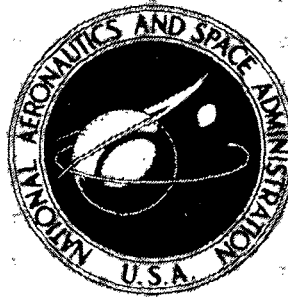


N72-20971

**NASA TECHNICAL
MEMORANDUM**



NASA TM X-2531

NASA TM X-2531

**CASE FILE
COPY**

**SUPERSONIC AERODYNAMIC CHARACTERISTICS
OF A LOW-ASPECT-RATIO MISSILE MODEL
WITH WING AND TAIL CONTROLS AND
WITH TAILS IN LINE AND INTERDIGITATED**

by Ernald B. Graves

Langley Research Center

Hampton, Va. 23365

1. Report No. NASA TM X-2531		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A LOW-ASPECT-RATIO MISSILE MODEL WITH WING AND TAIL CONTROLS AND WITH TAILS IN LINE AND INTERDIGITATED				5. Report Date April 1972	
				6. Performing Organization Code	
7. Author(s) Ernard B. Graves				8. Performing Organization Report No. L-8092	
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23365				10. Work Unit No. 760-74-01-03	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546				13. Type of Report and Period Covered Technical Memorandum	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>A study has been made to determine the aerodynamic characteristics of a low-aspect-ratio cruciform missile model with all-movable wings and tails. The configuration was tested at Mach numbers from 1.50 to 4.63 with the wings in the vertical and horizontal planes ($\phi = 0^\circ$) and with the wings in a 45° roll plane with tails in line and interdigitated.</p>					
17. Key Words (Suggested by Author(s)) Missile aerodynamic characteristics Wing and tail control Interdigitated			18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 272	22. Price* \$3.00

SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A
LOW-ASPECT-RATIO MISSILE MODEL WITH WING AND TAIL CONTROLS
AND WITH TAILS IN LINE AND INTERDIGITATED

By Ernald B. Graves
Langley Research Center

SUMMARY

A study has been made to determine the aerodynamic characteristics of a low-aspect-ratio cruciform missile model with all-movable wings and tails. The configuration was tested at Mach numbers from 1.50 to 4.63 with tails in line and interdigitated with the wings in the vertical and horizontal planes ($\phi = 0^\circ$) and with the wings in a 45° roll plane.

Test results indicate that the all-movable wings produce very nonlinear longitudinal control characteristics, while in general the tail provides linear incremental control characteristics. At the 0° roll attitude, the tails in the interdigitated position provide more linear control characteristics than in the in-line position. At the 45° roll attitude, some interference-induced nonlinearities are apparent with the tails interdigitated.

Tail control for this model permits a degree of maneuverability over the entire test Mach number range, whereas wing control permits maneuverability only at the lower Mach numbers.

INTRODUCTION

The National Aeronautics and Space Administration is engaged in a continuous program of missile research to better understand the parameters affecting the aerodynamic behavior of missiles. As part of this program, tests have been conducted in the Langley Unitary Plan wind tunnel on a cruciform wing-tail missile model with a fineness ratio of 10. This study compares wing control and tail control with tails both in line and interdigitated with respect to the wings. Test Mach numbers ranged from 1.50 to 4.63.

SYMBOLS

Values are given both in the International System of Units (SI) and in the U.S. Customary Units. Measurements were made in U.S. Customary Units. Force and

moment data are referred to both the body and stability systems of axes. The moment reference is located at 69.59 percent of the body length.

A	reference area (body cross section)
d	body diameter
C_A	axial-force coefficient, $\frac{\text{Axial force}}{qA}$
C_D	drag coefficient, $\frac{\text{Drag}}{qA}$
C_L	lift coefficient, $\frac{\text{Lift}}{qA}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qA}$
L/D	lift-drag ratio
M	Mach number
q	free-stream dynamic pressure
α	angle of attack, deg
δ_t	tail deflection, positive when leading edge is up, deg
δ_w	wing deflection, positive when leading edge is up, deg
ϕ	model roll orientation, deg ($\phi = 0^\circ$ when wings in horizontal and vertical planes)

APPARATUS AND METHODS

Tunnel

Tests were conducted in Langley Unitary Plan wind tunnel, a closed-circuit, variable-pressure facility which has two test sections. An asymmetrical sliding-block-type nozzle leading into the test sections permits a continuous variation in Mach number from about 1.50 to 2.86 in the low Mach number test section and from about 2.30 to 4.65 in the high Mach number test section.

Model

A dimensional drawing of the model used for these tests is shown in figure 1. The model had an ogive nose, a cylindrical afterbody, and all-movable cruciform wings and tails. The wings had a clipped-delta planform. The tails had a rectangular planform and could be positioned either in line with the wings or interdigitated at 45° with respect to the wings. Both the wings and the tails could be deflected for control either independently or simultaneously. A photograph of the model is shown as figure 2.

Test Conditions

The model was tested at Mach numbers from 1.50 to 4.63 at a constant Reynolds number of 8.20×10^6 per meter (2.5×10^6 per foot). Transition strips 0.159 cm (1/16 in.) wide (No. 40 carborundum for Mach numbers greater than 3.5 and No. 60 carborundum for Mach numbers less than 3.5) were placed 3.05 cm (1.2 in.) aft on the model nose and 1.02 cm (0.4 in.) aft streamwise on all wing and tail surfaces. The dewpoint temperature was maintained sufficiently low to insure negligible condensation effects.

Measurements and Corrections

Aerodynamic forces and moments were measured by means of an electrical strain-gage balance that was housed within the model and was connected to a sting-support system. Pressure in the model chamber was measured by means of a single static orifice.

Data presented herein have been corrected for balance and sting deflections due to aerodynamic loads and wind-tunnel airflow misalignment. Drag results have been adjusted to free-stream static pressure acting over the model base.

PRESENTATION OF RESULTS

The results of the tests are presented in the following figures:

	Figure
Effect of wing deflection on longitudinal aerodynamic characteristics; $\delta_t = 0^\circ$; $\phi = 0^\circ$; tails in line	3
Effect of wing deflection on longitudinal aerodynamic characteristics; $\delta_t = 0^\circ$; $\phi = 45^\circ$; tails in line	4
Effect of tail deflection on longitudinal aerodynamic characteristics of body-tail configuration; $\phi = 0^\circ$	5
Effect of tail deflection on longitudinal aerodynamic characteristics of body-tail configuration; $\phi = 45^\circ$	6
Effect of tail deflection on longitudinal aerodynamic characteristics of model; $\delta_w = 0^\circ$; $\phi = 0^\circ$; tails in-line	7

	Figure
Effect of tail deflection on longitudinal aerodynamic characteristics of model; $\delta_w = 0^\circ$; $\phi = 45^\circ$; tails in line	8
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 0^\circ$; $\phi = 0^\circ$	9
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 0^\circ$; $\phi = 45^\circ$	10
Effect of tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 10^\circ$; $\phi = 0^\circ$; tails in line	11
Effect of tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 20^\circ$; $\phi = 0^\circ$; tails in line	12
Effect of tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 10^\circ$; $\phi = 45^\circ$; tails in line	13
Effect of tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 20^\circ$; $\phi = 45^\circ$; tails in line	14
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 10^\circ$; $\phi = 0^\circ$	15
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 20^\circ$; $\phi = 0^\circ$	16
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 10^\circ$; $\phi = 45^\circ$	17
Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics; $\delta_w = 20^\circ$; $\phi = 45^\circ$	18

DISCUSSION

Effect of Wing Deflection

The effects of wing deflection on the longitudinal aerodynamic characteristics of the model with in-line control surfaces are shown in figure 3 for wings in a horizontal-vertical orientation ($\phi = 0^\circ$) and in figure 4 for wings in an \times -orientation ($\phi = 45^\circ$). Increasing δ_w leads to significant increases in C_L at small values of α , but the increment in C_L decreases with increasing α at low Mach numbers. The pitching-moment variation with lift coefficient with $\delta_w = 0^\circ$ is reasonably linear. With increasing wing deflection, however, the pitching-moment variations are very nonlinear with lift coefficient and indicate that wing-interference flow fields are affecting the tail. Increasing Mach number tends to alleviate this effect. The data indicate that the model could be trimmed stable over a range of lift coefficients at the low Mach numbers but only near $C_L = 0$ at the high Mach numbers. Thus it appears that for missiles requiring high maneuverability, wing control might be adequate only at the lower supersonic Mach numbers. It should be pointed out

that the wings of this model are rather small for a wing-control missile configuration and some differences might be obtained with a larger wing.

Effect of Tail Deflection

Effects of tail deflection for $\phi = 0^\circ$ and $\phi = 45^\circ$ are presented in figures 5 and 6, respectively, for the body-tail configuration and in figures 7 and 8, respectively, for the complete model. The tail is effective in producing pitch control, particularly at the lower Mach numbers. However, there is evidence of adverse interference affecting tail effectiveness for $\delta_t = -10^\circ$ at the higher Mach numbers. Further increase in δ_t to -20° tends to eliminate this effect. With the wing at 0° deflection and the tail at $\delta_t = -20^\circ$, the relative linearity of the pitching-moment data is such that the model may be trimmed in stable flight through a relatively large center-of-gravity range over the entire test Mach number range.

Effect of Interdigitated Surfaces, $\delta_w = 0^\circ$

With the wings in the $\phi = 0^\circ$ orientation and the fins in an interdigitated position, the stability and control characteristics are considerably improved in linearity and effectiveness relative to those obtained for the in-line position throughout the Mach number range (fig. 9). However, with the wings at $\phi = 45^\circ$ and the tails interdigitated (fig. 10), some nonlinear effects are still apparent and the tail control effectiveness is less than that shown in figure 9, particularly at the higher Mach numbers.

Effect of Combined Wing and Tail Deflection

The effectiveness of combined wing and tail control may be found in figures 11 to 18 for both in-line and interdigitated model surfaces. With the wings at deflections of either 10° or 20° the deflection of the tail produces essentially additive values of coefficients throughout the Mach number range, and the degree of linearity of C_m with C_L is essentially unaffected.

CONCLUDING REMARKS

A study has been made of a low-aspect-ratio cruciform missile model with all-movable wings and tails. The configuration was tested at Mach numbers from 1.50 to 4.63 with tails in line and interdigitated with the wings in the vertical and horizontal planes ($\phi = 0^\circ$) and with the wings in a 45° roll plane.

Test results indicate that the all-movable wings produce very nonlinear control characteristics, whereas in general the tail provides linear incremental control characteristics. At the 0° roll attitude, the tails in the interdigitated position provide more

linear control characteristics than in the in-line position. At the 45° roll attitude, some interference-induced nonlinearities are apparent with the tails interdigitated.

Tail control for this model permits a degree of maneuverability over the entire test Mach number range, whereas wing control permits maneuverability only at the lower Mach numbers.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 11, 1972.

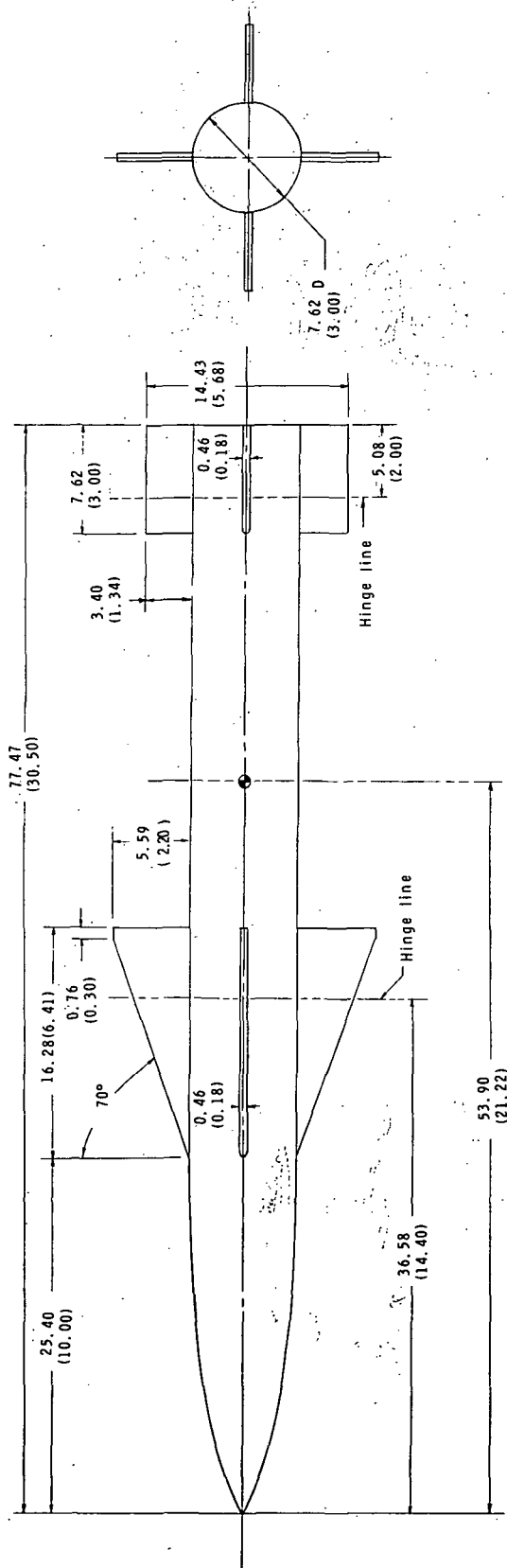
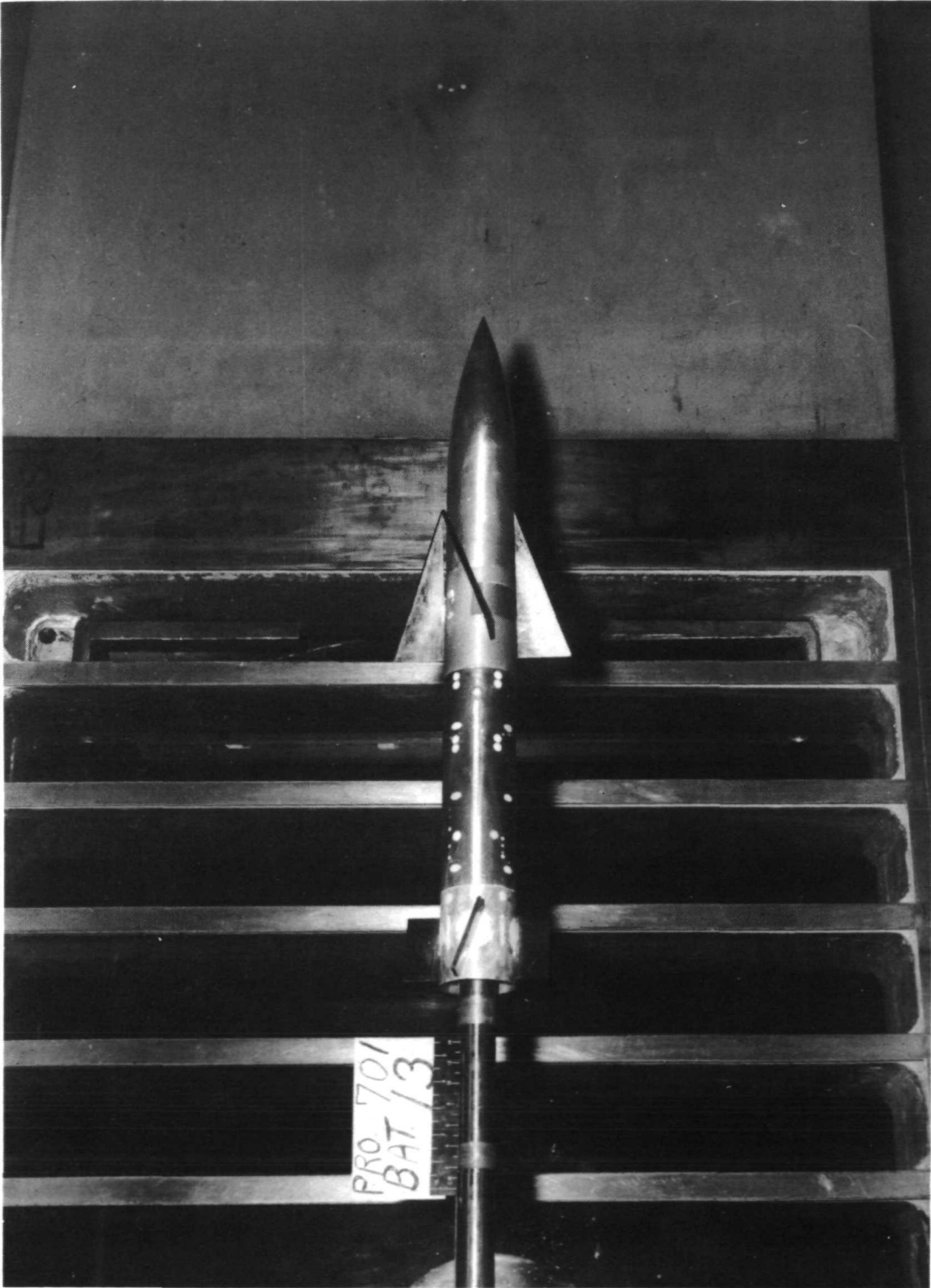


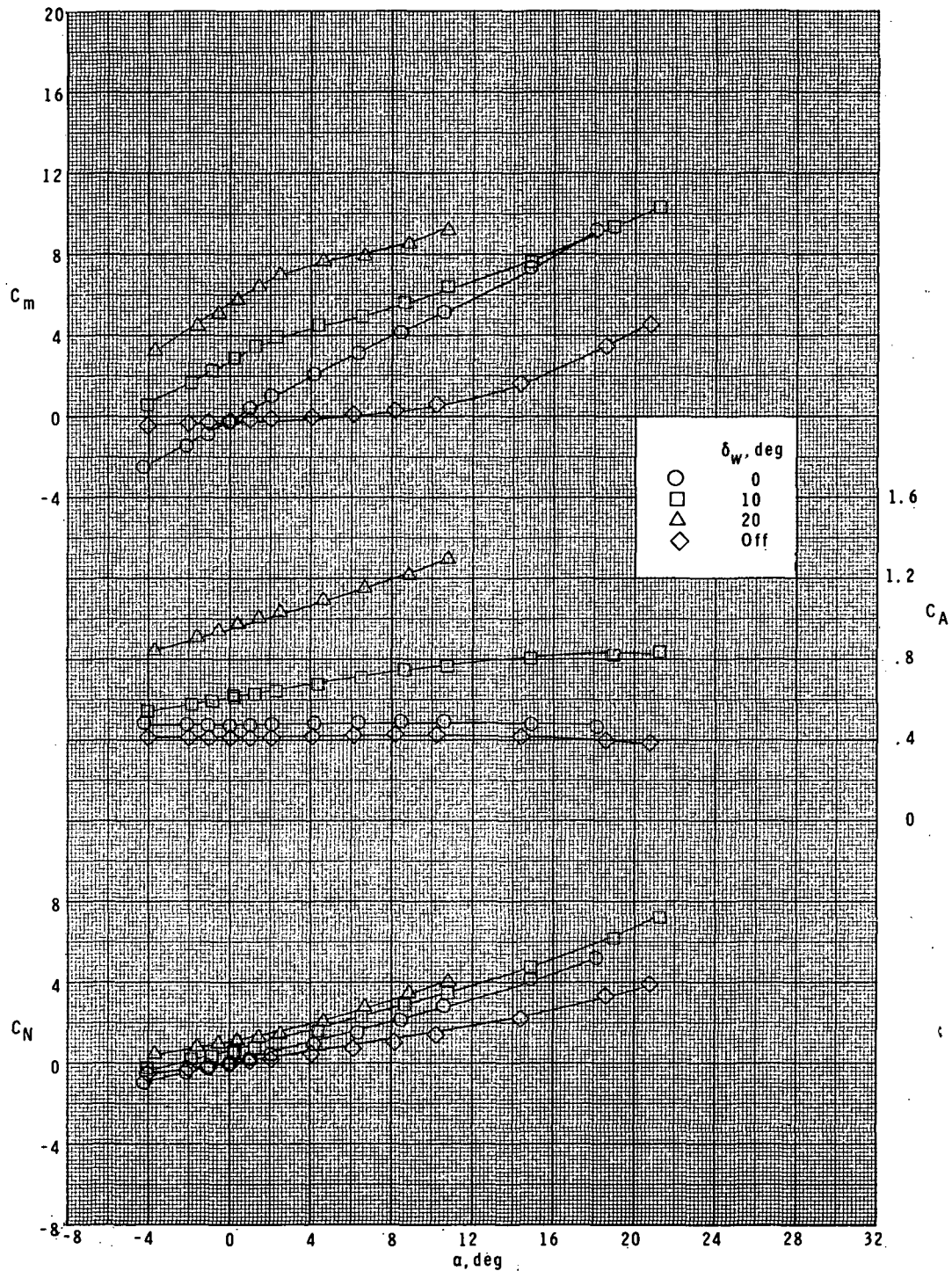
Figure 1. - Details of model. (Dimensions are given in centimeters and parenthetically in inches.)



PRO 701
BAT / 3

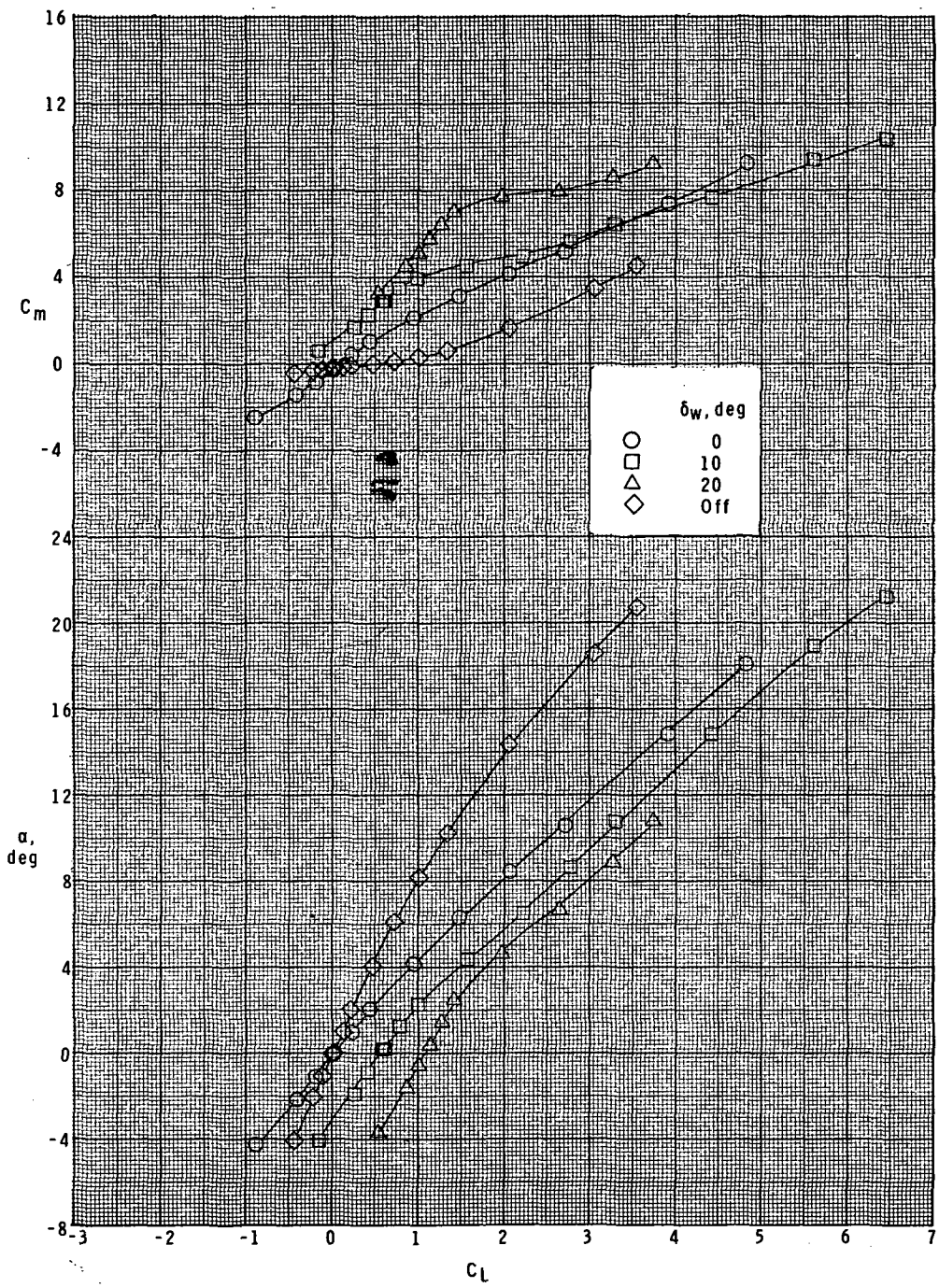
L-67-9730

Figure 2. - Photograph of model.



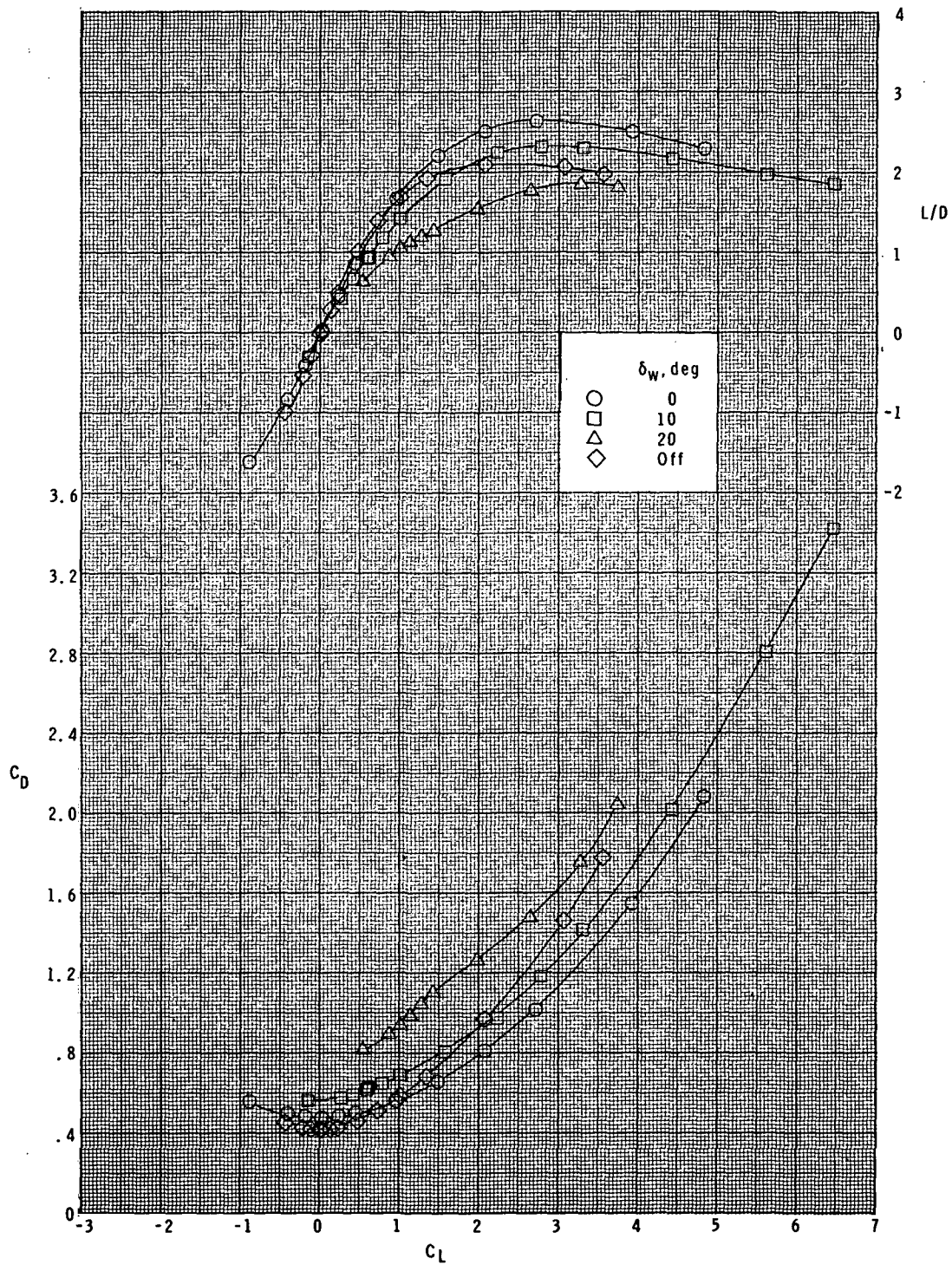
(a) $M = 1.50$.

Figure 3. - Effect of wing deflection on longitudinal aerodynamic characteristics.
 $\delta_t = 0^\circ$; $\phi = 0^\circ$; tails in line.



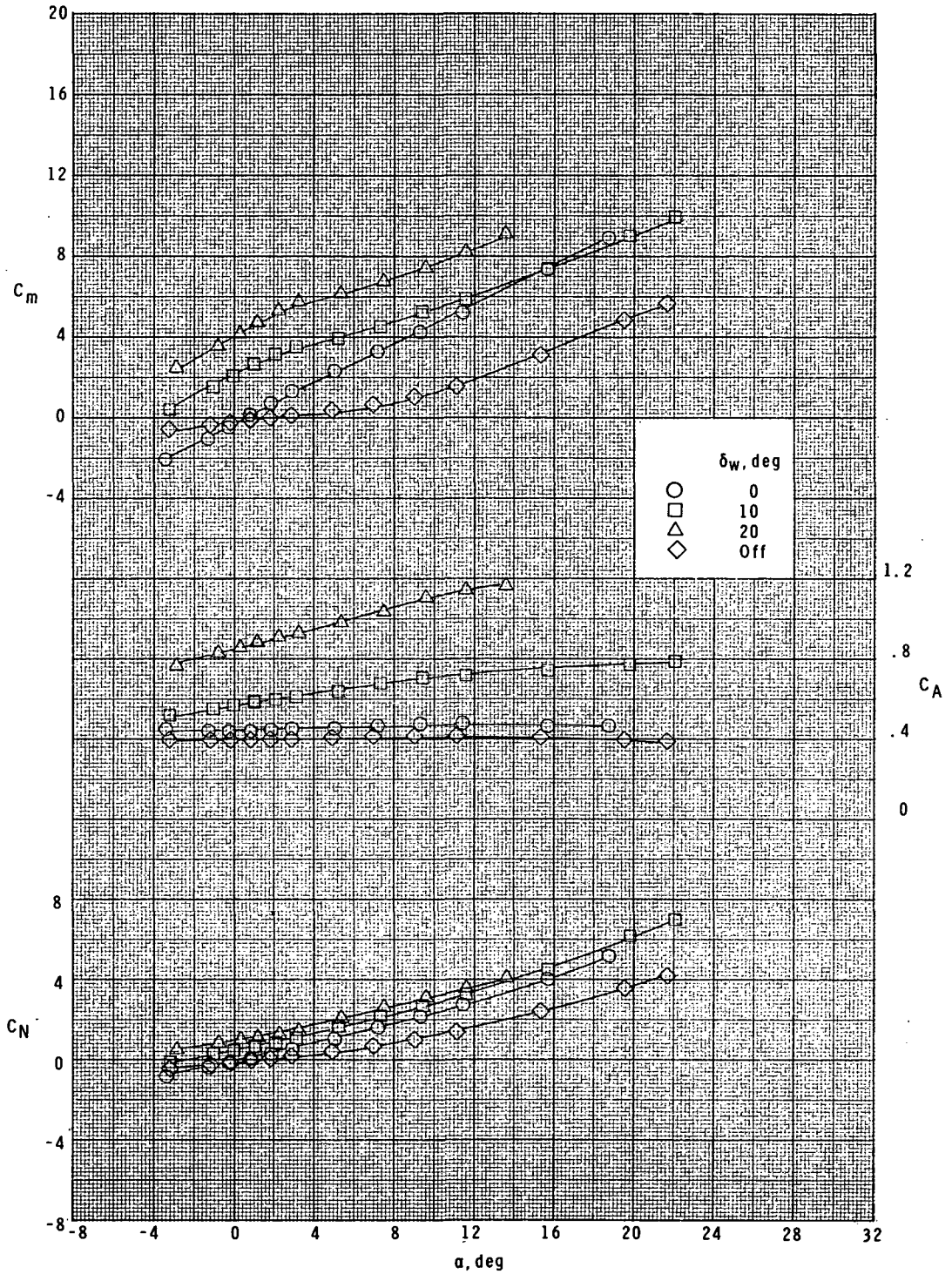
(a) Continued.

Figure 3.- Continued.



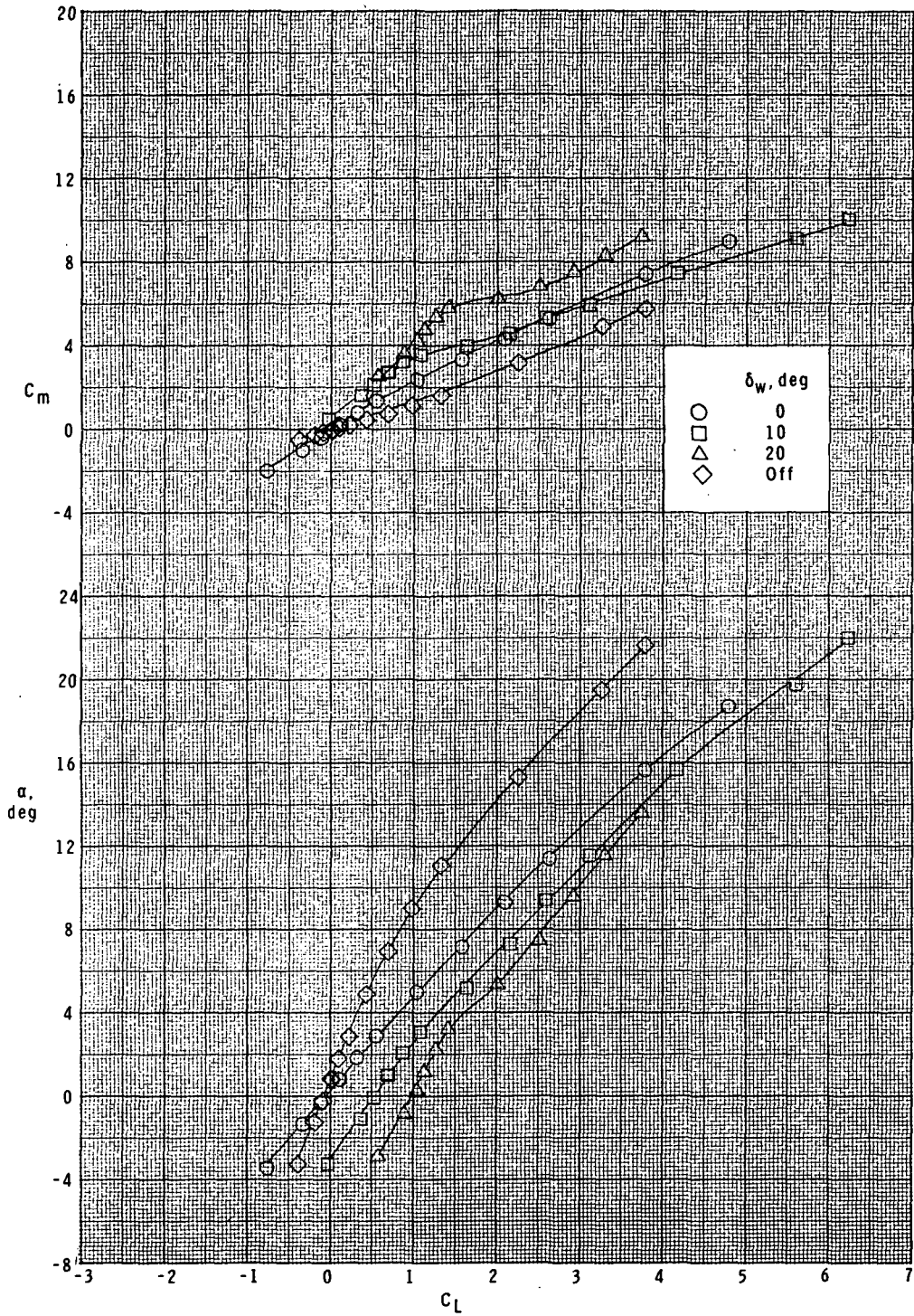
(a) Concluded.

Figure 3. - Continued.



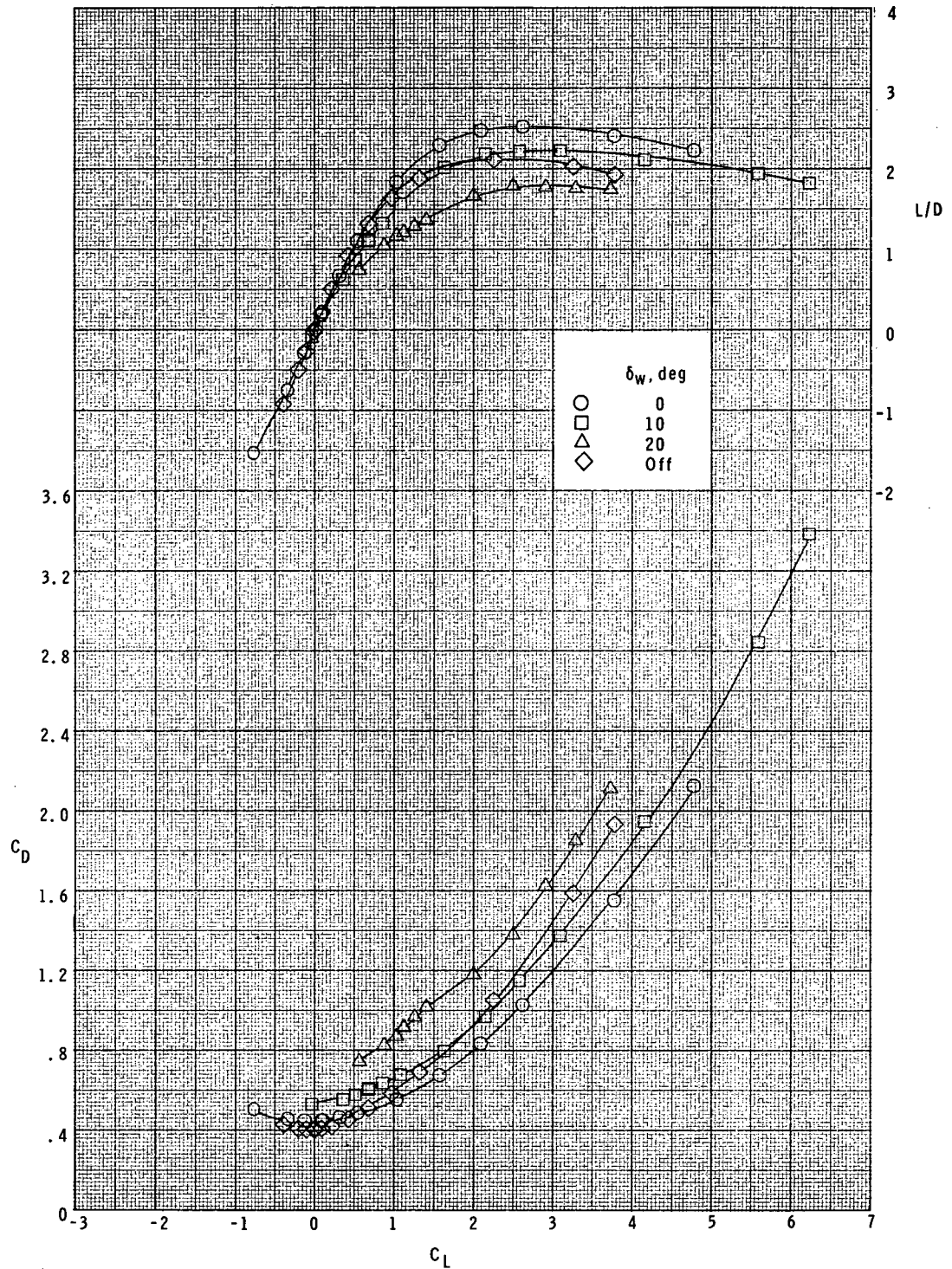
(b) $M = 1.90$.

Figure 3.- Continued.



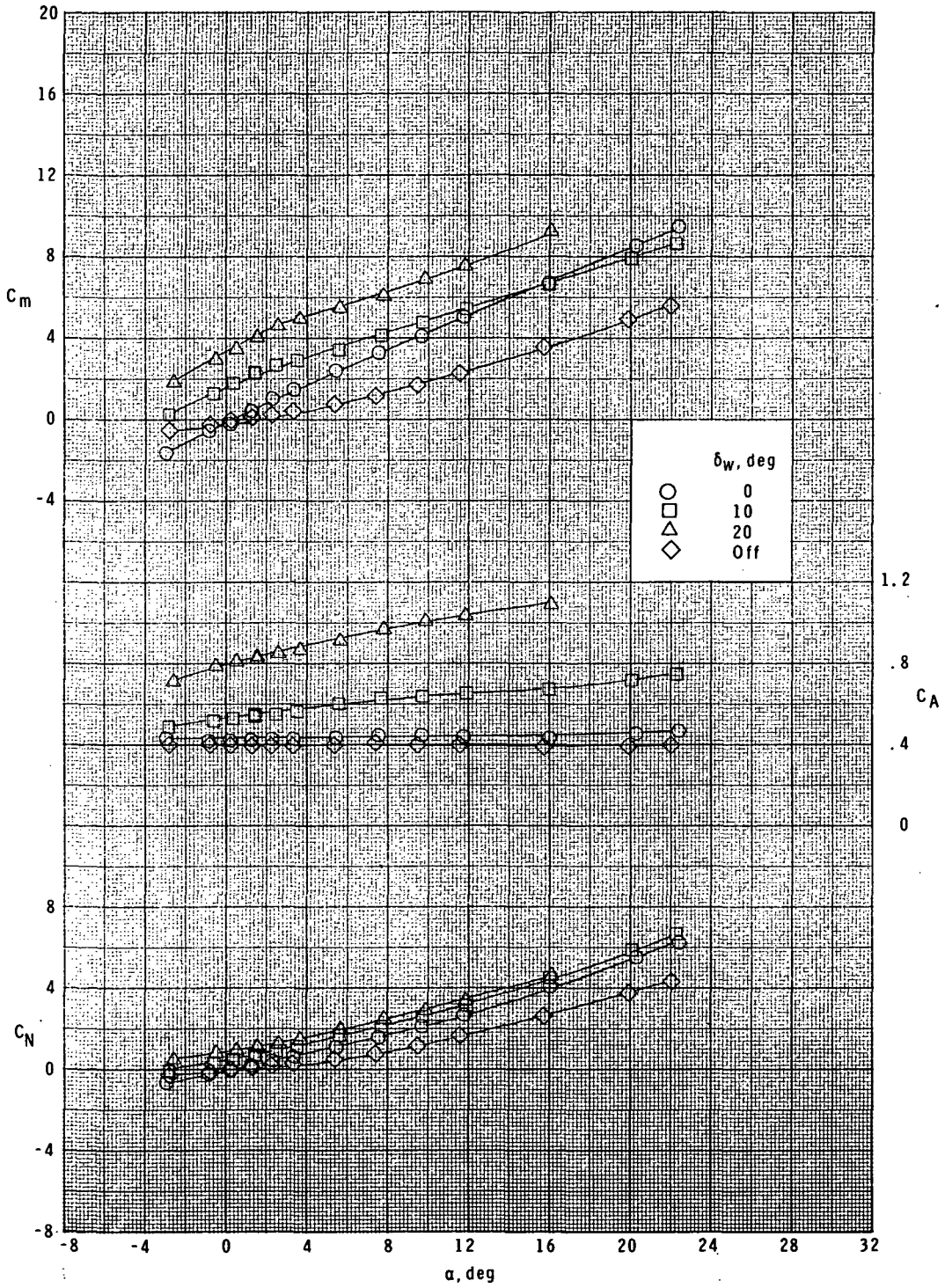
(b) Continued.

Figure 3.- Continued.



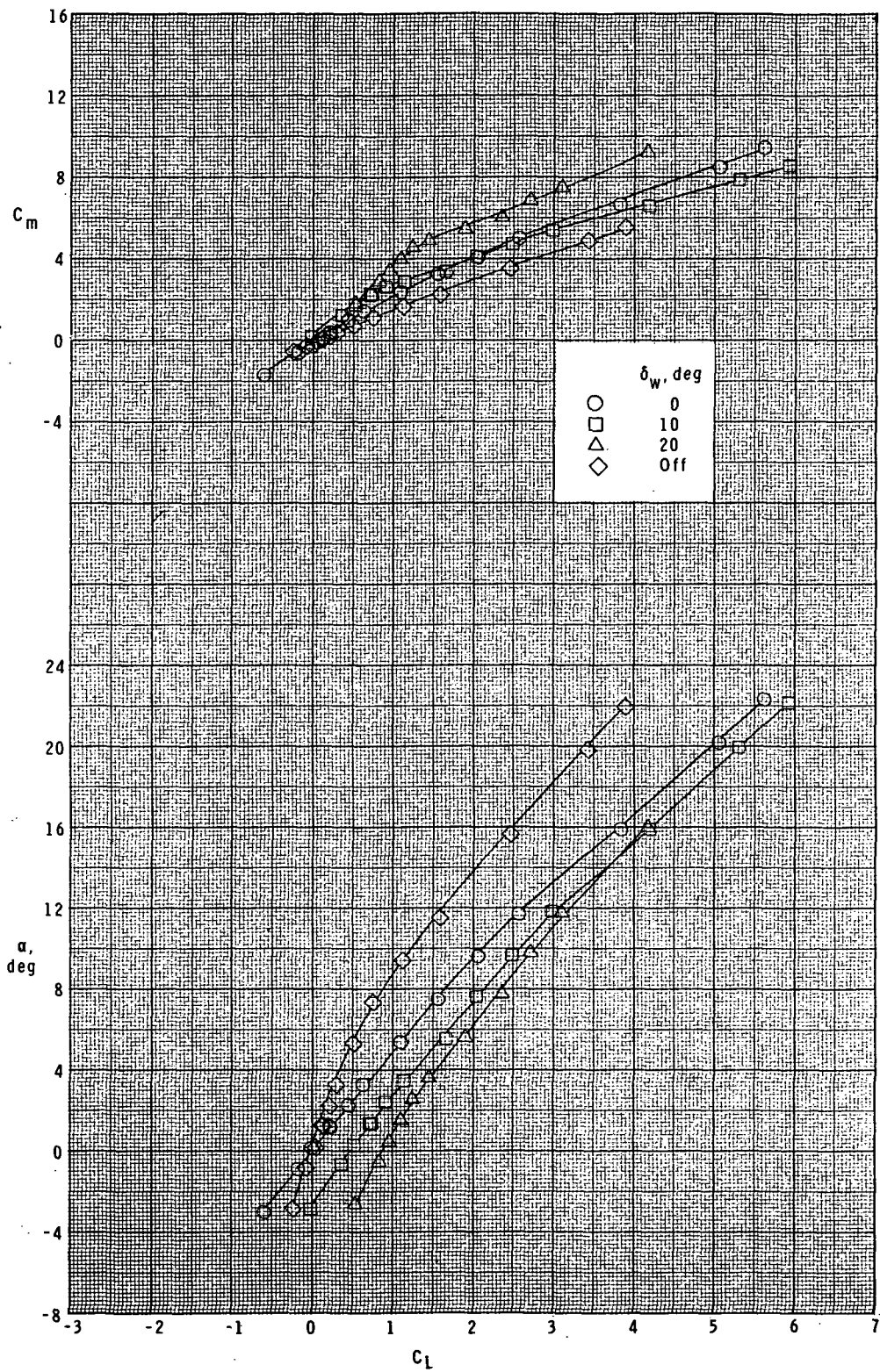
(b) Concluded.

Figure 3.- Continued.



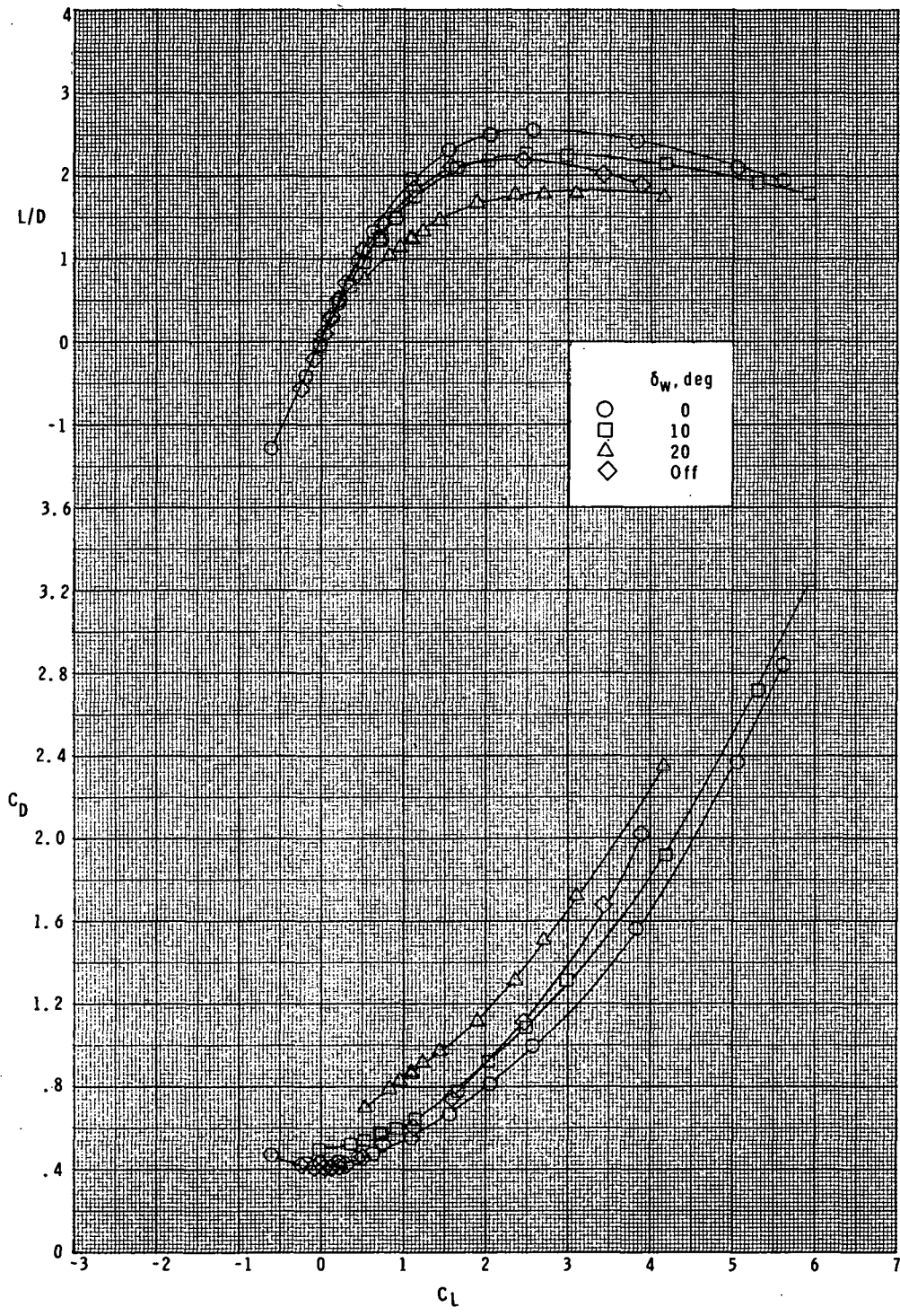
(c) $M = 2.36$.

Figure 3.- Continued.



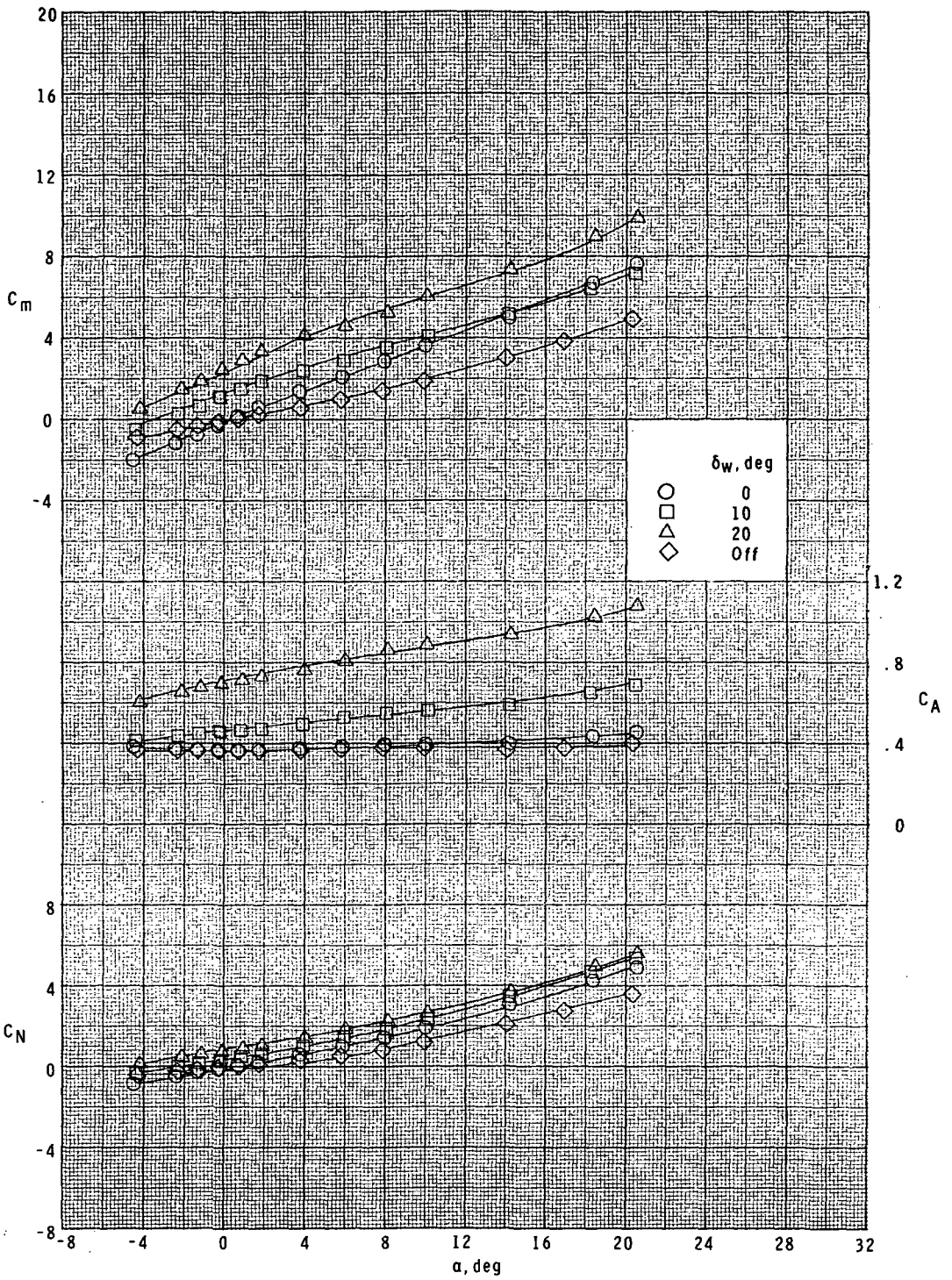
(c) Continued.

Figure 3. - Continued.



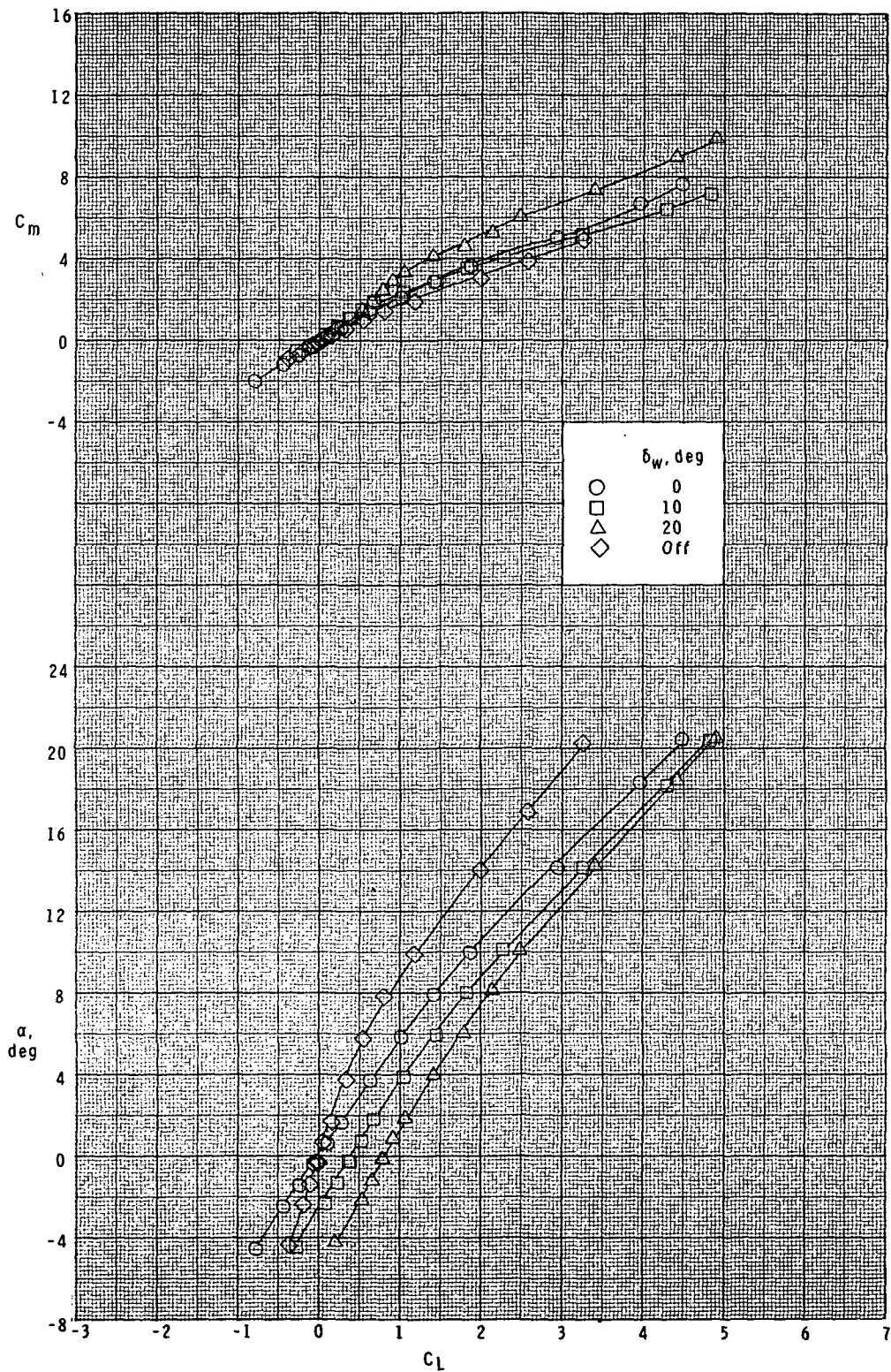
(c) Concluded.

Figure 3. - Continued.



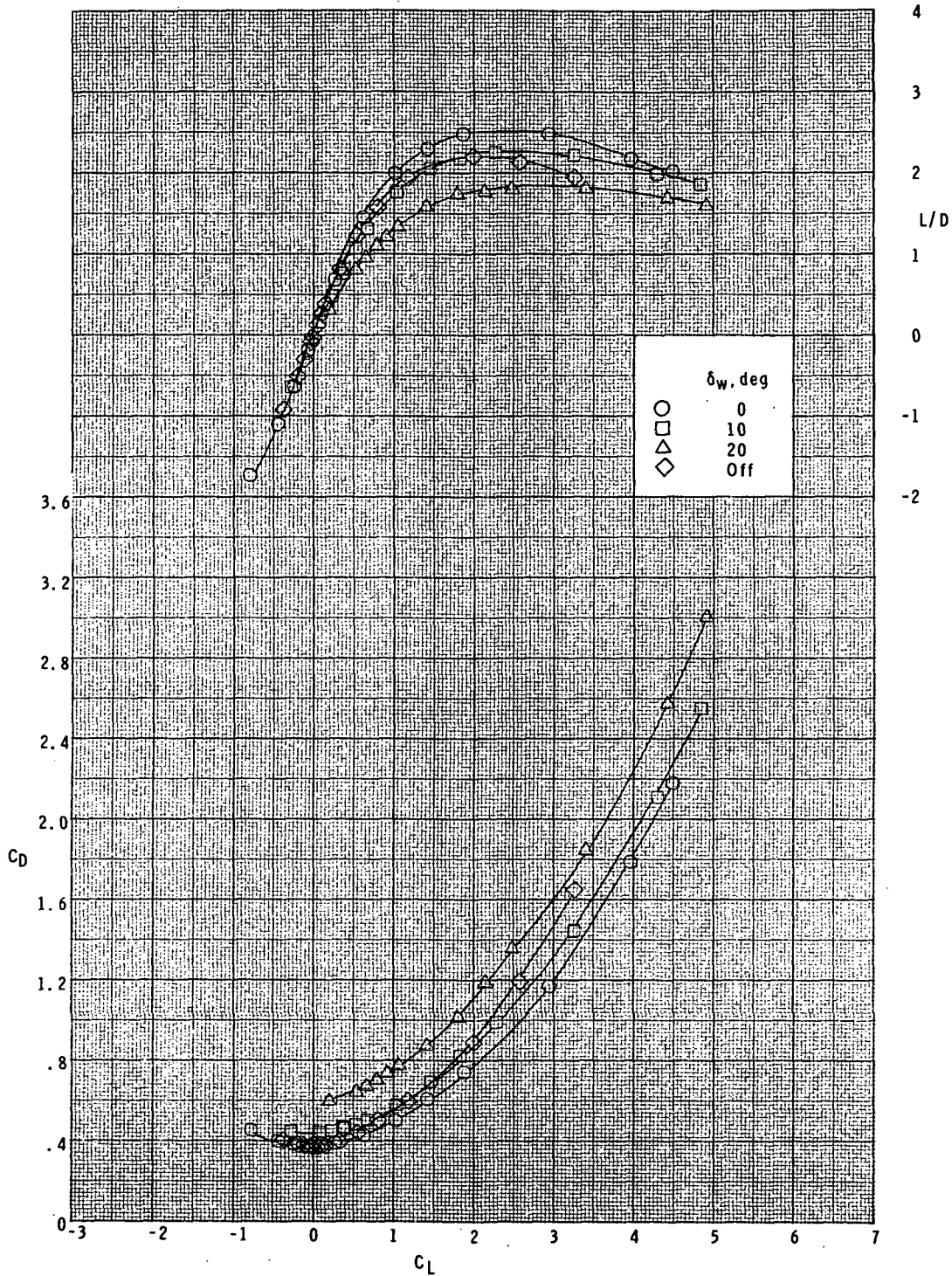
(d) $M = 2.86$.

Figure 3.- Continued.



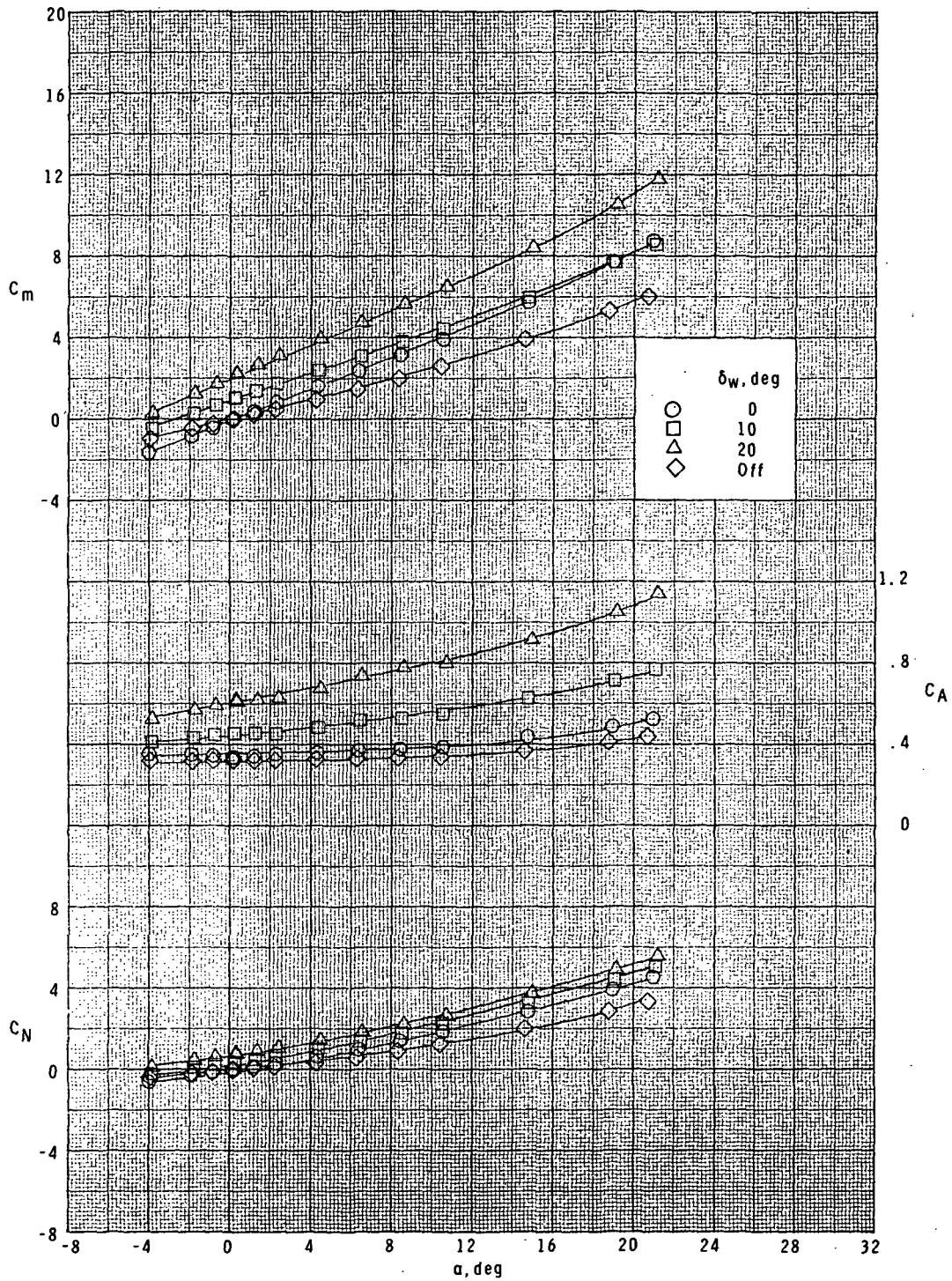
(d) Continued.

Figure 3.- Continued.



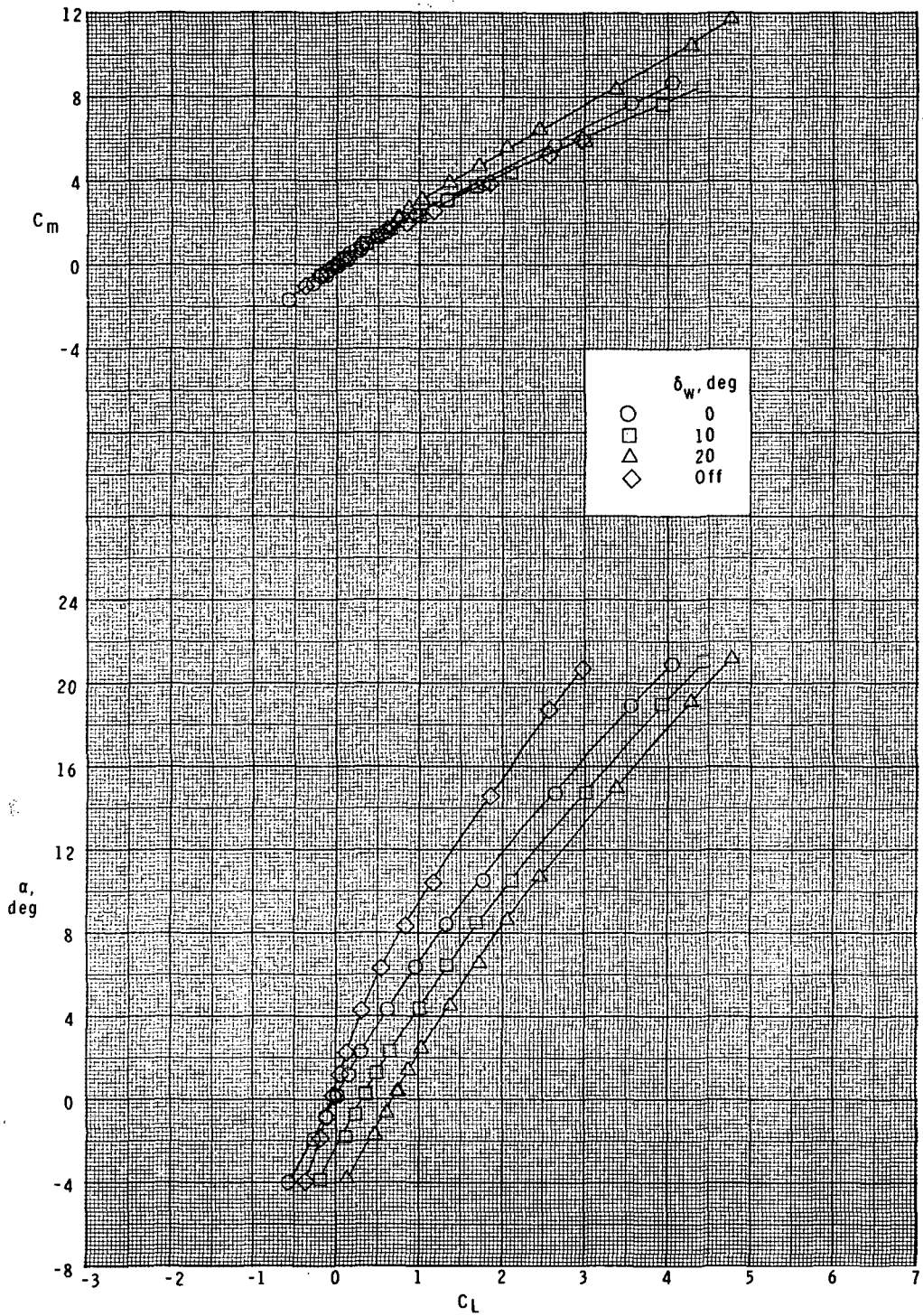
(d) Concluded.

Figure 3.- Continued.



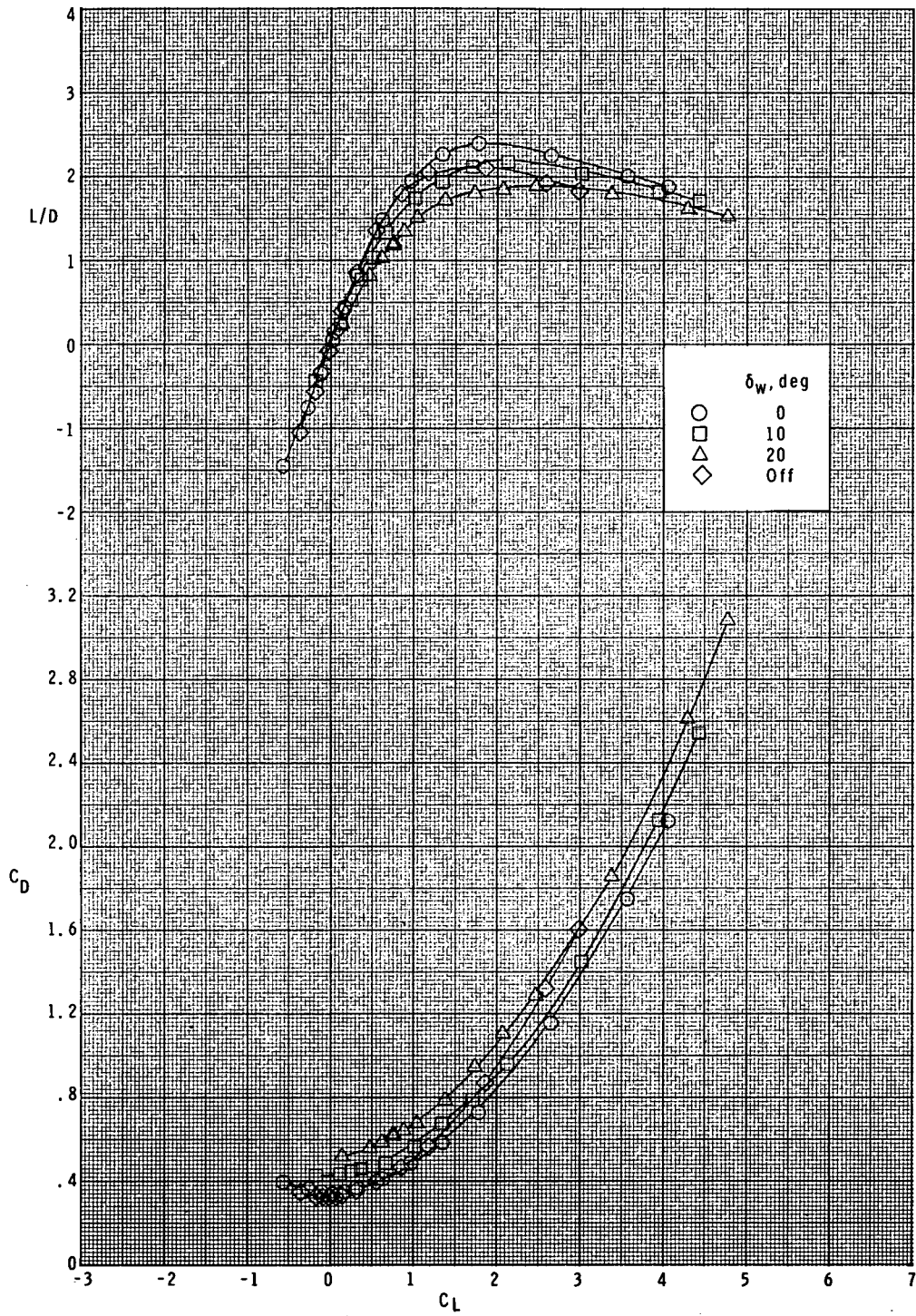
(e) $M = 3.95$.

Figure 3. - Continued.



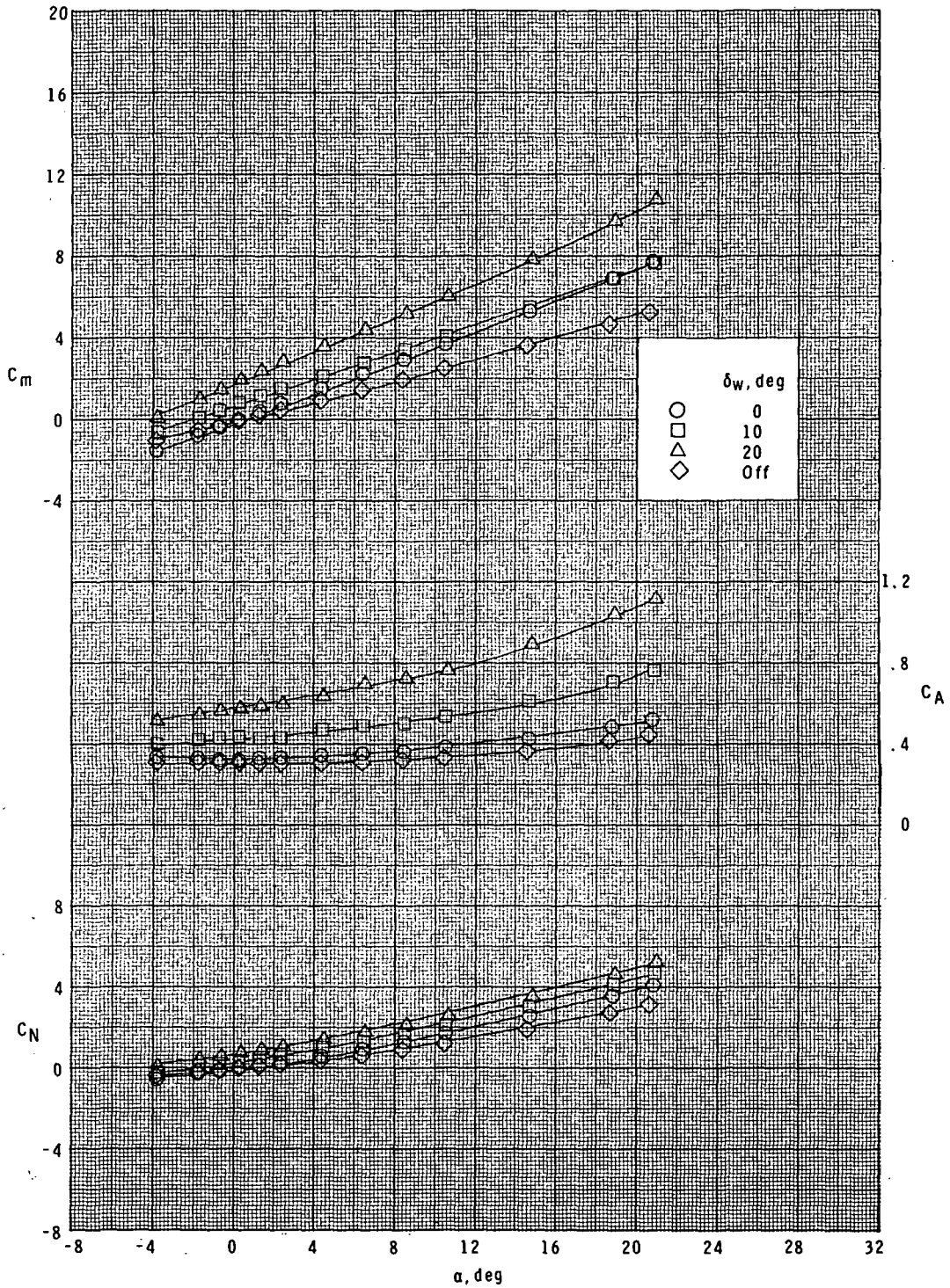
(e) Continued.

Figure 3. - Continued.



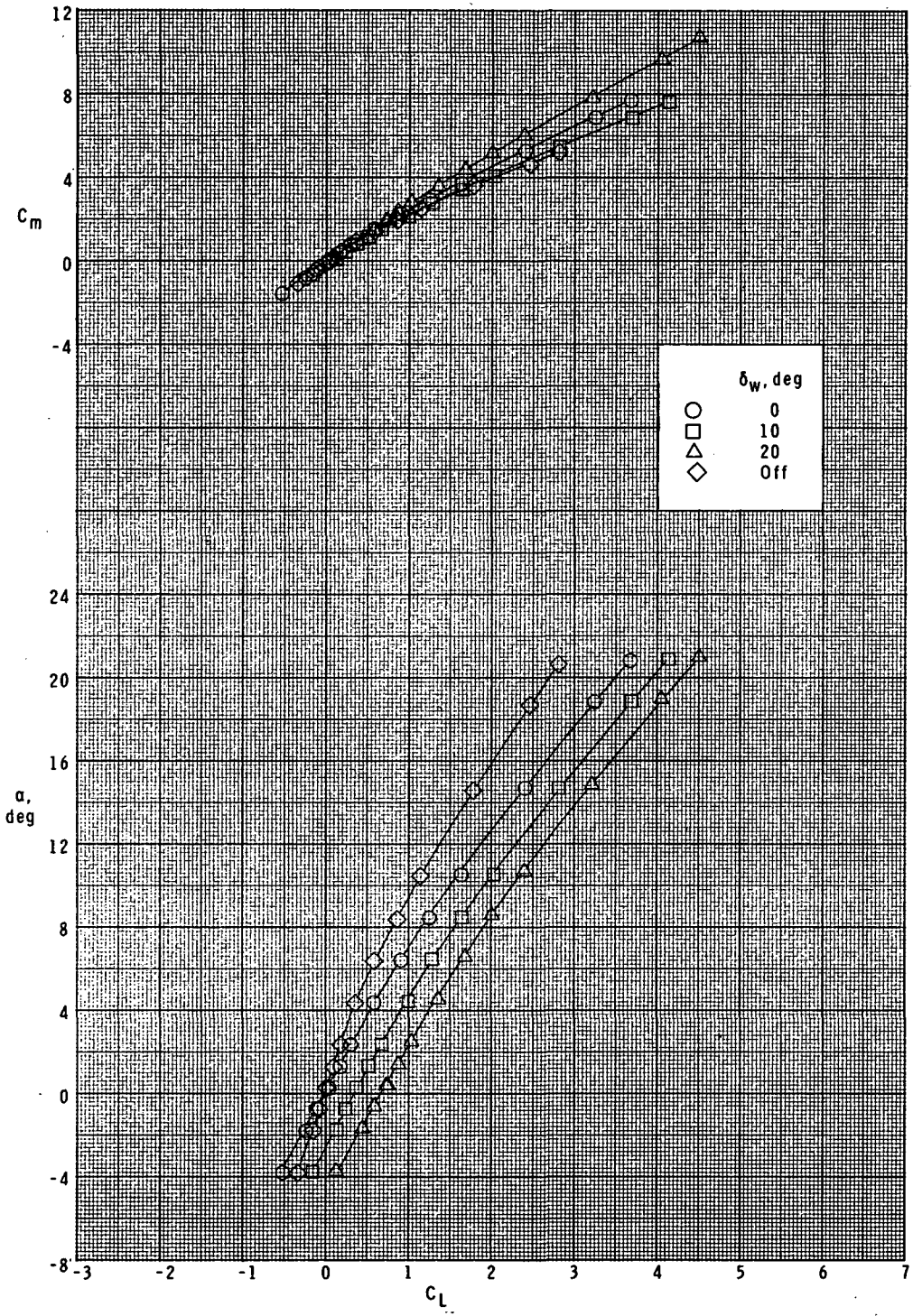
(e) Concluded.

Figure 3. - Continued.



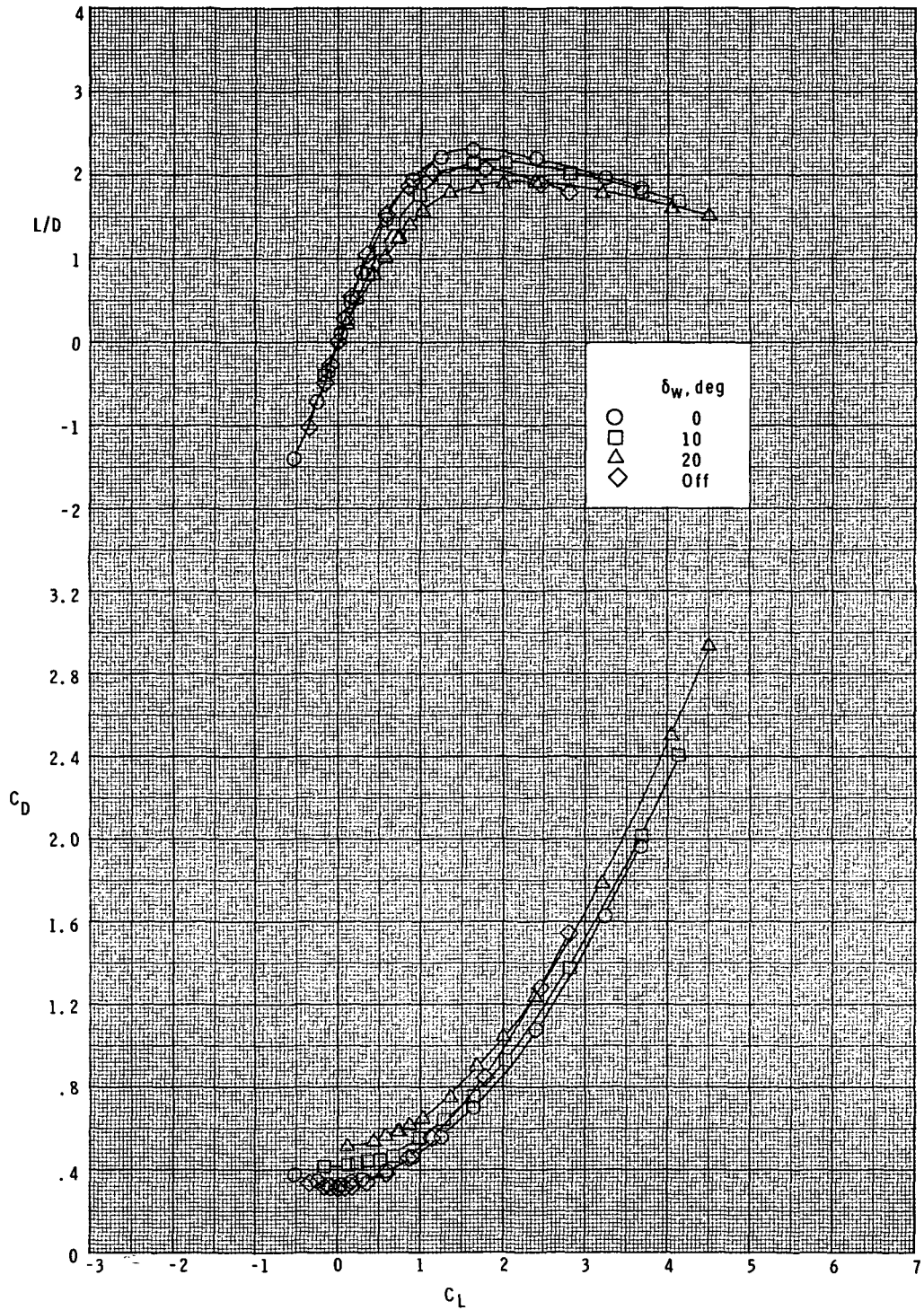
(f) $M = 4.63$.

Figure 3.- Continued.



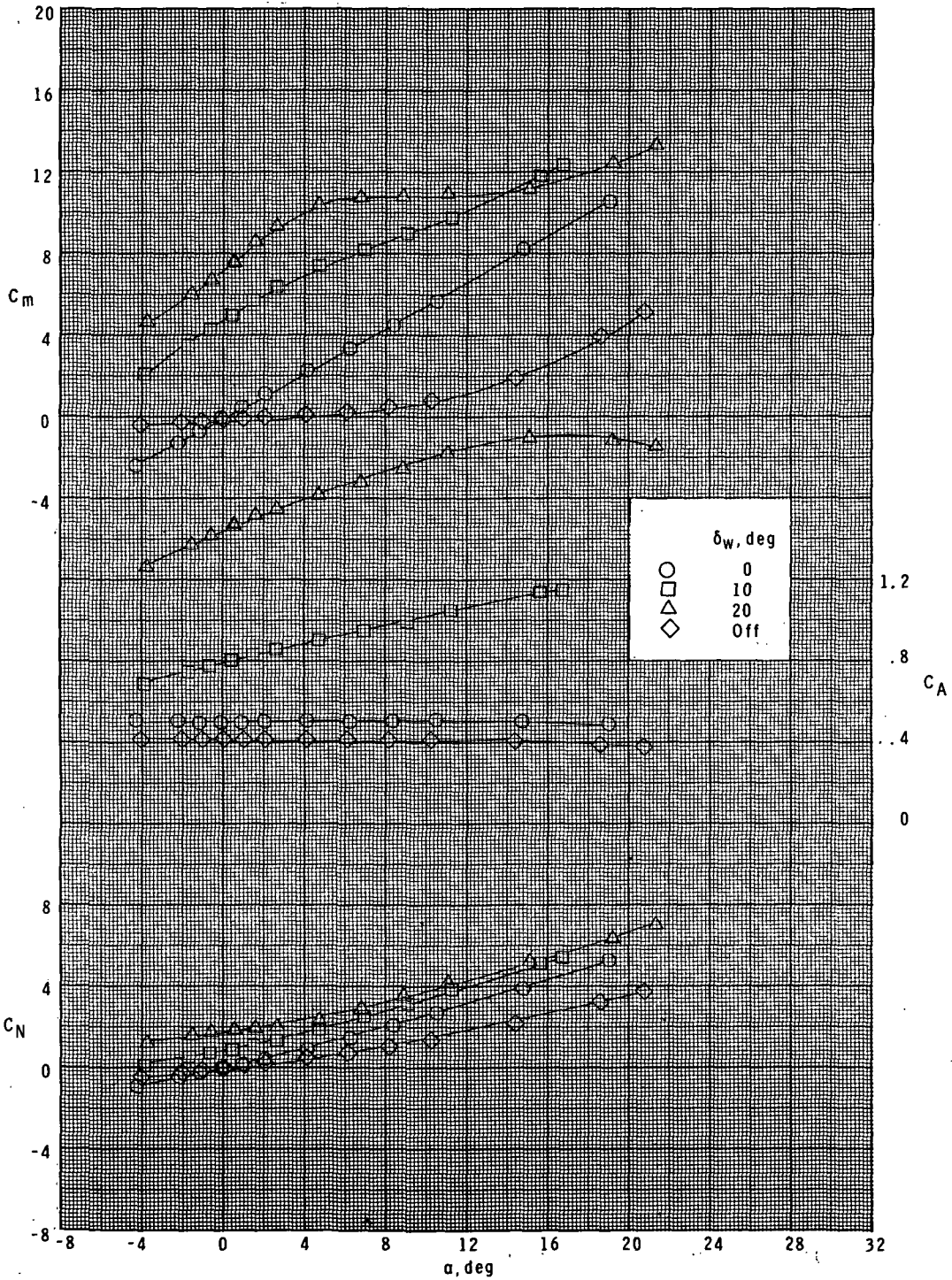
(f) Continued.

Figure 3.- Continued.



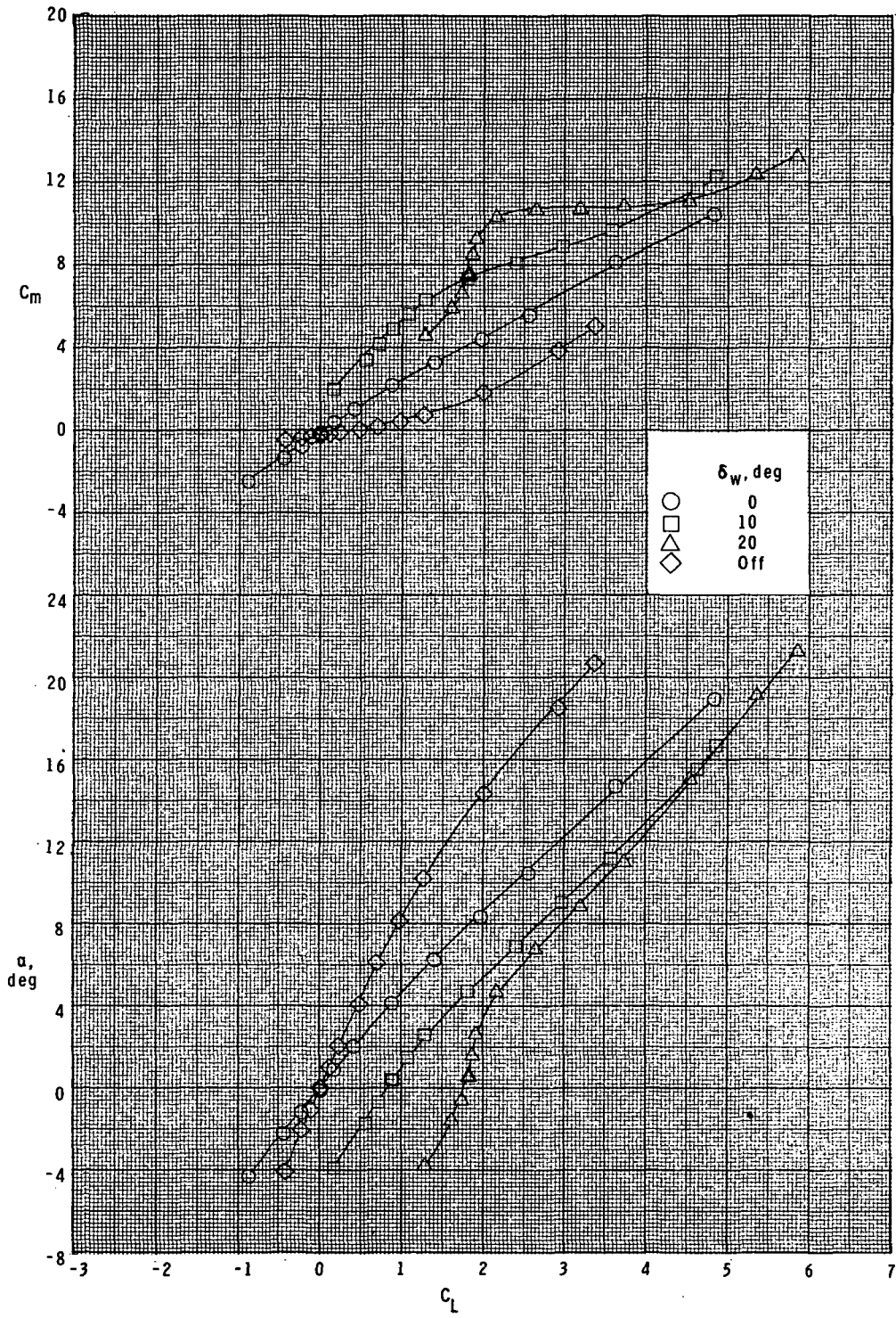
(f) Concluded.

Figure 3.- Concluded.



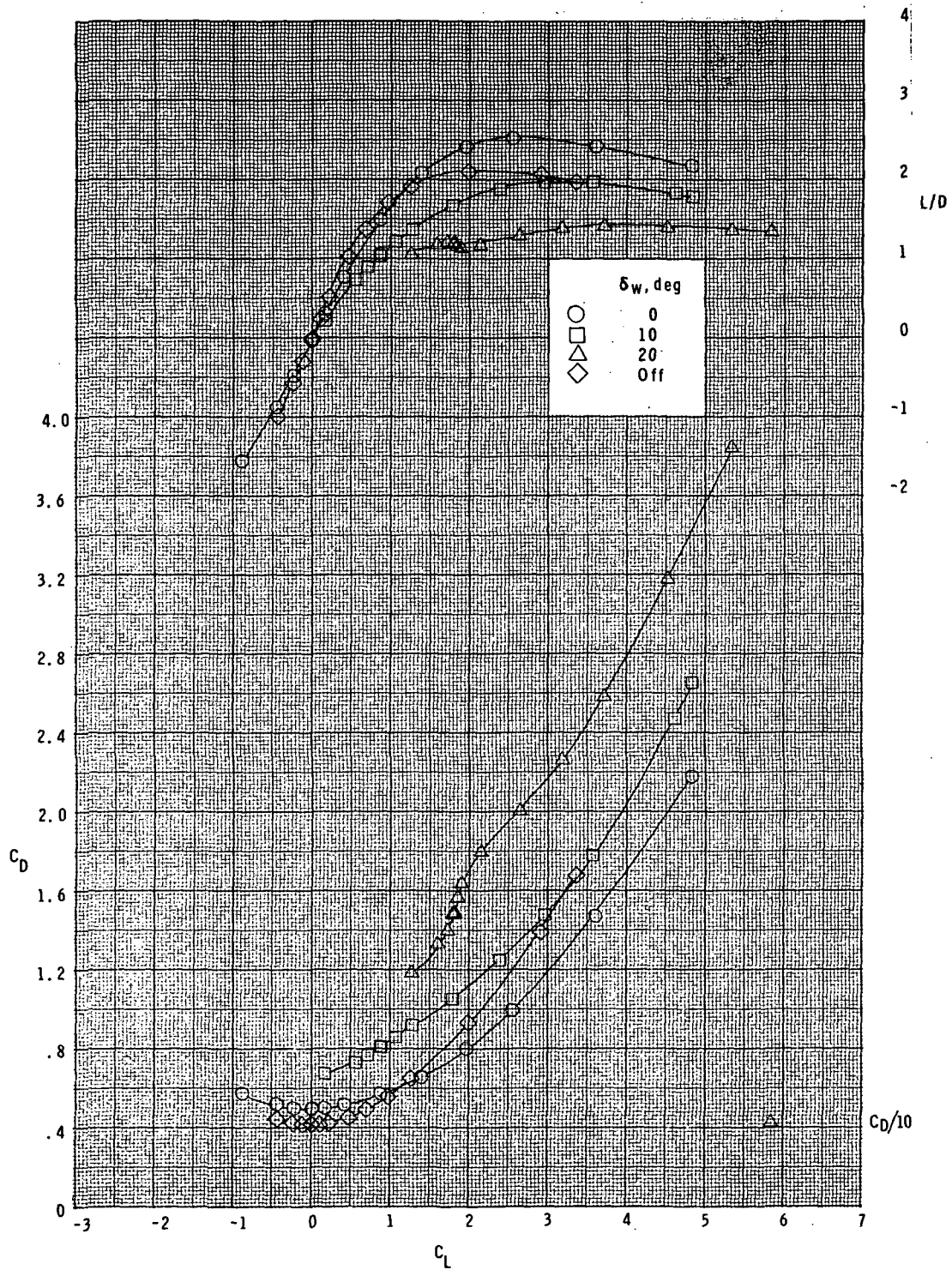
(a) $M = 1.50$.

Figure 4.- Effect of wing deflection on longitudinal aerodynamic characteristics.
 $\delta_t = 0^\circ$; $\phi = 45^\circ$; tails in line.



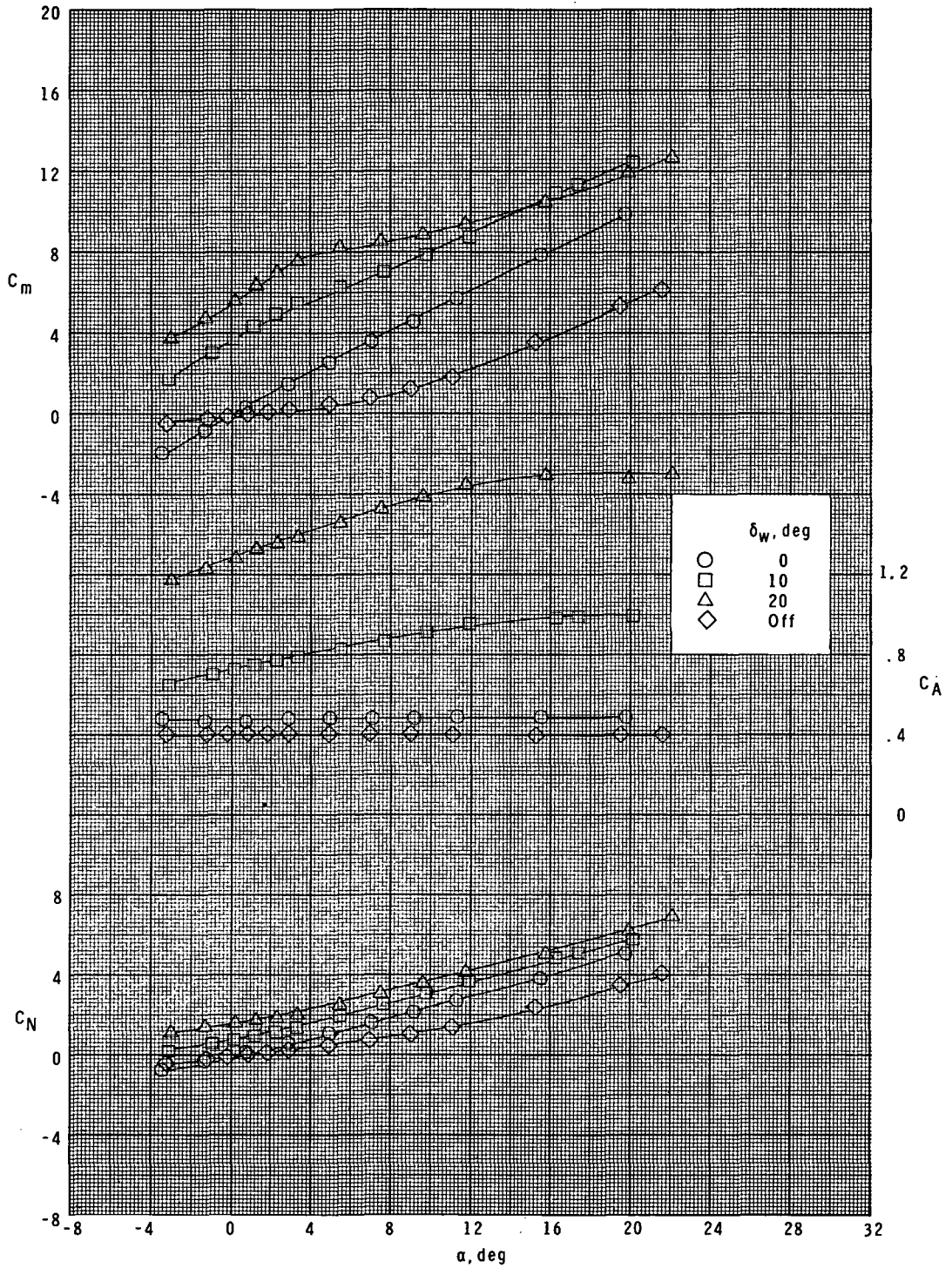
(a) Continued.

Figure 4. - Continued.



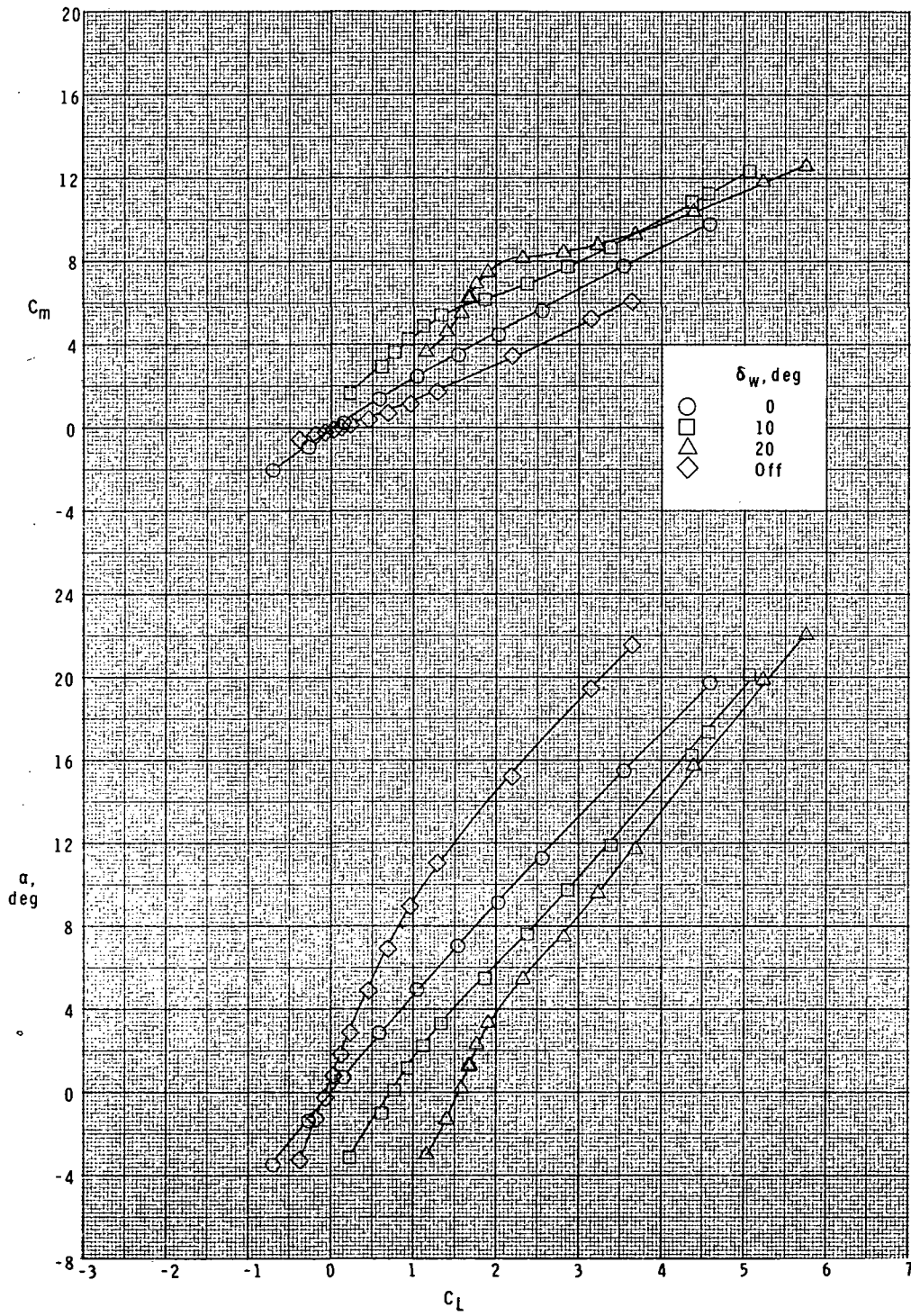
(a) Concluded.

Figure 4.- Continued.



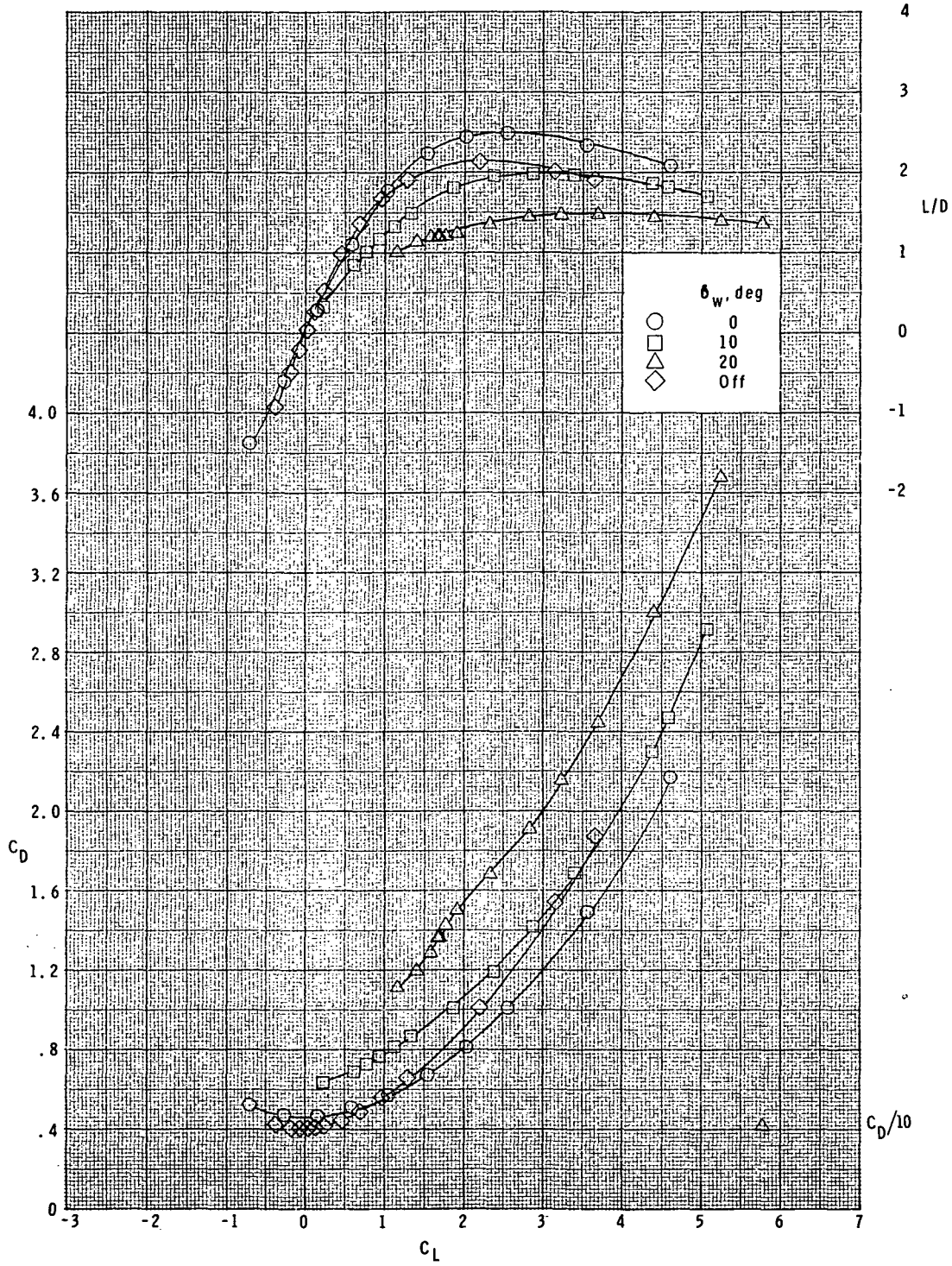
(b) $M = 1.90$.

Figure 4.- Continued.



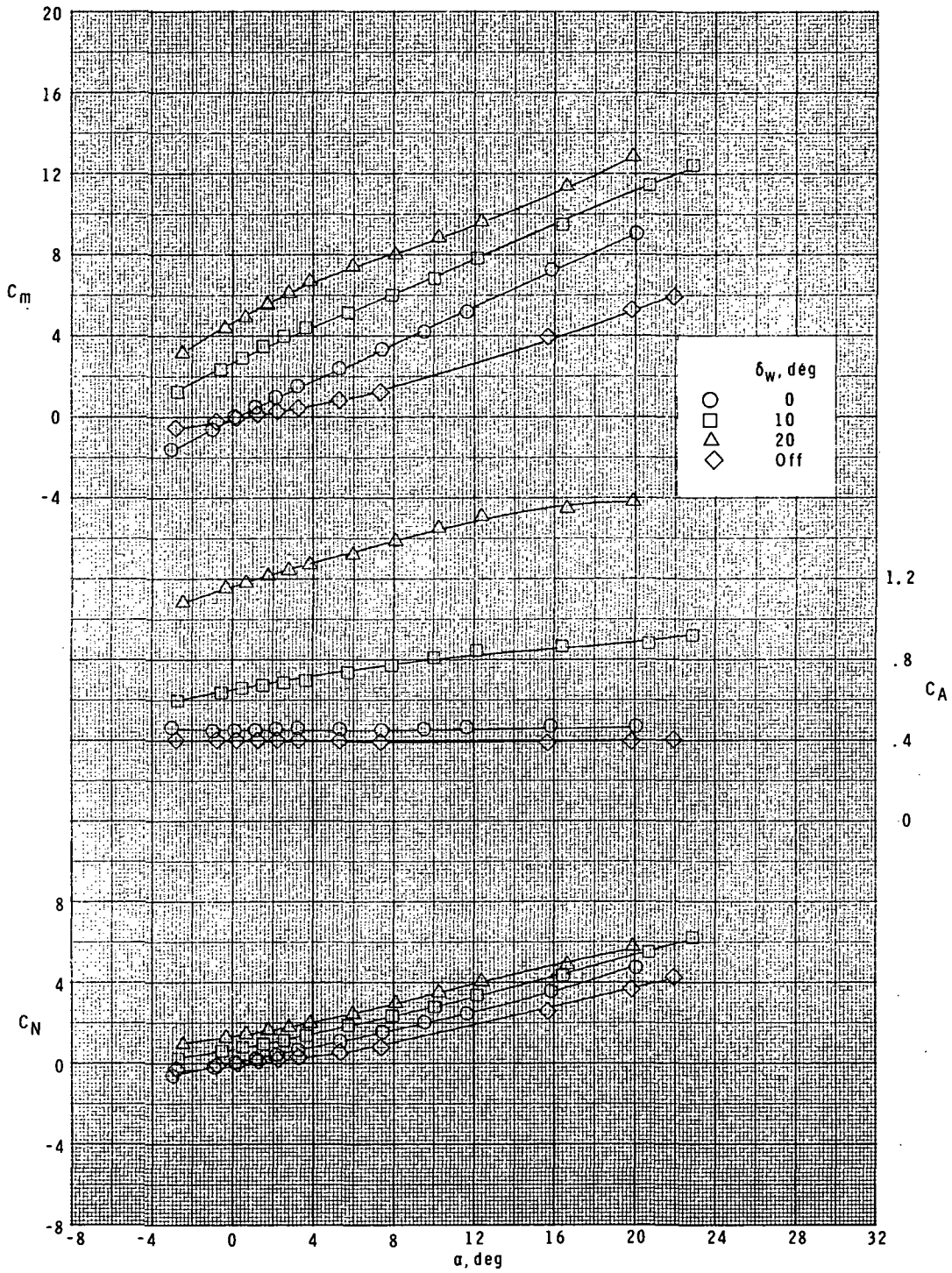
(b) Continued.

Figure 4.- Continued.



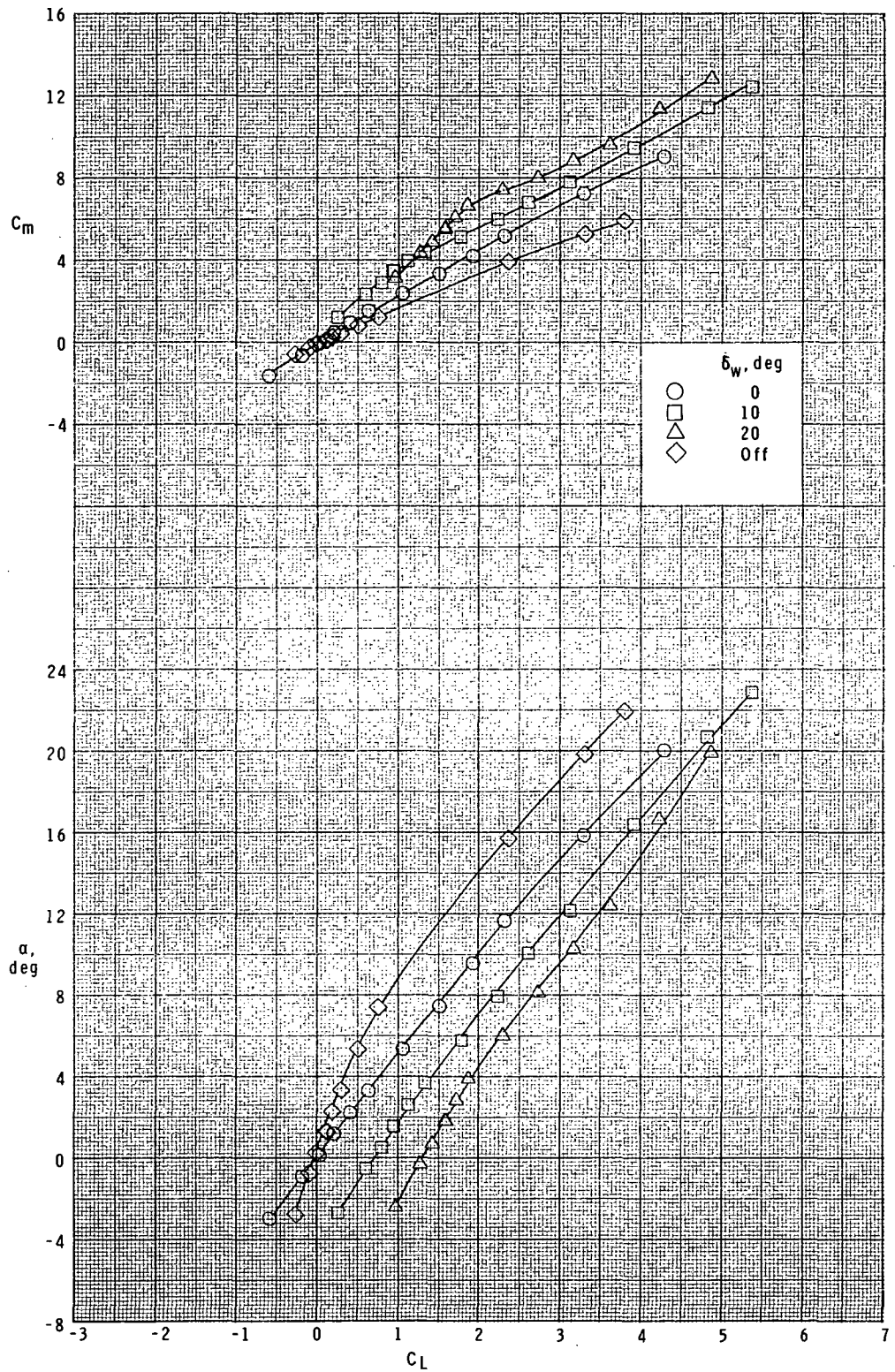
(b) Concluded.

Figure 4. - Continued.



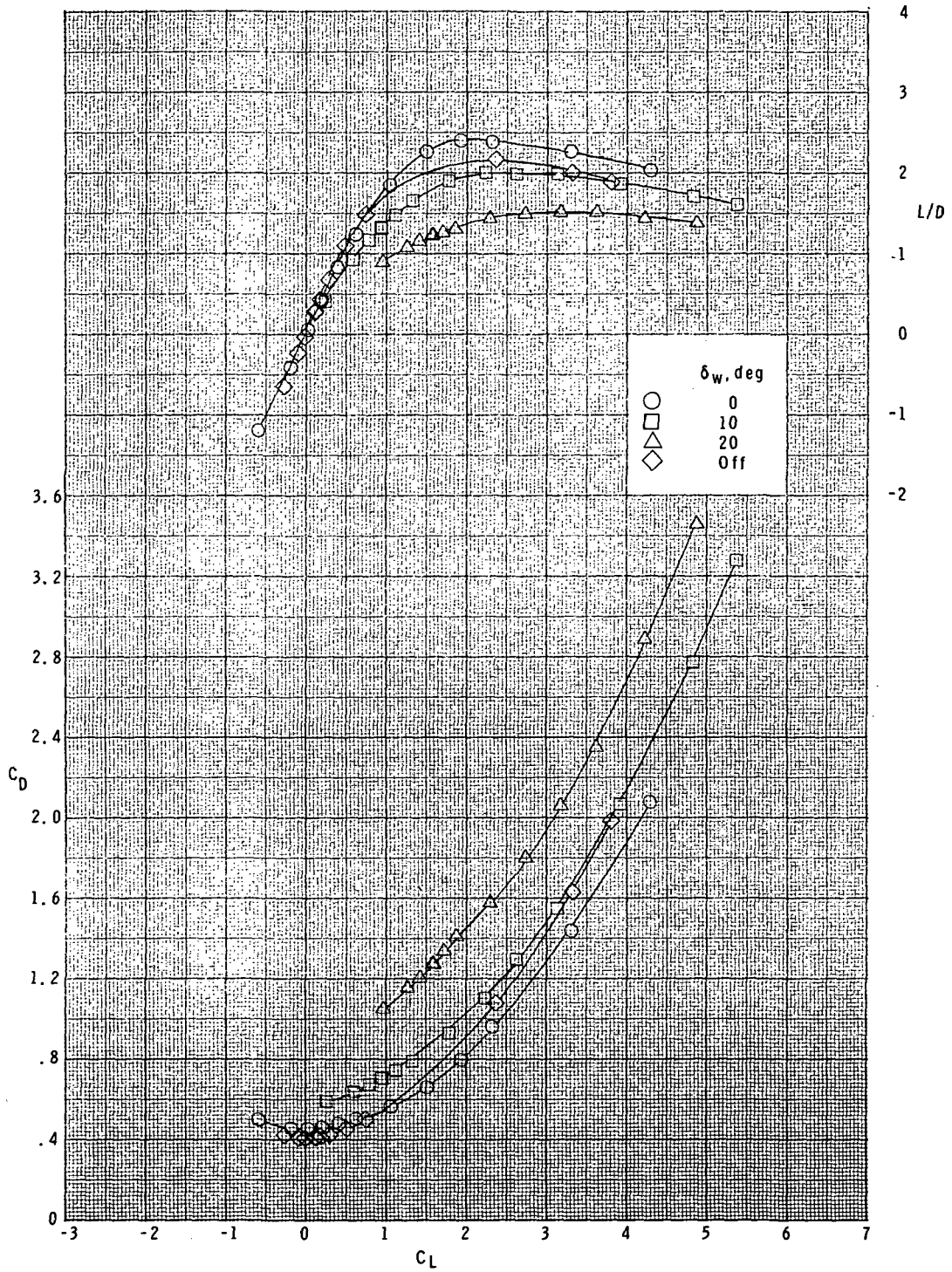
(c) $M = 2.36$.

Figure 4. - Continued.



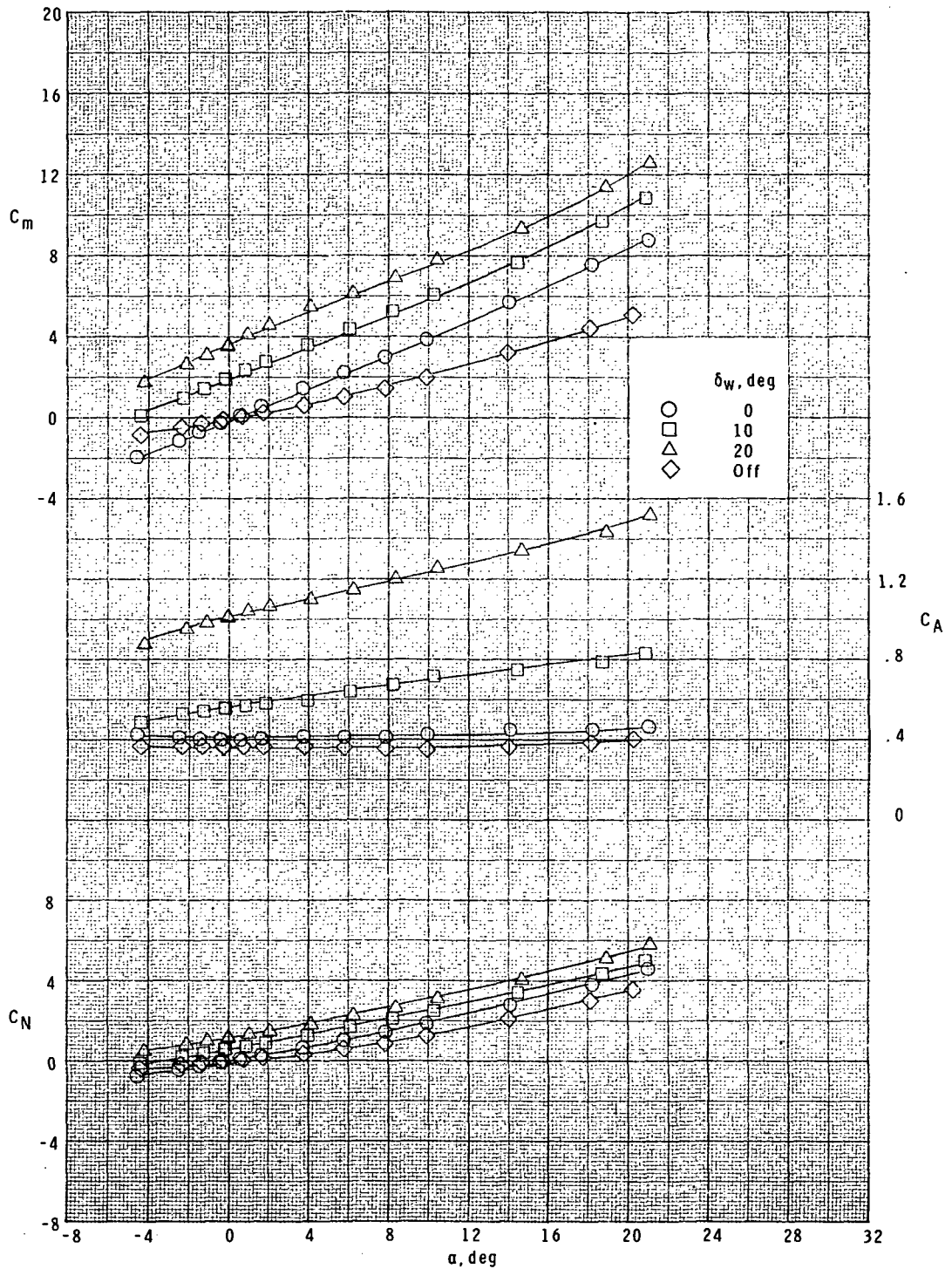
(c) Continued.

Figure 4.- Continued.



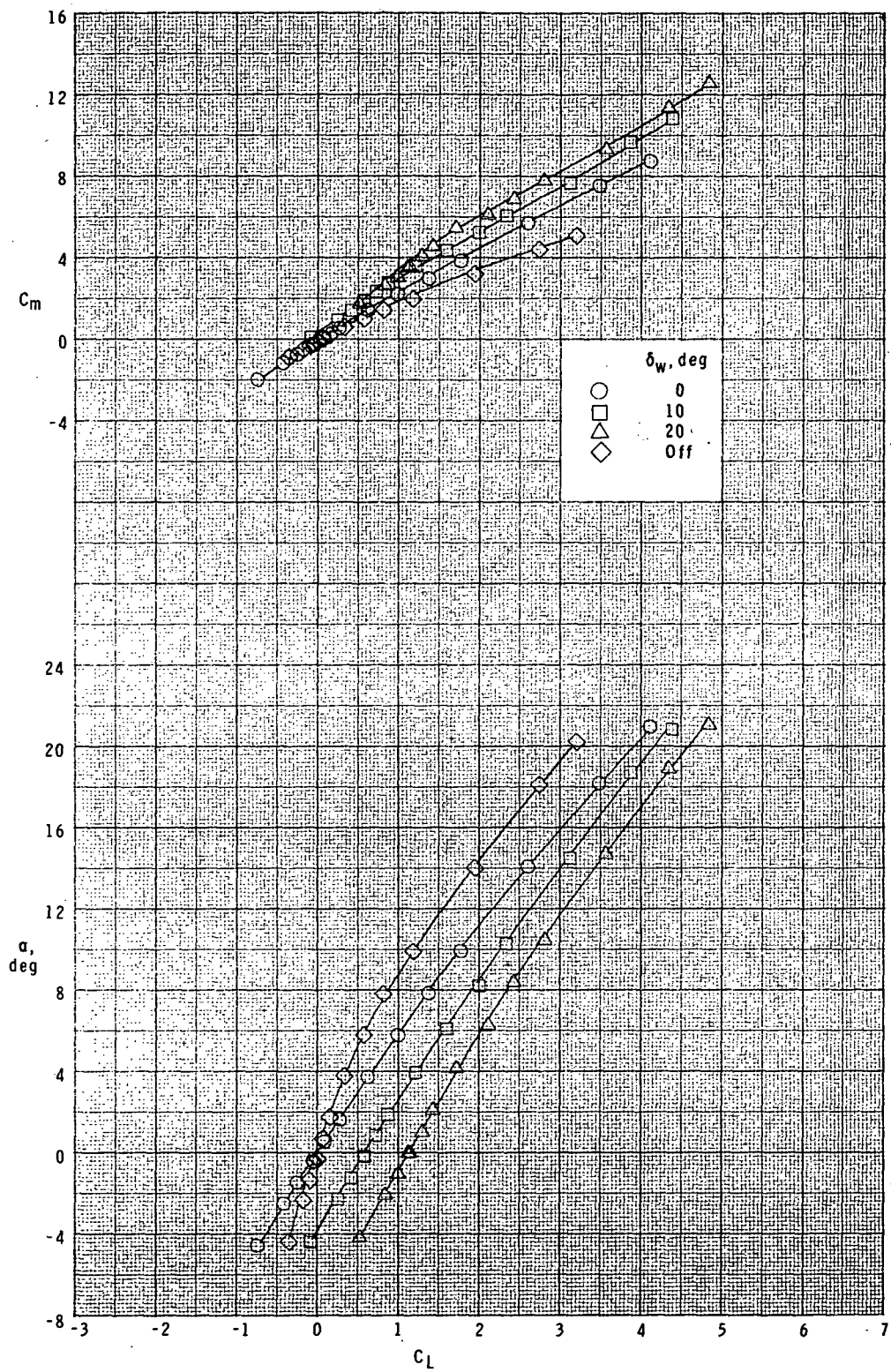
(c) Concluded.

Figure 4. - Continued.

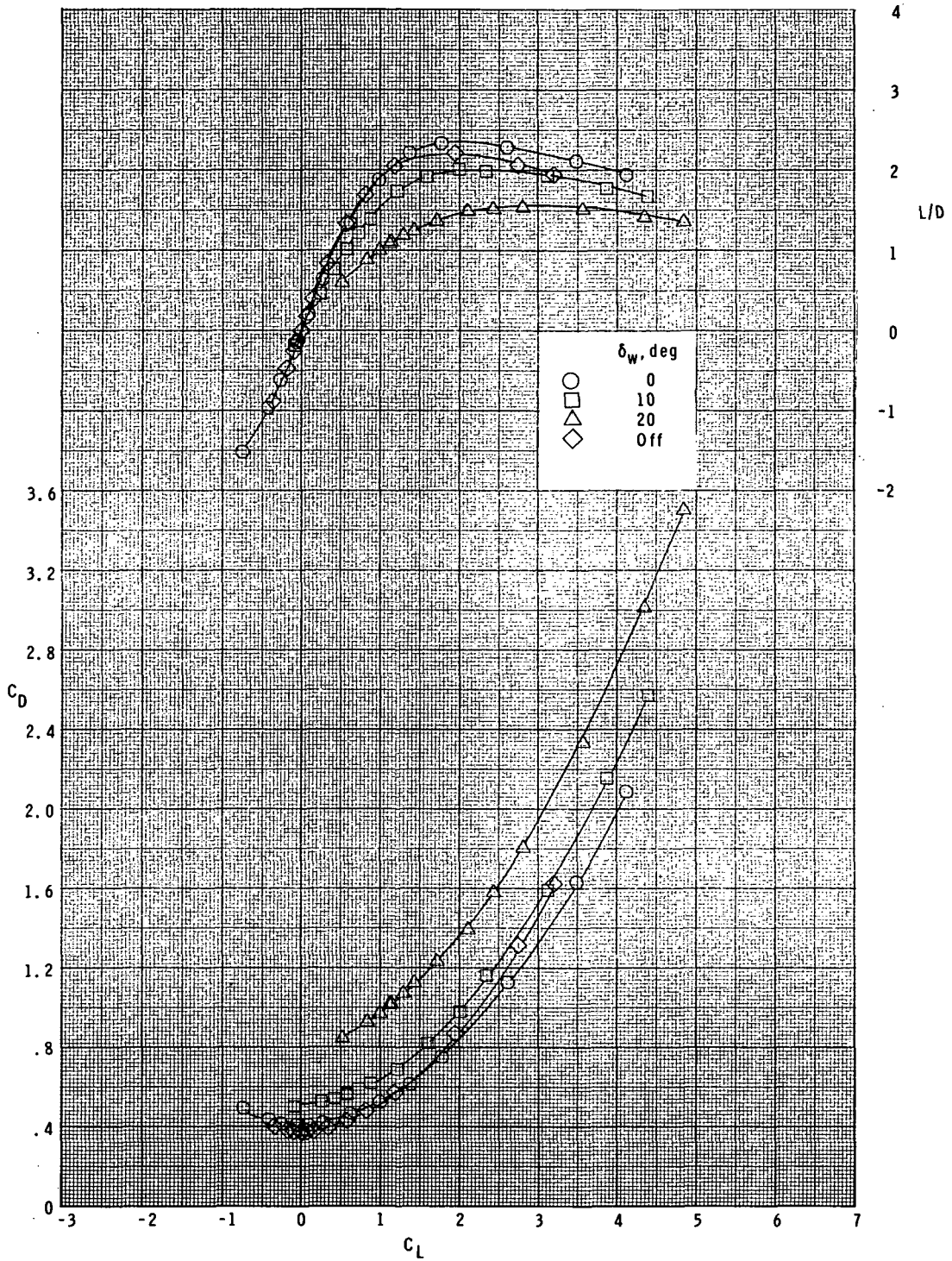


(d) $M = 2.86$.

Figure 4.- Continued.

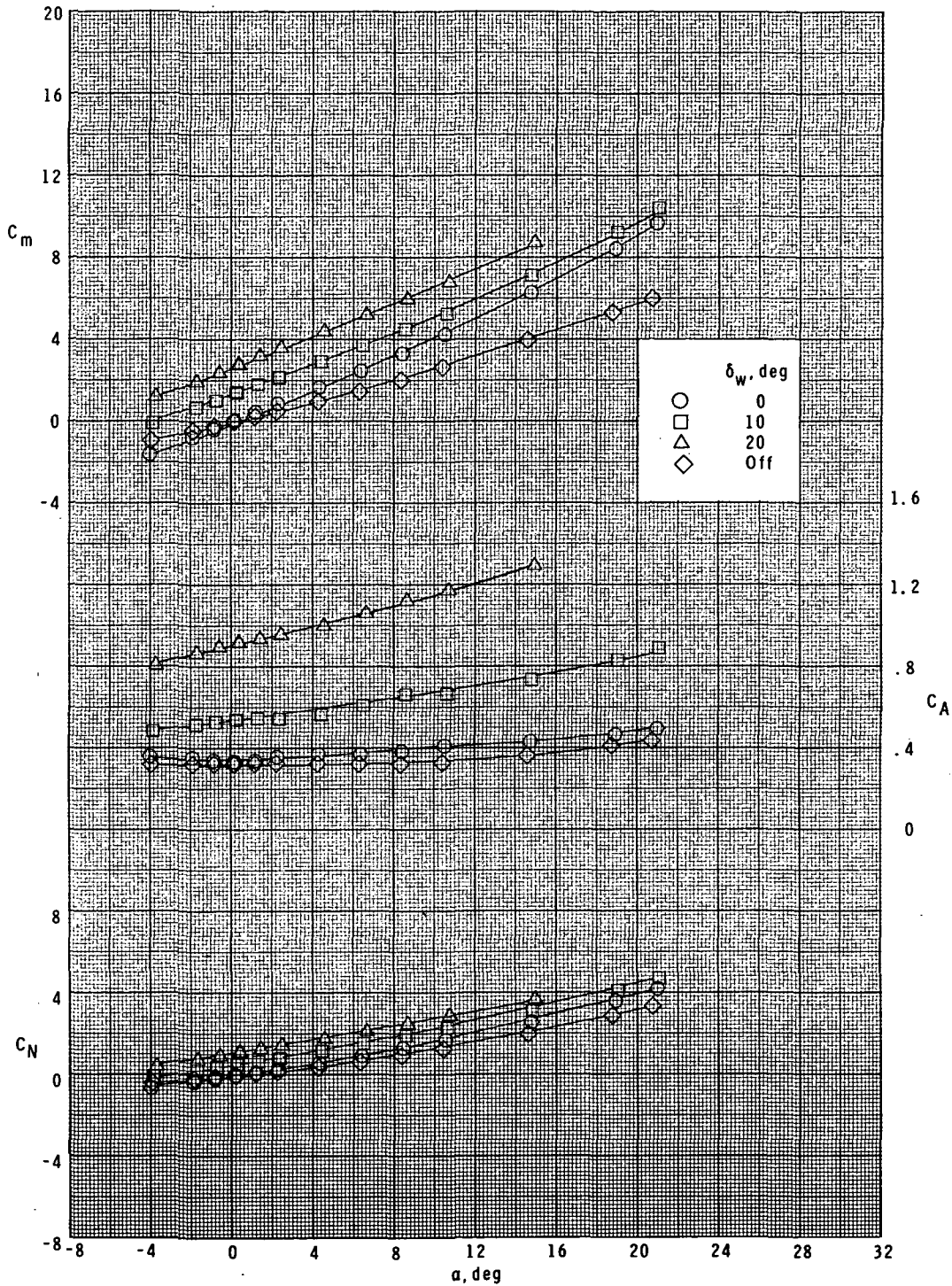


(d) Continued.
 Figure 4.- Continued.



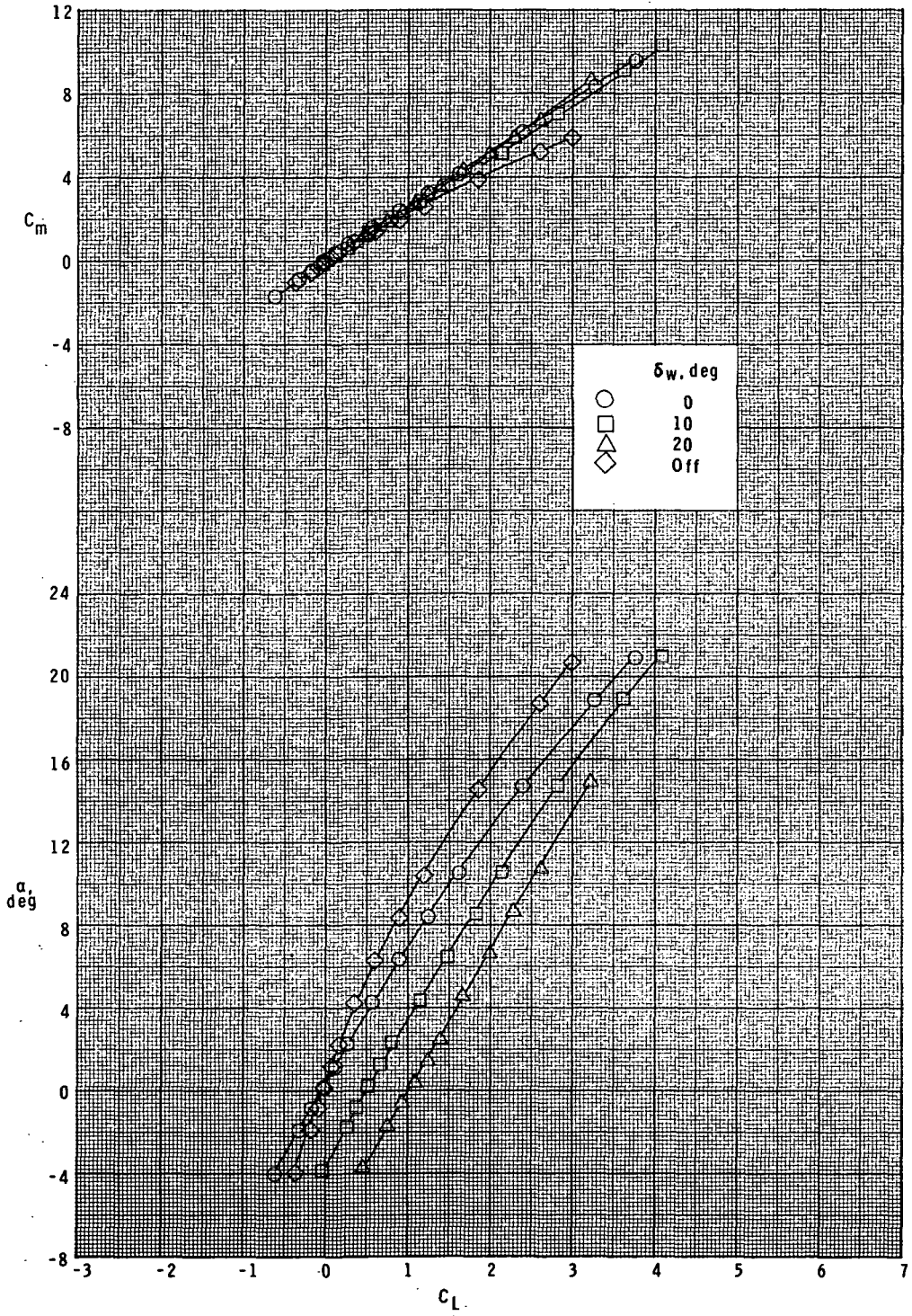
(d) Concluded.

Figure 4. - Continued.



(e) $M = 3.95$.

Figure 4.- Continued.

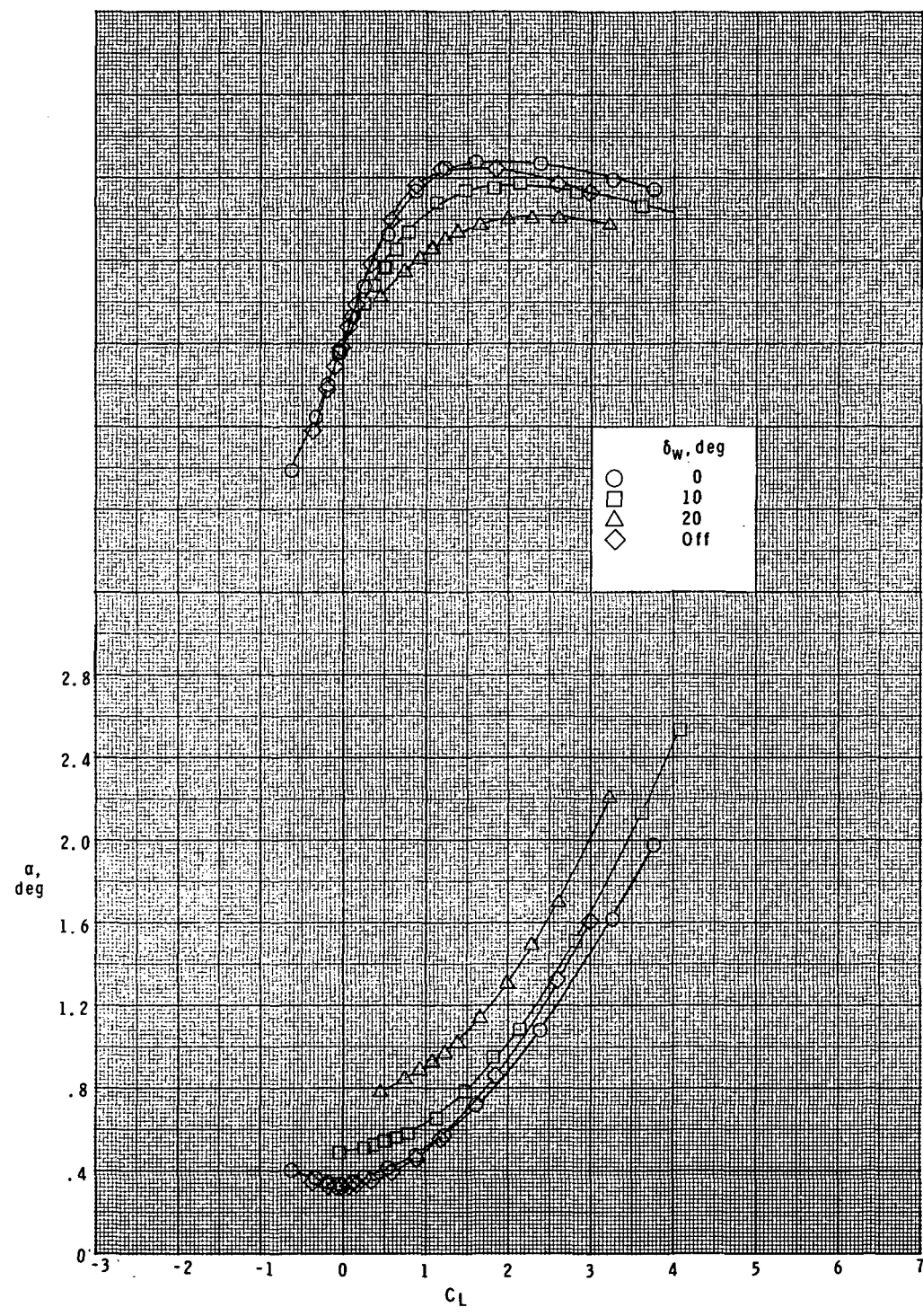


(e) Continued.

Figure 4. - Continued.

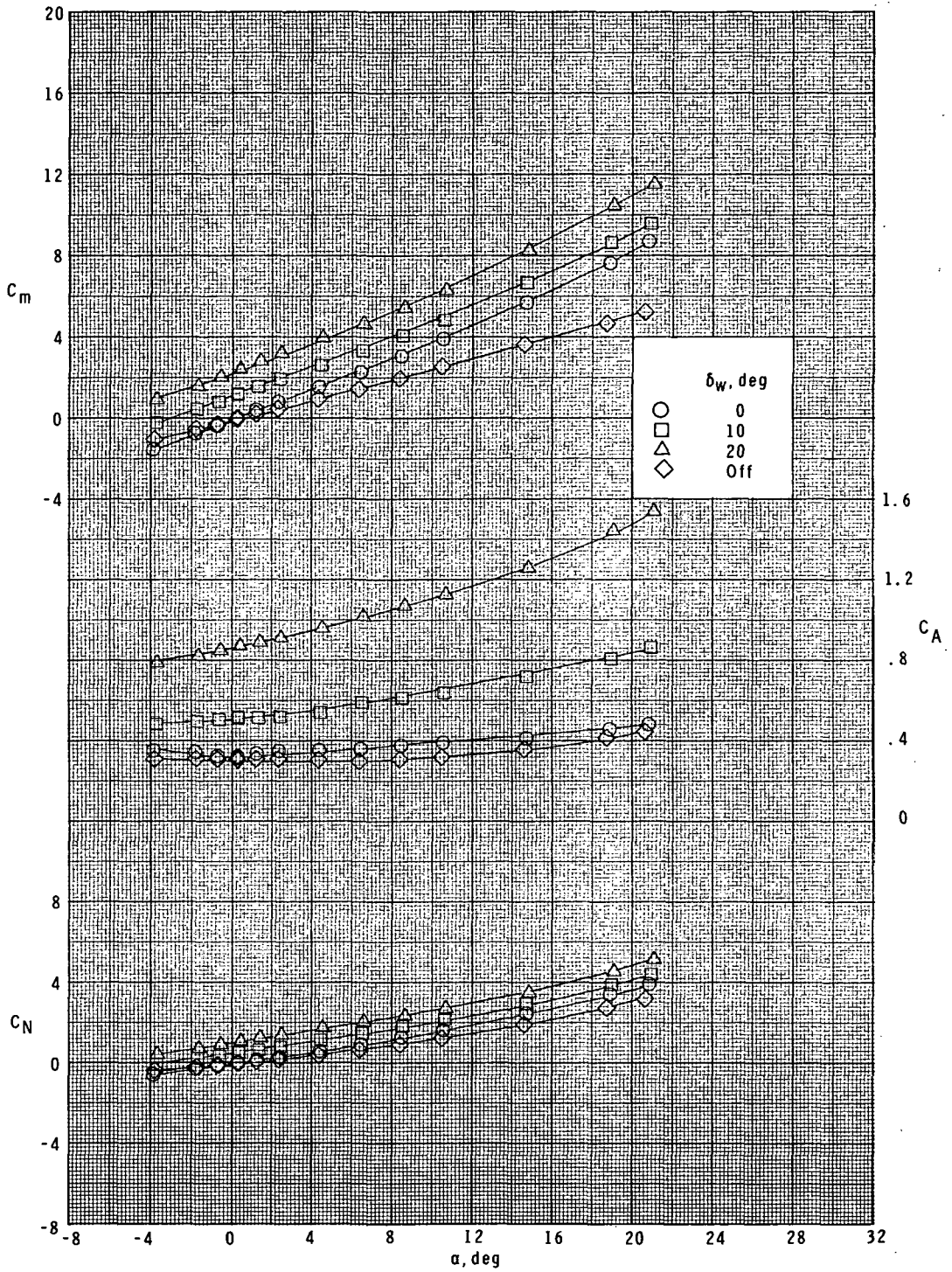
4
3
2
1
0
-1
-2

L/D



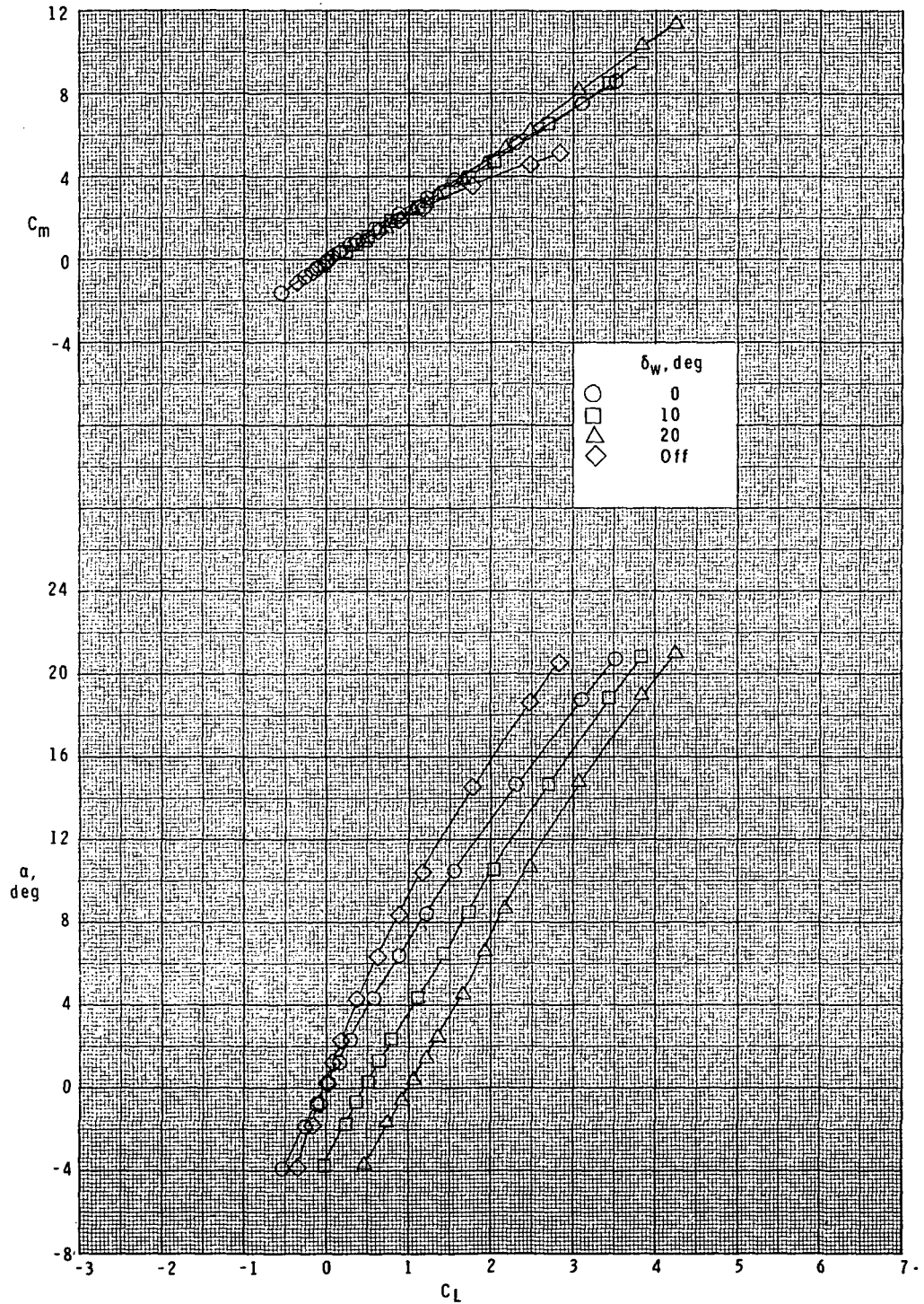
(e) Concluded.

Figure 4.- Continued.



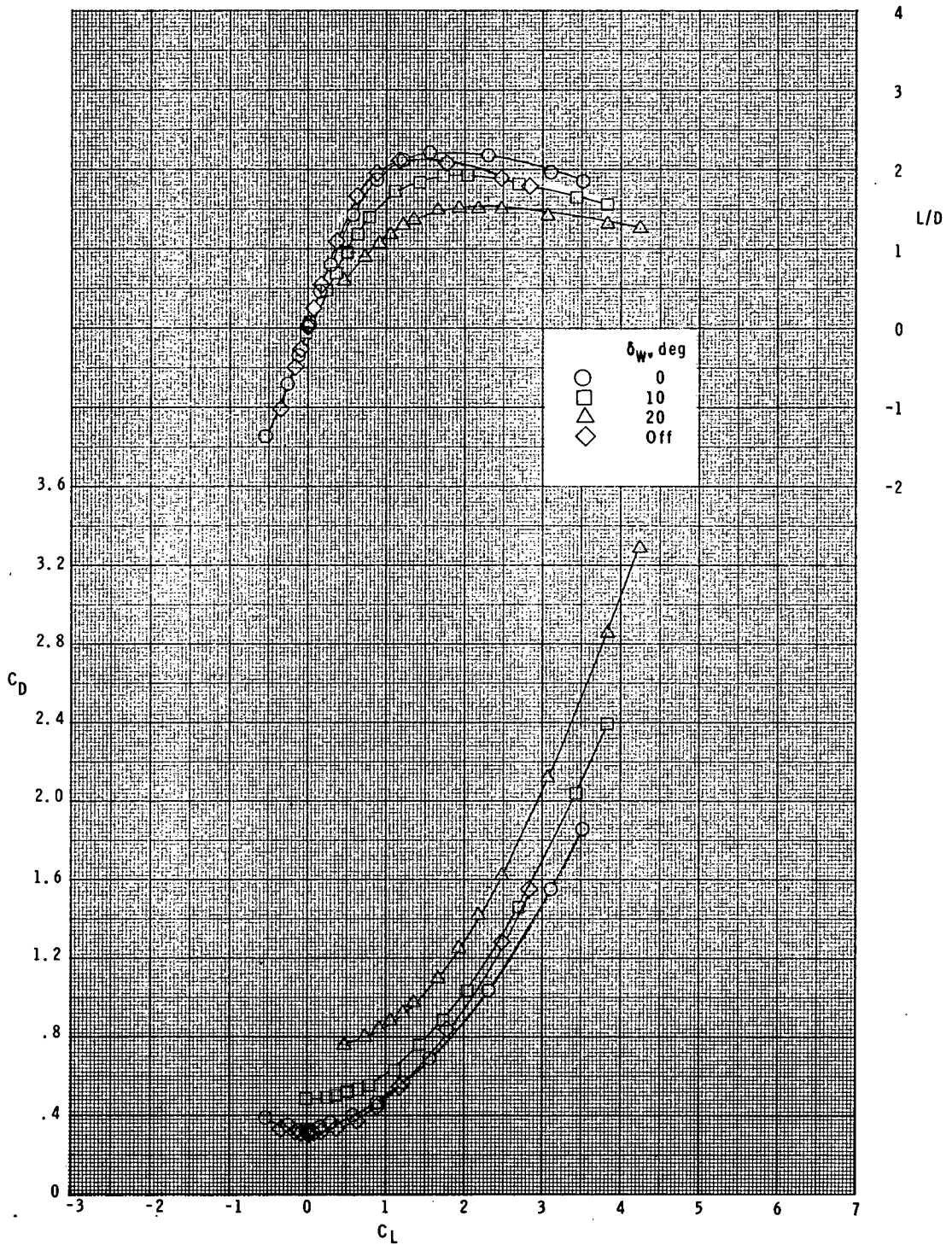
(f) $M = 4.63$.

Figure 4. - Continued.



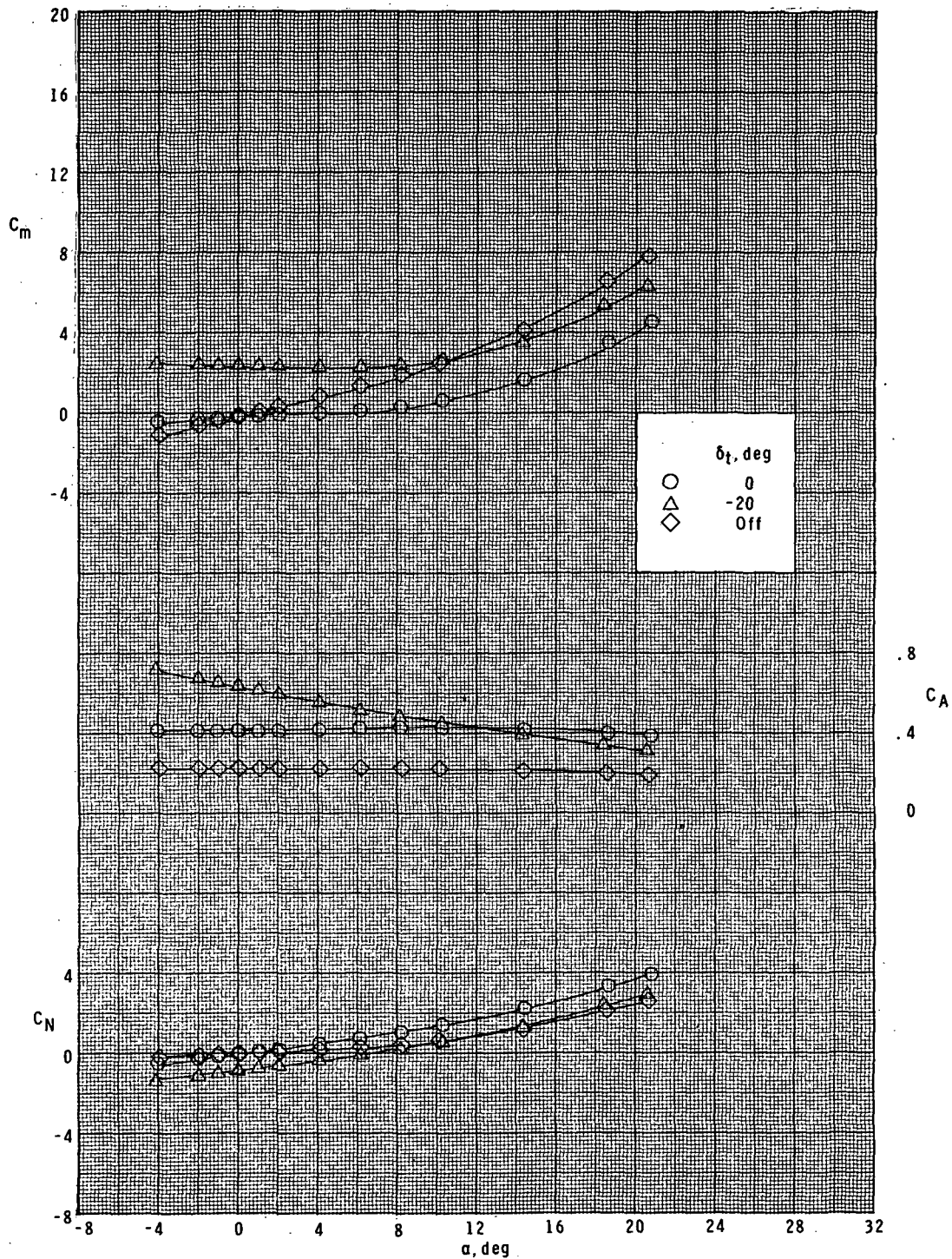
(f) Continued.

Figure 4. - Continued.



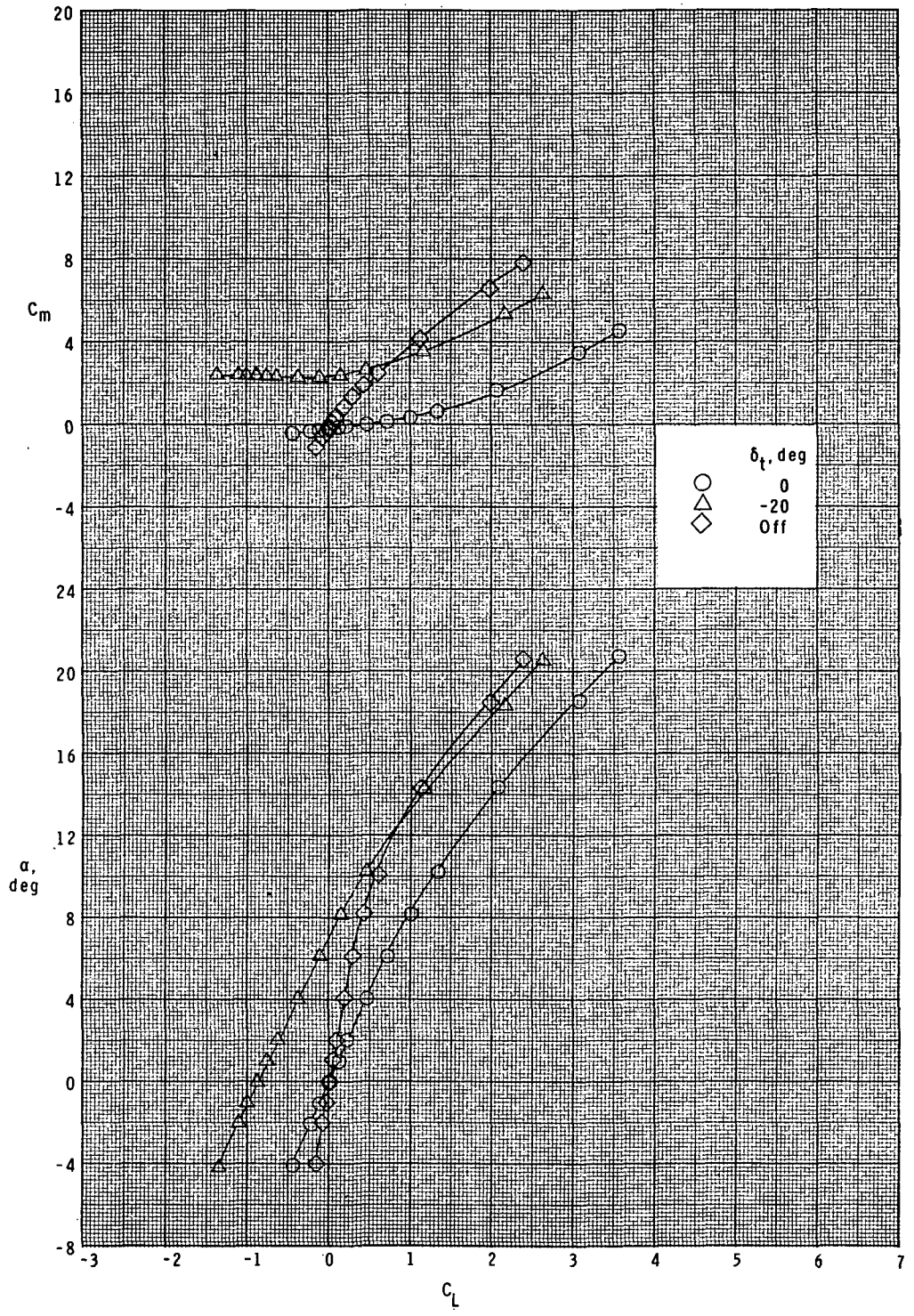
(f) Concluded.

Figure 4. - Concluded.



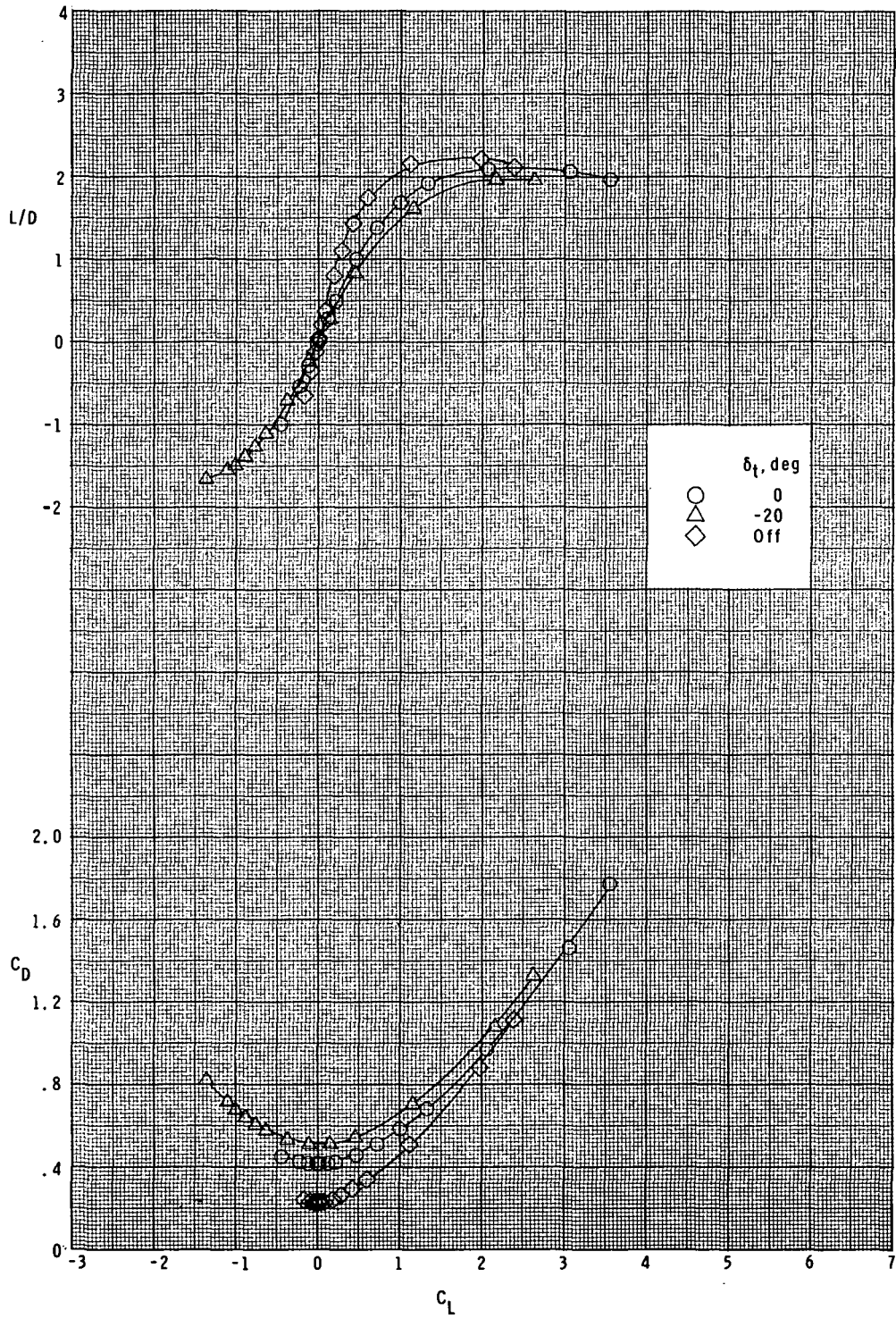
(a) $M = 1.50$.

Figure 5.- Effect of tail deflection on the longitudinal aerodynamic characteristics of the body-tail configuration. $\phi = 0^\circ$.



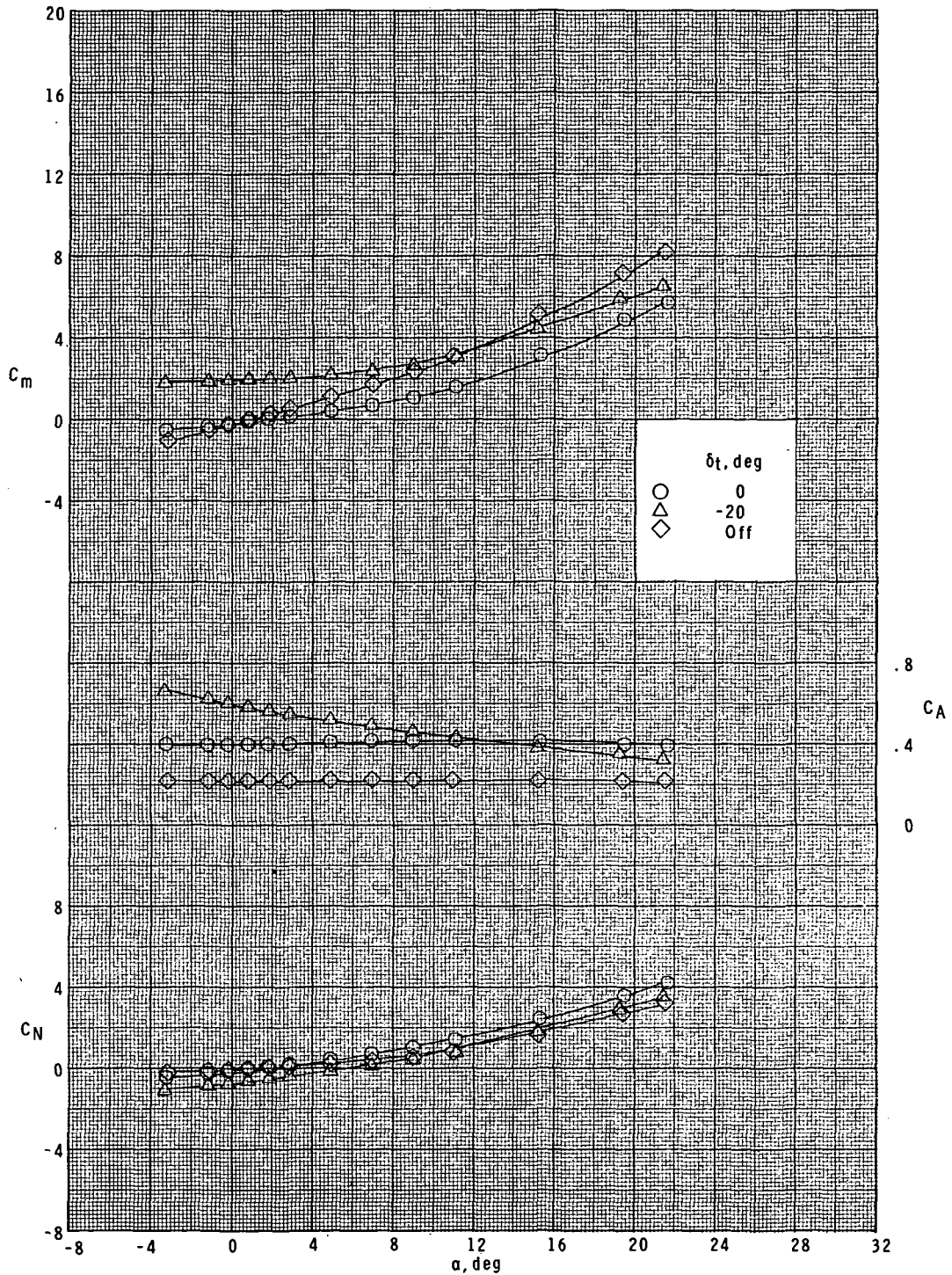
(a) Continued.

Figure 5.- Continued.



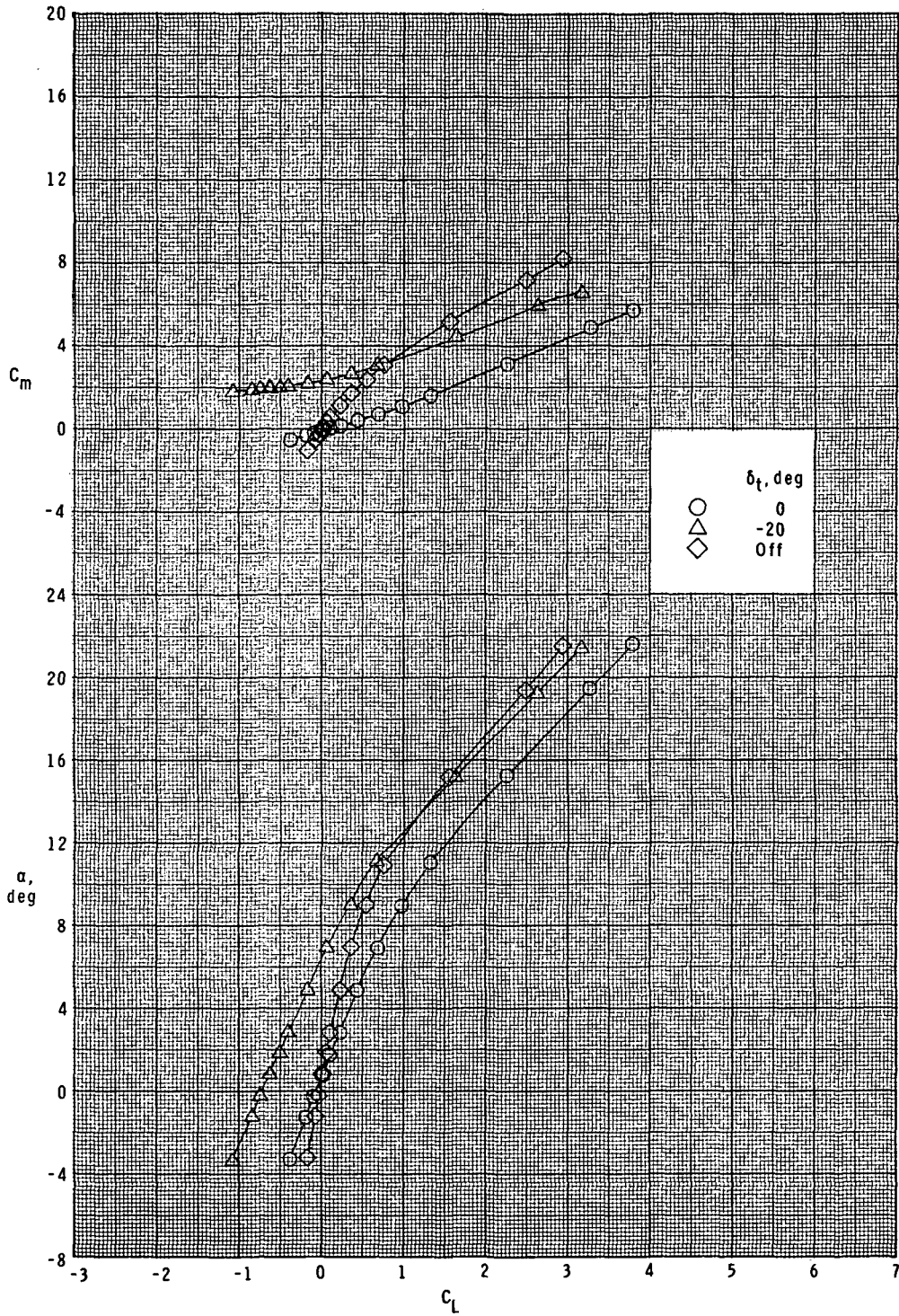
(a) Concluded.

Figure 5.- Continued.



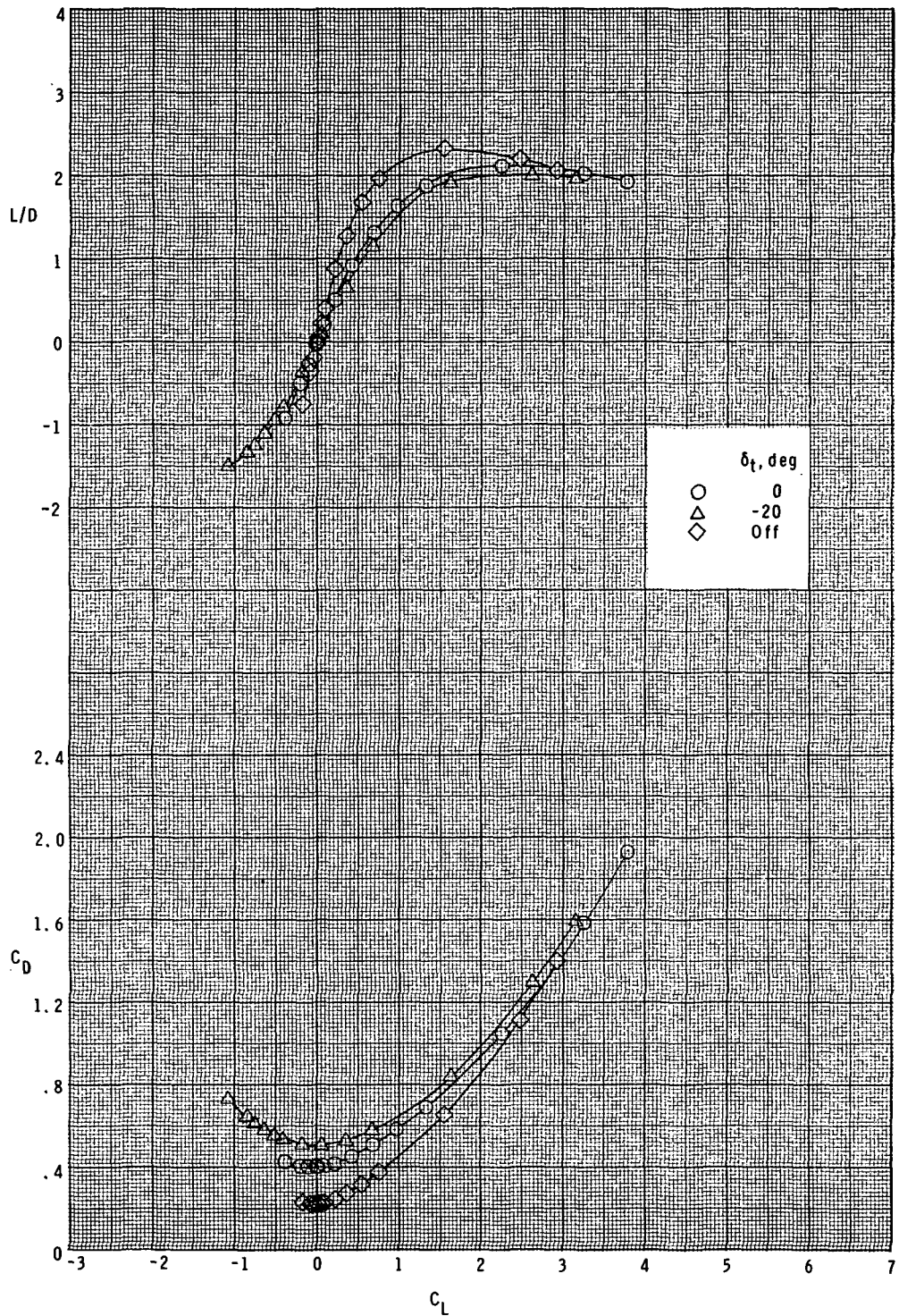
(b) $M = 1.90$.

Figure 5. - Continued.



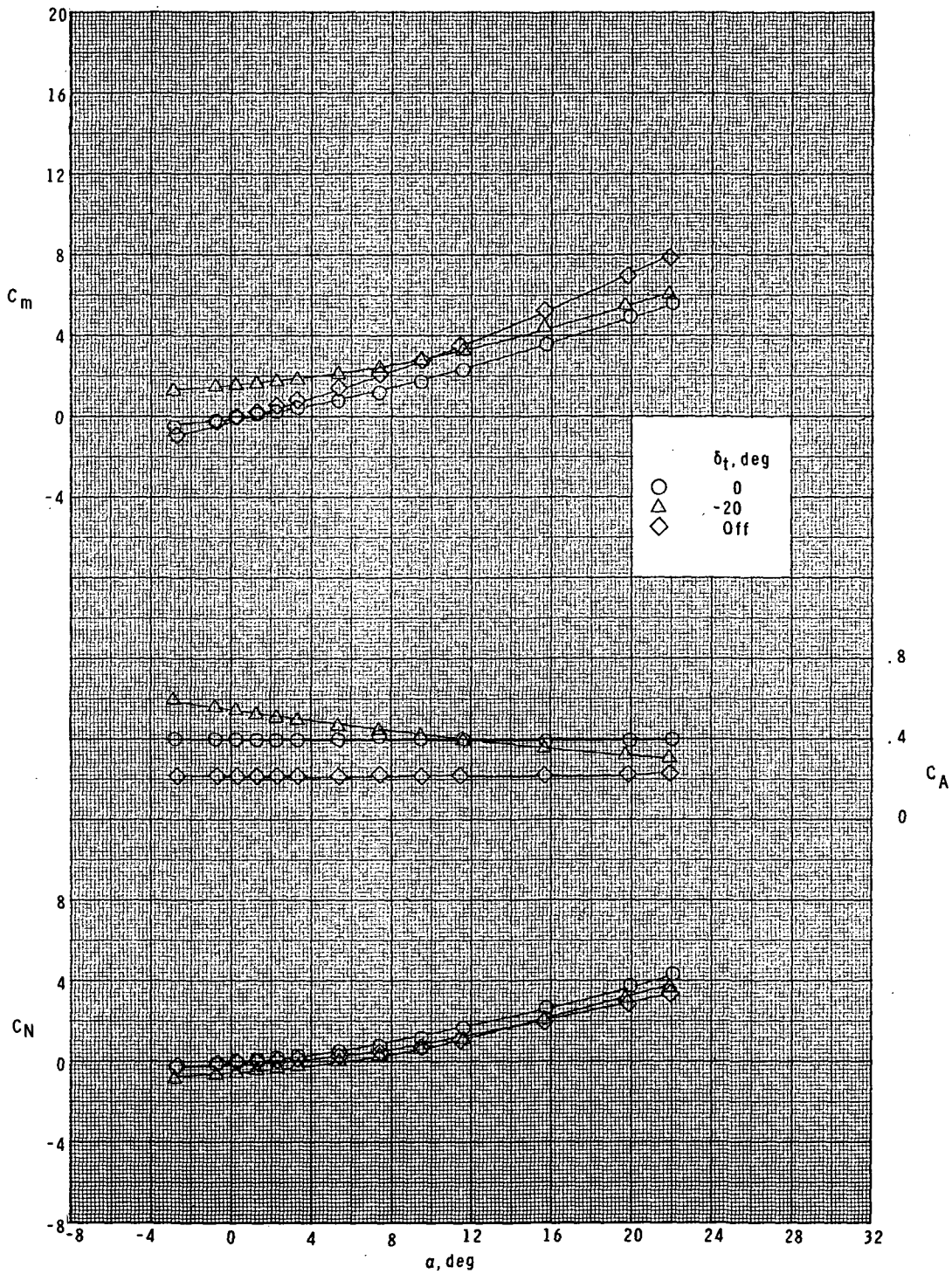
(b) Continued.

Figure 5. - Continued.



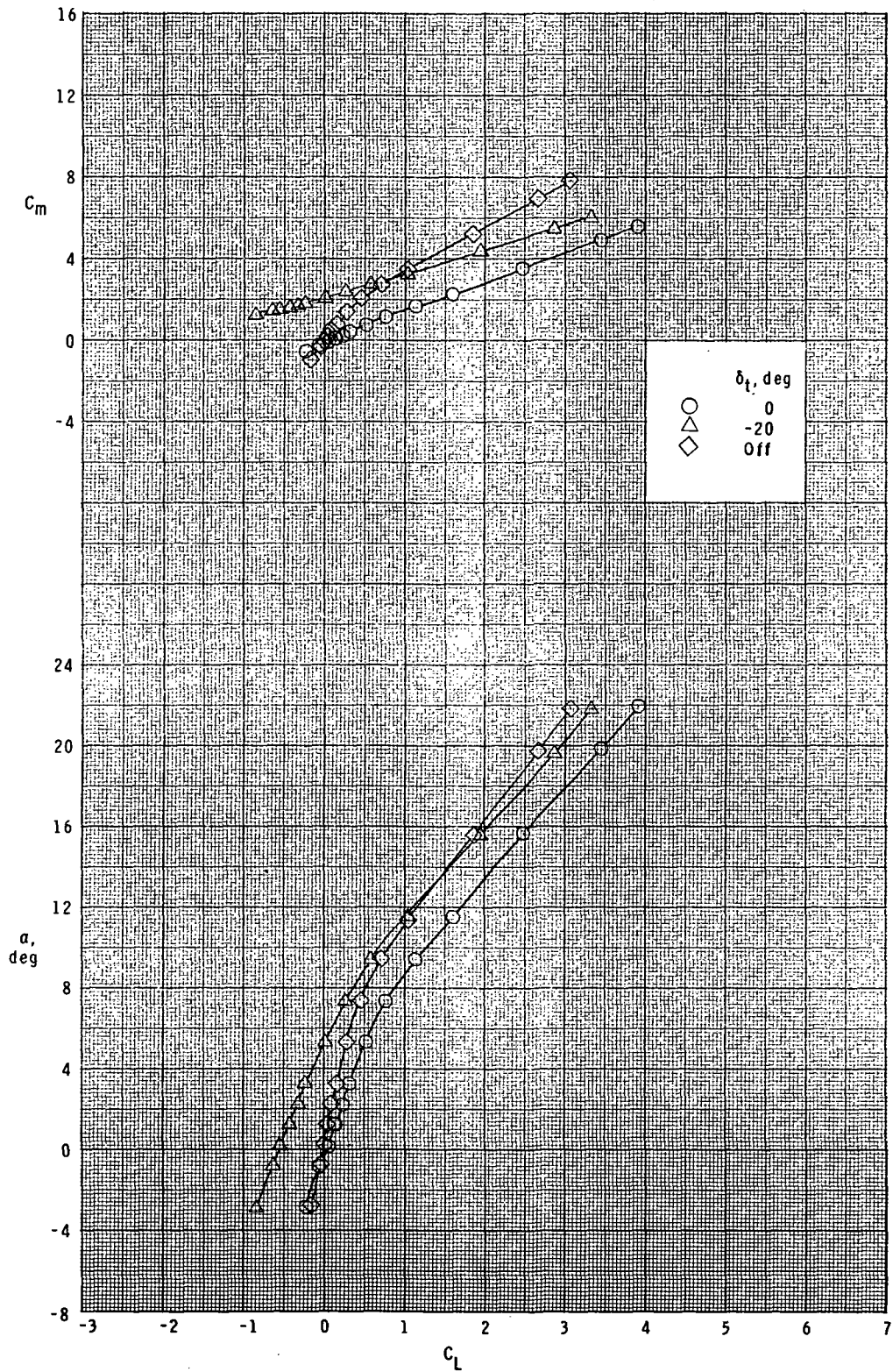
(b) Concluded.

Figure 5.- Continued.



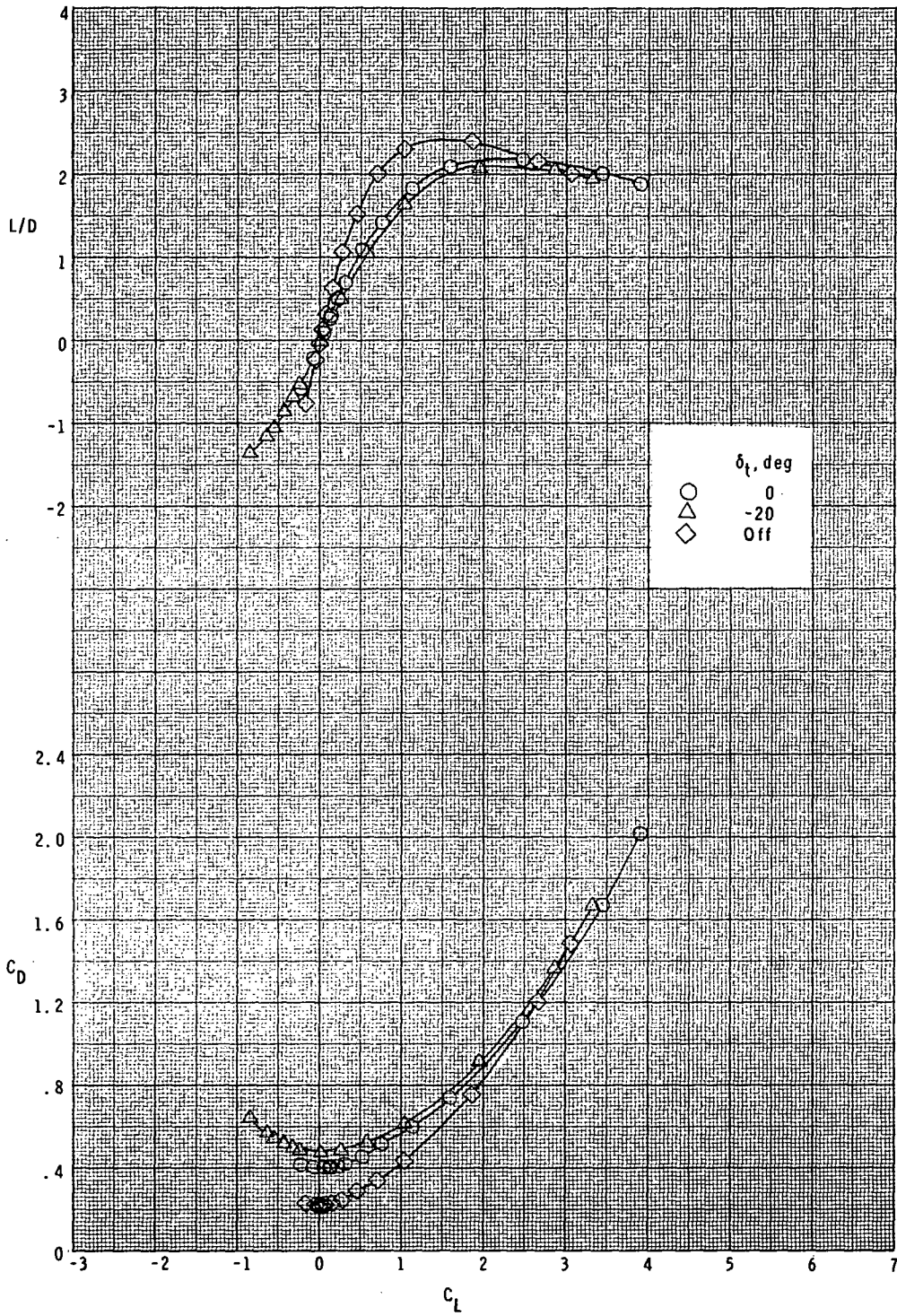
(c) $M = 2.36$.

Figure 5.- Continued.



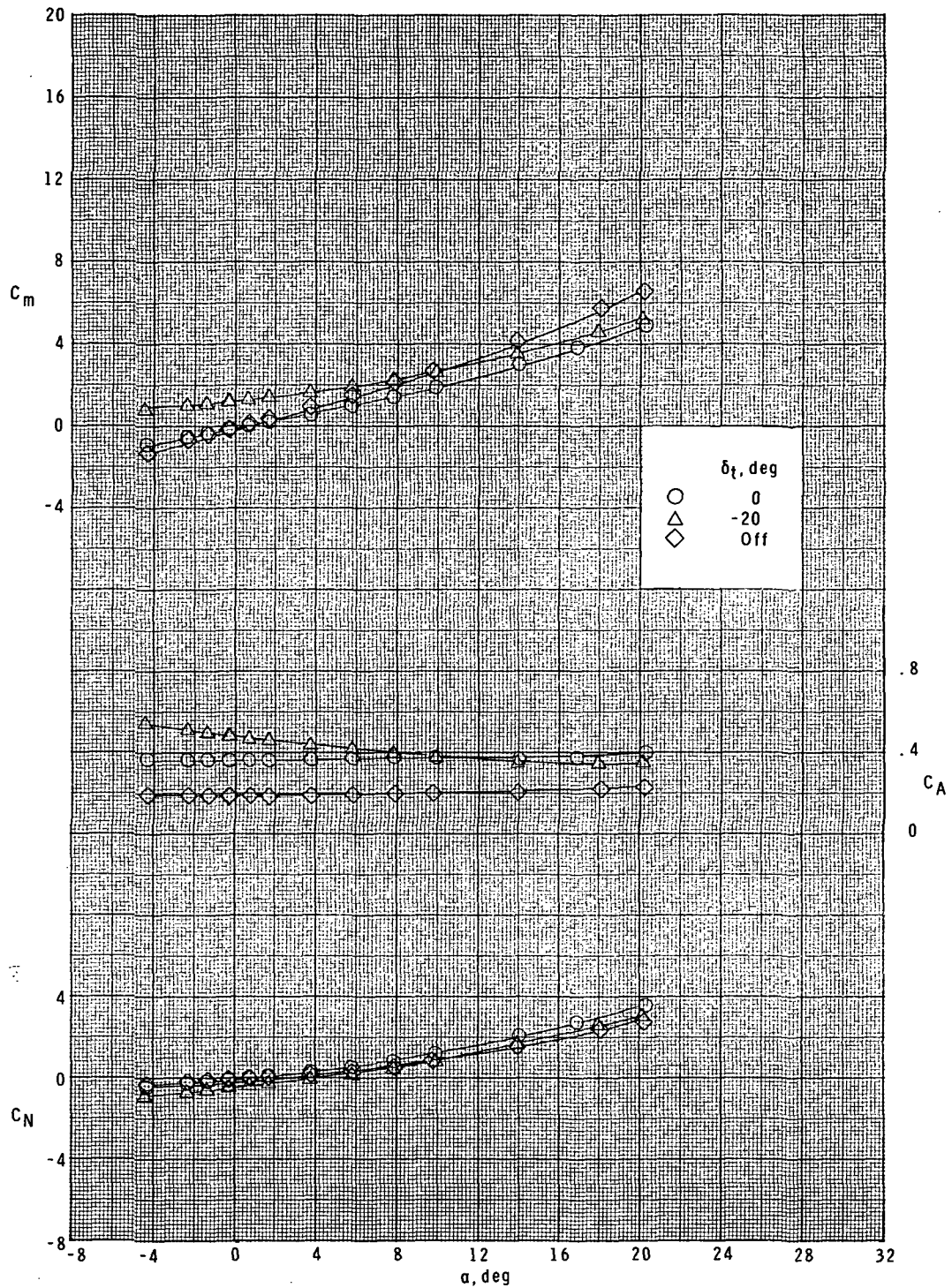
(c) Continued.

Figure 5.- Continued.



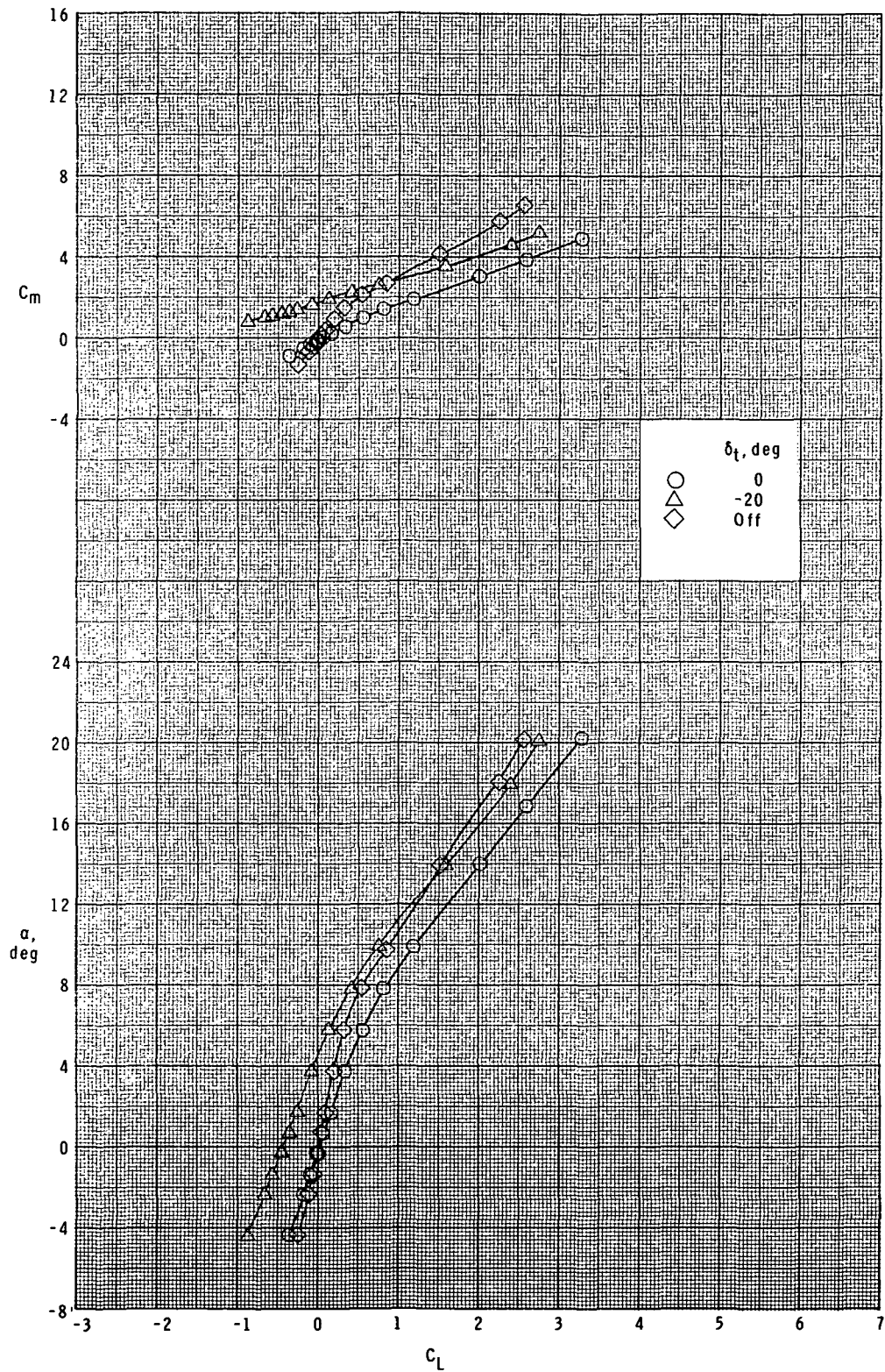
(c) Concluded.

Figure 5.- Continued.



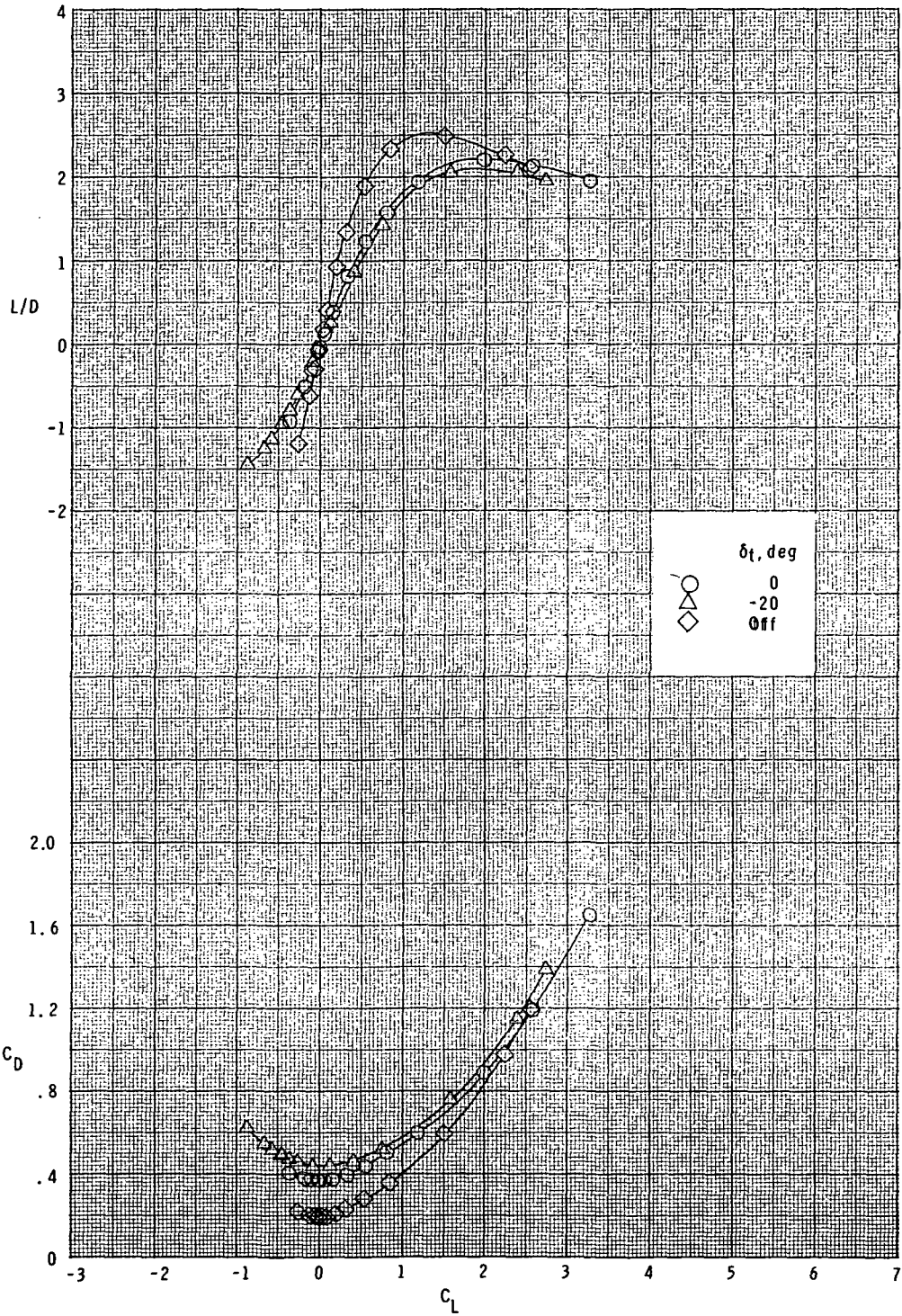
(d) $M = 2.86$.

Figure 5. - Continued.



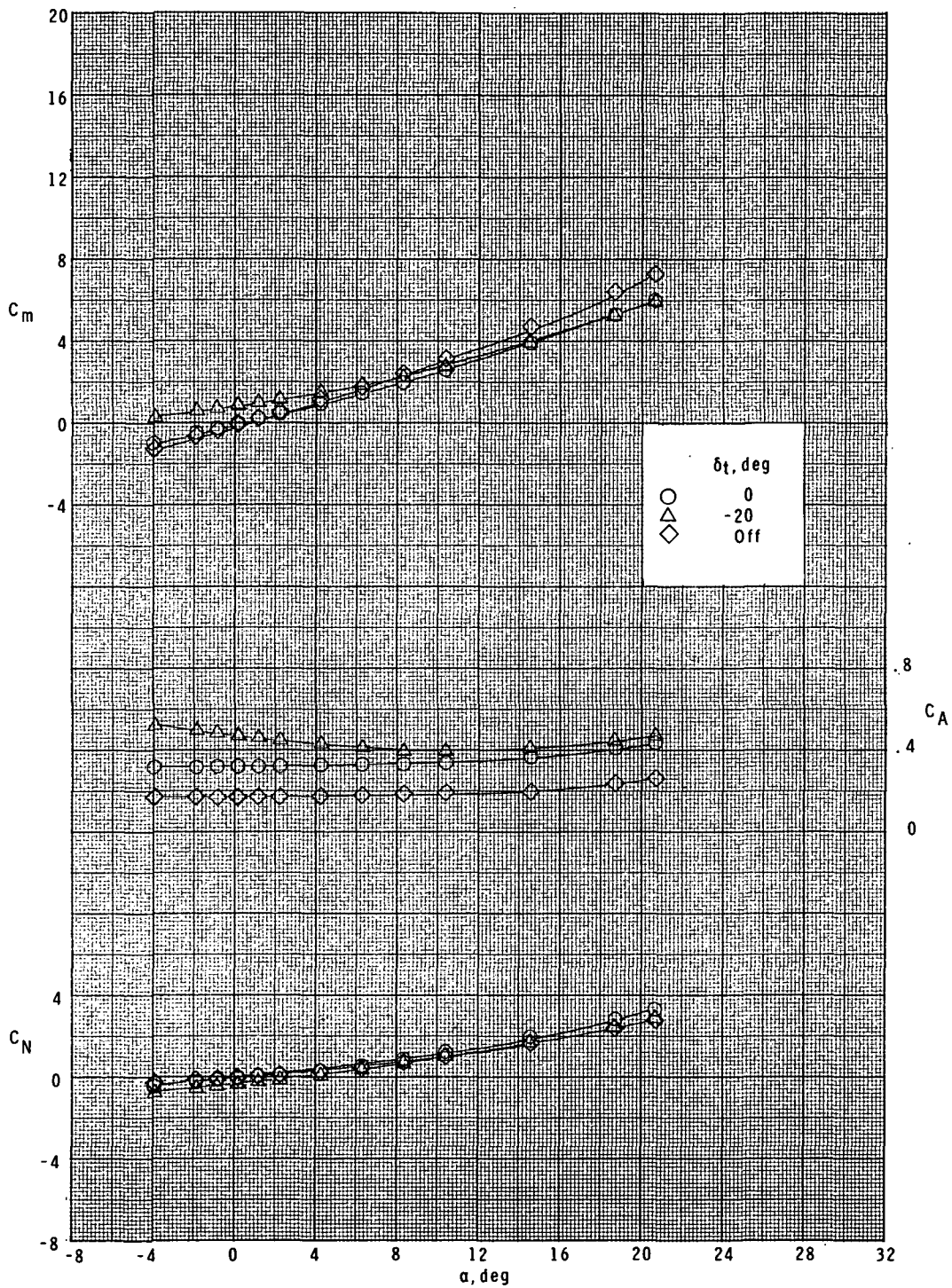
(d) Continued.

Figure 5.- Continued.



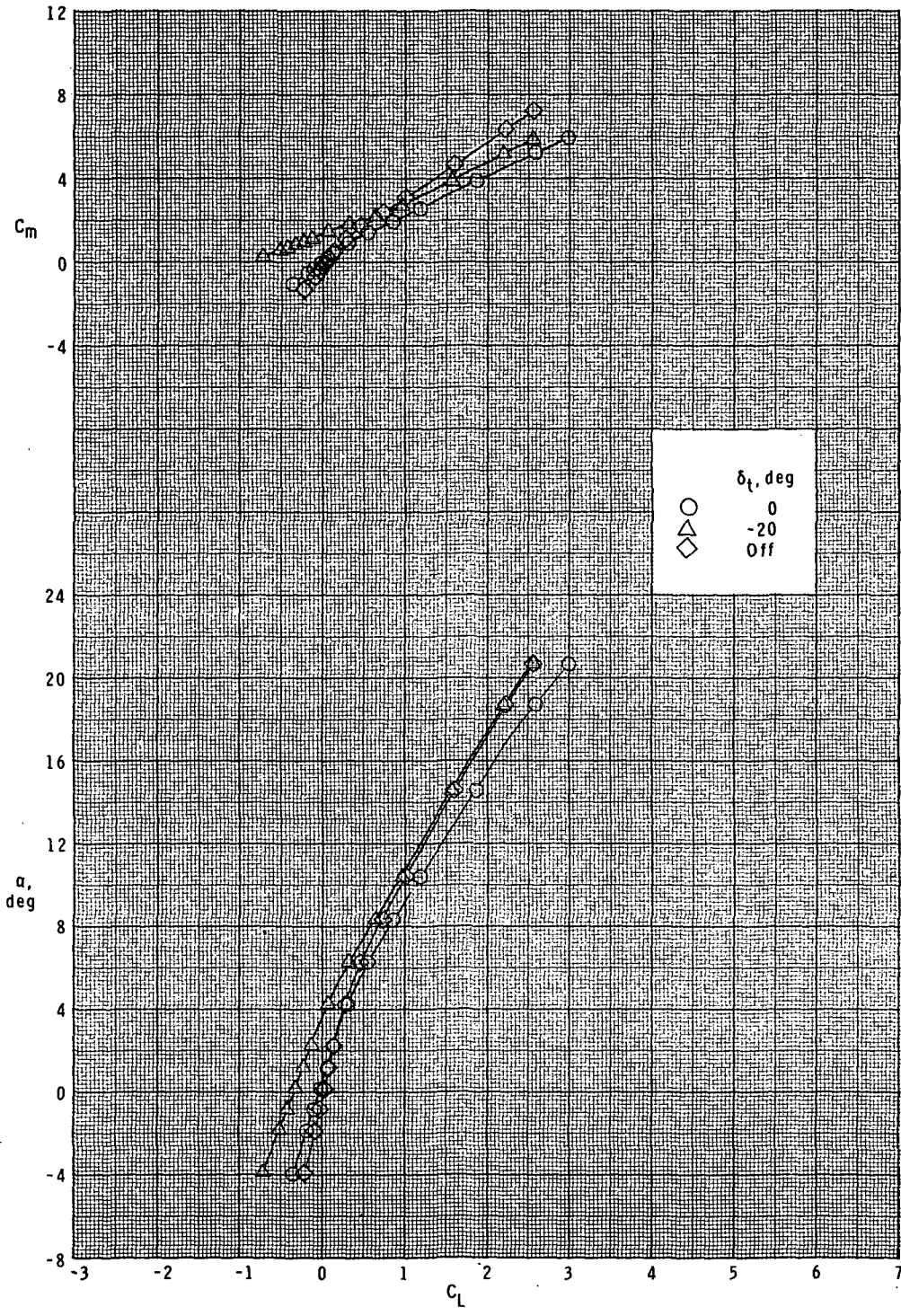
(d) Concluded.

Figure 5.- Continued.



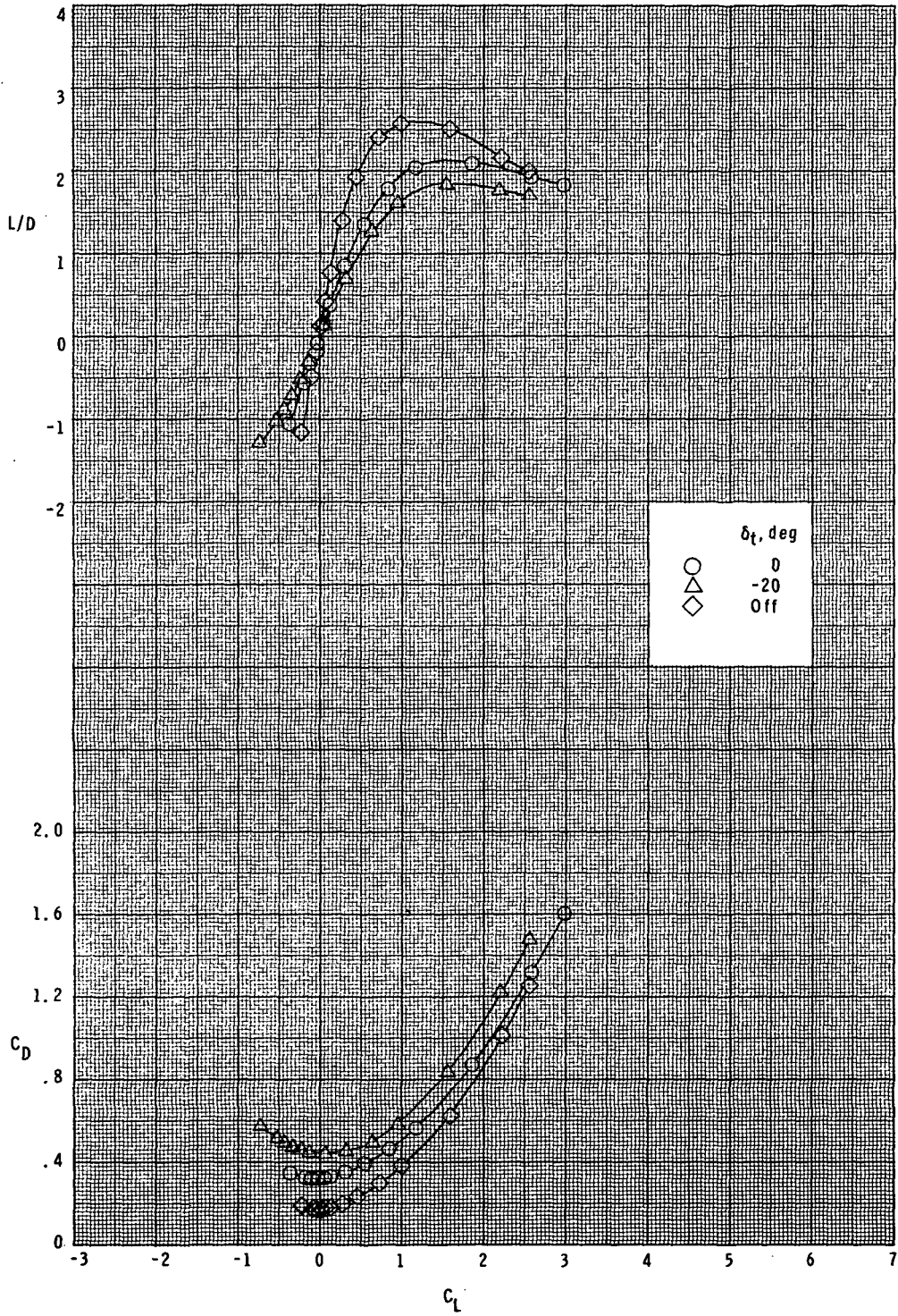
(e) $M = 3.95$.

Figure 5.- Continued.



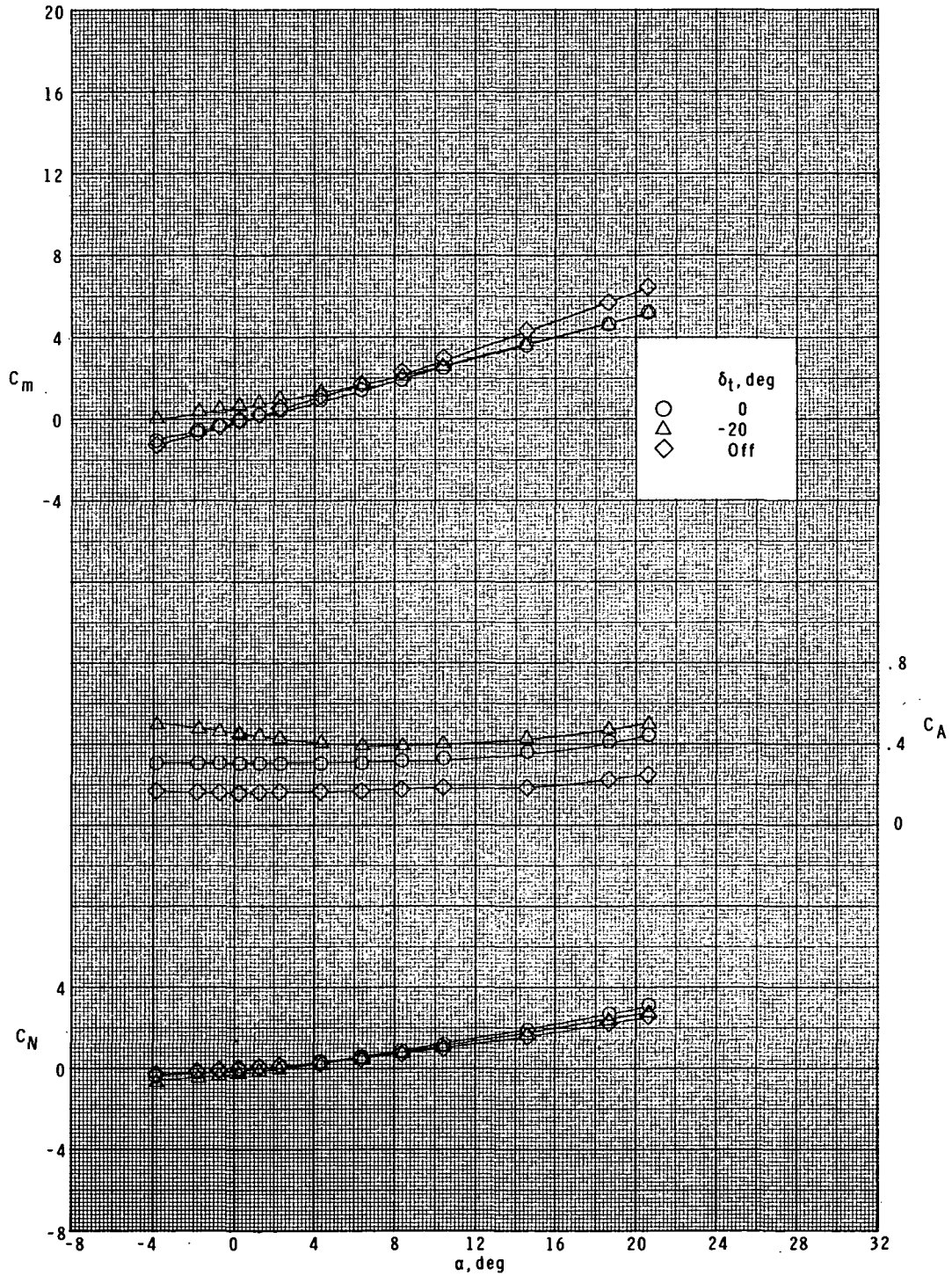
(e) Continued.

Figure 5. - Continued.



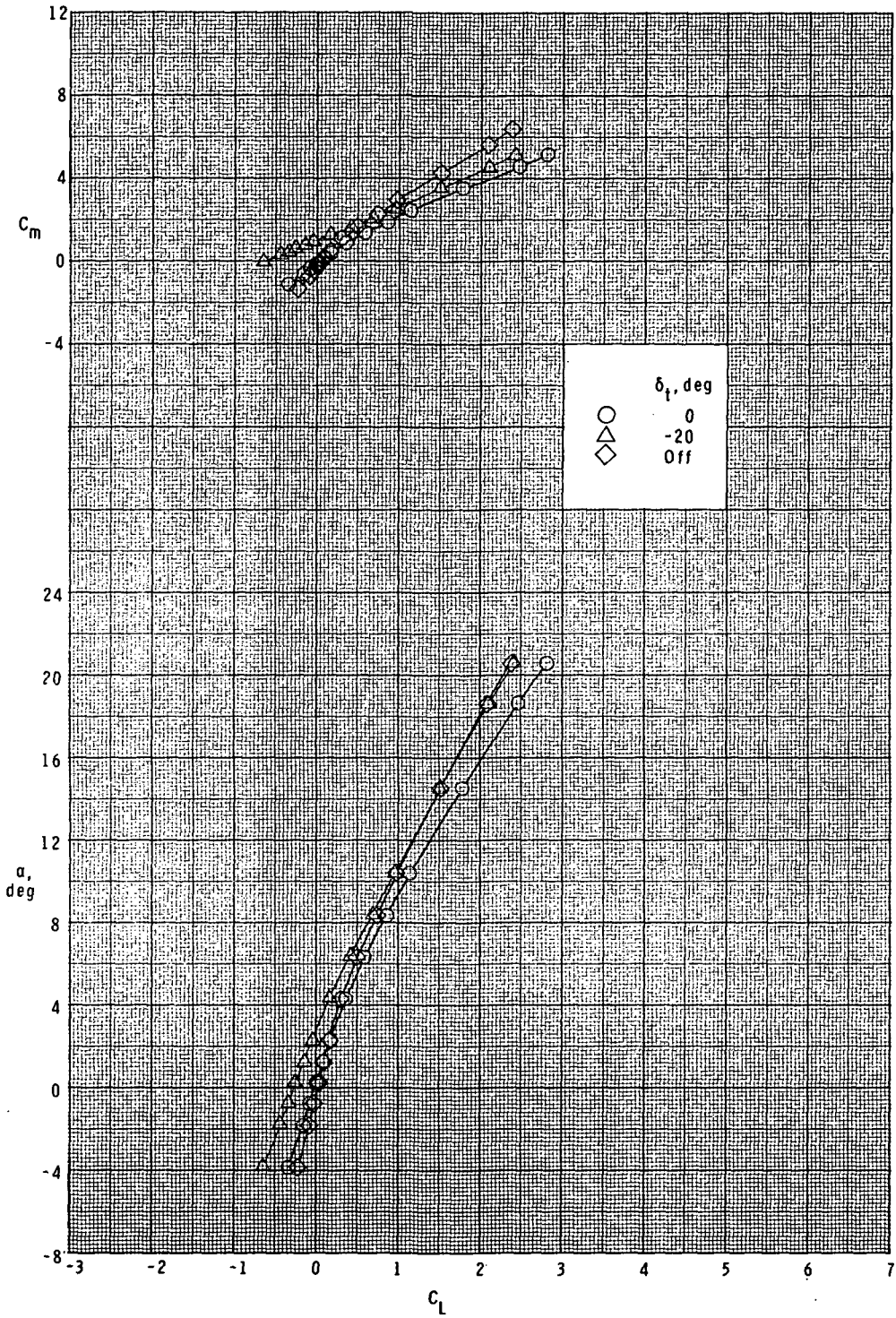
(e) Concluded.

Figure 5.- Continued.



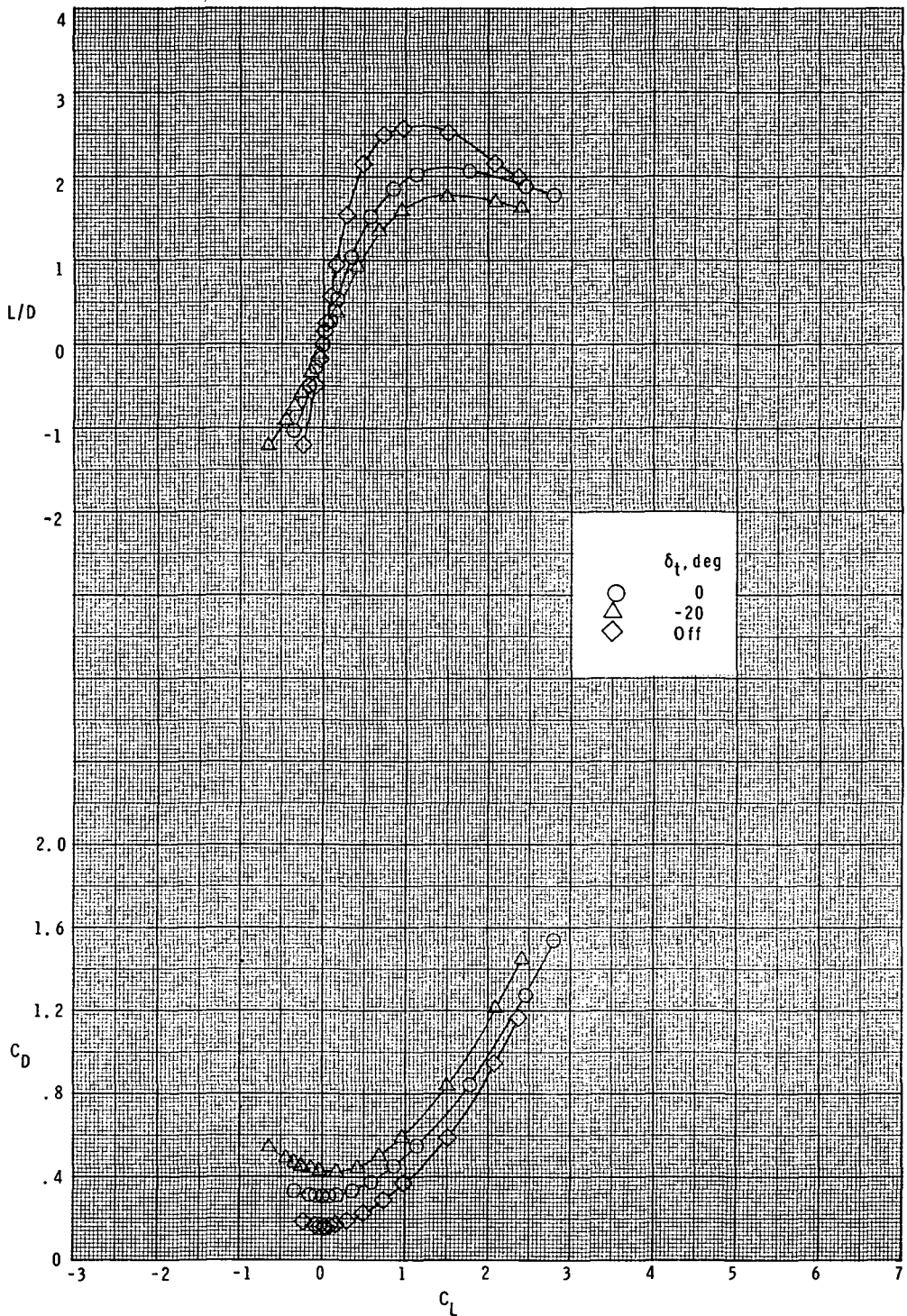
(f) $M = 4.63$.

Figure 5.- Continued.



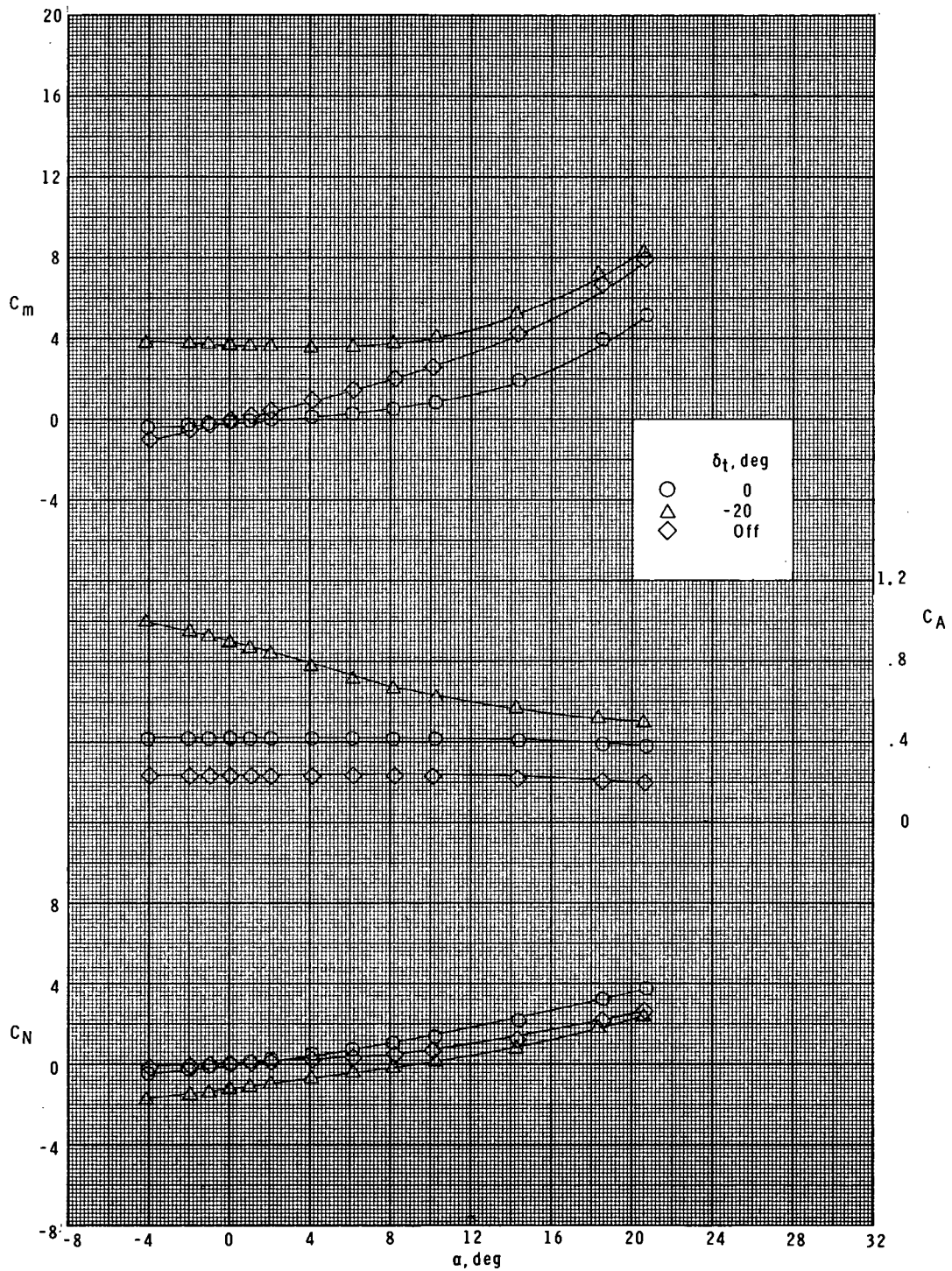
(f) Continued.

Figure 5. - Continued.



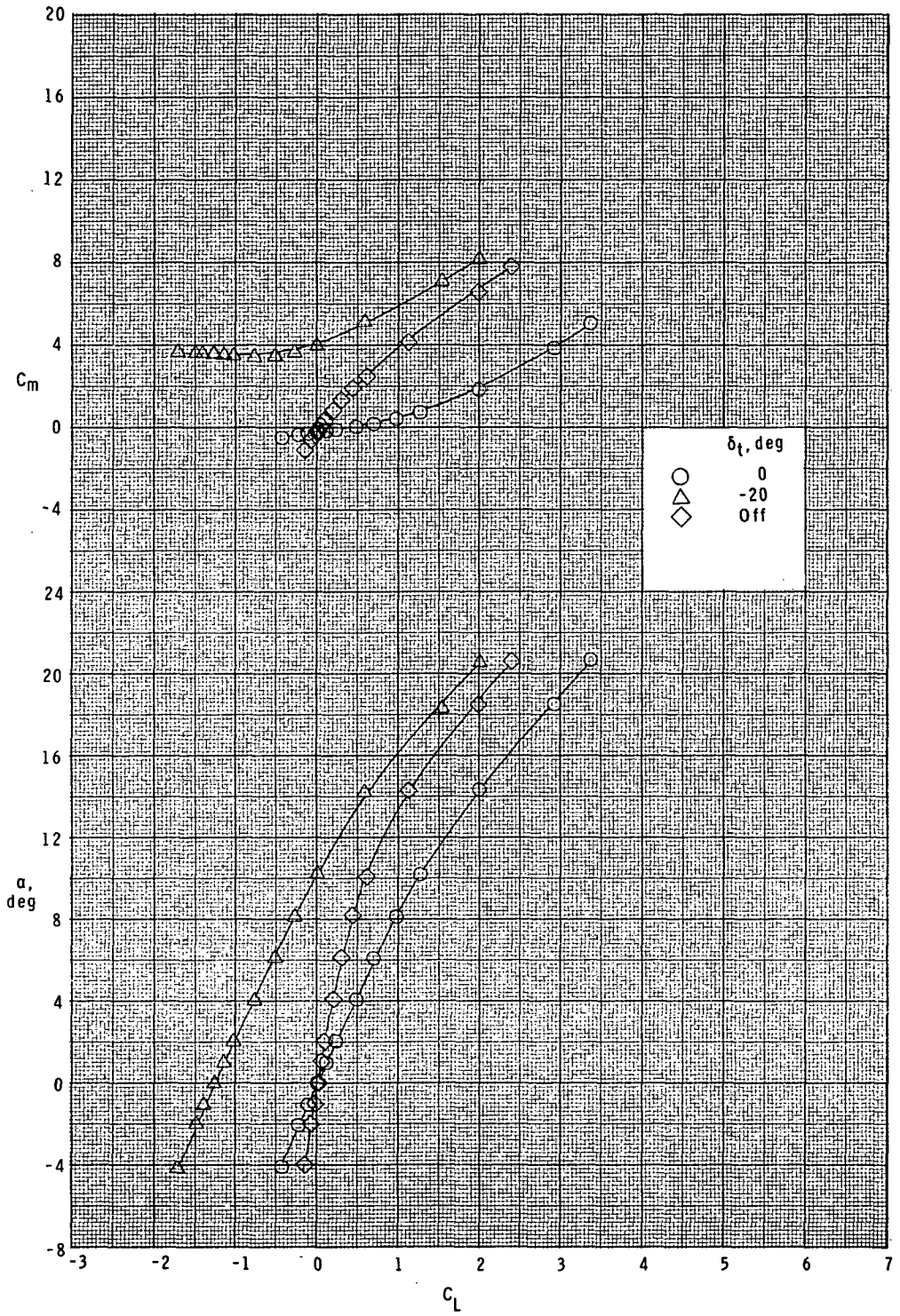
(f) Concluded.

Figure 5.- Concluded.



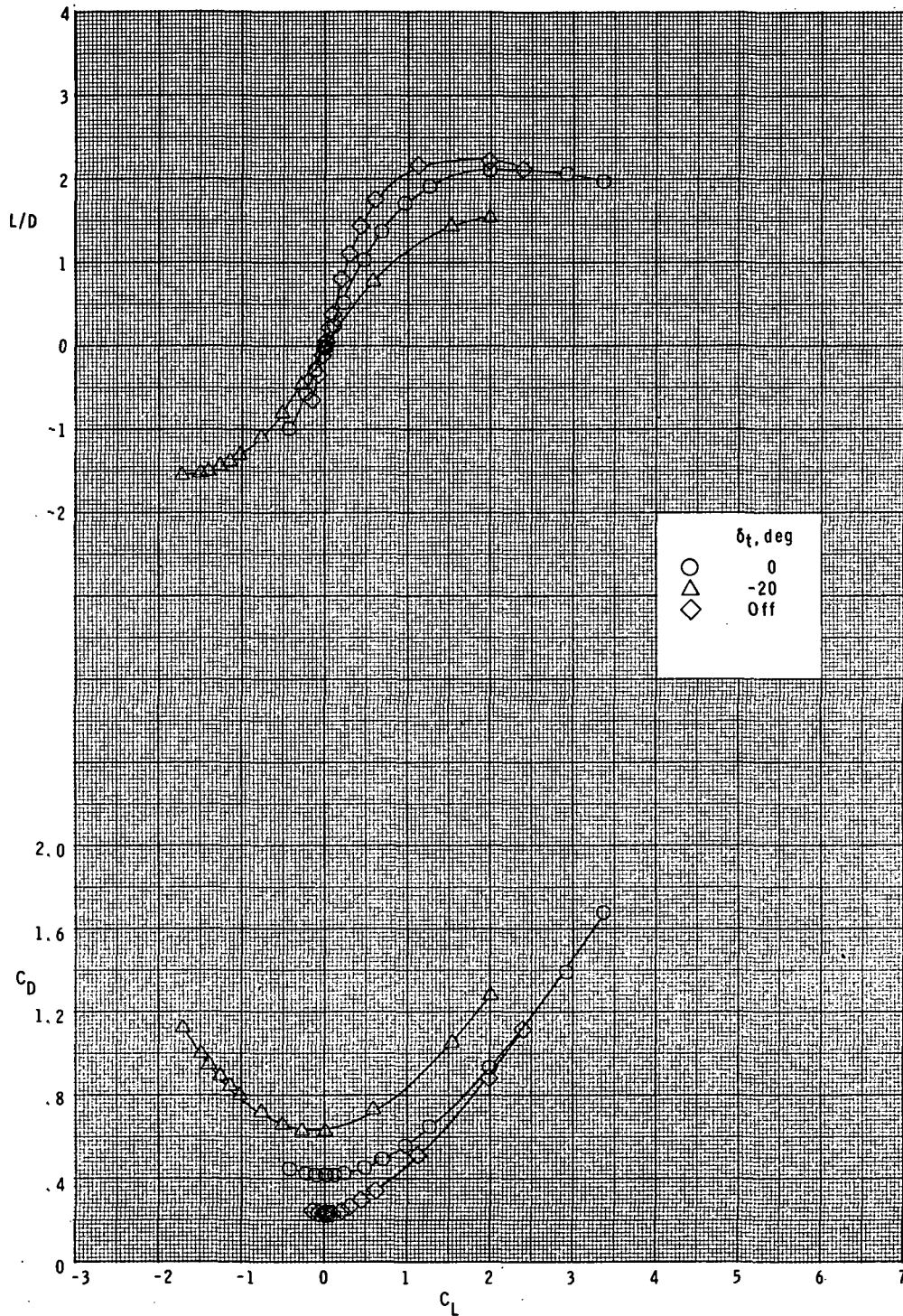
(a) $M = 1.50$.

Figure 6.- Effect of tail deflection on the longitudinal aerodynamic characteristics of the body-tail configuration. $\phi = 45^\circ$.



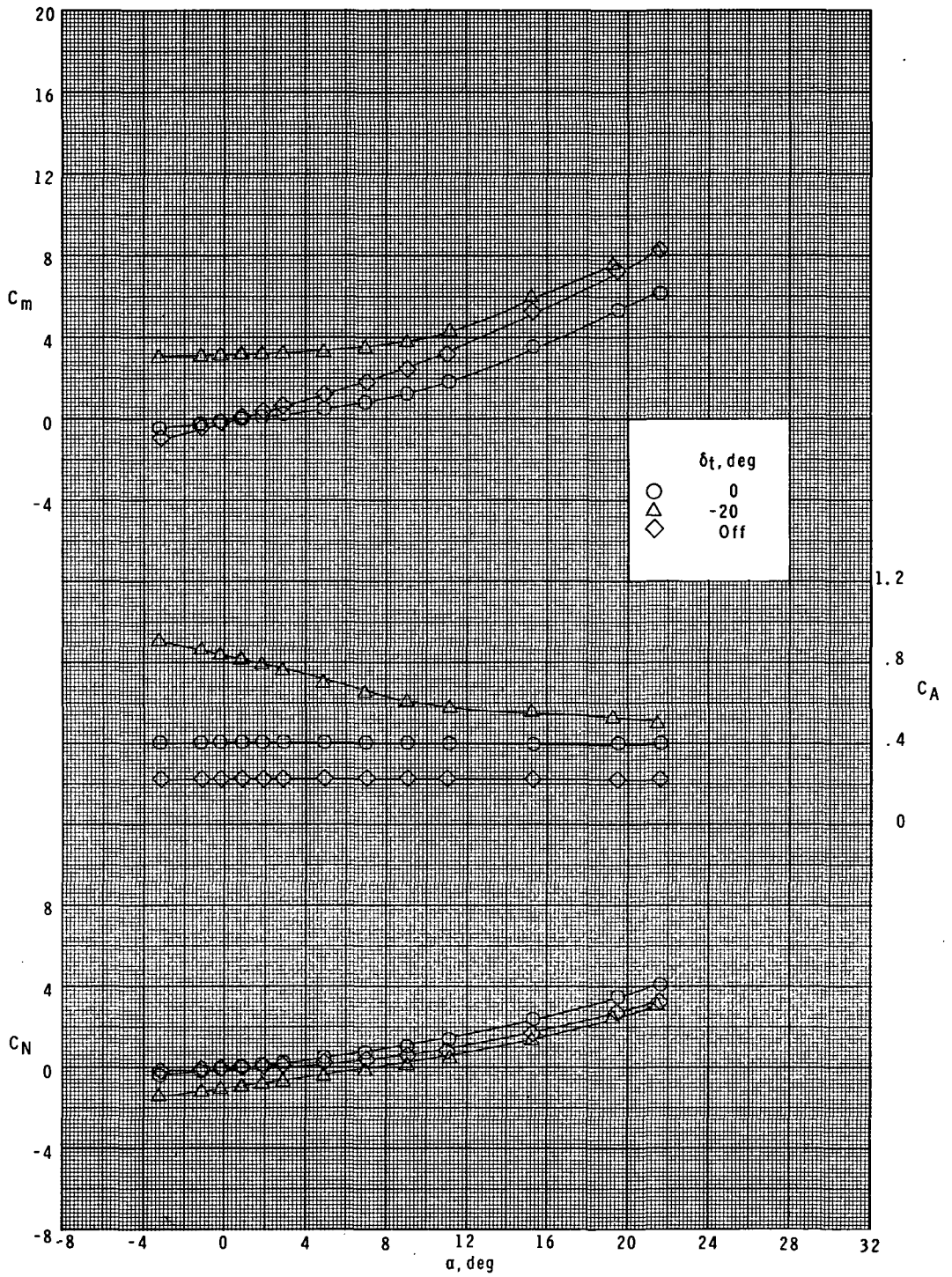
(a) Continued.

Figure 6.- Continued.



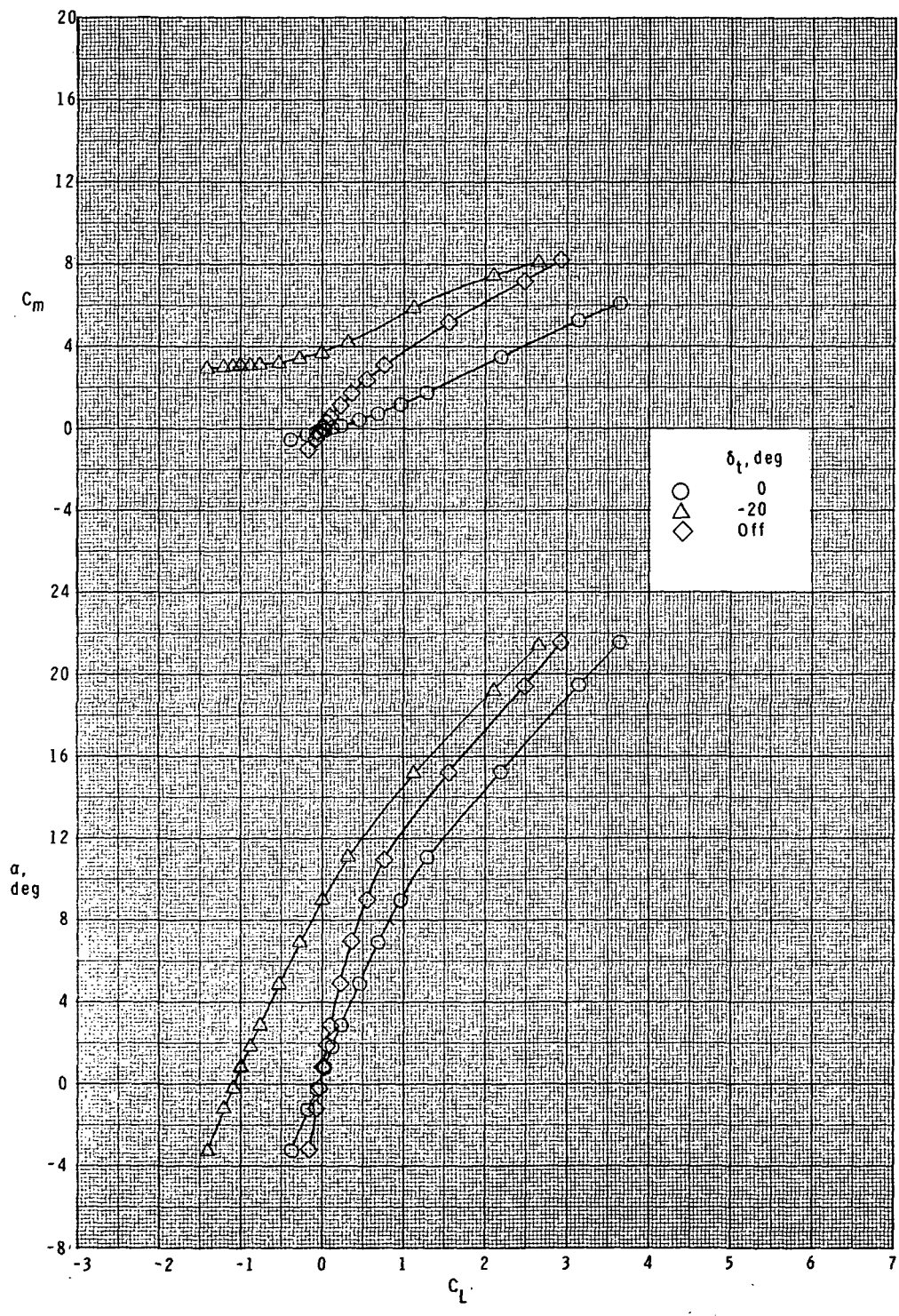
(a) Concluded.

Figure 6. - Continued.



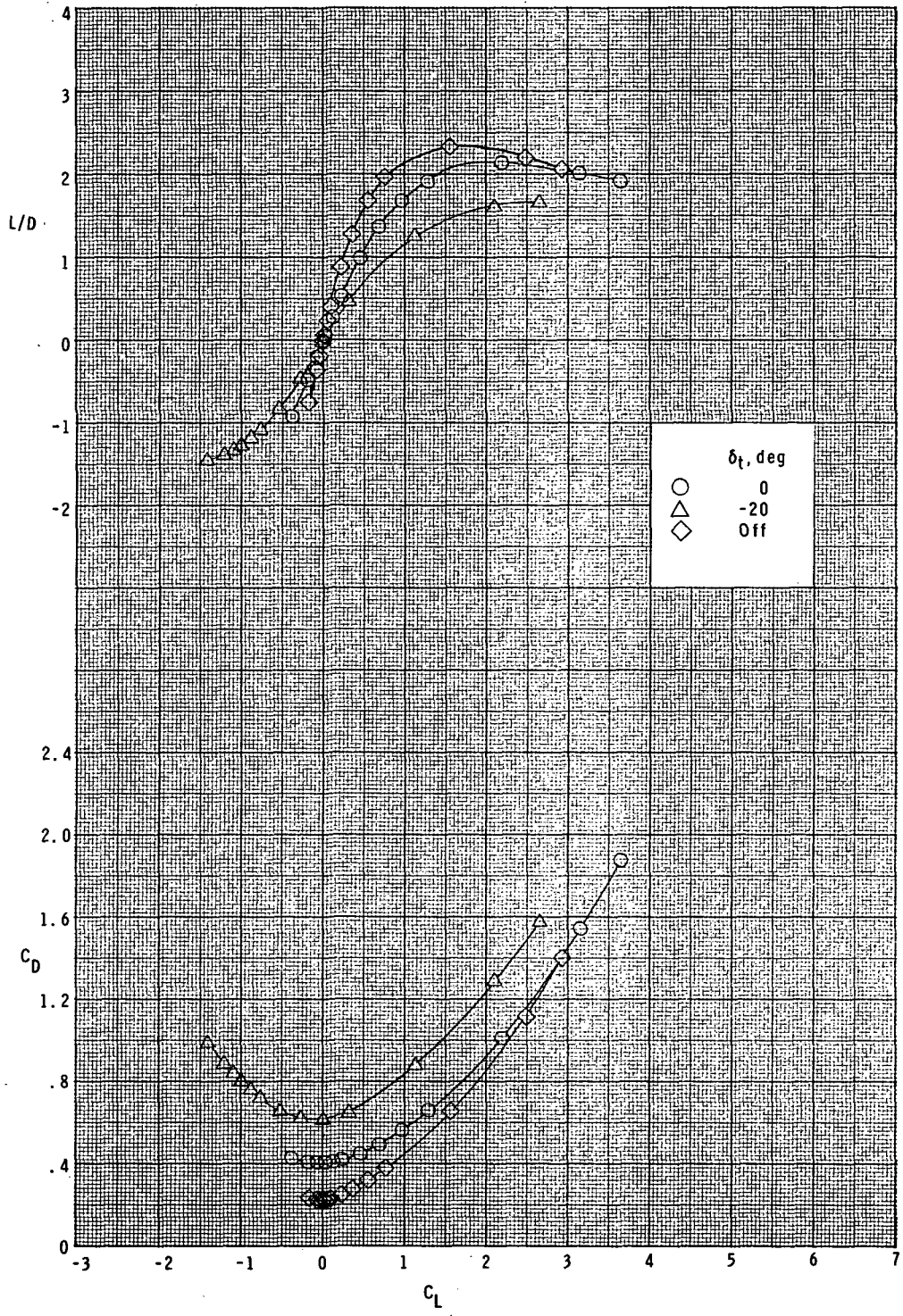
(b) $M = 1.90$.

Figure 6.- Continued.



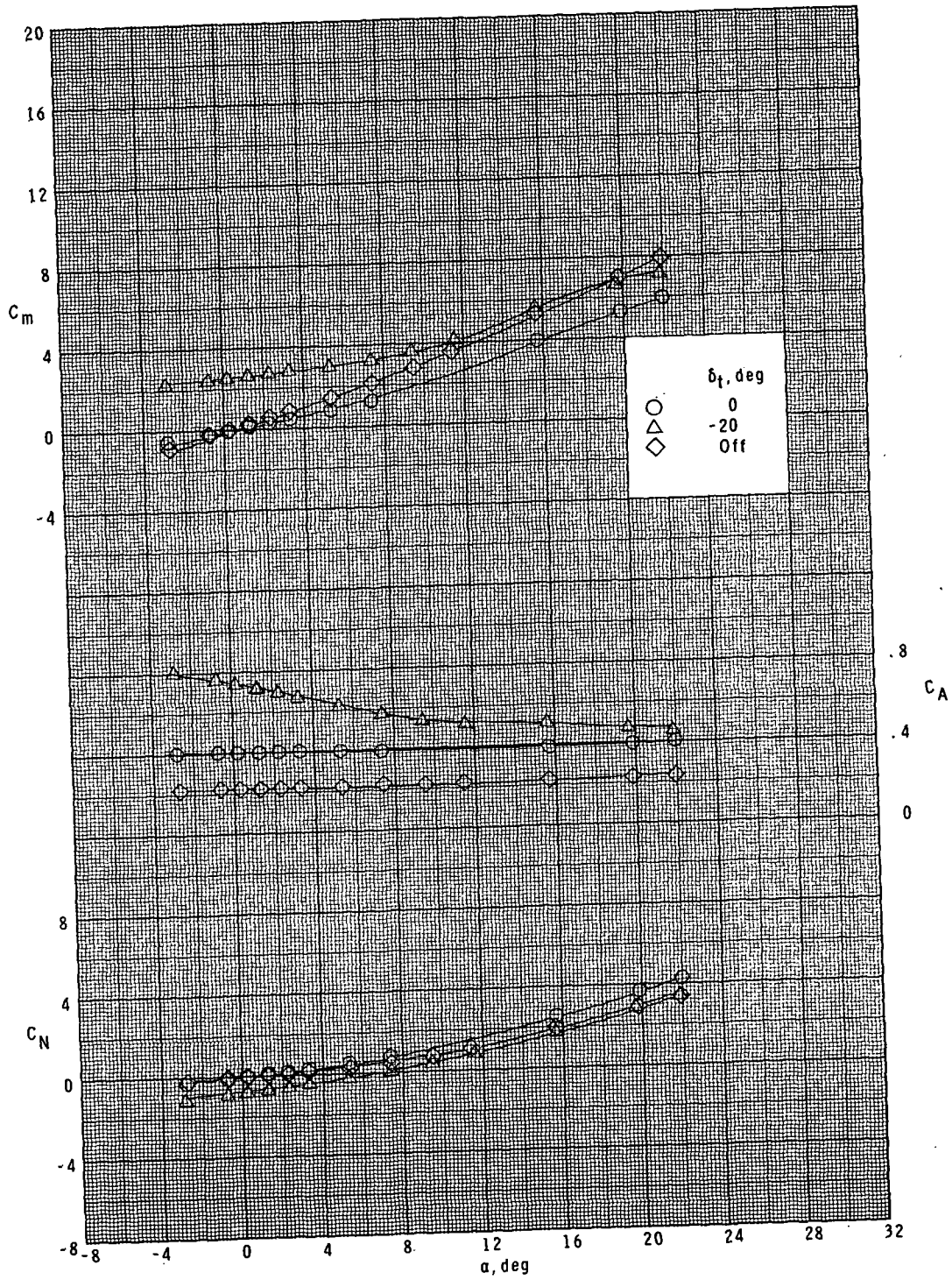
(b) Continued.

Figure 6. - Continued.



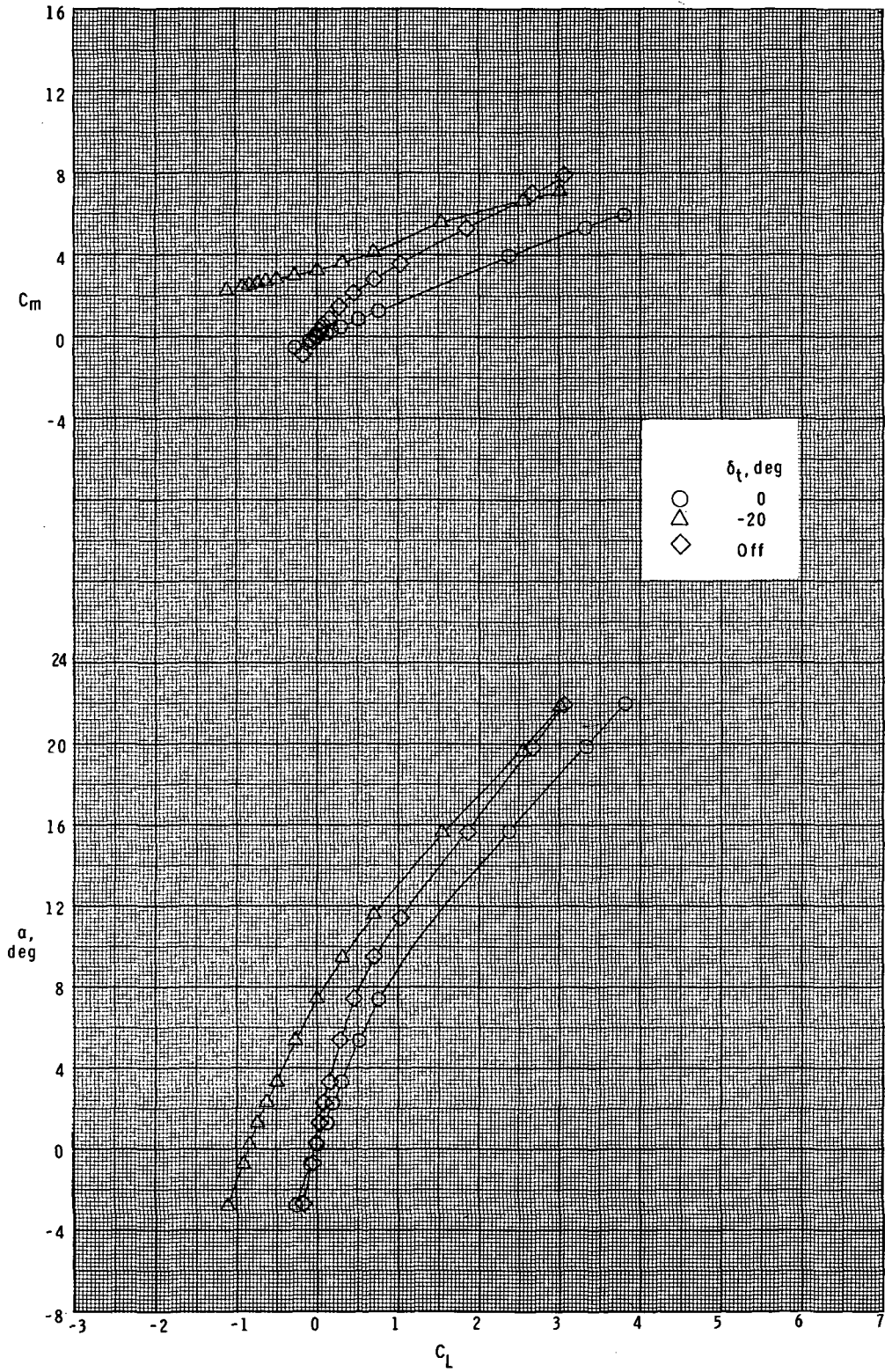
(b) Concluded.

Figure 6.- Continued.



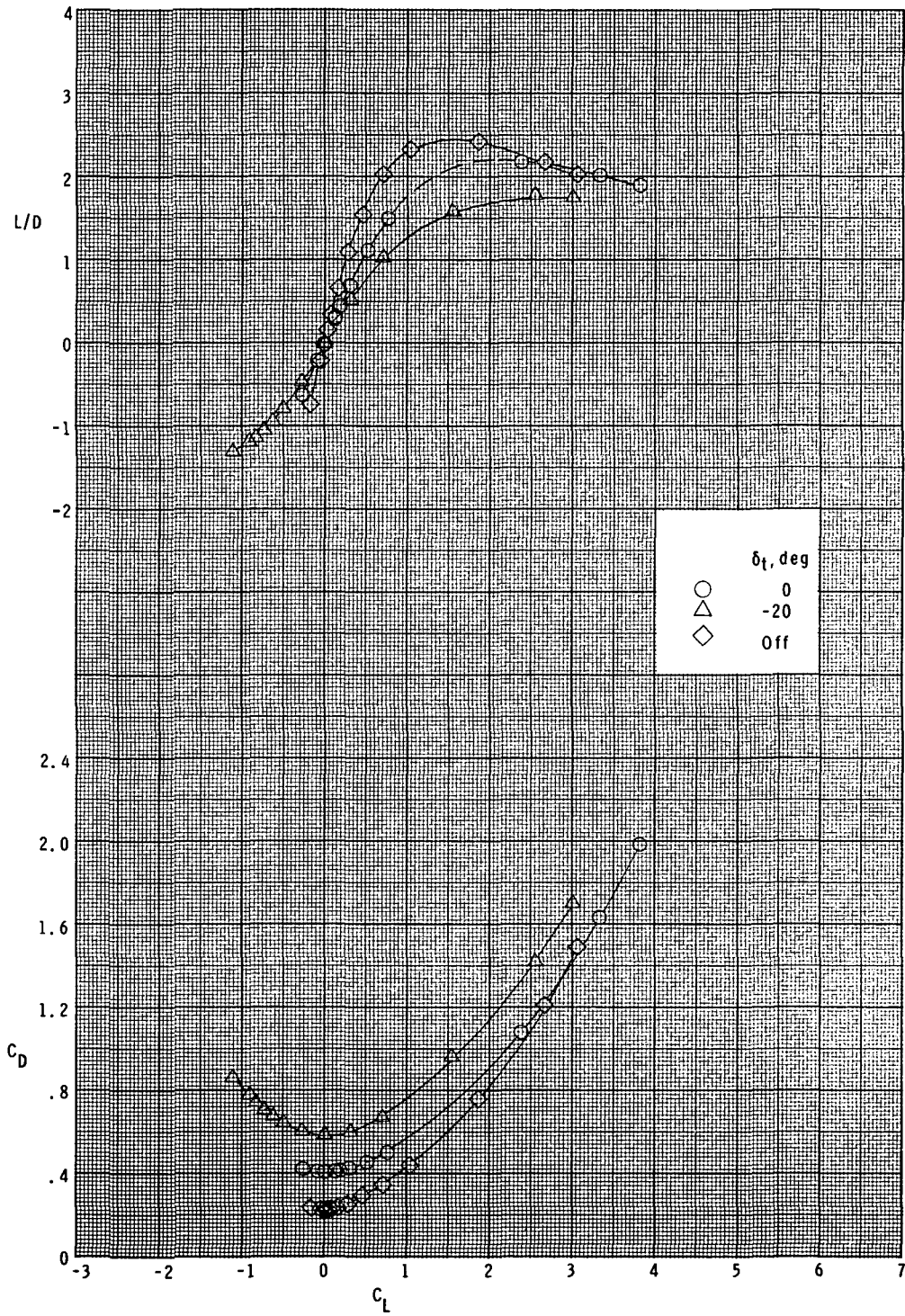
(c) $M = 2.36$.

Figure 6. - Continued.



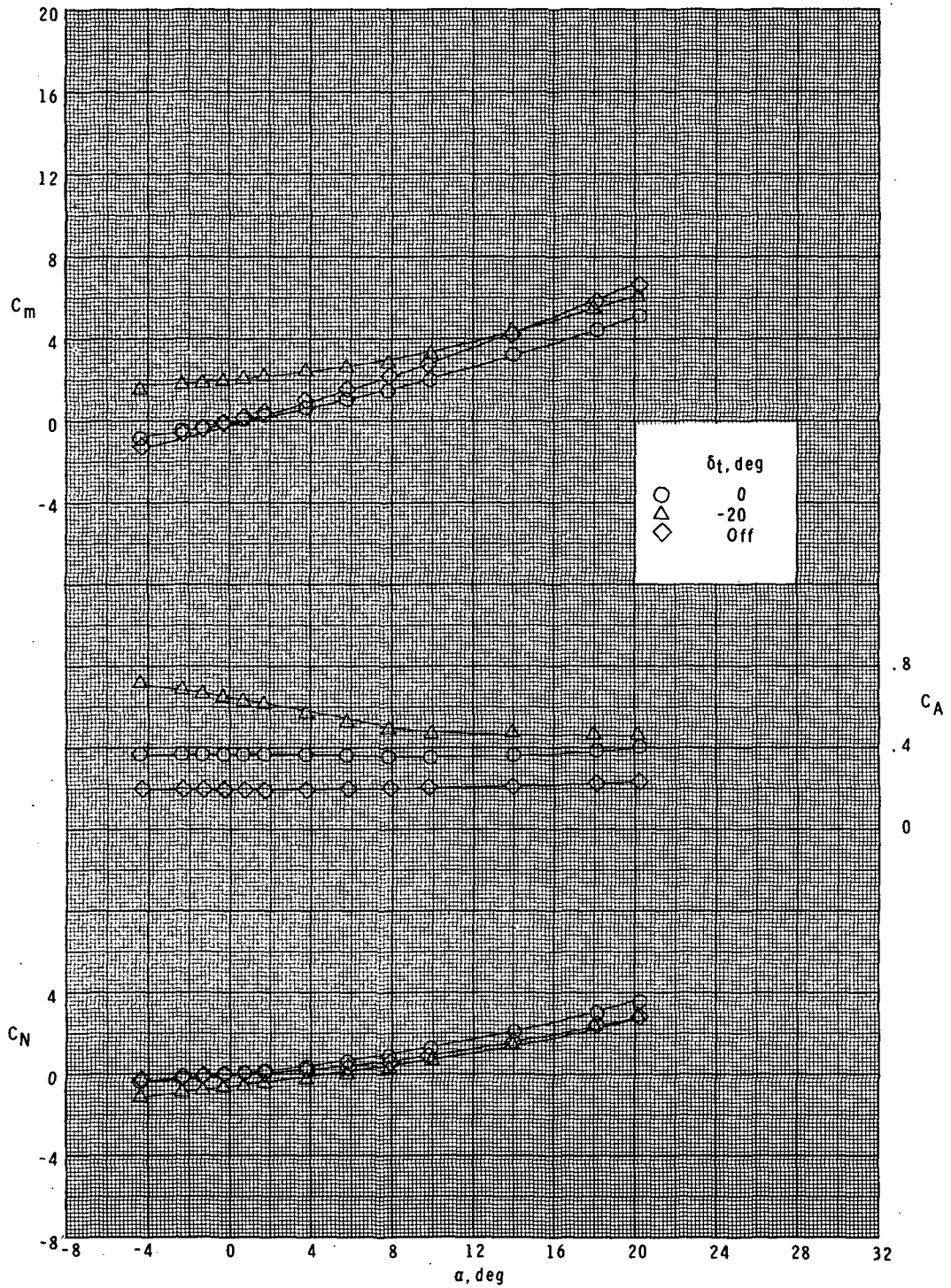
(c) Continued.

Figure 6.- Continued.



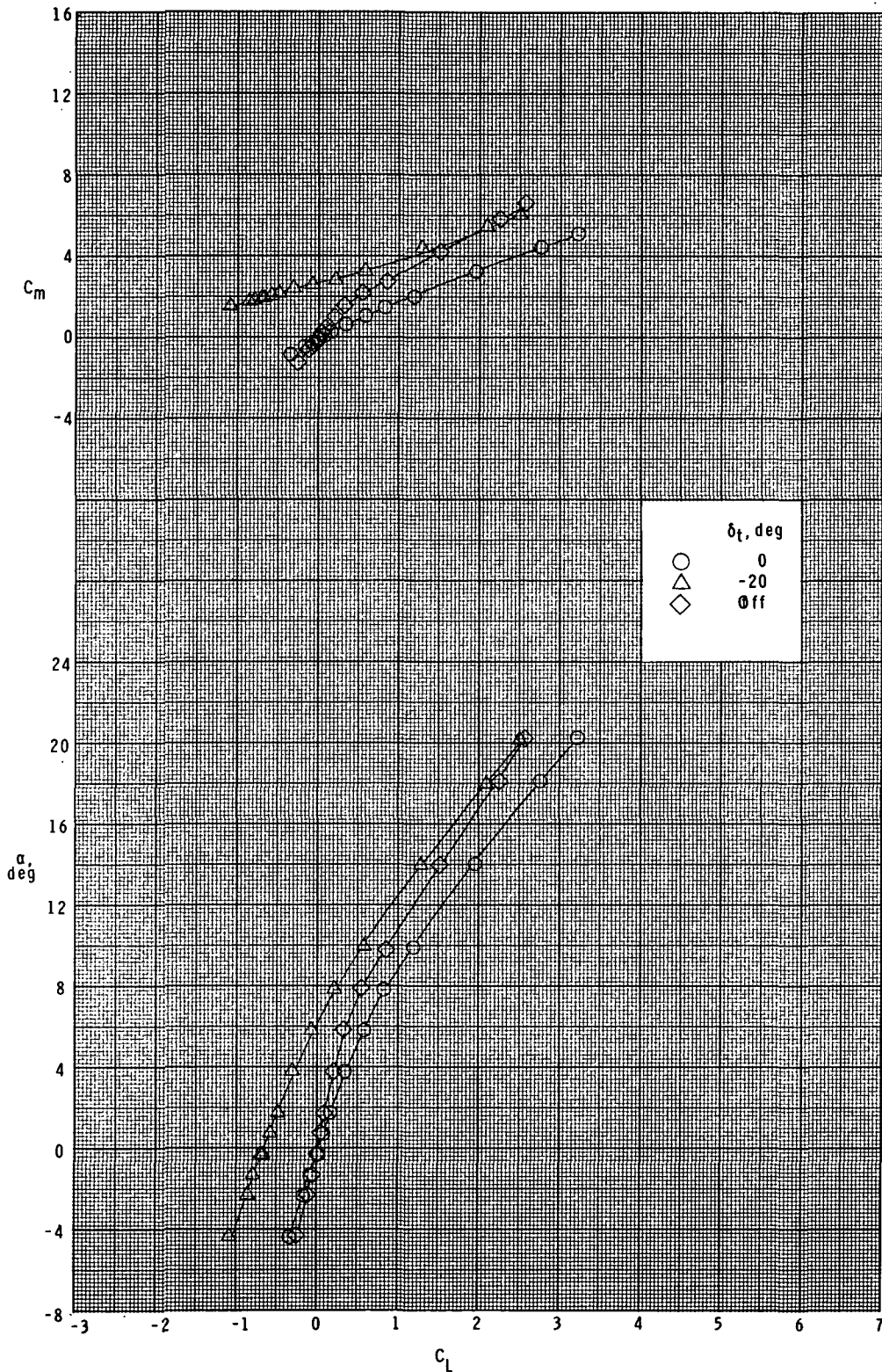
(c) Concluded.

Figure 6.- Continued.



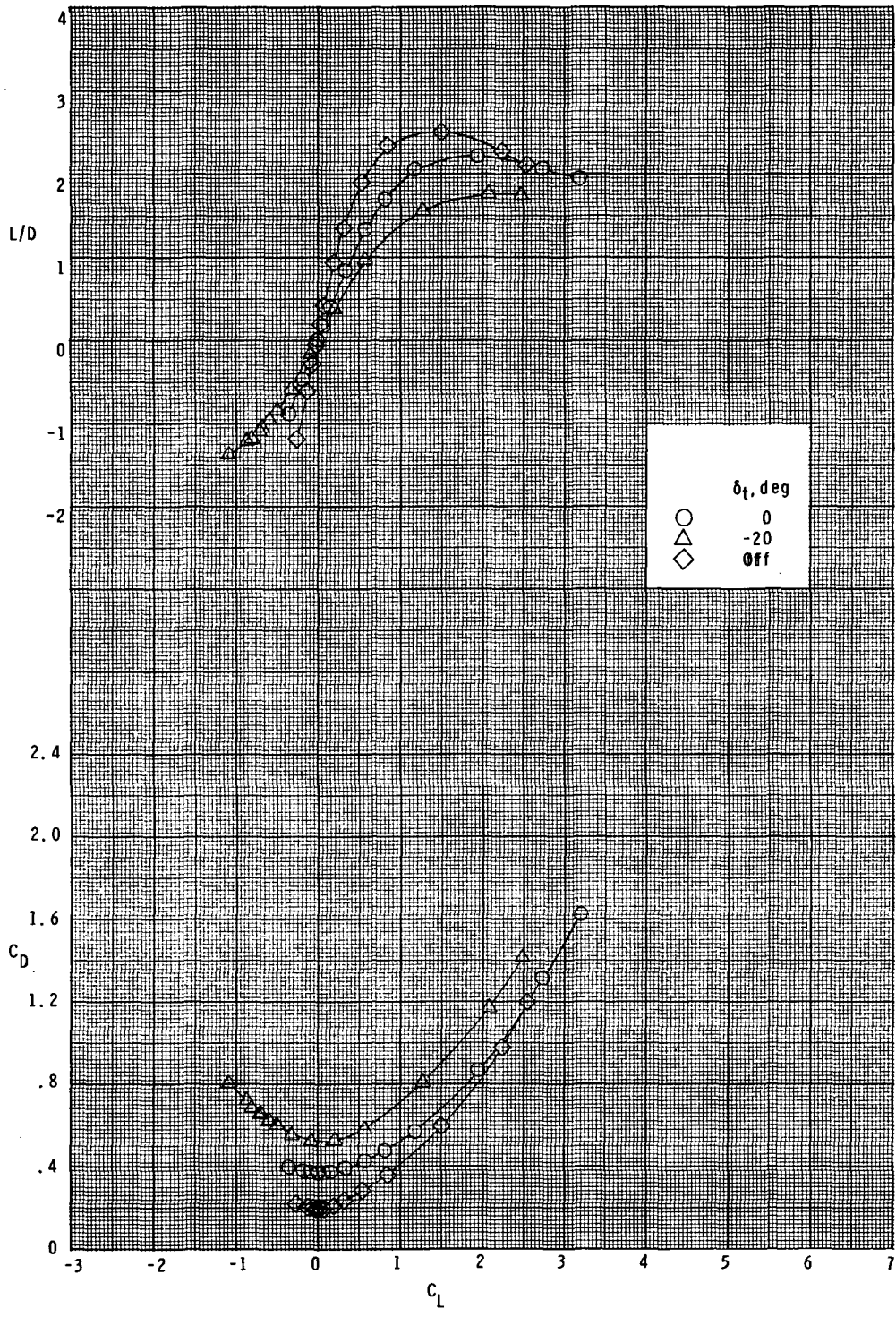
(d) $M = 2.86$.

Figure 6.- Continued.



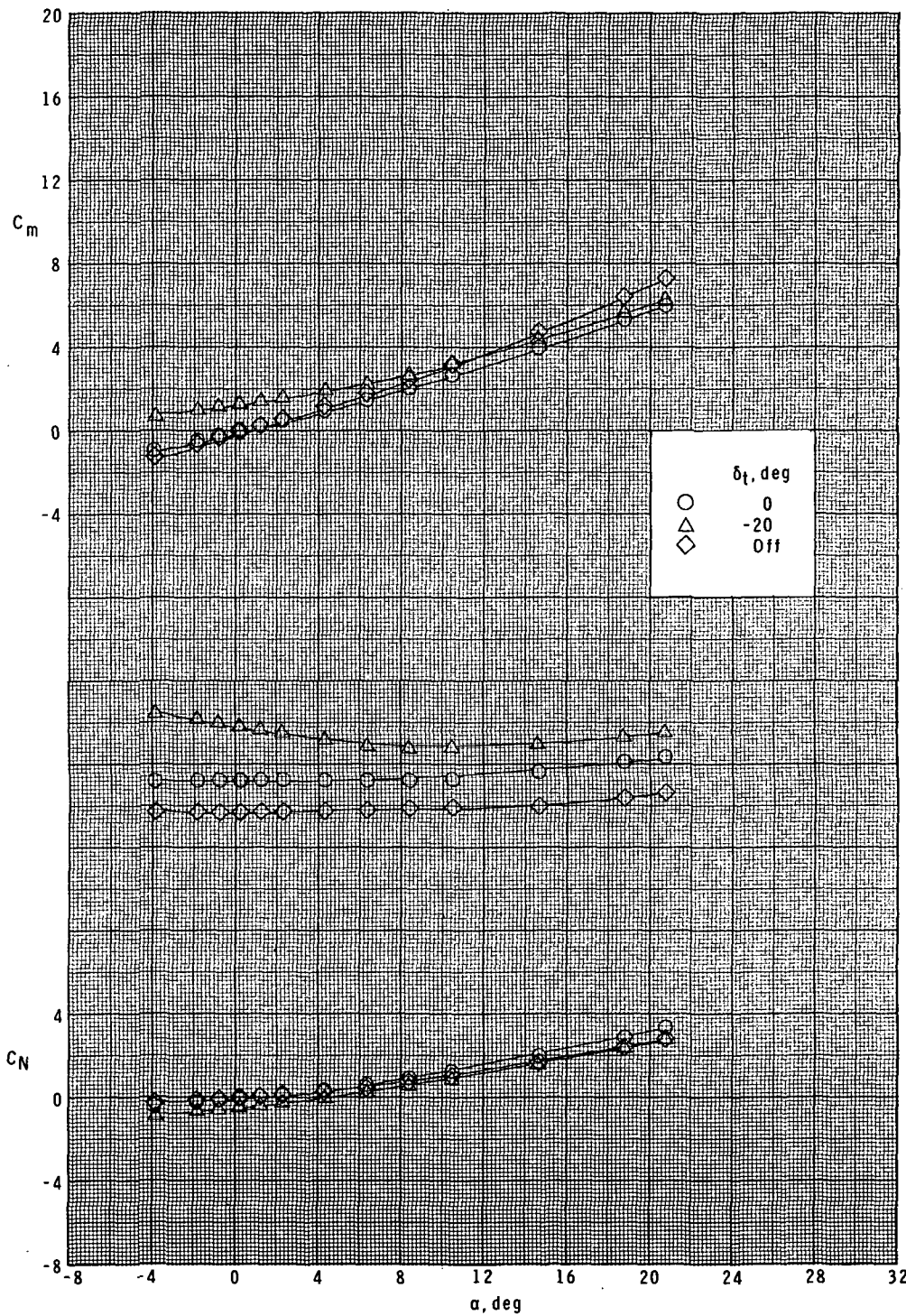
(d) Continued.

Figure 6.- Continued.



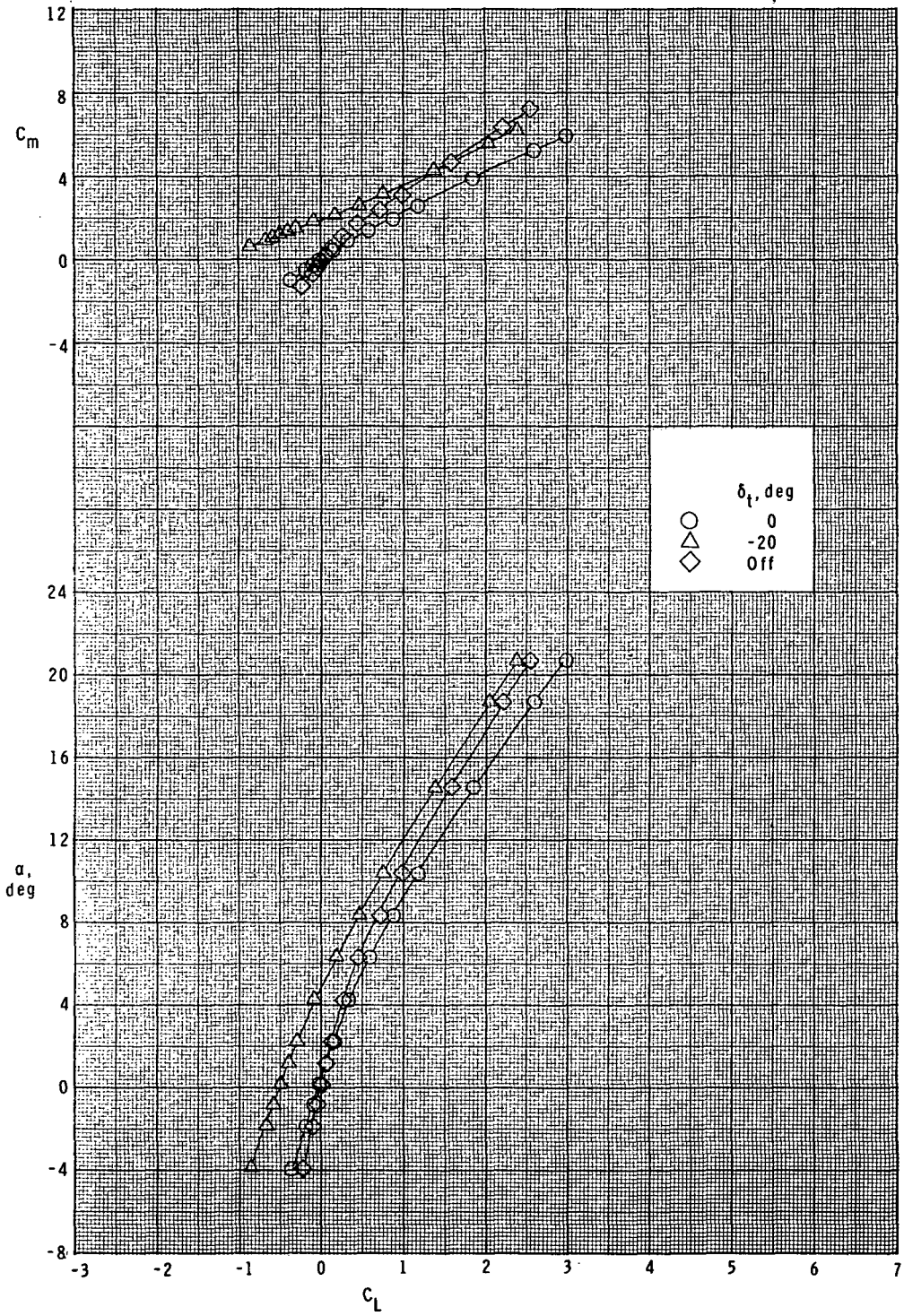
(d) Concluded.

Figure 6.- Continued.



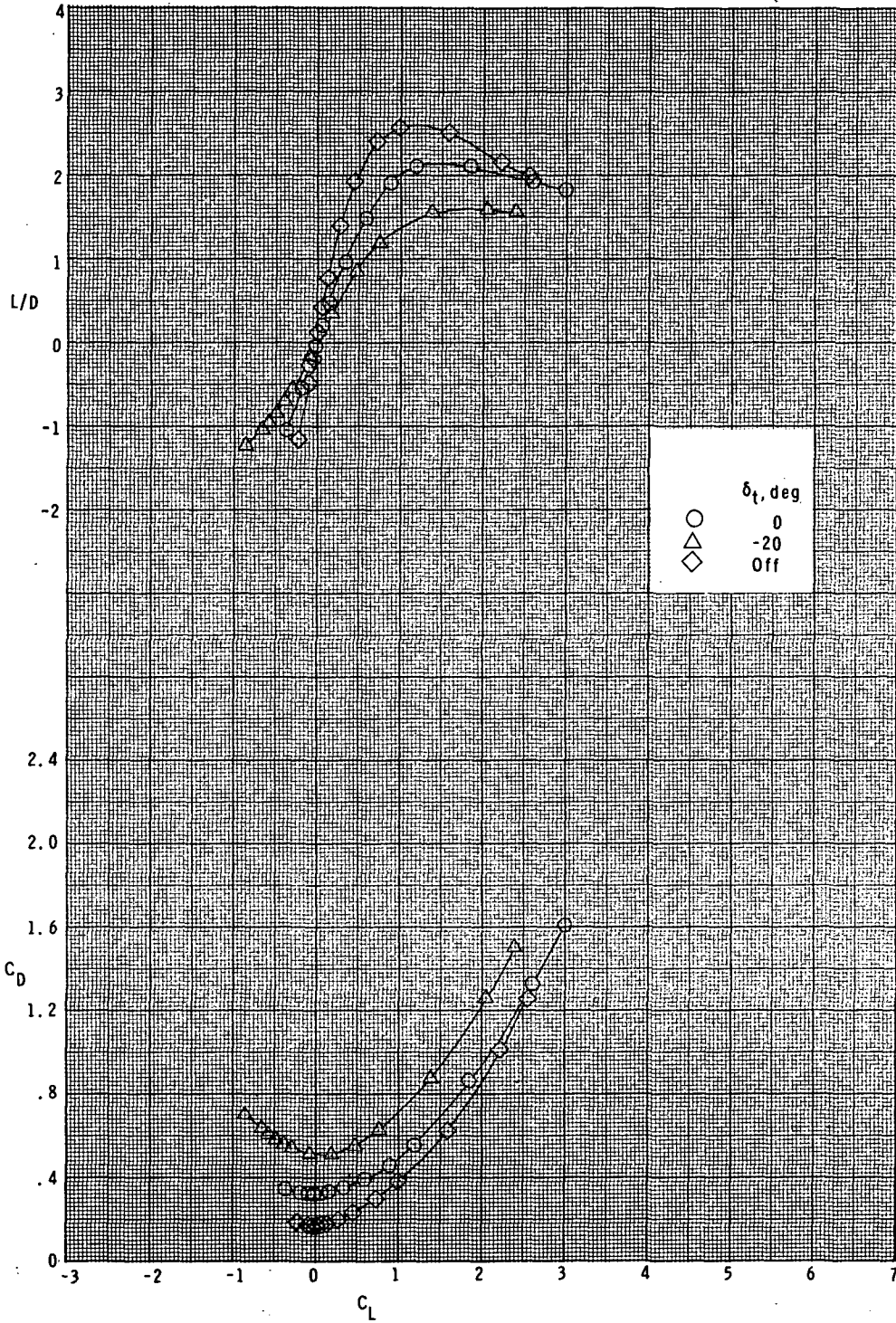
(e) $M = 3.95$.

Figure 6. - Continued.



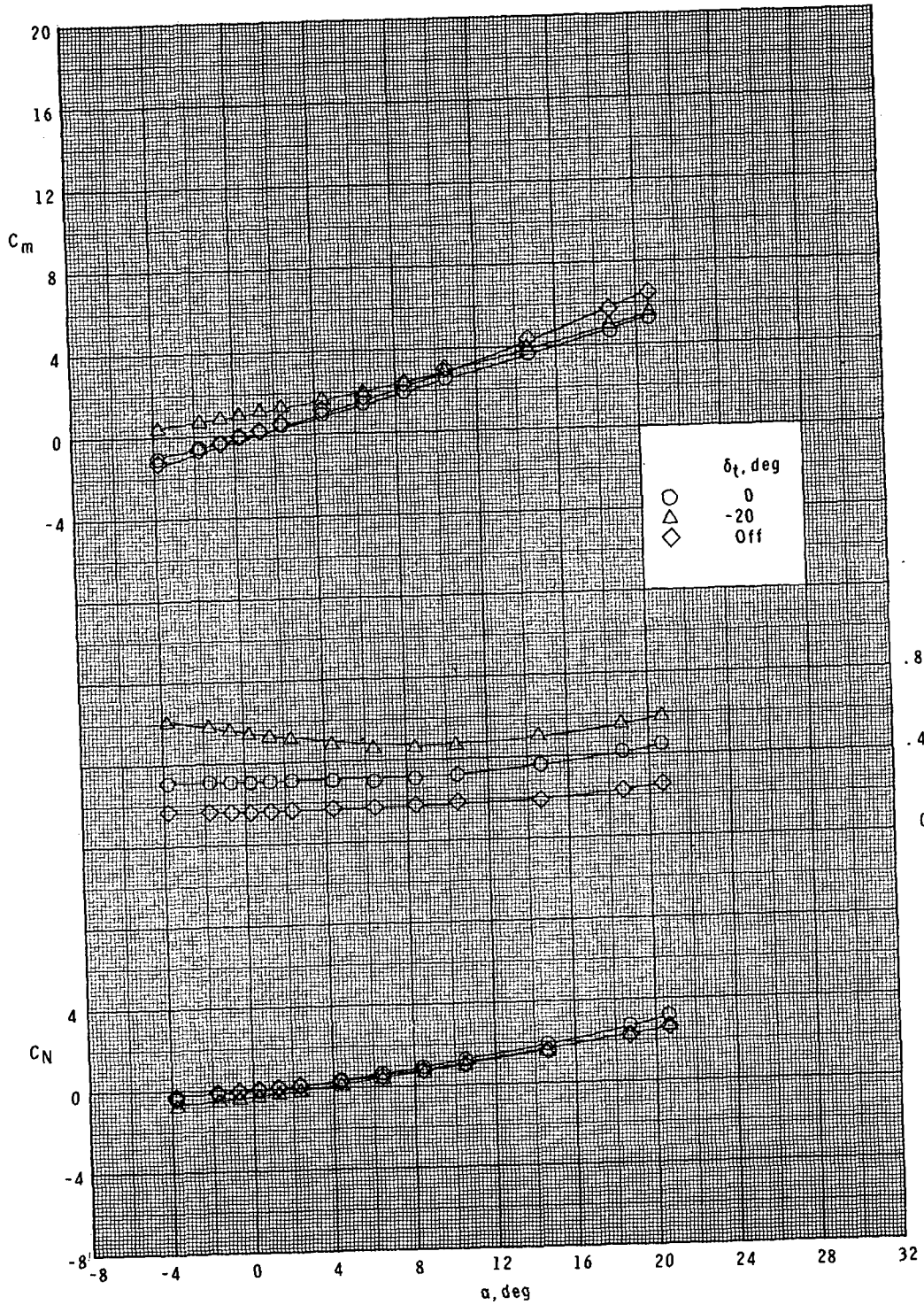
(e) Continued.

Figure 6.- Continued.



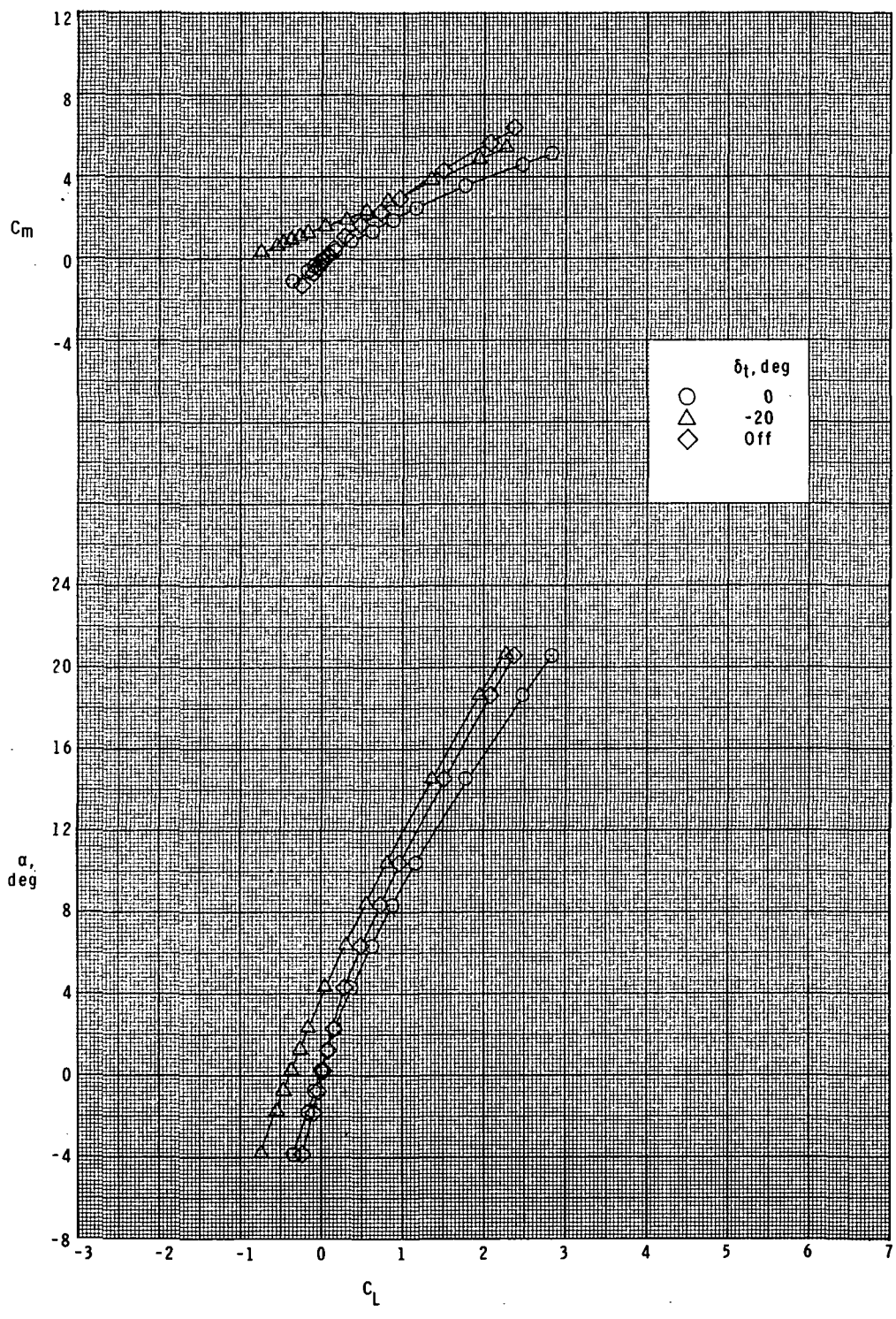
(e) Concluded.

Figure 6.- Continued.



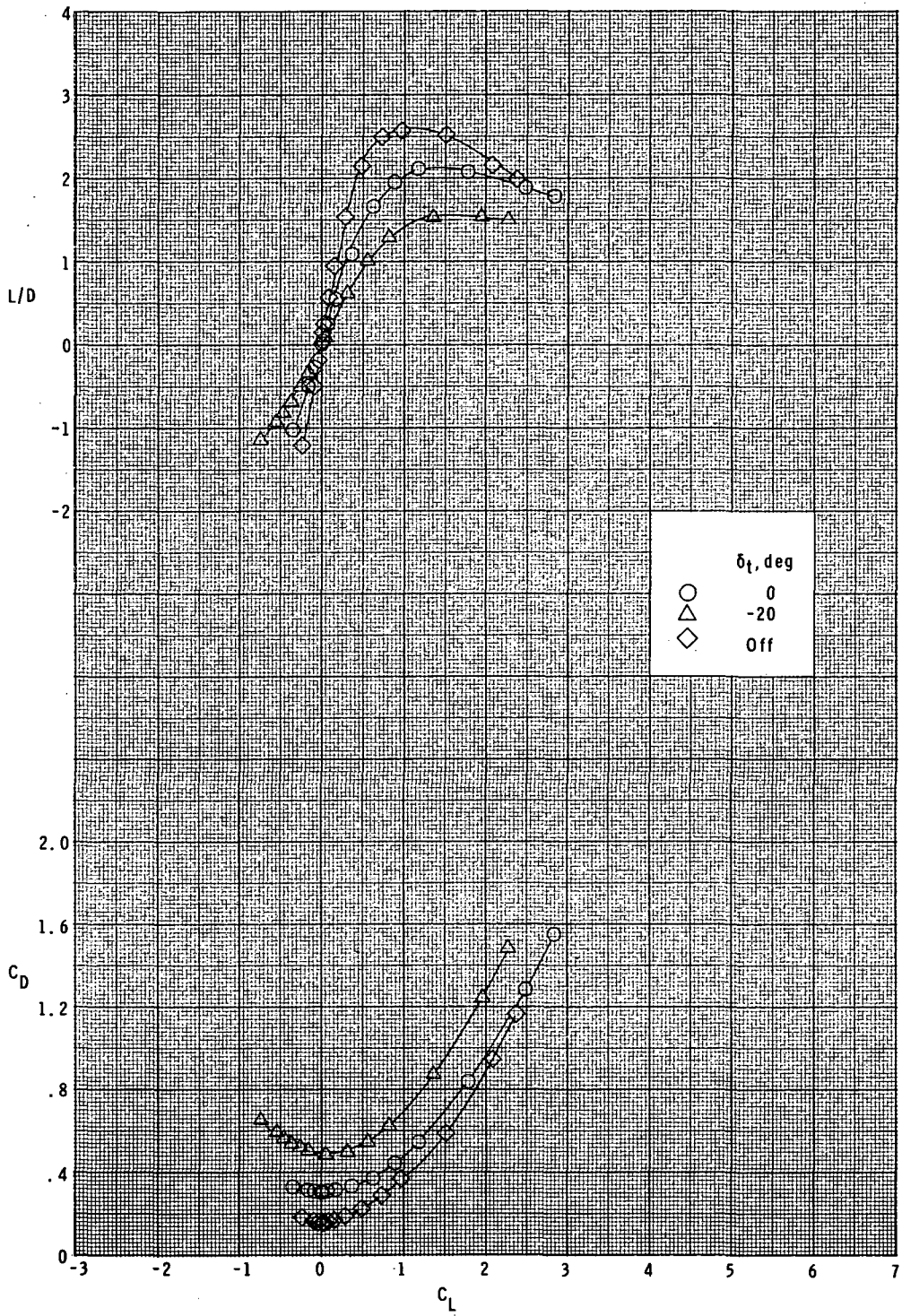
(f) $M = 4.63$.

Figure 6.- Continued.



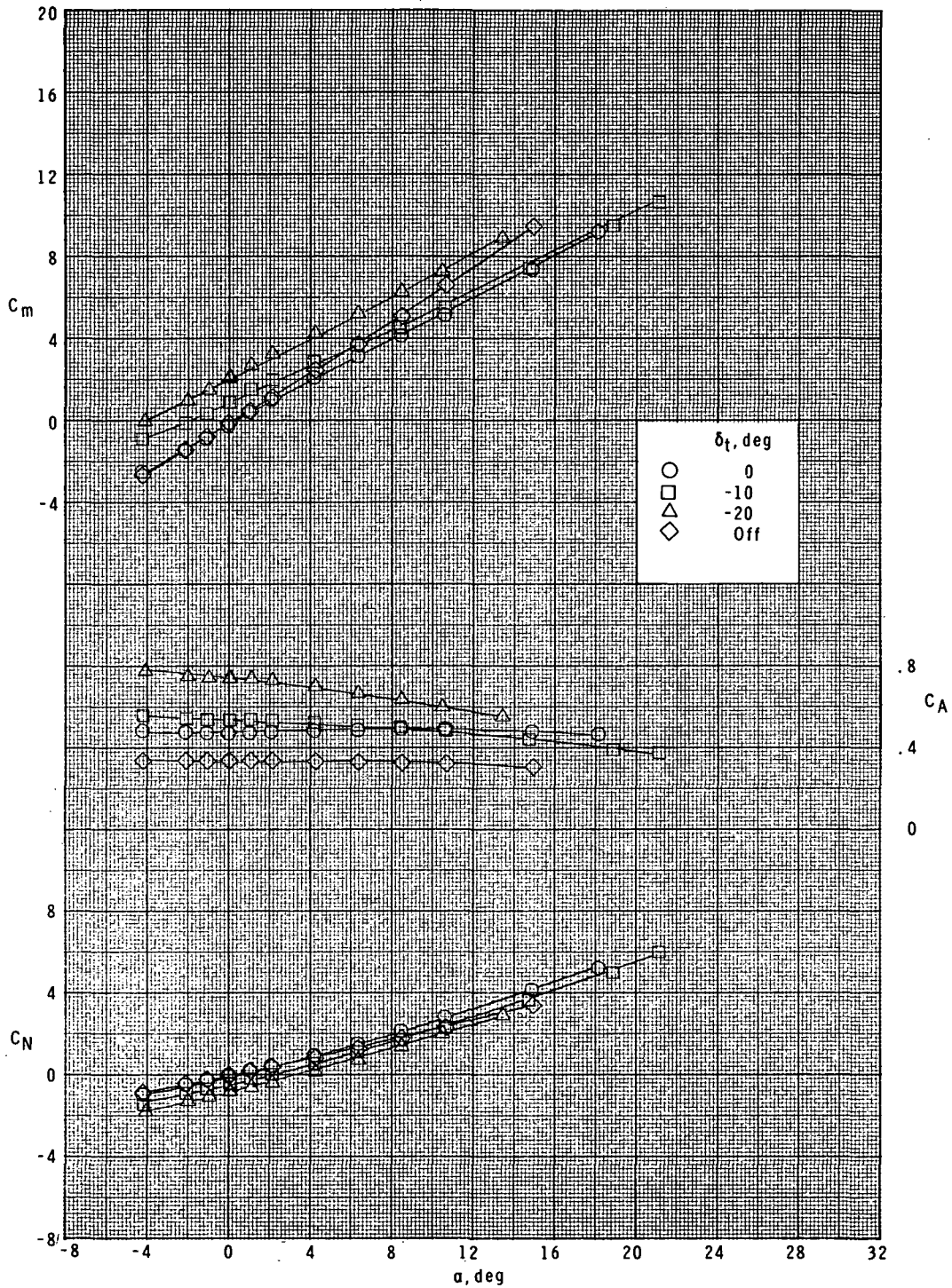
(f) Continued.

Figure 6.- Continued.



(f) Concluded.

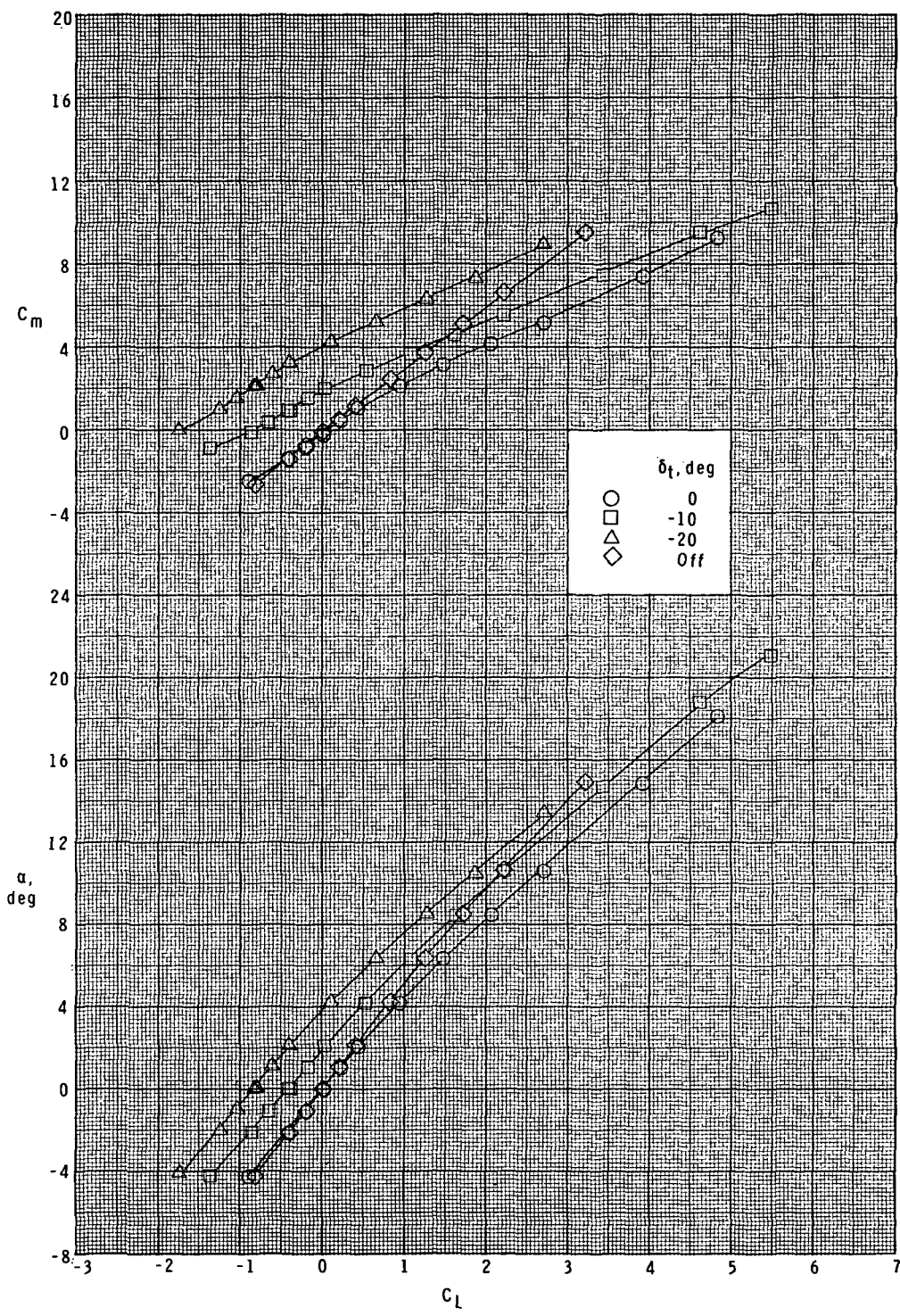
Figure 6.- Concluded.



(a) $M = 1.50$.

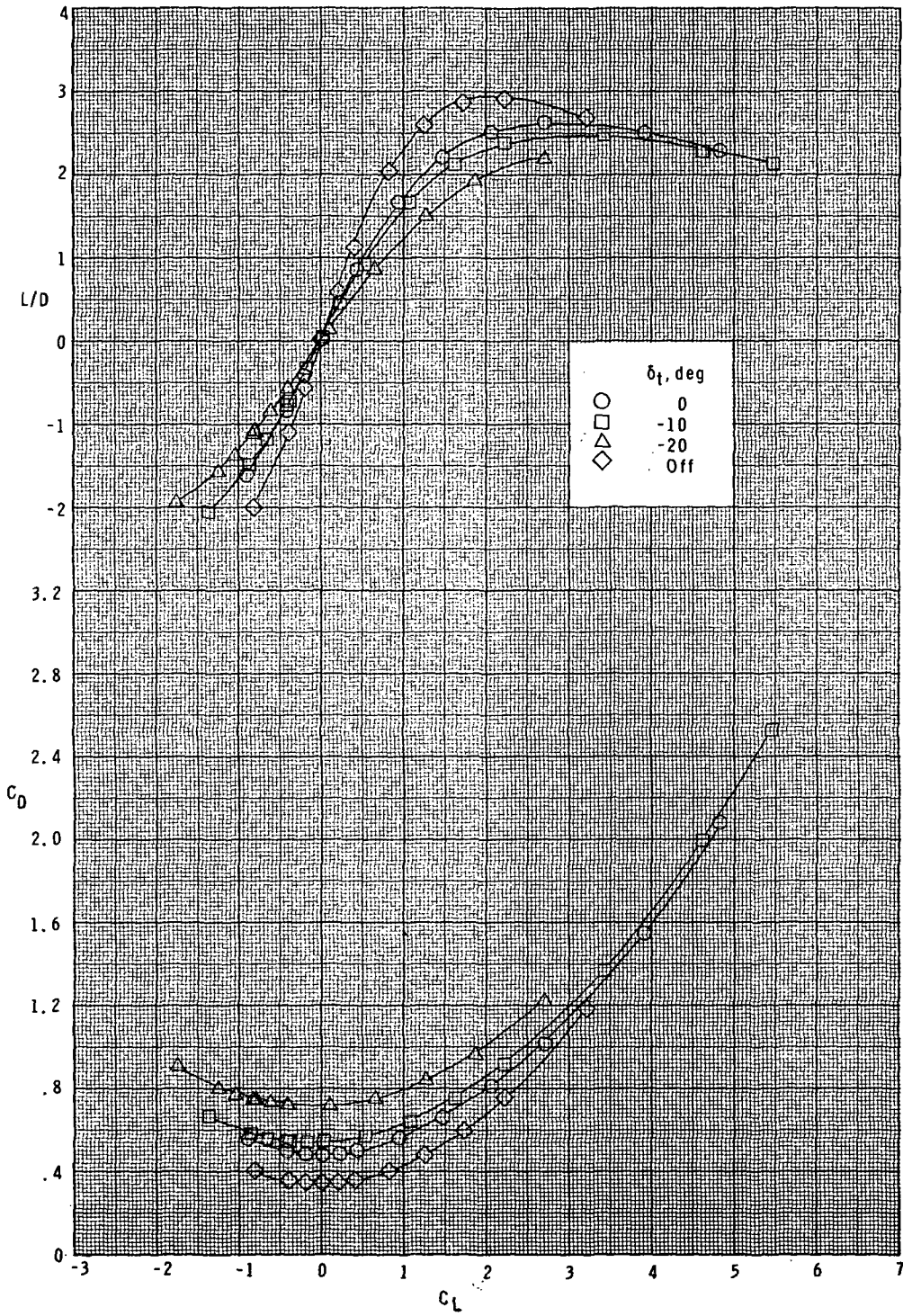
Figure 7.- Effect of tail deflection on longitudinal aerodynamic characteristics.

$\delta_w = 0^\circ$; $\phi = 0^\circ$; tails in line.



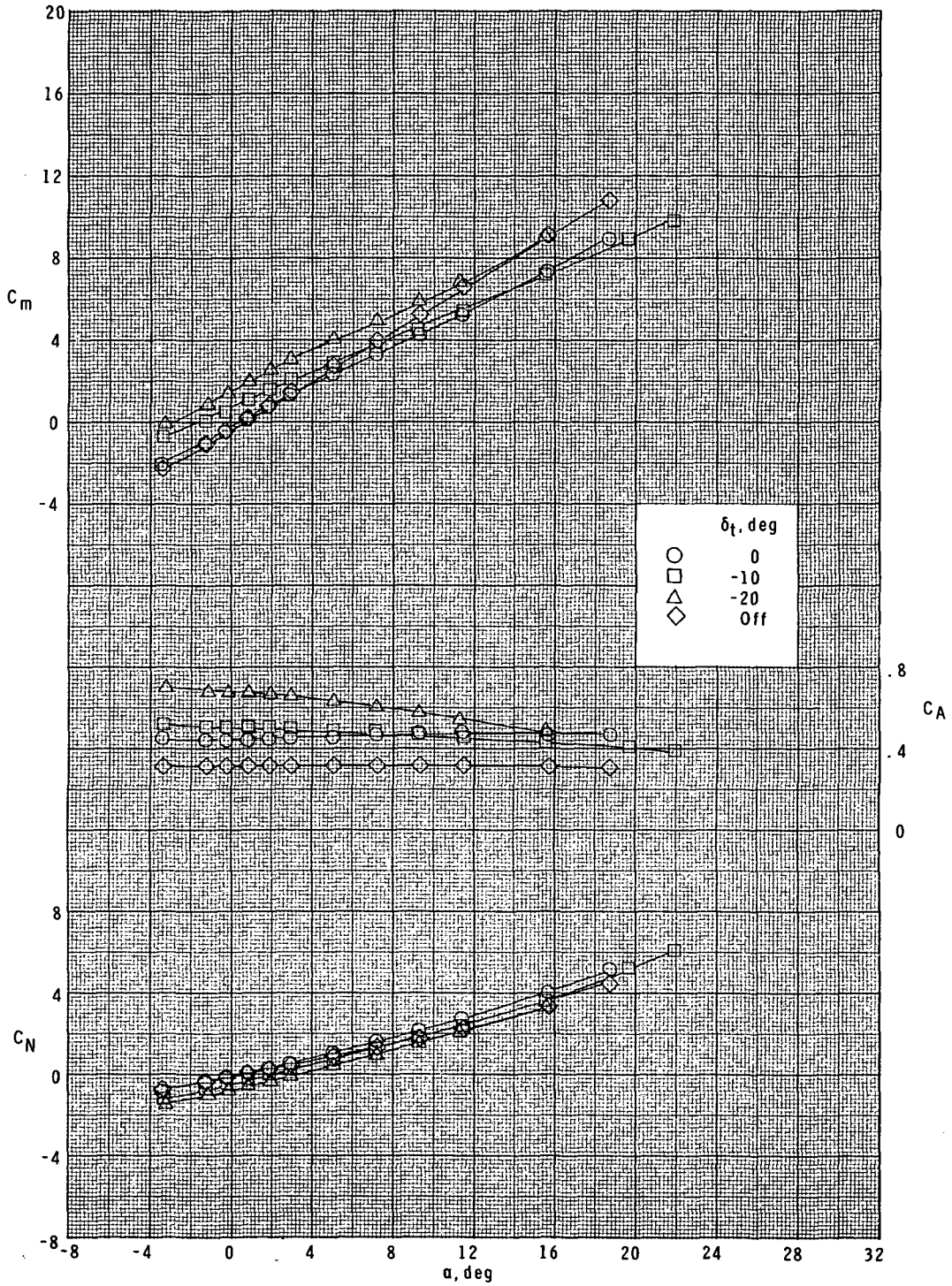
(a) Continued.

Figure 7.- Continued.



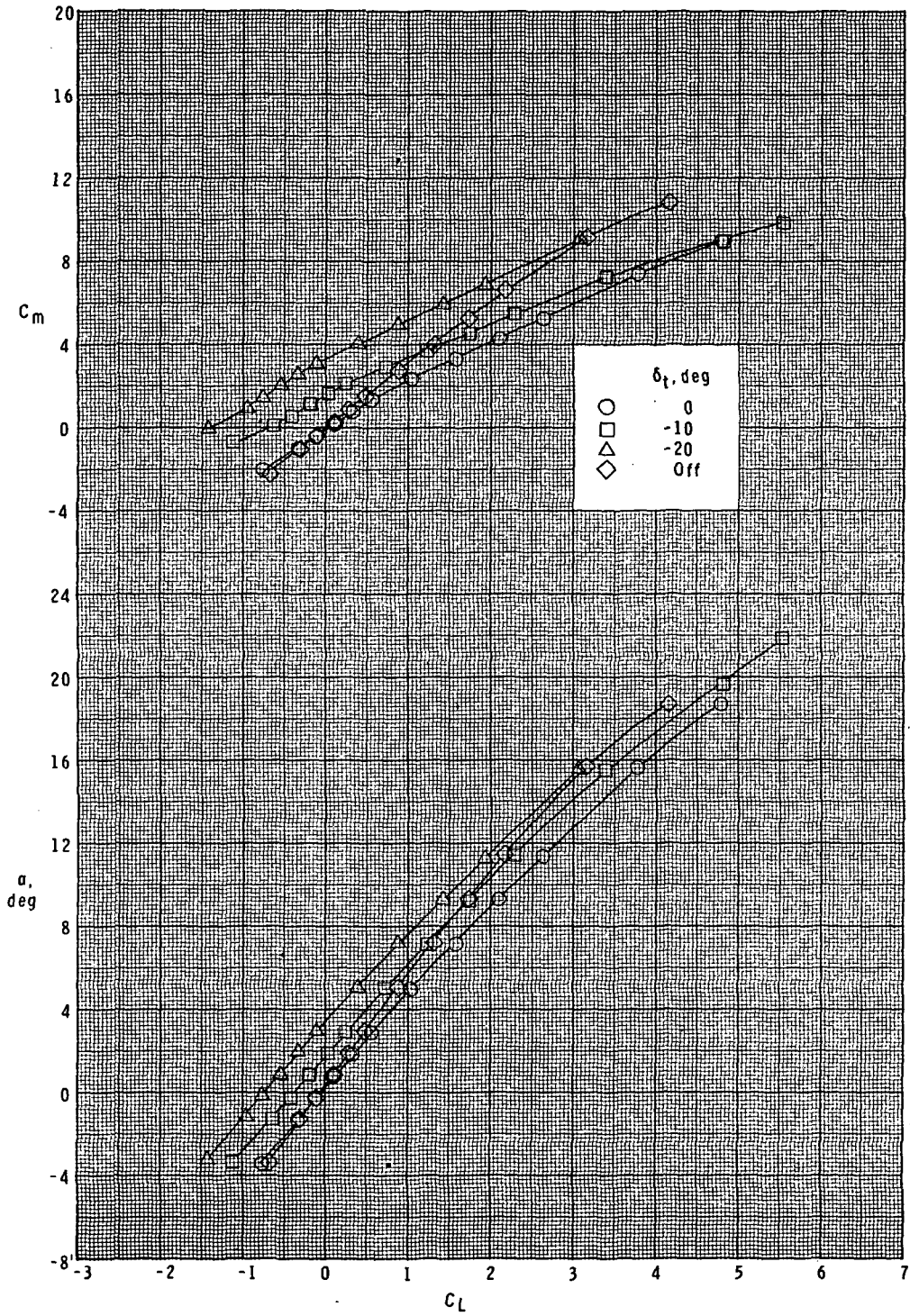
(a) Concluded.

Figure 7.- Continued.



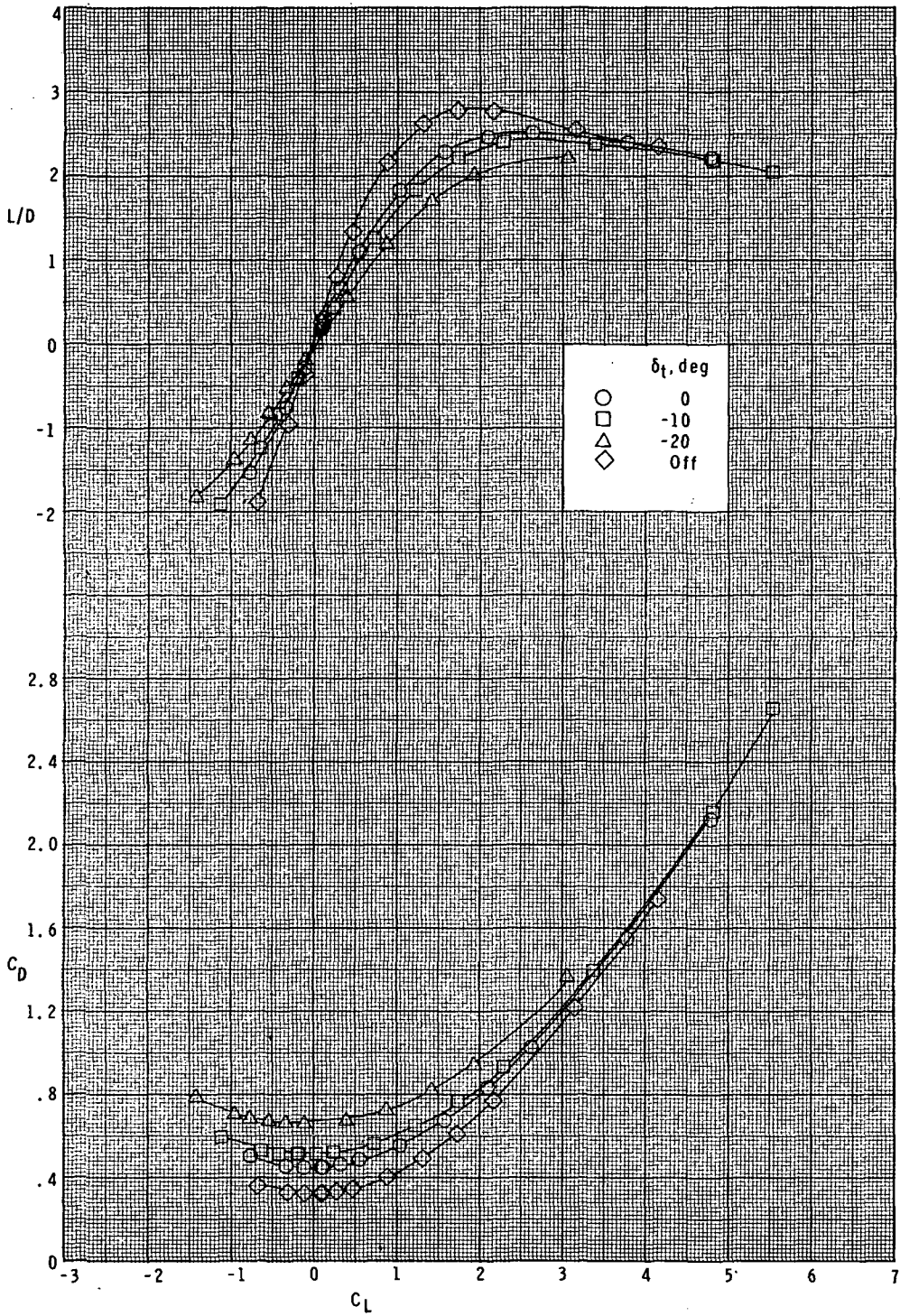
(b) $M = 1.90$.

Figure 7.- Continued.



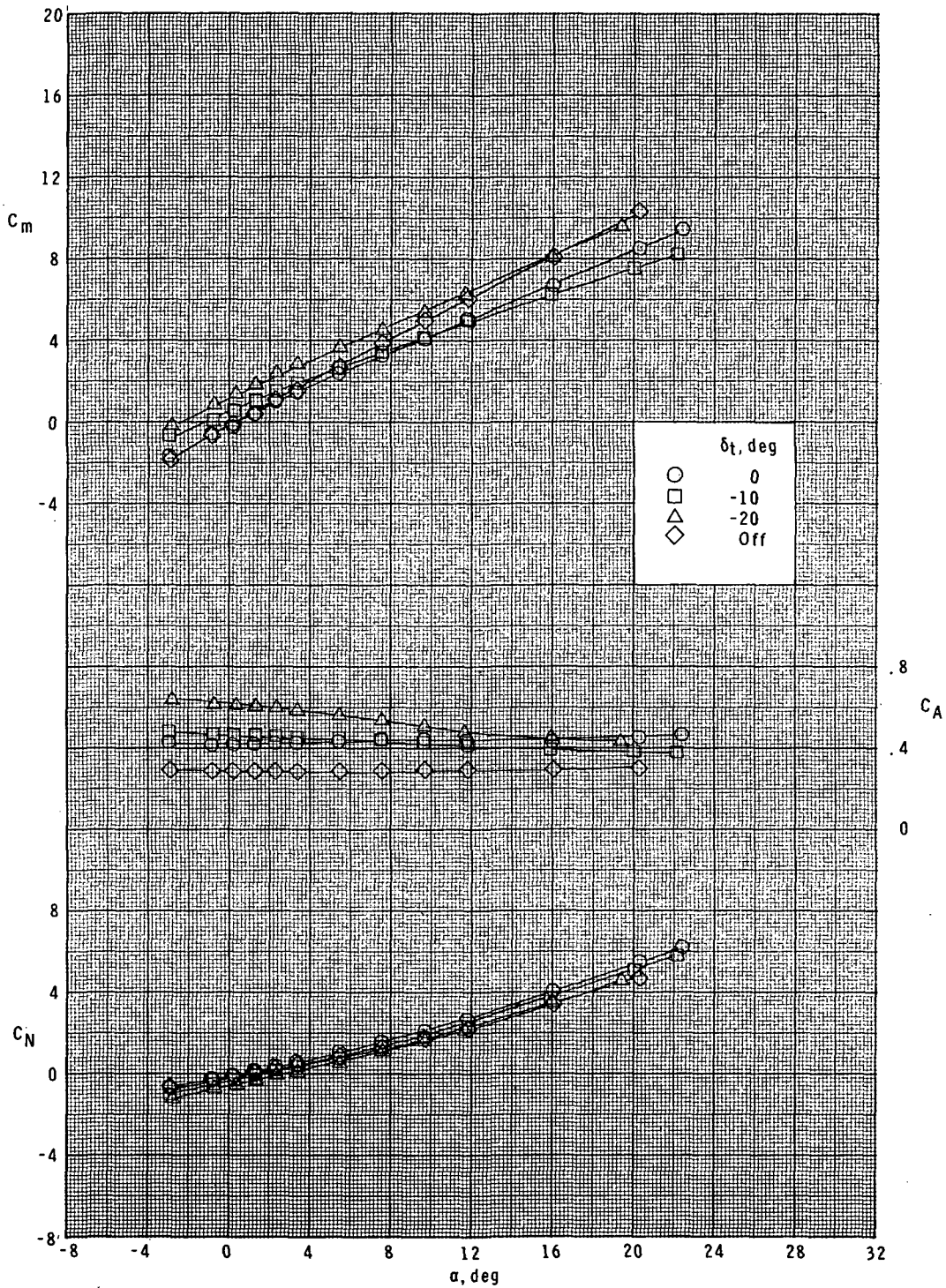
(b) Continued.

Figure 7.- Continued.



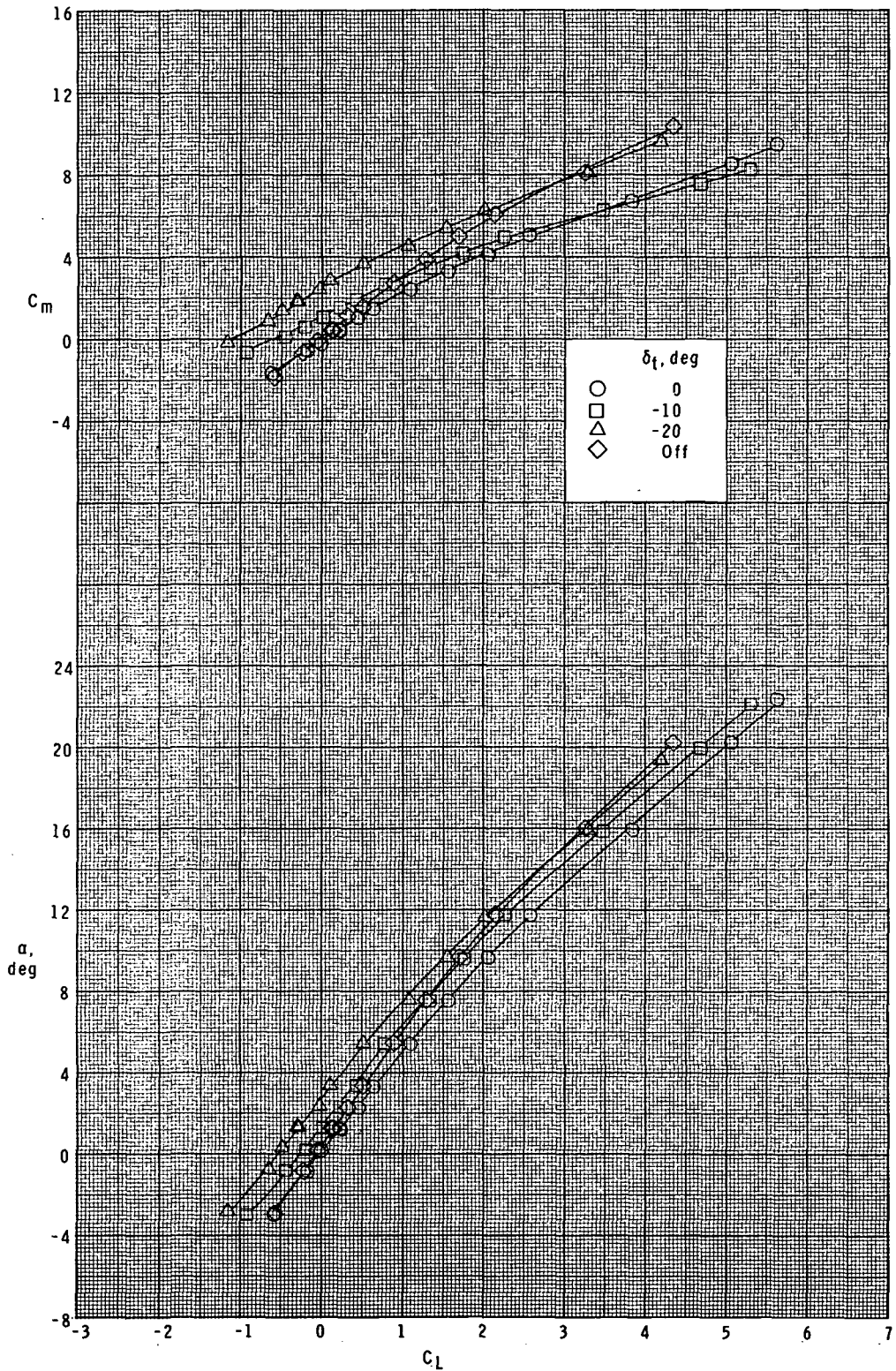
(b) Concluded.

Figure 7. - Continued.



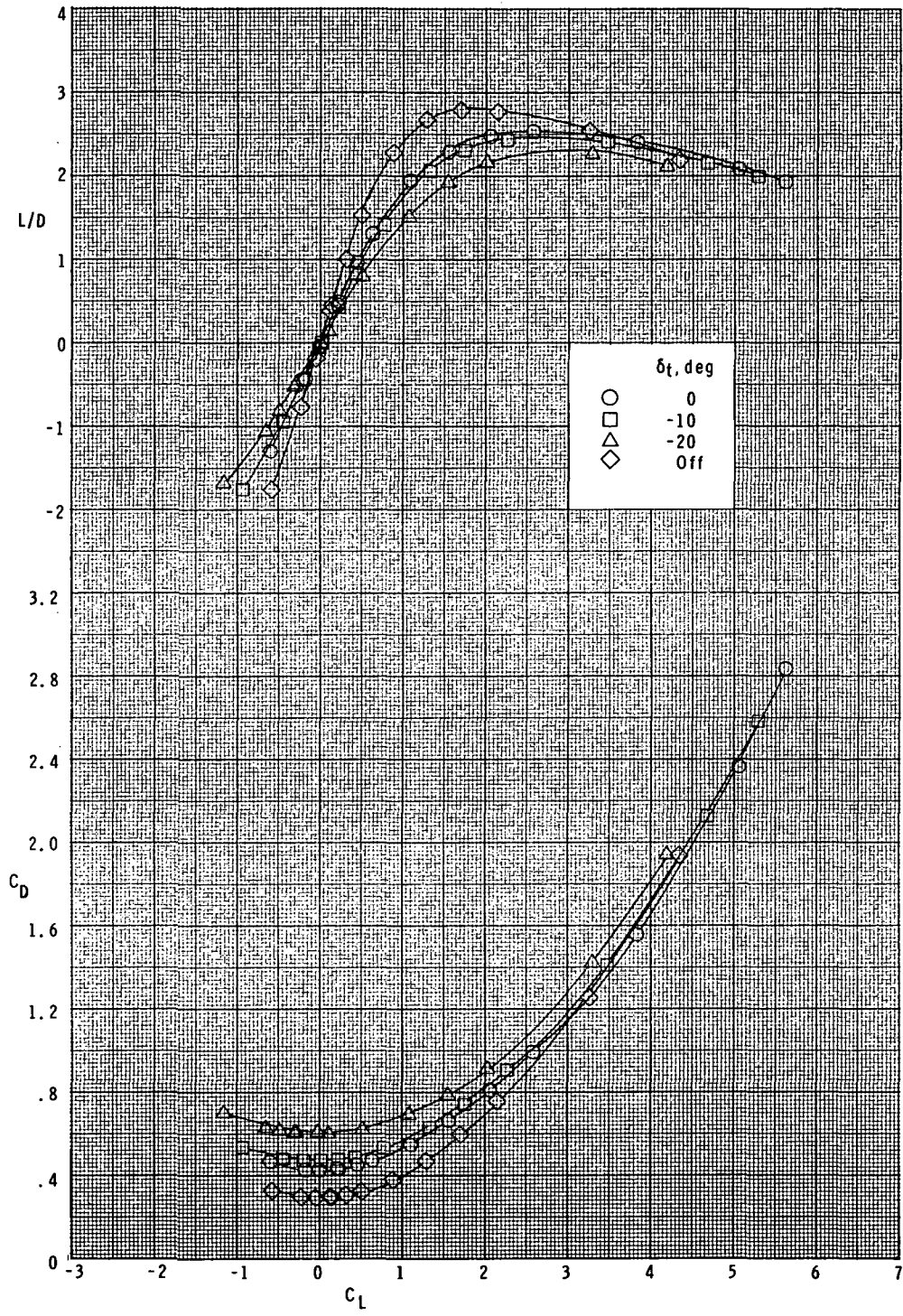
(c) $M = 2.36$.

Figure 7.- Continued.



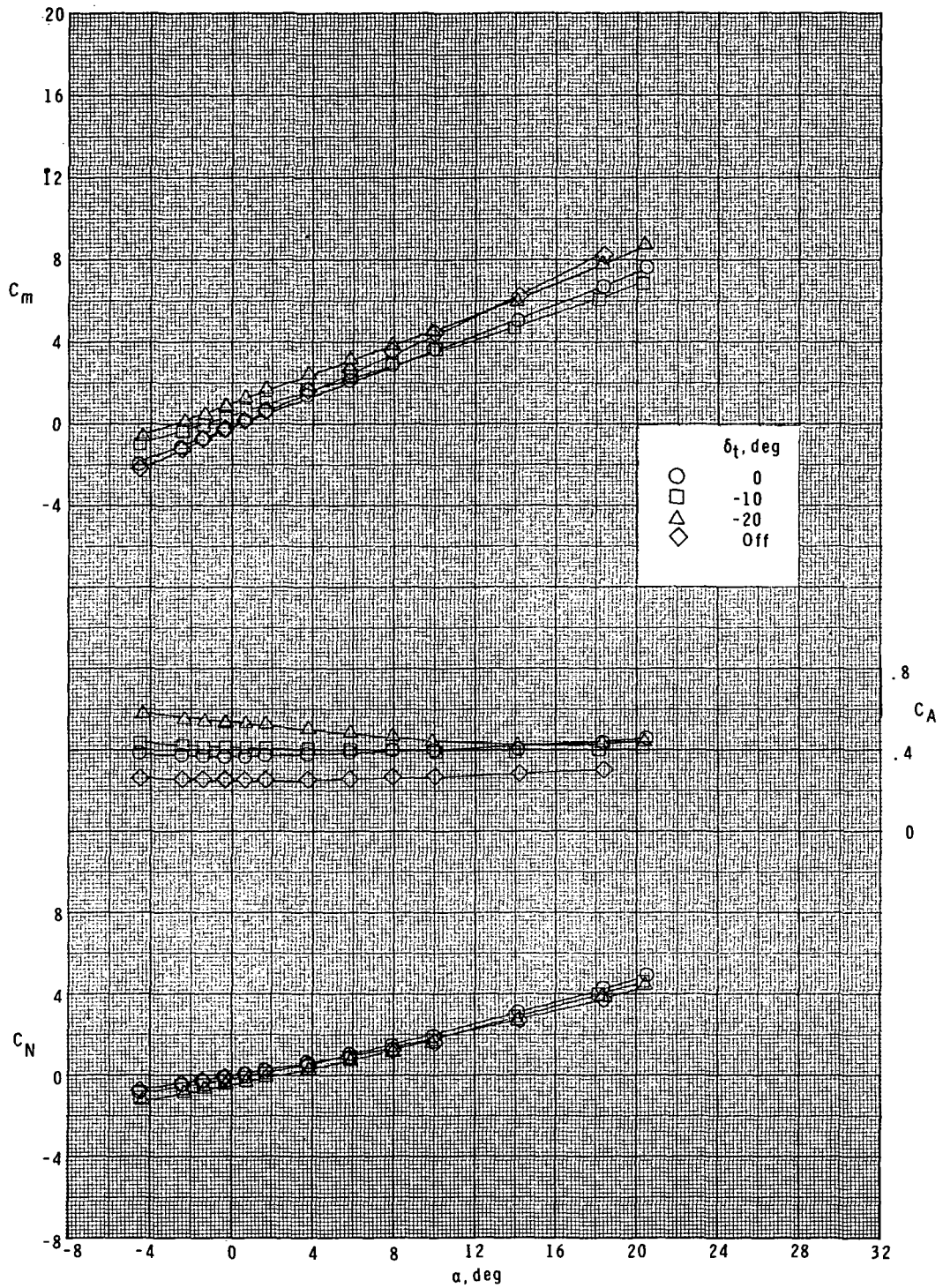
(c) Continued.

Figure 7.- Continued.



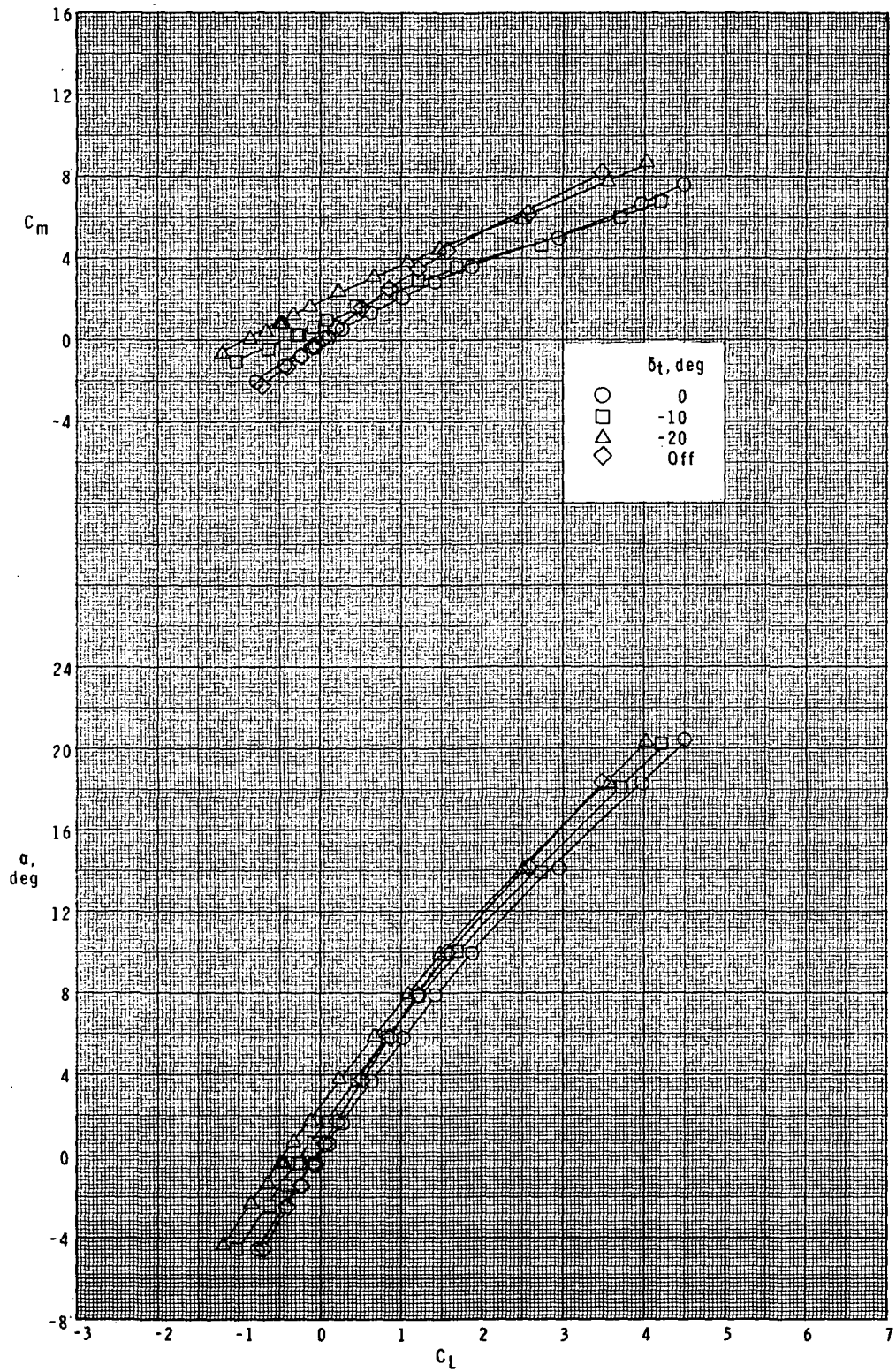
(c) Concluded.

Figure 7.- Continued.



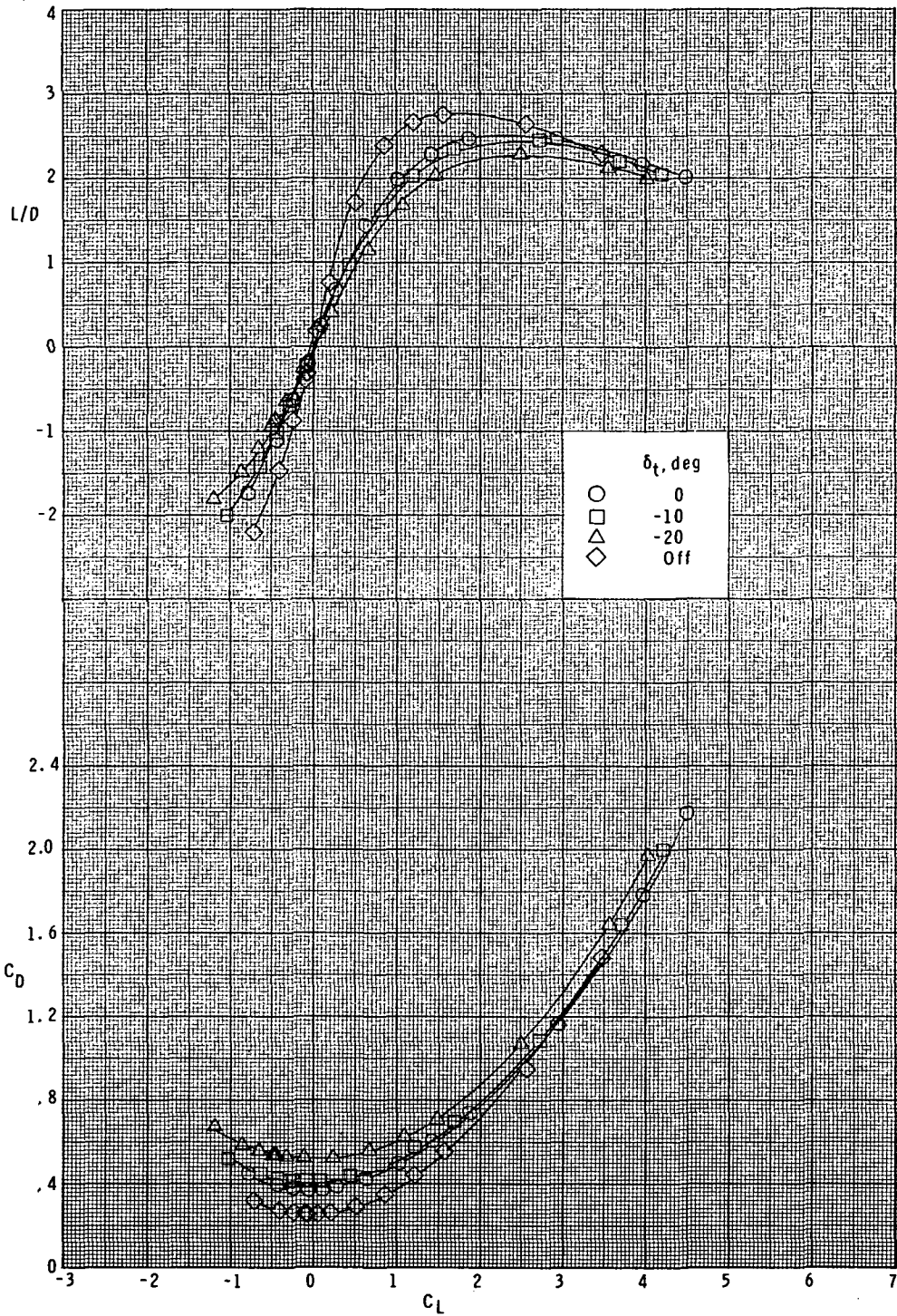
(d) $M = 2.86$.

Figure 7.- Continued.



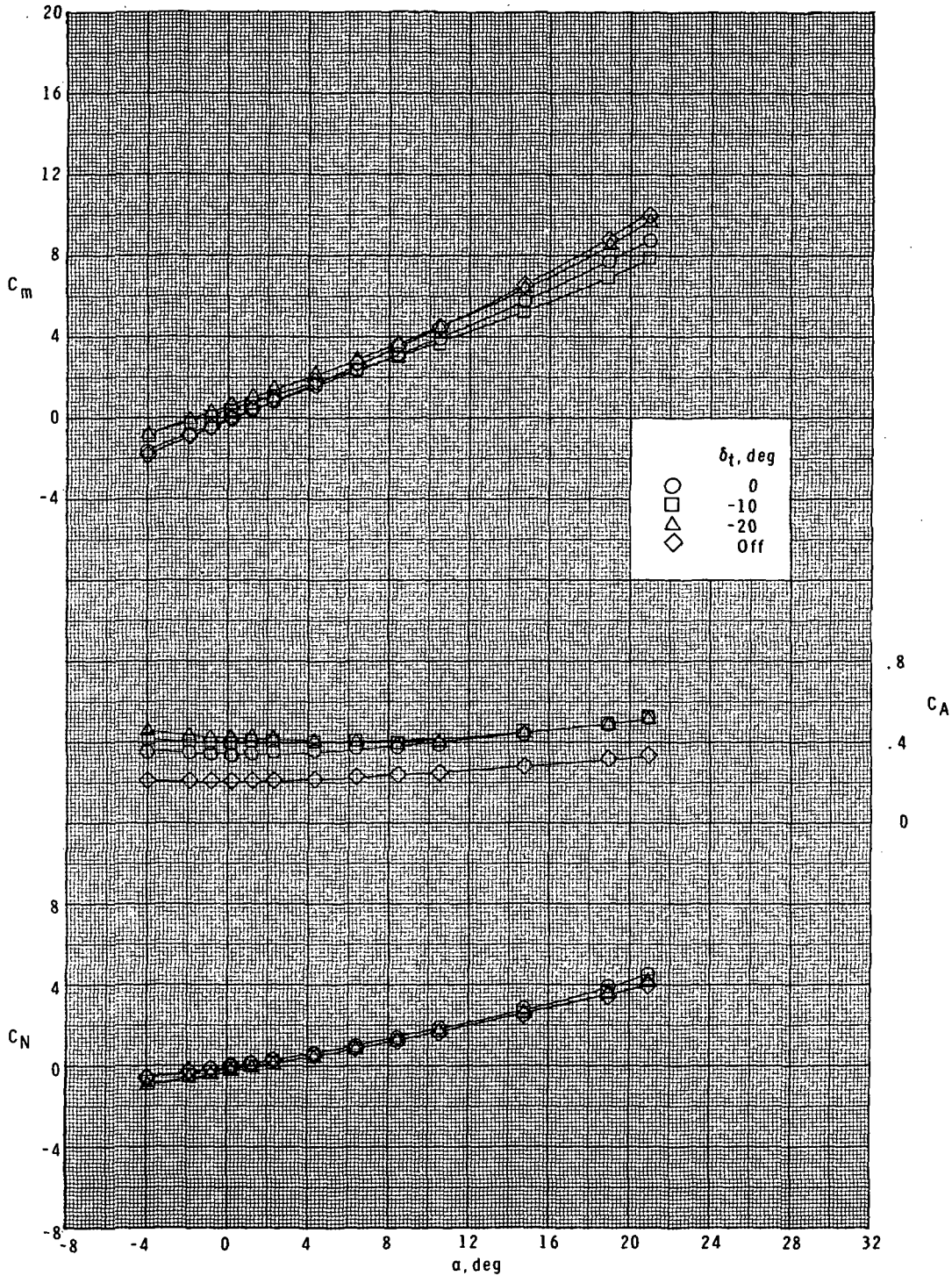
(d) Continued.

Figure 7. - Continued.



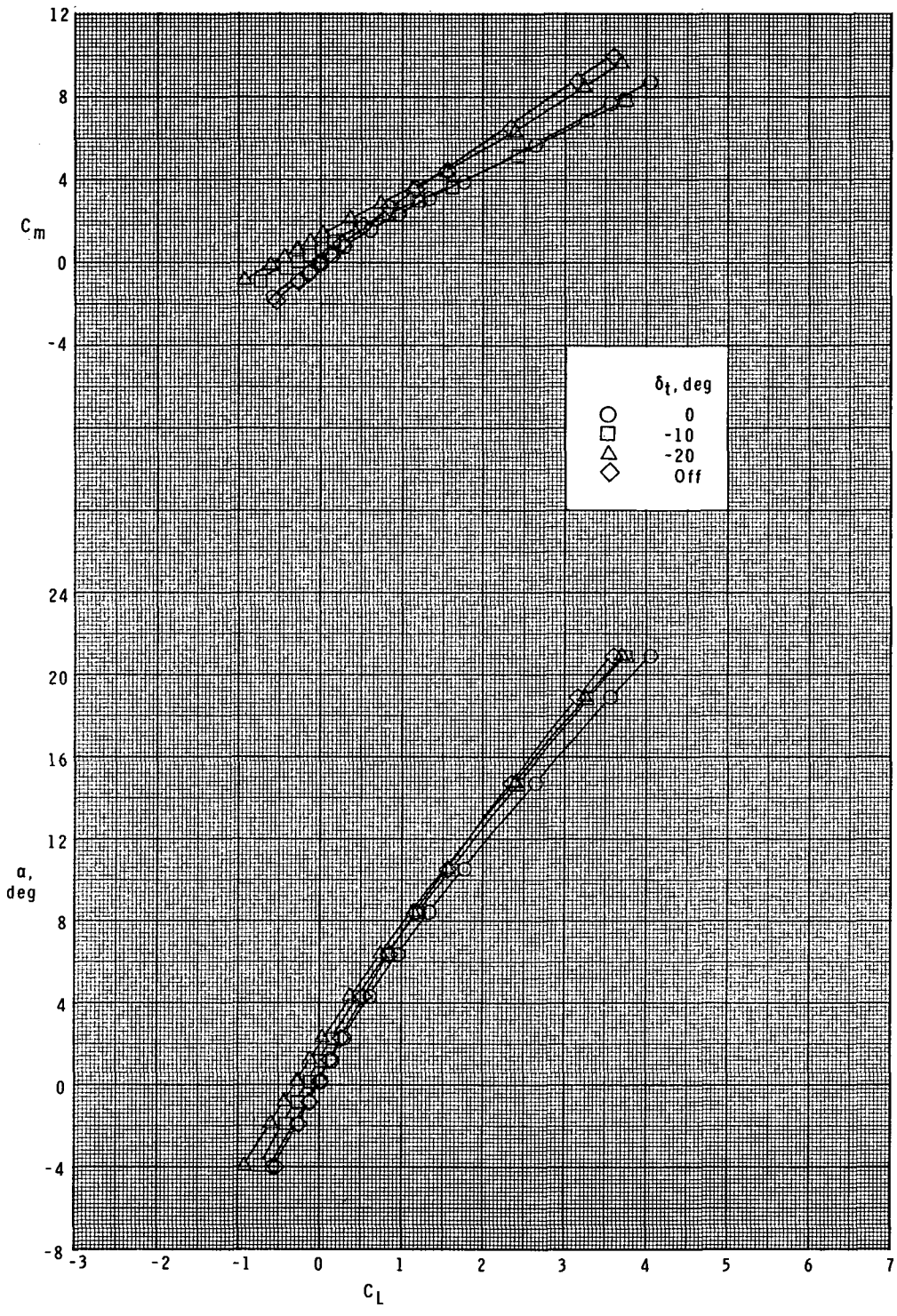
(d) Concluded.

Figure 7.- Continued.



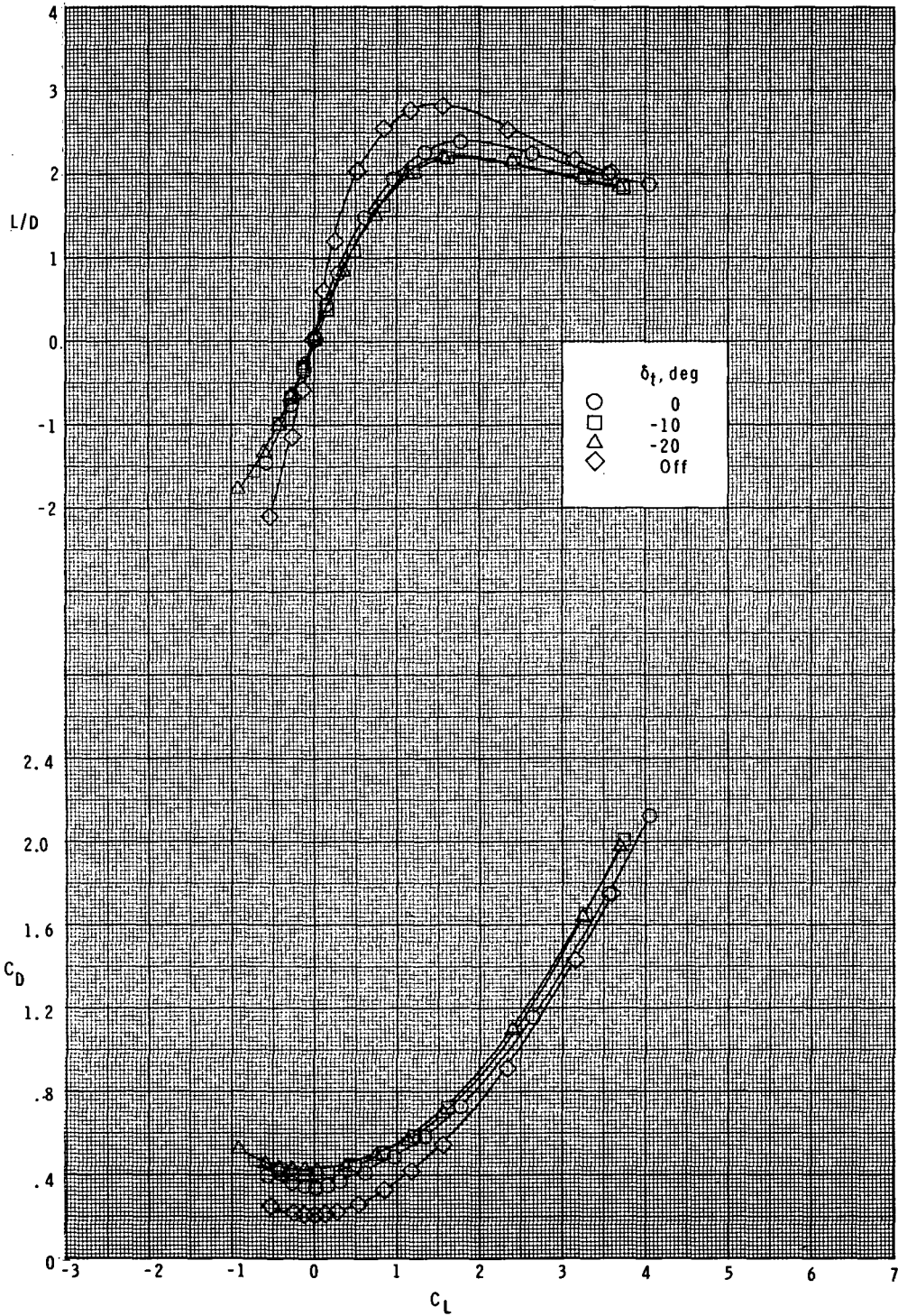
(e) $M = 3.95$.

Figure 7. - Continued.



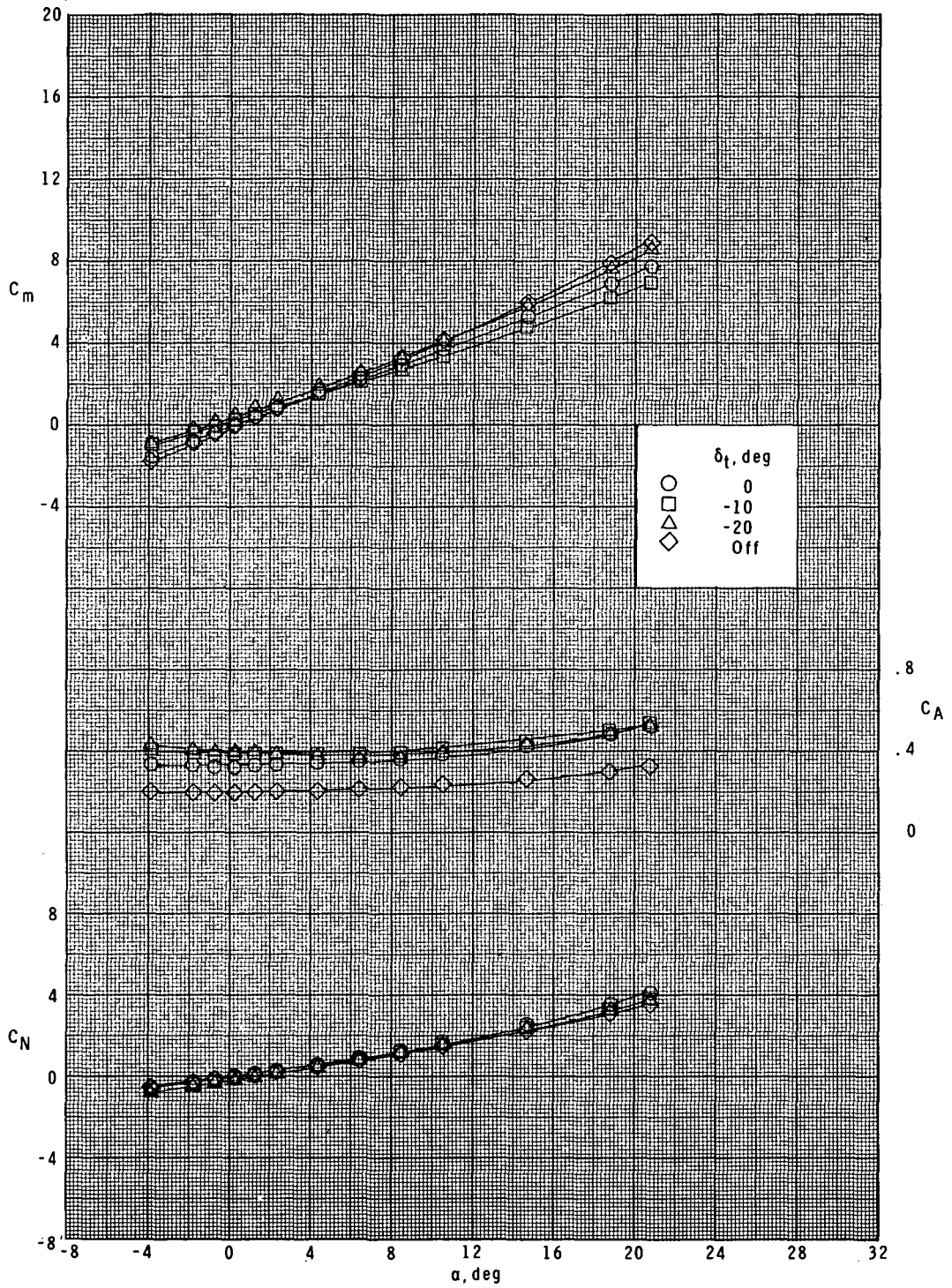
(e) Continued.

Figure 7.- Continued.



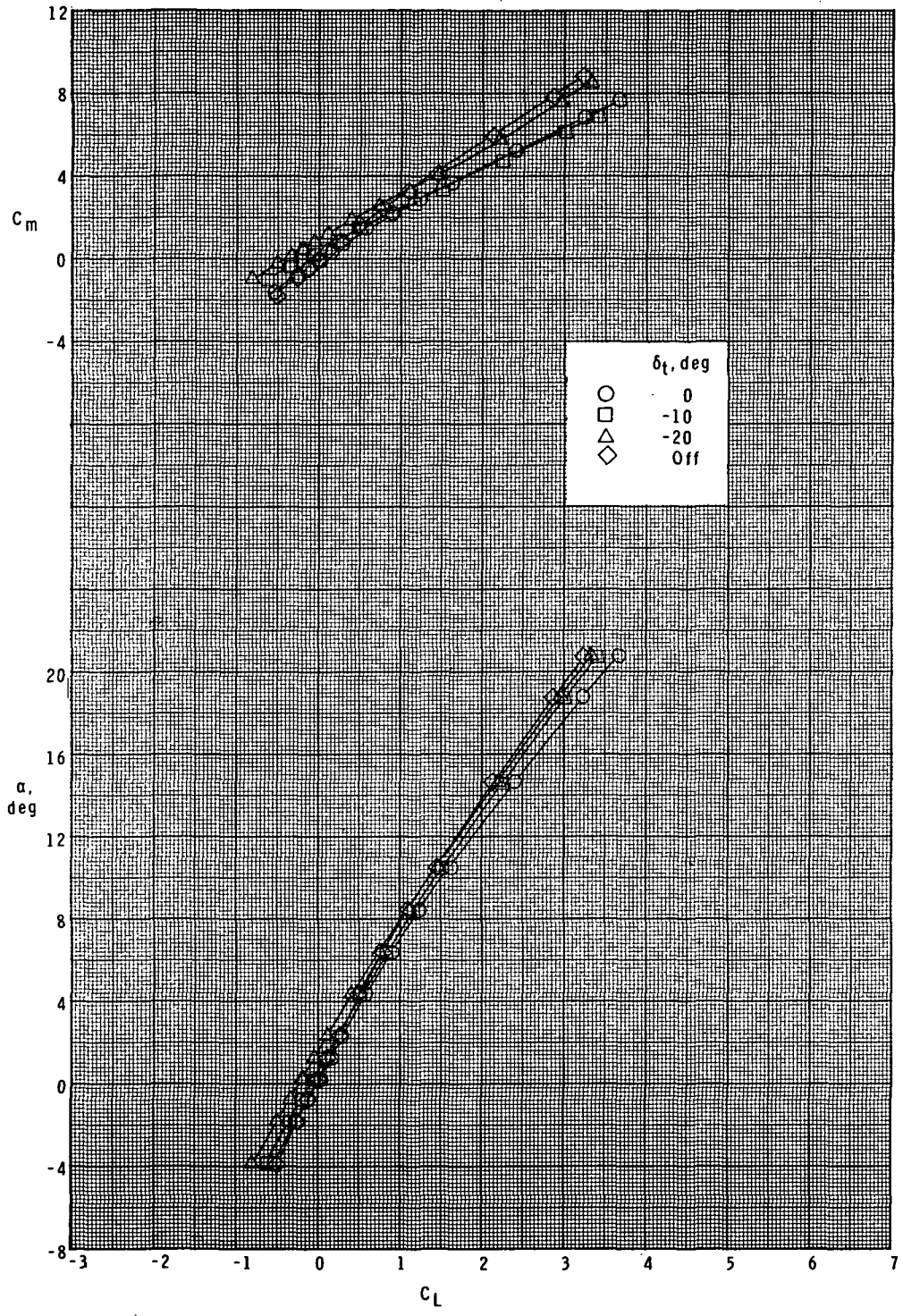
(e) Concluded.

Figure 7.- Continued.



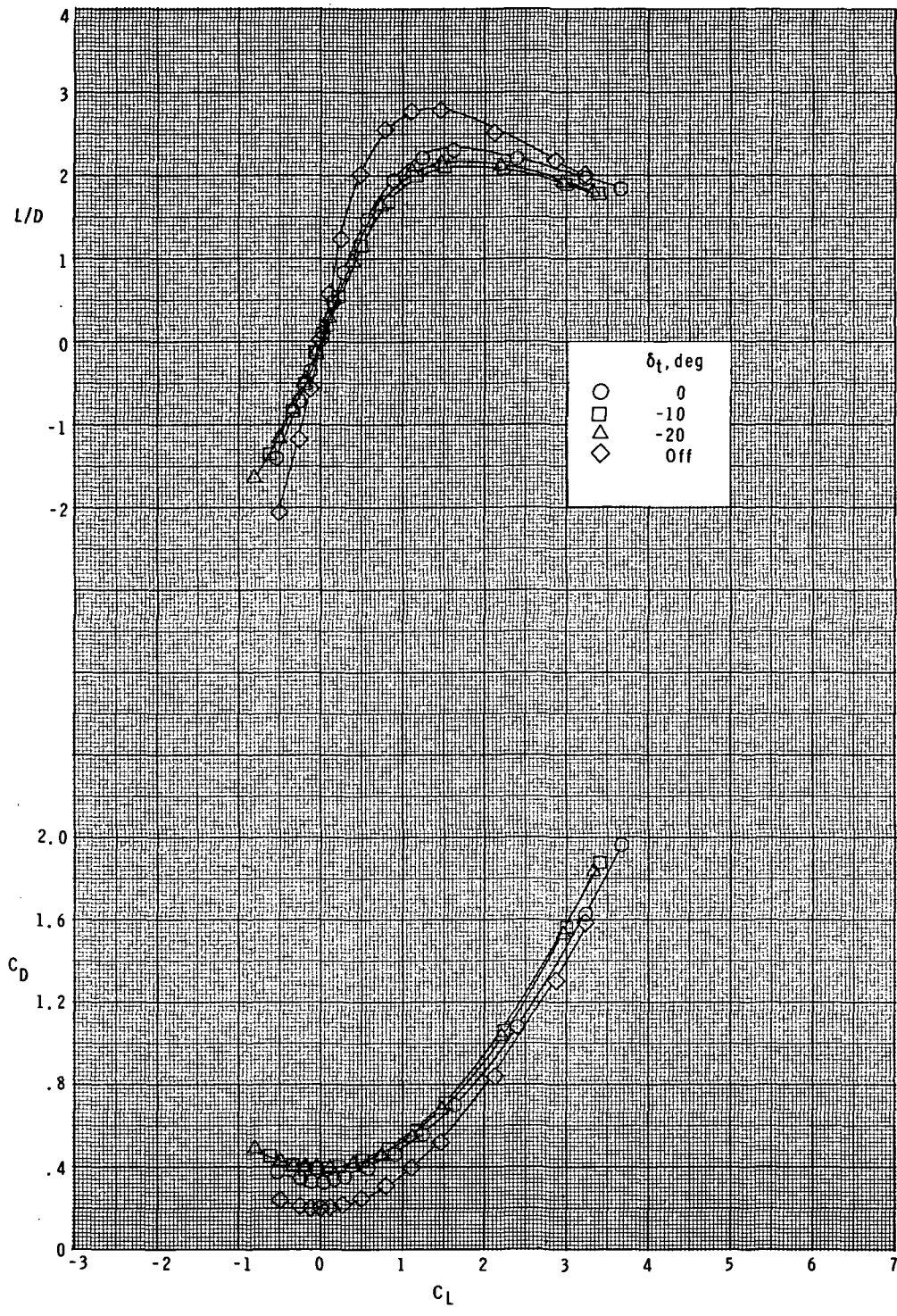
(f) $M = 4.63$.

Figure 7.- Continued.



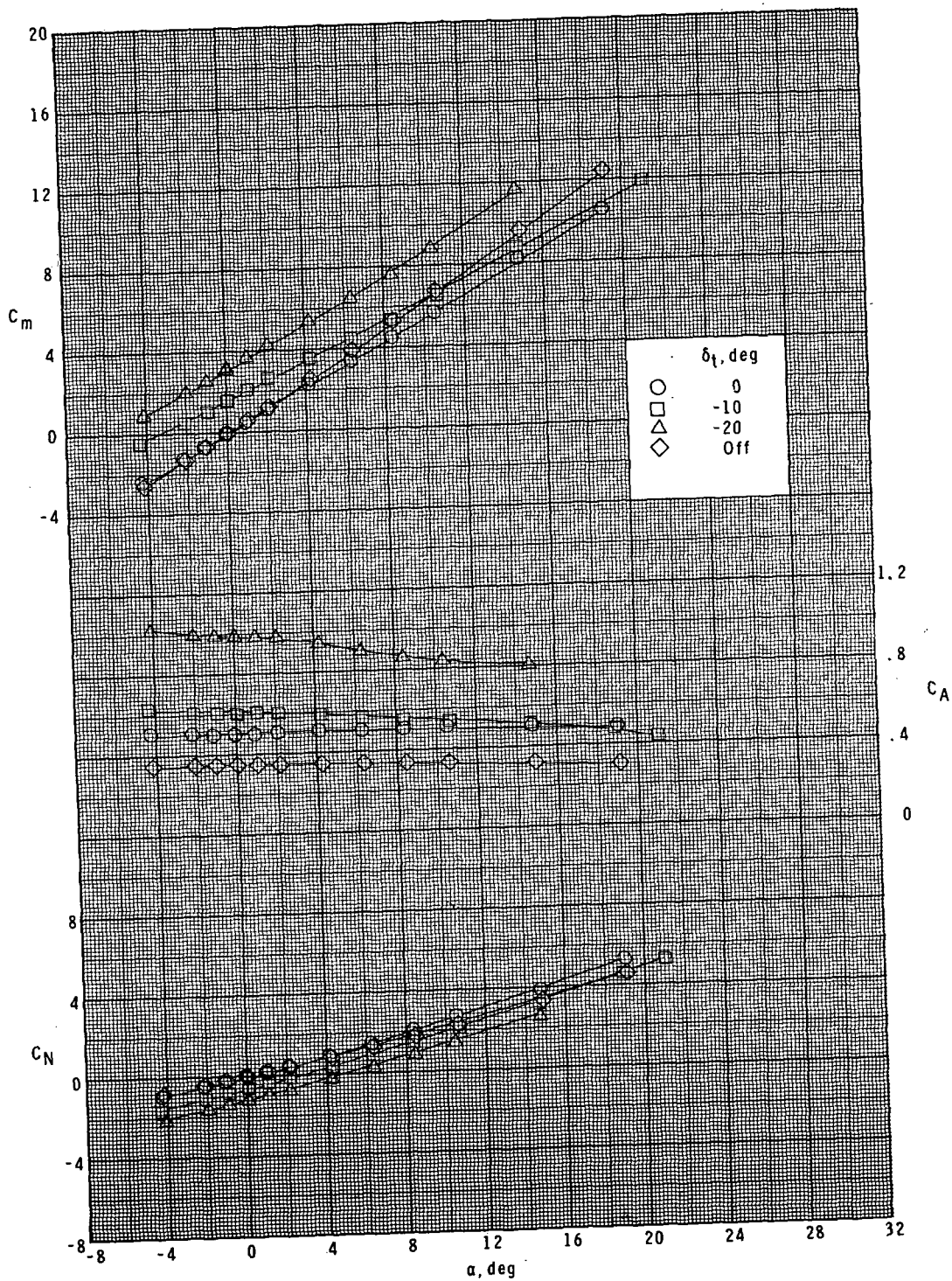
(f) Continued.

Figure 7.- Continued.



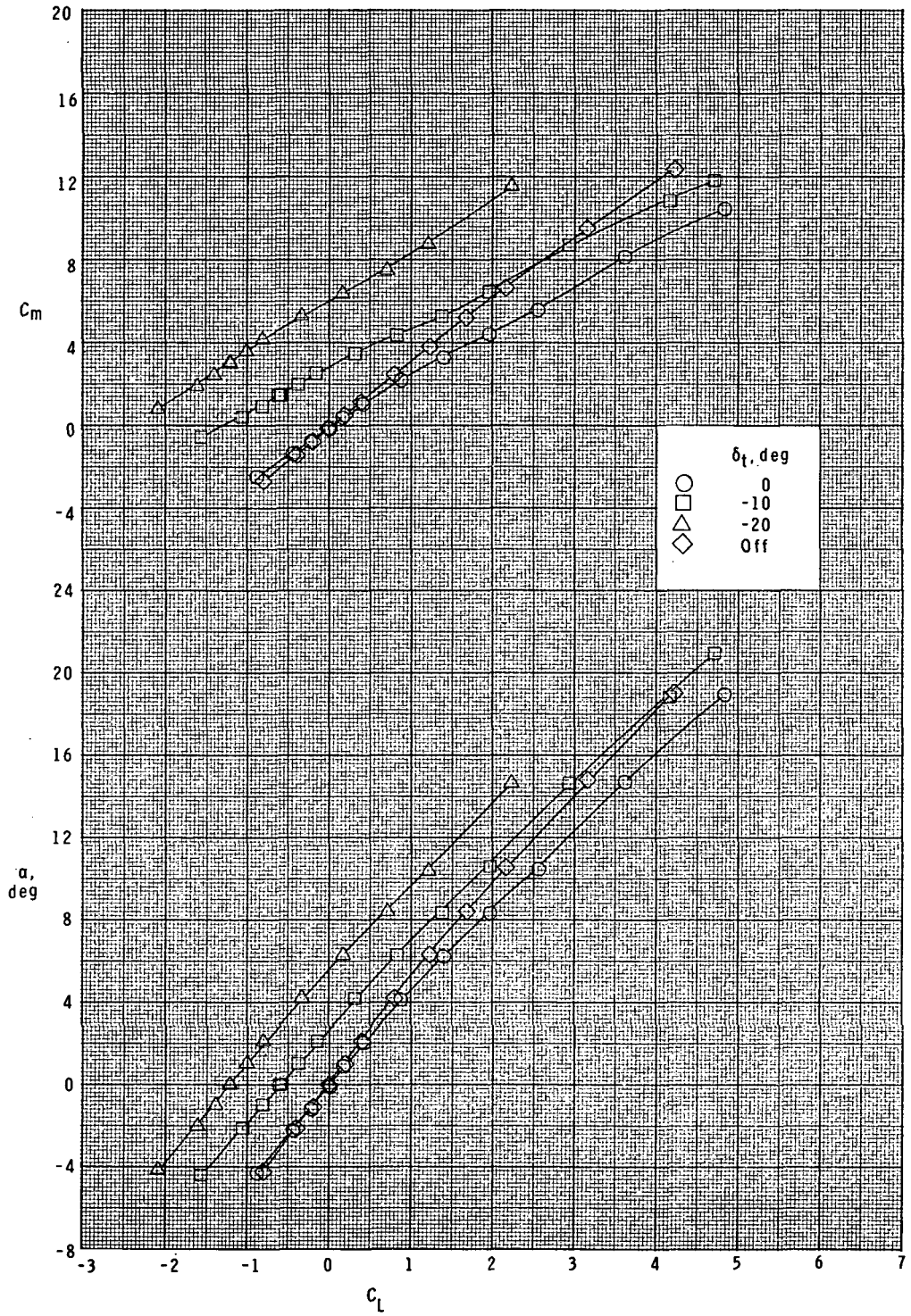
(f) Concluded.

Figure 7.- Concluded.



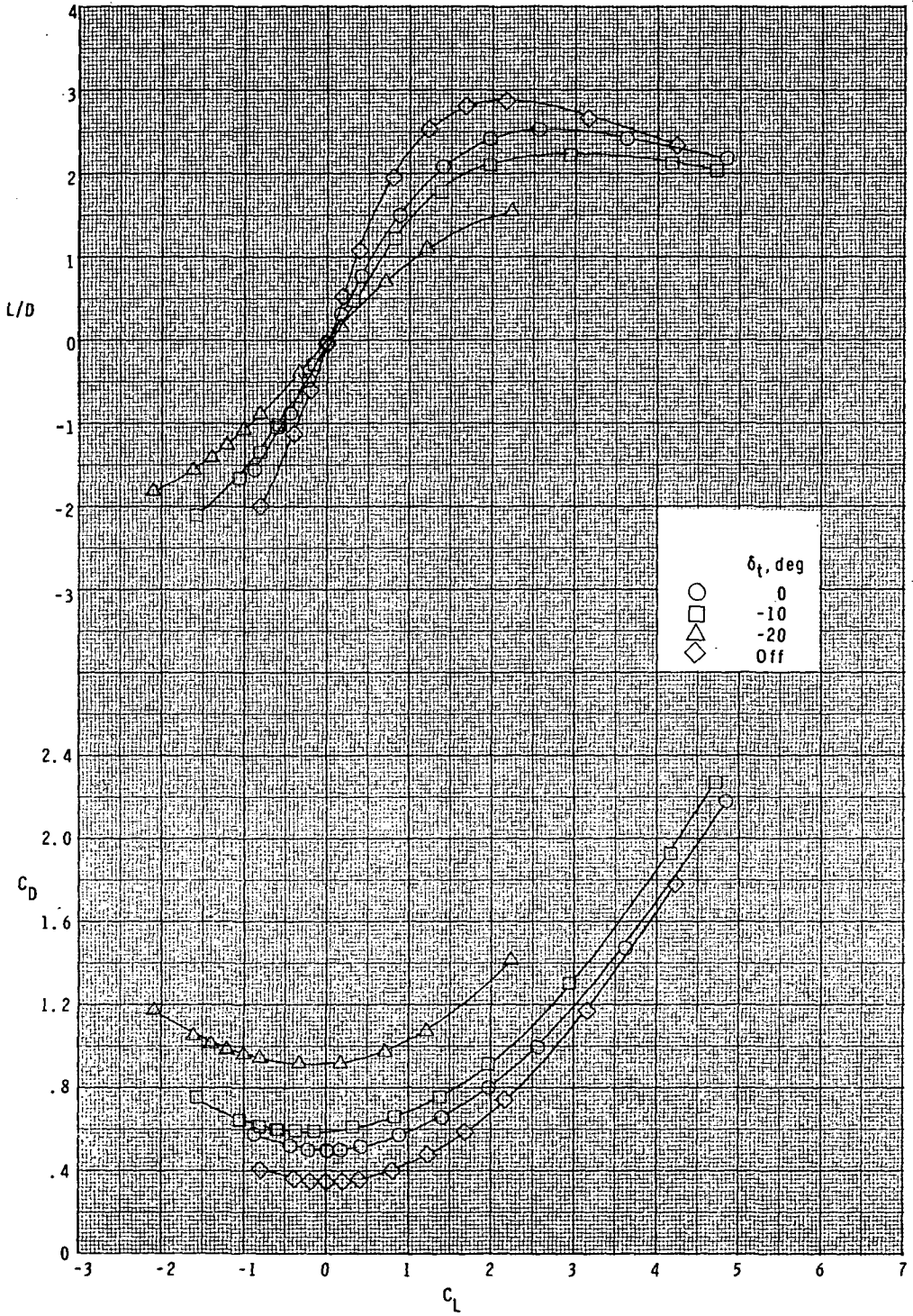
(a) $M = 1.50$.

Figure 8.- Effect of tail deflection on longitudinal aerodynamic characteristics.
 $\delta_w = 0^\circ$; $\phi = 45^\circ$; tails in line.



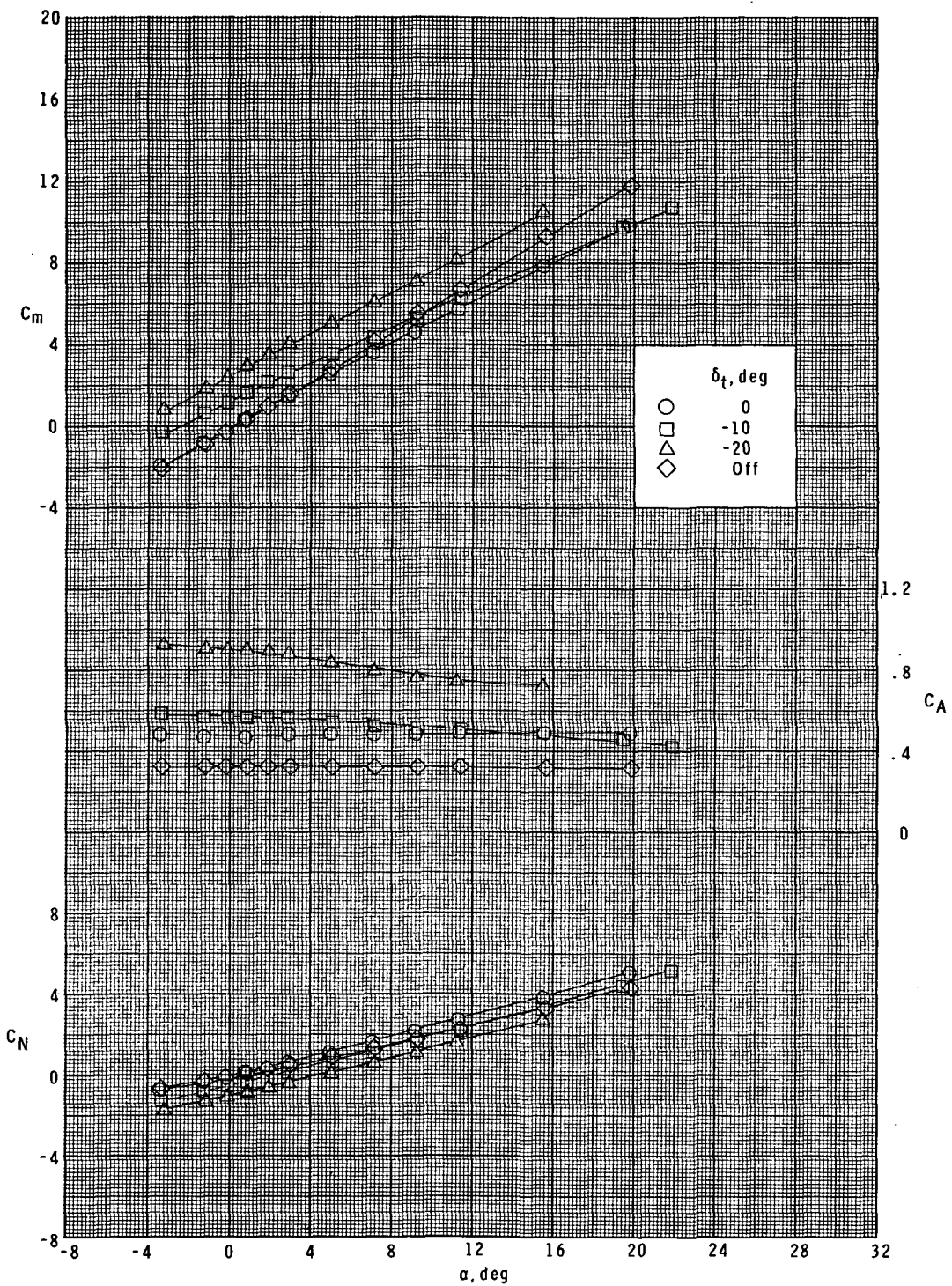
(a) Continued.

Figure 8.- Continued.



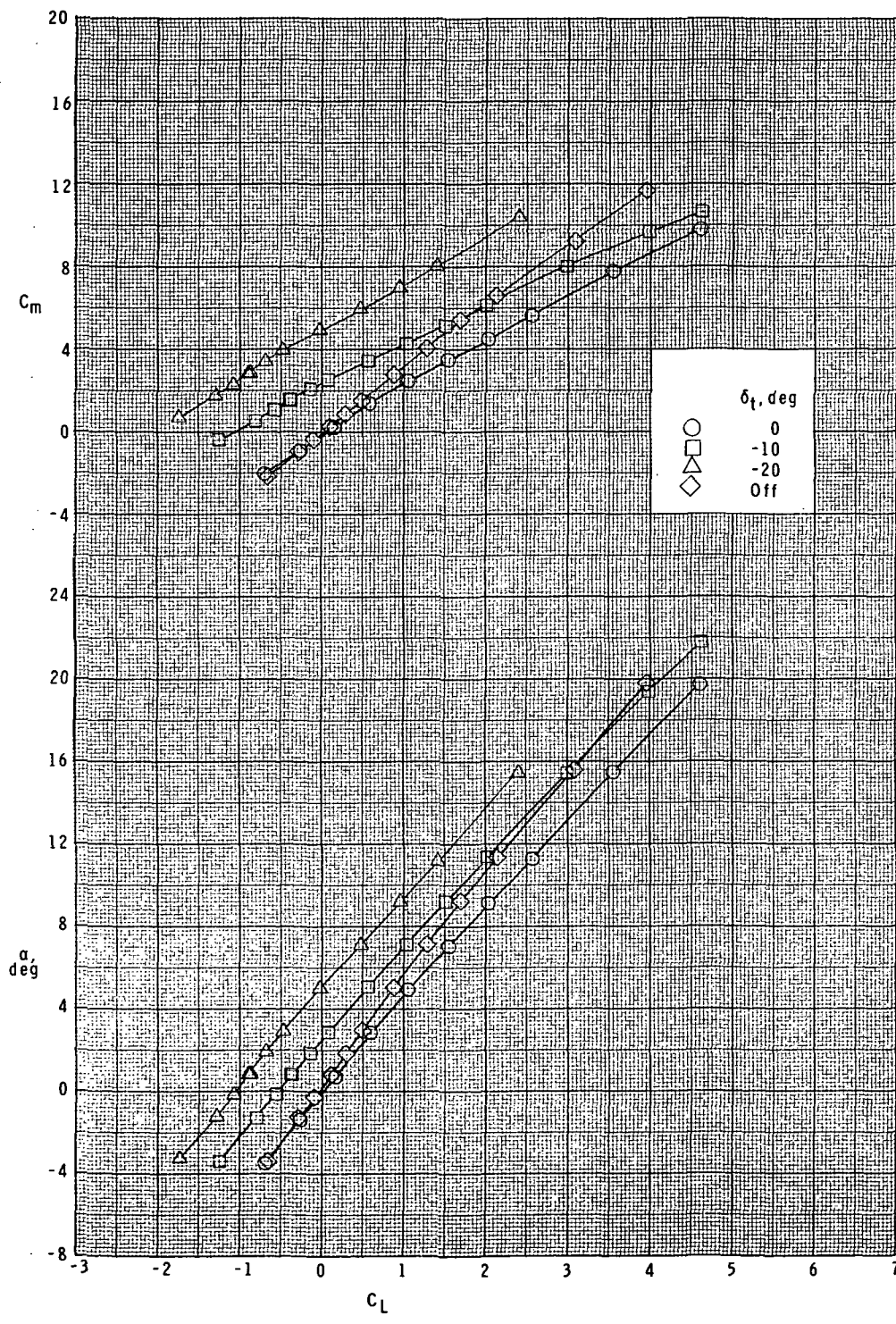
(a) Concluded.

Figure 8. - Continued.



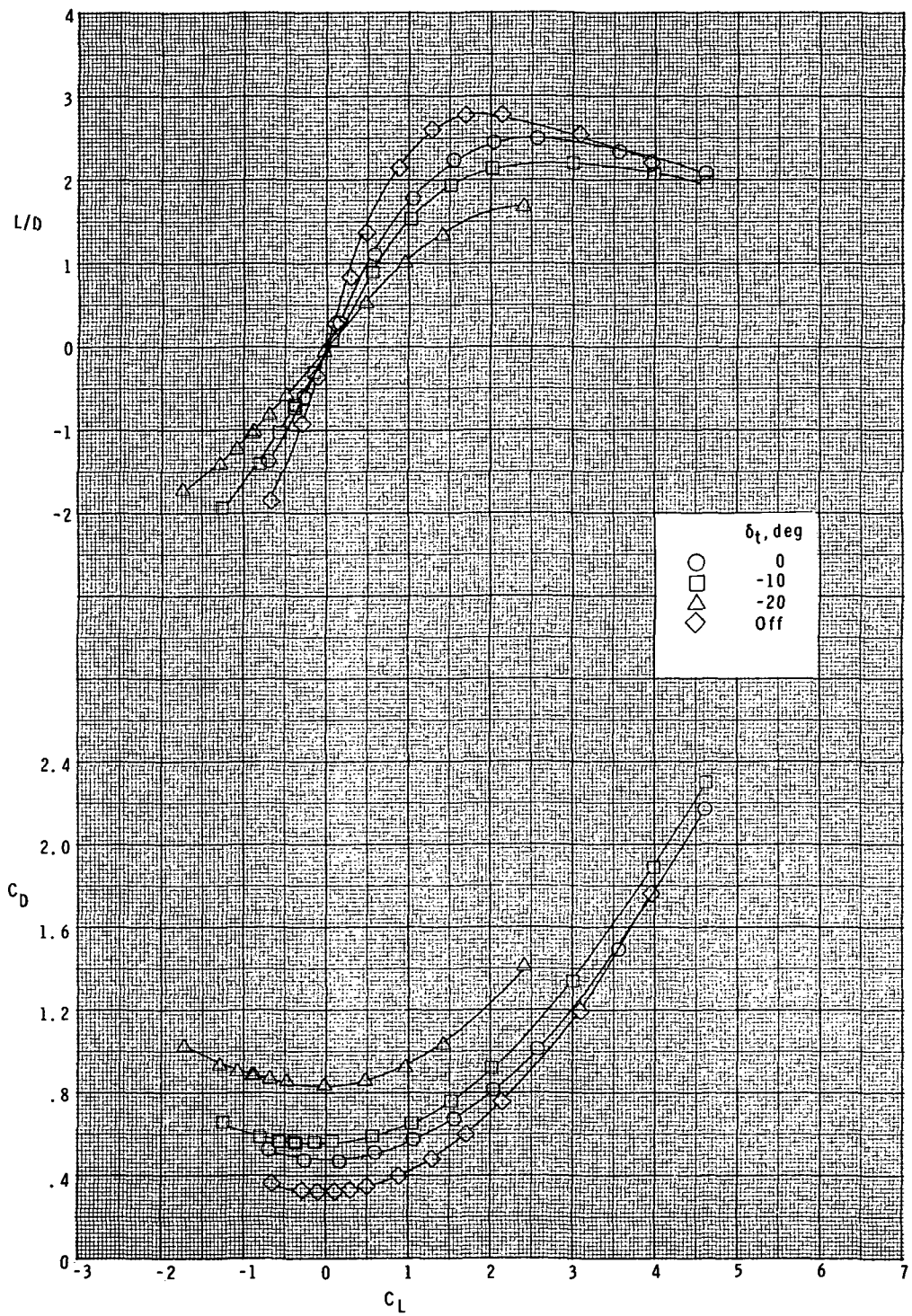
(b) $M = 1.90$.

Figure 8. - Continued.



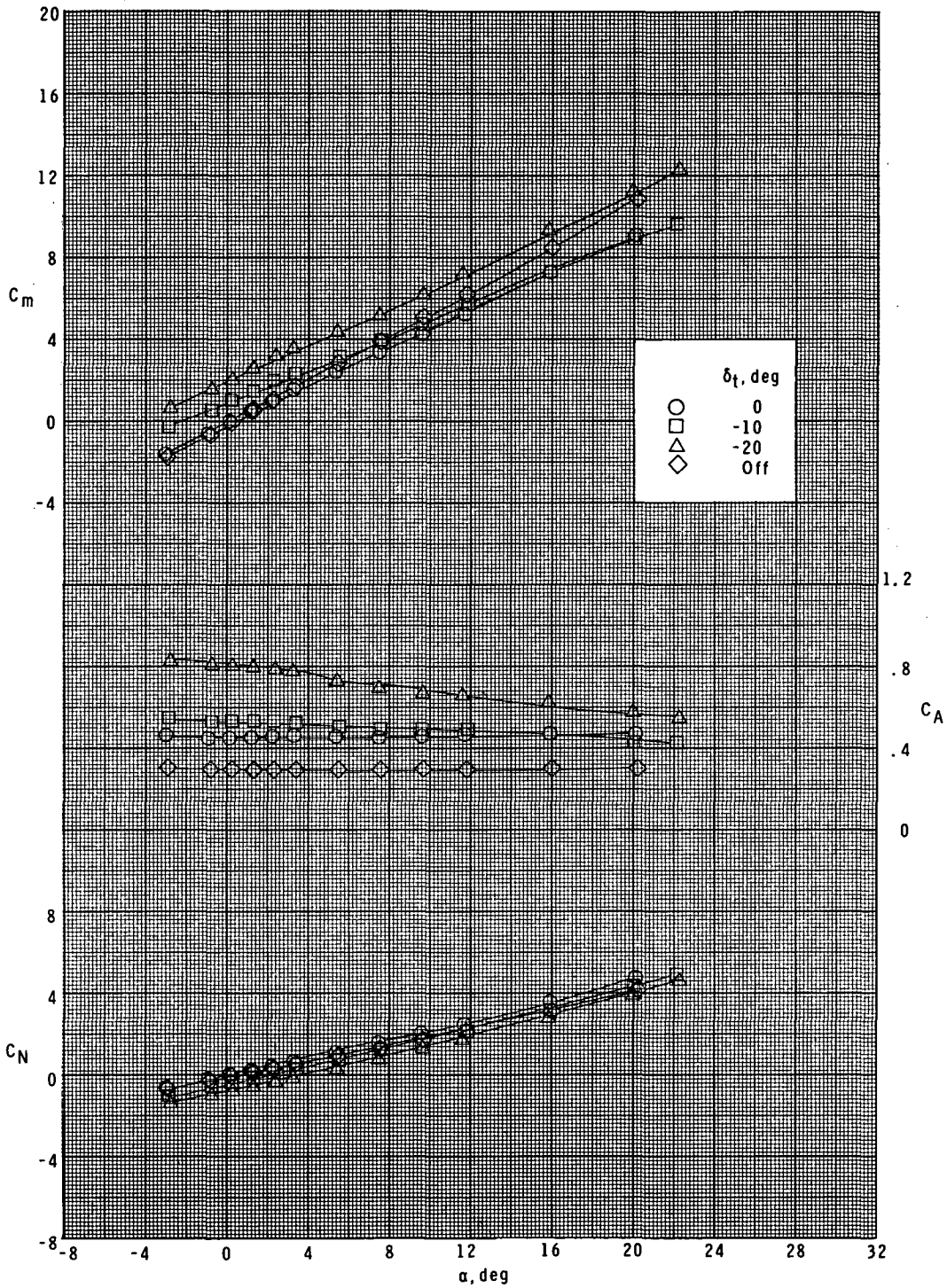
(b) Continued.

Figure 8.- Continued.



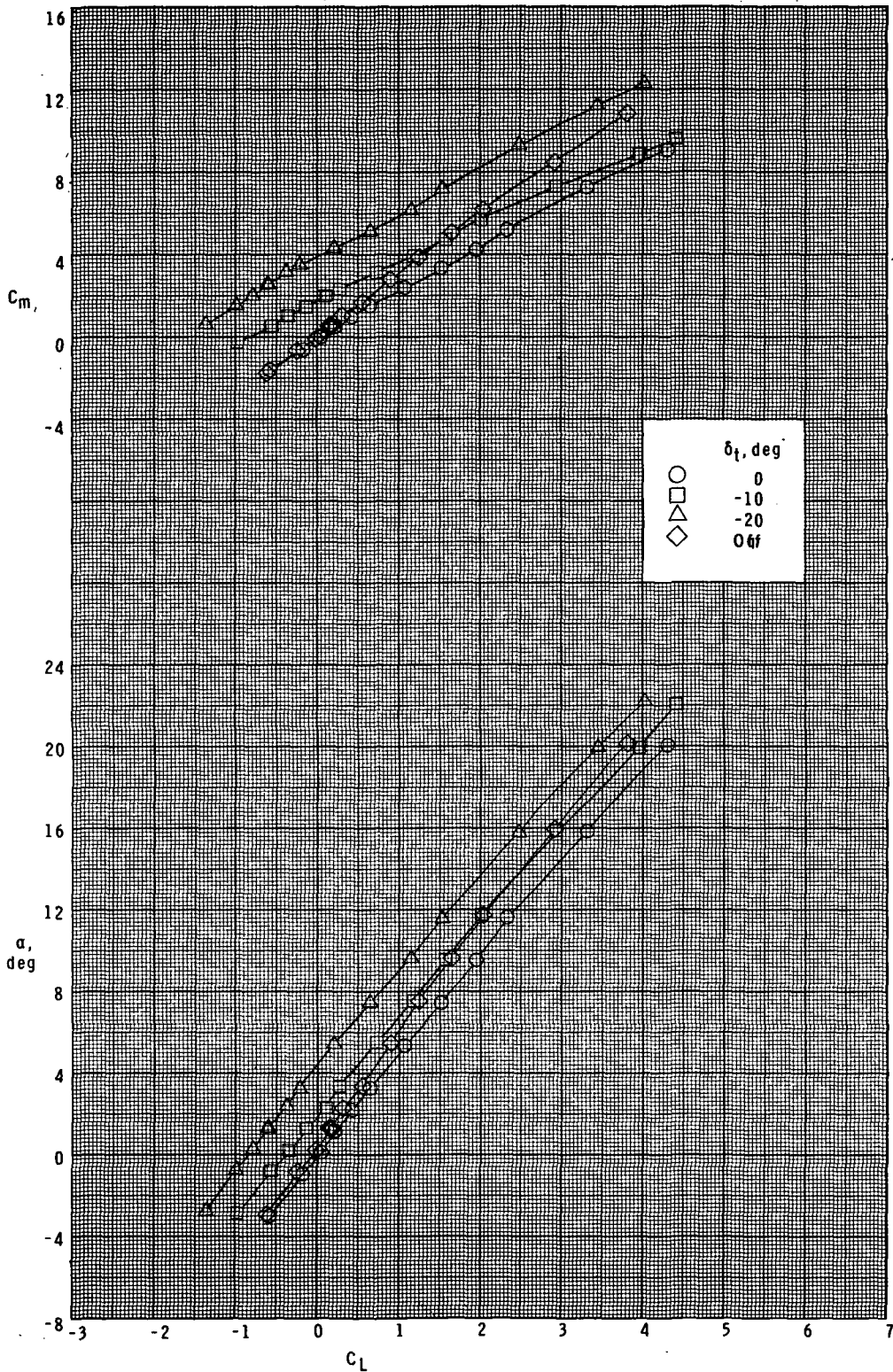
(b) Concluded.

Figure 8.- Continued.



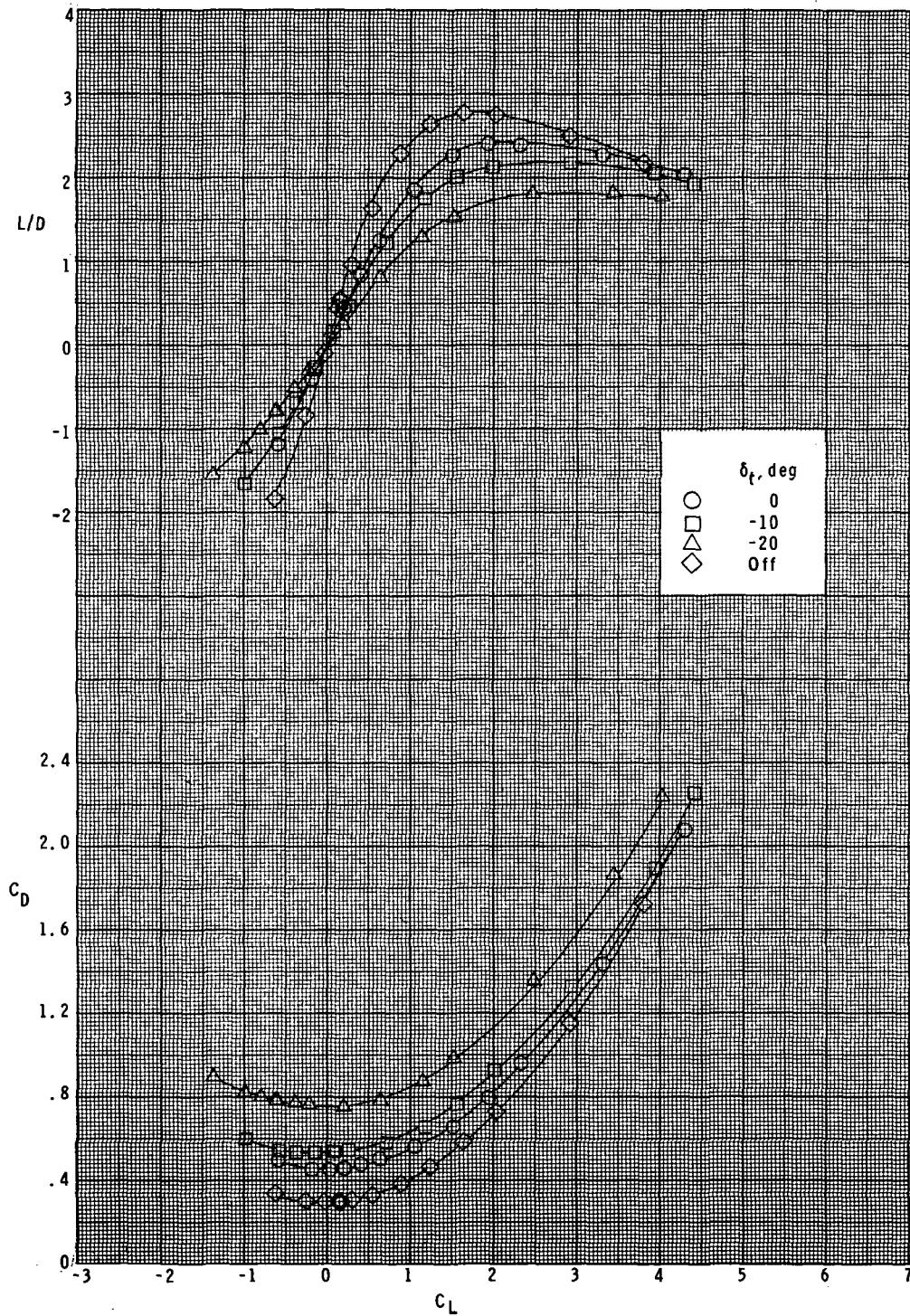
(c) $M = 2.36$.

Figure 8. - Continued.



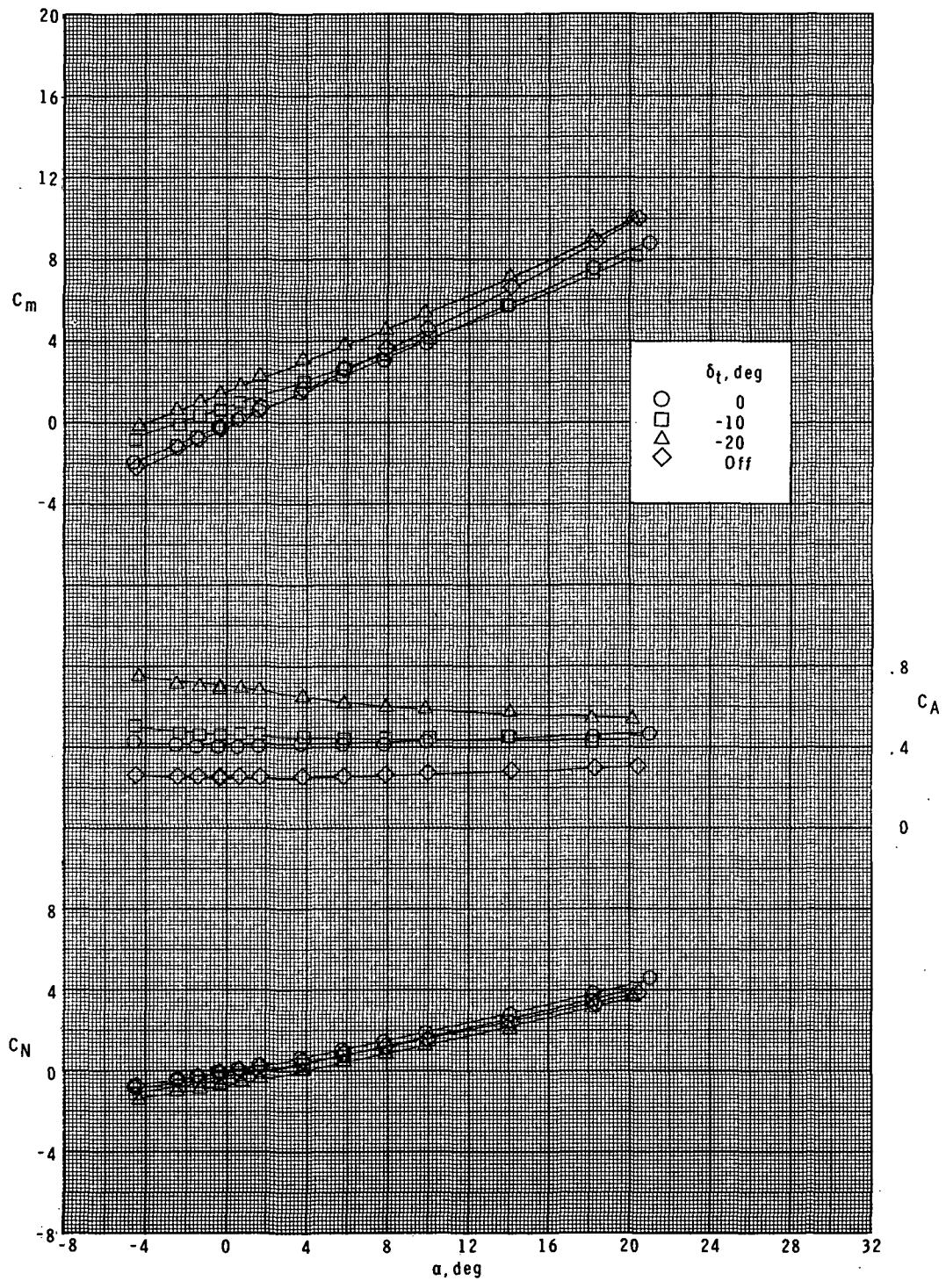
(c) Continued.

Figure 8.- Continued.



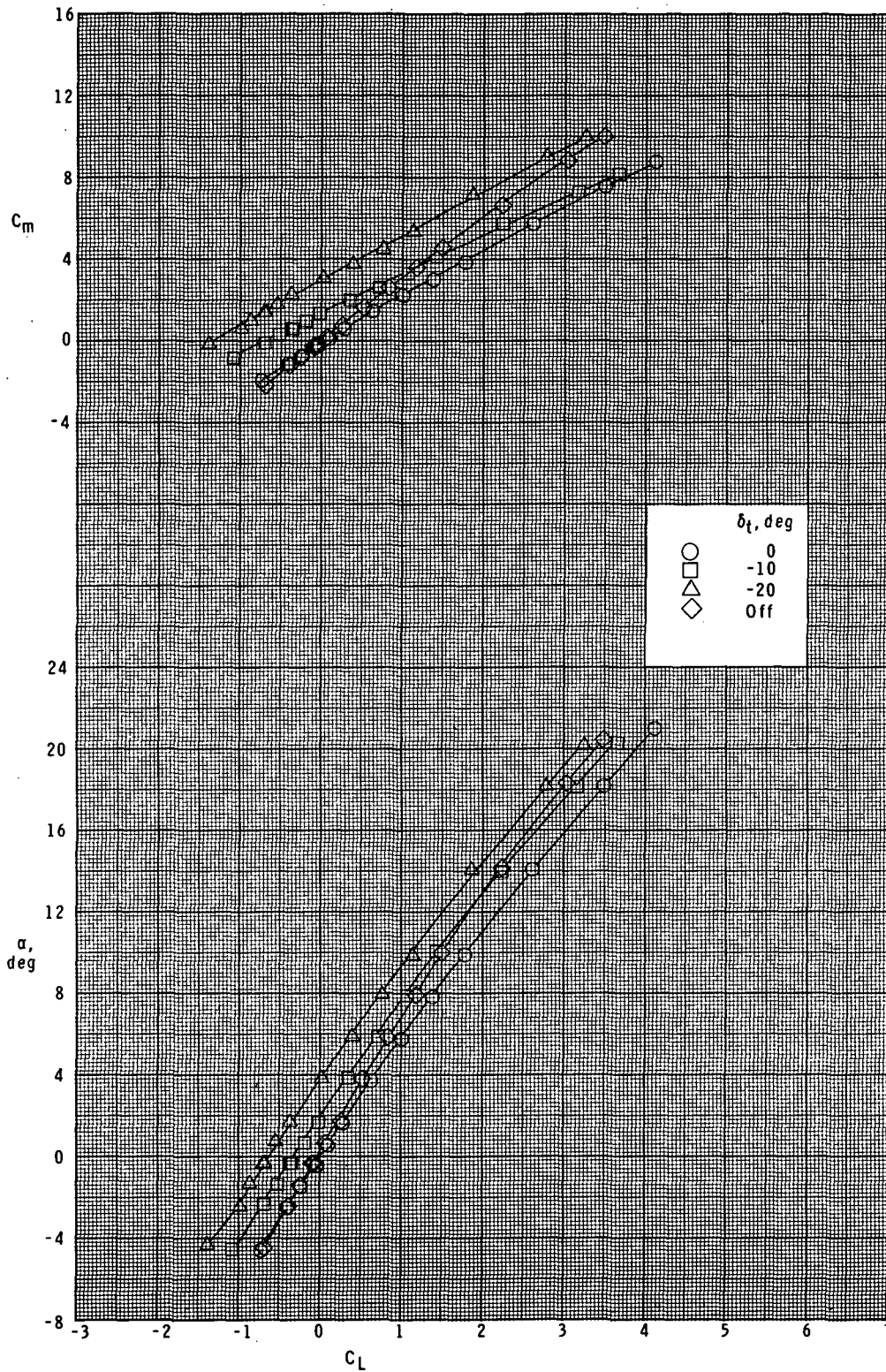
(c) Concluded.

Figure 8.- Continued.



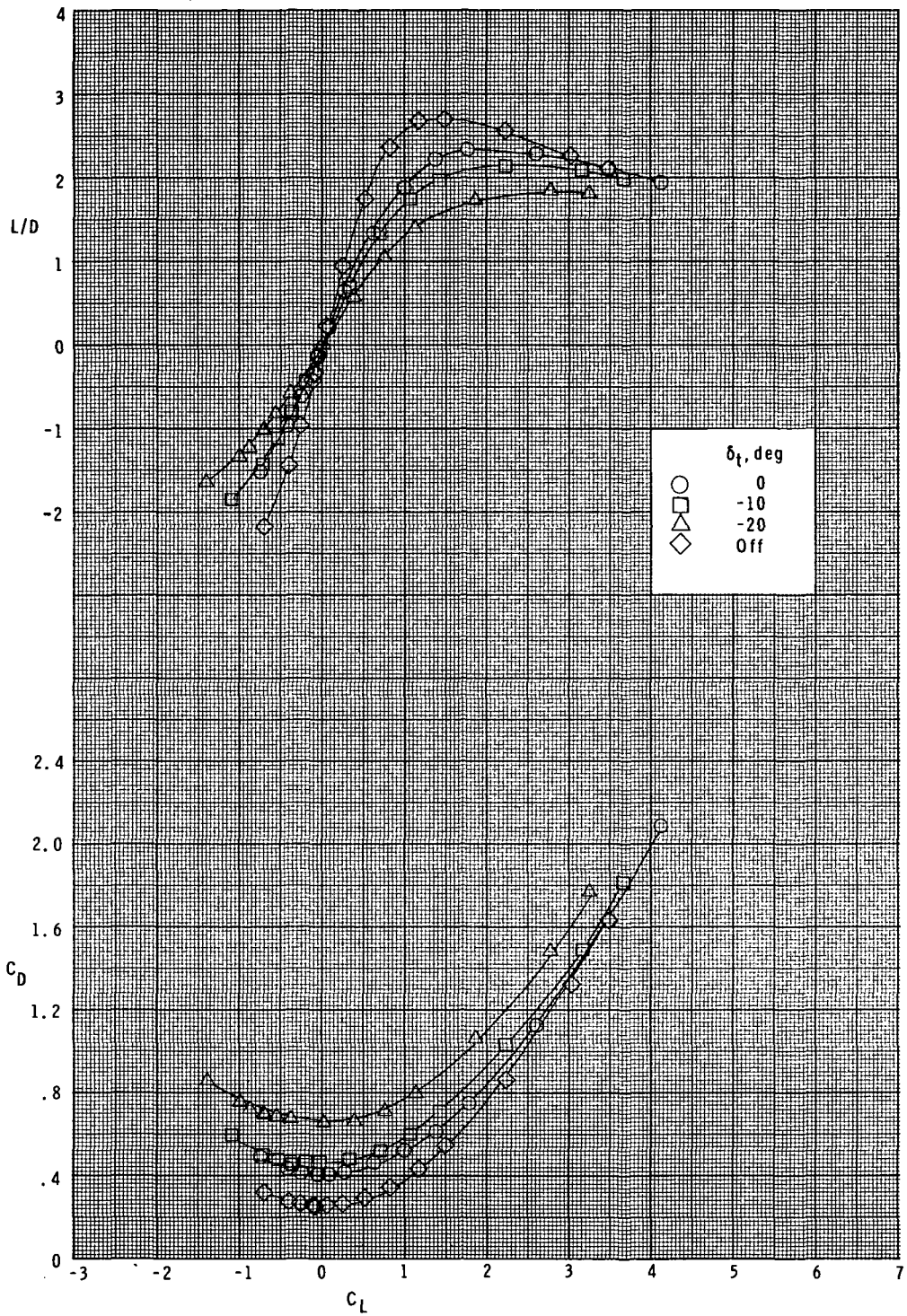
(d) $M = 2.86$.

Figure 8.- Continued.



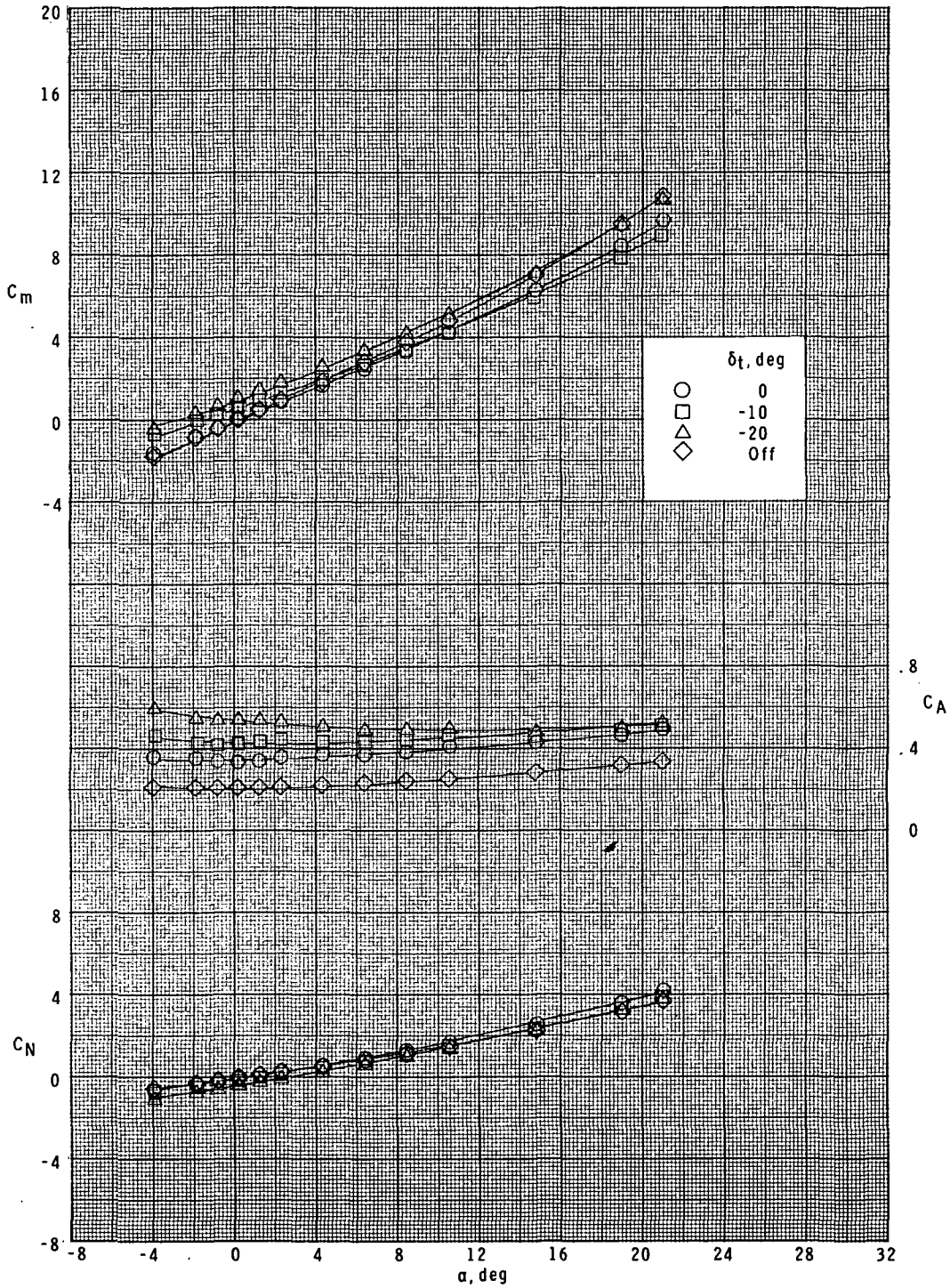
(d) Continued.

Figure 8.- Continued.



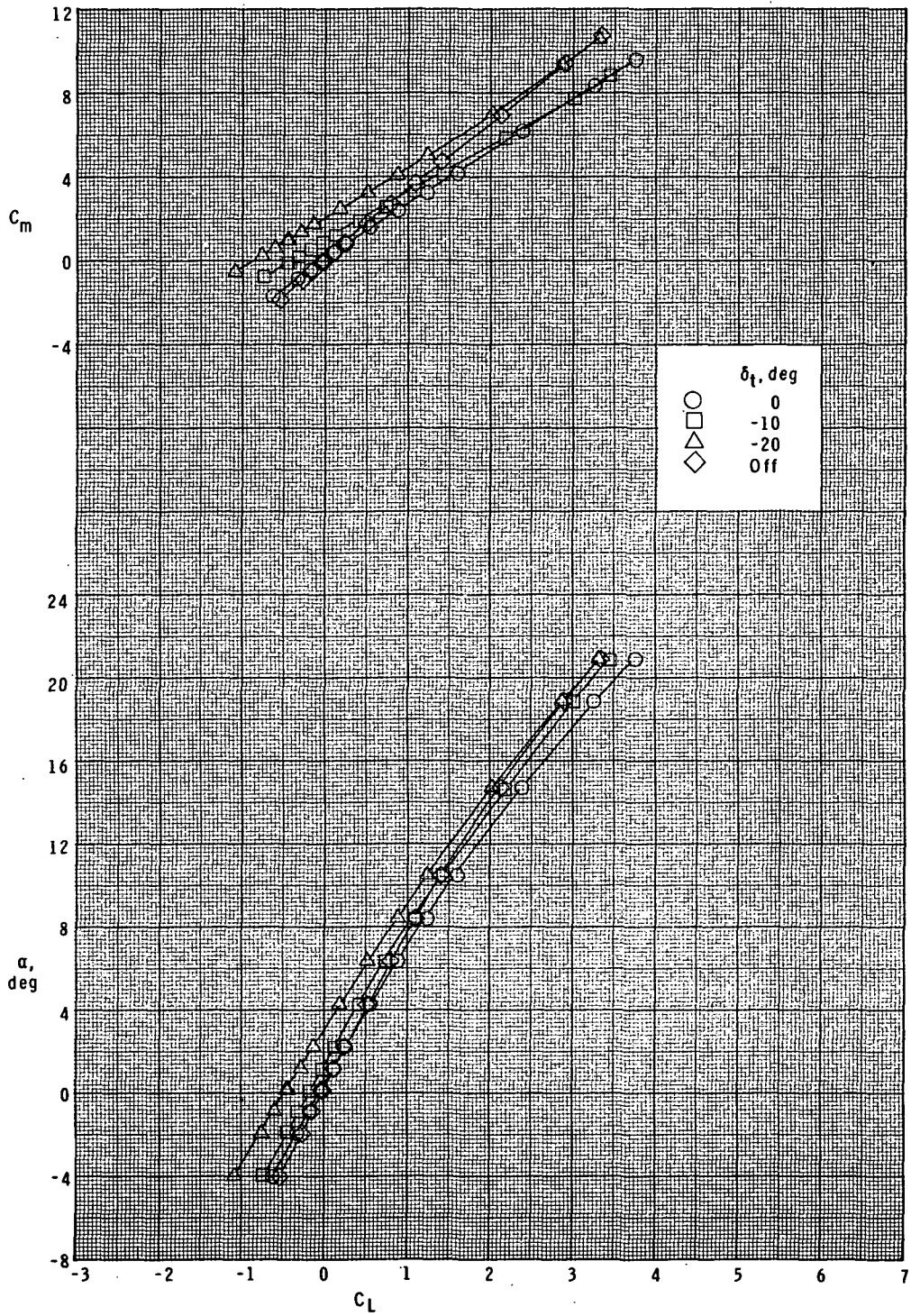
(d) Concluded.

Figure 8.- Continued.



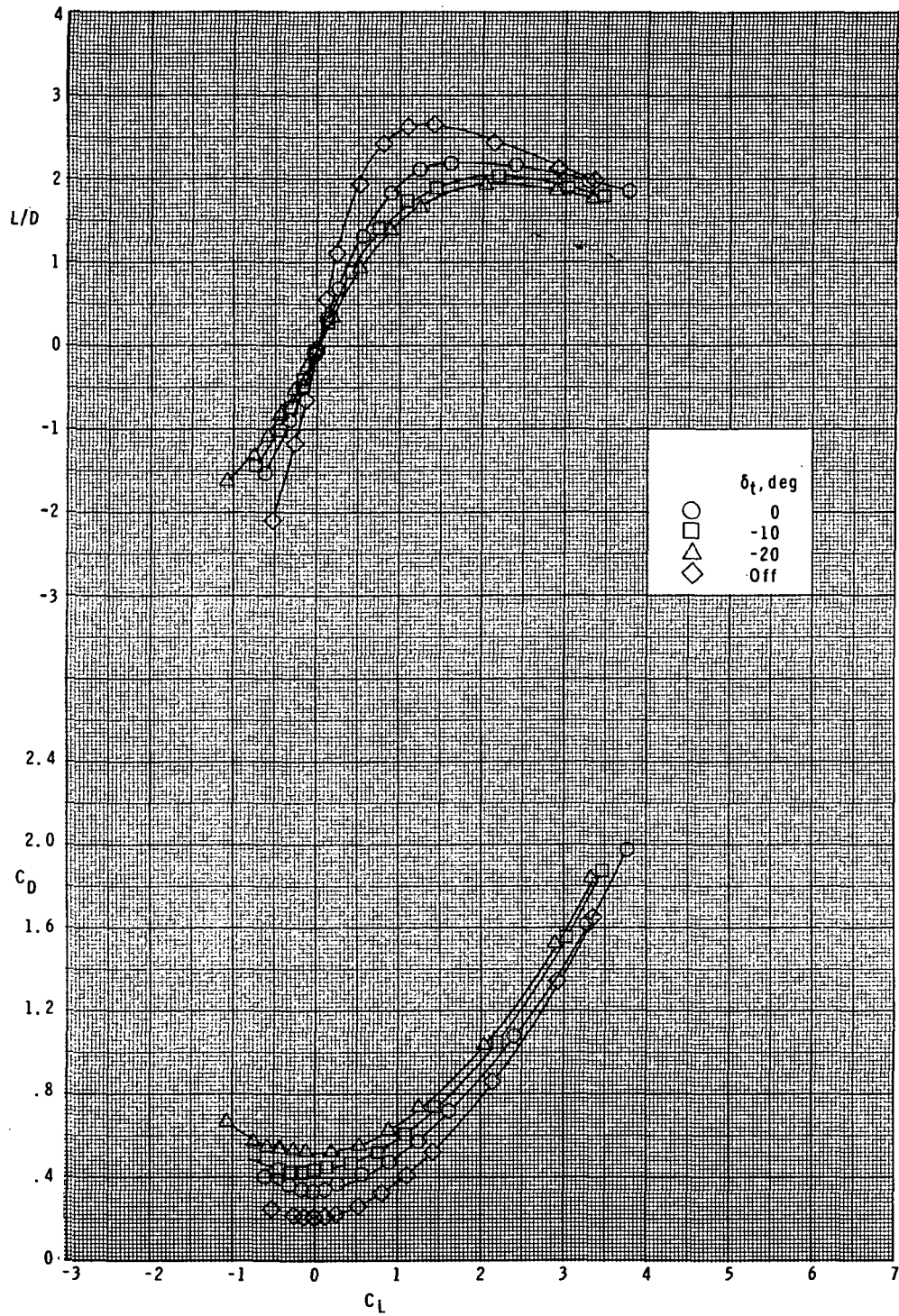
(e) $M = 3.95$.

Figure 8. - Continued.



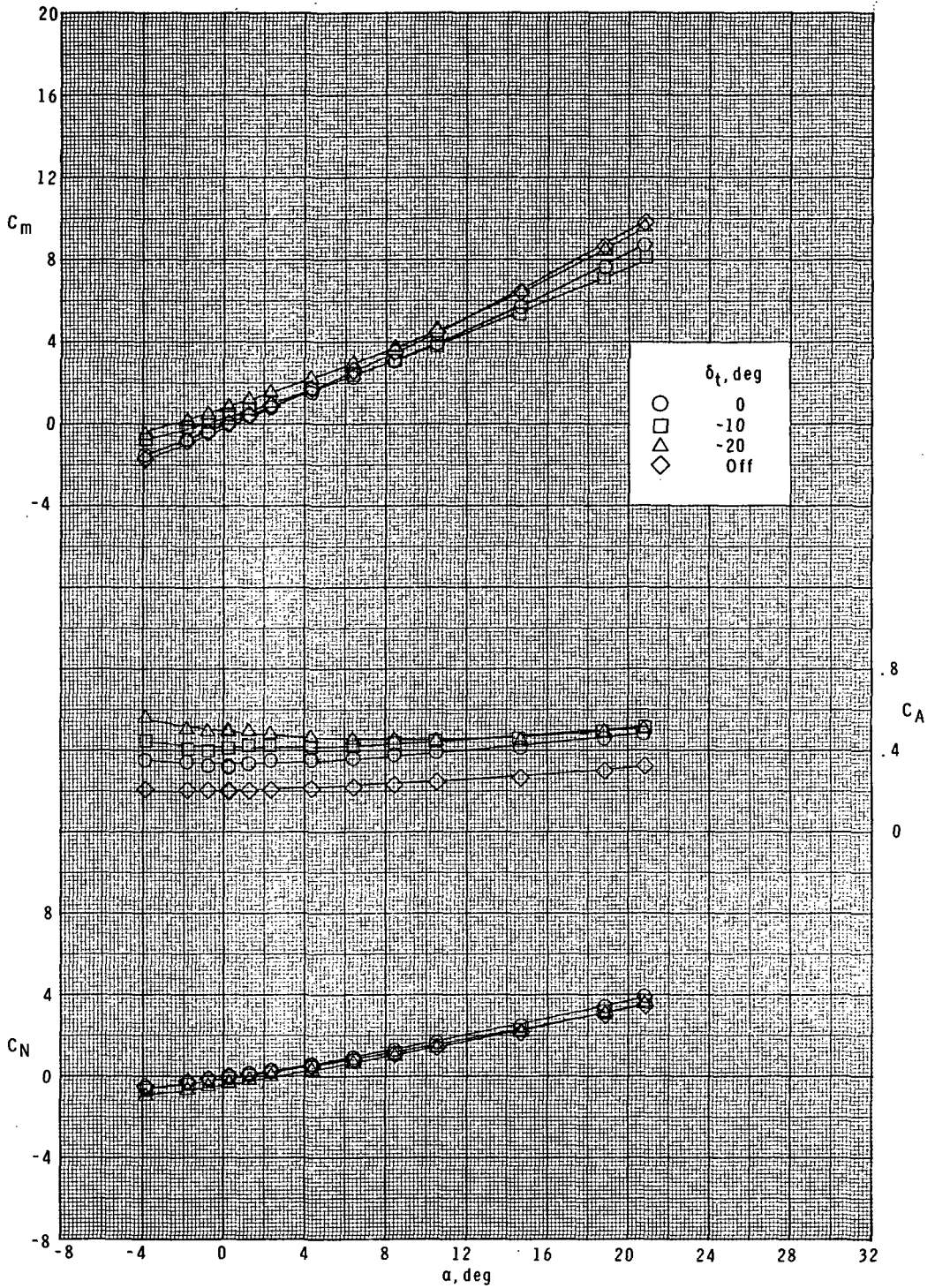
(e) Continued.

Figure 8. - Continued.



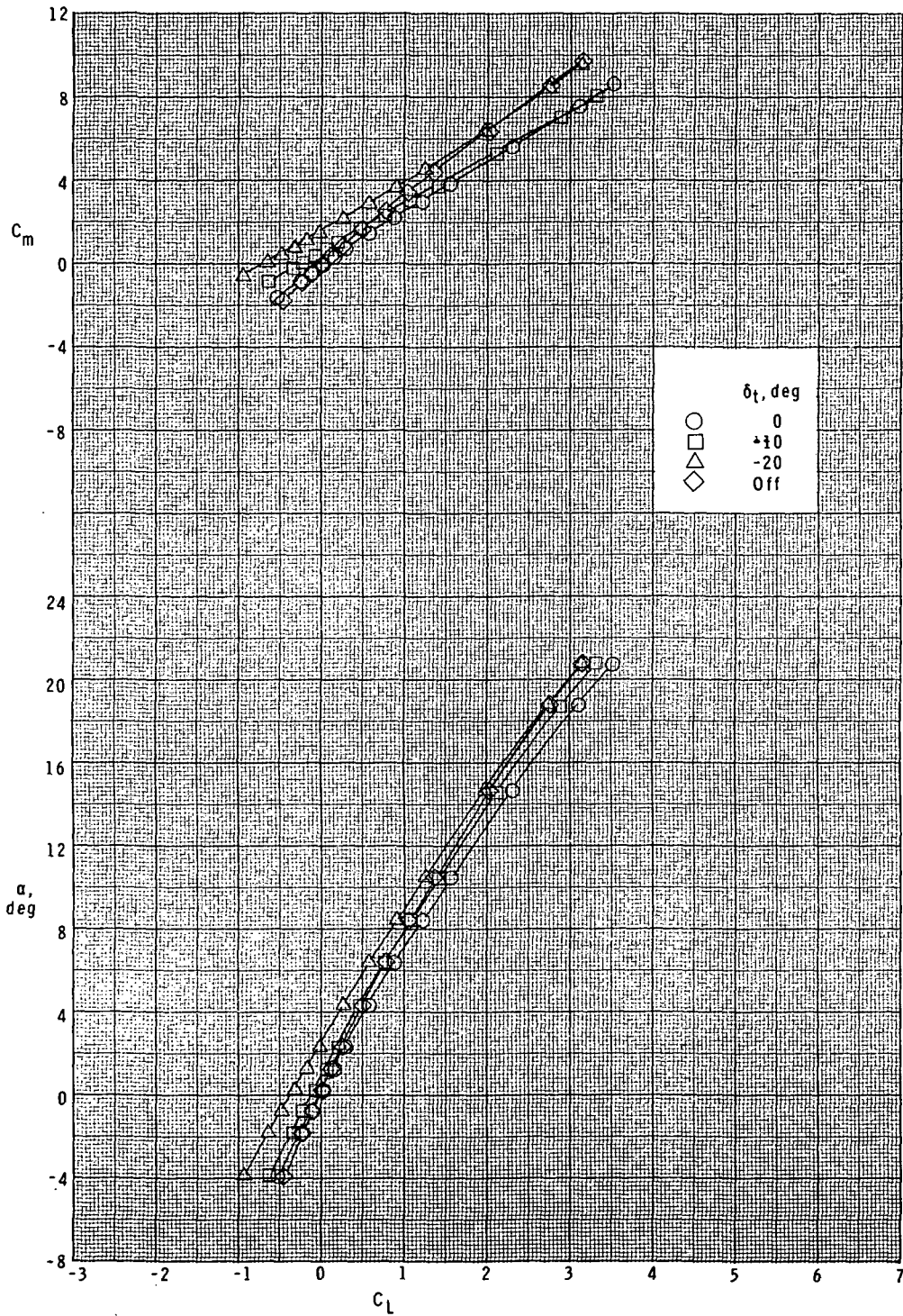
(e) Concluded.

Figure 8. - Continued.



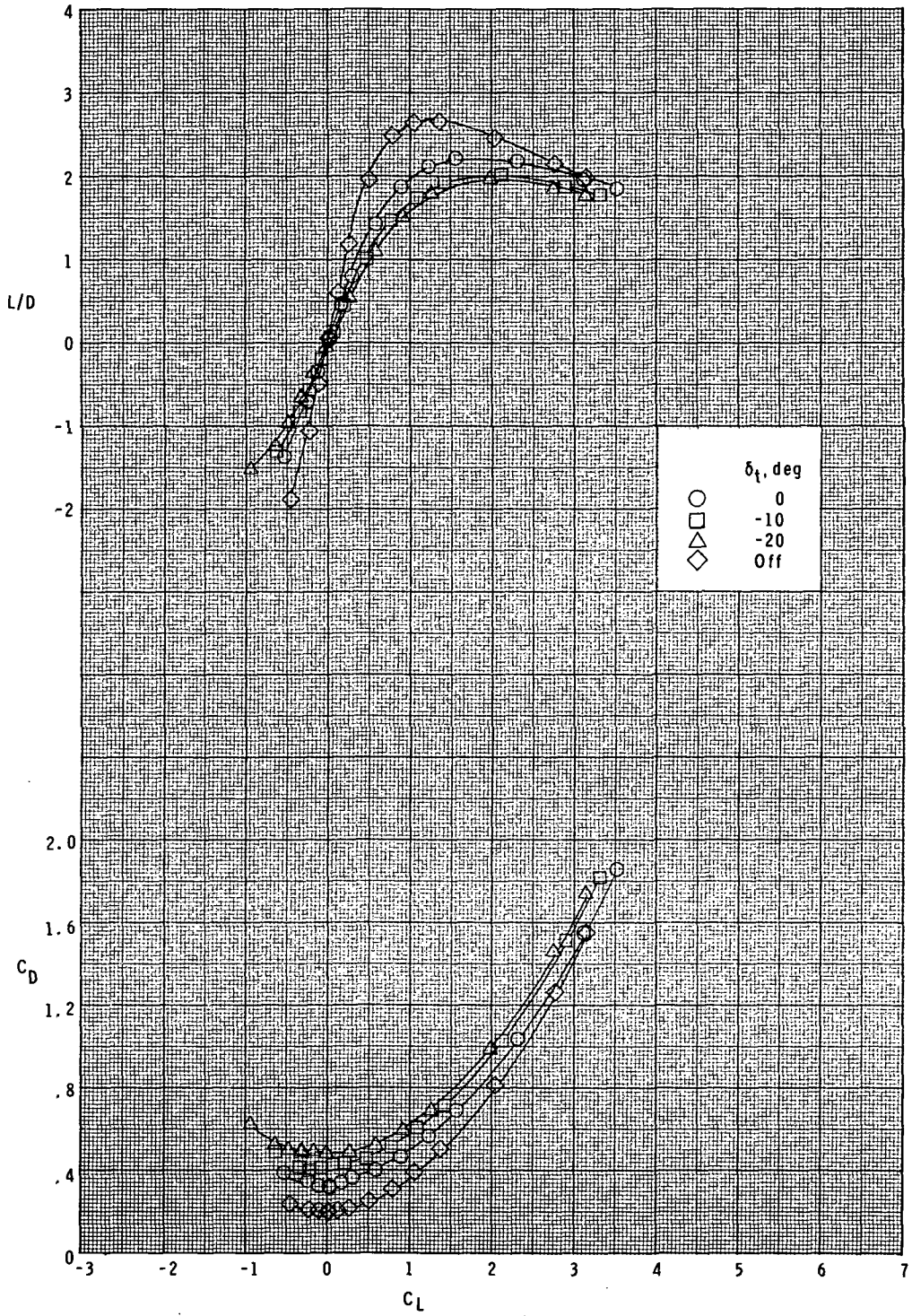
(f) $M = 4.63$.

Figure 8.- Continued.



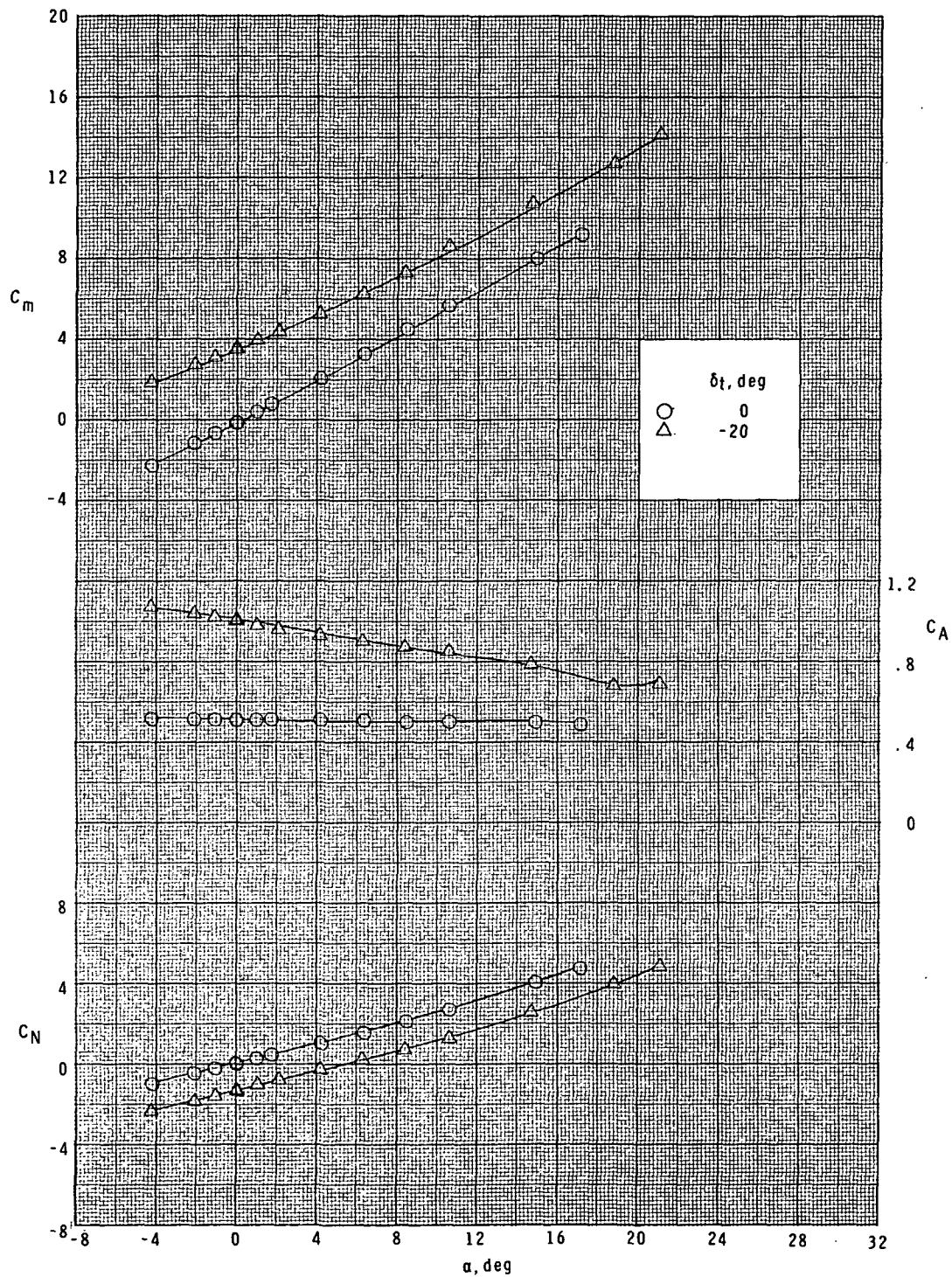
(f) Continued.

Figure 8. - Continued.



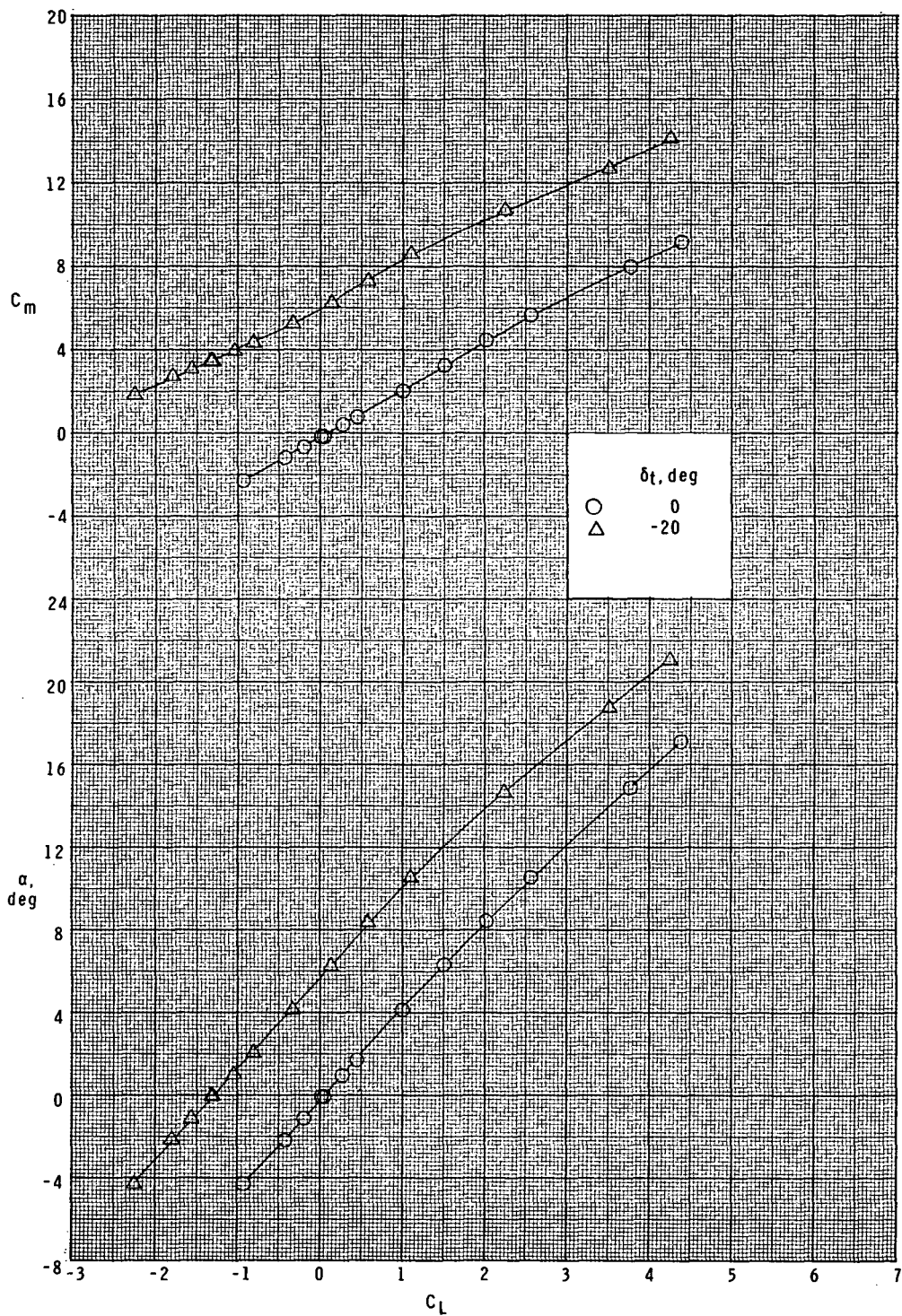
(f) Concluded.

Figure 8.- Concluded.



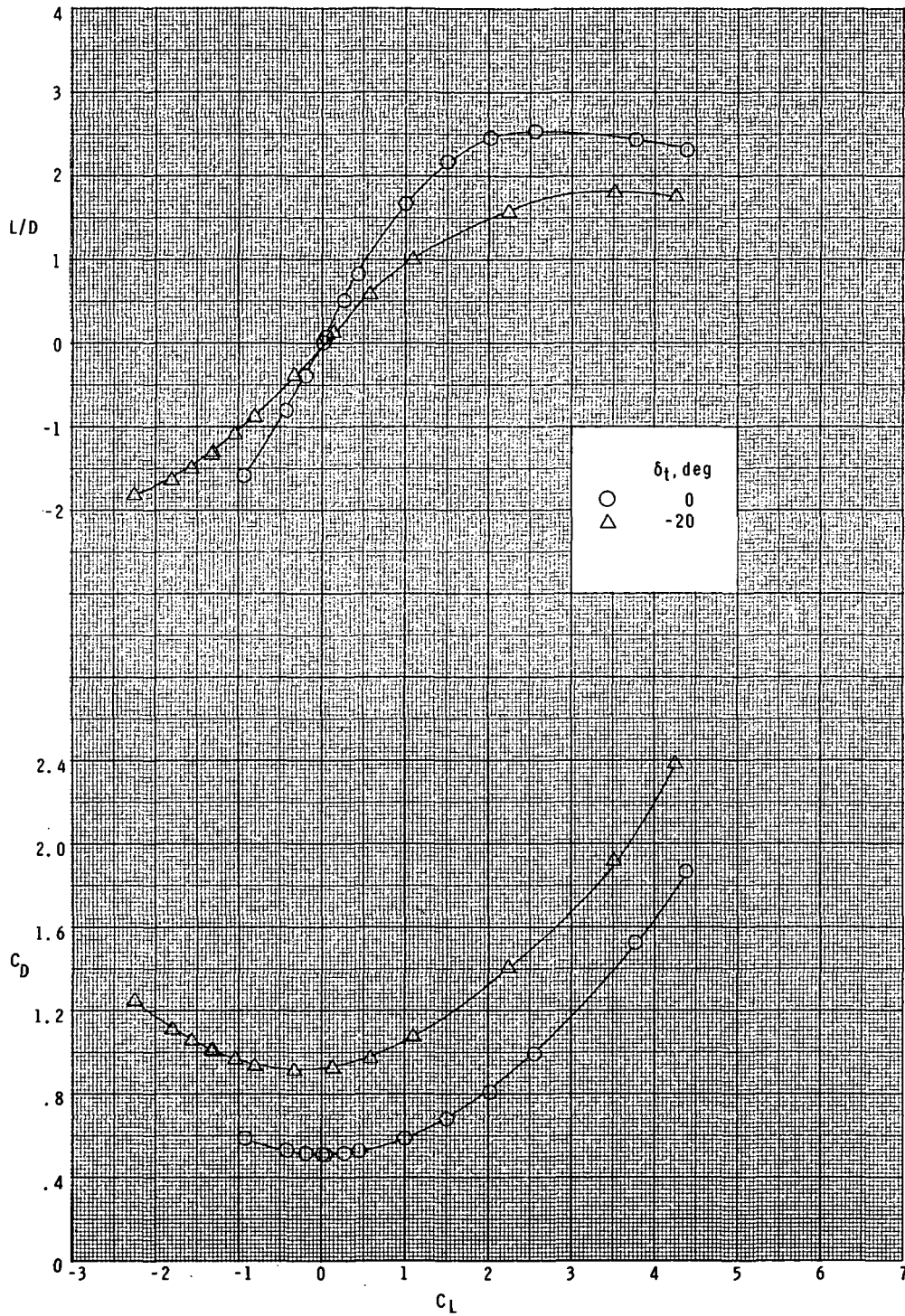
(a) $M = 1.50$.

Figure 9.- Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 0^\circ$; $\phi = 0^\circ$.



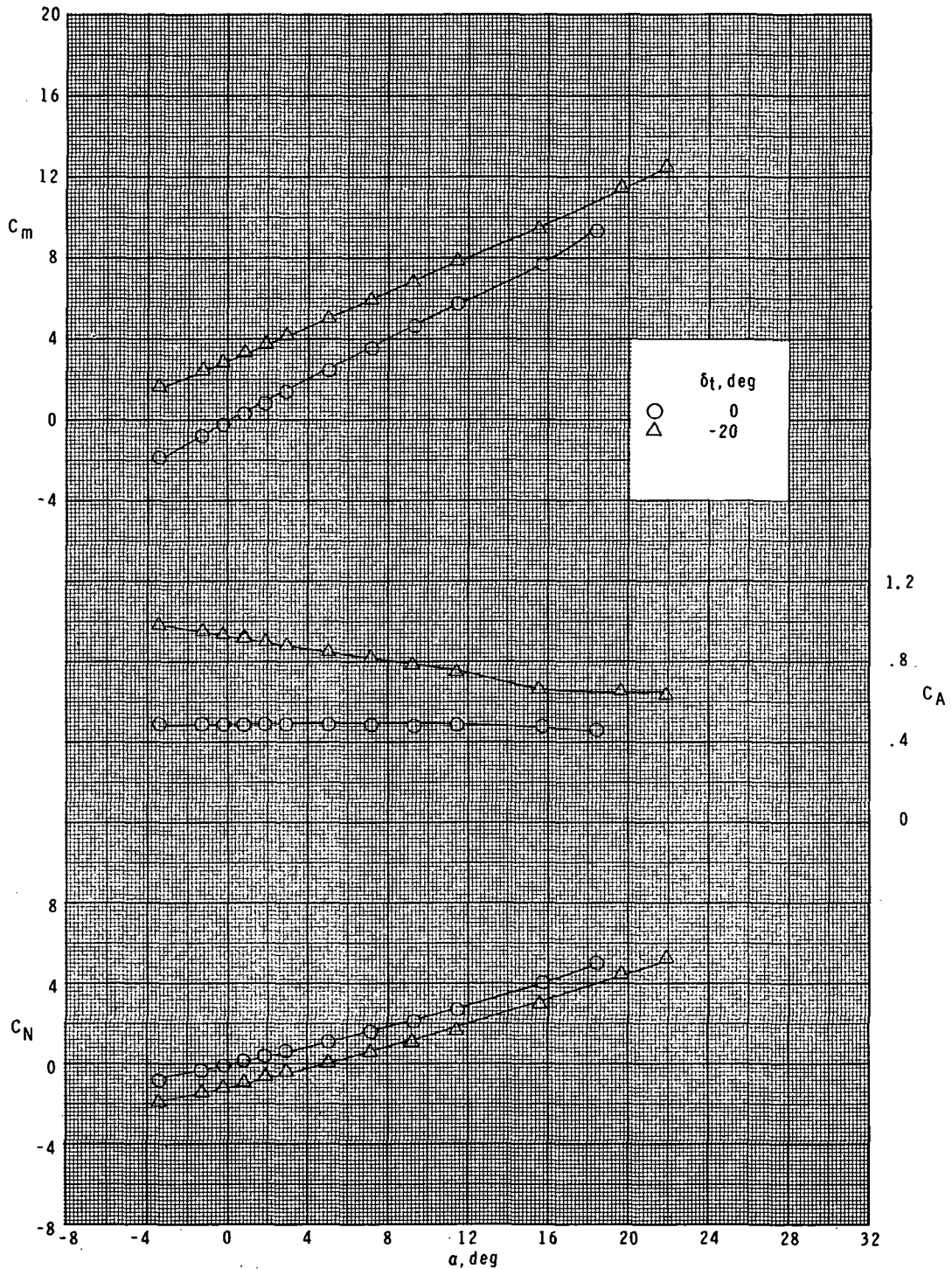
(a) Continued.

Figure 9. - Continued.



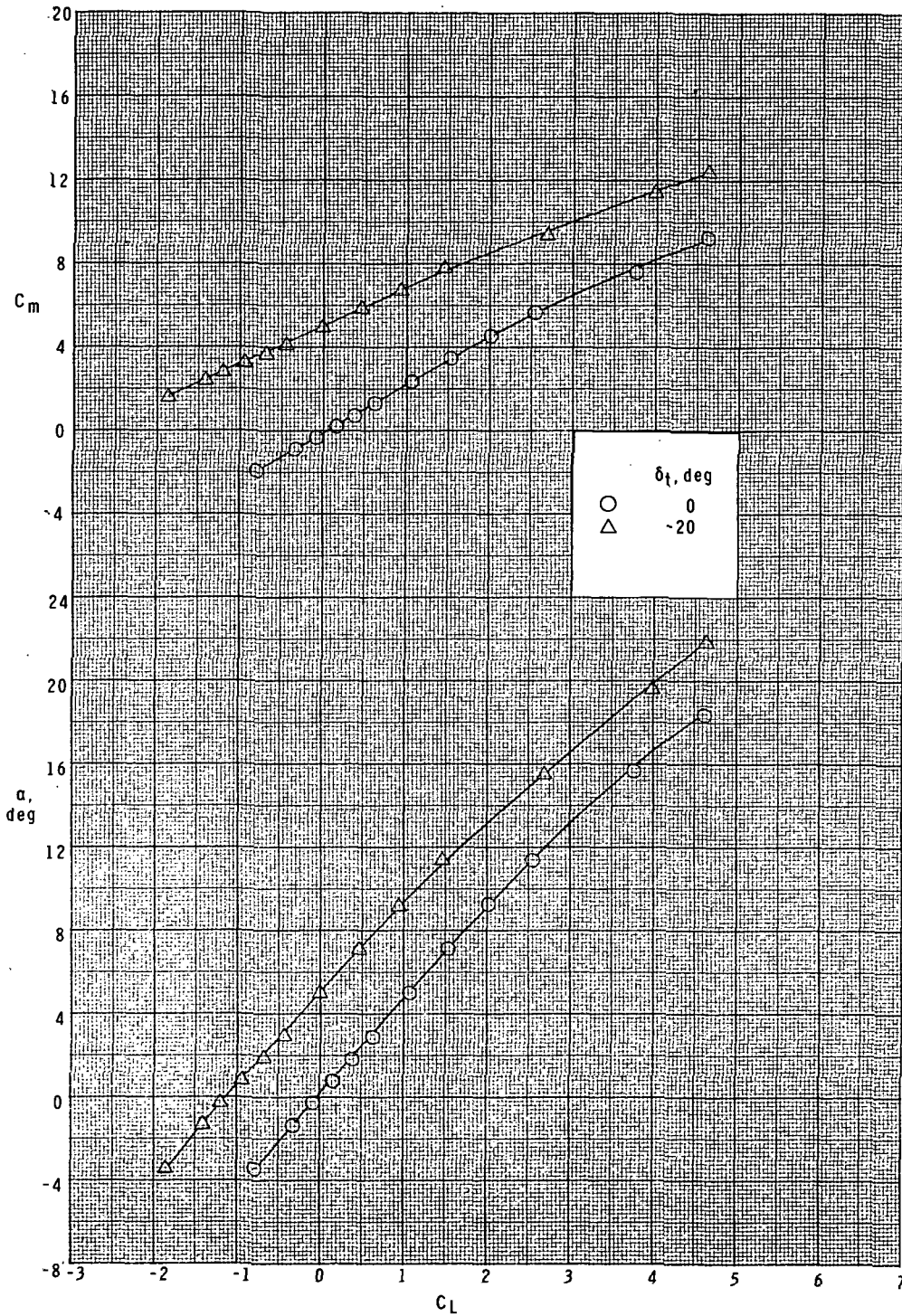
(a) Concluded.

Figure 9.- Continued.



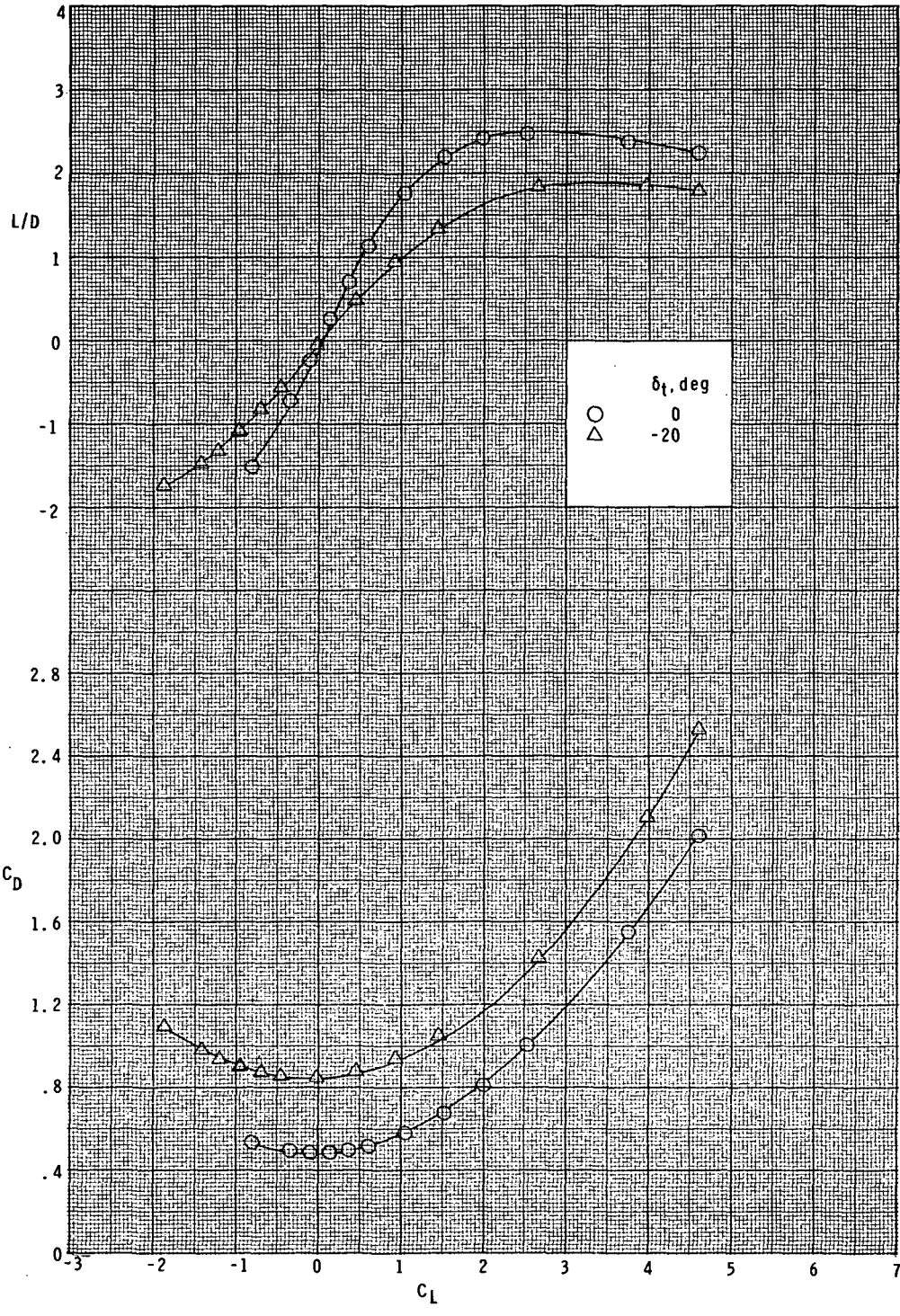
(b) $M = 1.90$.

Figure 9. - Continued.



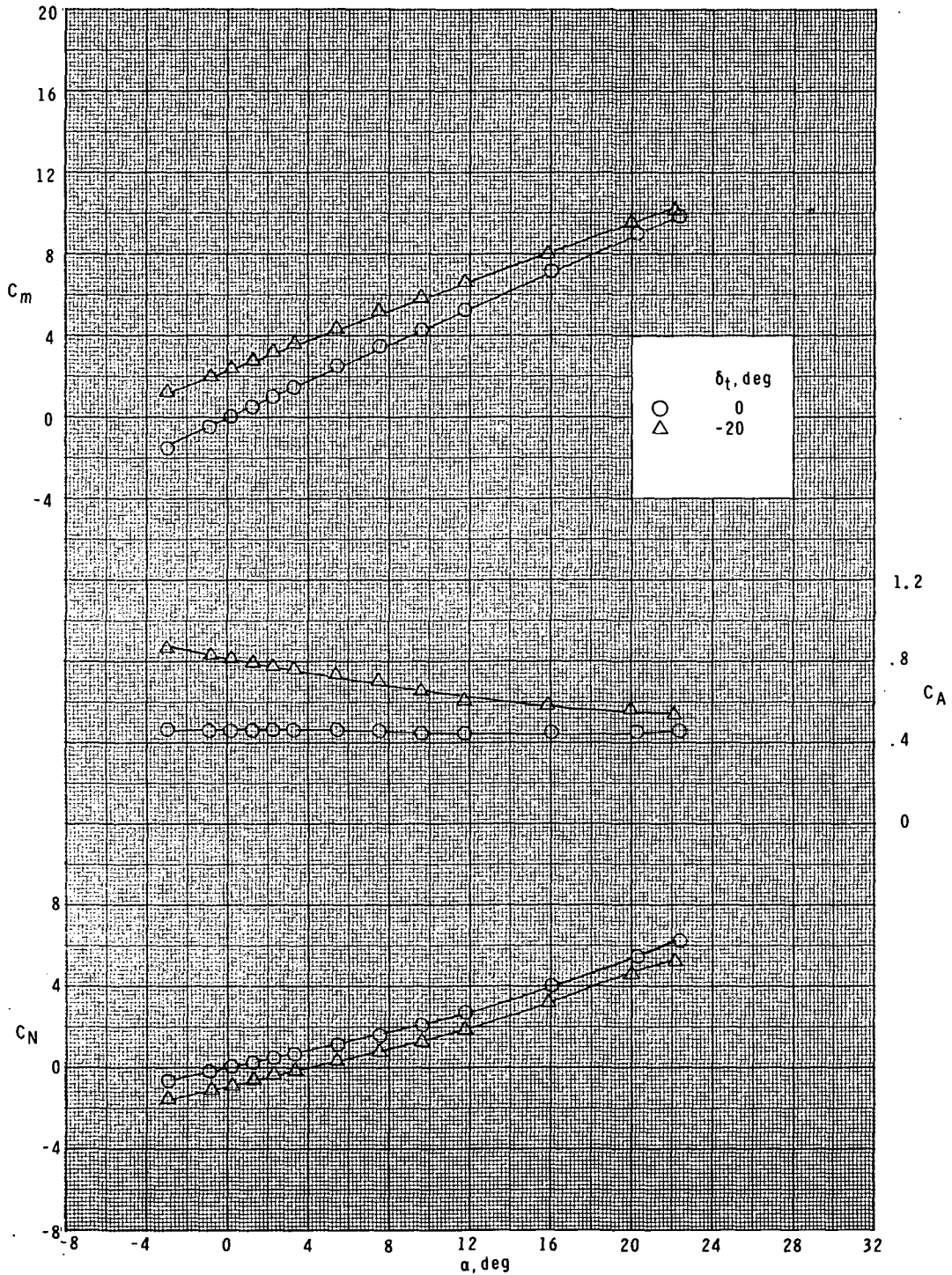
(b) Continued.

Figure 9.- Continued.



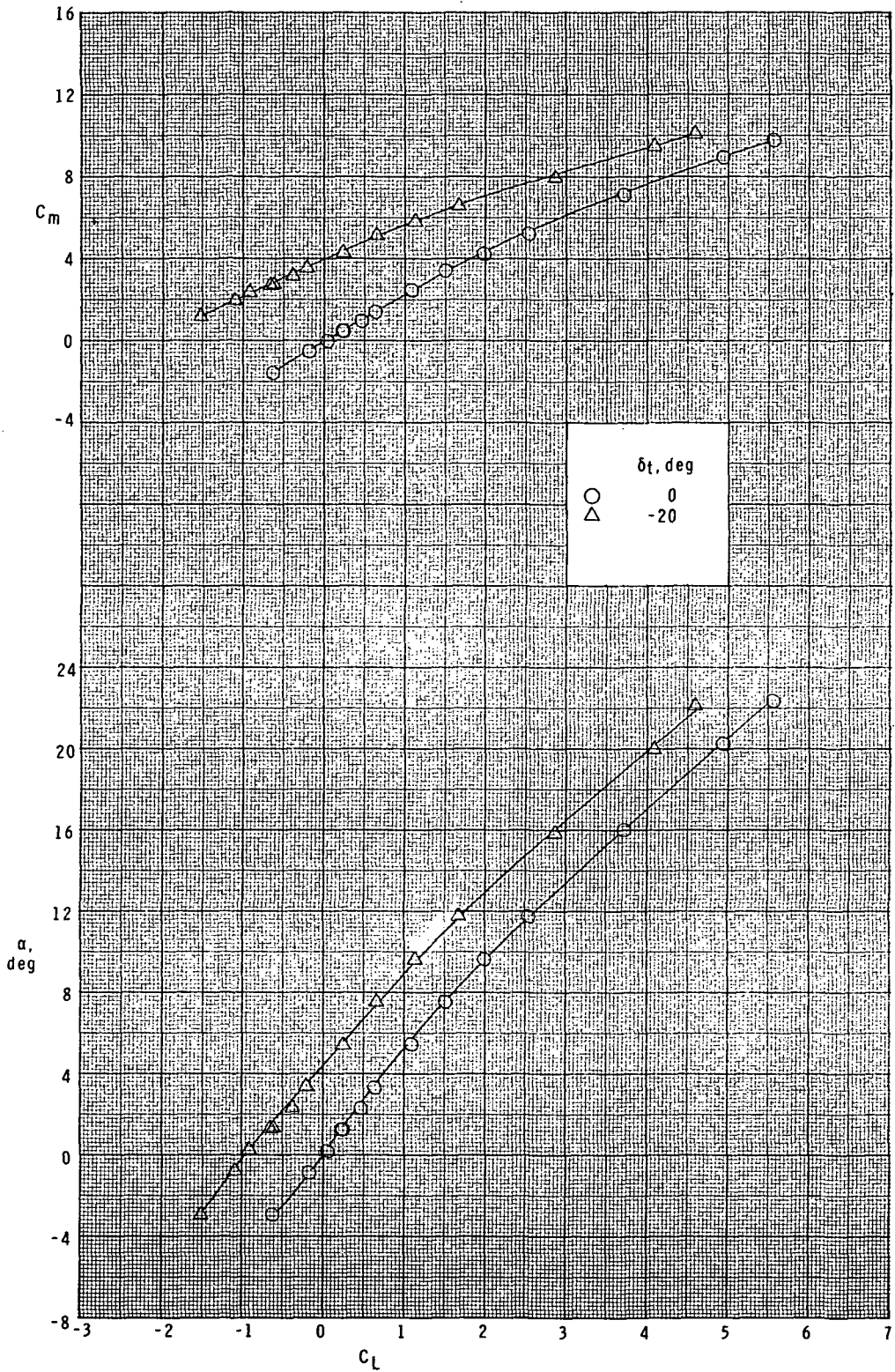
(b) Concluded.

Figure 9.- Continued.



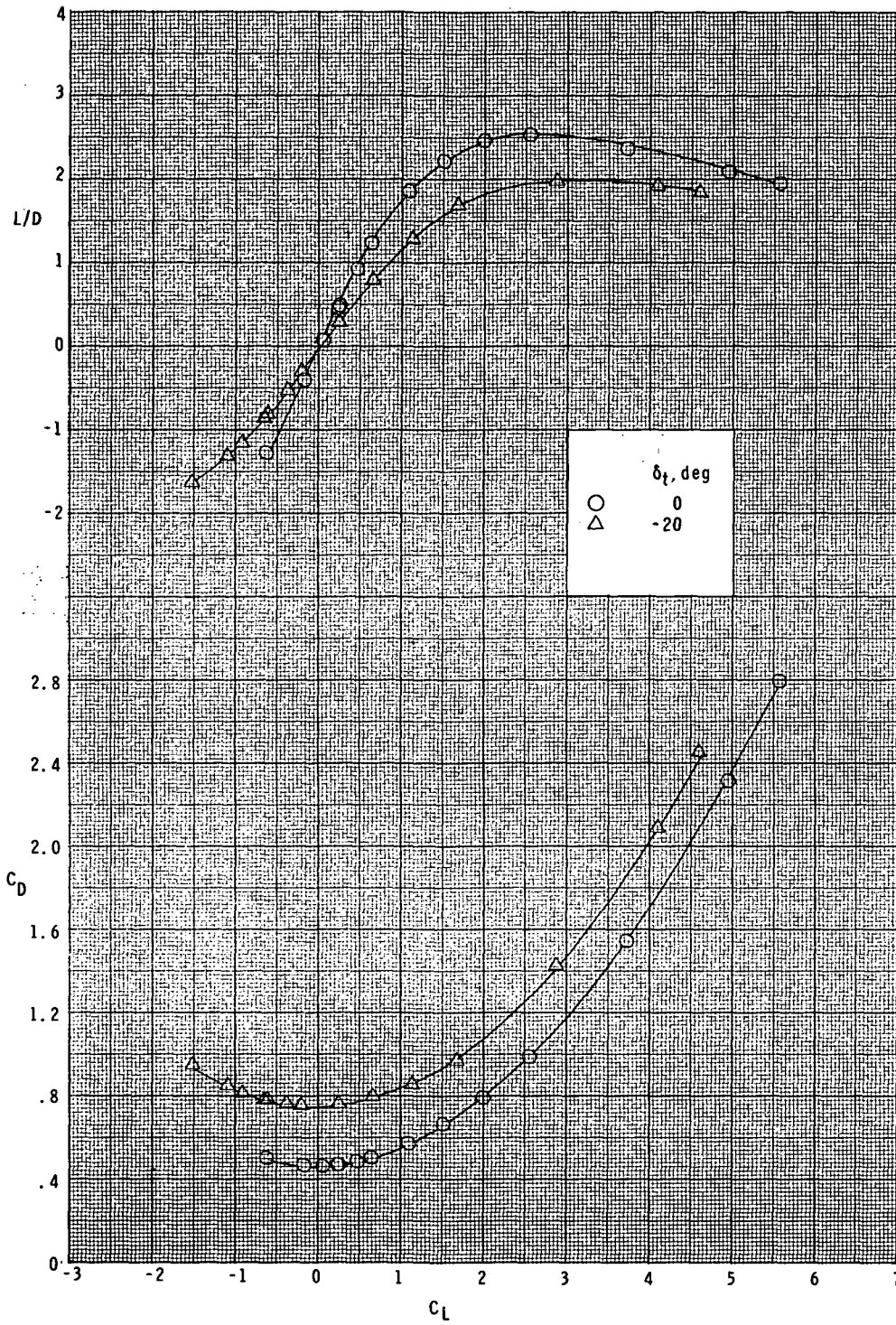
(c) $M = 2.36$.

Figure 9.- Continued.



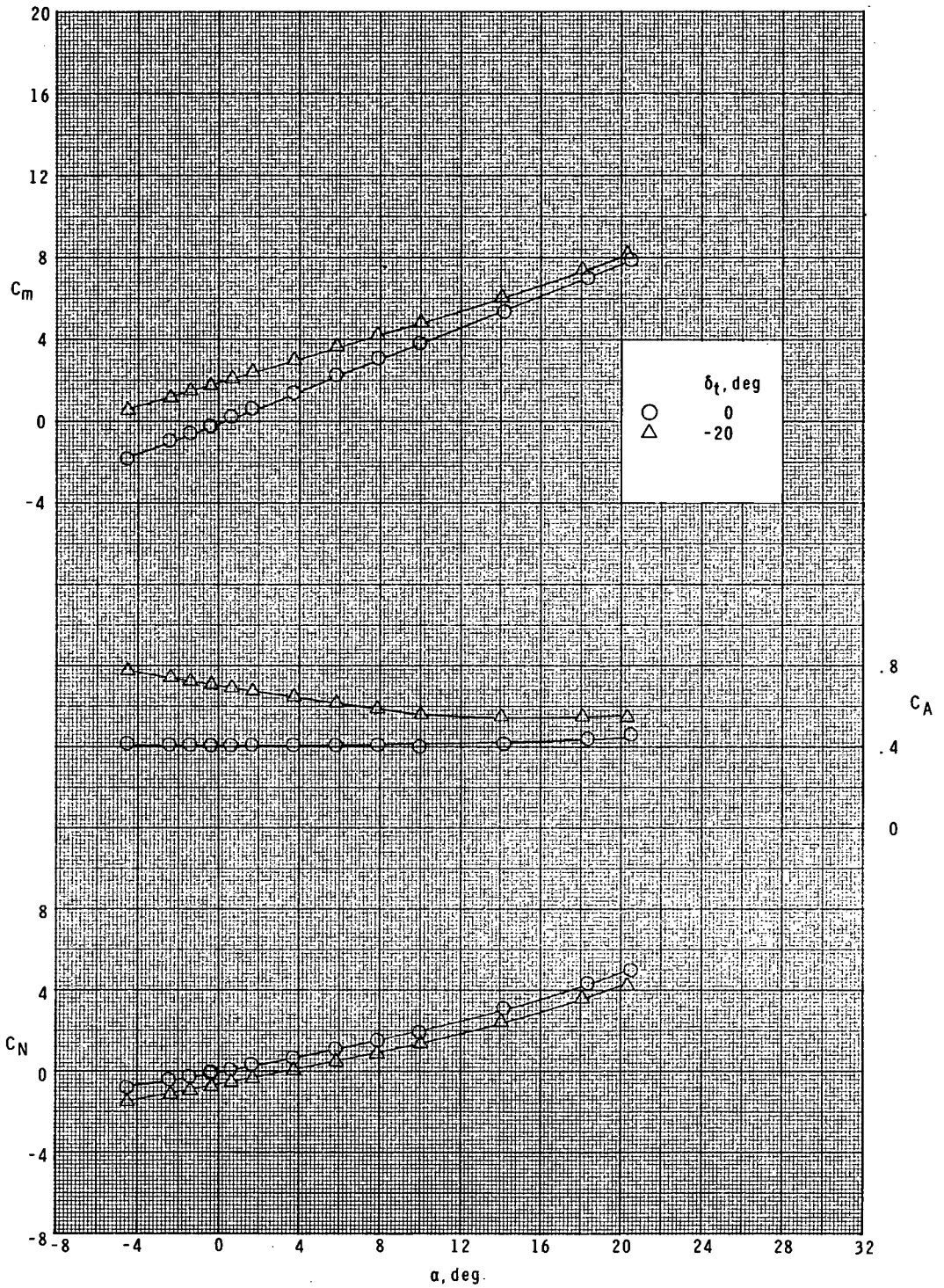
(c) Continued.

Figure 9.- Continued.



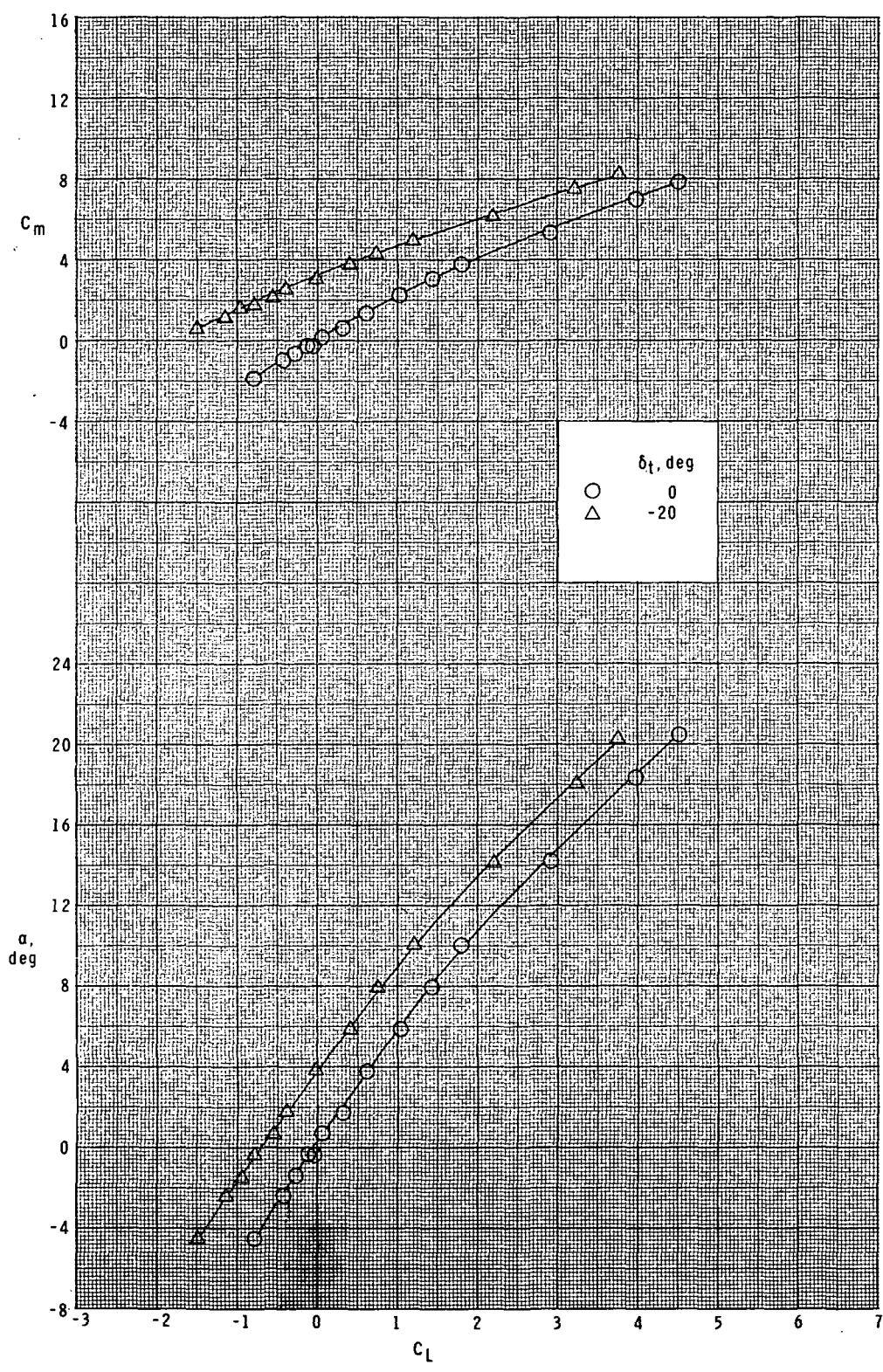
(c) Concluded.

Figure 9.- Continued.



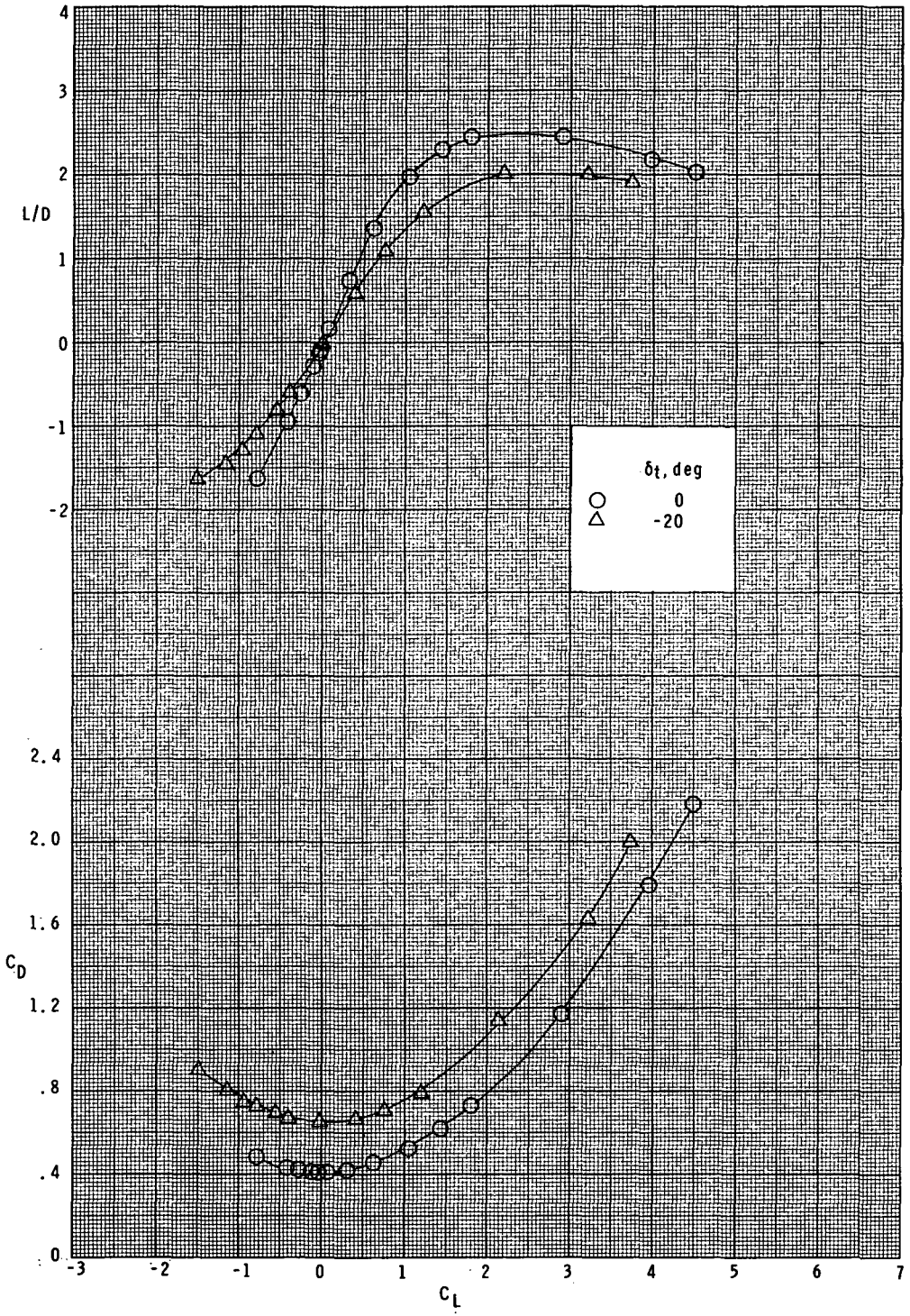
(d) $M = 2.86$.

Figure 9.- Continued.



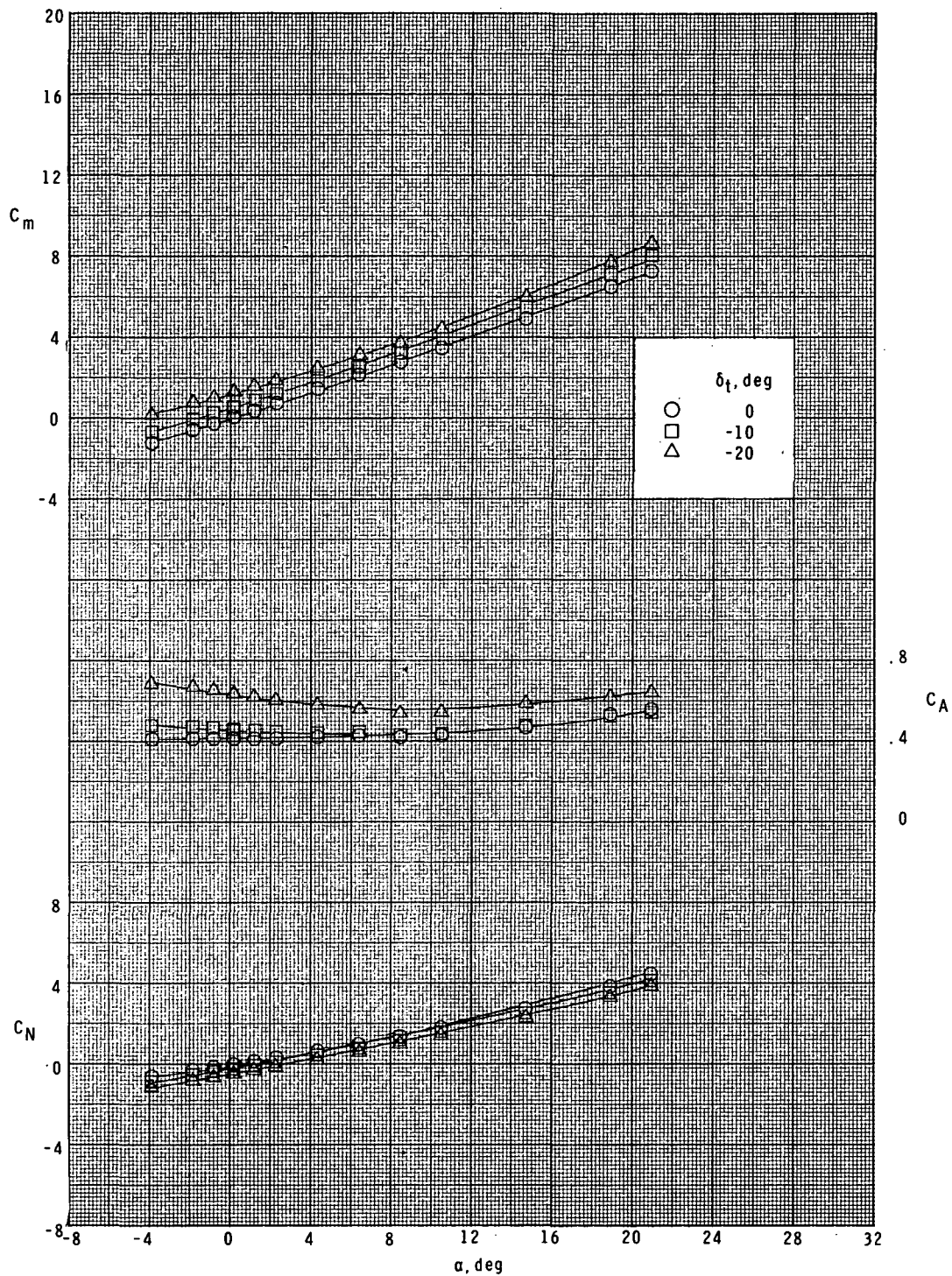
(d) Continued.

Figure 9.- Continued.



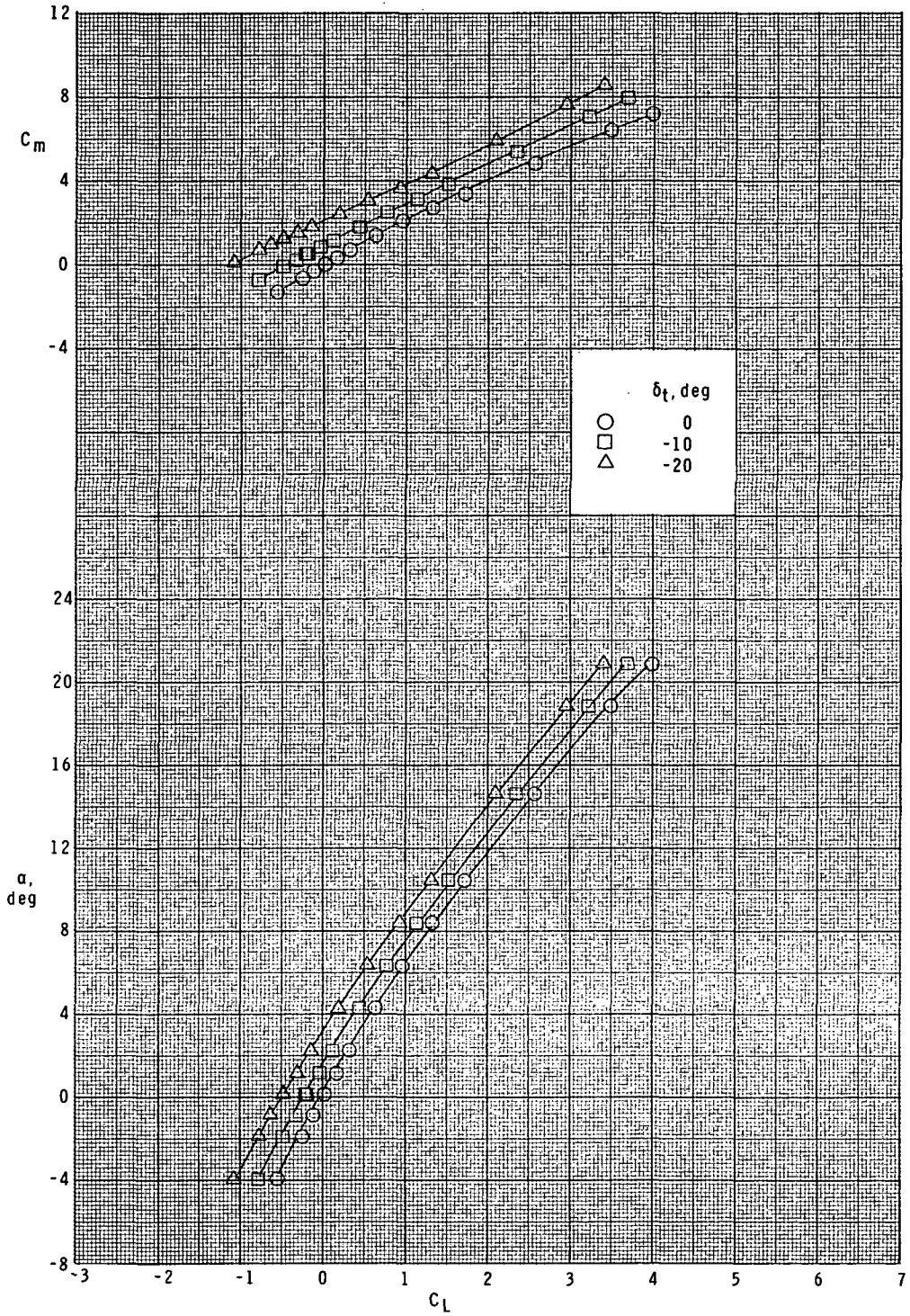
(d) Concluded.

Figure 9.- Continued.



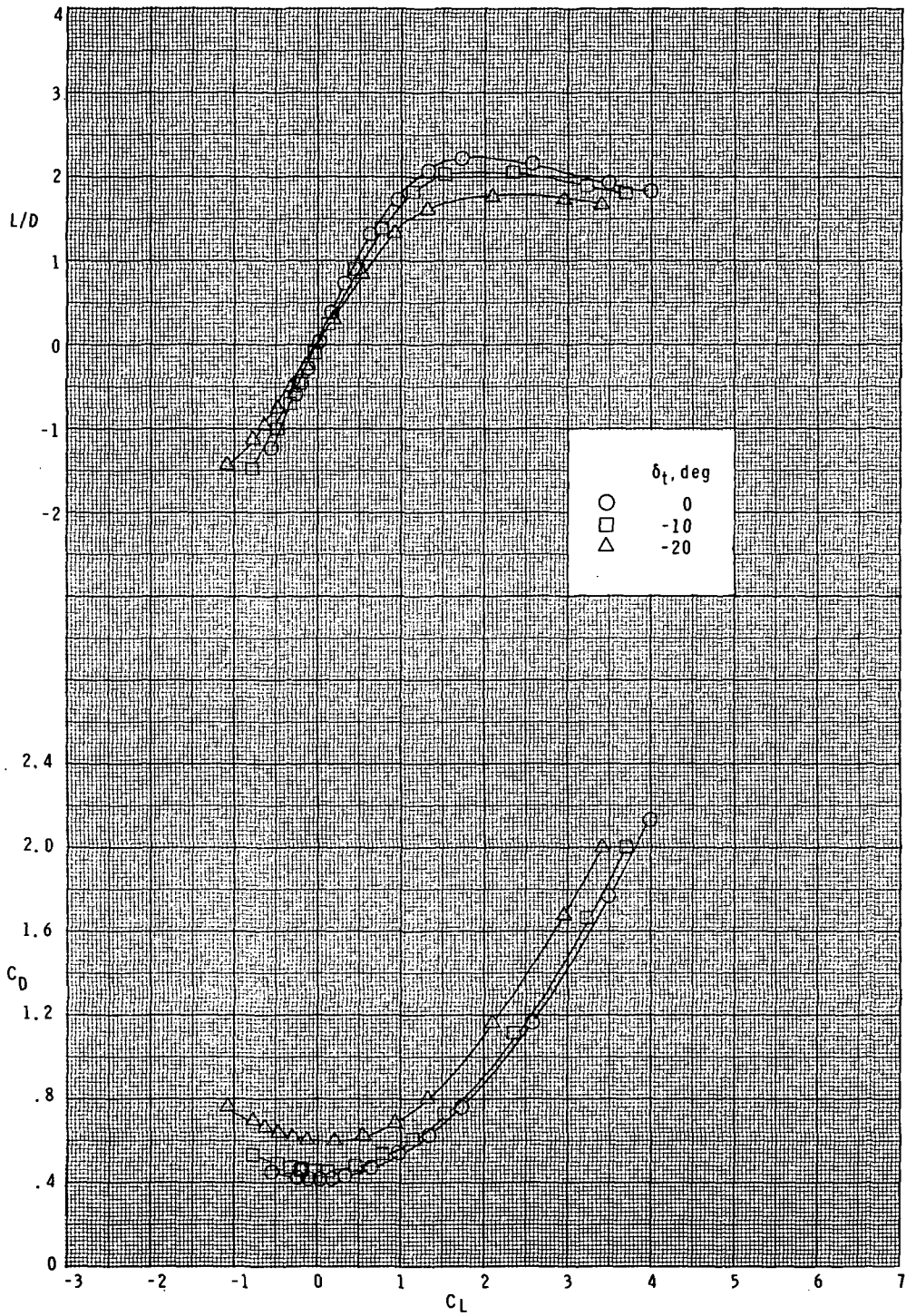
(e) $M = 3.95$.

Figure 9. - Continued.



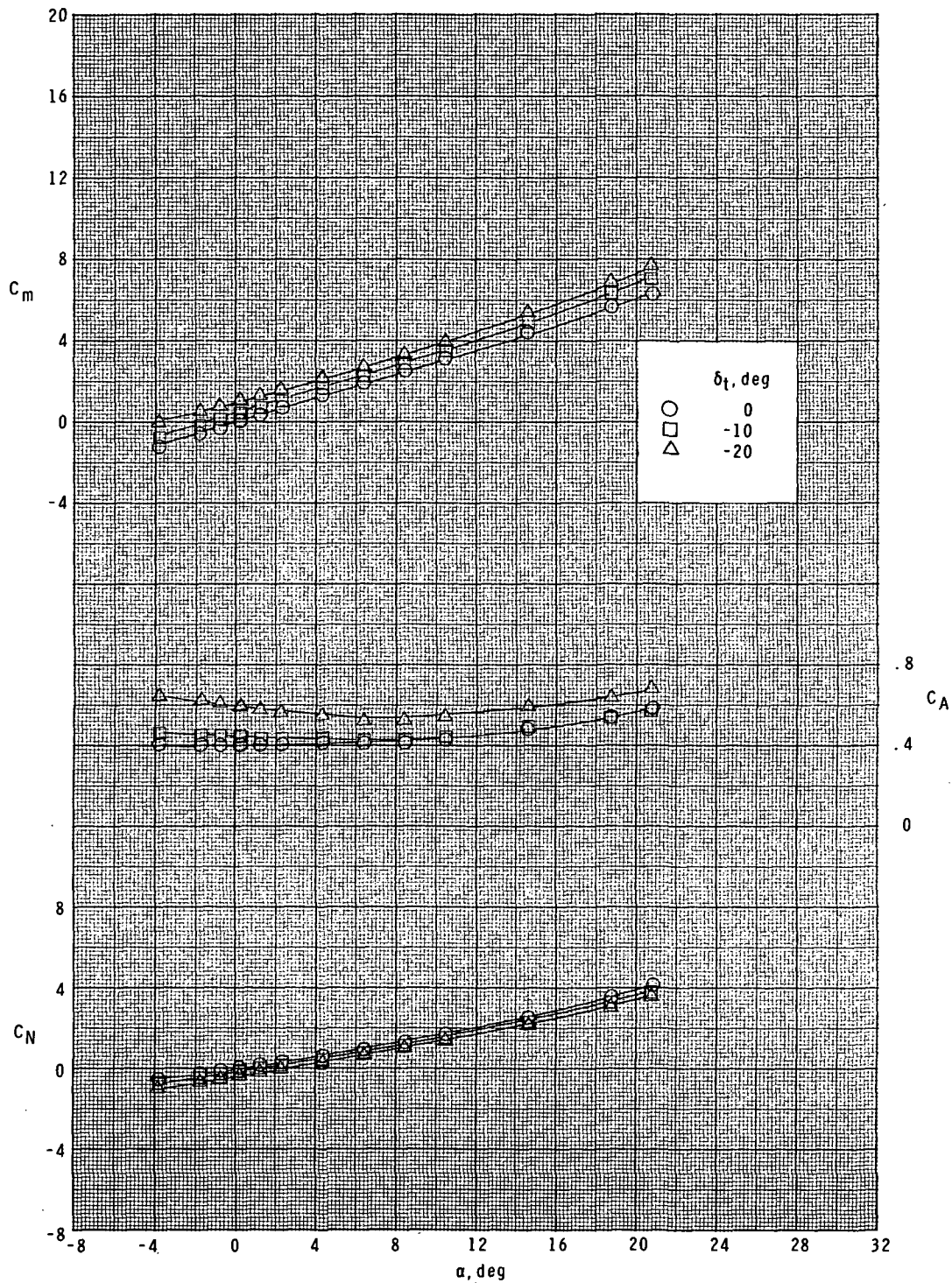
(e) Continued.

Figure 9. - Continued.



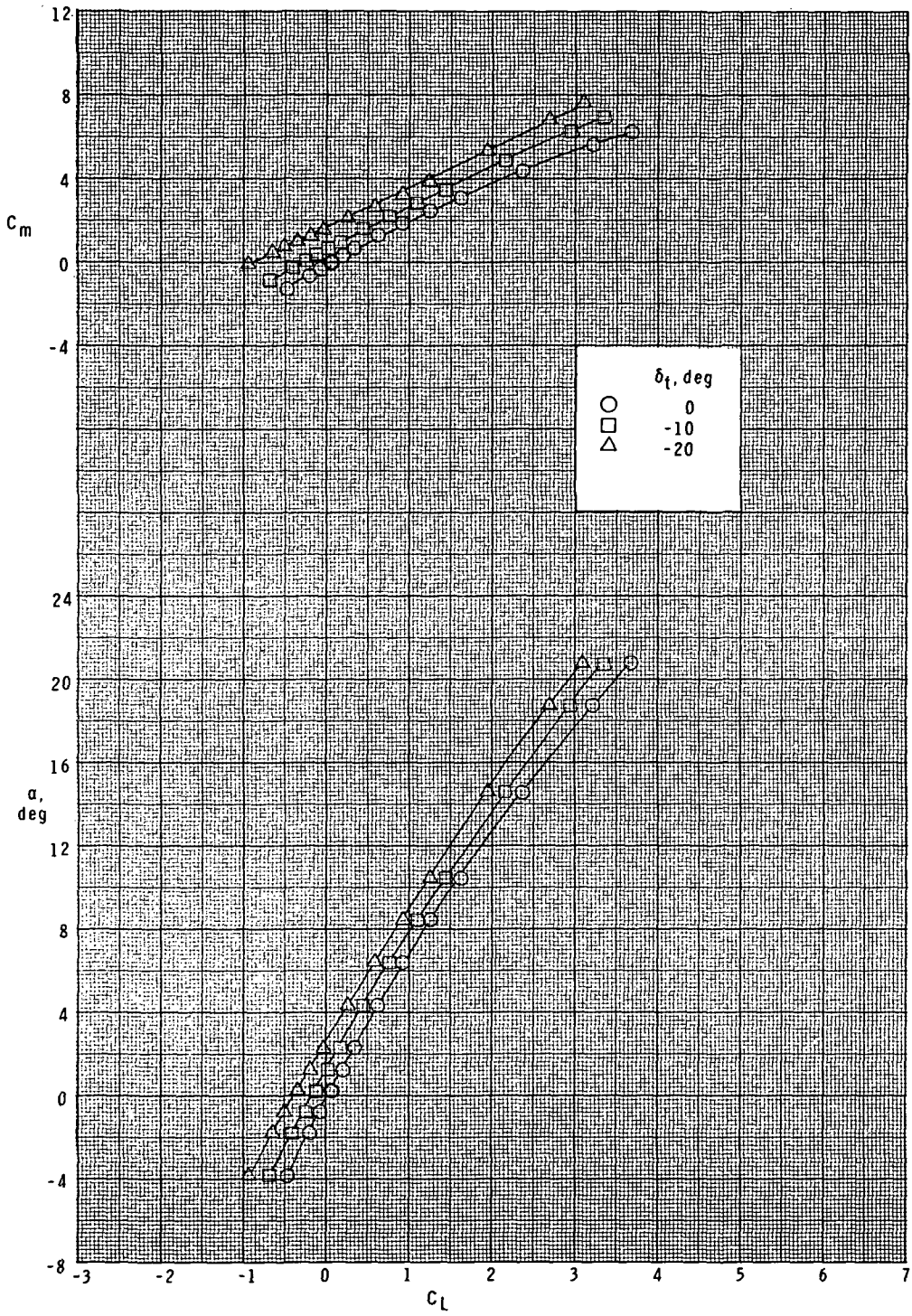
(e) Concluded.

Figure 9. - Continued.



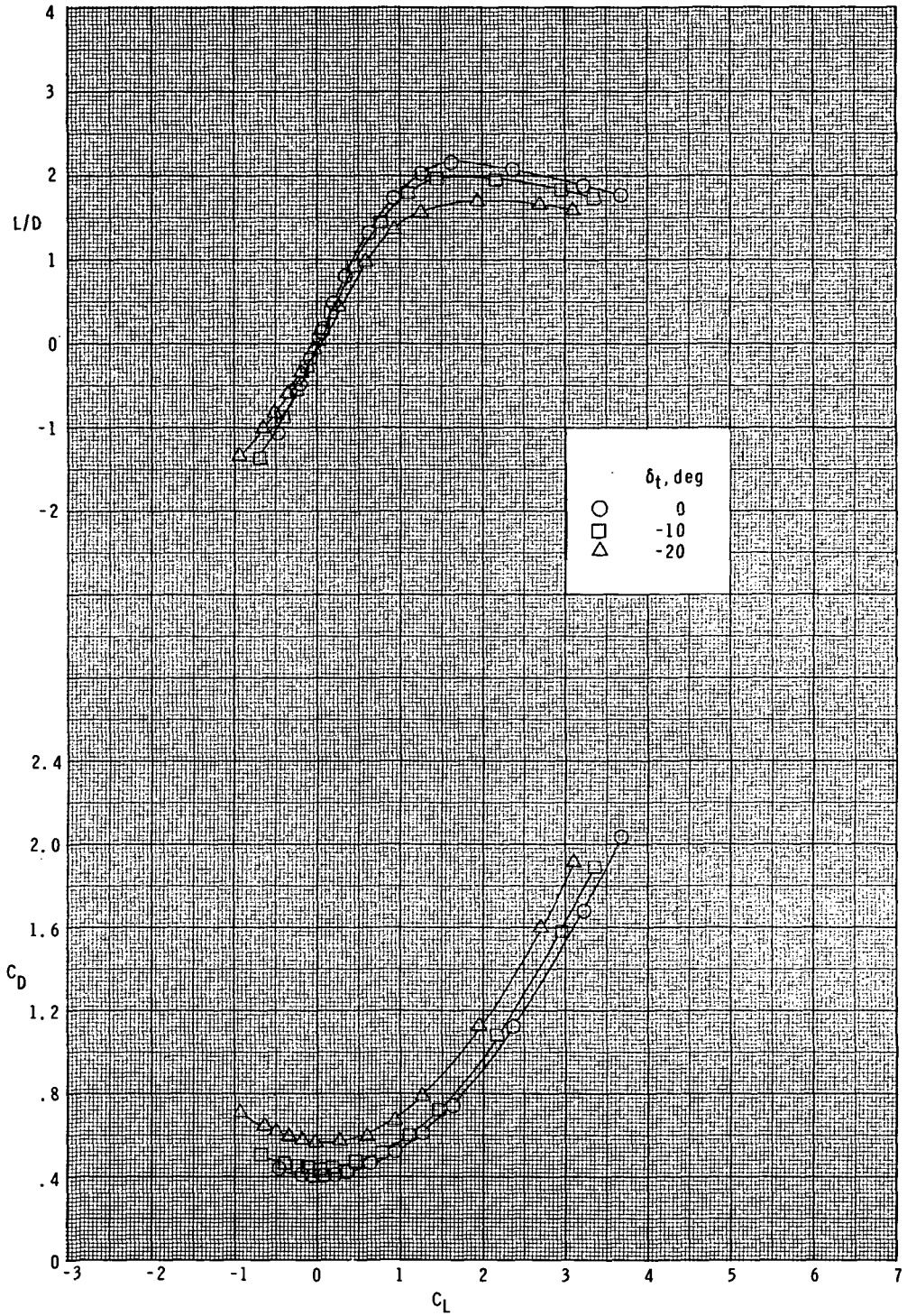
(f) $M = 4.63$.

Figure 9. - Continued.



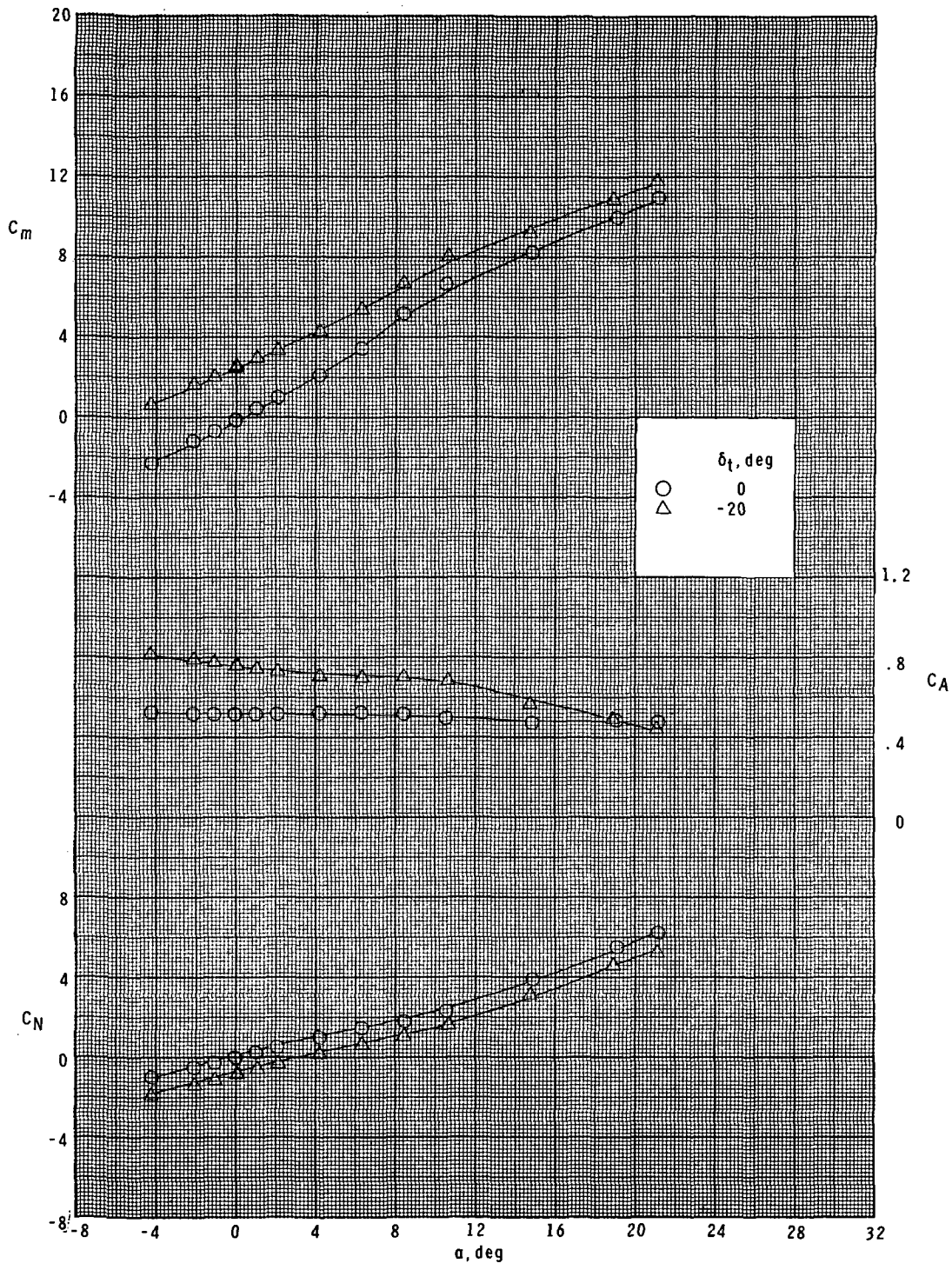
(f) Continued.

Figure 9. - Continued.



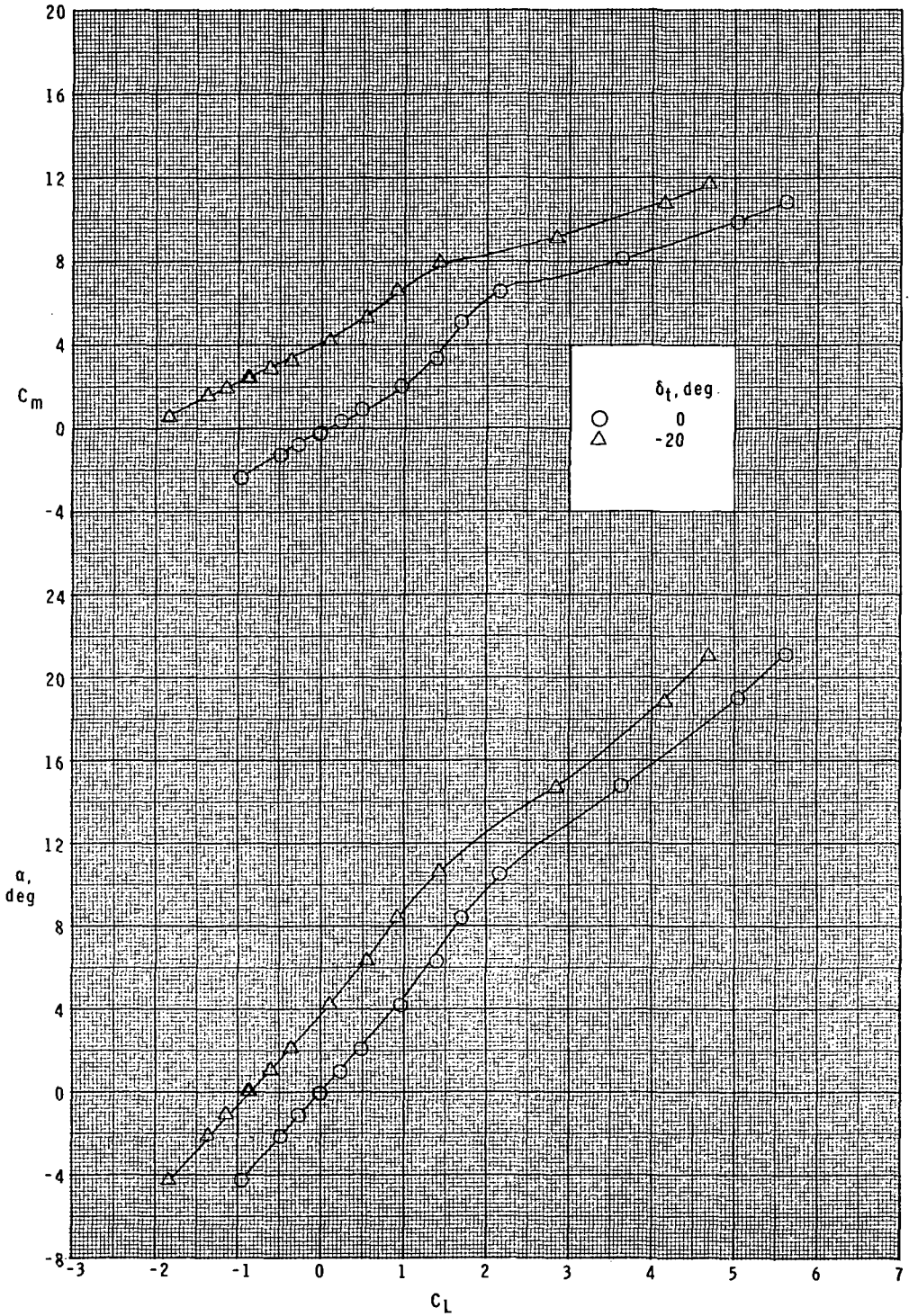
(f) Concluded.

Figure 9.- Concluded.



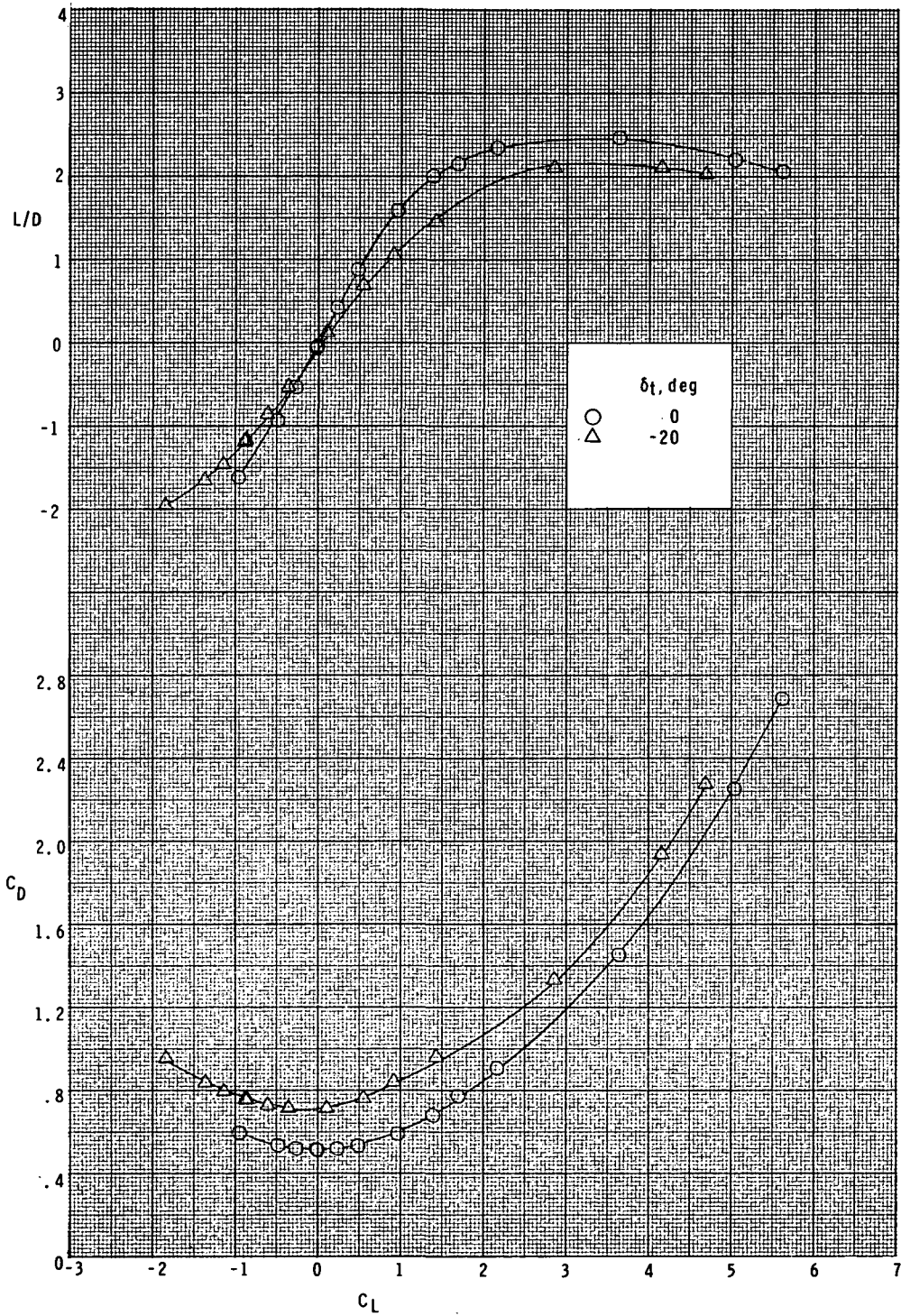
(a) $M = 1.50$.

Figure 10.- Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 0^\circ$; $\phi = 45^\circ$.



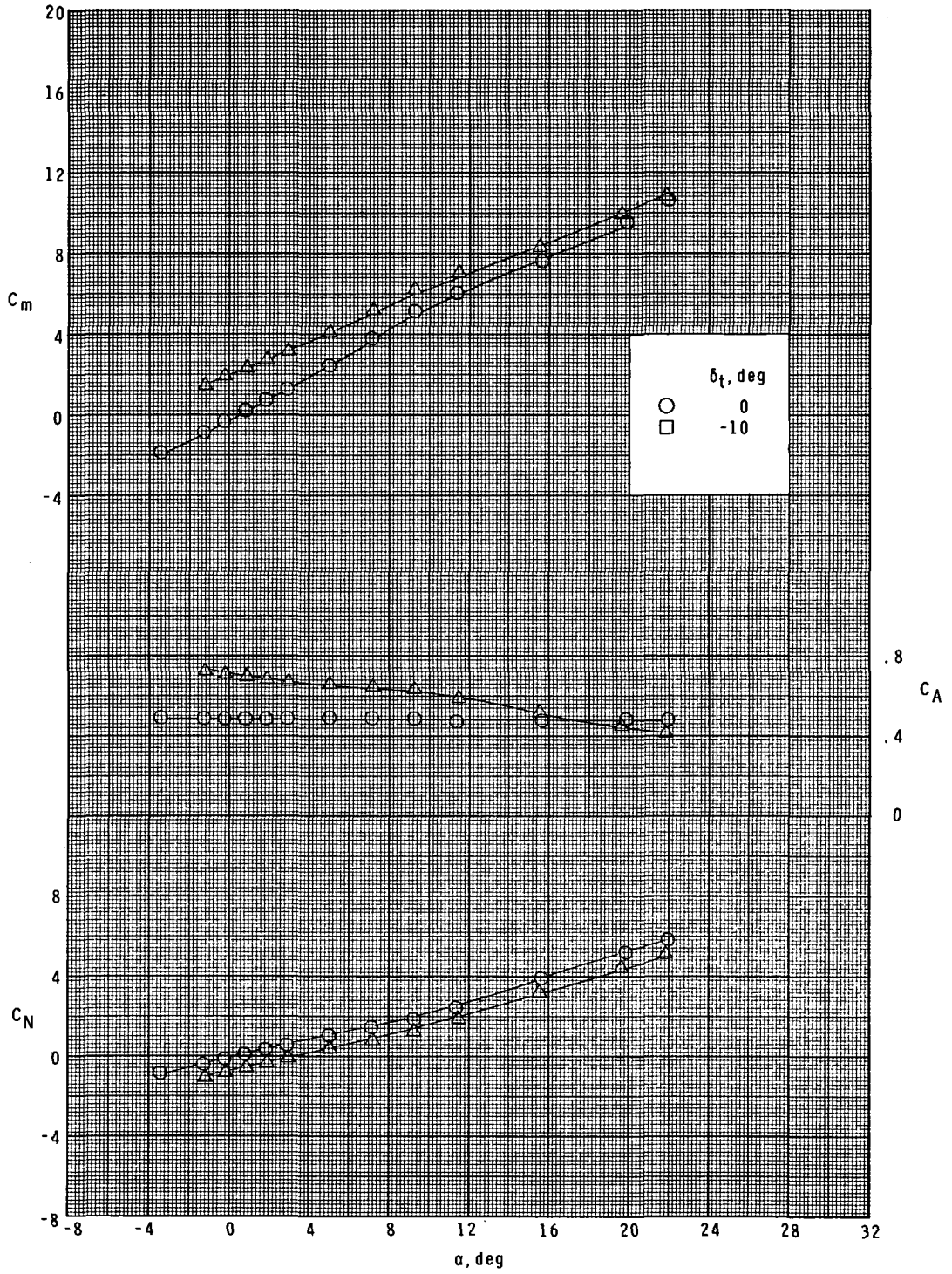
(a) Continued.

Figure 10.- Continued.



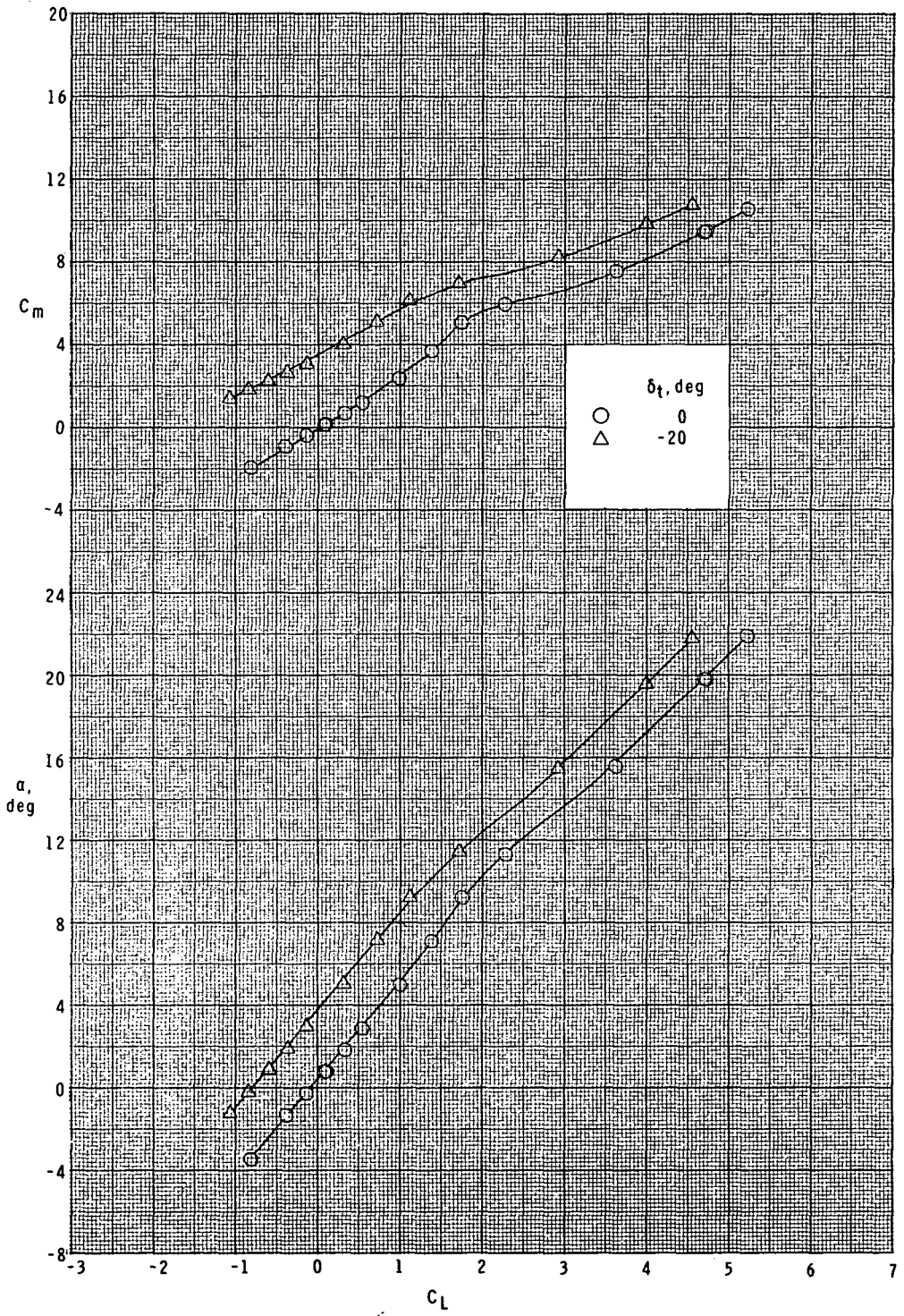
(a) Concluded.

Figure 10.- Continued.



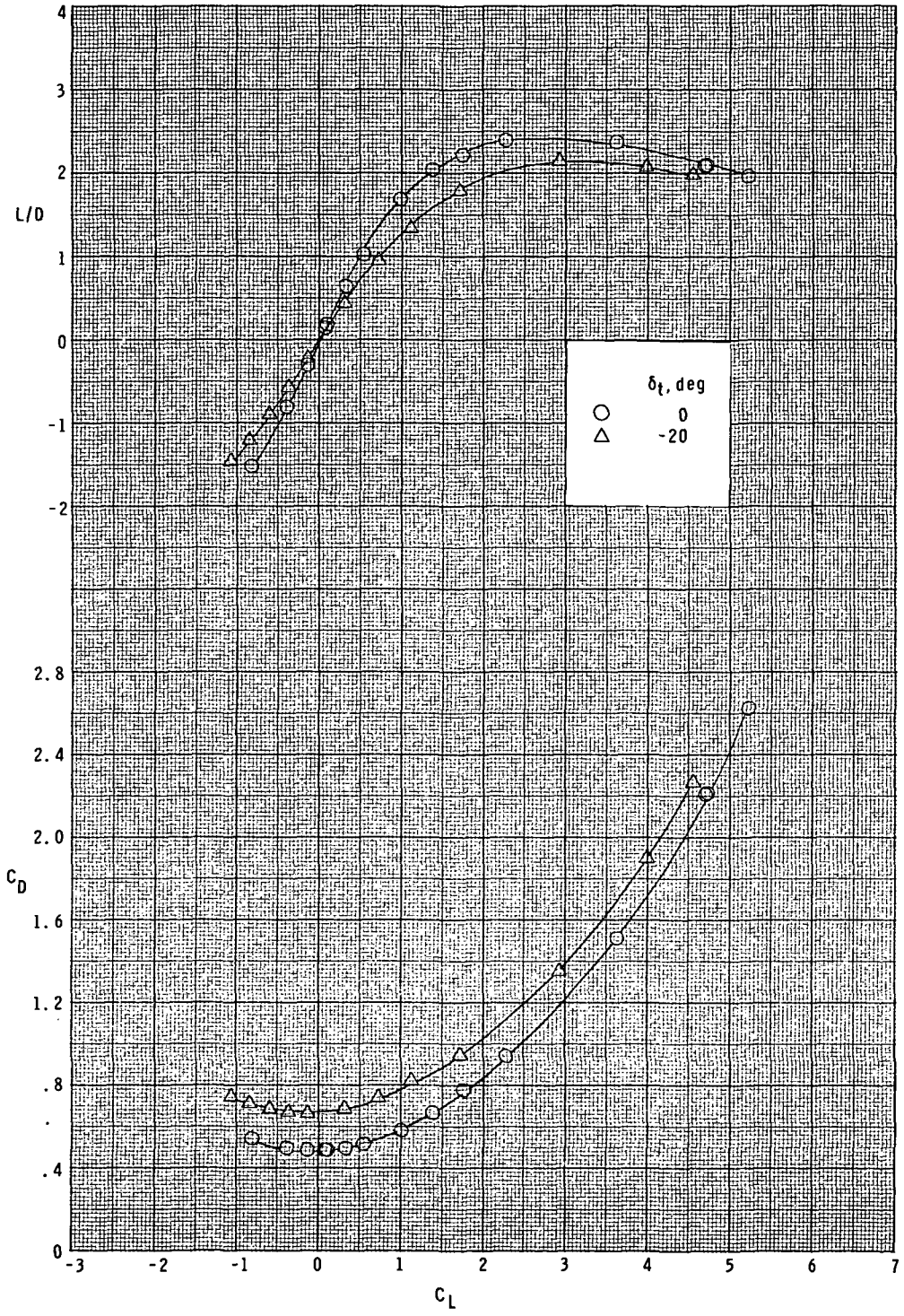
(b) $M = 1.90$.

Figure 10.- Continued.



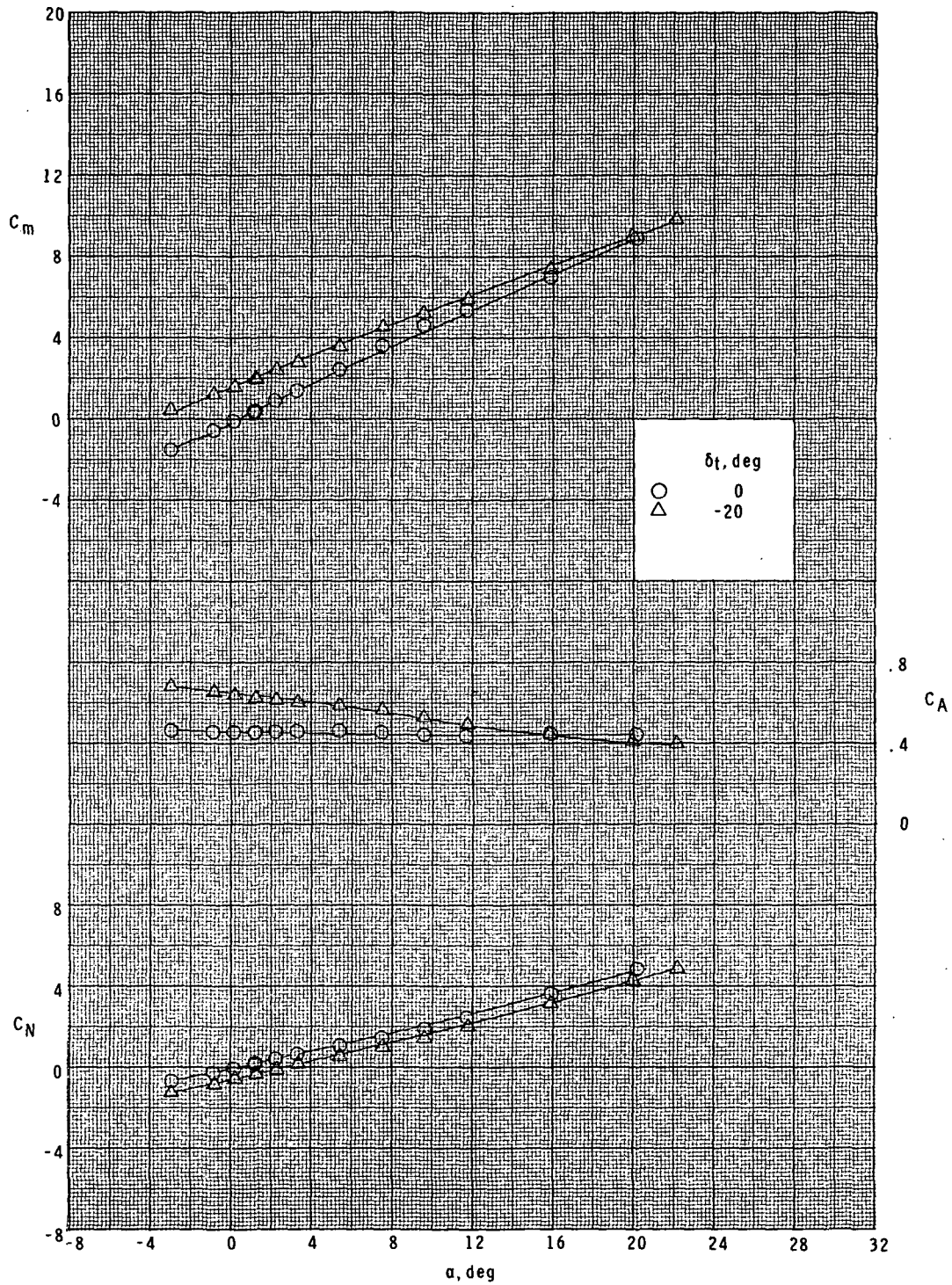
(b) Continued.

Figure 10. - Continued.



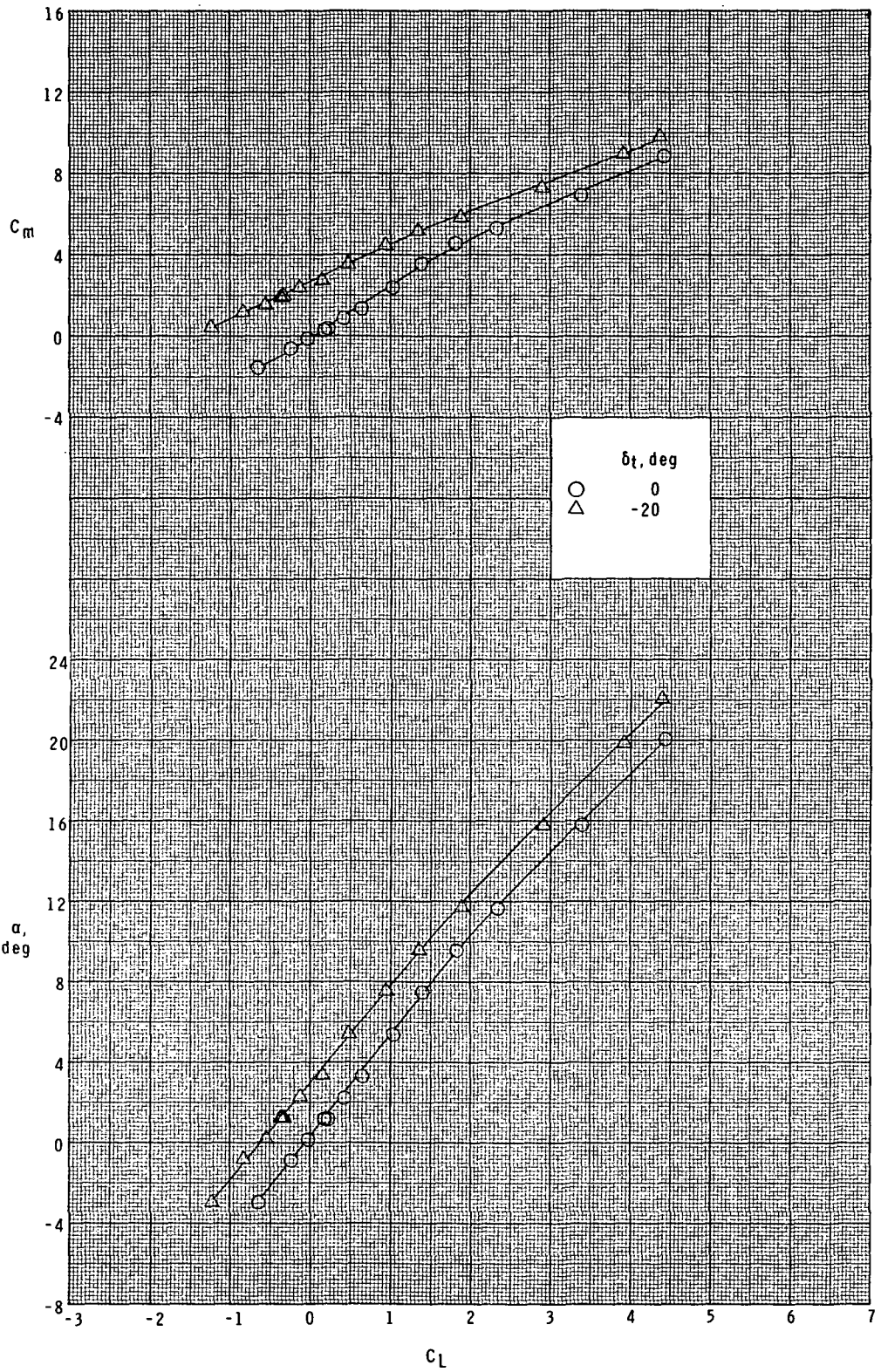
(b) Concluded.

Figure 10. - Continued.



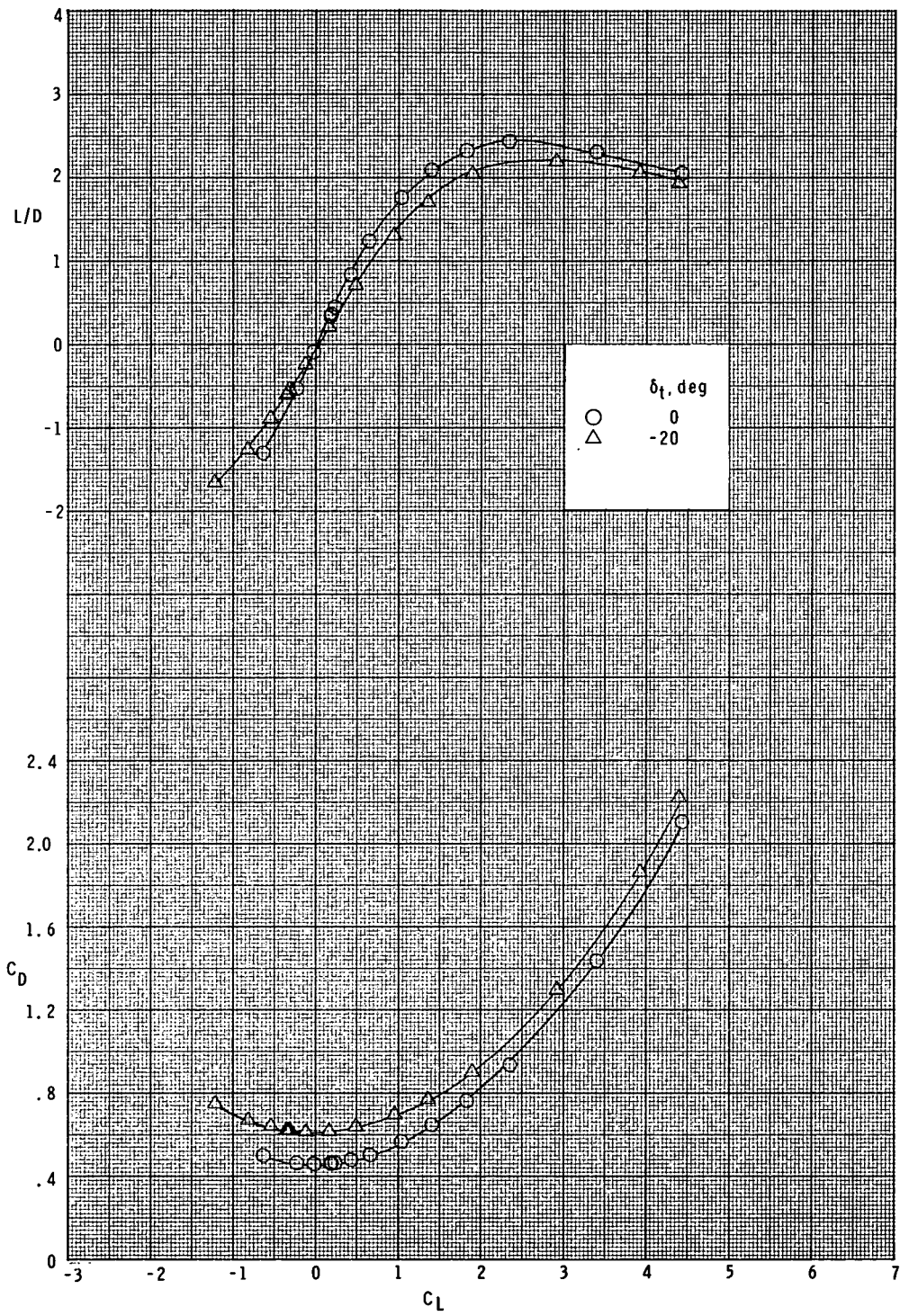
(c) $M = 2.36$.

Figure 10.- Continued.



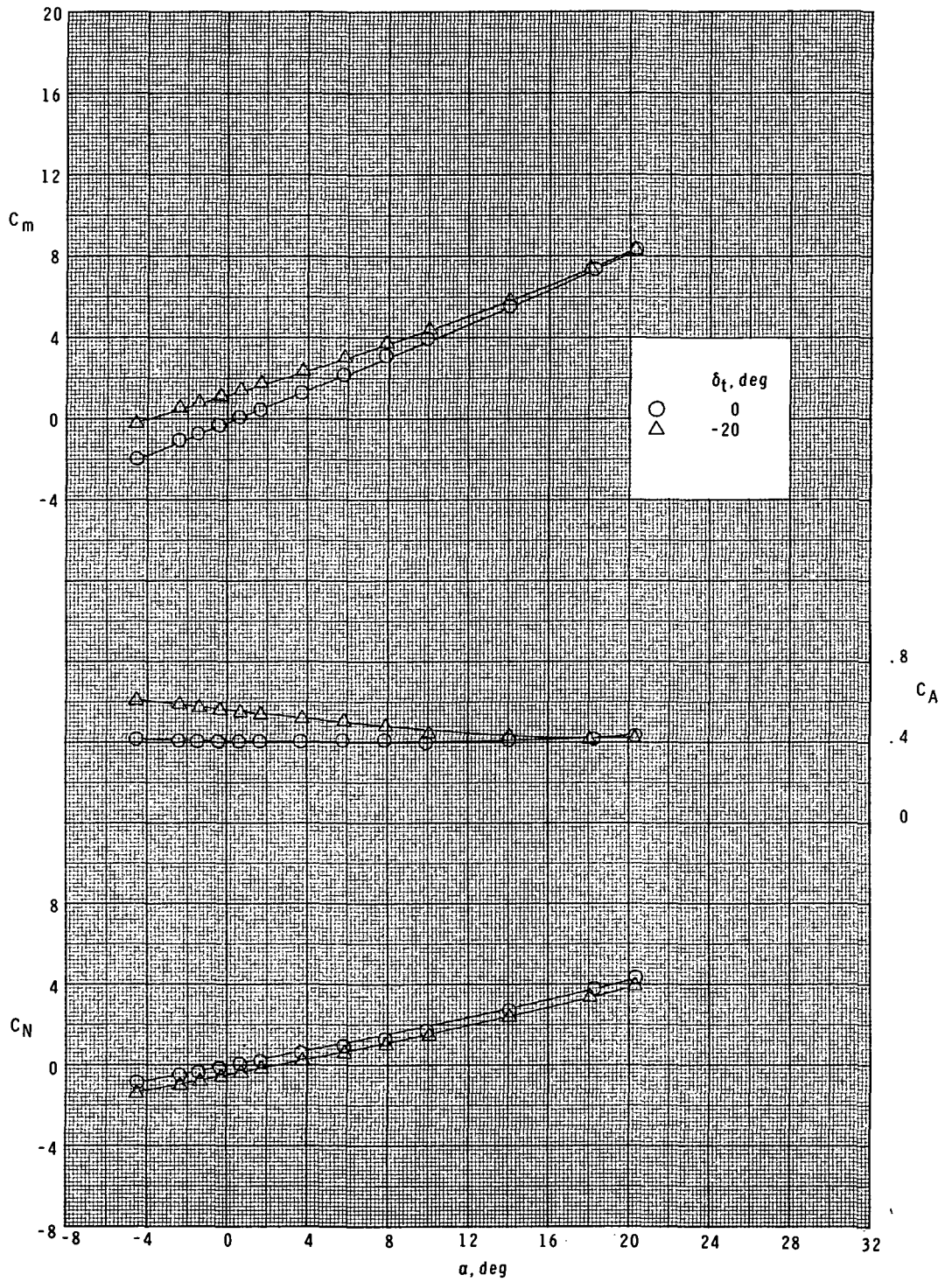
(c) Continued.

Figure 10.- Continued.



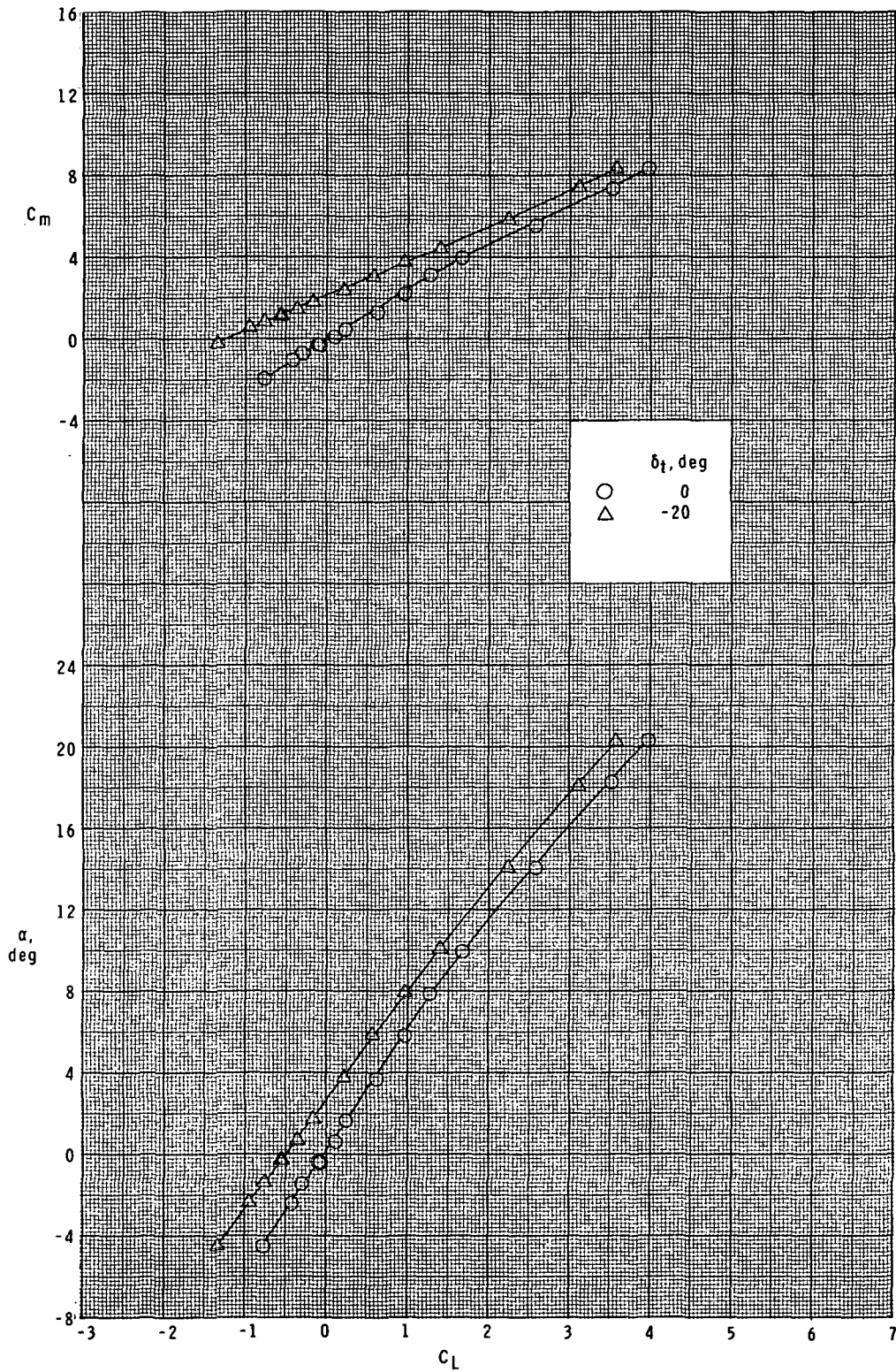
(c) Concluded.

Figure 10.- Continued.



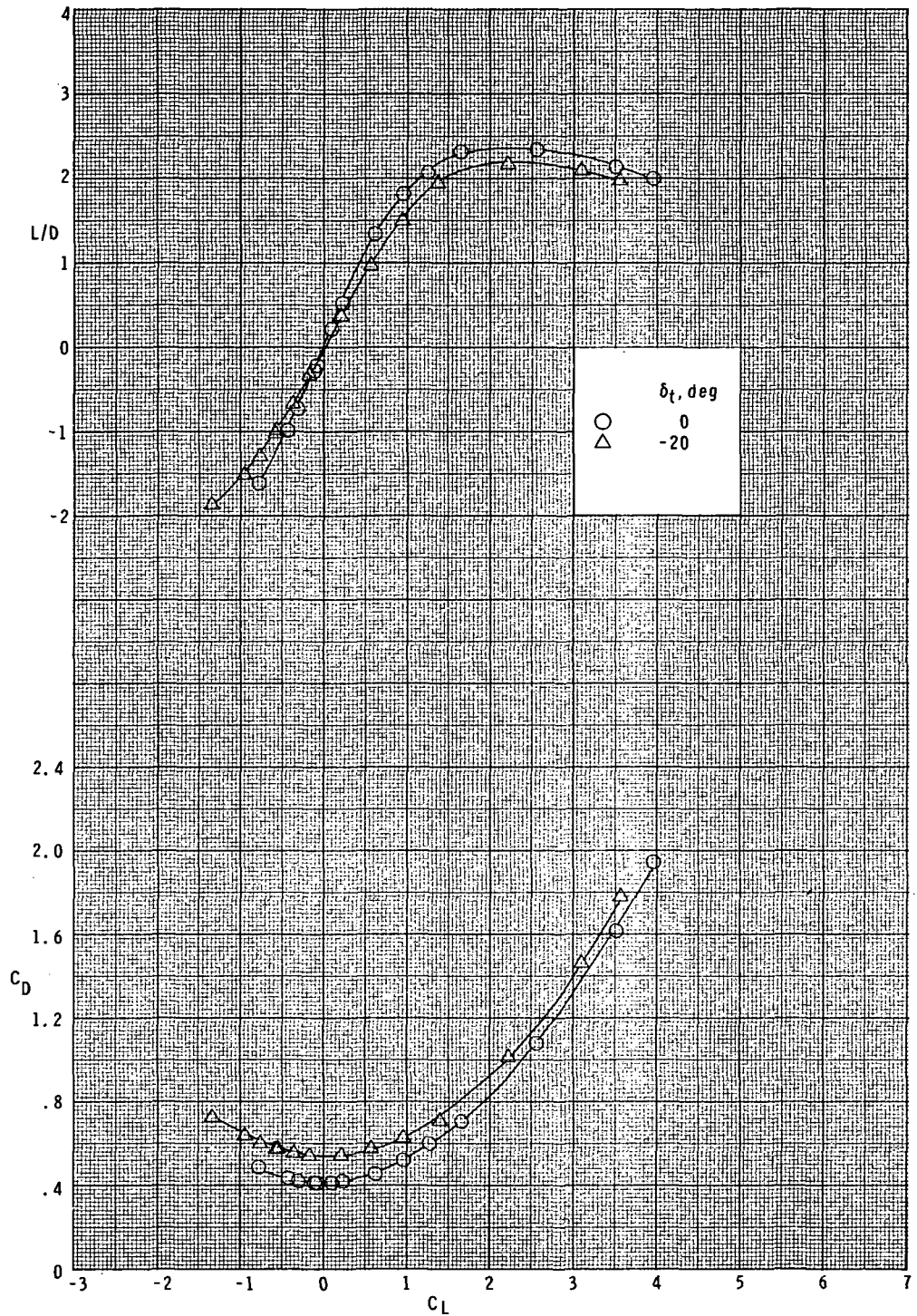
(d) $M = 2.86$.

Figure 10.- Continued.



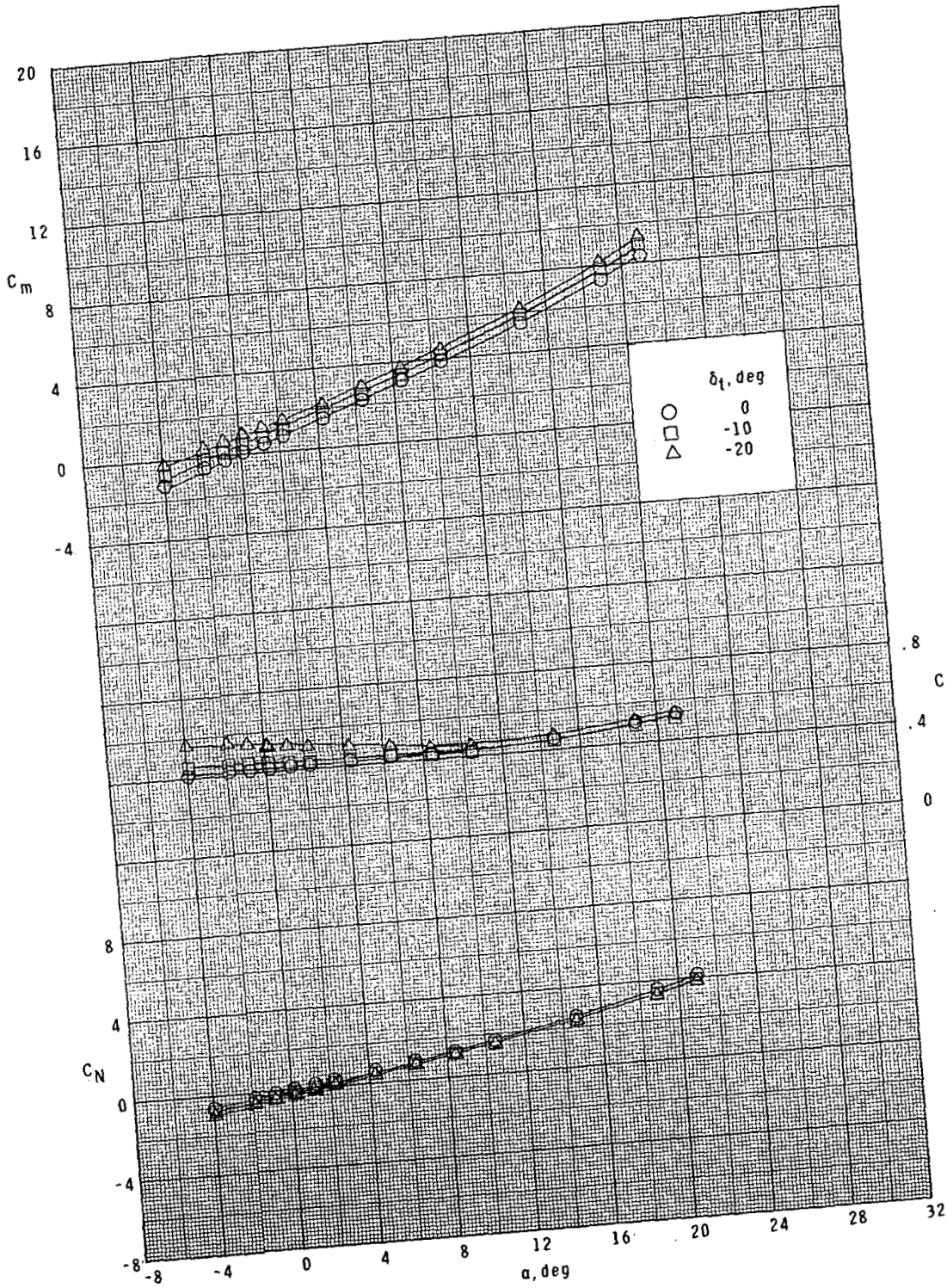
(d) Continued.

Figure 10.- Continued.

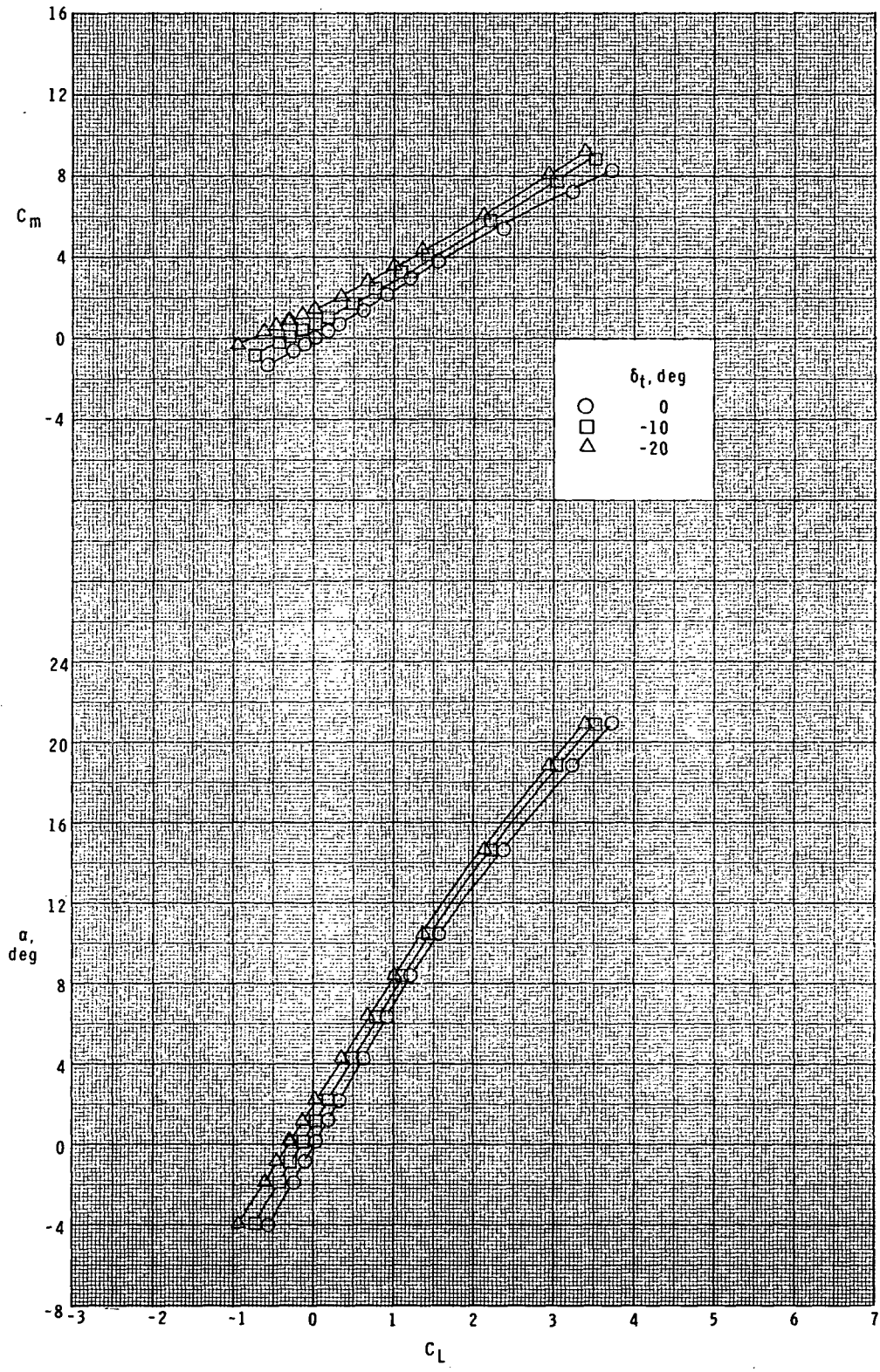


(d) Concluded.

Figure 10. - Continued.

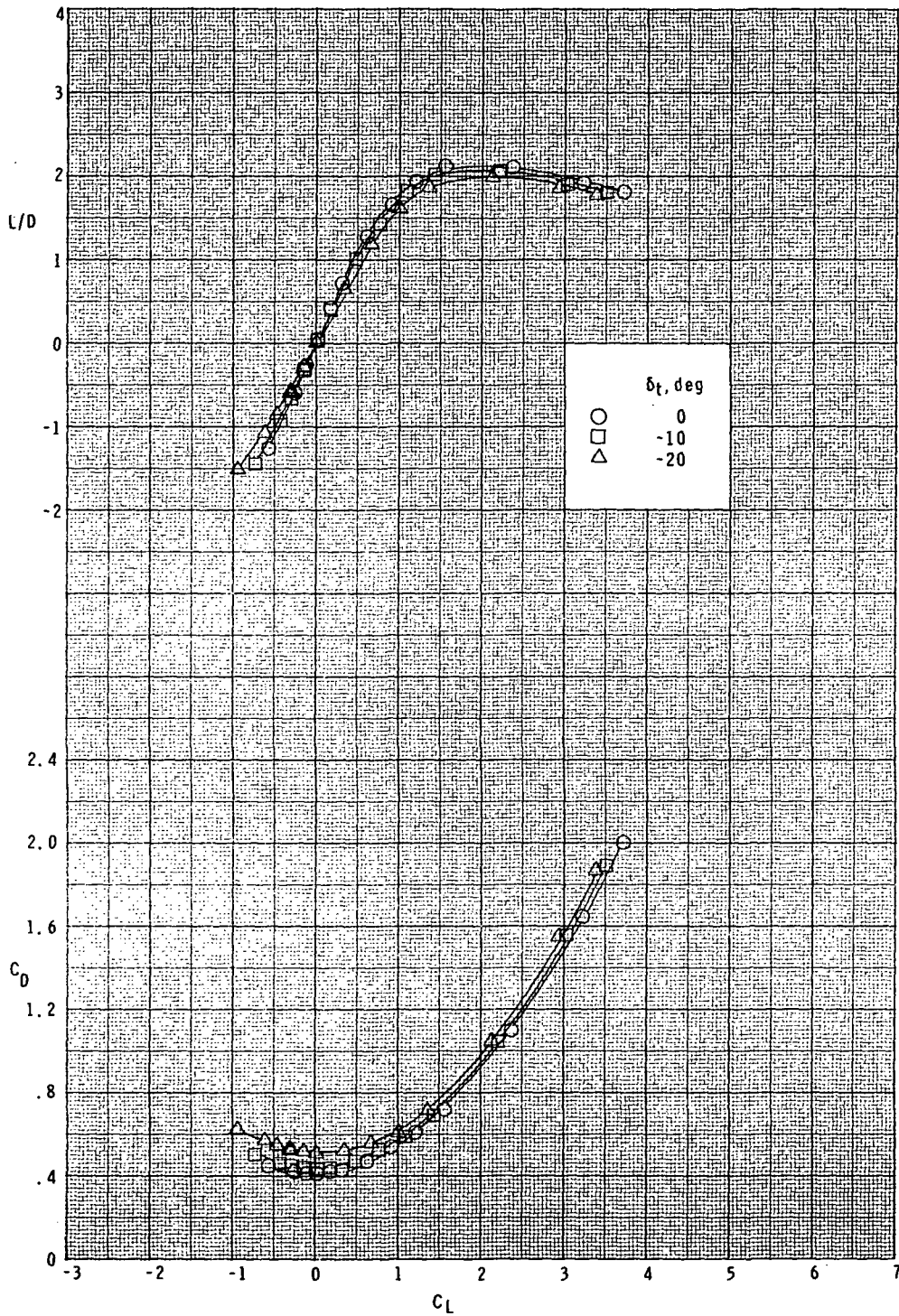


(e) $M = 3.95$.
 Figure 10. - Continued.



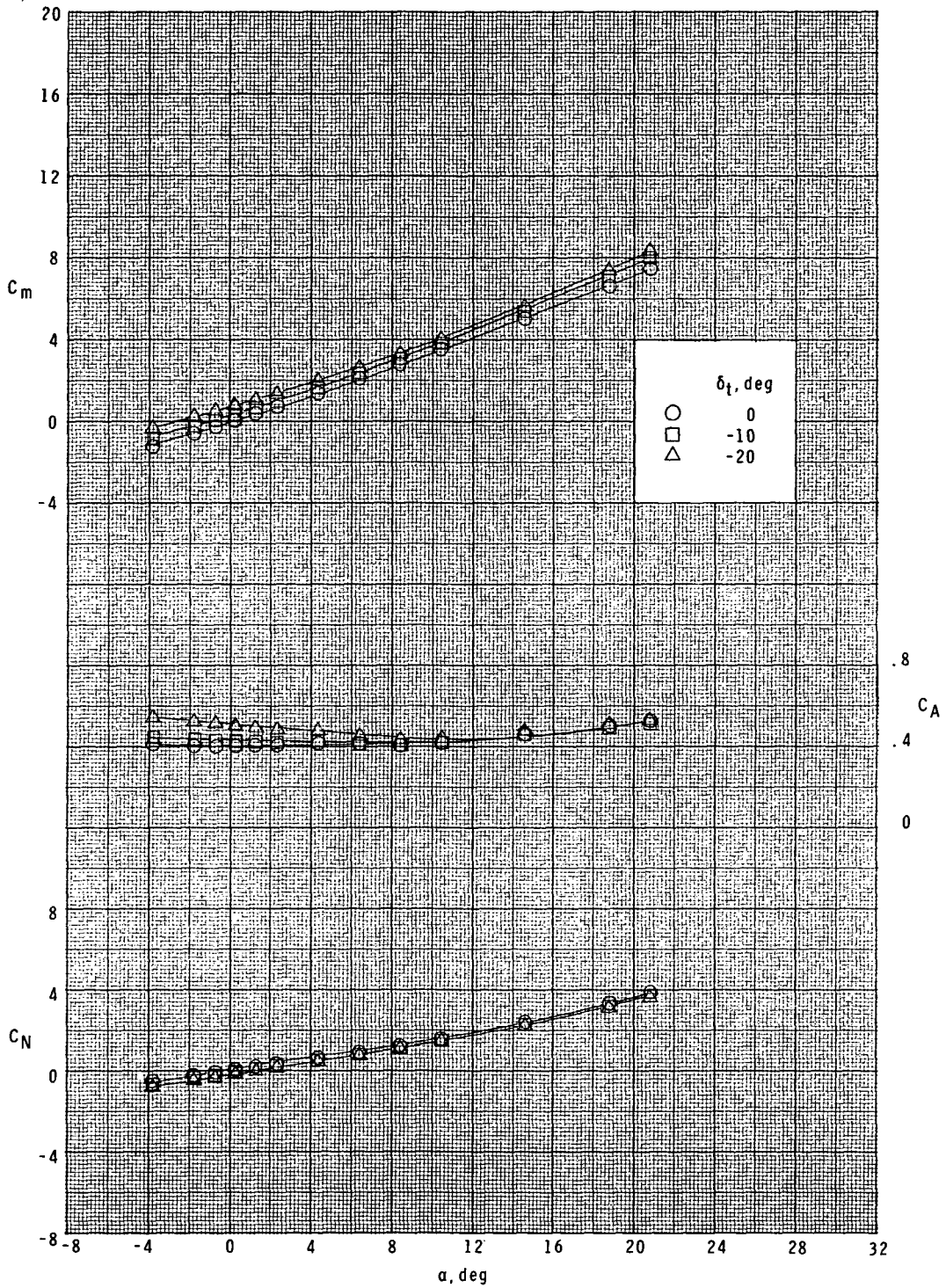
(e) Continued.

Figure 10. - Continued.



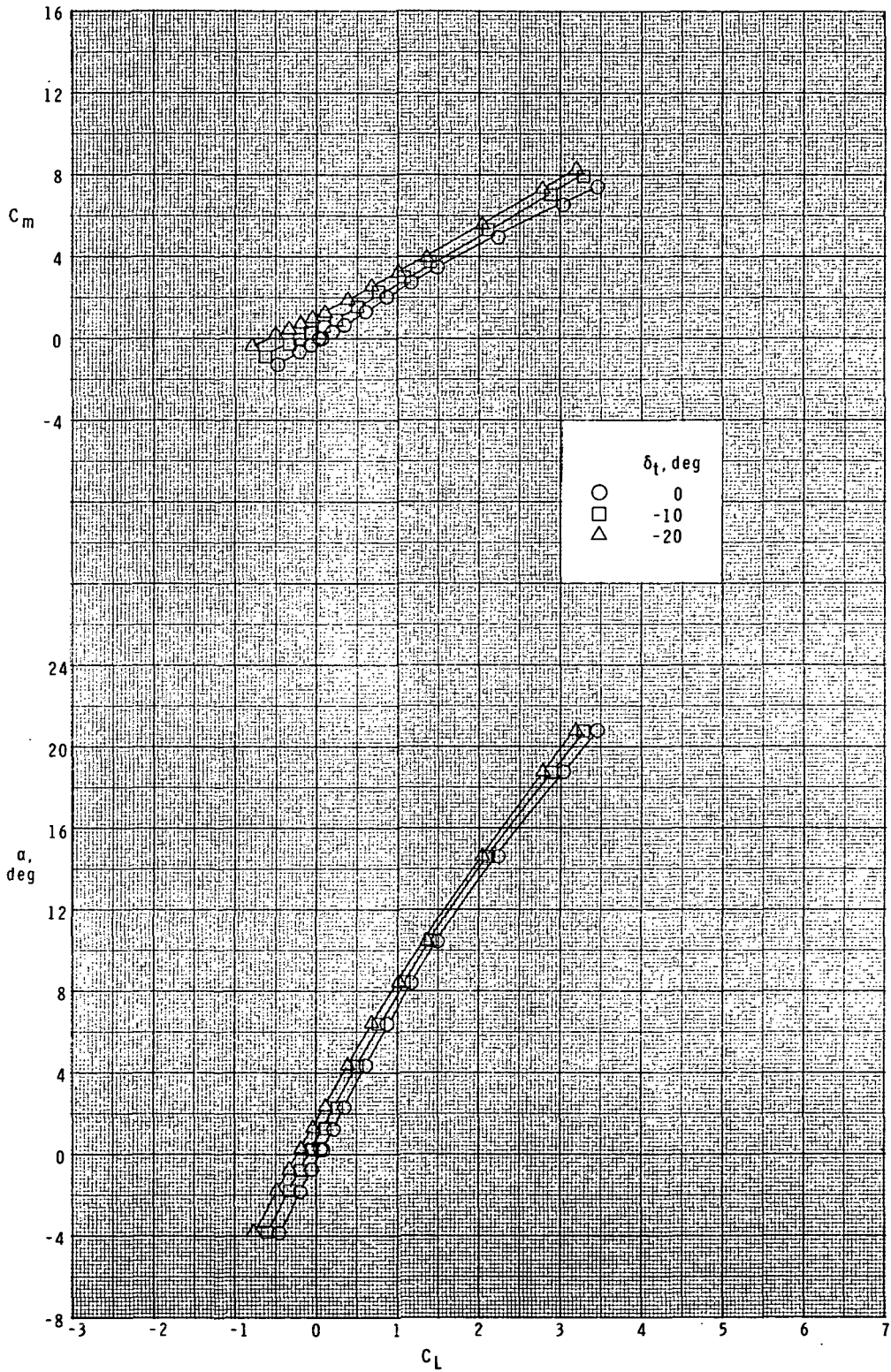
(e) Concluded.

Figure 10. - Continued.



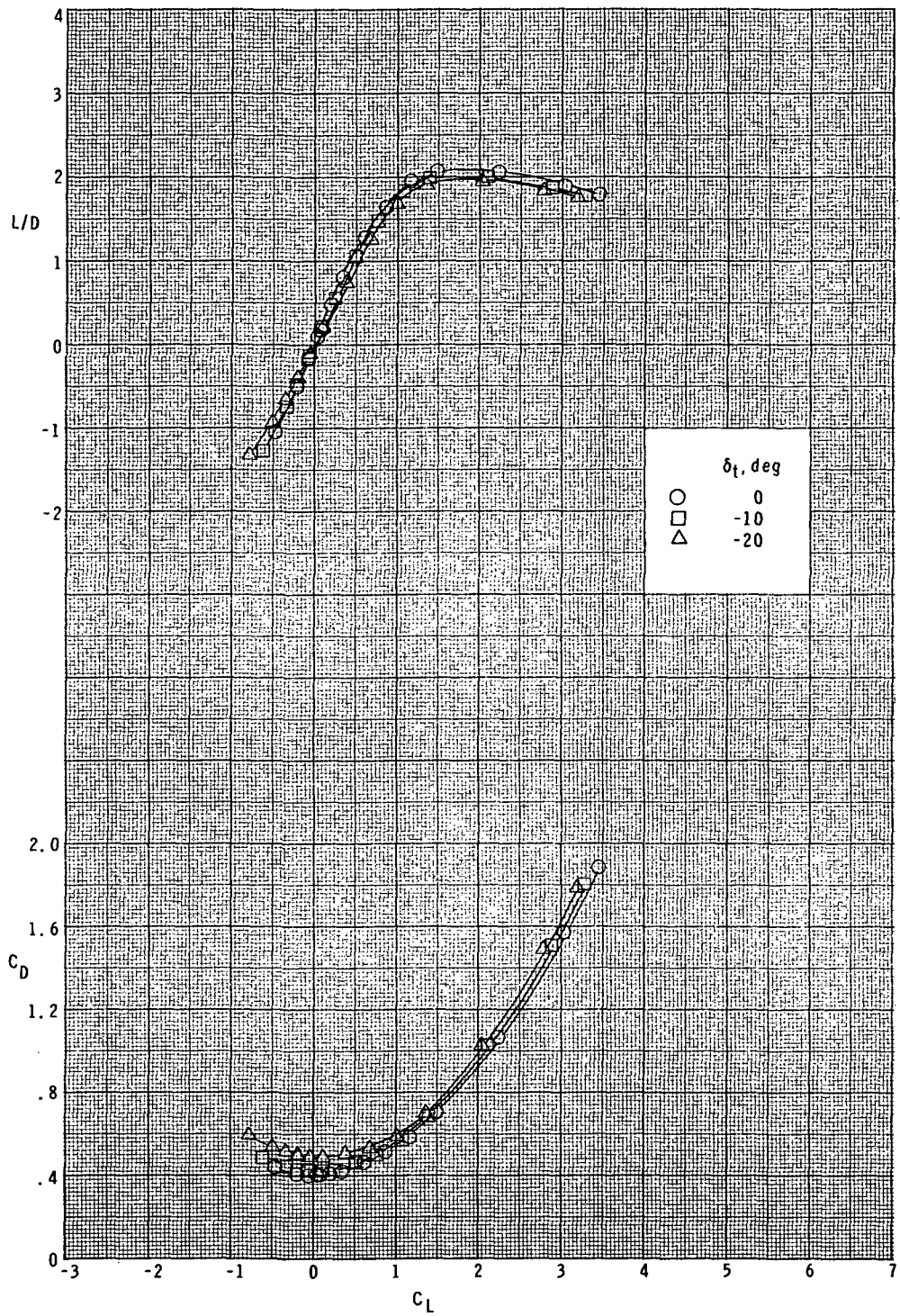
(f) $M = 4.63$.

Figure 10.- Continued.



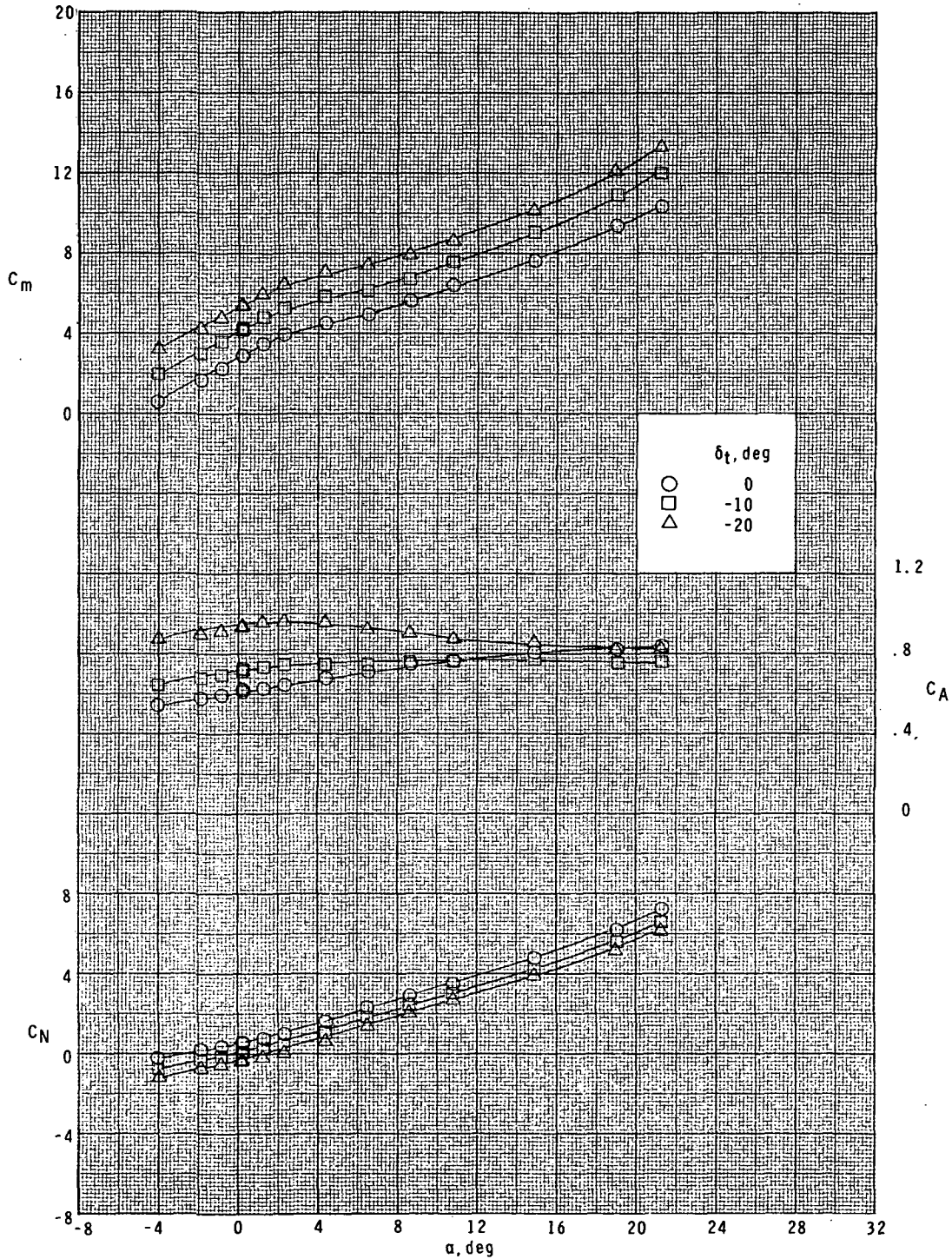
(f) Continued.

Figure 10.- Continued.



(f) Concluded.

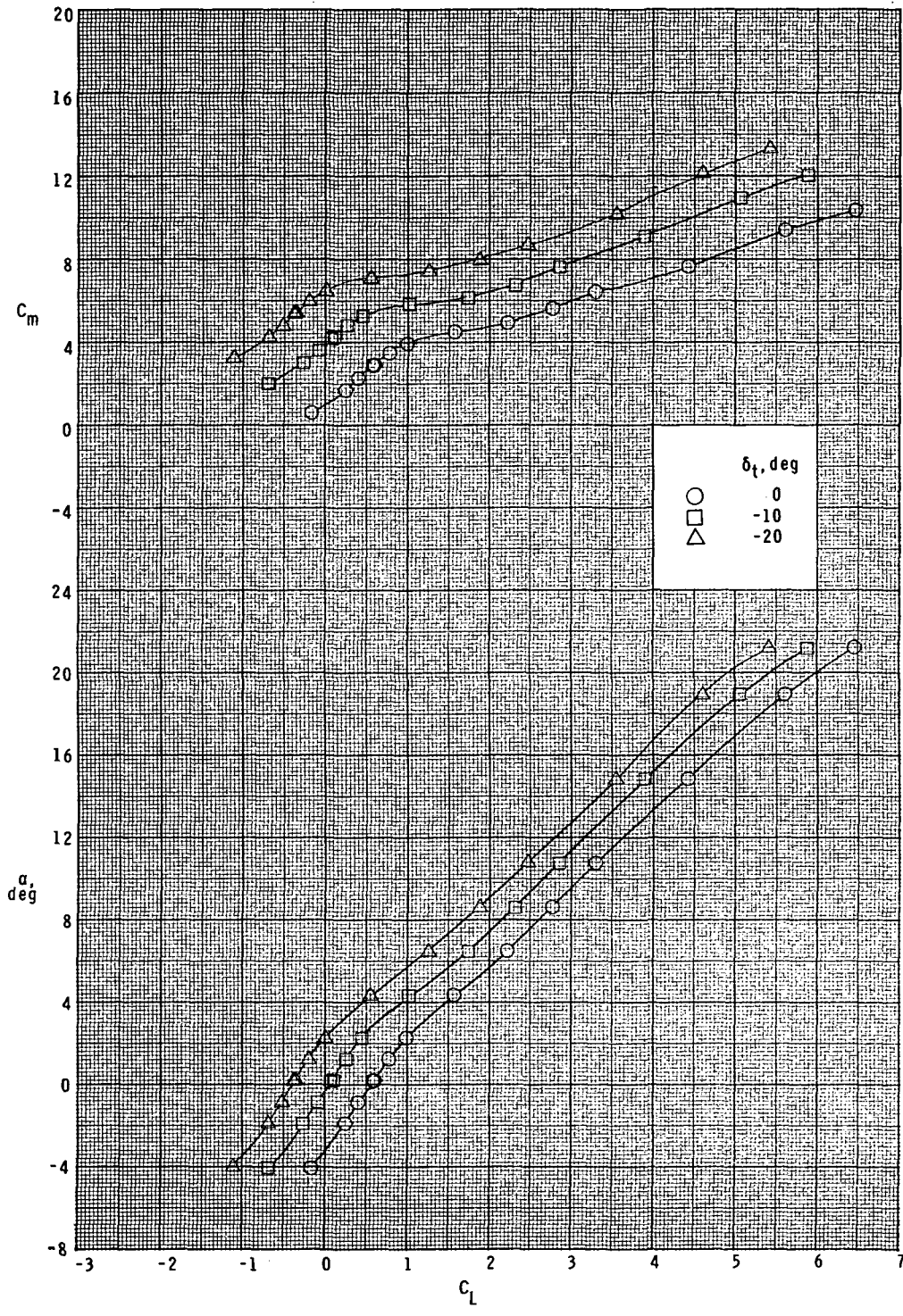
Figure 10.- Concluded.



(a) $M = 1.50$.

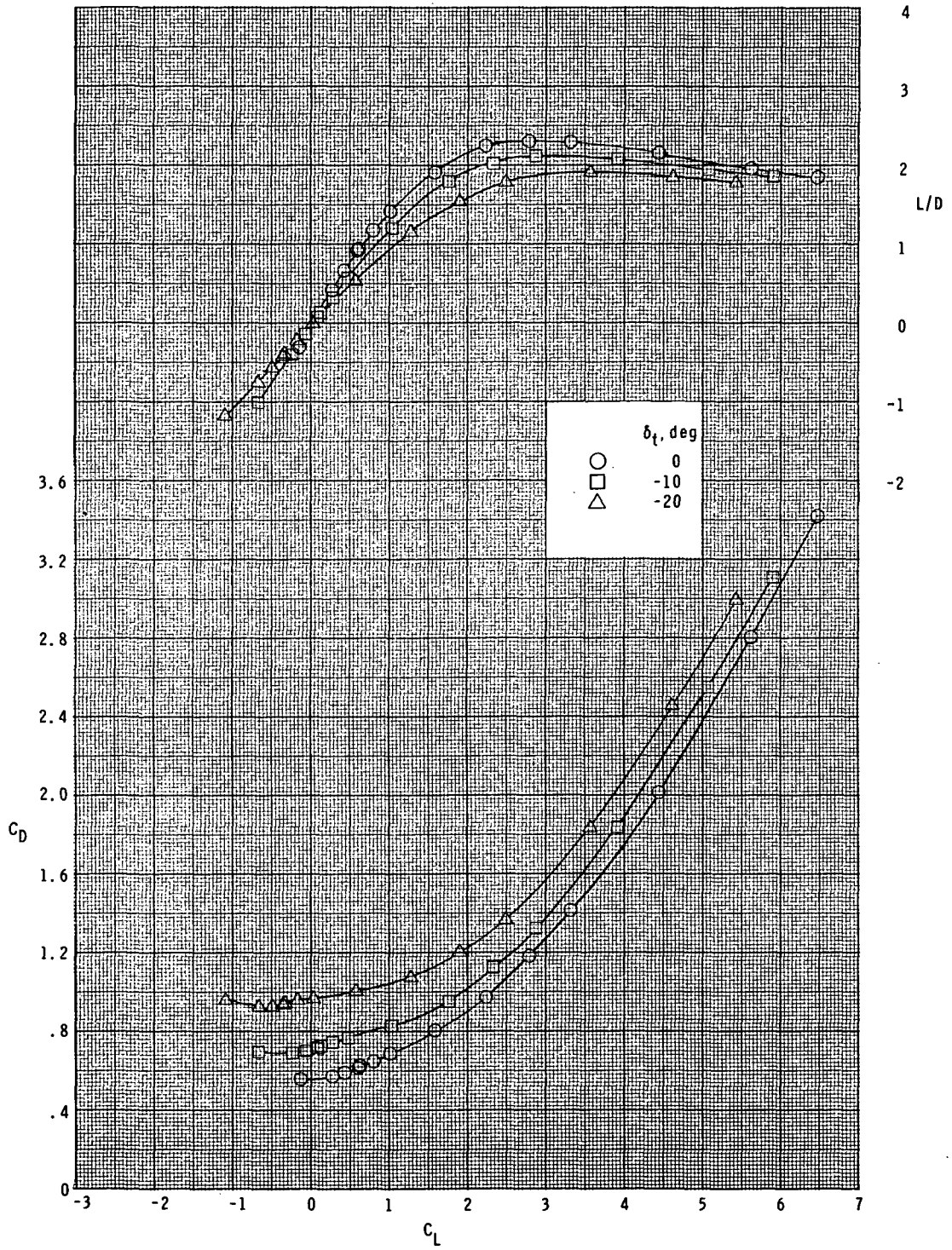
Figure 11.- Effect of tail deflection on longitudinal aerodynamic characteristics.

$\delta_w = 10^\circ$; $\phi = 0^\circ$; tails in line.



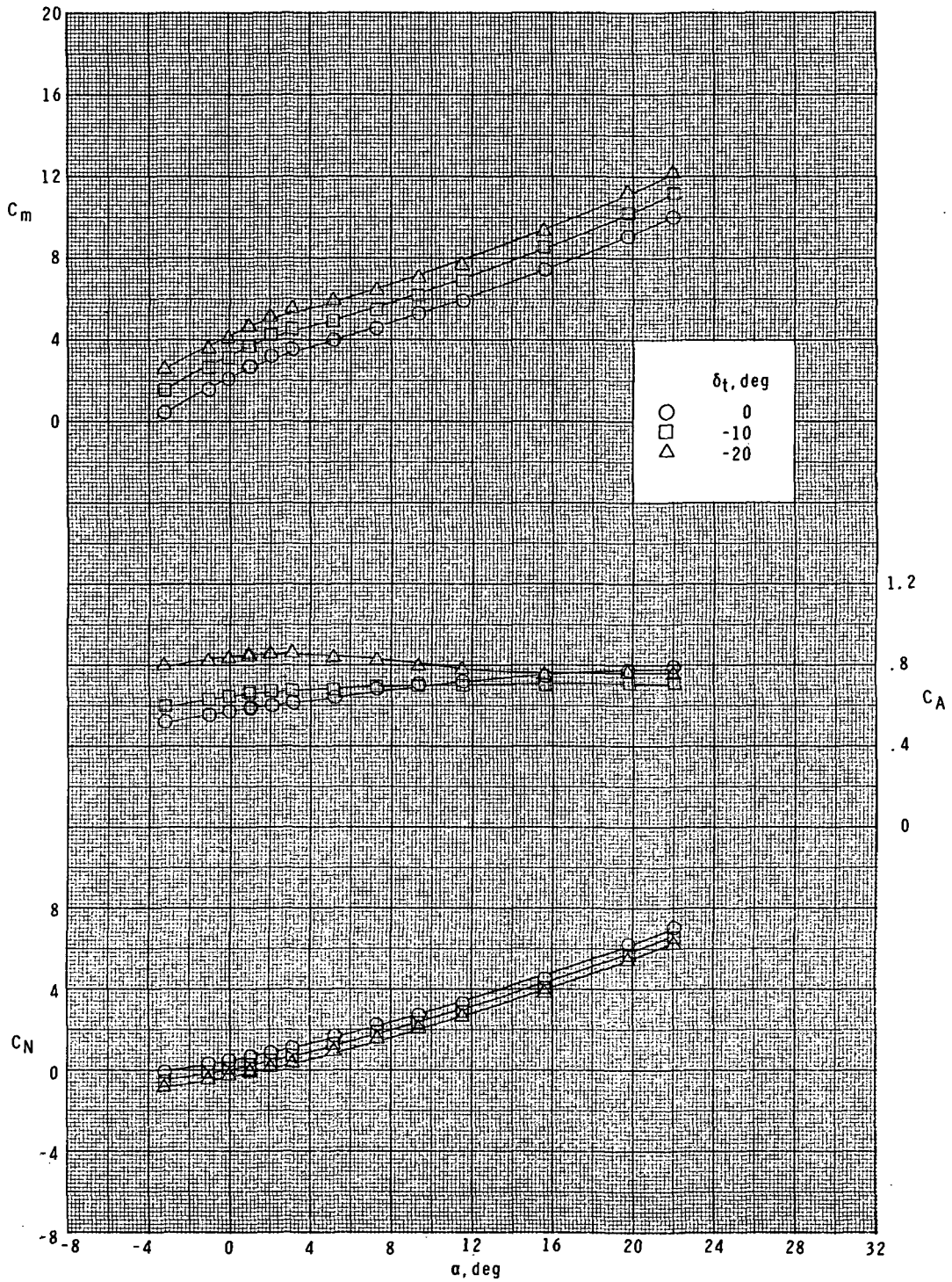
(a) Continued.

Figure 11.- Continued.



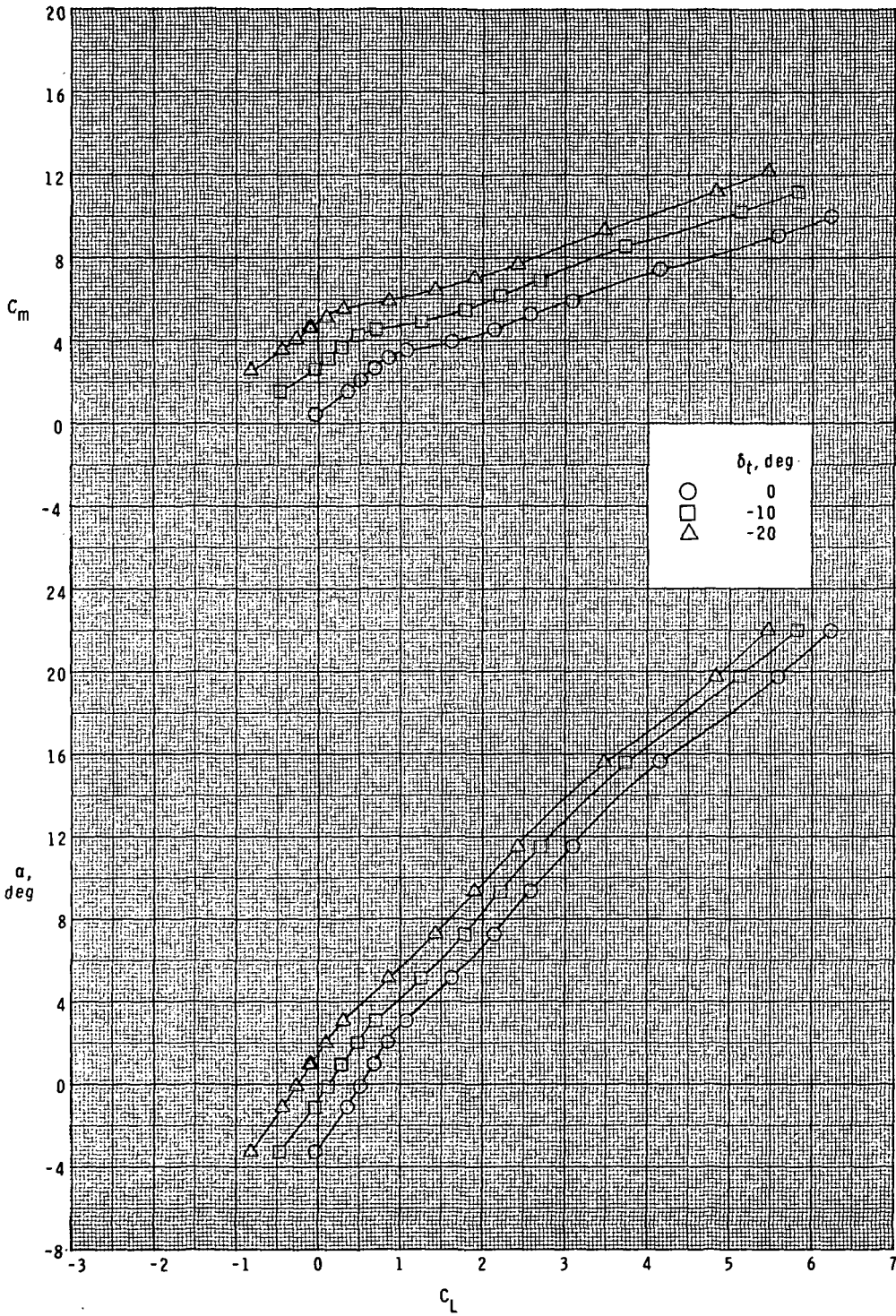
(a) Concluded.

Figure 11.- Continued.



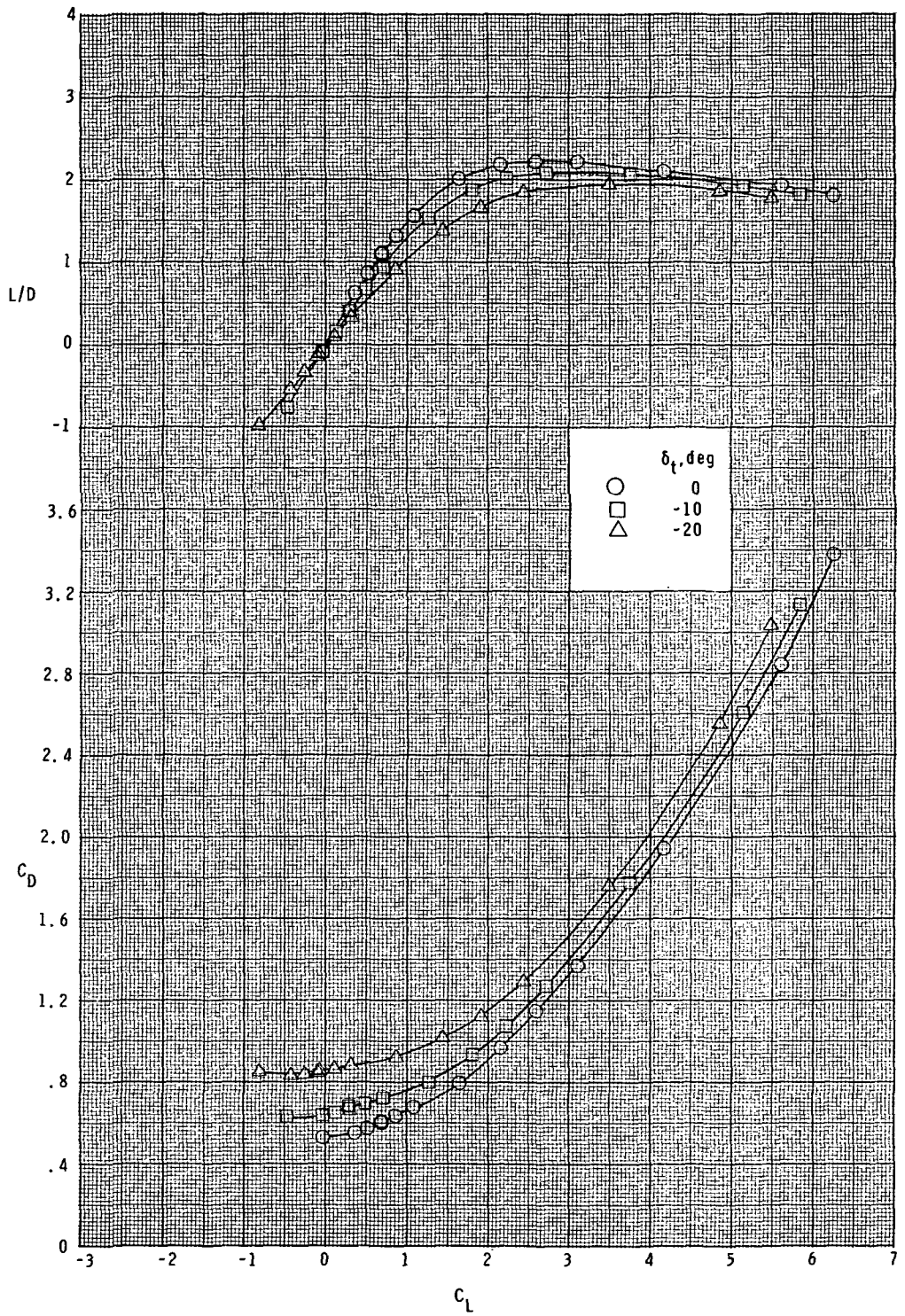
(b) $M = 1.90$.

Figure 11. - Continued.



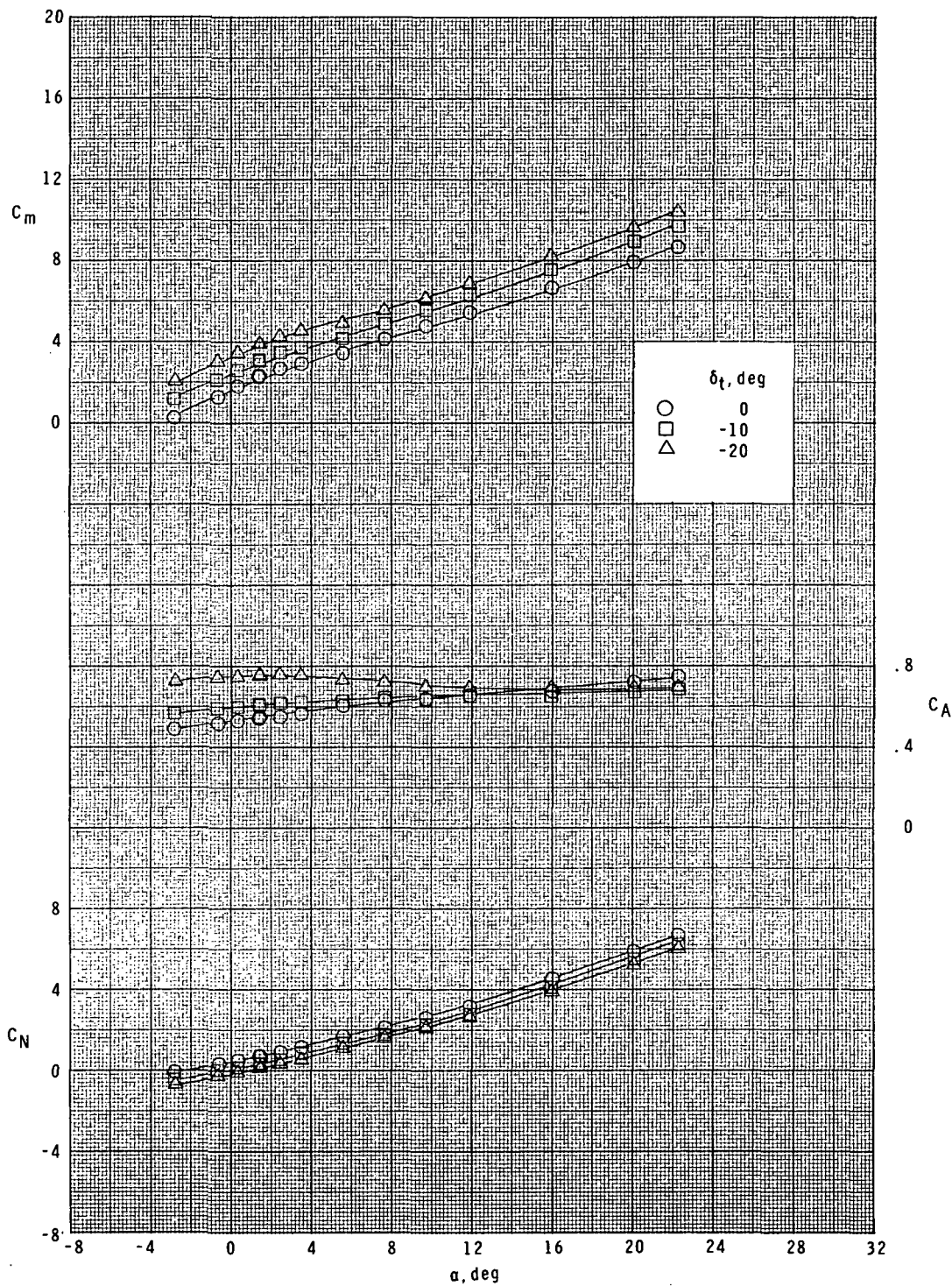
(b) Continued.

Figure 11.- Continued.



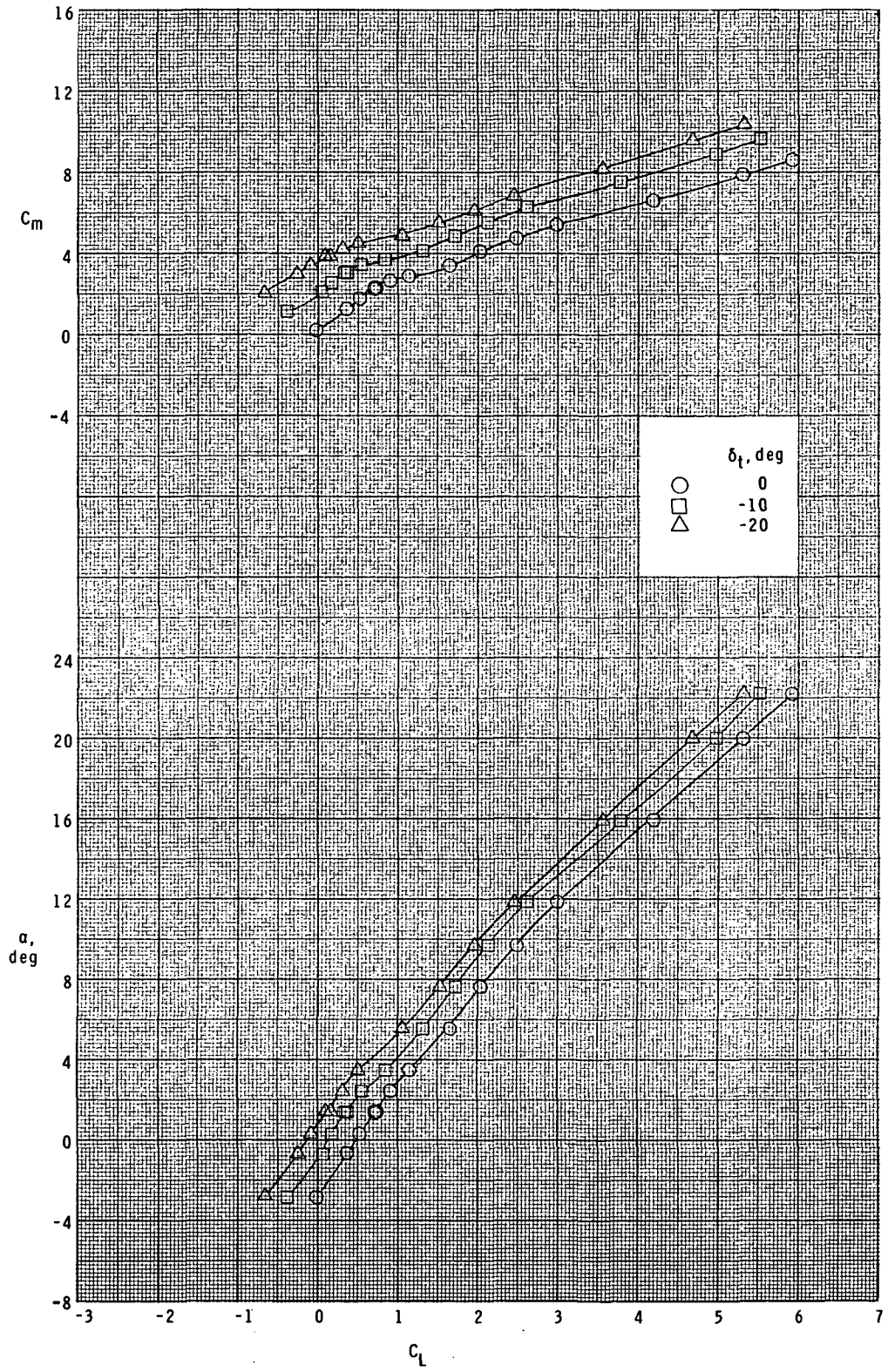
(b) Concluded.

Figure 11.- Continued.



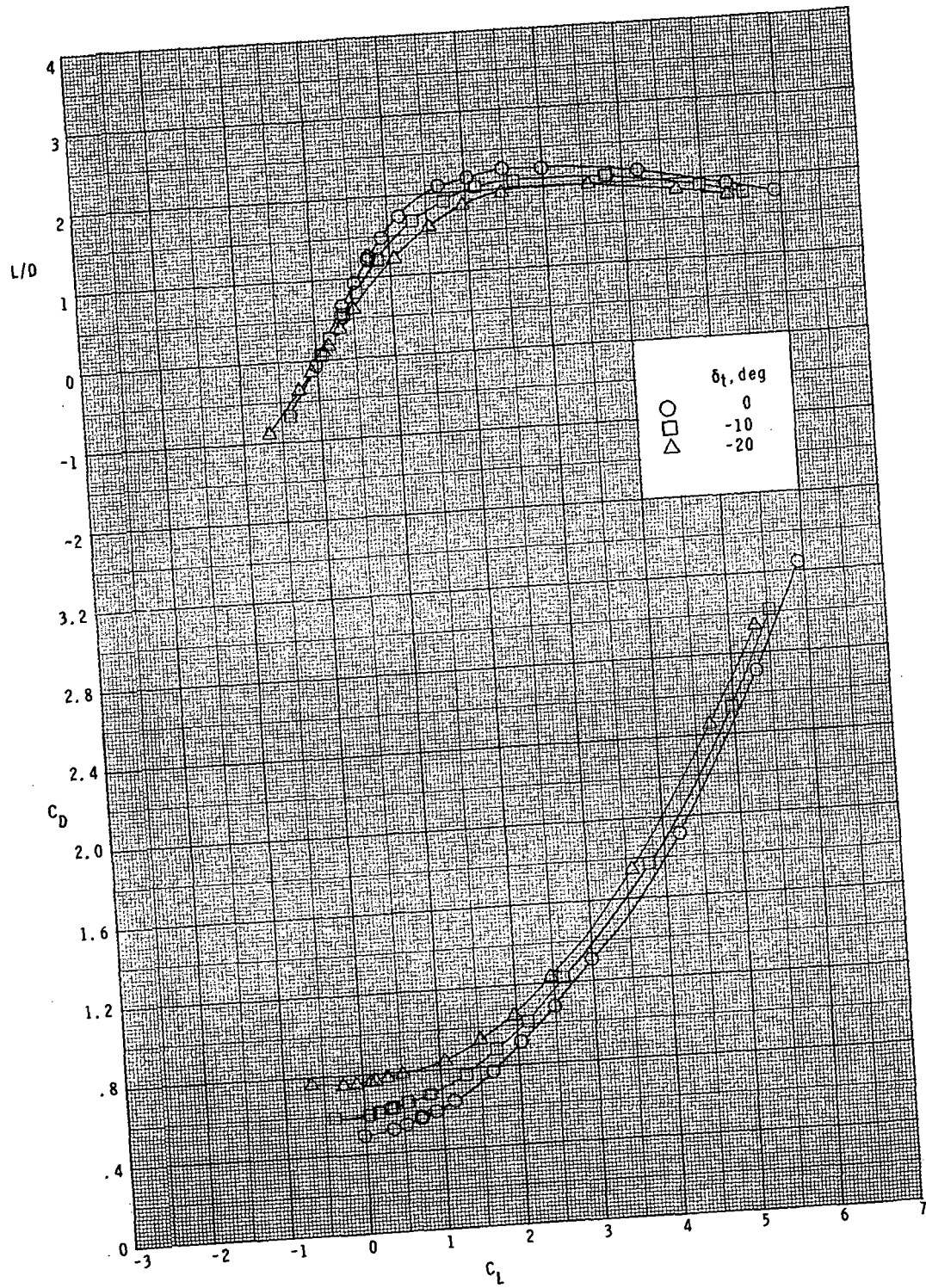
(c) $M = 2.36$.

Figure 11.- Continued.



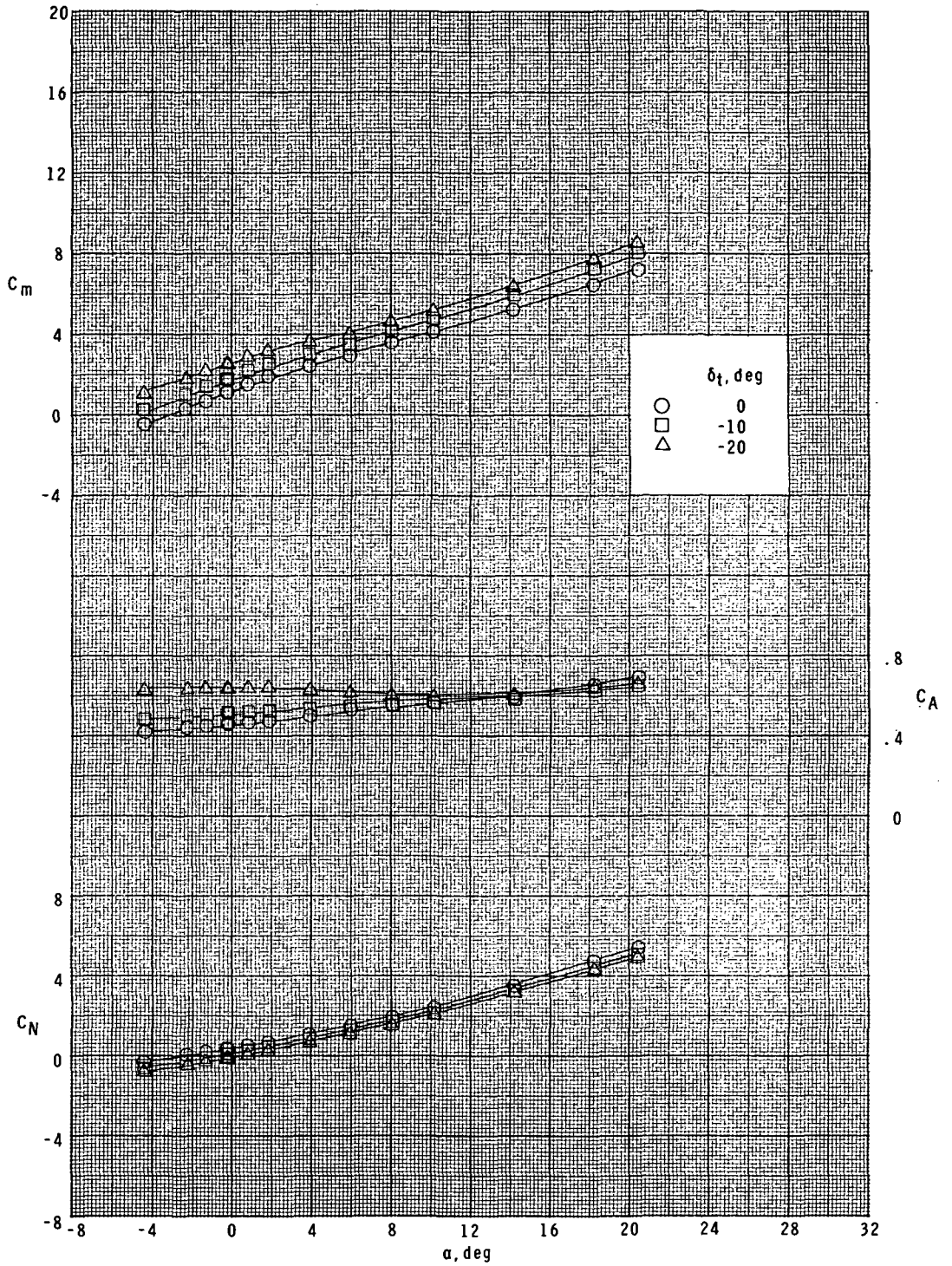
(c) Continued.

Figure 11. - Continued.



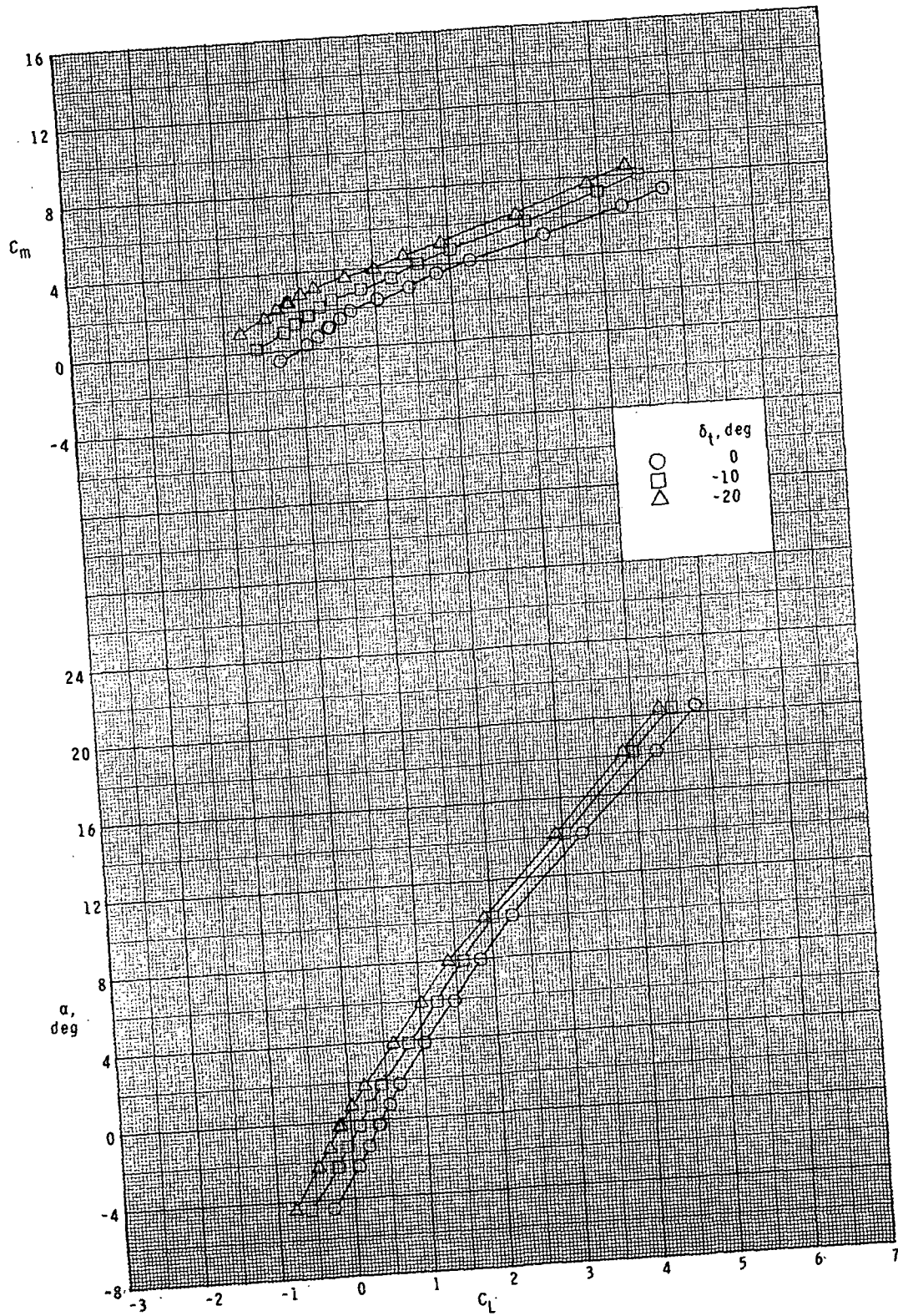
(c) Concluded.

Figure 11.- Continued.



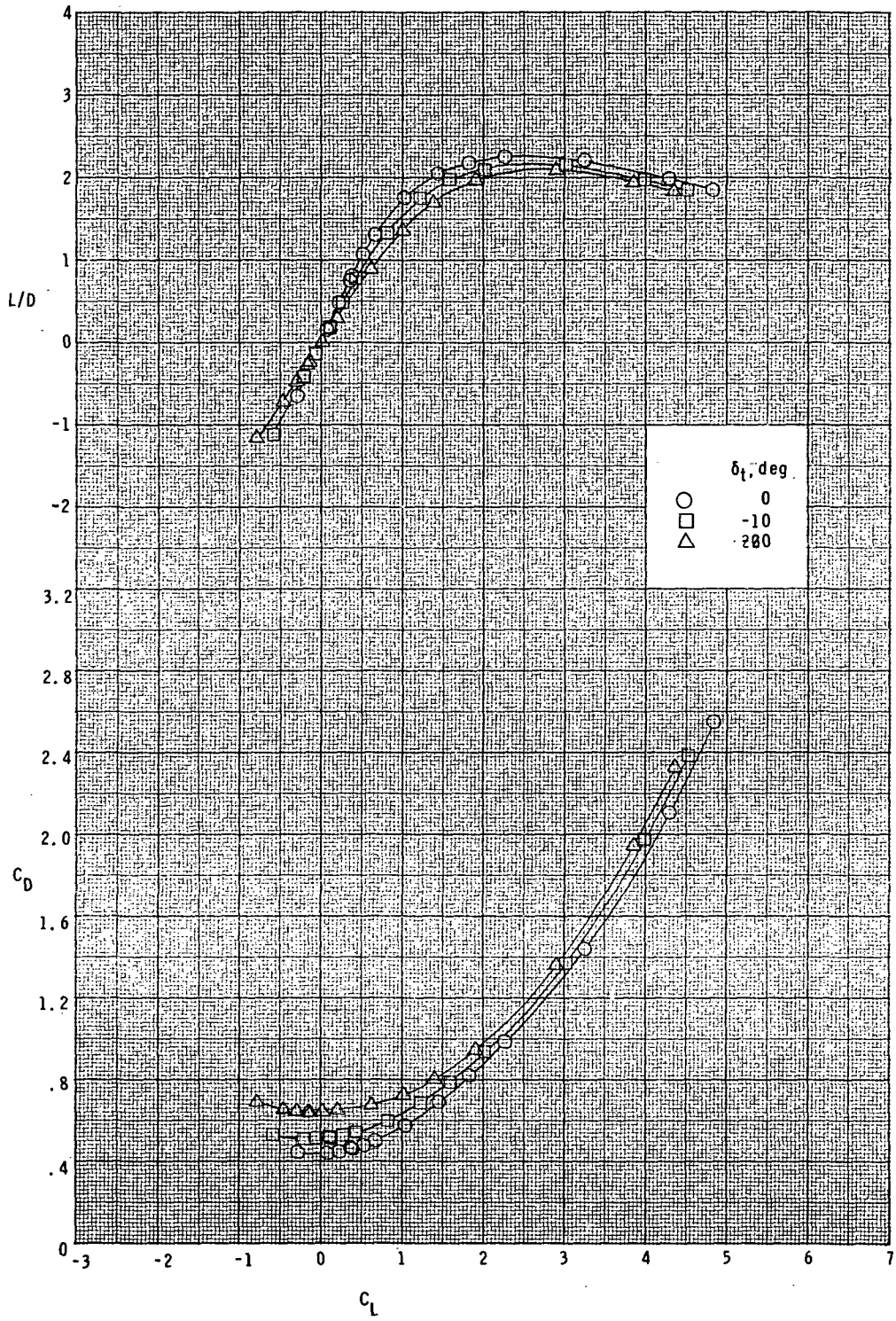
(d) $M = 2.86$.

Figure 11. - Continued.



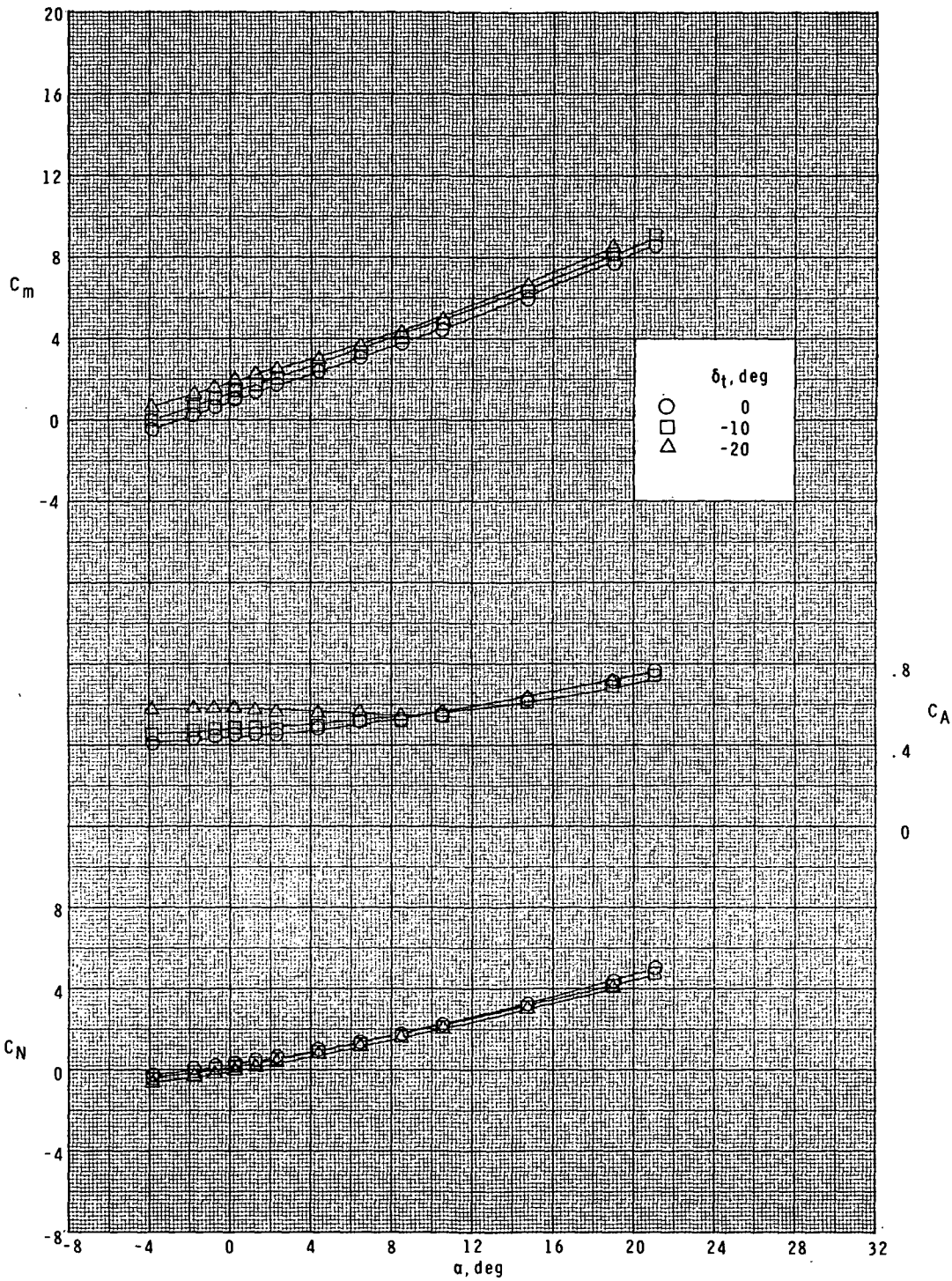
(d) Continued.

Figure 11.- Continued.



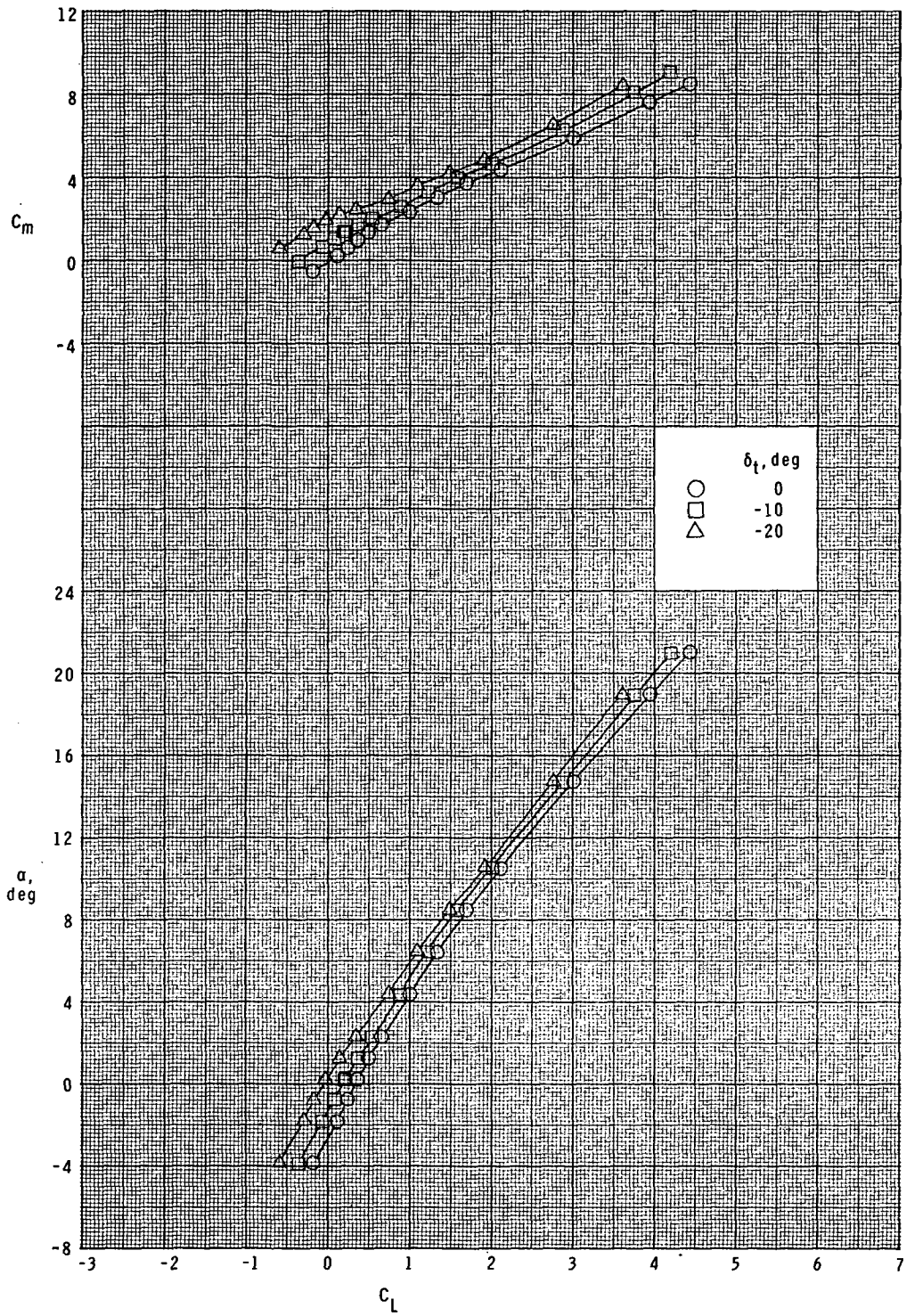
(d) Concluded.

Figure 11. - Continued.



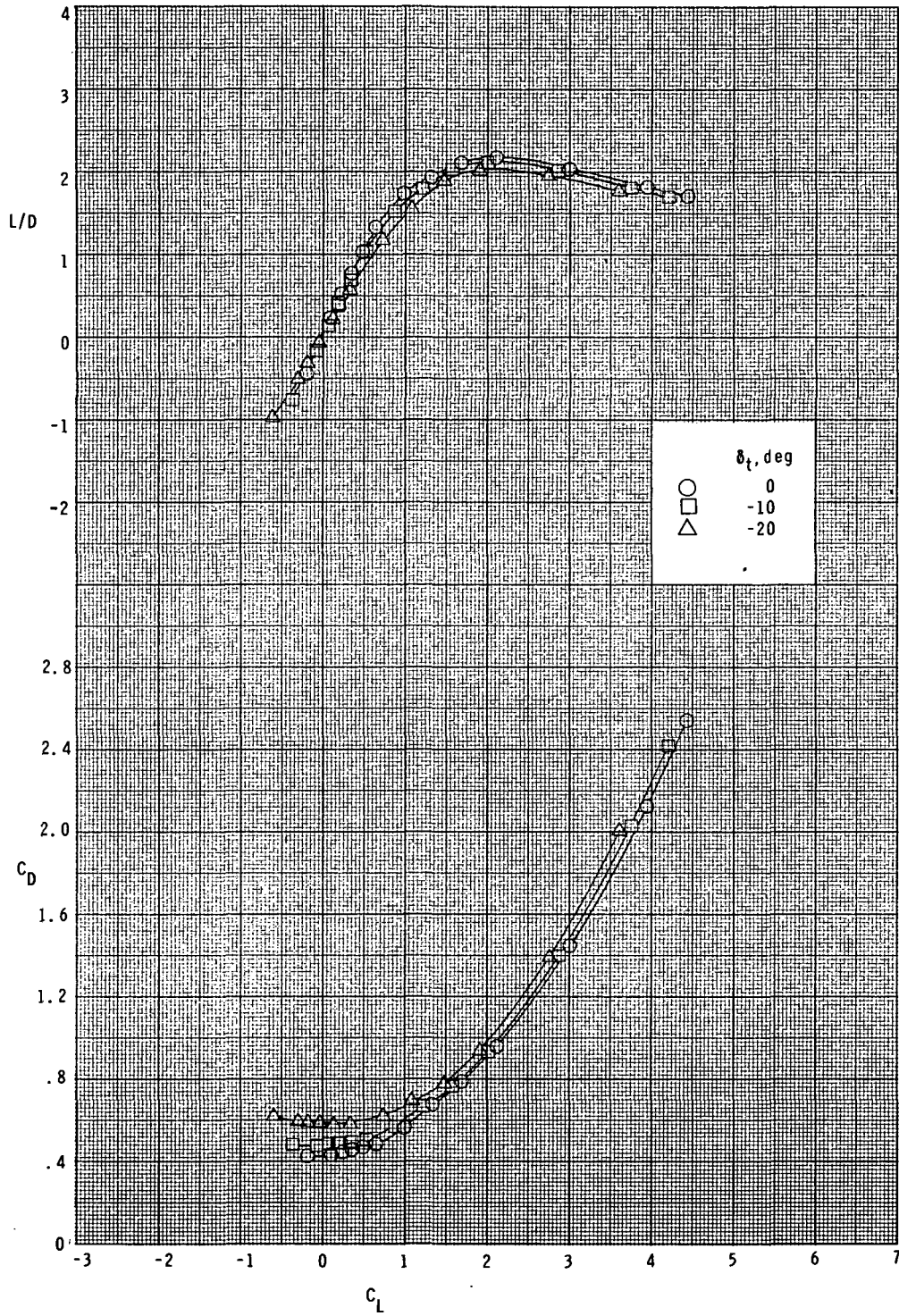
(e) $M = 3.95$.

Figure 11.- Continued.



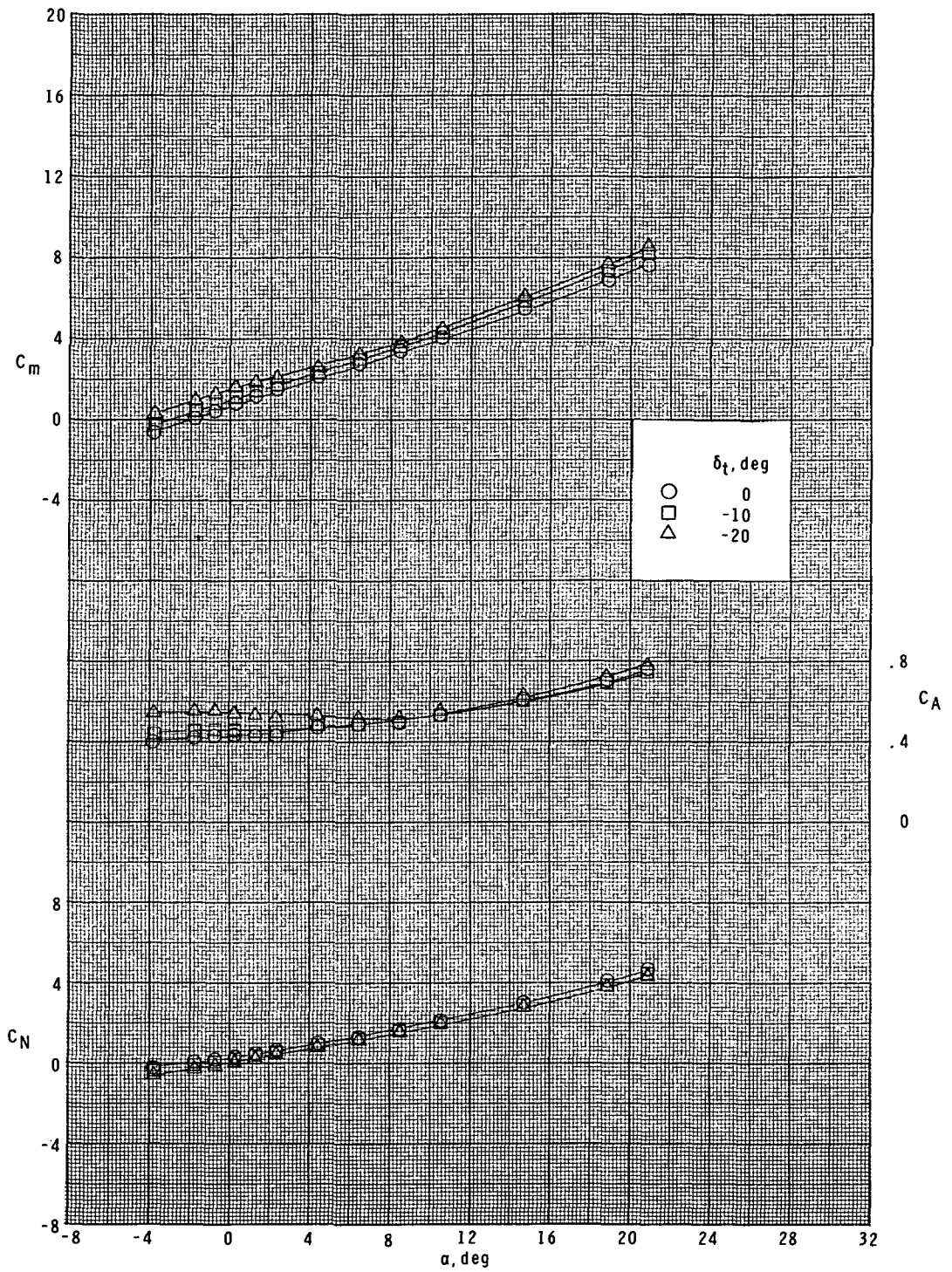
(e) Continued.

Figure 11.- Continued.



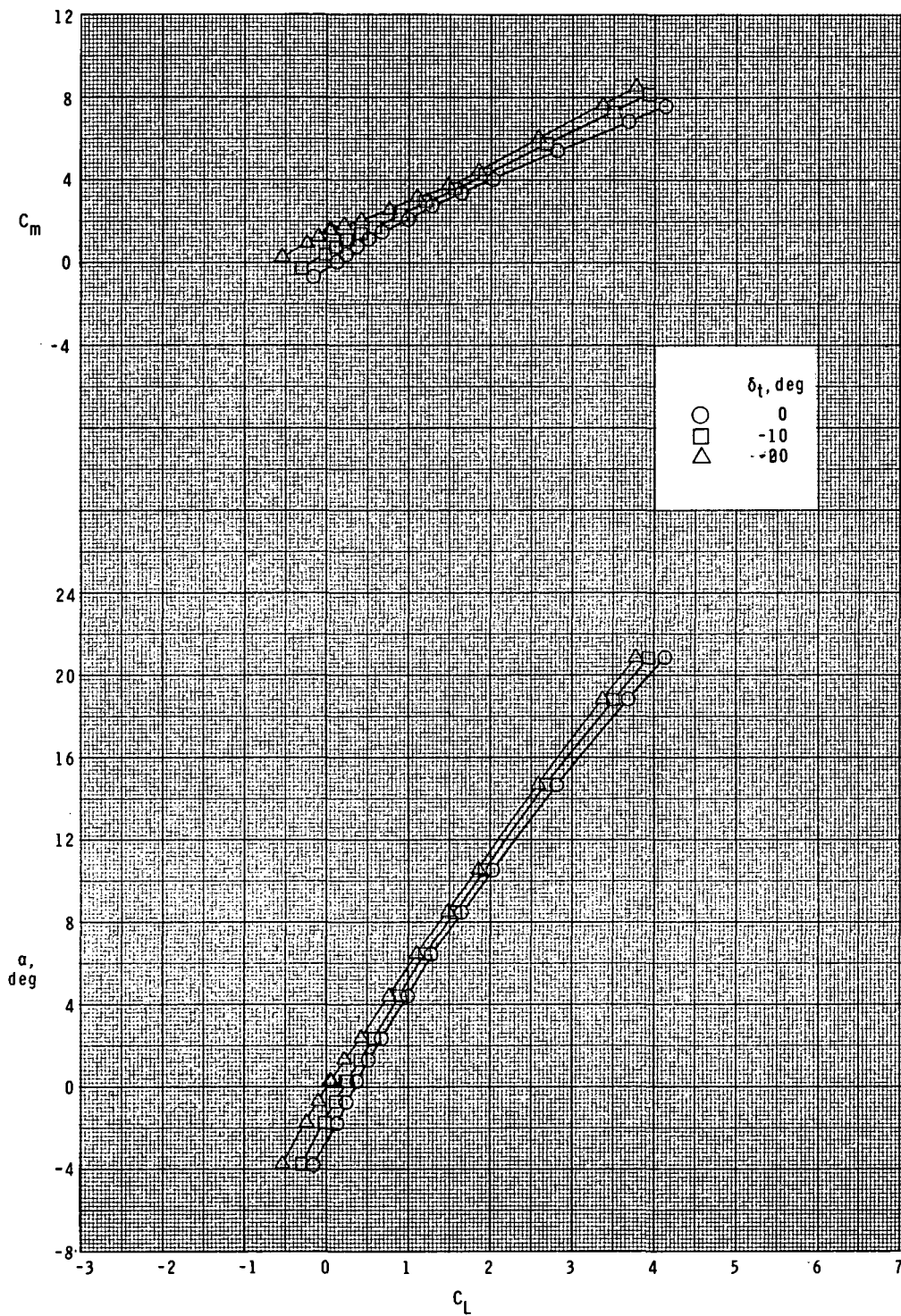
(e) Concluded.

Figure 11.- Continued.



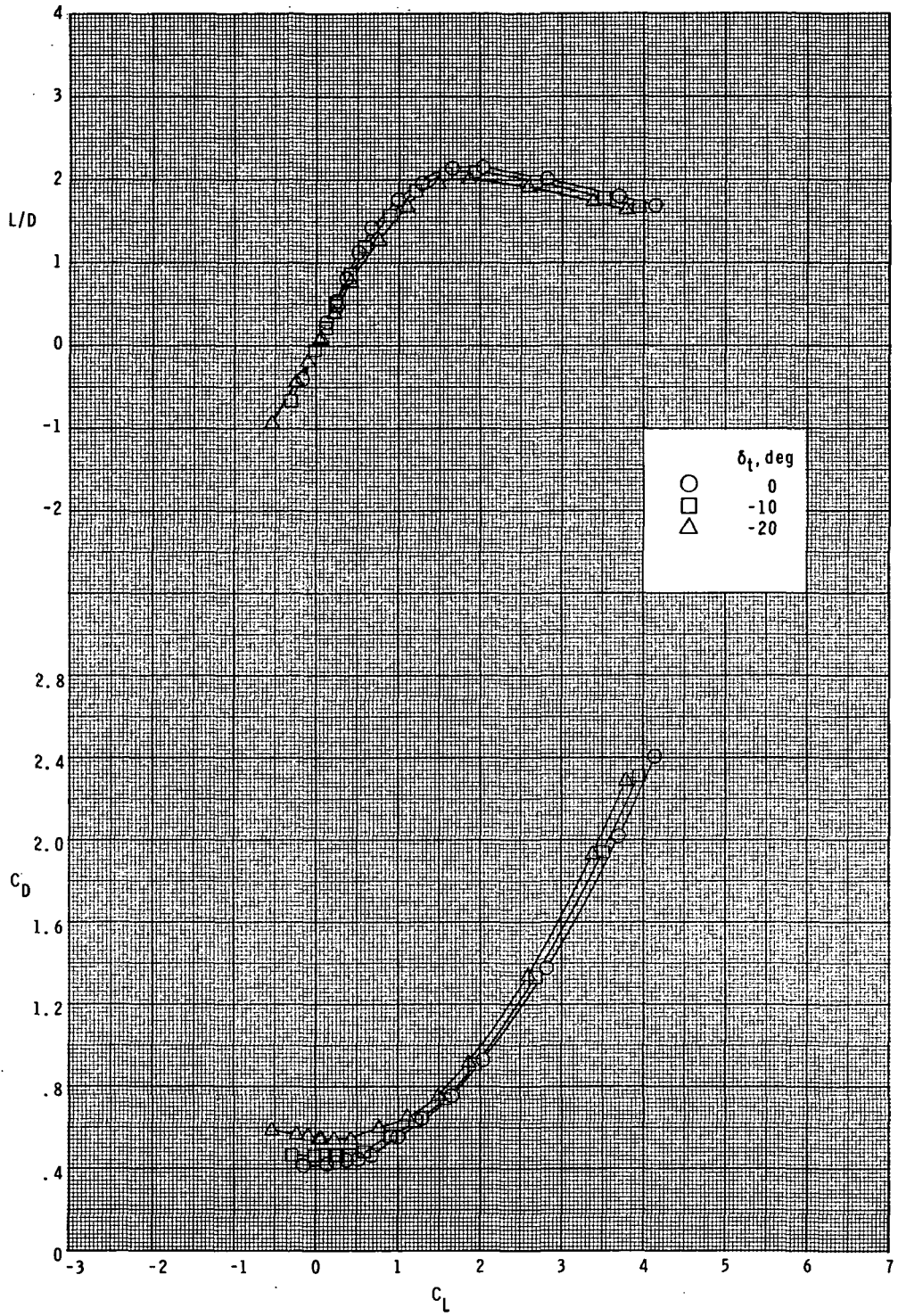
(f) $M = 4.63$.

Figure 11.- Continued.



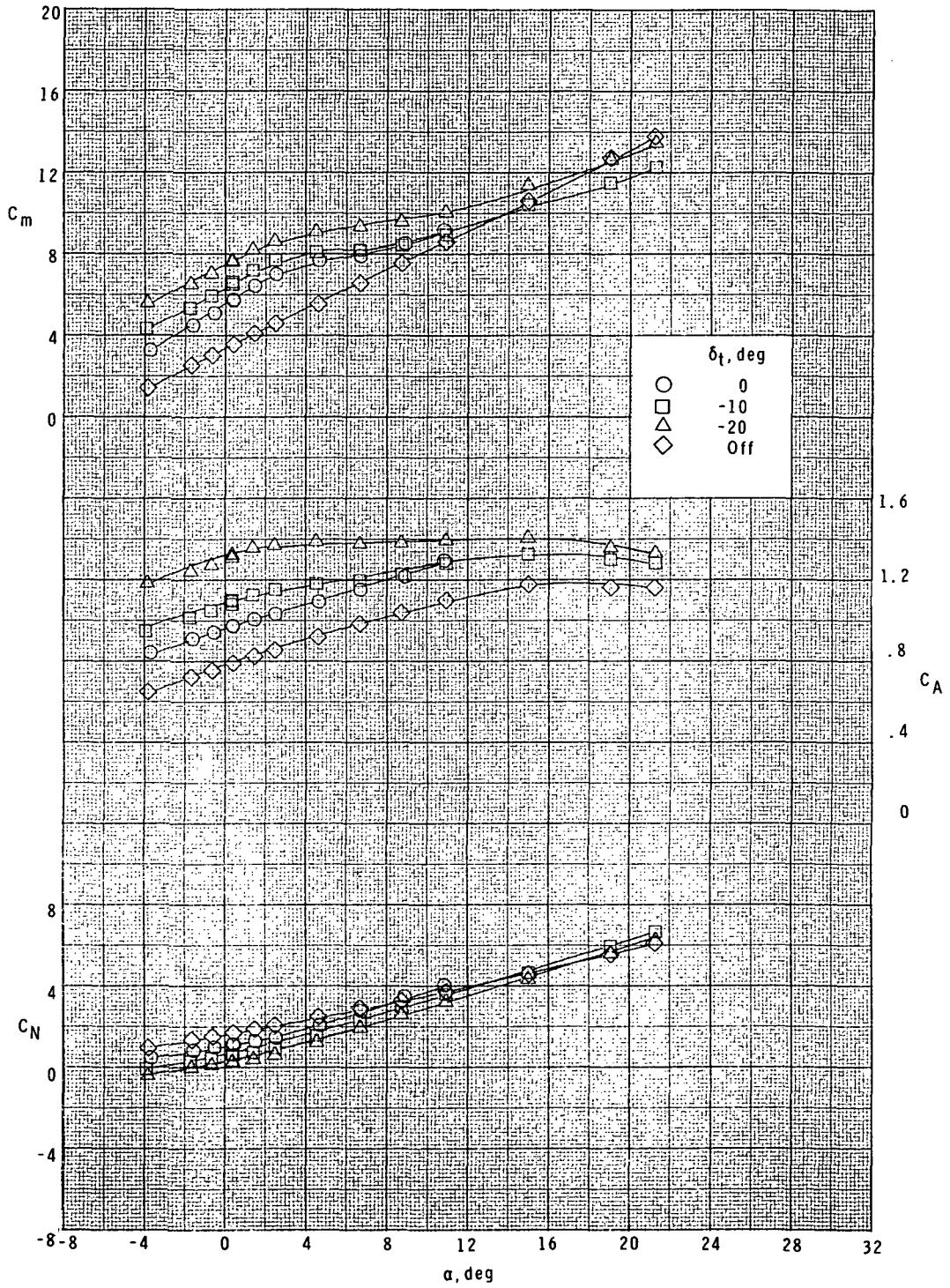
(f) Continued.

Figure 11.- Continued.



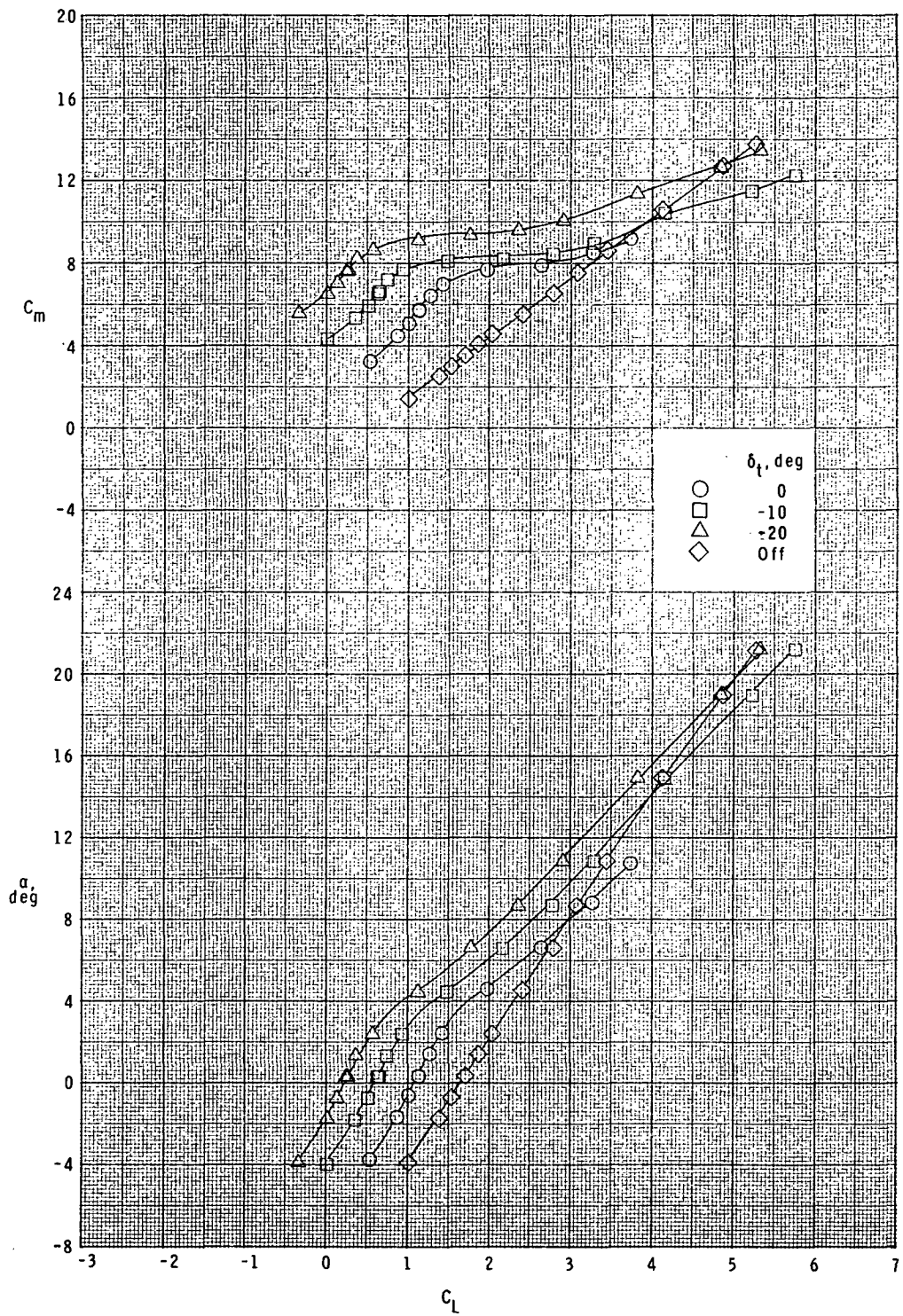
(f) Concluded.

Figure 11.- Concluded.



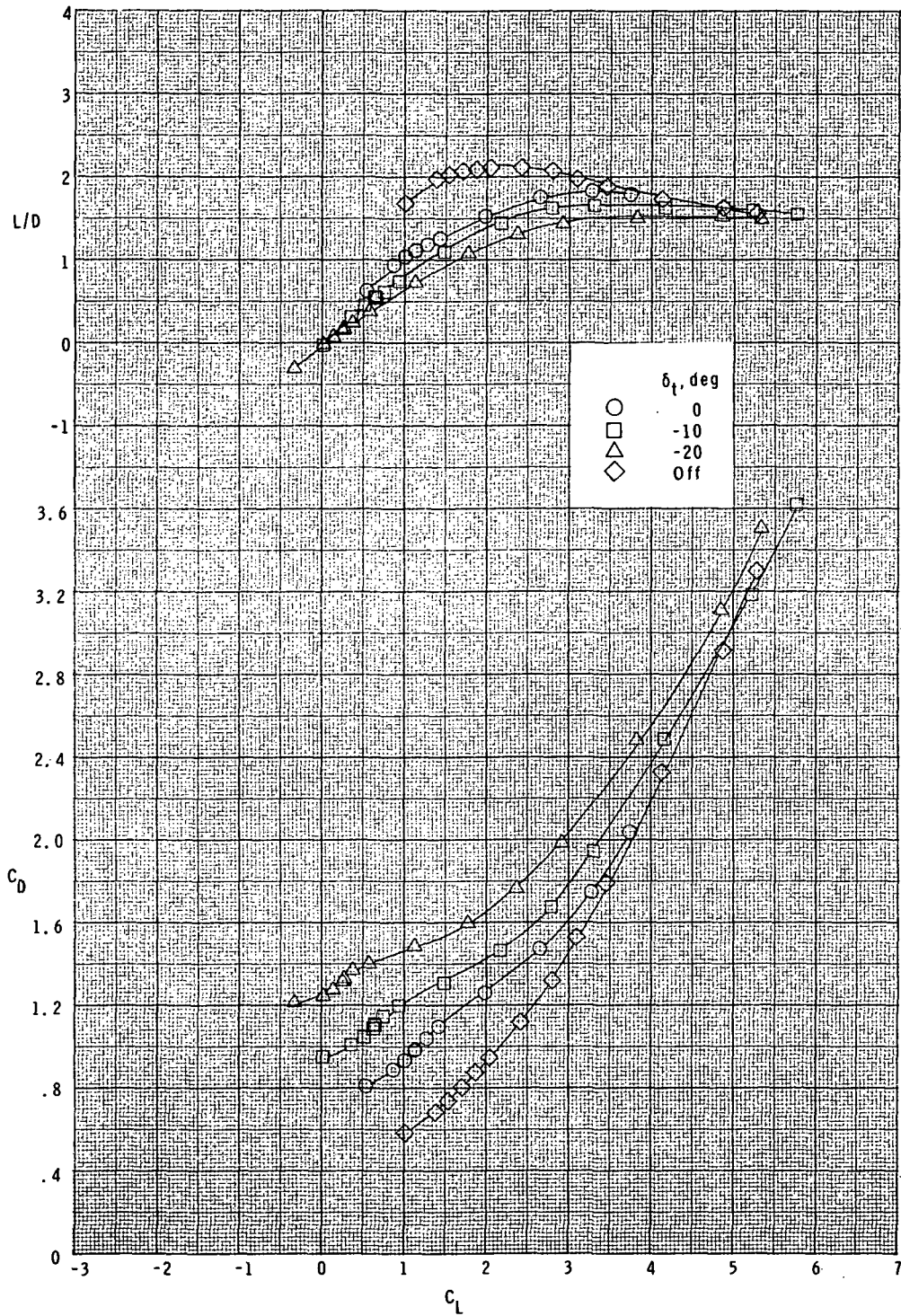
(a) $M = 1.50$.

Figure 12.- Effect of tail deflection on longitudinal aerodynamic characteristics.
 $\delta_w = 20^\circ$; $\phi = 0^\circ$; tails in line.



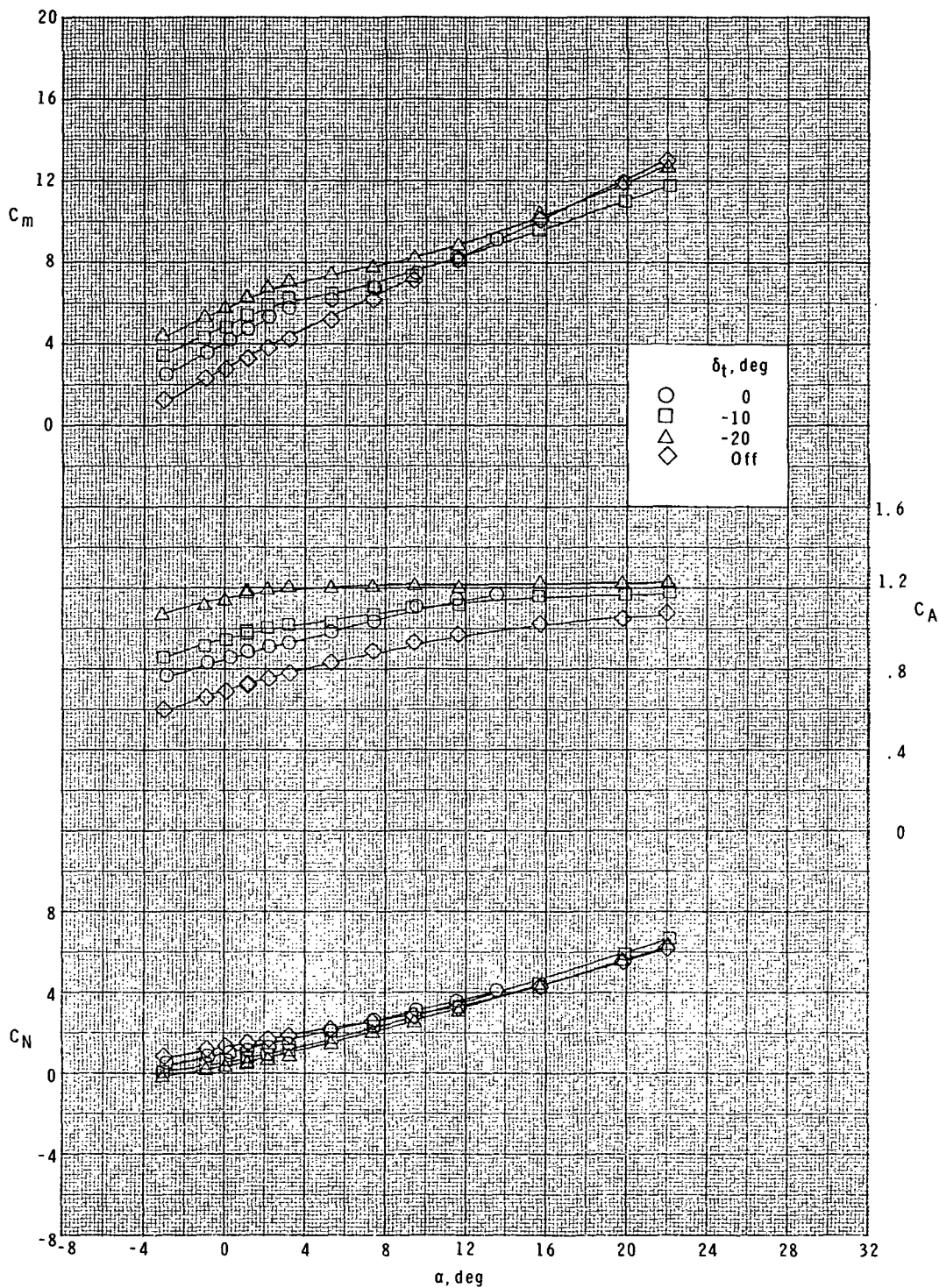
(a) Continued.

Figure 12. - Continued.



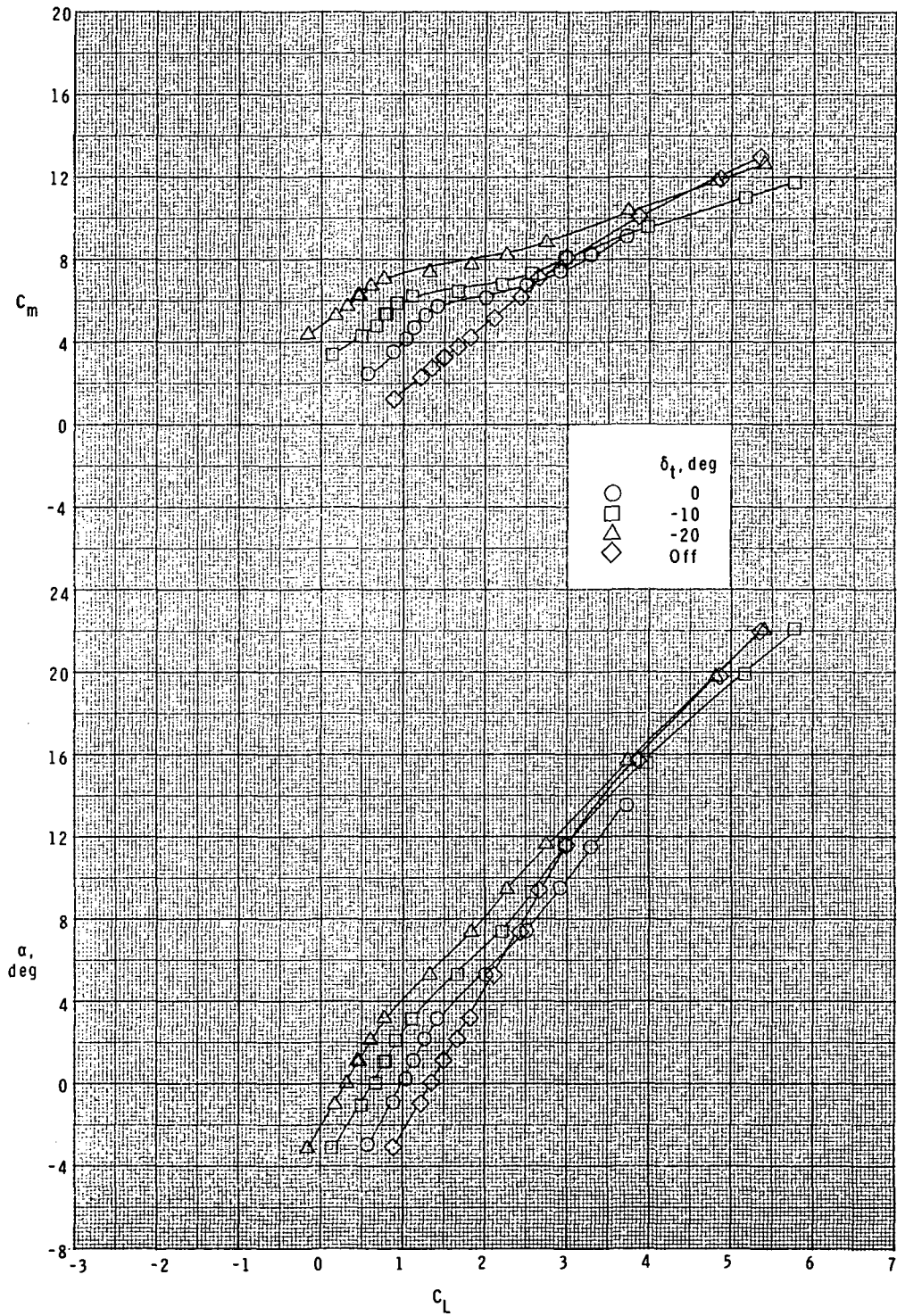
(a) Concluded.

Figure 12. - Continued.



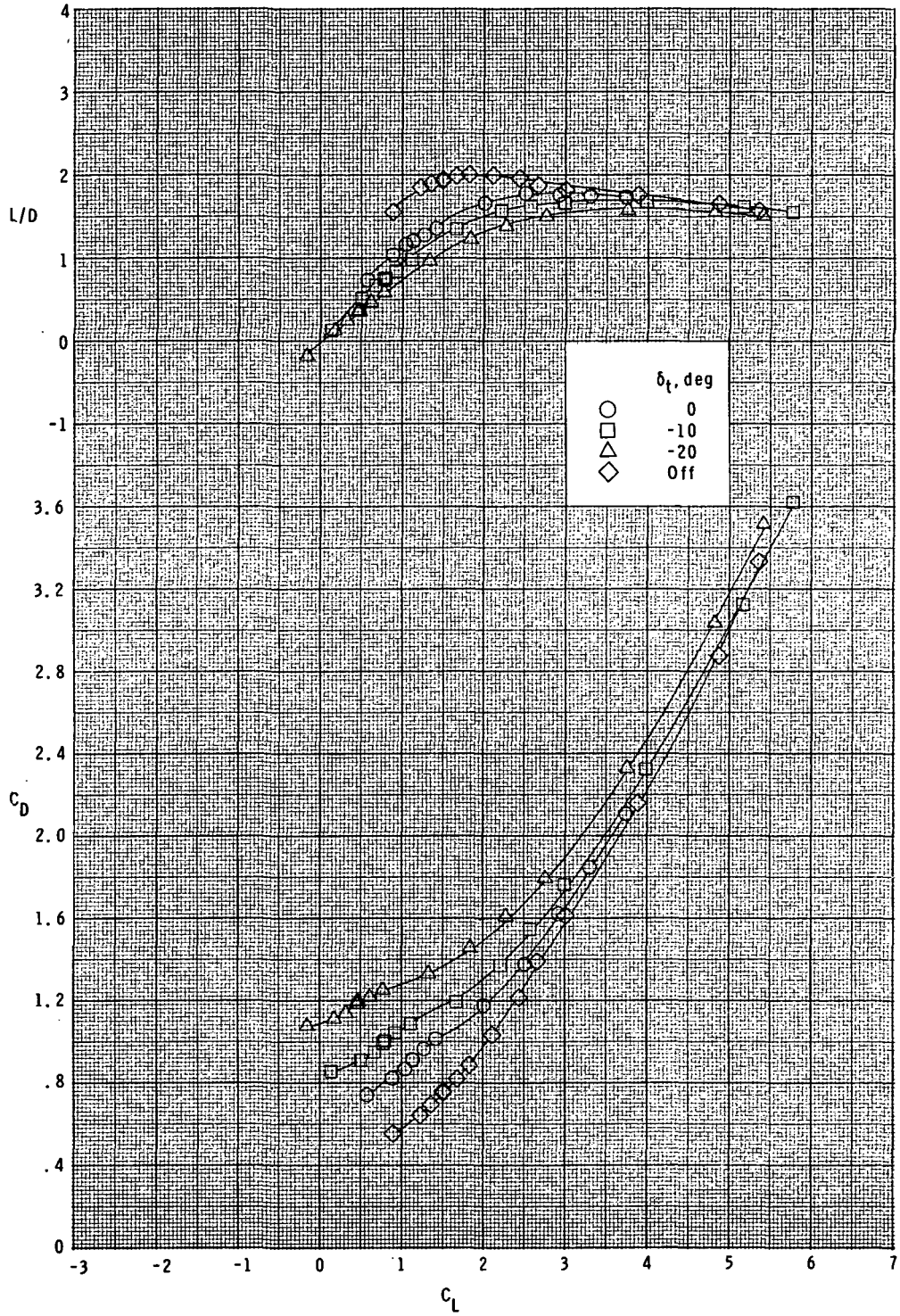
(b) $M = 1.90$.

Figure 12.- Continued.



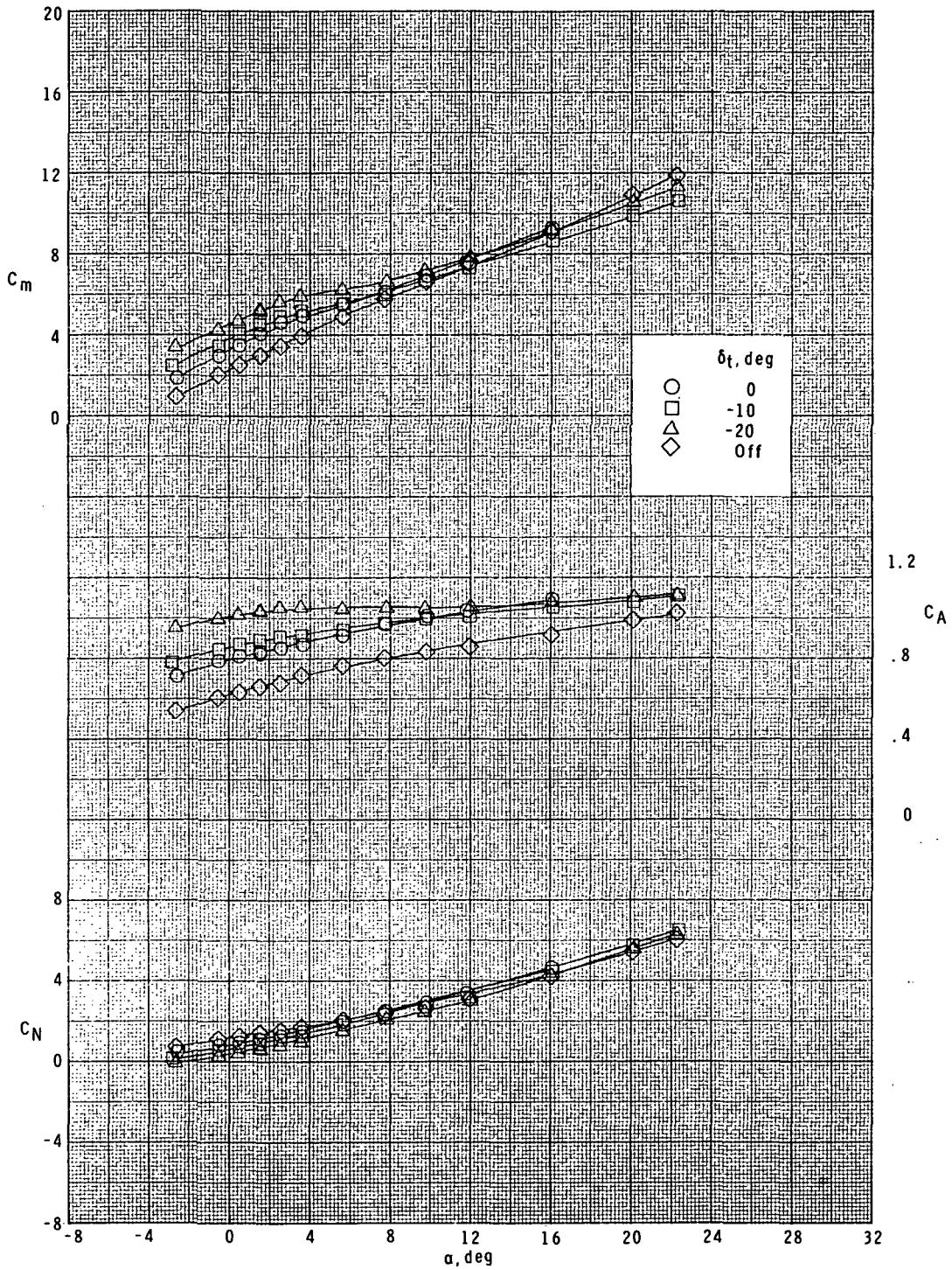
(b) Continued.

Figure 12.- Continued.



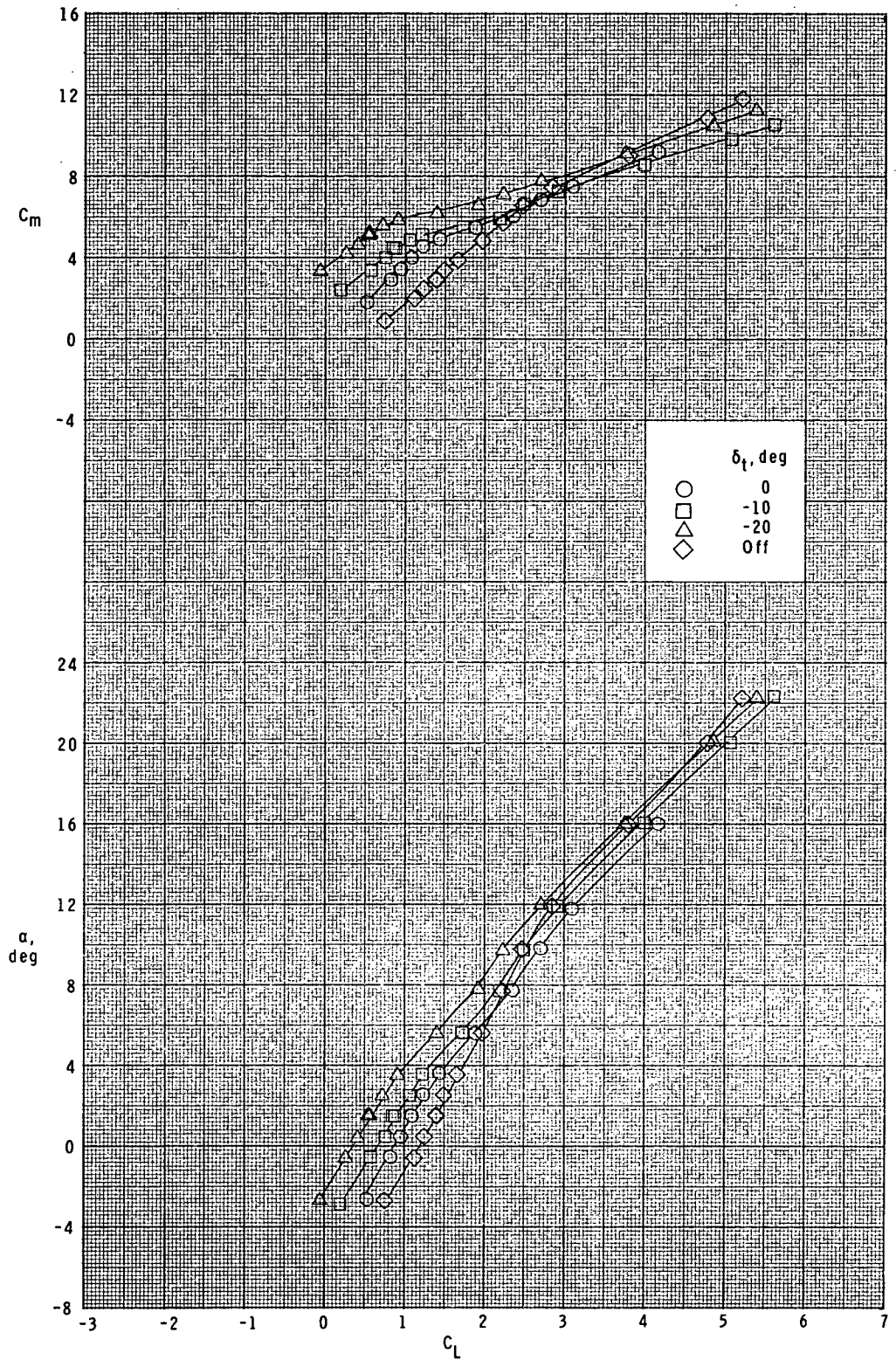
(b) Concluded.

Figure 12.- Continued.



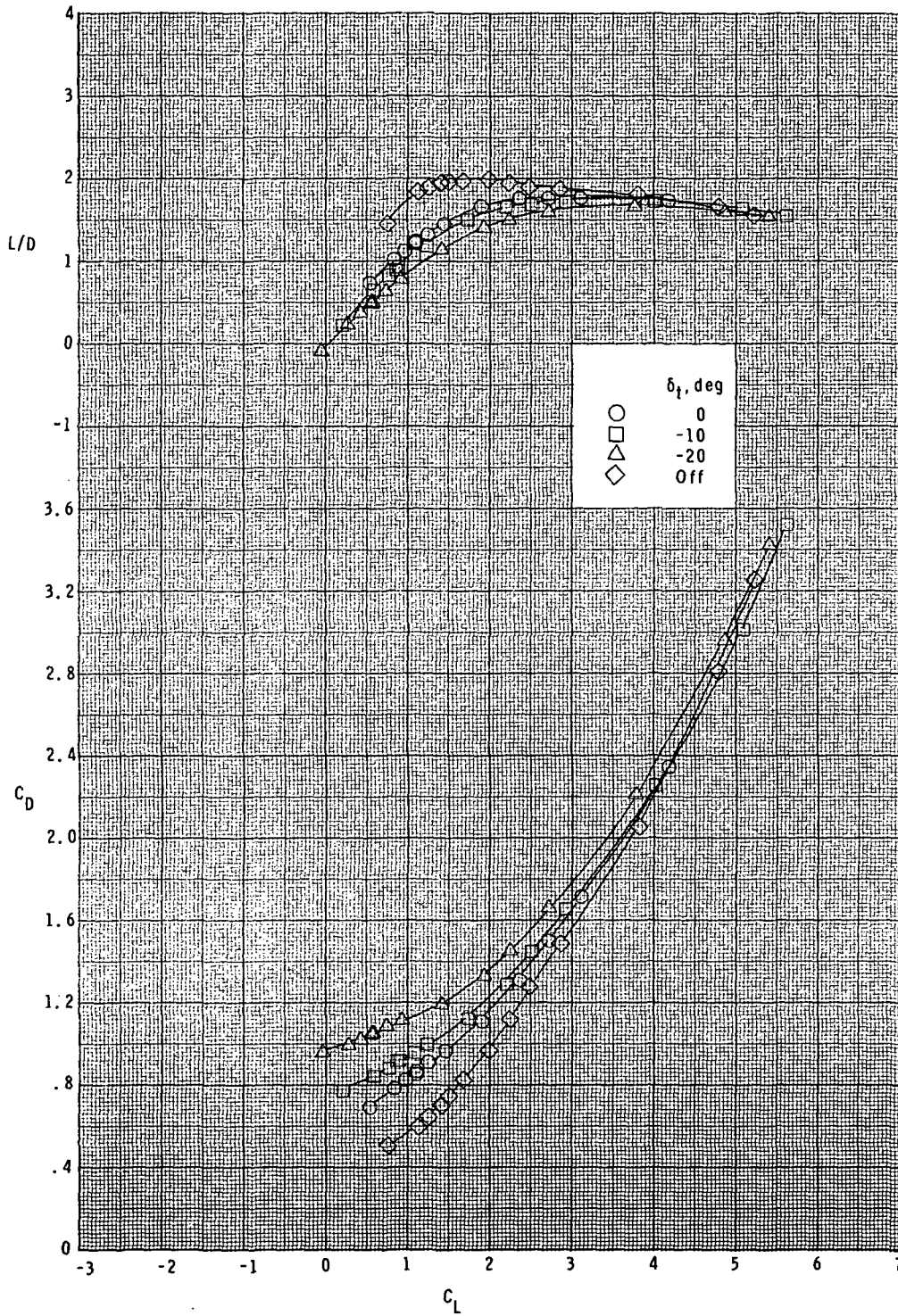
(c) $M = 2.36$.

Figure 12. - Continued.



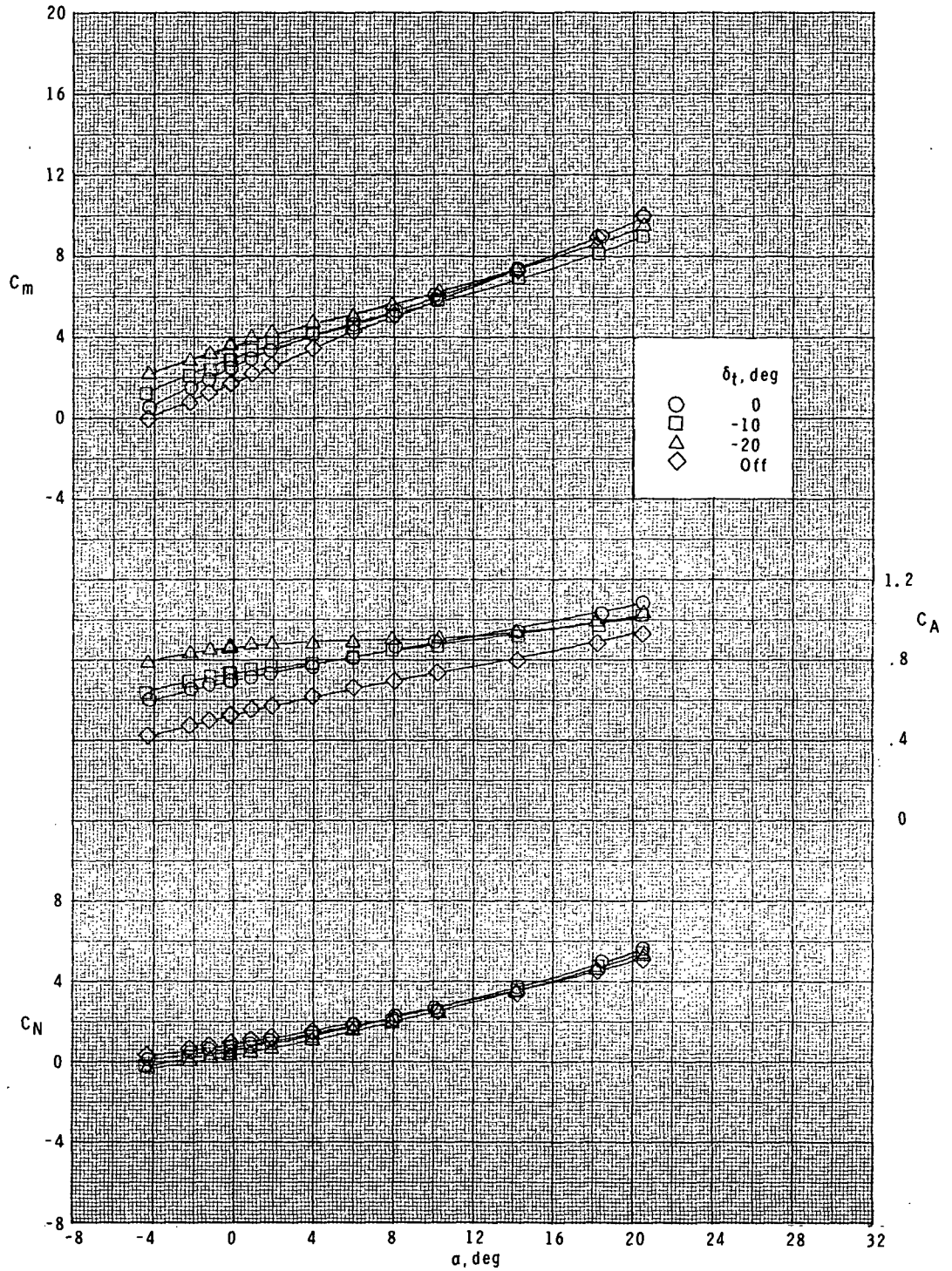
(c) Continued.

Figure 12. - Continued.



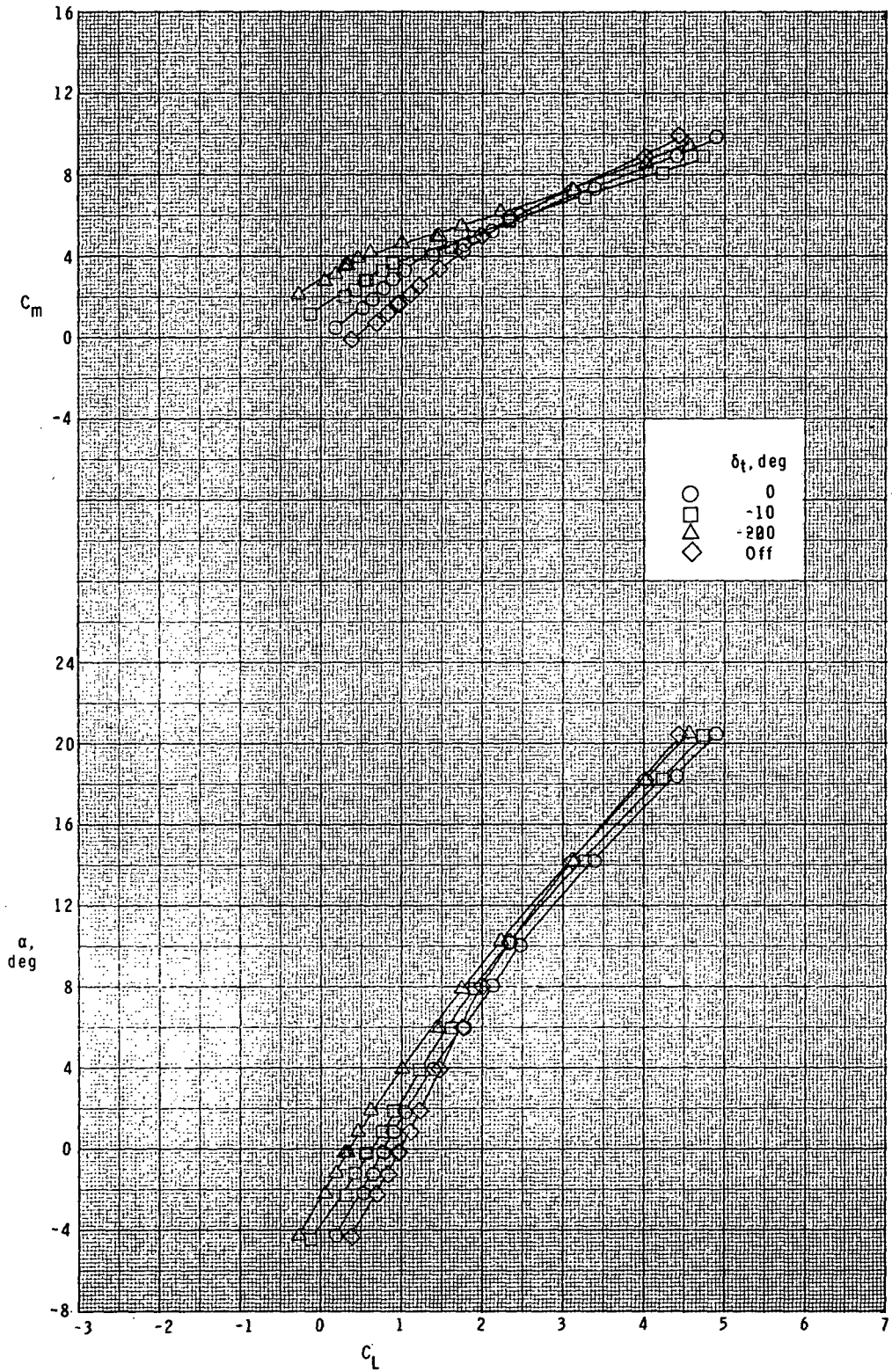
(c) Concluded.

Figure 12.- Continued.



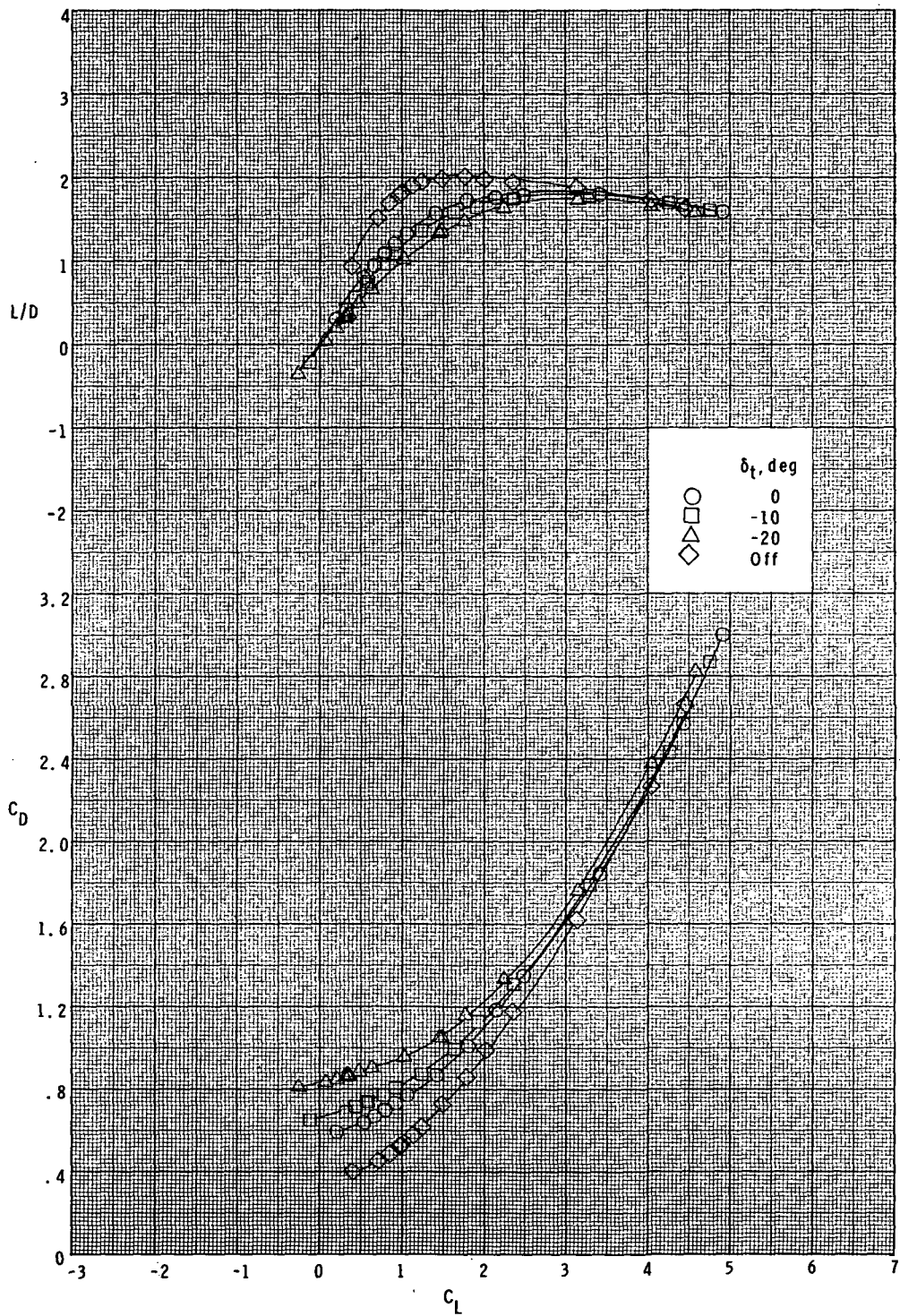
(d) $M = 2.86$.

Figure 12. - Continued.



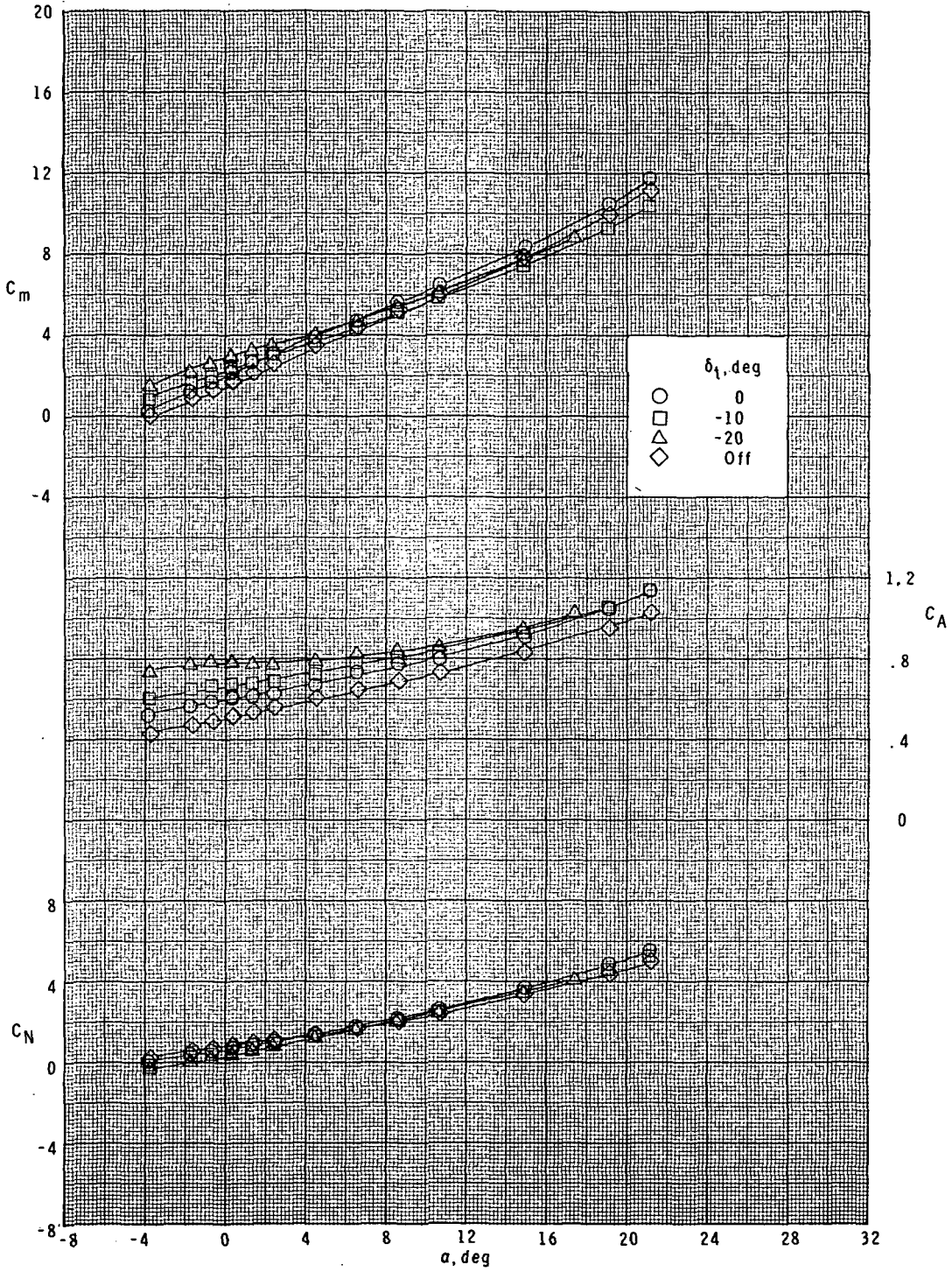
(d) Continued.

Figure 12.- Continued.



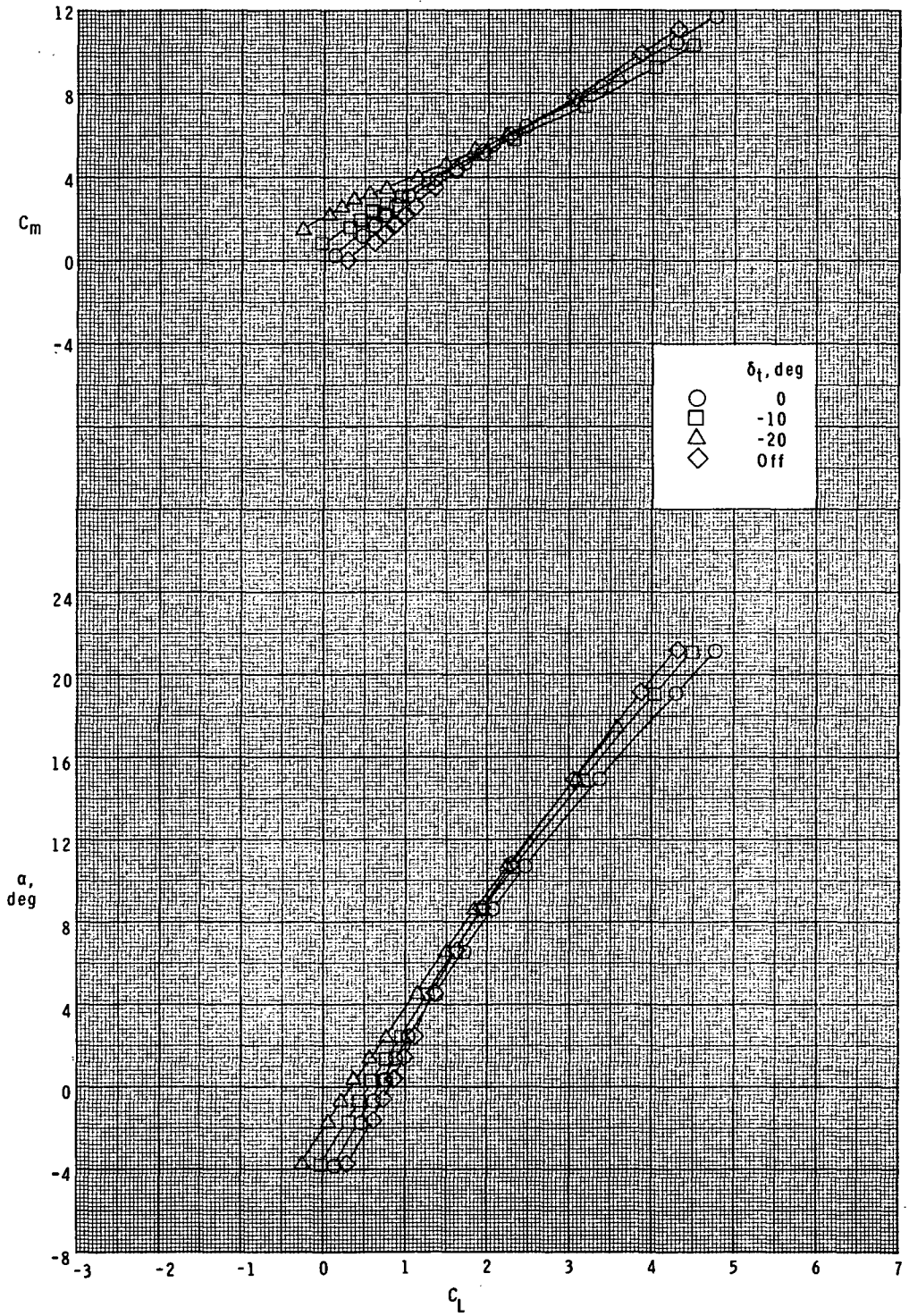
(d) Concluded.

Figure 12.- Continued.



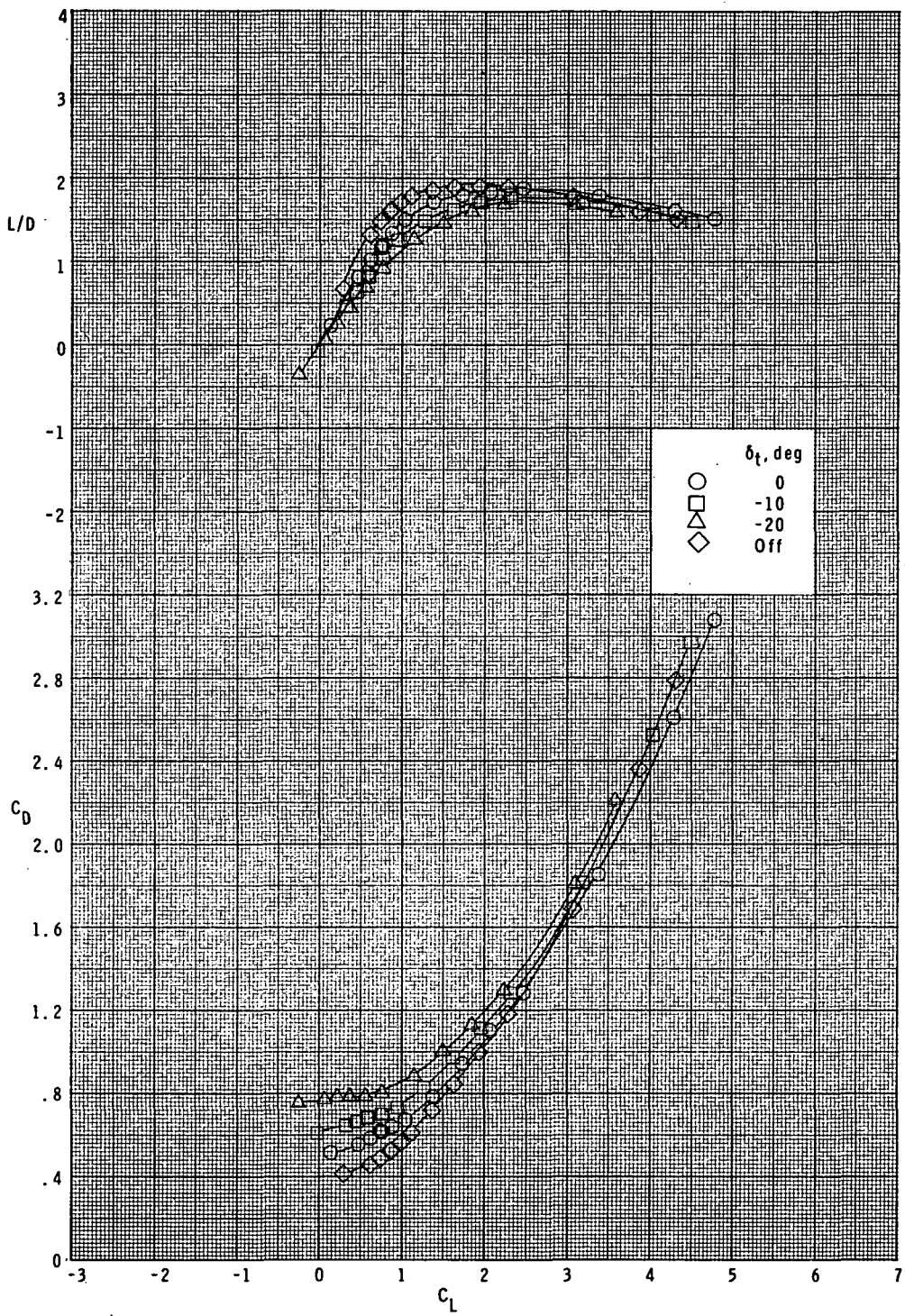
(e) $M = 3.95$.

Figure 12.- Continued.



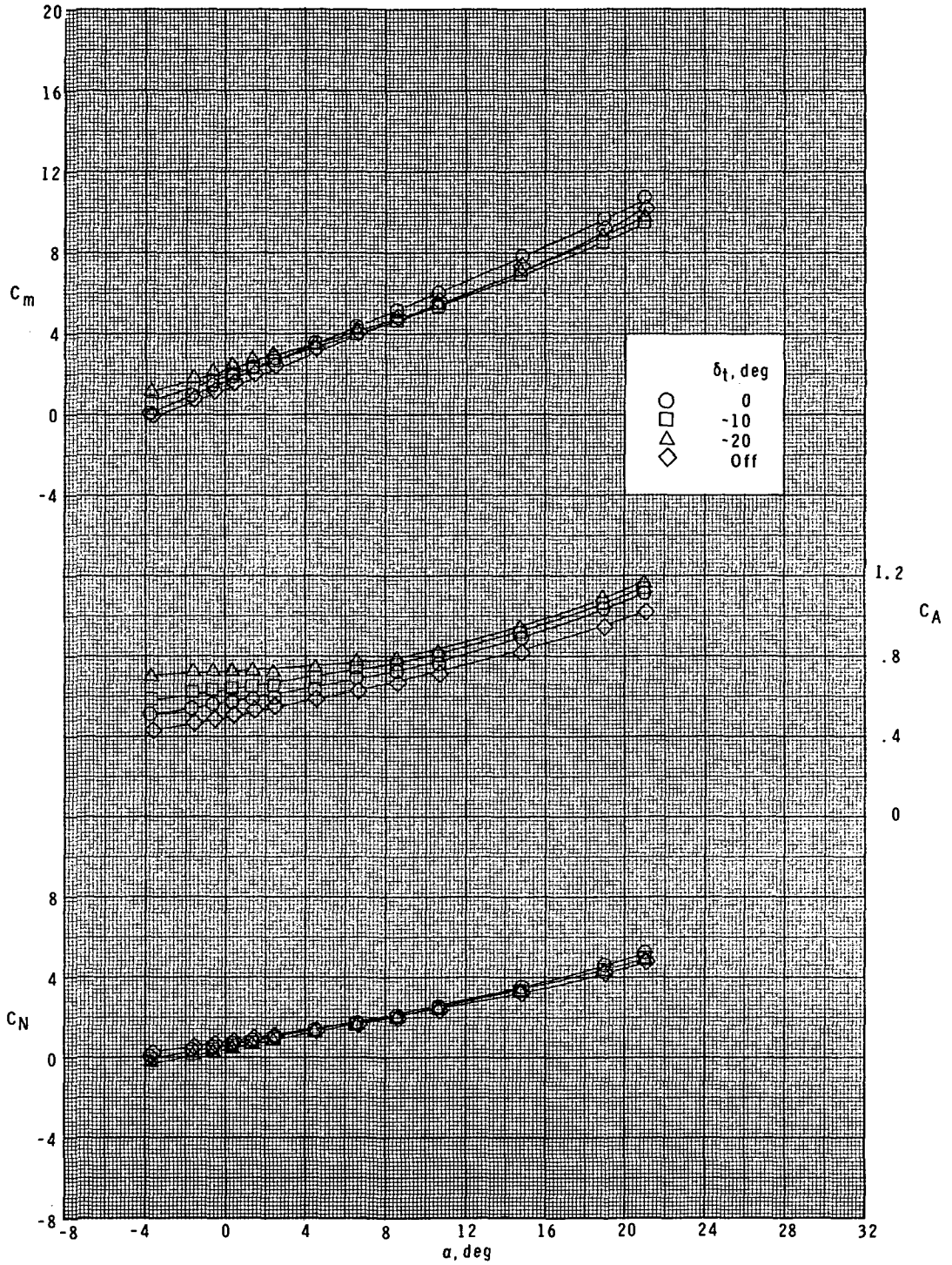
(e) Continued.

Figure 12. - Continued.



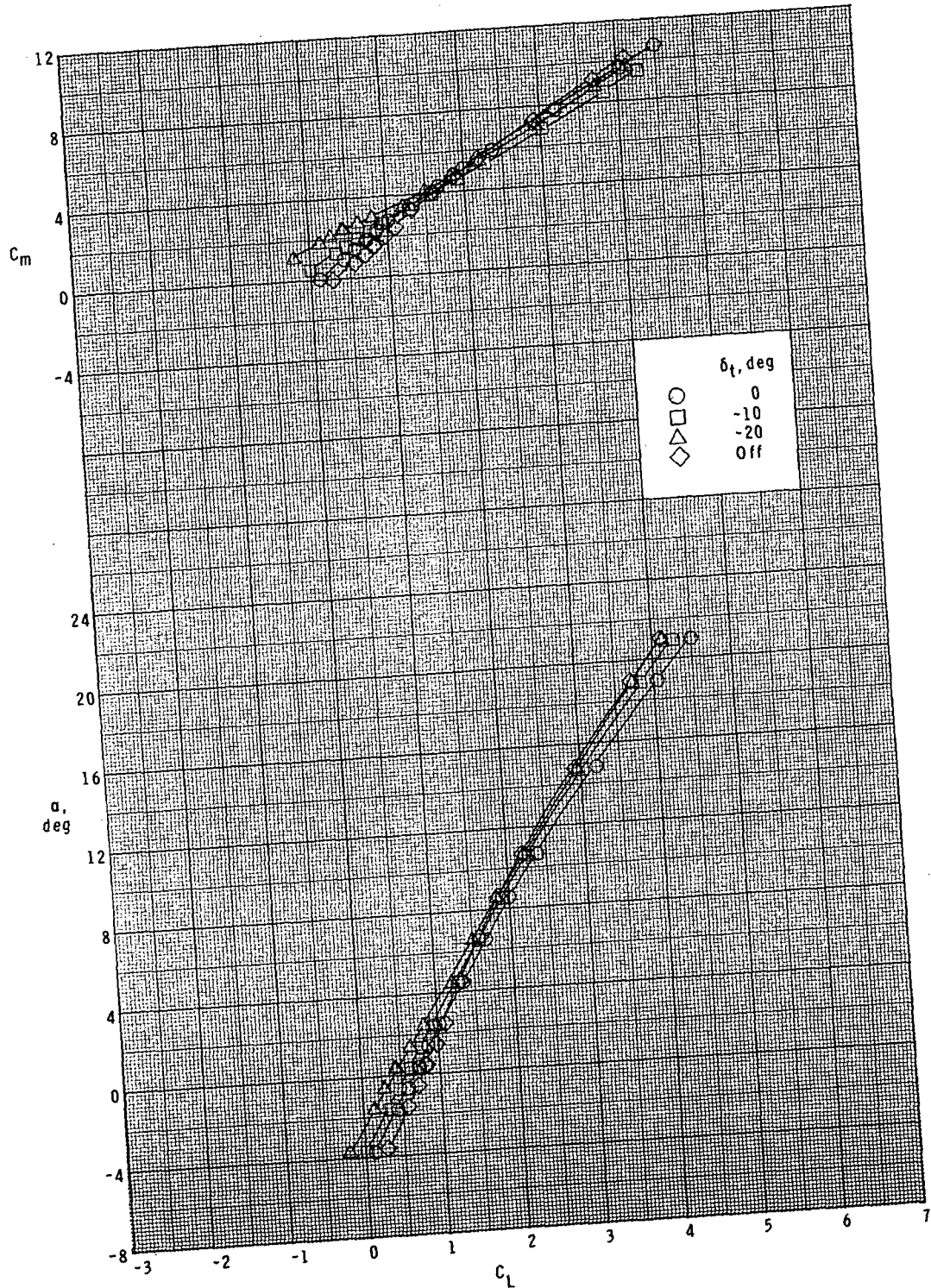
(e) Concluded.

Figure 12. - Continued.

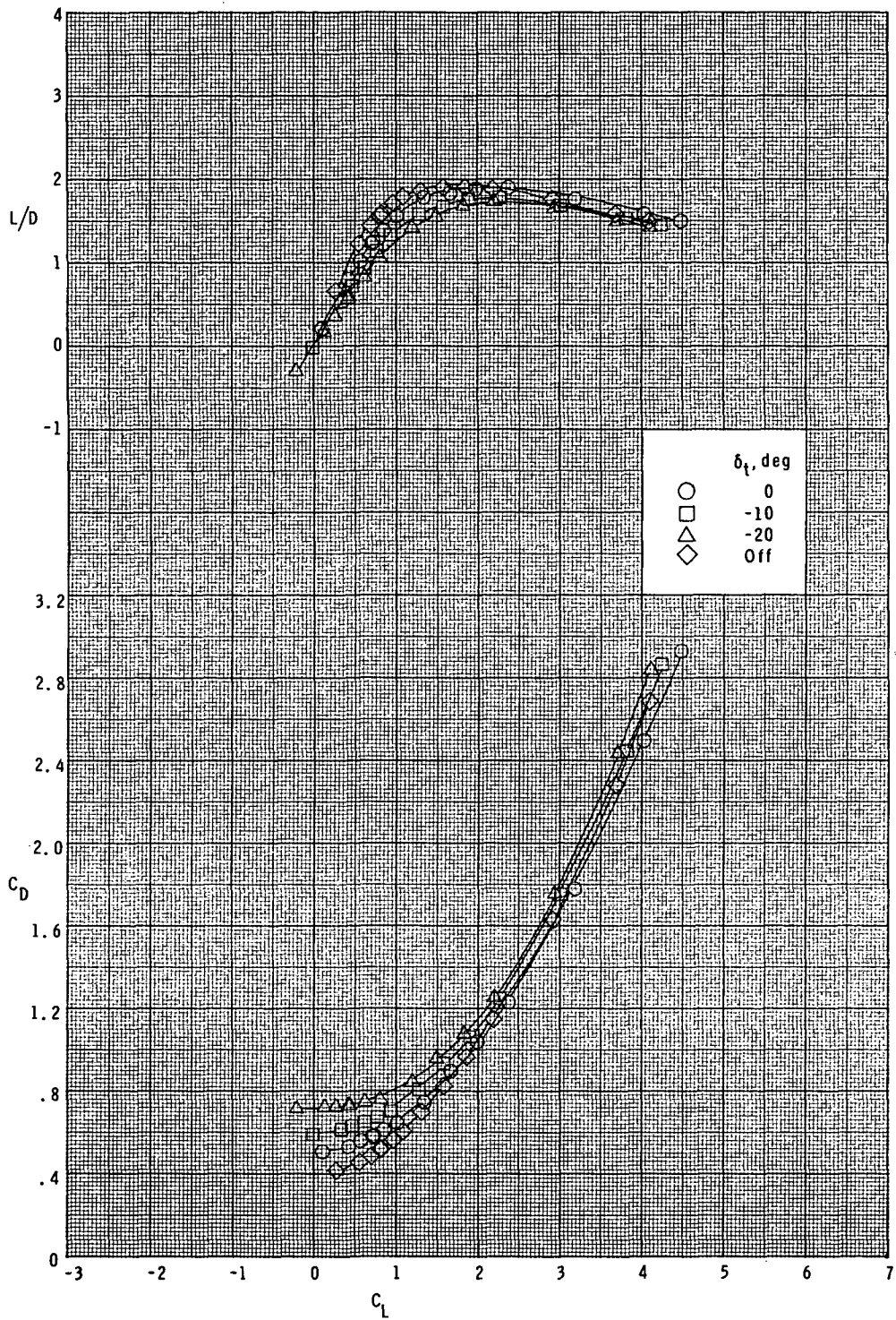


(f) $M = 4.63$.

Figure 12.- Continued.

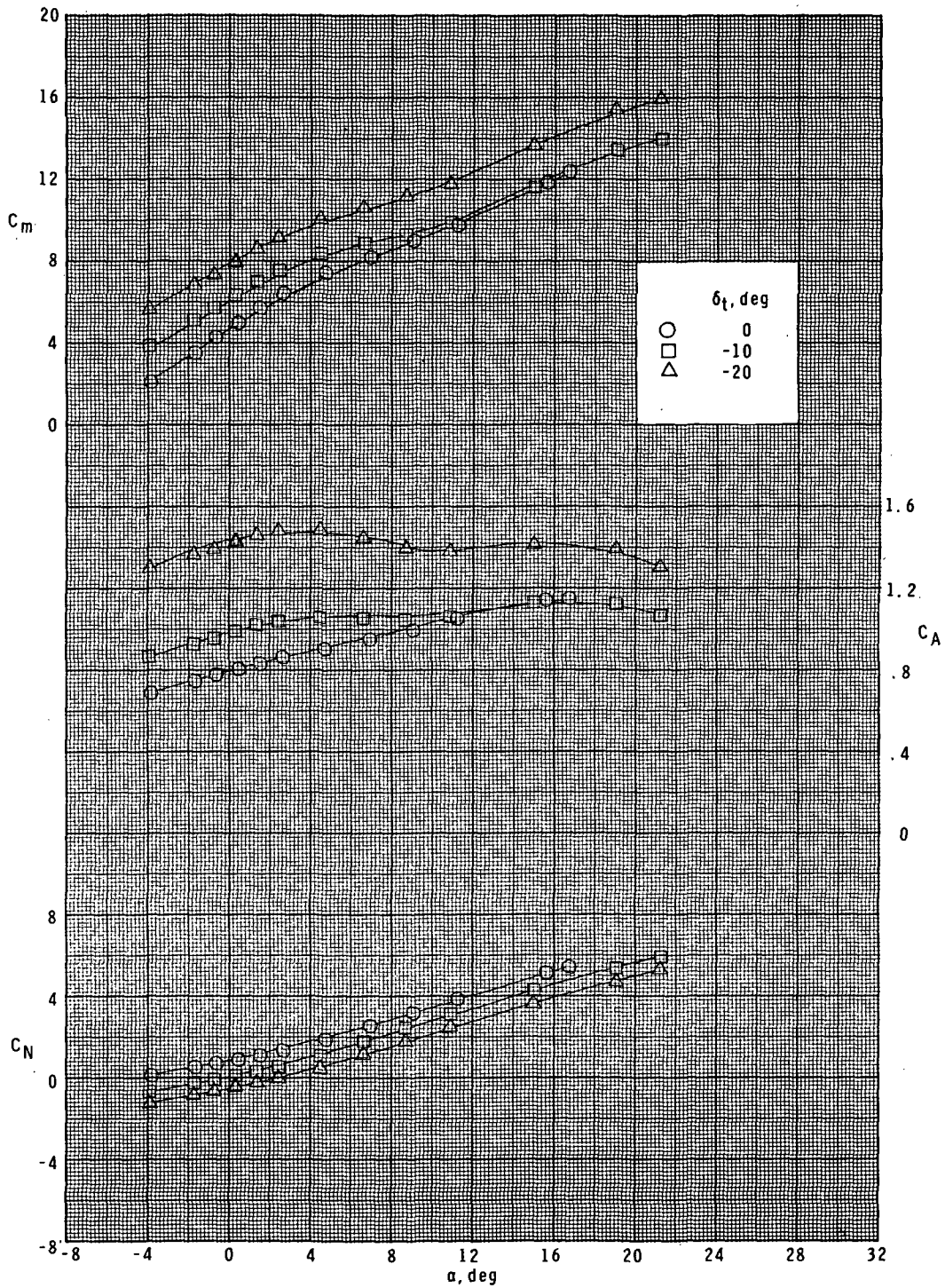


(f) Continued.
 Figure 12.- Continued.



(f) Concluded.

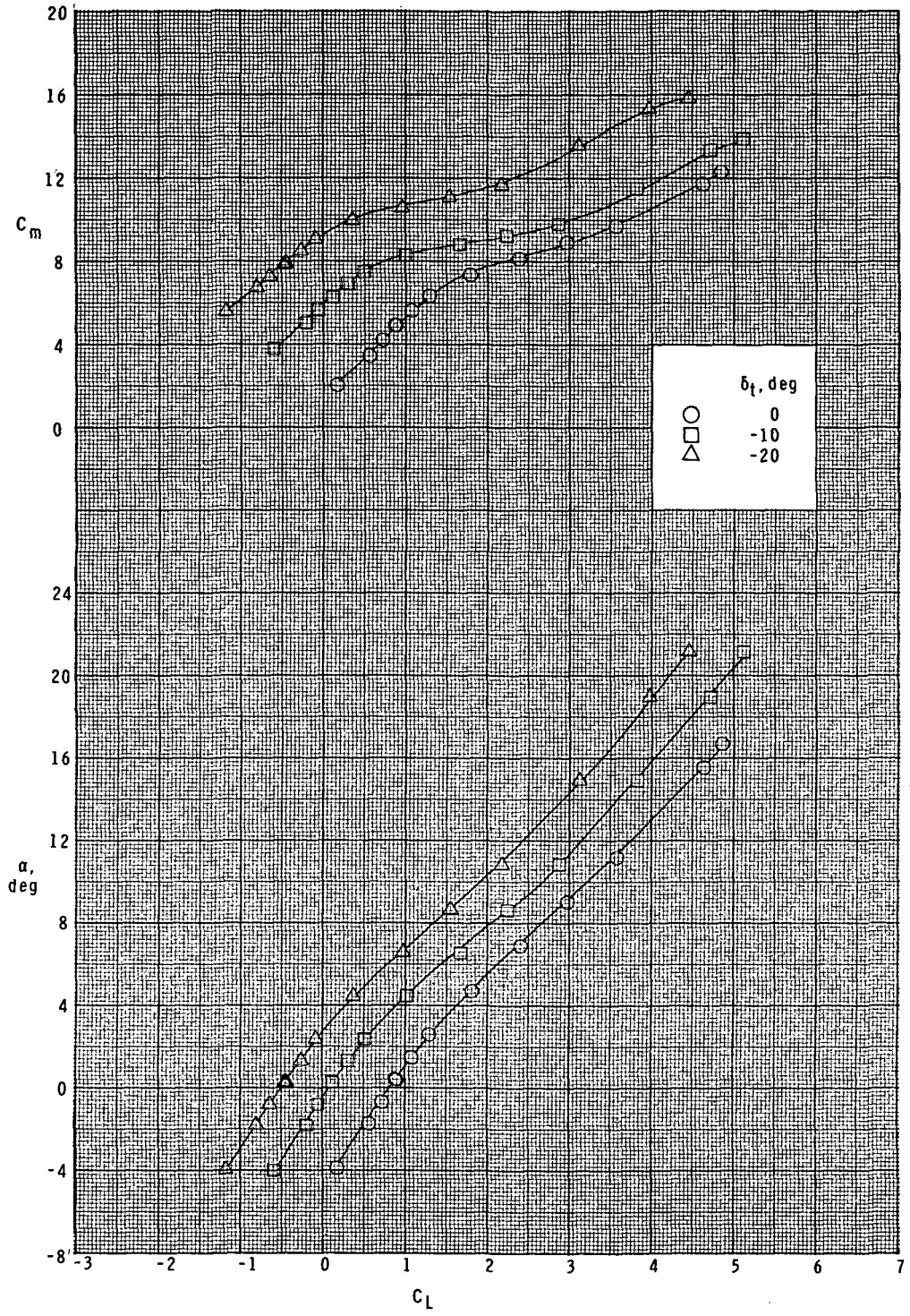
Figure 12. - Concluded.



(a) $M = 1.50$.

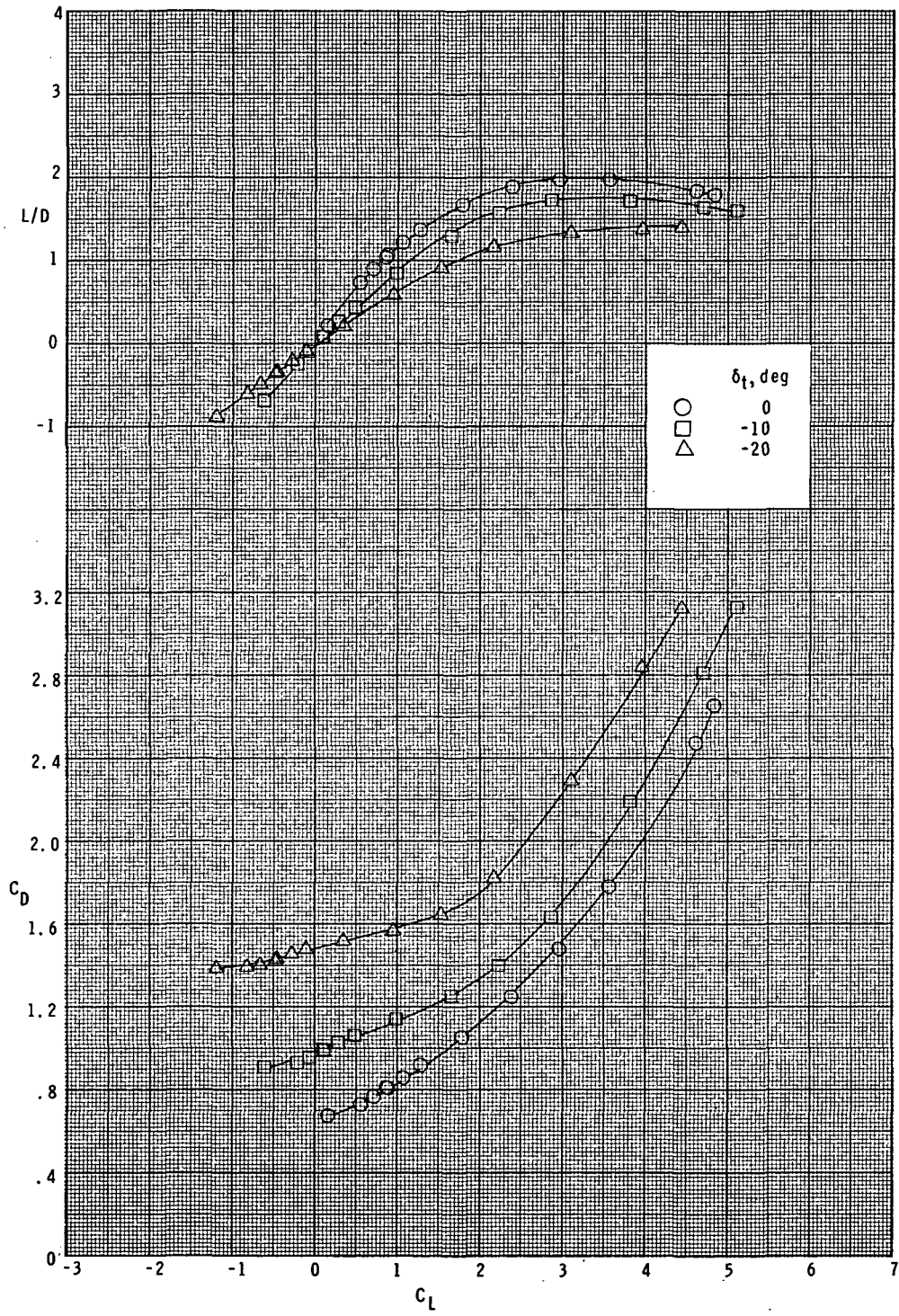
Figure 13.- Effect of tail deflection on longitudinal aerodynamic characteristics.

$\delta_w = 10^\circ$; $\phi = 45^\circ$; tails in line.



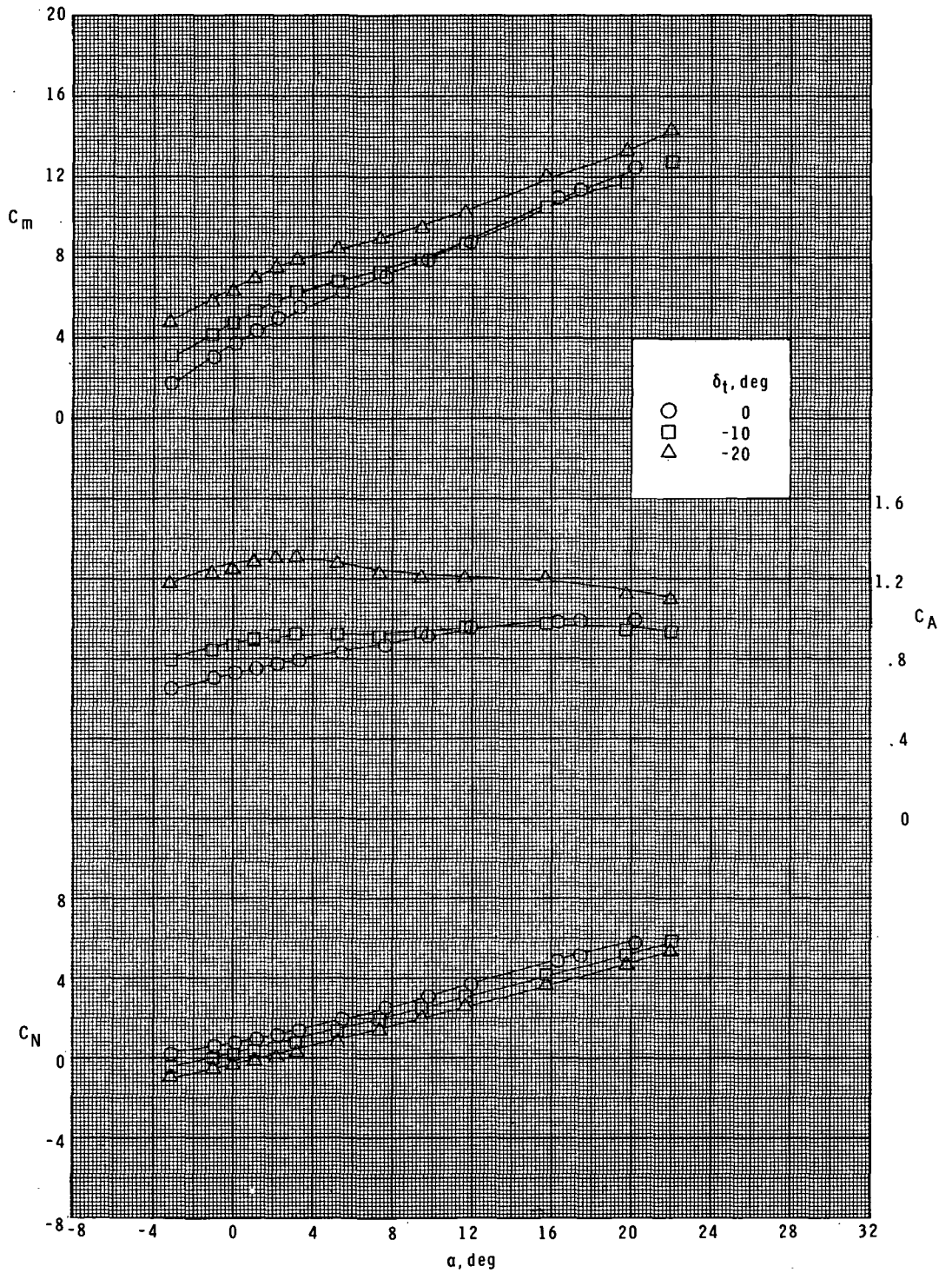
(a) Continued.

Figure 13.- Continued.



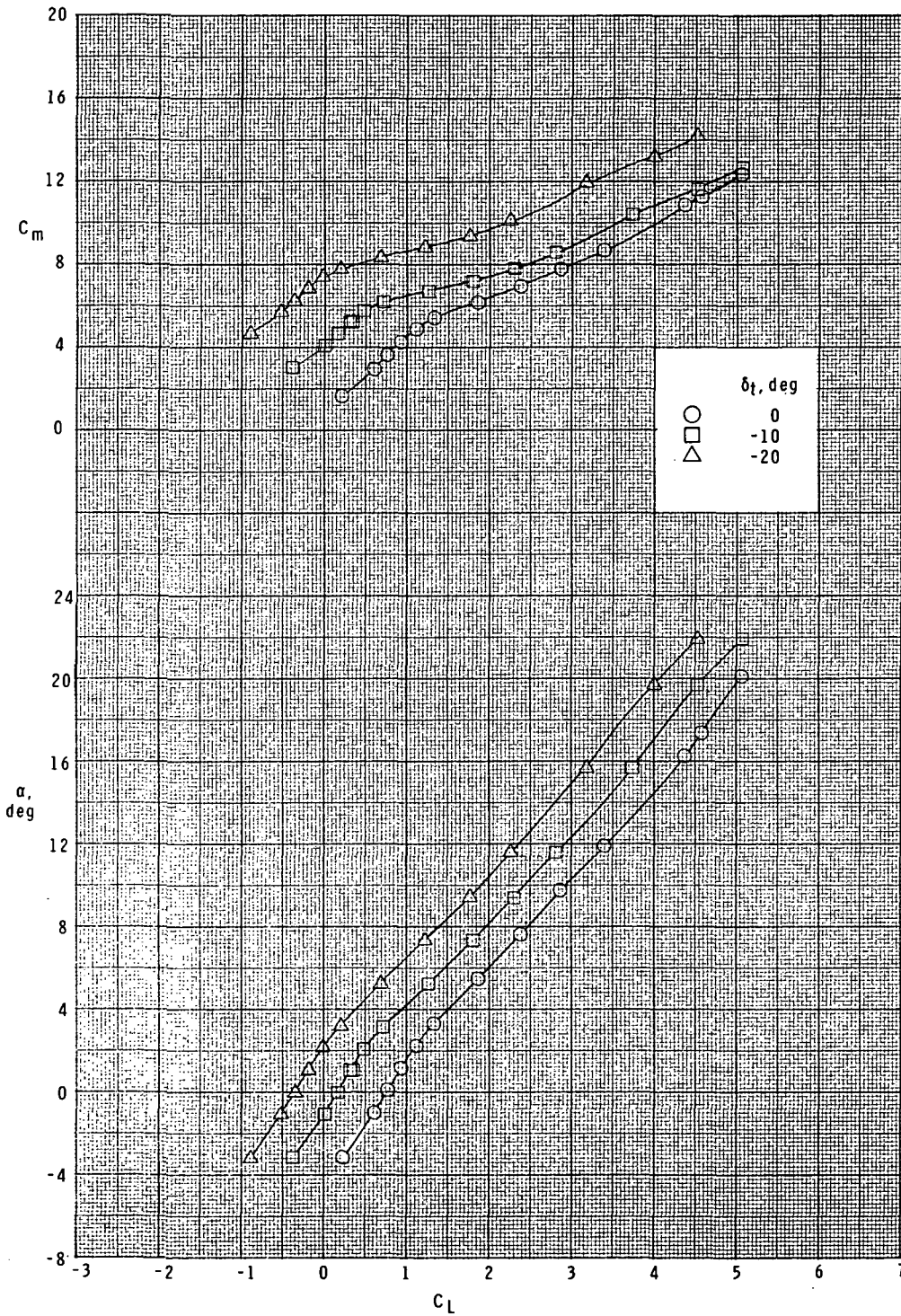
(a) Concluded.

Figure 13.- Continued.



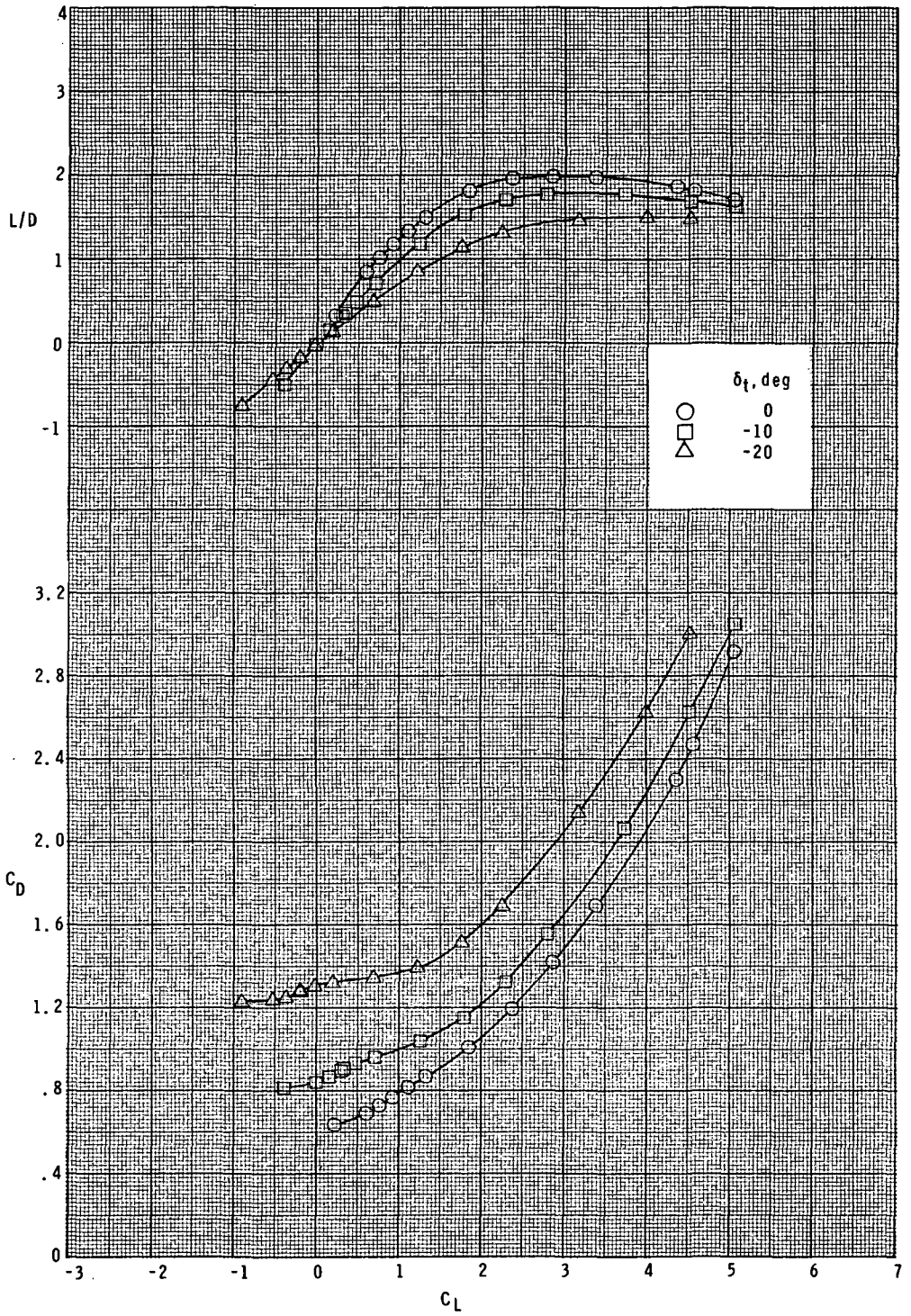
(b) $M = 1.90$.

Figure 13. - Continued.



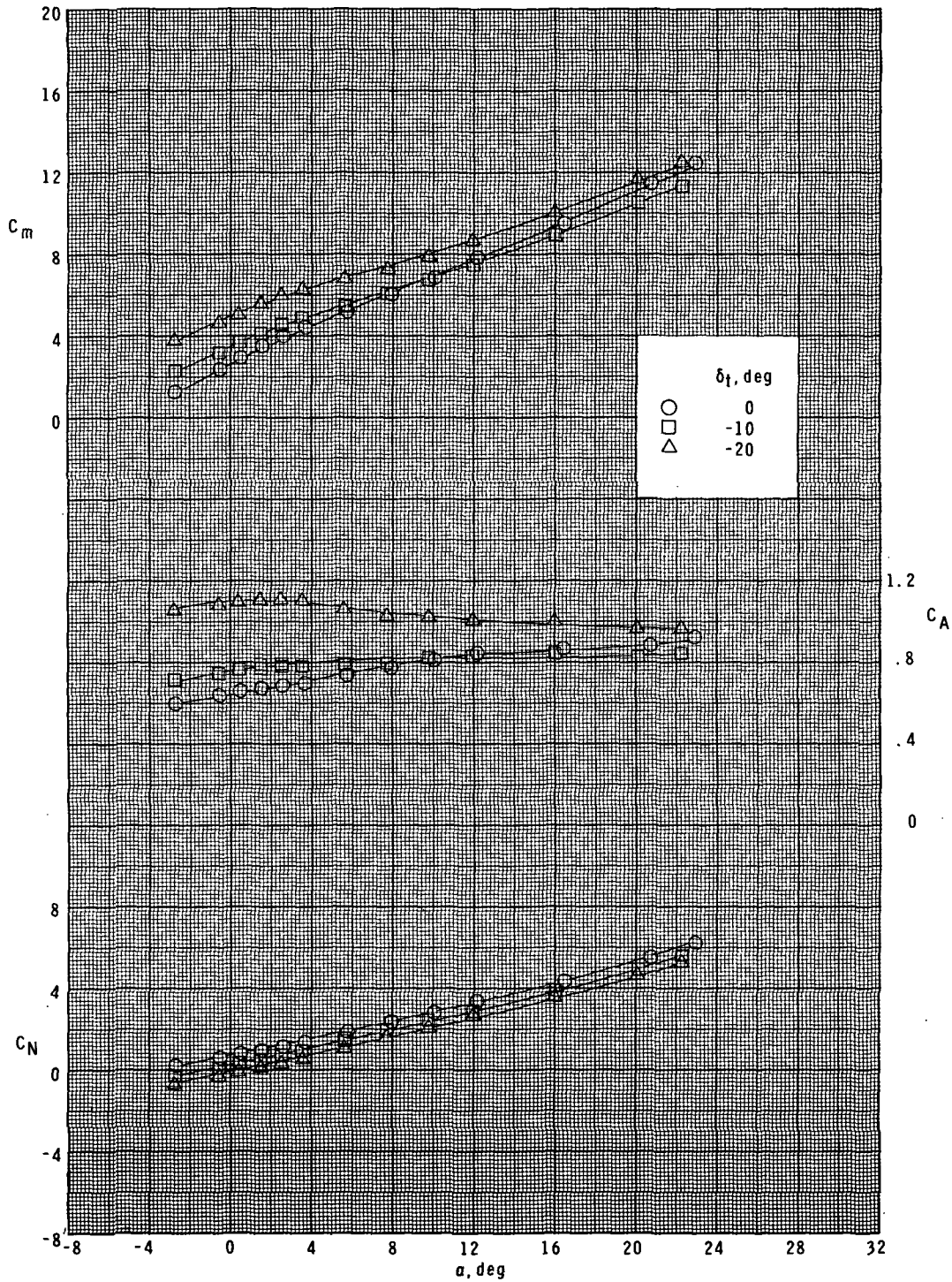
(b) Continued.

Figure 13.- Continued.



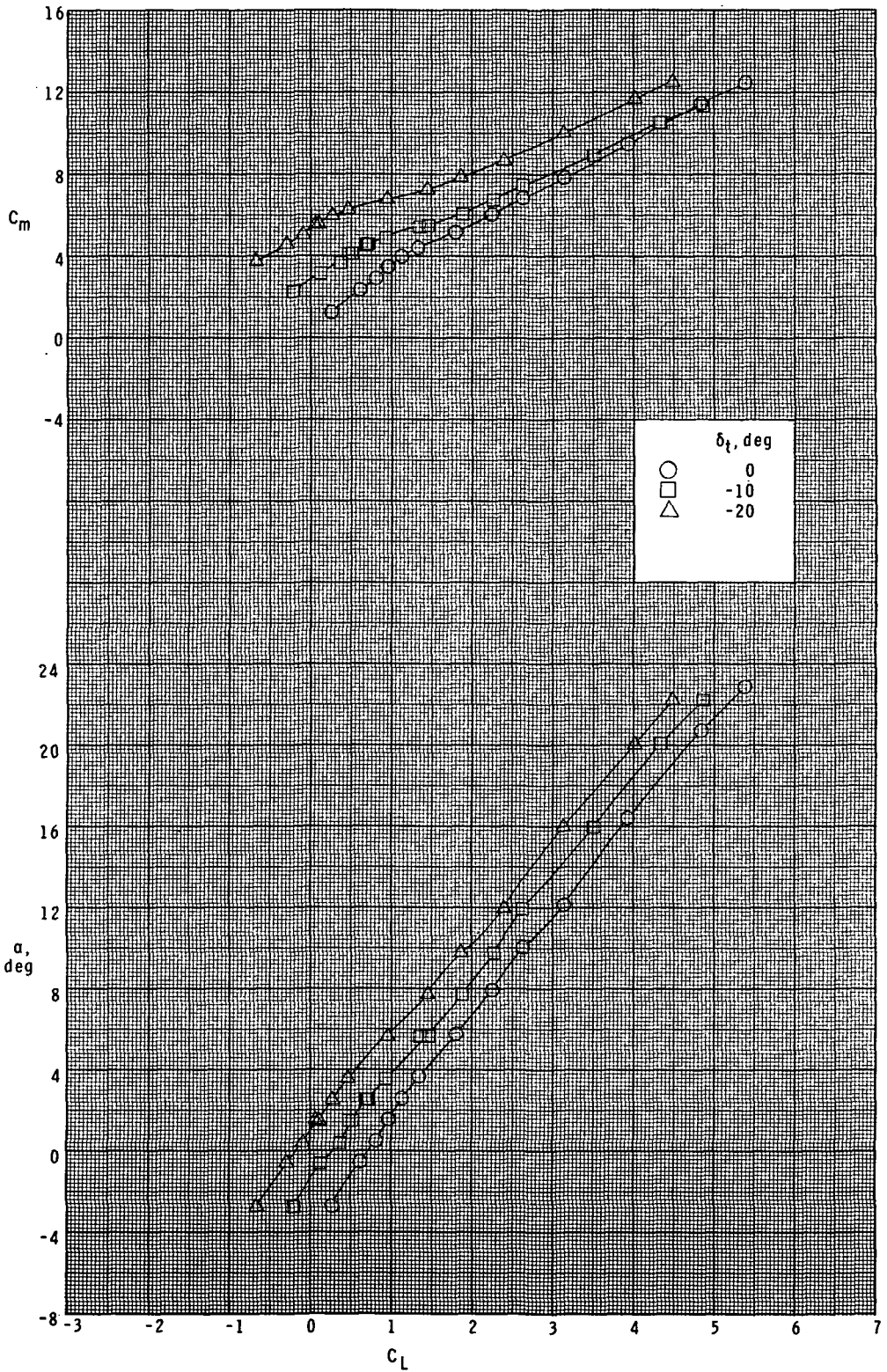
(b) Concluded.

Figure 13. - Continued.



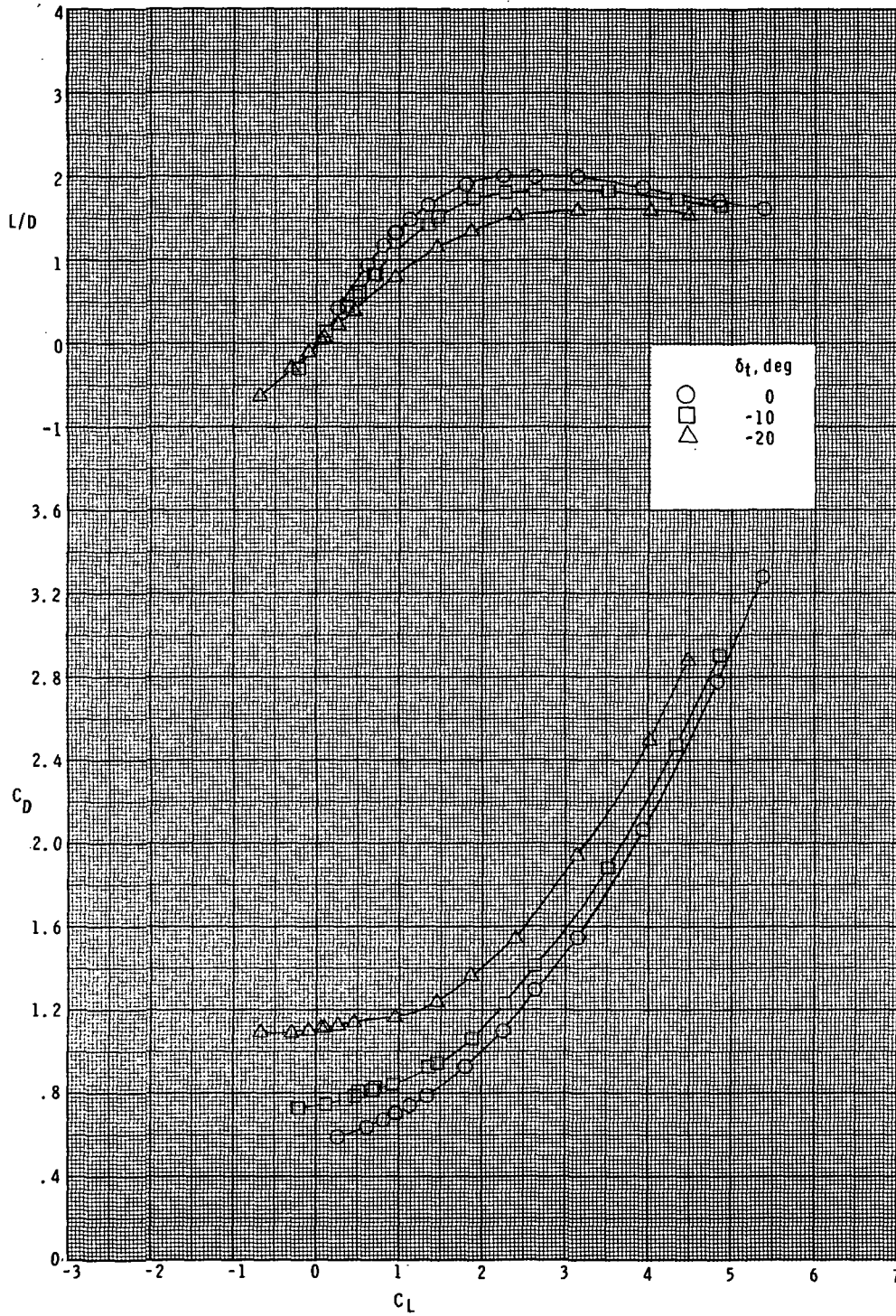
(c) $M = 2.36$.

Figure 13. - Continued.



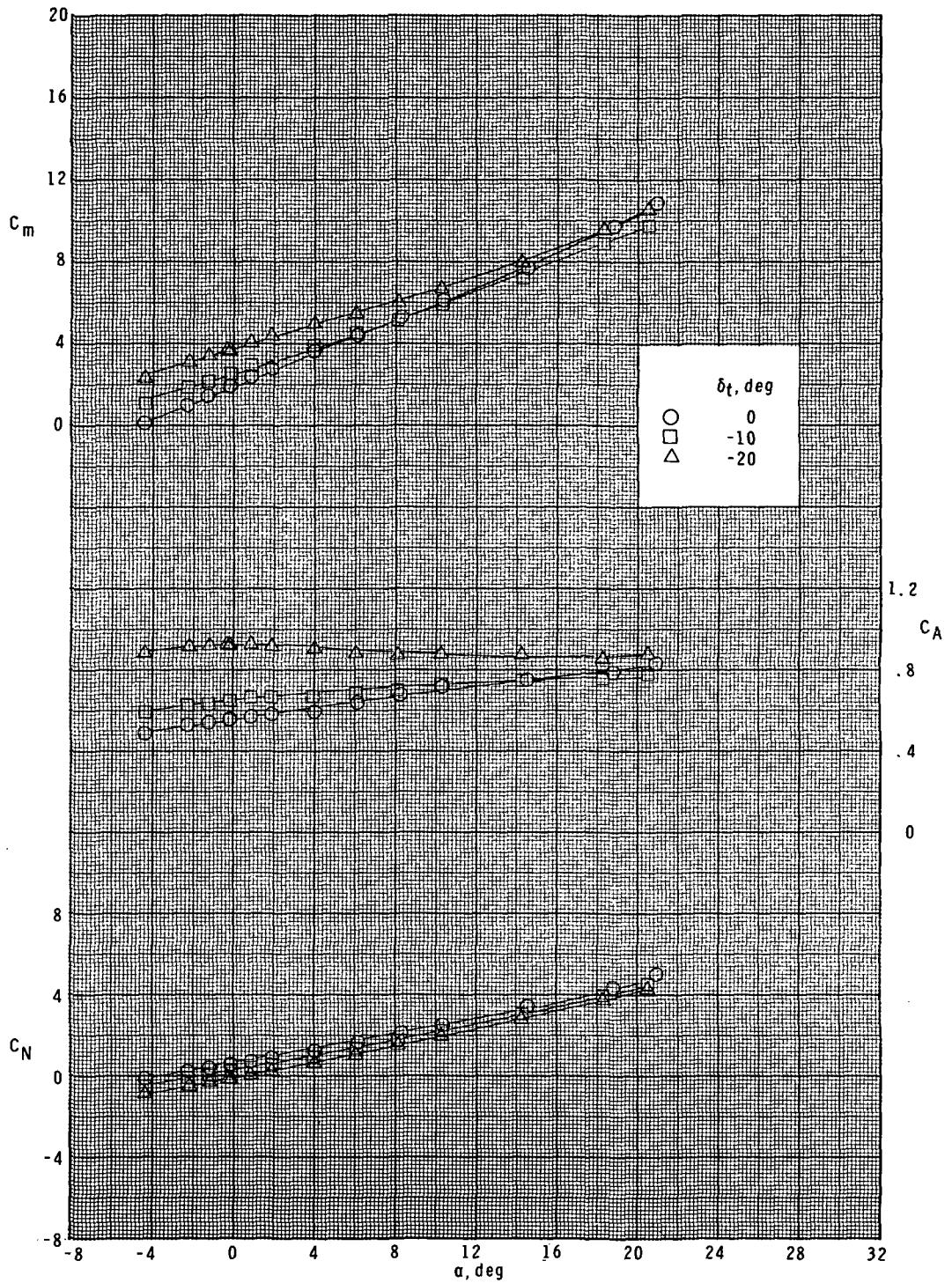
(c) Continued.

Figure 13.- Continued.



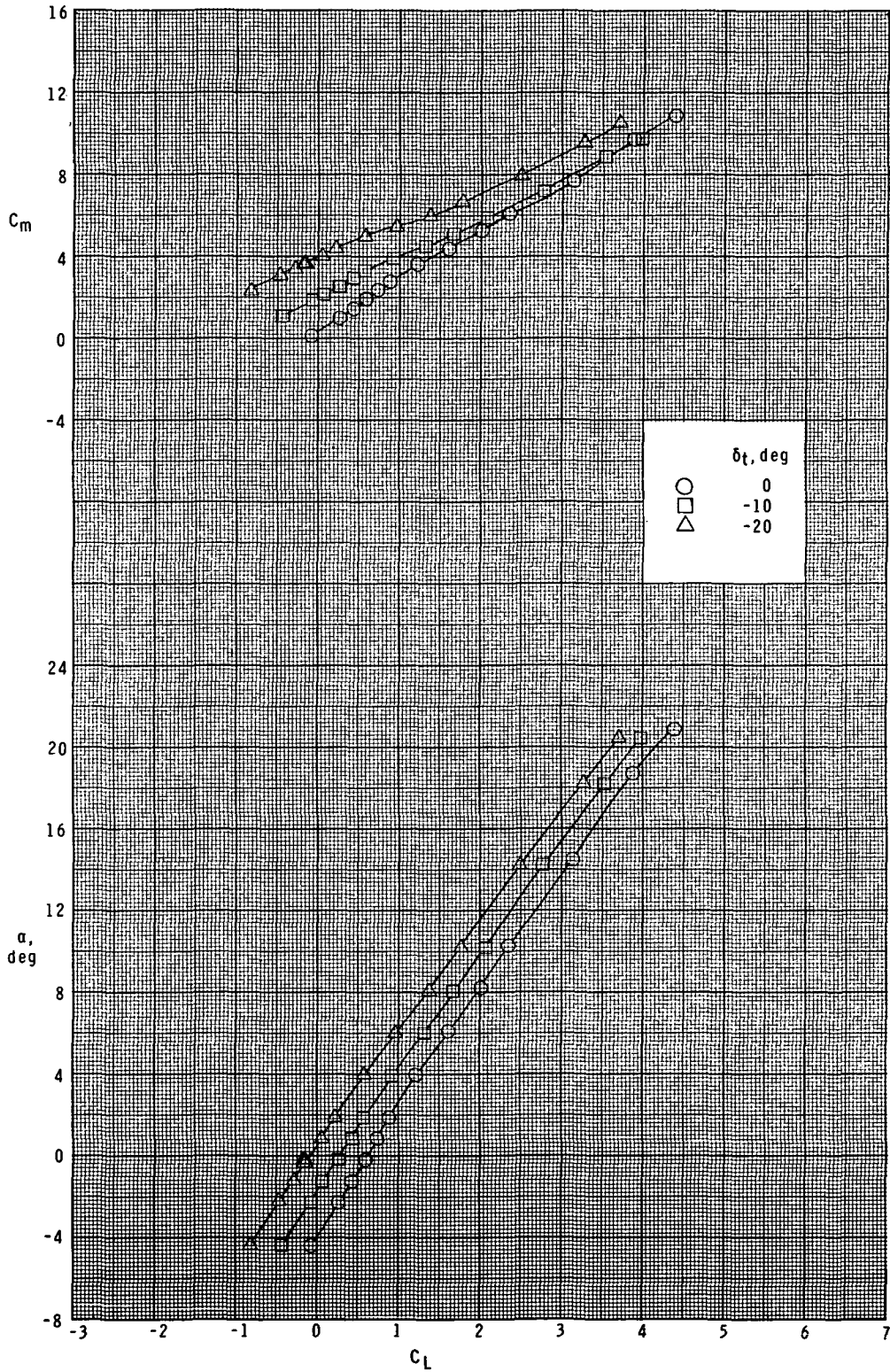
(c) Concluded.

Figure 13.- Continued.



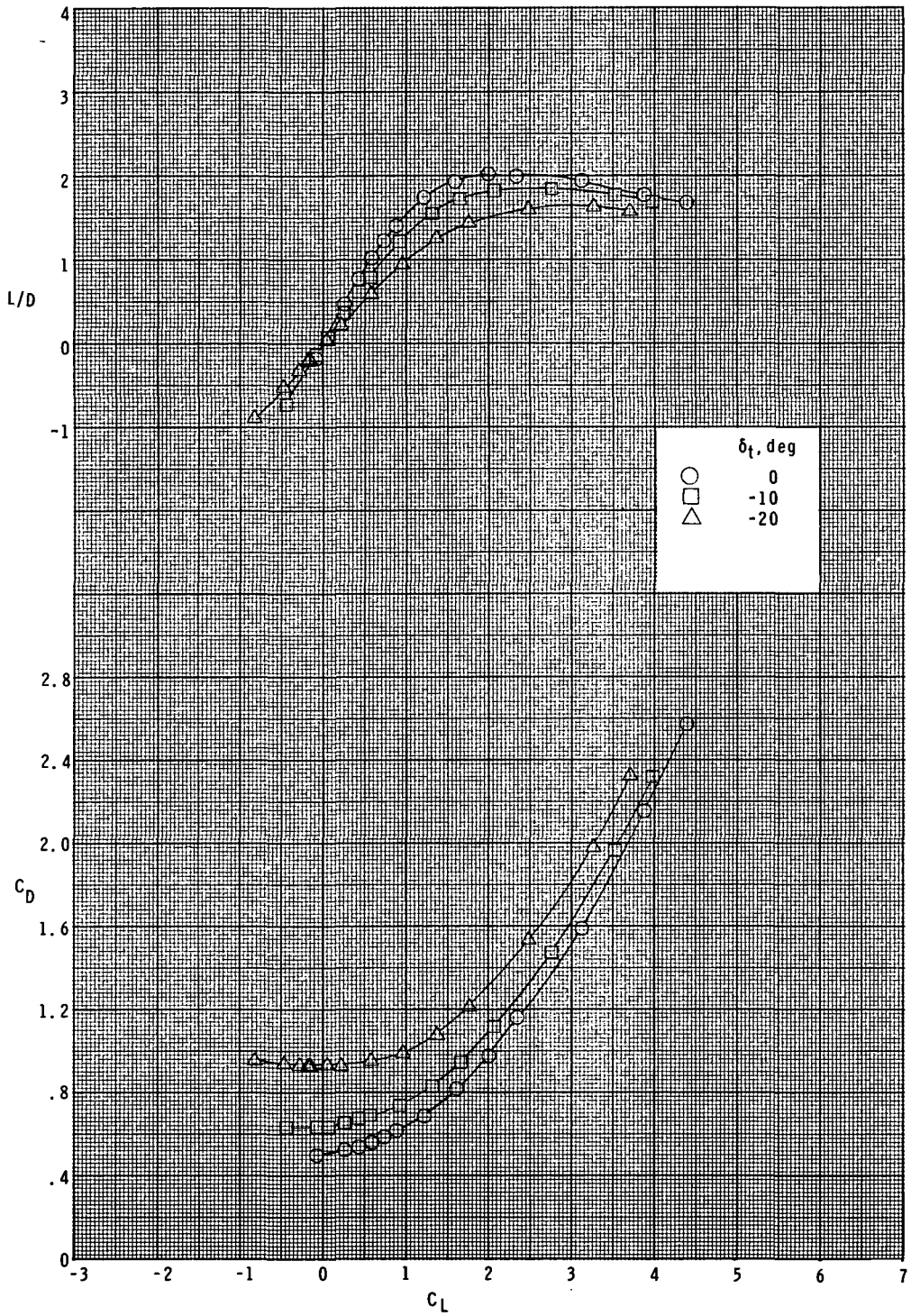
(d) $M = 2.86$.

Figure 13.- Continued.



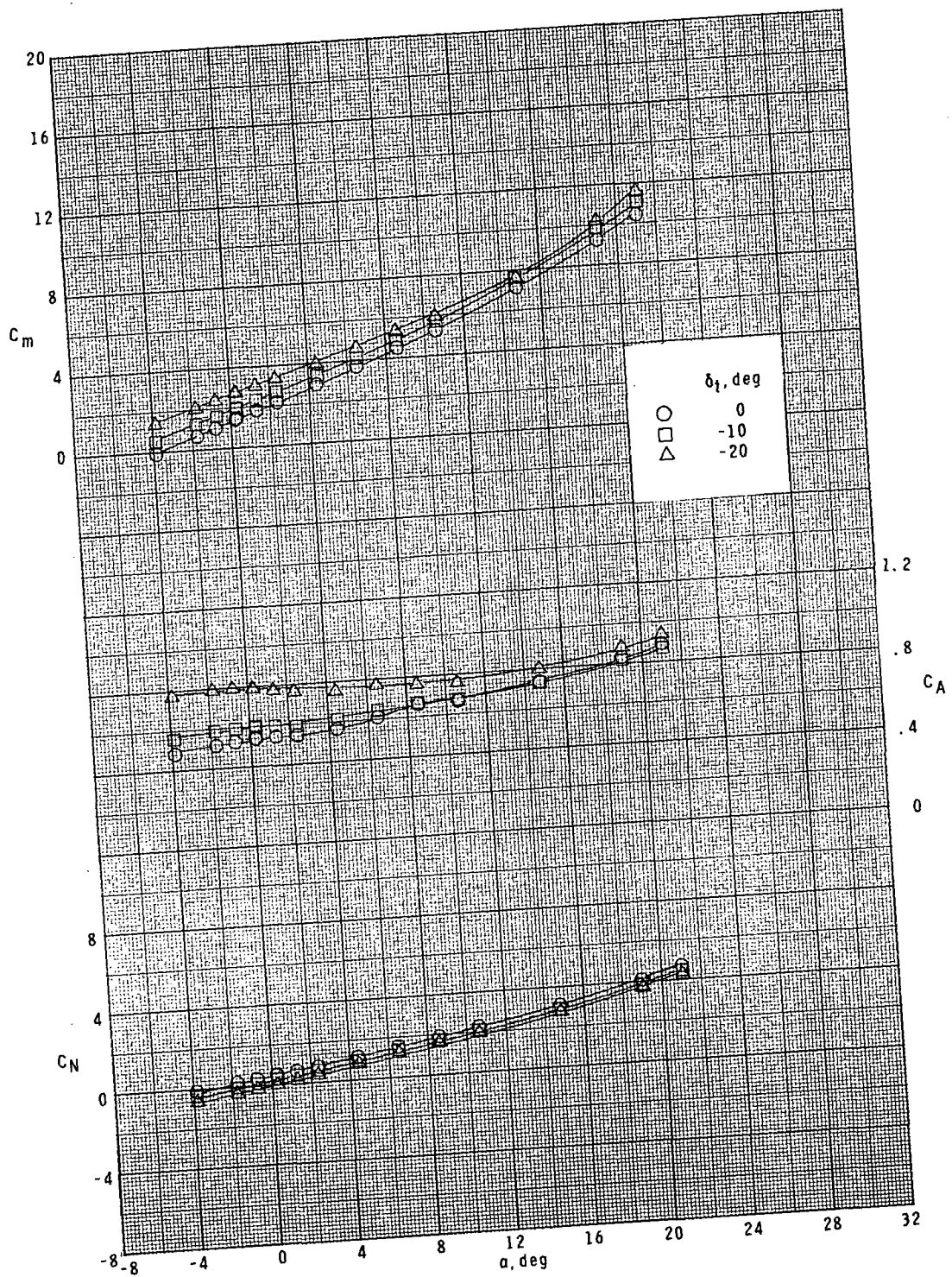
(d) Continued.

Figure 13.- Continued.



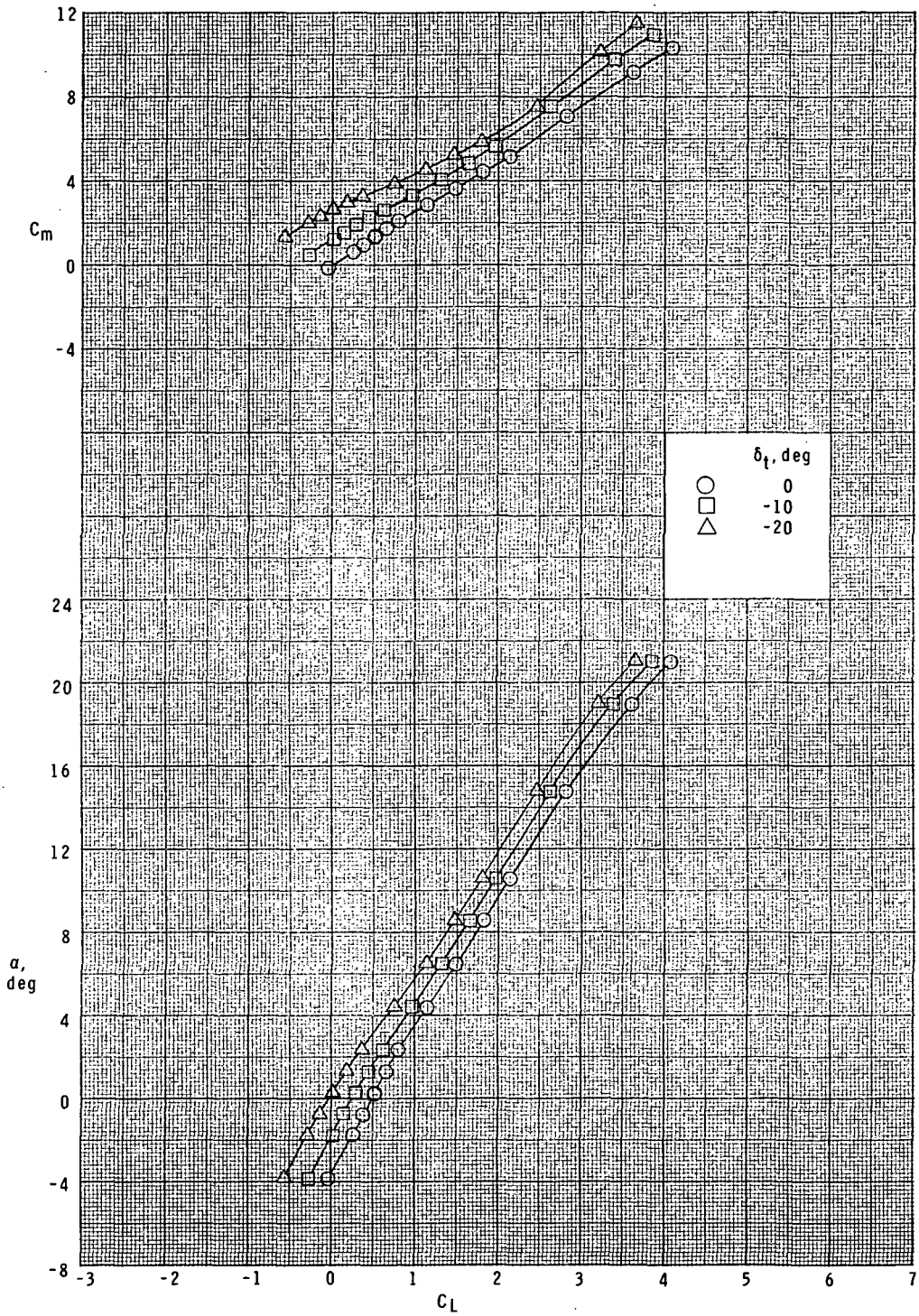
(d) Concluded.

Figure 13.- Continued.



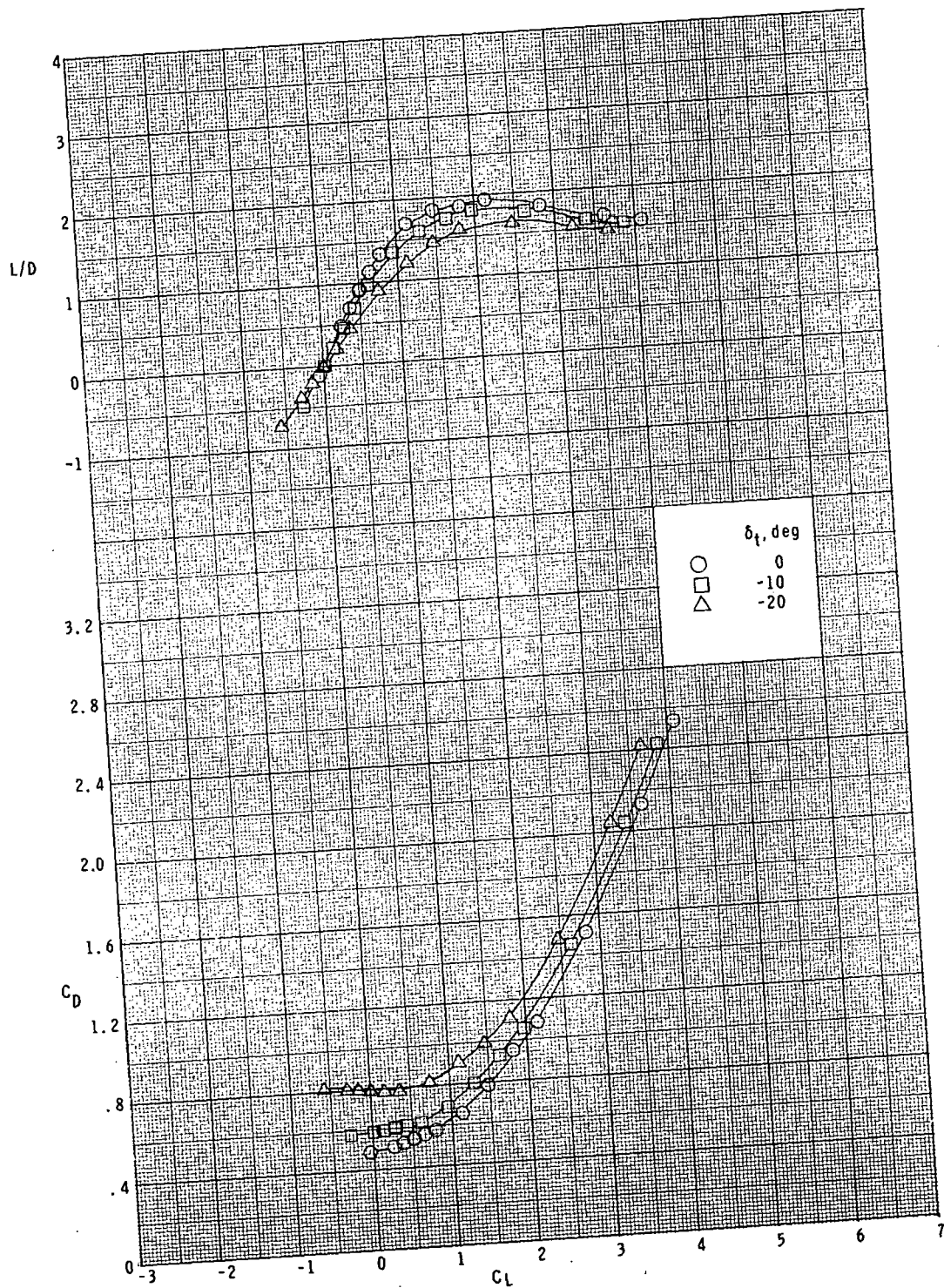
(e) $M = 3.95$.

Figure 13.- Continued.



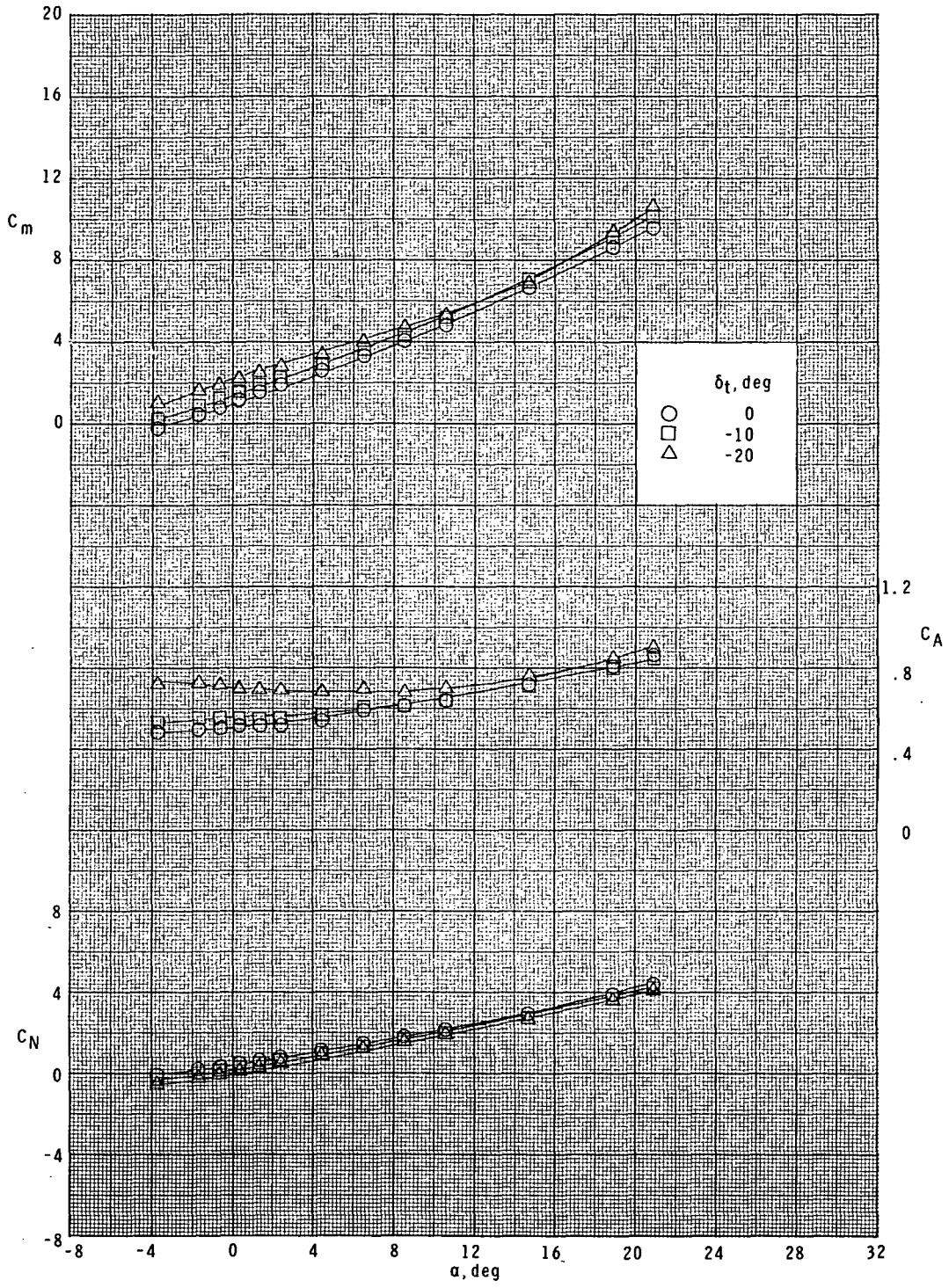
(e) Continued.

Figure 13.- Continued.



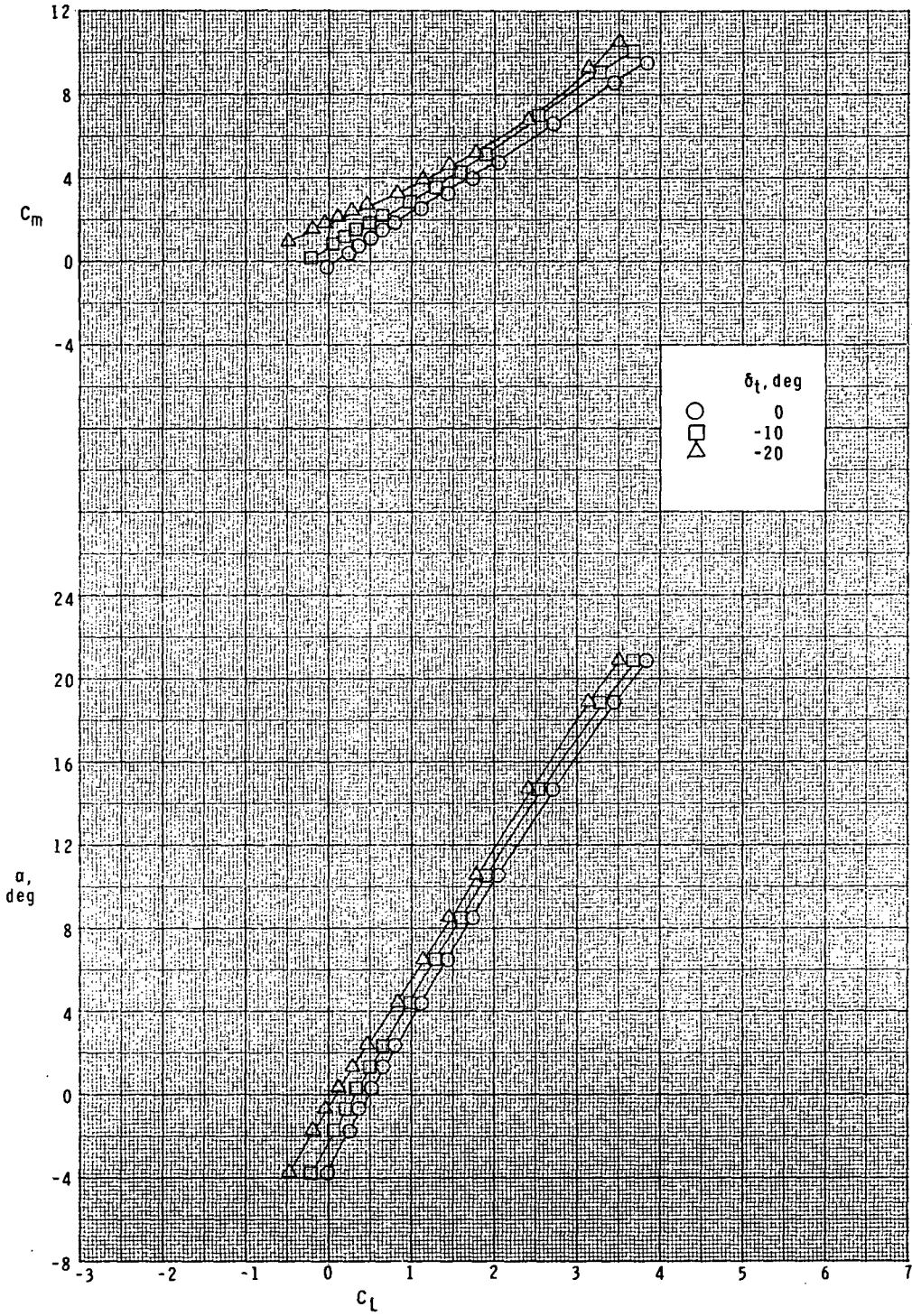
(e) Concluded.

Figure 13.- Continued.



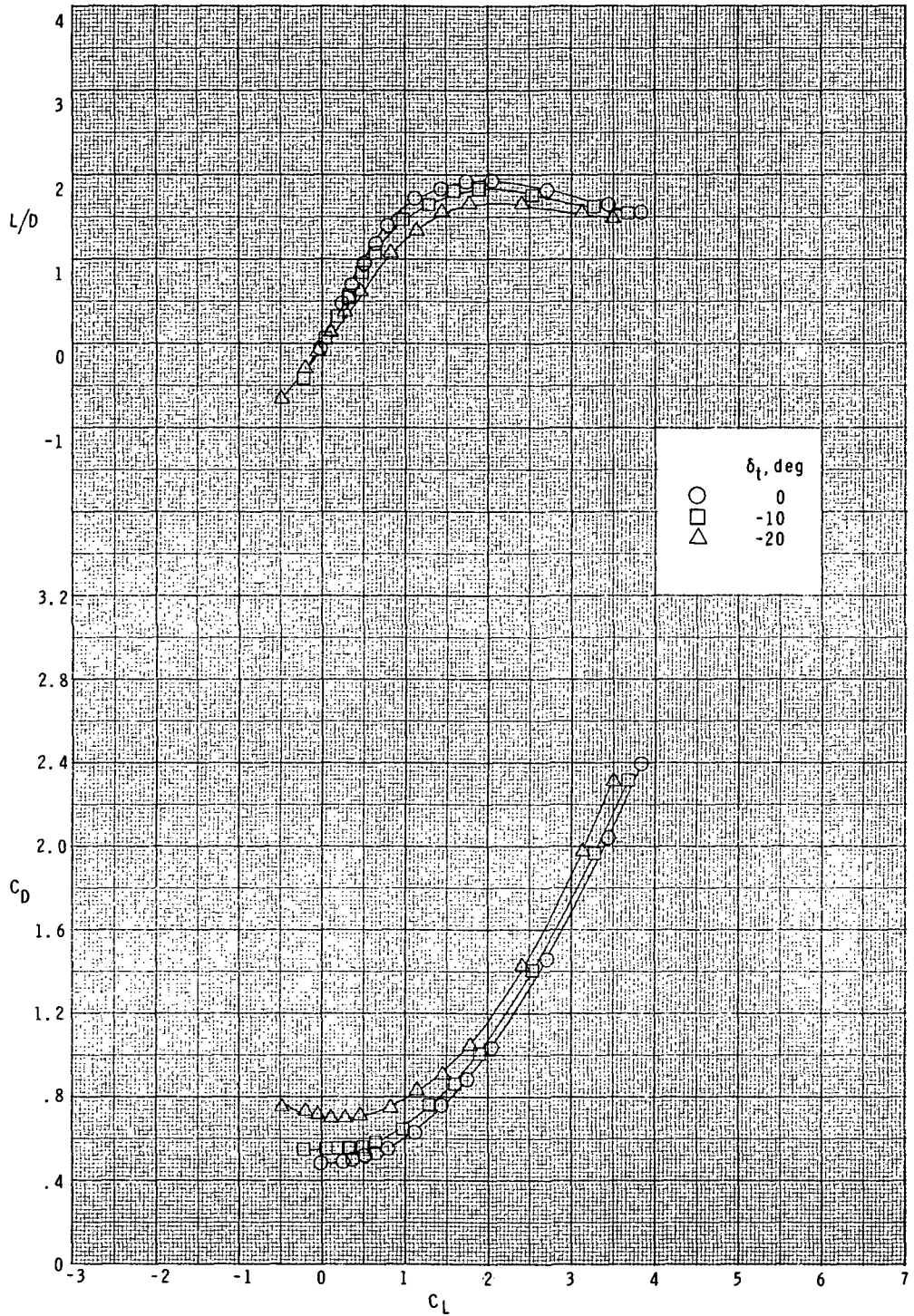
(f) $M = 4.63$.

Figure 13.- Continued.



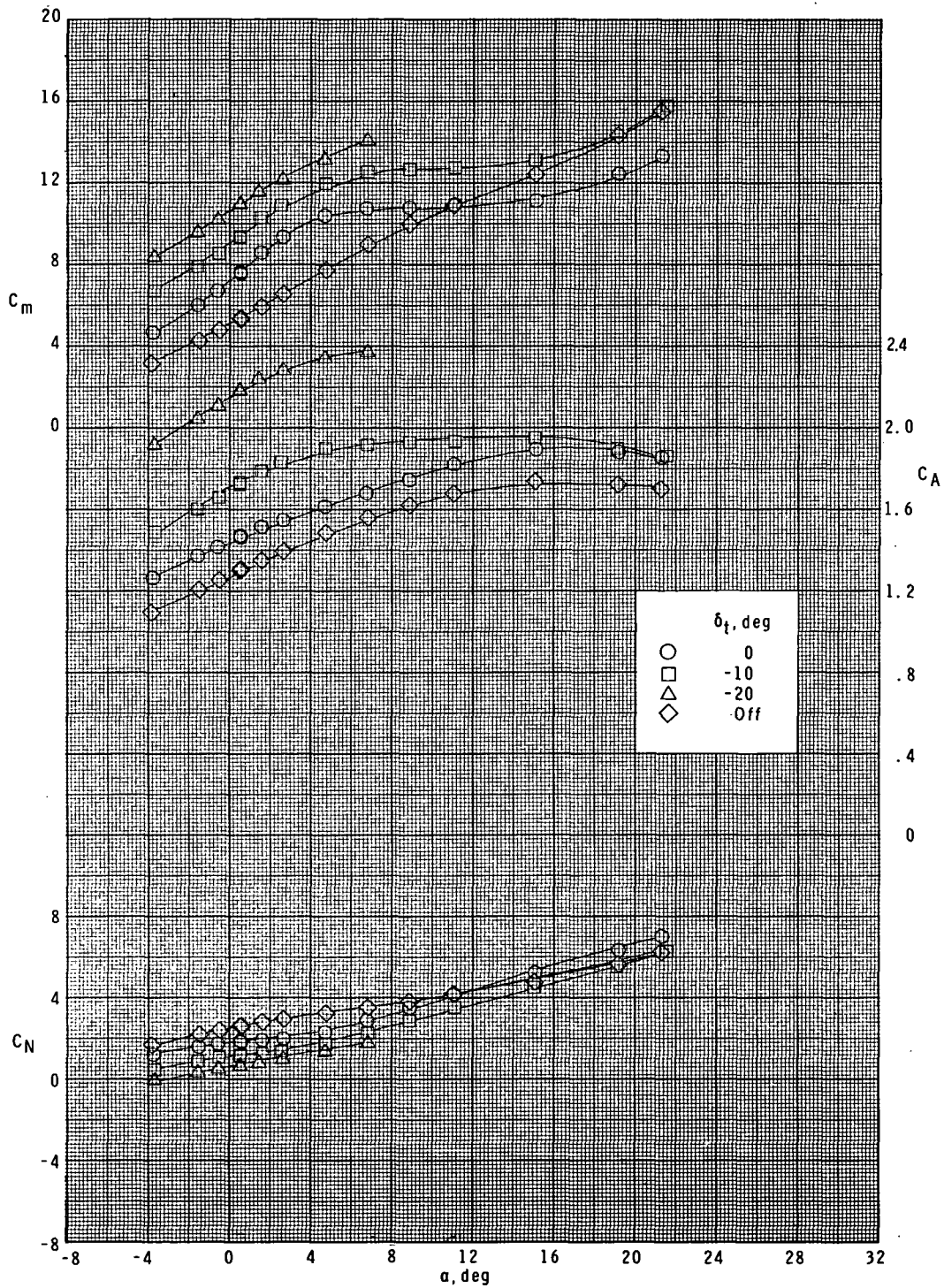
(f) Continued.

Figure 13.- Continued.



(f) Concluded.

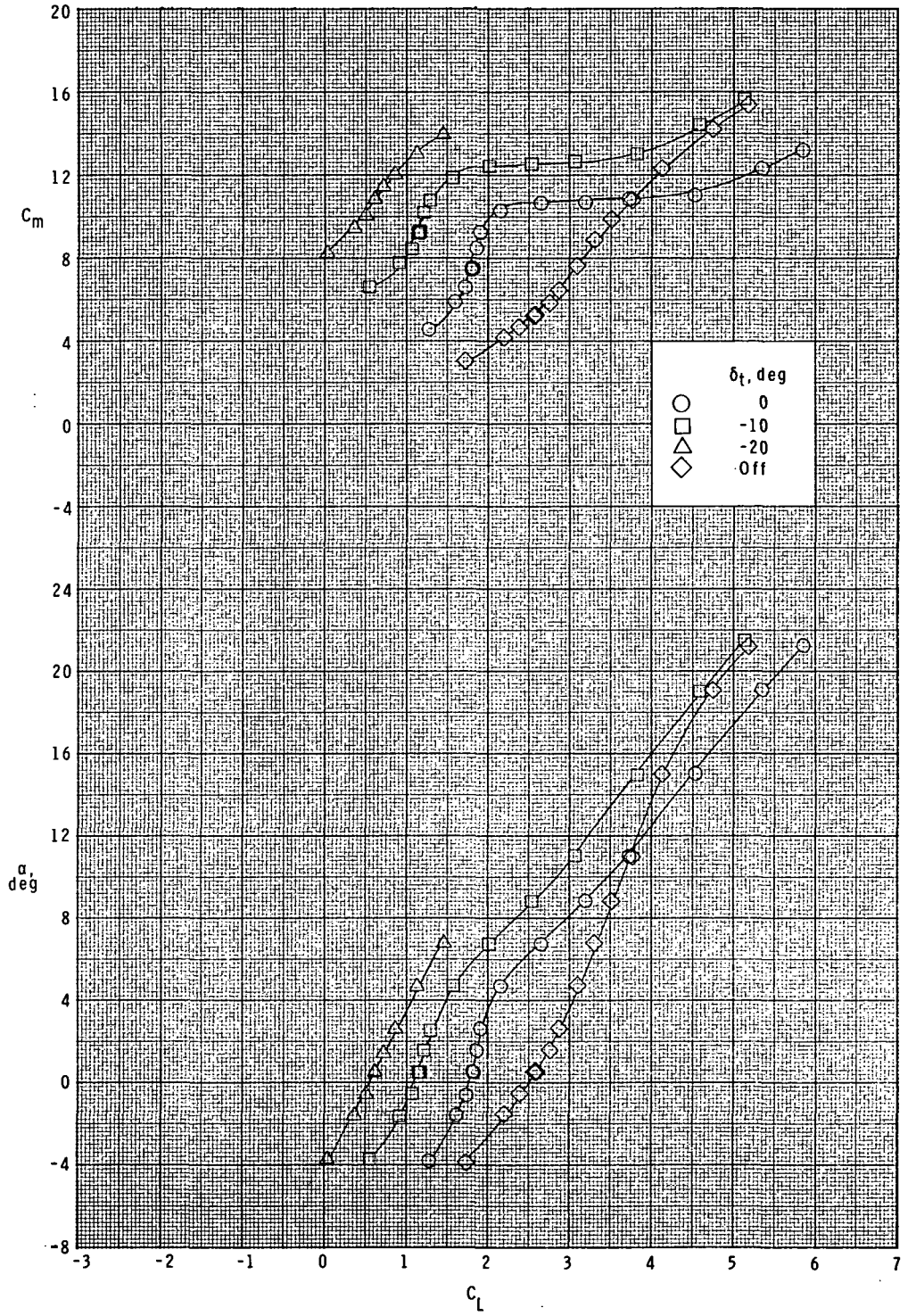
Figure 13.- Concluded.



(a) $M = 1.50$.

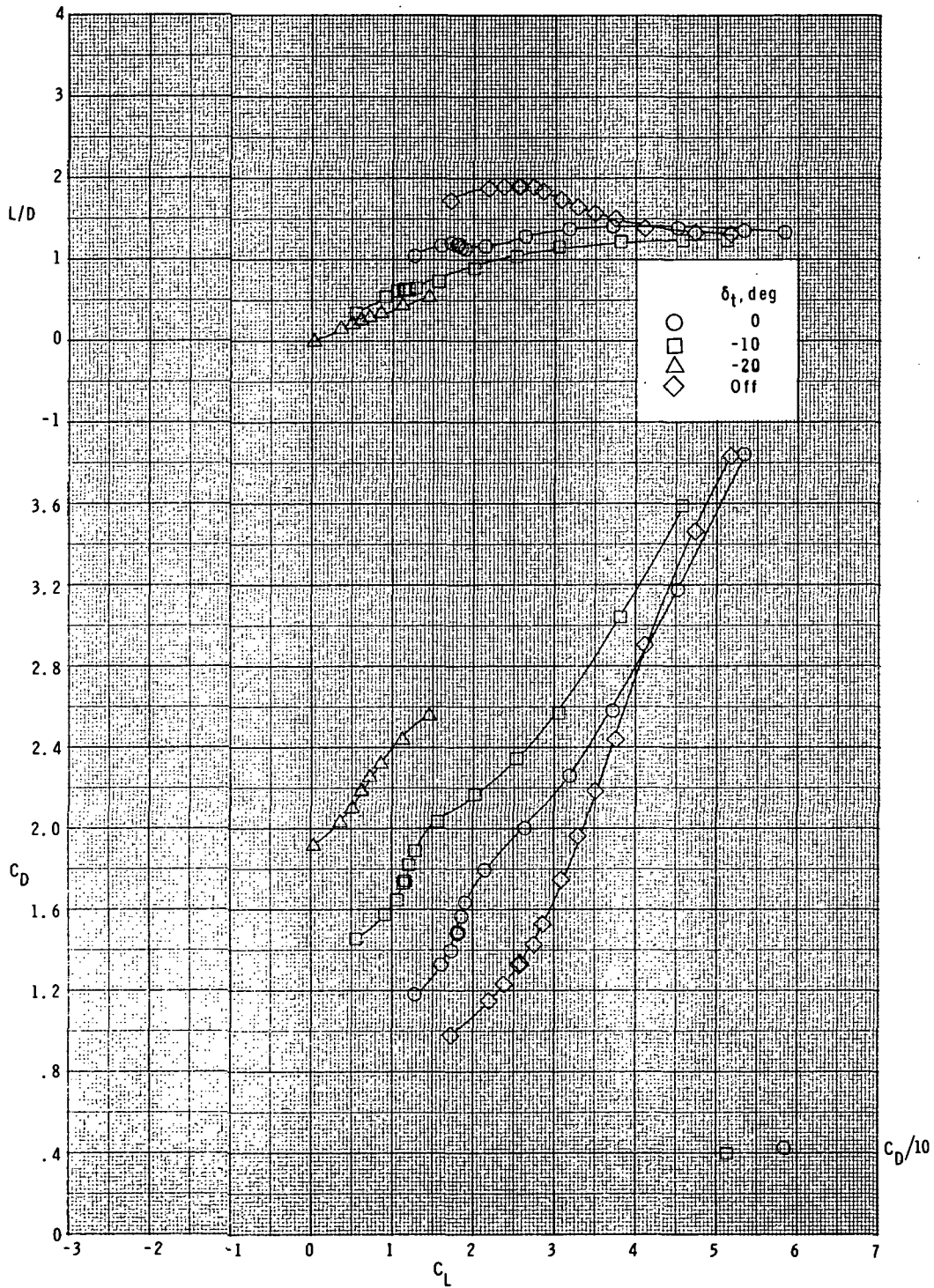
Figure 14.- Effect of tail deflection on longitudinal aerodynamic characteristics.

$\delta_w = 20^\circ$; $\phi = 45^\circ$; tails in line.



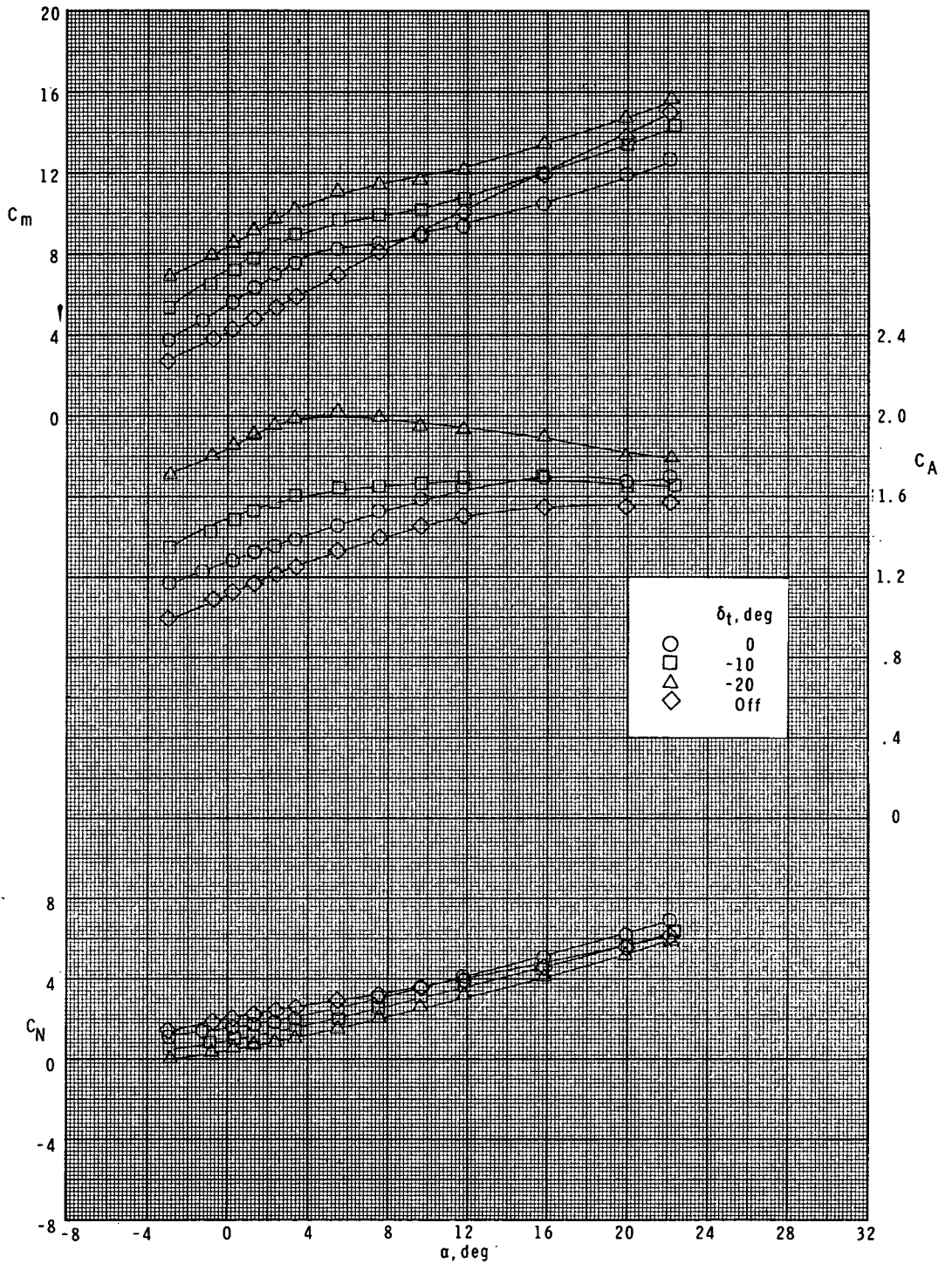
(a) Continued.

Figure 14. - Continued.



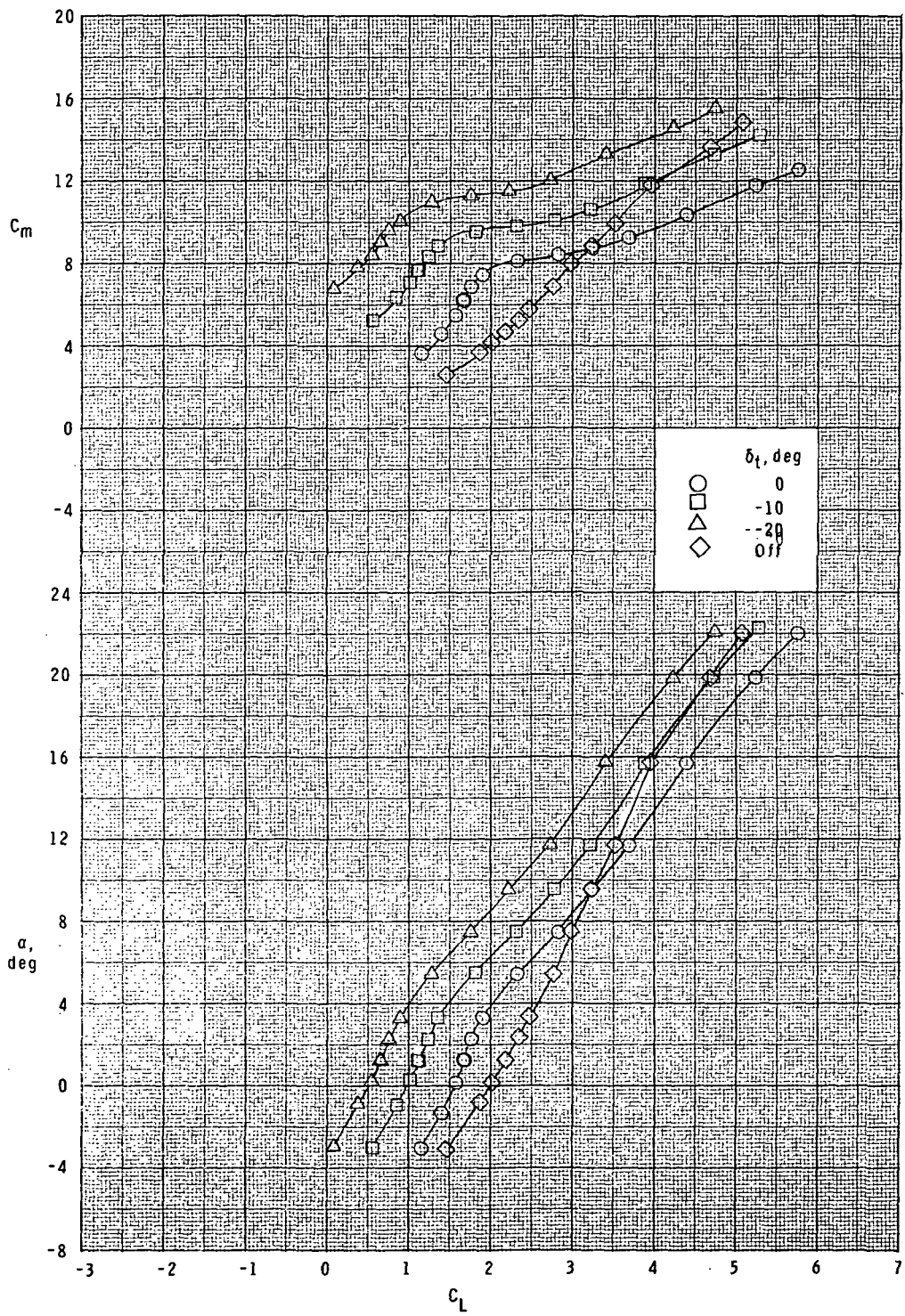
(a) Concluded.

Figure 14. - Continued.



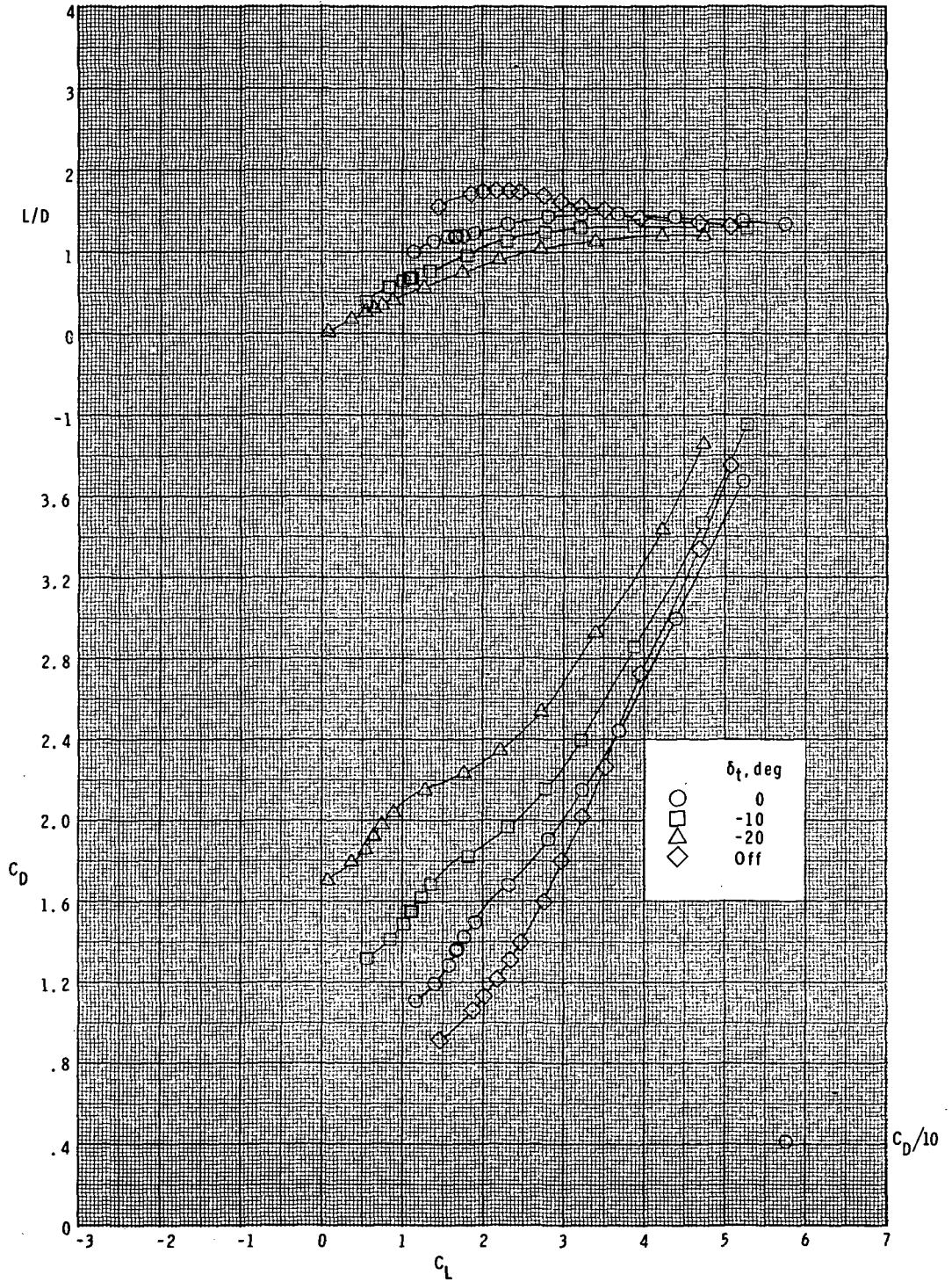
(b) $M = 1.90$.

Figure 14.- Continued.



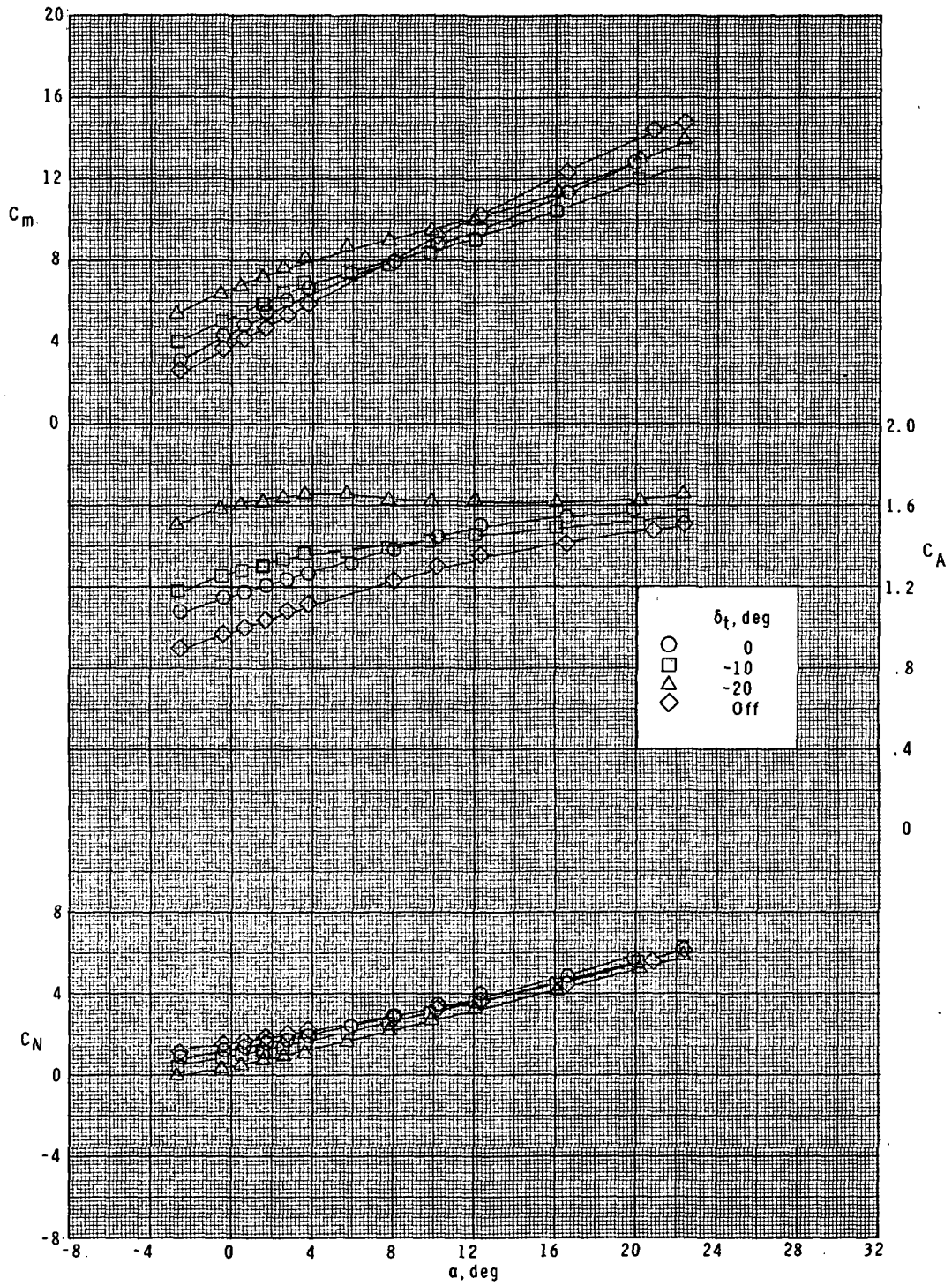
(b) Continued.

Figure 14.- Continued.



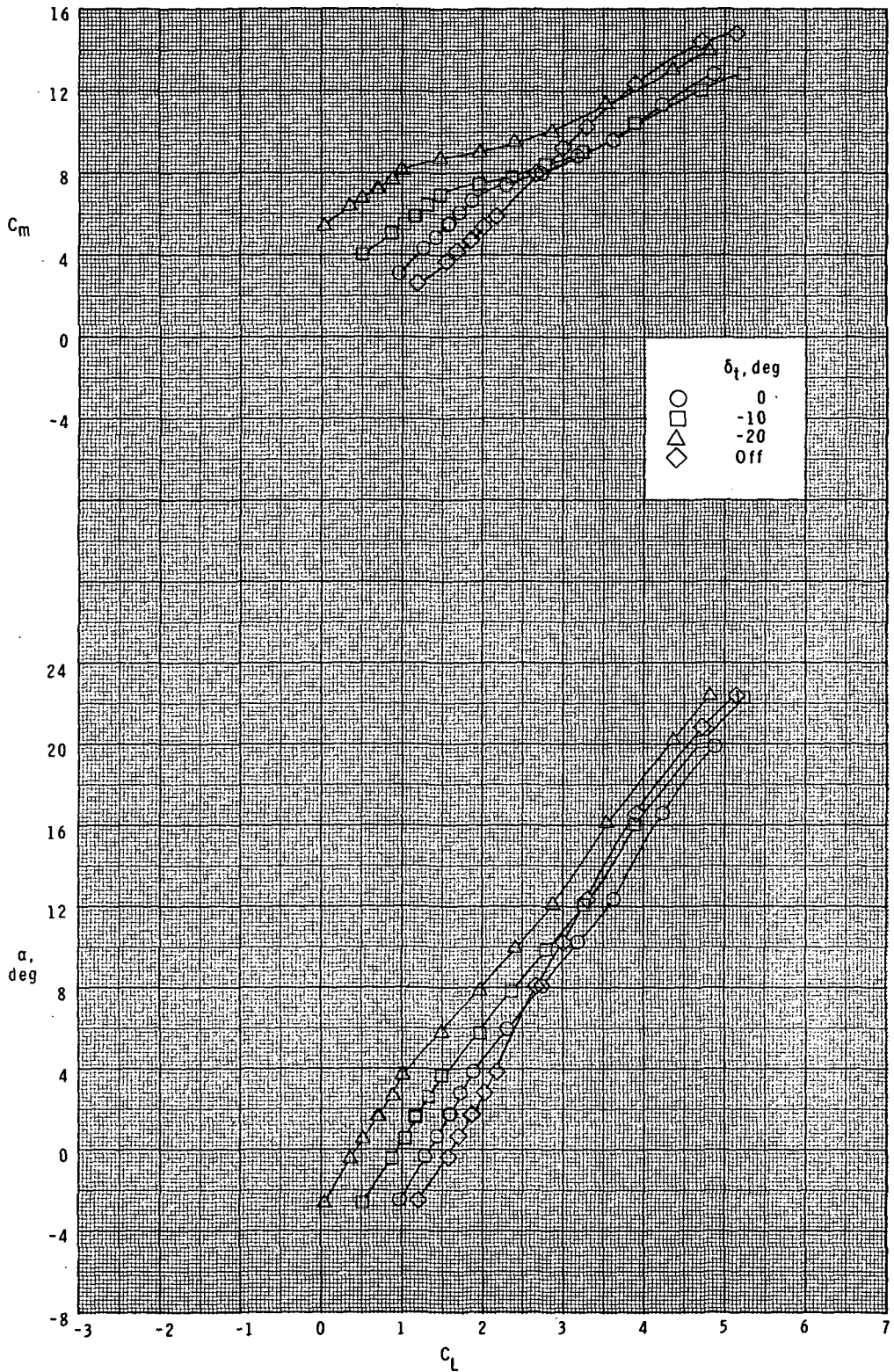
(b) Concluded.

Figure 14. - Continued.



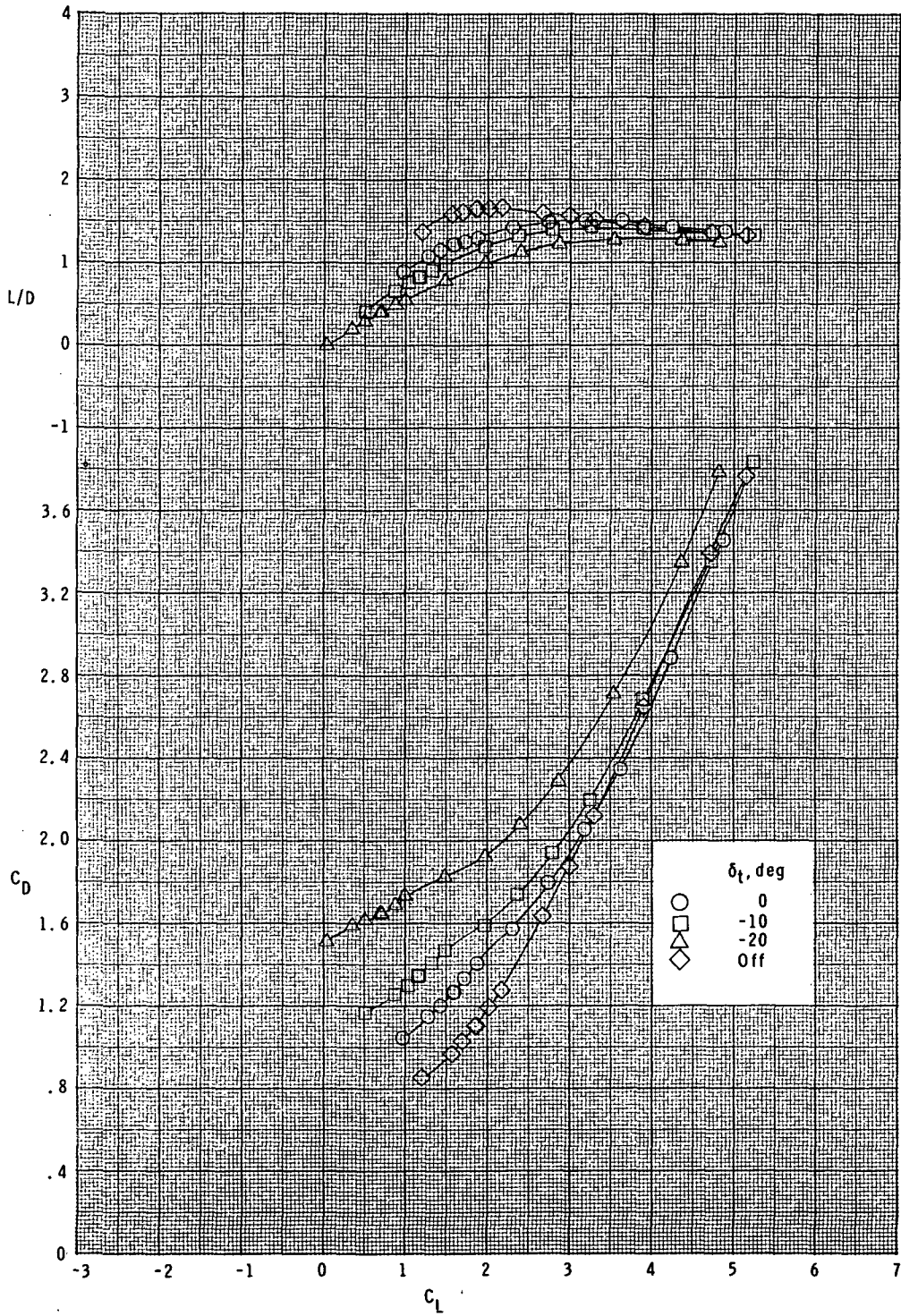
(c) $M = 2.36$.

Figure 14. - Continued.



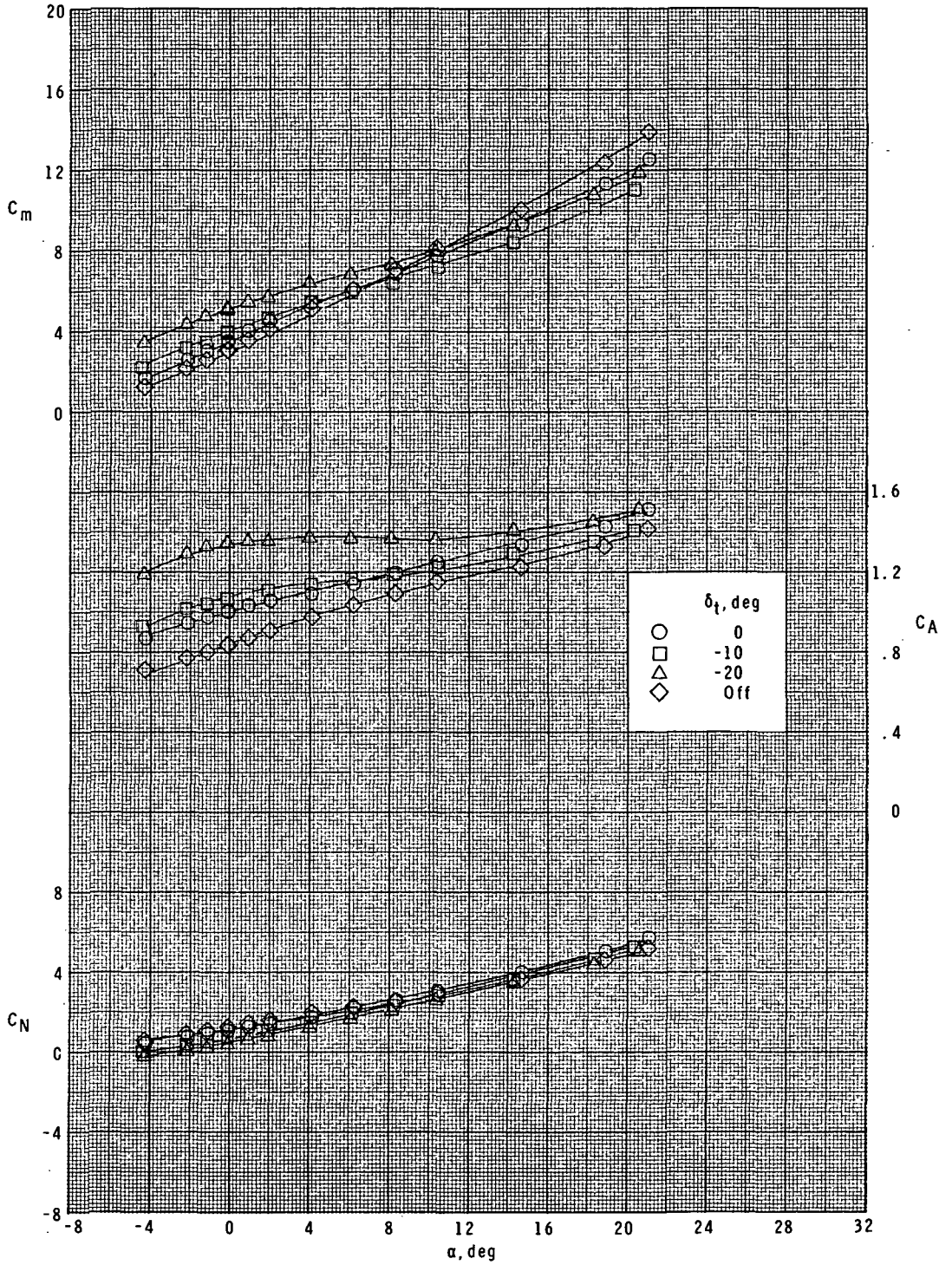
(c) Continued.

Figure 14.- Continued.



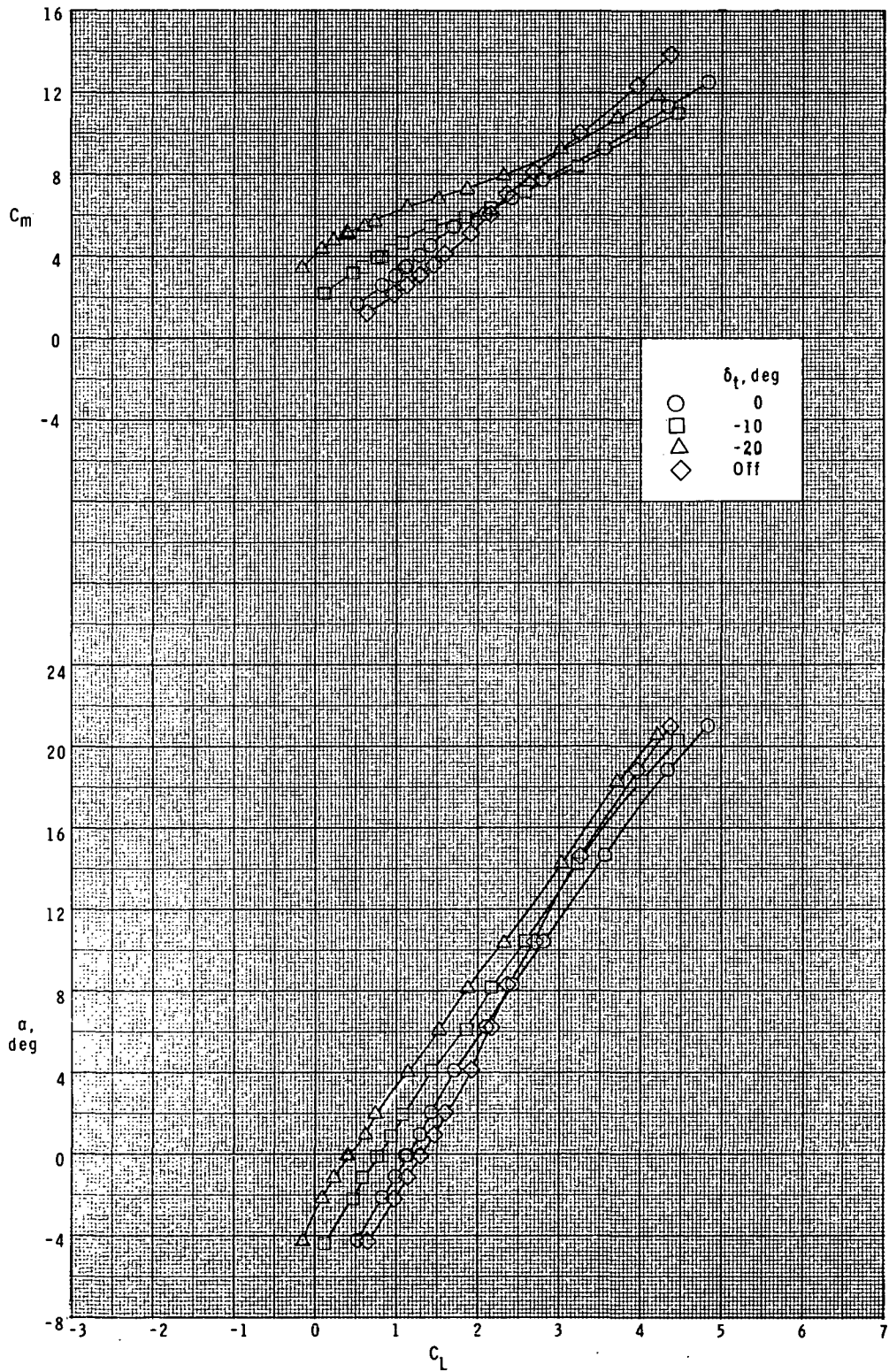
(c) Concluded.

Figure 14. - Continued.



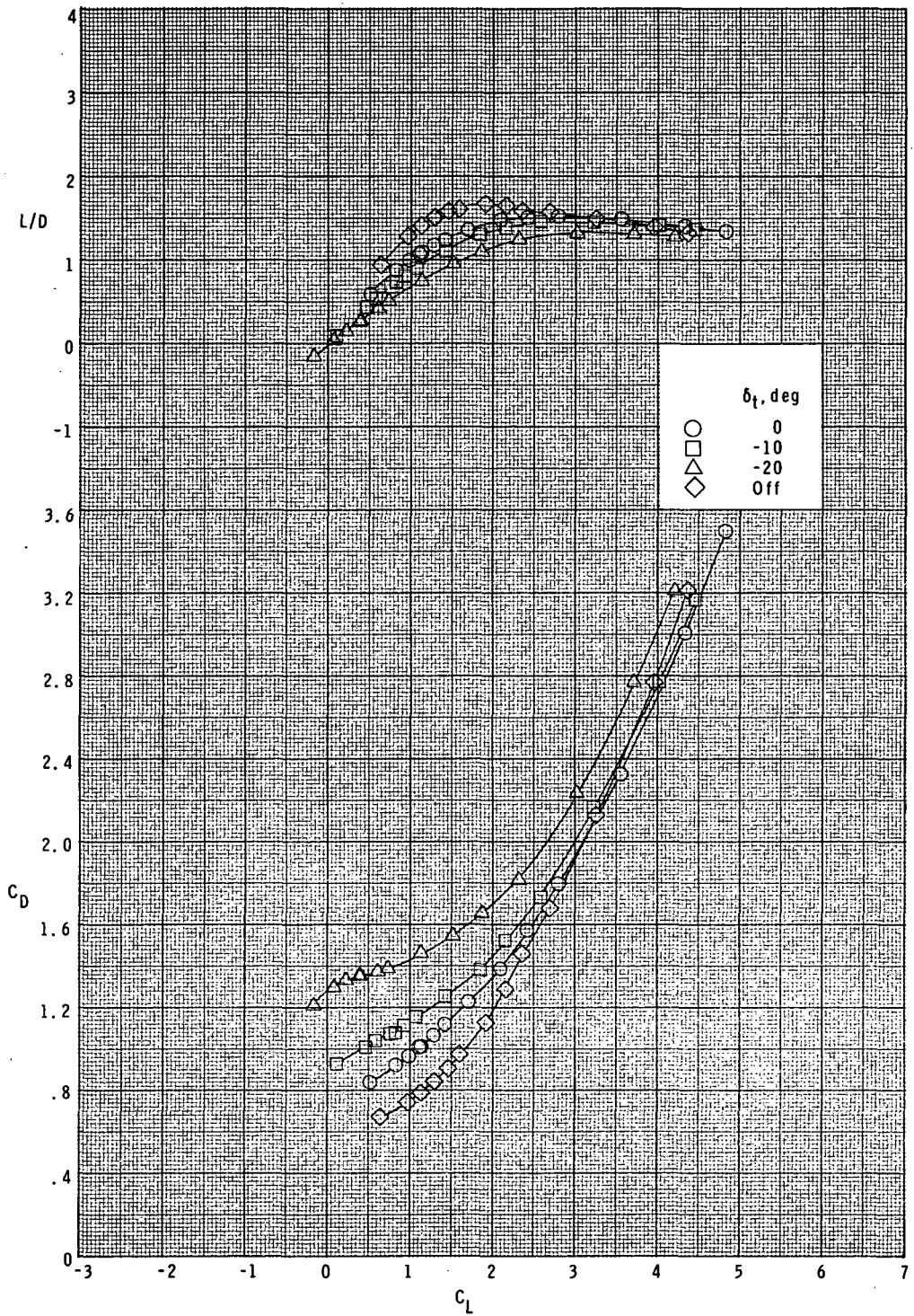
(d) $M = 2.86$.

Figure 14. - Continued.



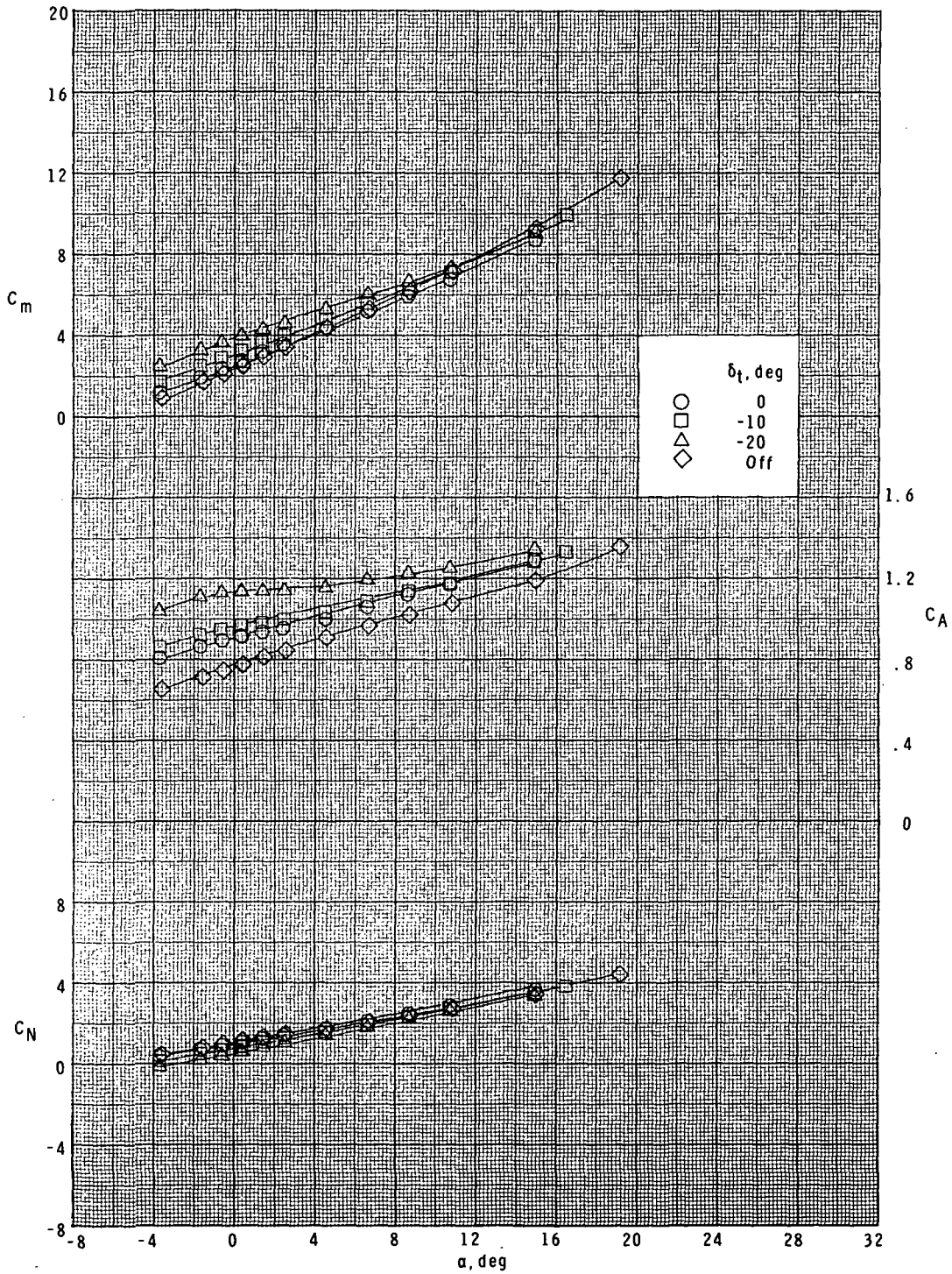
(d) Continued.

Figure 14. - Continued.



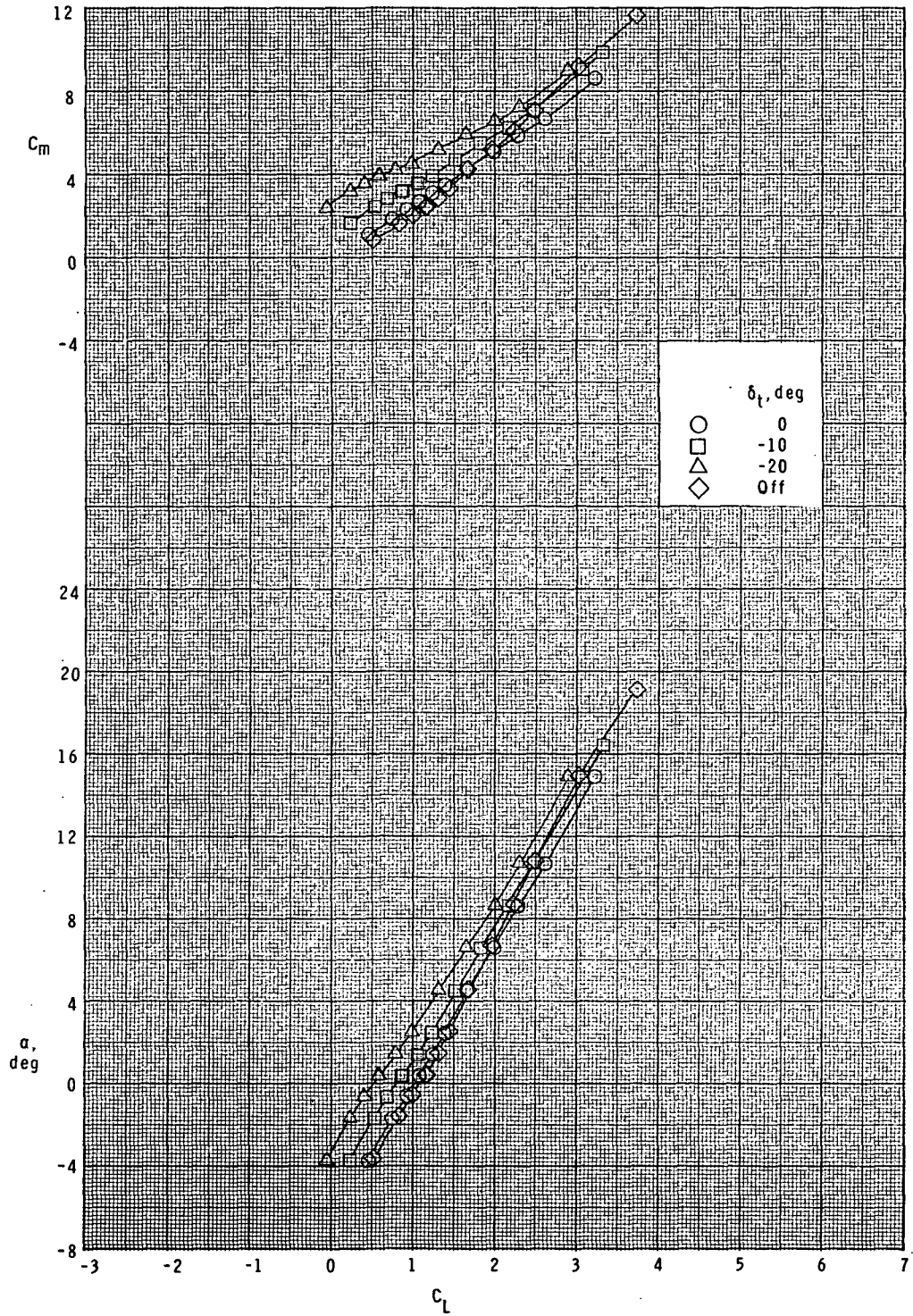
(d) Concluded.

Figure 14. - Continued.



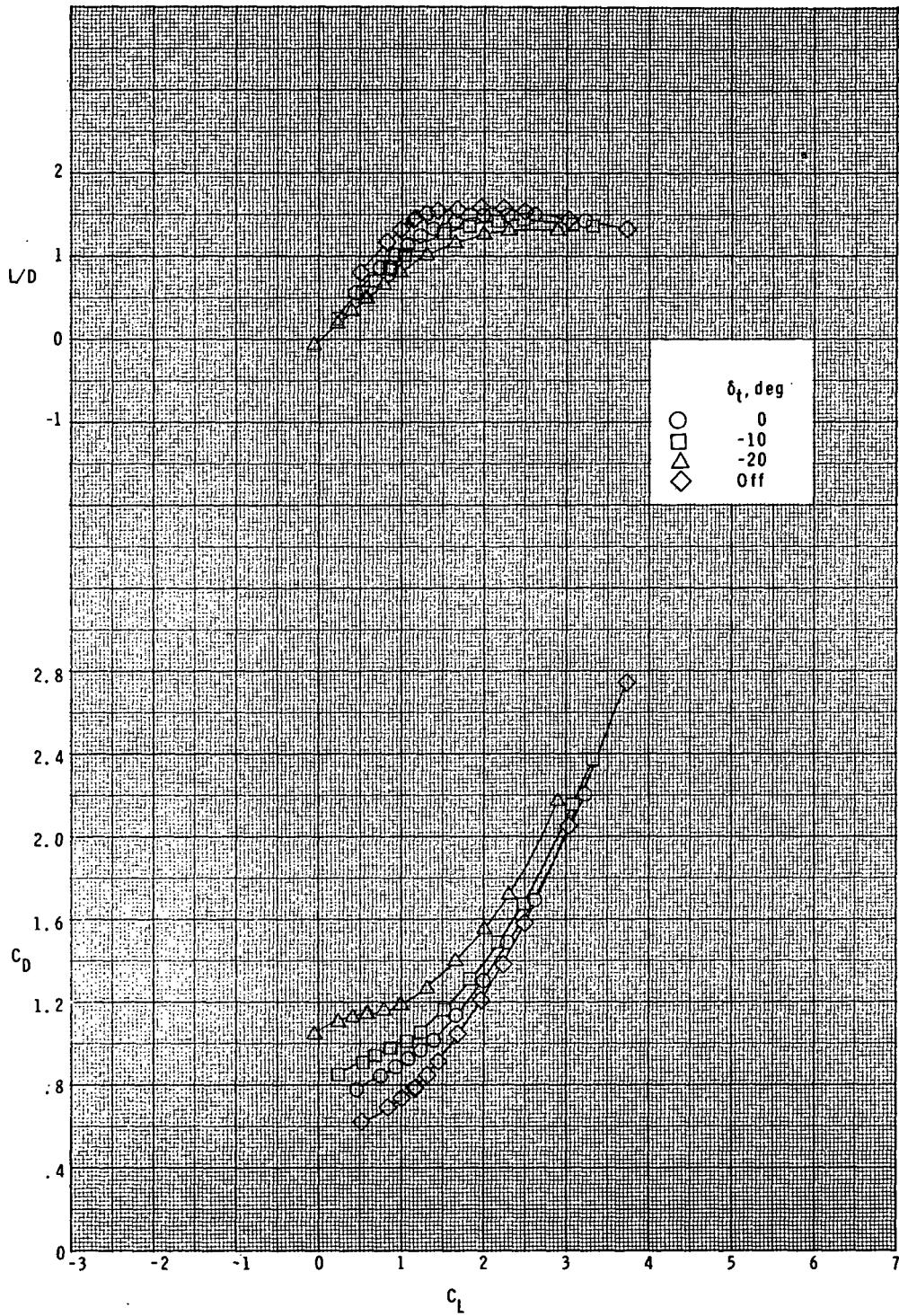
(e) $M = 3.95$.

Figure 14.- Continued.



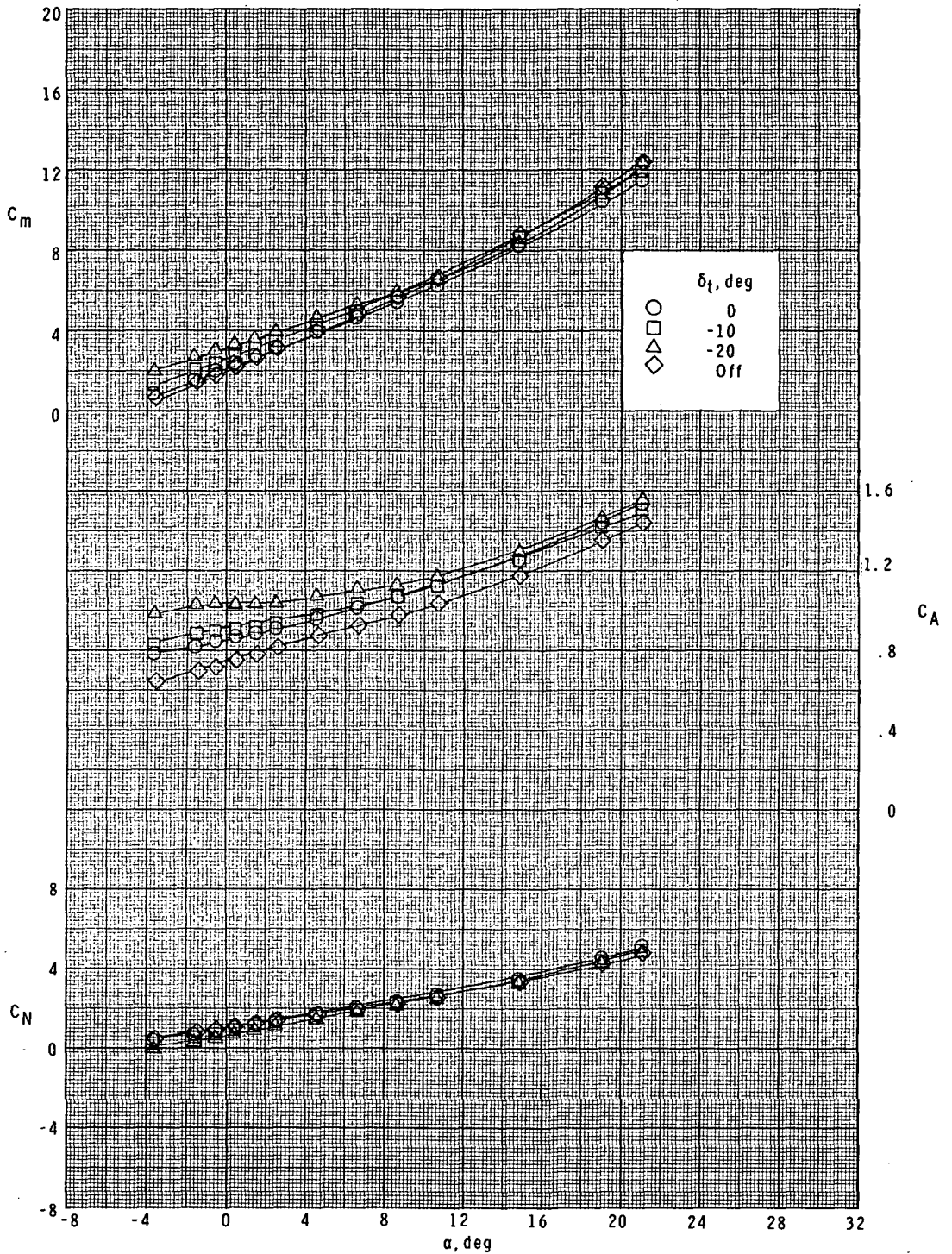
(e) Continued.

Figure 14. - Continued.



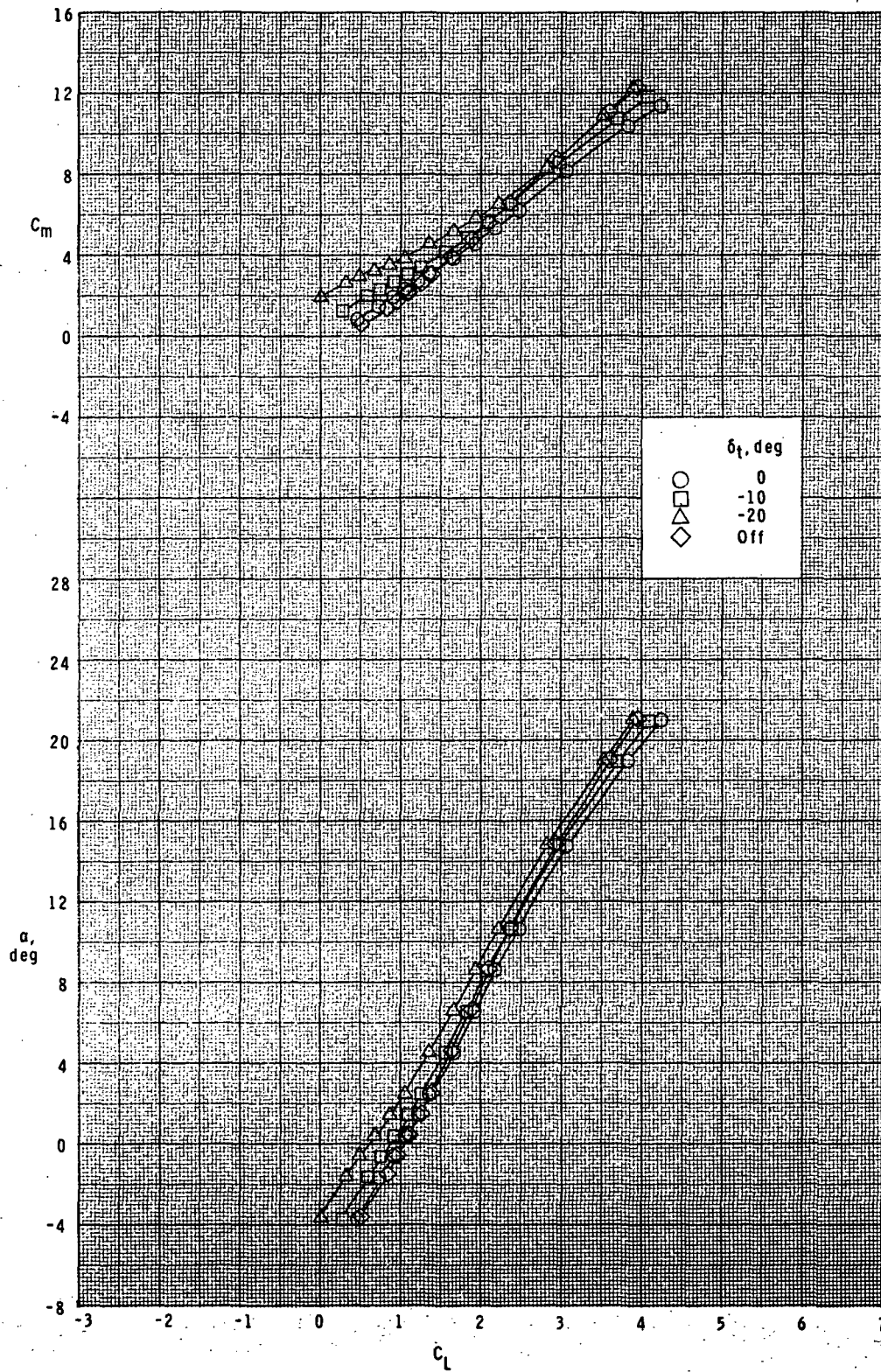
(e) Concluded.

Figure 14. - Continued.



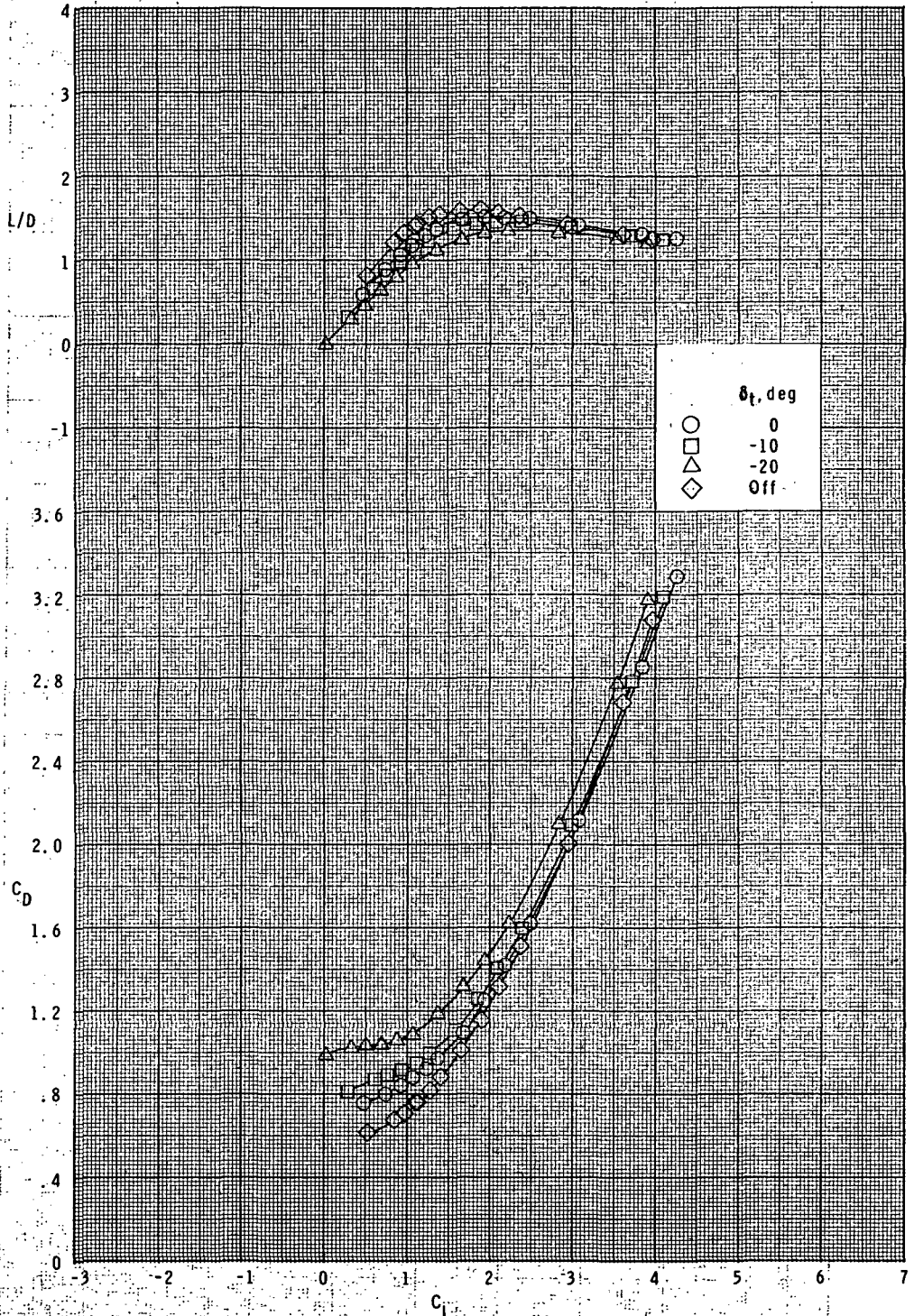
(f) $M = 4.63$.

Figure 14. - Continued.



(f) Continued.

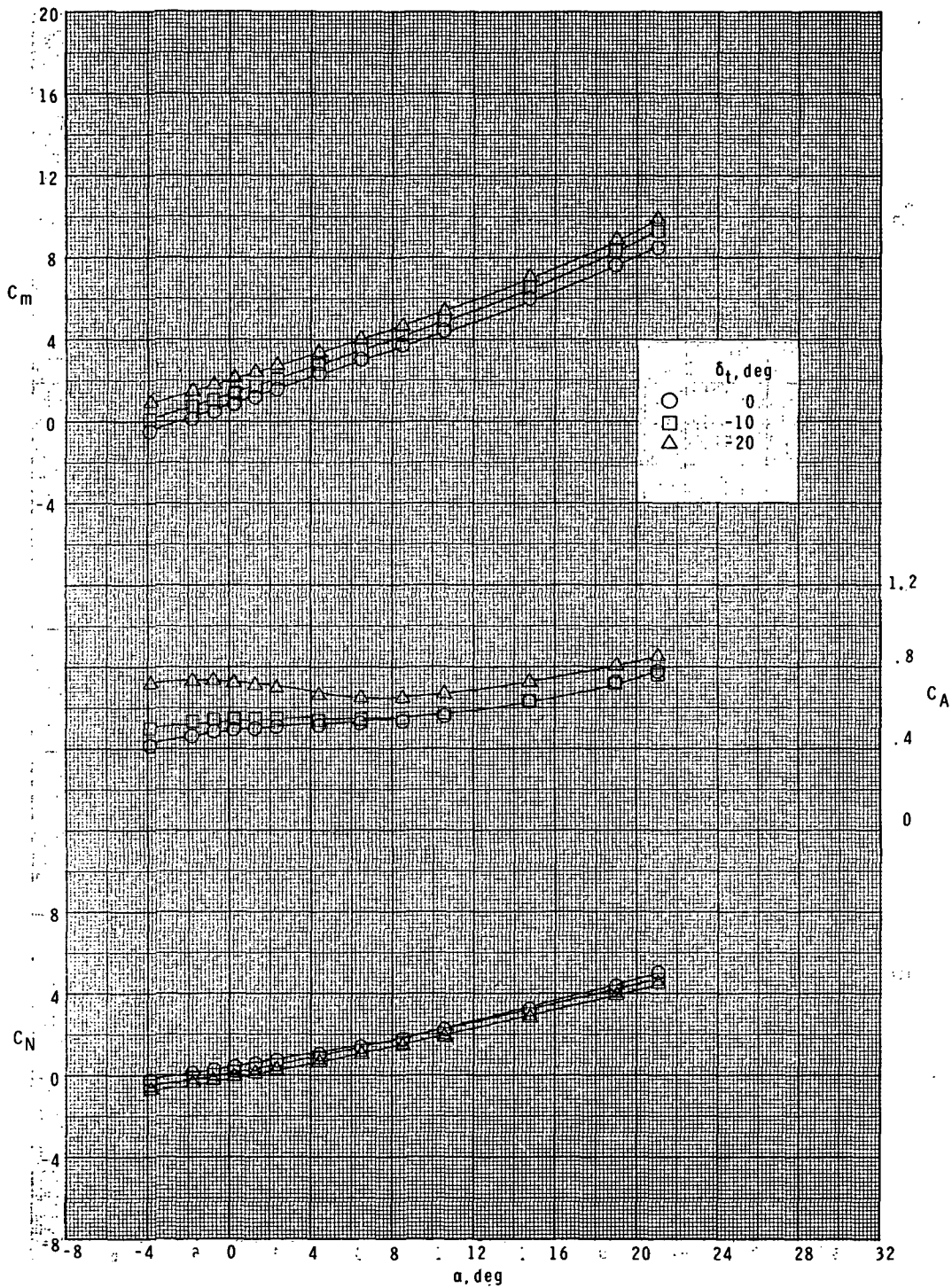
Figure 14.- Continued.



(f) Concluded.

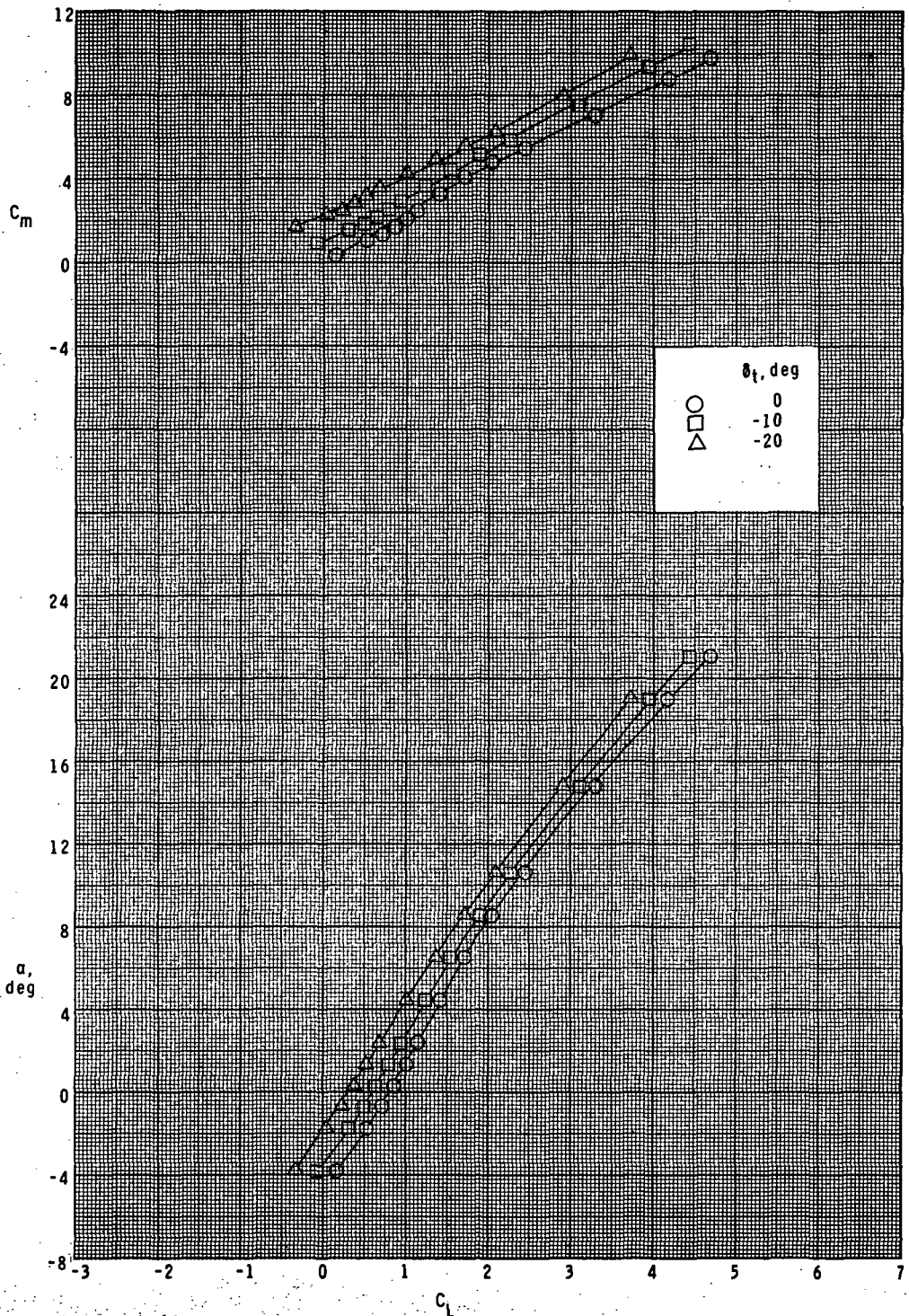
Figure 14. - Concluded.

Continued - Al on 17



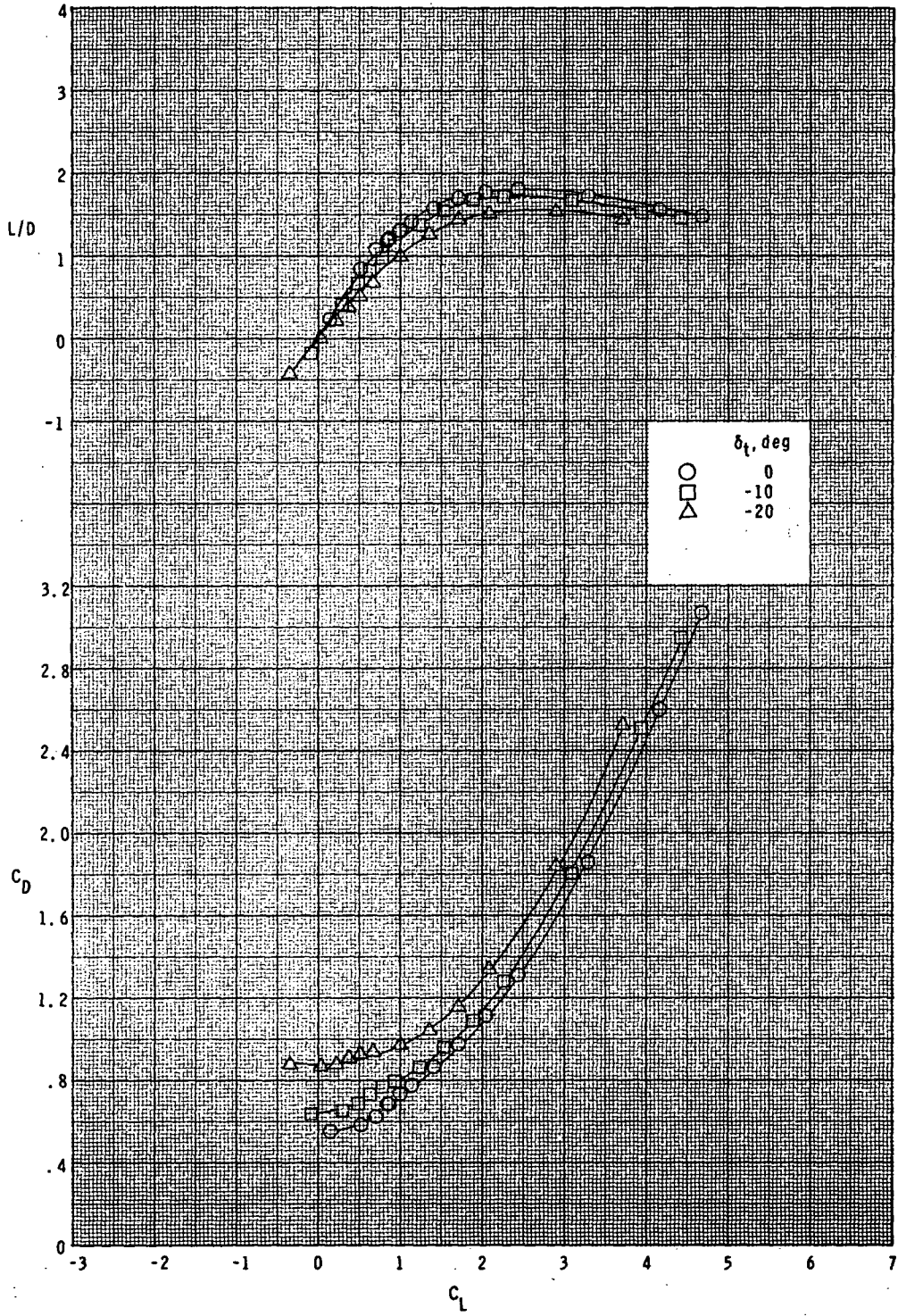
(a) $M = 3.95$.

Figure 15. - Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 10^\circ$; $\phi = 0^\circ$.



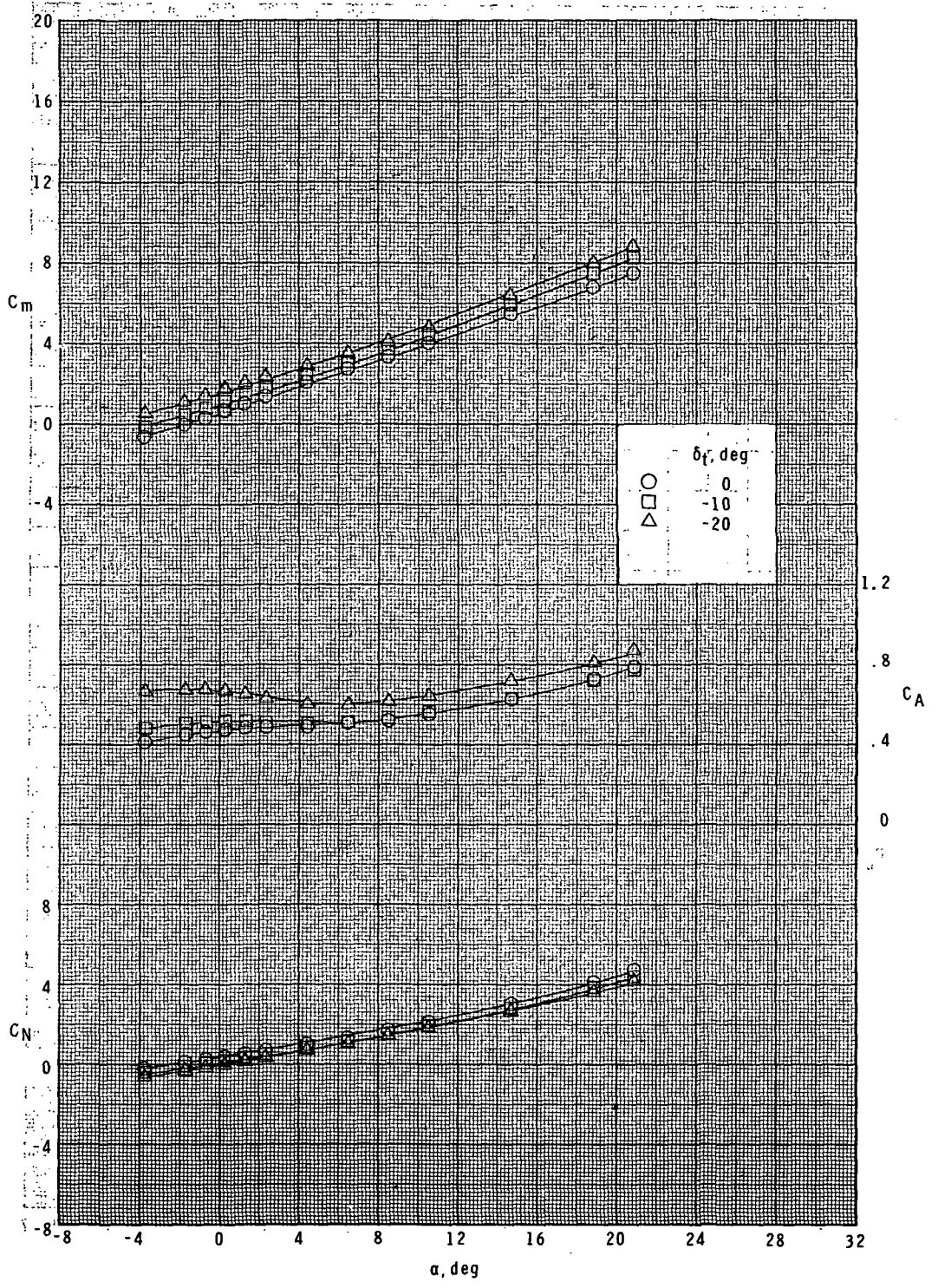
(a) Continued.

Figure 15.- Continued.



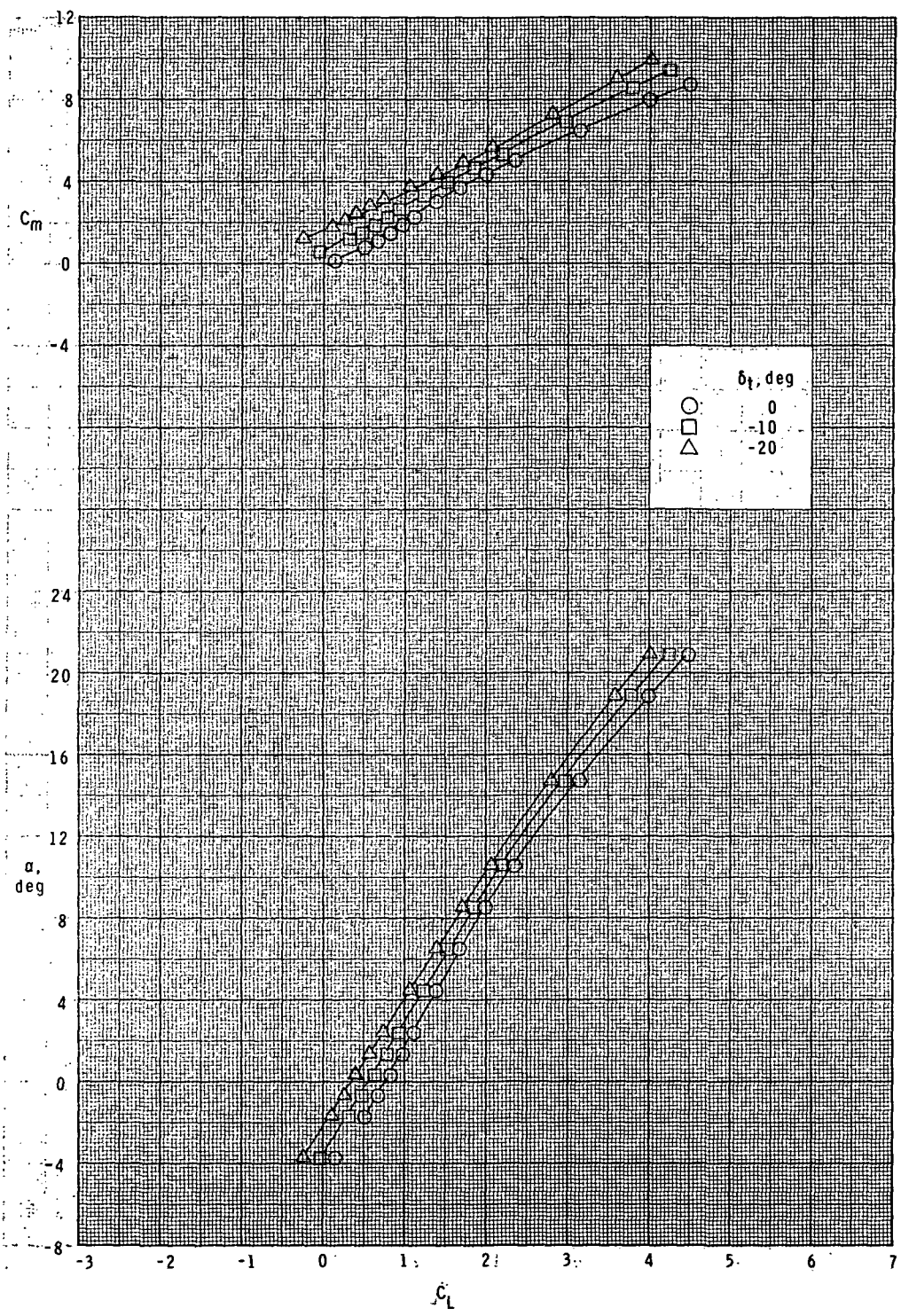
(a) Concluded.

Figure 15. - Continued.



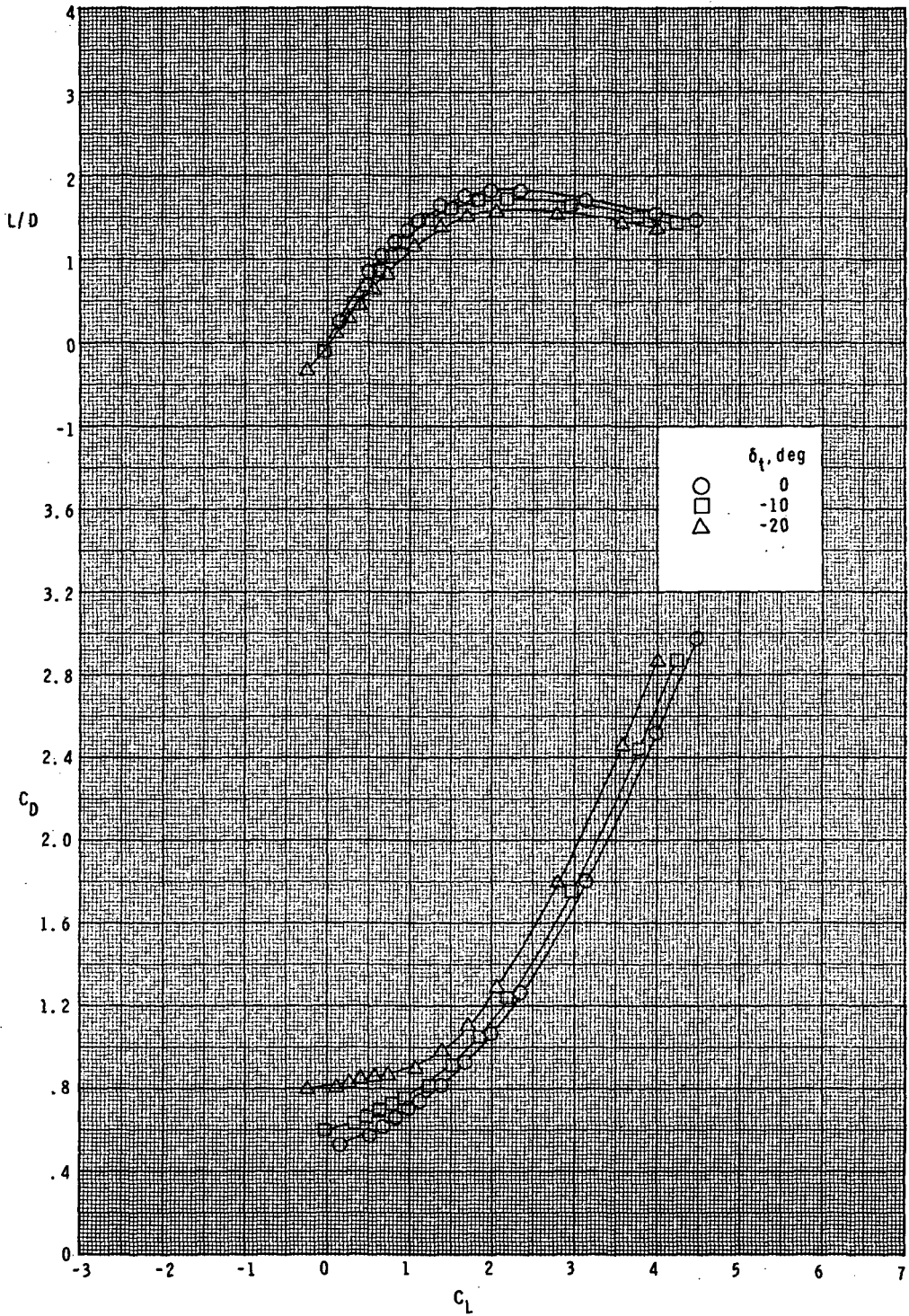
(b) $M = 4.63$.

Figure 15.- Continued.



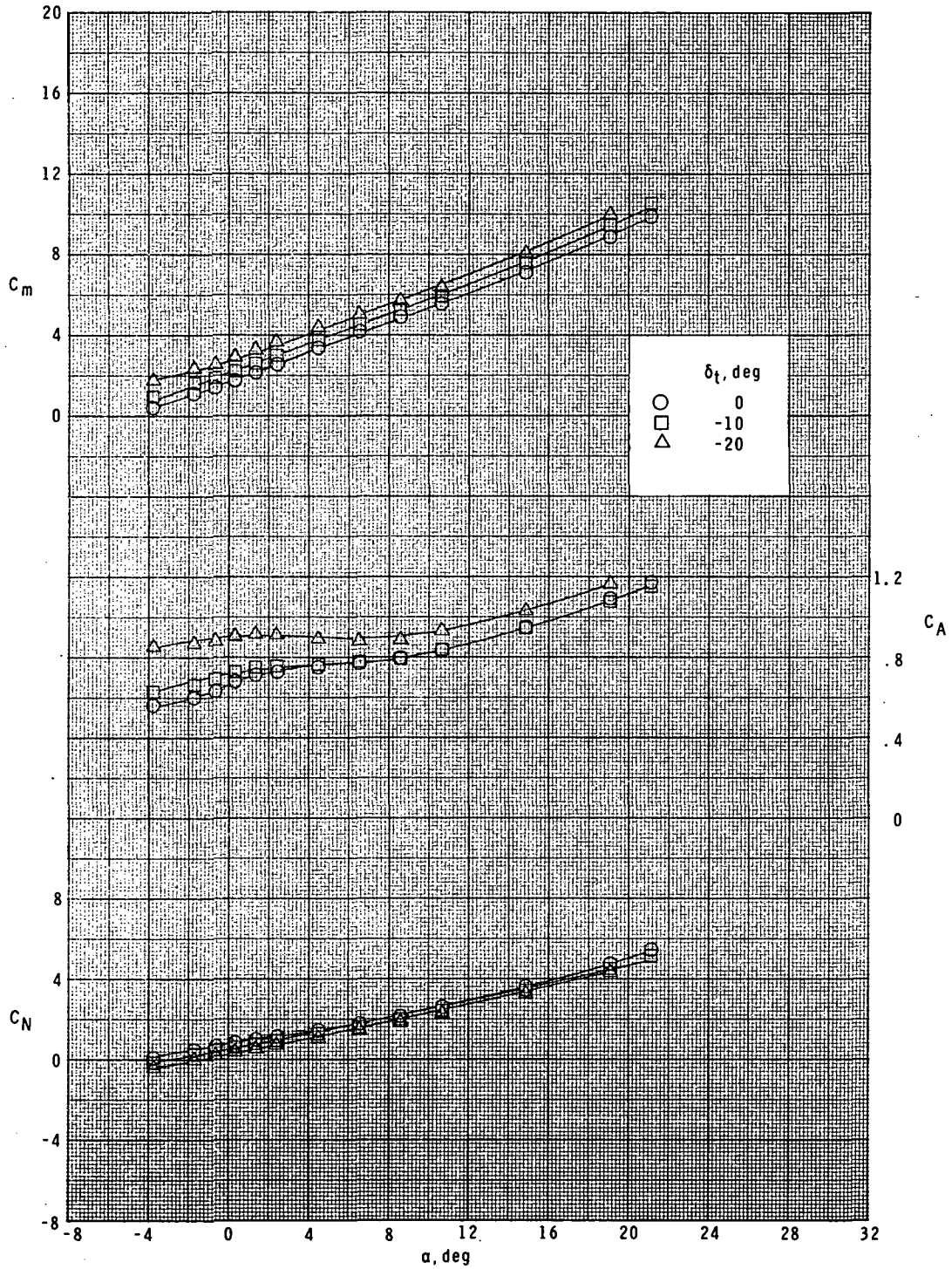
(b) Continued.

Figure 15. - Continued.



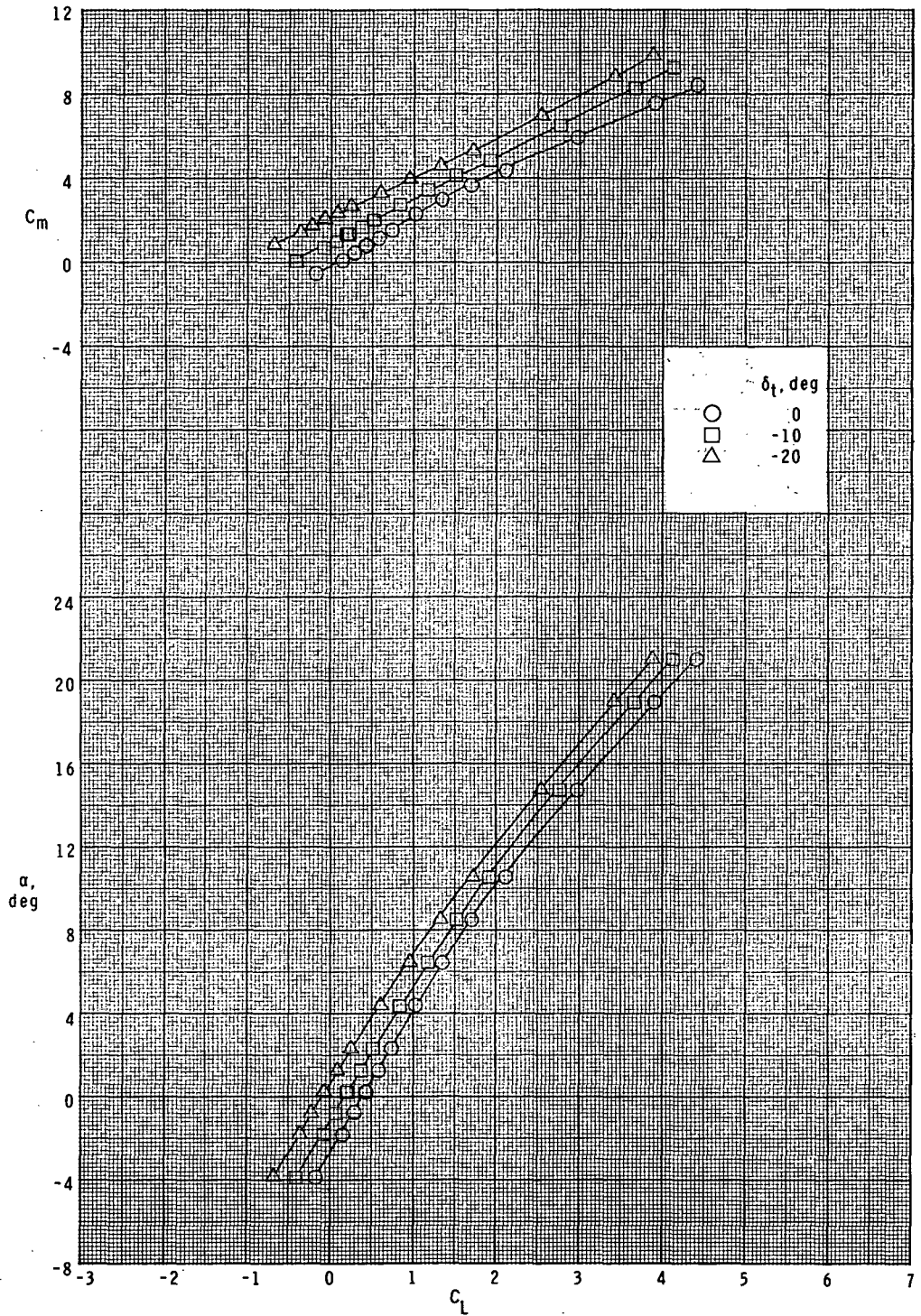
(b) Concluded.

Figure 15.- Concluded.



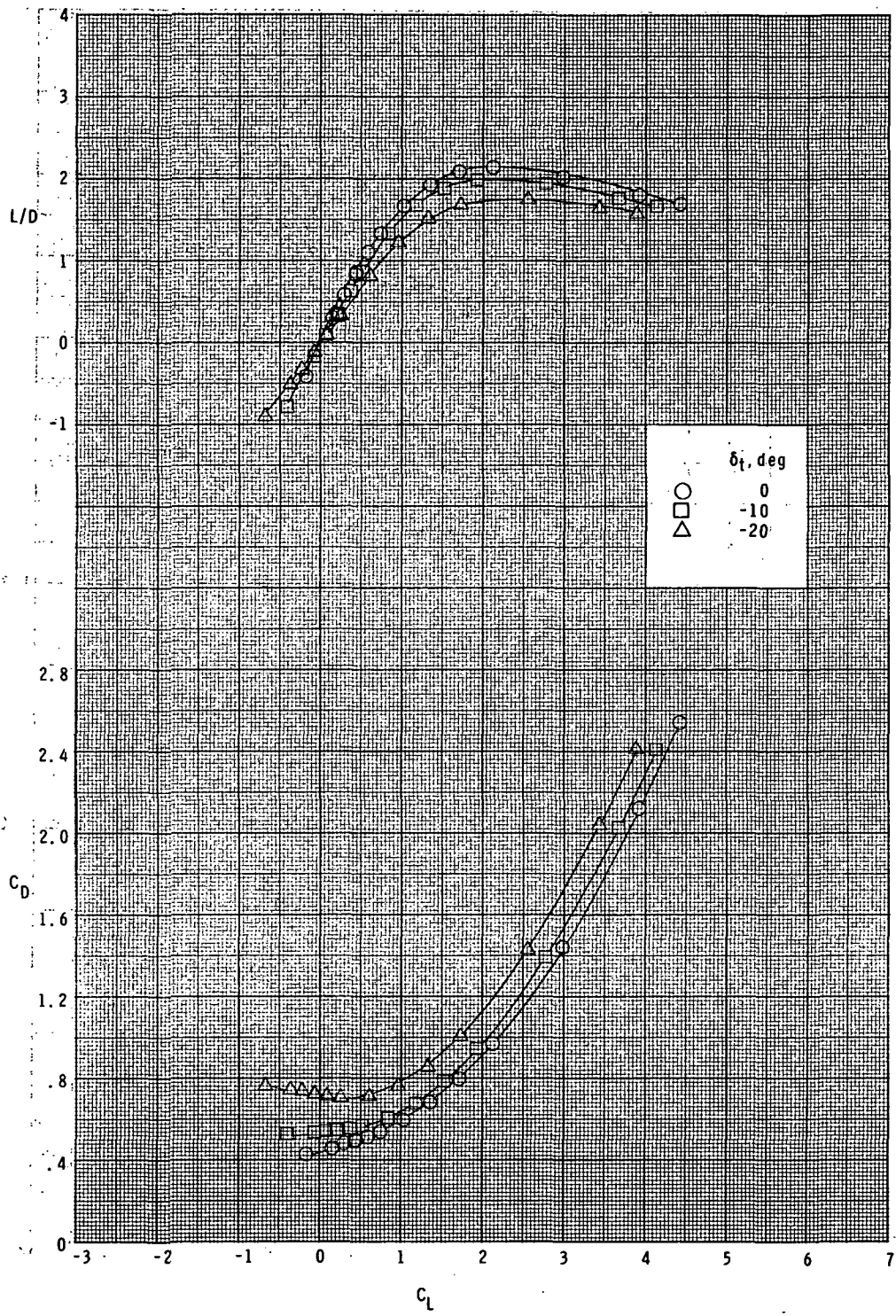
(a) $M = 3.95$.

Figure 16.- Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 20^\circ$; $\phi = 0^\circ$.



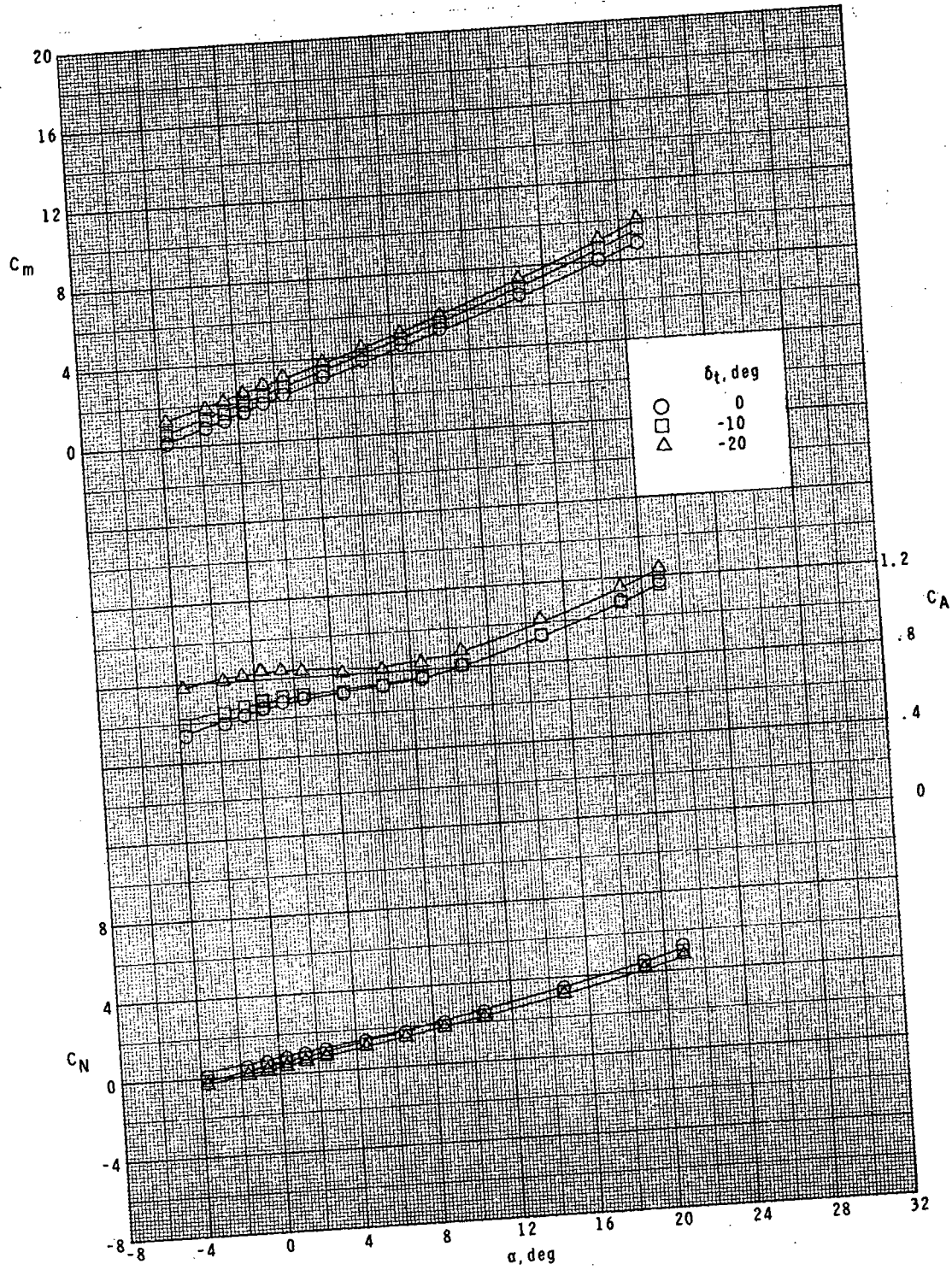
(a) Continued.

Figure 16.- Continued.

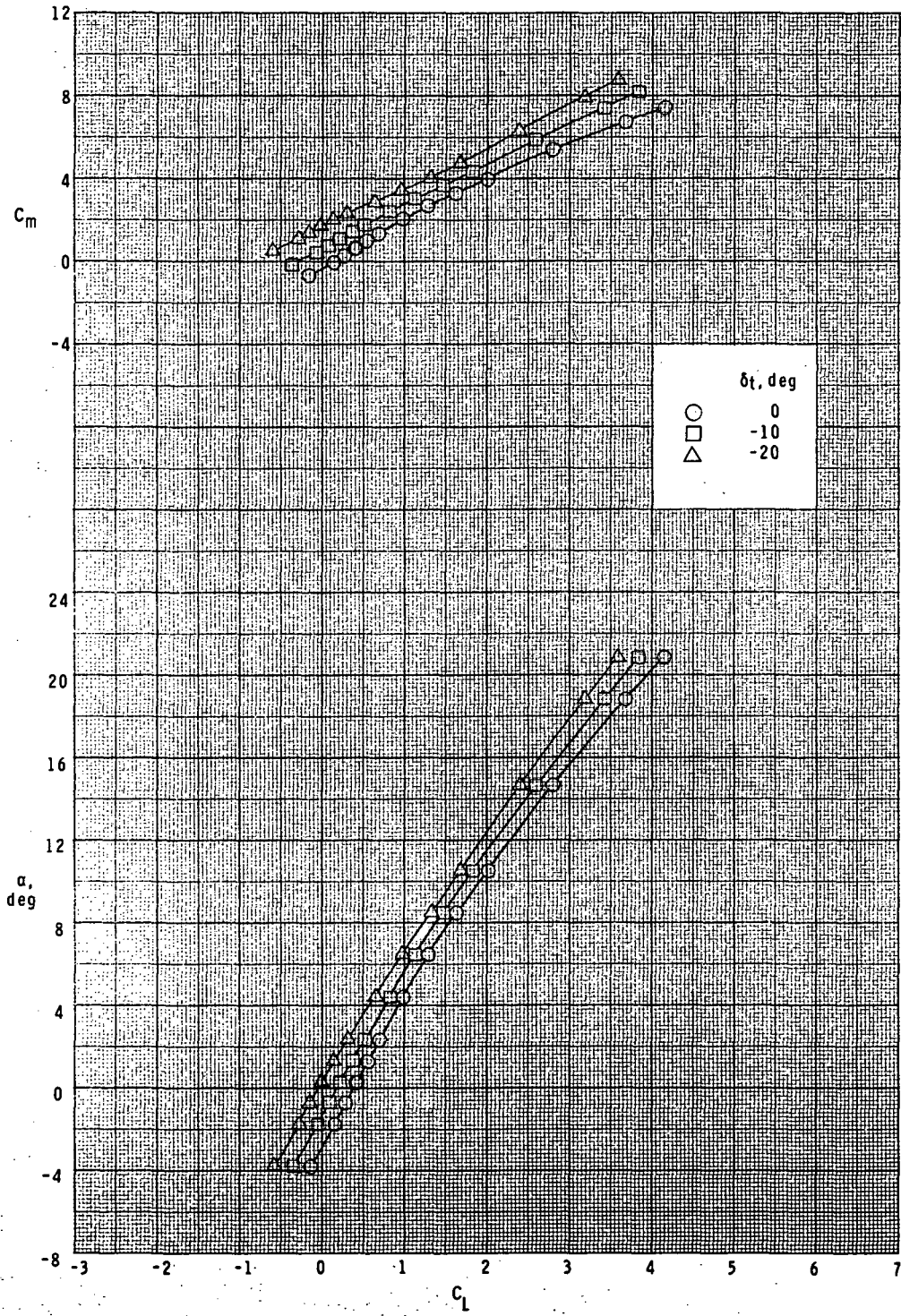


(a) Concluded.

Figure 16. - Continued.

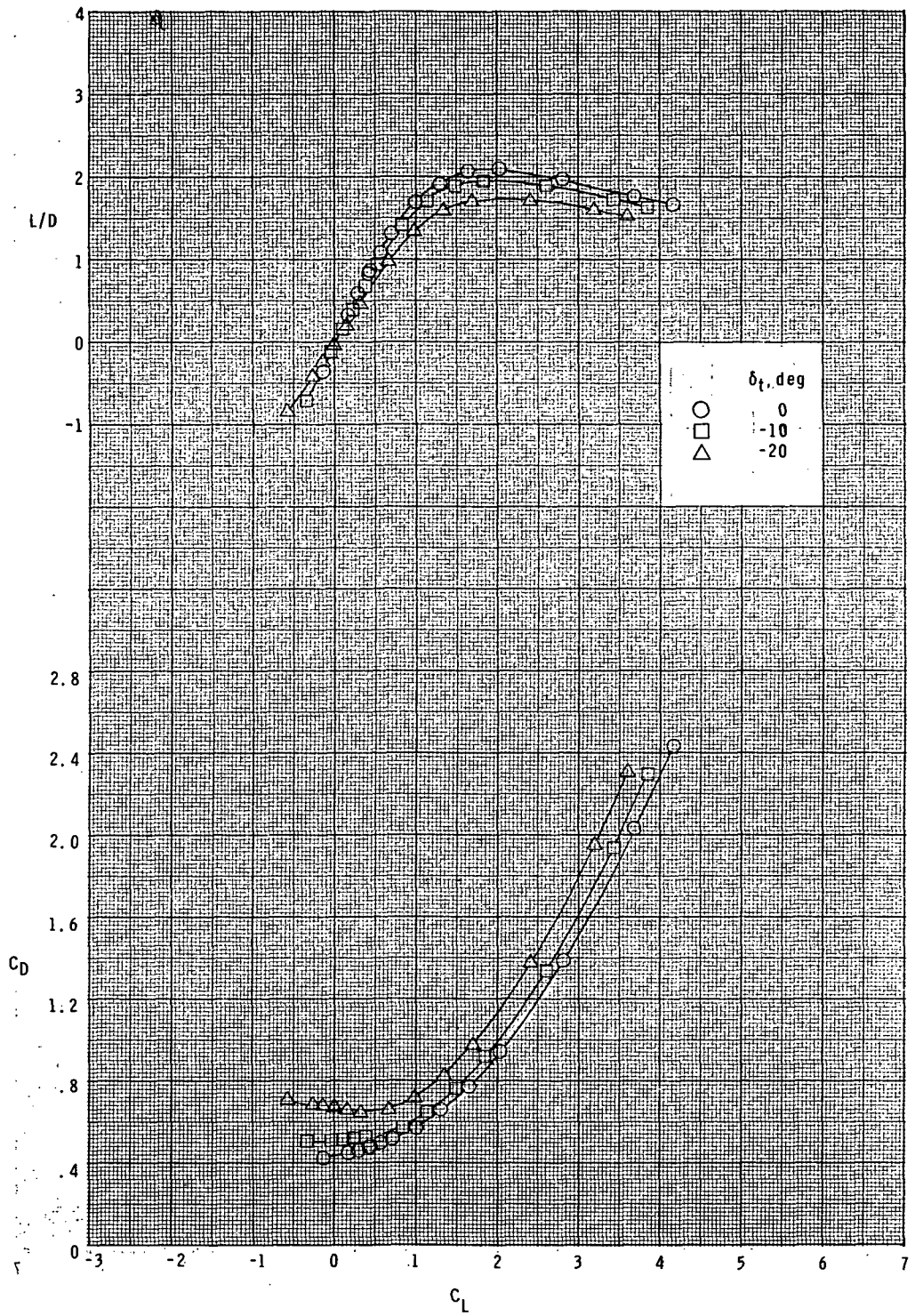


(b) $M = 4.63$.
 Figure 16.- Continued.



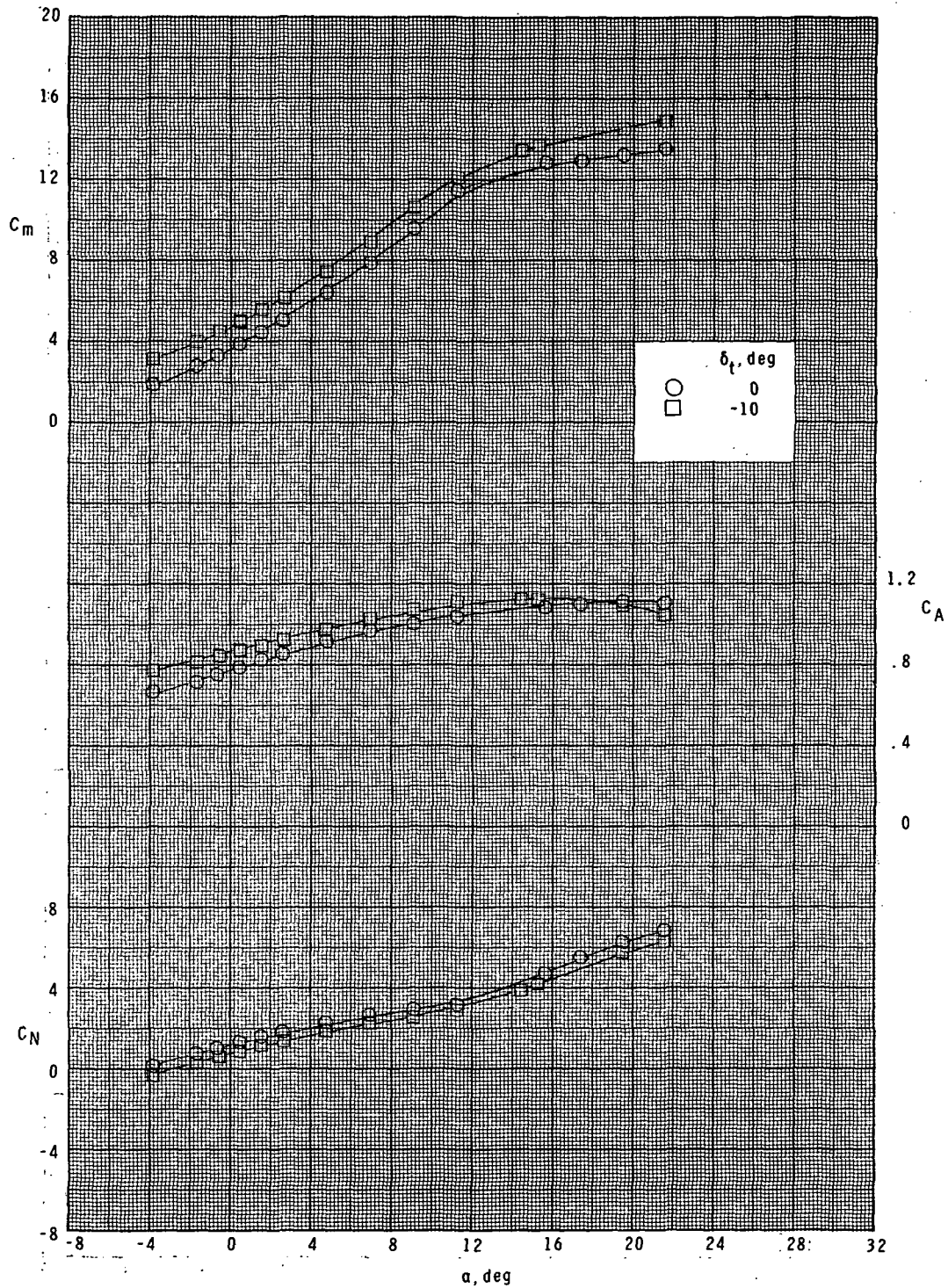
(b) Continued.

Figure 16. - Continued.



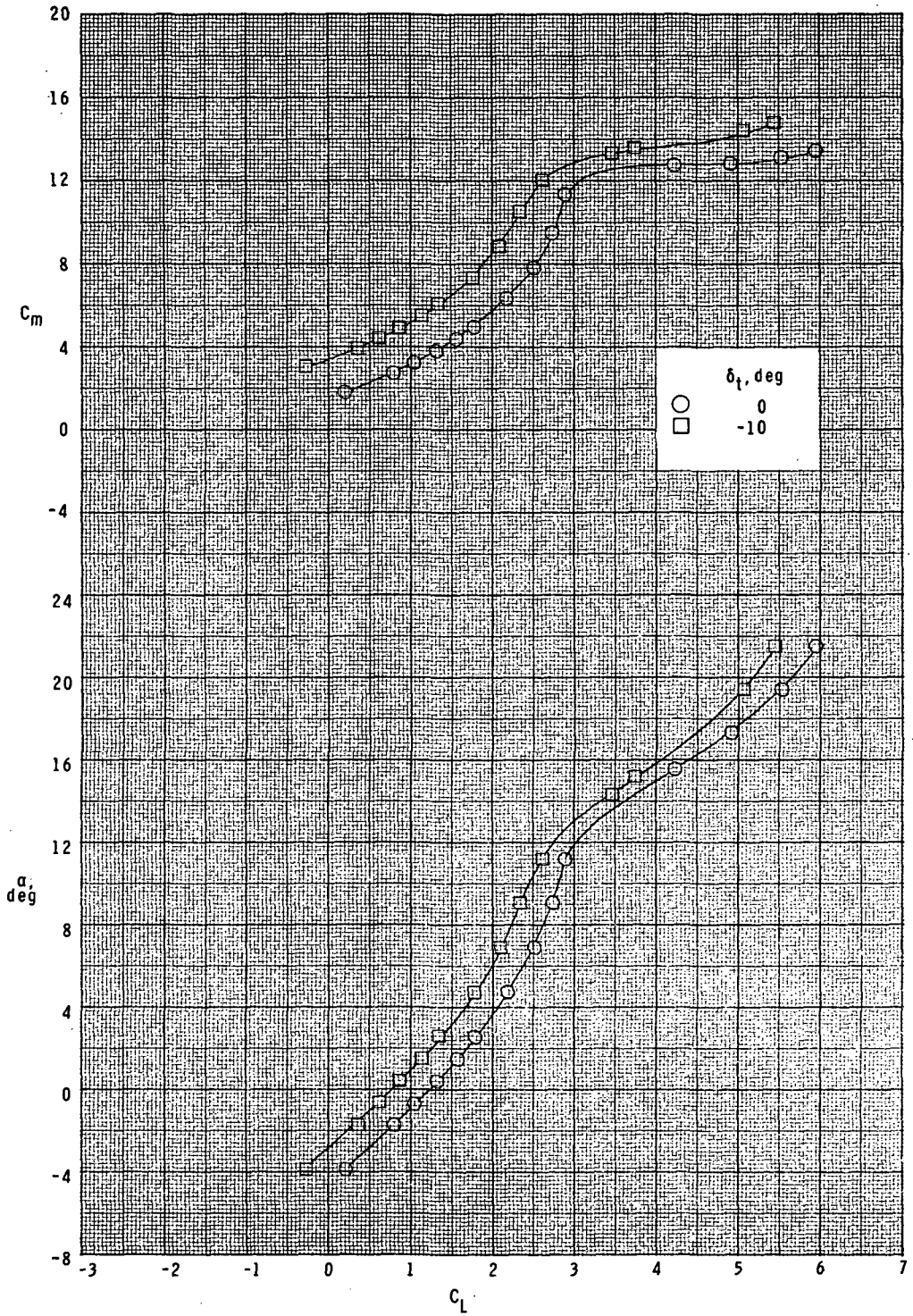
(b) Concluded.

Figure 16.- Concluded.



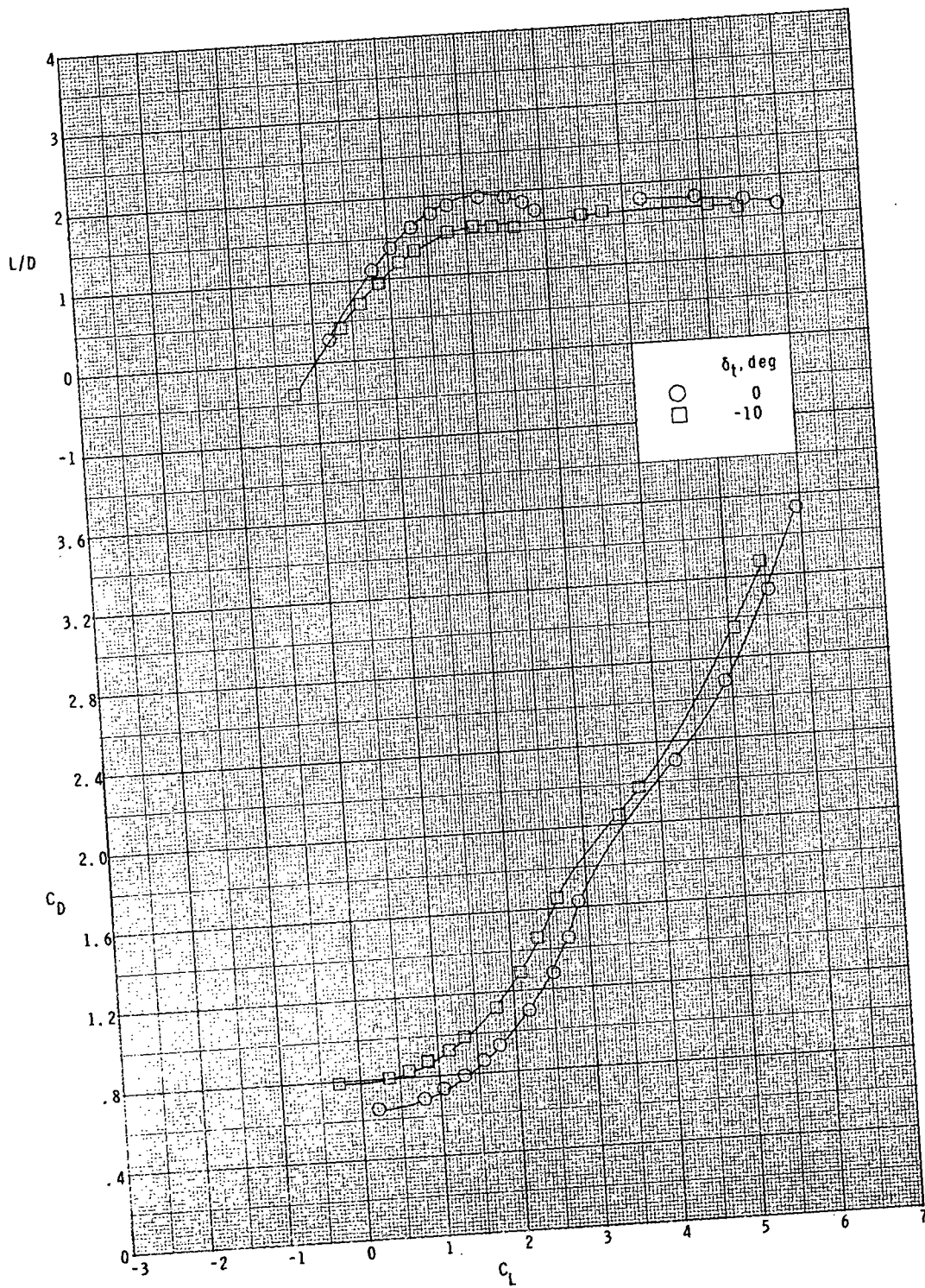
(a) $M = 1.50$.

Figure 17.- Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 10^\circ$; $\phi = 45^\circ$.



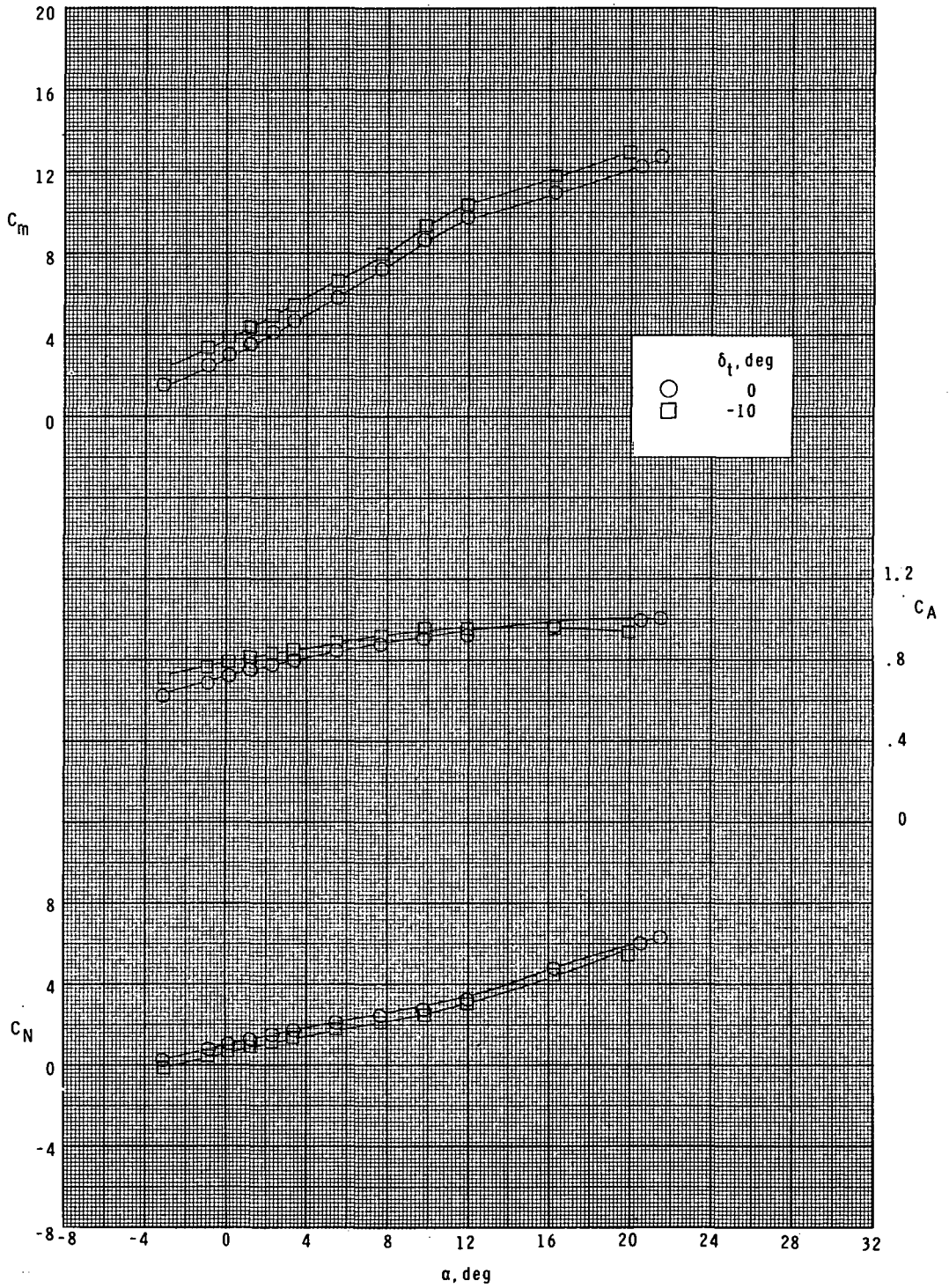
(a) Continued.

Figure 17.- Continued.



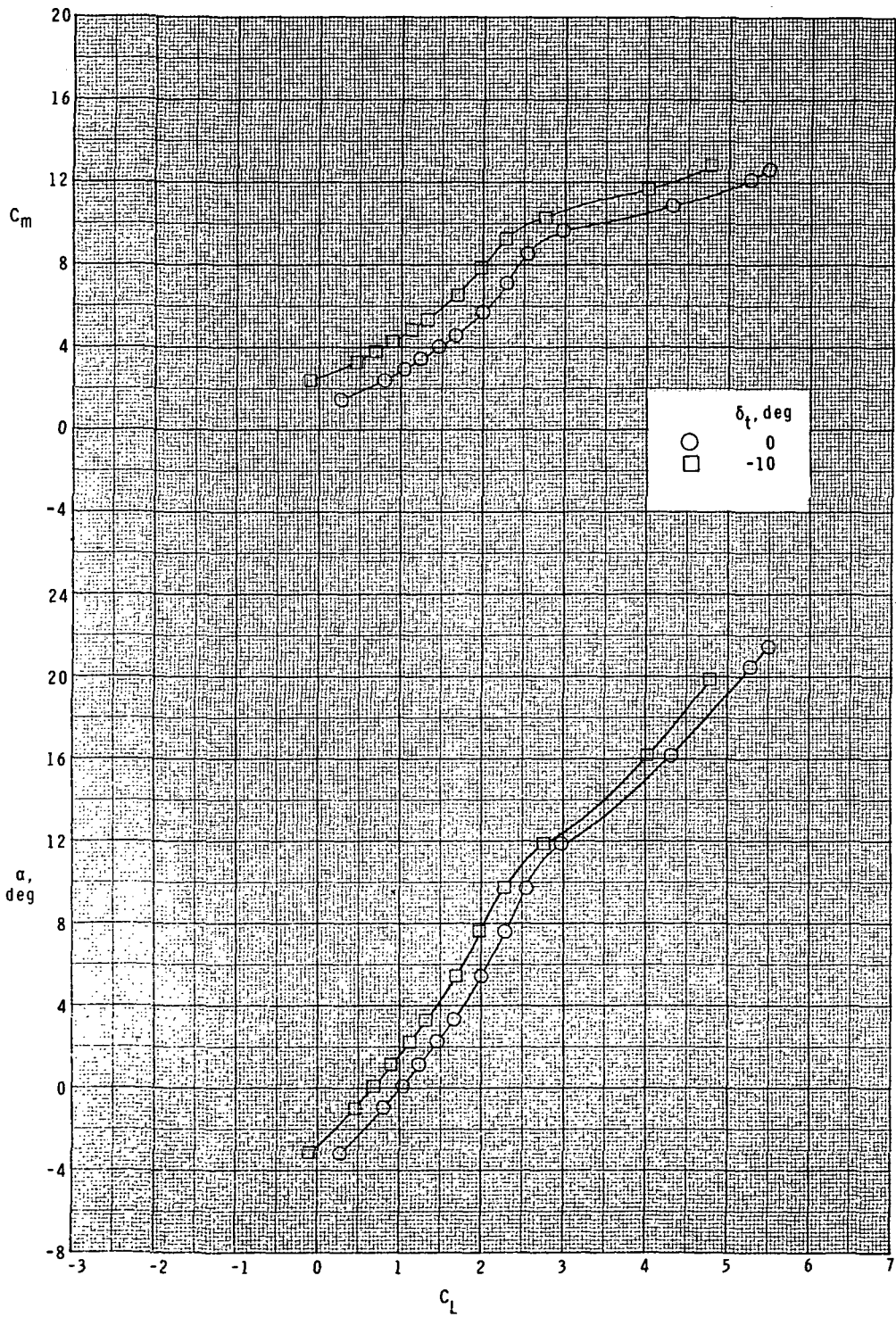
(a) Concluded.

Figure 17. - Continued.



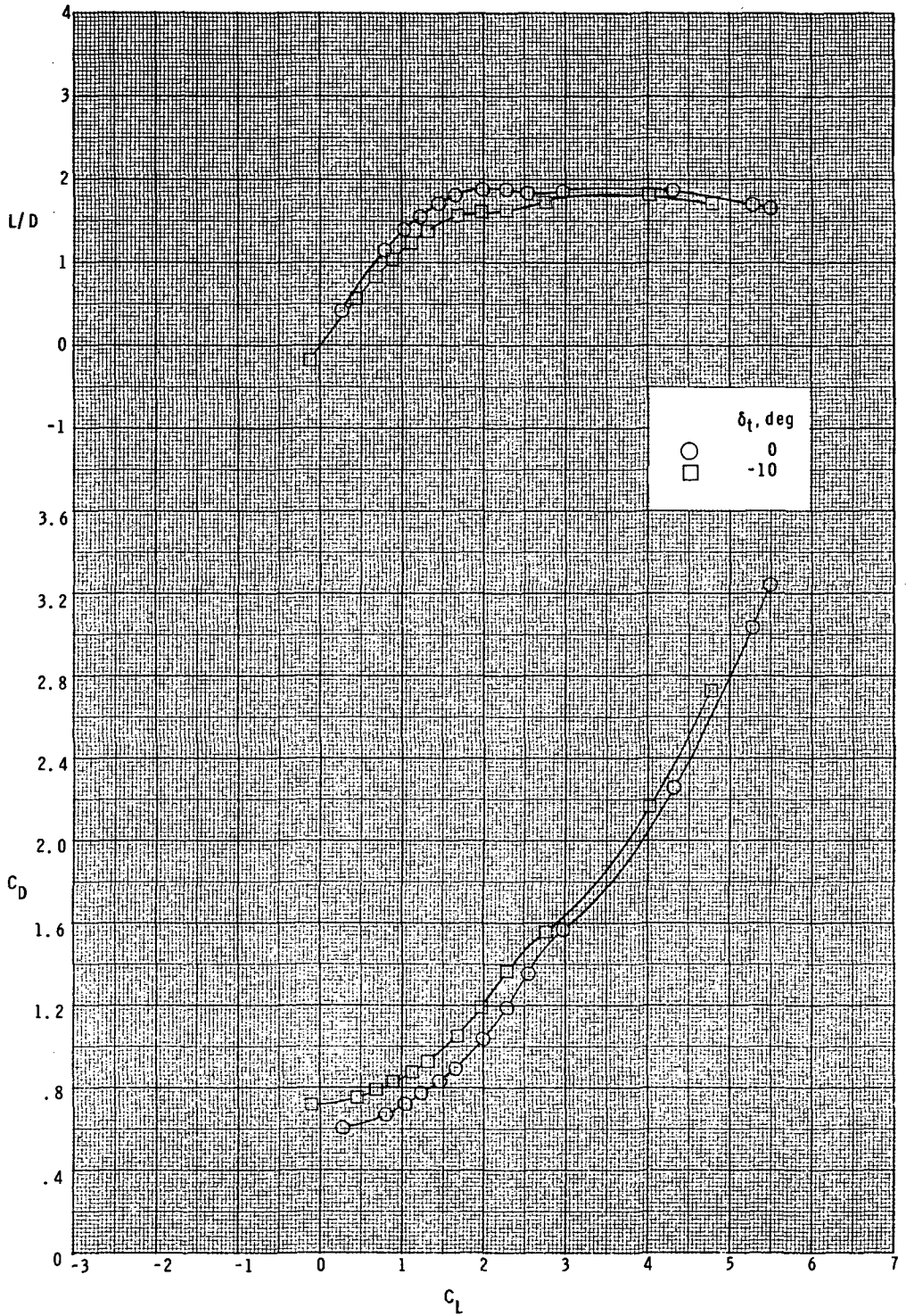
(b) $M = 1.90$.

Figure 17. - Continued.



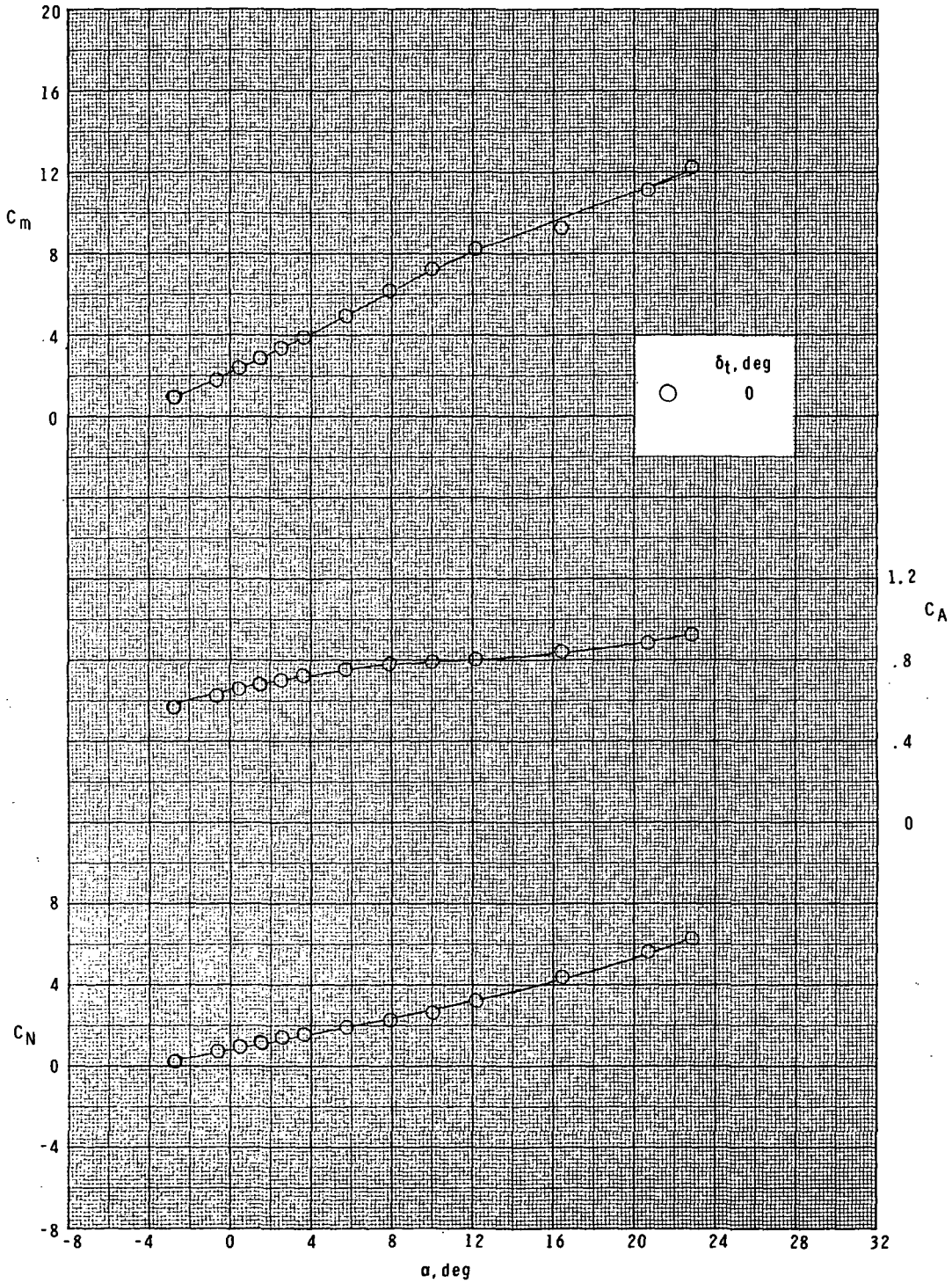
(b) Continued.

Figure 17.- Continued.



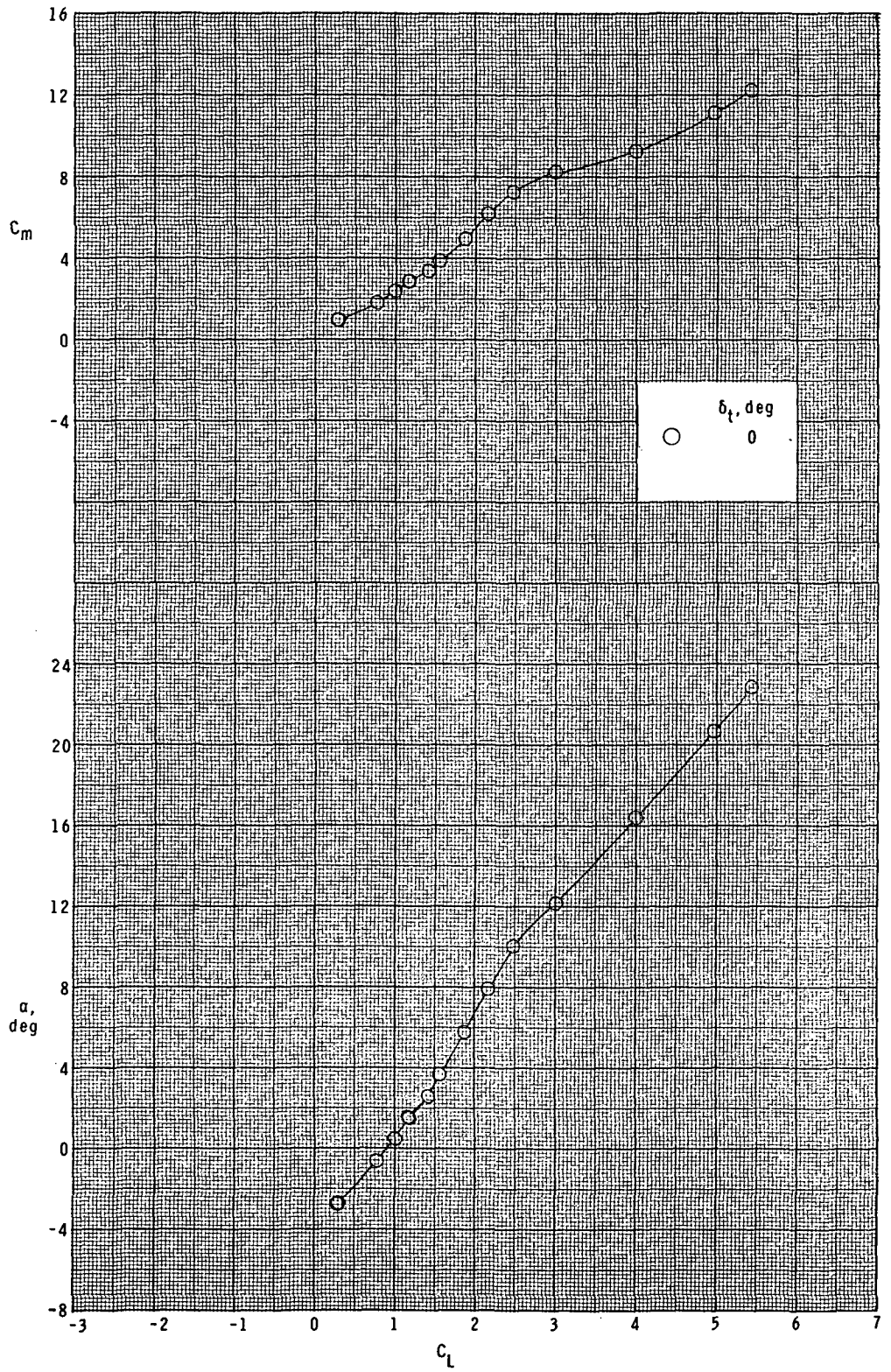
(b) Concluded.

Figure 17.- Continued.



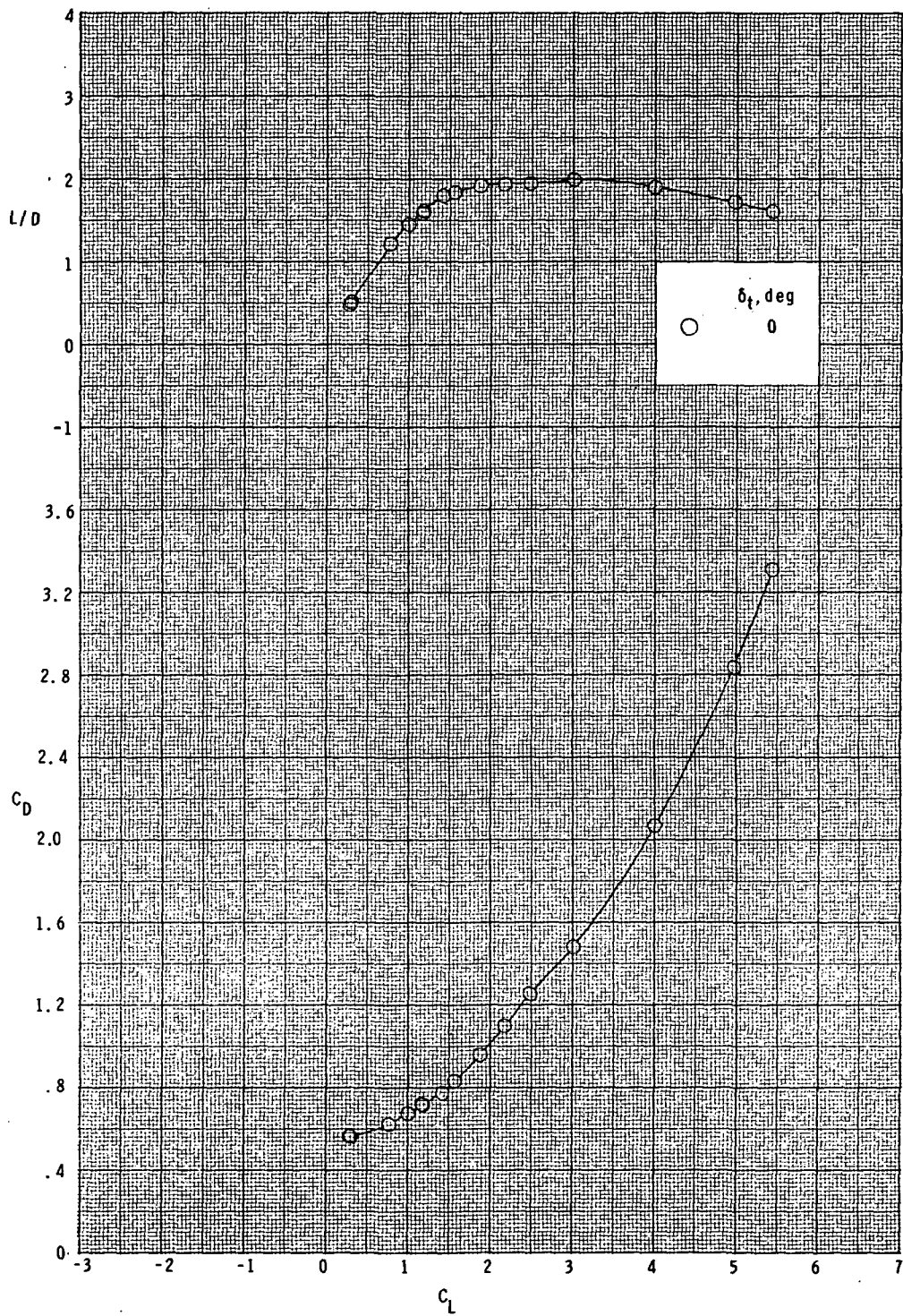
(c) $M = 2.36$.

Figure 17. - Continued.



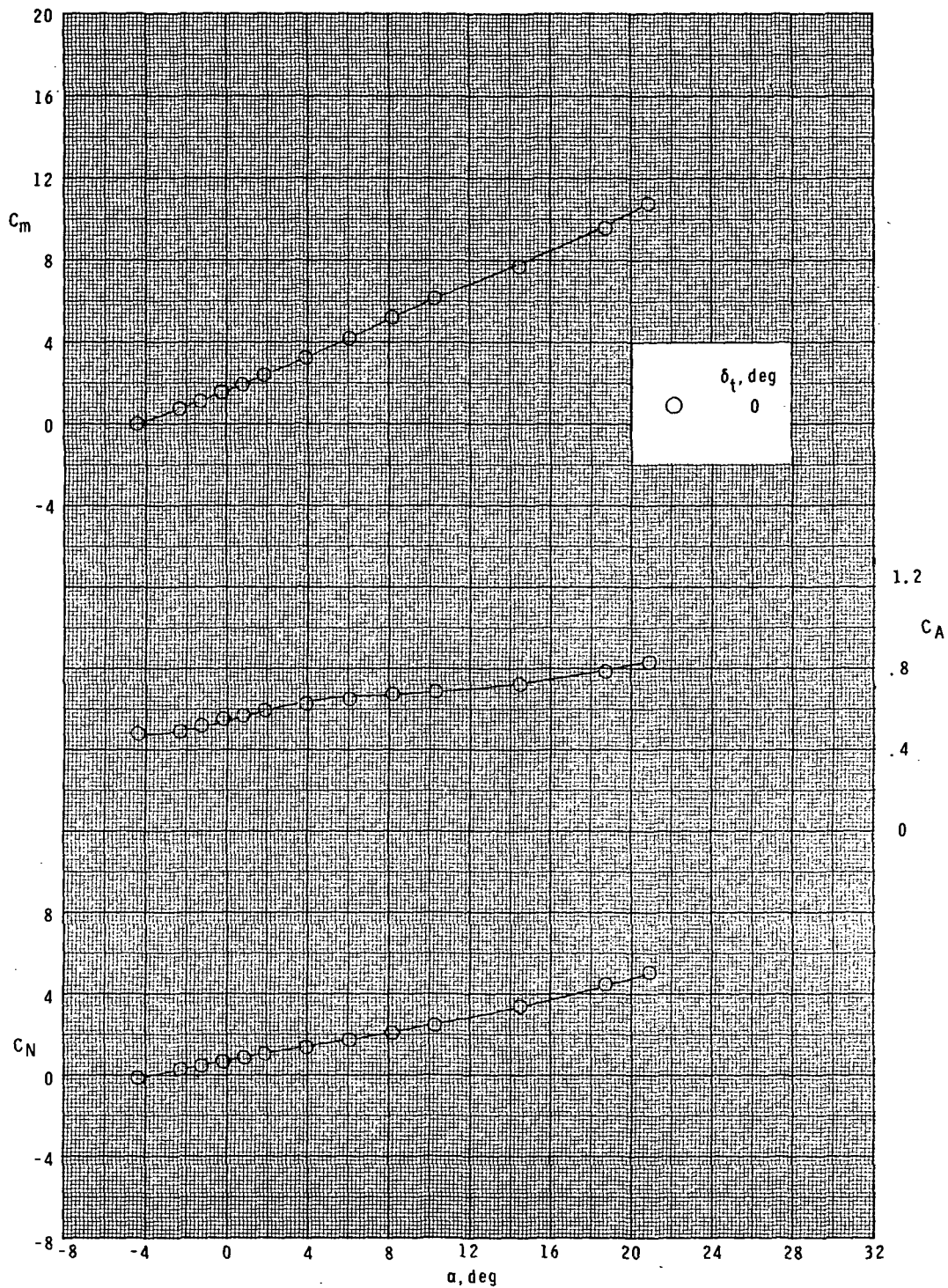
(c) Continued.

Figure 17.- Continued.



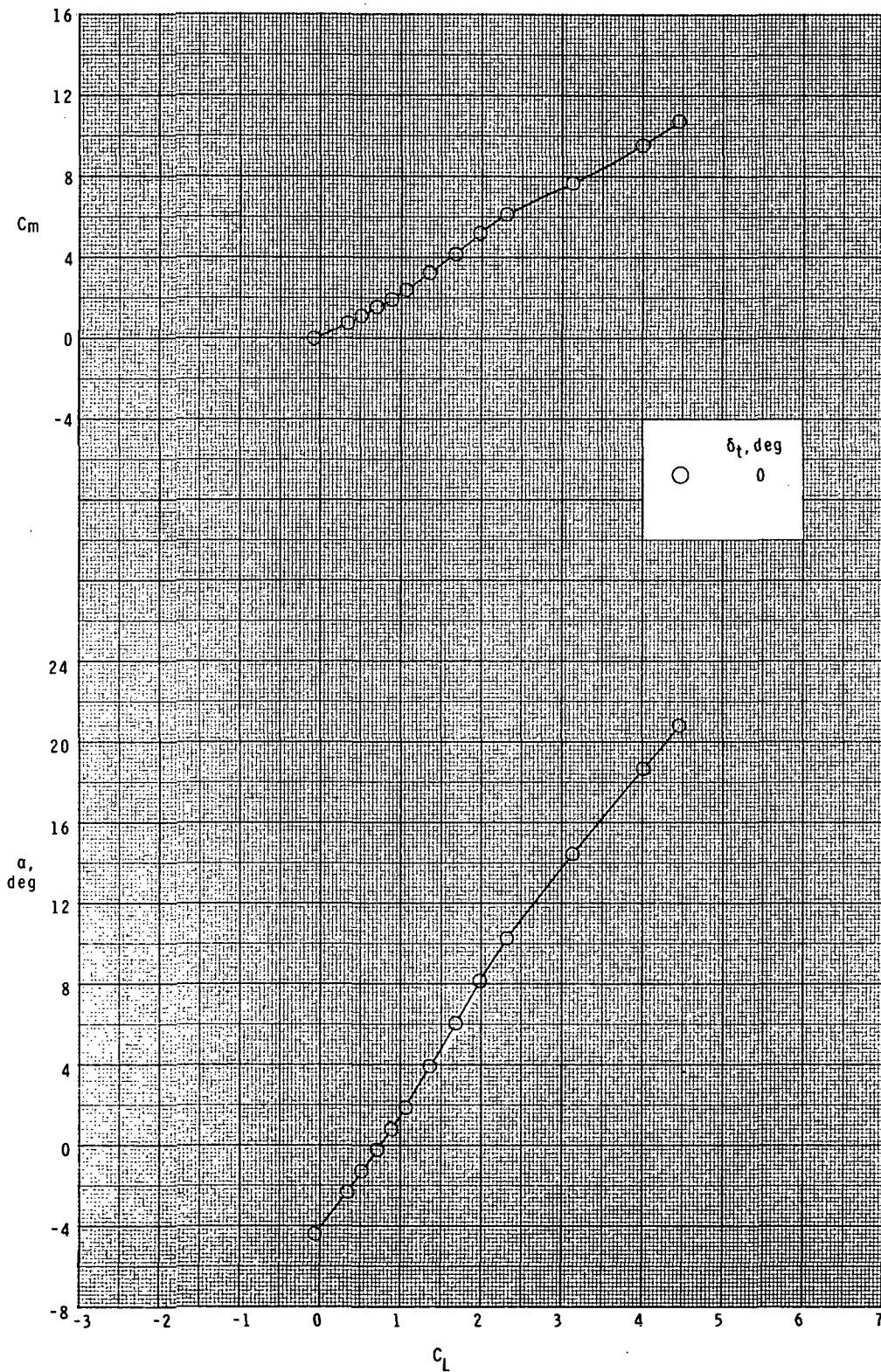
(c) Concluded.

Figure 17.- Continued.



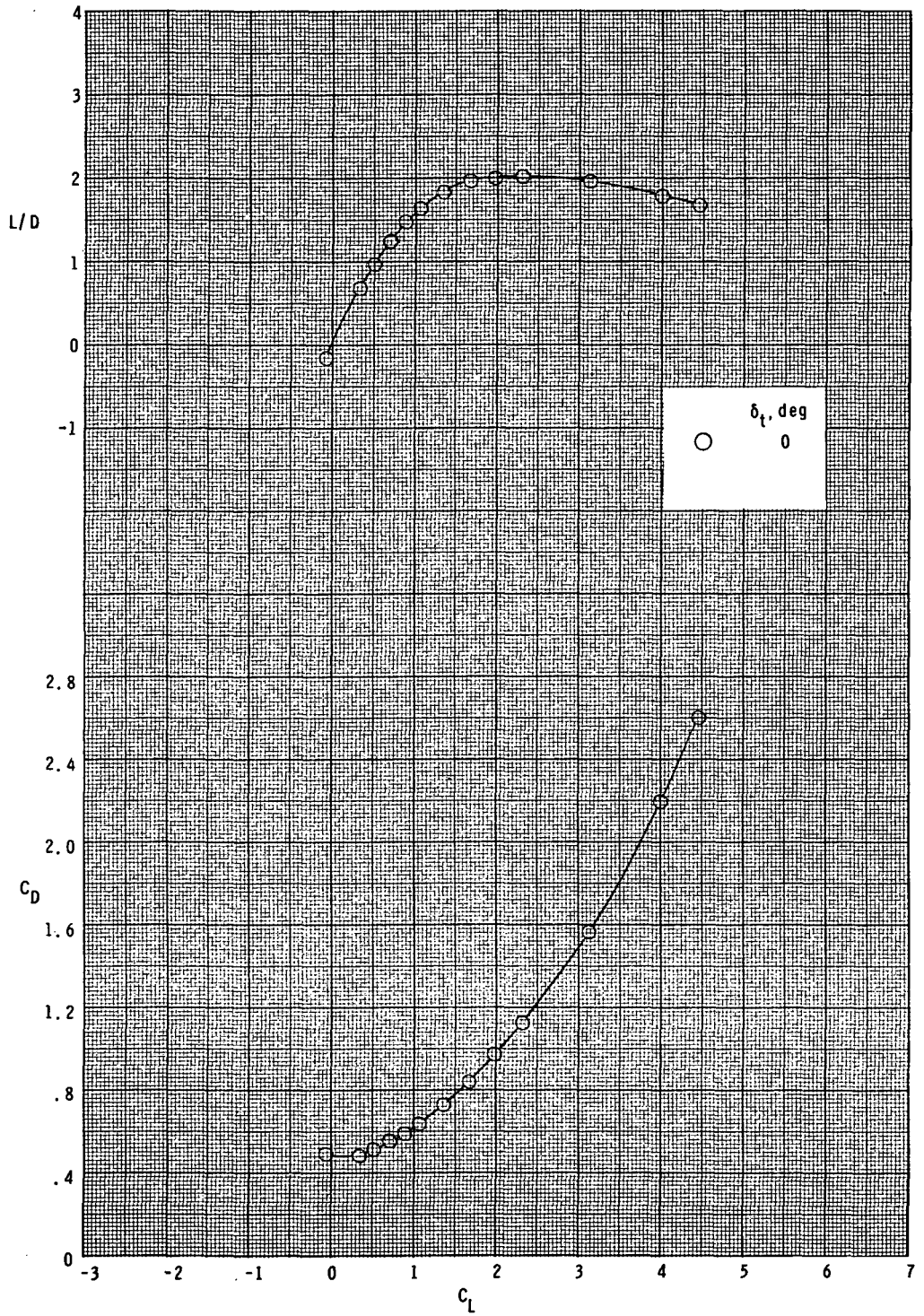
(d) $M = 2.86$.

Figure 17.- Continued.



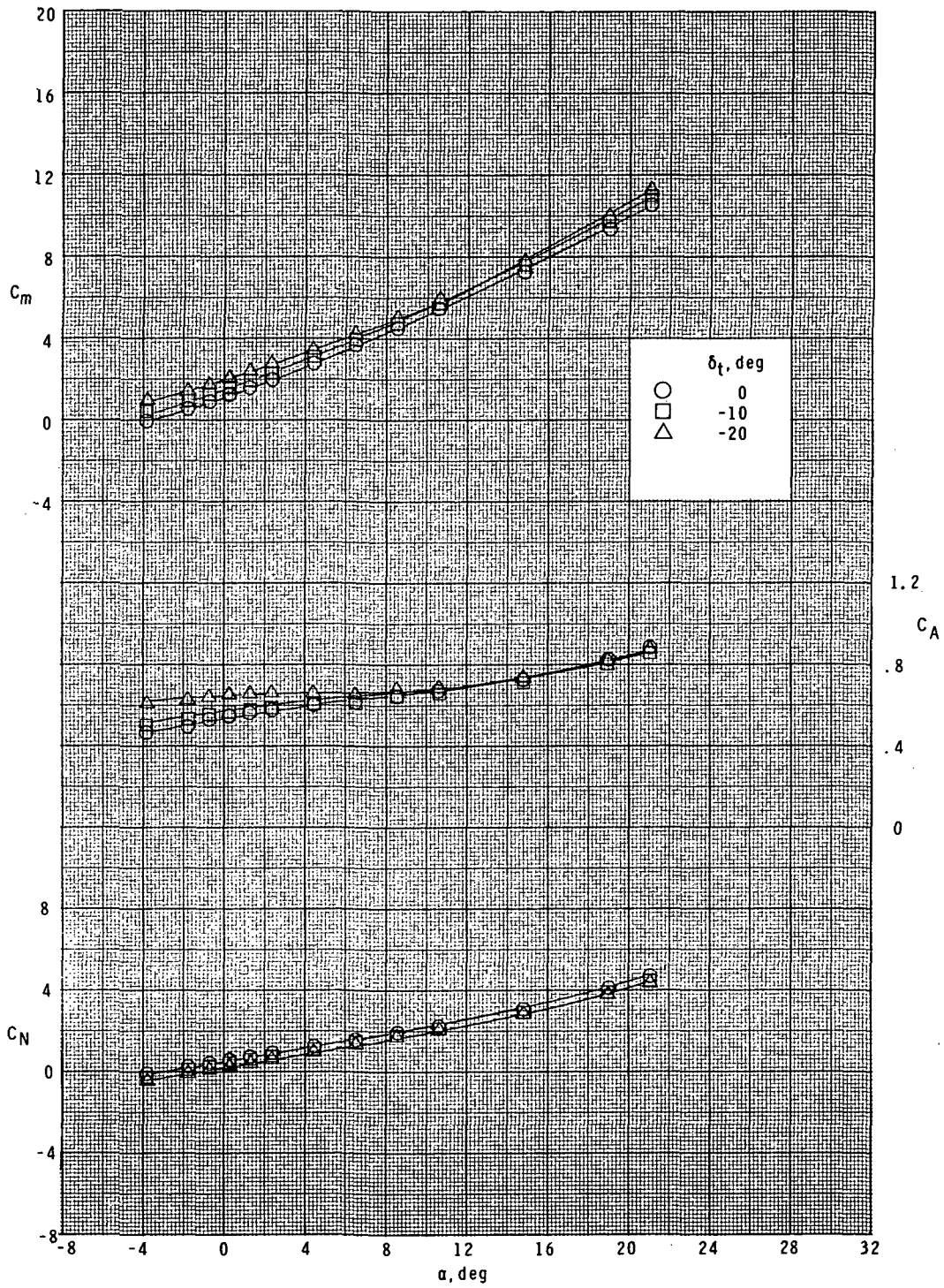
(d) Continued.

Figure 17.- Continued.



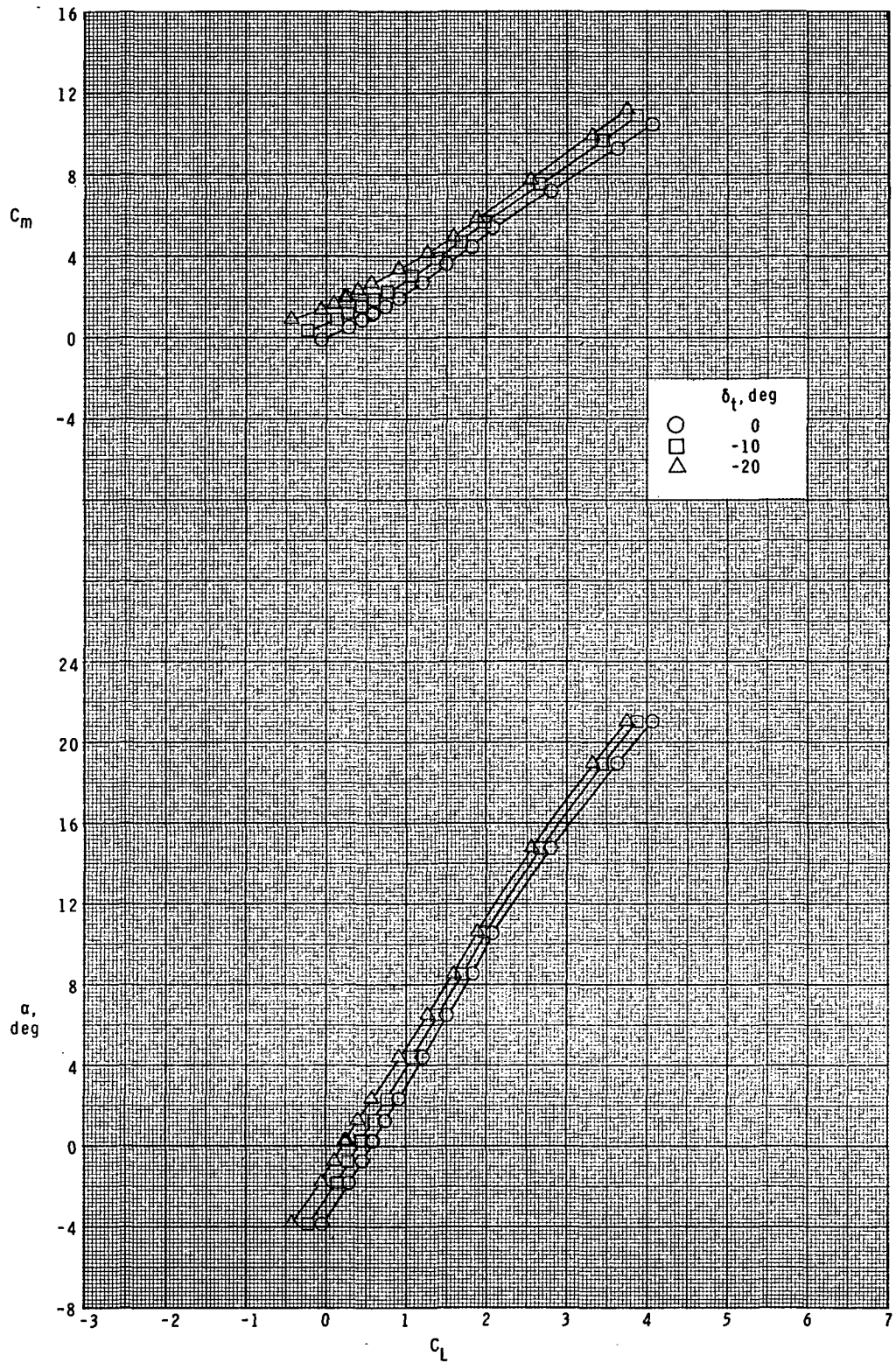
(d) Concluded.

Figure 17.- Continued.



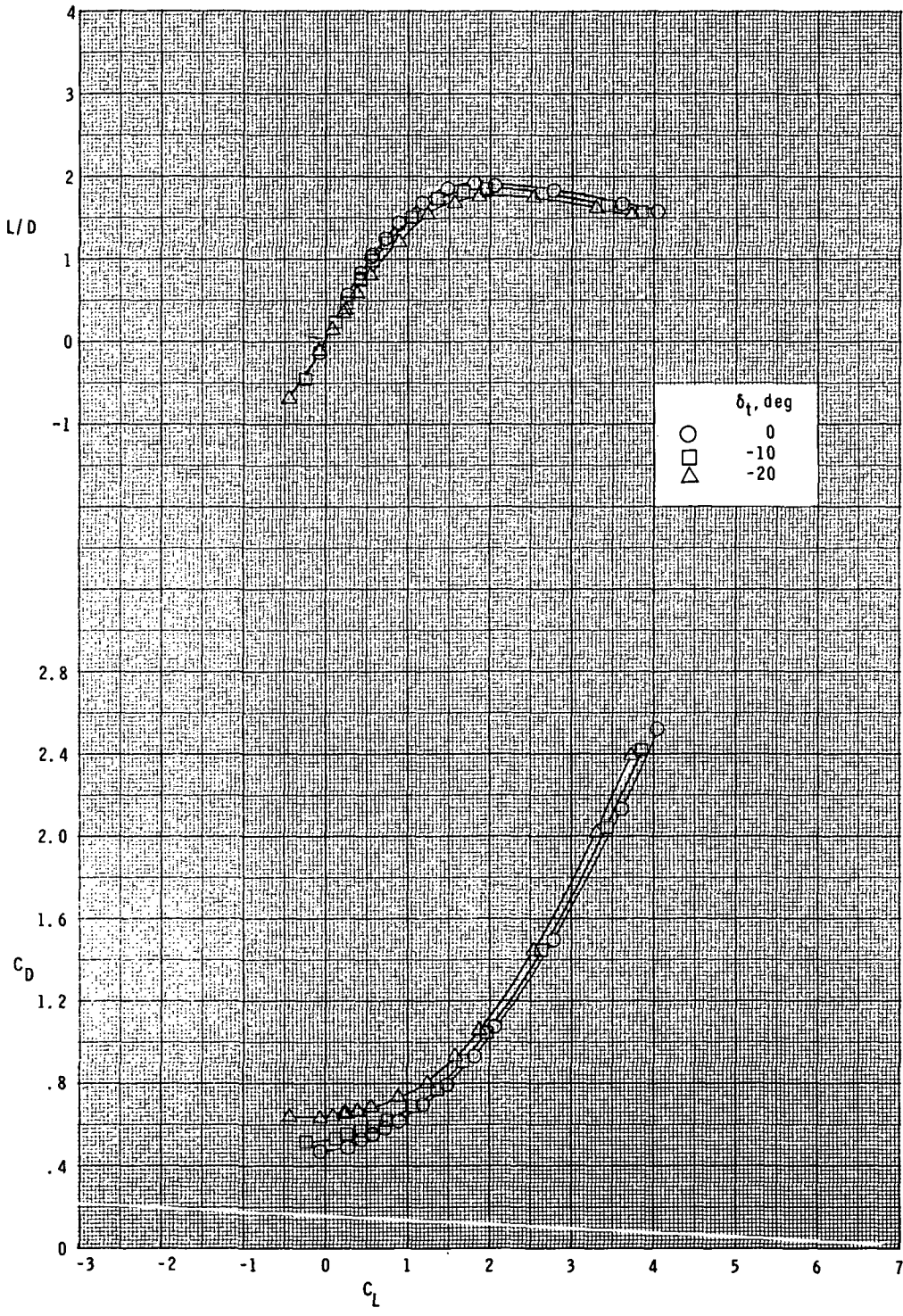
(e) $M = 3.95$.

Figure 17.- Continued.



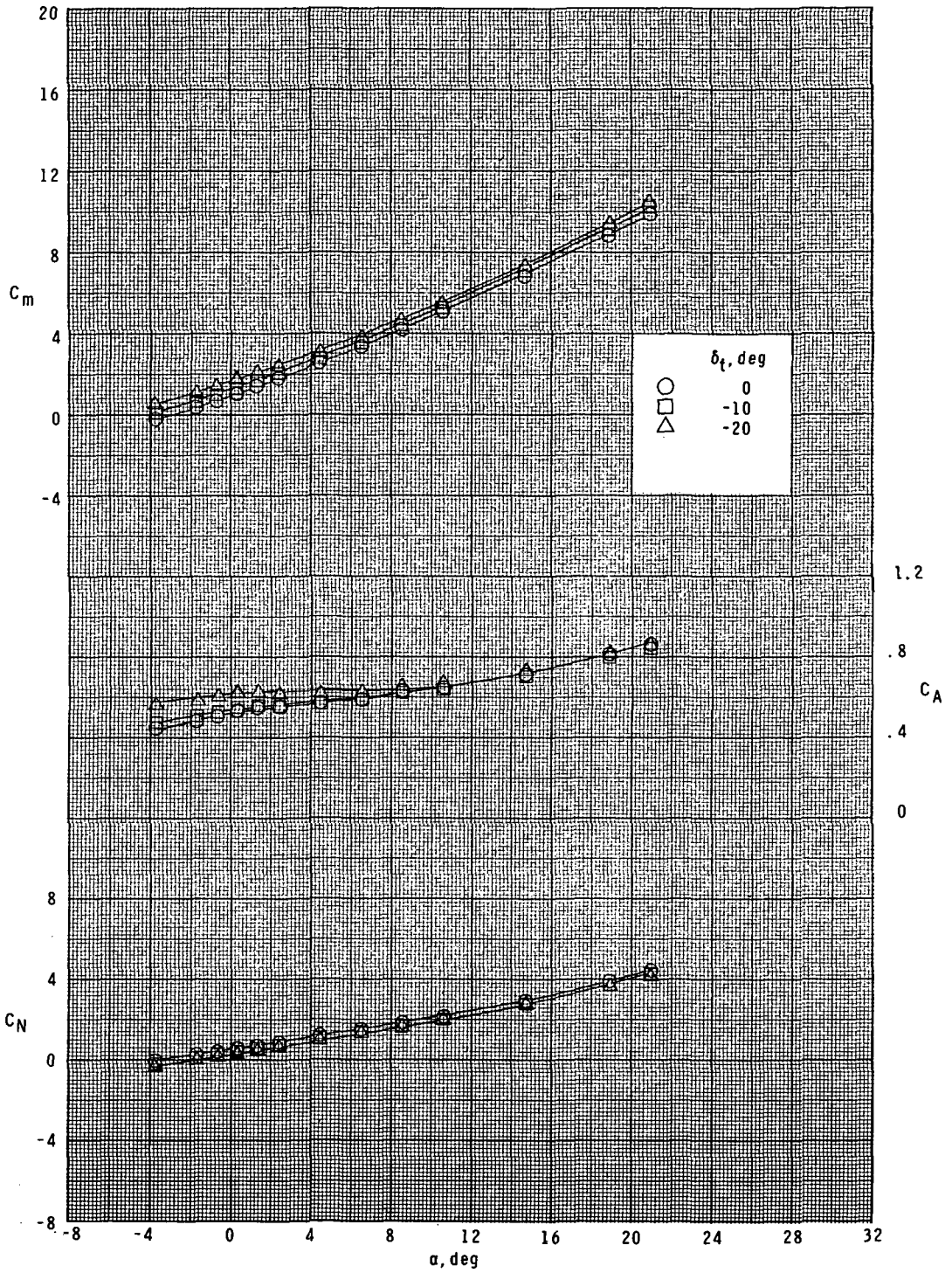
(e) Continued.

Figure 17.- Continued.



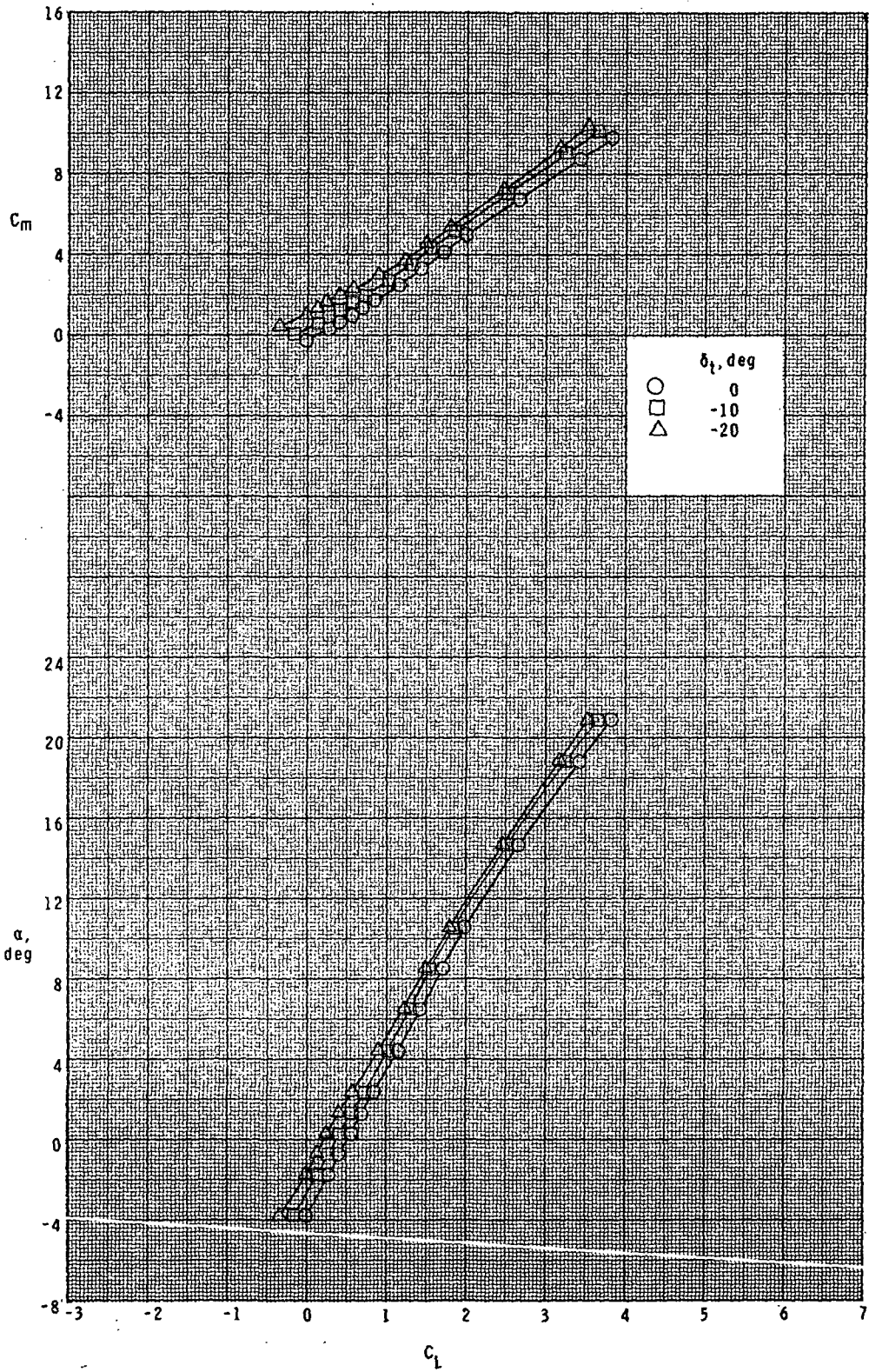
(e) Concluded.

Figure 17.- Continued.



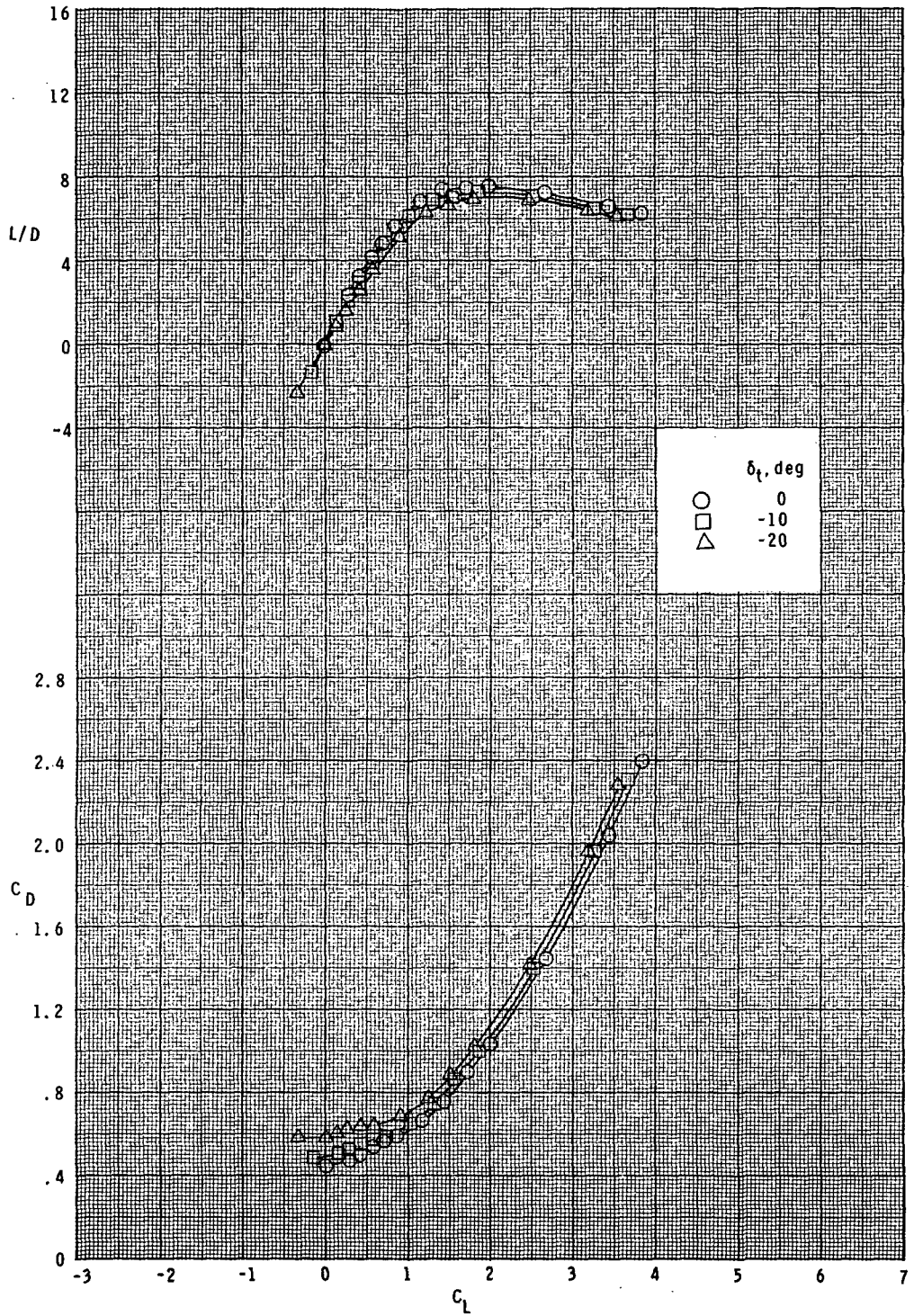
(f) $M = 4.63$.

Figure 17. - Continued.



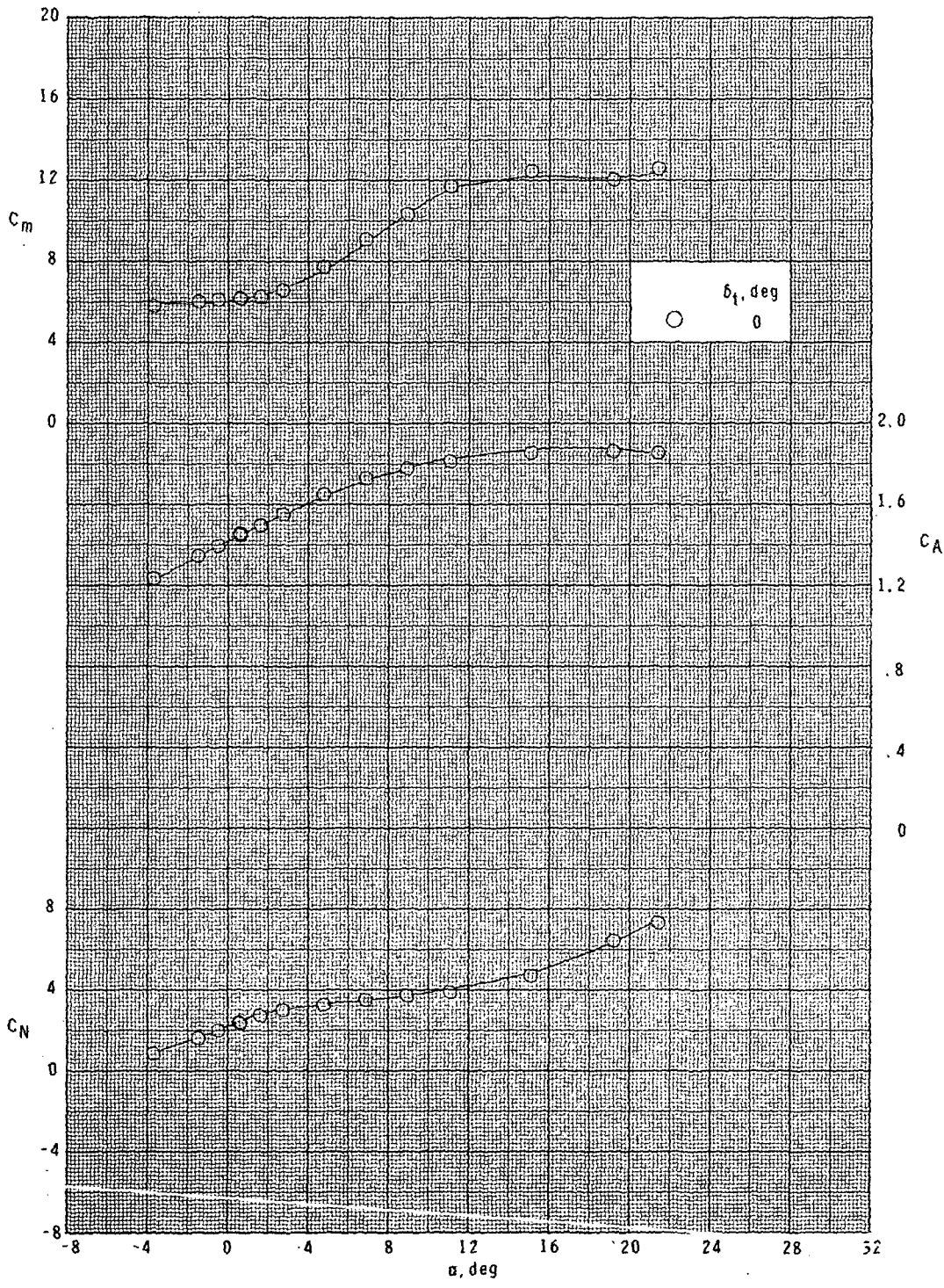
(f) Continued.

Figure 17. - Continued.



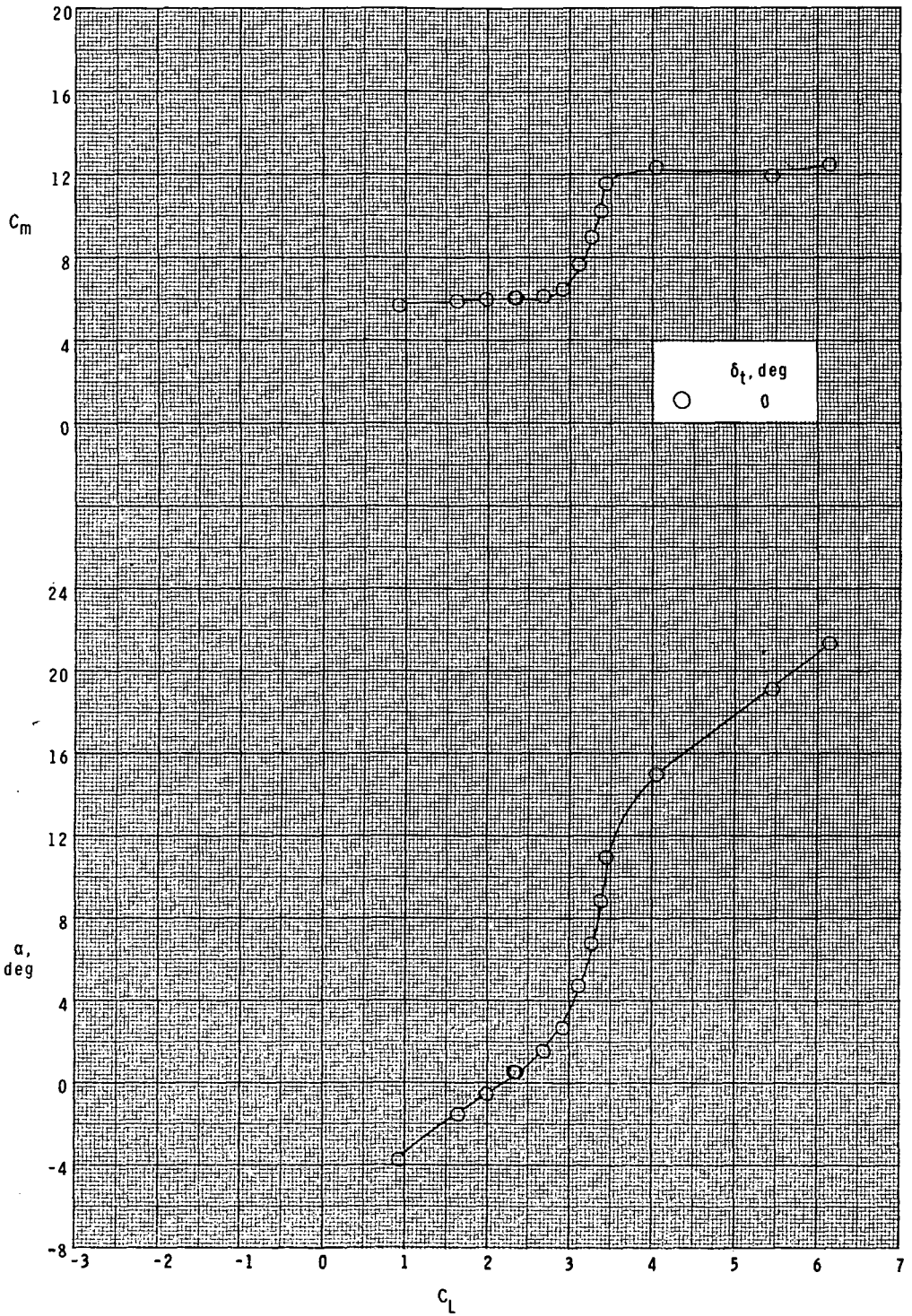
(f) Concluded.

Figure 17.- Concluded.



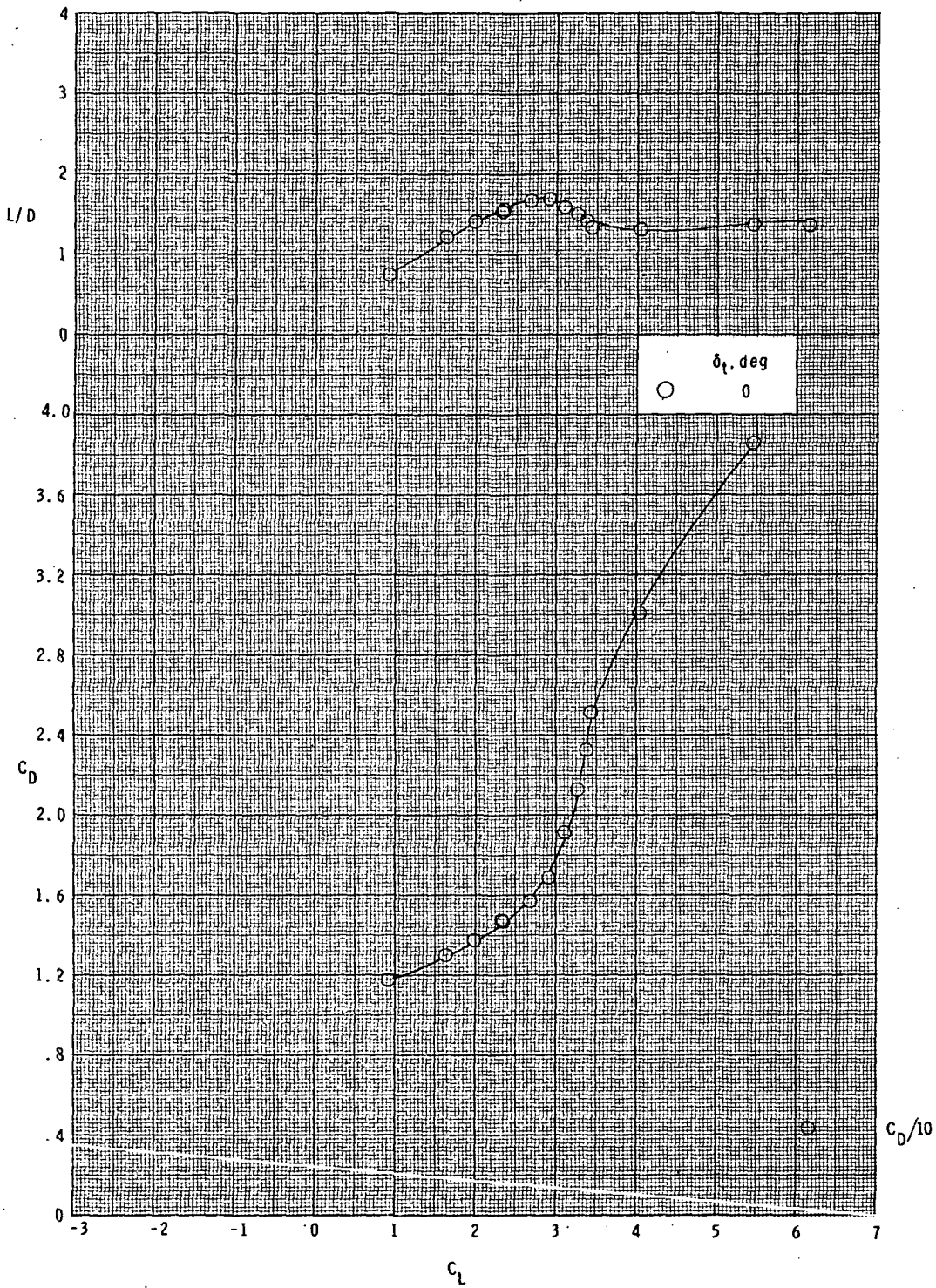
(a) $M = 1.50$.

Figure 18. - Effect of interdigitated-tail deflection on longitudinal aerodynamic characteristics. $\delta_w = 20^\circ$; $\phi = 45^\circ$.



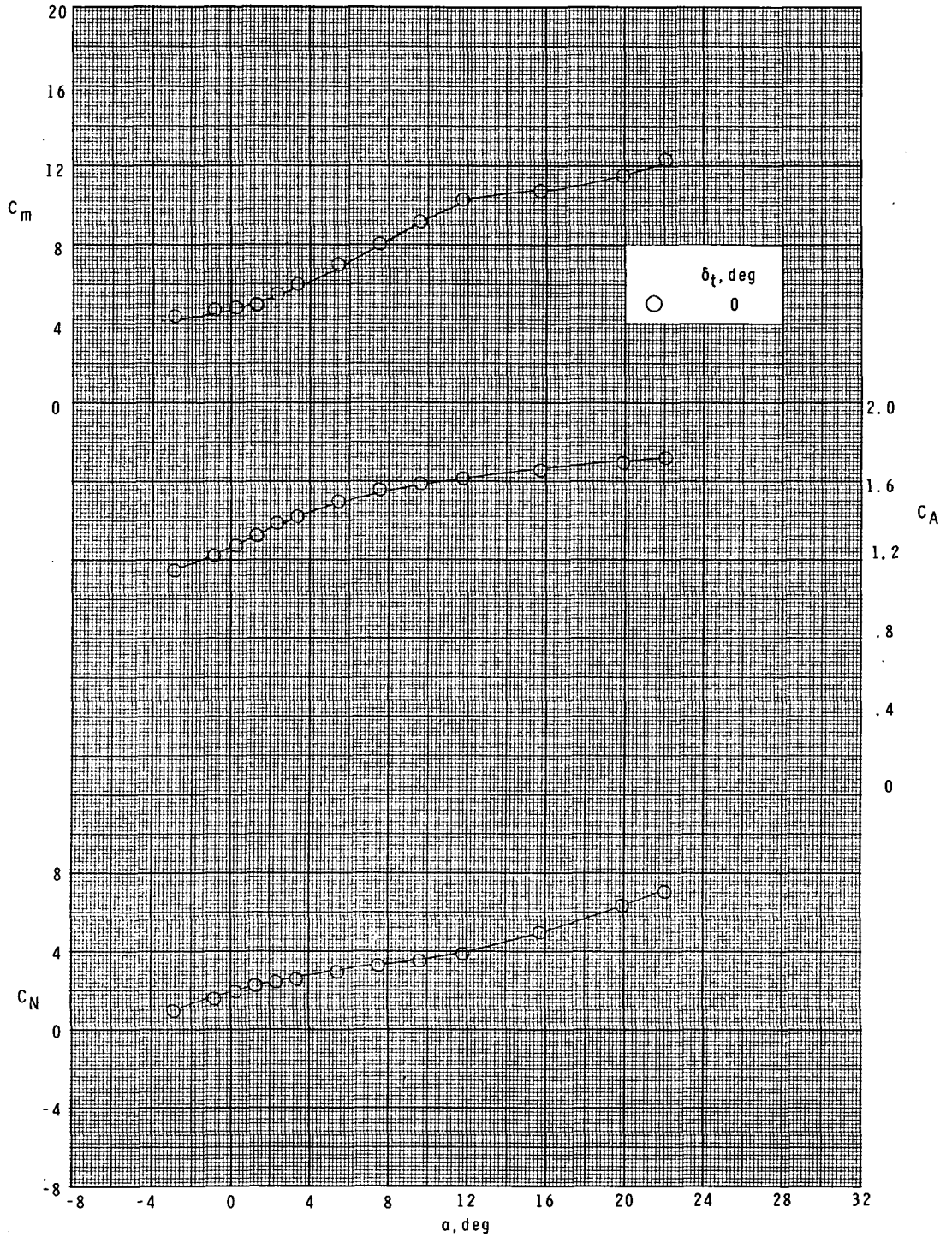
(a) Continued.

Figure 18.- Continued.



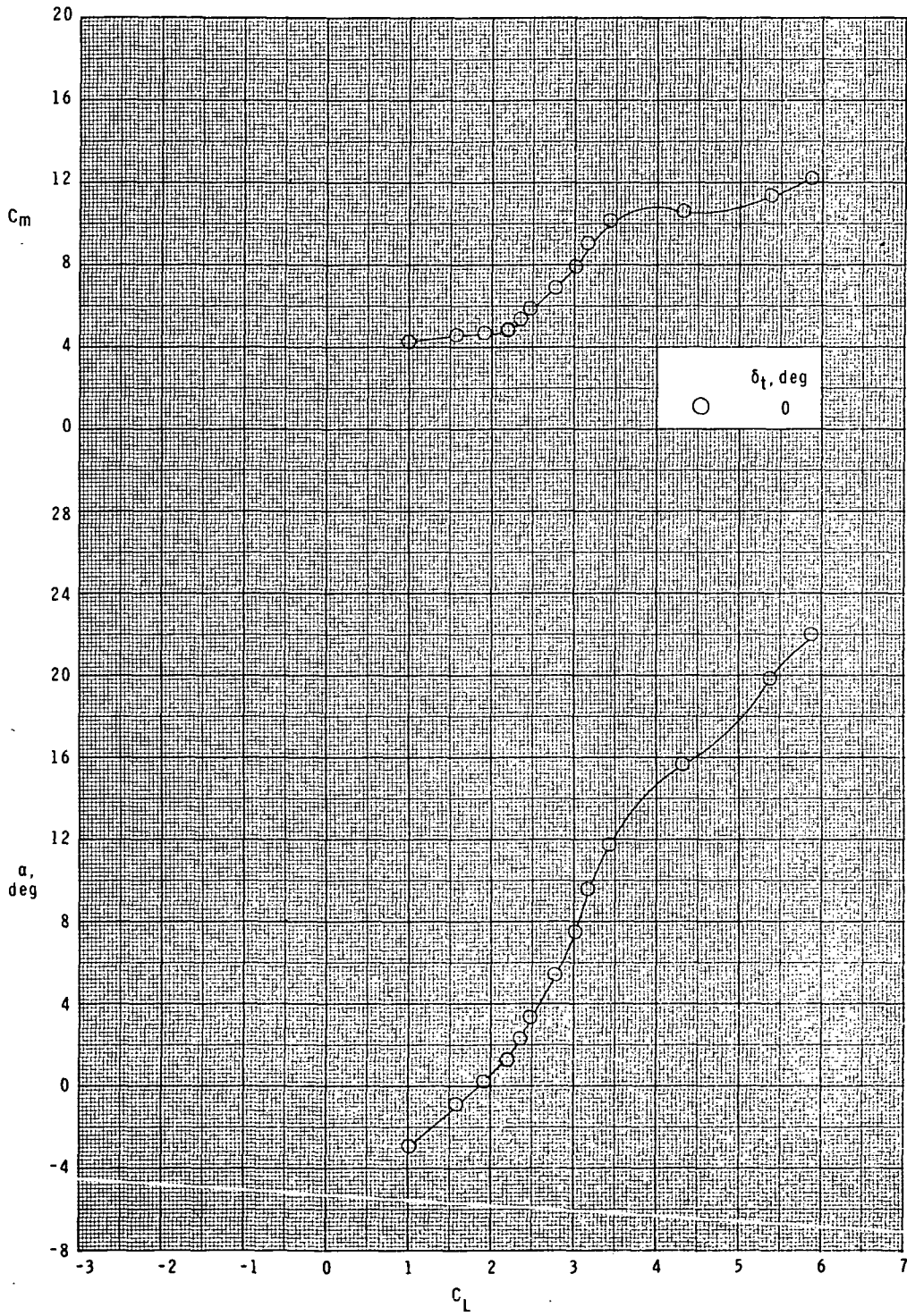
(a) Concluded.

Figure 18.- Continued.



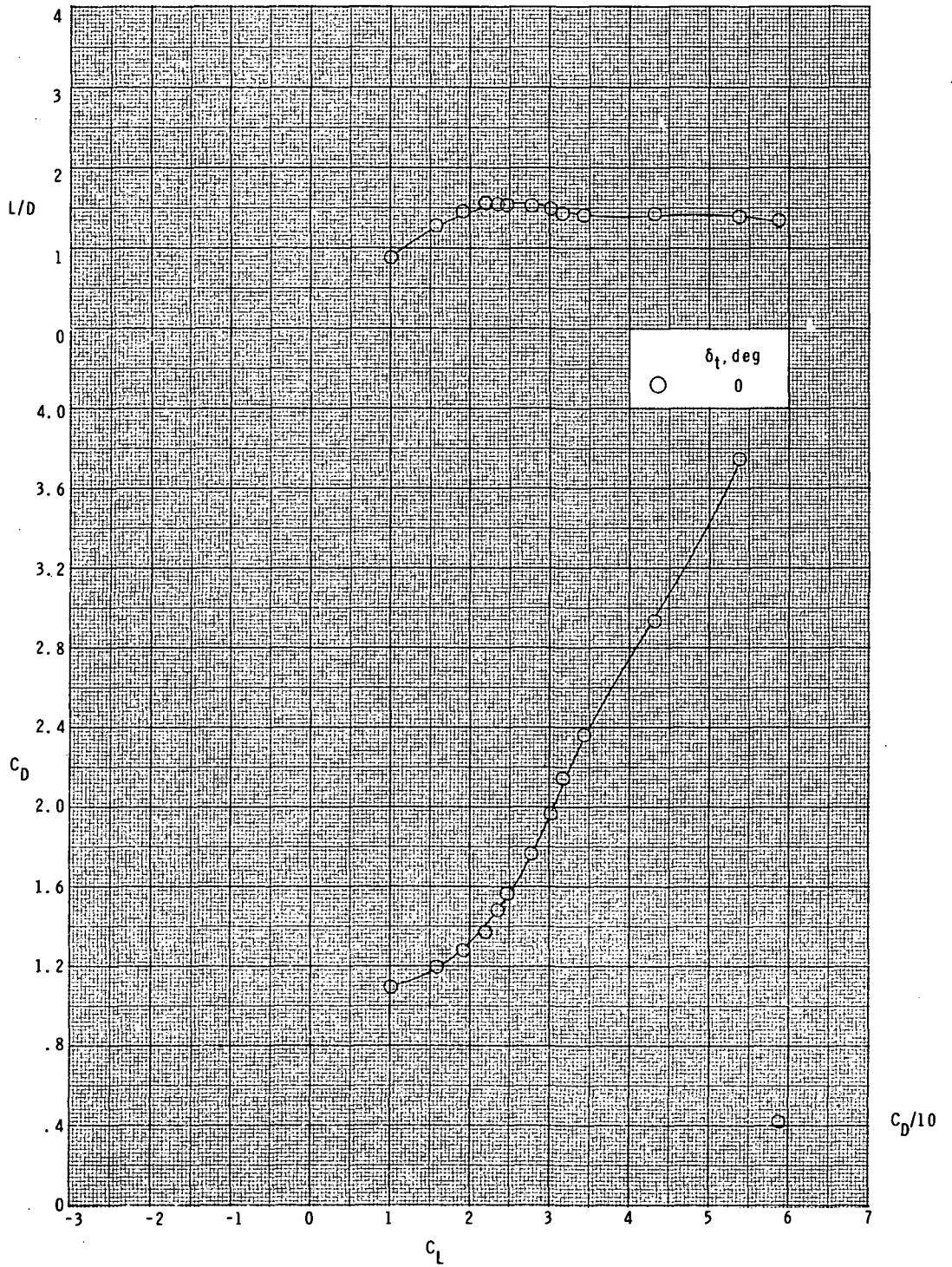
(b) $M = 1.90$.

Figure 18.- Continued.



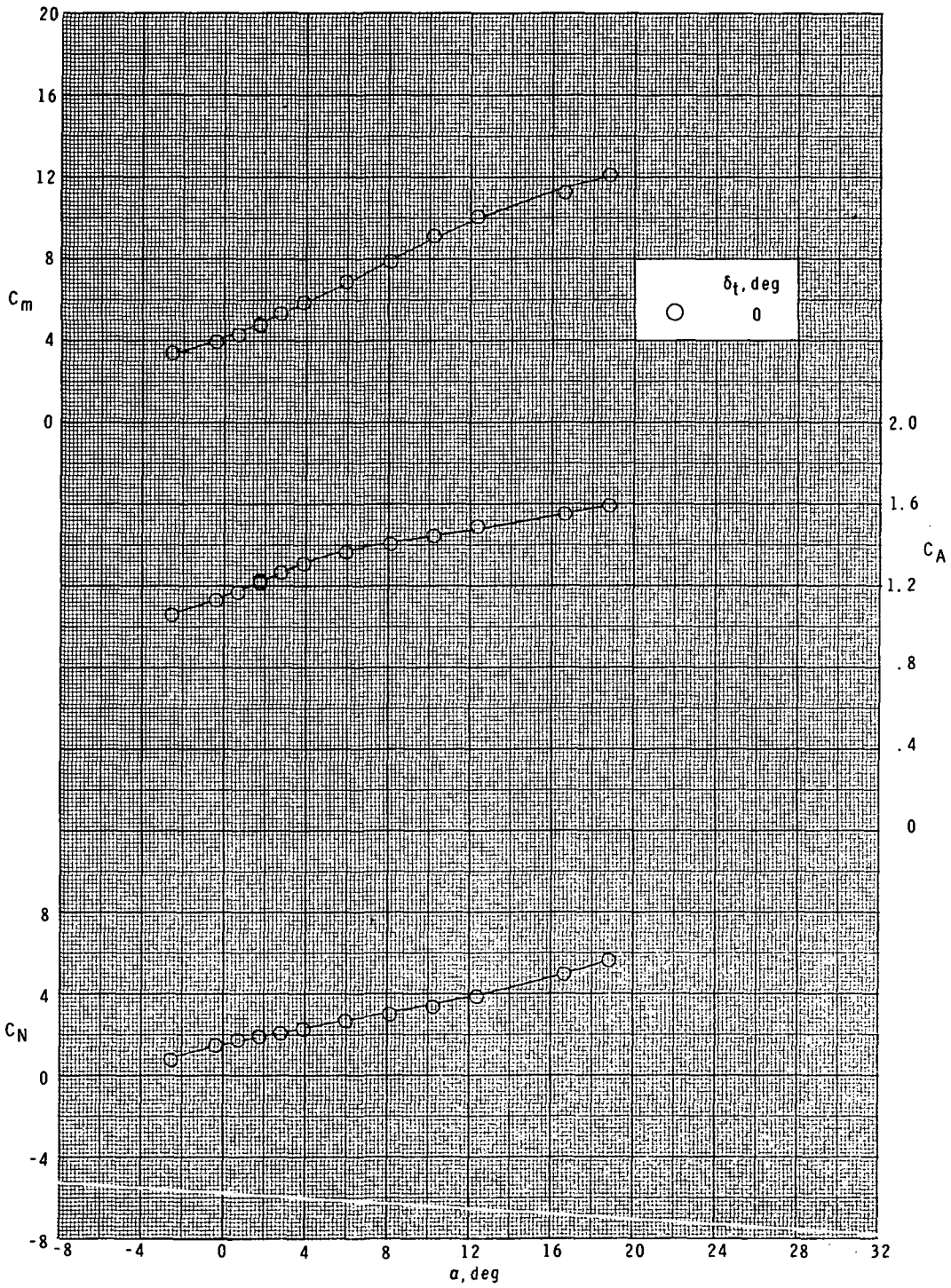
(b) Continued.

Figure 18. - Continued.



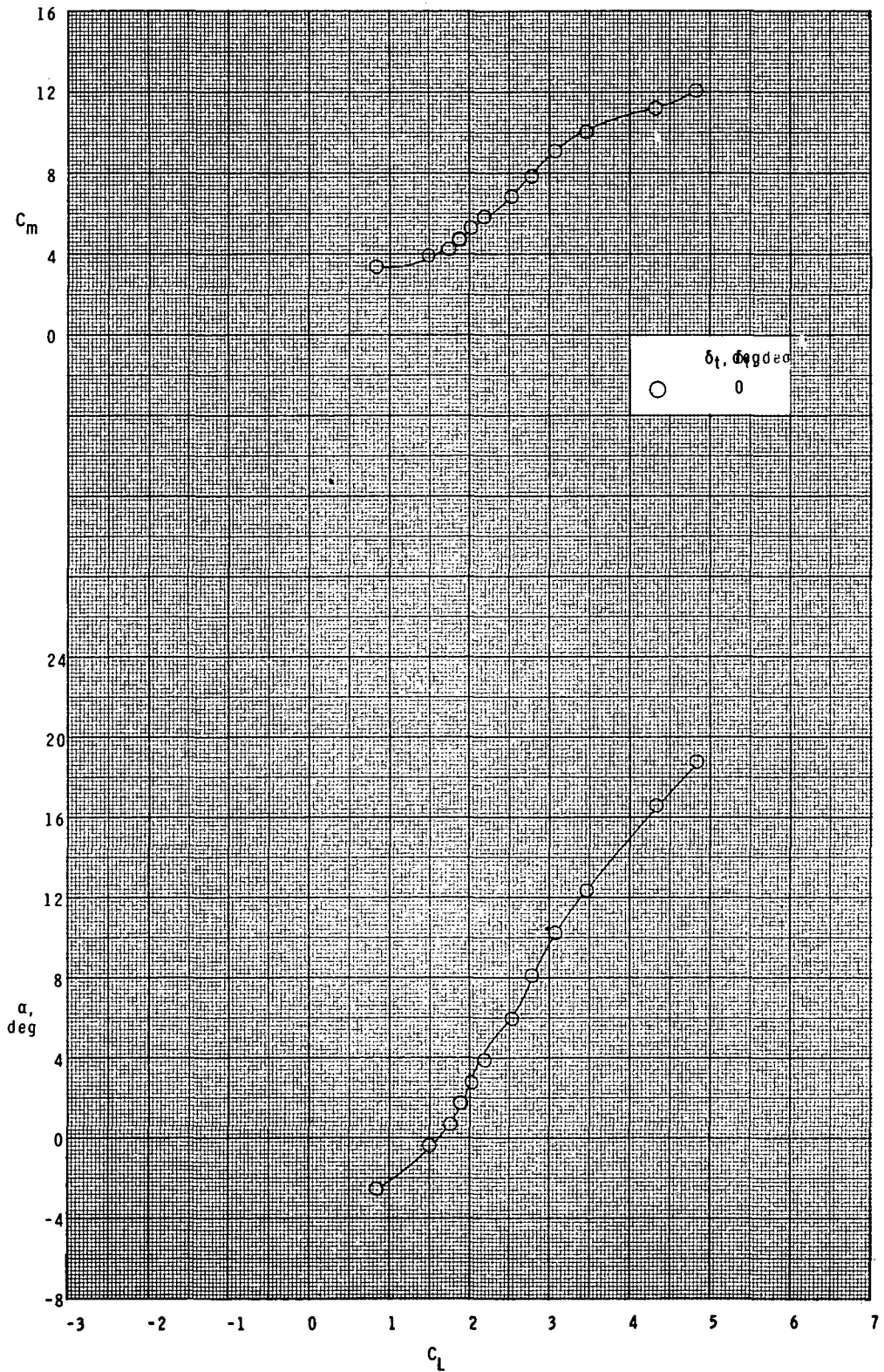
(b) Concluded.

Figure 18. - Continued.



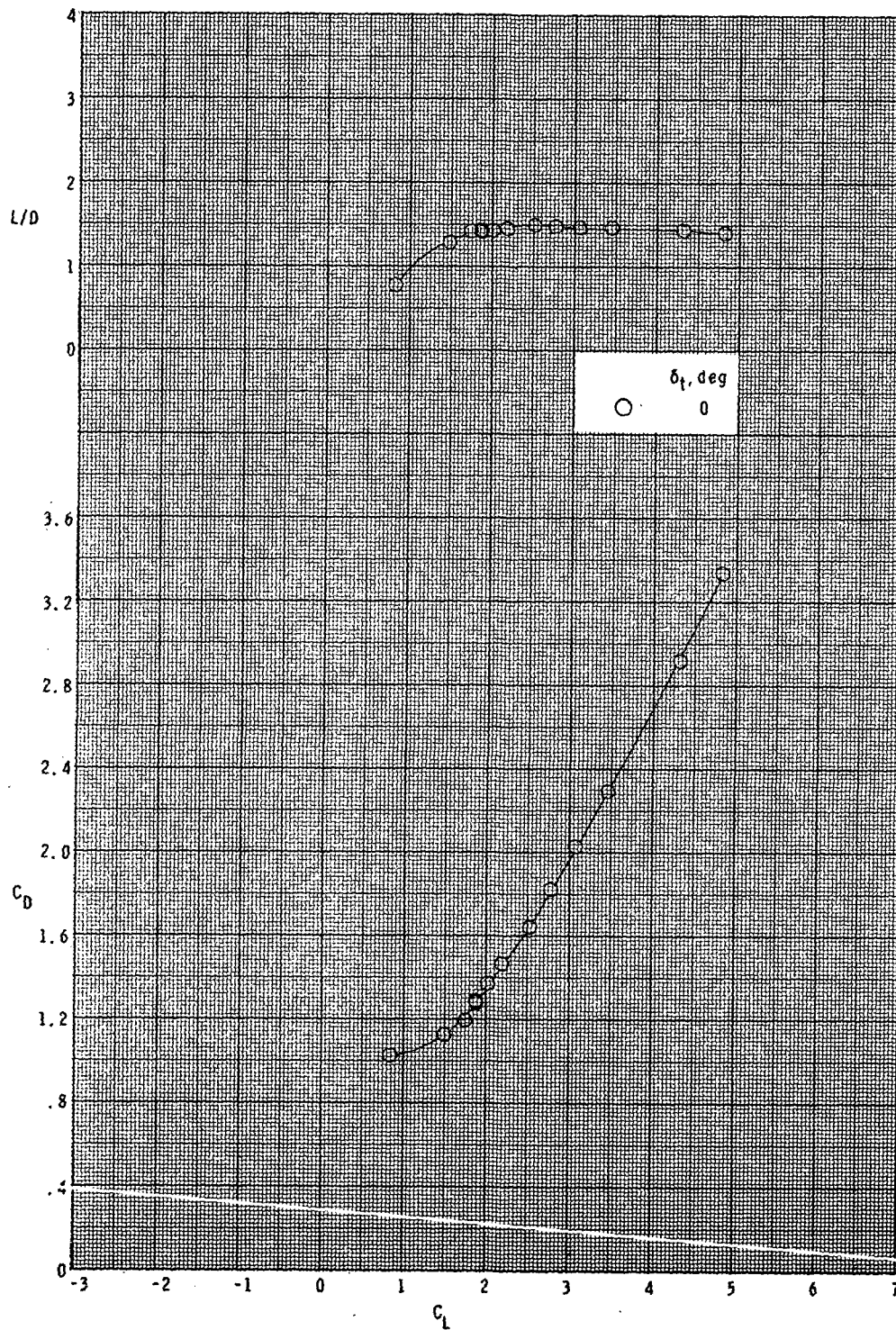
(c) $M = 2.36$.

Figure 18. - Continued.

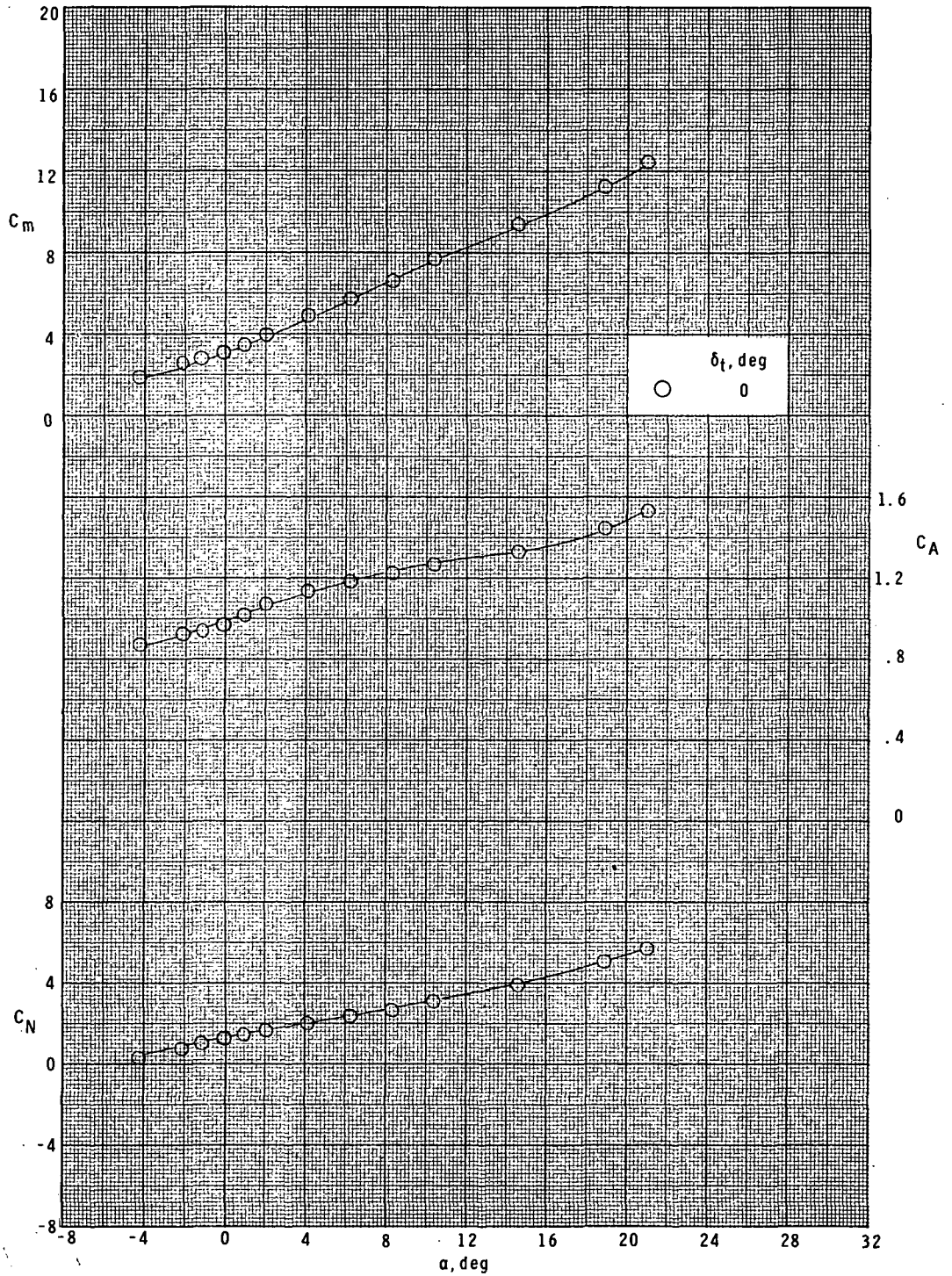


(c) Continued.

Figure 18.- Continued.

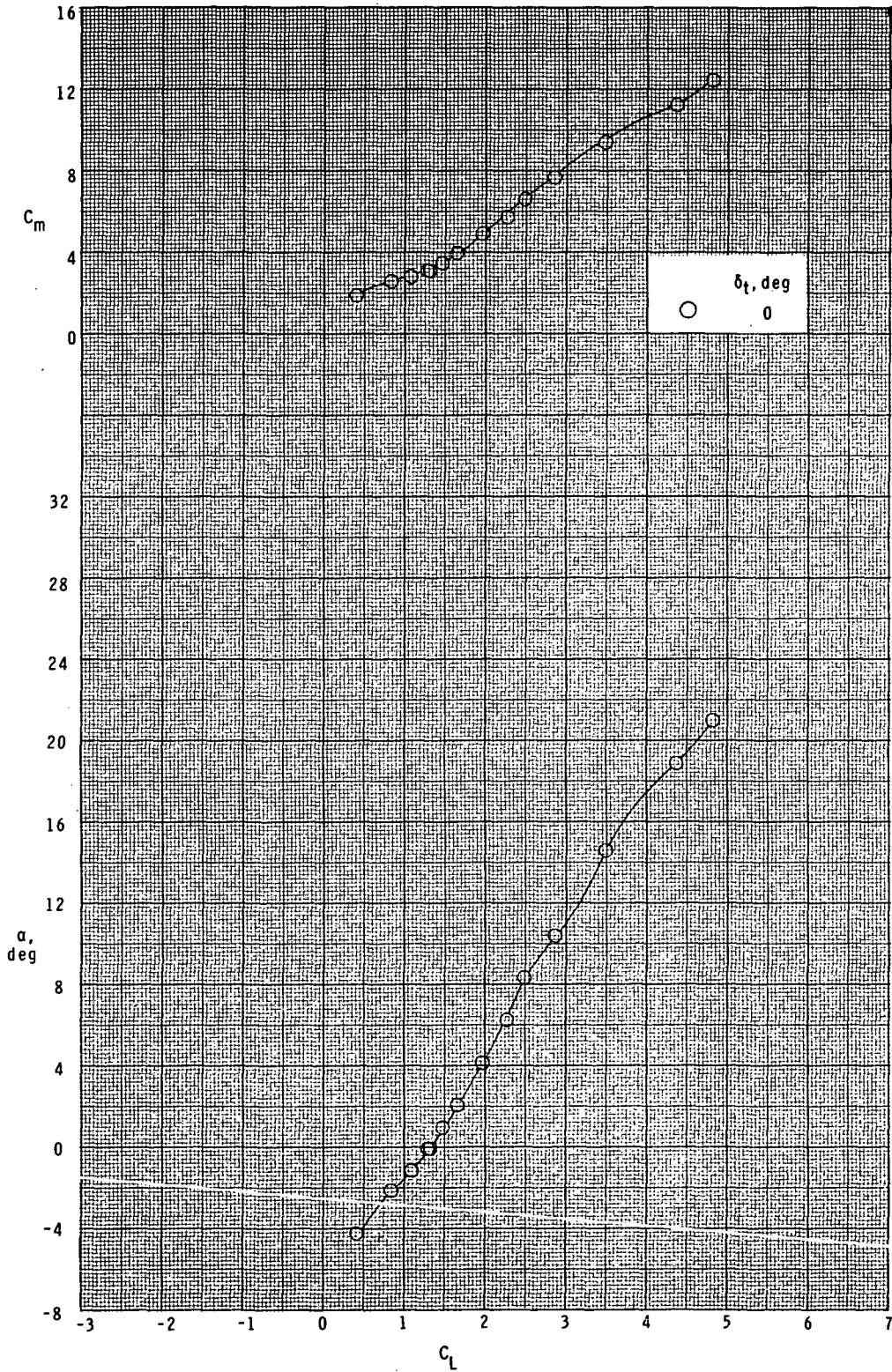


(c) Concluded.
 Figure 18.- Continued.



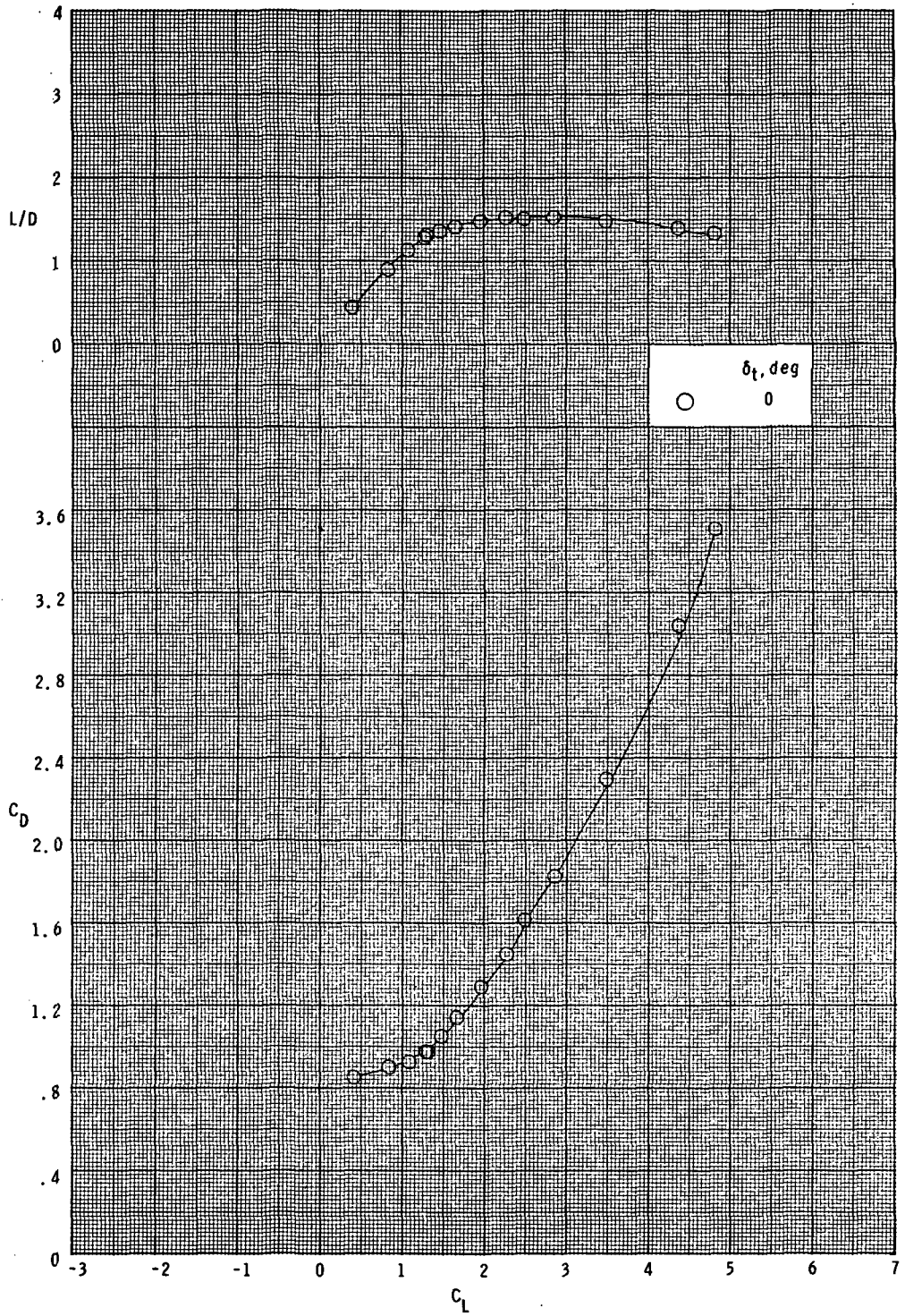
(d) $M = 2.86$.

Figure 18. - Continued.



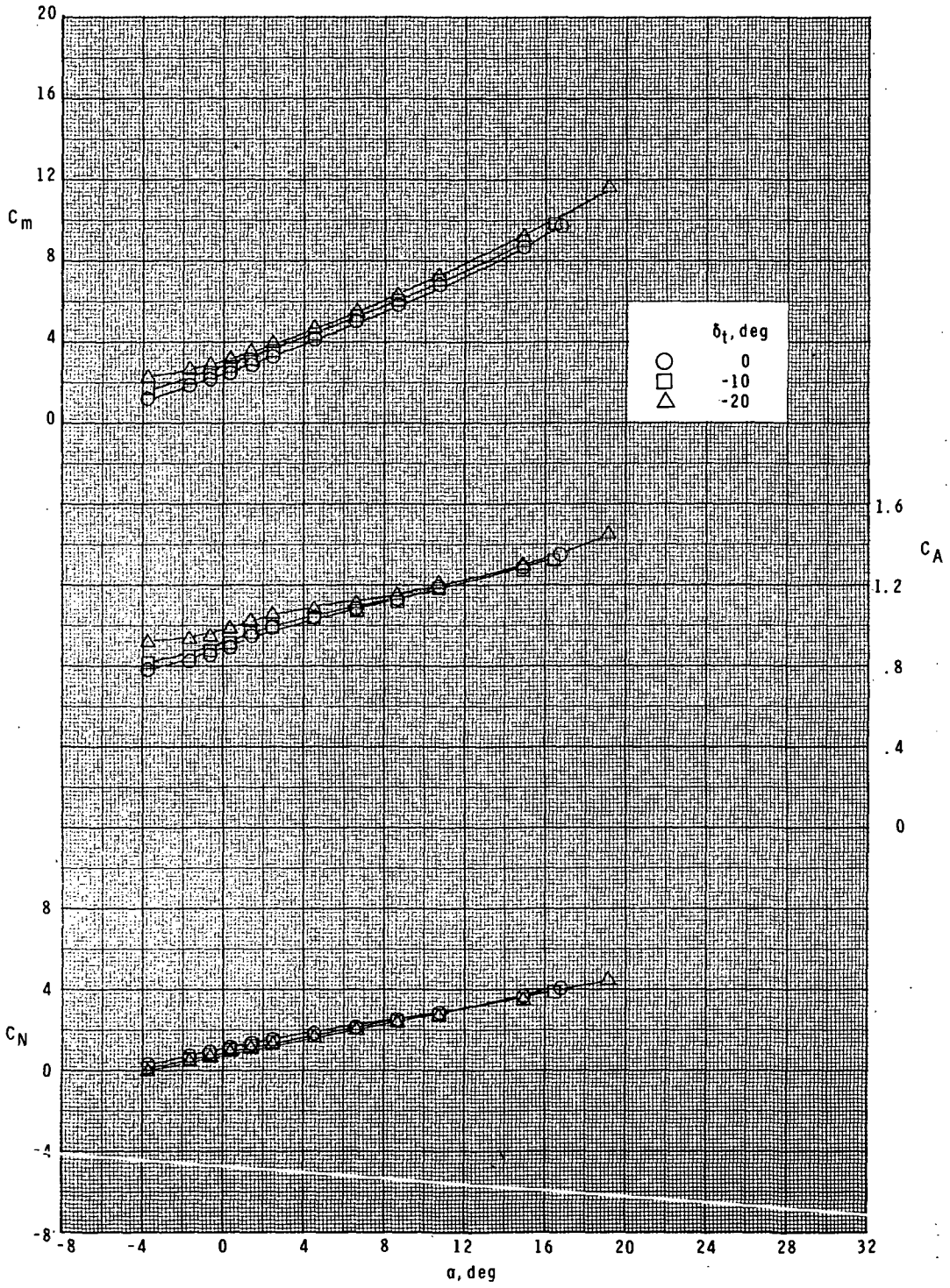
(d) Continued.

Figure 18. - Continued.



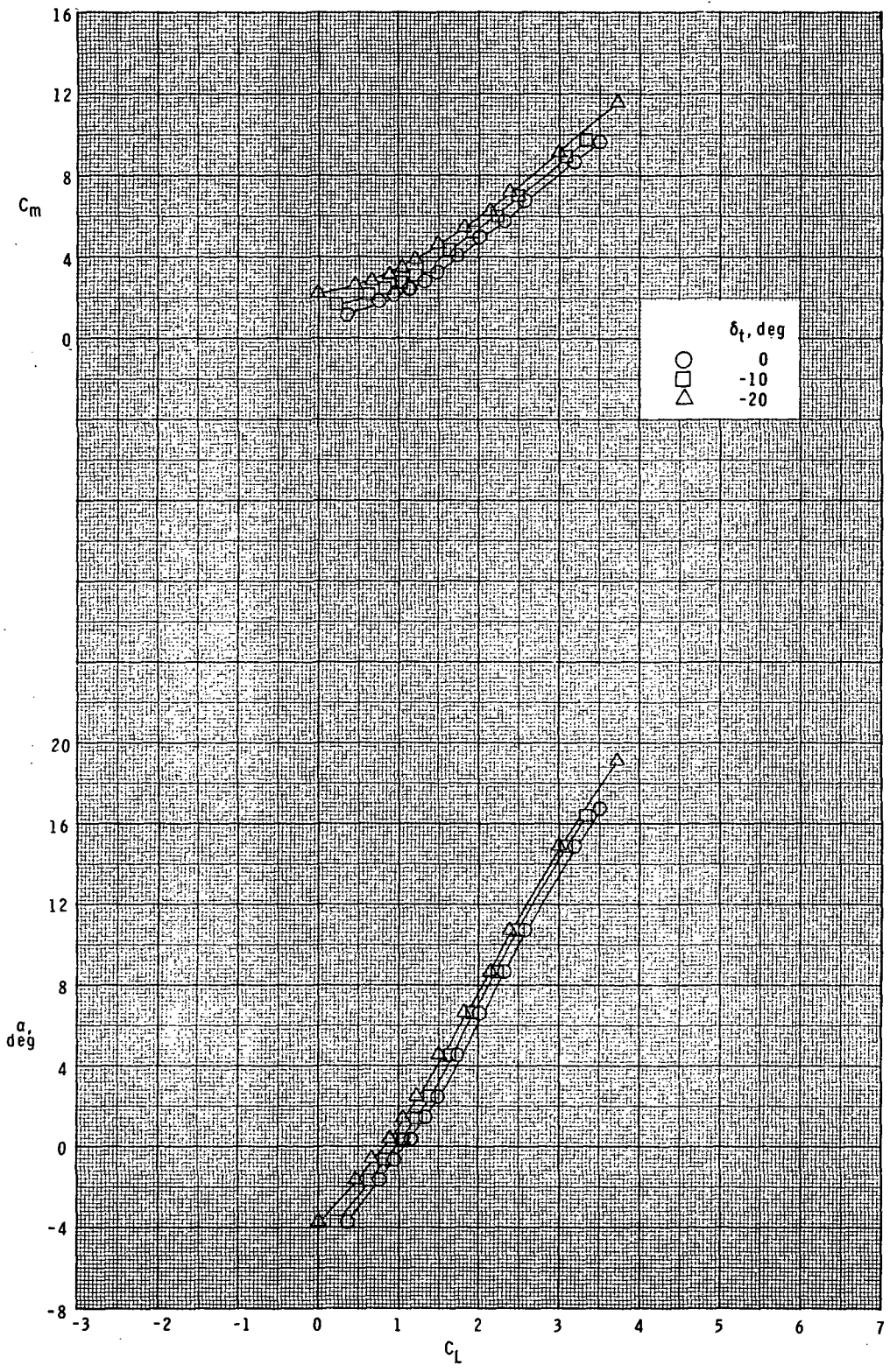
(d) Concluded.

Figure 18.- Continued.



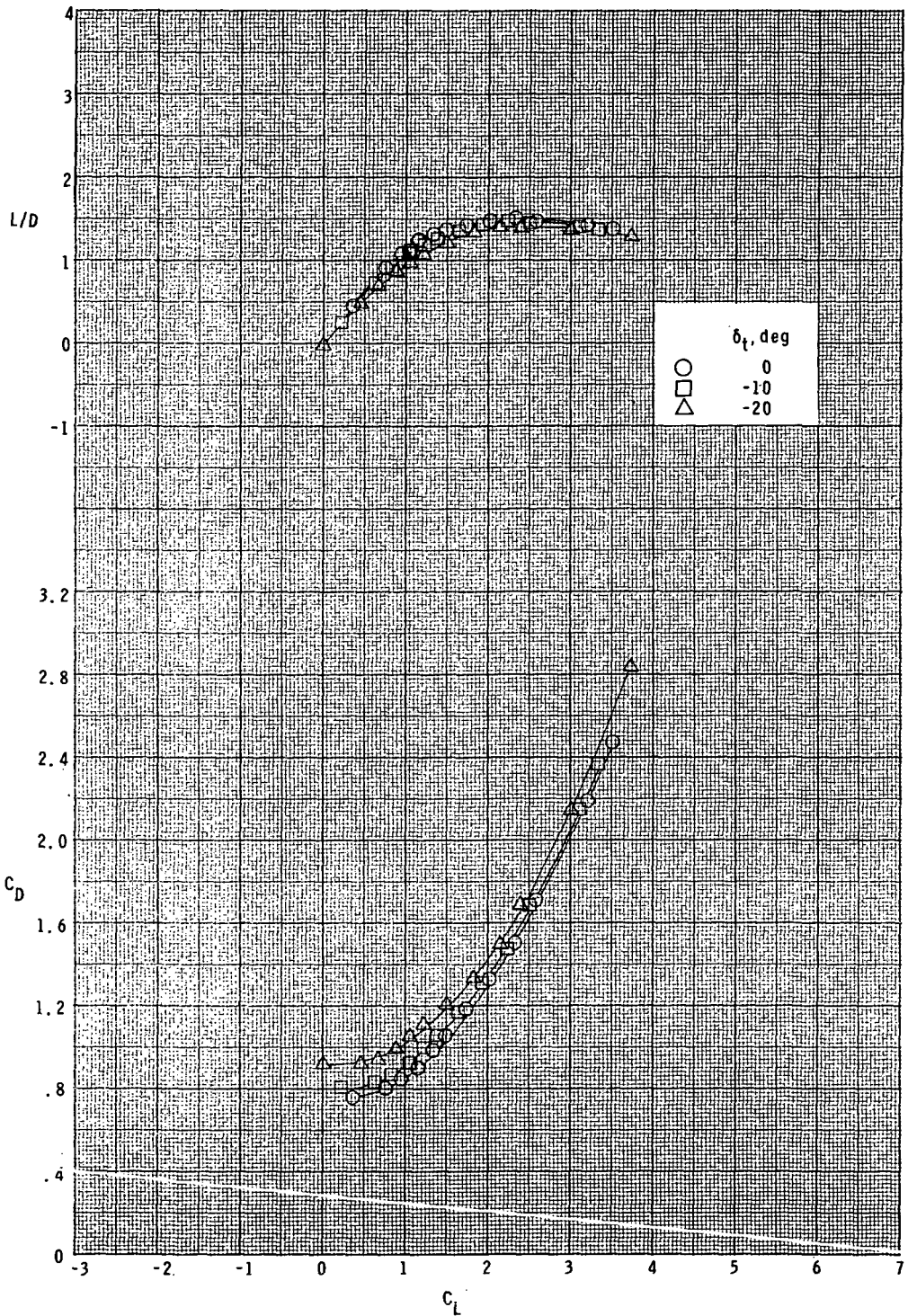
(e) $M = 3.95$.

Figure 18.- Continued.



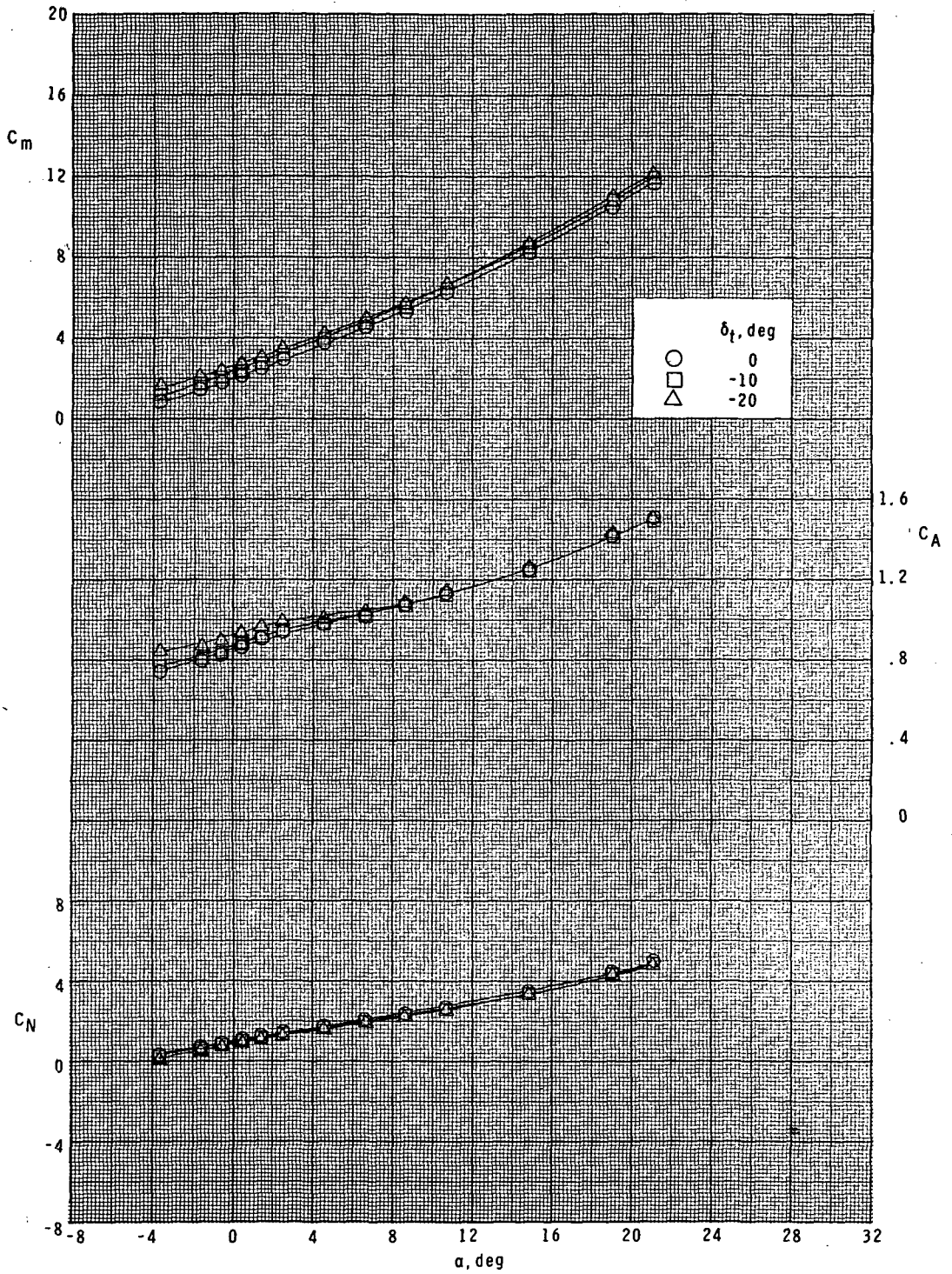
(e) Continued.

Figure 18. - Continued.



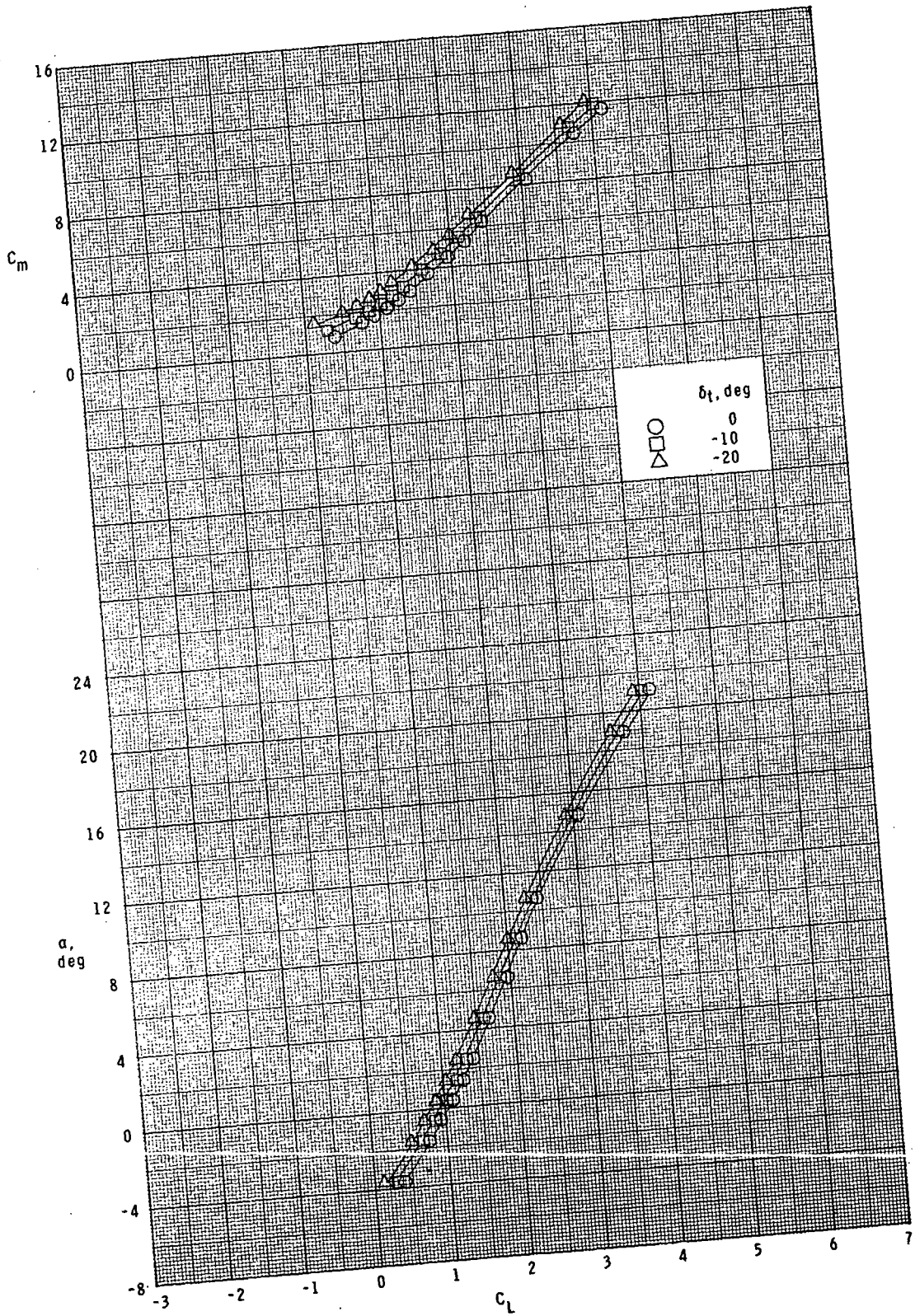
(e) Concluded.

Figure 18. - Continued.



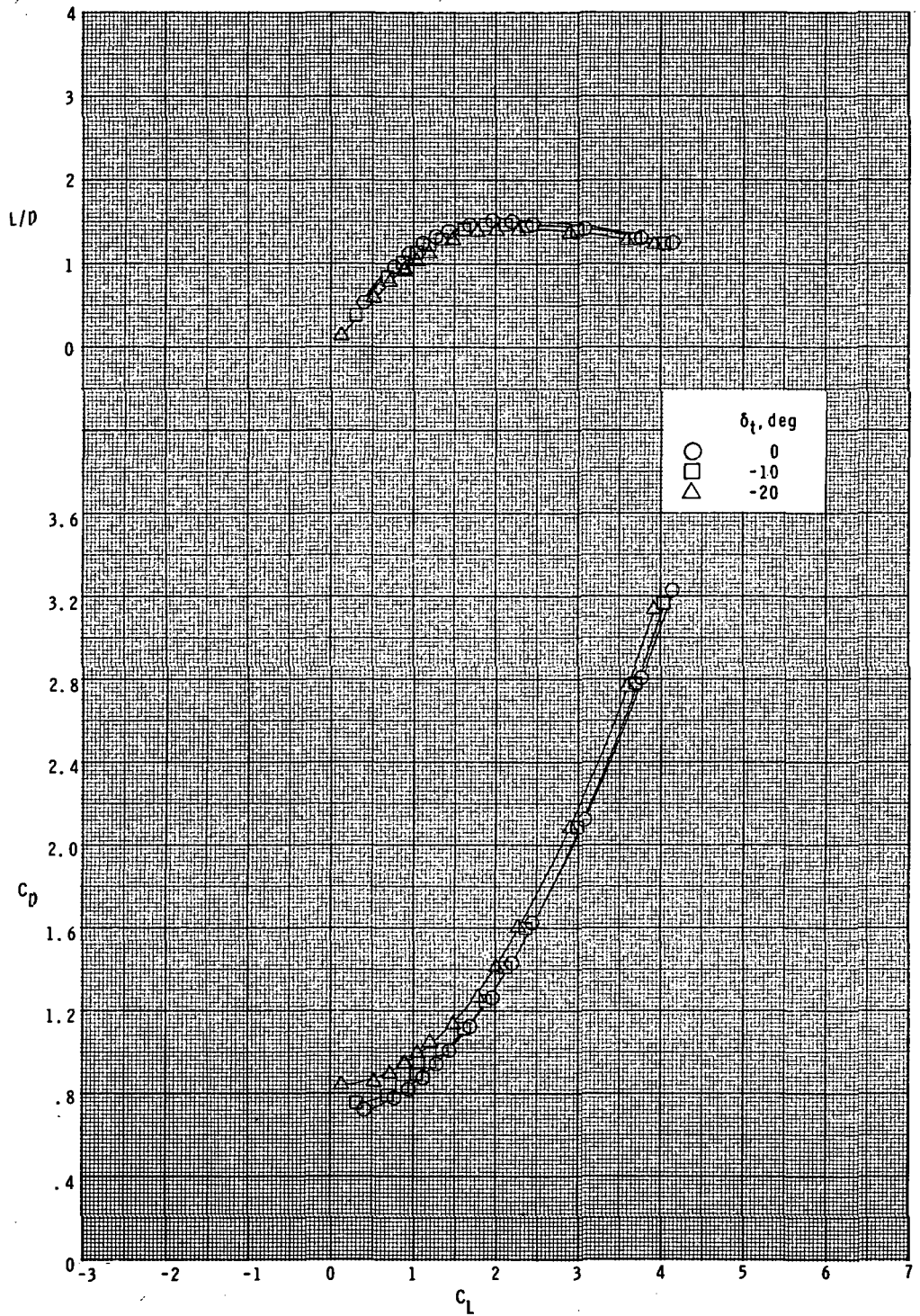
(f) $M = 4.63$.

Figure 18.- Continued.



(f) Continued.

Figure 18. - Continued.



(f) Concluded.

Figure 18. - Concluded.



POSTMASTER: If Undeliverable (Section
Postal Manual) Do Not

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546