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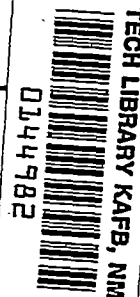
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1802

WIND-TUNNEL INVESTIGATION OF AN NACA 65-210 SEMISPAN WING

EQUIPPED WITH CIRCULAR PLUG AILERONS AND

A FULL-SPAN SLOTTED FLAP

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SUMMARY

A wind-tunnel investigation was made of the lateral-control charac-
teristics of a thin, low-drag, semispan wing equipped with three configura-
tions of circular plug ailerons and a full-span, 25-percent-chord, slotted
flap. The plug ailerons were located at the 68-percent-chord station,
spanned 49.2 percent of the semispan wing, and were constructed in five
equal spanwise segments. The investigation was performed through a Mach
number range from 0.13 to 0.61. The Mach and Reynolds numbers were varied
simultaneously during the investigation.

The results of the investigation indicated that a satisfactory plug-
aileron configuration (a double-walled circular-plug-aileron configuration)
has been developed for use on high-speed unswept-wing airplanes in conjunc-
tion with a full-span slotted flap. This plug-aileron configuration produced
increases in aileron effectiveness with increase in the Mach and Reynolds
numbers, produced a fairly linear variation of rolling moment with aileron
projection, and produced appreciably larger rolling moments with the flap
deflected than with the flap retracted. In addition, this plug-aileron
configuration generally produced favorable yawing moments and also produced
hinge moments which were of moderate value, had a stable variation over the
projection range, and exhibited either small or inconsistent changes with
increases in the Mach and Reynolds numbers.

INTRODUCTION

As a solution to the high-lift and lateral-control problems presented
at take-off and landing by the high-performance airplanes currently in use
or in the design stage, the National Advisory Committee for Aeronautics
has been investigating the characteristics of spoiler-type lateral-control
devices to be used in conjunction with full-span flaps.

The results of several relatively low-speed investigations made on
wings having conventional airfoil sections (references 1 to 8) indicated

some of the merits of spoiler-type lateral-control devices, such as control
at high angles of attack, favorable yawing moments, higher reversal speeds
than conventional ailerons because of the lower twisting moments of spoiler-
type devices, small stick forces, and the increased effectiveness of
spoiler-type controls when full-span flaps are deflected. In addition,
these investigations indicated the increased effectiveness obtainable with
the plug-type spoiler-slot aileron (known as the "plug aileron") as compared
with the effectiveness of the retractable aileron and also indicated the
large increase in wing lift obtainable through use of a full-span flap and
the generally superior characteristics obtainable with a slotted flap. The
results of other investigations performed on unswept wings having high
critical speeds (references 9 to 11) showed an increase in aileron effective-
ness of the spoiler-type ailerons when the Mach number was increased in the
high Reynolds number range as contrasted with a decrease in aileron effective-
ness obtained with conventional ailerons as the Mach number increased.

In order to eliminate the unfavorable rolling moments sometimes
produced by the downgoing conventional plug aileron and still provide a
slot through the wing for up deflections, a new-type plug-aileron arrange-
ment was constructed. The aileron is so designed that down (positive)
deflections do not produce any changes in the lower surface of the wing;
however, deflecting the aileron up opens a slot and provides a scoop on
the lower surface of the wing. The present investigation therefore was
performed to ascertain the lateral-control characteristics of a thin, low-
drag, semispan wing equipped with a full-span slotted flap and three con-
figurations of the new-type plug aileron. The present investigation,
which was performed in the Langley 300 MPH and high-speed 7- by 10-foot
tunnels, is an extension of the investigations reported in references 10
and 11 and was performed on the same wing model used in these investiga-
tions. Tests of the 0.492-semispan, new-type, plug ailerons - known herein
as "circular plug ailerons" to distinguish them from the conventional or
regular plug ailerons of references 5, 6, 11, and 12 - were performed
through a projection range at several angles of attack with the full-span
flap retracted or deflected and at various speeds up to a Mach number of
0.61; lateral-control data obtained in these tests are presented and
discussed herein. Wing lift, drag, and pitching-moment data are presented
only with the plug aileron and flap in their neutral positions over a speed
range up to a Mach number of about 0.835 with the wing at a low angle of
attack, since these data had been presented previously through an angle-of-
attack range at various speeds with the flap retracted and deflected.
(See references 10 and 11.)

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 $\left(\dfrac{\text{Twice lift of semispan model}}{qS}\right)$

C_D drag coefficient (D/qS)

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 (L/qSb)

C_n yawing-moment coefficient (N/qSb)

C_h aileron hinge-moment coefficient $\Big(H_a/qM$ where M is area moment of exposed aileron top edge about hinge line$\Big)$

C_{l_p} damping-in-roll coefficient $\left(\dfrac{\partial C_l}{\partial \frac{pb}{2V}}\right)$

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

c local wing chord

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

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 13. 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 14.

MODEL AND APPARATUS

The right-semispan-wing model was mounted in an inverted position in the Langley high-speed 7- by 10-foot tunnel and in an erect position in the Langley 300 MPH 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. (See fig. 1.) The wing was constructed according to the plan-form dimensions shown in figure 2 and had an aspect ratio of 5.76 and a ratio of tip chord to root chord of 0.57. The model was constructed with neither twist nor dihedral and had an NACA 65-210 airfoil section (table I) from root to tip. 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 shown in figure 2. The flap deflection (45°) and position with respect to the upper-surface airfoil lip used in the present investigation for the normal flap-deflected position are the same as those employed in the investigations reported in references 10 and 11 and are shown in figure 2.

Each of the circular-plug-aileron configurations tested had a span equal to 49.2 percent of the semispan wing and was fabricated from sheet steel in five equal spanwise segments. Plan-form dimensions of the plug-aileron configurations are shown in figure 2, section dimensions are shown in figure 3, and one of the aileron configurations on the wing model is shown in figure 1. The aileron segments were actuated by $\frac{1}{16}$-inch steel arms which were fastened to each end of each segment and also firmly attached to a steel shaft 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. By this mechanism, the steel shaft was rotated to produce the various aileron projections employed in the investigation, and the aileron hinge moments were simultaneously obtained.

TESTS

All tests with the thin-plate circular-plug-aileron configuration (fig. 3(a)) on the semispan-wing model were performed in the Langley high-speed 7- by 10-foot tunnel. All tests with each of the double-walled circular-plug-aileron configurations (figs. 3(b) and (c)) on the semispan-wing model were performed in the Langley 300 MPH 7- by 10-foot tunnel.

With the flap retracted, a speed test was made at a constant wing angle of attack (α = 0.3°) through a Mach number range from 0.40 to 0.835 with a corresponding Reynolds number range of approximately 7.5×10^6 to 12.5×10^6 based on the mean aerodynamic chord of 2.86 feet.

With the flap retracted or deflected, lateral-control tests were performed with each of the circular plug ailerons at various aileron projections, at several angles of attack, and at Mach numbers from 0.13 to 0.61. Negative projections indicate that the ailerons were extended above the wing upper surface.

The variation of Reynolds number with Mach number for these tests is shown in figure 4. The Mach and Reynolds numbers were varied simultaneously during the investigation.

DISCUSSION

Wing Aerodynamic Characteristics

Variation with Mach number of the wing aerodynamic characteristics at a constant angle of attack of 0.3°, with the thin-plate circular plug aileron neutral and the flap retracted, is shown in figure 5. Additional lift, drag, and pitching-moment data were obtained through an angle-of-attack range with each of the double-walled circular-plug-aileron configurations installed on the wing and with the flap retracted and deflected but are not presented herein. These data agree quite well with the data obtained in the pitch tests reported in reference 10 and indicate that installation of any of the circular-plug-aileron configurations on the wing had no material effect in altering the aerodynamic characteristics obtained with the plain wing. Figure 5 shows almost no change in the aerodynamic characteristics for Mach numbers below 0.7; however, above 0.7 somewhat different Mach numbers for lift, drag, and pitching-moment divergence are apparent. Because the choking Mach number of the Langley high-speed 7- by 10-foot tunnel was obtained with the present model at the angle of attack tested near a Mach number of 0.835, the data shown for Mach numbers above approximately 0.80 probably are not reliable.

Aileron Control Characteristics

Thin-plate circular plug aileron.- Data obtained through the projection range of the thin-plate circular plug aileron are presented in figures 6 to 9 to exhibit the effects of angle of attack and Mach number (also Reynolds number) on the flap-retracted and flap-deflected lateral-control characteristics of the complete wing.

In both the flap-retracted and flap-deflected conditions, the slopes of the curves of rolling-moment coefficient against aileron projection are observed to be generally nonlinear. (See figs. 6 to 9.) In the flap-retracted configuration, an ineffective region for small aileron projections at a low angle of attack is shown and a region of constant or slightly reduced effectiveness (with increase in aileron projection) at large projections and large angles of attack is shown. (See figs. 6 and 7.) The ineffective region observed herein for small aileron projections at a low angle of attack has been observed previously with the basic plug aileron of reference 11 and is believed to result principally from the probably weak "scoop effect" of the particular plug-aileron configuration (because of the square lower edge of the thin-plate circular plug aileron) as will be discussed in a subsequent section of this report - and also from the small differences in pressure existing between the two wing surfaces in the vicinity of the plug slot. At large angles of attack with the flap retracted or with the flap deflected the pressure difference

between the two wing surfaces near the plug slot was sufficient to cause
the air flow through the plug slot to increase the aileron effectiveness.
The region of constant or slightly reduced effectiveness observed at large
projections and large angles of attack probably results from the combina-
tion of the effects produced by the wing angle of attack (and hence the
pressure difference between the two wing surfaces near the plug slot), the
position of the lower edge of the plug aileron (which affects the aileron
"scoop effect"), and the position of the upper edge of the aileron (which
affects any "ram effect" - such as to produce a downward flow through the
plug slot).

The aileron effectiveness generally increased with increase in the
Mach and Reynolds numbers in both flap conditions. (See figs. 6 and 8.)
An exception to this statement is noted in the data shown in figure 6(a),
for projections below -5 percent chord, in which a decrease in the
effectiveness is observed as the Mach number increased from 0.27 to 0.41.
This decrease in effectiveness is similar to the effect observed in the
plug-aileron investigation reported in reference 11 and probably results
from changes in the wing pressure distribution in the vicinity of the plug
slot as the Mach number increased, which effect in turn influenced the
flow through the slot and thereby the aileron effectiveness.

Increase of the angle of attack in the flap-retracted condition
increased the aileron effectiveness over almost the entire aileron-
projection range, particularly for small projections, and tended to
linearize the curve of rolling-moment coefficient against aileron projec-
tion for projections of less than -3 percent chord. (See figs. 6 and 7.)
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 approximately

125 percent larger than the corresponding values obtained with flap
retracted. Although no data were obtained above the flap-deflected wing-
stall angle, it is believed that the thin-plate circular plug aileron
will retain effectiveness in this condition, and the data presented in
reference 11 tend to substantiate this belief.

The values of yawing-moment coefficient obtained by projection of
the thin-plate circular plug aileron were generally favorable (having
the same sign as the values of C_l), particularly in the flap-retracted
condition, and generally became more positive with increase in aileron
projection and less positive with increase in angle of attack. The values
of C_n obtained over the projection range generally were less favorable
with the flap deflected than with flap retracted. Mach number, as was
shown in the investigation reported in reference 11, has only a small
effect on the yawing-moment characteristics.

The variation of aileron hinge-moment coefficient with aileron
projection was irregular over the projection range. The curves of C_h

against aileron projection generally were unstable for small projections, stable for large projections, and became unstable over a greater part of the projection range as α increased. The values of C_h generally were slightly or inconsistently affected by increase in the Mach number, but generally became more negative as the angle of attack increased. (See figs. 6 to 9.) Deflecting the flap resulted in values of hinge-moment coefficient more negative than those obtained with the flaps retracted. Despite the large values shown for the hinge-moment coefficients, which result from the small area upon which the coefficient is based, the actual hinge moments of the plug aileron are very small.

Double-walled circular plug aileron.- The lateral-control characteristics of the double-walled circular plug aileron at various angles of attack and Mach and Reynolds numbers are presented in figures 10 and 11 for the flap-retracted condition and in figures 12 and 13 for the flap-deflected condition. It will be noted that the Mach number range covered in tests of this configuration was quite small and in the range of Mach number where compressibility effects are usually small; therefore, any aerodynamic effects occurring as a result of changing the Mach and Reynolds numbers (simultaneously) are probably mostly Reynolds number effects. In the ensuing discussion, Mach and Reynolds number changes are not discussed where the aerodynamic effects produced by such changes are negligible.

The variation of rolling-moment coefficient with aileron projection is observed to be fairly linear over most of the aileron-projection range for the flap-retracted condition but generally slightly nonlinear for the flap-deflected condition. Increases in the Mach and Reynolds numbers generally resulted in increases in the aileron effectiveness for either flap condition. (See figs. 10 and 12.) It is anticipated that the aileron effectiveness of the double-walled circular plug aileron would exhibit additional increases (similar to those exhibited by the plug ailerons of reference 11 and the thin-plate circular plug ailerons of the present investigation) when the Mach and Reynolds numbers are increased beyond the range of the present investigation and up to the critical Mach number.

Increase in the wing angle of attack resulted in an increase in the aileron effectiveness over most of the aileron-projection range in the flap-retracted condition and generally resulted in a decrease in the aileron effectiveness over the aileron-projection range in the flap-deflected condition. 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 85 percent larger than the maximum values of C_l obtained with flap retracted. The data of figure 12(d) (which were obtained above the flap-deflected wing stall angle) also indicate that the double-walled circular plug aileron was quite effective and produced large rolling moments above the flap-deflected stall angle. It will be noted that small favorable

rolling moments were produced by positive aileron projections for both flap conditions. Although the upper edge of the aileron is below the upper-surface wing contour for positive aileron projections and the lower edge of the aileron extends no further below the lower-surface wing contour than it does when neutral, the favorable rolling moments are thought to result from the more complete plug-slot seal produced by positive aileron projections.

The values of yawing-moment coefficient produced by projection of the double-walled circular plug aileron were generally favorable and became more favorable with increase in aileron projection with the flap retracted but were generally favorable only for large aileron projections with the flap deflected. The values of C_n generally were more favorable with the flap retracted than with the flap deflected and became less favorable with increase in the wing angle of attack in either flap condition. (See figs. 10 to 13.)

The variation of hinge-moment coefficient with aileron projection was only slightly irregular and was generally stable in the negative projection range in both flap conditions and became less stable over most of the projection range as the wing angle of attack increased. Deflection of the flap resulted in a larger variation of C_h over the projection range and in values of C_h more negative than those obtained with the flap retracted.

Modified double-walled circular plug aileron.- The characteristics of the double-walled circular plug aileron modified by removing the 0.015c top plate and replacing it with one as wide as the aileron forward wall (3/32 inch) are shown in figures 14 to 17. As was discussed in the preceding section for the unmodified double-walled circular plug aileron, the Mach number range covered in tests of this modified aileron was quite small and in the range of Mach number where compressibility effects are usually small. In the ensuing discussion, Mach and Reynolds number changes are not discussed when the aerodynamic effects produced by such changes are negligible; when these aerodynamic effects are significant, they probably result mostly from changes in Reynolds number.

The aileron-effectiveness characteristics of this modified plug aileron were generally quite similar to the characteristics of the unmodified plug aileron discussed in the preceding section. The values of C_l obtained with the modified aileron were fairly linear over most of the aileron projection range in both flap conditions and increased with increase in the Mach and Reynolds numbers. In addition, when the wing angle of attack was increased, the values of C_l generally increased in the flap-retracted condition and decreased in the flap-deflected condition. The data of figures 14 to 17 also indicate that the aileron effectiveness with flap deflected was appreciably larger than that obtained with flap retracted (approximately 85 percent larger for maximum values of C_l) and that the

modified aileron was quite effective up to and above the angle of wing stall. (Compare the values of C_L and α with corresponding values from reference 10.)

The yawing-moment characteristics of the modified plug aileron were generally similar to those of the unmodified aileron; the same effects and trends of the C_n curves with changes in angle of attack and flap deflection discussed in the preceding section for the unmodified aileron generally were obtained with the modified plug aileron.

The variation of hinge-moment coefficient with projection of the modified plug aileron was markedly nonlinear, and generally became less stable (or more unstable) over a greater part of the negative projection range as the wing angle of attack increased. In addition, the values of C_h generally became more negative as the wing angle of attack increased, and more negative values of C_h were generally obtained with the flap deflected than with the flap retracted. (See figs. 14 to 17.) The afore-mentioned effects on C_h, when compared with the C_h data of the unmodified double-walled circular plug aileron, are generally the effects expected to result from removing the aileron top plate and have been found in previous investigations. (See references 5 and 11.)

Comparison of Lateral-Control Characteristics of

the Three Configurations of Circular Plug Aileron

For purposes of direct comparison, some of the lateral-control data previously presented for the thin-plate, double-walled, and modified double-walled circular plug ailerons have been replotted for similar test conditions in the same figure and are shown in figures 18 and 19. A more complete comparison of these data can be made with figures 6 to 17.

For each of the three circular-plug-aileron configurations investigated, increases in the aileron effectiveness with increase in Mach and Reynolds numbers were generally obtained in both the flap-retracted and flap-deflected conditions. In the flap-retracted condition, the aileron effectiveness of each of the circular plug ailerons increased when the angle of attack increased; the thin-plate circular plug aileron exhibited the largest effects on C_l produced by changes in α. In the flap-deflected condition, increases in α had an inconsistent effect on the aileron effectiveness of the thin-plate plug aileron but generally tended to decrease the aileron effectiveness of each of the double-walled plug ailerons. Deflecting the flap had more effect in increasing the values of C_l for the thin-plate plug aileron than for either of the double-walled plug ailerons.

The thin-plate plug aileron generally produced larger values of C_l over the projection range in both flap conditions than did either of the double-walled plug ailerons, except possibly at low values of α with the

flap retracted. As may be seen from the data in figures 6 to 19, each
of the double-walled circular plug ailerons produced a more linear variation
of C_l over the projection range than did the thin-plate circular plug
aileron, and the double-walled plug ailerons did not exhibit the ineffective
region exhibited by the thin-plate plug aileron for small projections at
a low angle of attack with the flap retracted. The greater linearity
exhibited by the rolling-moment curves of the double-walled circular plug
aileron over the projection range is thought to result from a dual effect
produced by the basic physical differences between the double-walled and
thin-plate plug-aileron configurations. At small aileron projections and
low angles of attack the beveled lower edge of the double-walled plug
aileron produces a greater "scoop effect" and hence a greater aileron
effectiveness than the thin-plate plug aileron. At all aileron projections
and large angles of attack, the upper edge of the double-walled plug
aileron permits the air flowing up through the plug slot to exit behind
the aileron, whereas the air would exit ahead of the upper edge of the
thin-plate plug aileron; thus, the combination "ram effect" at the upper
edge and the "scoop effect" at the lower edge of the thin-plate plug
aileron probably offset each other in some manner to produce the region
of constant or reduced aileron effectiveness observed in figure 18(b) and
in figures 6 and 7.

Computations to determine the helix angle $pb/2V$ generated by the
wing tip in a roll were made by utilizing the relationship $\dfrac{pb}{2V} = \dfrac{C_l}{C_{l_p}}$,
where C_{l_p} is the damping-in-roll coefficient, and indicated the large
rolling effectiveness of the circular plug ailerons investigated, parti-
cularly in the flap-deflected condition. These computations showed that
a value of C_l of 0.036, which was usually exceeded at large aileron
projections with the flap retracted and easily exceeded with the flap
deflected, corresponded to a value of $pb/2V$ of 0.09, based on a value
of C_{l_p} (obtained from reference 15) of 0.40.

The yawing-moment characteristics of the three circular plug ailerons
investigated were generally similar and exhibited the same trends with
change in the Mach and Reynolds numbers, angle of attack, and flap
deflection.

The data for the unmodified double-walled circular plug aileron
exhibited the most stable variation of C_h and the smallest variation of
C_h over the aileron-projection range of the three circular plug ailerons
investigated. Because the area moments of the top edge of the thin-plate
and the modified double-walled plug ailerons were almost similar, these
ailerons exhibited generally similar variations and values of C_h over
the projection range. For each of the circular plug ailerons, the curves
of C_h against aileron projection generally became less stable and the
values of C_h generally became more negative as α increased. In general,

the values of C_h for each of the circular plug ailerons were only slightly affected by changes in the Mach and Reynolds numbers, and more negative values of C_h were generally produced by each of the circular plug ailerons with the flap deflected than with the flap retracted.

It is well to note that the hinge moments of the double-walled circular plug aileron are of fairly moderate value, whereas the hinge moments produced by the thin-plate and modified double-walled circular plug ailerons are extremely small. These hinge moments may be masked in an airplane installation by a booster system, a mechanical device providing "stick feel," or by a "feeler aileron" (reference 16). For example, the hinge moments produced 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 were approximately 1.2, 5.4, and 1.1 foot-pounds for the thin-plate, the double-walled, and the modified double-walled circular plug ailerons, respectively.

Comparison of Lateral-Control Characteristics of the Circular

Plug Ailerons, a Conventional Plug Aileron,

and a Retractable Aileron

Comparisons were made of the lateral-control characteristics of the circular plug ailerons of the present investigation with the corresponding characteristics of the conventional plug and retractable ailerons reported in reference 11. Several of these comparisons are shown in figures 18 and 19.

Larger values of rolling-moment coefficient generally were obtained over the projection range in both flap conditions with each of the circular plug ailerons than with either the conventional plug or retractable ailerons. One notable exception to this statement is observed for the flap-retracted condition at a low angle of attack where the thin-plate circular plug aileron is seen to be less effective, for small projections, than either of the other spoiler-type devices. (See fig. 18(a).) The ineffective region at low projections and low angles of attack exhibited by the thin-plate circular plug aileron is quite similar to the results obtained on the conventional plug without the top plate (reference 11); and, as previously indicated, modifying this circular plug aileron by beveling the lower edge of the aileron and installing a double plug wall and a top plate, thereby producing the double-walled circular plug aileron, alleviated this condition appreciably. The two double-walled circular plug ailerons thereby produced more linearity in the variation of C_l with aileron projection than either of the other ailerons. The circular

plug ailerons also exhibited larger increases in aileron effectiveness than either of the other ailerons when the angle of attack was increased in the flap-retracted condition. In addition, the circular plug ailerons showed the same trends of C_l with flap deflection and with increase in the Mach and Reynolds numbers as the conventional plug and retractable ailerons.

The values of C_n obtained with each of the circular plug ailerons generally were slightly more positive (more favorable) in all configurations than those obtained with either the conventional plug or retractable ailerons. (See figs. 18 and 19.) The trends of C_n with angle of attack, flap deflection, and Mach and Reynolds numbers were the same for the ailerons of the subject investigation as for the ailerons of the investigation reported in reference 11.

The thin-plate and modified double-walled circular plug ailerons displayed a larger variation of C_h over the projection range in the flap-retracted condition than either the conventional plug or retractable ailerons considered in the comparison, whereas the variation of C_h with projection for the unmodified double-walled circular plug aileron was almost similar to that of the conventional plug and retractable ailerons. Generally, a less stable variation of C_h over a larger part of the projection range was displayed by the thin-plate and modified double-walled circular-plug-aileron data, and a more stable variation of C_h over the projection range was displayed by the data for the unmodified double-walled circular plug aileron than by the data for the conventional plug and retractable ailerons. The hinge-moment-coefficient curves of the circular plug ailerons showed slightly larger effects produced by changes in the angle of attack and flap deflection and about the same effects produced by changes in the Mach and Reynolds numbers as the C_h curves of the conventional plug and retractable ailerons.

It would therefore appear that the main advantages to be gained by using any of the subject plug ailerons instead of the conventional plug aileron are to eliminate the adverse rolling moments produced by the downgoing conventional plug and to provide larger rolling moments for a given plug-aileron projection.

<div align="center">
Comparison of Lateral-Control Characteristics

of the Circular Plug Ailerons with Those

of a Sealed Plain Aileron
</div>

The variation of helix angle $pb/2V$ and aileron hinge moment with deflection (or projection) of the double-walled circular plug aileron and

a 0.20c, 0.38$\frac{b}{2}$, sealed plain aileron investigated on the same wing

(reference 10) are compared for several representative conditions in the
flap-retracted condition in figure 20. As was discussed in a preceding

section, the helix angle was computed from the relationship $\frac{pb}{2v} = \frac{C_l}{C_{l_p}}$

and the value of C_{l_p} employed was 0.40.

The comparison shown in figure 20 illustrates the effectiveness of
both types of lateral-control devices and, in particular, the degree of
linearity of the plug-aileron effectiveness over the deflection (or
projection) range, especially near zero deflection. Further comparisons
of the circular-plug-aileron data with the plain-aileron data of refer-
ence 10 illustrate the increase in aileron effectiveness with increase
in the angle of attack and Mach and Reynolds numbers obtained with the
circular plug ailerons contrasted with opposite effects obtained with
the sealed plain aileron. Also, the plug ailerons produced extremely
large values of rolling moment in the flap-deflected condition and were
quite effective above the flap-deflected stall angle; whereas the plain-
aileron effectiveness probably would not be increased by deflecting the
flap and probably would be inadequate above the wing stall. It should
also be noted that plug ailerons permit use of full-span flaps - with
an accompanying increase in airplane performance - whereas plain ailerons
restrict the flap span.

A comparison of the yawing-moment data obtained with the present
plug ailerons and the plain aileron of reference 10 shows the generally
favorable yawing characteristics - such as to increase aileron effective-
ness - of the plug ailerons contrasted with the unfavorable yawing
characteristics of the plain aileron.

The hinge moments of the double-walled circular plug aileron (as
well as those of the other circular plug ailerons) are extremely small
compared with the hinge moments of the plain aileron (fig. 20) and indicate
a marked degree of linearity over the deflection range. The hinge moments
presented in figure 20 were computed for the ailerons on the present wing;
therefore, if these controls were applied to a specific airplane, the
hinge moments would be magnified by the cube of the ratio of airplane wing
span to model wing span. Because the hinge moments of the plug ailerons
investigated were relatively unaffected by increase in Mach number and
these ailerons produced small hinge moments that could be altered (refer-
ences 5, 6, and 11) or masked, large control deflections, hence control,
would be available at all speeds. Conversely, the plain ailerons of
reference 10 exhibited adverse affects of Mach number on the hinge moments,
and the large hinge moments obtained at high speeds probably would limit
the aileron deflection and the lateral control of the airplane.

CONCLUSIONS

A wind-tunnel investigation was made of the lateral-control charac-
teristics of a thin, low-drag, semispan wing equipped with three configura-
tions of circular plug ailerons and a full-span, 25-percent-chord, slotted
flap. The plug ailerons were located at the 68-percent-chord station,
spanned 49.2 percent of the semispan wing, and were constructed in five
equal spanwise segments. The investigation was performed through a Mach
number range from 0.13 to 0.61. The Mach and Reynolds numbers were varied
simultaneously during the investigation. The results of the investigation
led to the following conclusions:

1. For each of the three circular-plug-aileron configurations
investigated, increases in the aileron effectiveness with increase in Mach
and Reynolds numbers were generally obtained in both the flap-retracted
and flap-deflected conditions. In the flap-retracted condition, the aileron
effectiveness of each of the circular plug ailerons increased when the angle
of attack was increased; the thin-plate circular plug aileron exhibited the
largest increases in aileron effectiveness with increase in angle of attack.
In the flap-deflected condition, increase in angle of attack had an incon-
sistent effect on the rolling moments produced by the thin-plate circular
plug aileron but generally tended to decrease the aileron effectiveness of
each of the double-walled circular plug ailerons investigated. Appreciably
larger values of rolling-moment coefficient were produced by each of the
circular plug ailerons with the full-span flap deflected than were produced
with the flap retracted, and the ailerons produced large rolling moments up
to and above the flap-deflected stall angle. The thin-plate circular plug
aileron generally produced larger values of rolling-moment coefficient in
both flap conditions than did either of the double-walled circular plug
ailerons, but the double-walled circular plug ailerons produced a more linear
variation of rolling moment over the aileron-projection range.

2. Each of the circular plug ailerons produced yawing moments that
were generally favorable, became more favorable with aileron projection,
less favorable with increase in angle of attack and flap deflection, and
were only slightly affected by increases in the Mach and Reynolds numbers.

3. The variation of hinge-moment coefficient with aileron projection
for each of the circular plug ailerons was nonlinear and exhibited either
small or inconsistent changes with increase in Mach and Reynolds numbers.
The double-walled circular plug aileron equipped with a top plate exhibited
the most linear variation of hinge-moment coefficient with aileron projection
and also had a fairly stable variation of hinge moment with projection.
For each of the ailerons, the variation of hinge-moment coefficient with
projection became less stable over a greater part of the projection range

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and the values of hinge-moment coefficient became more negative as the
angle of attack increased. In addition, more negative values of hinge-
moment coefficient were generally produced by each of the ailerons with
flap deflected than with the flap retracted.

Langley Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Air Force Base, Va., December 1, 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
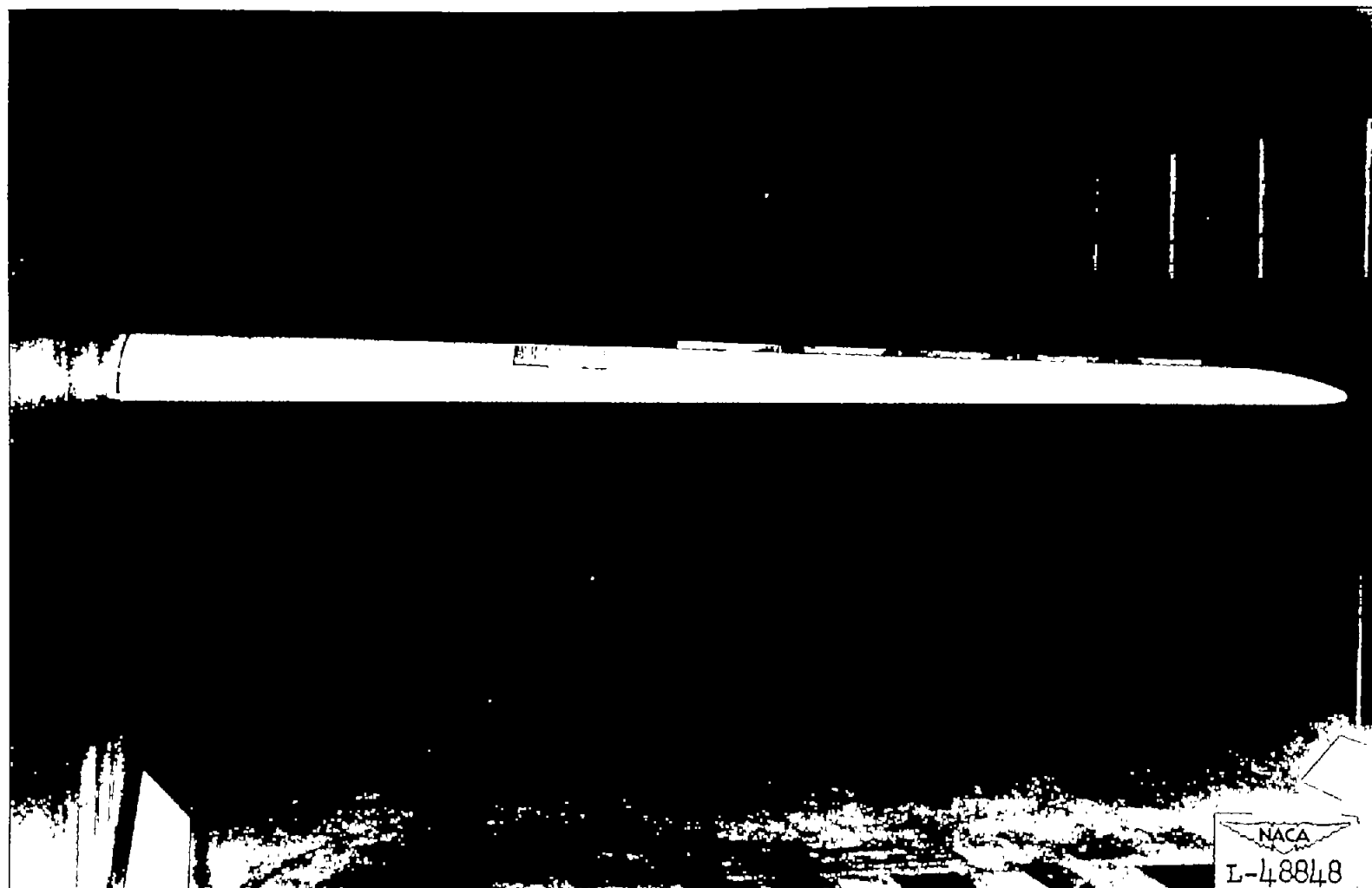
Figure 1.— Front view of the reflection—plane model in inverted position in the Langley high—speed 7— by 10—foot tunnel. Full—span slotted flap retracted.

$\frac{b}{2} = 8.000'$

$90°$

0.25c line

Mounting axis

$.9486\frac{b}{2}$

$.0955\frac{b}{2}$

$.0026\frac{b}{2}$

1.244'

2.418'

1.382'

2.032'

$.4566\frac{b}{2}$

$.9200\frac{b}{2}$

$.0067\frac{b}{2}$

$.9200\frac{b}{2}$

$.0026\frac{b}{2}$

3.556'

0.68c line

Flap nose

Ailerons

Lower-surface lip

Upper-surface lip

$0.95\frac{b}{2}$

To L.E. — .85c

.01c

.01c

To L.E. — .765c

Flap
nose

45°

Flap section

.25c

NACA
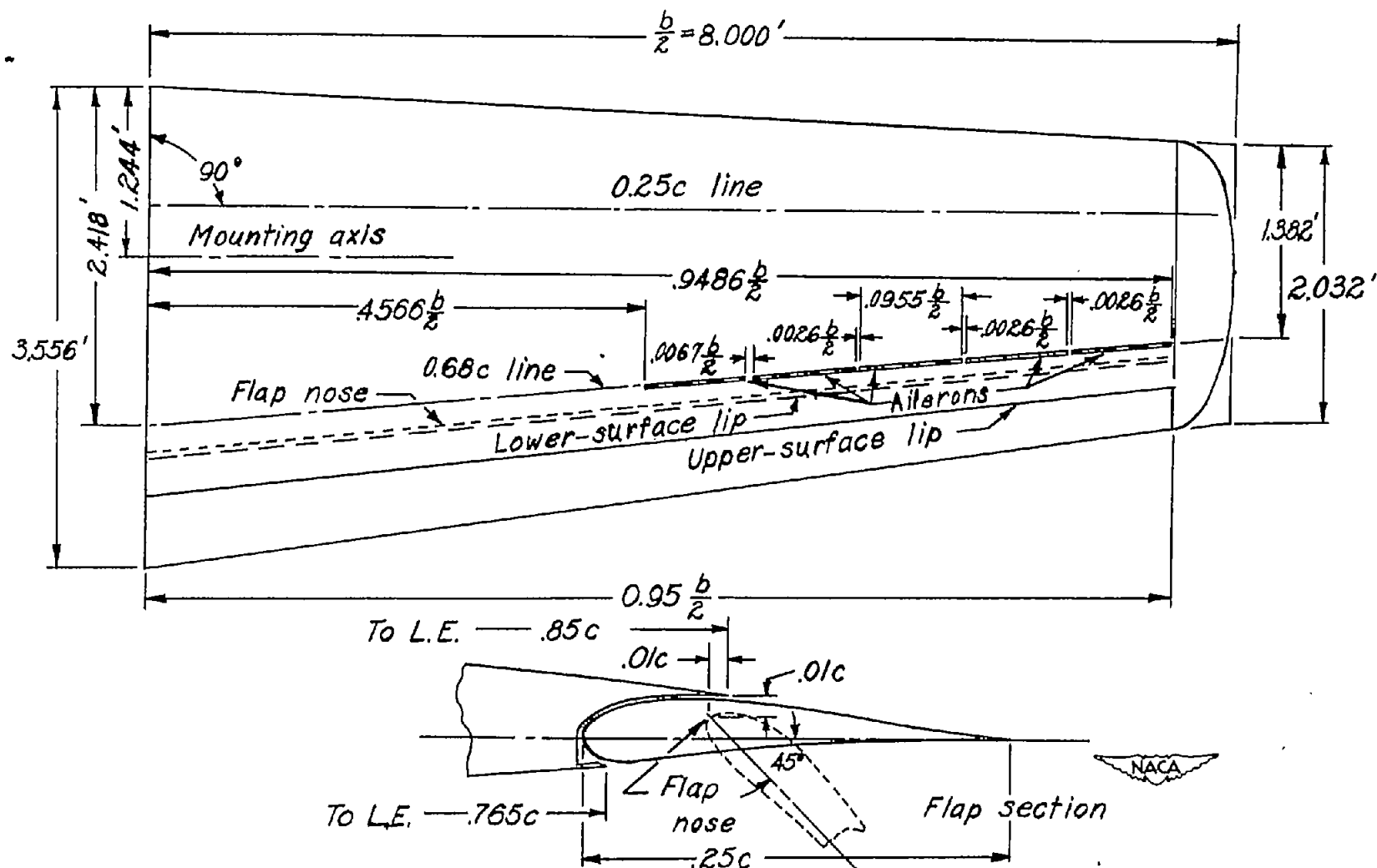
Figure 2.— Schematic drawing of right—semispan—wing model equipped with circular plug ailerons and a full—span slotted flap.

(a) Thin-plate circular-plug-aileron configuration.

(b) Double-walled circular-plug-aileron configuration.

(c) Double-walled circular-plug-aileron configuration
with 0.015c top plate removed from aileron.

Figure 3.— Schematic drawing of circular—plug—aileron configurations
tested on semispan wing.

Reynolds number, R (vertical axis, values: 14×10^6, 12, 10, 8, 6, 4, 2)

Mach number, M (horizontal axis, values: .1, .2, .3, .4, .5, .6, .7, .8, .9)

NACA
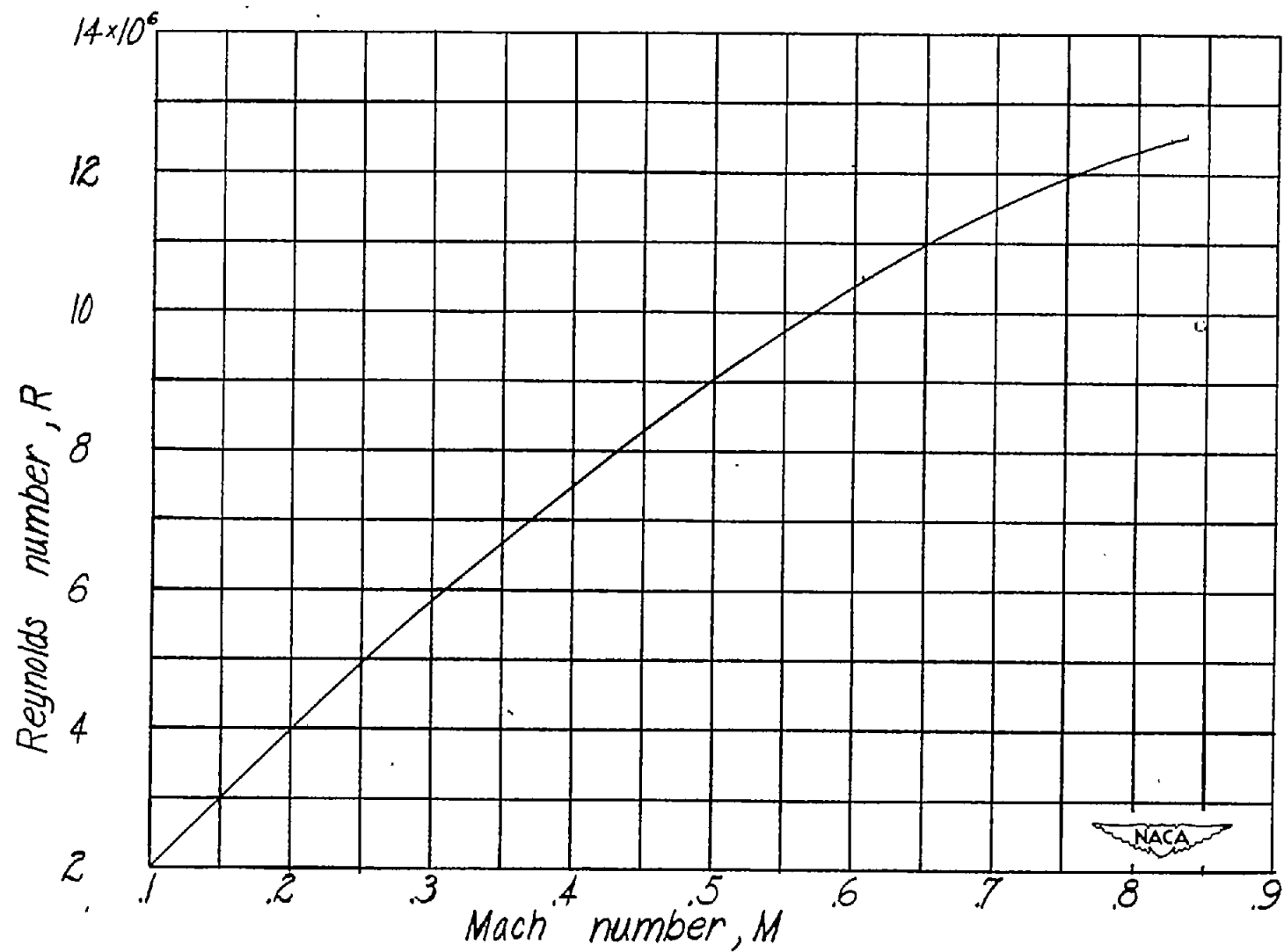
Figure 4.— Variation of Reynolds number with Mach number. Reynolds number is based on wing mean aerodynamic chord of 2.86 feet.
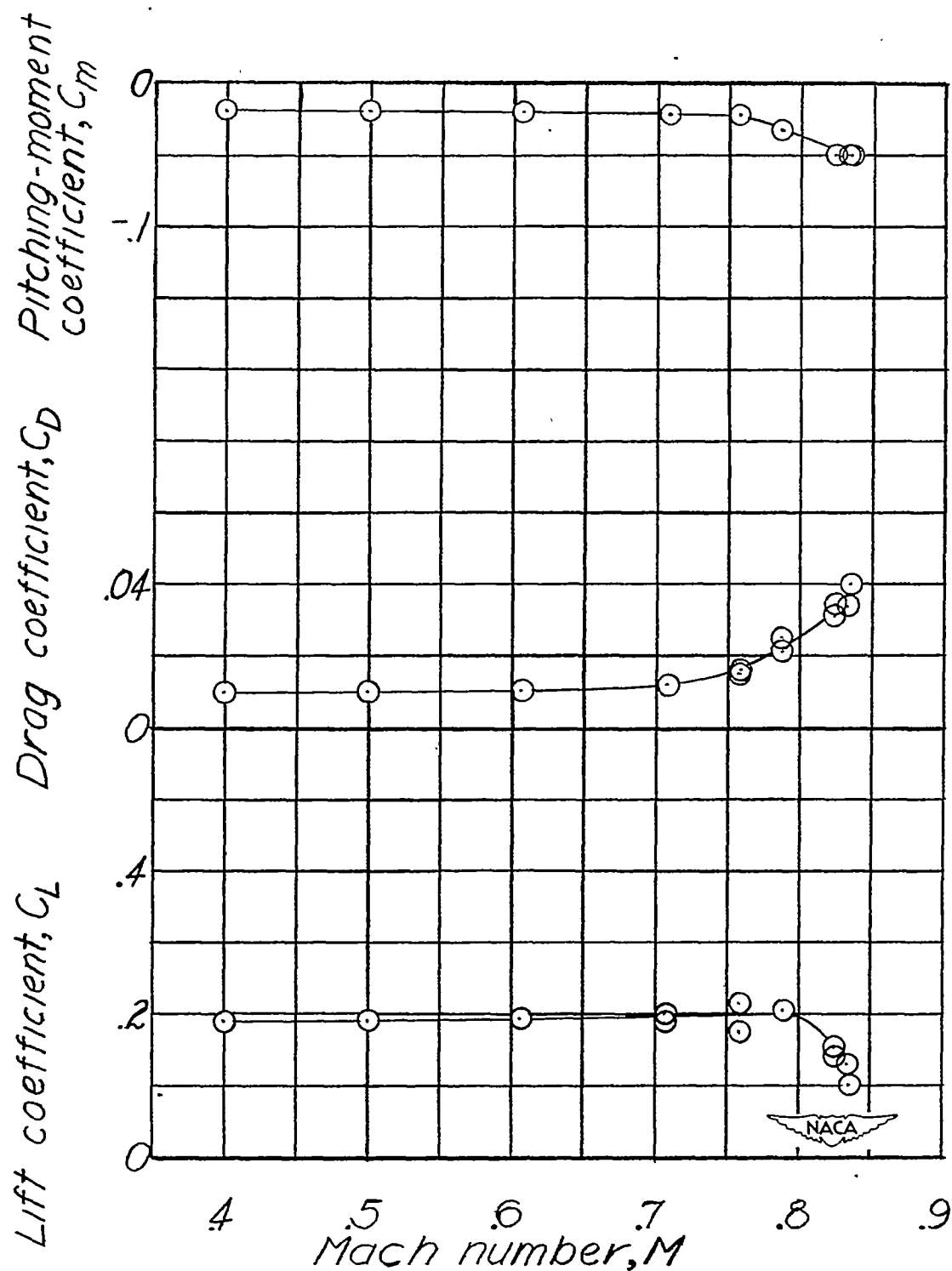
Figure 5.— Variation with Mach number of aerodynamic characteristics of semispan—wing model with flap retracted. Thin—plate circular plug aileron neutral. $\alpha = 0.3^\circ$.
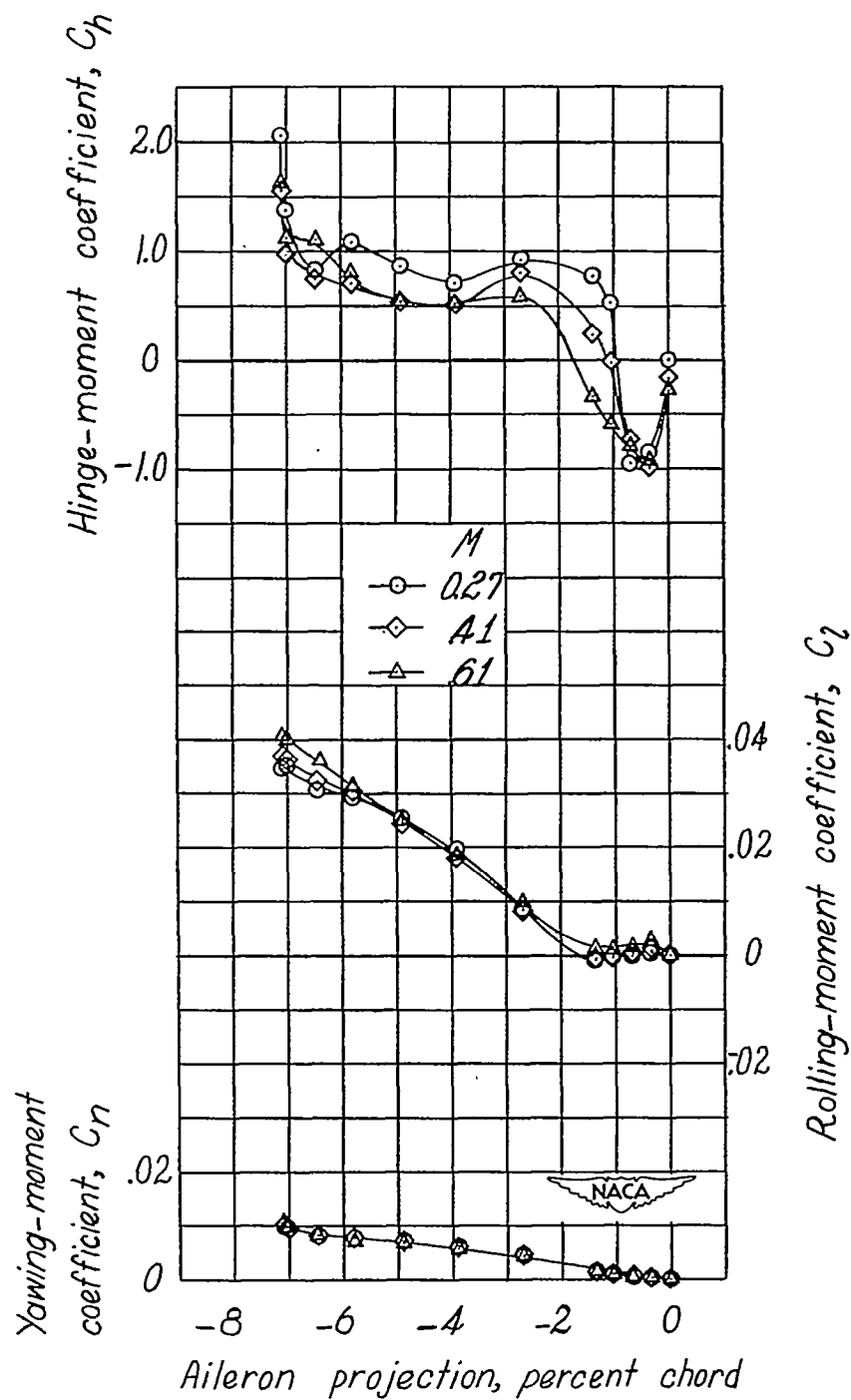
(a) $\alpha \approx 0.2°$; $C_L \approx 0.14$.

Figure 6.— Variation of lateral—control characteristics of complete wing
with projection of thin—plate circular plug aileron at various Mach
numbers. Flap retracted.
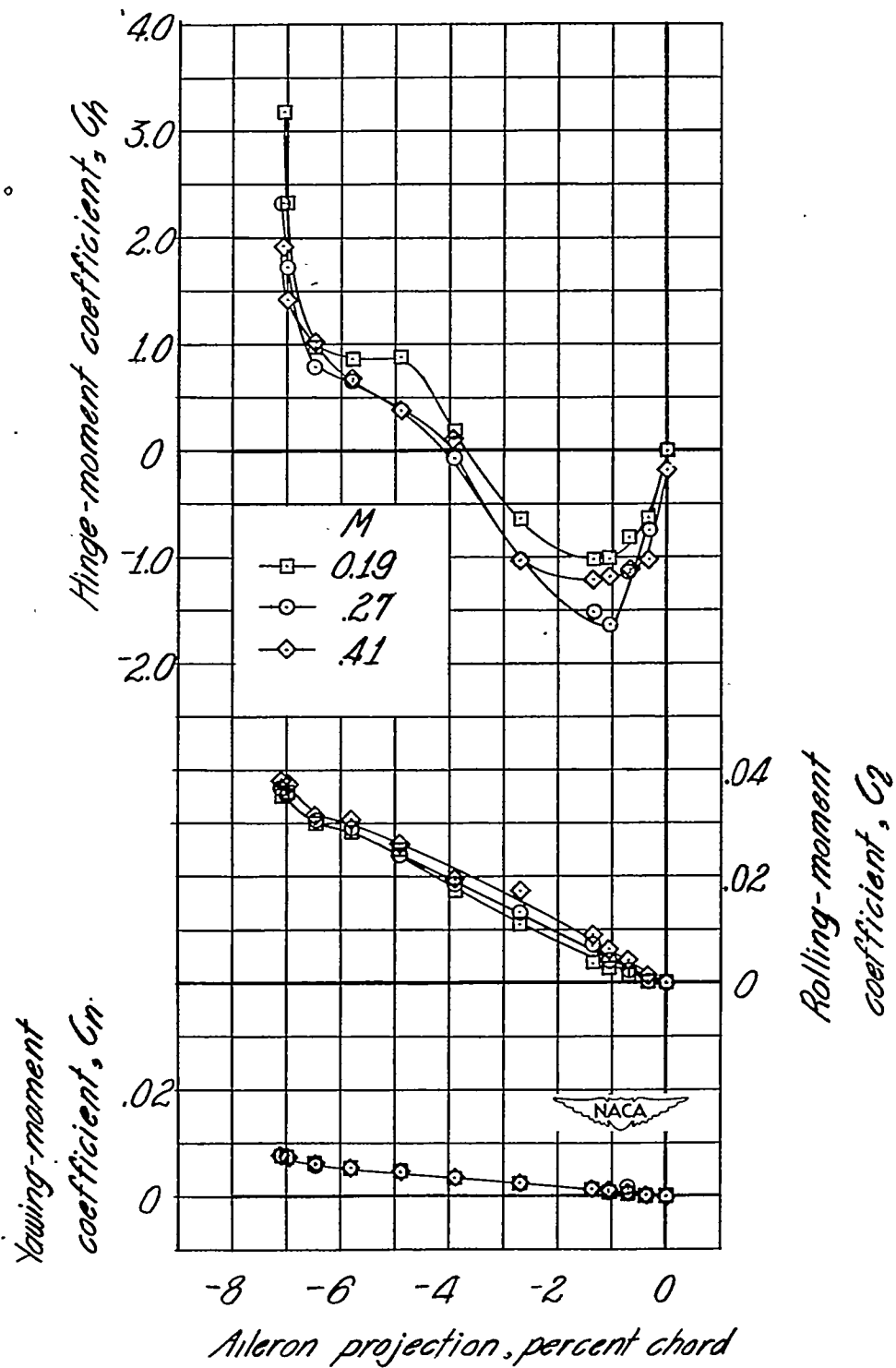
(b) $\alpha \approx 4.8°$; $C_L \approx 0.47$.

Figure 6.— Continued.
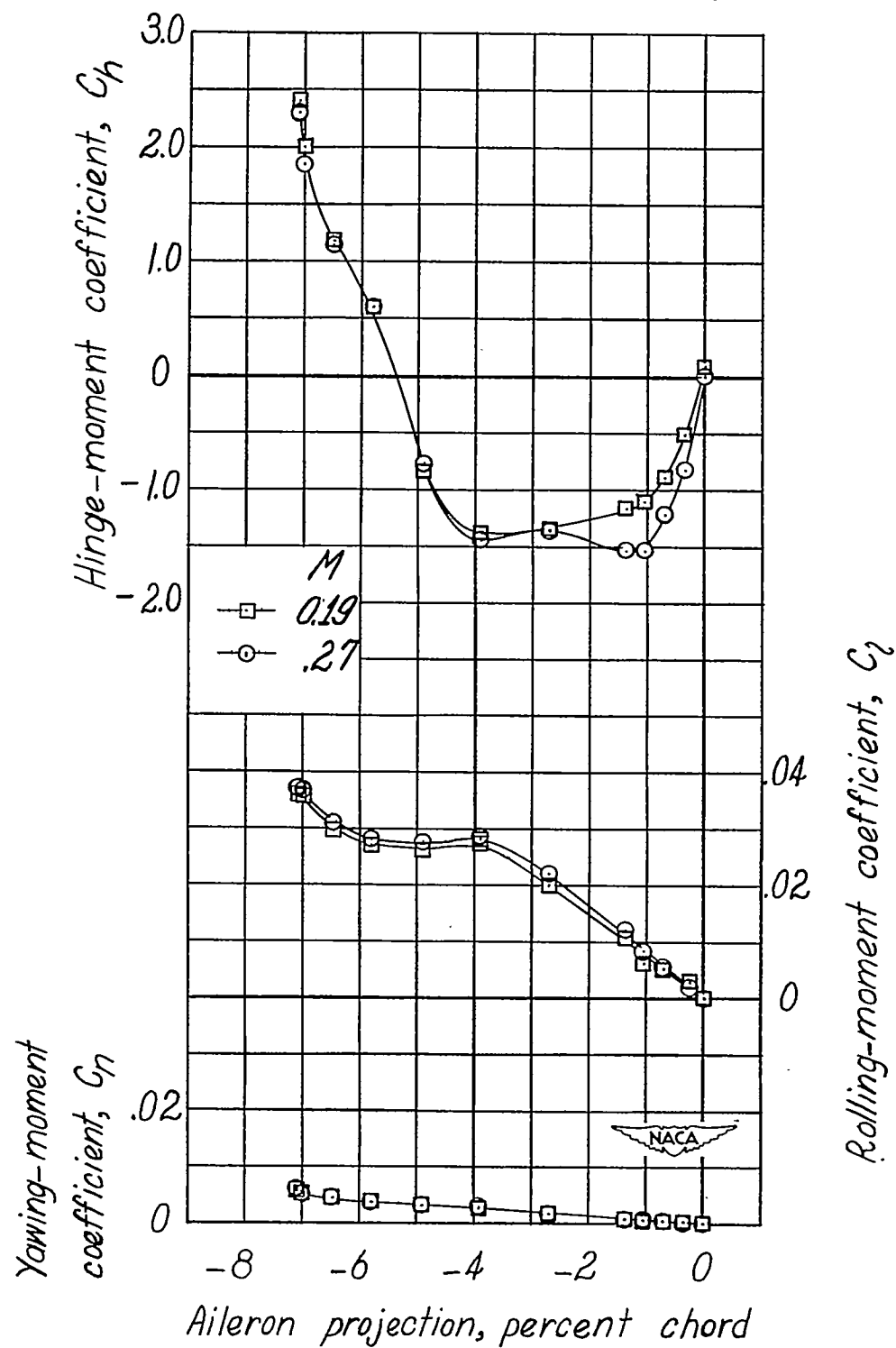
(c) $\alpha \approx 8.2°$; $c_L \approx 0.72$.

Figure 6.— Continued.
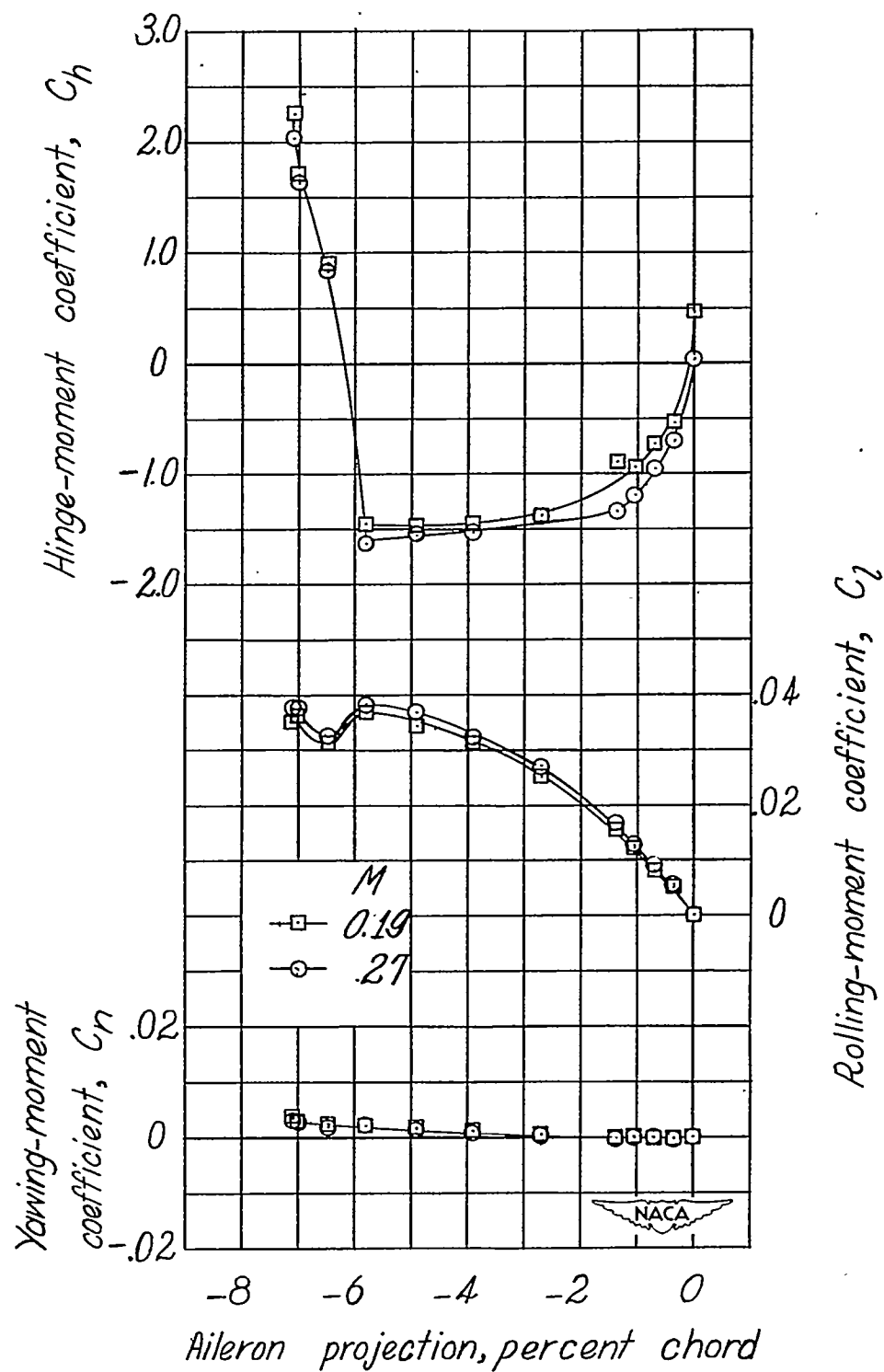
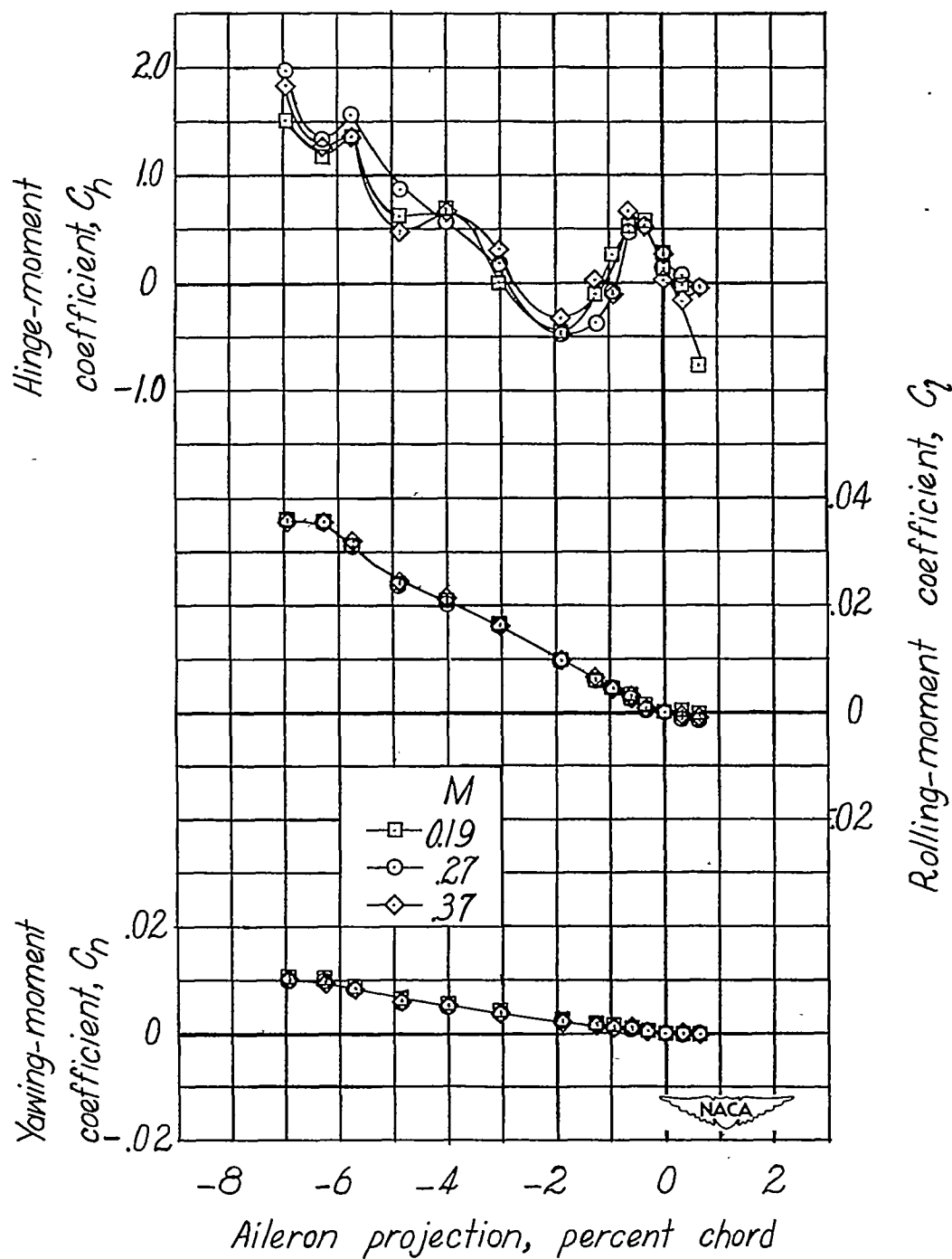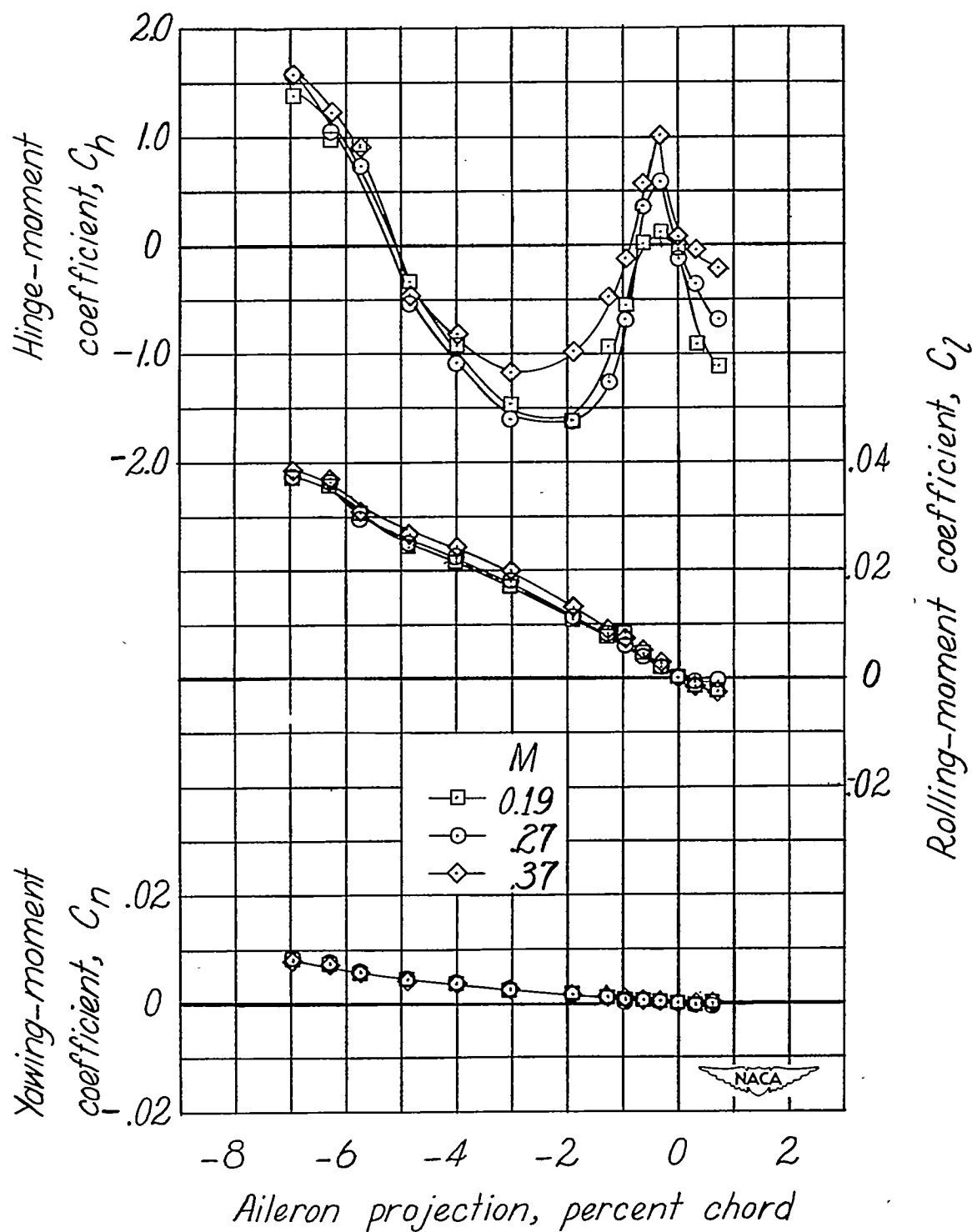(d) $\alpha \approx 11.7°$; $C_L \approx 1.01$.

Figure 6.— Concluded.
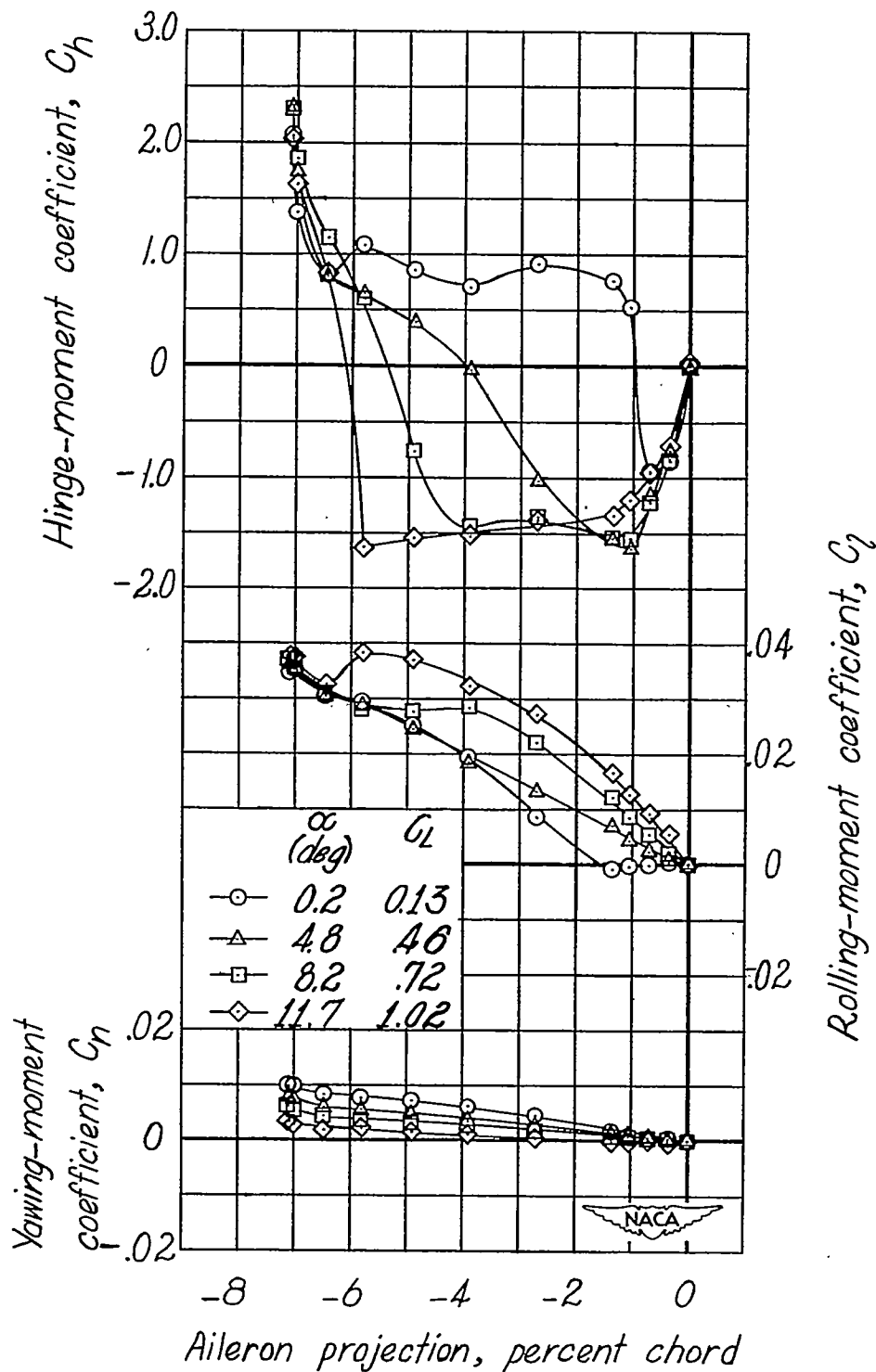
Figure 7.— Variation of lateral—control characteristics of complete wing with projection of thin—plate circular plug aileron at various angles of attack. Flap retracted. M = 0.27.
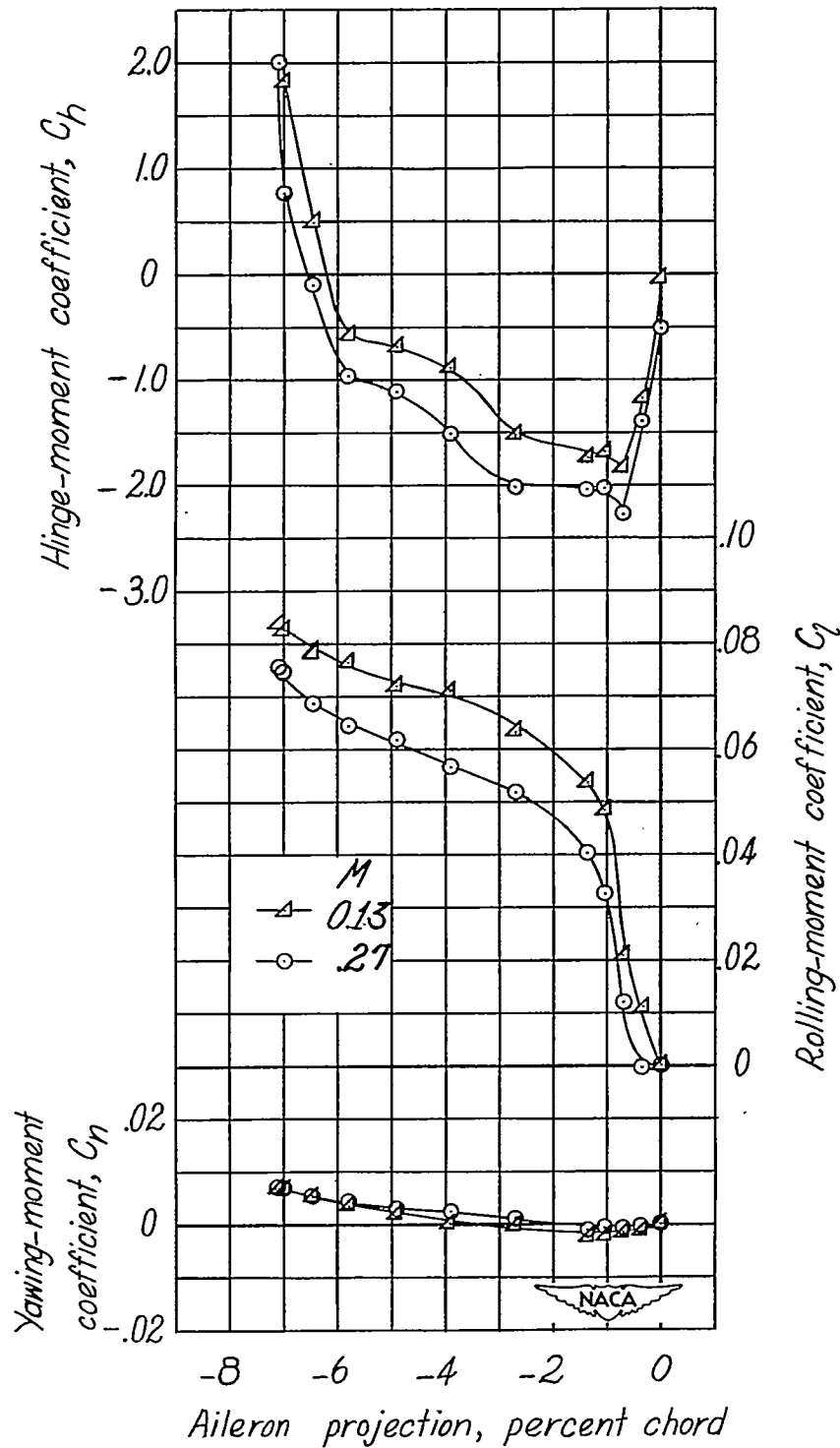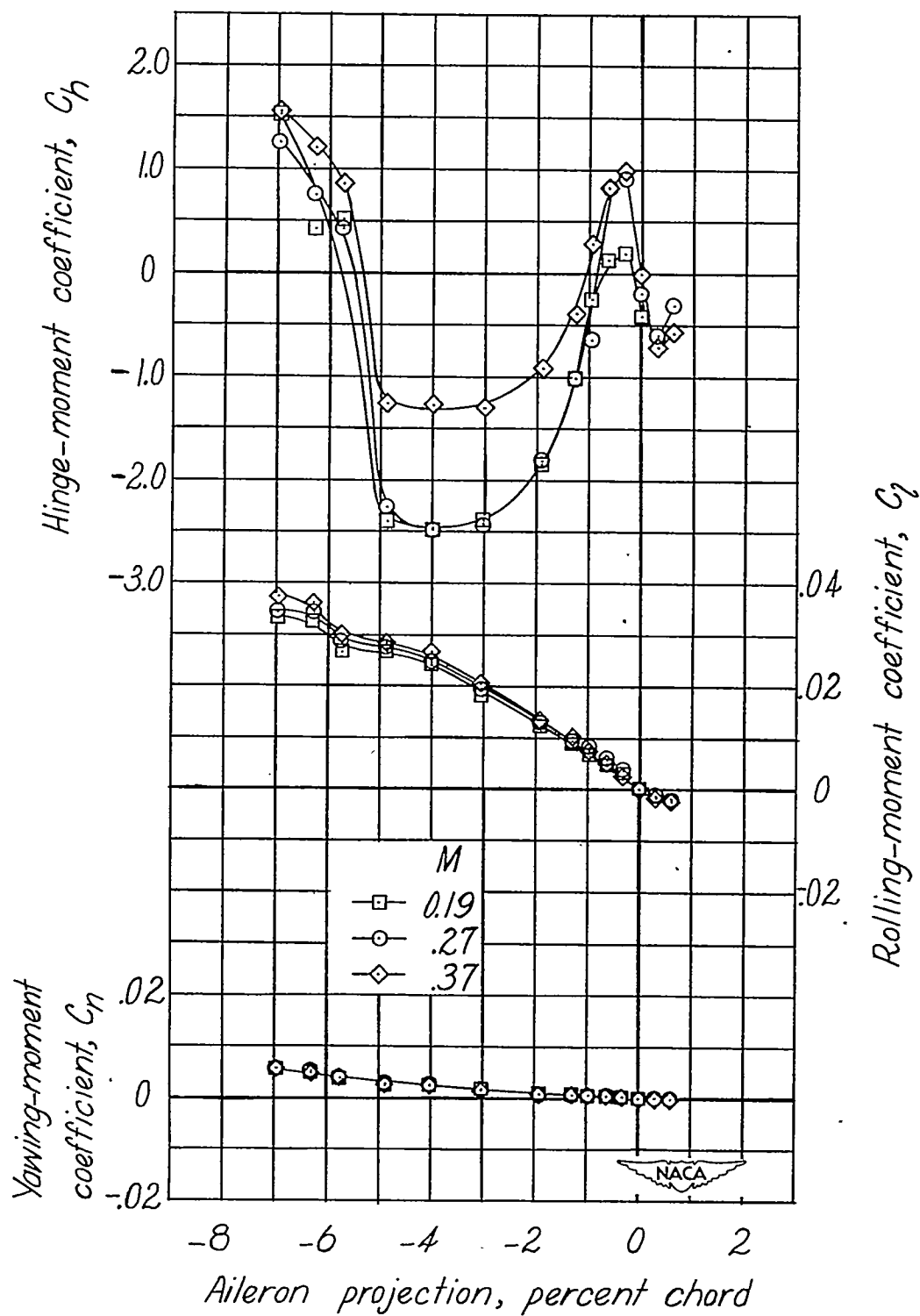
(a) $\alpha \approx -1.6^\circ$; $C_L \approx 1.38$.

Figure 8.— Variation of lateral-control characteristics of complete wing
with projection of thin-plate circular plug aileron at various Mach
numbers. Flap deflected 45°.
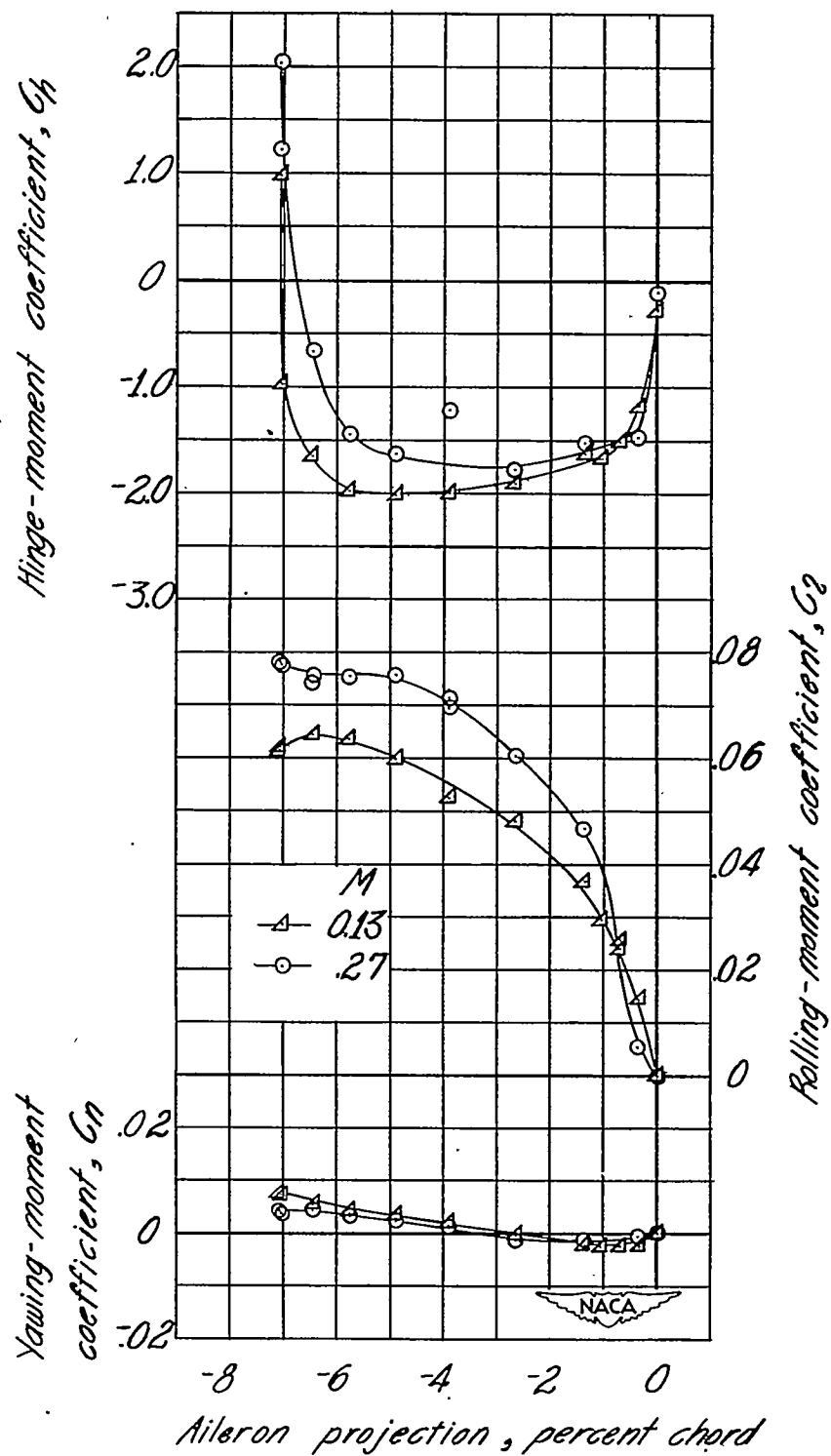
(b) $\alpha \approx 2.7°$; $c_L \approx 1.56$.

Figure 8.— Continued.
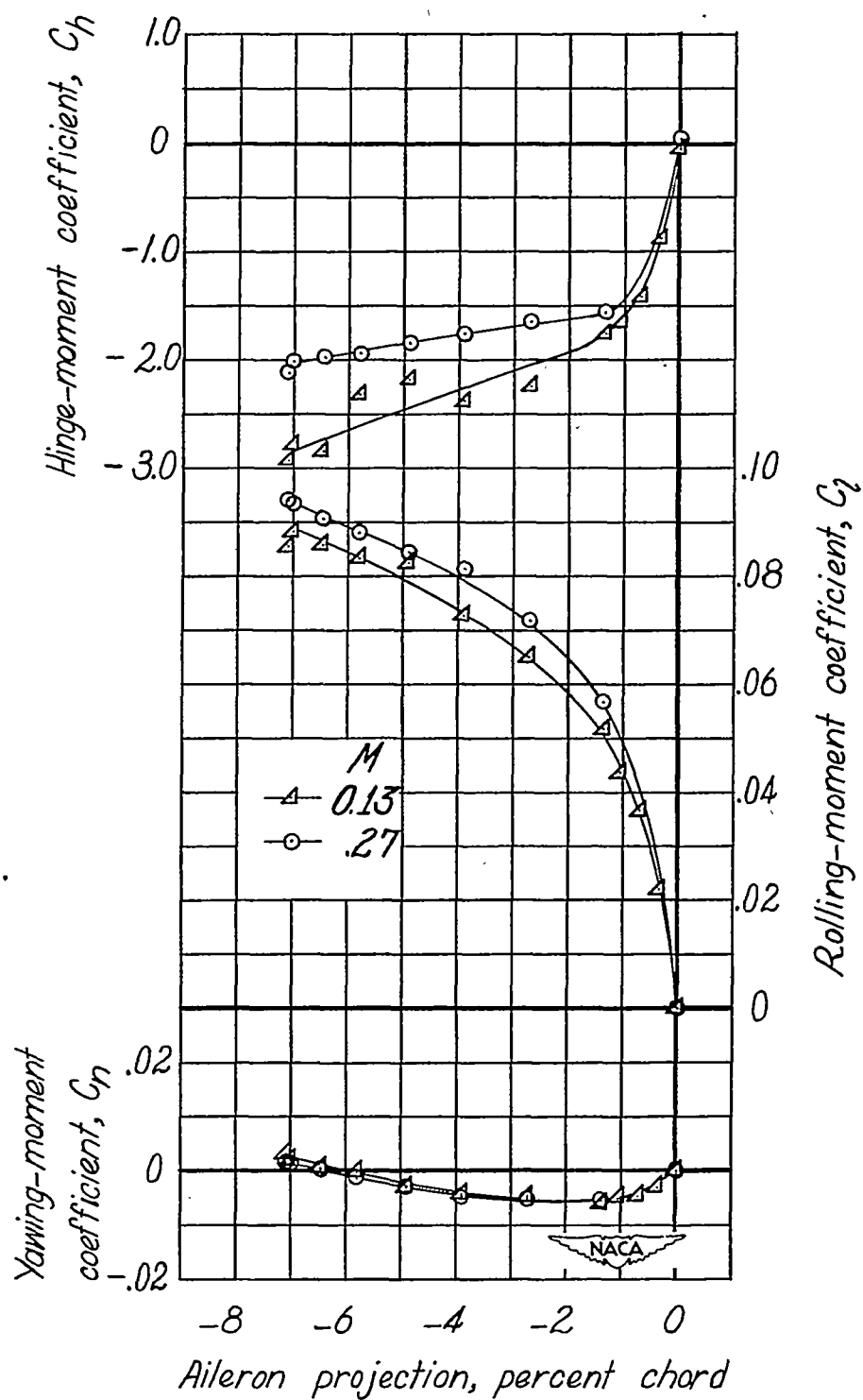
(c) $\alpha \approx 7.2°$; $C_L \approx 1.87$.

Figure 8.— Concluded.
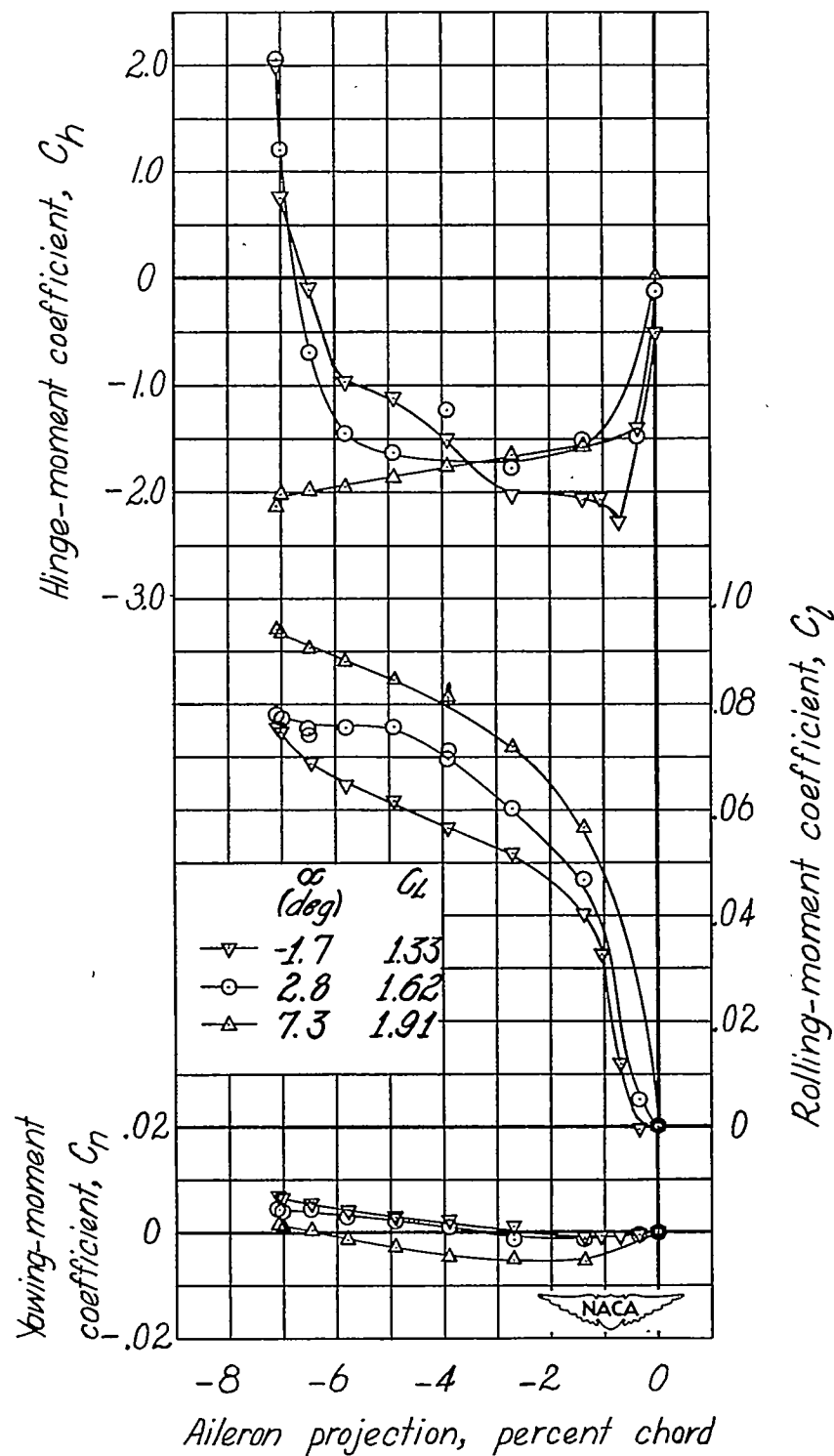
Figure 9.— Variation of lateral—control characteristics of complete wing
with projection of thin—plate circular plug aileron at various angles
of attack. Flap deflected 45°. M = 0.27.
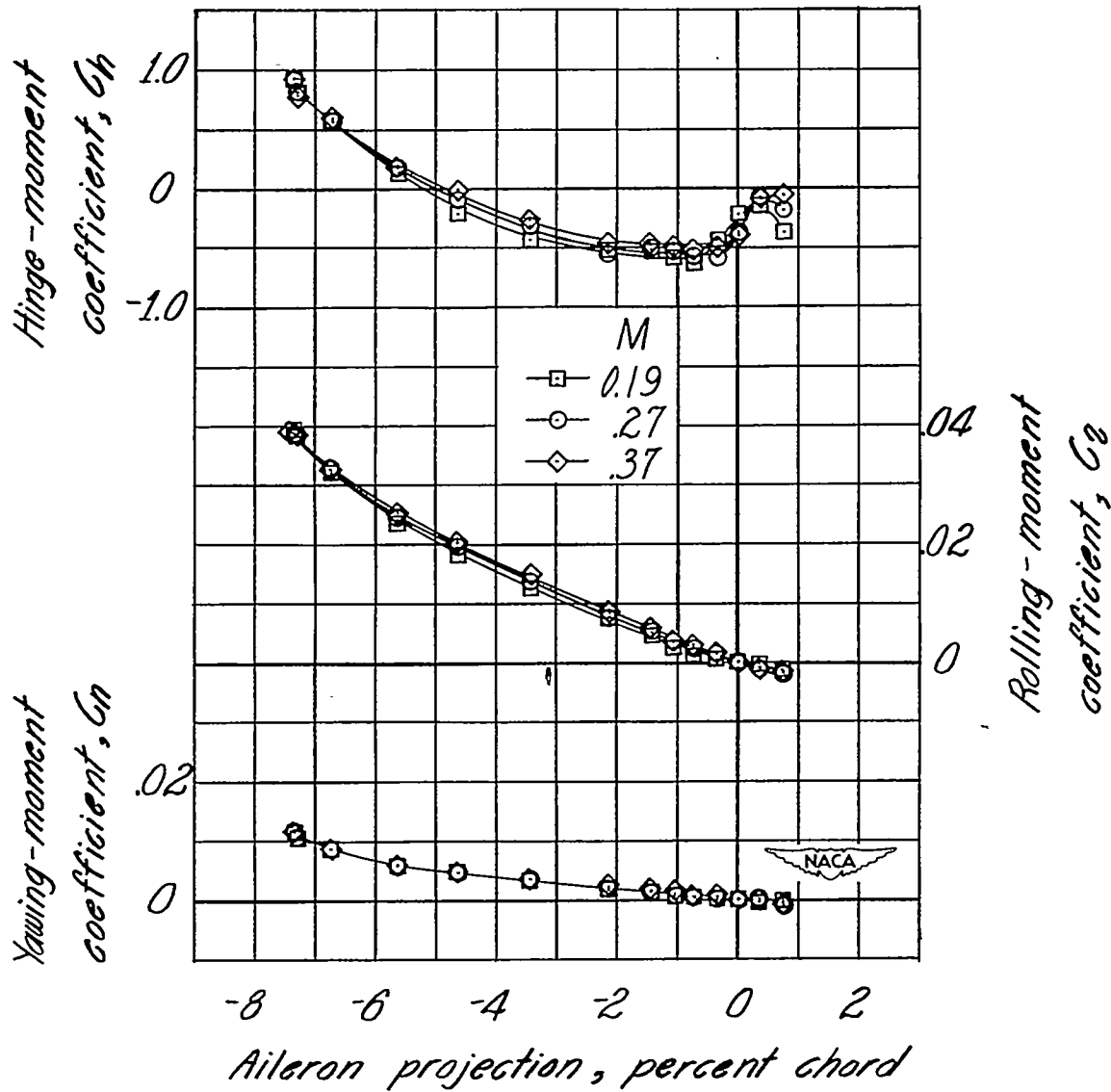
(a) $\alpha \approx 0.2^\circ$; $C_L \approx 0.11$.

Figure 10.— Variation of lateral-control characteristics of complete wing
   with projection of double-walled circular plug aileron at various Mach
   numbers.   Flap retracted.
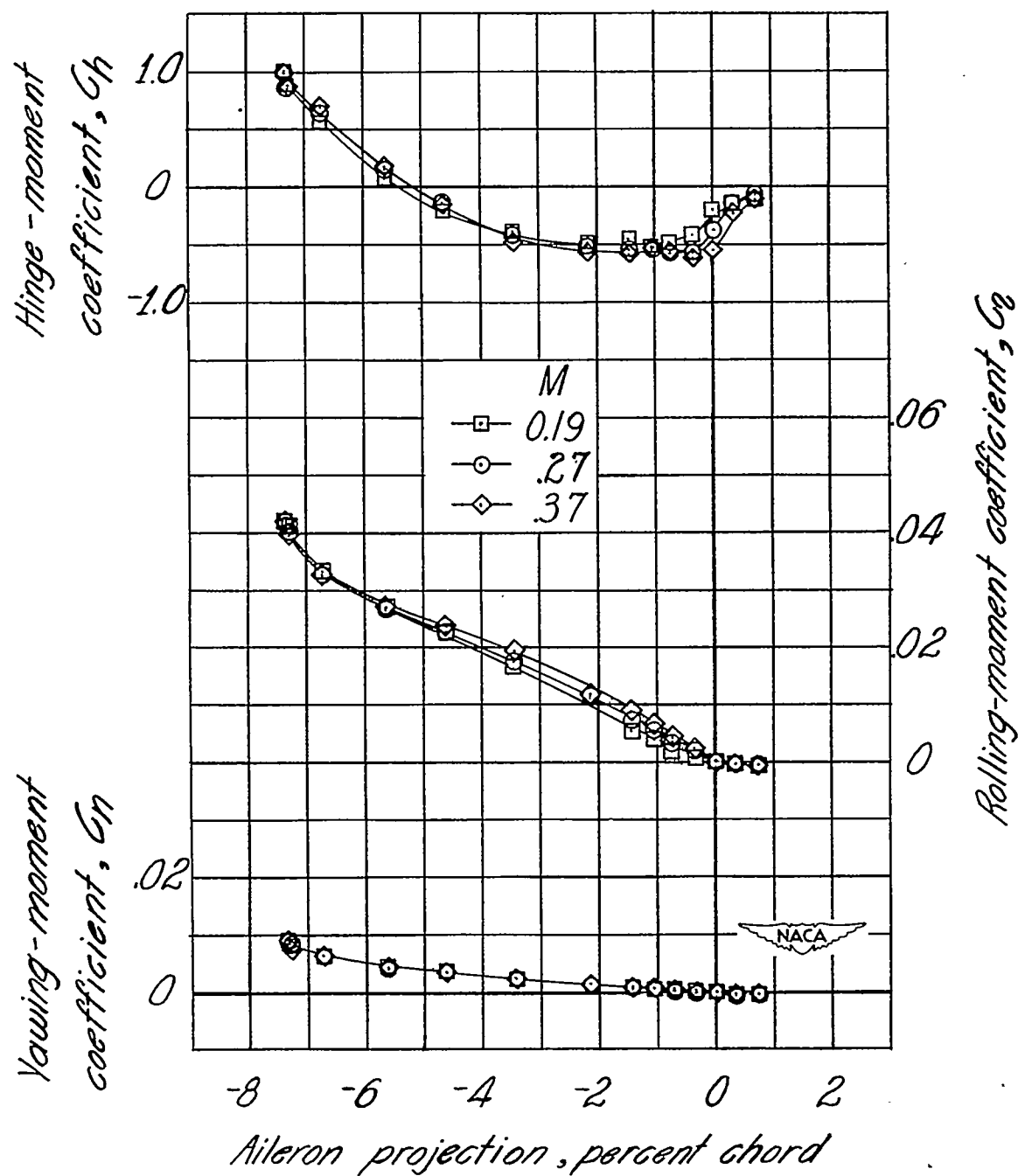
(b) $\alpha \approx 4.7^{\circ}$; $C_L \approx 0.44$.

Figure 10.— Continued.
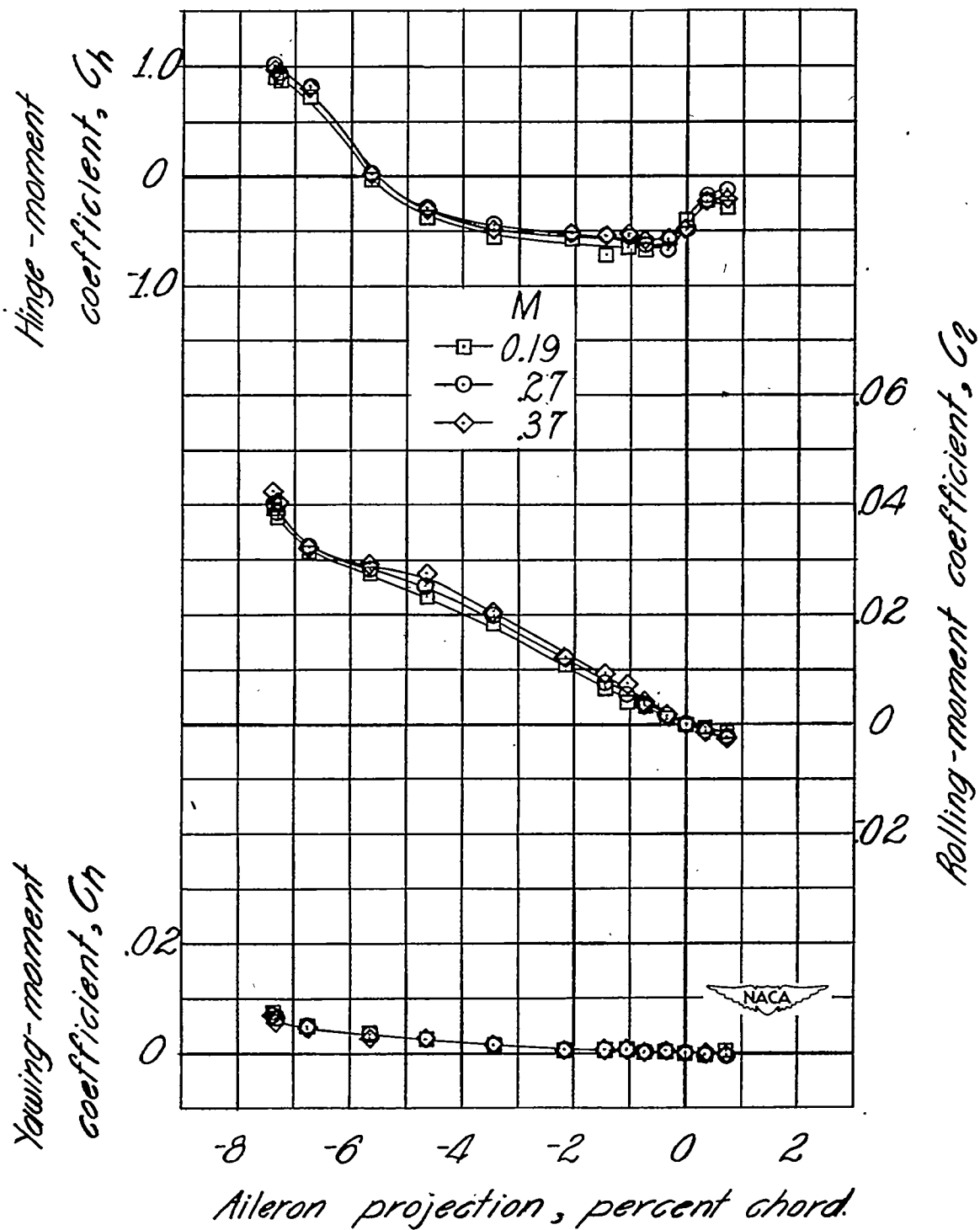
(c) $\alpha \approx 8.1°$; $C_L \approx 0.70$.

Figure 10.— Continued.
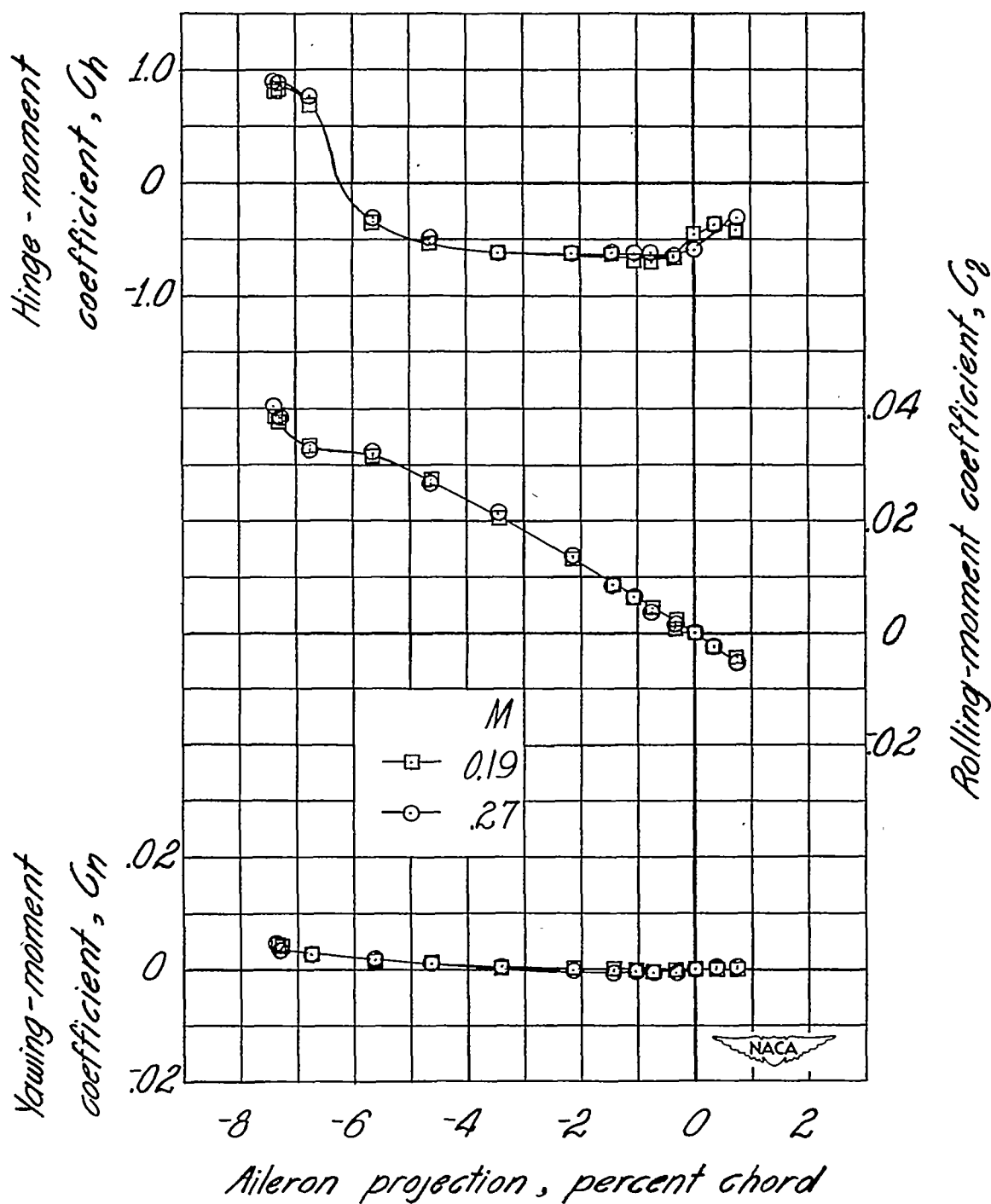
(d) α ≈ 11.5°; C_L ≈ 0.91.

Figure 10.— Continued.
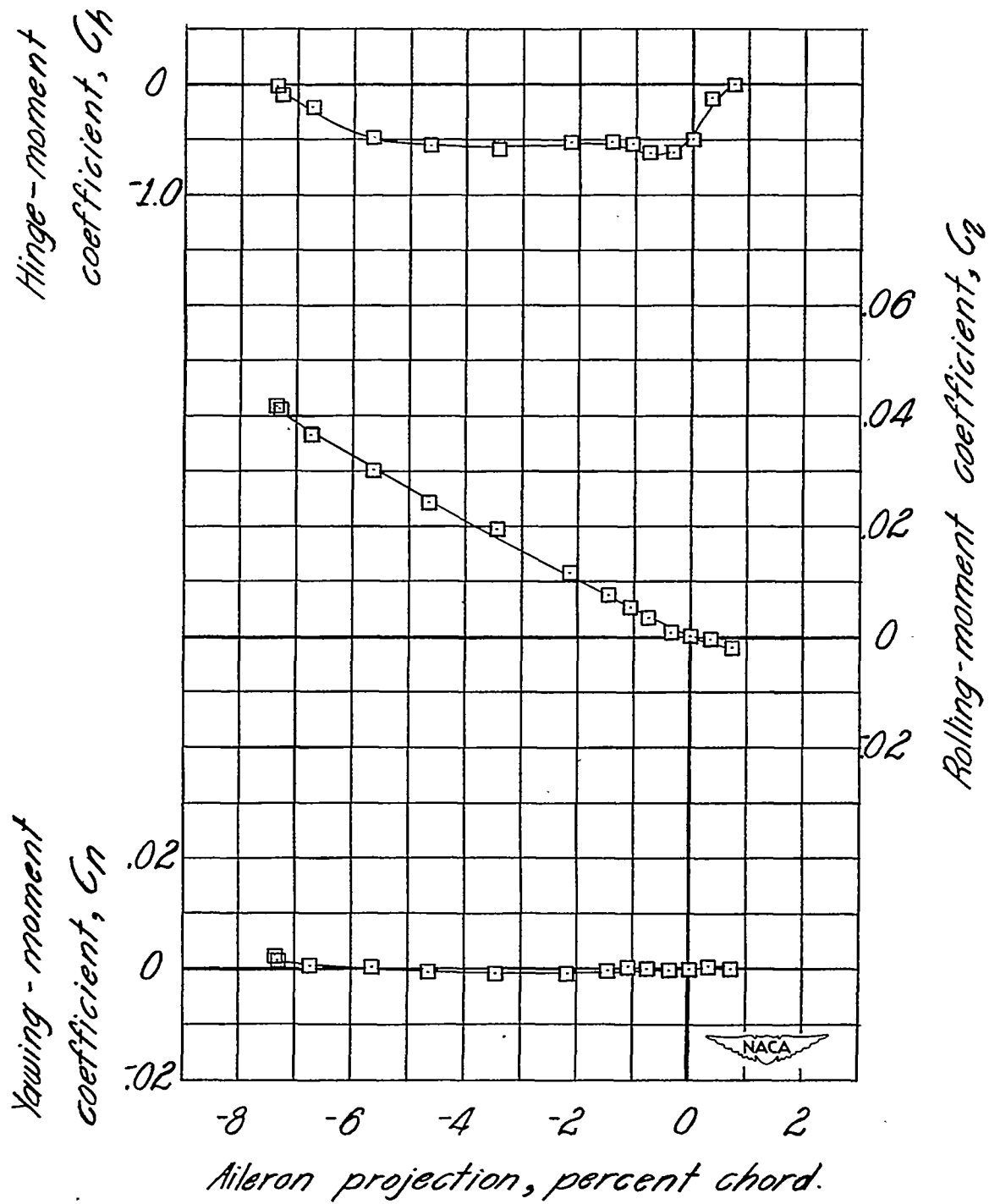
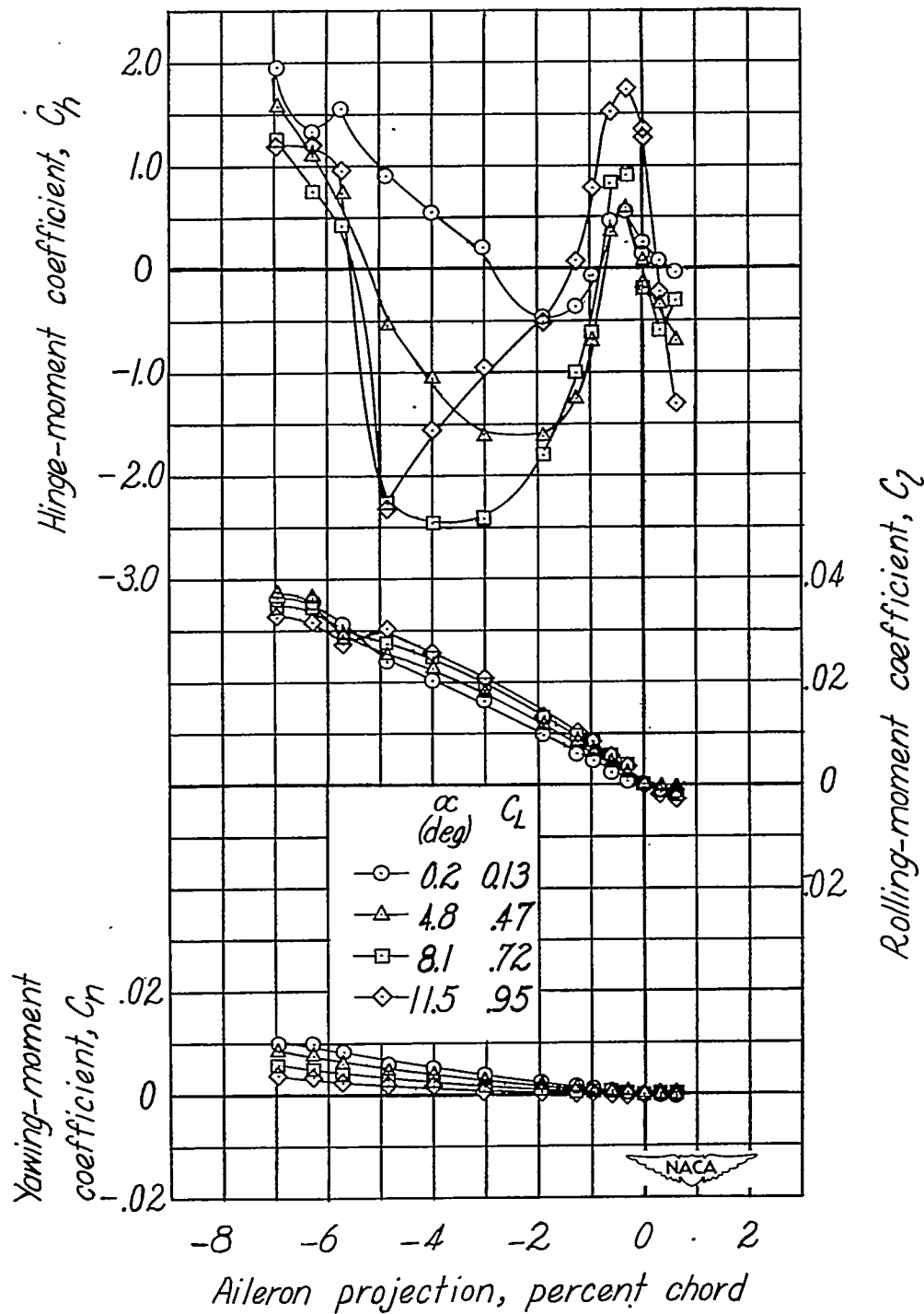(e) $\alpha = 14.8^\circ$; $C_L = 1.13$; M = 0.19.

Figure 10.— Concluded.
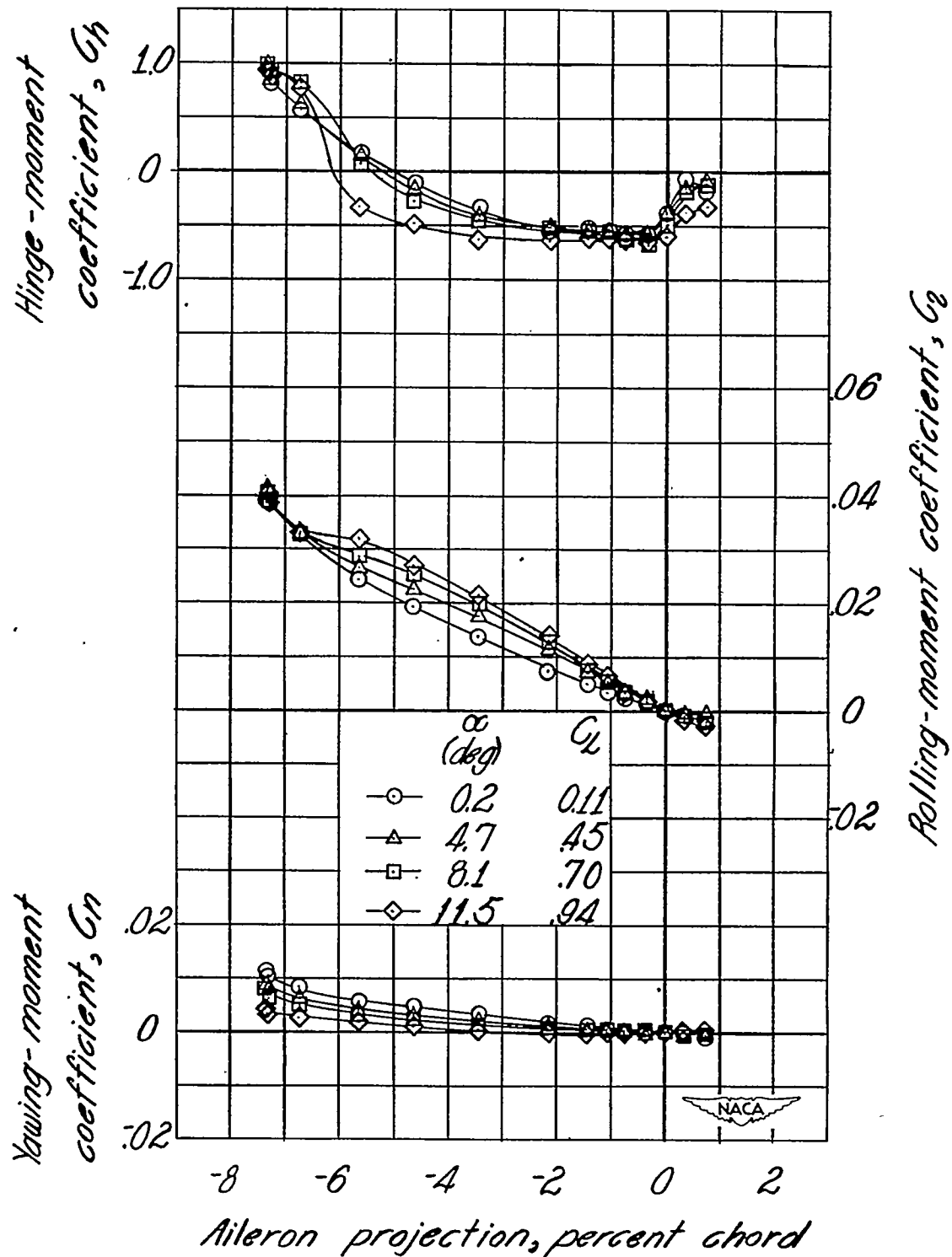
Figure 11.— Variation of lateral-control characteristics of complete wing
with projection of double-walled circular plug aileron at various
angles of attack.   Flap retracted.   M = 0.27.
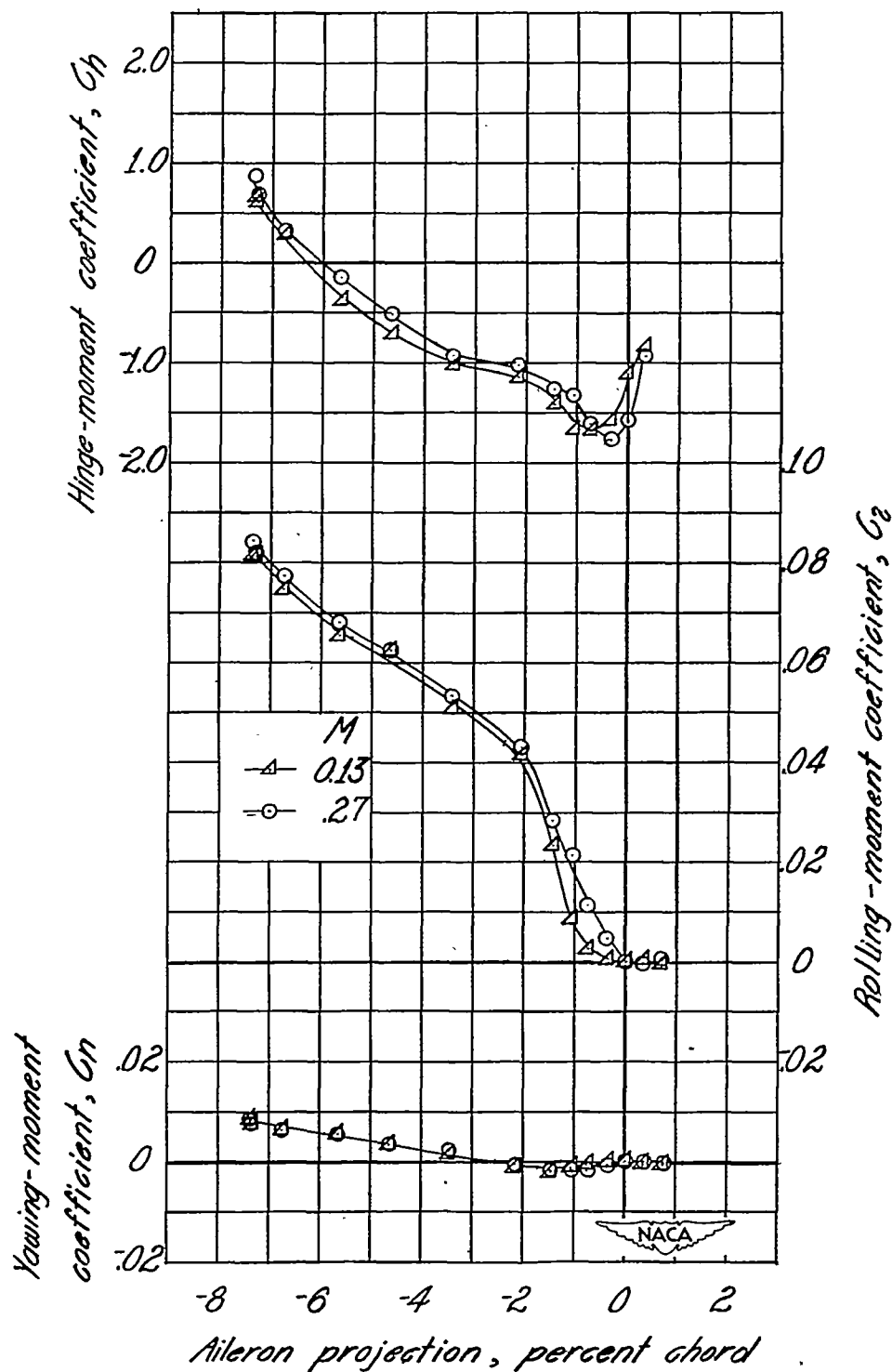
(a) $\alpha \approx -1.9°$; $C_L \approx 1.31$.
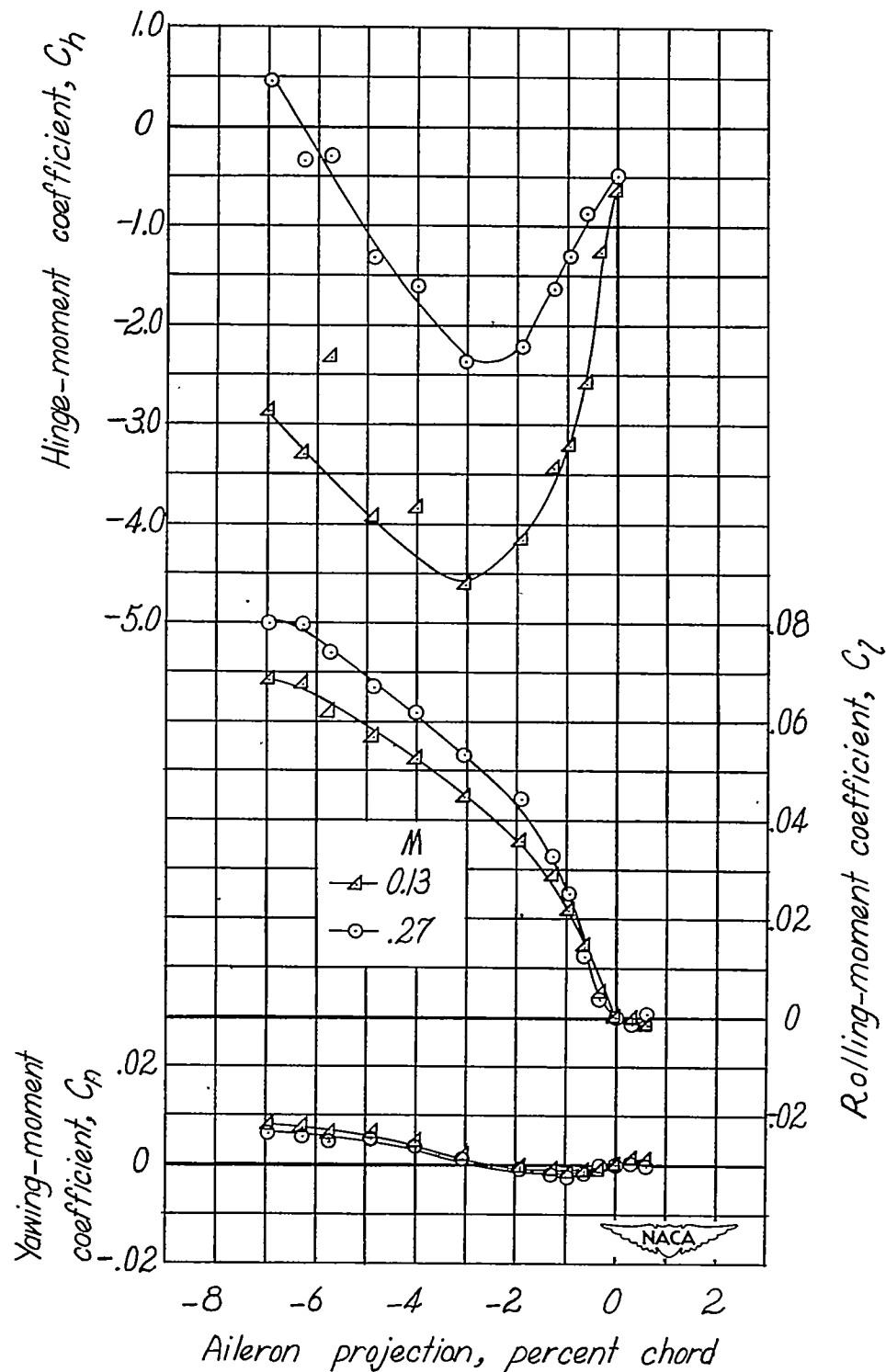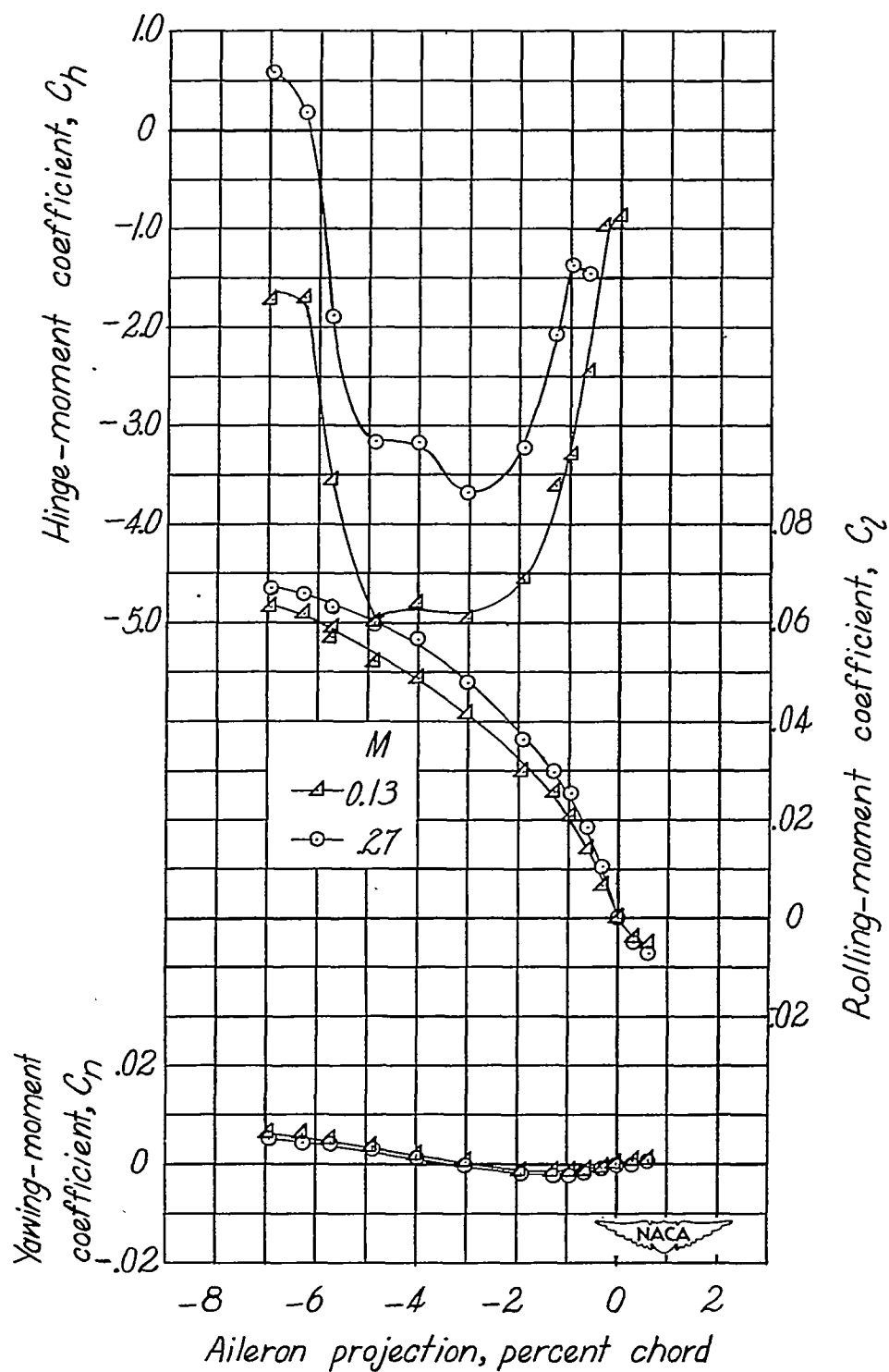
Figure 12.— Variation of lateral—control characteristics of complete wing with projection of double—walled circular plug aileron at various Mach numbers. Flap deflected 45°.
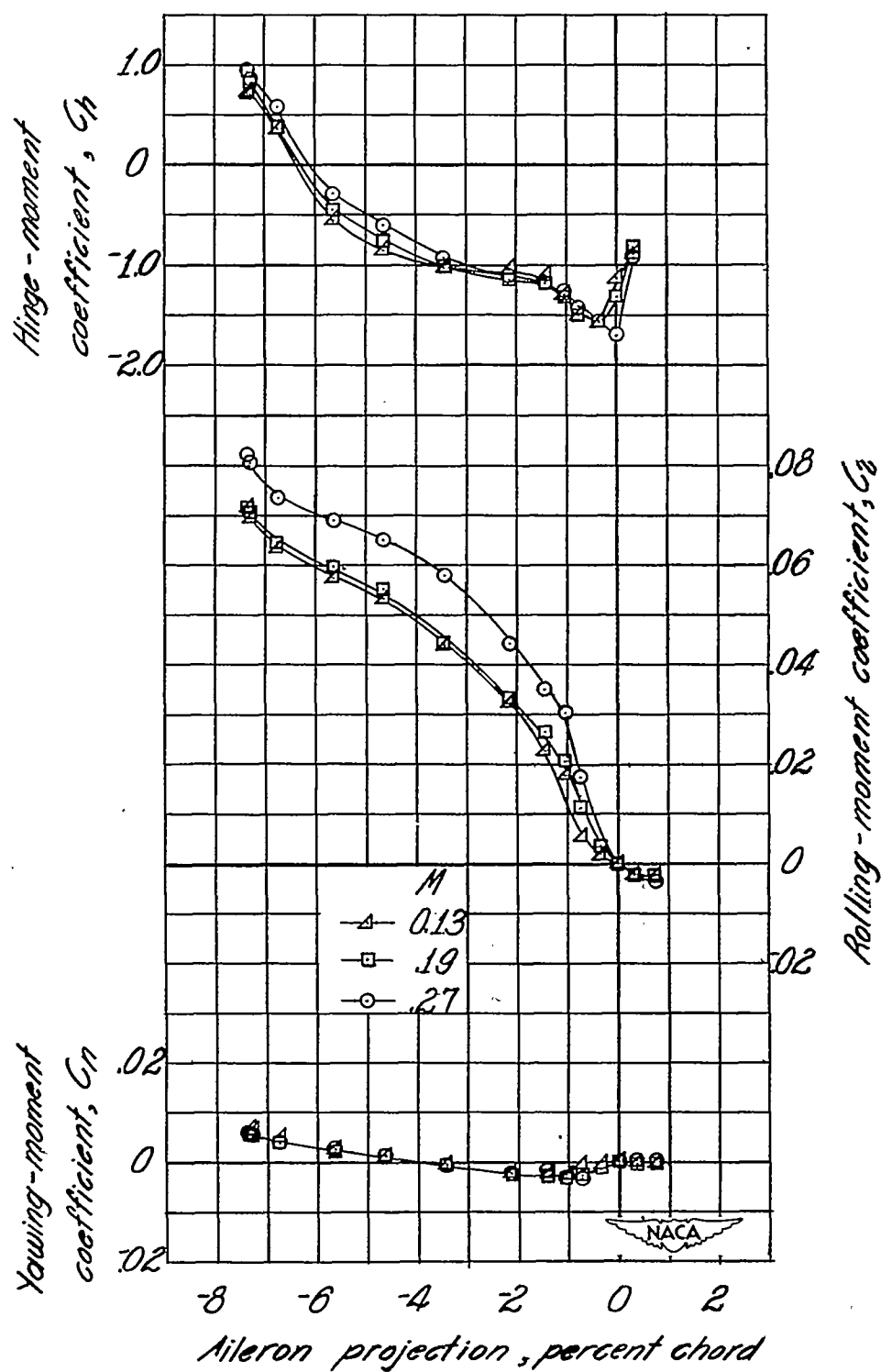
(b) $\alpha \approx 2.4^\circ$; $C_L \approx 1.52$.

Figure 12.— Continued.
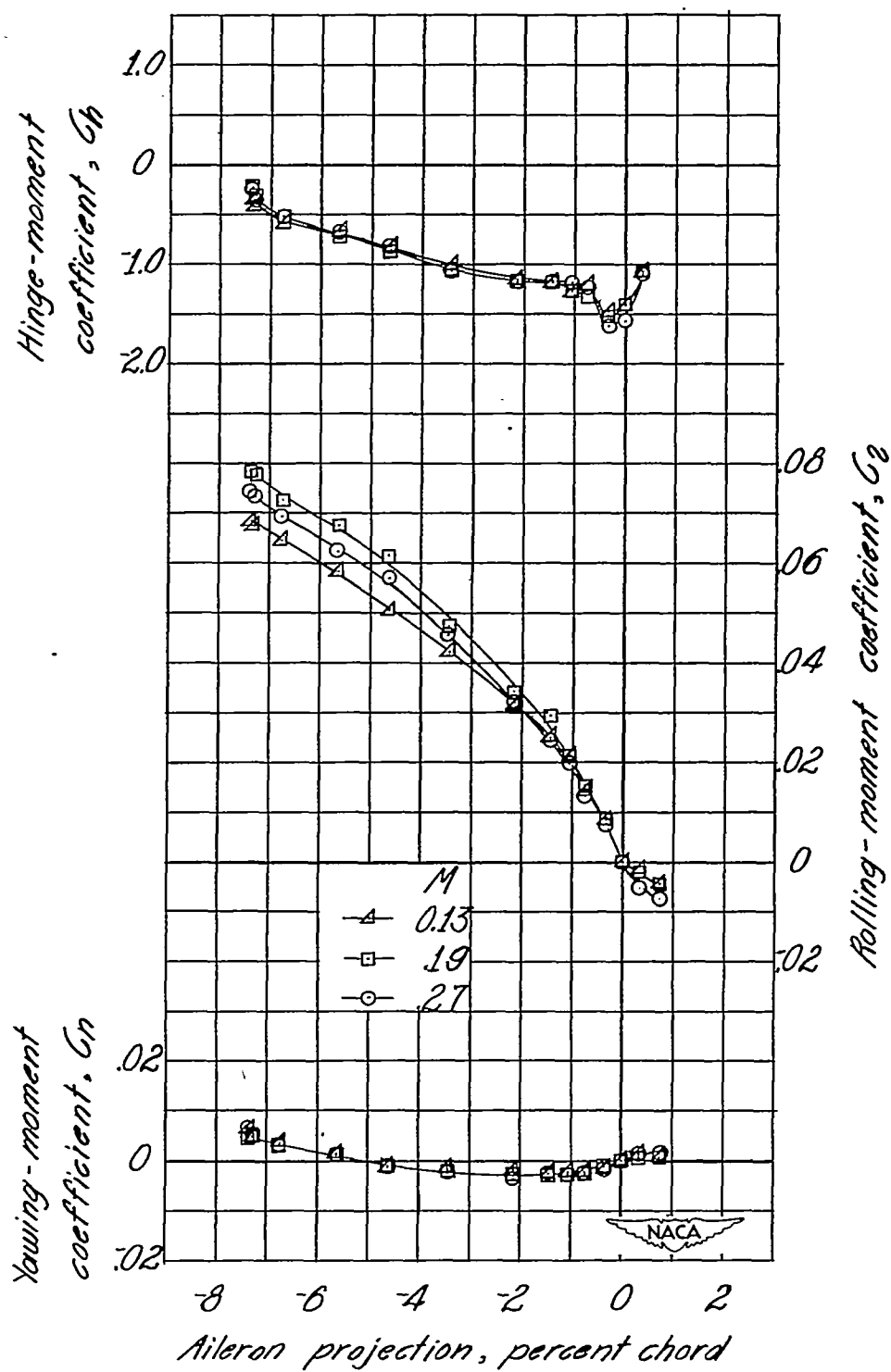
(c) $\alpha \approx 6.8°$; $C_L \approx 1.75$.

Figure 12.— Continued.
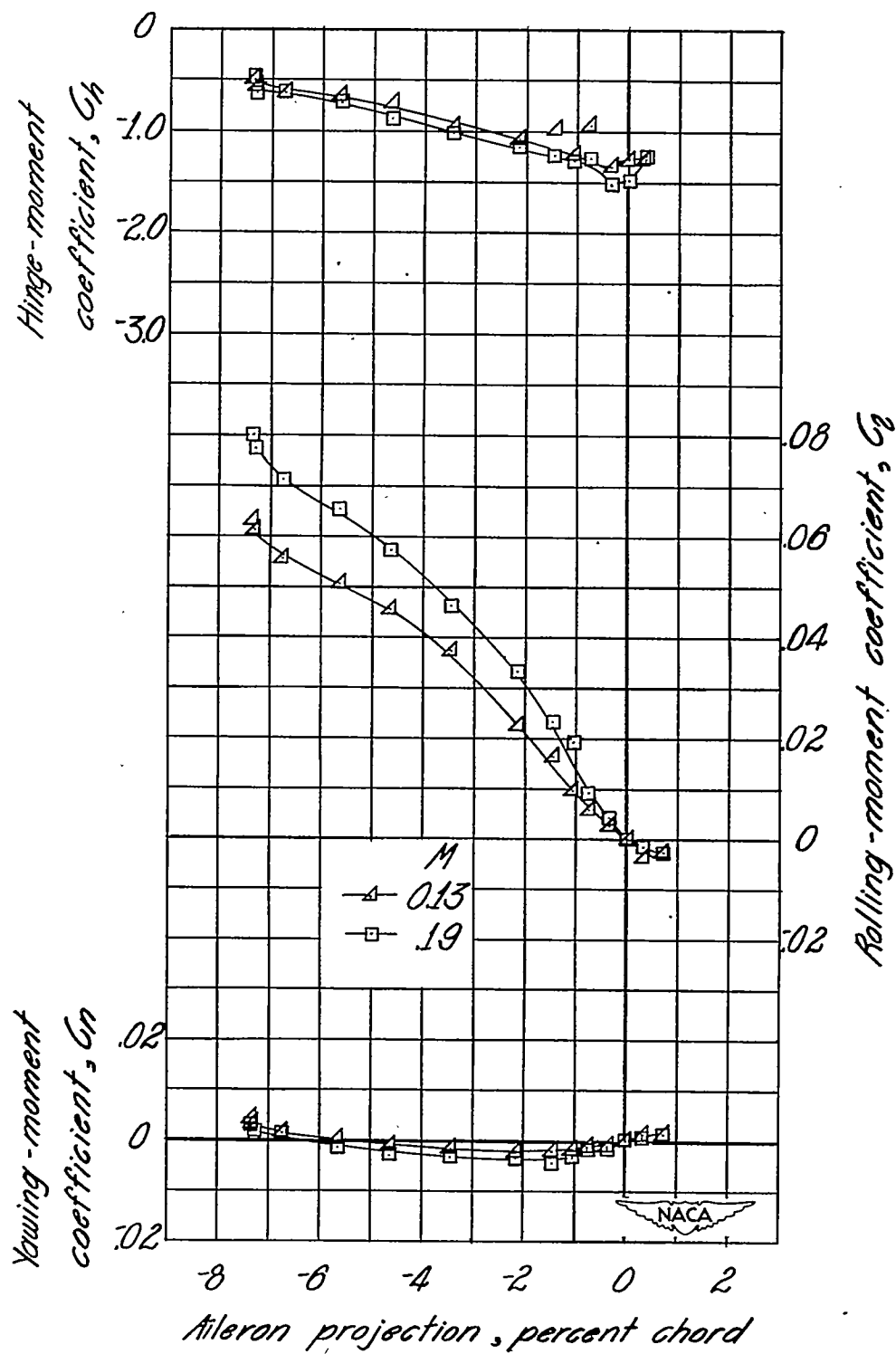
(d) $\alpha \approx 10.0°$; $C_L \approx 1.88$.

Figure 12.— Concluded.
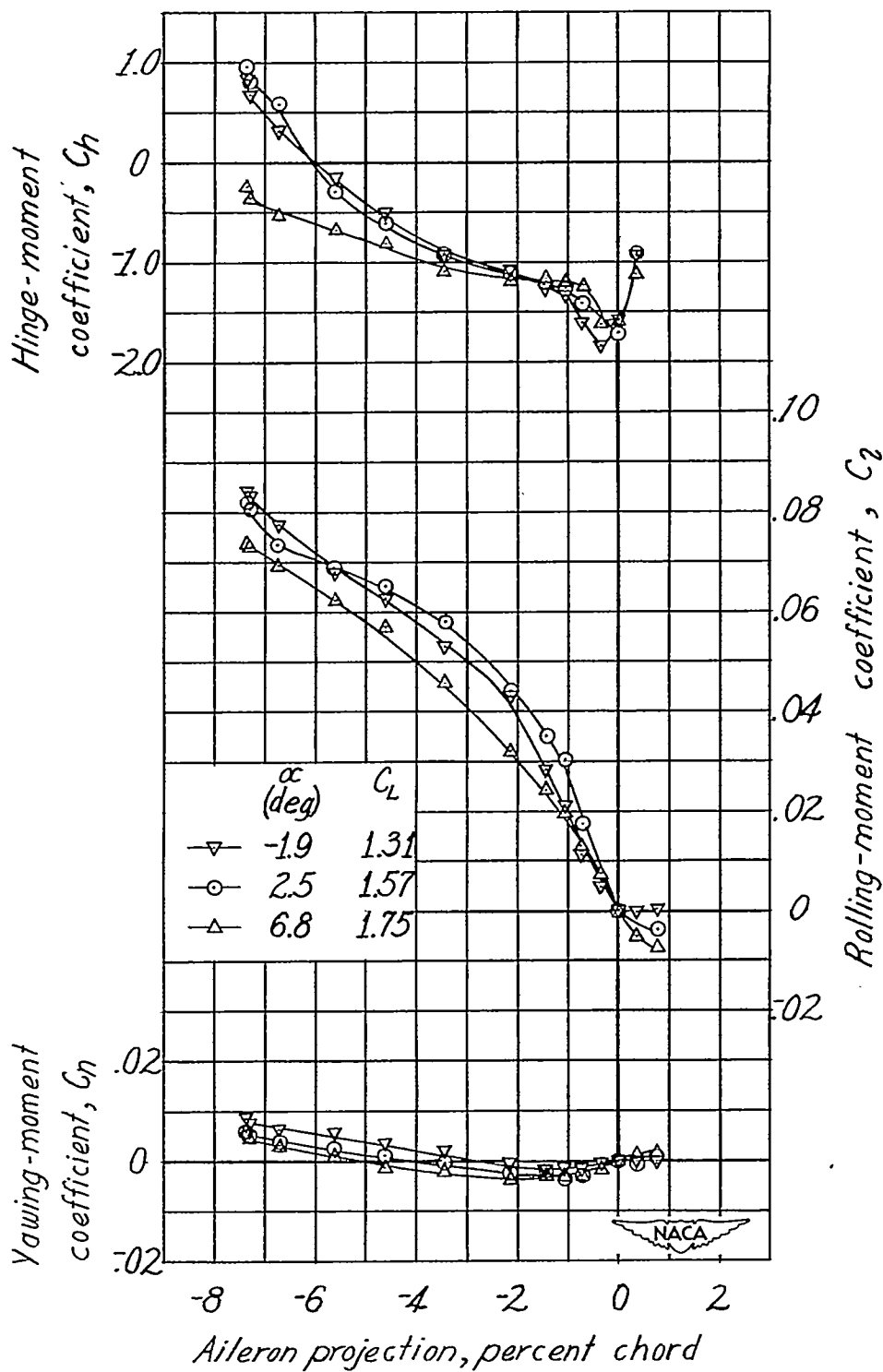
Figure 13.— Variation of lateral–control characteristics of complete wing
with projection of double–walled circular plug aileron at various
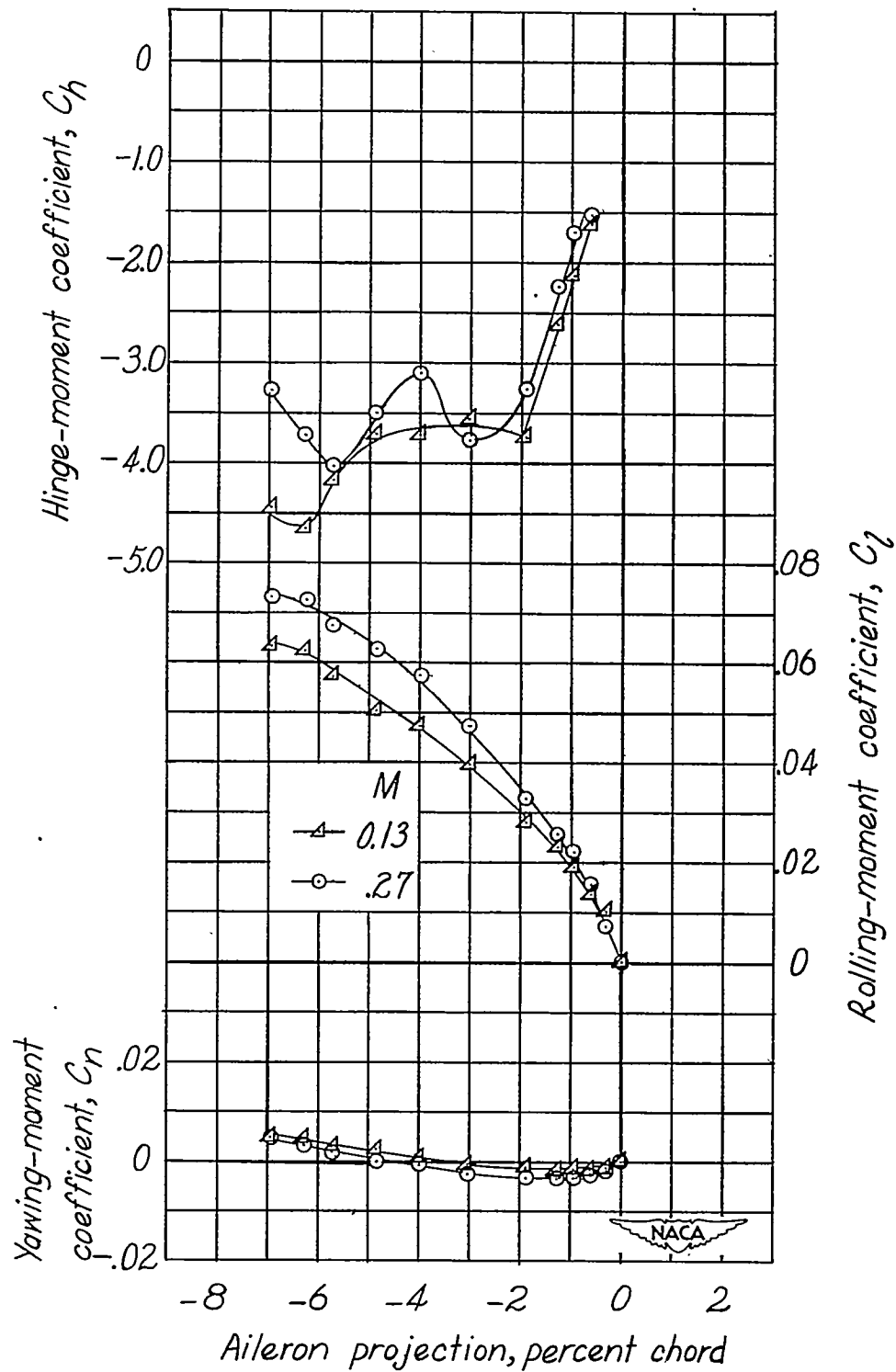angles of attack. Flap deflected 45°. M = 0.27.

(a) $\alpha \approx 0.2°$; $C_L \approx 0.13$.

Figure 14.— Variation of lateral—control characteristics of complete wing
with projection of modified double—walled circular plug aileron at
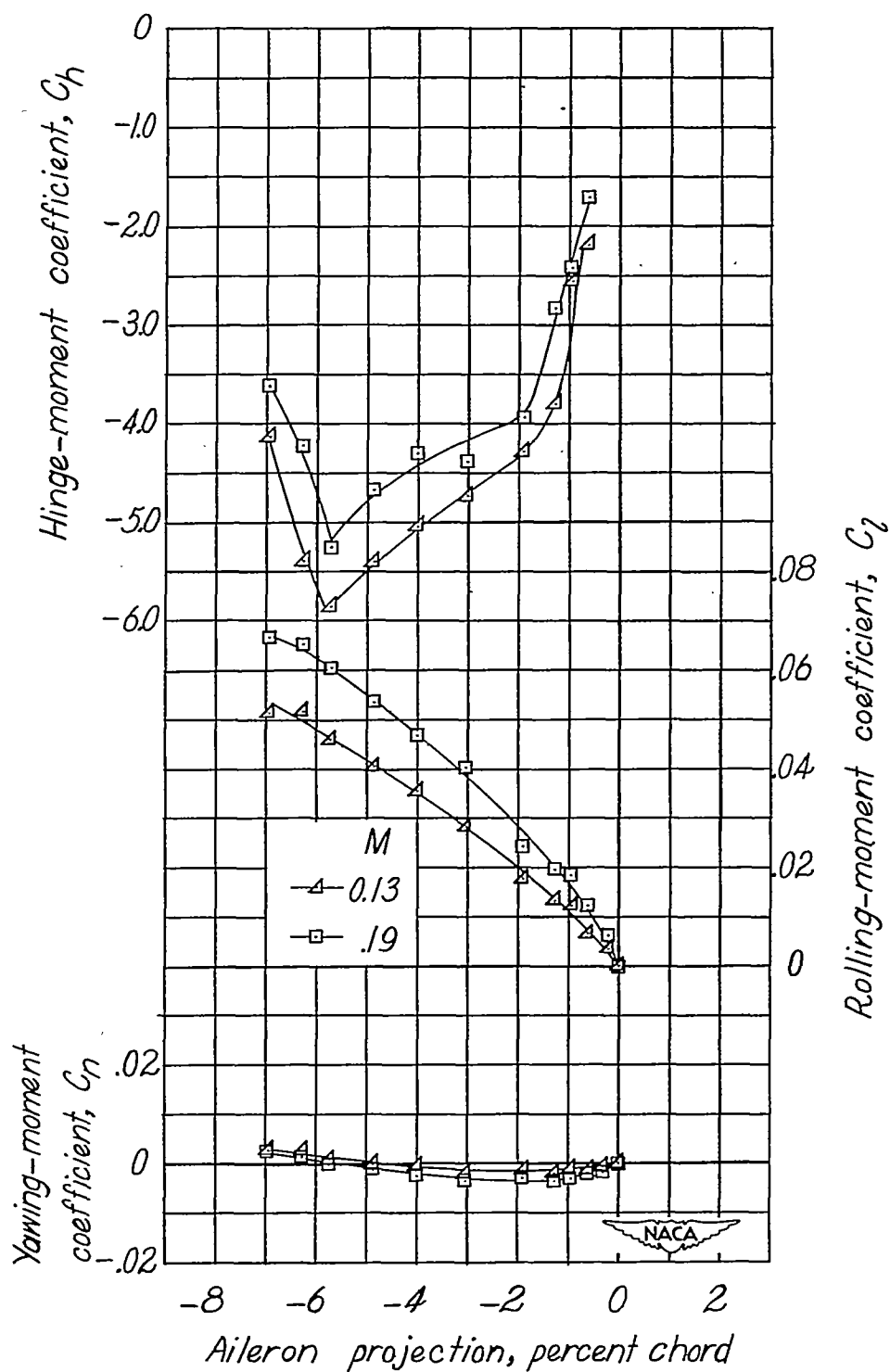various Mach numbers. Plug aileron modified by removing 0.015c top
plate. Flap retracted.

(b) $\alpha \approx 4.7°$; $c_L \approx 0.47$.

Figure 14.— Continued.

(c) $\alpha \approx 8.1°$; $C_L \approx 0.71$.

Figure 14.— Continued.
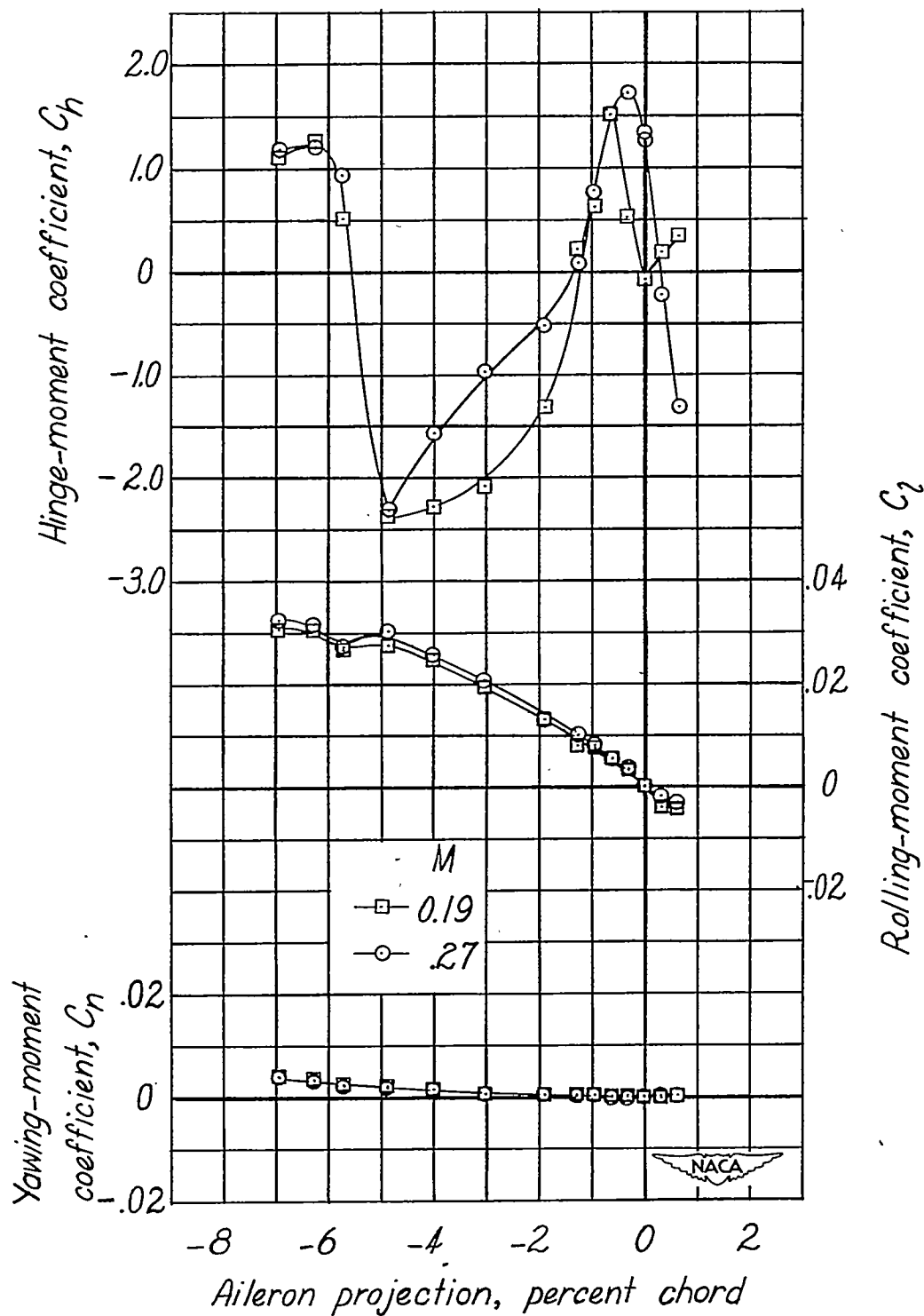
(d) $\alpha \approx 11.5°$; $C_L \approx 0.94$.

Figure 14.— Continued.
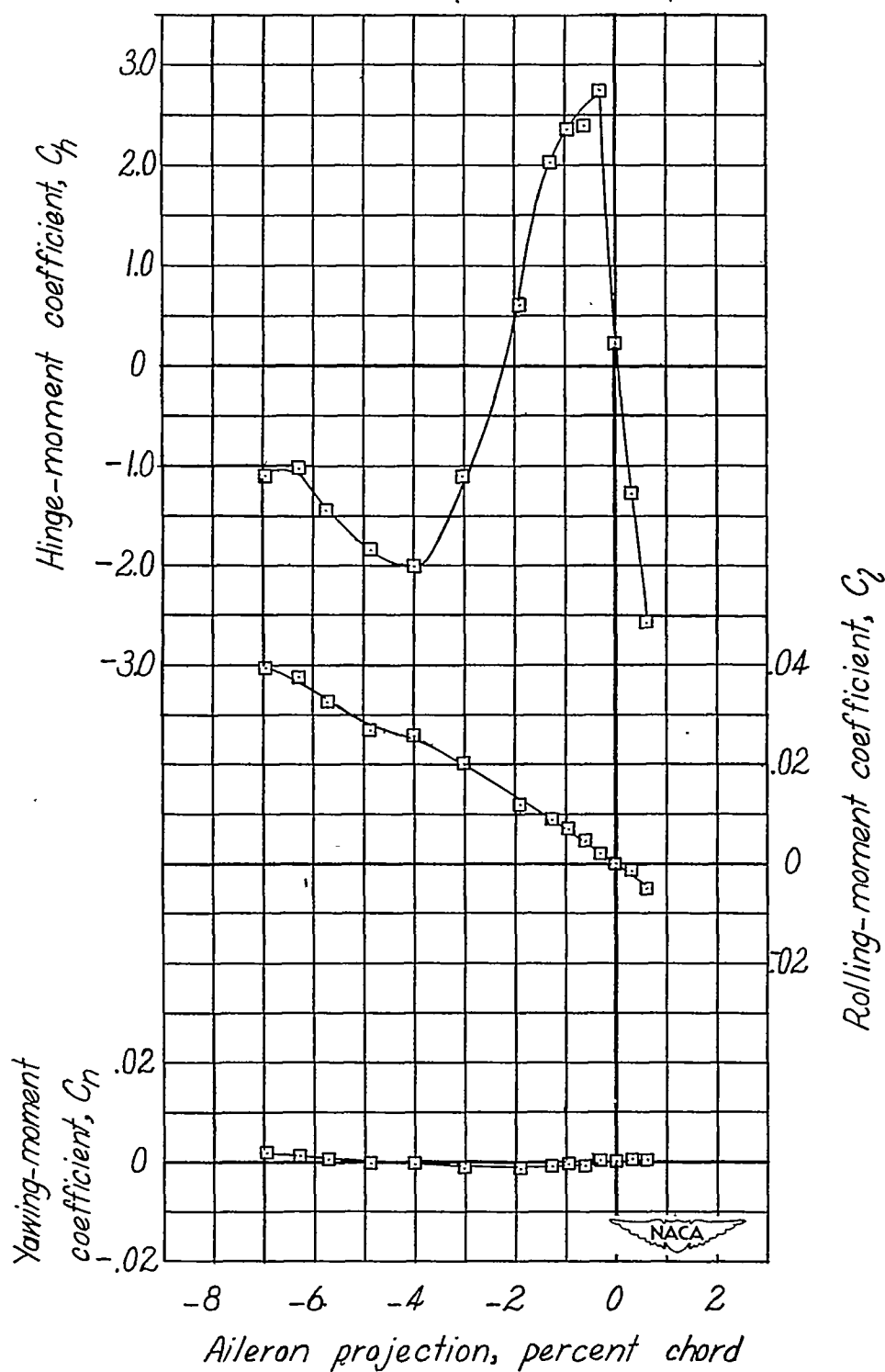
(e) $\alpha = 14.8^\circ$; $C_L = 1.14$; $M = 0.19$.
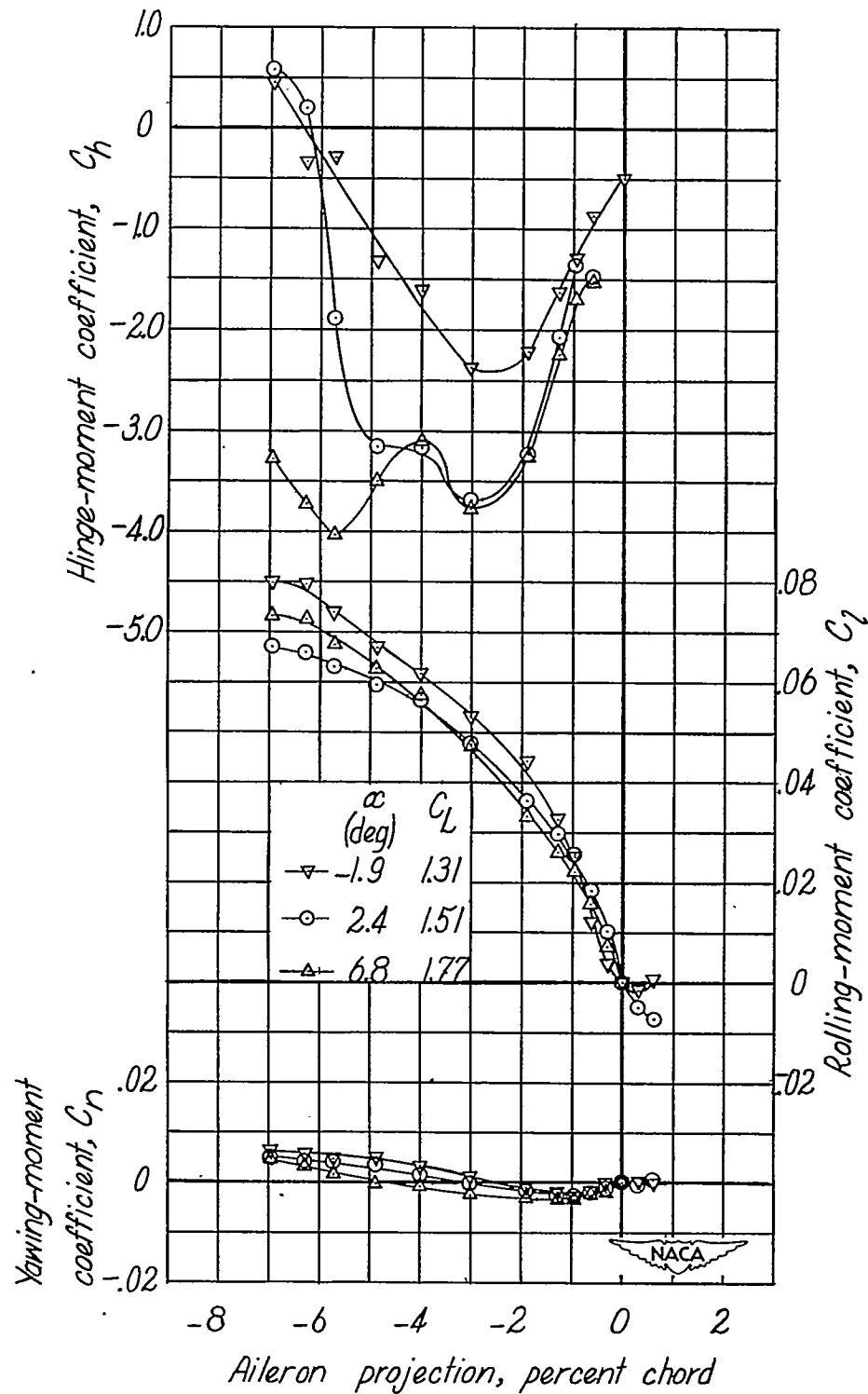
Figure 14.— Concluded.

Figure 15.— Variation of lateral—control characteristics of complete wing
with projection of modified double—walled circular plug aileron at
various angles of attack. Plug aileron modified by removing 0.015c
top plate. Flap retracted. M = 0.27.

(a) $\alpha \approx -1.9°$; $C_L \approx 1.31$.

Figure 16.— Variation of lateral—control characteristics of complete wing
with projection of modified double—walled circular plug aileron at
various Mach numbers. Plug aileron modified by removing 0.015c top
plate. Flap deflected 45°.

(b) α ≈ 2.4°; C_L ≈ 1.50.

Figure 16.— Continued.

(c) $\alpha \approx 6.8°$; $C_L \approx 1.73$.

Figure 16.— Continued.

(d) α = 9.8°; C_L = 1.81.

Figure 16.— Concluded.

Figure 17.— Variation of lateral—control characteristics of complete wing
with projection of modified double—walled circular plug aileron at
various angles of attack. Plug aileron modified by removing 0.015c
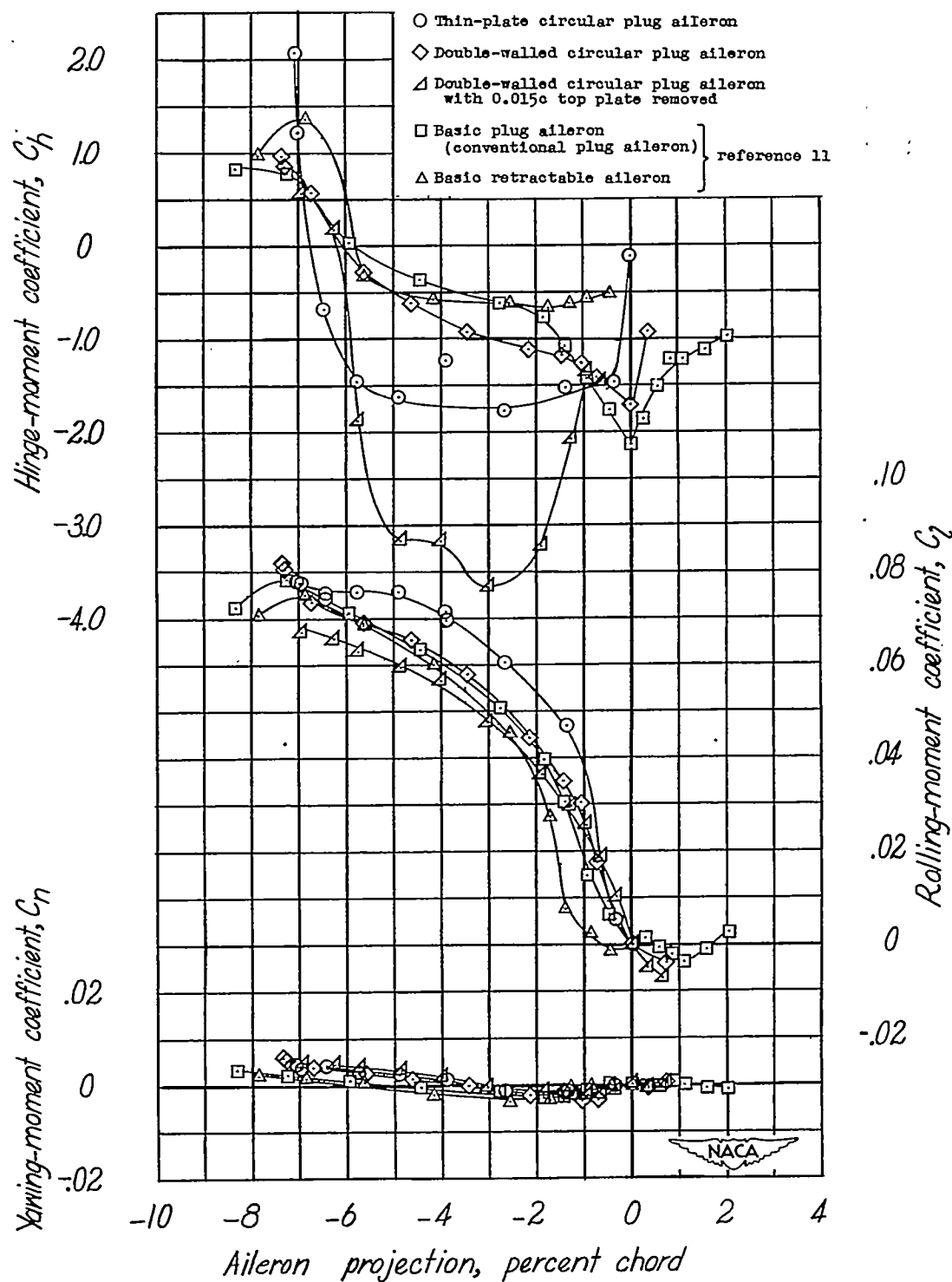top plate. Flap deflected 45°. M = 0.27.
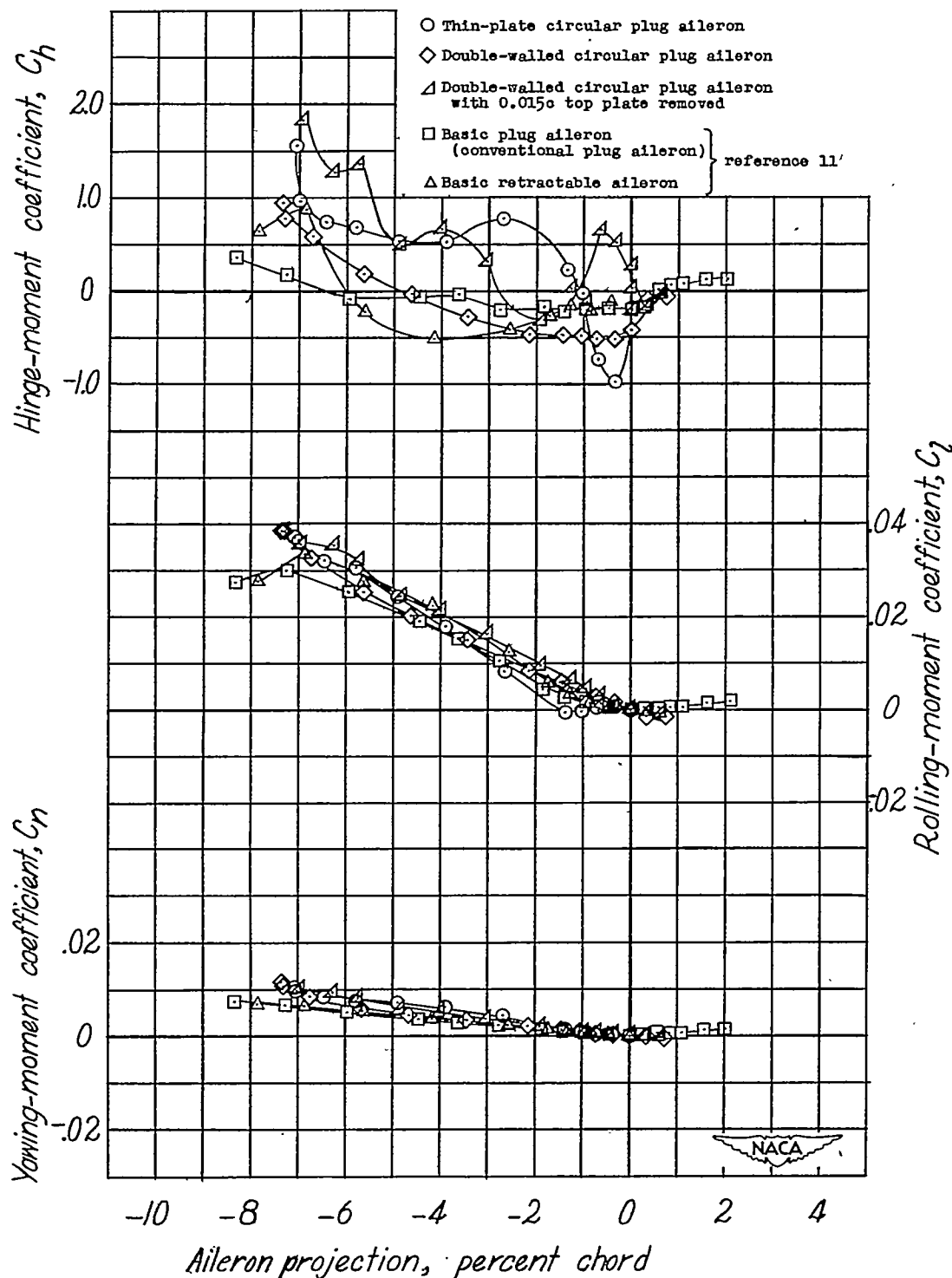
(a) $\alpha \approx 0.2°$; $C_L \approx 0.12$; $M \approx 0.39$.

Figure 18.— Comparison of lateral—control characteristics of the three
circular plug ailerons, a conventional plug aileron, and a retractable
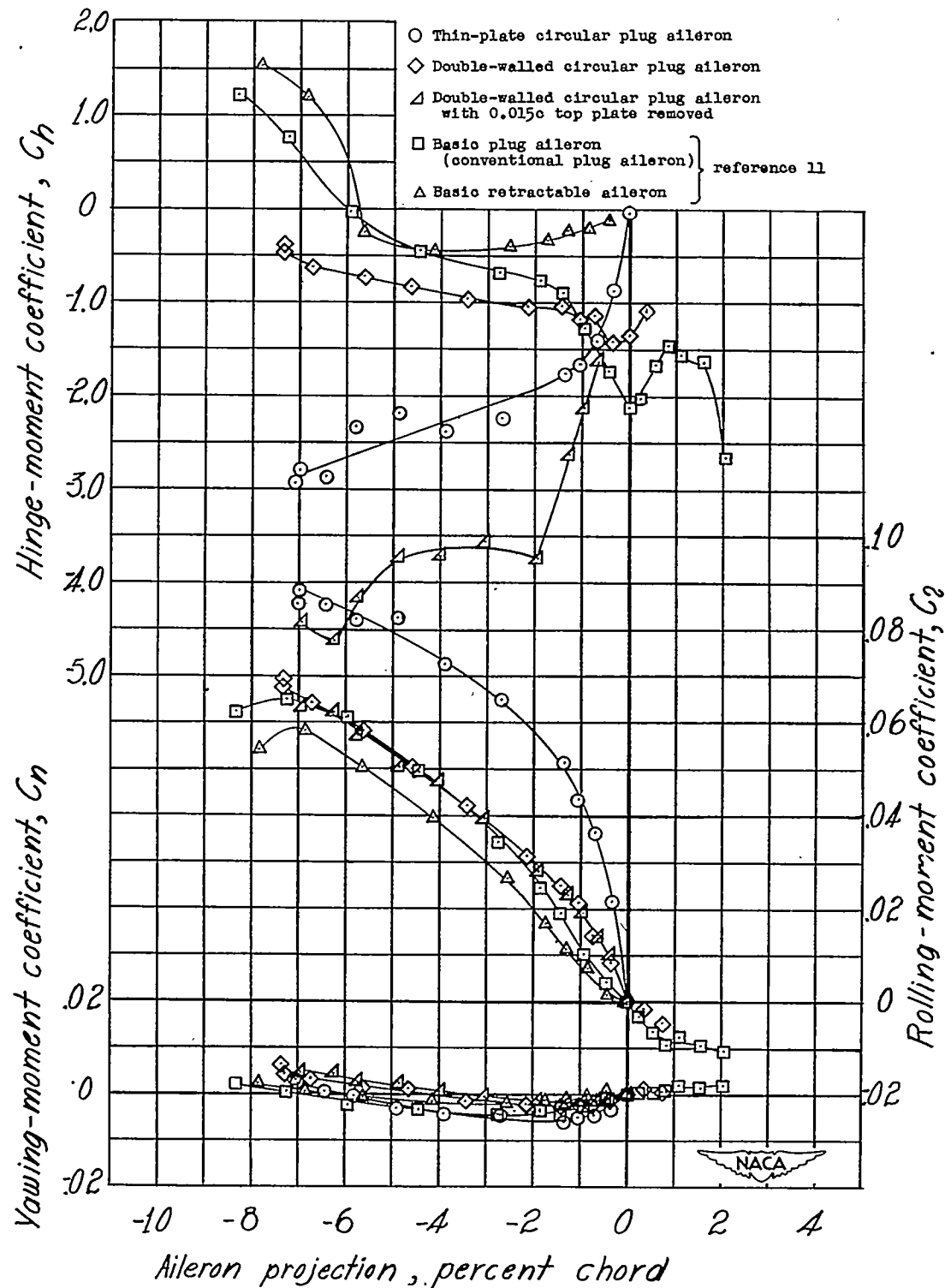aileron investigated on the subject wing. Flap retracted.

Legend:

○ Thin-plate circular plug aileron
◇ Double-walled circular plug aileron
◁ Double-walled circular plug aileron with 0.015c top plate removed
□ Basic plug aileron (conventional plug aileron) } reference 11
△ Basic retractable aileron }
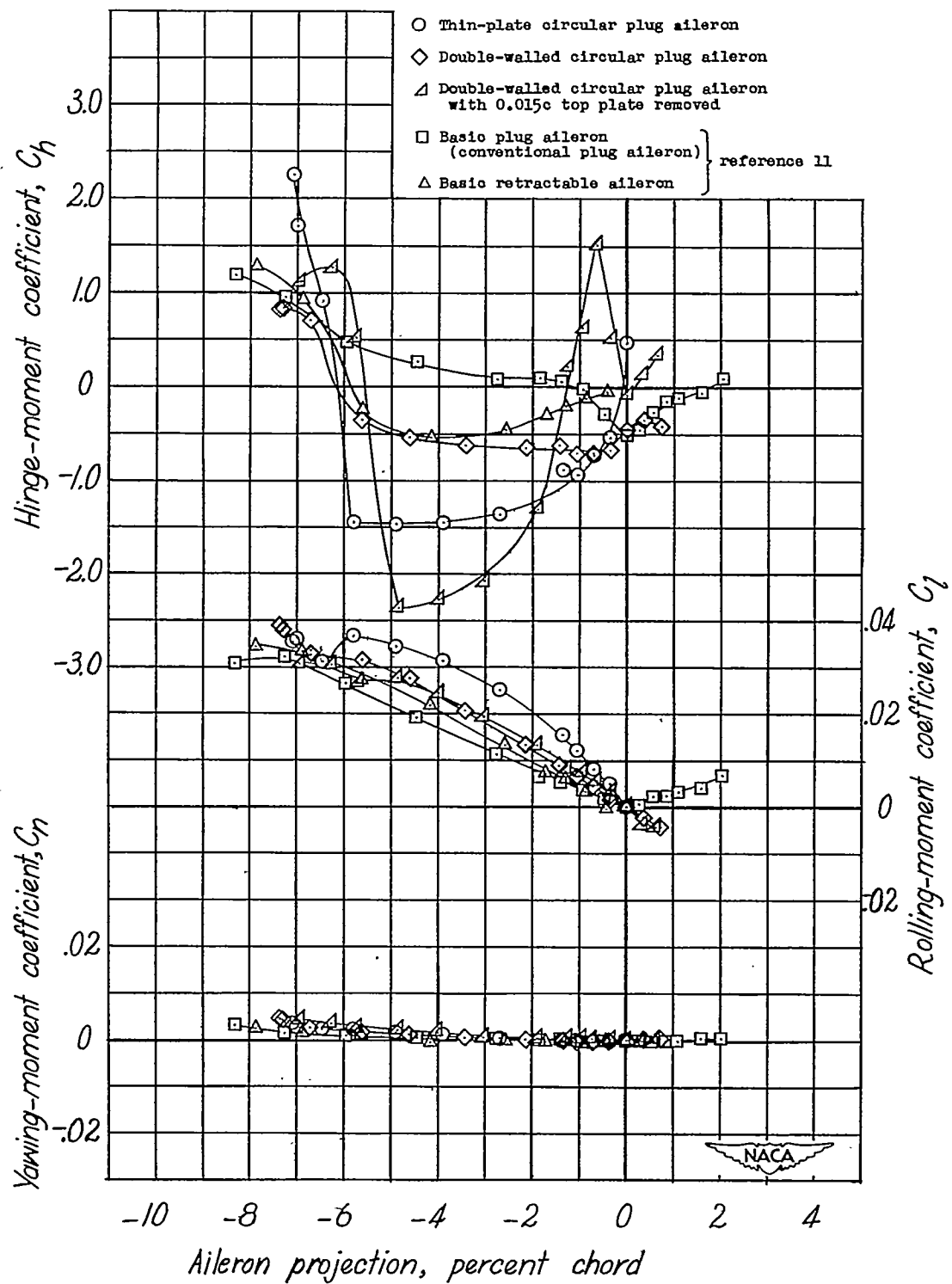
(b) α ≈ 11.6°; C_L ≈ 0.94; M = 0.19.

Figure 18.— Concluded.

(a) $\alpha \approx 2.6°$; $C_L \approx 1.57$; $M = 0.27$.

Figure 19.— Comparison of lateral—control characteristics of the three
circular plug ailerons, a conventional plug aileron, and a retractable
aileron investigated on the subject wing. Flap deflected 45°.

(b) $\alpha \approx 6.9°$; $C_L \approx 1.74$; $M = 0.13$.

Figure 19.— Concluded.
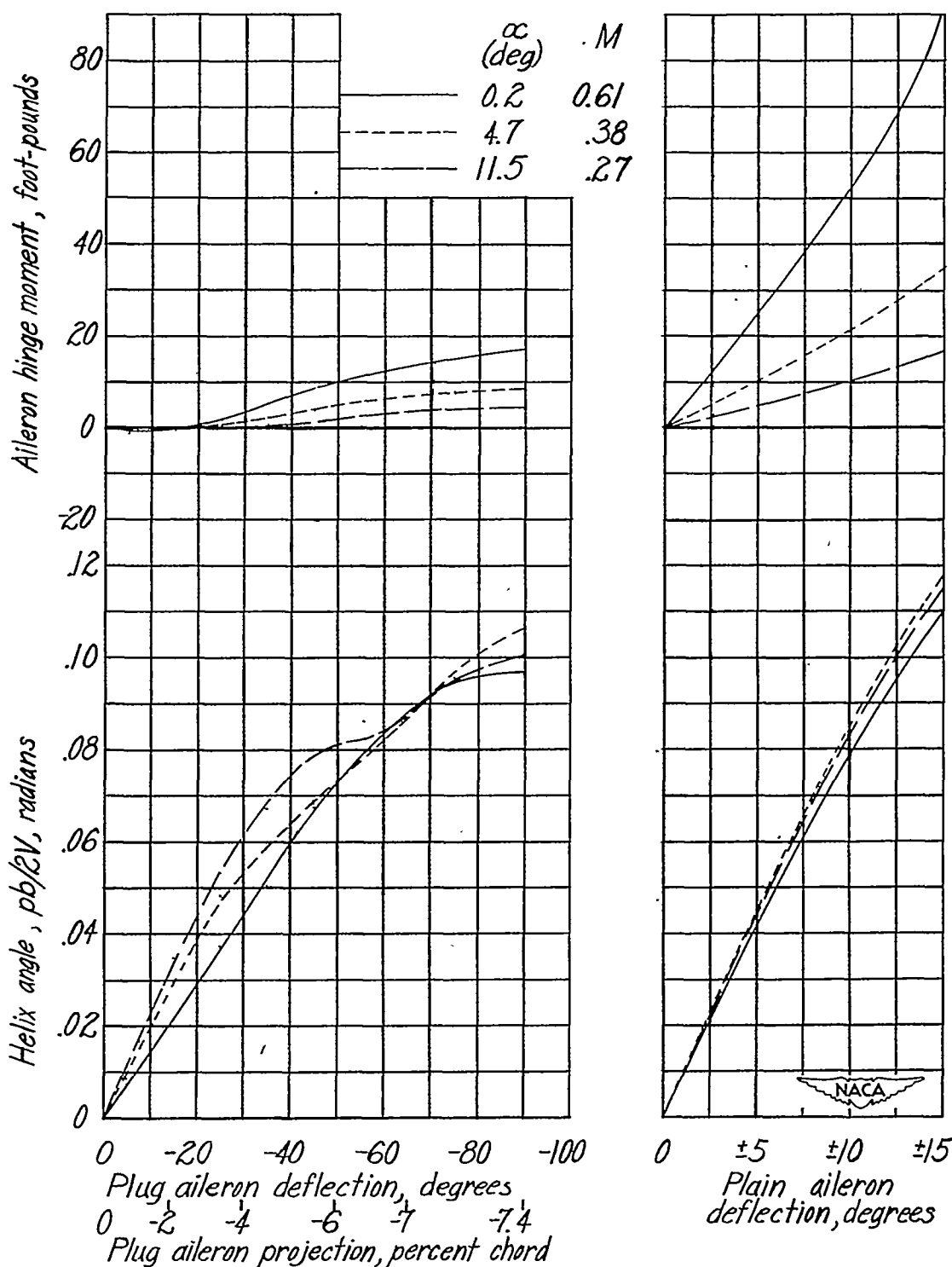
Figure 20.— Comparison of lateral—control characteristics of the double—walled circular plug aileron and a 0.20c, $0.38\frac{b}{2}$, sealed plain aileron investigated on the same wing (reference 10). Flap retracted.