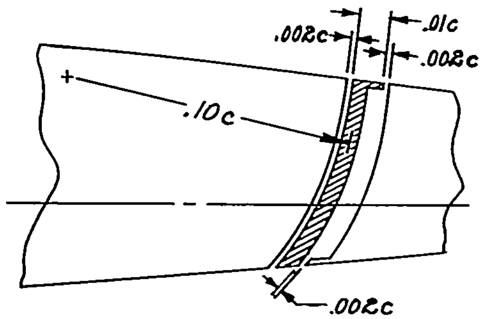
(a) Plug aileron with 0.01c top plate removed.



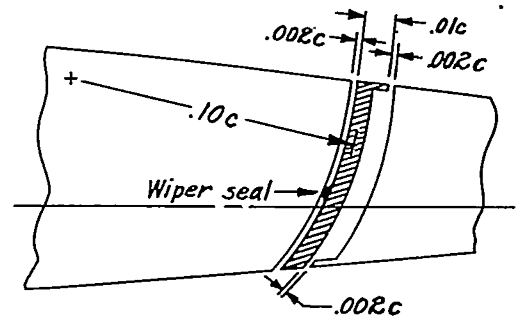
(b) Plug aileron with enlarged plug slot on wing lower surface.



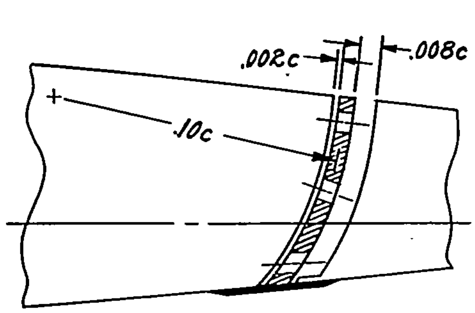
(c) Plug aileron with enlarged wing slot ahead of aileron.



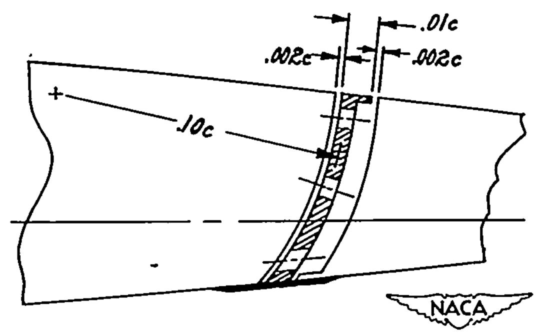
(d) Plug aileron with perforations sealed.



(e) Plug aileron with perforations sealed and wiper seal installed in slot ahead of aileron.



(f) Retractable aileron with enlarged wing slot behind aileron.



(g) Retractable aileron equipped with an 0.01c top plate.

Figure 6.- Sketches of modified plug-aileron and modified retractable-aileron arrangements tested on semispan wing.

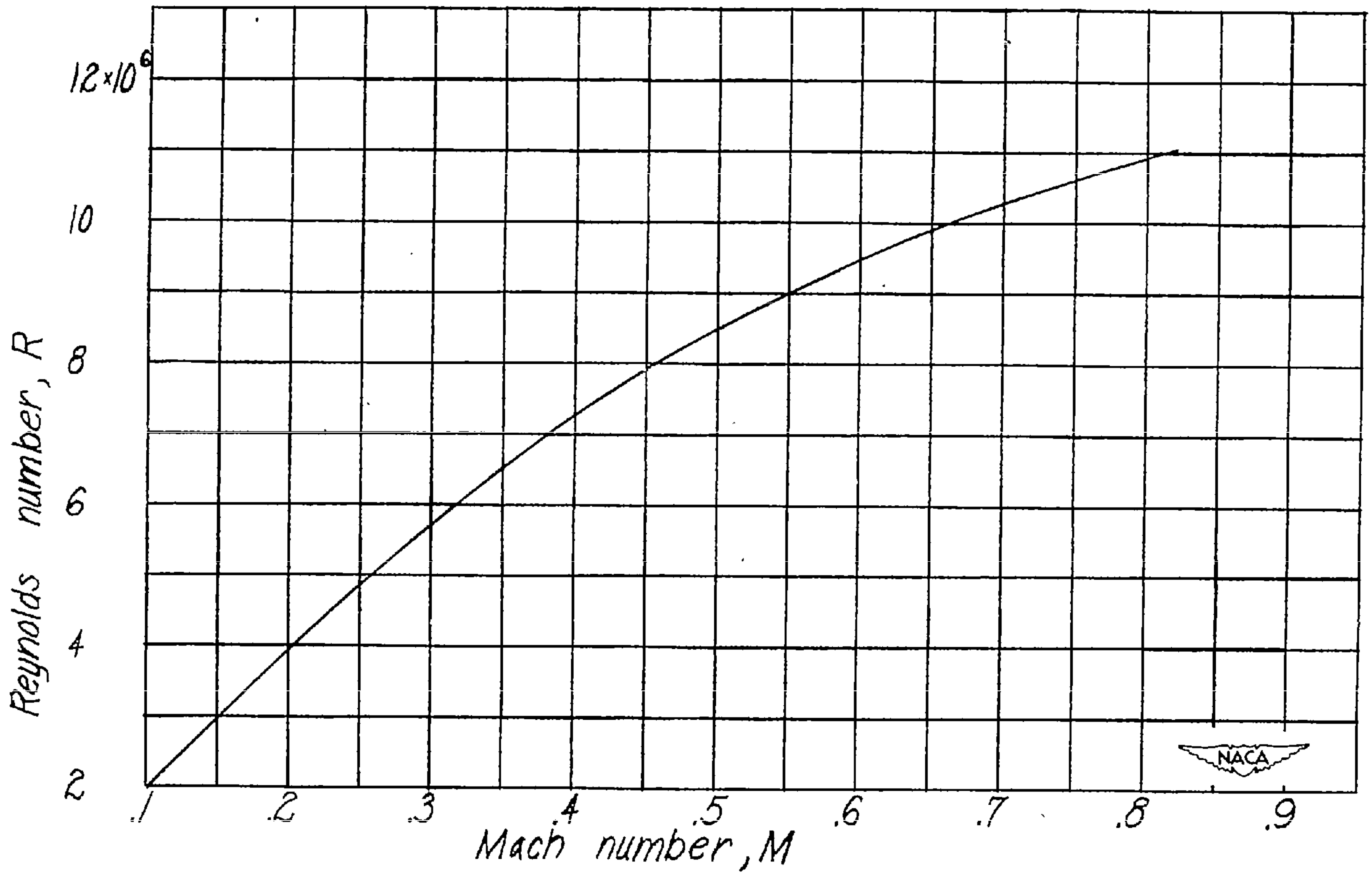


Figure 7.- Variation of Reynolds number with Mach number. Reynolds number is based on wing mean aerodynamic chord of 2.86 feet.

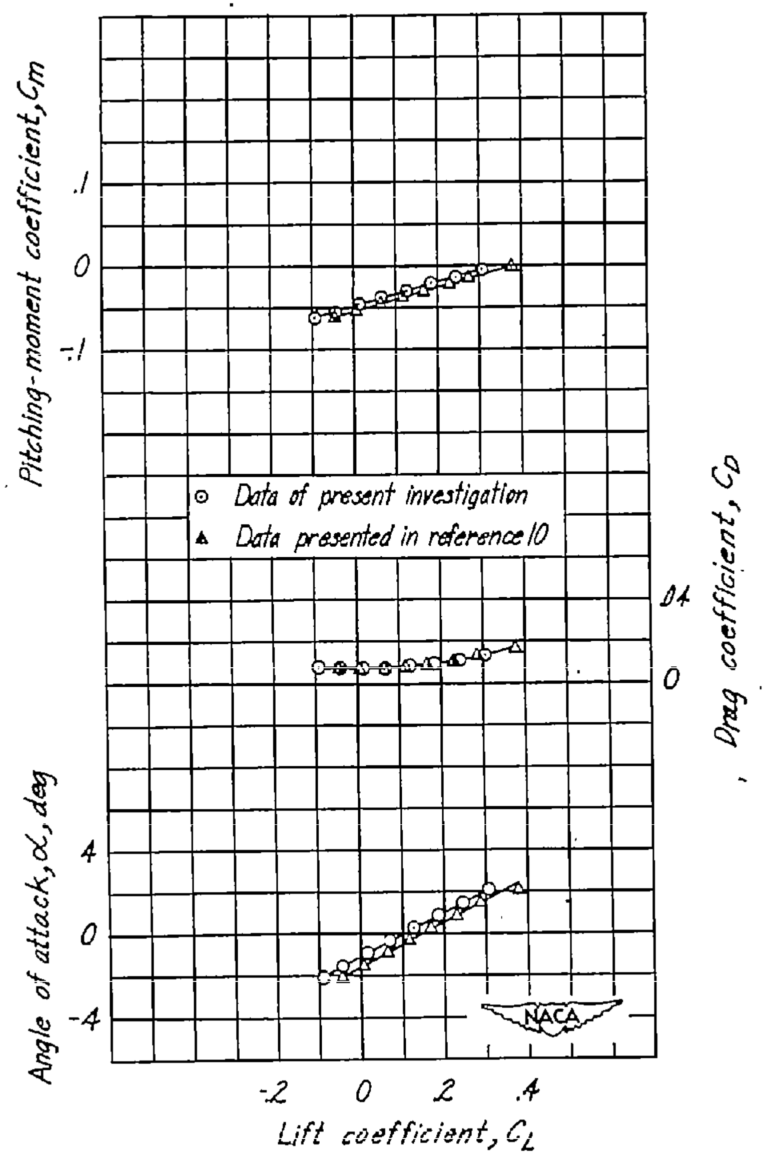


Figure 8.- Aerodynamic characteristics of semispan wing model with flap retracted at Mach number of 0.71.

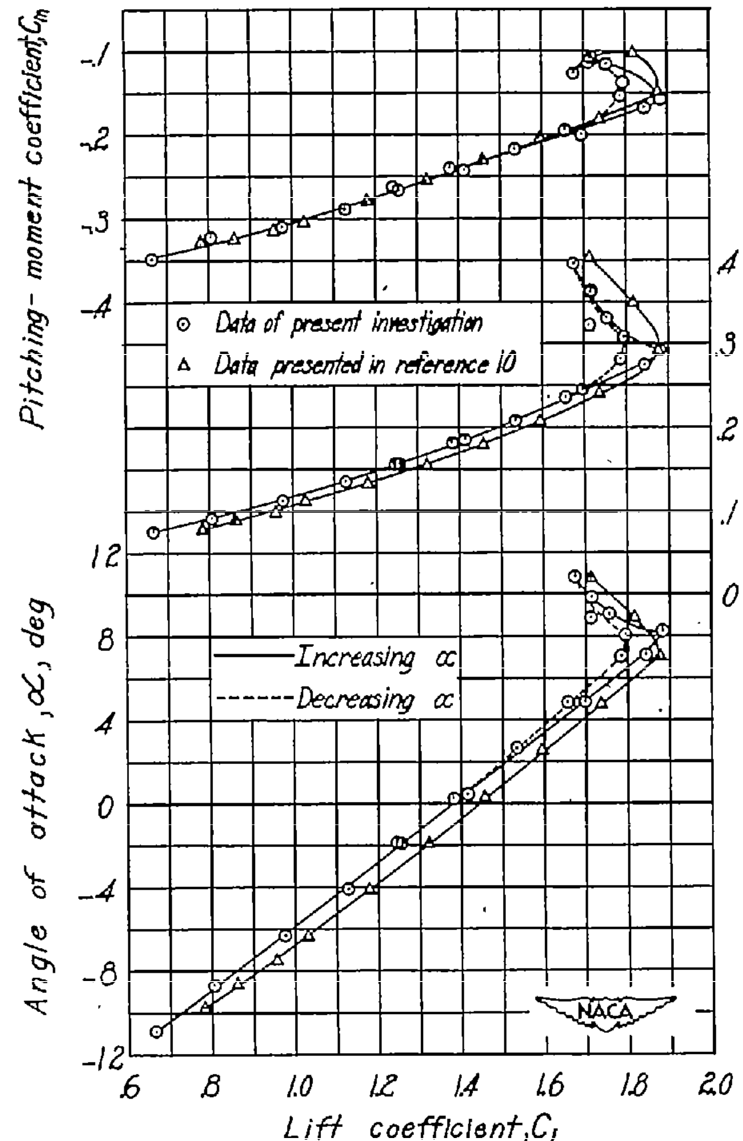
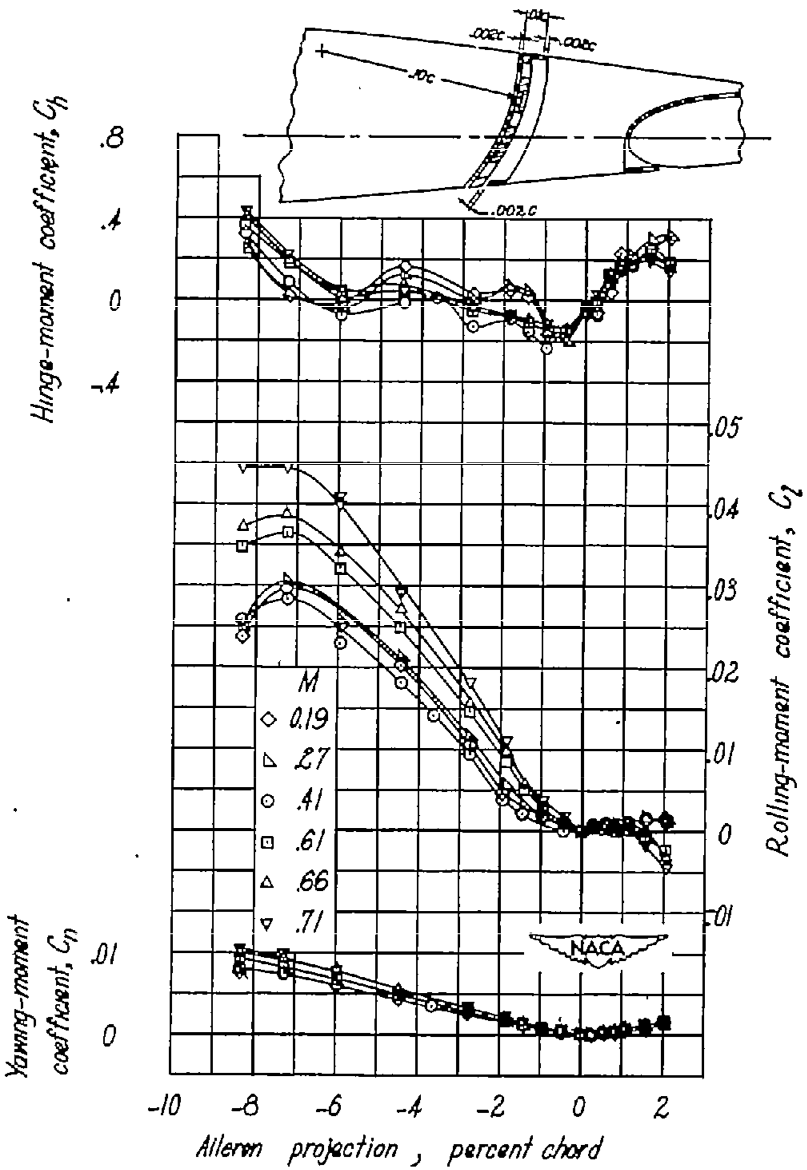
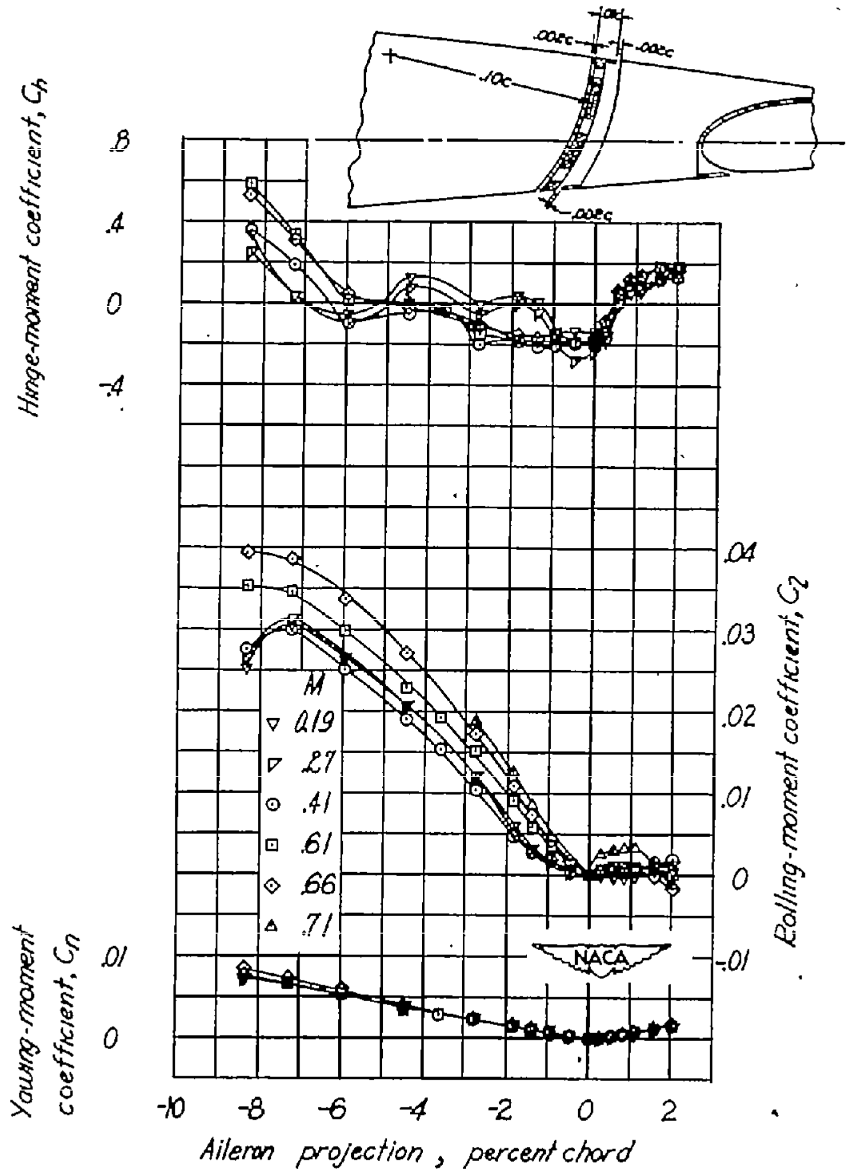


Figure 9.- Aerodynamic characteristics of semispan wing model with full-span slotted flap deflected 45° at Mach number of 0.13.

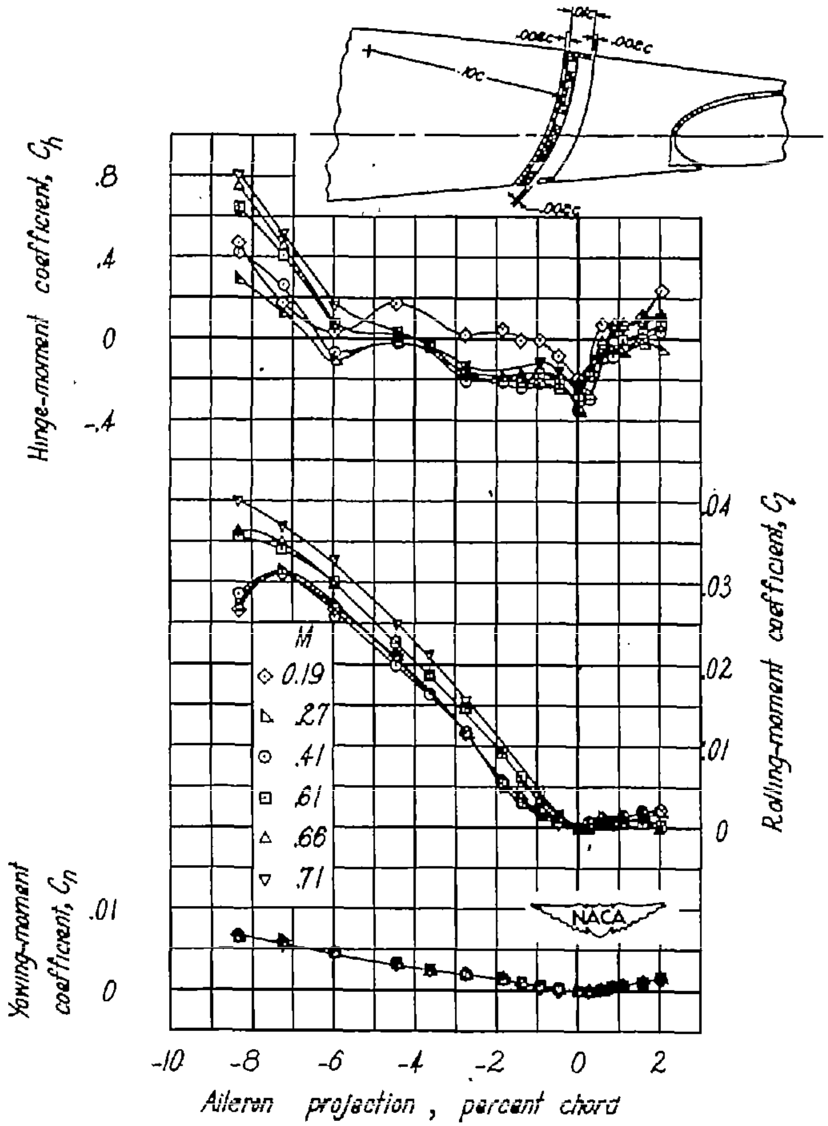


(a) $\alpha \approx -2.1^{\circ}$; $C_L \approx -0.07$.

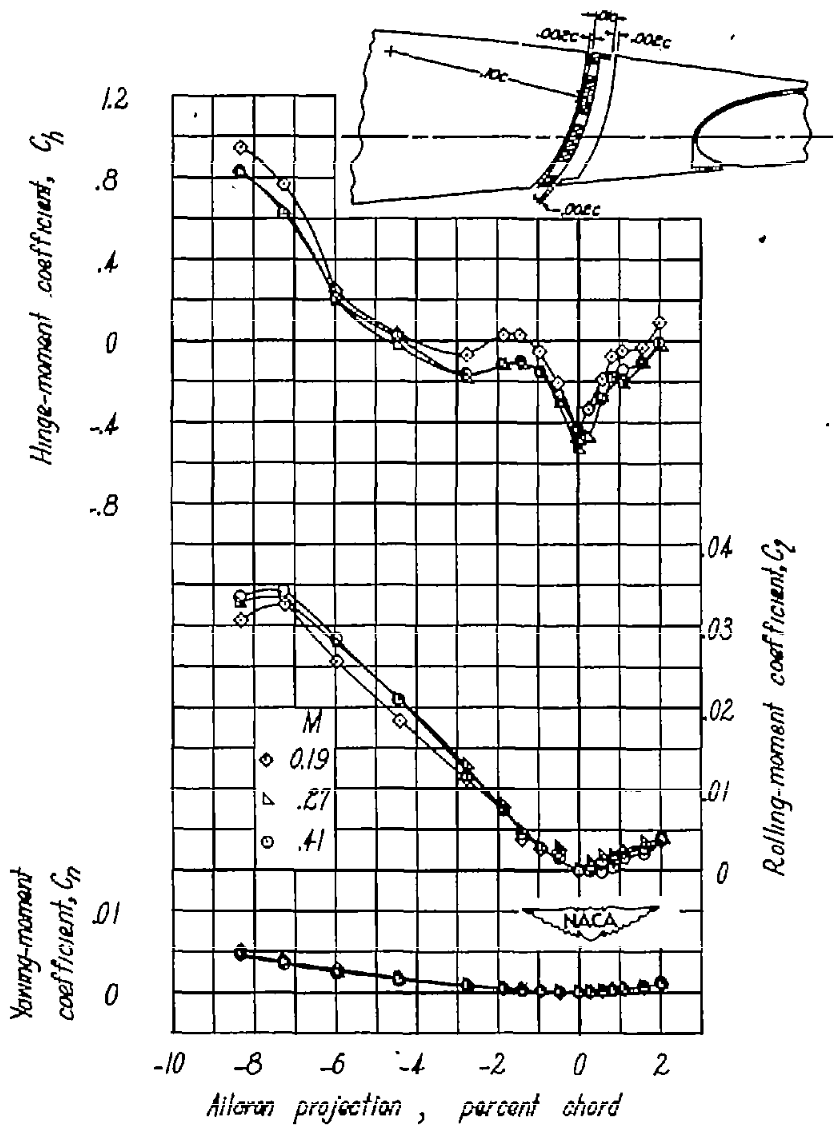


(b) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.13$.

Figure 10.- Variation of lateral-control characteristics of complete wing with plug-aileron projection at various Mach numbers. Full-span flap retracted.

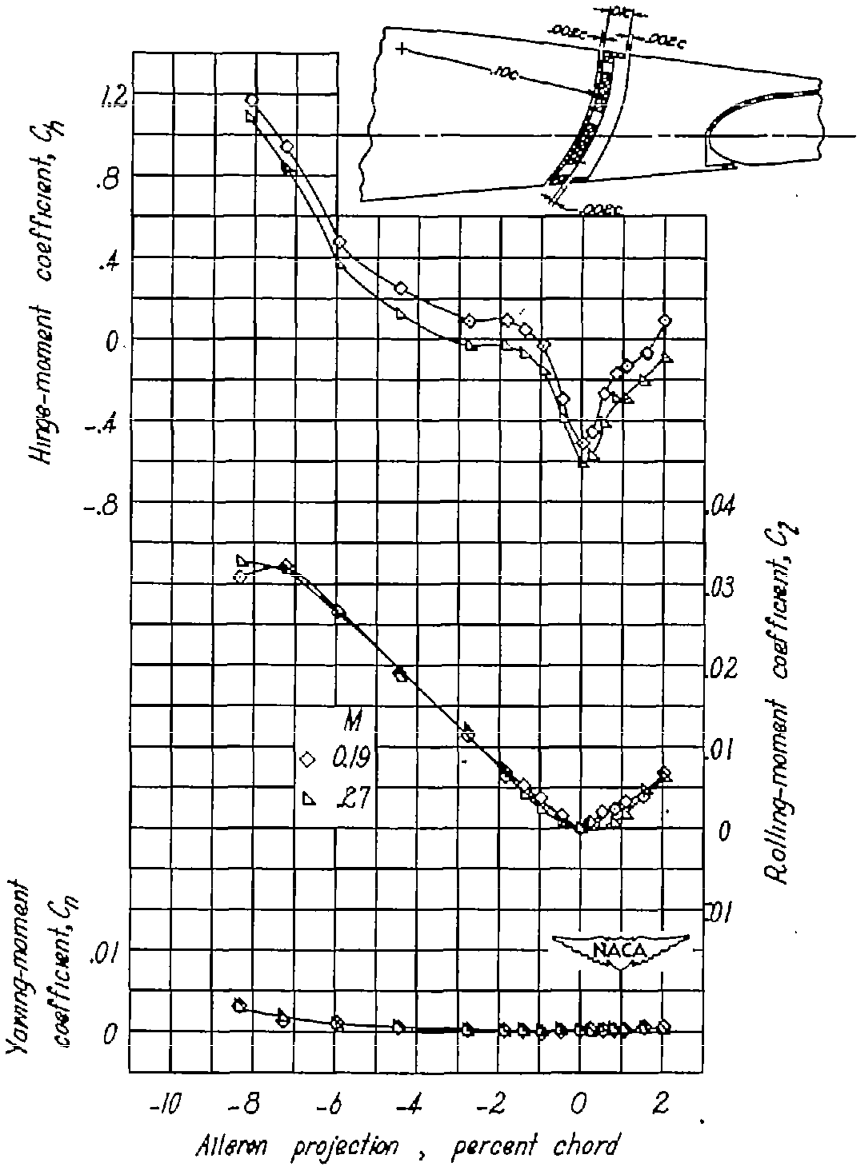


(c) $\alpha \approx 2.5^{\circ}$; $C_L \approx 0.32$.



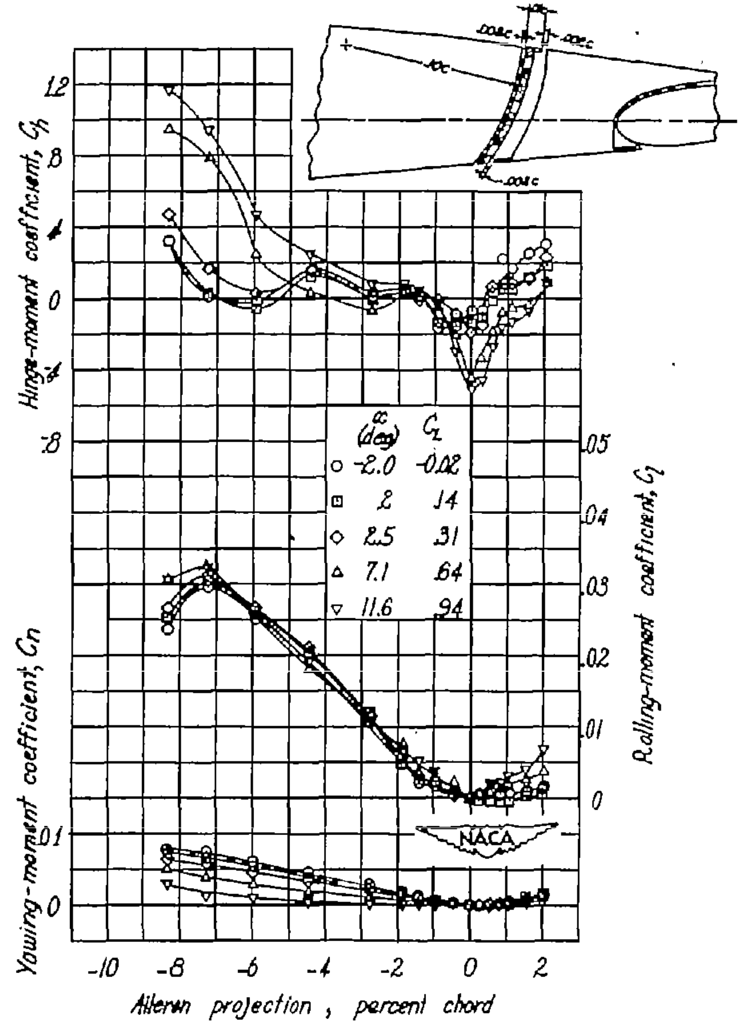
(d) $\alpha \approx 7.1^{\circ}$; $C_L \approx 0.65$.

Figure 10.- Continued.



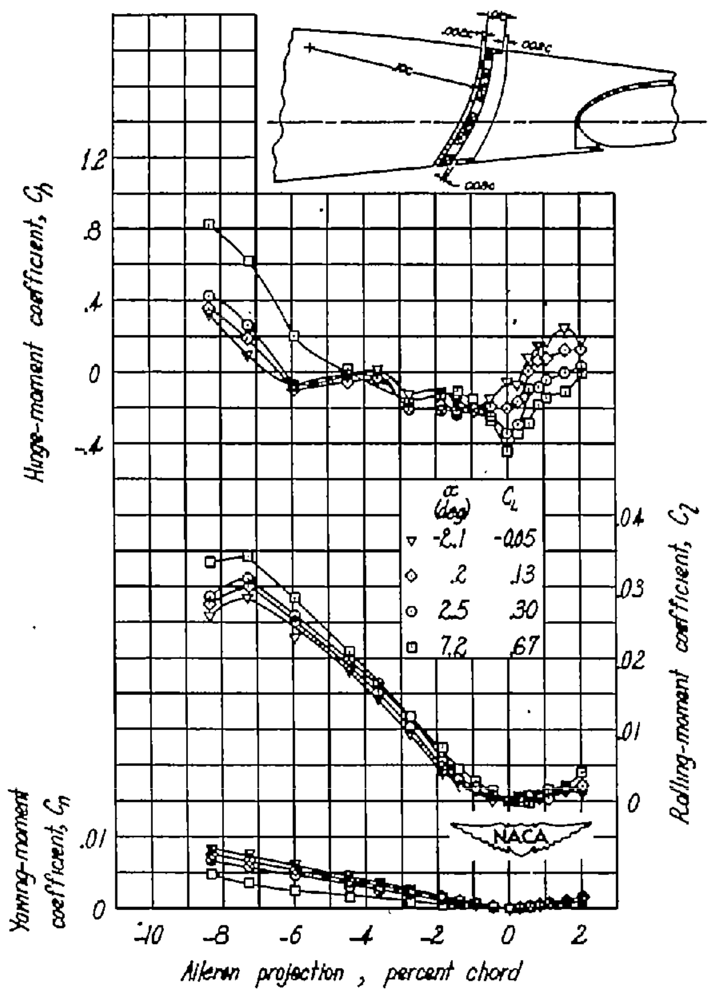
(e) $\alpha \approx 11.7^{\circ}$; $C_L \approx 0.95$.

Figure 10.- Concluded.

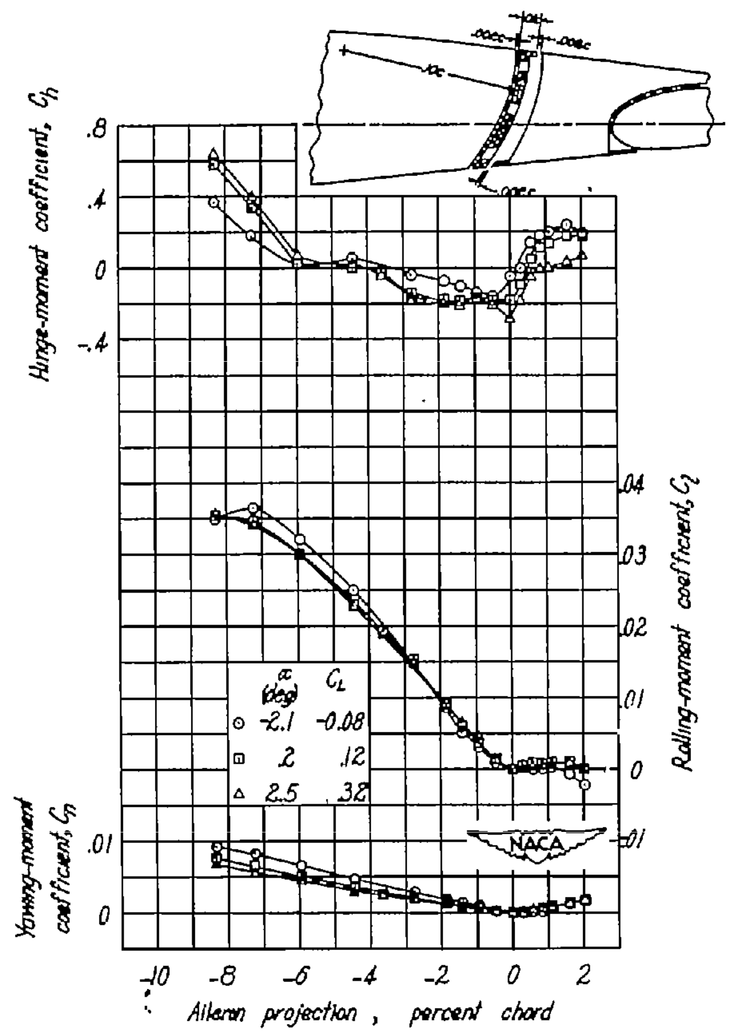


(a) M = 0.19.

Figure 11.- Variation of lateral-control characteristics of complete wing with plug-aileron projection at various angles of attack. Full-span flap retracted.

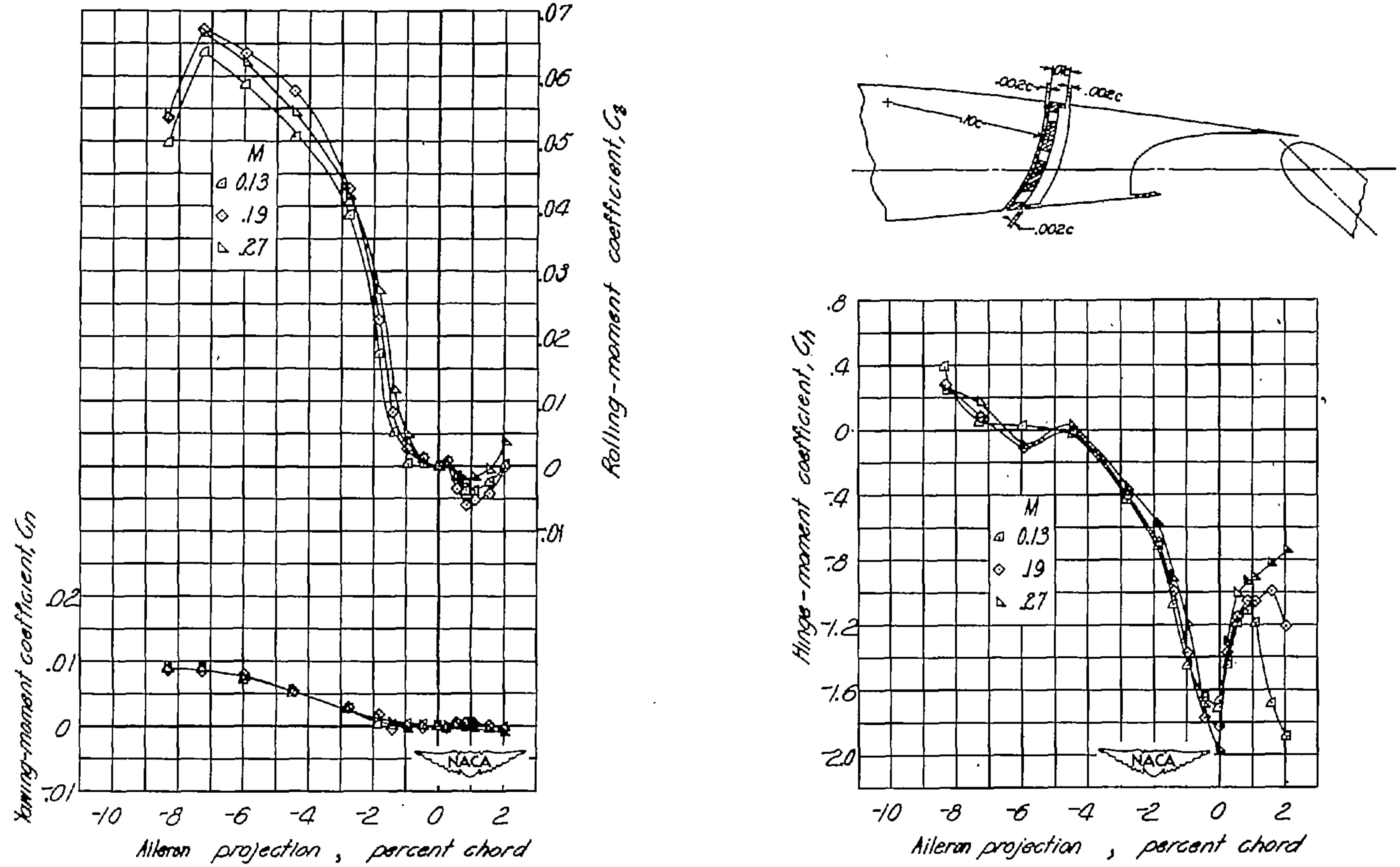


(b) M = 0.41.



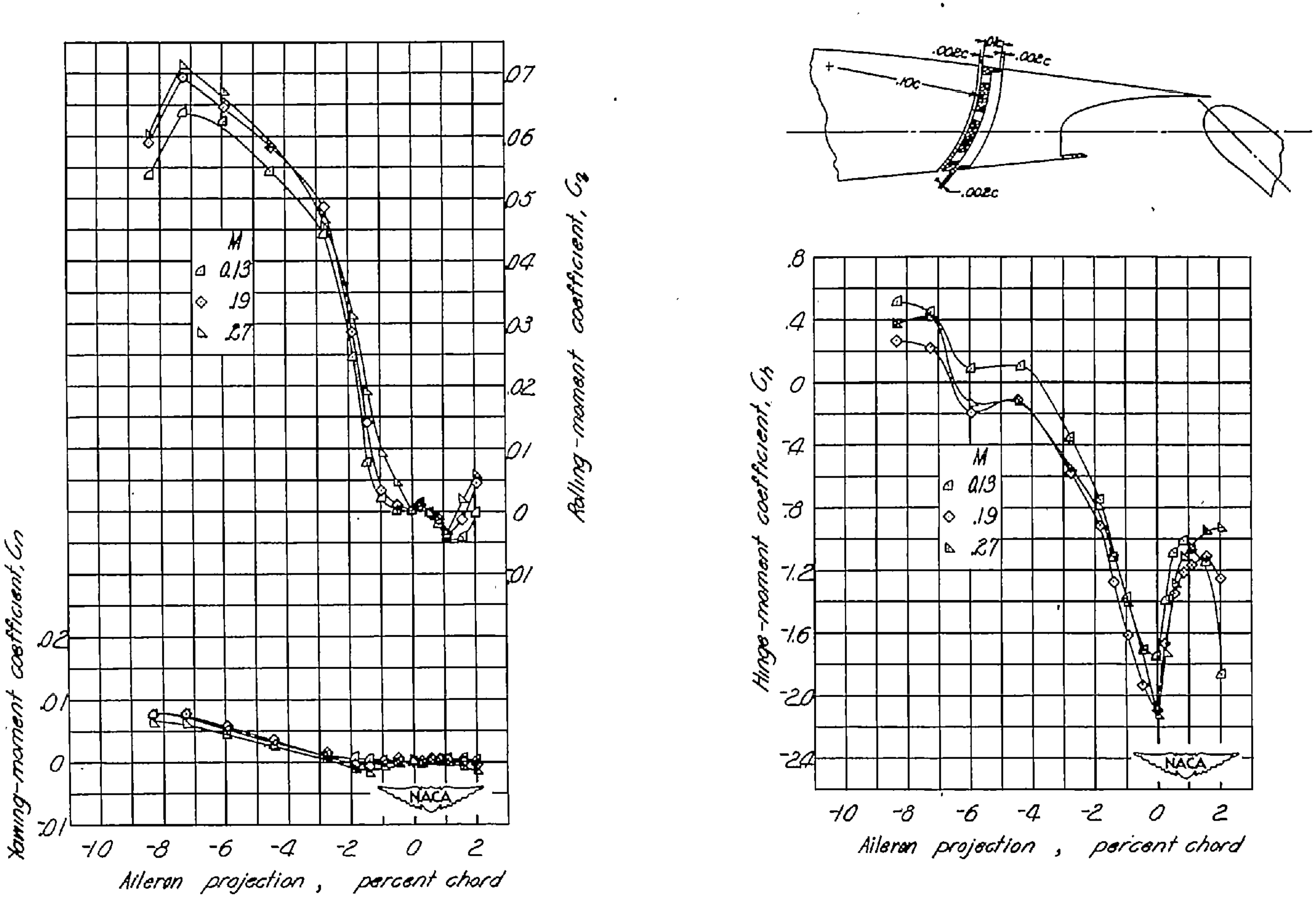
(c) M = 0.61.

Figure 11.- Concluded.



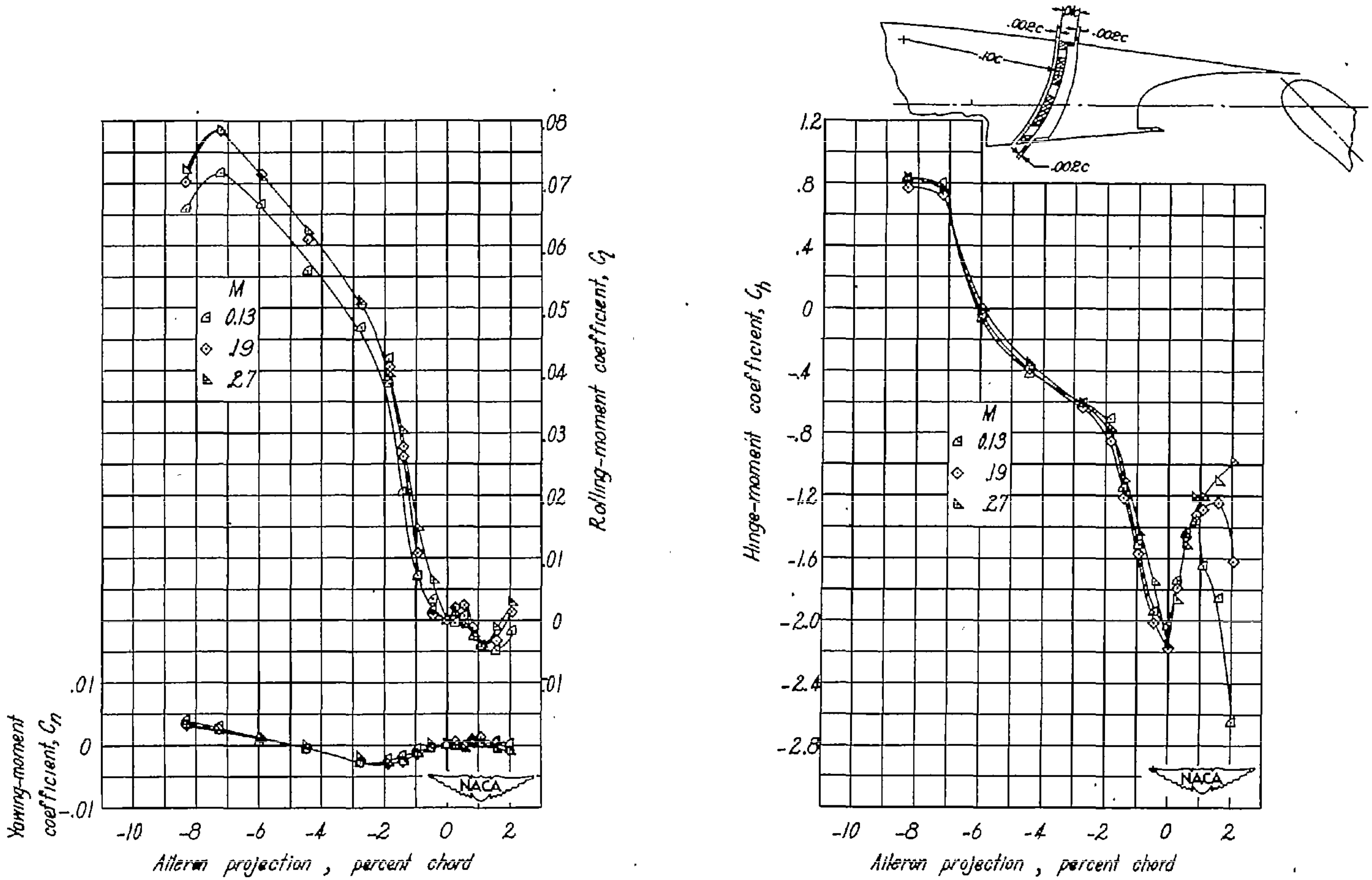
(a) $\alpha \approx -6.3^{\circ}$; $C_L \approx 0.98$.

Figure 12.- Variation of lateral-control characteristics of complete wing with plug-aileron projection at various Mach numbers. Full-span flap deflected 45°.



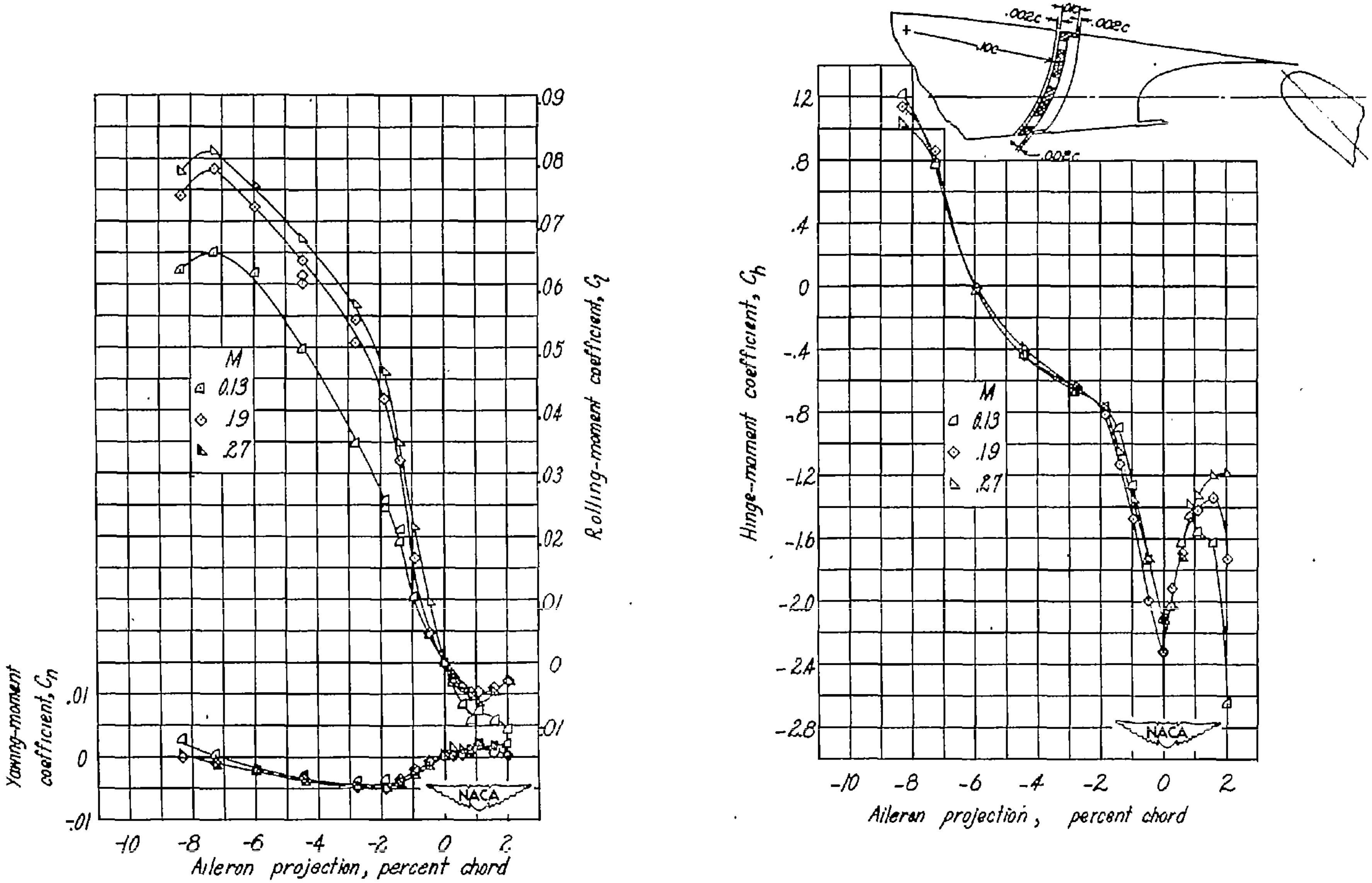
(b) $\alpha \approx -1.8^{\circ}$; $C_L \approx 1.29$.

Figure 12.- Continued.



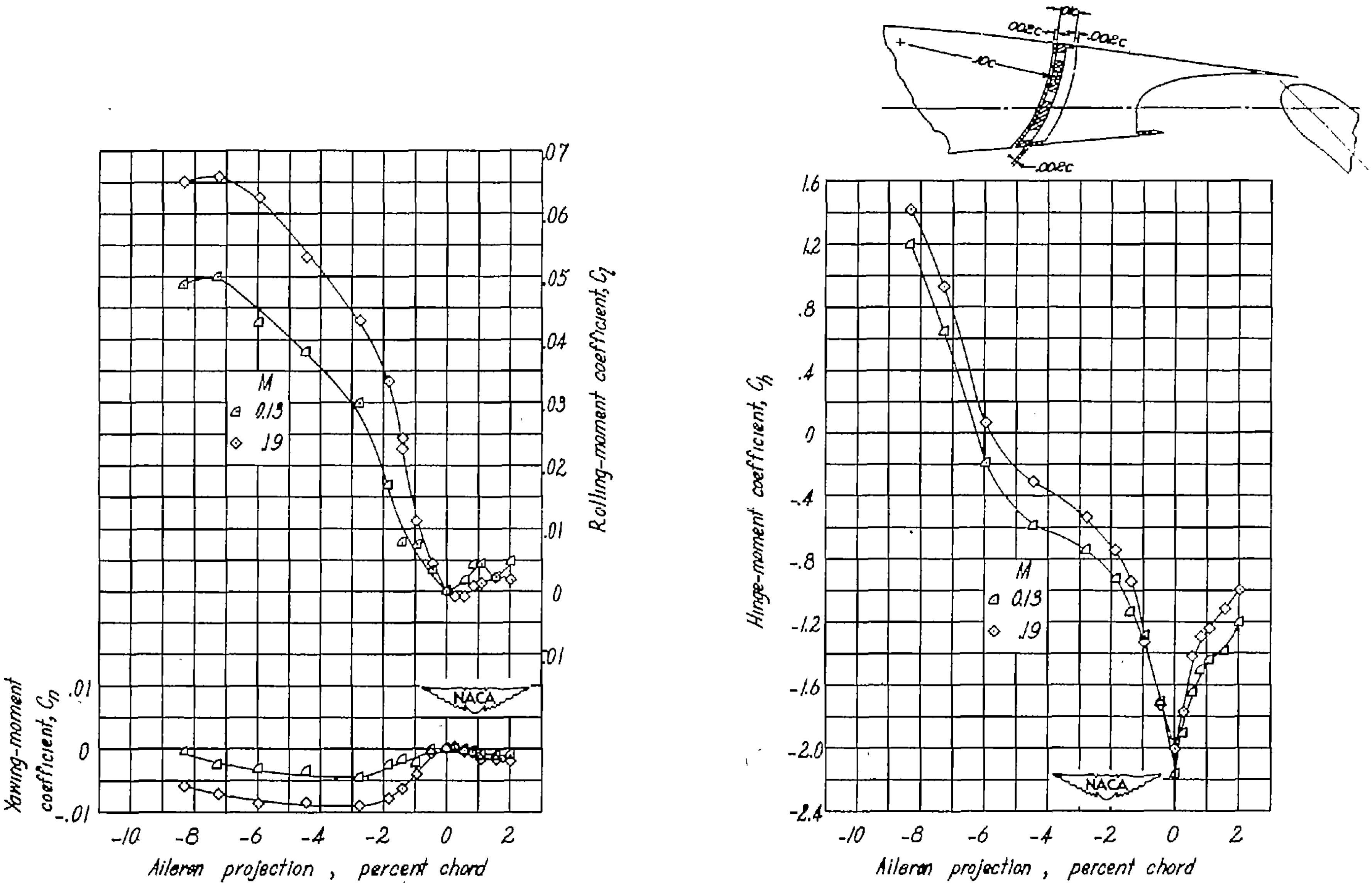
(c) $\alpha \approx 2.8^{\circ}$; $C_L \approx 1.59$.

Figure 12.- Continued.



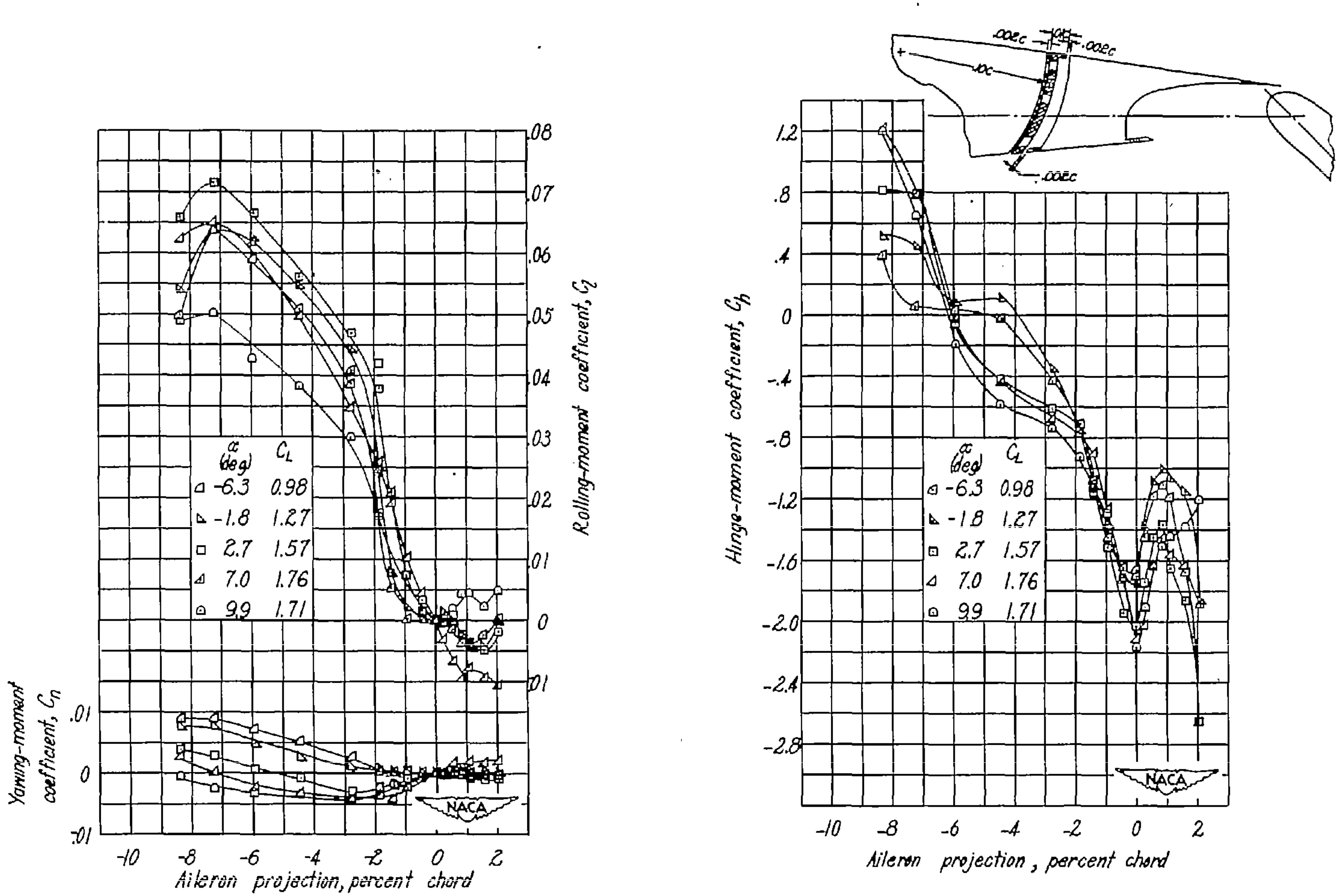
(d) $\alpha \approx 7.1^{\circ}$; $C_L \approx 1.82$.

Figure 12.- Continued.



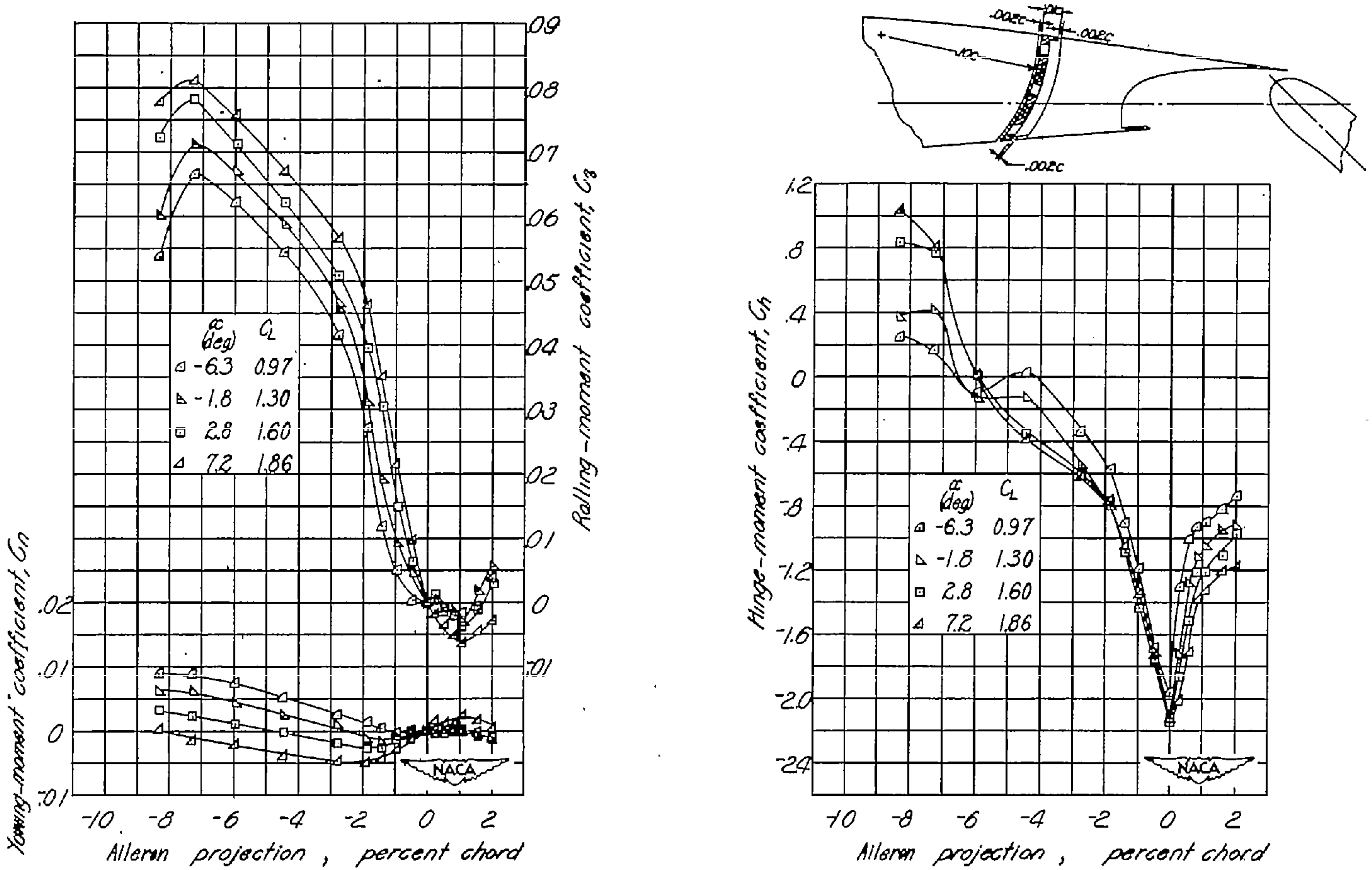
(e) $\alpha \approx 10.0^{\circ}$; $C_L \approx 1.76$.

Figure 12.- Concluded.



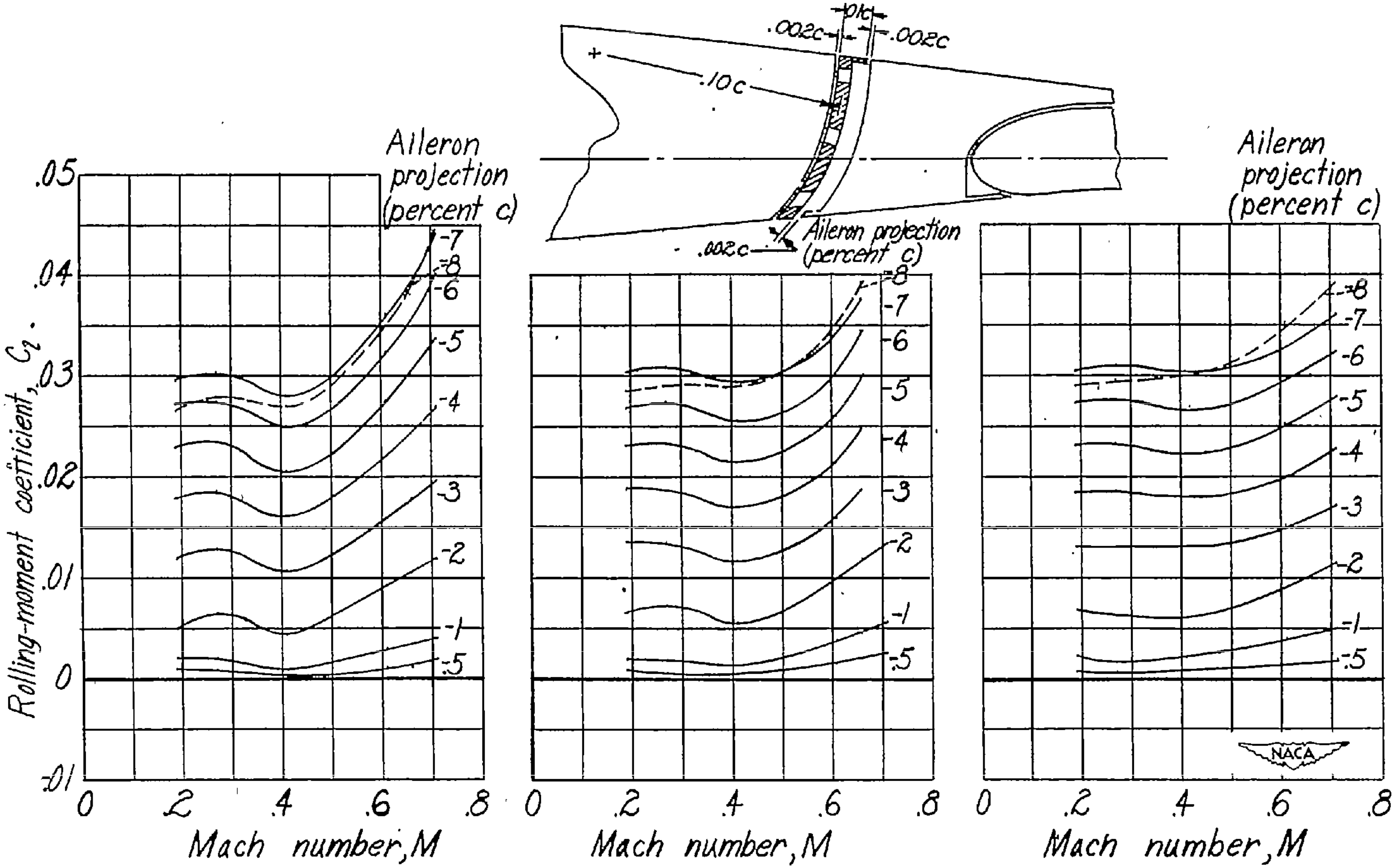
(a) M = 0.13.

Figure 13.- Variation of lateral-control characteristics of complete wing with plug-aileron projection at various angles of attack. Full-span flap deflected 45°.



(b) M = 0.27.

Figure 13.- Concluded.

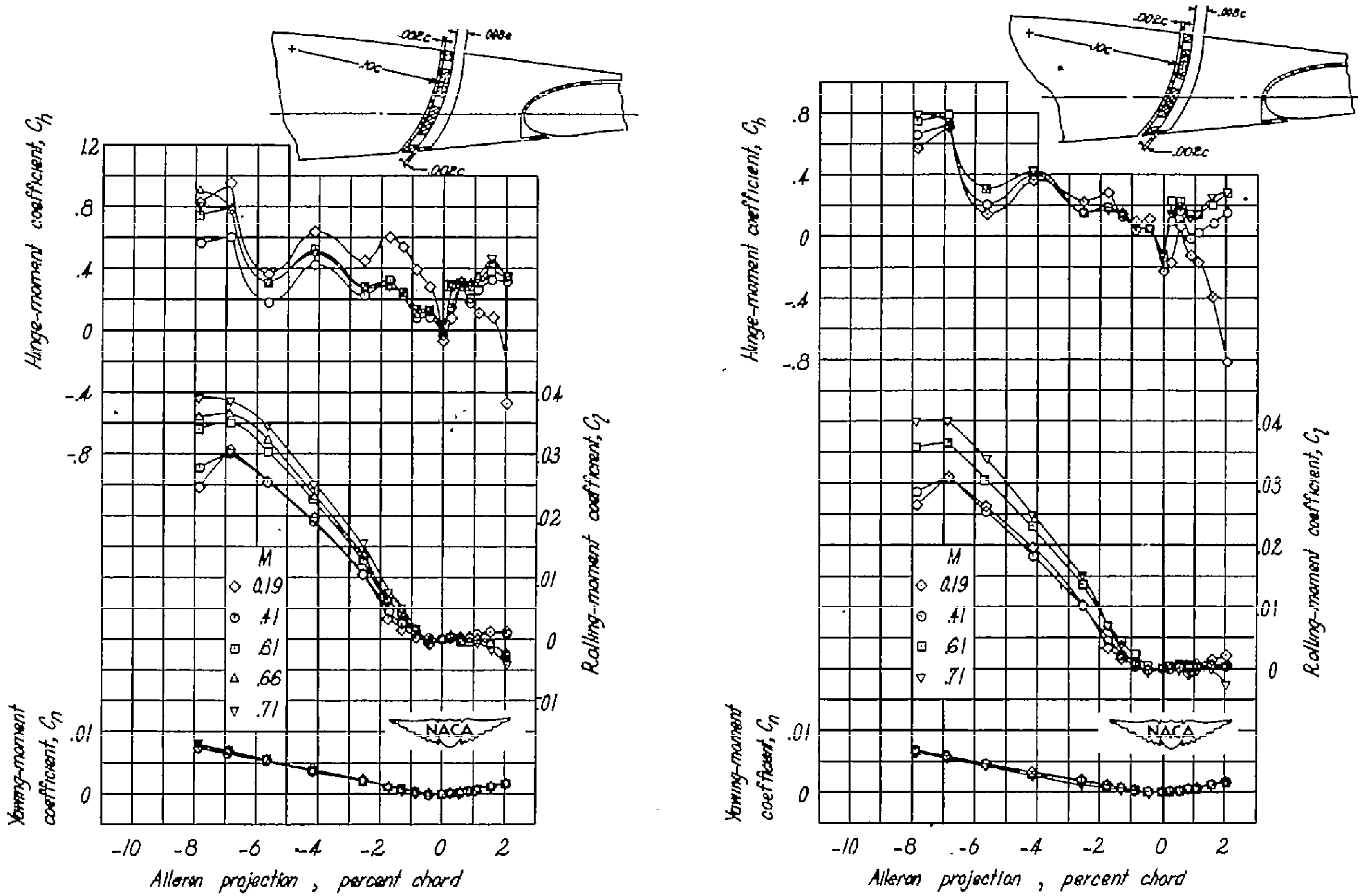


(a) α ≈ -2.1°.

(b) α ≈ 0.2°.

(c) α ≈ 2.5°.

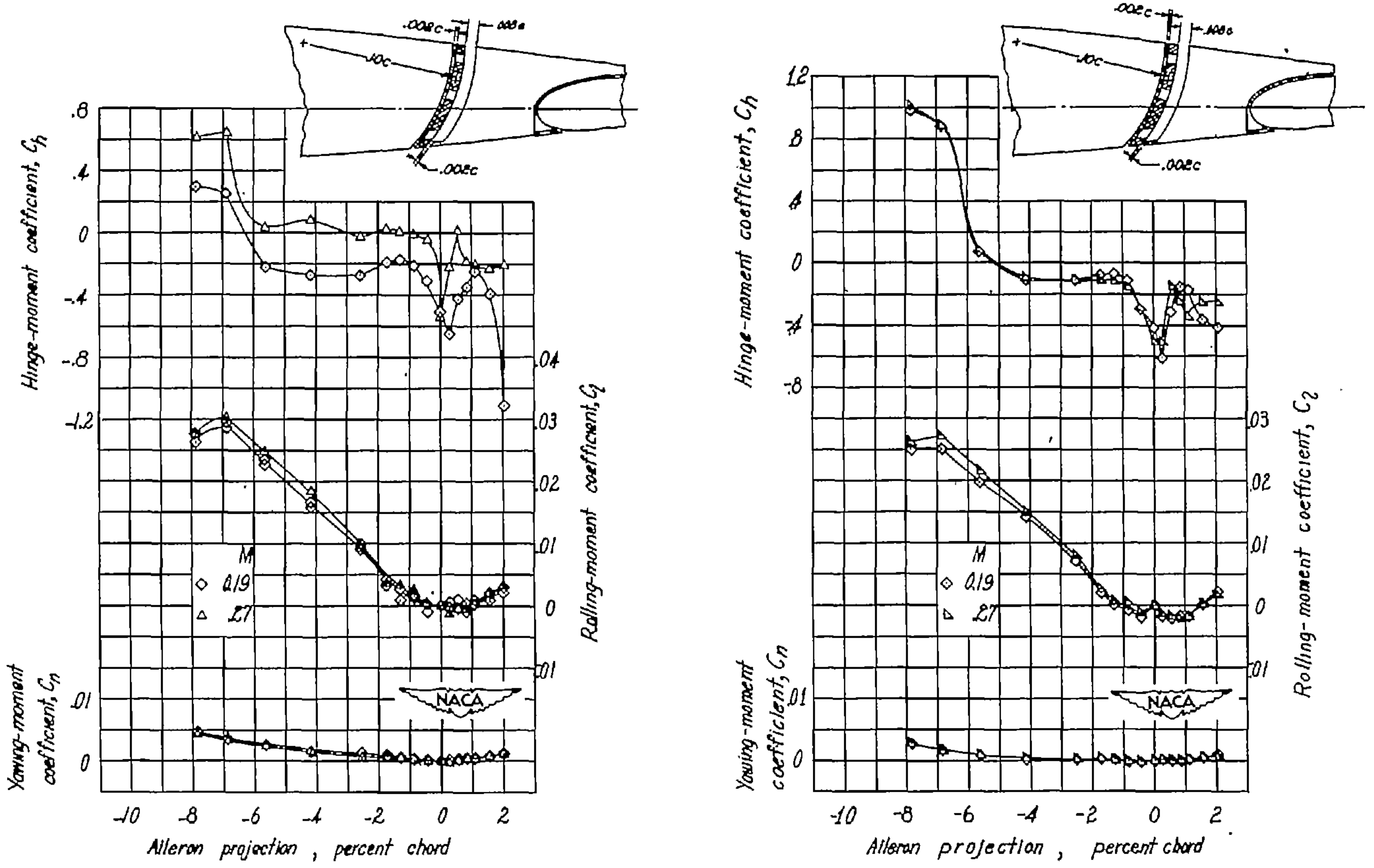
Figure 14.- Variation of lateral-control characteristics of complete wing with Mach number at various plug-aileron projections. Full-span flap retracted.



(a) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.13$.

(b) $\alpha \approx 2.6^{\circ}$; $C_L \approx 0.33$.

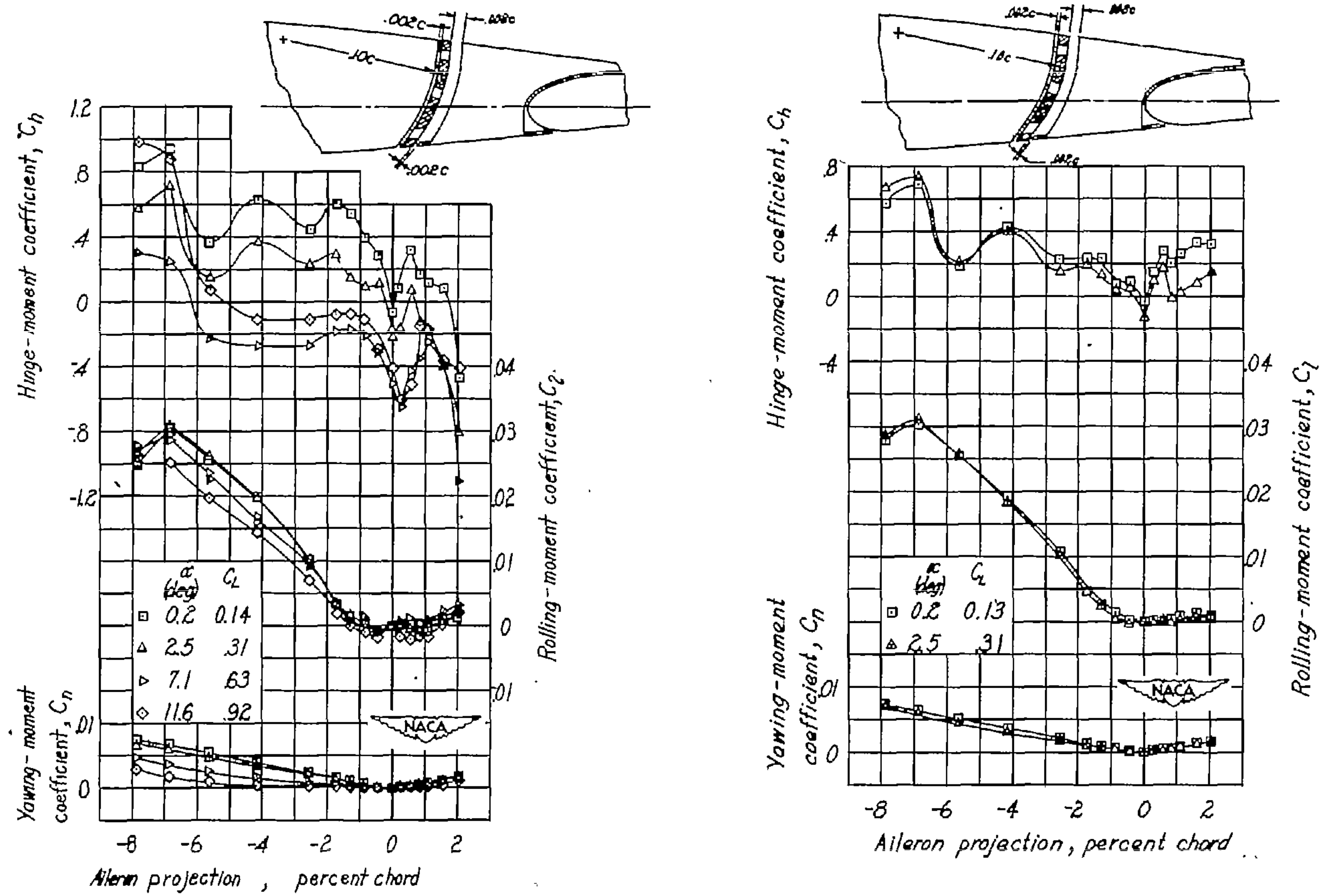
Figure 15.- Variation of lateral-control characteristics of complete wing with projection of modified plug aileron at various Mach numbers. Plug aileron modified by removing 0.01c top plate. Full-span flap retracted.



(c) $\alpha \approx 7.1^{\circ}$; $C_L \approx 0.64$.

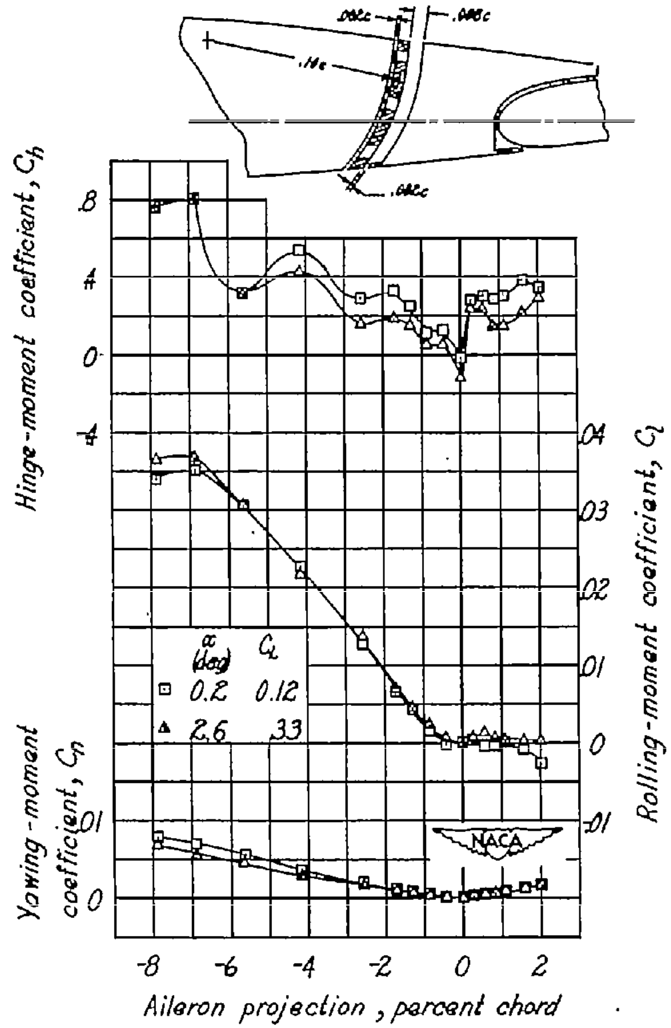
(d) $\alpha \approx 11.6^{\circ}$; $C_L \approx 0.93$.

Figure 15.- Concluded.



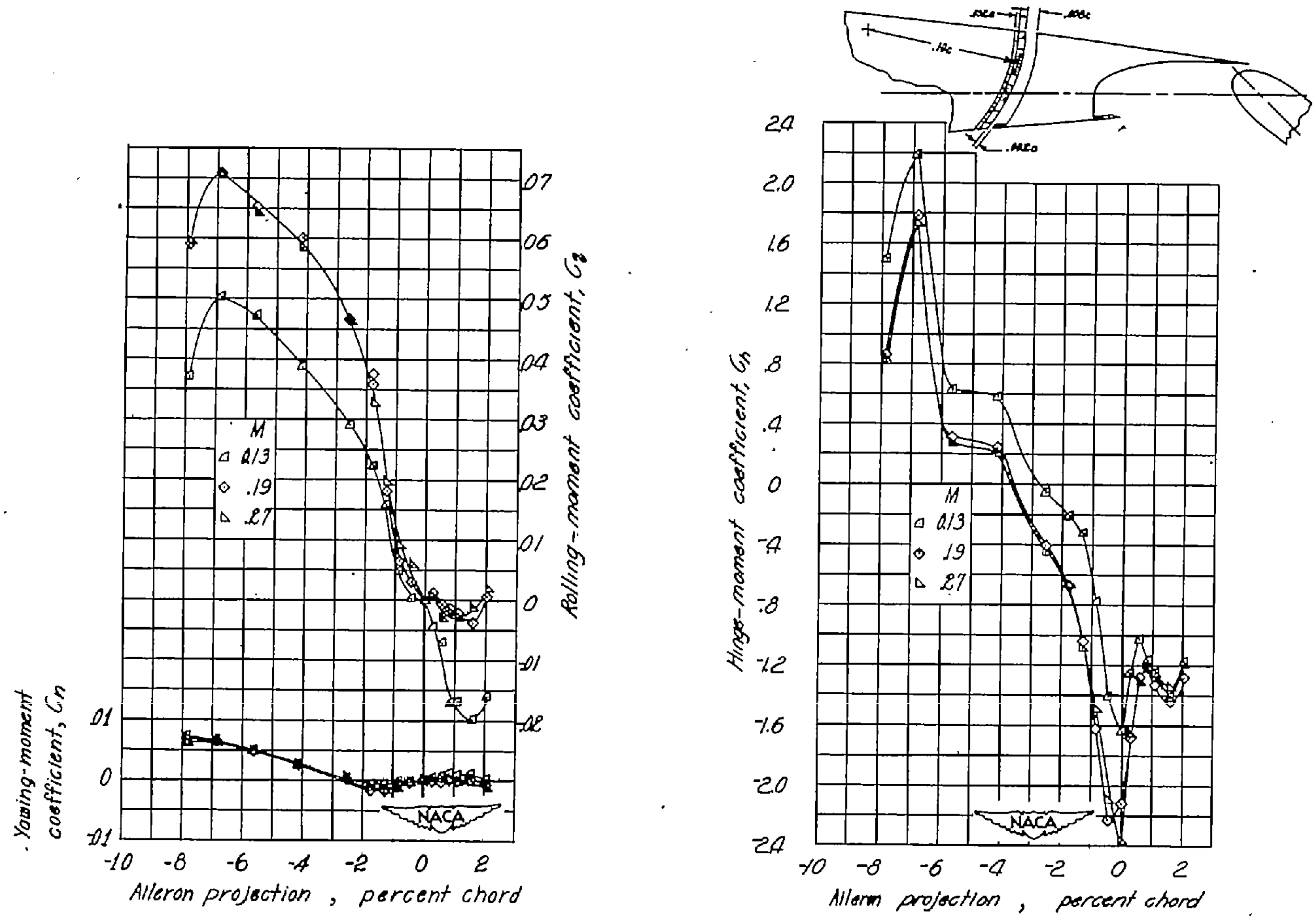
(a) M = 0.19. (b) M = 0.41.

Figure 16.- Variation of lateral-control characteristics of complete wing with projection of modified plug aileron at various angles of attack. Plug aileron modified by removing 0.01c top plate. Full-span flap retracted.



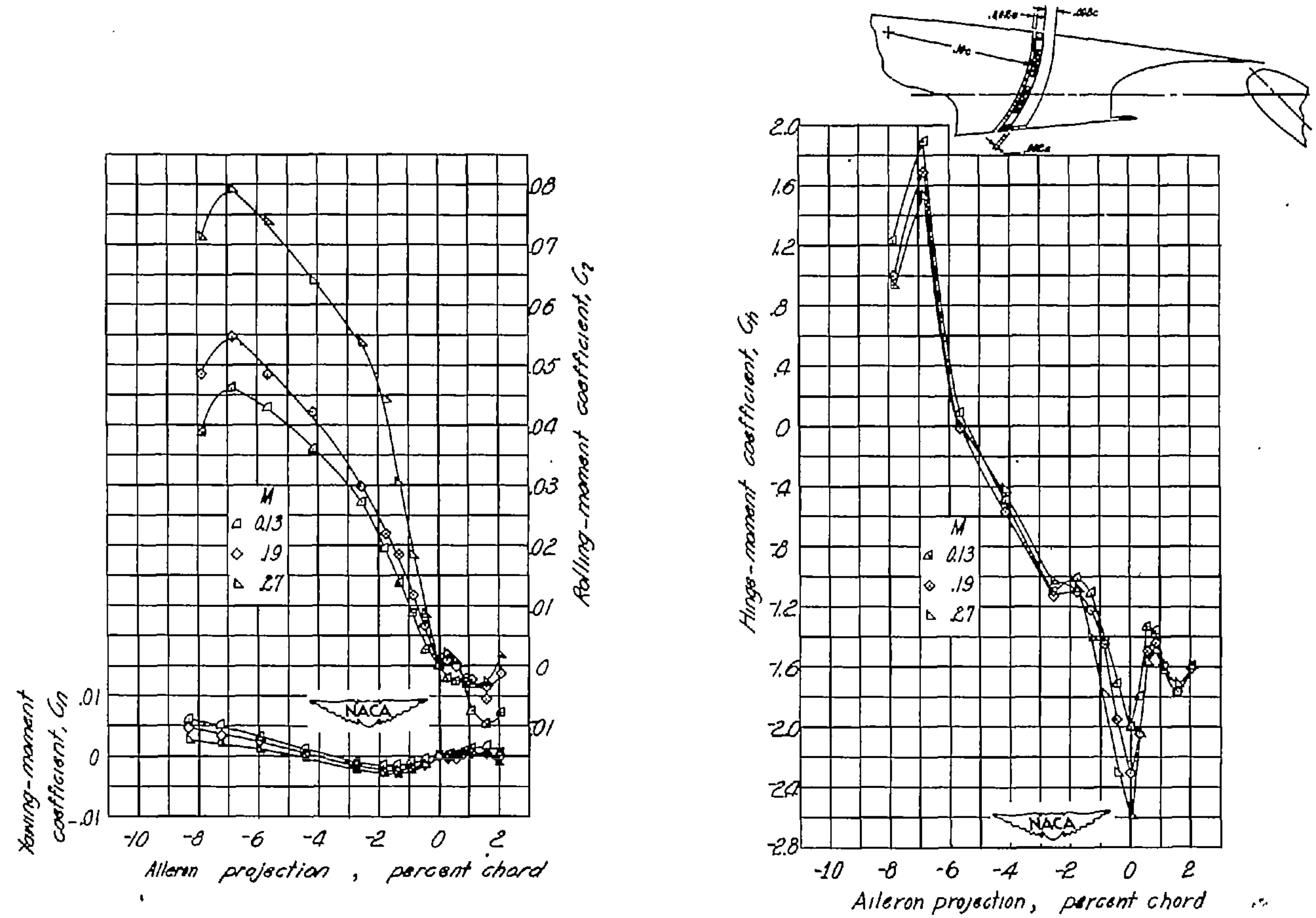
(c) M = 0.61.

Figure 16.- Concluded.



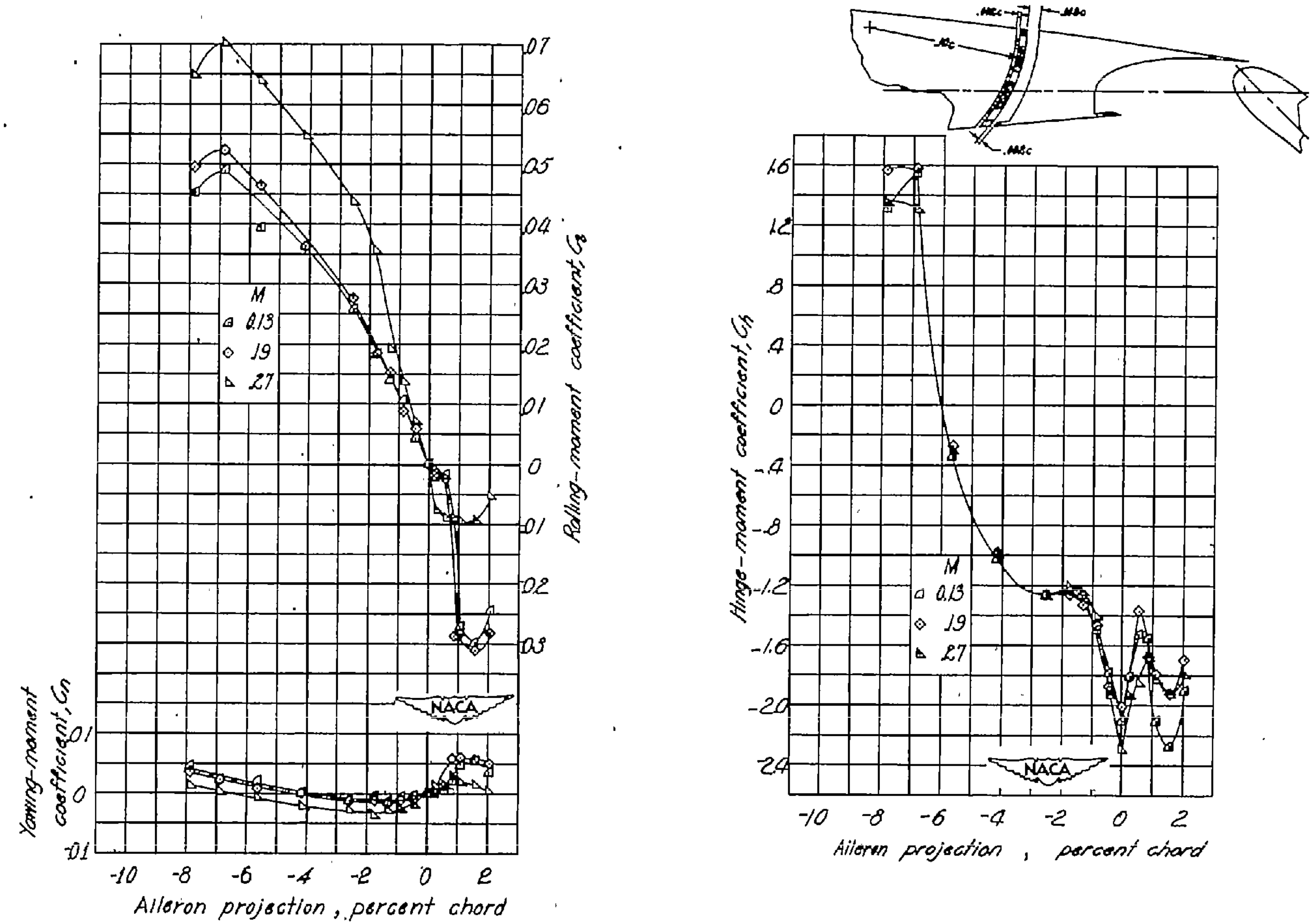
(a) $\alpha \approx -1.9^{\circ}$; $C_L \approx 1.25$.

Figure 17.- Variation of lateral-control characteristics of complete wing with projection of modified plug aileron at various Mach numbers. Plug aileron modified by removing 0.01c top plate. Full-span flap deflected 45°.



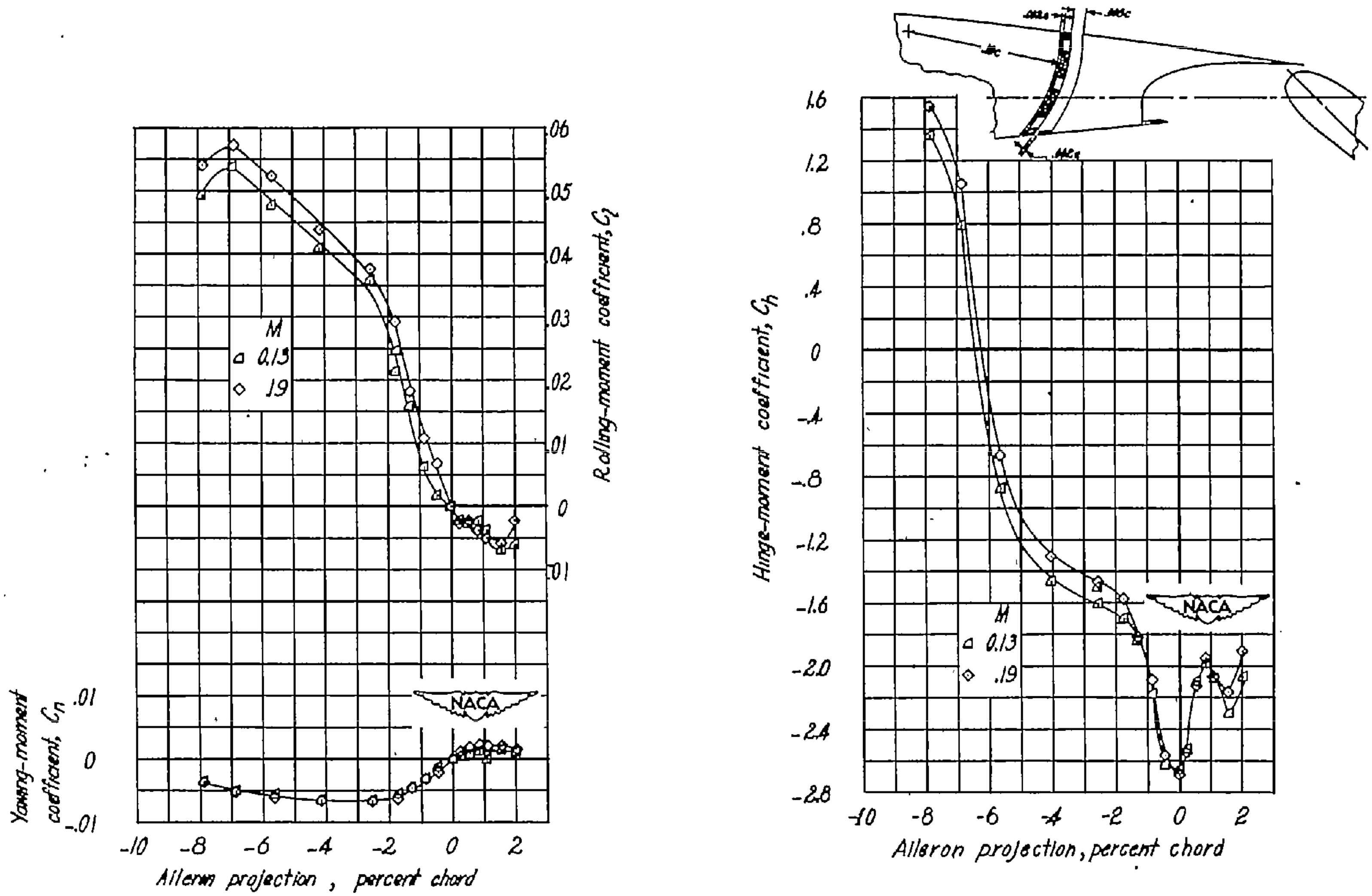
(b) $\alpha \approx 2.6^{\circ}$; $C_L \approx 1.50$.

Figure 17.- Continued.



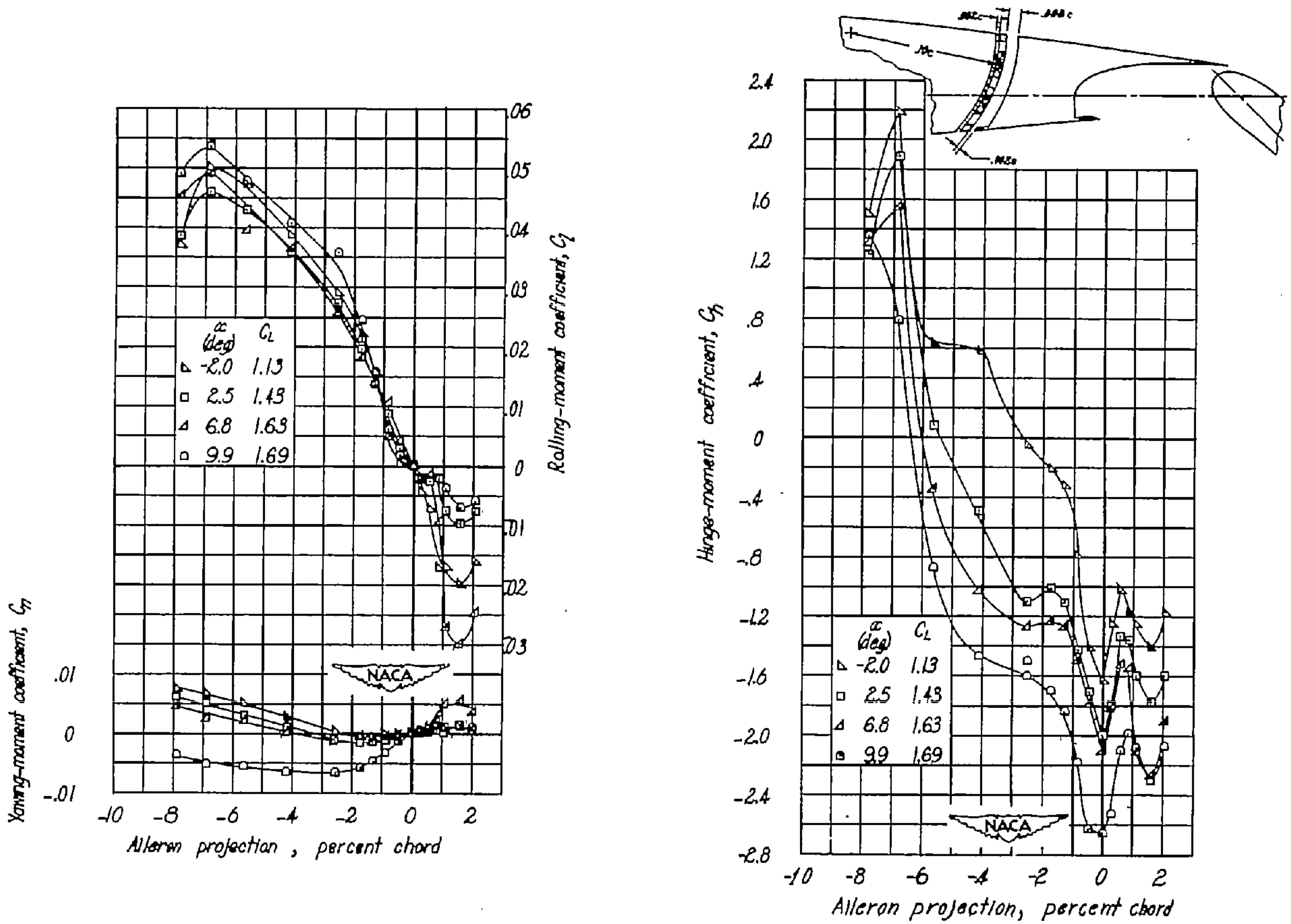
(c) $\alpha \approx 6.9^{\circ}$; $C_L \approx 1.70$.

Figure 17.- Continued.



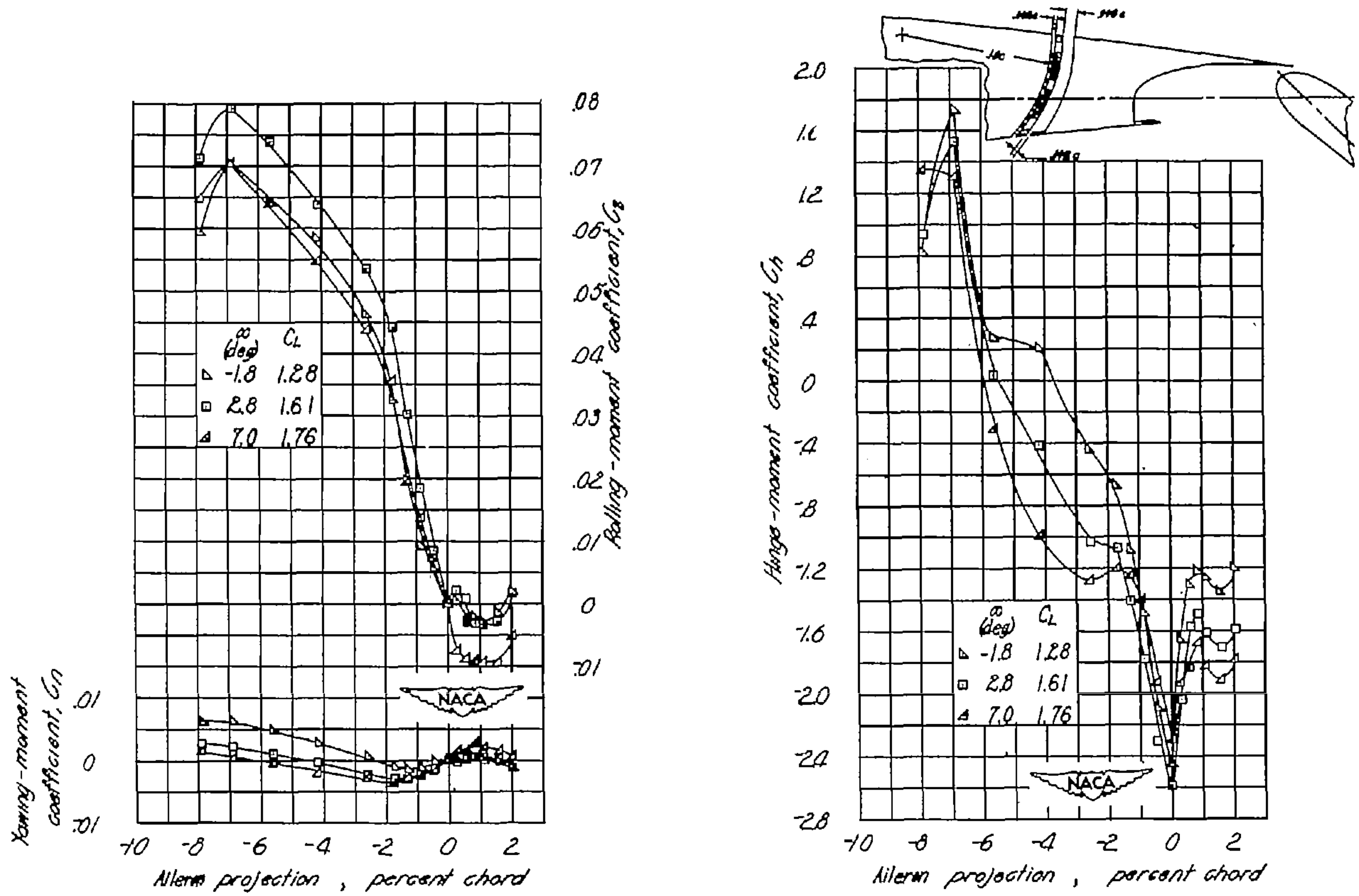
(d) $\alpha \approx 10.0^{\circ}$; $C_L \approx 1.73$.

Figure 17.- Concluded.



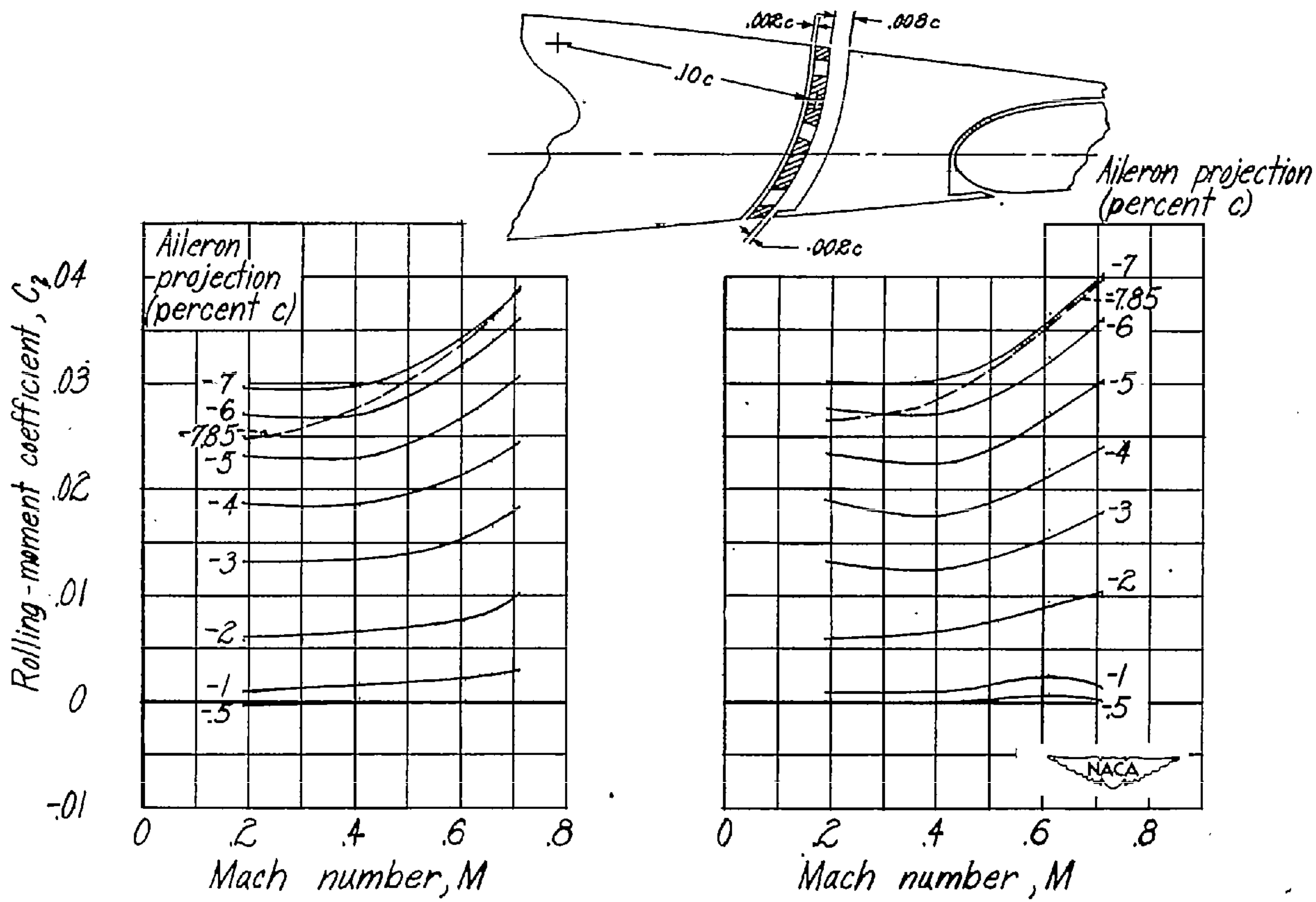
(a) M = 0.13.

Figure 18.- Variation of lateral-control characteristics of complete wing with projection of modified plug aileron at various angles of attack. Plug aileron modified by removing 0.01c top plate. Full-span flap deflected 45°.



(b) M = 0.27.

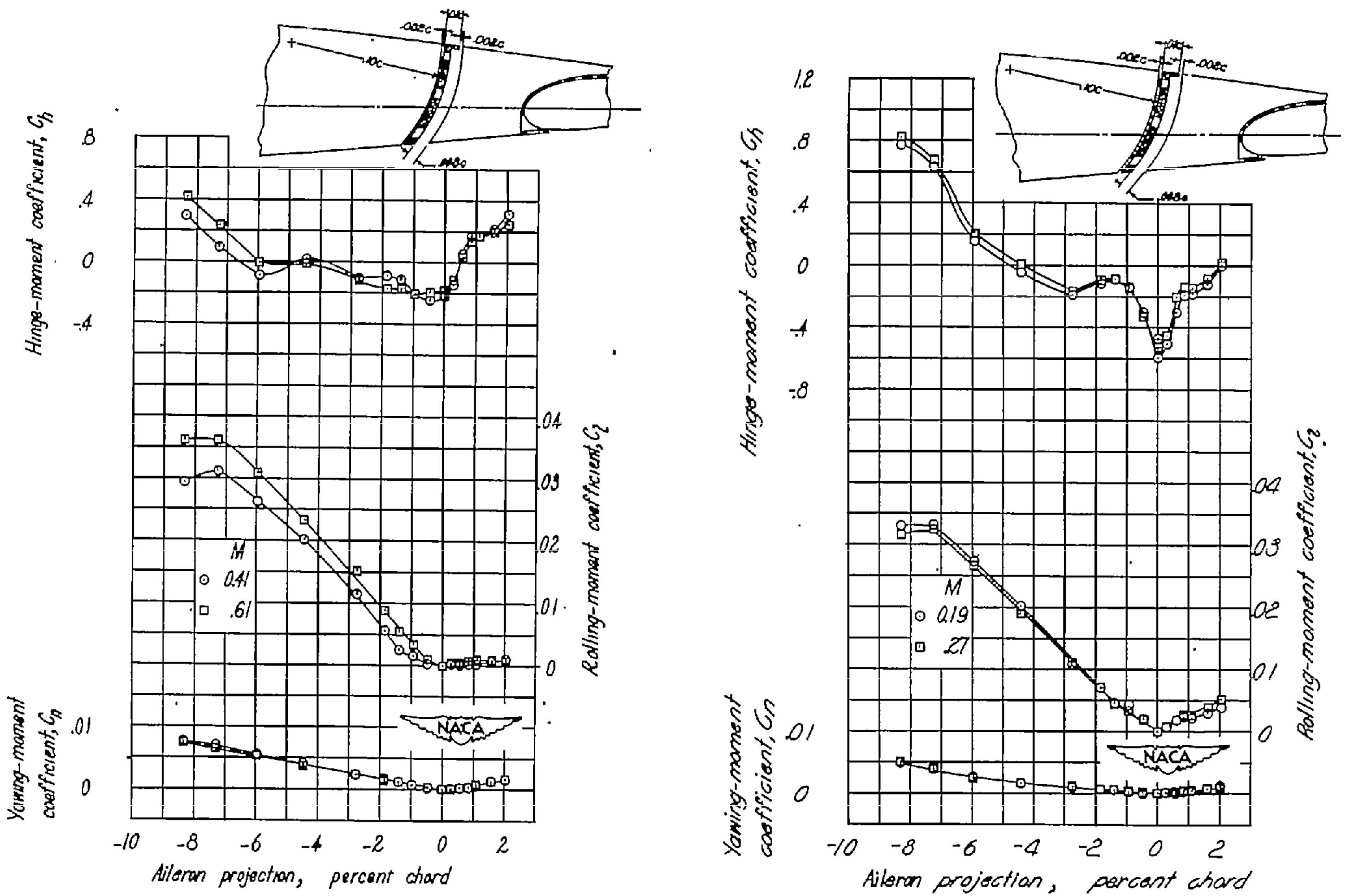
Figure 18.- Concluded.



(a) $\alpha \approx 0.2^{\circ}$.

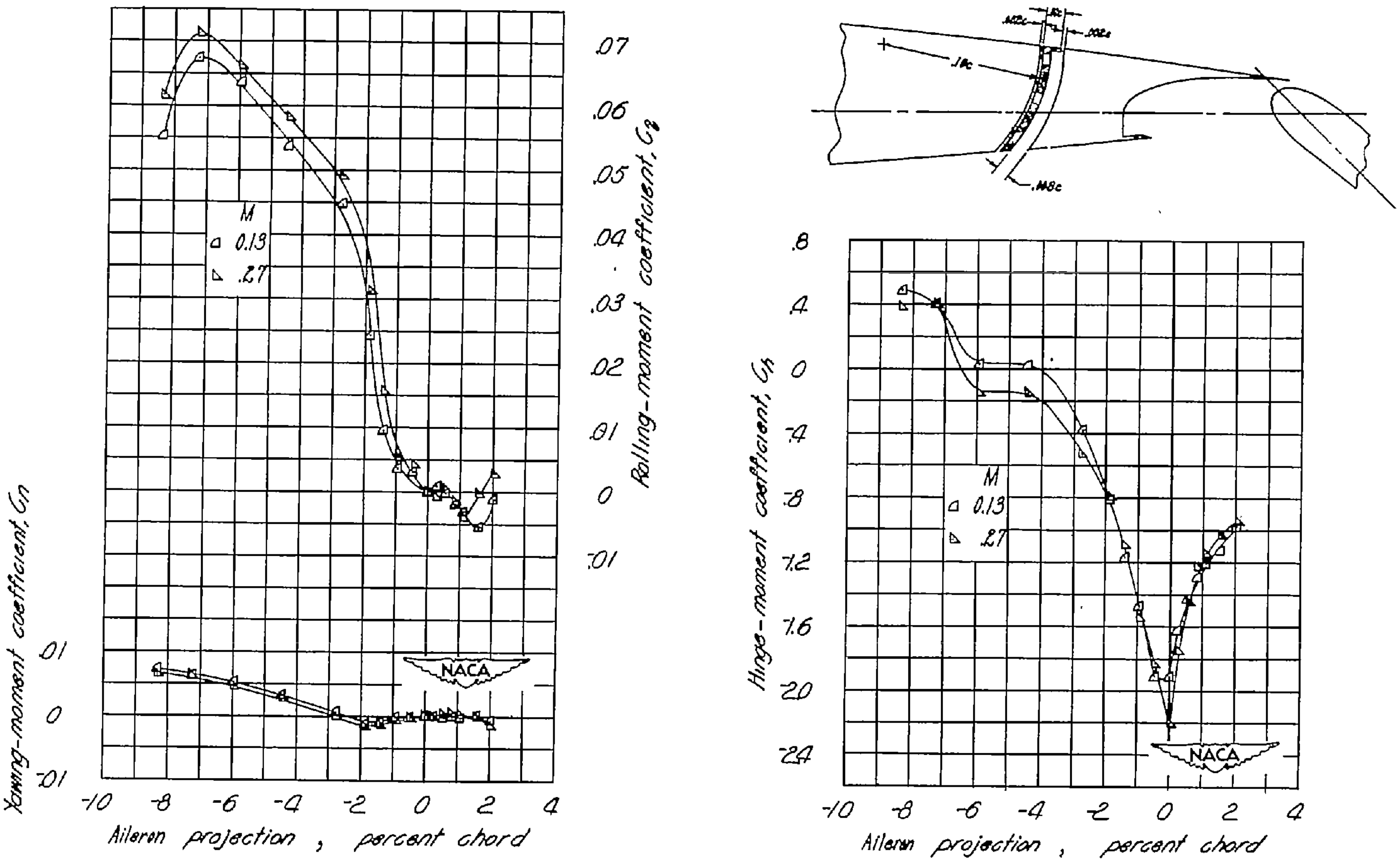
(b) $\alpha \approx 2.6^{\circ}$.

Figure 19.- Variation of lateral-control characteristics of complete wing with Mach number at various projections of modified plug aileron. Plug aileron modified by removing 0.01c top plate. Full-span flap retracted.



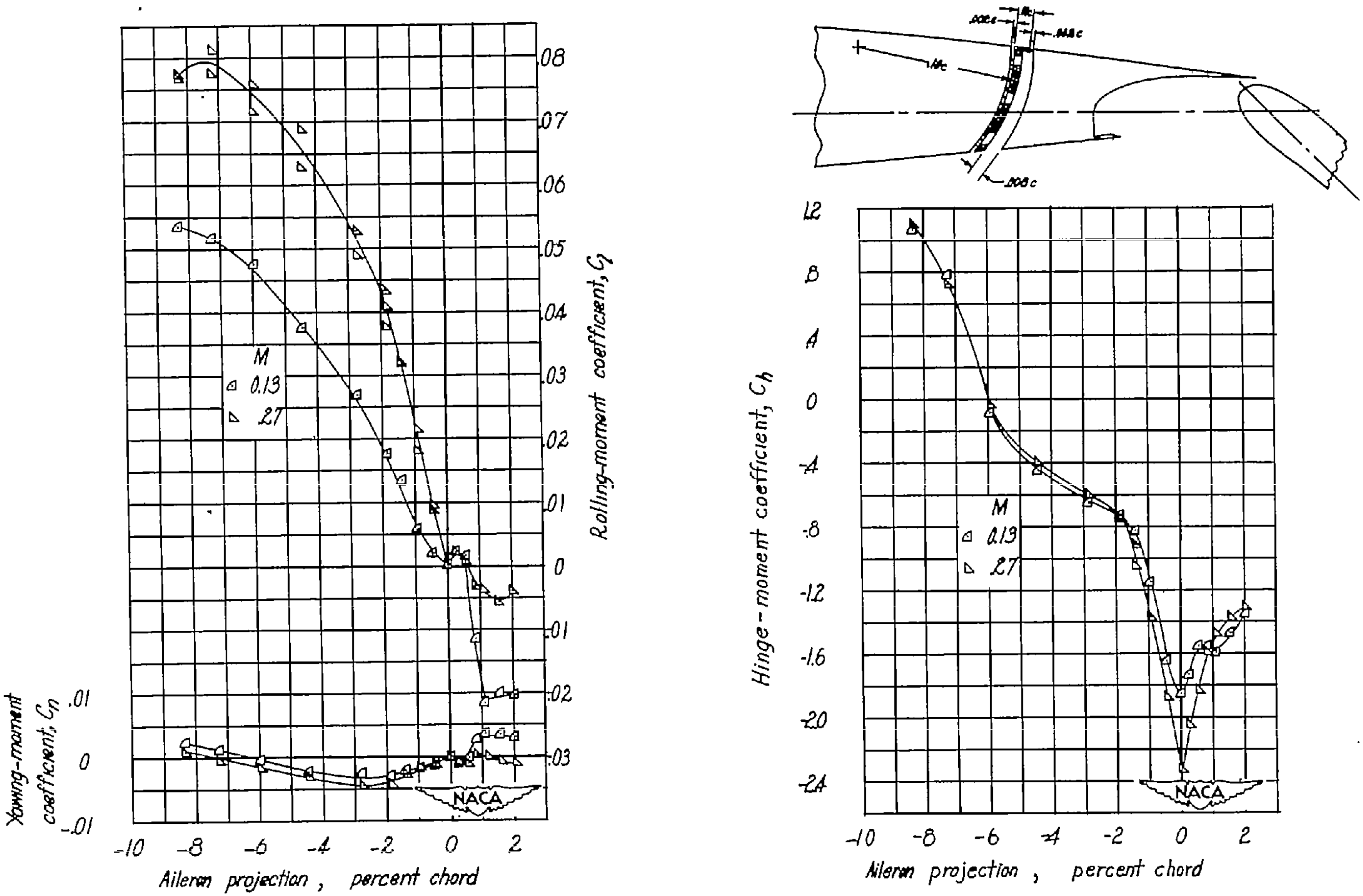
(a) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.12$. (b) $\alpha \approx 7.1^{\circ}$; $C_L \approx 0.65$.

Figure 20.- Variation of lateral-control characteristics of complete wing with aileron projection of modified plug aileron. Plug aileron modified by enlarging plug slot on wing lower surface. Full-span flap retracted.



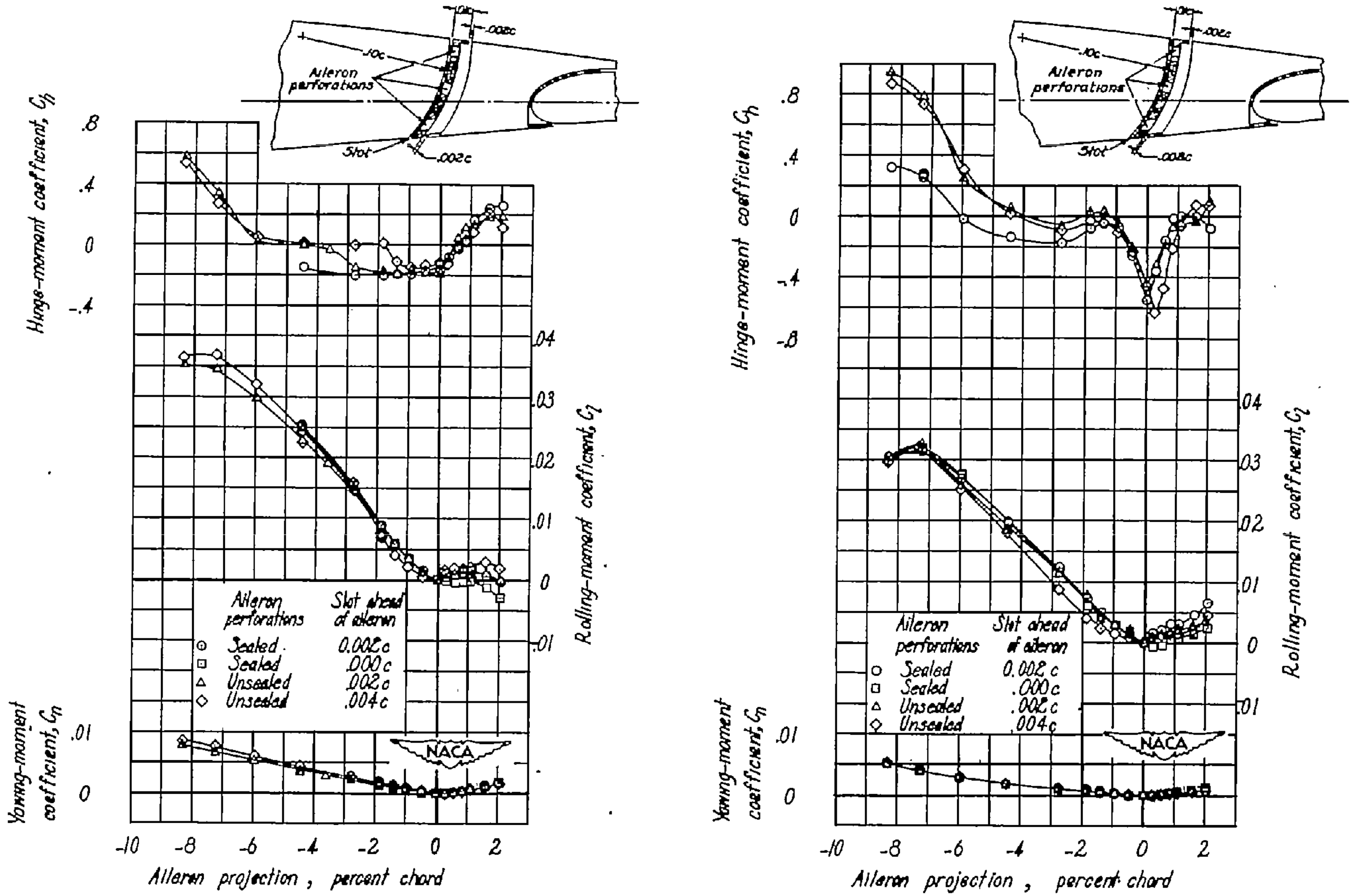
(a) $\alpha \approx -1.7^{\circ}$; $C_L \approx 1.29$.

Figure 21.- Variation of lateral-control characteristics of complete wing with aileron projection of modified plug aileron. Plug aileron modified by enlarging plug slot on wing lower surface. Full-span flap deflected 45°.



(b) $\alpha \approx 7.0^{\circ}$; $C_L \approx 1.76$.

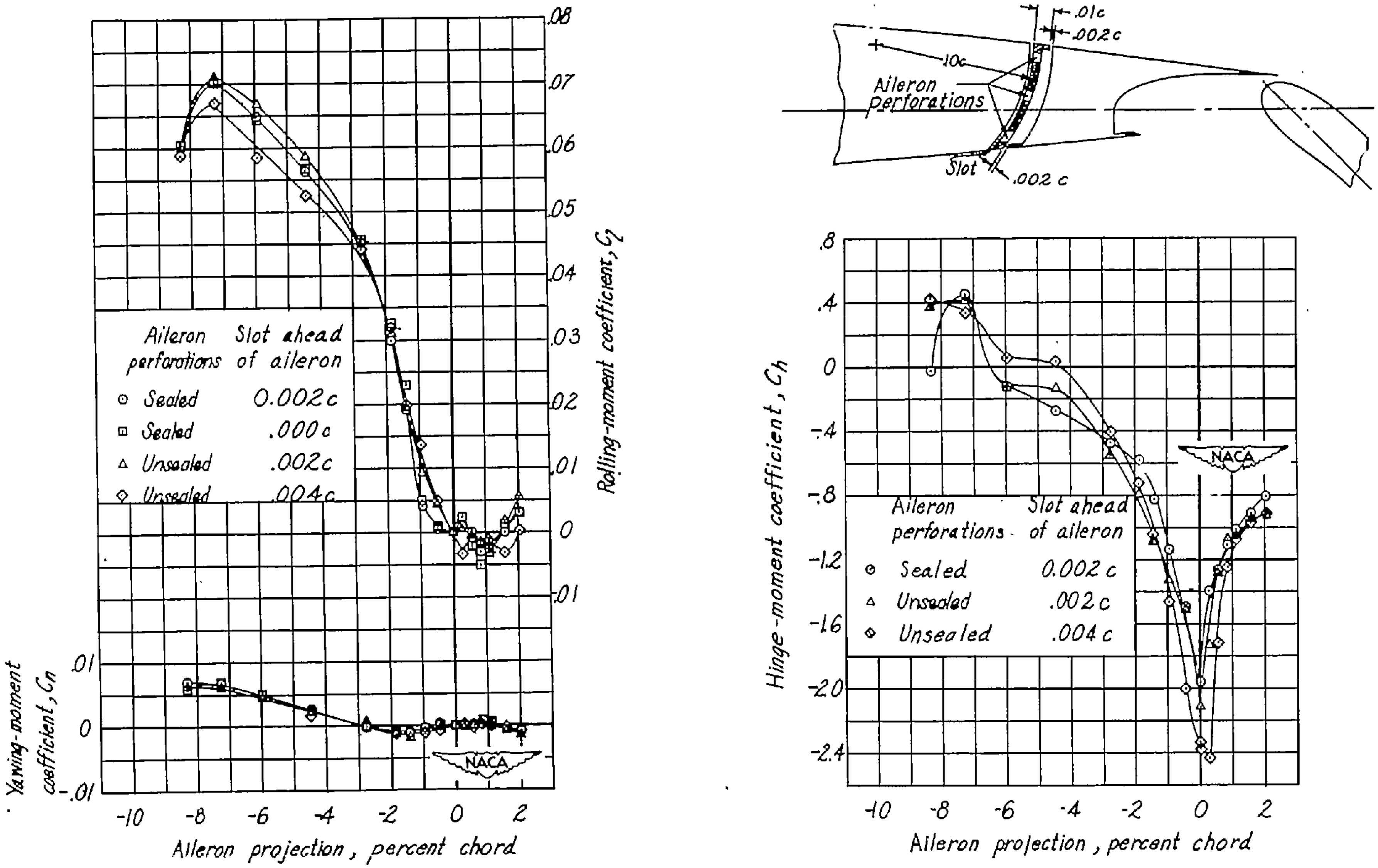
Figure 21.- Concluded.



(a) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.12$; M = 0.61.

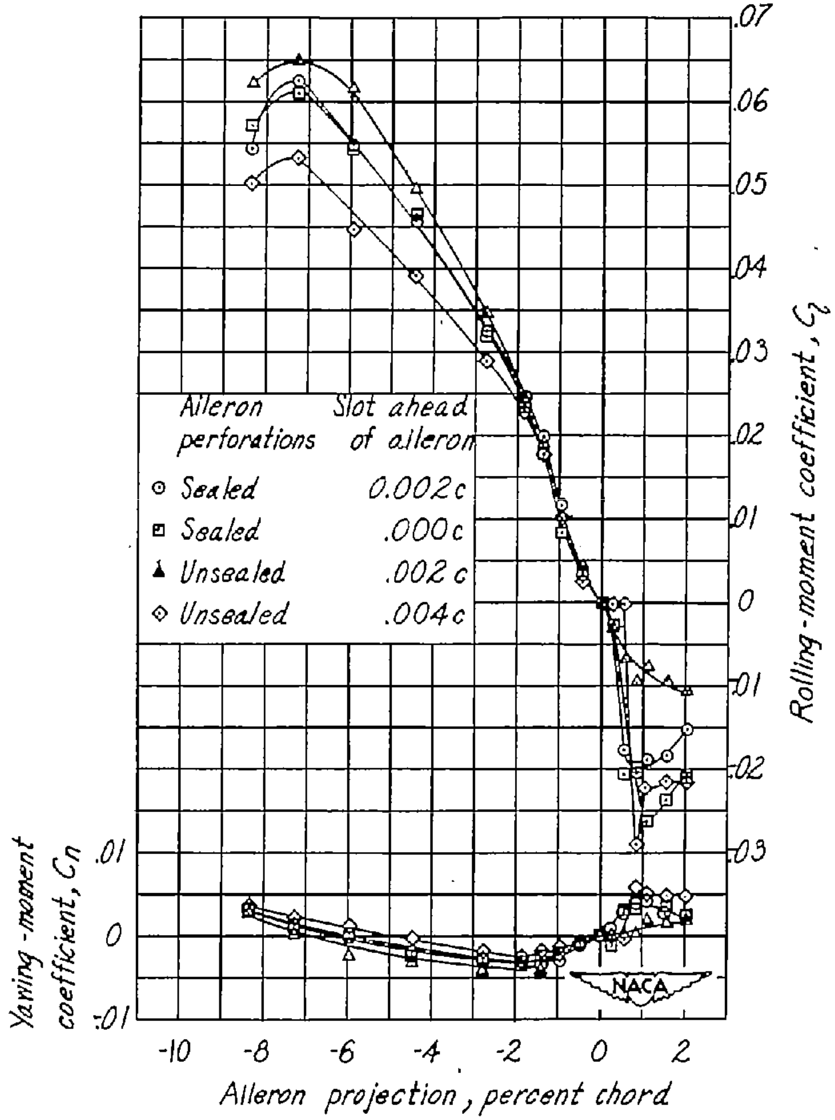
(b) $\alpha \approx 7.1^{\circ}$; $C_L \approx 0.64$; M = 0.19.

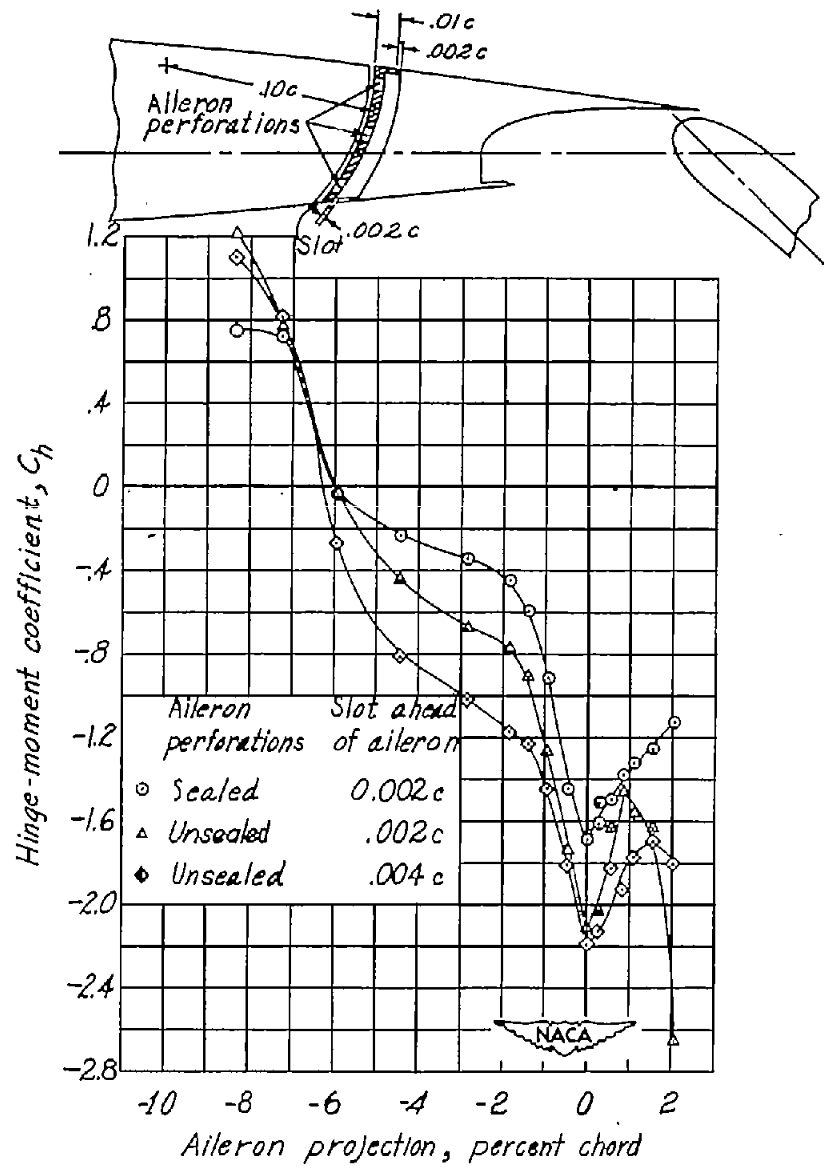
Figure 22.- Variation of lateral-control characteristics of complete wing with aileron projection for several modifications of plug aileron. Full-span flap retracted.



(a) $\alpha \approx -1.8^{\circ}$; $C_L \approx 1.29$; $M = 0.27$.

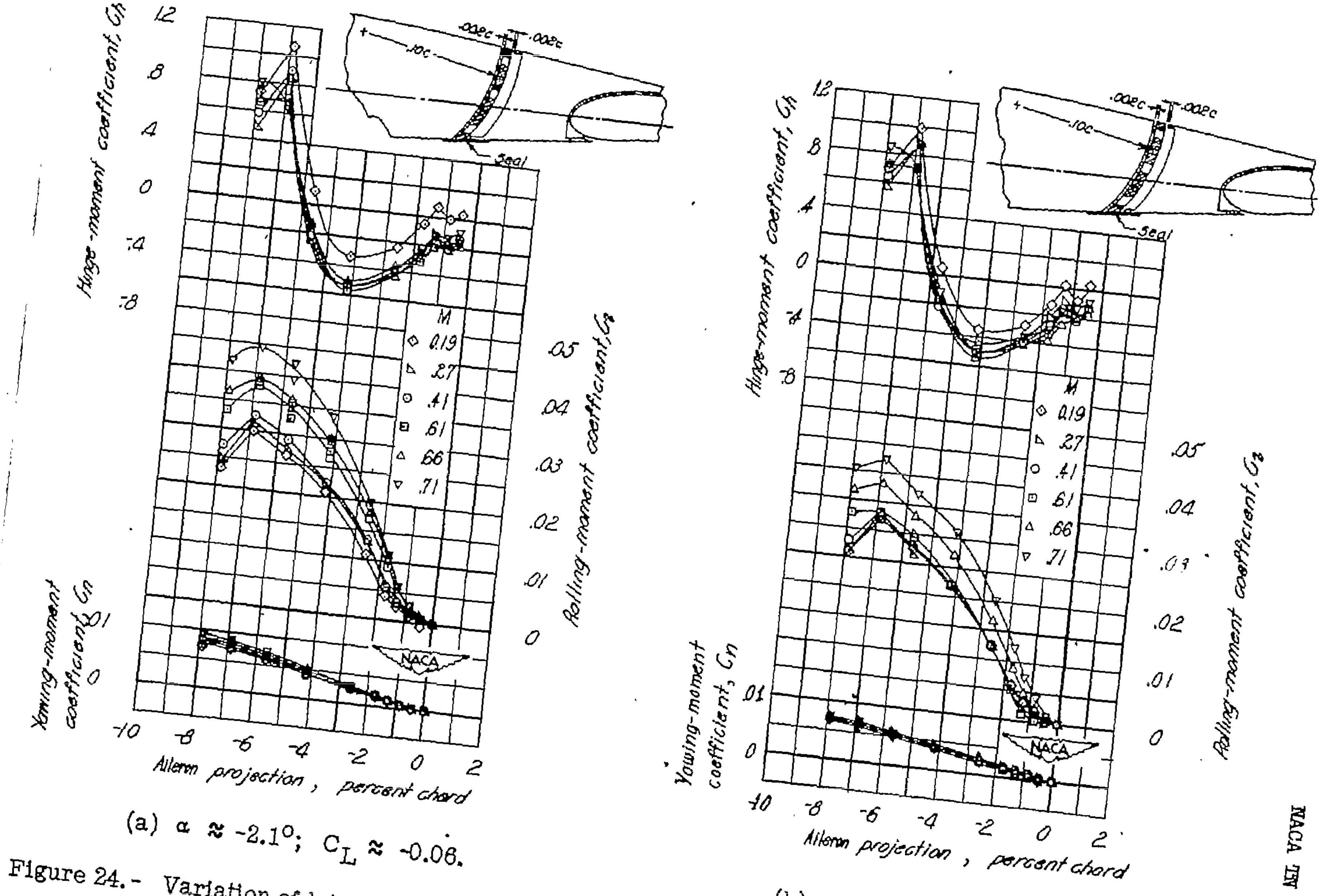
Figure 23.- Variation of lateral-control characteristics of complete wing with aileron projection for several modifications of plug aileron. Full-span flap deflected 45°.





(b) $\alpha \approx 7.0^{\circ}$; $C_L \approx 1.71$; $M = 0.13$.

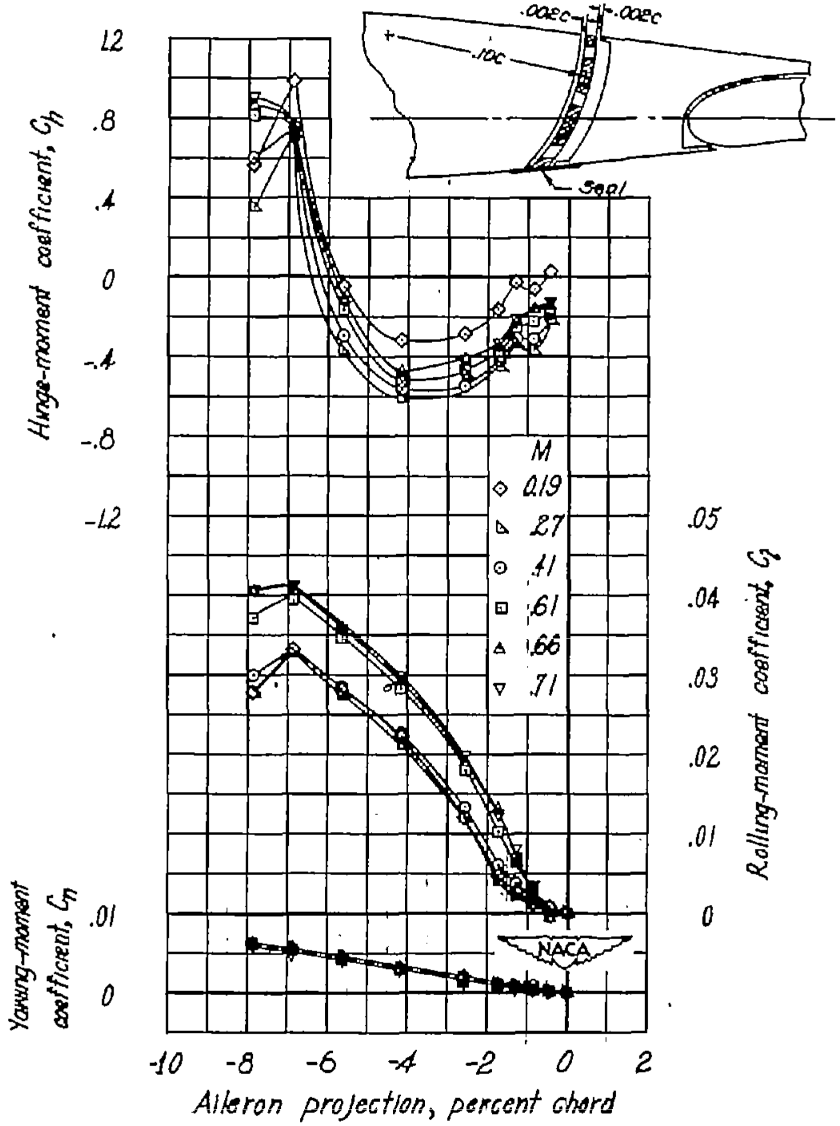
Figure 23.- Concluded.



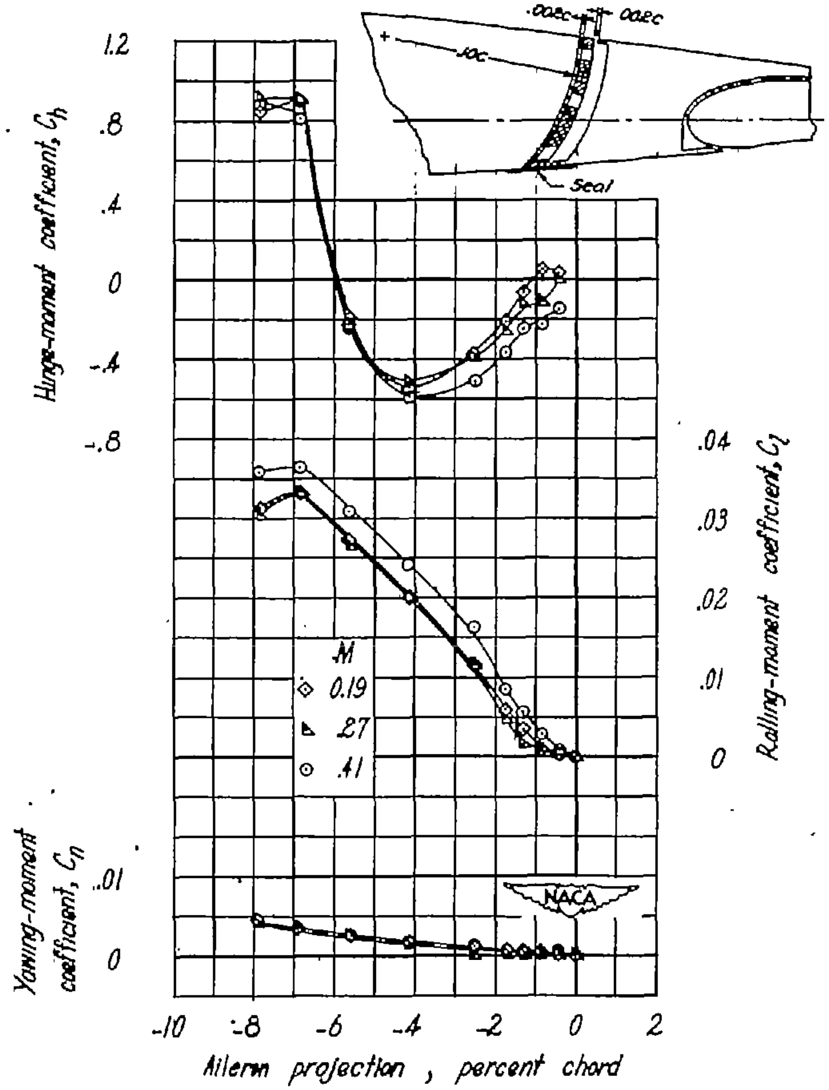
(a) $\alpha \approx -2.1^{\circ}$; $C_L \approx -0.06$.

(b) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.13$.

Figure 24.- Variation of lateral-control characteristics of complete wing with retractable-aileron projection at various Mach numbers. Full-span flap retracted.

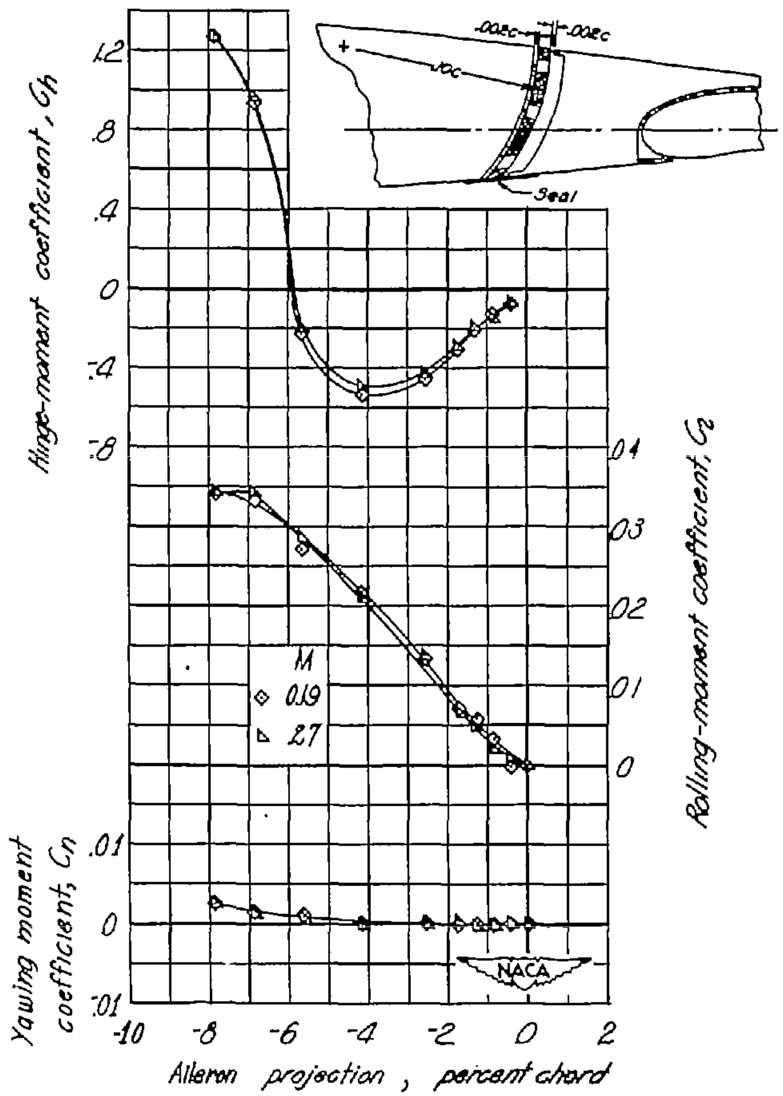


(c) $\alpha \approx 2.6^{\circ}$; $C_L \approx 0.33$.



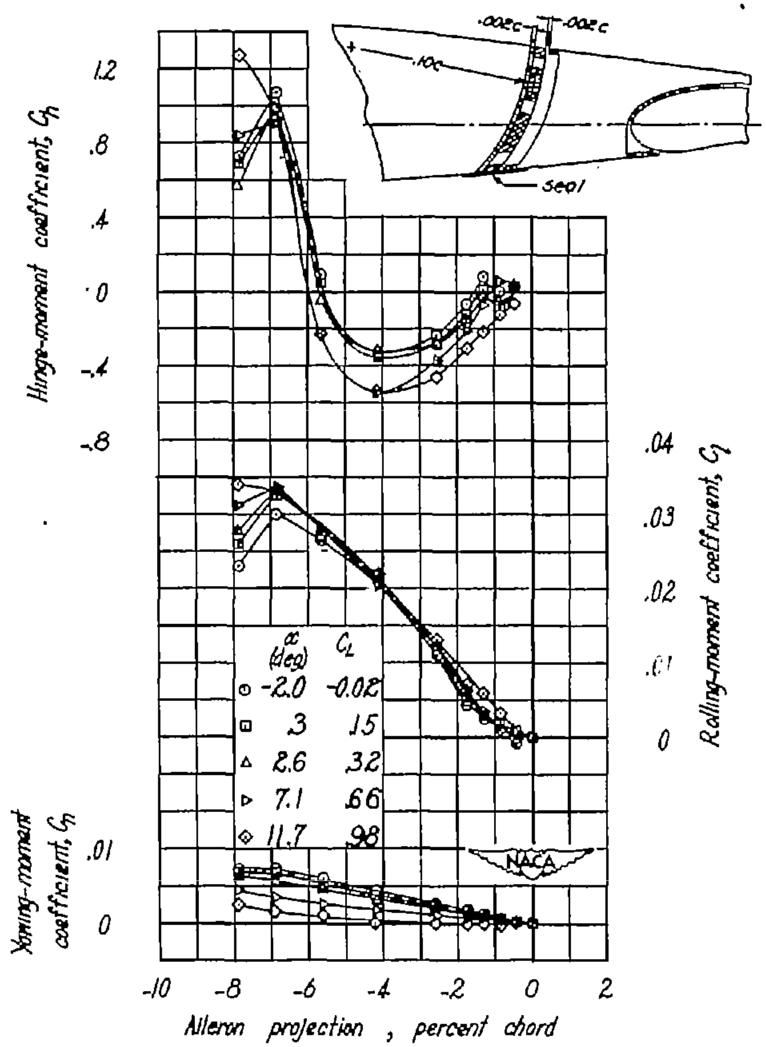
(d) $\alpha \approx 7.2^{\circ}$; $C_L \approx 0.67$.

Figure 24.- Continued.



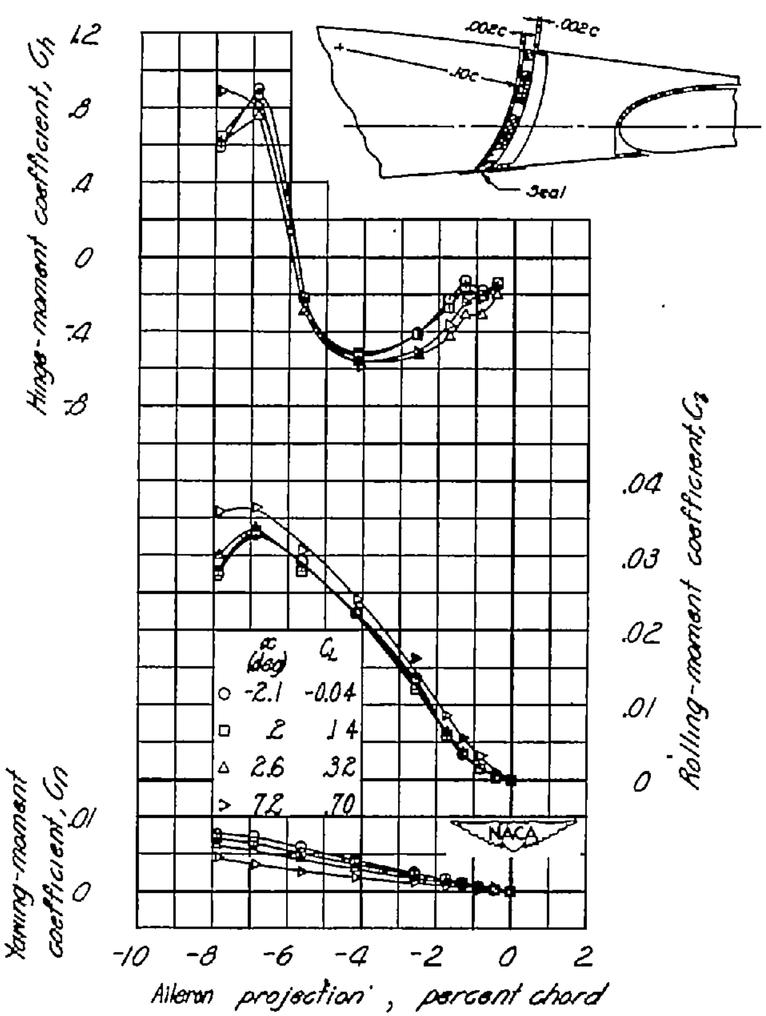
(e) $\alpha \approx 11.7^{\circ}$; $C_L \approx 0.99$.

Figure 24.- Concluded.

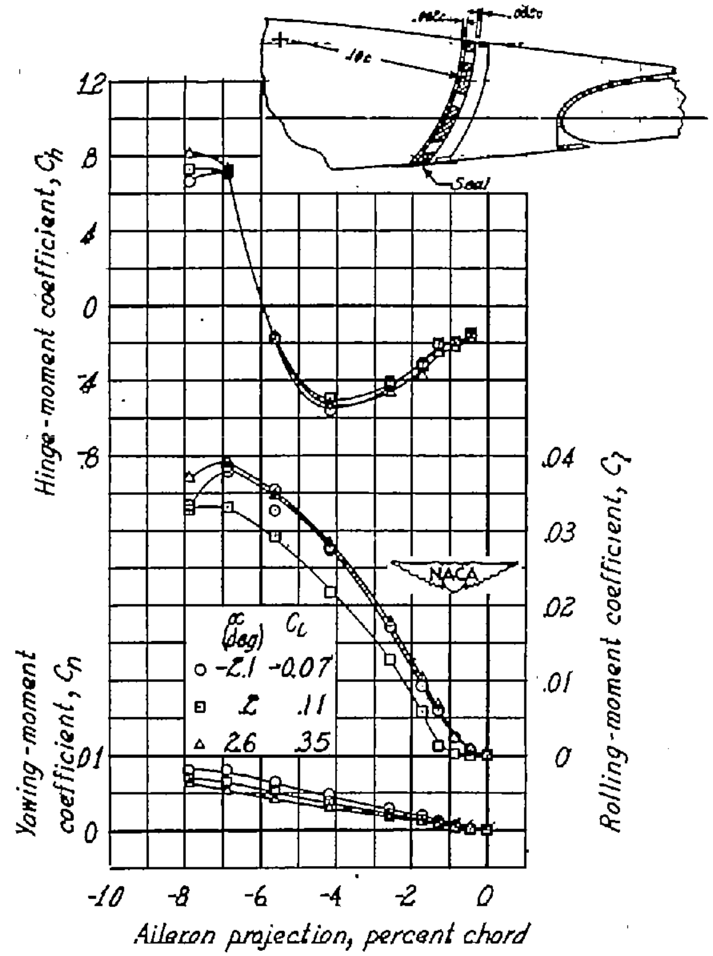


(a) M = 0.19.

Figure 25.- Variation of lateral-control characteristics of complete wing with retractable-aileron projection at various angles of attack. Full-span flap retracted.

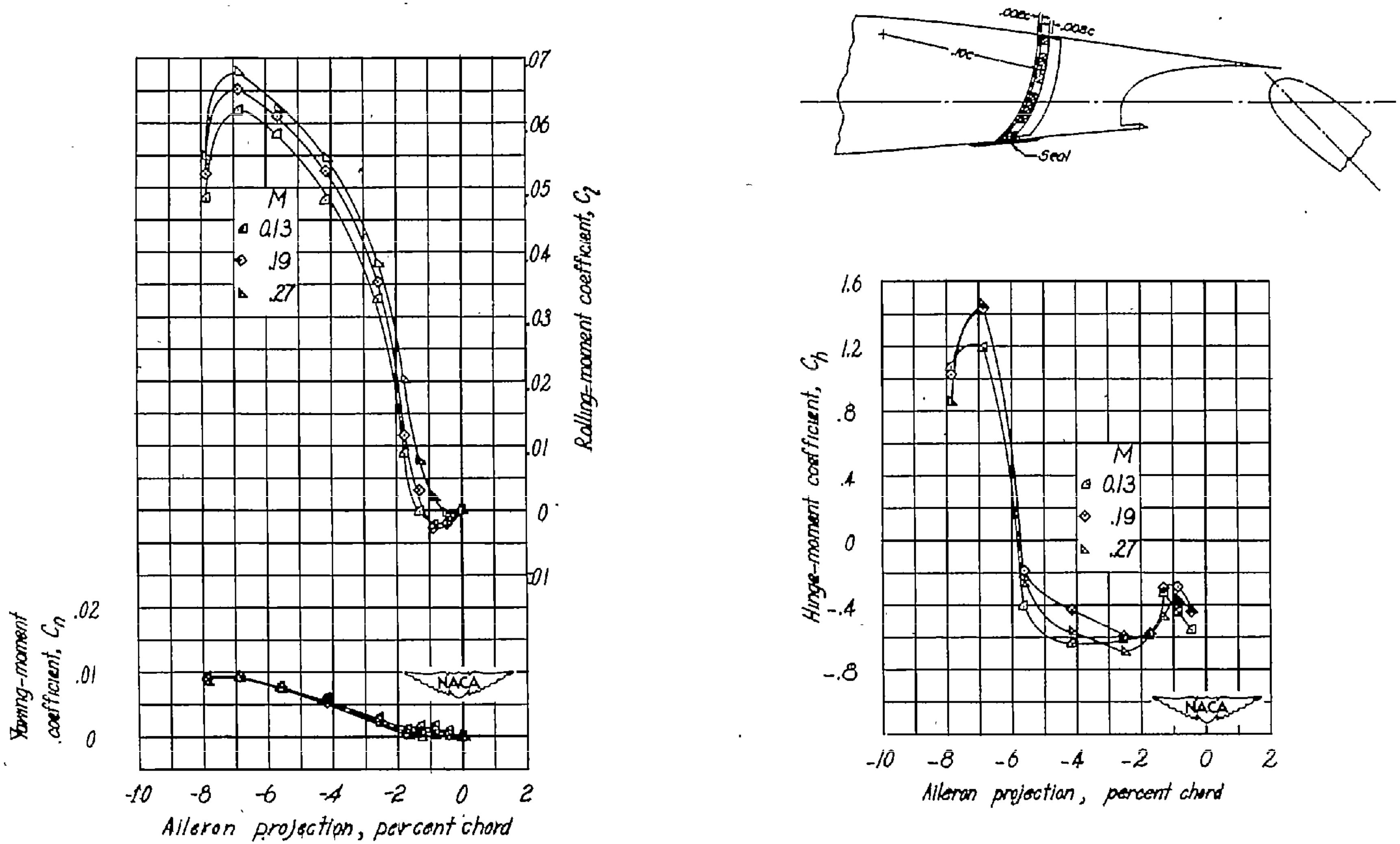


(b) M = 0.41.



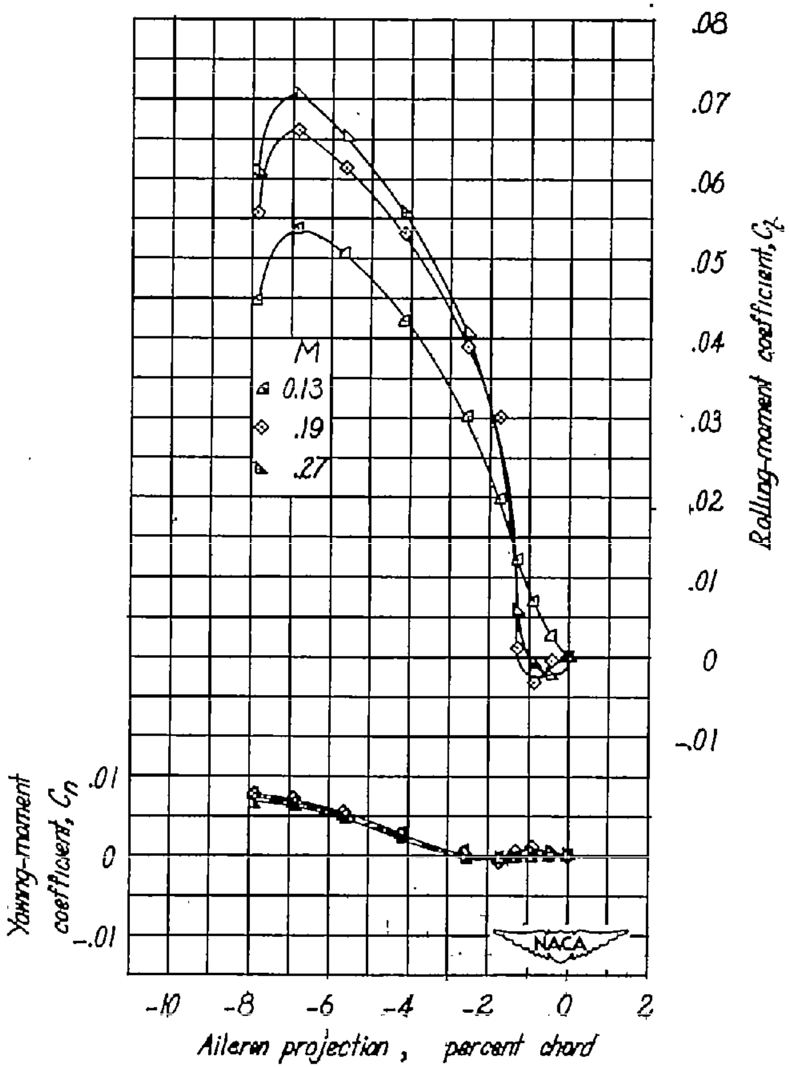
(c) M = 0.61.

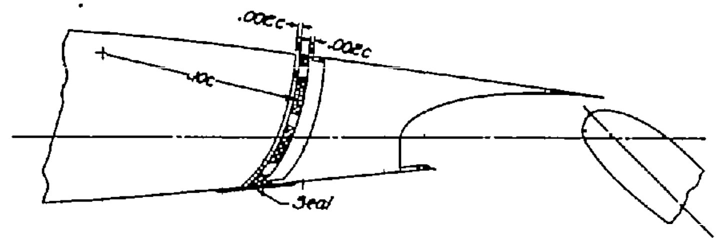
Figure 25.- Concluded.

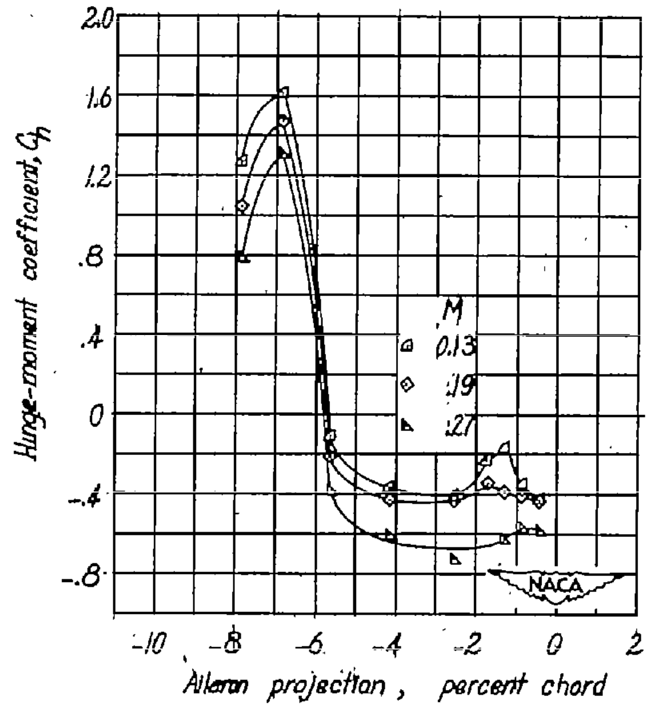


(a) $\alpha \approx -6.3^{\circ}$; $C_L \approx 0.98$.

Figure 26.- Variation of lateral-control characteristics of complete wing with retractable-aileron projection at various Mach numbers. Full-span flap deflected 45°.

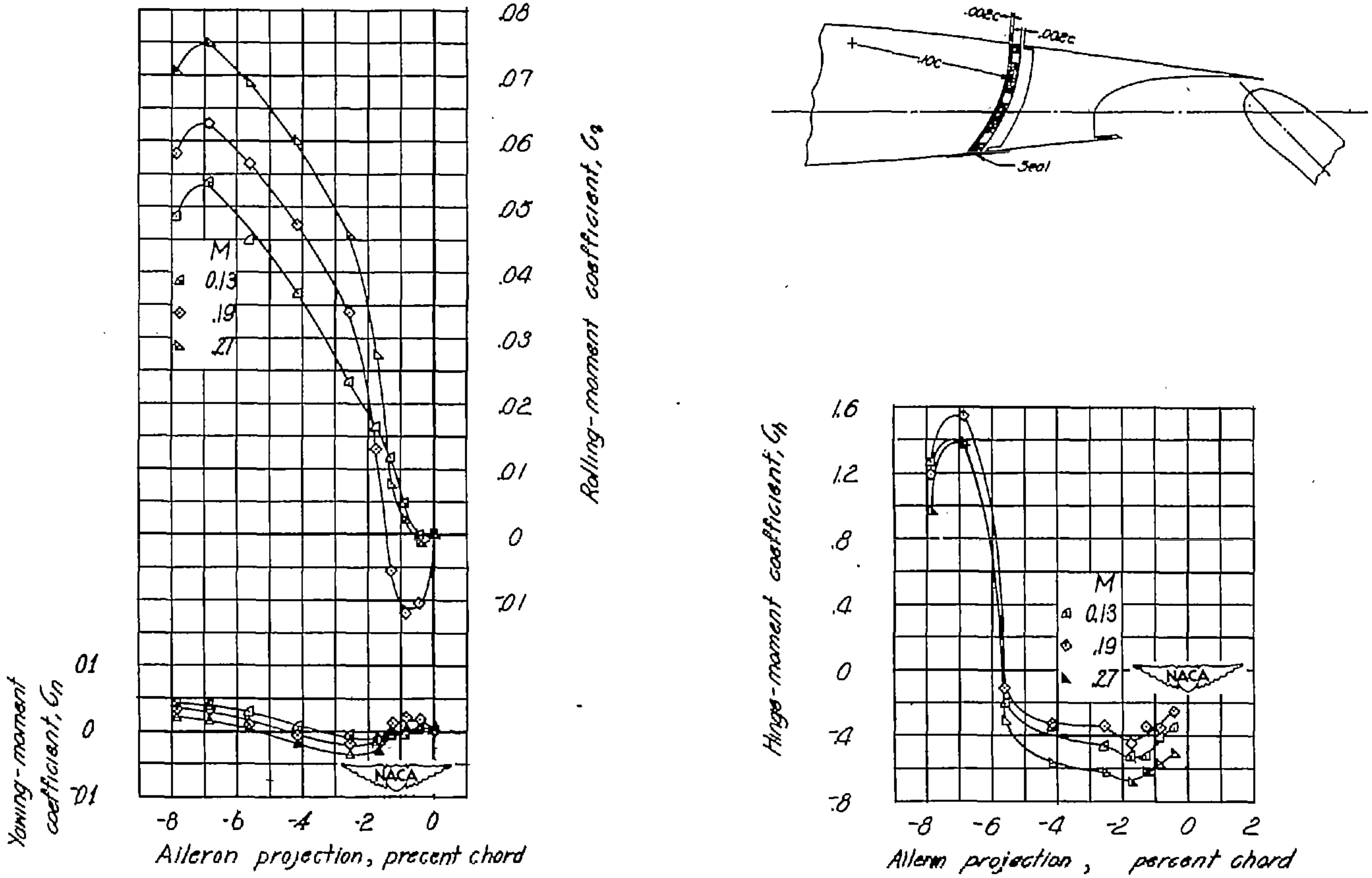






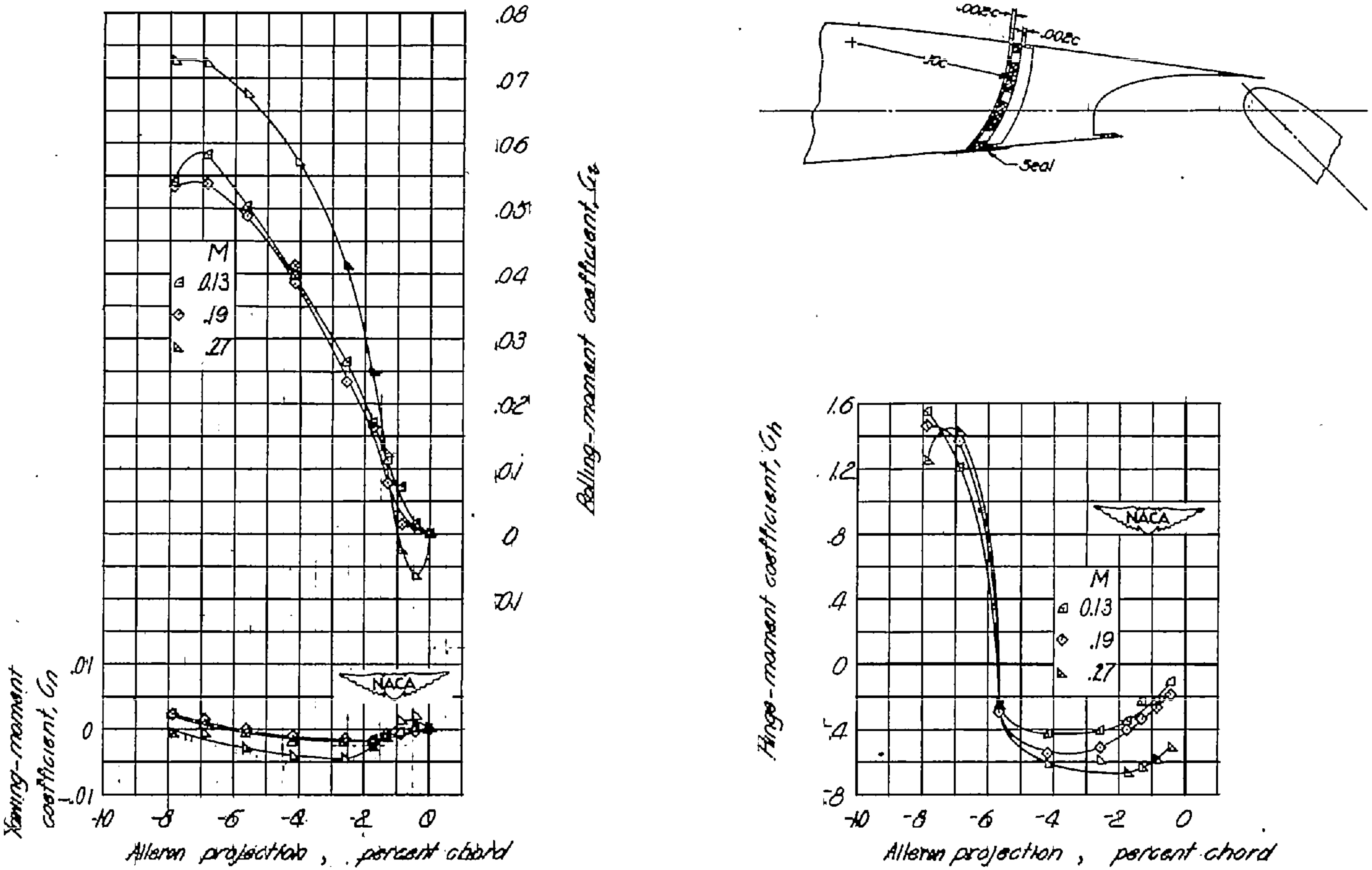
(b) $\alpha \approx -1.8^{\circ}$; $C_L \approx 1.27$.

Figure 26.- Continued.



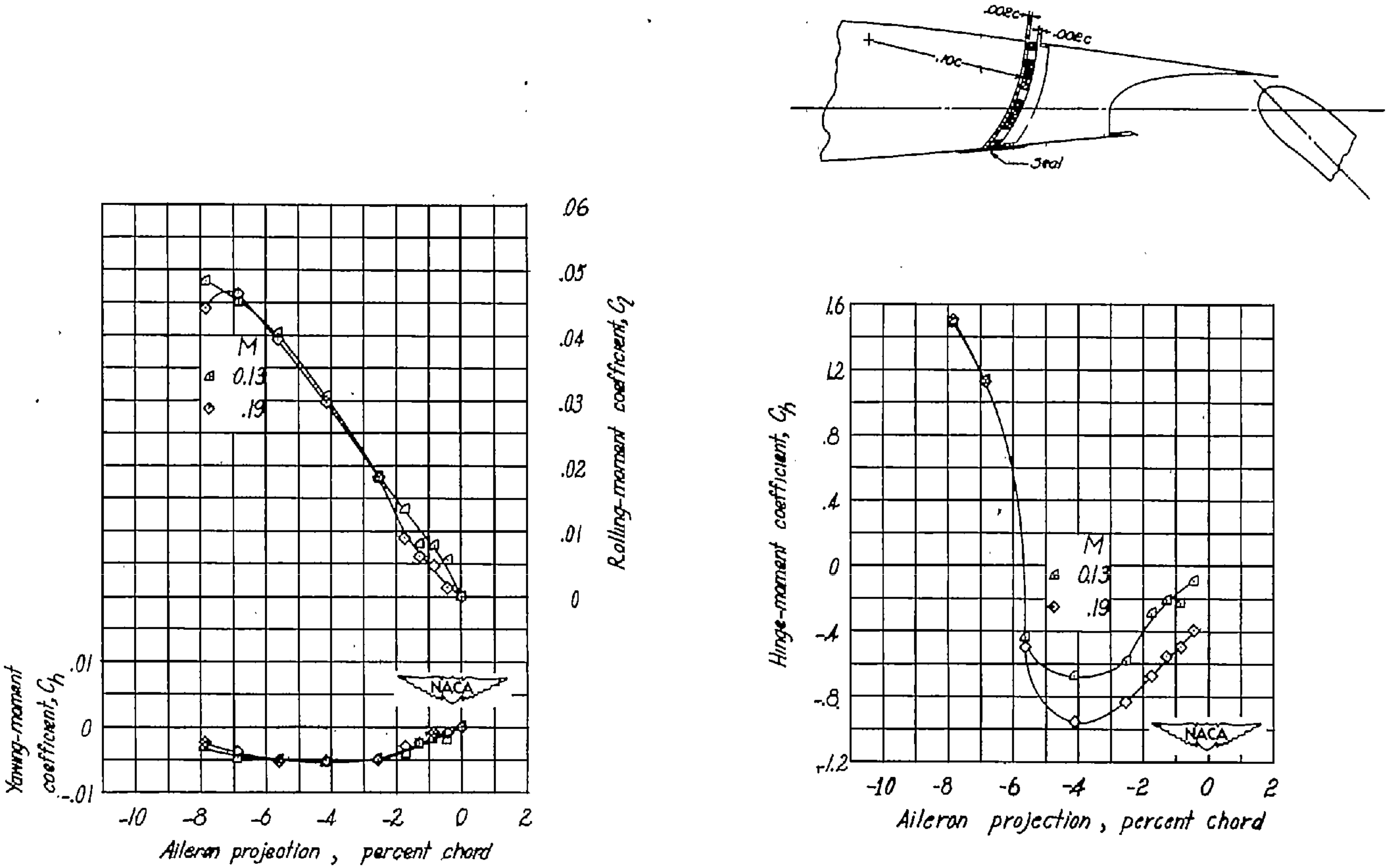
(c) $\alpha \approx 2.7^{\circ}$; $C_L \approx 1.55$.

Figure 26.- Continued.



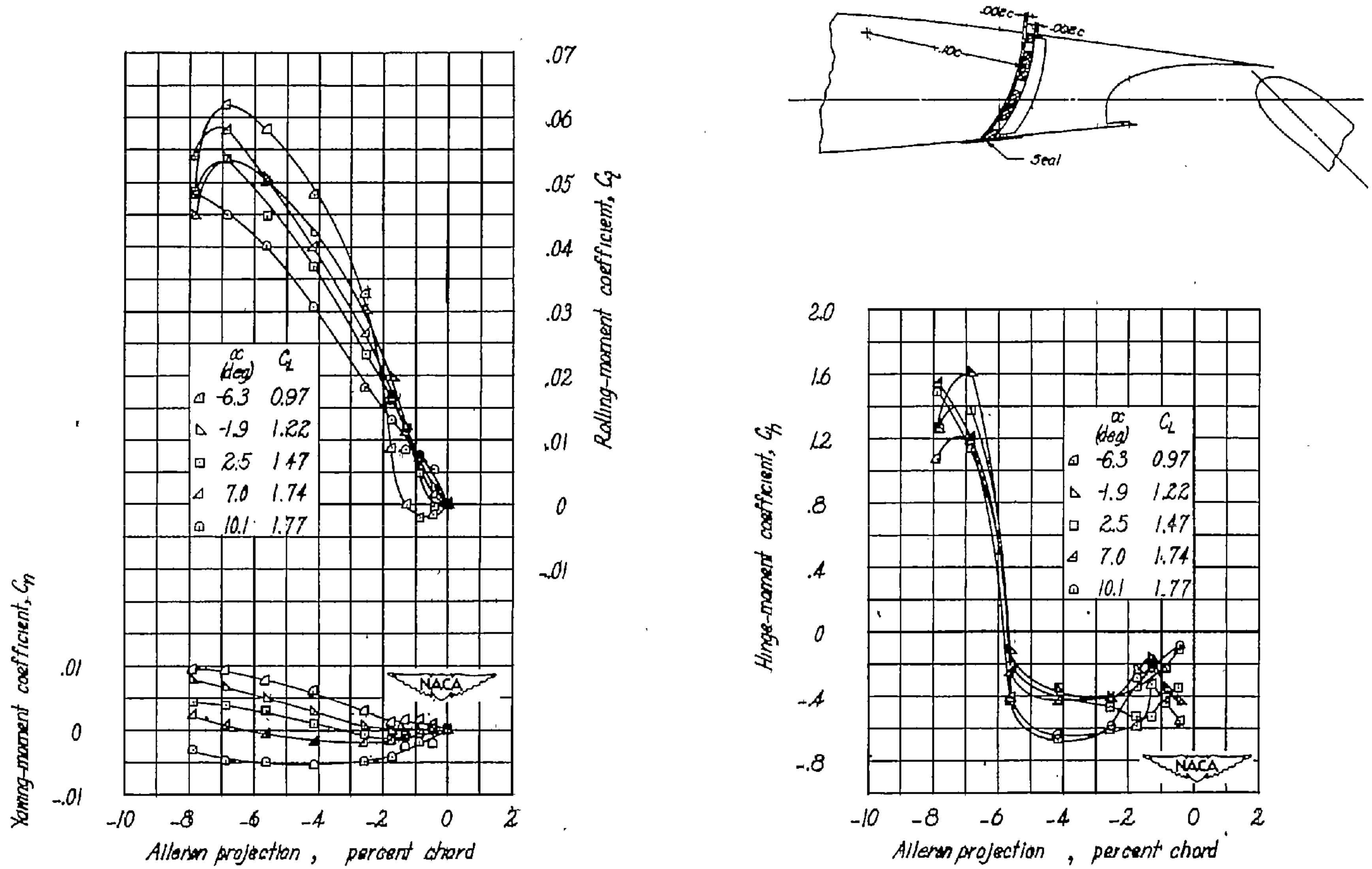
(d) $\alpha \approx 7.1^{\circ}$; $C_L \approx 1.79$.

Figure 26.- Continued.



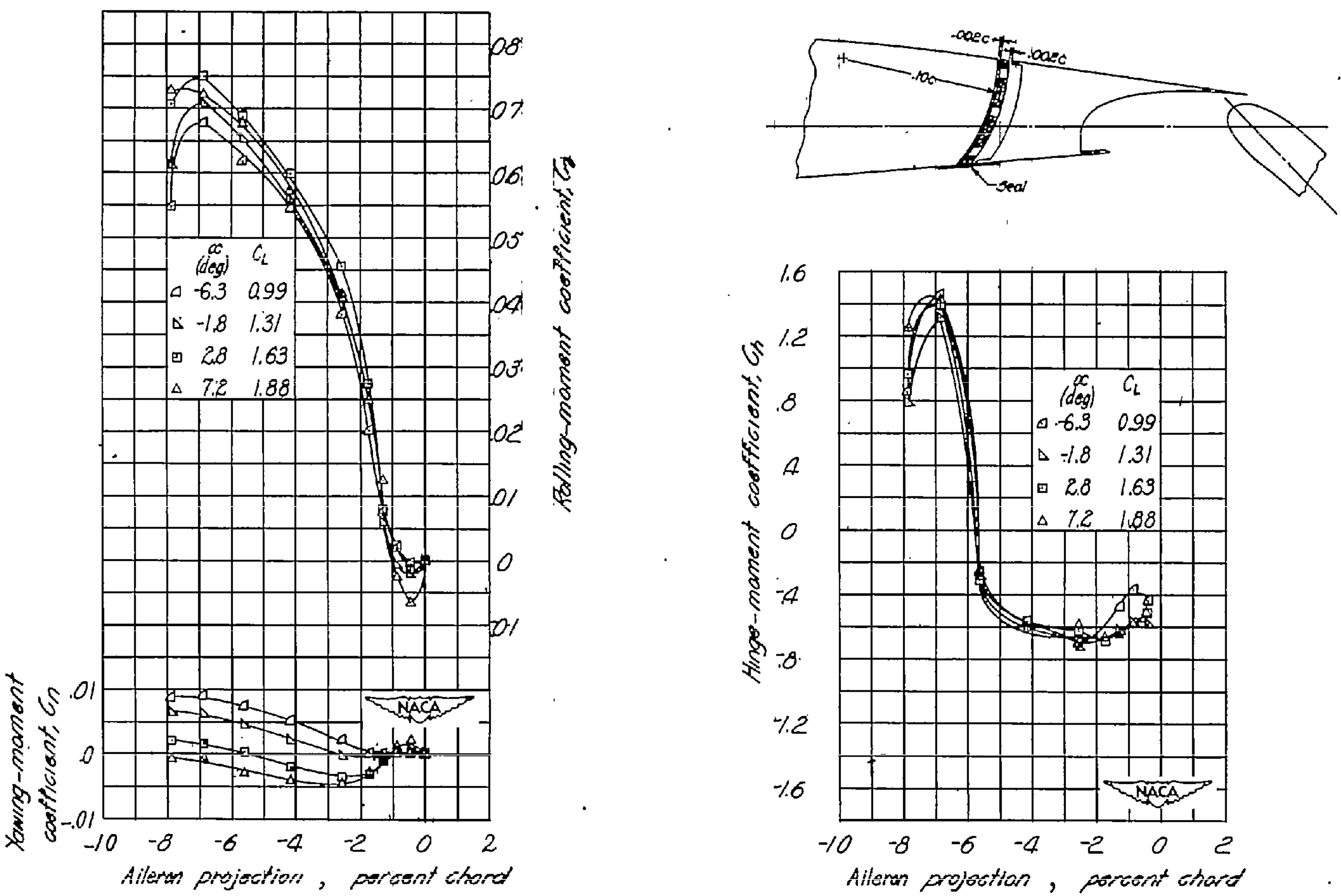
(e) $\alpha \approx 10.1^{\circ}$; $C_L \approx 1.77$.

Figure 26.- Concluded.



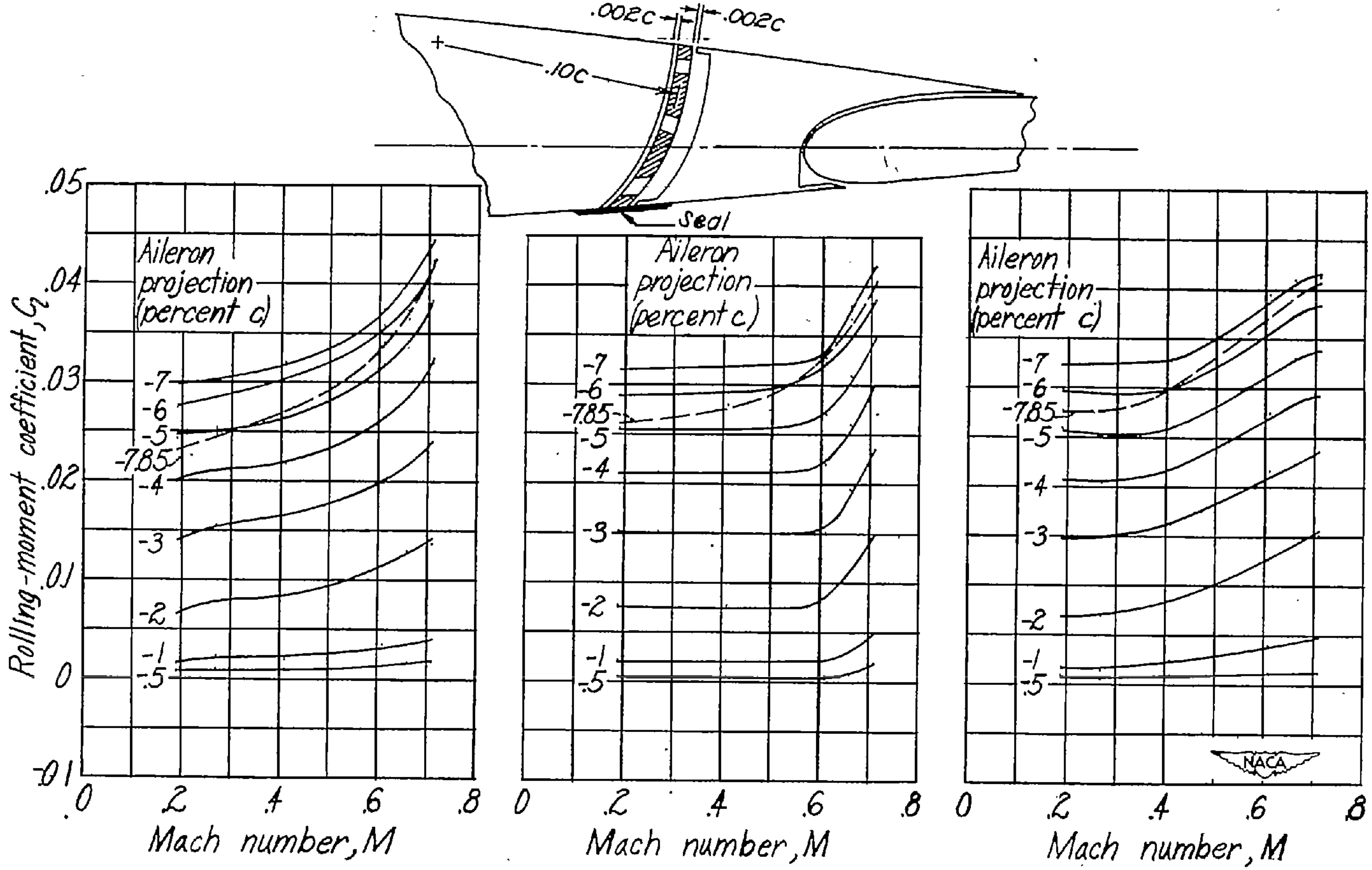
(a) M = 0.13.

Figure 27.- Variation of lateral-control characteristics of complete wing with retractable-aileron projection at various angles of attack. Full-span flap deflected 45°.



(b) M = 0.27.

Figure 27.- Concluded.

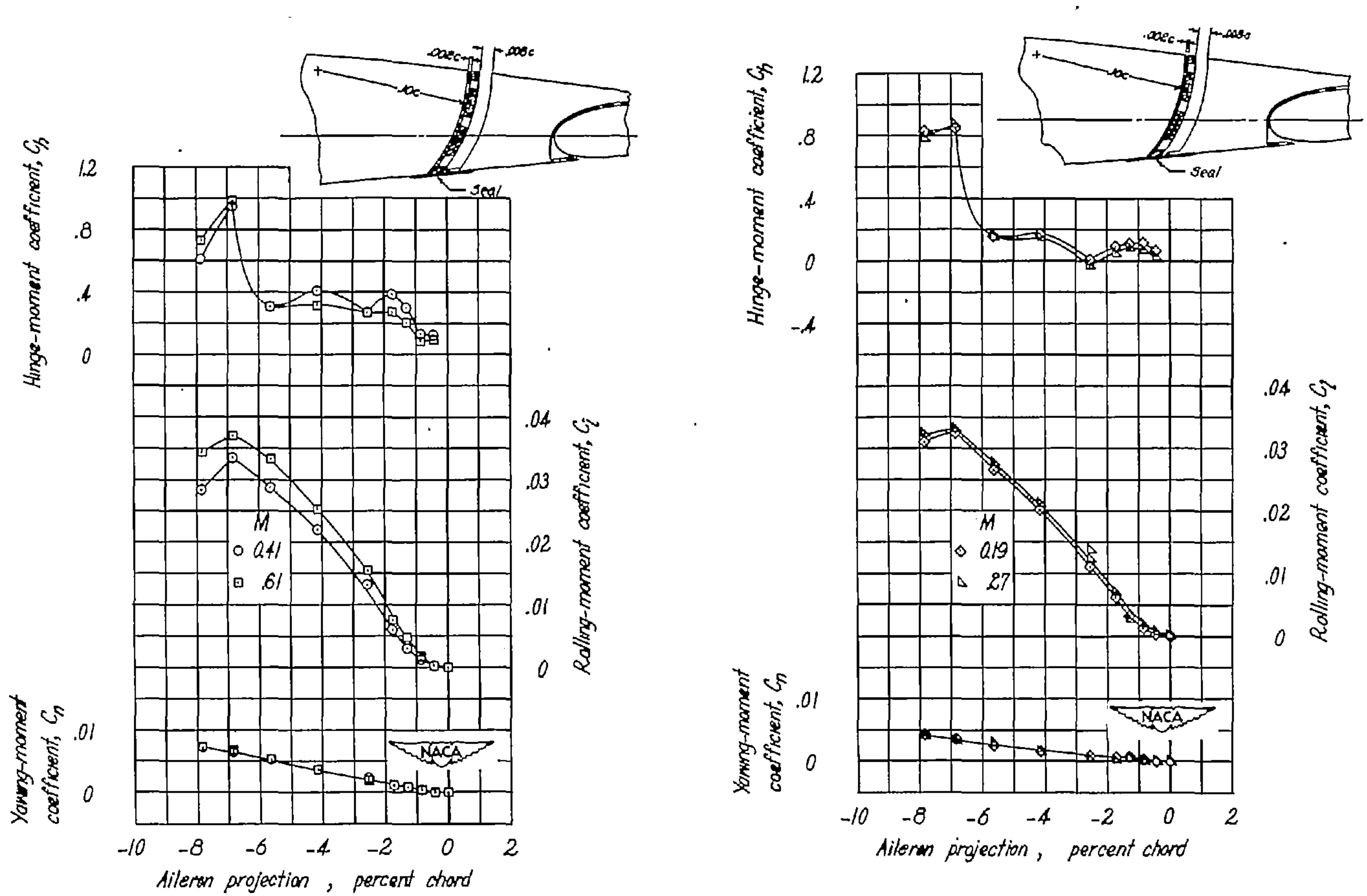


(a) $\alpha \approx -2.1^{\circ}$.

(b) $\alpha \approx 0.2^{\circ}$.

(c) $\alpha \approx 2.6^{\circ}$.

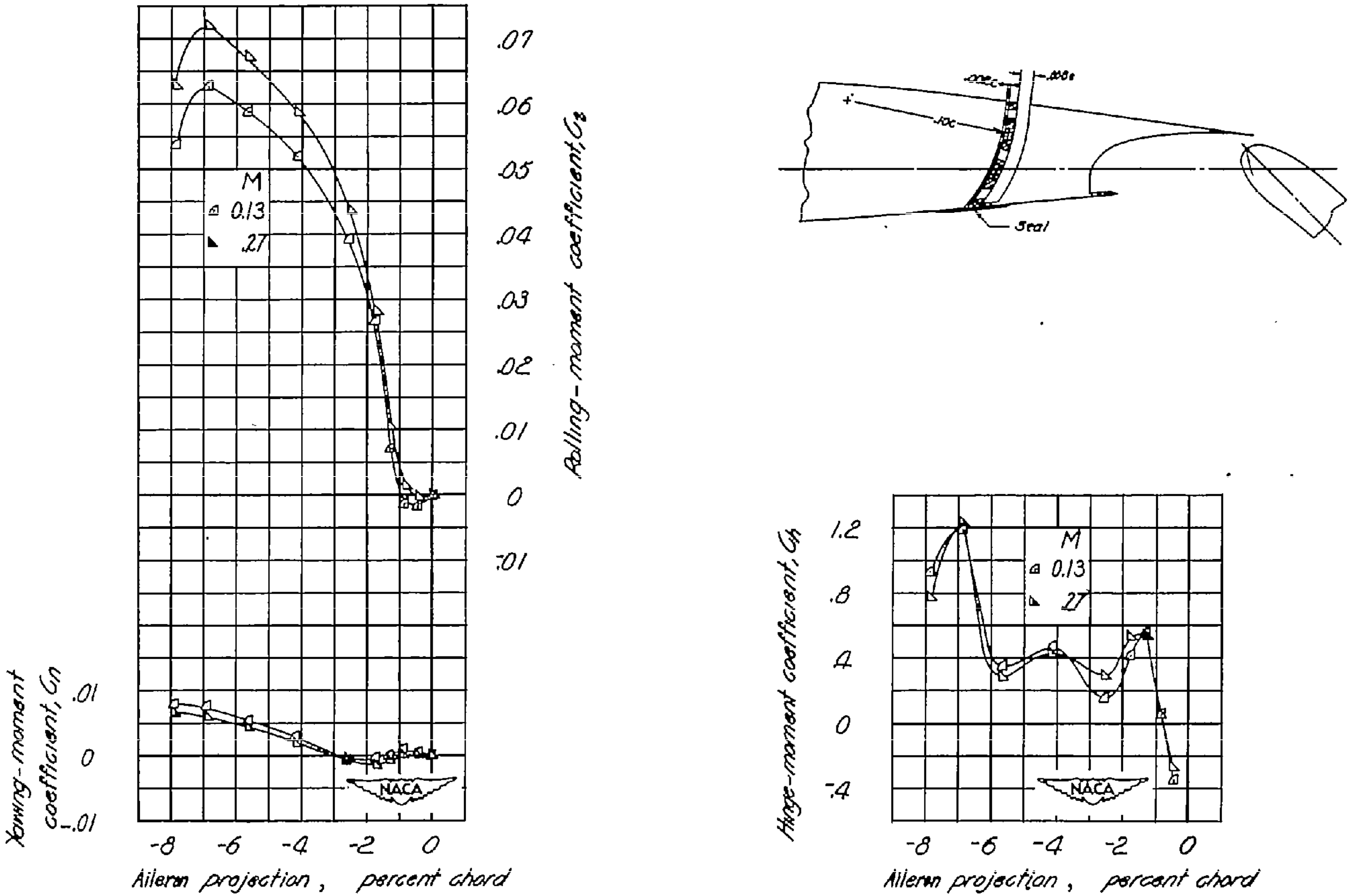
Figure 28.- Variation of lateral-control characteristics of complete wing with Mach number at various retractable-aileron projections. Full-span flap retracted.



(a) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.13$.

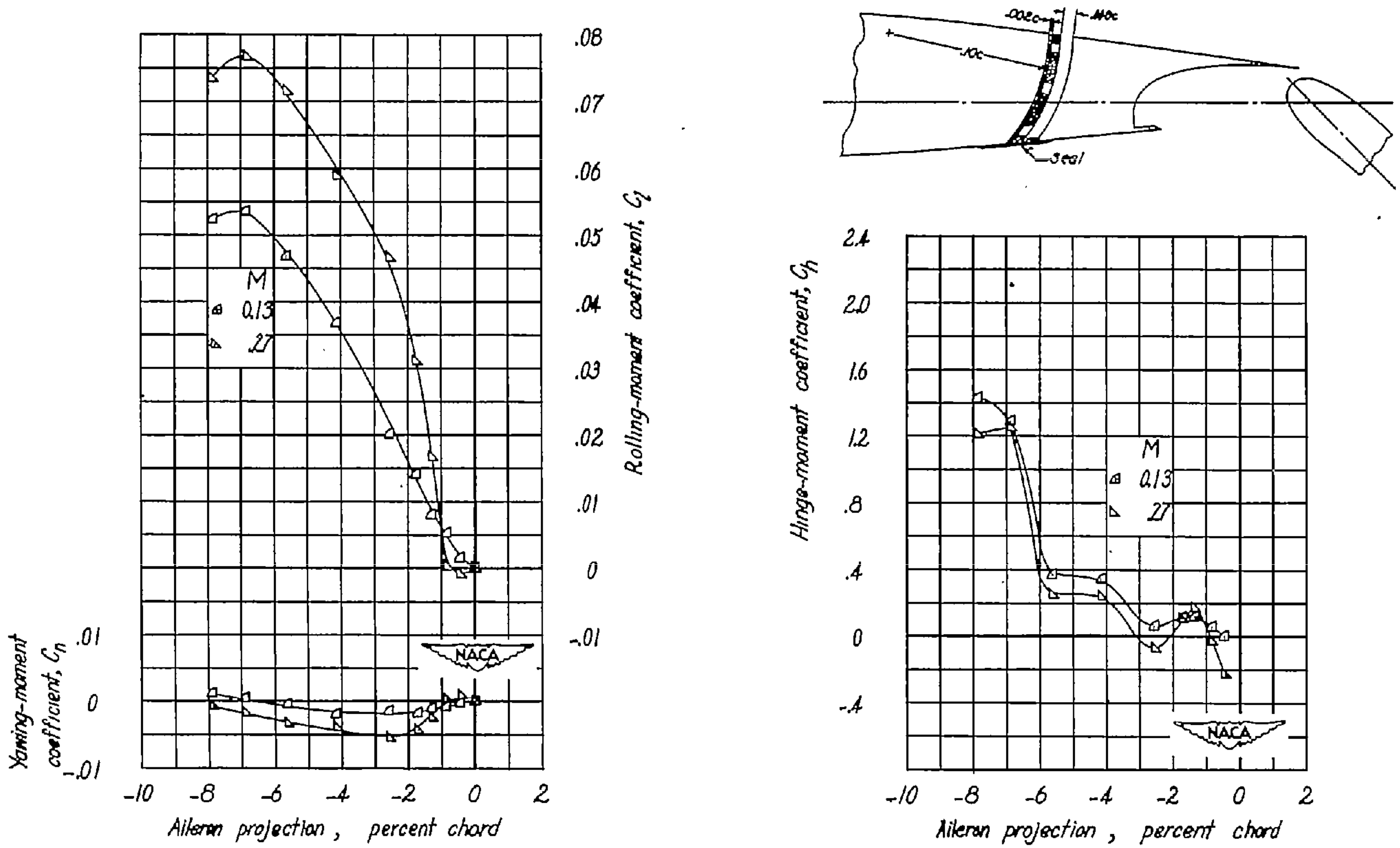
(b) $\alpha \approx 7.1^{\circ}$; $C_L \approx 0.65$.

Figure 29.- Variation of lateral-control characteristics of complete wing with projection of modified retractable aileron at various Mach numbers. Retractable aileron modified by enlarging slot behind aileron on wing upper surface. Full-span flap retracted.



(a) $\alpha \approx -1.8^{\circ}$; $C_L \approx 1.29$.

Figure 30.- Variation of lateral-control characteristics of complete wing with projection of modified retractable aileron at various Mach numbers. Retractable aileron modified by enlarging slot behind aileron on wing upper surface. Full-span flap deflected 45°.



(b) $\alpha \approx 7.1^{\circ}$; $C_L \approx 1.81$.

Figure 30.- Concluded.

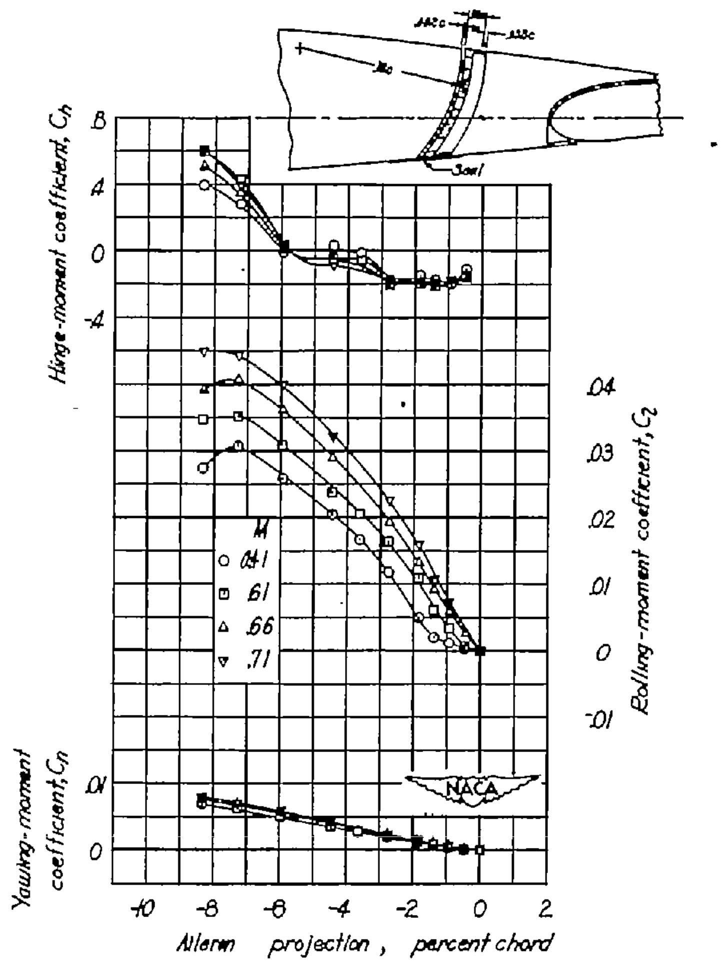
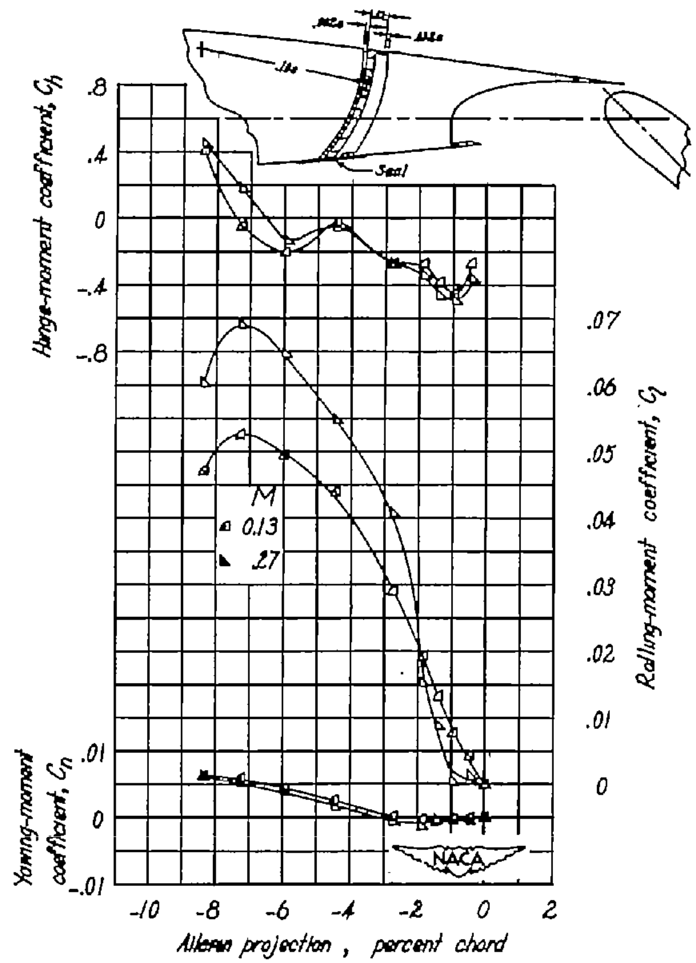
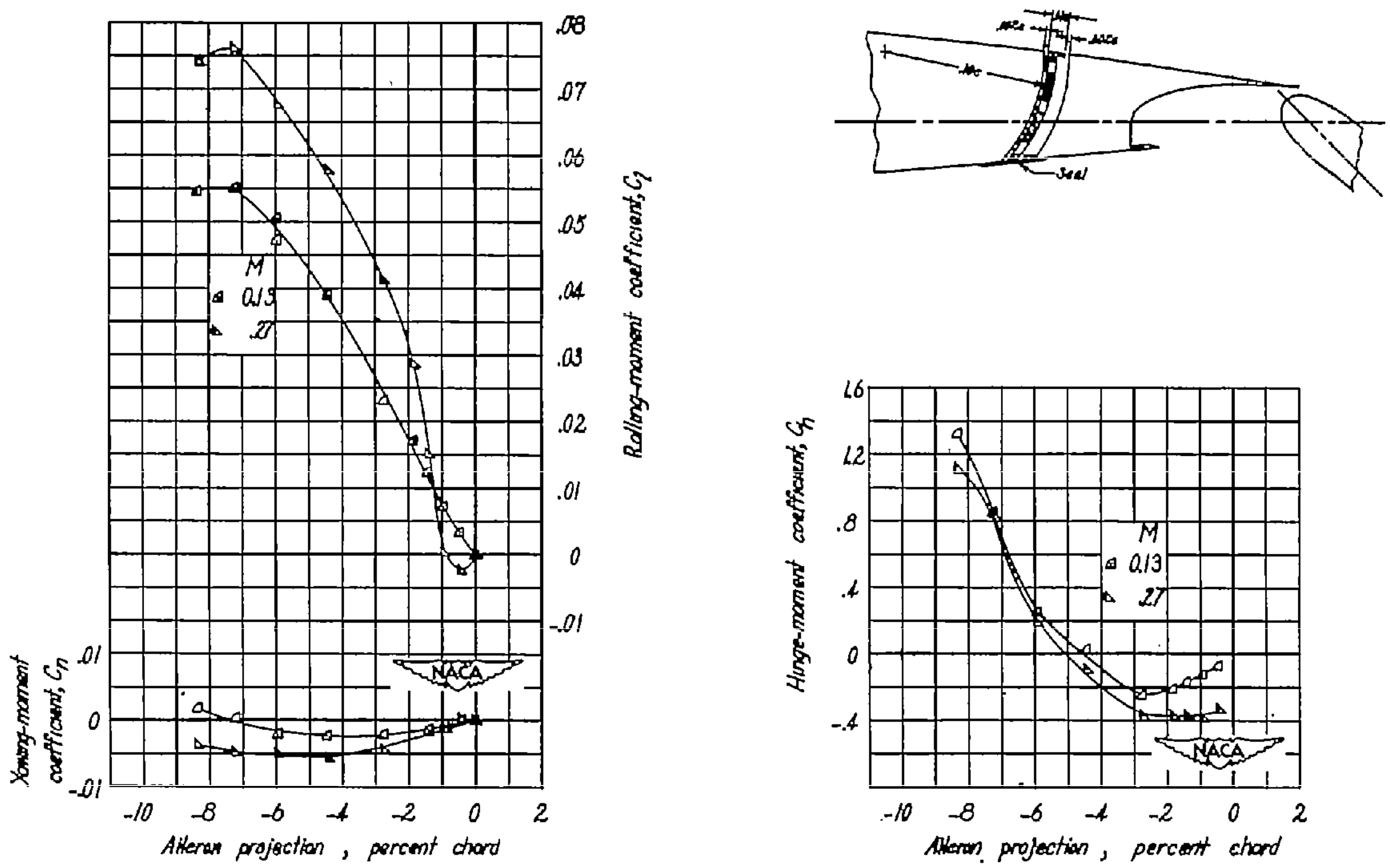


Figure 31.- Variation of lateral-control characteristics of complete wing with projection of modified retractable aileron at various Mach numbers. Retractable aileron modified by installing 0.01c top plate on aileron. Full-span flap retracted. $\alpha \approx 0.2^\circ$; $C_L \approx 0.12$.



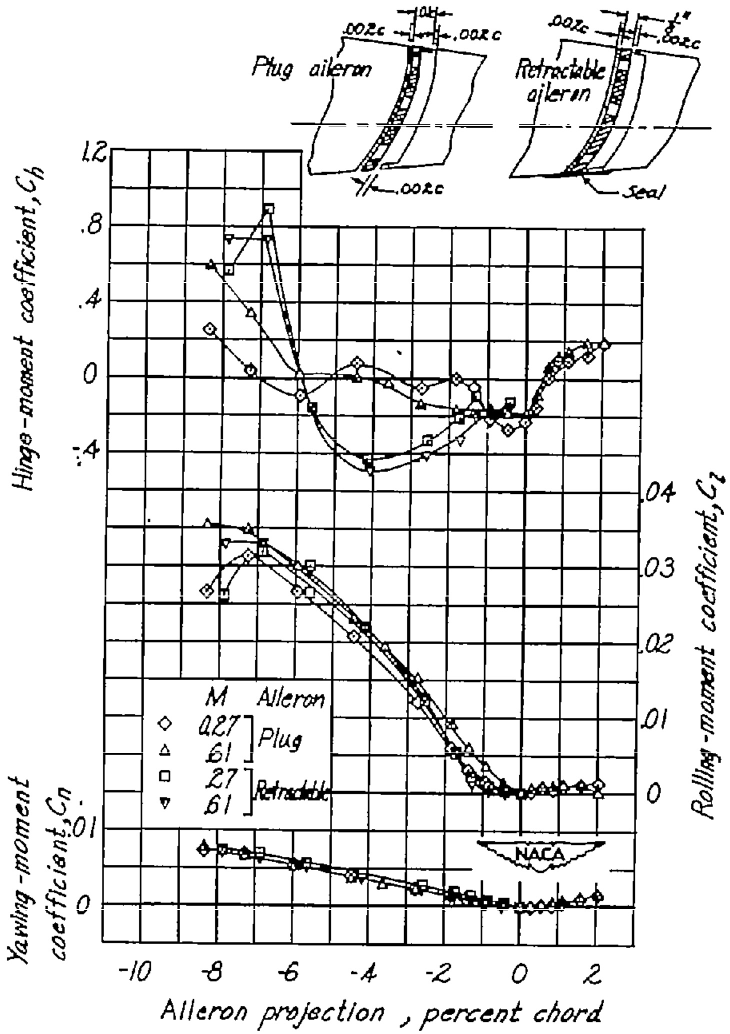
(a) $\alpha \approx -1.8^\circ$; $C_L \approx 1.27$.

Figure 32.- Variation of lateral-control characteristics of complete wing with projection of modified retractable aileron at various Mach numbers. Retractable aileron modified by installing 0.01c top plate on aileron. Full-span flap deflected 45°.

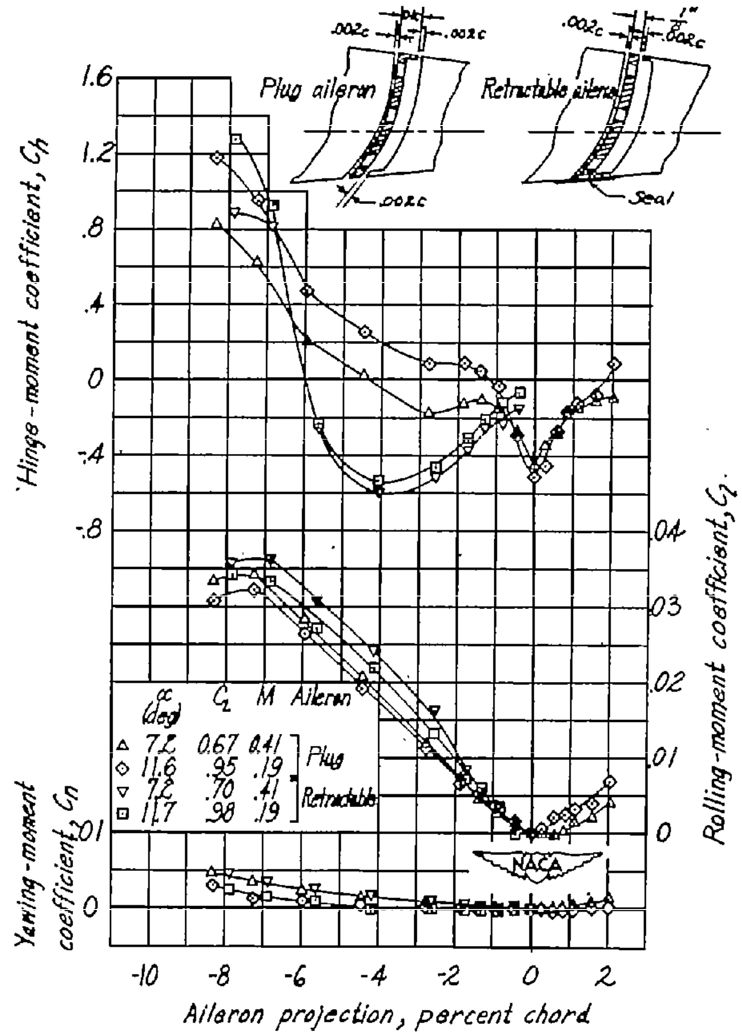


(b) $\alpha \approx 7.2^{\circ}$; $C_L \approx 1.82$.

Figure 32.- Concluded.



(a) $\alpha \approx 0.2^{\circ}$; $C_L \approx 0.13$.



(b) $\alpha \approx 7.2^{\circ}$; $C_L \approx 0.68$; $M = 0.41$; and
$\alpha \approx 11.6^{\circ}$; $C_L \approx 0.96$; $M = 0.19$.

Figure 33.- Comparison of plug-aileron and retractable-aileron lateral-control characteristics on complete wing at various angles of attack and Mach numbers. Full-span flap retracted.

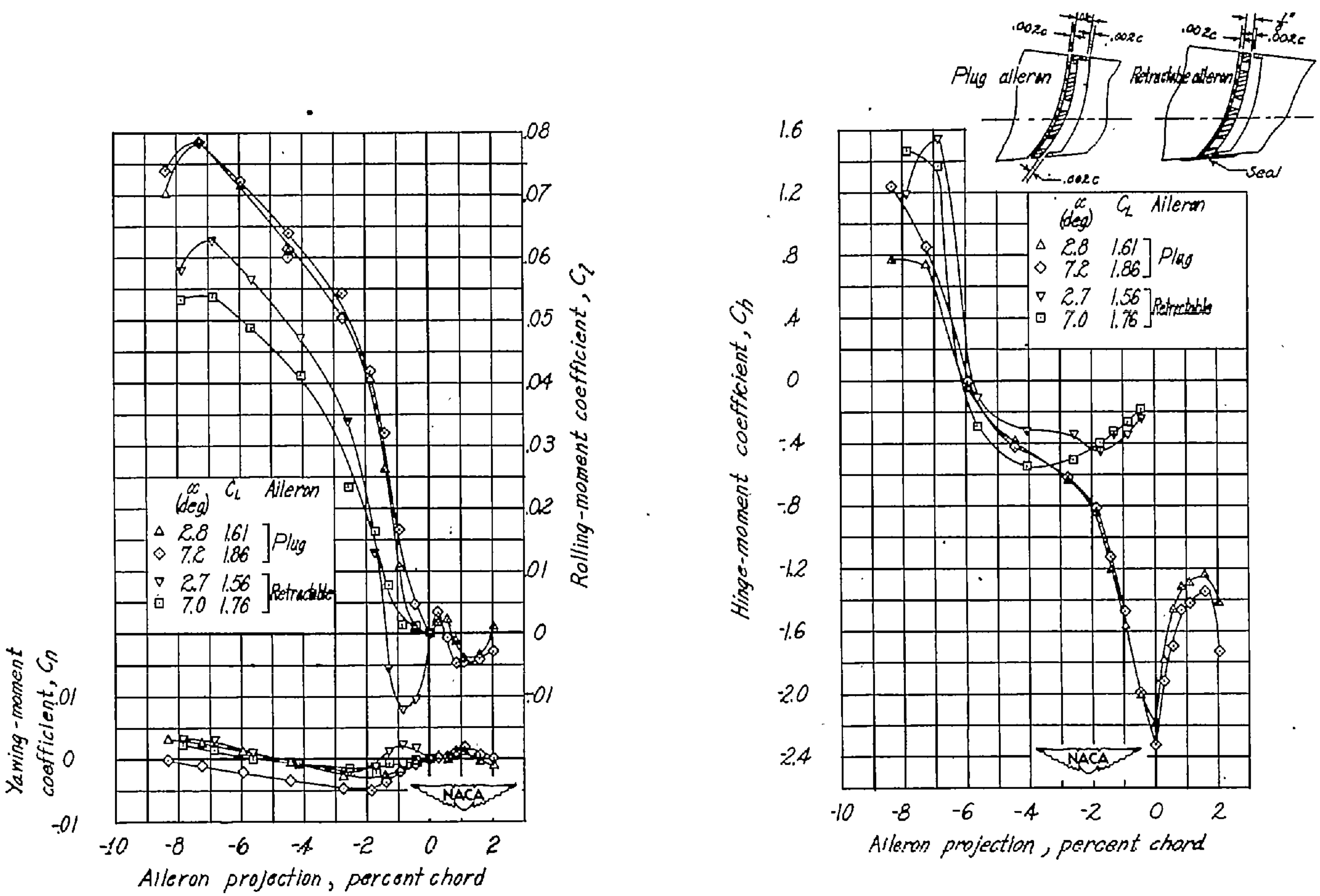
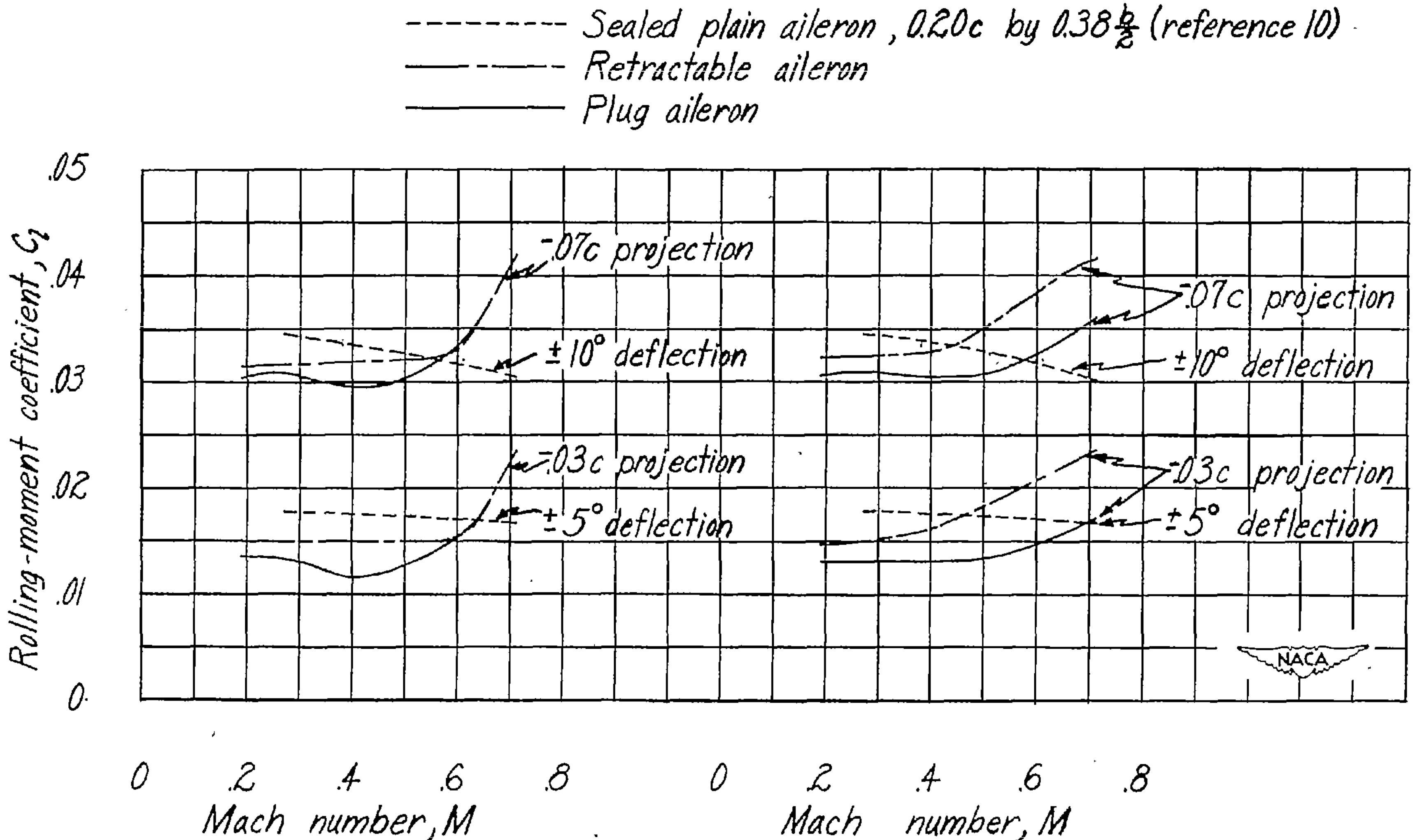


Figure 34.- Comparison of plug-aileron and retractable-aileron lateral-control characteristics on complete wing at various angles of attack. Full-span flap deflected 45°. M = 0.19.



(a) $\alpha \approx 0.2^{\circ}$.

(b) $\alpha \approx 2.6^{\circ}$.

Figure 35.- Comparison of variation of rolling-moment coefficient with Mach number for plug, retractable, and sealed plain ailerons on complete wing model. Full-span flap retracted.