[redacted]

NACA RM L54D13

NACA

RESEARCH MEMORANDUM

EFFECT AT TRANSONIC SPEEDS OF INBOARD SPOILERS ON THE STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF A 45° SWEPTBACK WING-BODY COMBINATION HAVING A LEADING-EDGE CHORD-EXTENSION

By James H. Henderson

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
June 14, 1954

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT AT TRANSONIC SPEEDS OF INBOARD SPOILERS ON THE STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF A 45° SWEPTBACK WING-BODY COMBINATION HAVING A LEADING-EDGE CHORD-EXTENSION

By James H. Henderson

SUMMARY

An exploratory investigation was made in the Langley 9- by 12-inch blowdown tunnel primarily to determine the effect of inboard spoilers located along the 20- and 30-percent-chord lines on the static longitudinal stability characteristics of a semispan 45° sweptback wing-body combination having a leading-edge chord-extension. The model was usually tested through a Mach number range from 0.86 to 0.99 and an angle-of-attack range from about -4° to about 14°. Reynolds number varied from about 1.25×10^6 to 1.60×10^6. The effects of the chord-extension on longitudinal stability characteristics and of the spoilers on rolling-moment characteristics were also determined.

The model pitching-moment characteristics were improved by spoilers extending from 15 percent semispan to 45 percent semispan. Spoilers having shorter spans caused little or no improvement in the pitching-moment characteristics. Changing spoiler height from 5 to 8 percent of the local wing chord or changing the spoiler location from the 20- to 30-percent-wing-chord line generally had only small effects on the linearity of the pitching-moment curves. The increase in incremental drag coefficient due to spoiler deflection varied linearly with spoiler projection area and ranged from about 0.04 at zero lift to a maximum value of 0.07 at a lift coefficient of about 0.6 for the largest spoiler. Changing spoiler location from the 20- to the 30-percent-wing-chord line had little effect on drag.

INTRODUCTION

Leading-edge chord-extensions have been found to be among the most effective devices for improving the undesirable longitudinal stability characteristics of sweptback wing configurations at subsonic speeds and transonic speeds (refs. 1 and 2). However, for a small Mach number range (the Mach number limits of this range are dependent on model geometry) at transonic speeds leading-edge chord-extensions do not prevent pitch-up tendencies because they have only a slight effect in reducing large areas of shock-induced flow separation that cause lift losses over the outboard portions of sweptback wings (see ref. 3). Other modifications to swept-back wing configurations such as fences and leading-edge slats have also been unsuccessful in eliminating this outboard flow separation. Another method of reducing the pitch-up tendencies of a sweptback wing configuration for the critical Mach number range would be to reduce the wing lift ahead of the pitch axis simultaneously with the loss of lift over the outboard wing sections. It seemed possible that these pitch-up tendencies could be decreased by spoilers which were positioned on the wing to reduce the upper-surface leading-edge pressure peaks lying ahead of the pitch axis.

Hence, in order to determine whether large-scale tests were warranted, it appeared to be desirable to make an exploratory investigation of several spoilers on a semispan 45° sweptback wing-body configuration having a 35-percent-semispan leading-edge chord-extension in the transonic nozzle of the Langley 9- by 12-inch blowdown tunnel. The model was tested at Mach numbers from 0.86 to 0.99 and at angles of attack from about -4° to 14°. The Reynolds number of the investigation based on the mean aerodynamic chord ranged from about 1.25×10^{6} to 1.60×10^{6}. For the same test conditions the model was also investigated without either spoilers or a chord-extension. In this paper are presented the results of force and moment measurements made during the investigation. For the spoiler configurations the effects of varying height, span, and chordwise location of the spoilers on the lift, drag, pitching-moment, and rolling-moment characteristics are shown.

SYMBOLS

Coefficients are presented about the wind axes.

b wing span (twice distance from rolling-moment axis to wing tip)

b_i spanwise location of inboard end of spoiler

b_o spanwise location of outboard end of spoiler

c local wing chord

$\bar{c}$ wing mean aerodynamic chord

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

$C_{l_{gross}}$ gross rolling-moment coefficient, $\frac{\text{Semispan-wing rolling moment}}{2qSb}$ (reference axis shown in fig. 1)

C_m pitching-moment coefficient, $\frac{\text{Pitching moment about } 0.25\bar{c}}{qS\bar{c}}$

h height of spoiler above wing surface (measured normal to wing-chord plane)

M free-stream Mach number

q free-stream dynamic pressure

S semispan-wing area without chord-extension

$\frac{y_{cp}}{b/2}$ lateral center-of-pressure position, $\frac{\text{Bending moment about body axis}}{(\text{Normal force})b/2}$

α angle of attack of body axis measured with respect to free-stream direction

ΔC_D increment in drag coefficient due to spoiler projection

$\Delta C_{l_{gross}}$ increment in gross rolling-moment coefficient due to spoiler projection

DESCRIPTION OF MODEL

The geometric details of the semispan wing-body combination, chord-extension, and various spoiler configurations are given in figure 1 and a photograph of the model is shown as figure 2. The steel wing had 45° sweepback of the quarter-chord line, aspect ratio 4, taper ratio 0.6, and NACA 65A006 airfoil sections (see ref. 4 for ordinates) parallel to the plane of symmetry. The blunt streamwise wing tip was not faired.

The brass chord-extension, which was symmetrical about the chord plane, projected 0.15c ahead of the wing leading edge and extended from 0.65b/2 to 1.00b/2. The chord-extension had the same section ordinates back to its point of maximum thickness as the corresponding spanwise wing airfoil sections, and the airfoil contour between the maximum thickness points of the chord-extension and the wing was parallel to the wing-chord line.

The spoilers, which were made of 1/32-inch brass sheet, had constant-percent-chord heights above the wing surface and were located along constant-percent-chord lines. The spoilers were mounted on the upper surface of the wing which was considered as the right wing for the present investigation. The various spoilers tested in conjunction with the model having the chord-extension are described in the table in figure 1.

A test body consisting of a half-body of revolution together with a 0.25-inch Micarta shim was integral with the wing for all tests.

TUNNEL

The tests were made in the Langley 9- by 12-inch blowdown tunnel which operates from the compressed air of the Langley 19-foot pressure tunnel. The absolute stagnation pressure of the air entering the test section ranges from 2 to $2\frac{1}{3}$ atmospheres. The compressed air is treated to insure condensation-free flow by being passed through a silica-gel drier and then through banks of finned electrical heaters. Criteria for condensation-free flow were obtained from reference 5. Turbulence damping screens are located in the settling chamber. A single removable nozzle block provides test-section Mach numbers of 0.70 to 1.4.

The model was investigated in a nozzle having a slotted transonic test section for which preliminary calibration tests have indicated satisfactory test-section flow characteristics for the Mach number range of the present investigation. The maximum deviation in Mach number from the average Mach number in the region occupied by the model ranges from

± 0.005 for the lowest test Mach number (0.86) to ± 0.008 for the highest Mach number (0.99). Limited stream-angle data indicated that the flow angularity probably would not exceed $\pm 0.1^\circ$ for any Mach number.

TEST TECHNIQUE

The semispan model was cantilevered from a five-component strain-gage balance set flush with the tunnel floor. The balance rotated with the model as the angle of attack was changed. The forces and moments were measured with respect to the body axes and then rotated to the wind axes. In order to minimize the tunnel-wall boundary-layer effect on the flow over the surface of the half-body of revolution (see ref. 6) it was shimmed out 0.25 inch from the tunnel wall. A clearance gap of about 0.010 inch was maintained between the test body and the tunnel wall.

CORRECTIONS

No corrections have been applied to the data to account for lift interference or tunnel-wall blockage. Although evaluation of the transonic nozzle is incomplete, preliminary work indicates that despite the large size of the model relative to the tunnel (wing area is 16 percent of the test-section cross-sectional area) these corrections are small except perhaps at the highest angles of attack above a Mach number of 0.94. From these considerations as well as consideration of the submergence of the test body in the tunnel boundary layer, it appears that the absolute value of the force and moment coefficients are of questionable value. However it is believed that the changes in force and moment coefficients due to the spoilers and chord-extension are approximately correct. No corrections are available for effects of reflection-plane interference on the rolling-moment coefficients and consequently the incremental values of rolling moment due to spoilers are questionable.

ACCURACY OF MEASUREMENTS

An estimate of the probable errors introduced in the present data by instrument reading errors, measuring-equipment errors, and balance calibration errors are presented in the following table:

α, deg	±0.04
C_L	±0.005
C_l	±0.0005
C_m	±0.001
C_D	±0.001

RESULTS AND DISCUSSION

Lift, drag, and pitching-moment characteristics of the model with and without the chord-extension are compared in figure 3. The effect of spoilers on the lift, drag, pitching-moment characteristics of the model with the chord-extension are shown in figure 4 for spoilers having various heights and chordwise locations and in figure 5 for spoilers having various spans. Incremental rolling-moment characteristics for the spoiler configurations are also shown in figures 4 and 5. Presented in figure 6 are the lateral centers of pressure for several configurations.

Pitching Moment

As has been previously shown (for example, see ref. 1) figure 3(c) indicates that there are Mach numbers where the addition of a chord-extension to a model only partially alleviates the magnitude and abruptness of the pitching-moment variations with lift. In the present investigation these Mach numbers were 0.95 and 0.99. At the lower Mach numbers this alleviation was considerably greater, and it is probable that with a practical tail configuration the improvement at a Mach number of 0.86 would be satisfactory.

The addition of spoilers having a span extending from 0.15b/2 to 0.45b/2 generally improved the pitching-moment characteristics (figs. 4(c) and 4(d)); whereas addition of the spoilers having shorter spans generally provided little or no improvement (fig. 5(c)). Figures 4(c) and 4(d) show that the addition of the larger span spoilers either delayed the large unstable pitching-moment break to higher values of lift coefficient and angle of attack or reduced the abruptness of this break. However, the departure from linearity was still undesirable for most cases.

Changes of spoiler height and spoiler chordwise location generally had only small effects on the linearity of the pitching-moment curves.

Lift

The addition of the chord-extension to the model increased the lift at high angles of attack and generally increased the linearity of the lift curves (fig. 3(a)). The lift curves in figures 4(a) and 5(a) show that the addition of the spoilers resulted in lift decrements which increased with increasing angle of attack up to moderate angles of attack and decreased with further increases in angle of attack. At low and moderate angles of attack these lift decrements varied almost linearly with the projected areas of the spoilers.

Drag

The addition of the chord-extension to the model had little effect on the drag at low lift coefficients but caused a reduction in drag at high lift coefficients (fig. 3(b)). Figures 4(b) and 5(b) show that the addition of spoilers resulted in large drag increments through the low and moderate lift-coefficient range. These increments varied linearly with the projected areas of the spoilers up to a lift coefficient of about 0.6. The chordwise location of the spoilers apparently had little effect on the drag. For the spoilers with the largest projected area the increments in drag coefficient amounted to as much as 0.04 at zero lift and 0.07 for a lift coefficient of about 0.6 and they diminished at higher lifts.

Because of the large increases in drag, the use of the particular inboard spoilers tested as a device for improving the longitudinal stability of sweptback wing configurations may be impracticable; however, there is a possibility that spoilers might be used effectively as speed brakes provided that no large trim changes occur with a horizontal tail present.

Rolling Moment

The effectiveness of the various spoilers as lateral-control devices is shown by the incremental gross rolling-moment data of figures 4(e) and 5(d). The rolling effectiveness of the spoilers having a span extending from $0.15b/2$ to $0.45b/2$ usually was increased with angle of attack up to about 6° or 8° and was generally reduced considerably or lost at angles of attack of about 10° to 12° (see fig. 4(e)). Increasing the spoiler projection from $0.05b/c$ to $0.08b/c$ increased the effectiveness and prevented the complete loss of effectiveness at the higher angles of attack (see also lift curves of fig. 4(a)). No consistent differences in the effectiveness of spoilers located along the 20- and 30-percent-chord lines were apparent. Decreasing the span of the spoilers (fig. 5(d)) generally resulted in reduced rolling-moment effectiveness.

Lateral Center of Pressure

Shown in figure 6 are the lateral center-of-pressure locations for the model with and without the chord-extension and for a representative spoiler configuration. Addition of the chord-extension to the model resulted in an outboard shift in the center of pressure at low angles of attack and at angles of attack above the large unstable pitching-moment break. At angles of attack near the unstable break in the pitching-moment curves ($\alpha \approx 8^{\circ}$) addition of the chord-extension resulted in very little change in the center of pressure for most Mach numbers. Mach number had no consistent effect on the lateral center-of-pressure position for the model with and without the chord-extension.

Deflection of the spoiler resulted in an inboard shift in the lateral center-of-pressure position that was appreciable at low angles of attack but was reduced considerably at moderate and high angles of attack. This inboard shift may have been due to both an increase in lift over the wing sections that were near the inboard end of the spoiler and a reduction of lift over the portion of the wing outboard of the spoiler. The increase in lift over the inboard wing sections may have been caused by lift increases behind the spoiler which resulted from high induced velocities due to turning of the flow over the spoiler and separation of the flow downstream of the spoiler (see ref. 7). The reduction in lift outboard of the spoiler may have been due to flow separation associated with boundary-layer outflow caused by the spoiler. In general, increasing the Mach number tended to cause an outboard shift in the lateral center-of-pressure position for the spoiler configuration.

SUMMARY OF RESULTS

The results of an investigation made at Mach numbers from 0.86 to 0.99 primarily to determine the effects of inboard spoilers on the longitudinal stability characteristics of a 45° sweptback wing-body combination with a leading-edge chord-extension indicated the following results:

1. The model pitching characteristics were improved by spoilers extending from 15 percent semispan to 45 percent semispan. Spoilers having shorter spans caused little or no improvement in the pitching-moment characteristics.

2. Changing spoiler height from 5 to 8 percent of the local wing chord or changing spoiler location from the 20- to 30-percent-wing-chord line generally had only small effects on the linearity of the pitching-moment curves.

3. The increase in drag coefficient due to spoiler deflection varied linearly with spoiler projection area and ranged from about 0.04 at zero lift to a maximum value of 0.07 at a lift coefficient of about 0.6 for the largest spoiler. Changing spoiler location from the 20- to the 30-percent-wing-chord line had little effect on drag. The large drags associated with the particular spoiler configurations tested may prohibit their use as a device for improving longitudinal stability characteristics; however, the spoilers may be effective as speed brakes.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 23, 1954.

REFERENCES

1. West, F. E., Jr., Liner, George, and Martz, Gladys S.: Effect of Leading-Edge Chord-Extensions on the Aerodynamic Characteristics of 45° Sweptback Wing-Fuselage Combination at Mach Numbers of 0.40 to 1.03. NACA RM L53B02, 1953.

2. Goodson, Kenneth W., and Few, Albert G., Jr.: Effect of Leading-Edge Chord-Extensions on Subsonic and Transonic Aerodynamic Characteristics of Three Models Having 45° Sweptback Wings of Aspect Ratio 4. NACA RM L52K21, 1953.

3. West, F. E., Jr., and Henderson, James H.: Relationship of Flow Over a 45° Sweptback Wing With and Without Leading-Edge Chord-Extensions to Longitudinal Stability Characteristics at Mach Numbers From 0.60 to 1.03. NACA RM L53H18b, 1953.

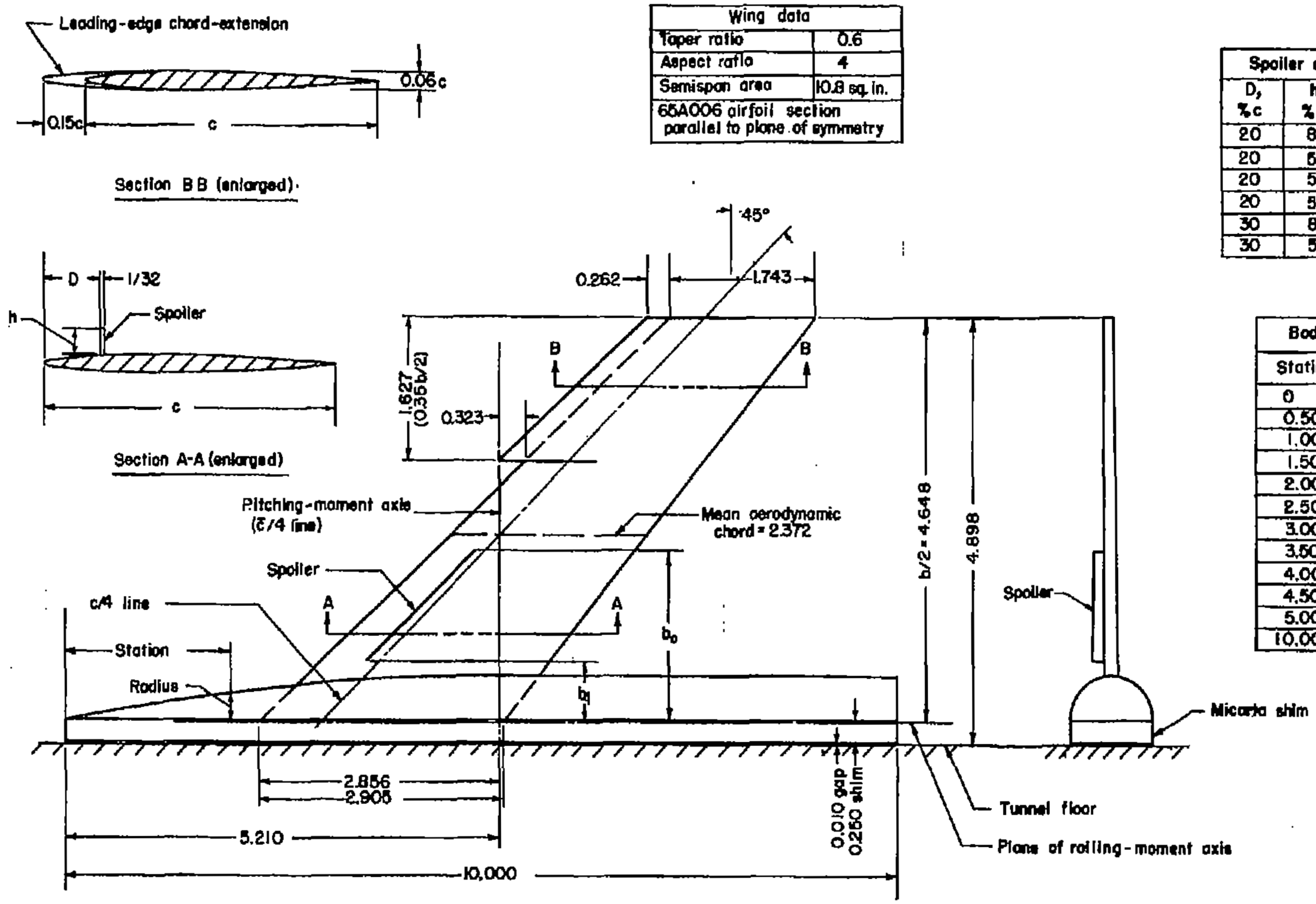
4. Loftin, Laurence K., Jr.: Theoretical and Experimental Data for a Number of 6A-Series Airfoil Sections. NACA Rep. 903, 1948. (Supersedes NACA TN 1368.)

5. Burgess, Warren C., Jr., and Seashore, Ferris L.: Criterions for Condensation-Free Flow in Supersonic Tunnels. NACA TN 2518, 1951.

6. Conner, D. William: Aerodynamic Characteristics of Two All-Movable Wings Tested in the Presence of a Fuselage at a Mach Number of 1.9. NACA RM L8H04, 1948.

7. Hallissy, Joseph M., West, F. E., Jr., and Liner, George: Effects of Spoiler Ailerons on the Aerodynamic Load Distribution Over a 45° Sweptback Wing at Mach Numbers From 0.60 to 1.03. NACA RM L54C17a, 1954.

[redacted]



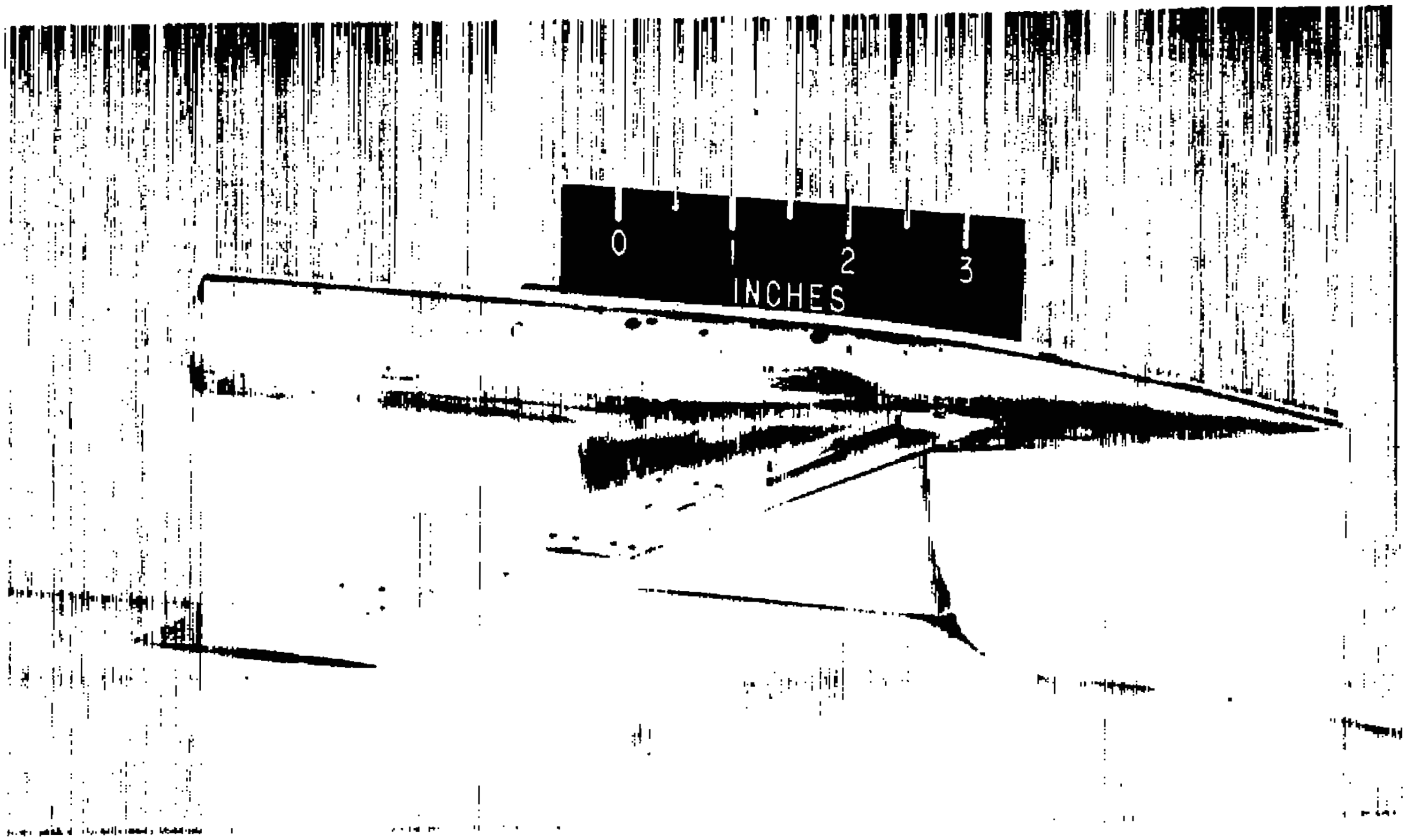
Wing data	
Taper ratio	0.6
Aspect ratio	4
Semispan area	10.8 sq. in.
65A006 airfoil section parallel to plane of symmetry	

Spoiler configurations			
D, %c	h, %c	b_i, %b/2	b_o, %b/2
20	8	15	45
20	5	15	45
20	5	15	35
20	5	20	35
30	8	15	45
30	5	15	45

Body coordinates	
Station	Radius
0	0
0.500	0.087
1.000	0.166
1.500	0.240
2.000	0.305
2.500	0.361
3.000	0.410
3.500	0.453
4.000	0.480
4.500	0.497
5.000	0.500
10.000	0.500

Figure 1.- Dimensions of model, leading-edge chord-extension, and spoilers. All dimensions in inches.

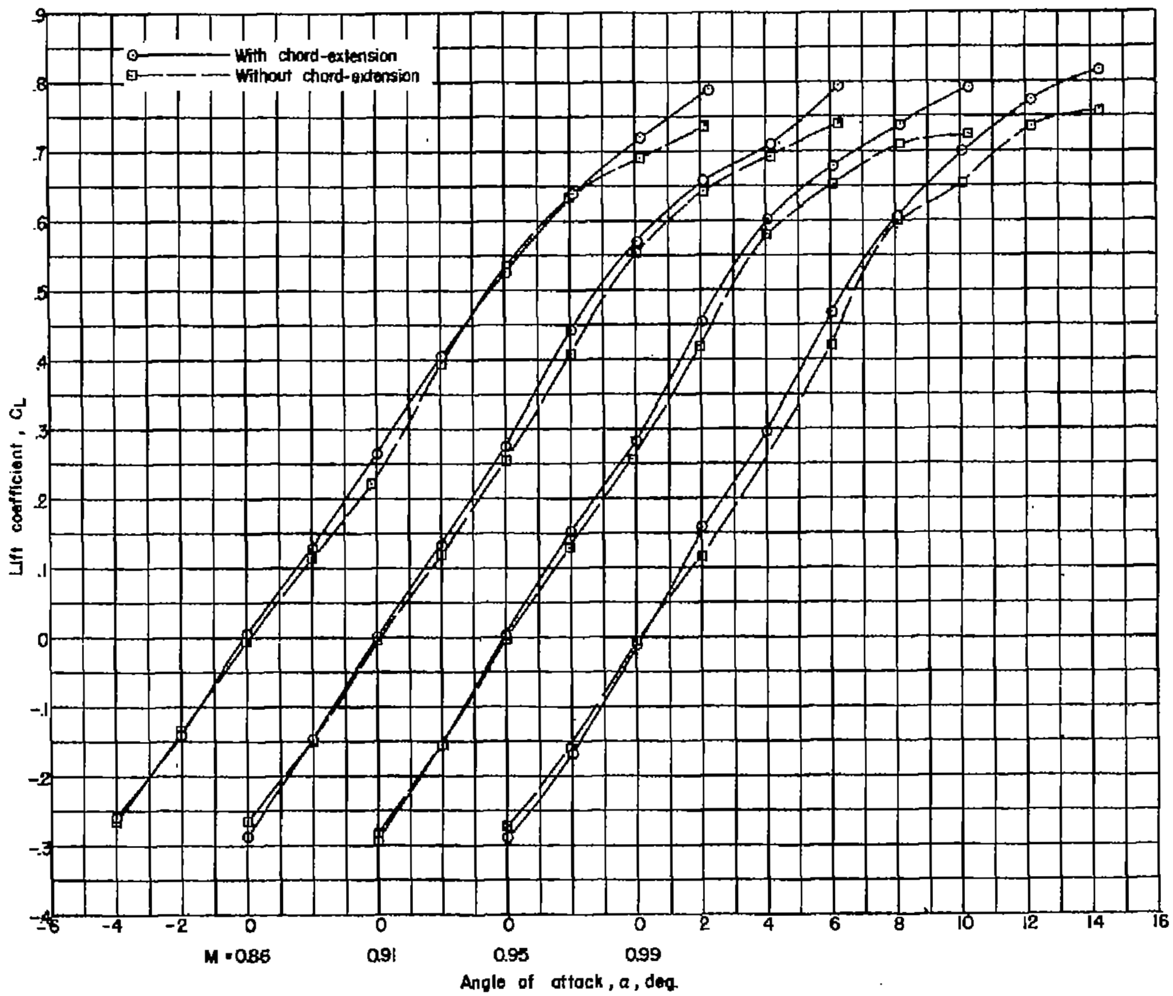
[redacted]



L-80948

Figure 2.- Photograph of model with spoiler located at the 20-percent-chord line. Spoiler extends from 0.15b/2 to 0.35b/2; h = 0.05c.

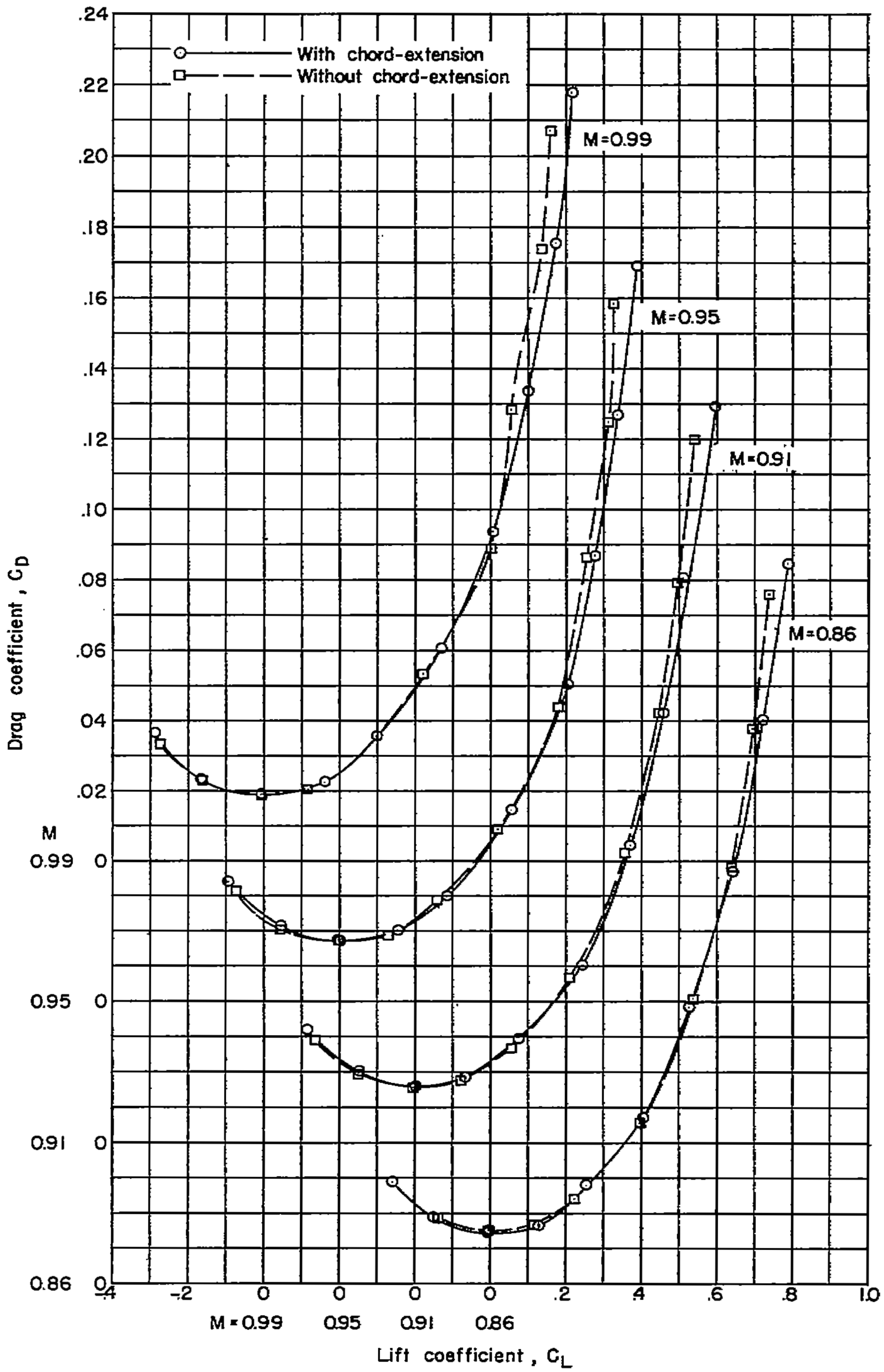
[redacted]



(a) Lift.

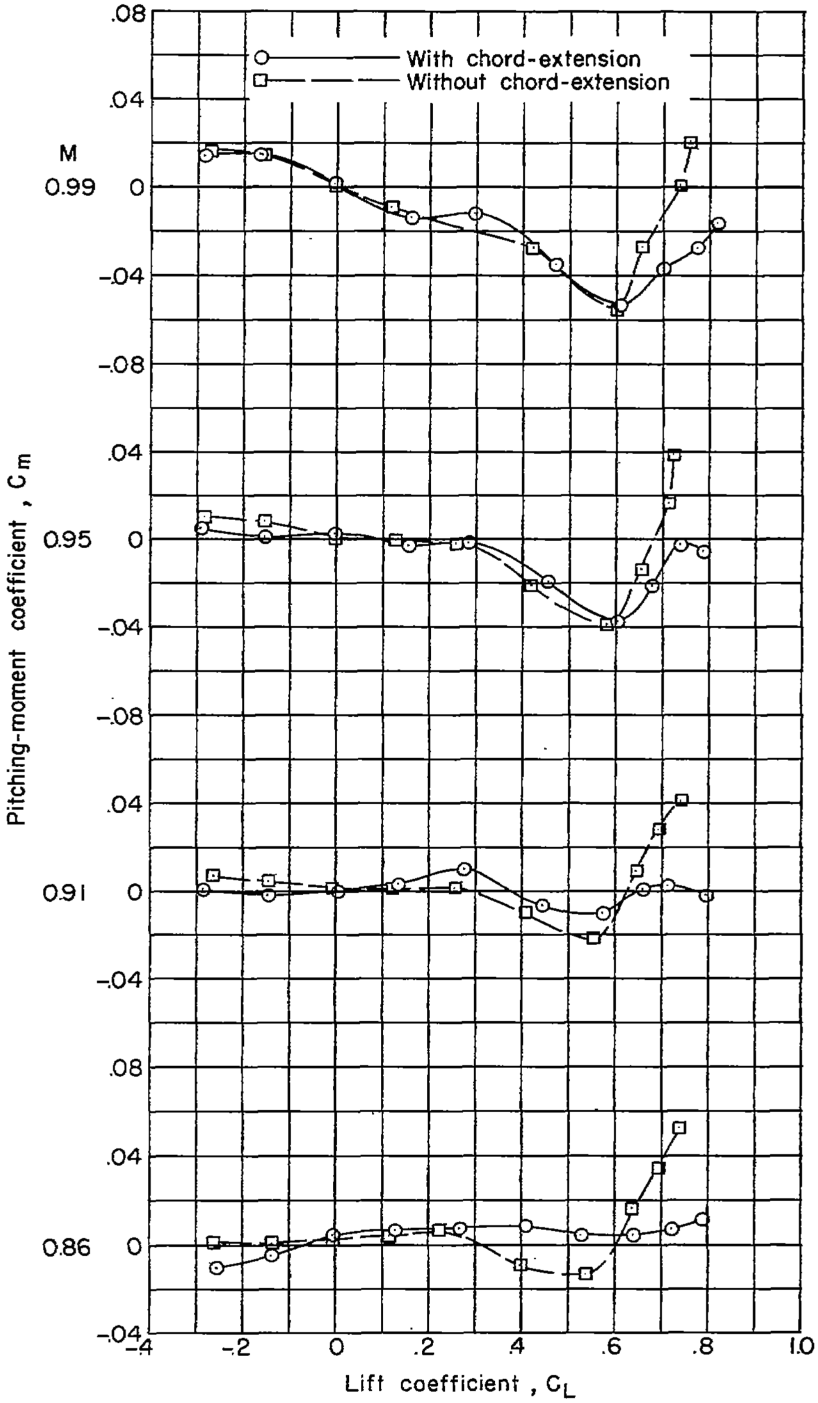
Figure 3.- Comparison of aerodynamic characteristics of model with and without a chord-extension.

[redacted]



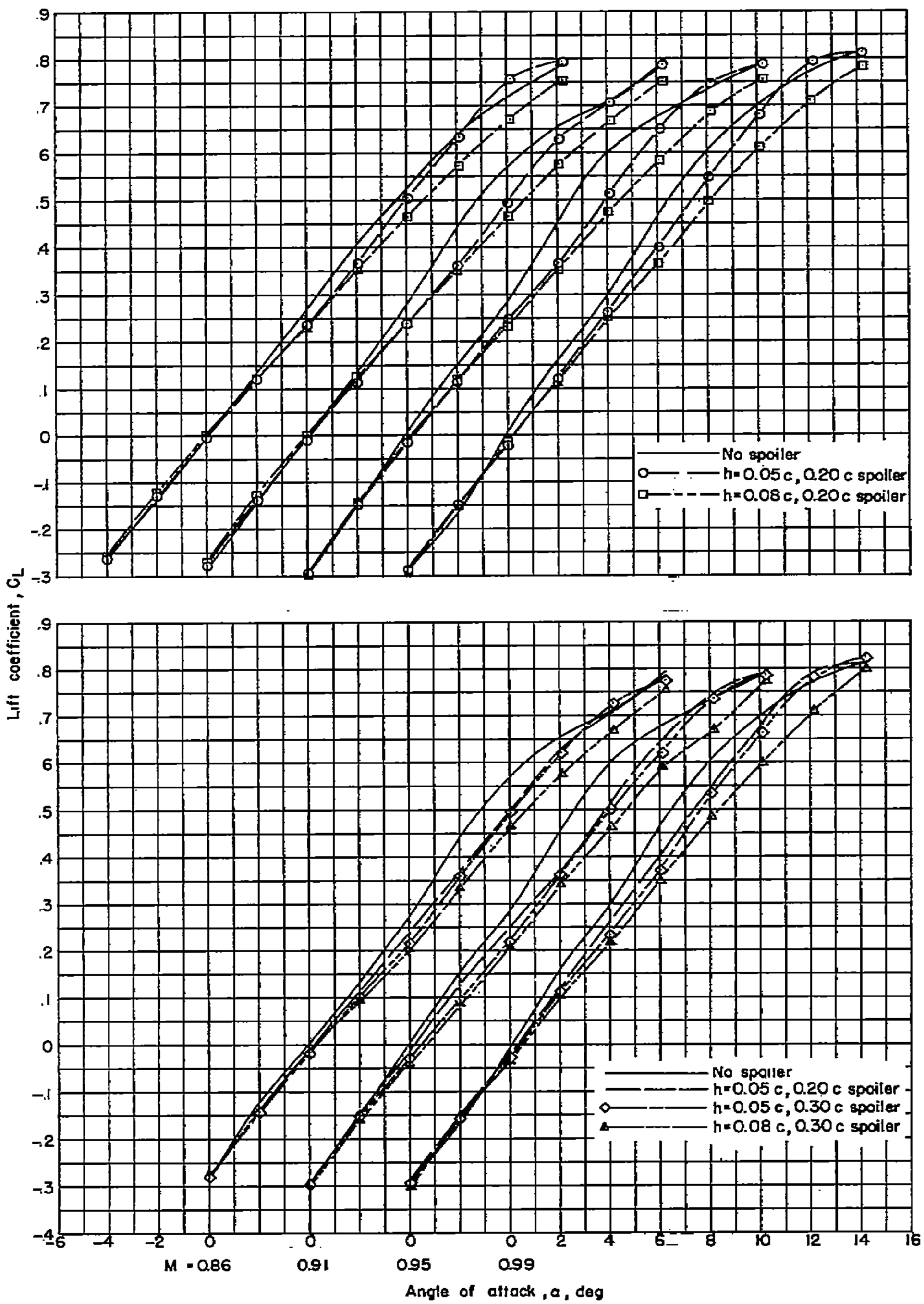
(b) Drag.

Figure 3.- Continued.



(c) Pitching moment.

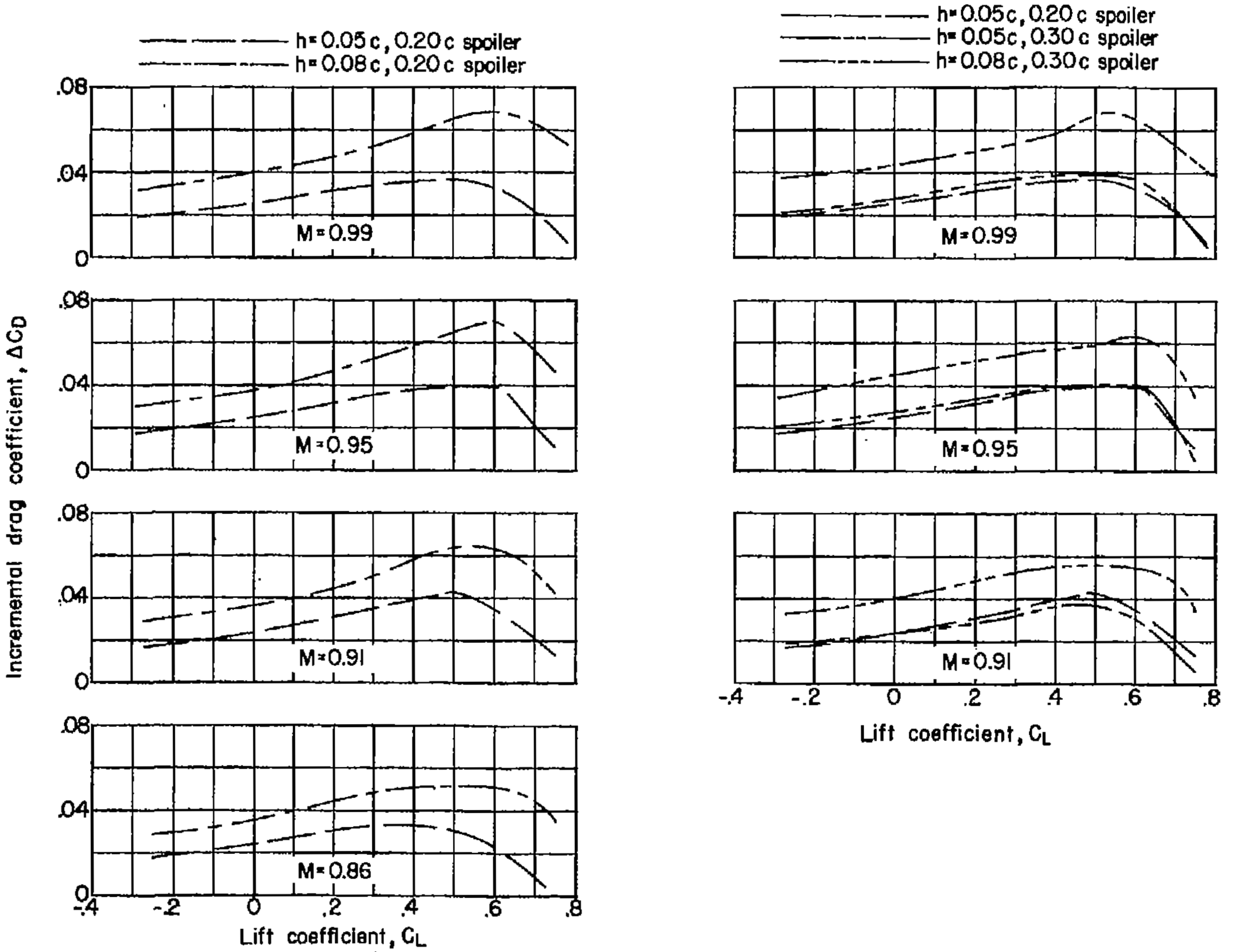
Figure 3.- Concluded.



(a) Lift.

Figure 4.- Effect of varying height and chordwise location of a spoiler having span extending from 0.15b/2 to 0.45b/2 on the aerodynamic characteristics of the model with a leading-edge chord-extension.

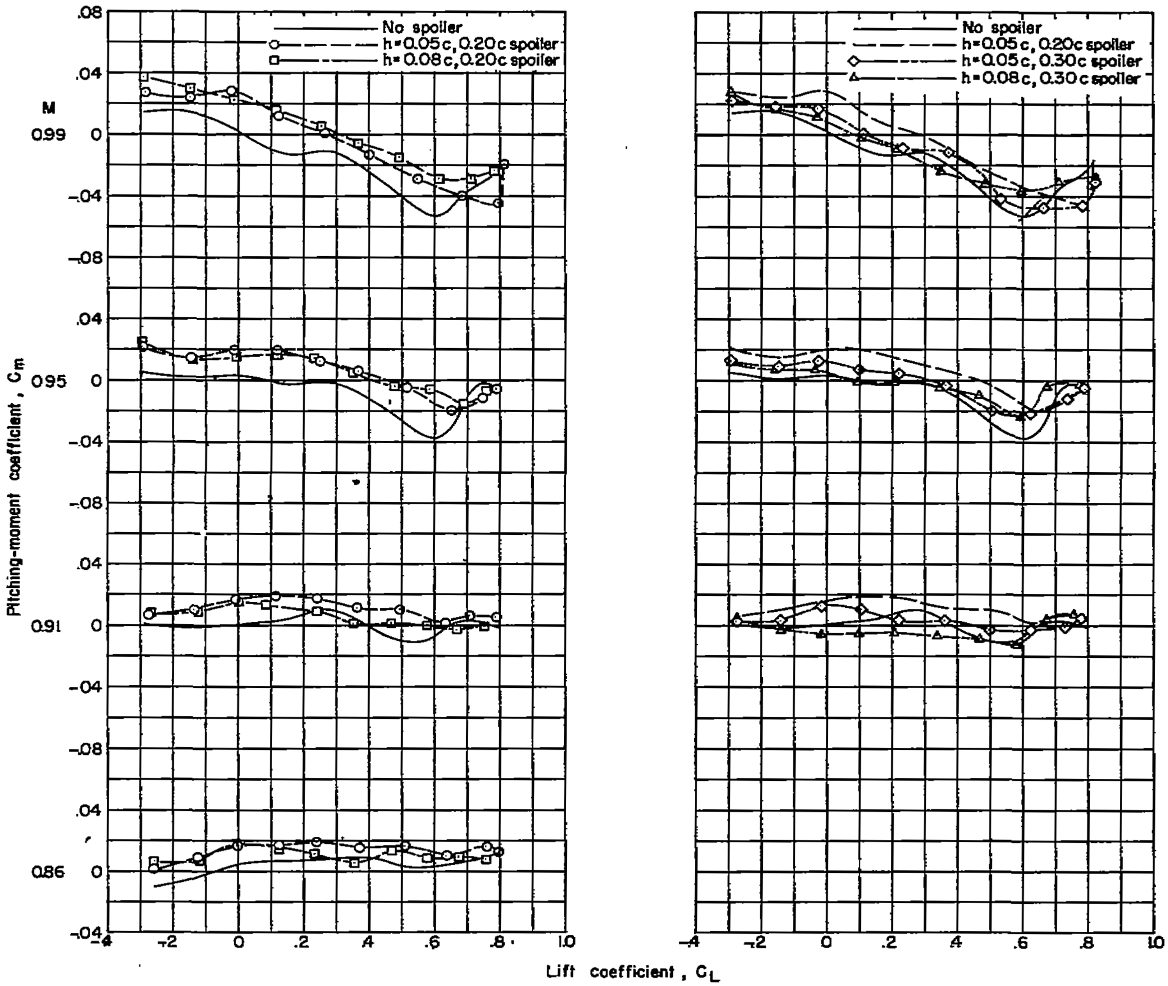
[redacted]



(b) Incremental drag.

Figure 4.- Continued.

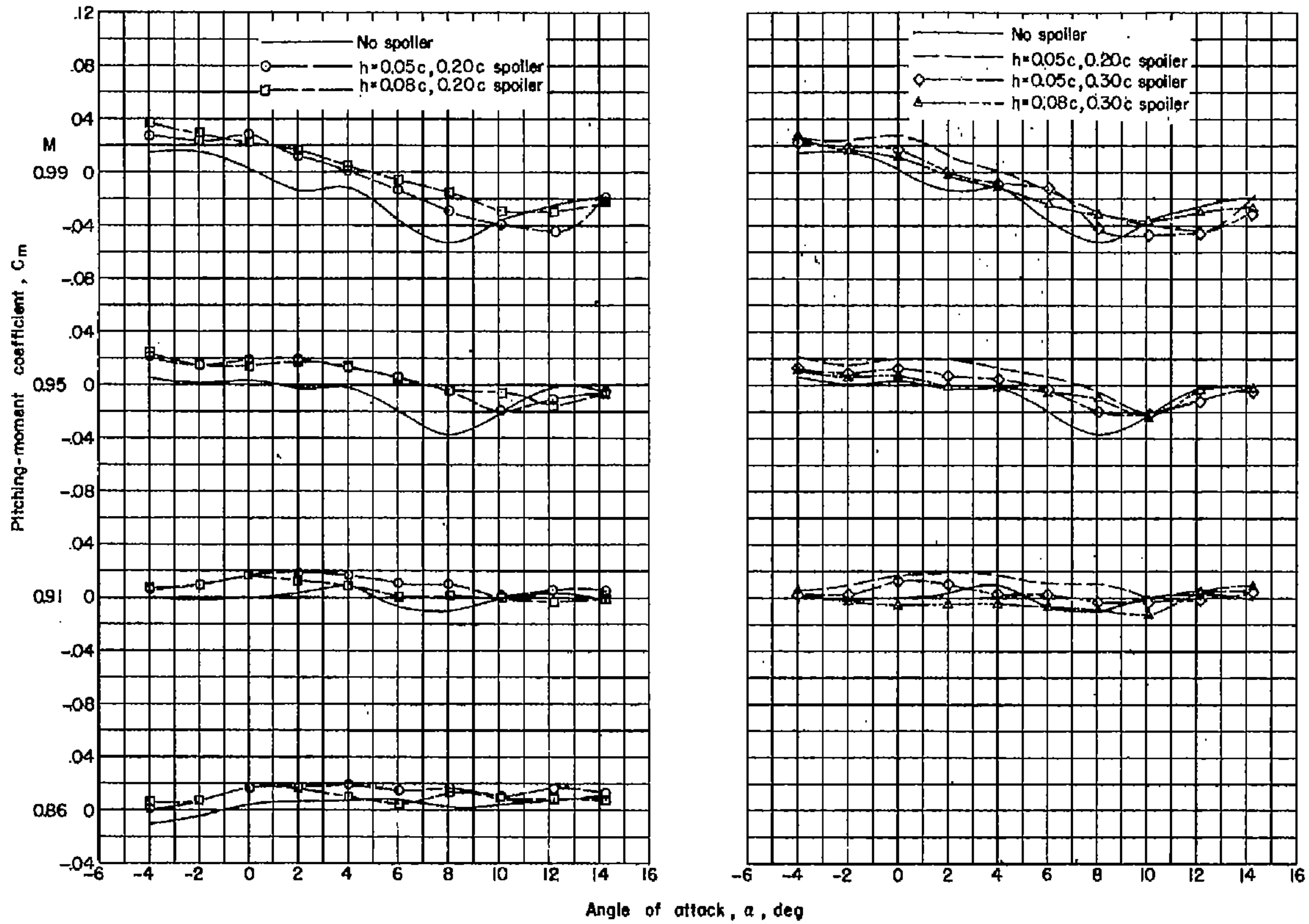
[redacted]



(c) Pitching moment.

Figure 4.- Continued.

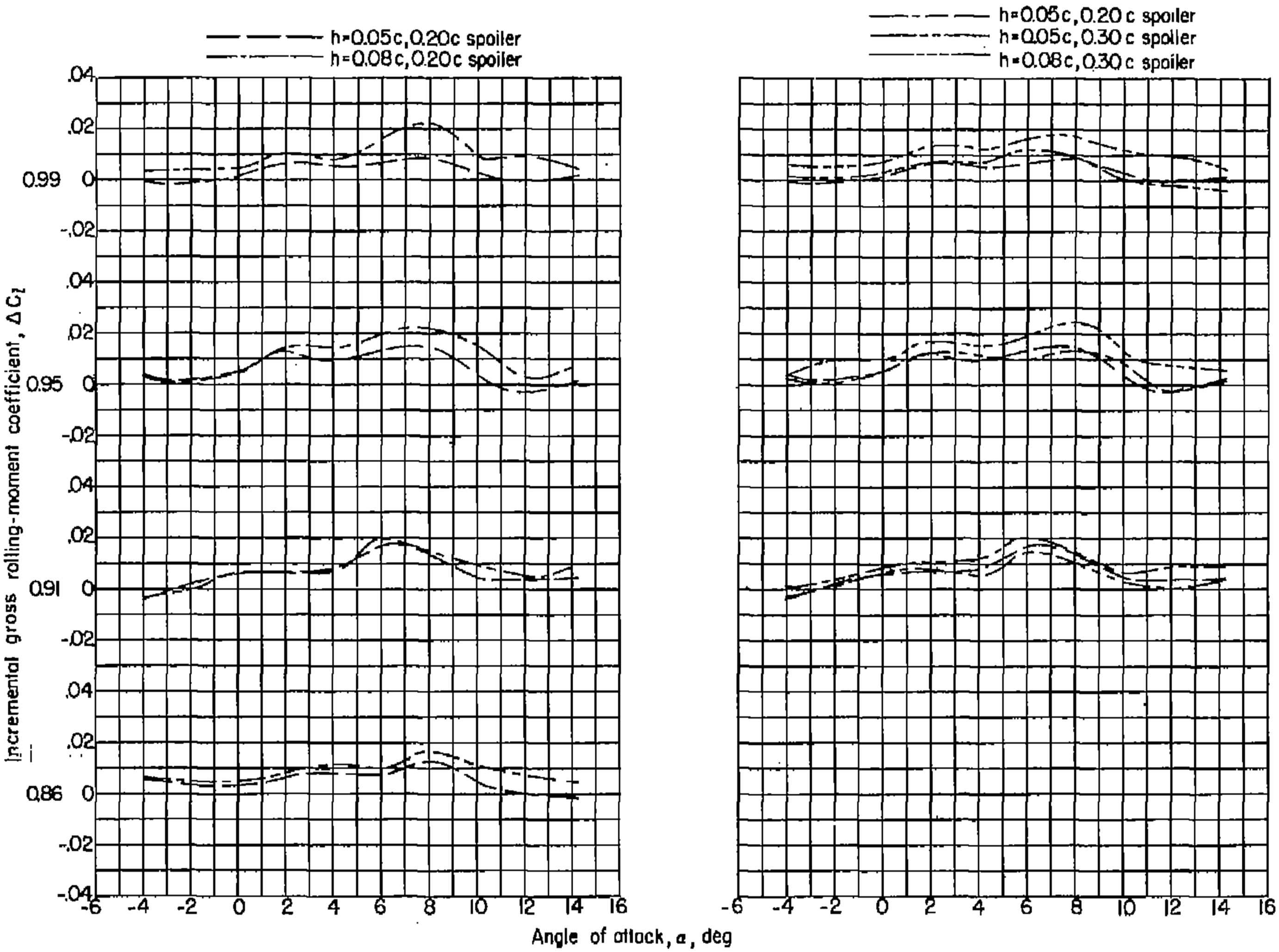
[redacted]



(d) Pitching moment.

Figure 4.- Continued.

[redacted]

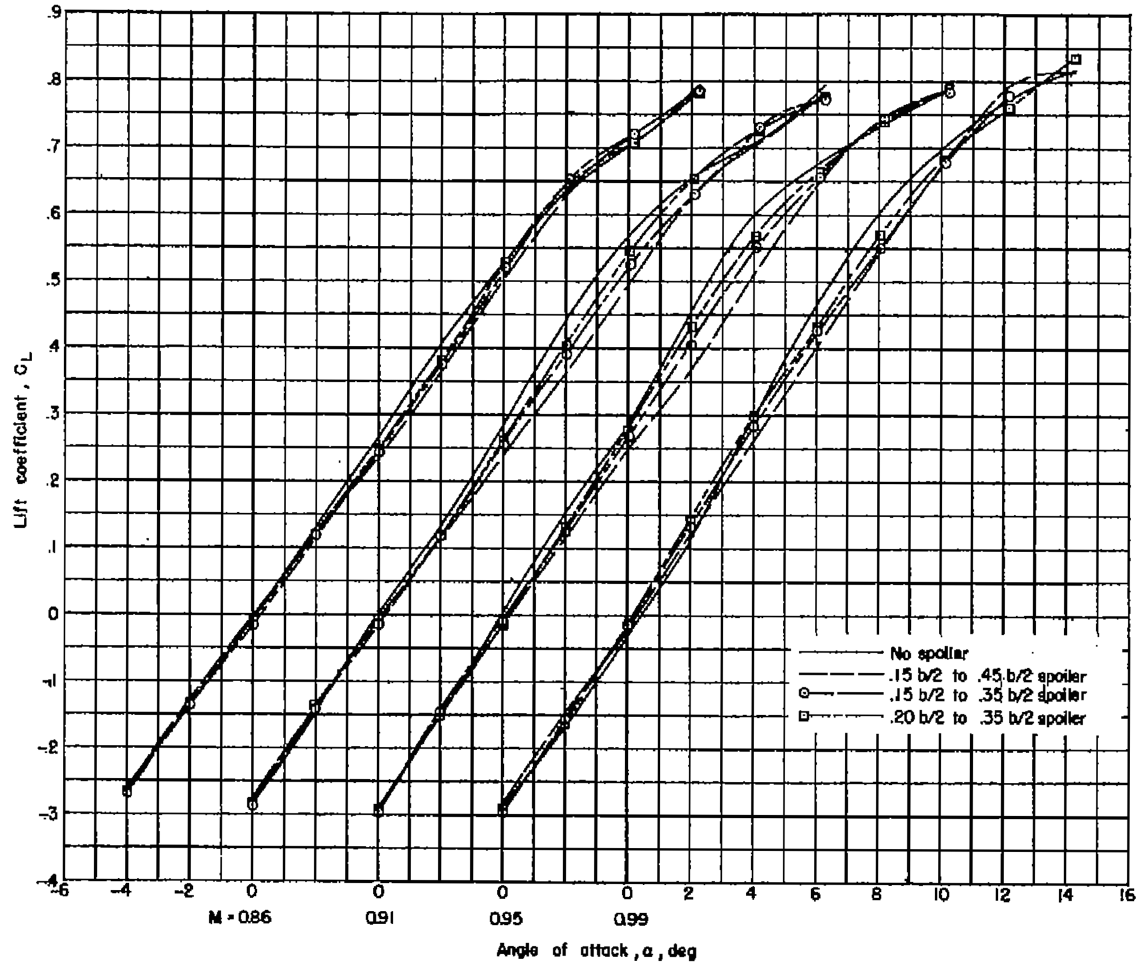


(e) Incremental gross rolling moment.

Figure 4.- Concluded.

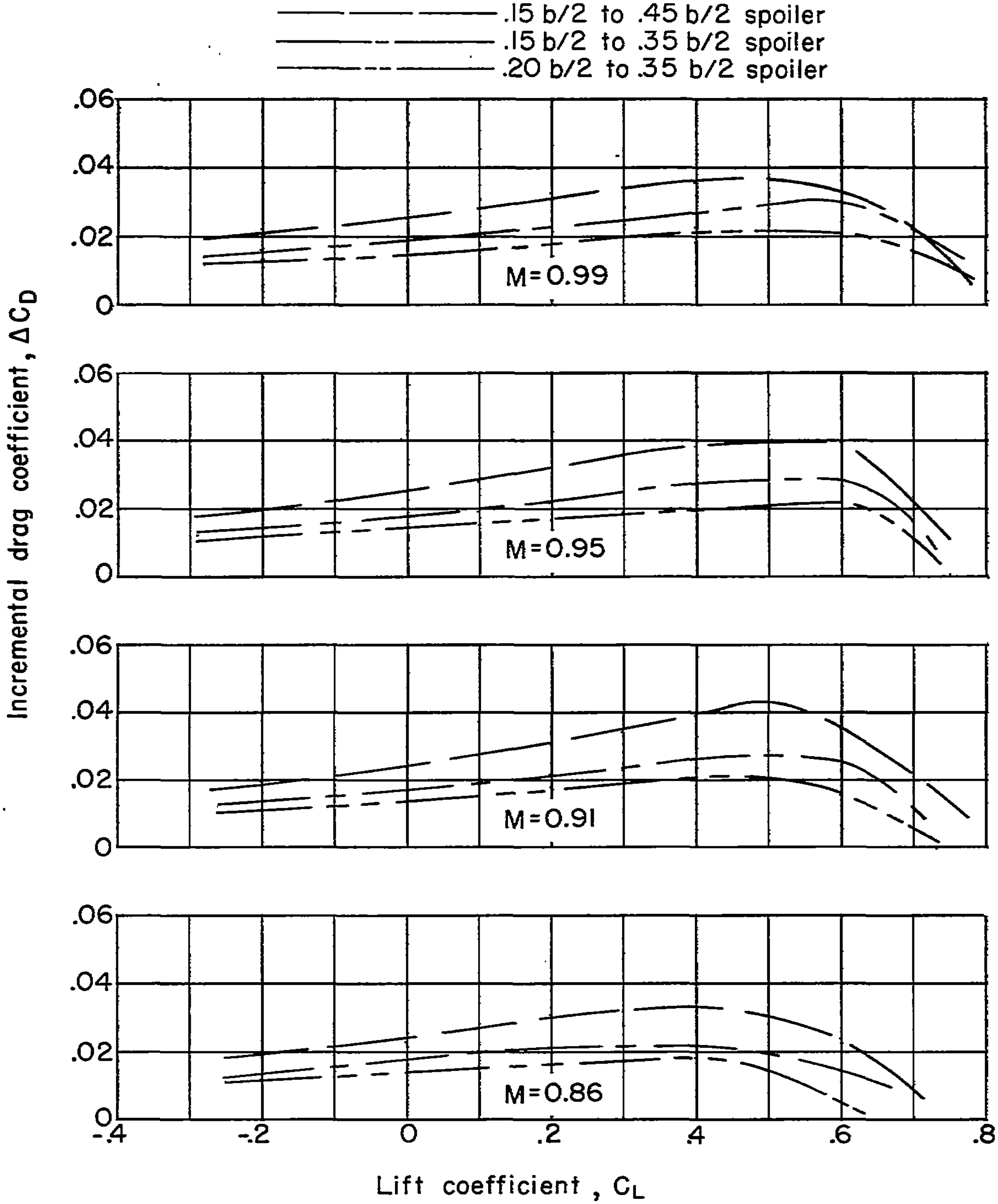
[redacted]

[redacted]



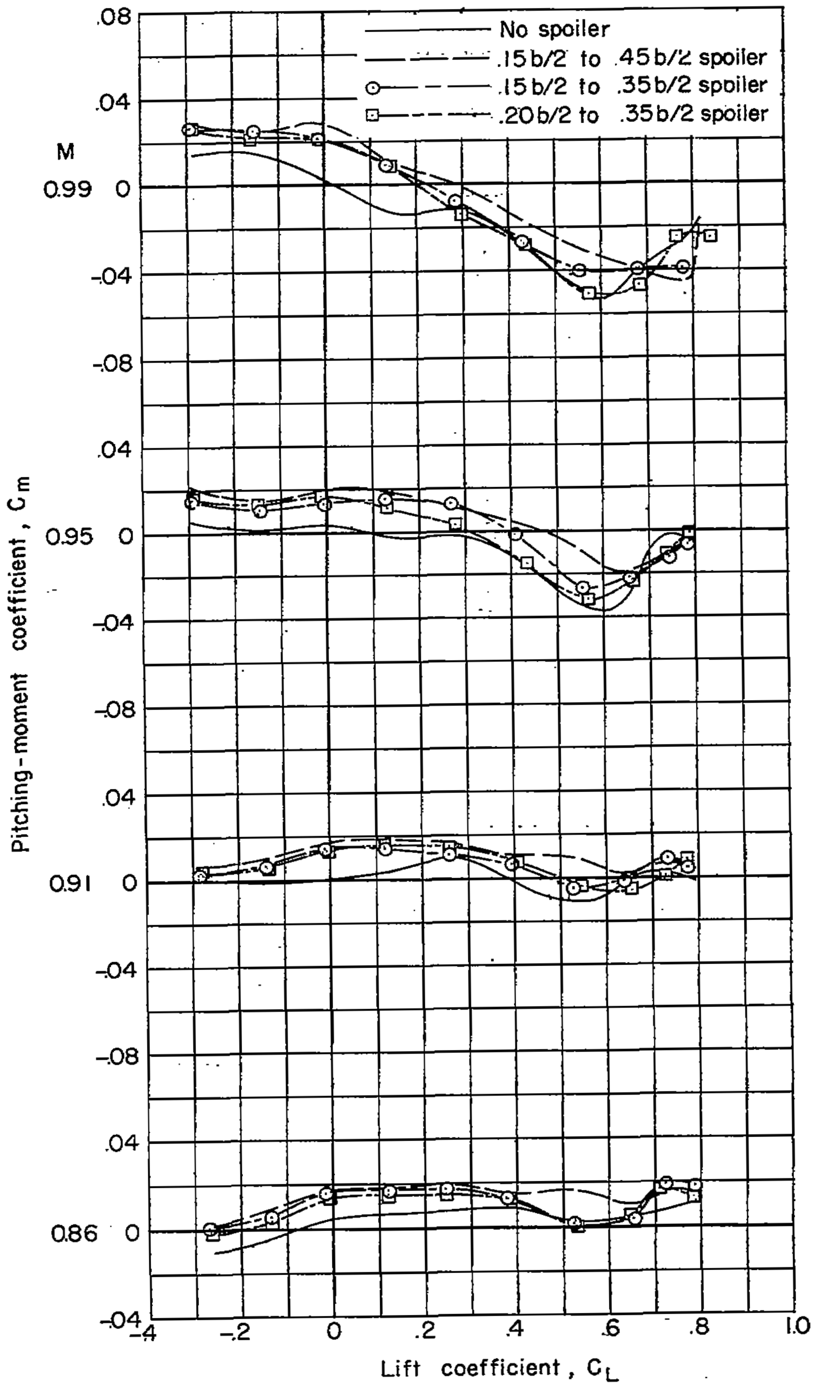
(a) Lift.

Figure 5.- Effect of varying span of spoiler having 5-percent-chord height located at 20 percent chord on the aerodynamic characteristics of the model with a leading-edge chord-extension.



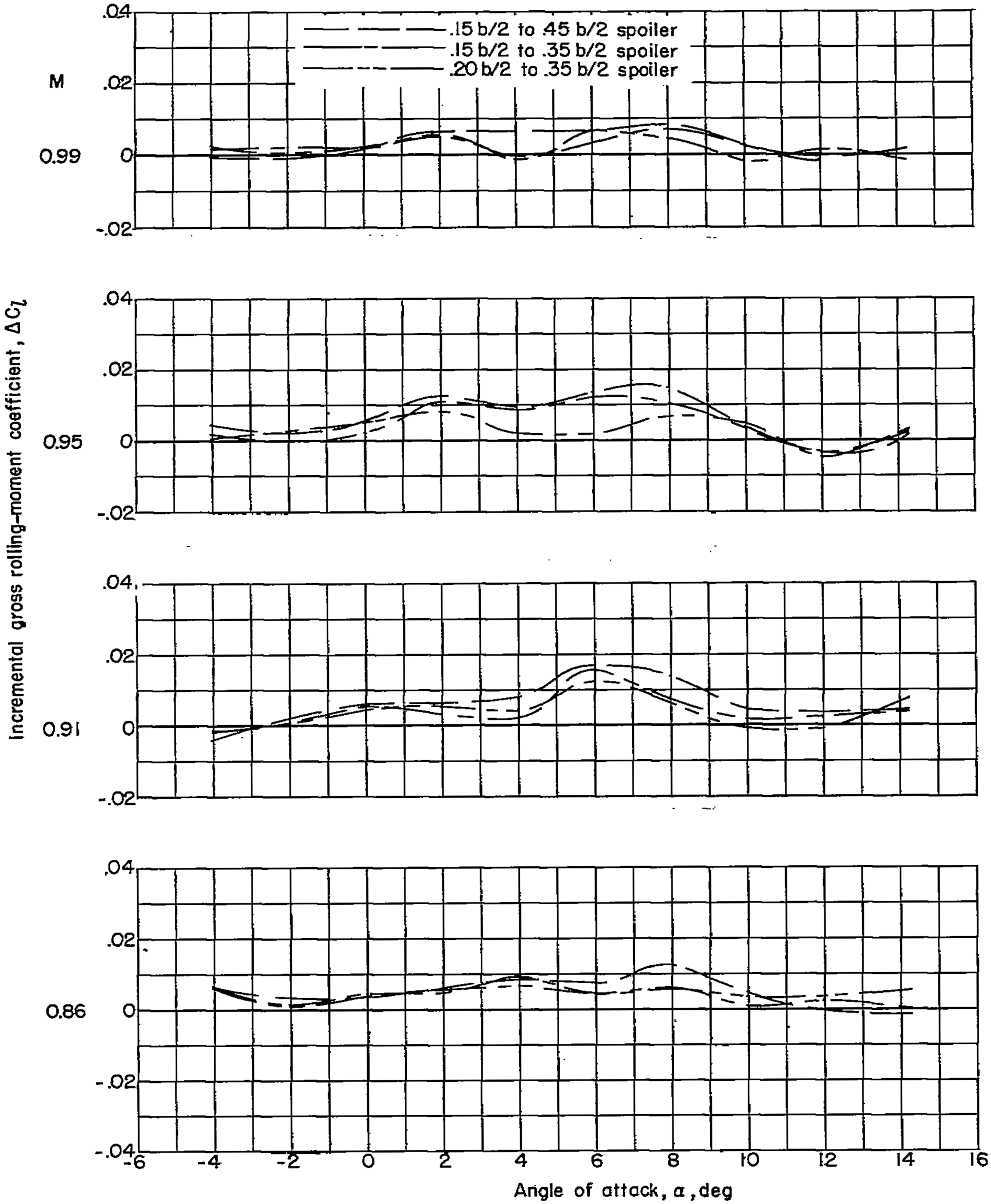
(b) Incremental drag.

Figure 5.- Continued.



(c) Pitching moment.

Figure 5.- Continued.



(d) Incremental gross rolling moment.

Figure 5.- Concluded.

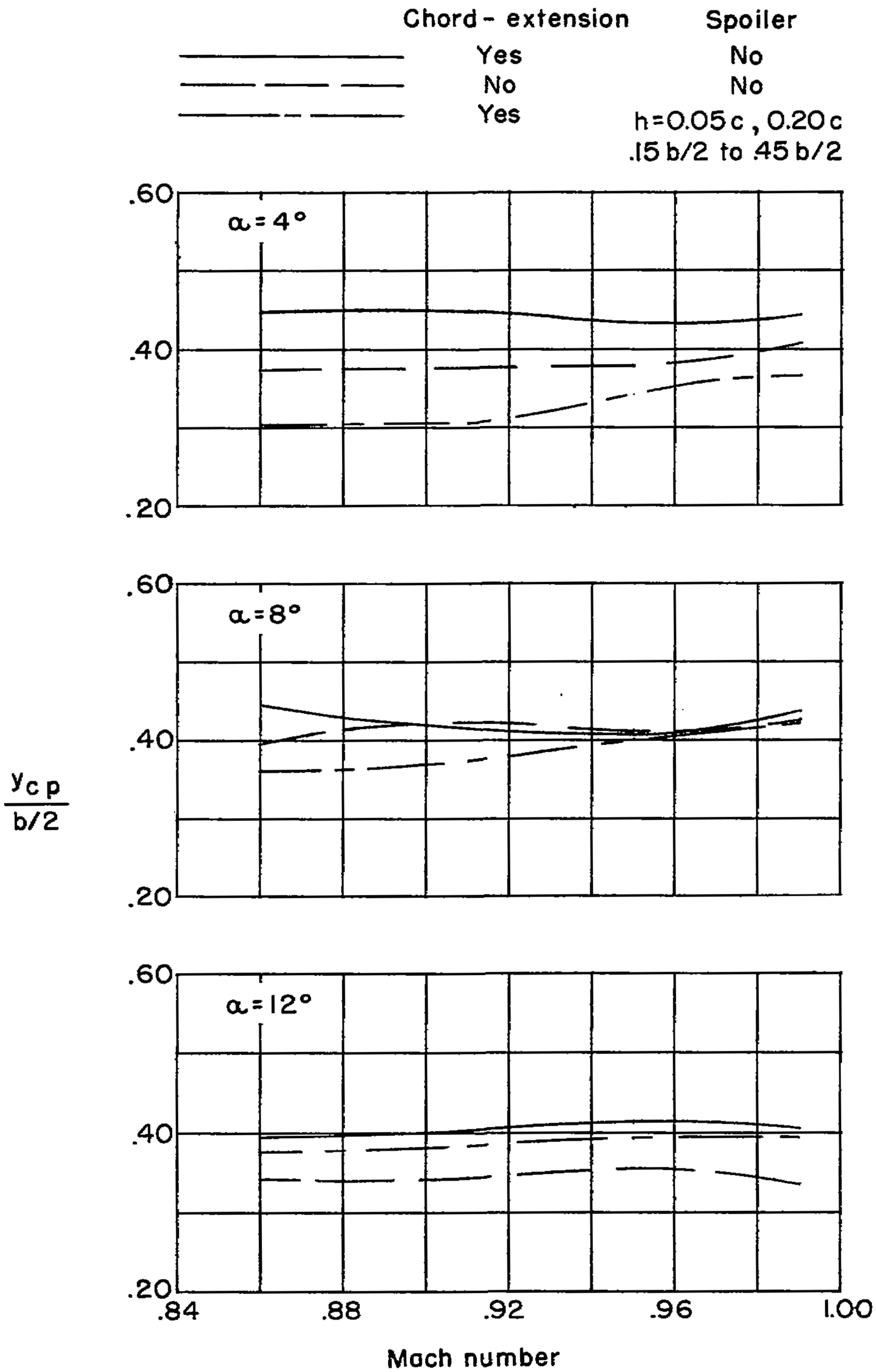


Figure 6.- Effect of Mach number on lateral center-of-pressure position.

NACA-Langley - 6-14-54 - 350

[redacted]

[redacted]