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WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC SPEEDS OF SPOILERS OF LARGE PROJECTION ON AN NACA 65A006 WING WITH QUARTER-CHORD LINE SWEPT BACK 32.6°

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC SPEEDS OF SPOILERS OF LARGE PROJECTION ON AN NACA 65A006 WING WITH QUARTER-CHORD LINE SWEPT BACK 32.6°

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SUMMARY

An investigation was made in the Langley high-speed 7- by 10-foot tunnel through a Mach number range from 0.4 to 0.91 to determine the effects of spoiler projection on the aerodynamic characteristics of a wing-fuselage with the wing quarter-chord line swept back 32.6°. The wing had an NACA 65A006 section, an aspect ratio of 4, and a taper ratio of 0.6. Lift, drag, rolling, pitching, and yawing moments of the model were obtained with one wing panel equipped with 50-percent-semispan inboard spoilers located on the 70-percent-chord line. The spoiler projections varied from 5 percent chord on the wing lower surface to 25 percent chord on the wing upper surface. In addition, the aerodynamic characteristics of the model were determined with one wing equipped with a perforated spoiler and with 20-percent-chord, 40-percent-semispan, outboard ailerons on each wing.

The data indicated that an increase in spoiler projection produced an increase in rolling moment for projections as great as 25 percent chord at the lower angles of attack, but that the effectiveness of spoilers at any of the given projections decreased rapidly above an angle of attack of 8° and became practically zero at 16° and above. At the lower angles of attack the effectiveness of the spoilers in producing rolling moments increased with increase in Mach number. Spoilers of 5-percent-chord projection located on the wing lower surface were only slightly less effective than spoilers on the wing upper surface. Spoiler projection from the upper surface produced small positive increments in pitching moment but had little effect on the variation of pitching-moment coefficient with lift coefficient. The perforated spoiler was less effective in producing rolling moments than the nonperforated, and plain outboard ailerons deflected 10° were much more effective than either at high angles of attack.

[redacted]

INTRODUCTION

The spoiler used as a lateral-control device has been the subject of considerable investigation at low and high speeds, and on both swept and unswept wings (references 1 to 7). Many of the advantages as well as some of the disadvantages of the spoiler have been discussed. Spoilers of various spans located at various spanwise and chordwise positions and skew angles have been tested in order to determine the more effective locations. Most of the wings used in these previous investigations were 10 percent thick or more, and the spoiler projections were limited to 10 percent or less of the wing chord.

The purpose of the investigation reported herein was to determine the rolling-moment effectiveness and other aerodynamic characteristics of spoilers of projections greater than 10 percent chord on a 6-percent-thick sweptback wing. This investigation was conducted in the Langley high-speed 7- by 10-foot tunnel through a Mach number range from 0.4 to 0.91 and an angle-of-attack range from 0° to 24° except when limited by tunnel operating conditions. Lift, drag, rolling, pitching, and yawing moments were obtained with spoiler projections as great as 25 percent of the local wing chord.

SYMBOLS AND COEFFICIENTS

The forces and moments measured on the model are presented about an orthogonal system of axes, the longitudinal axis being parallel to the free-stream air flow and the vertical axis being in the vertical plane of symmetry. The origin of the axes is at a longitudinal position corresponding to the quarter-chord point of the mean aerodynamic chord (fig. 1).

C_L	lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$
C_m	pitching-moment coefficient $\left(\frac{\text{Pitching moment}}{qS\bar{c}}\right)$
C_l	rolling-moment coefficient resulting from spoiler projection or aileron deflection $\left(\frac{\text{Rolling moment}}{qSb}\right)$

C_n	yawing-moment coefficient resulting from spoiler projection or aileron deflection $\left(\frac{\text{Yawing moment}}{qSb}\right)$
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
ρ	mass density of air, slugs per cubic foot
V	free-stream air velocity, feet per second
S	wing area, 2.25 square feet
b	wing span, 3.0 feet
$\bar{c}$	mean aerodynamic chord of wing, 0.765 foot $\left(2/S \int_0^{\frac{b}{2}} c^2 dy\right)$
c	local wing chord, feet
y	spanwise distance from vertical plane of symmetry
M	Mach number
R	Reynolds number based on $\bar{c}$
α	angle of attack, degrees

APPARATUS AND MODEL

A drawing of the model and pertinent information are given in figure 1. The solid aluminum-alloy wing had an NACA 65A006 airfoil section parallel to the fuselage center line, a quarter-chord line sweptback 32.6°, an aspect ratio of 4, and a taper ratio of 0.6. The spoilers were made of aluminum angle, the foot of the angle being about 0.8 inch wide, and the projecting face varying from 0.05 to -0.25 of the local wing chord, the positive sign indicating projection from the lower surface and the negative sign projection from the upper surface of the wing. The perforated spoiler was made by drilling holes in the projecting face of the aluminum angle. The holes varied in diameter from 0.25 inch at the outboard end to 0.36 inch at the inboard end. The holes eliminated about 37 percent of the area of the nonperforated spoiler. The ailerons were made of steel and attached to the wing by screws through tongue and groove cutouts.

The model was mounted on a sting-type support system in the Langley high-speed 7- by 10-foot tunnel. The sting was supported by a vertical strut downstream from the test section. The system allowed the angle of attack of the model to be varied by rotating the model and sting in the vertical plane about a point near the quarter-chord position longitudinally. The forces and moments on the model were measured by means of electrical strain gages mounted inside the aluminum fuselage. The fuselage ordinates are given in table I.

TESTS

The Mach number range was from 0.4 to 0.91 for this investigation. The angle-of-attack range was 0° to 24° for the low Mach numbers and 0° to 12° for a Mach number of 0.91. The negative (upper wing surface) spoiler projection varied from 0 to 25 percent of the local wing chord in increments of 5 percent. The only positive (lower wing surface) projection was 5 percent of the local wing chord. The perforated spoiler was tested at only one projection (-0.10c) and the ailerons at only one deflection, 10° up on one wing and 10° down on the other.

The variation of Reynolds number with Mach number is given in figure 2.

CORRECTIONS

The test data have been corrected for jet-boundary effects by the method given in reference 8. Blockage corrections based on the plain wing model as determined from reference 9 to account for the constriction effects of the model on the tunnel free-stream flow were applied to the data. To account for the error caused by the sting mount the drag has been corrected to a value corresponding to a pressure at the base of the fuselage equal to free-stream static pressure. No corrections for wing bending or twisting have been applied. These corrections as calculated from static loads on the wing were found to be small for the bending and negligible for the twisting of the plain wing.

RESULTS AND DISCUSSION

The lift, drag, and pitching-moment characteristics of the model with plain wing and wing with spoilers are given in figure 3. At all Mach numbers an increase in negative spoiler projection produced an increase in drag and a decrease in lift over most of the angle-of-attack range. The drag increment was approximately proportional to spoiler projection at small and moderate angles of attack, but the lift decrement was greater proportionally for small projections for lift coefficients up to 0.6. In the higher angle-of-attack range, the spoiler effect on the lift and drag was greatly reduced. Recent unpublished pressure-distribution data on a very similar wing showed that separation started between angles of attack of 8° and 12° and that the separation had reached the leading edge at 16° angle of attack. This angle-of-attack range where pressure data indicated separation corresponds very closely with the angle-of-attack range where spoilers lost effectiveness as indicated by the present data, and separation may very well have been the cause of this loss in effectiveness.

Negative (wing upper surface) spoiler projections produced small increments of positive pitching moments but very little change in stability as measured by the slope of the pitching-moment curve. Spoiler projection on the bottom surface of the wing produced small increments of negative pitching moment which increased with increase in Mach number but had little effect on the stability of the model except possibly in the semistalled condition.

The variation of lateral control characteristics with angle of attack for various spoiler projections is given in figure 4. The rolling-moment coefficient decreased rapidly above an angle of attack of 8°, becoming zero or slightly negative at 16° and above. The spoilers of small projection began losing effectiveness below an angle of attack of 8°, but the larger projections tended to increase in effectiveness with angle of attack up to about 8°. This loss in effectiveness is probably a result of leading-edge separation as previously discussed. While it is apparent from figure 5 that the variation of rolling-moment coefficient with spoiler projection is not linear, there is a considerable increase in rolling-moment coefficient with increase in spoiler projection up to a projection of 0.25c over the angle-of-attack range for which the spoilers are effective. The 0.05c spoiler appeared to be only slightly less effective on the lower than on the upper surface of the wing. Most of the yawing-moment coefficients of the spoilers on the upper surface were small; if not small, they had the same sign as the rolling-moment coefficients which is usually considered a favorable condition. Figure 6 indicates that the rolling-moment coefficients generally increased with increase in Mach number for small angles of attack. In the angle-of-attack range (near 12°) where the spoilers rapidly lost effectiveness, rolling-moment coefficients were larger at $M = 0.4$ than at $M = 0.6$ and 0.8.

The comparative effects of perforated and nonperforated spoilers and plain ailerons on the lift, drag, and pitching-moment characteristics of the model are shown in figure 7. A comparison of the lateral control characteristics is shown in figure 8. A perforated spoiler of

0.10c projection, which had about 37 percent of the area of the projecting surface removed, had less drag at all Mach numbers than the nonperforated, and the perforated produced rolling moments that were 20 to 35 percent less than the nonperforated at small angles of attack. This percentage difference became less as the Mach number increased. There was very little difference in pitching-moment characteristics between the two spoiler configurations.

Plain ailerons of 0.20c and 40 percent semispan located outboard were deflected 10° up on one wing and 10° down on the opposite wing. This aileron configuration was a little better at the lower Mach numbers in producing rolling moment than the 0.10c spoiler (fig. 8). The effectiveness of the spoilers at the lower angles of attack increased with Mach number, whereas the effectiveness of the ailerons decreased above a Mach number of 0.6. The ailerons retained much of their effectiveness at the higher angles of attack, but the spoilers became ineffective at 16° and above.

CONCLUSIONS

A wind-tunnel investigation was made through a Mach number range from 0.4 to 0.91 to determine the effect of spoilers on the aerodynamic characteristics of a model with the quarter-chord line of the wing swept back 32.6° and having an NACA 65A006 airfoil section. The right wing was equipped with 50-percent-semispan spoilers of 0.25 chord maximum projection located inboard on the 70-percent-chord line. For comparison with nonperforated spoilers, a perforated spoiler and plain outboard ailerons of 0.20 chord and 40-percent semispan deflected 10° up and down were tested. As a result of the investigation, the following conclusions based on tests of the configurations described are justified:

1. At the lower wing angles of attack an increase in spoiler projection produced an increase in rolling moment for spoiler projections up to 0.25 chord.

2. Spoilers rapidly lost effectiveness above a wing angle of attack of 8° and were ineffective at 16° and above.

3. Spoilers of small projection (0.05c) located on the wing lower surface were only slightly less effective in producing rolling moments than spoilers of the same projection located on the wing upper surface.

4. At the lower wing angles of attack the effectiveness of the spoilers in producing rolling moments increased with increase in Mach number.

5. Spoiler projection on the wing upper surface produced small positive increments of pitching moment but had little effect on stability.

6. A perforated spoiler was less effective in producing rolling moments than a nonperforated one.

7. Plain outboard ailerons retained much of their effectiveness in producing rolling moments at high angles of attack, whereas spoilers became ineffective at high angles of attack.

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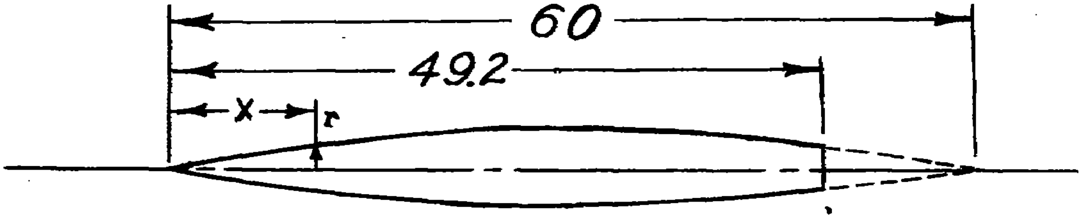
9. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Formerly NACA RM A7B28.)

TABLE I

FUSELAGE ORDINATES

[Basic fineness ratio 12, actual fineness ratio 9.8 achieved by cutting off the rear one-sixth of the body]



Ordinates (in.)	
x	r
0	0
.30	.1386
.45	.1788
.75	.2568
1.50	.4332
3.00	.7230
4.50	.9678
6.00	1.1826
9.00	1.5558
12.00	1.8540
15.00	2.0790
18.00	2.2446
21.00	2.3598
24.00	2.4378
27.00	2.4858
30.00	2.5002
33.00	2.4780
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39.00	2.3052
42.00	2.1372
49.20	1.65
L.E. radius = 0.030 inch	

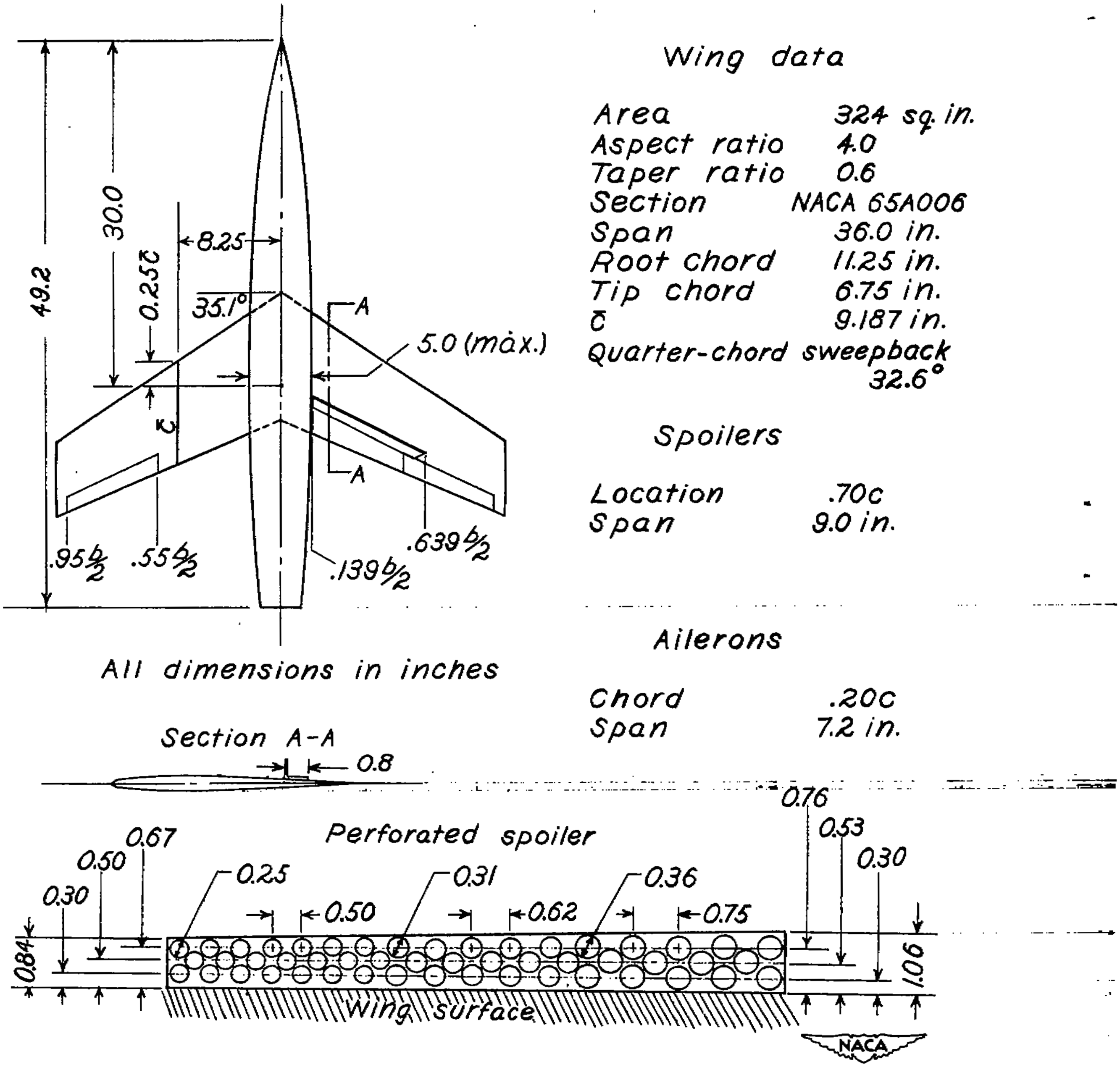


Figure 1.- General arrangement of model and controls.

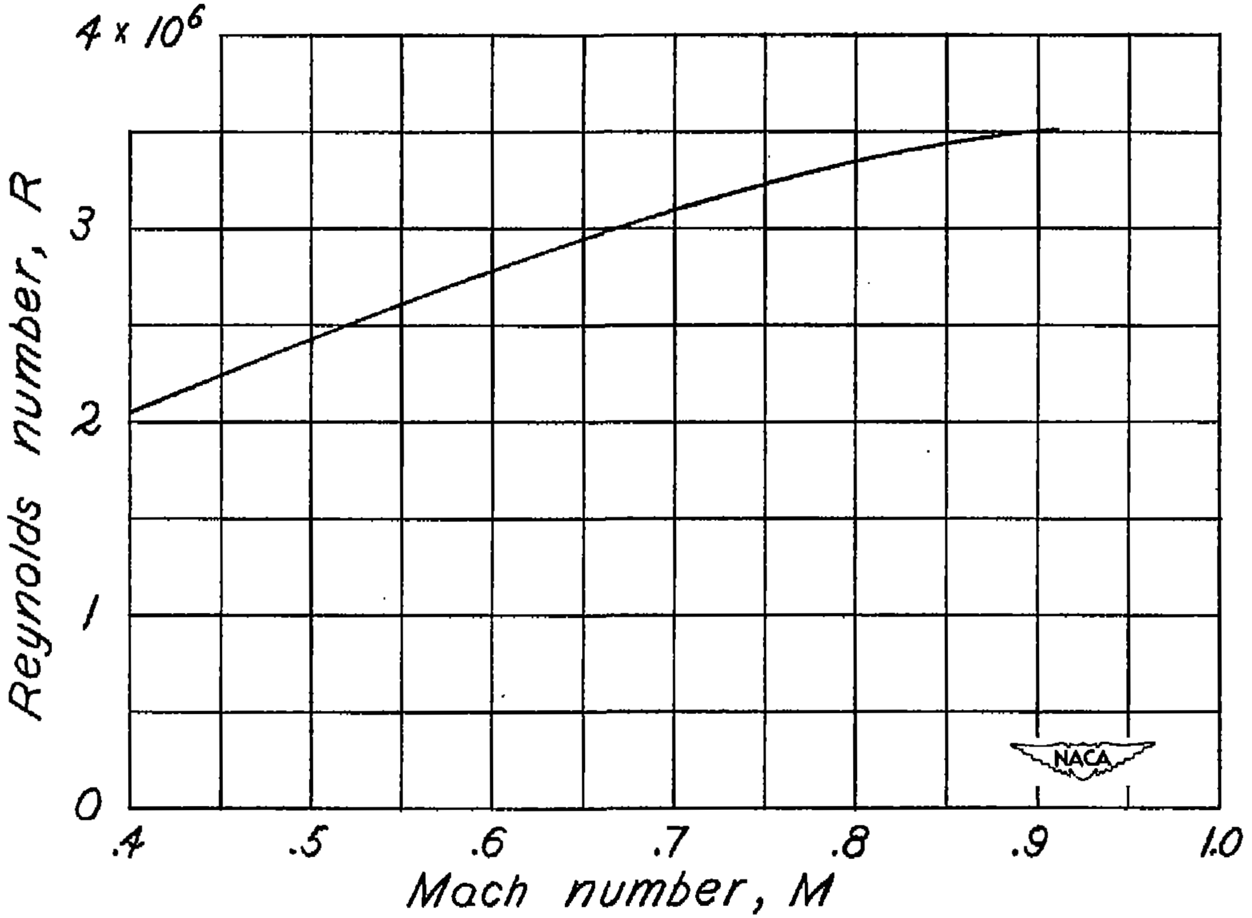
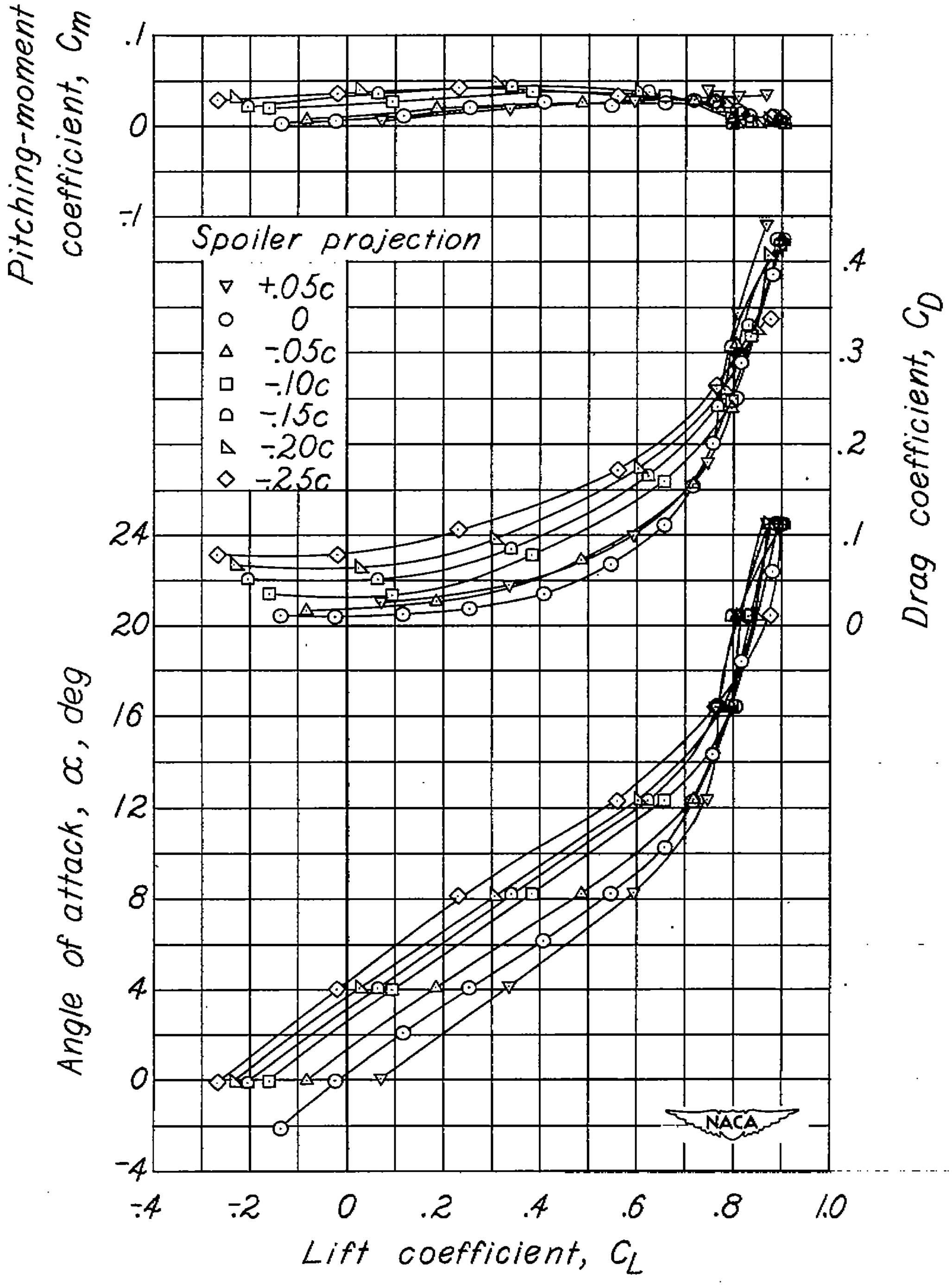
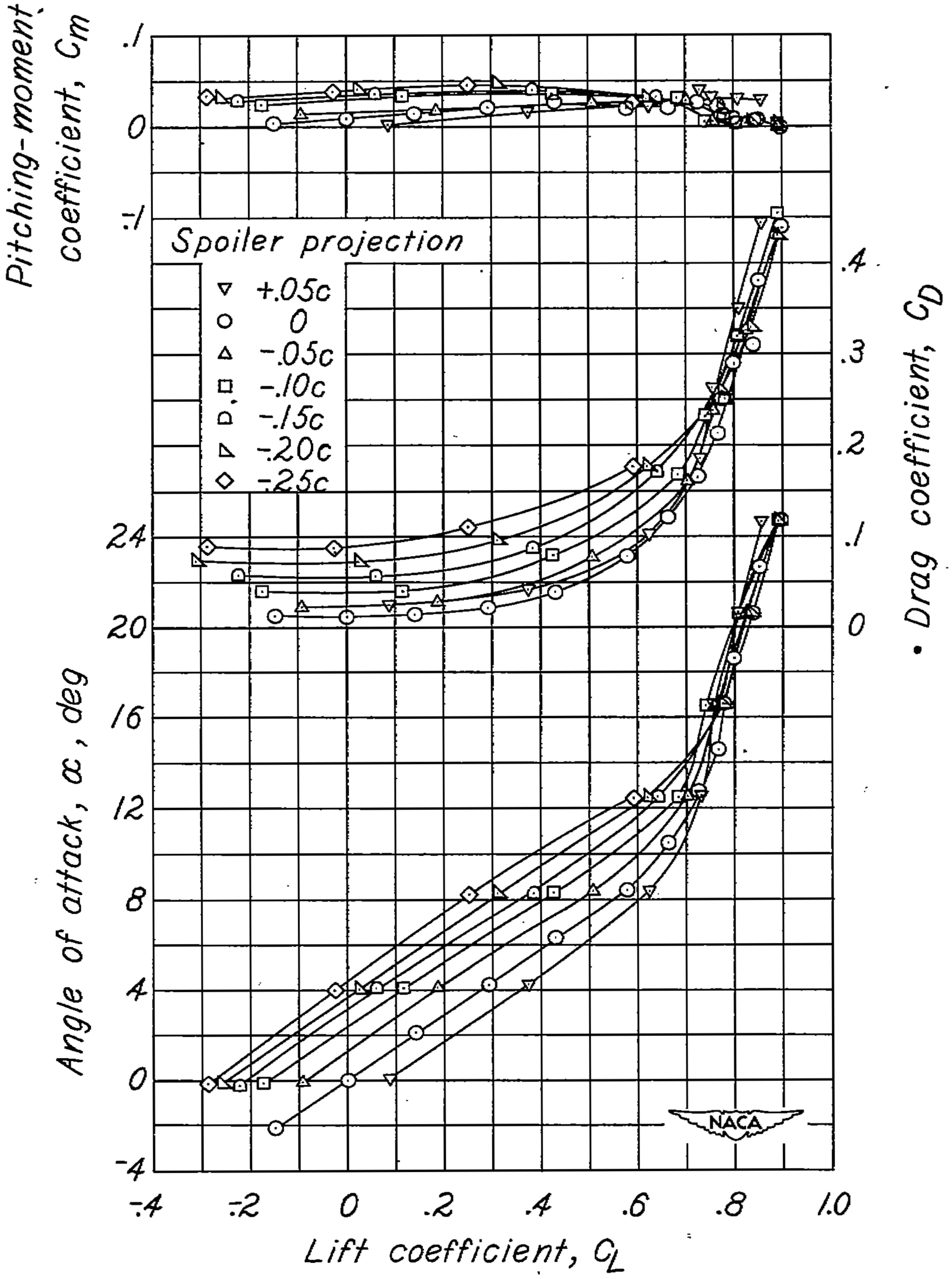


Figure 2.- Variation of Reynolds number with Mach number.



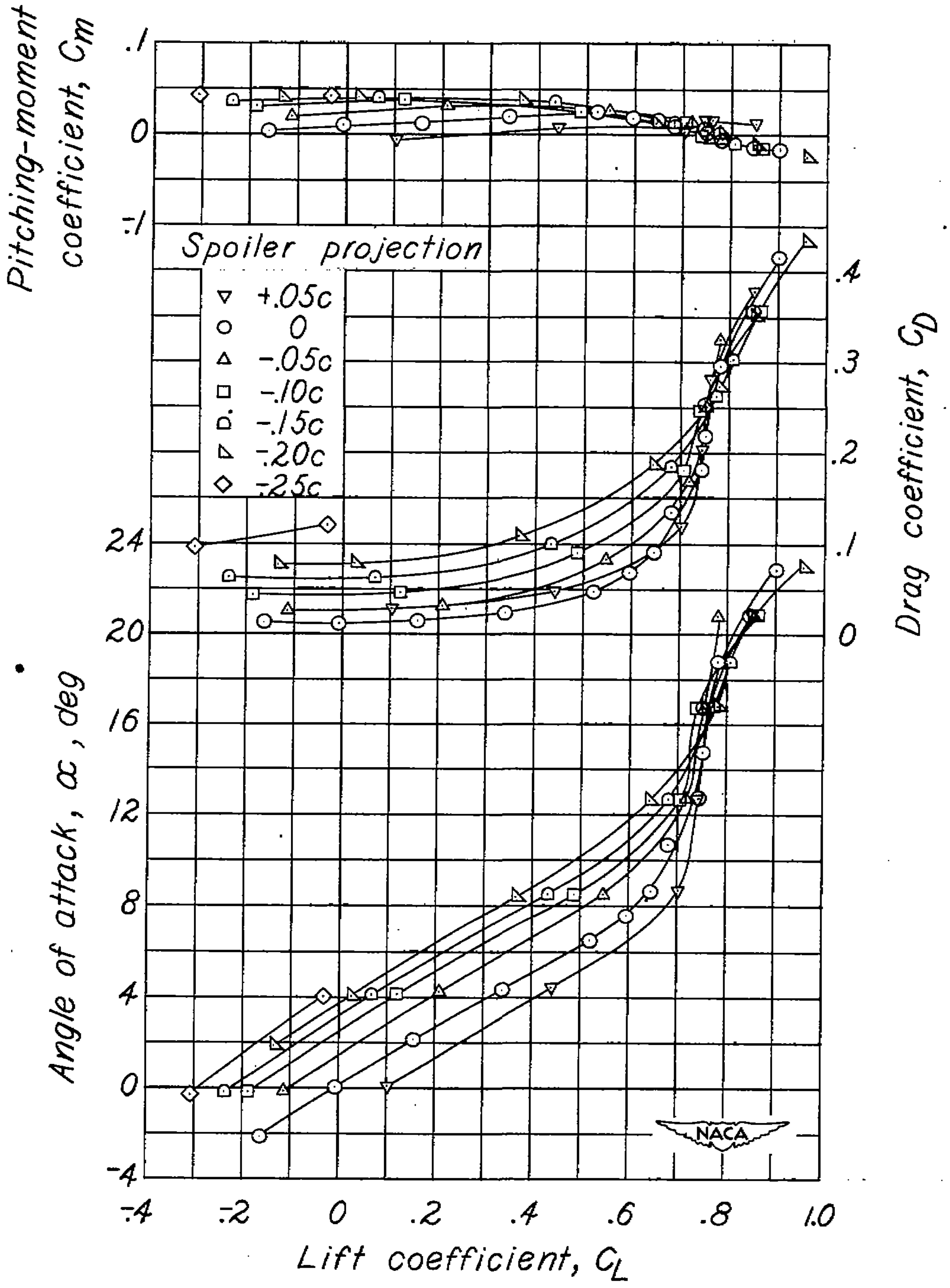
(a) M ≈ 0.4.

Figure 3.- Effect of spoiler projection on the aerodynamic characteristics in pitch.



(b) M ≈ 0.6.

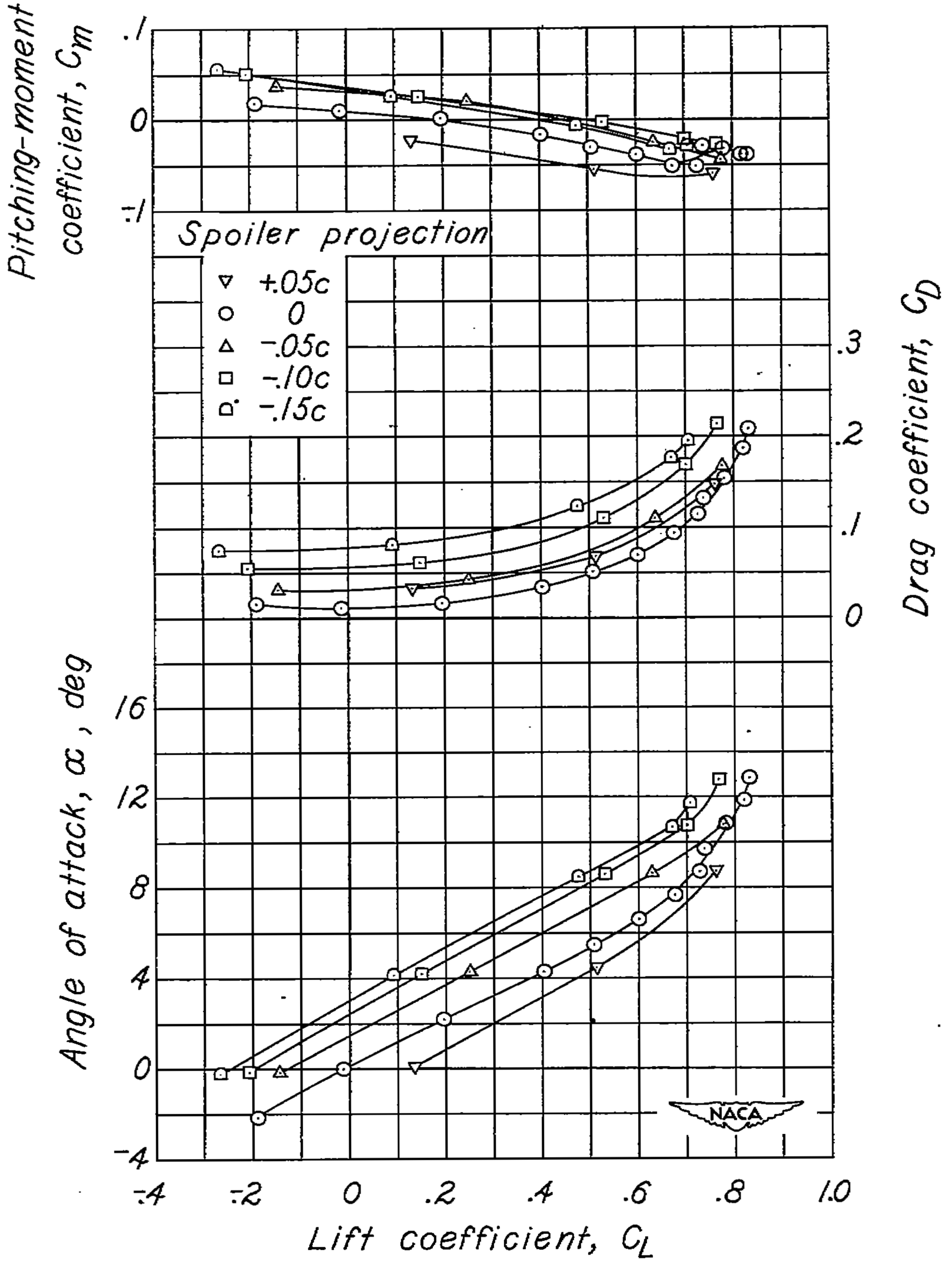
Figure 3.- Continued.



(c) $M \approx 0.8$.

Figure 3.- Continued.

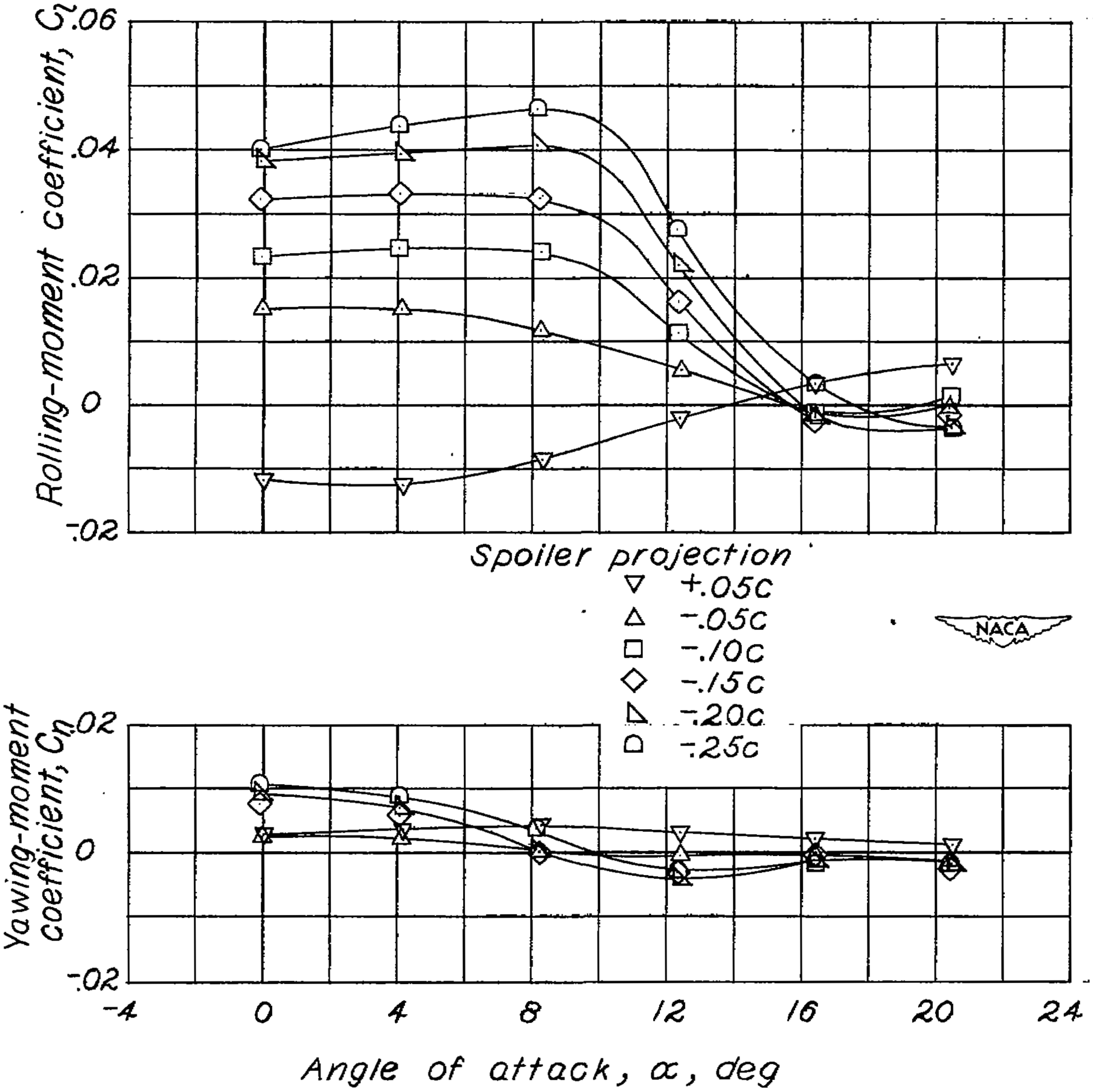
[redacted]



(d) M ≈ 0.91.

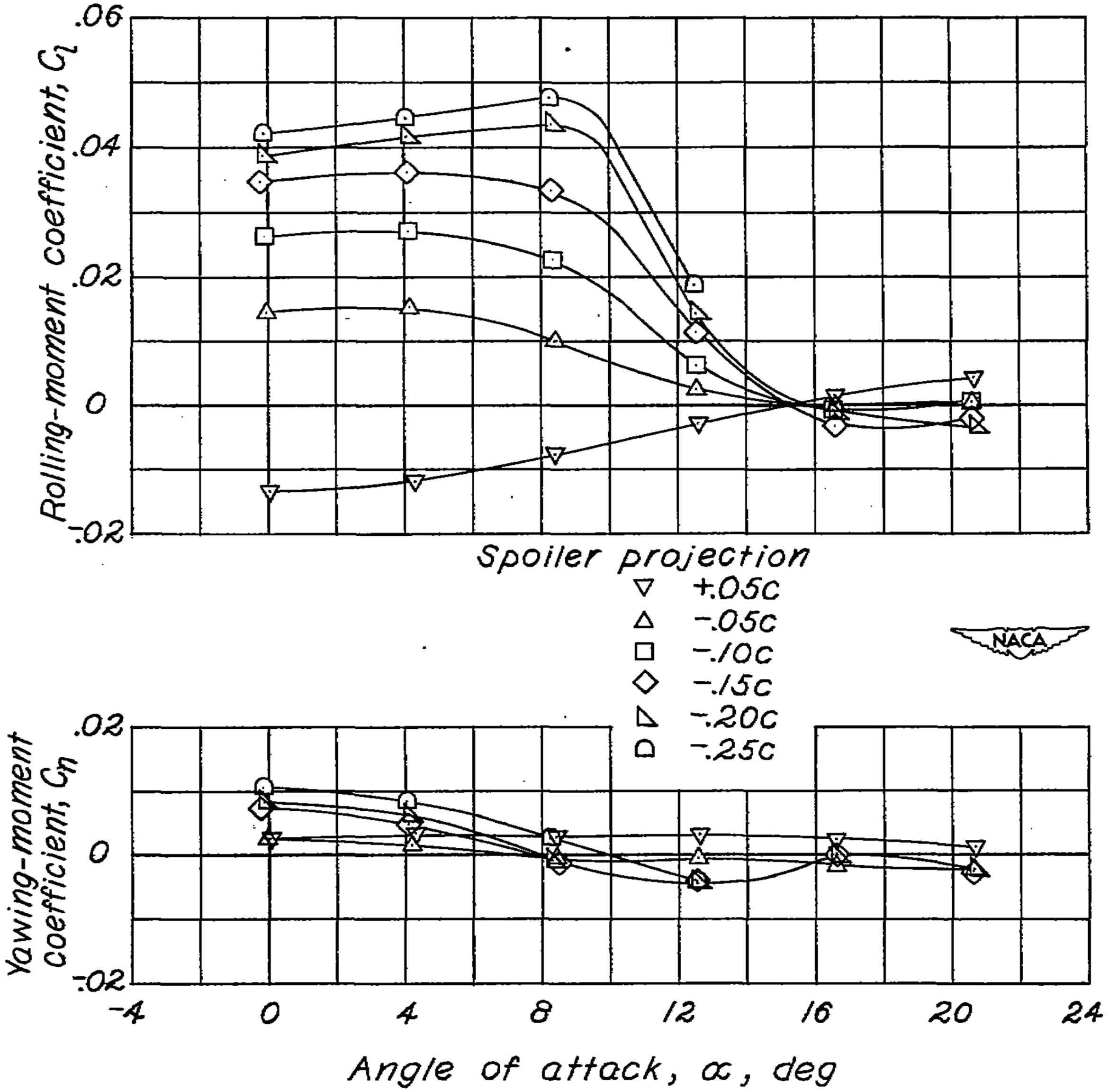
Figure 3.- Concluded.

[redacted]



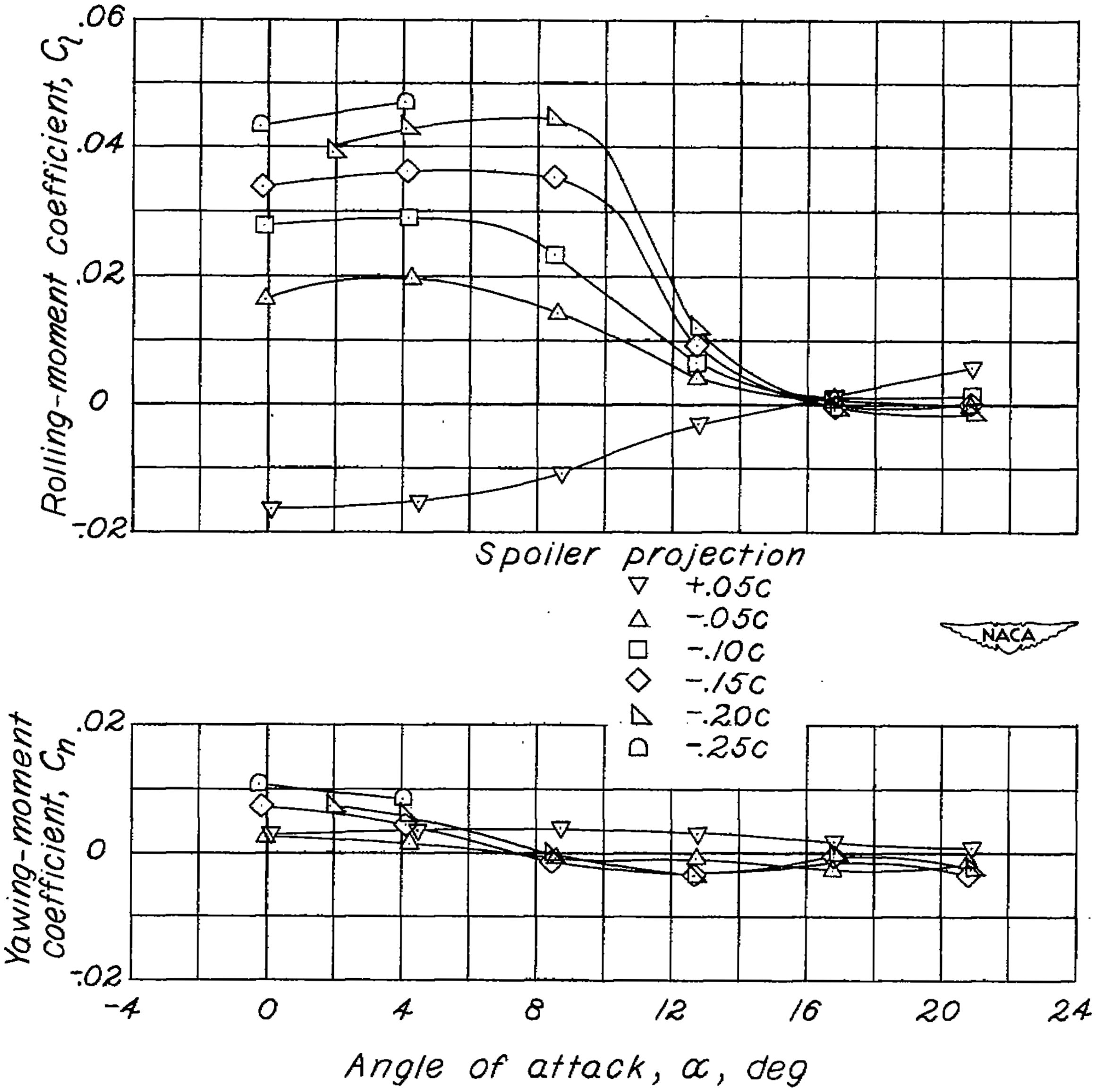
(a) $M \approx 0.4$.

Figure 4.- Variation of lateral control characteristics with angle of attack for various spoiler projections.



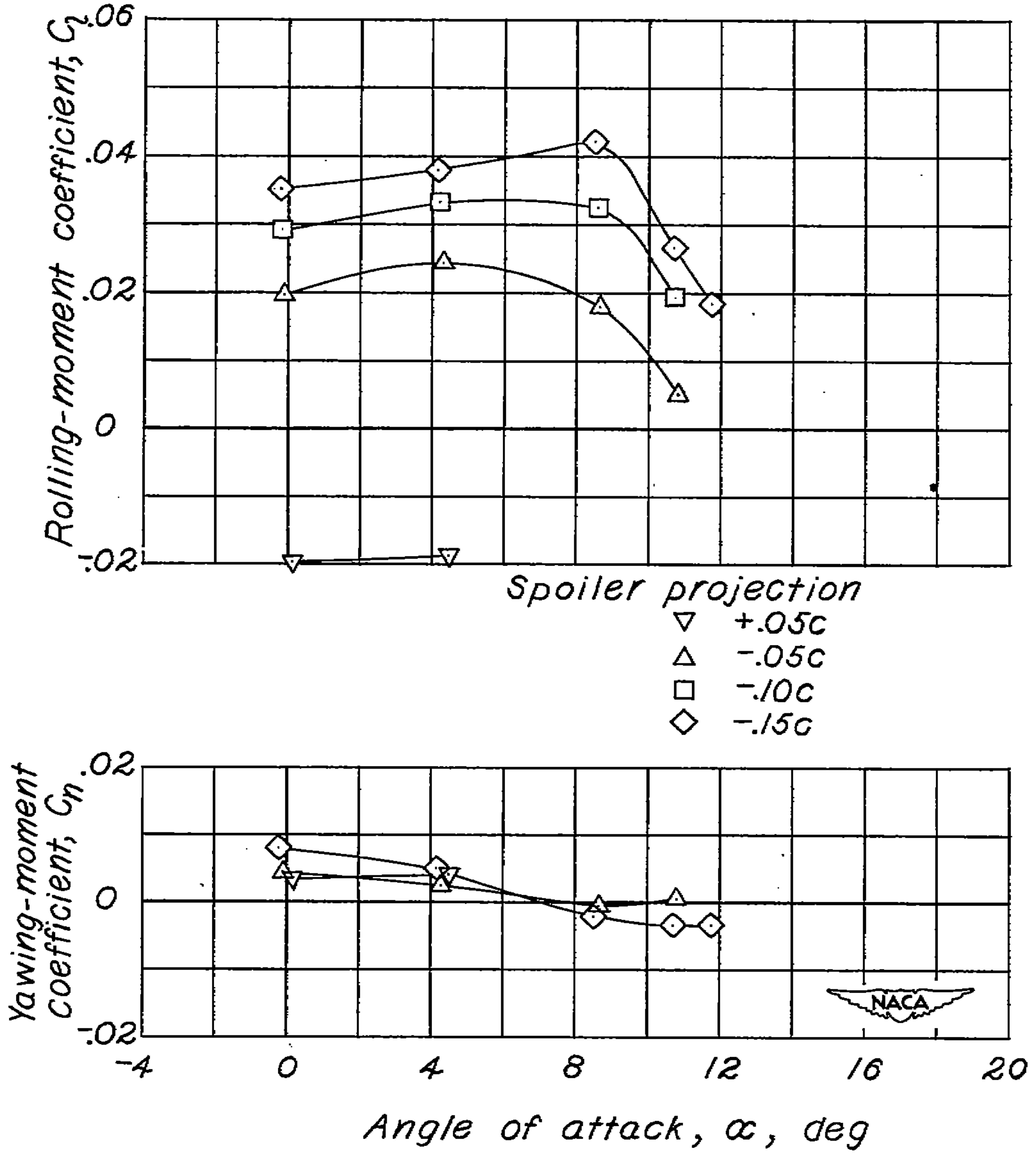
(b) M ≈ 0.6.

Figure 4.- Continued.



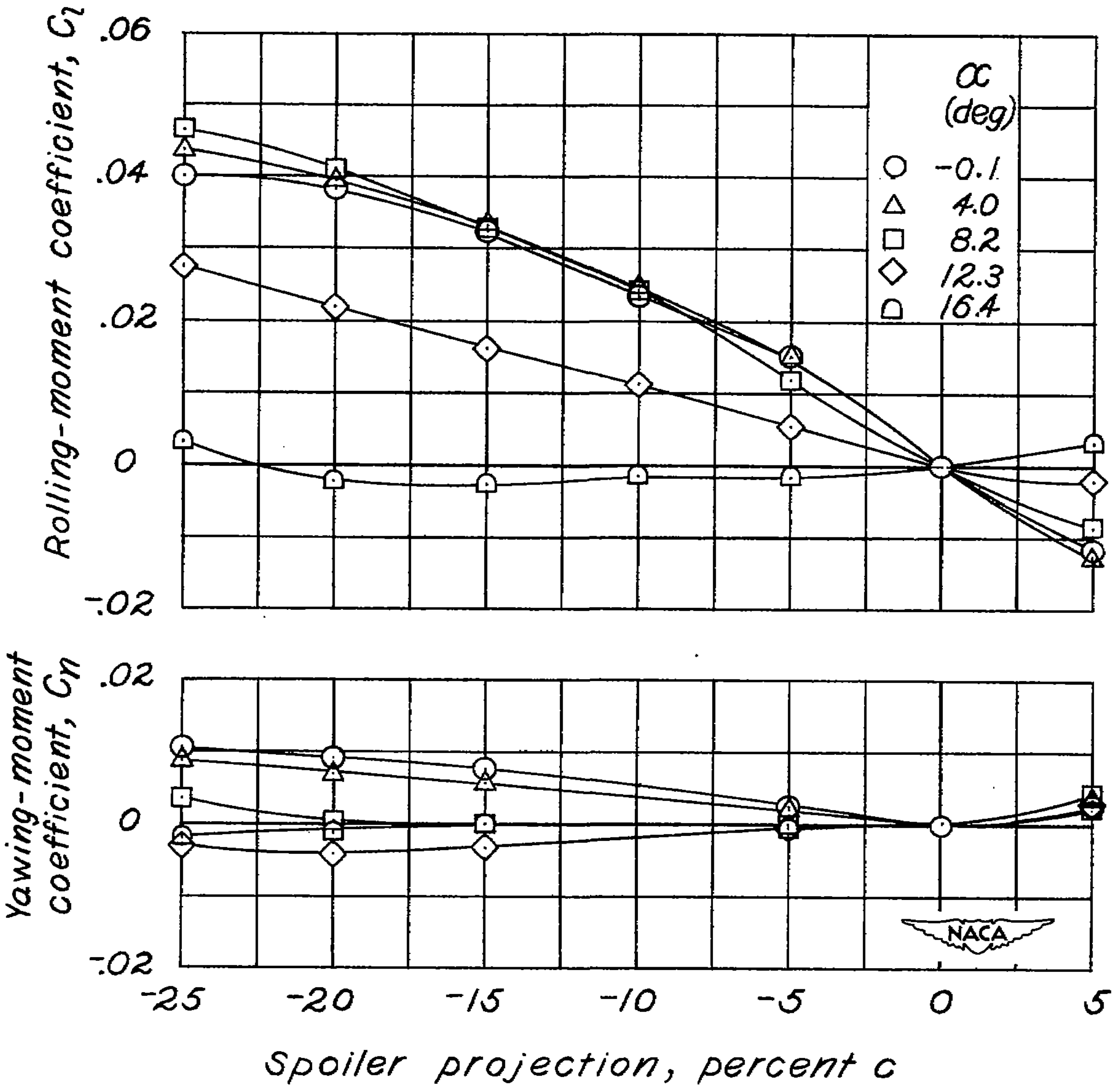
(c) M ≈ 0.8.

Figure 4.- Continued.



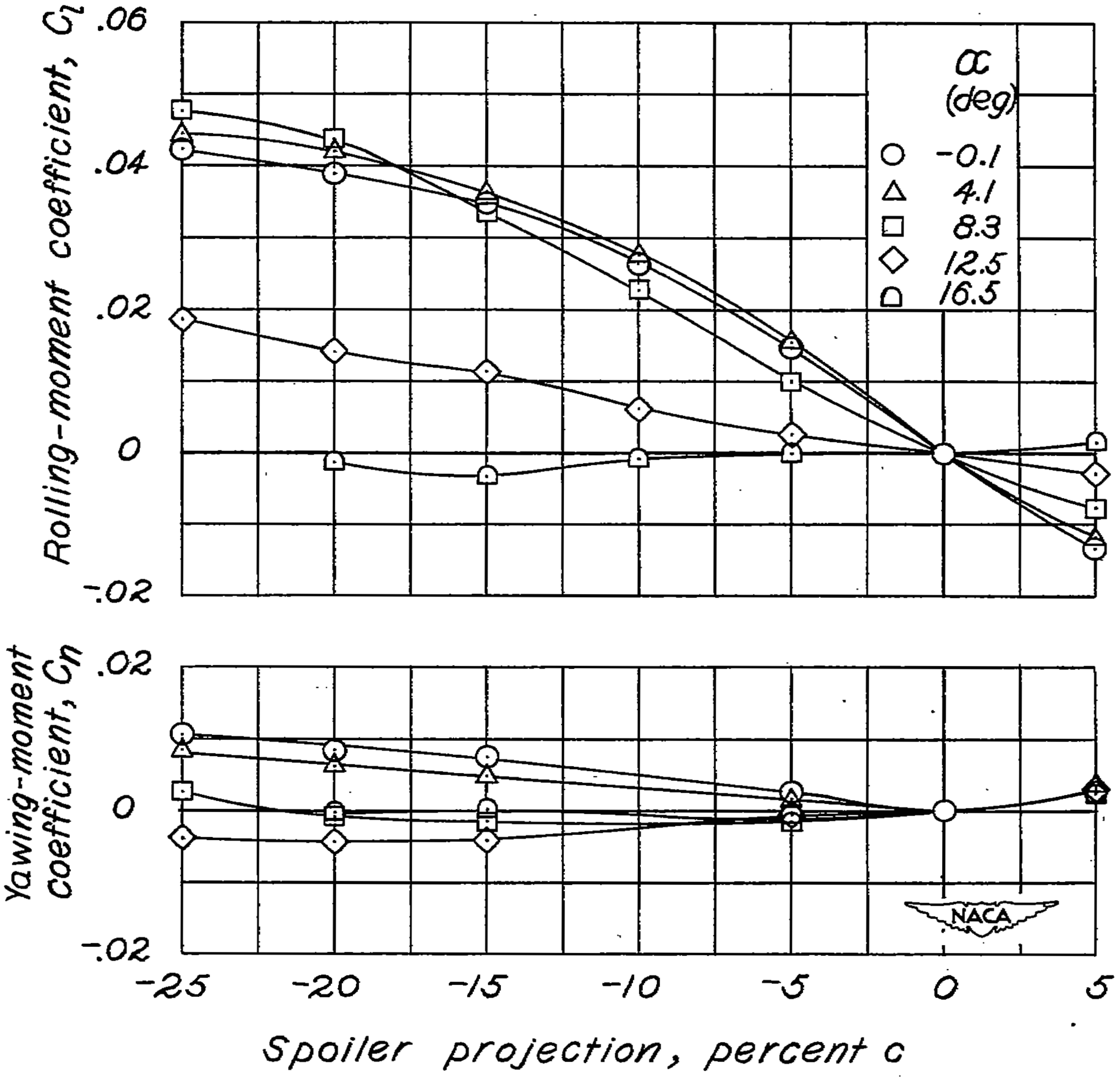
(d) M ≈ 0.91.

Figure 4.- Concluded.



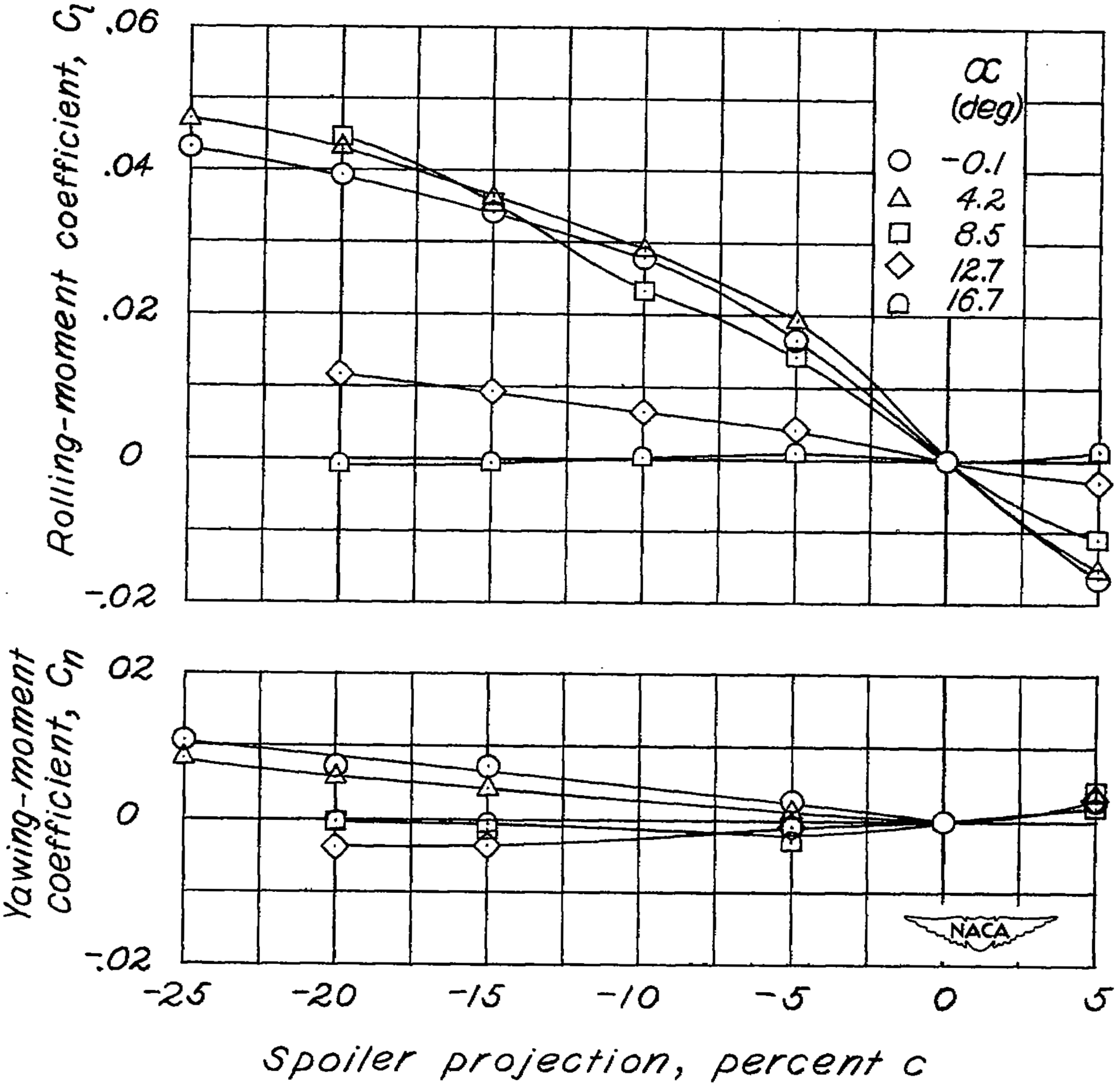
(a) $M \approx 0.4$.

Figure 5.- Variation of lateral control characteristics with spoiler projection for several angles of attack.



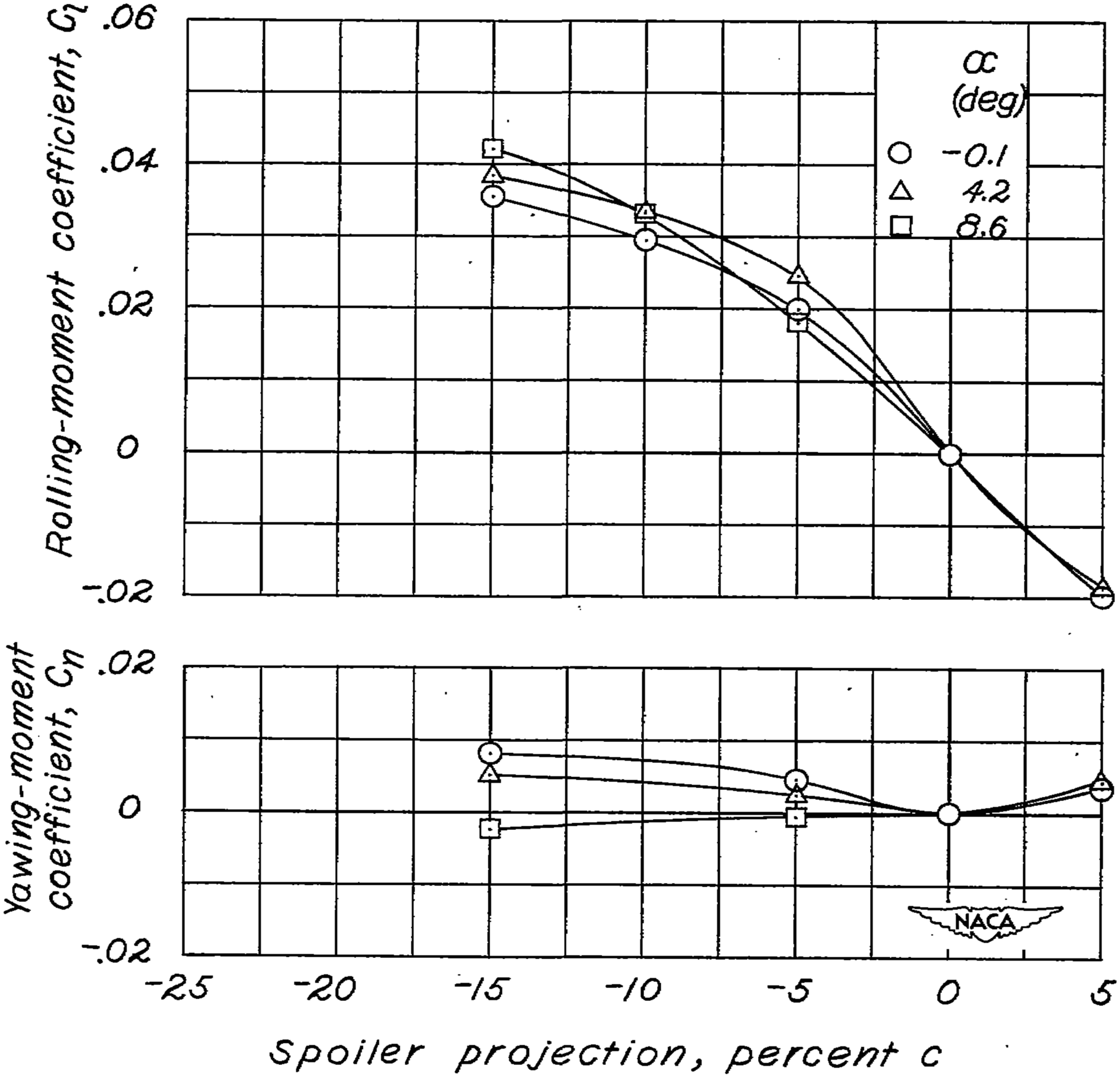
(b) M $\approx$ 0.6.

Figure 5.- Continued.



(c) M ≈ 0.8.

Figure 5.- Continued.



(d) M ≈ 0.91.

Figure 5.- Concluded.

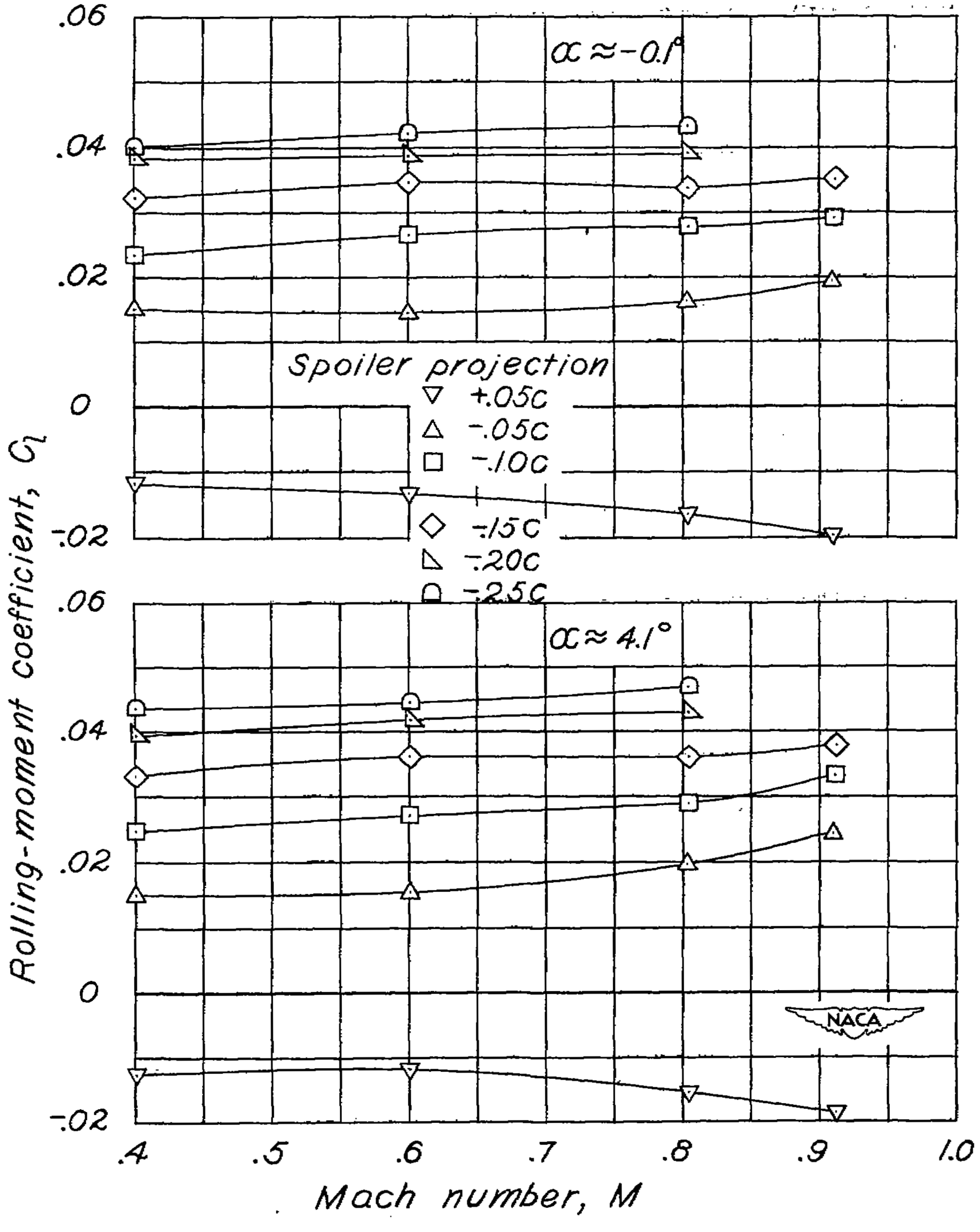


Figure 6.- Variation of rolling-moment coefficient with Mach number for various spoiler projections and angles of attack.

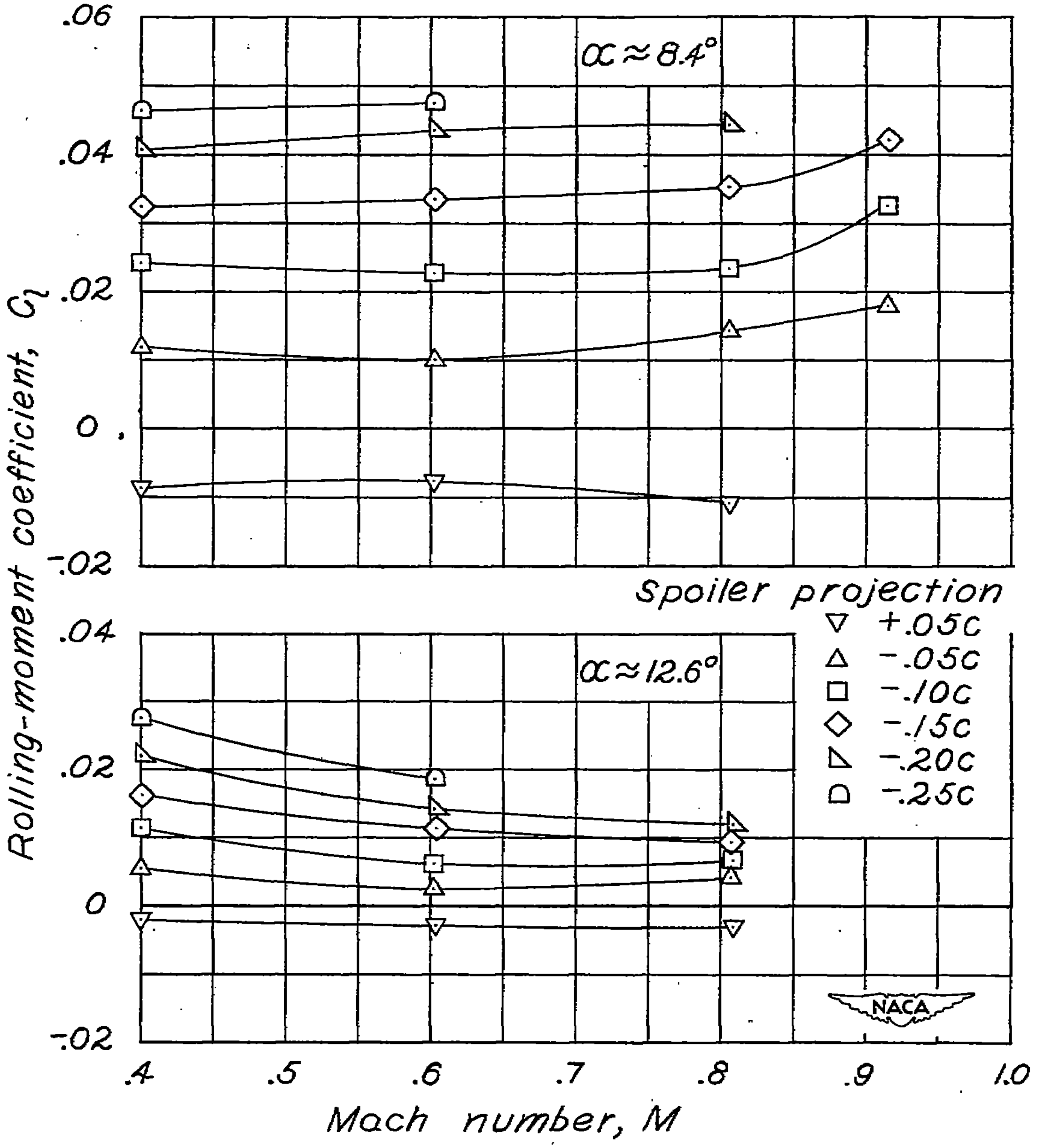
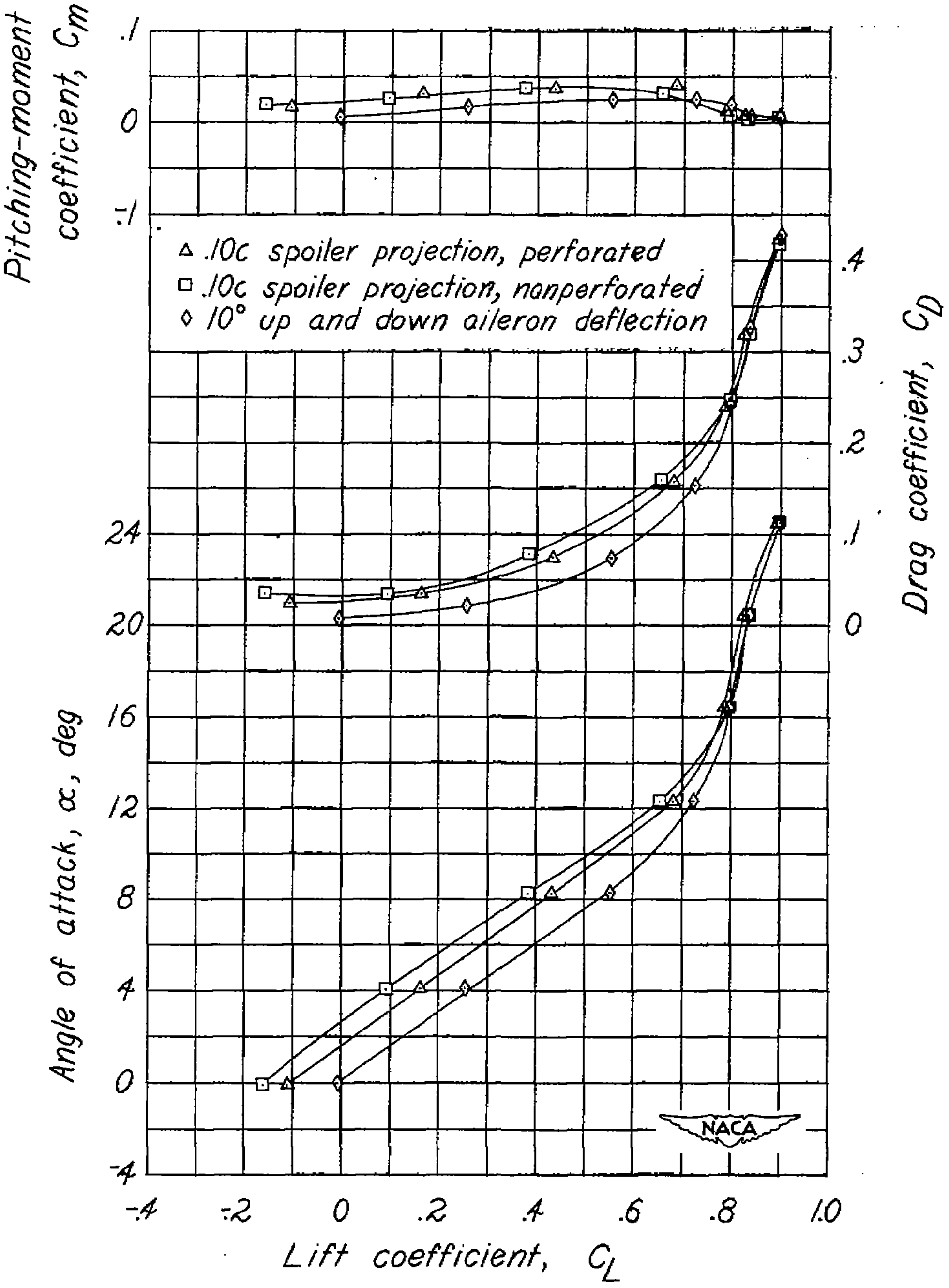


Figure 6.- Concluded.



(a) $M \approx 0.4$.

Figure 7.- Comparison of the effect of perforated and nonperforated spoilers and plain ailerons on the aerodynamic characteristics in pitch.

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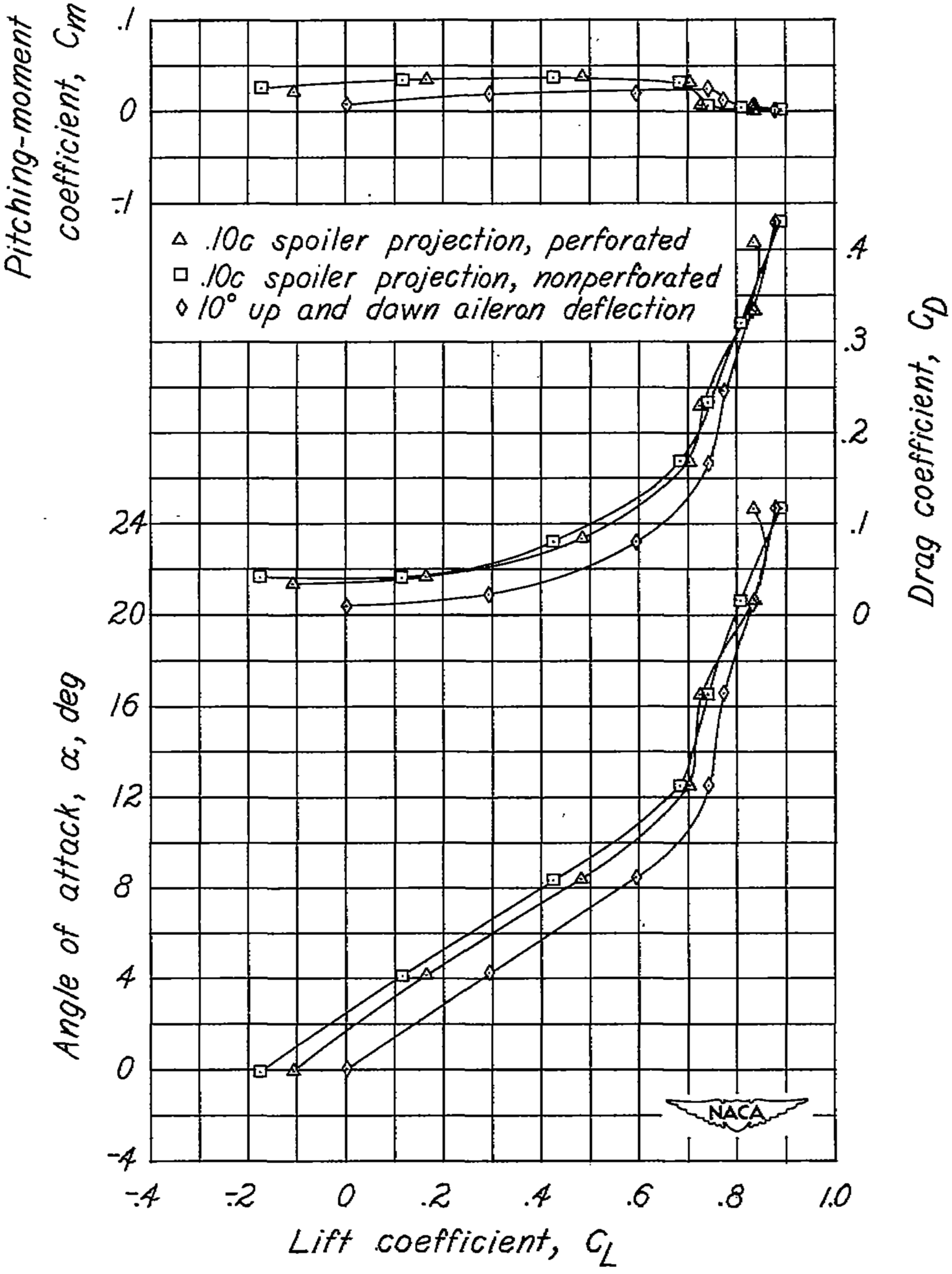

(b) $M \approx 0.6$.

Figure 7.- Continued.

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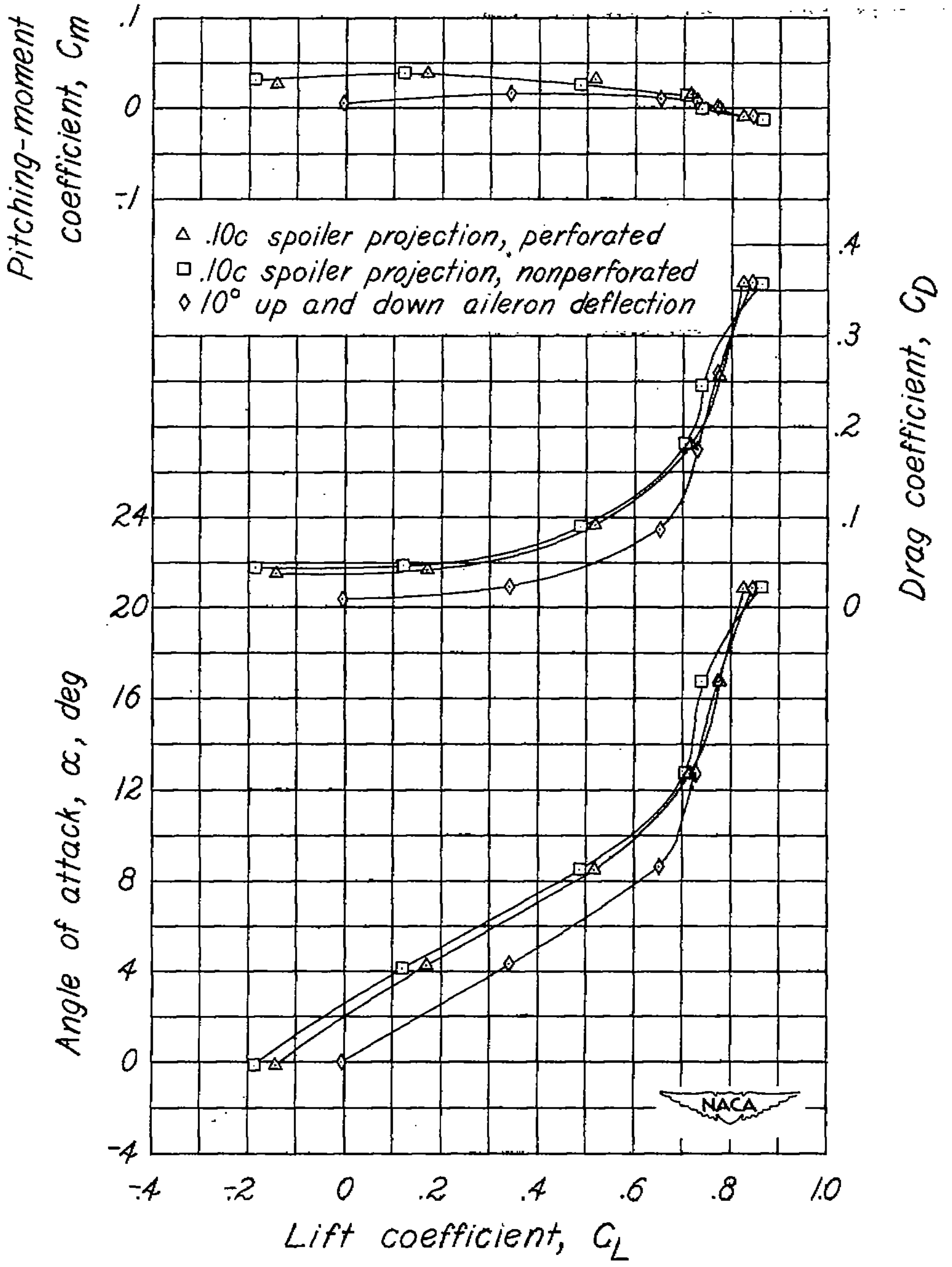
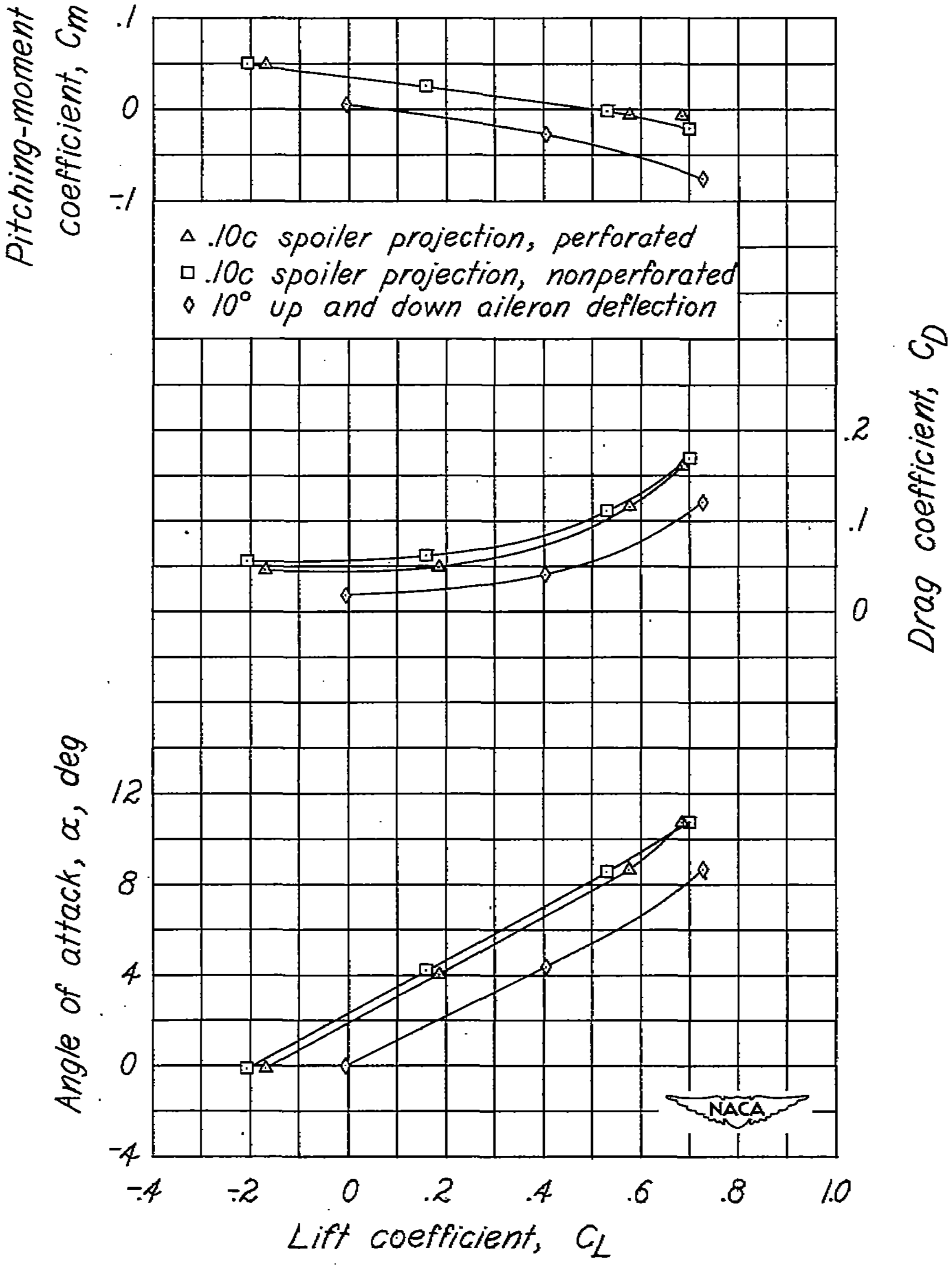


(c) M $\approx$ 0.8.

Figure 7.- Continued.



(d) $M \approx 0.91$.

Figure 7.- Concluded.

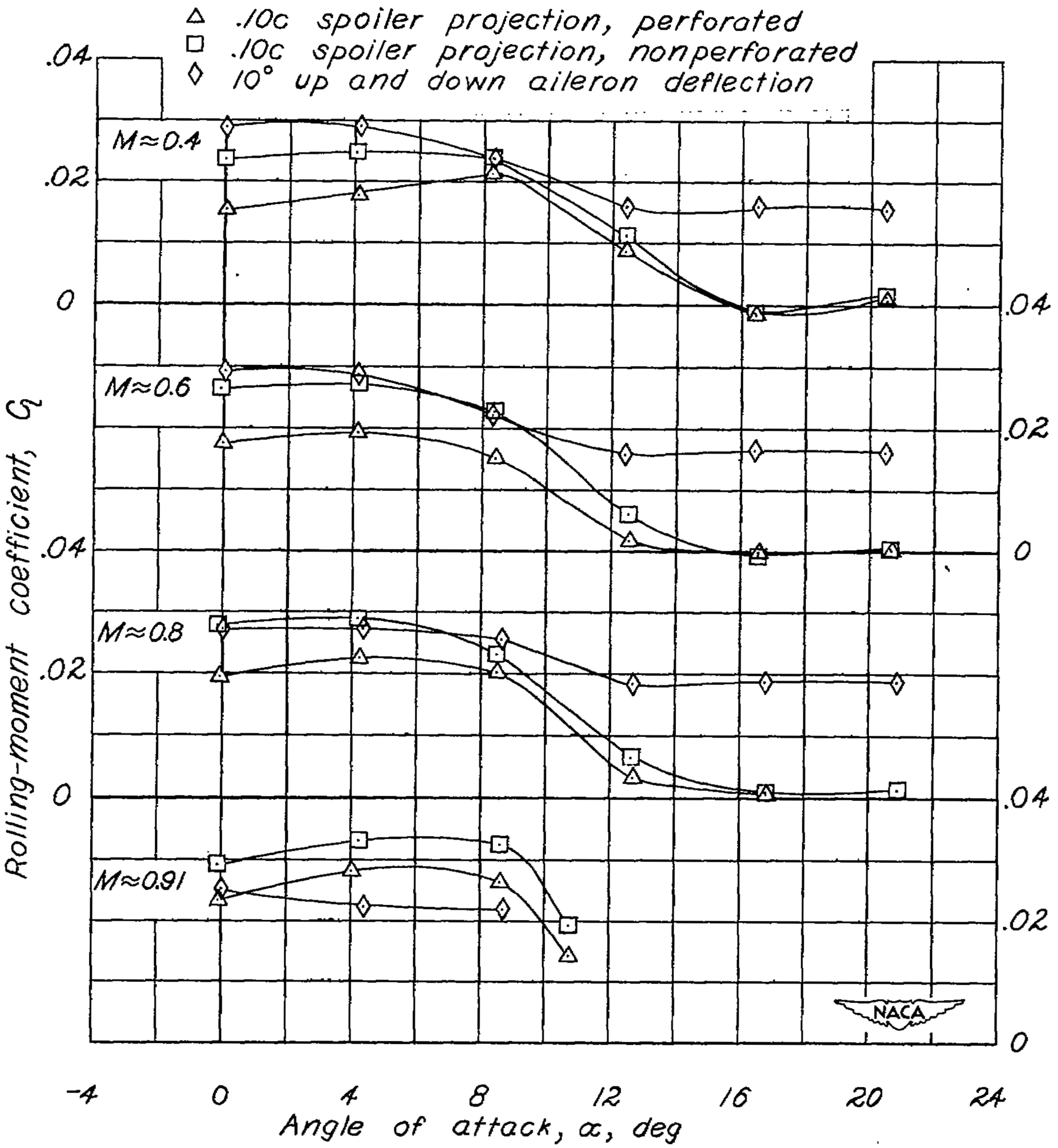


Figure 8.- Comparison of the lateral control characteristics produced by perforated and nonperforated spoilers and plain ailerons.

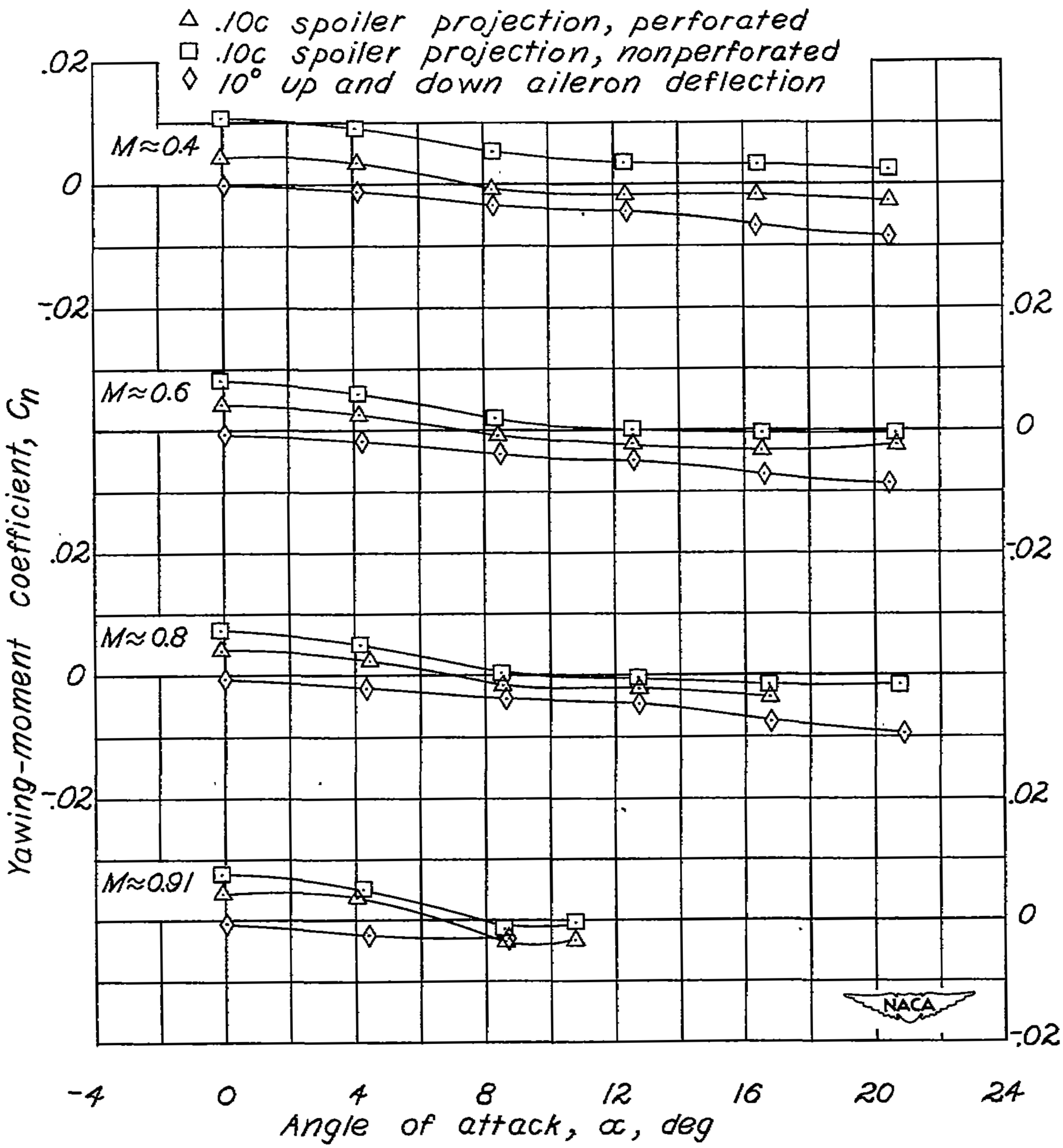


Figure 8.- Concluded.

[redacted]