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PRELIMINARY STUDY OF DRAG REDUCTION
FOR COASTING MISSILES AT
MACH NUMBERS FROM 1.57 TO 4.63

by Dennis E. Fuller and Donald L. Wassum

Langley Research Center
Langley Station, Hampton, Va.

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SUMMARY

An investigation of various body alterations aimed at reducing the drag of a missile during power-off flight has been made in the Langley Unitary Plan wind tunnel. Tests were made for conical afterbody closures of two lengths (with and without slots), afterbody perforations, and afterbody scoops. The investigation was made at Mach numbers from 1.57 to 4.63, angles of attack from about -4° to 4°, and a Reynolds number of 9.84×10^6 per meter.

The results indicated that a conical afterbody closure with a closure-length—body-diameter ratio of about 2.9 effected sizable reductions in drag and increases in lift-drag ratio for the test Mach number range; for the lower test Mach numbers an afterbody closure with a closure-length—body-diameter ratio of about 1.4 provided an increase in drag and a decrease in lift-drag ratio. A reduction in the ratio of a slot area to cone area for the long afterbody closure led to progressive decreases in drag coefficient with corresponding increases in lift-drag ratio. Afterbody perforations provided a means of obtaining moderate drag reductions throughout the test Mach number range.

INTRODUCTION

The National Aeronautics and Space Administration is conducting a continuing program of missile configuration research. One goal in this research program is to reduce the missile drag so that the overall power requirements may be reduced or the operational range may be increased for the missile. One area where potential gains might be realized is in the reduction of base drag during power-off flight, which constitutes a considerable portion of the flight time for many missile configurations.

Therefore, a preliminary wind-tunnel investigation was initiated to determine the effects of three relatively simple modifications intended to reduce base drag. An ogive-cylinder was utilized for the general test configuration. Modifications to the basic model included conical afterbody closures, afterbody perforations, and afterbody scoops. The Mach number range was from 1.57 to 4.63 for angles of attack from about -4° to 4° at a Reynolds number of 9.84×10^6 per meter.

SYMBOLS

The coefficients of forces and moments are referred to the stability-axis system. The moments were taken about a point 42.63 cm aft of the nose.

A   reference area, 0.004560 meter^2

C_D drag coefficient, $\dfrac{\text{Drag}}{qA}$

$C_{D,o}$ drag coefficient at zero lift coefficient

C_L lift coefficient, $\dfrac{\text{Lift}}{qA}$

C_m pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qAd}$

C_p pressure coefficient, $\dfrac{p_\infty - p_l}{q}$

d   reference diameter, 7.63 centimeters

L/D   lift-drag ratio

M   free-stream Mach number

p_l local static pressure

p_∞ free-stream static pressure

q   free-stream dynamic pressure, $\dfrac{\text{newtons}}{\text{meter}^2}$

α angle of attack of fuselage center line, degrees

APPARATUS AND TESTS

Wind Tunnel

Tests were conducted in both the low and high Mach number test sections of the Langley Unitary Plan wind tunnel, which is a variable-pressure, continuous-flow tunnel. The test sections are approximately 4 by 4 feet (1.22 by 1.22 m) square and 7 feet (2.14 m) long. The nozzles leading to the test sections are of the asymmetric sliding-block type, which permit a continuous variation in Mach number from about 1.5 to 2.9 in

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the low Mach number test section and from about 2.3 to 4.7 in the high Mach number test section.

Model

Dimensional details of the test configurations are given in figure 1, and photographs of the test model with some of the modifications are presented as figure 2. The basic model was a cylindrical body with an ogive nose.

Two lengths of conical afterbody closures (which would conceivably be formed by rearward-sliding leaves at the onset of coasting flight) were investigated; one afterbody closure had a closure-length—body-diameter ratio of about 1.4 (short closure) and the other had a closure-length—body-diameter ratio of about 2.9 (long closure). The short closure was tested with four slots and as a solid cone (slots filled). The long closure was tested with narrow and wide slots and as a solid cone.

Two sizes of perforations were investigated. One configuration had 36 perforations, each with a nominal area of 4.4516 mm^2, over a 2.54-cm-wide band around the afterbody for a perforation-to-band area ratio of about 0.026. The second configuration had 10 perforations, each with a nominal area of 31.68 mm^2, over a 2.54-cm-wide band around the afterbody for a perforation-to-band area ratio of about 0.052.

For the remaining configuration, four scoops, each about 0.95 cm high and 2.54 cm wide, were placed 90° apart around the afterbody.

Test Conditions

Tests were performed at the following Mach numbers, temperatures, and pressures:

Mach number	Stagnation temperature, $^\circ K$	Stagnation pressure, N/m^2
1.57	339	81 220.24
2.16	339	102 593.98
2.50	339	121 692.46
2.96	339	157 131.51
3.95	352	276 686.60
4.63	352	377 487.96

The Reynolds number was 9.84×10^6 per meter, and the dewpoint, measured at stagnation pressure, was maintained below 238.71° K to assure negligible condensation effects. The angle of attack was varied from about -4° to 4°.

A 0.16-cm-wide transition strip of No. 60 carborundum grit (nominal diameter of 0.0274 cm) was fixed around the nose 3.05 cm aft of the apex.

The aerodynamic forces and moments were measured by means of an internally mounted strain-gage balance which was in turn fastened to a strut support and thence to the tunnel support system. Balance-chamber pressure was measured except for the solid cone models.

Corrections

Angles of attack have been corrected for deflection of sting and balance due to aerodynamic loads. Variations of chamber pressure coefficients with angle of attack are presented in figure 3. No adjustments, however, were applied to the axial-force data for the chamber pressure coefficients. Also, no attempt has been made to apply flow angularity corrections to the data presented herein because of the undefined effects of the support strut on the flow over the afterbodies.

RESULTS AND DISCUSSION

The effects of the short afterbody closure (closure-length—body-diameter ratio of 1.4) on the longitudinal aerodynamic characteristics of the model are presented in figure 4. This closure was investigated with and without slots, and the results indicate that the slots have little effect on the longitudinal aerodynamic characteristics of the vehicle over the test angle-of-attack and Mach number ranges. Throughout the test Mach number range the short closure produces a decrease in lift-curve slope with a corresponding decrease in stability level. For Mach numbers through 2.50 the short closure causes an increase in drag coefficient near $C_L = 0$ and a general decrease in L/D over the lift range. However, at the higher Mach numbers a general decrease in drag coefficient is realized and there is an increase in L/D over the lift range.

The drag coefficients for the long closure configurations (closure-length—body-diameter ratio of 2.9) are less than those for the basic model throughout the angle-of-attack and Mach number ranges. (See fig. 5.) Further, as the ratio of the closure-slot area to cone area is reduced, the drag coefficient is progressively reduced. Similar to the effects noted for the short closures, the long closures caused a decrease in both the lift-curve slope and stability level at all test Mach numbers, and these effects are accentuated by the length of the closure. (No data are presented for the closure with wide slots at Mach numbers of 1.57 and 2.16.) In addition, as the closure-slot-area—cone-area ratio is decreased, the lift-curve slope and stability of the model decrease. The long closures materially increased the lift-drag ratios of the vehicle with the solid closure providing the highest values. Although the model support strut has some effect on the flow over the aft portion of the model, it is believed that this will have no significant effect on the comparative results.

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Perforations near the afterbody base of the basic model cause small reductions in drag coefficient with corresponding small increases in L/D (fig. 6). The large perforations (more total perforated area) reduce the drag more than do the small perforations. It thus appears possible that larger performance gains may be obtained with greater perforation area. (No data are presented for the small perforations at M = 1.57 and 2.16.)

The effects of afterbody scoops on the longitudinal aerodynamic characteristics of this model are presented in figure 7. The scoops cause large increases in drag coefficient with corresponding decreases in L/D. In addition, the scoops produce a slight increase in stability level. These scoops, however, were not properly sized with regard to the boundary-layer thickness, and it is believed that with an improved slot design a net decrease in drag coefficient could be achieved similar to that for the perforations.

A summary of the variation of $C_{D,o}$ with Mach number for the basic model with long slotted afterbody closure and the basic model with large afterbody perforations is presented in figure 8. These data illustrate the decreases in drag coefficient available from two of the test configurations. Further research of afterbody modification is needed to optimize the drag reductions that can be obtained.

CONCLUSIONS

Results of preliminary tests of afterbody modifications intended to reduce the drag of missiles during coasting flight at Mach numbers from 1.57 to 4.63 indicate the following conclusions:

1. An afterbody closure with an afterbody-length—body-diameter ratio of about 2.9 effected sizable reductions in drag and increases in lift-drag ratio for the test Mach number range; for the lower test Mach numbers, an afterbody closure with a closure-length—body-diameter ratio of about 1.4 caused an increase in drag and a decrease in lift-drag ratio.

2. Reducing the ratio of closure-slot area to total cone area for the long afterbody closure resulted in a decrease in drag coefficient.

3. Afterbody perforations produced moderate drag reduction throughout the test Mach number range.

Langley Research Center,
    National Aeronautics and Space Administration,
        Langley Station, Hampton, Va., August 23, 1967,
            126-13-02-01-23.
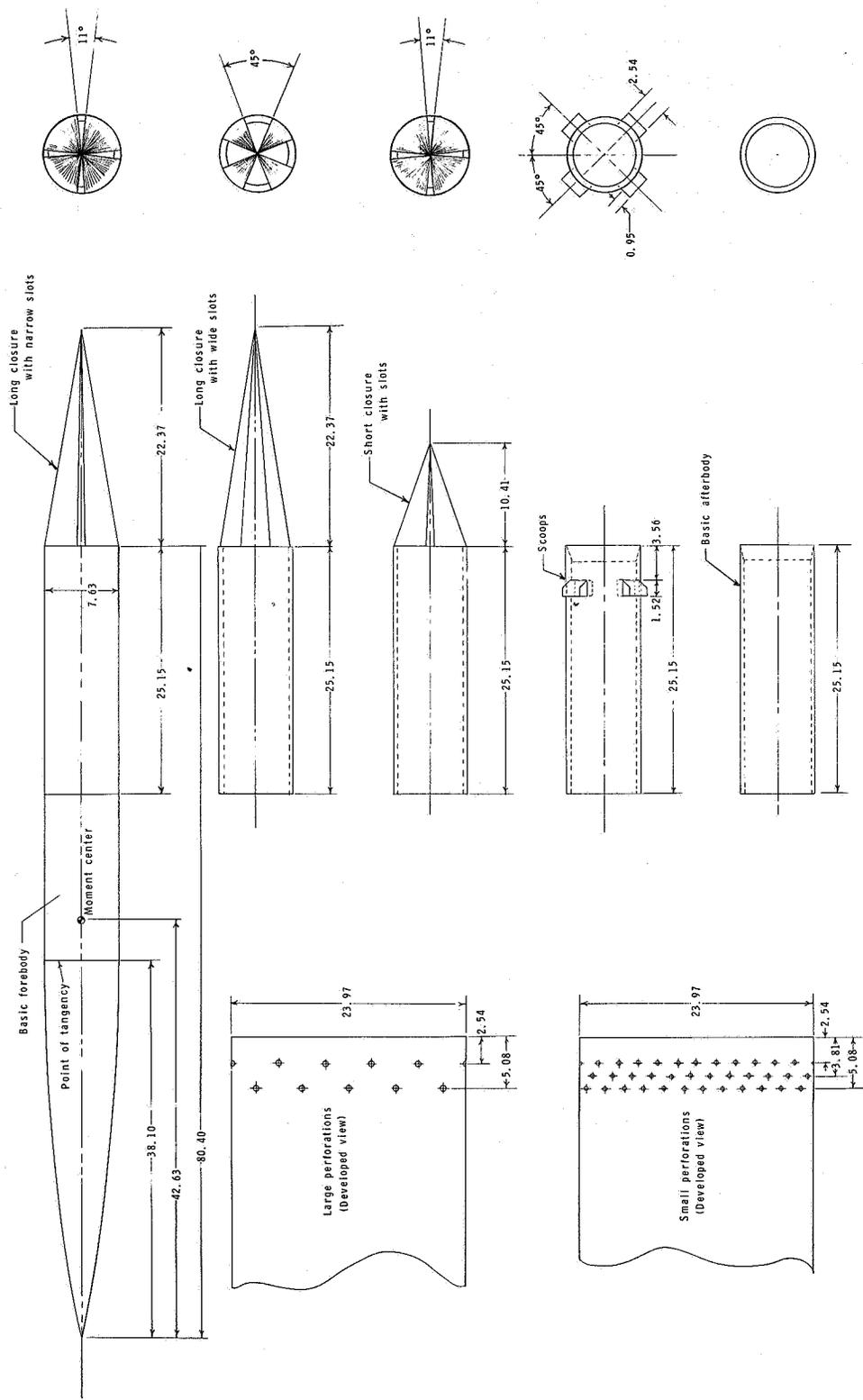
Figure 1.- Test configurations. (All dimensions are in cm unless otherwise noted.)
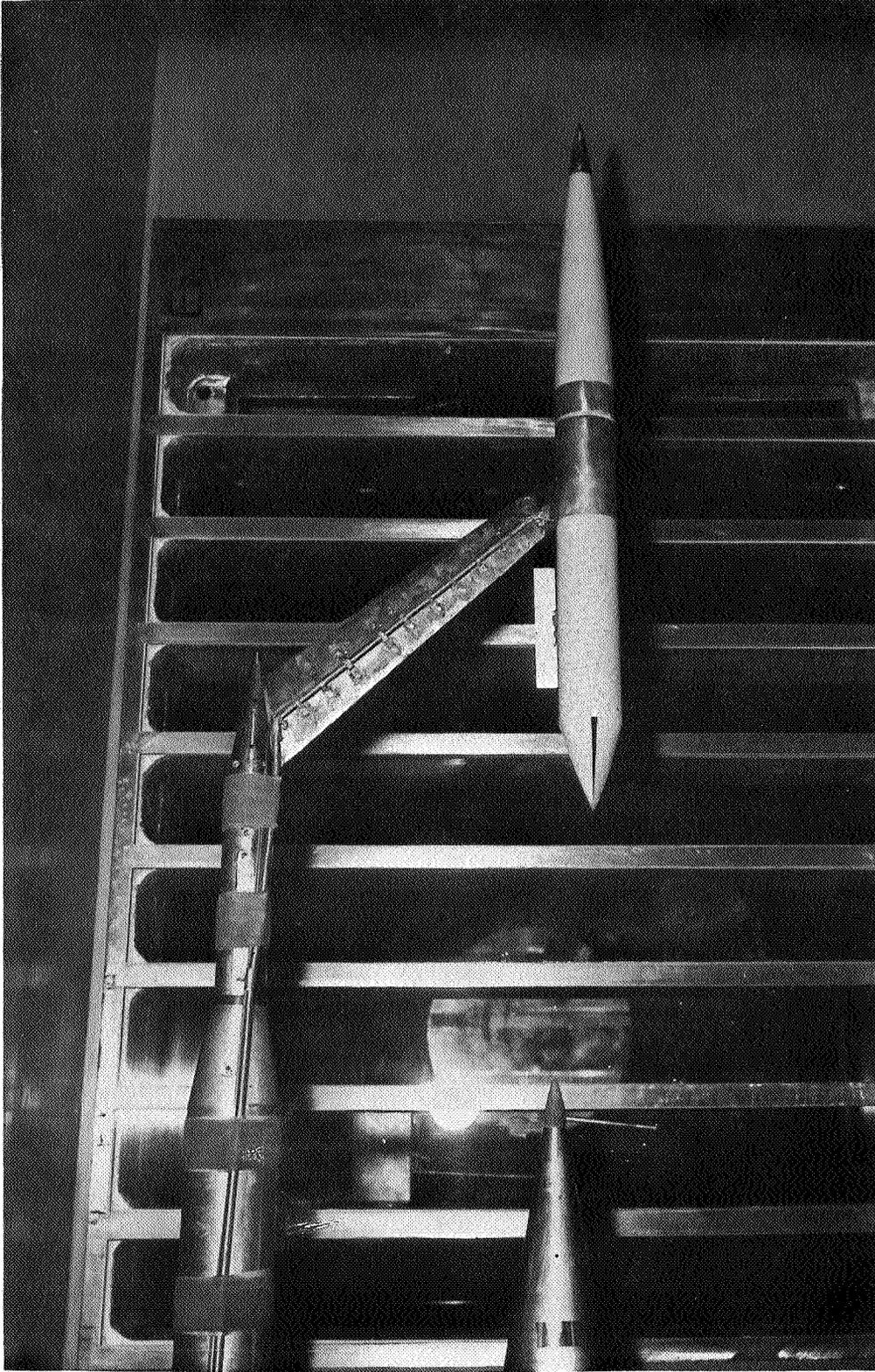
(a) Short afterbody closure with slots.

Figure 2.- Basic model with modifications.

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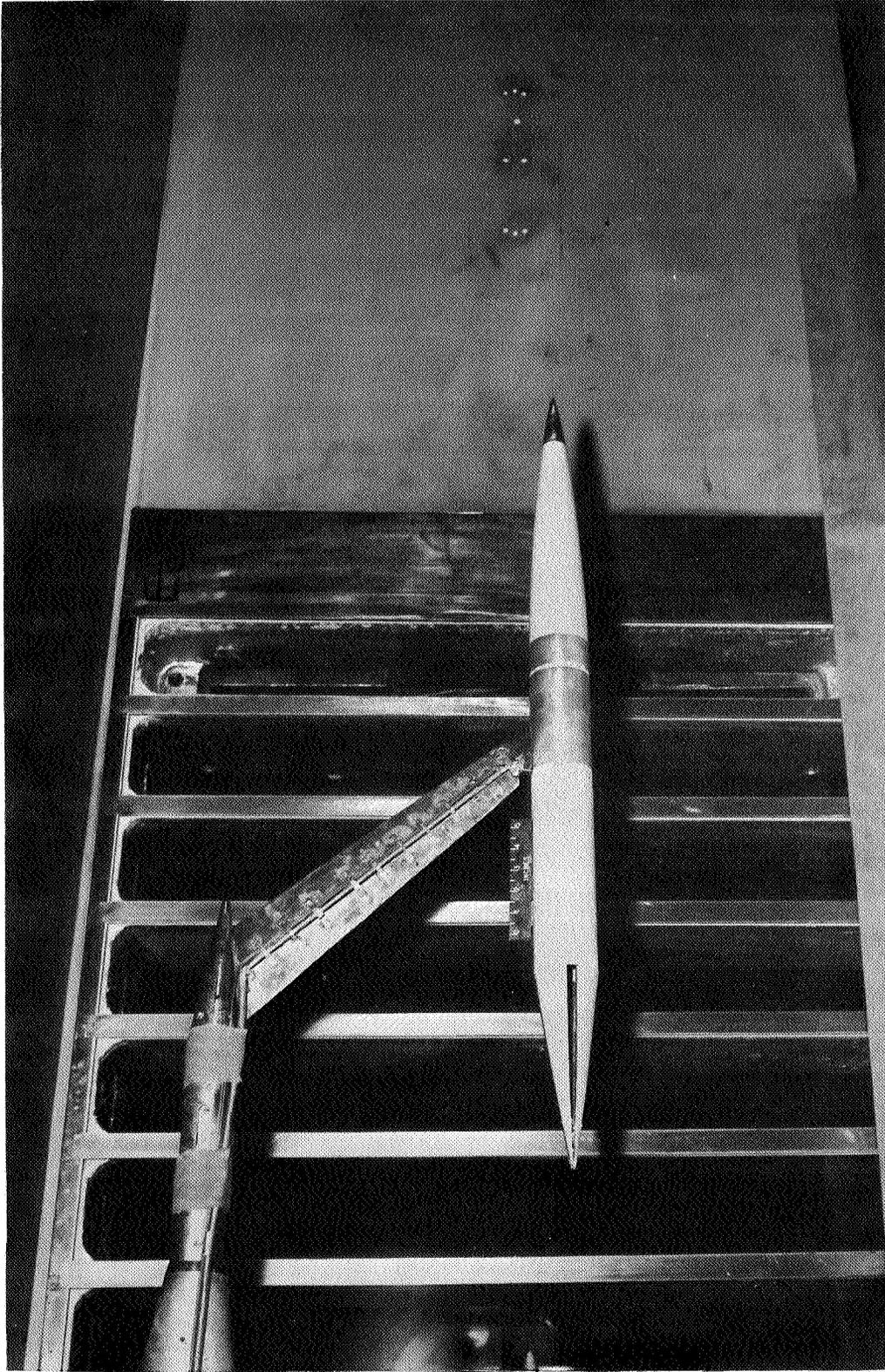
(b) Long afterbody closure with narrow slots.

Figure 2.- Continued.
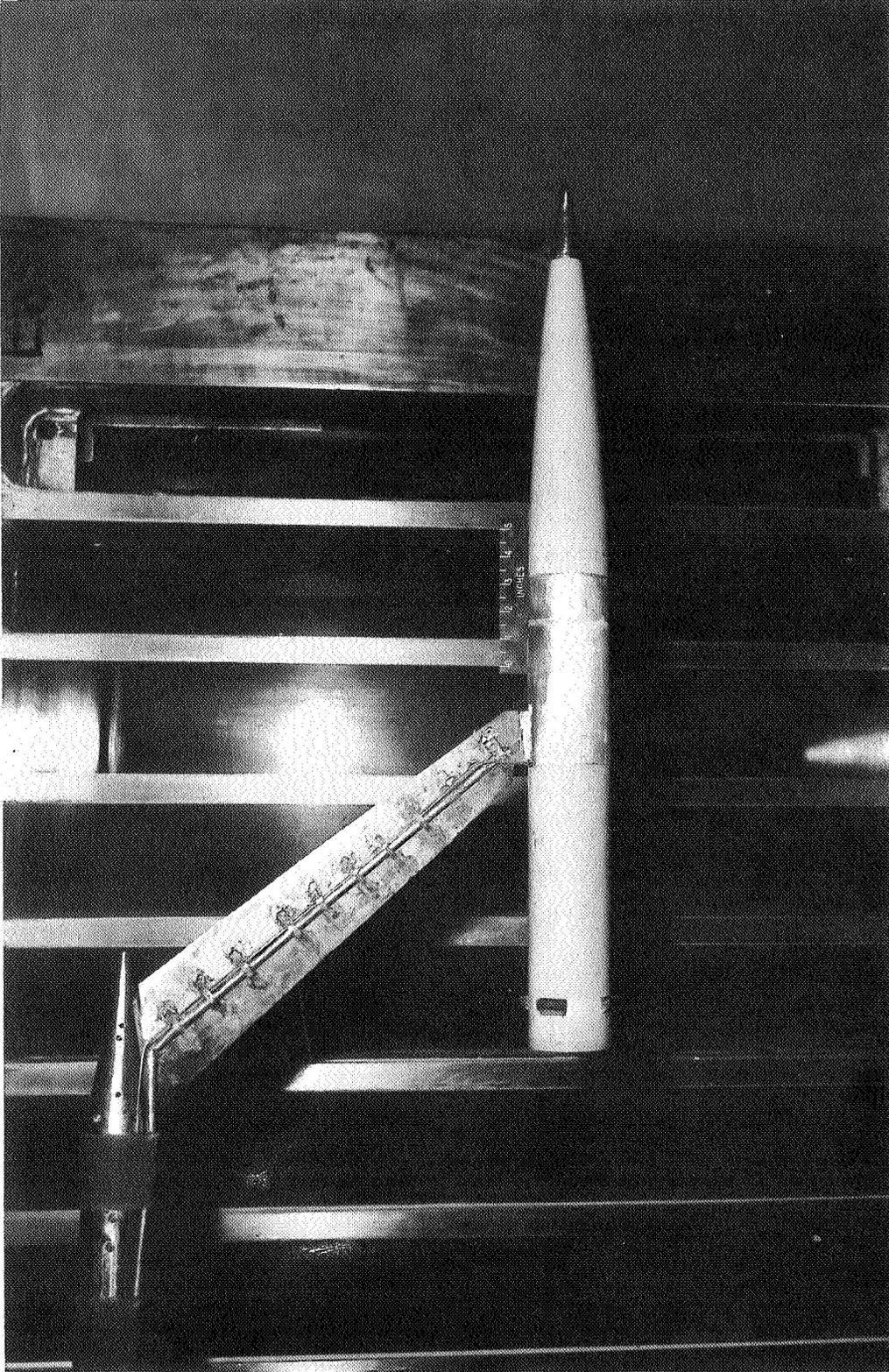
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(c) Scoops.- Concluded.

Figure 2.- Concluded.
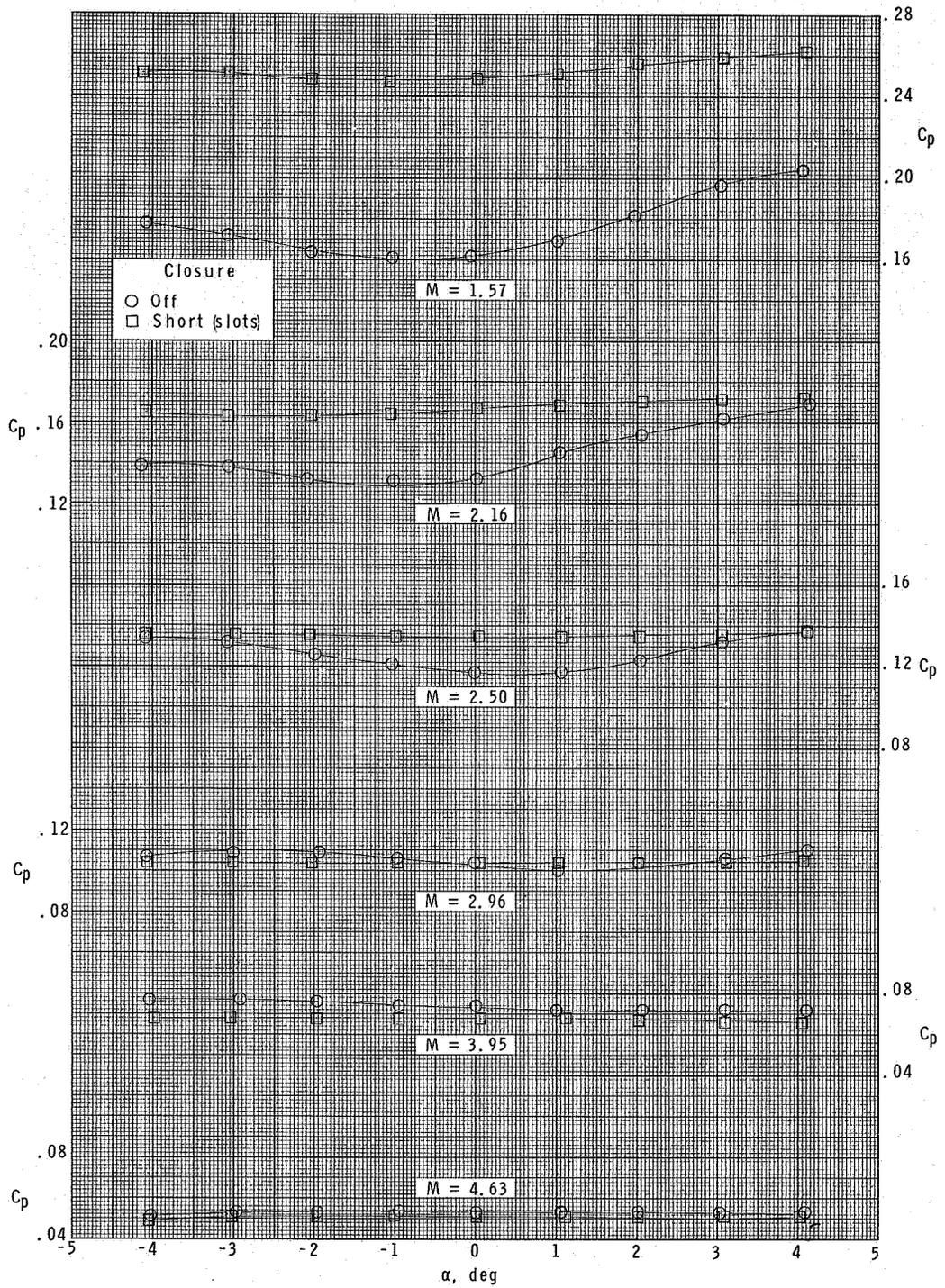
(a) Effect of short conical closure.

Figure 3.- Chamber pressure coefficient.
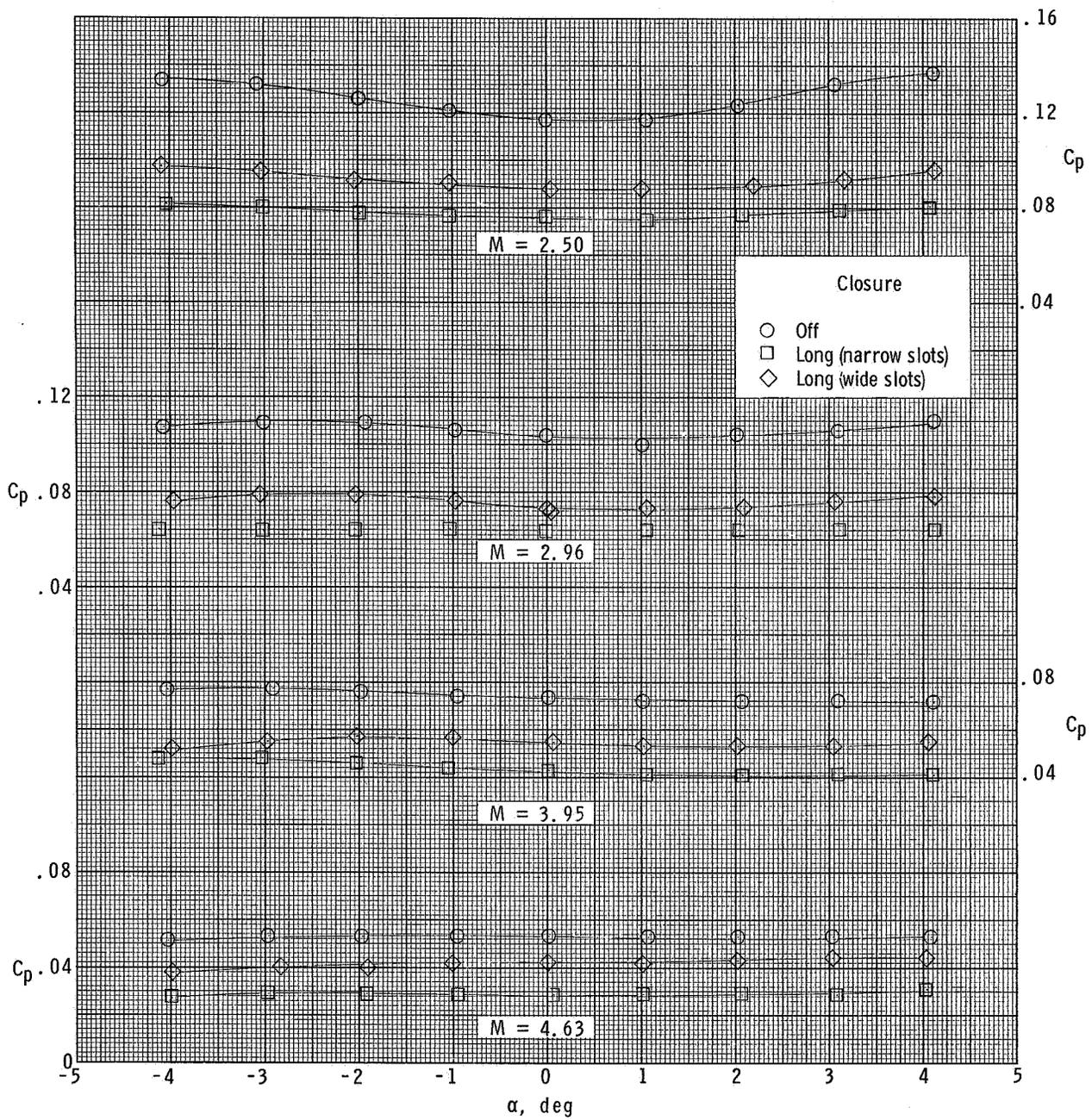
(b) Effect of long conical closure.

Figure 3.- Continued.
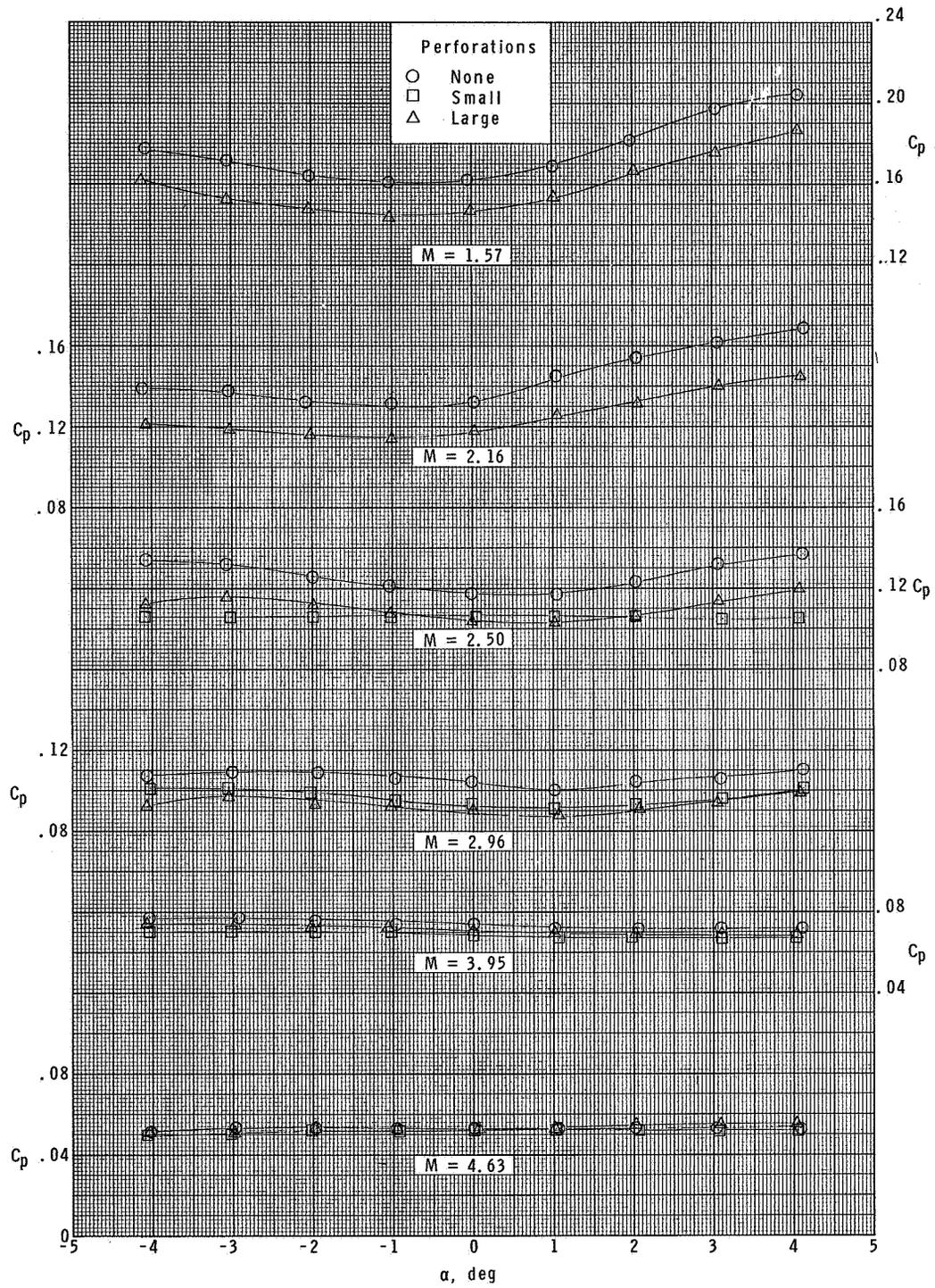
(c) Effect of perforations.

Figure 3.- Continued.
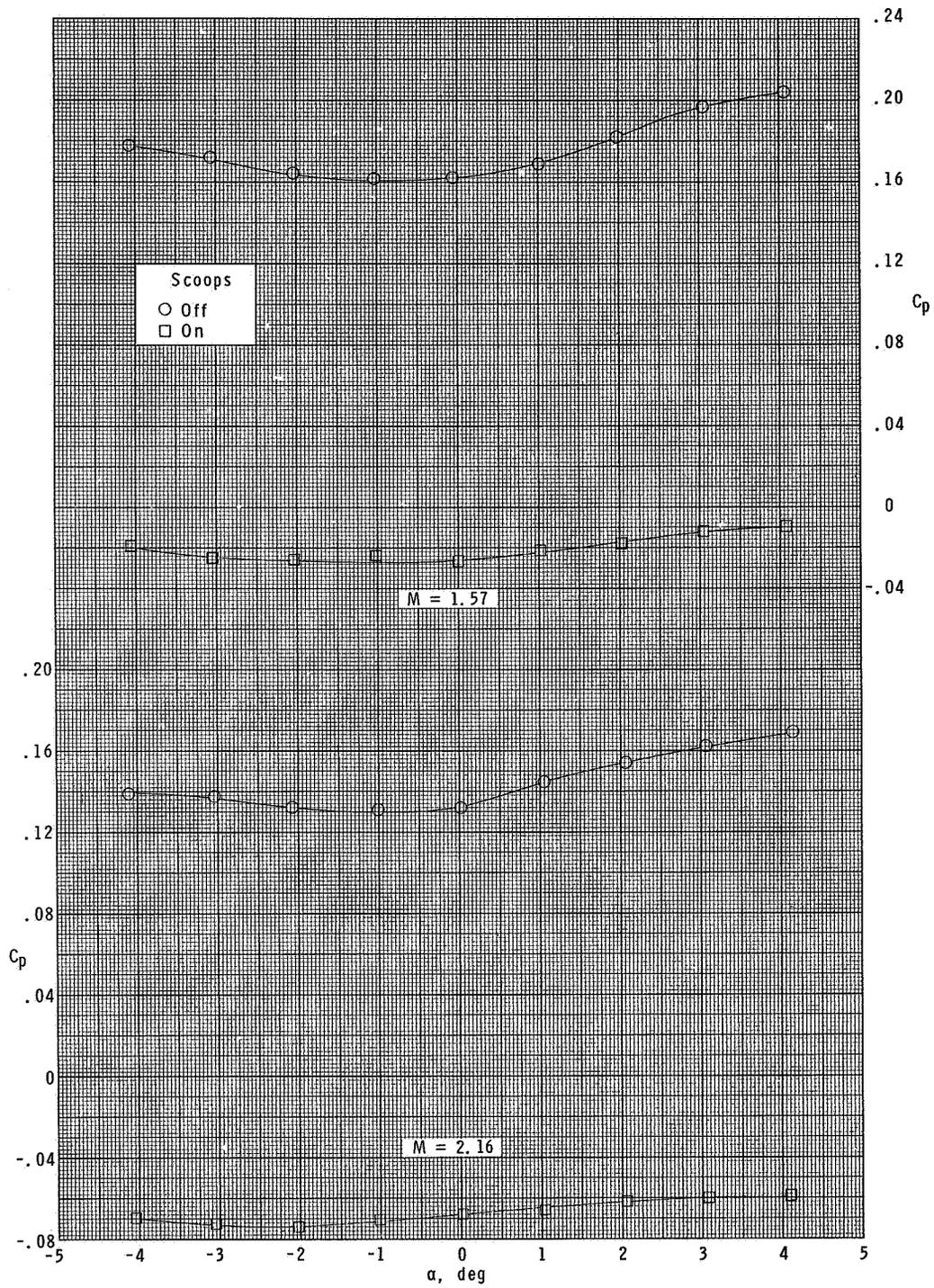
(d) Effect of scoops.

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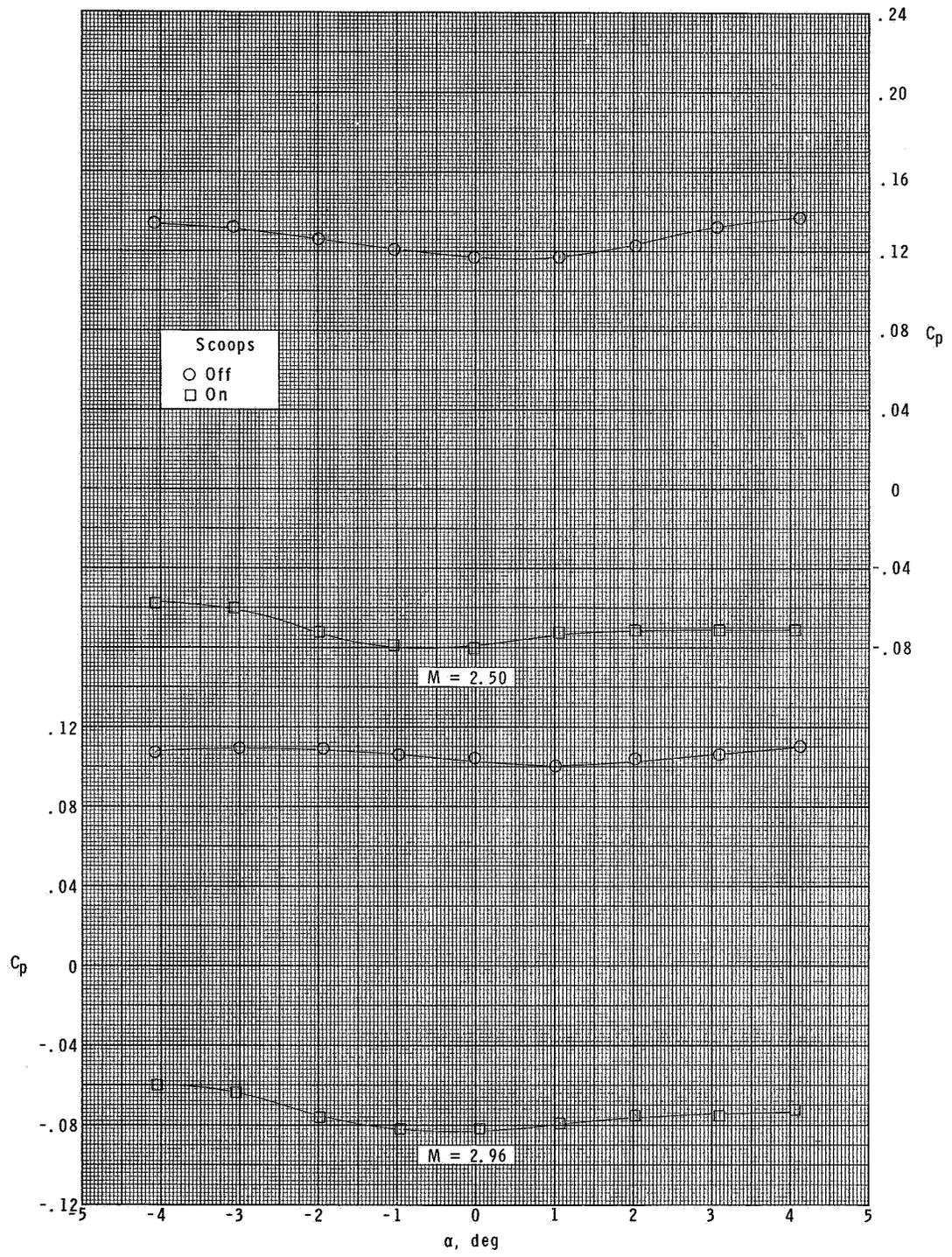
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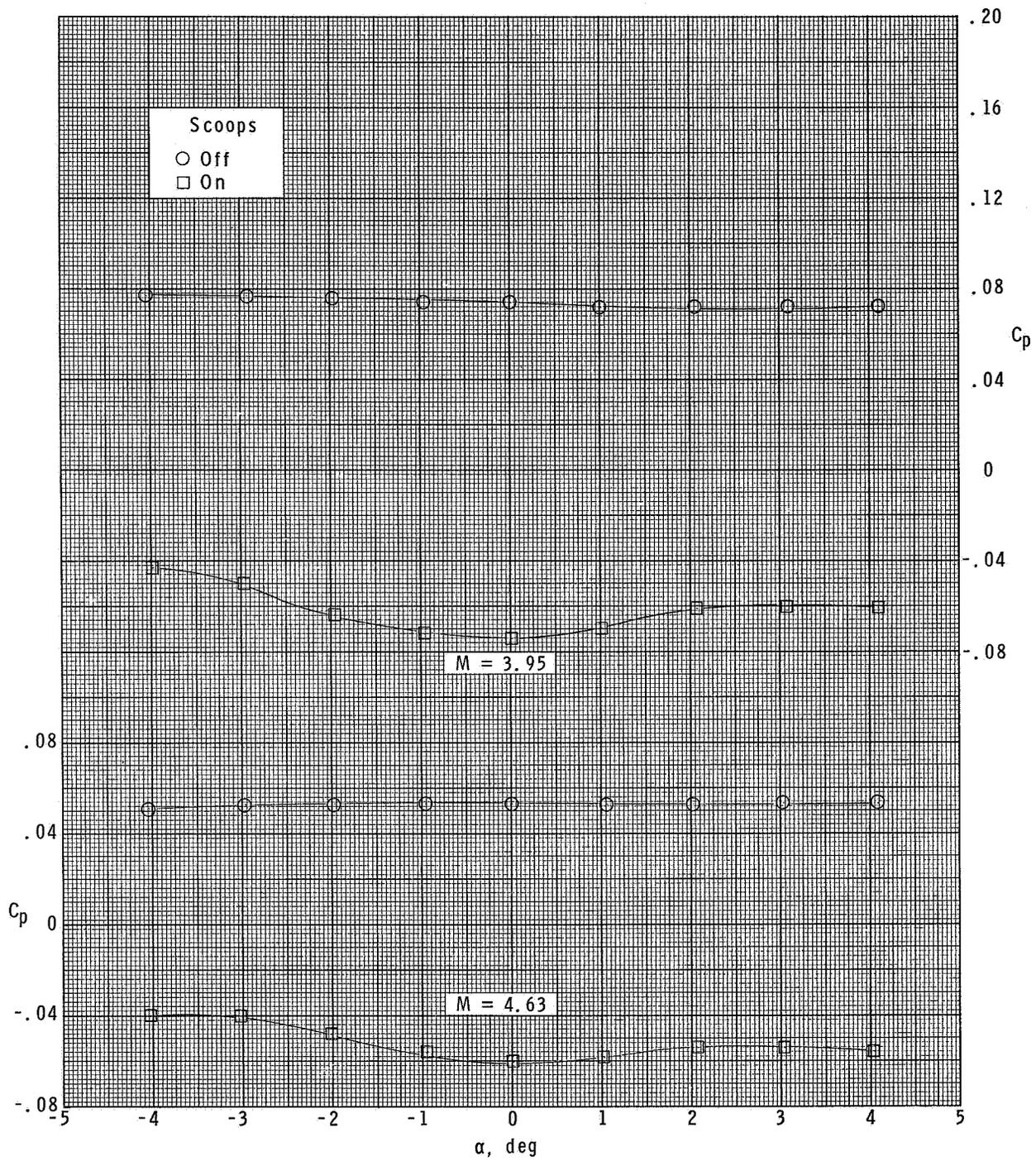
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Figure 3.- Concluded.
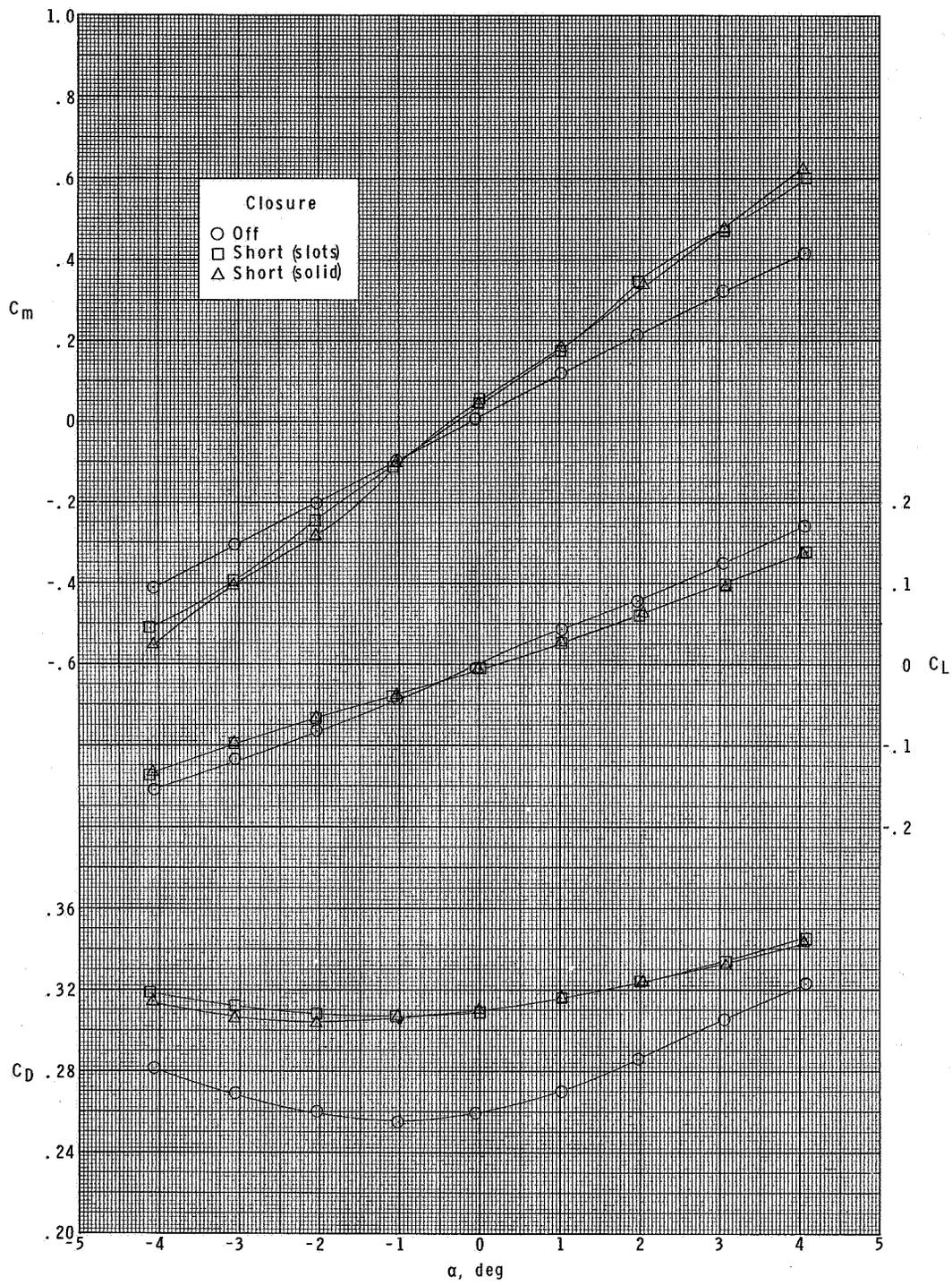
(a) M = 1.57.

Figure 4.- Effect of short afterbody closure on longitudinal aerodynamic characteristics.
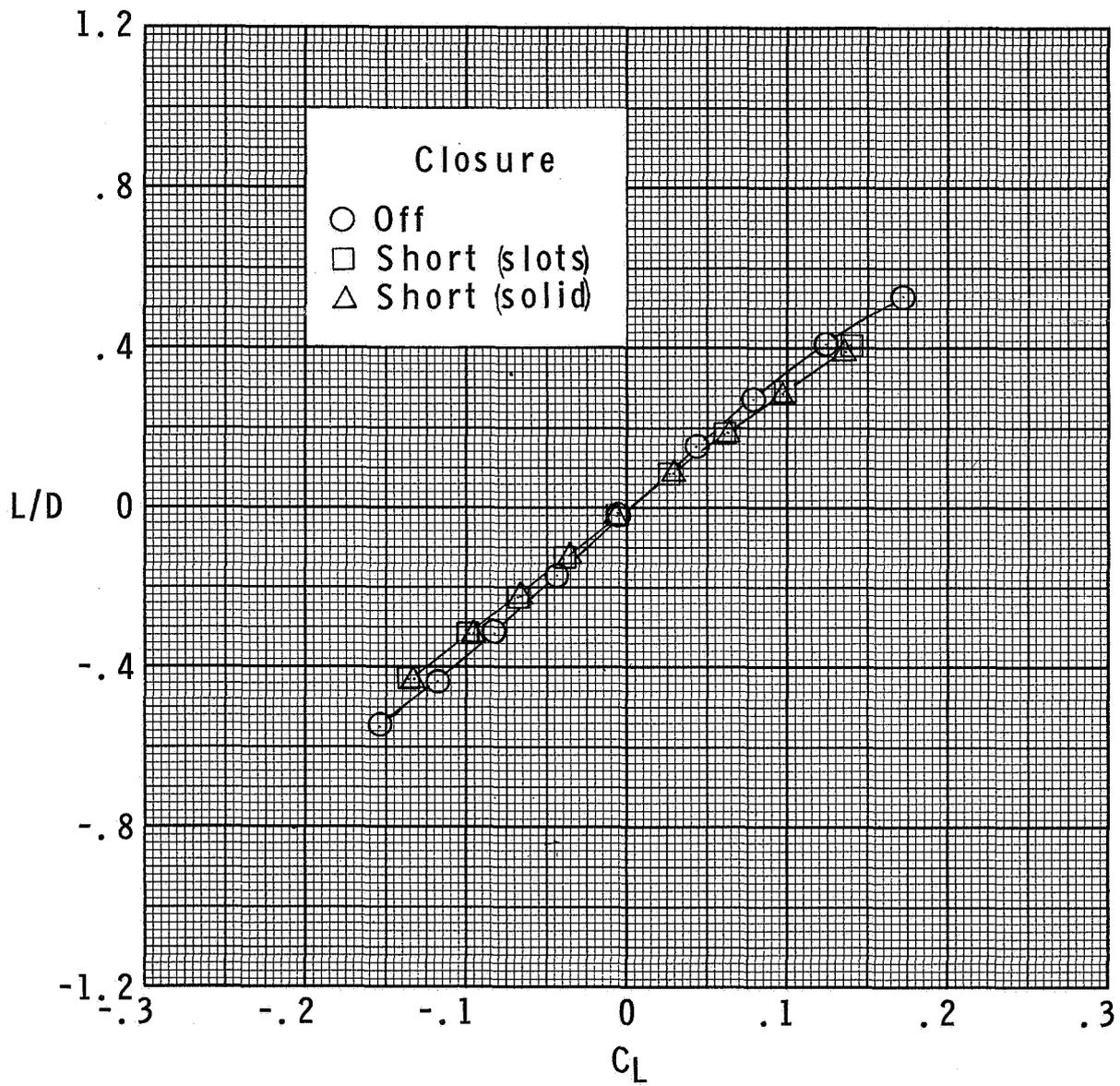
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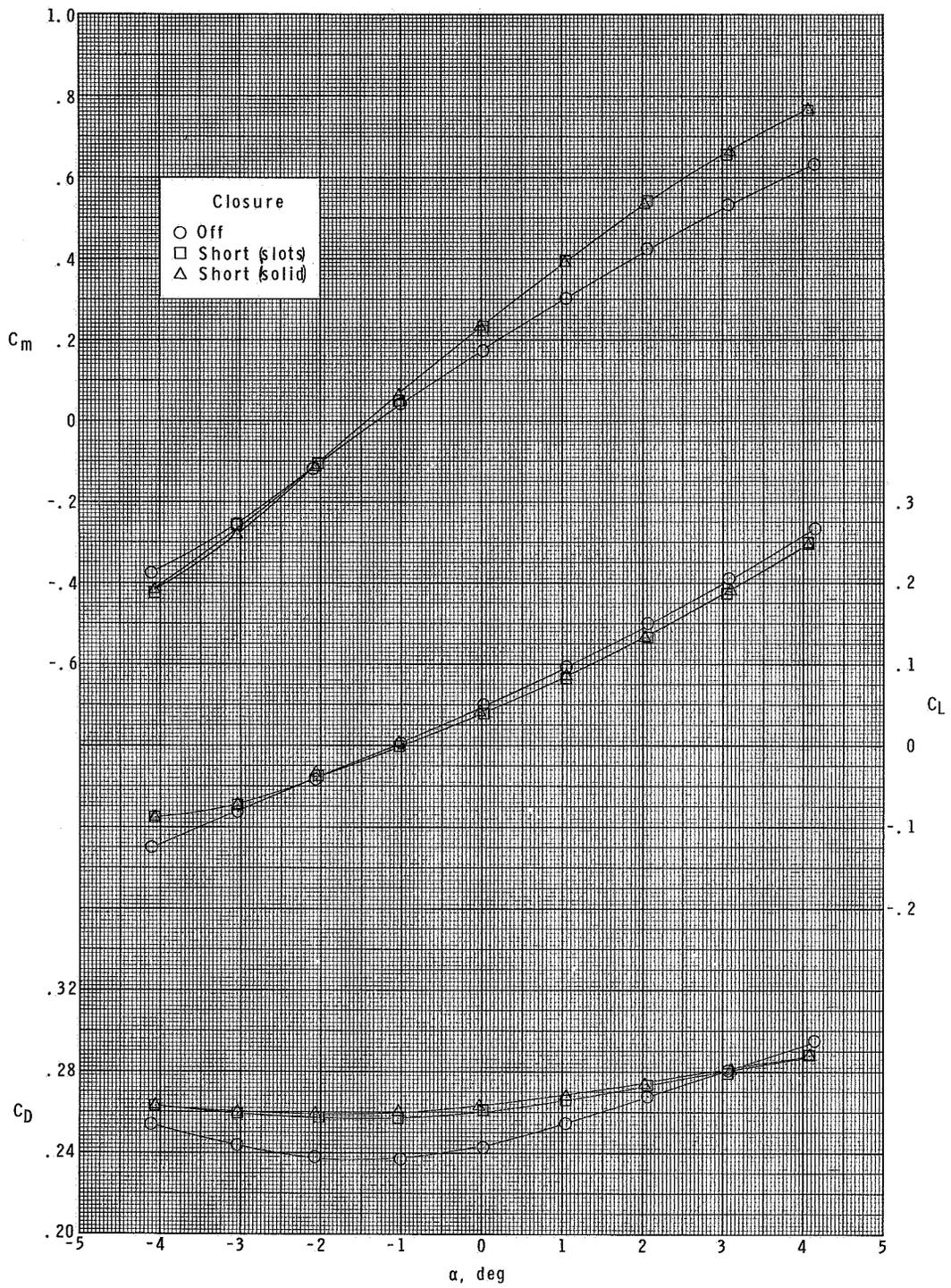
Figure 4.- Continued.

(b) M = 2.16.

Figure 4.- Continued.
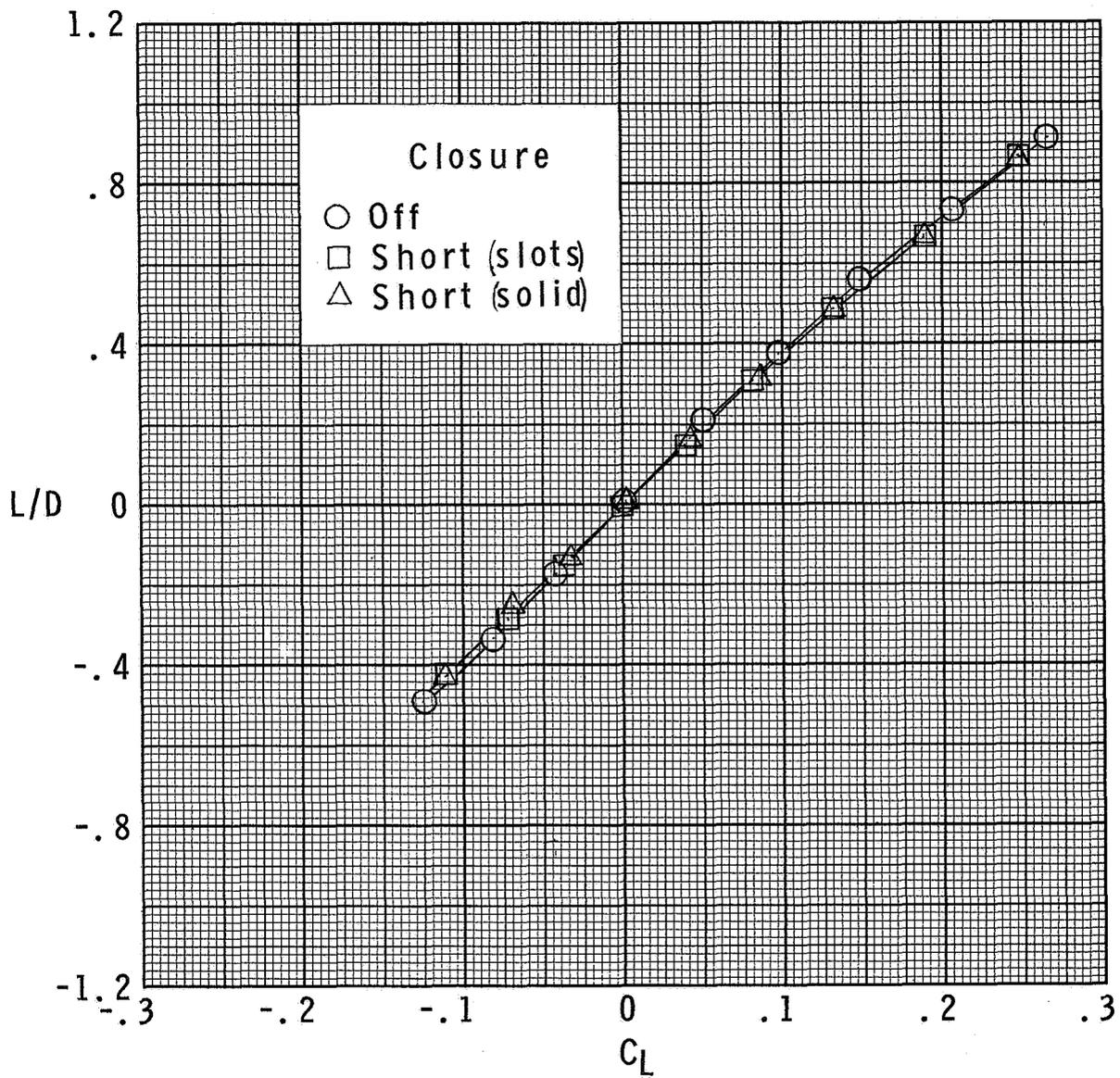
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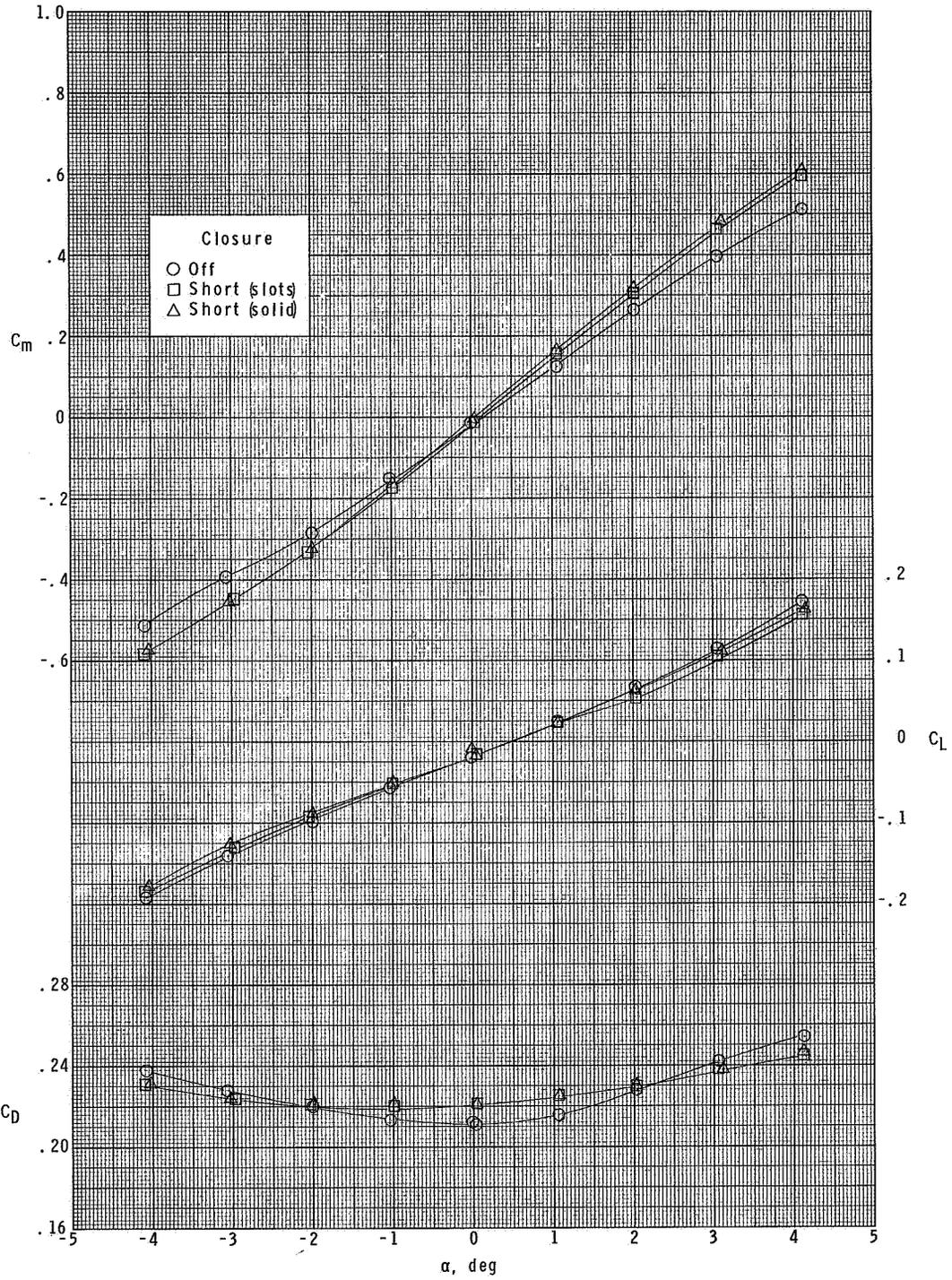
Figure 4.- Continued.

(c) M = 2.50.

Figure 4.- Continued.
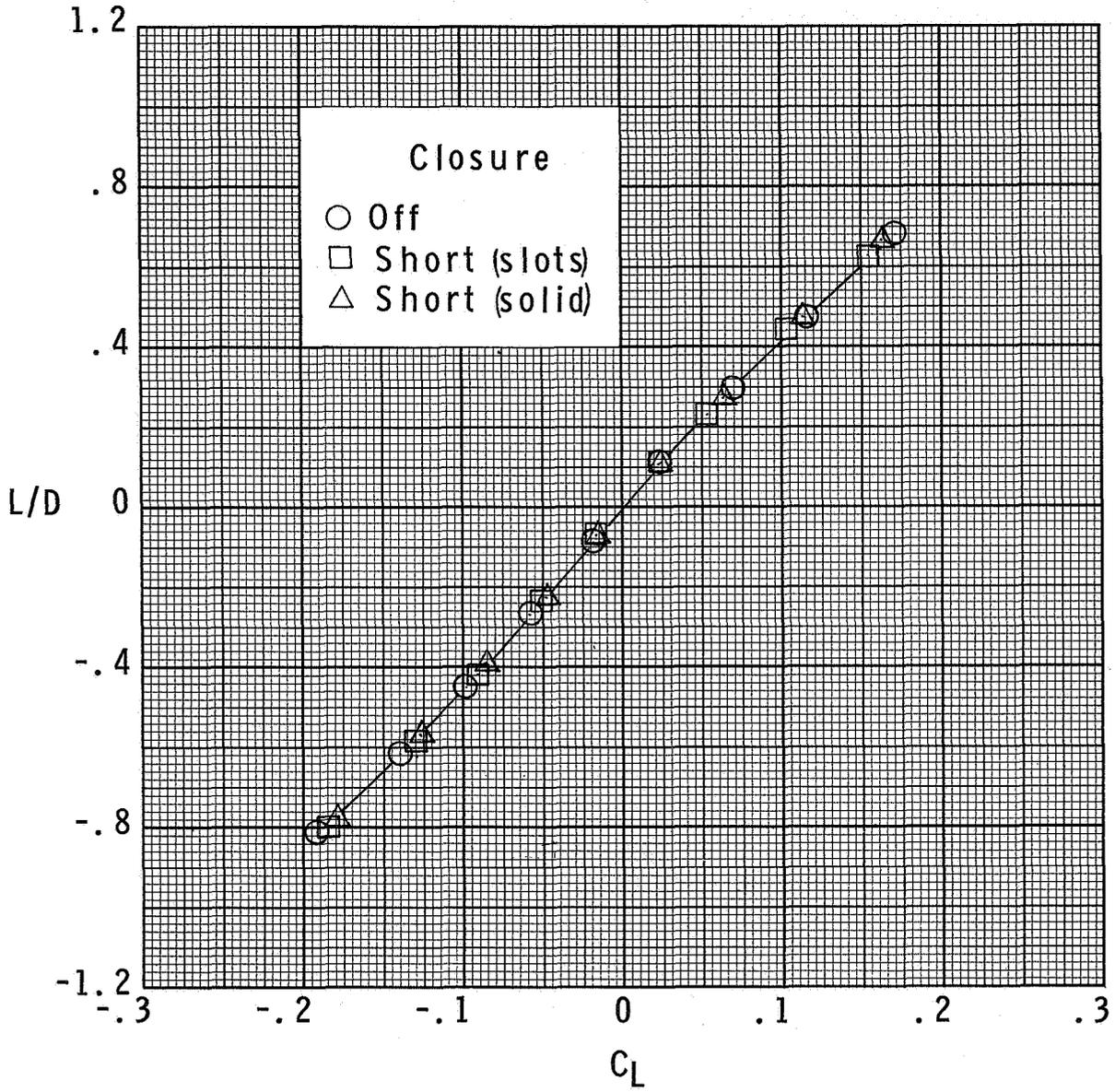
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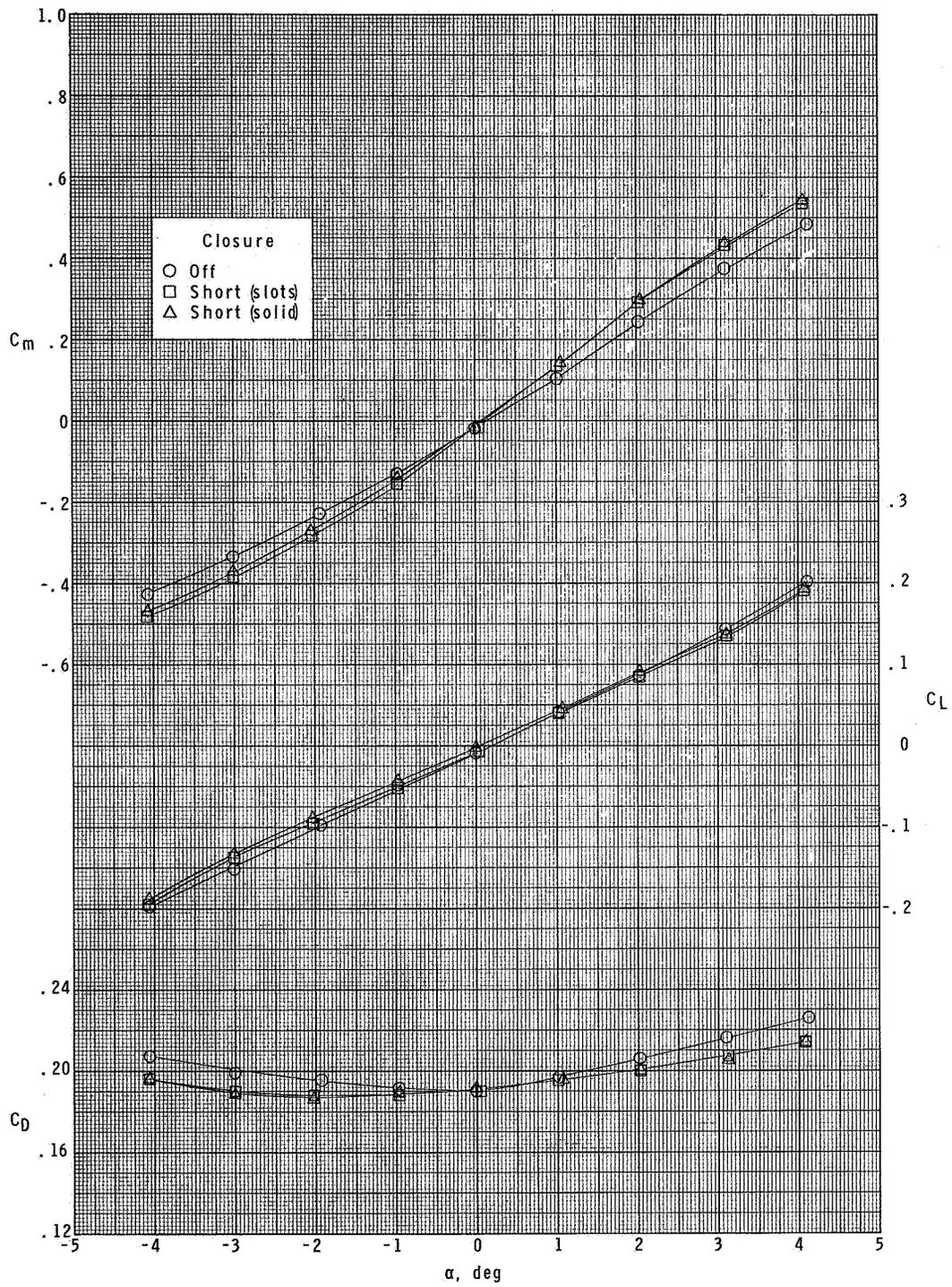
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(d) M = 2.96.

Figure 4.- Continued.
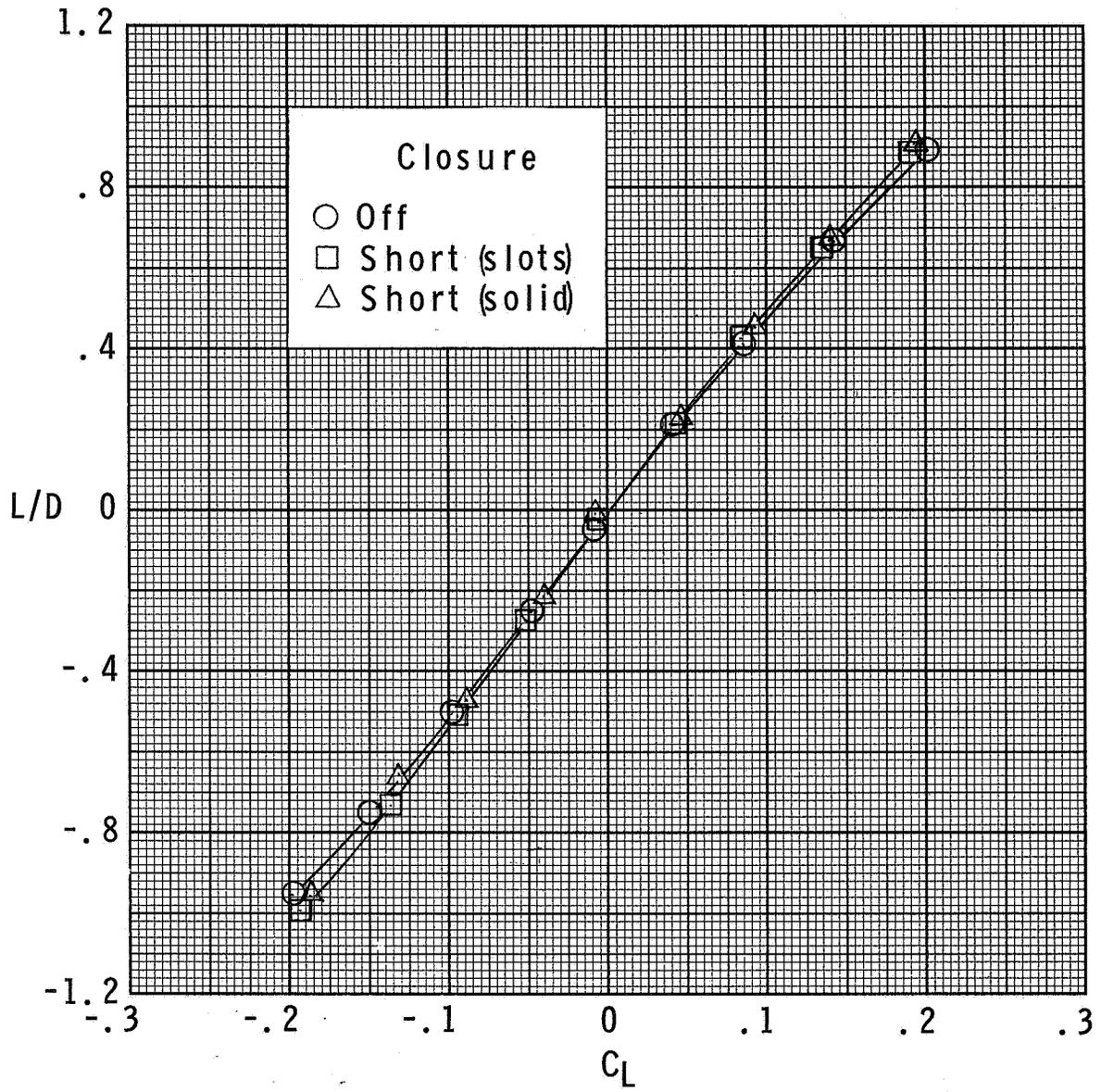
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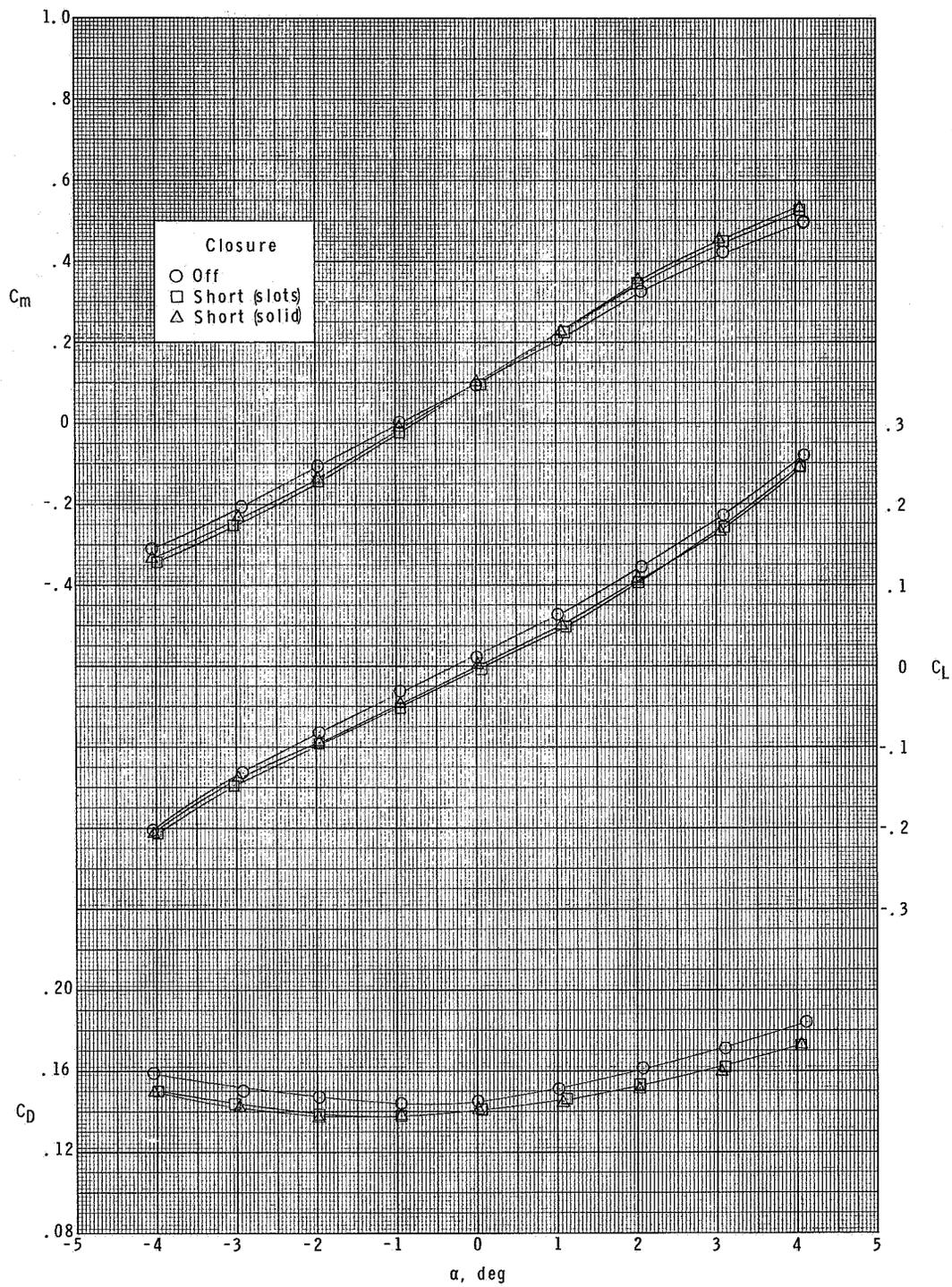
Figure 4.- Continued.

(e) M = 3.95.

Figure 4.- Continued.
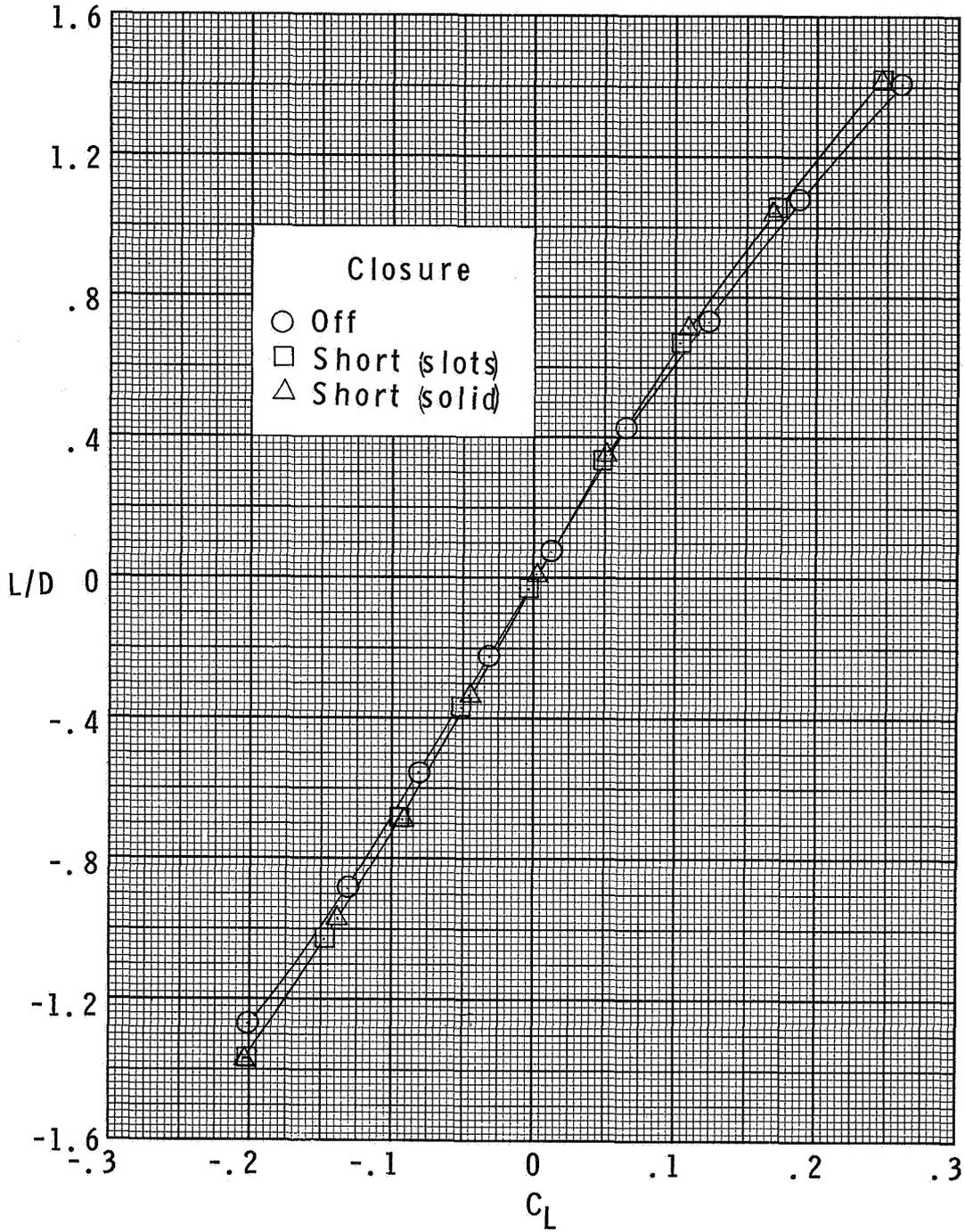
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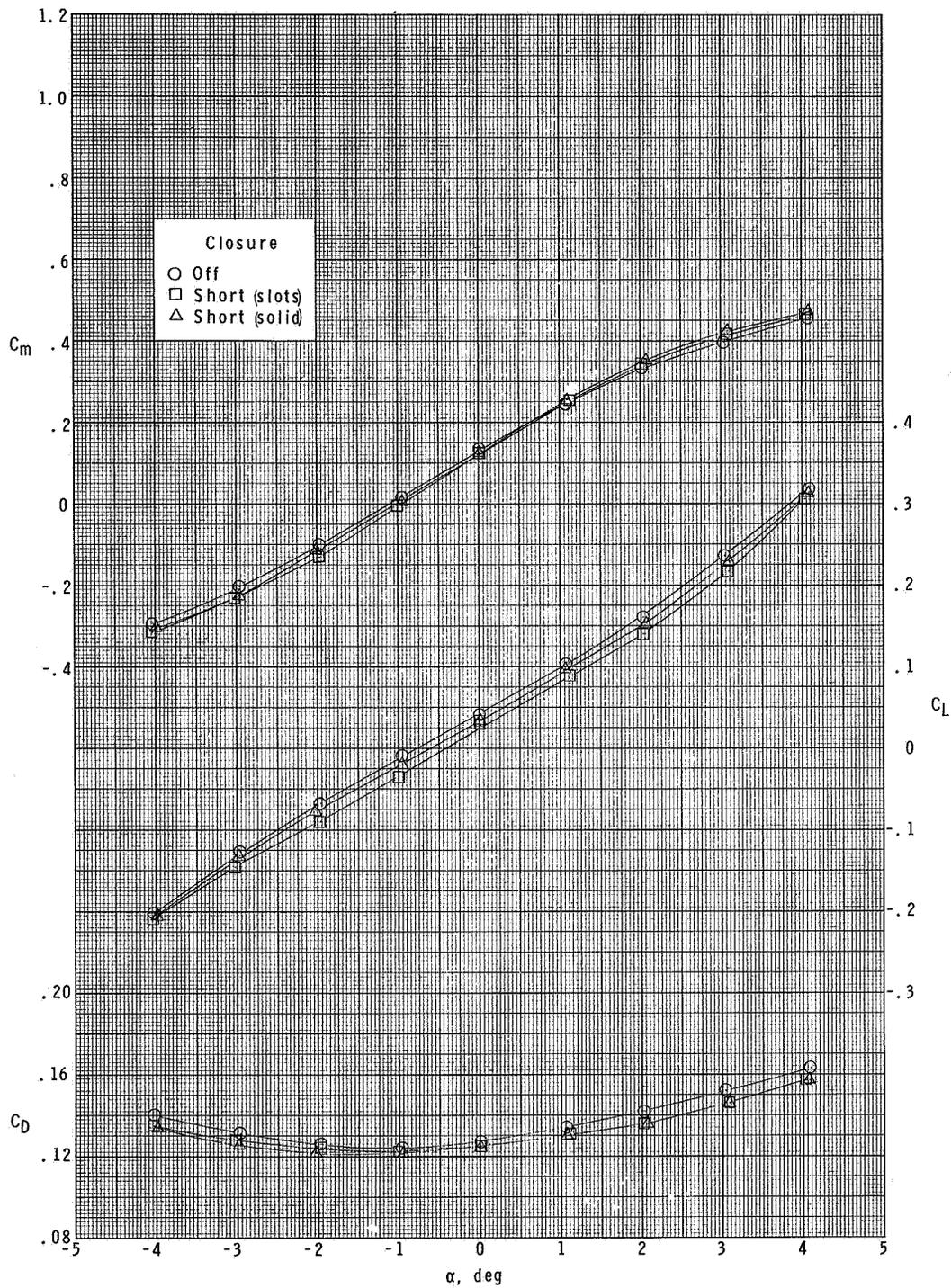
Figure 4.- Continued.

(f) M = 4.63.

Figure 4.- Continued.
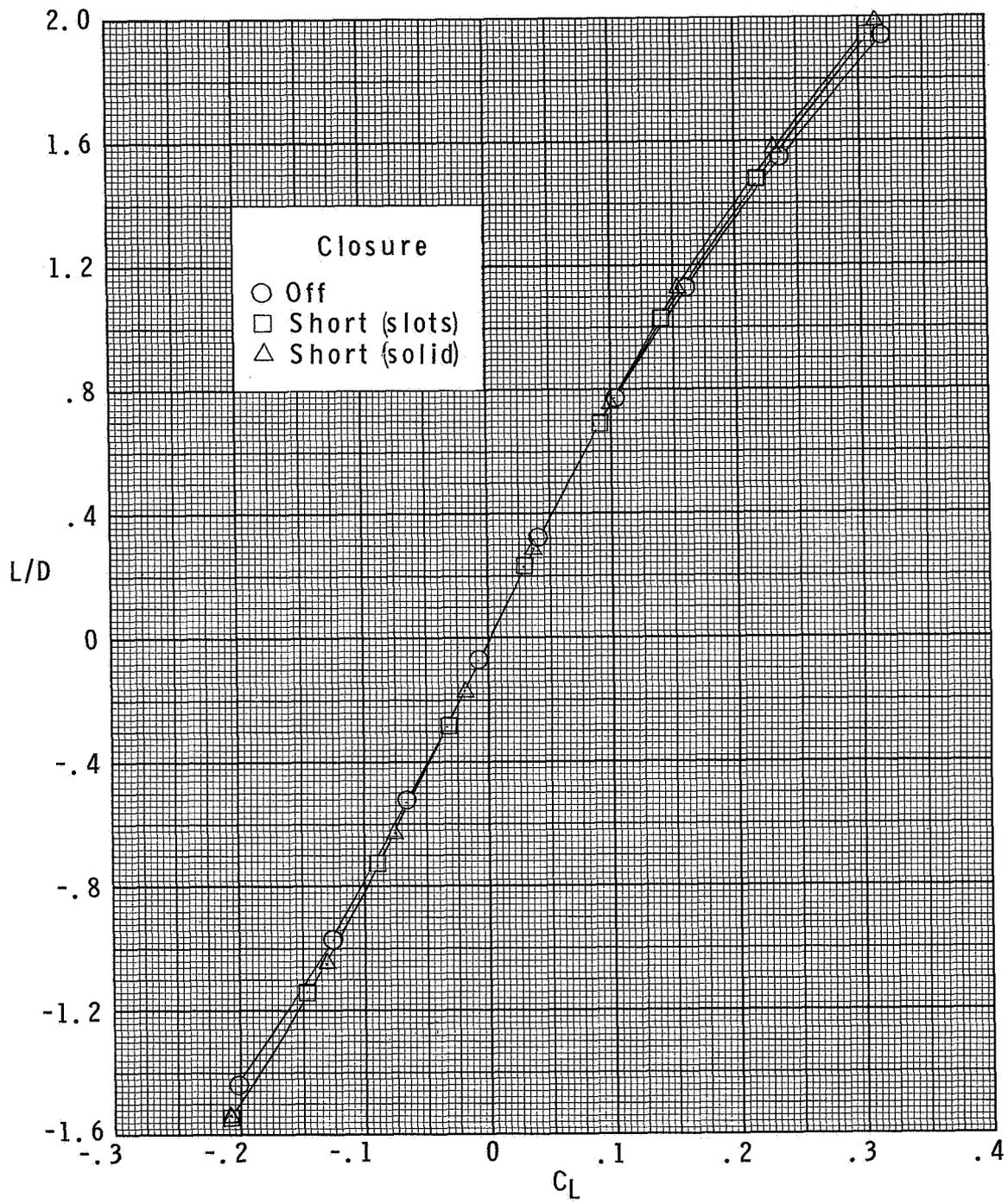
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Figure 4.- Concluded.
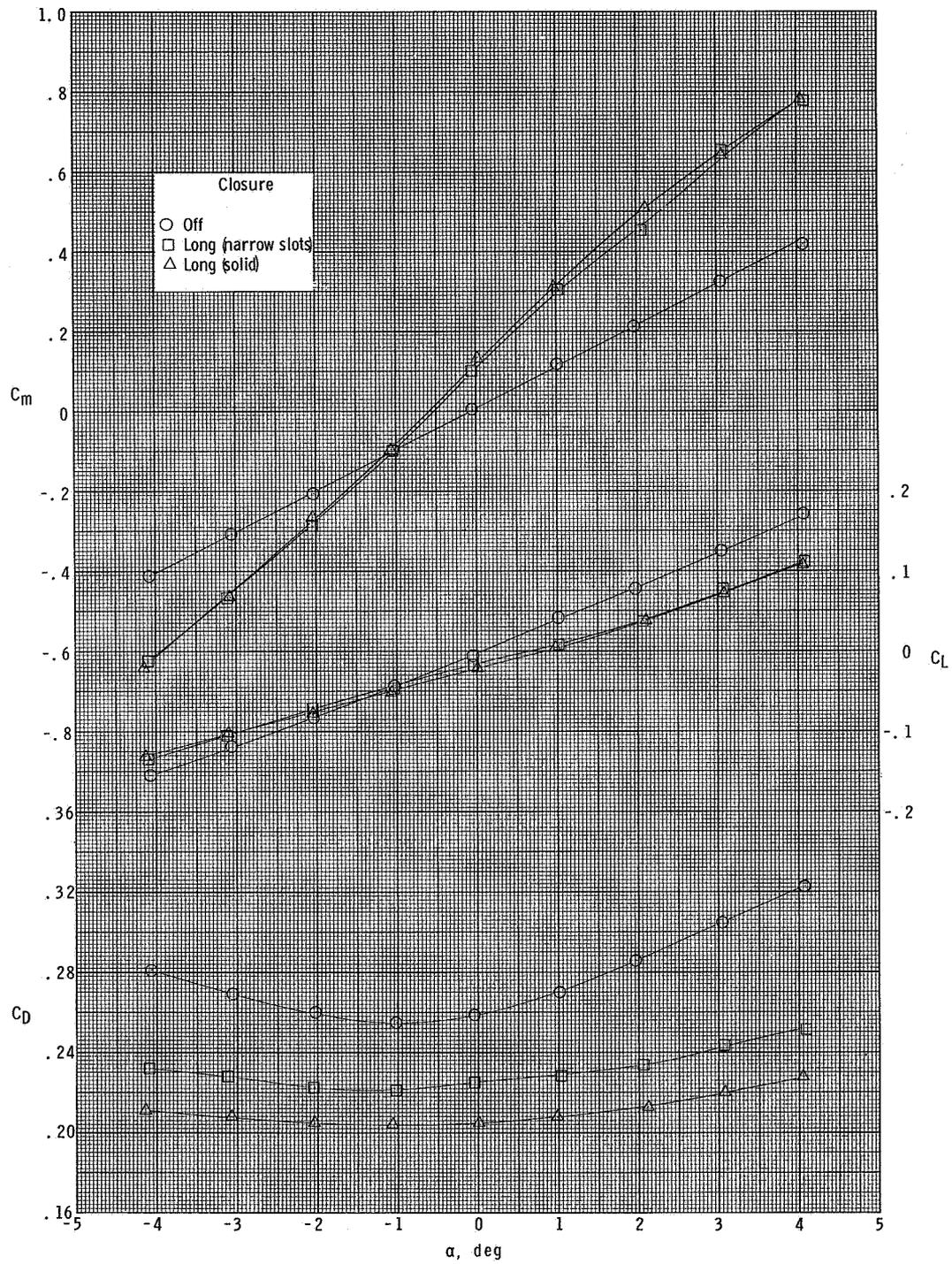
(a) M = 1.57.

Figure 5.- Effect of long afterbody closure on longitudinal aerodynamic characteristics.

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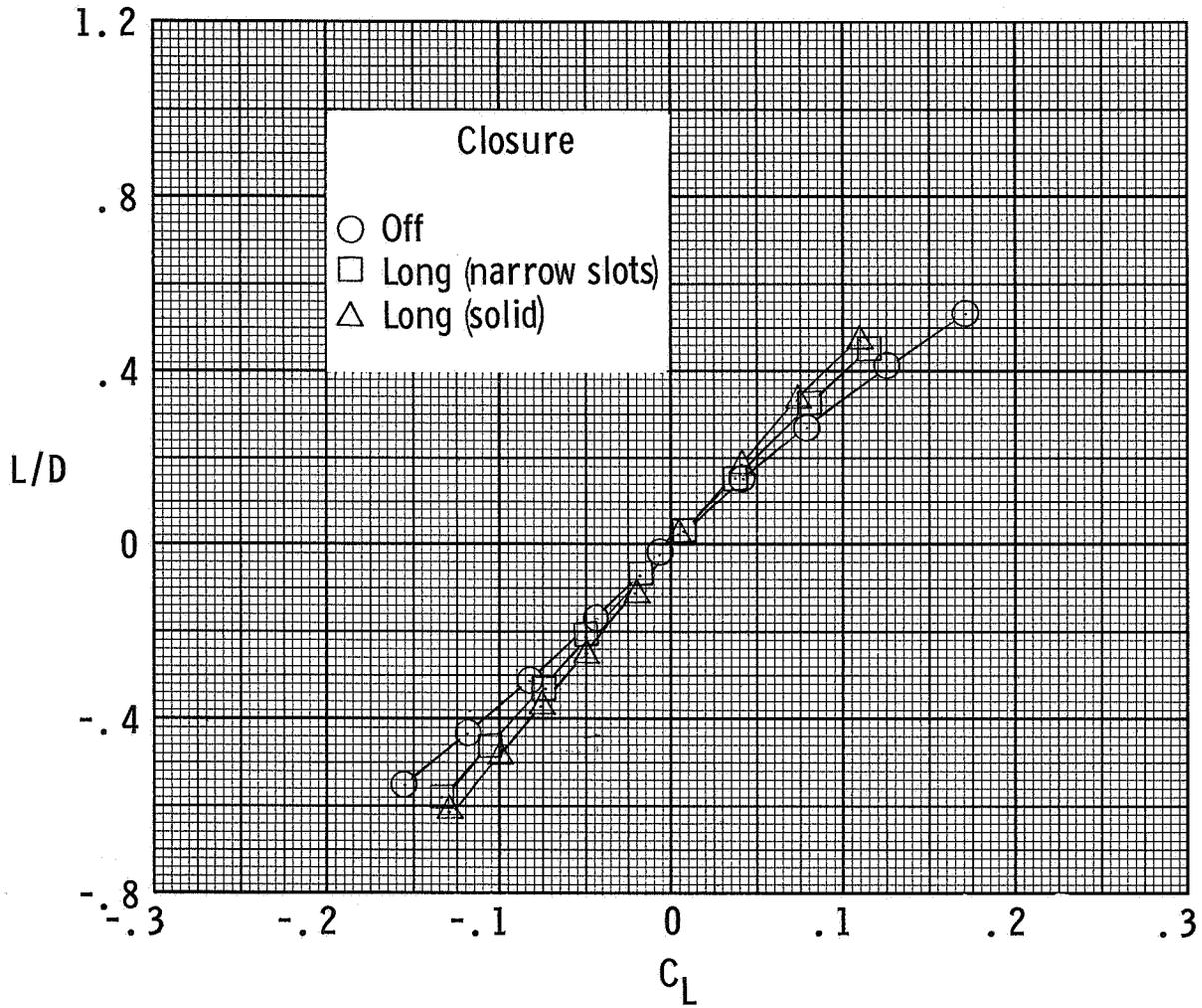
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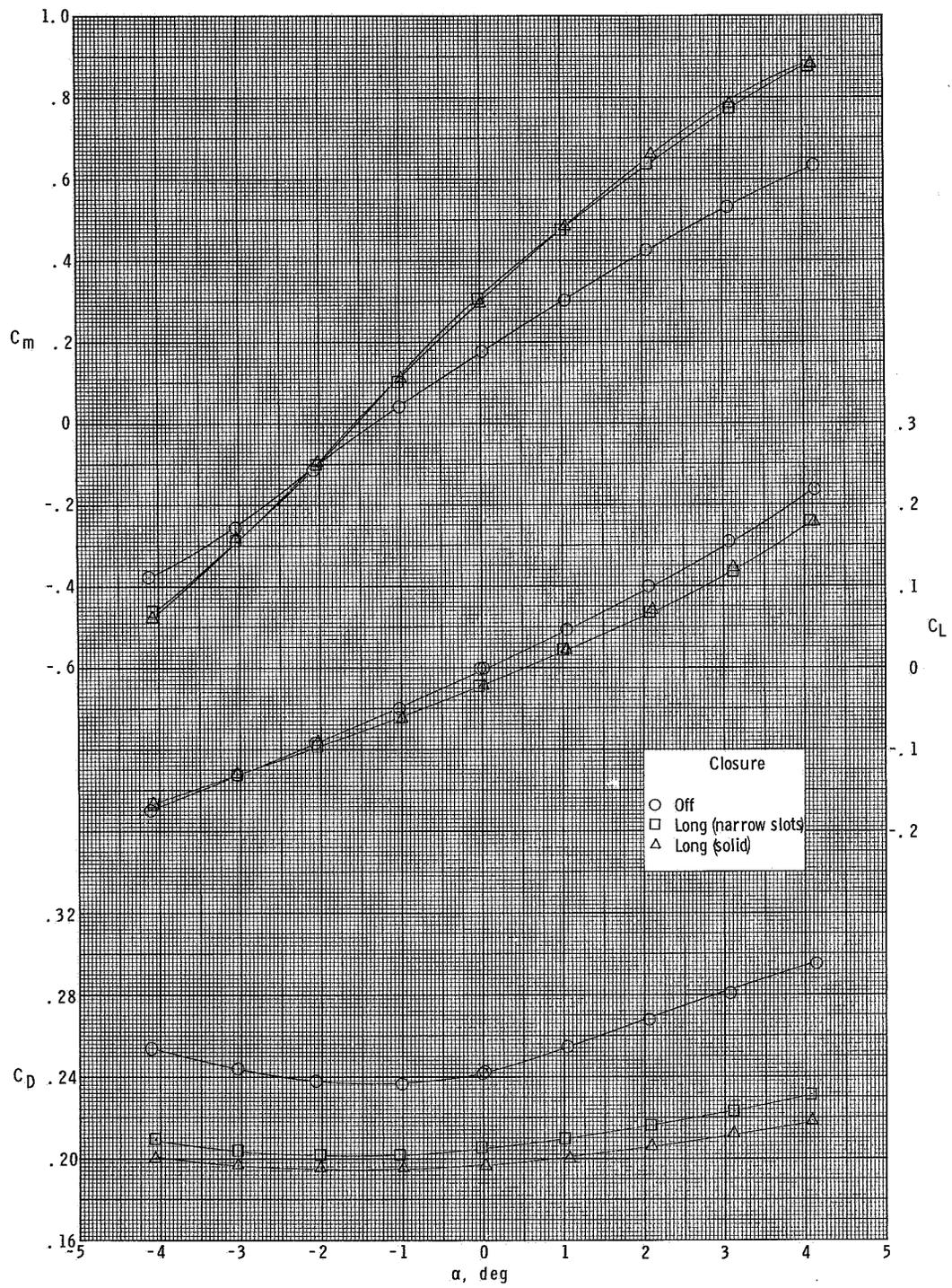
Figure 5.- Continued.

(b) M = 2.16.

Figure 5.- Continued.
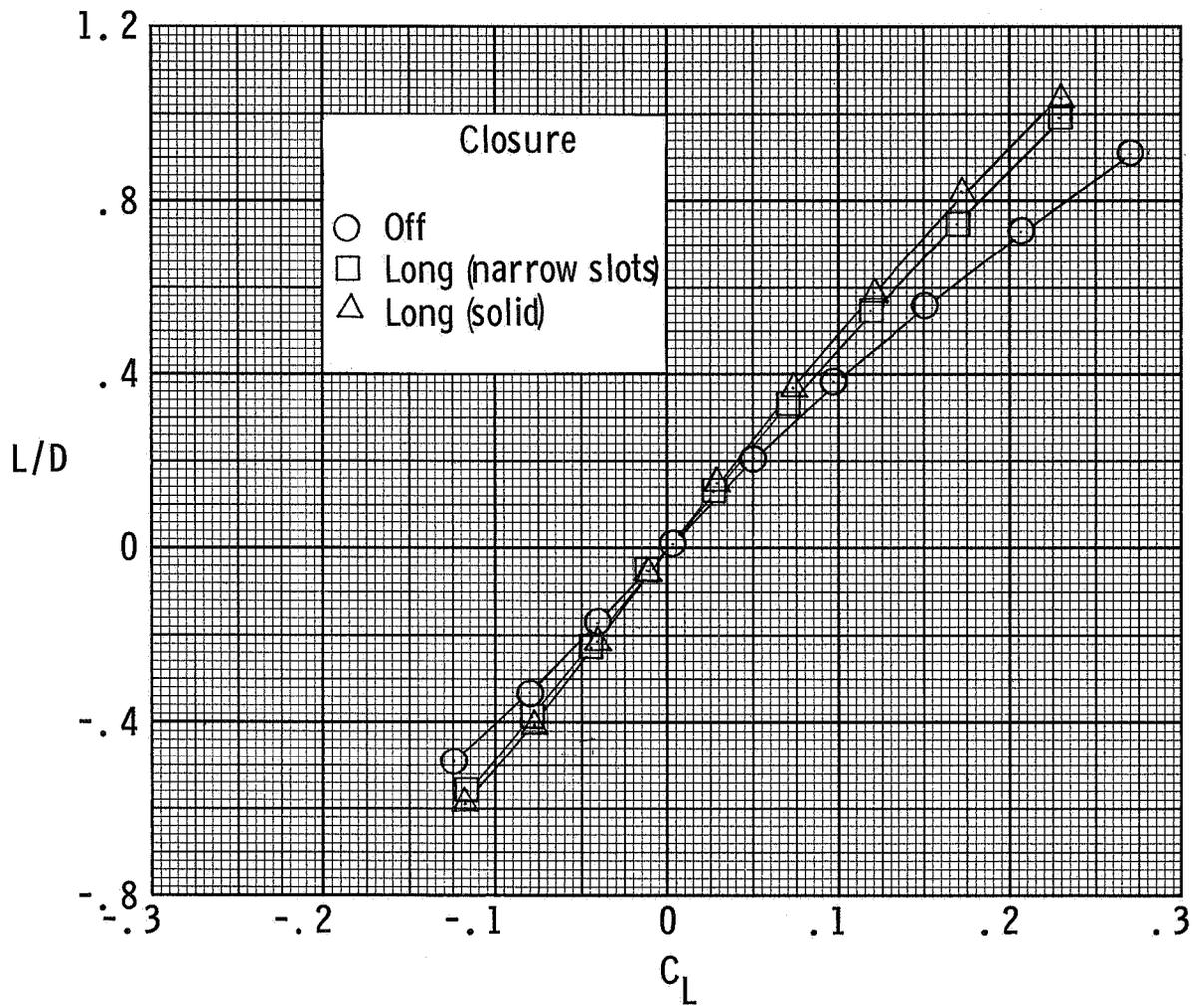
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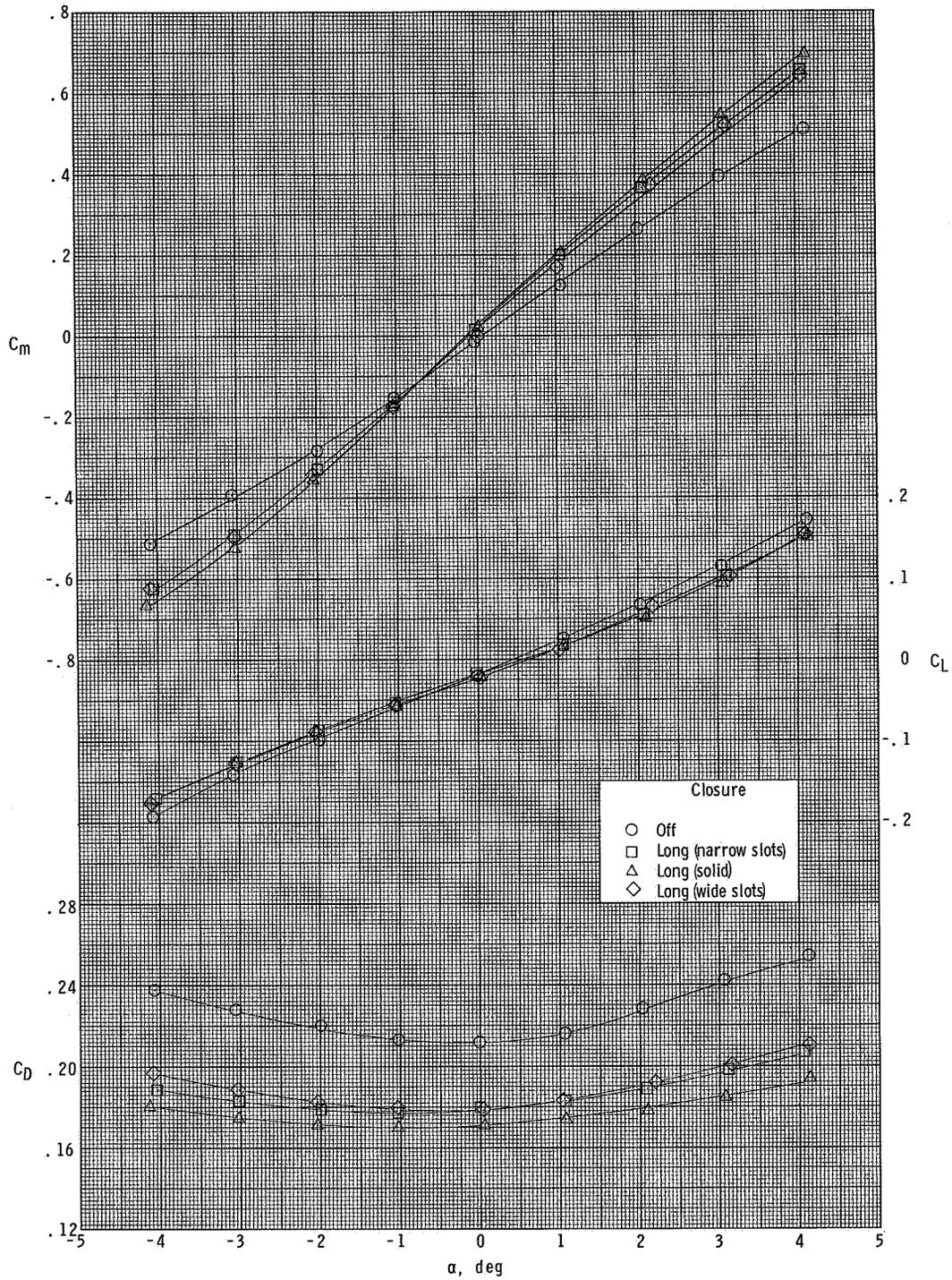
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(c) M = 2.50.

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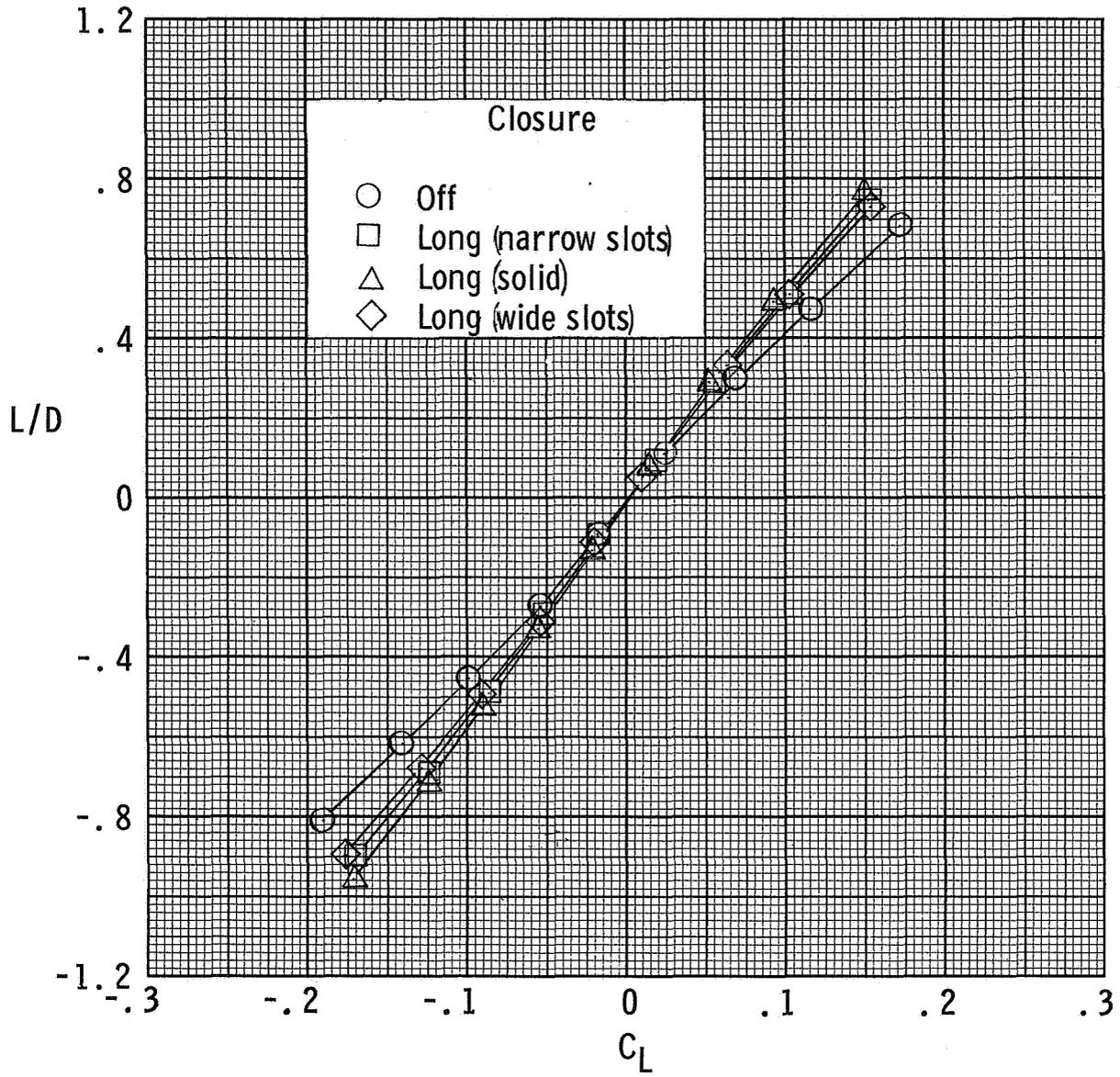
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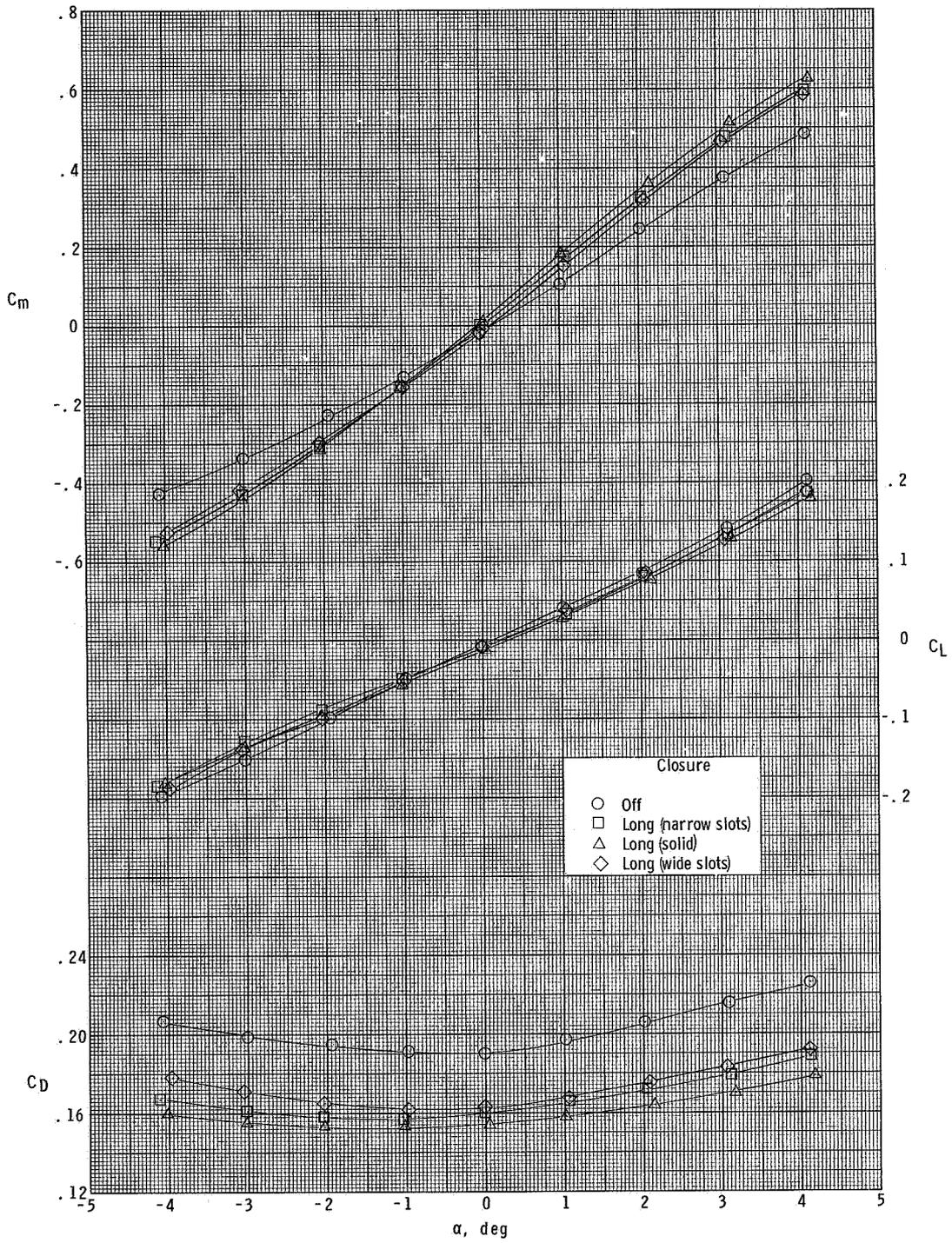
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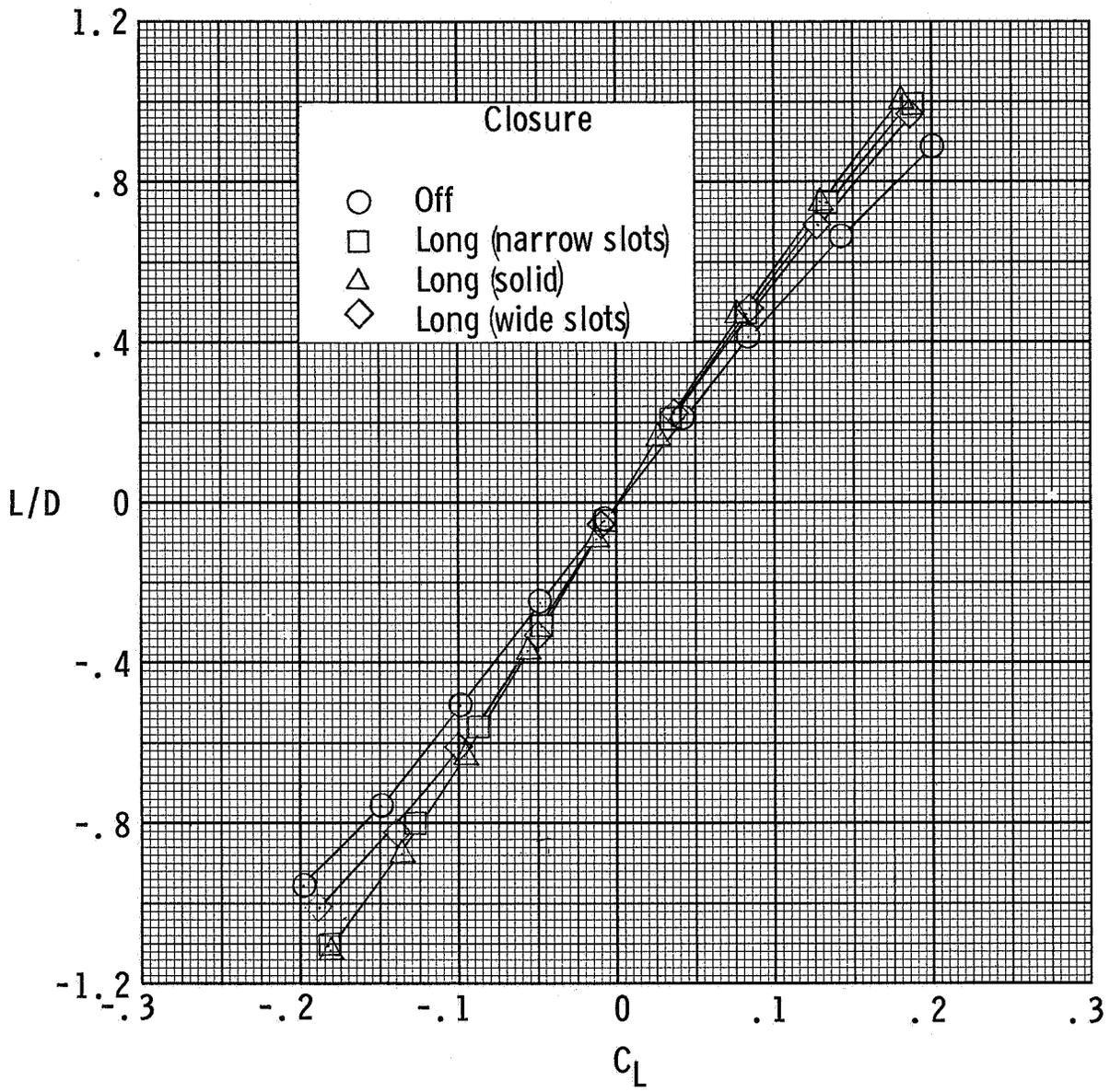
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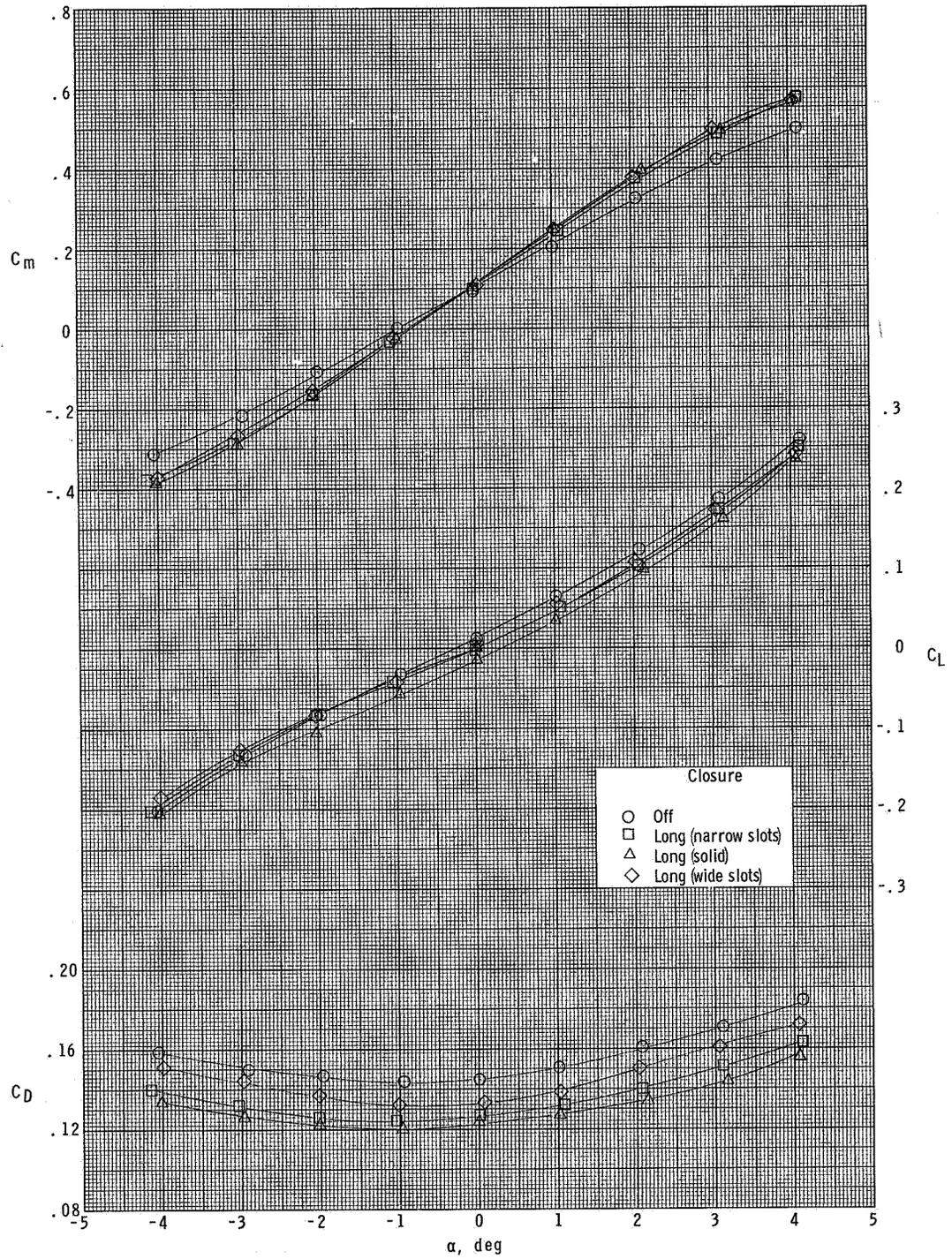
Figure 5.- Continued.

(e) M = 3.95.

Figure 5.- Continued.
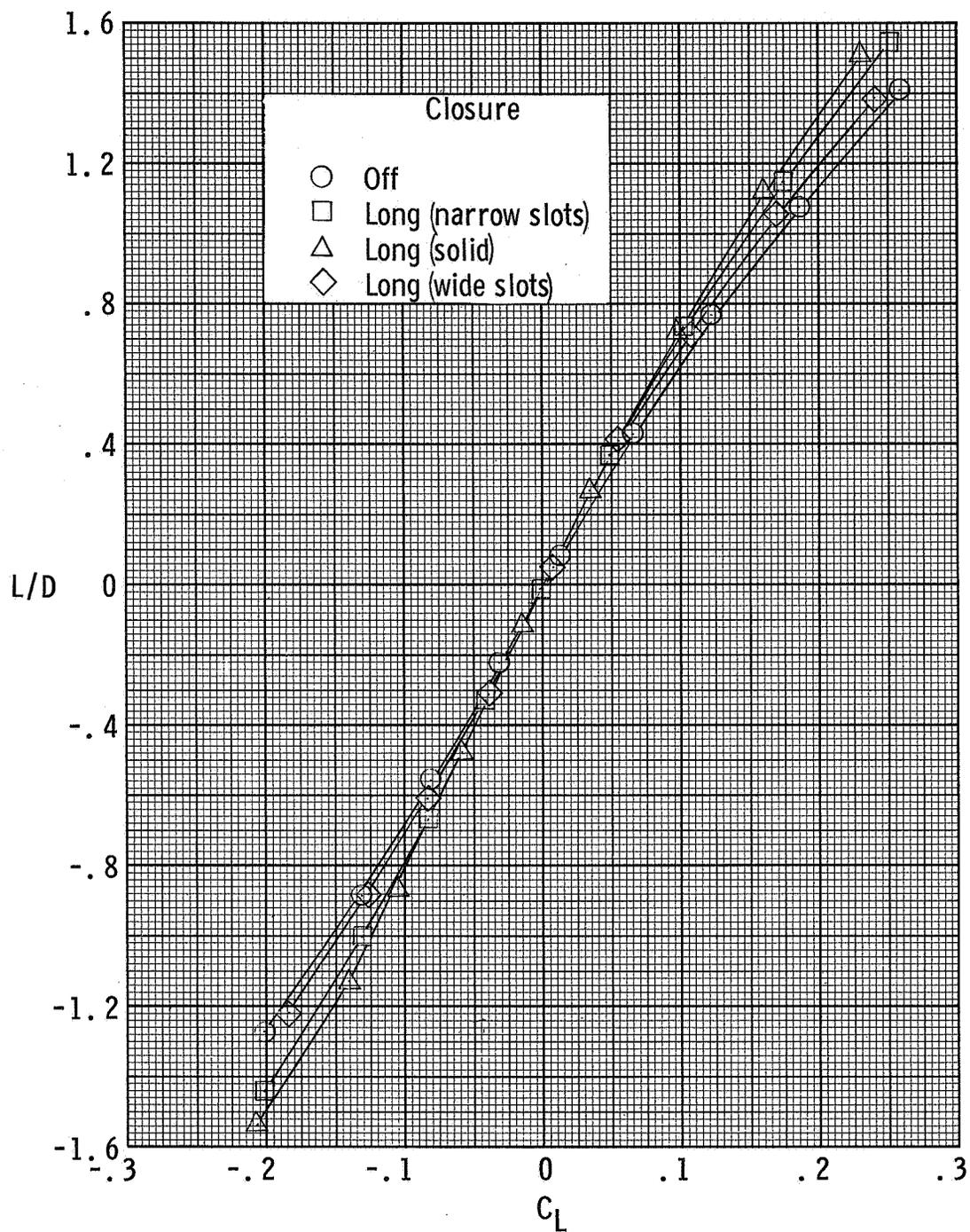
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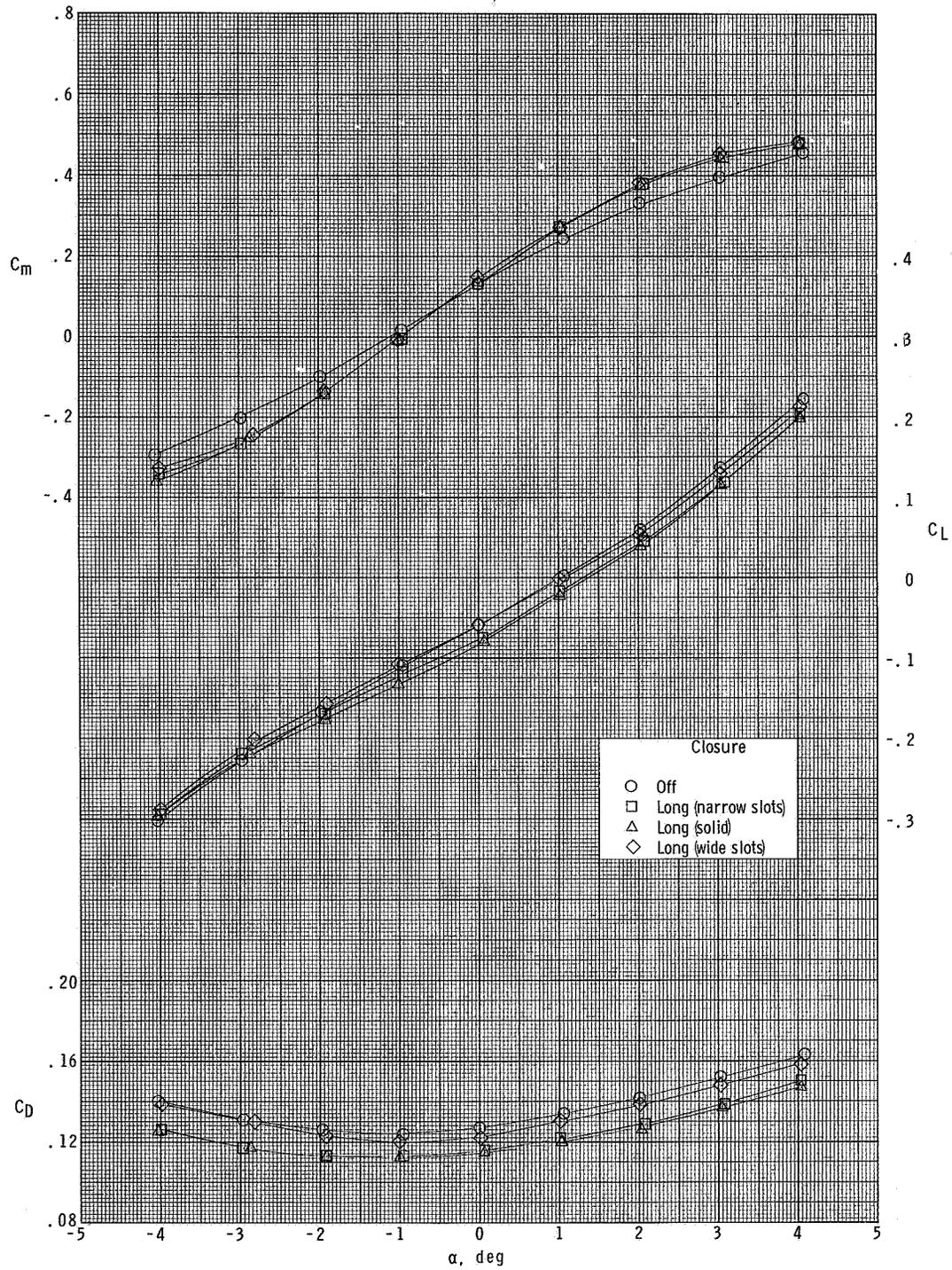
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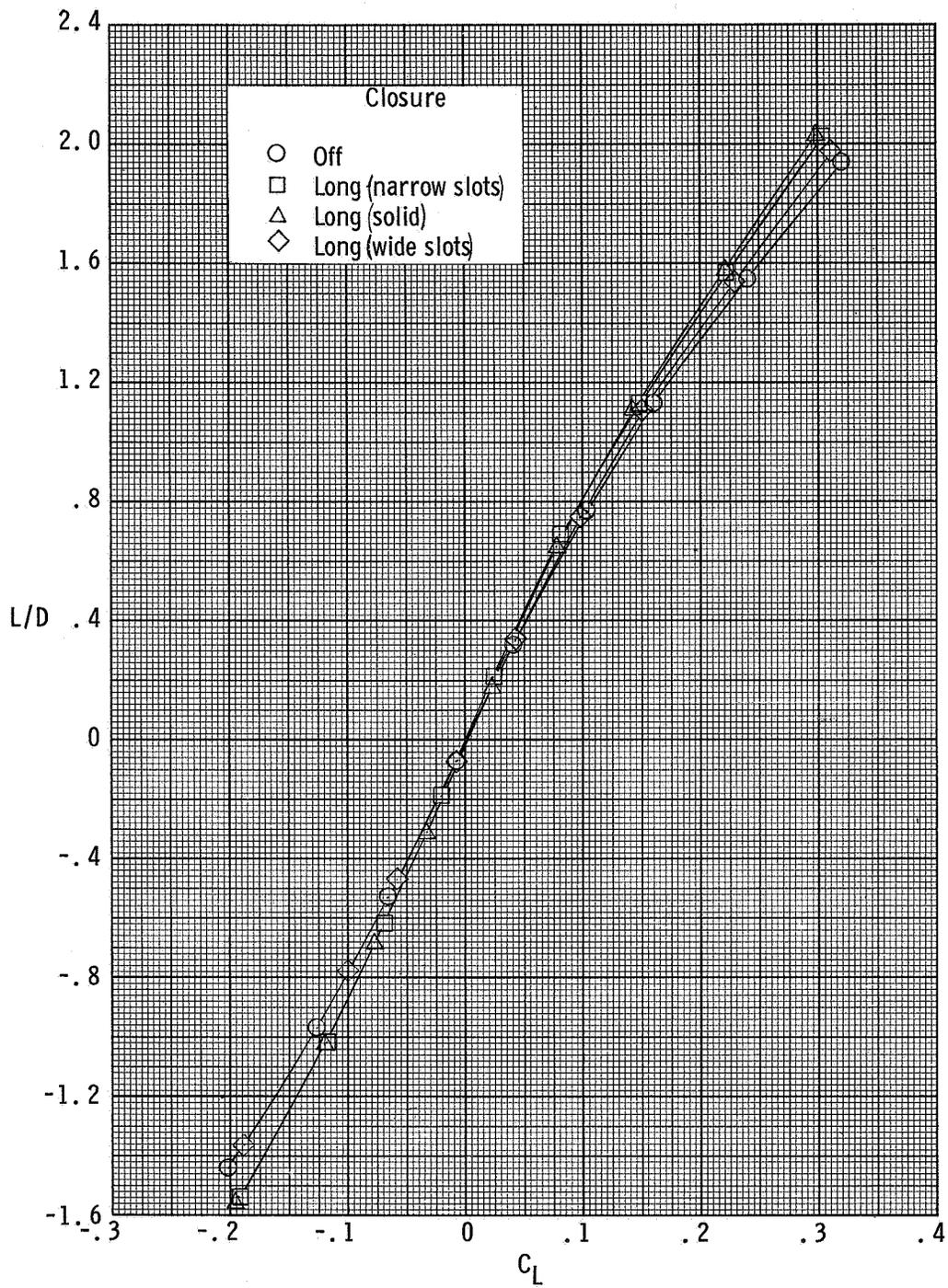
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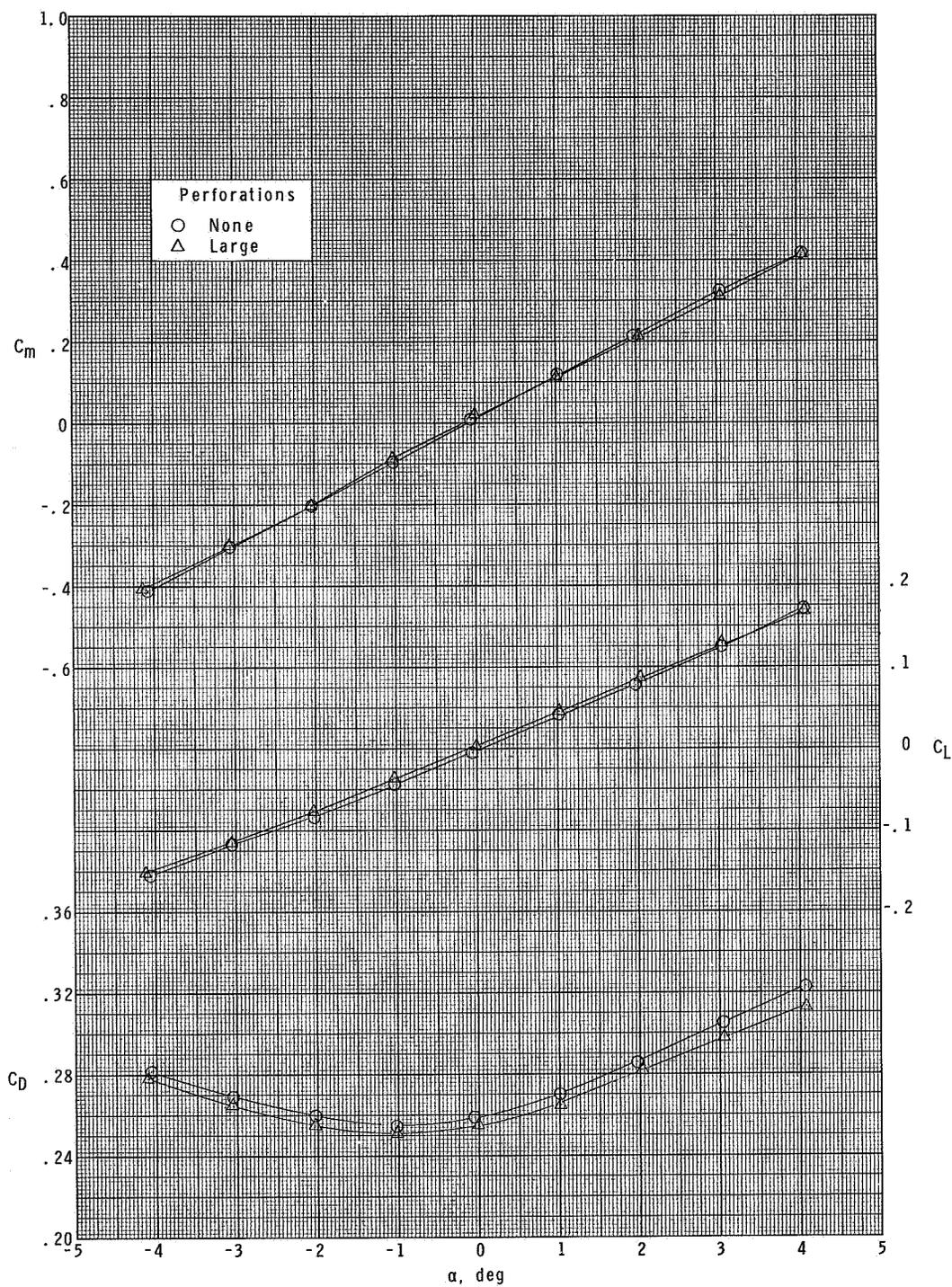
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Figure 6.- Effect of afterbody perforations on longitudinal aerodynamic characteristics.
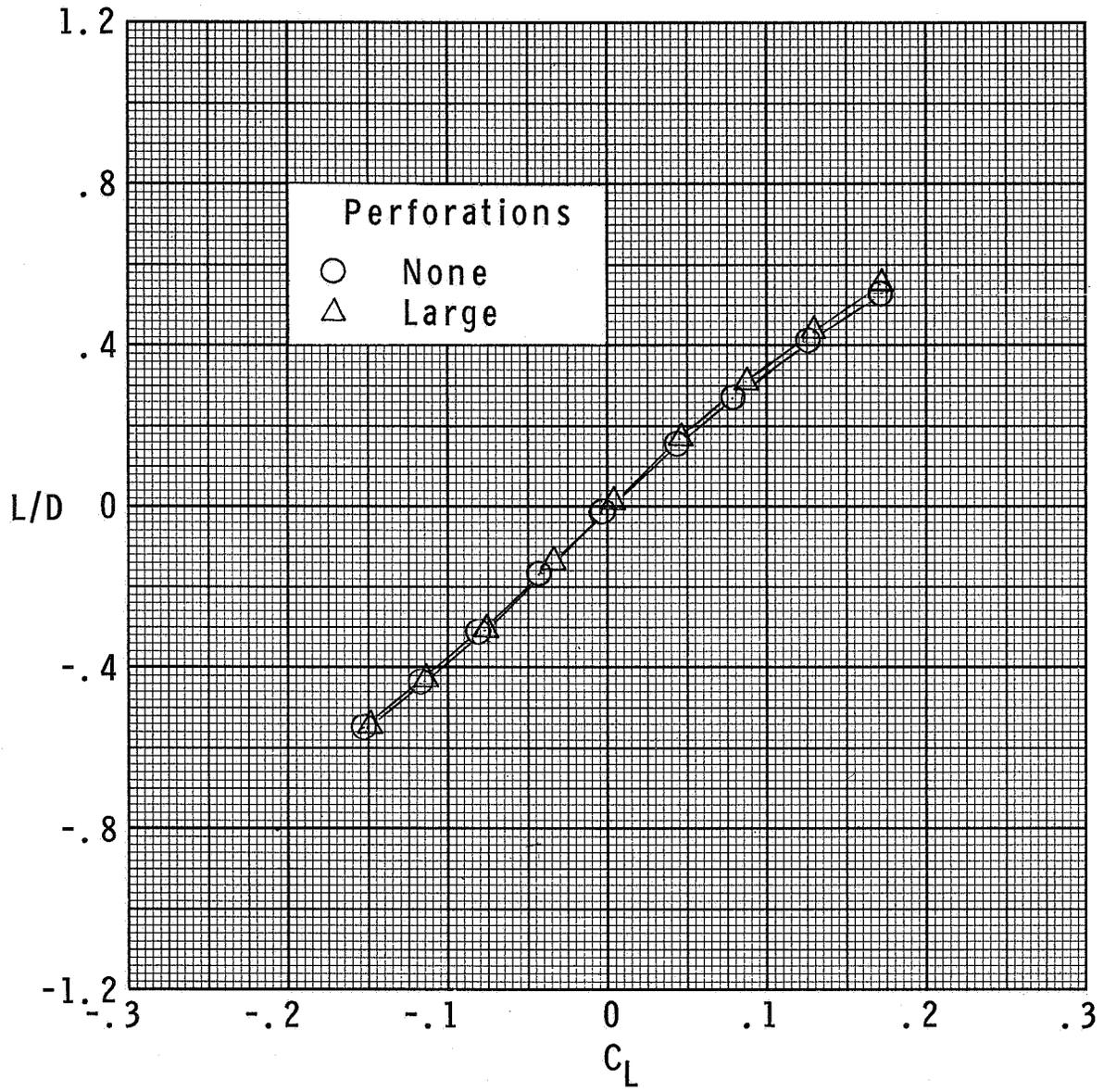
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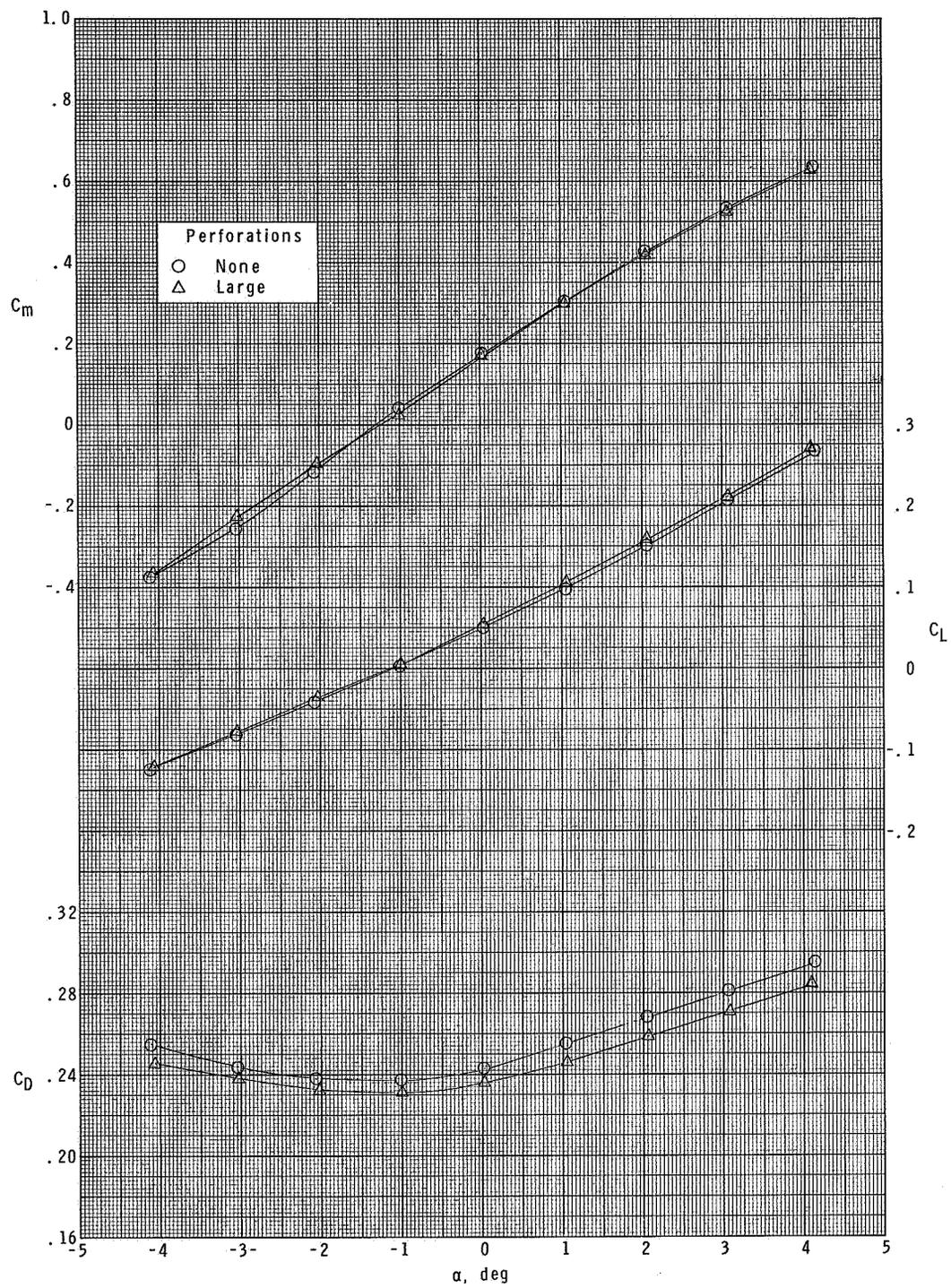
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(b) M = 2.16.

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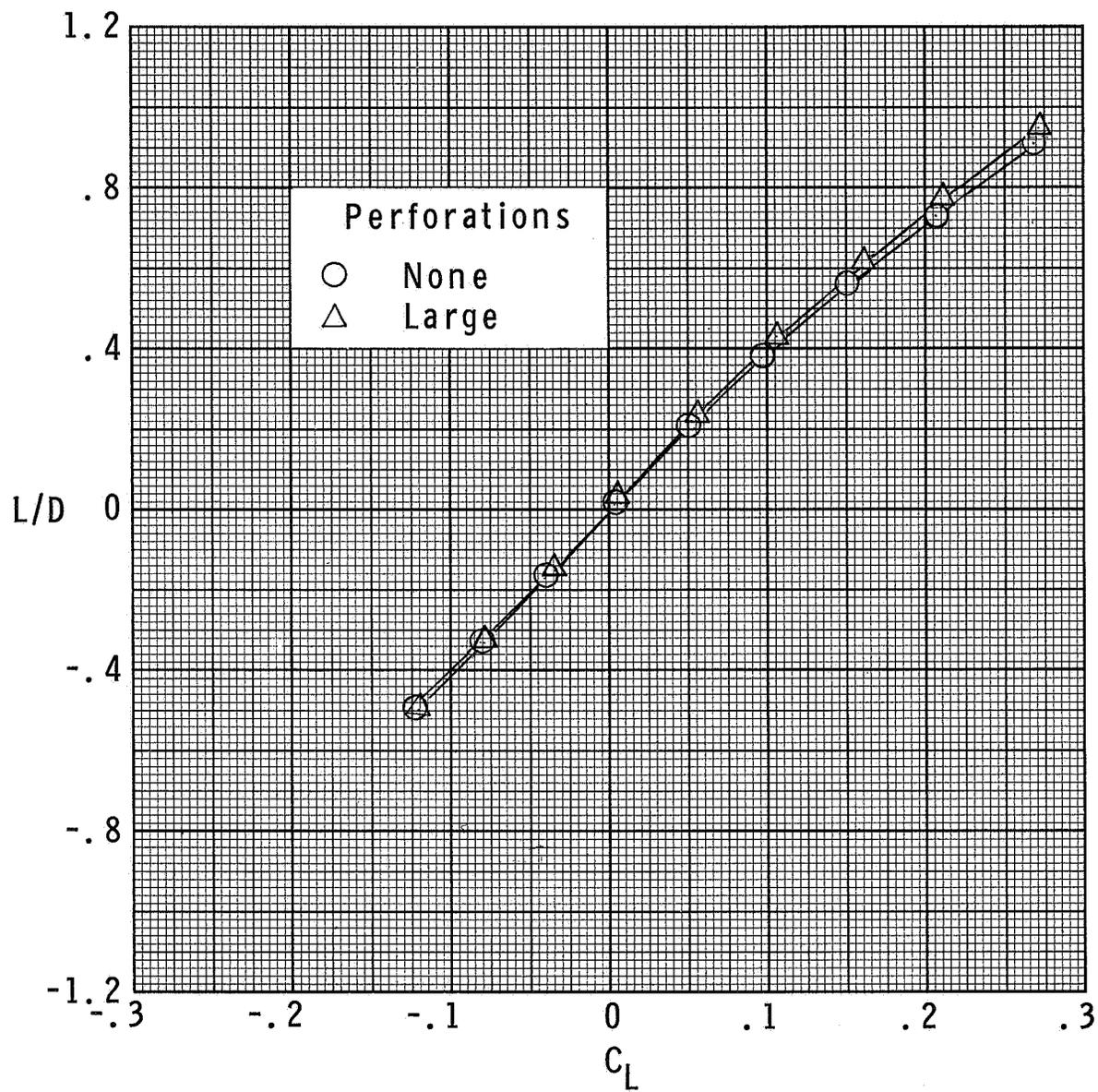
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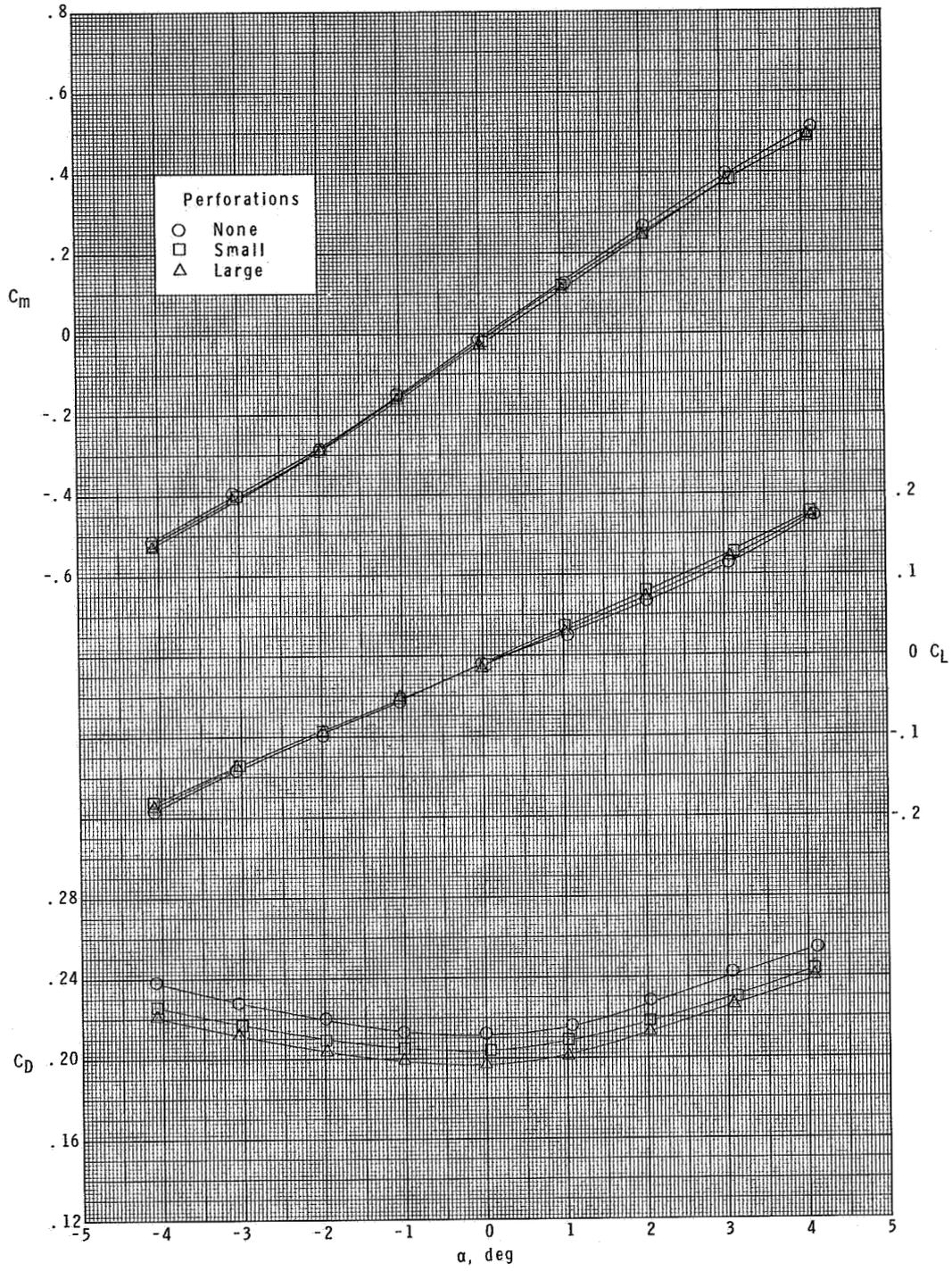
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Figure 6.- Continued.

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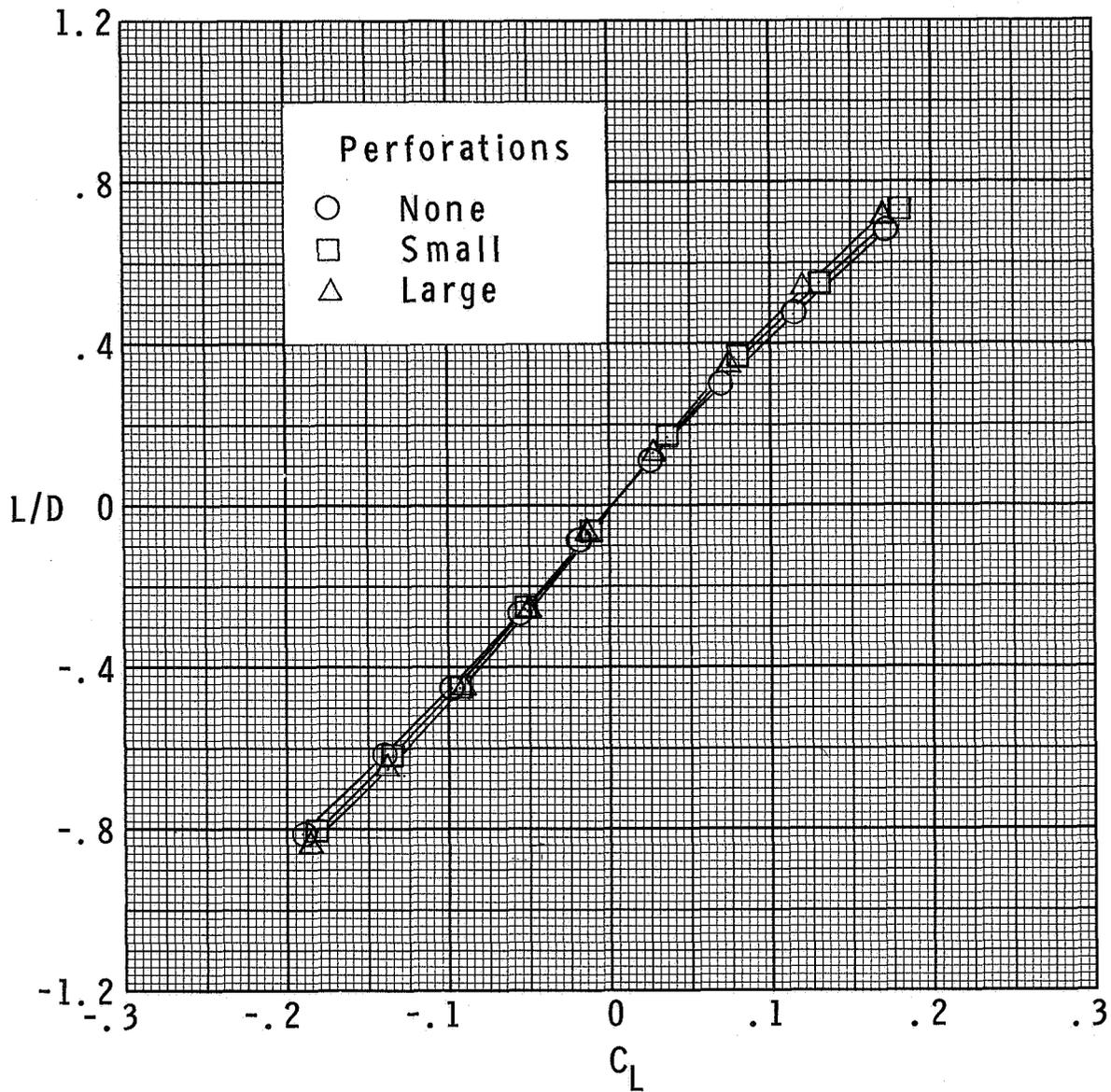
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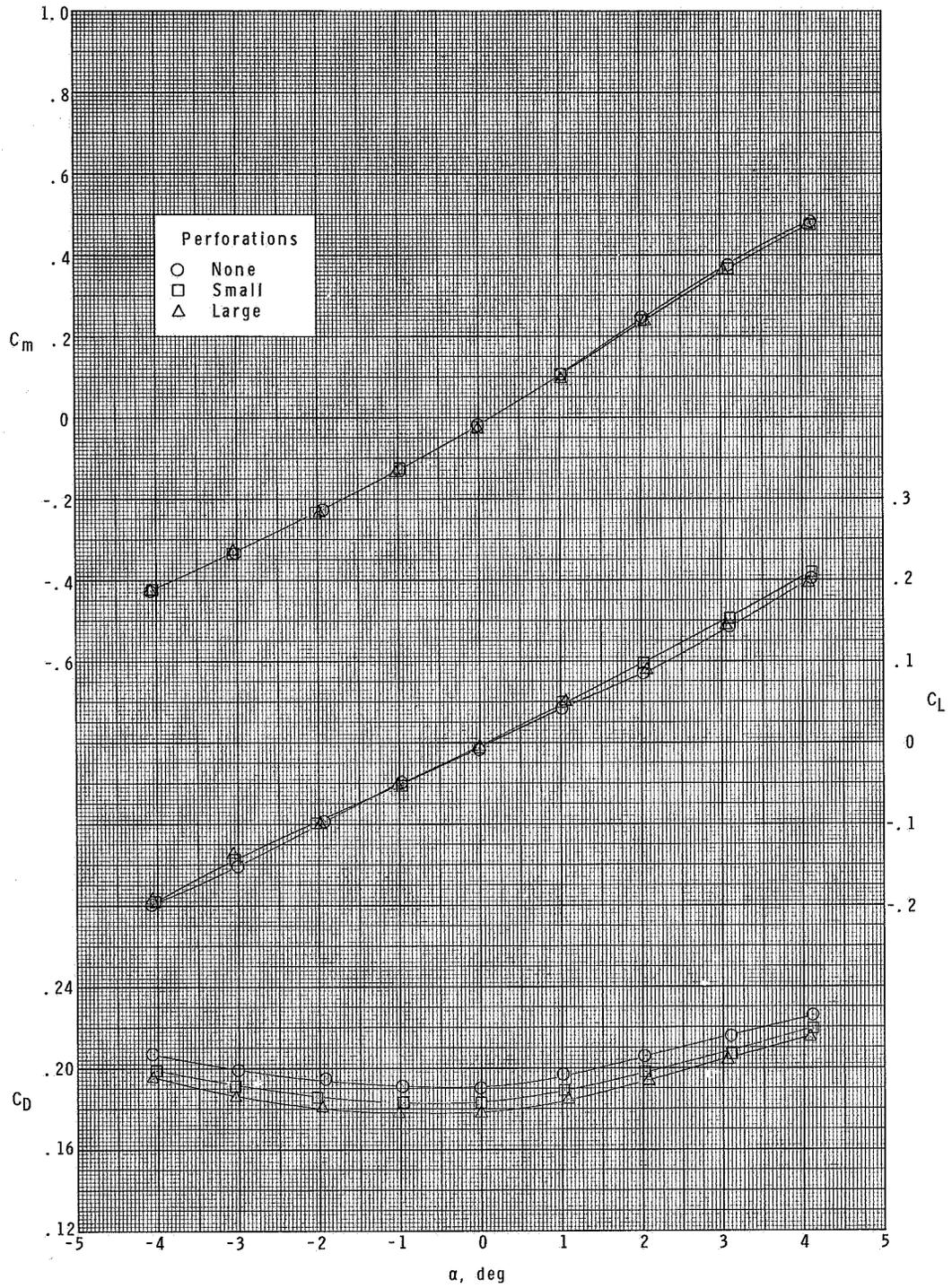
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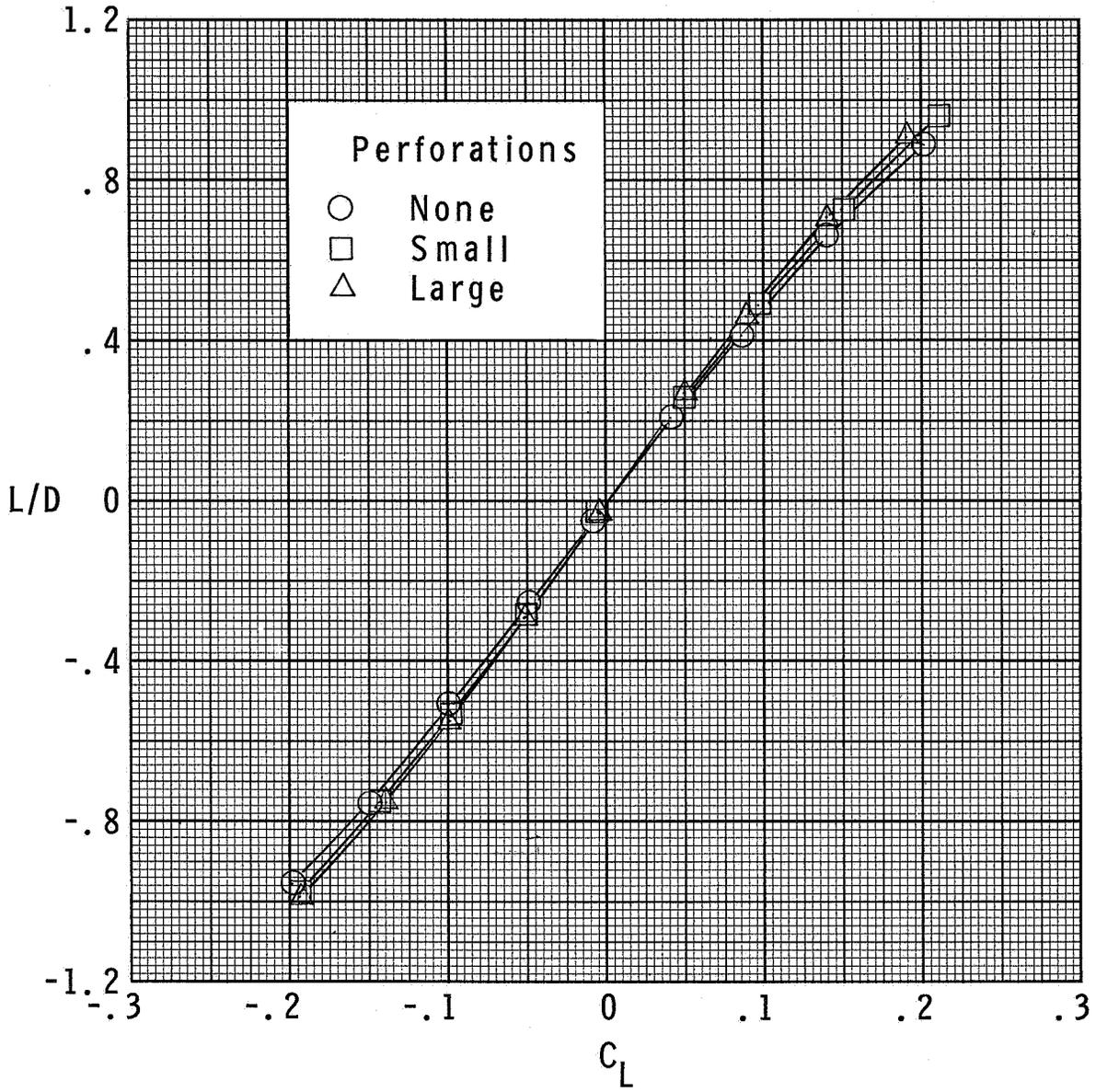
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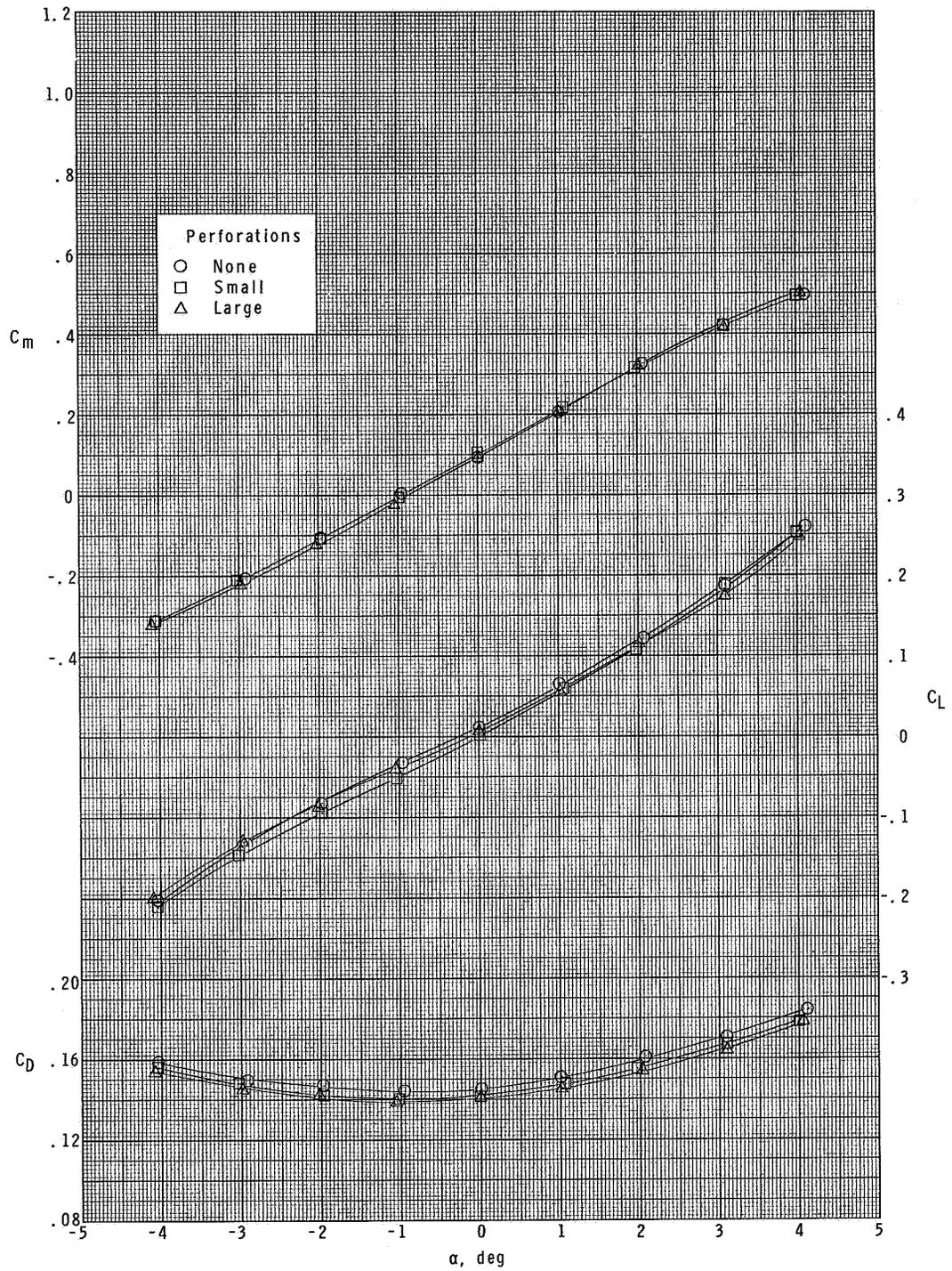
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(e) M = 3.95.

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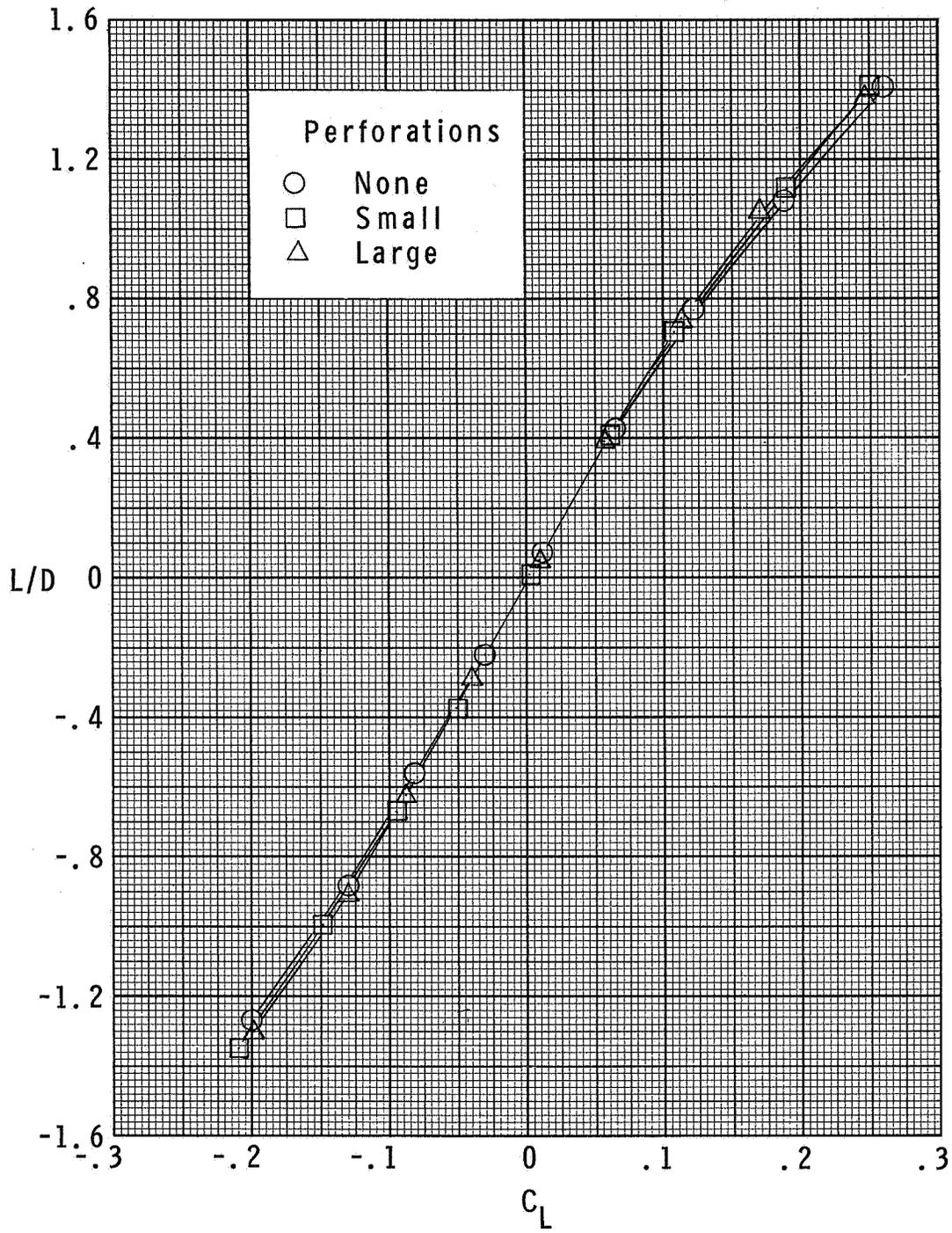
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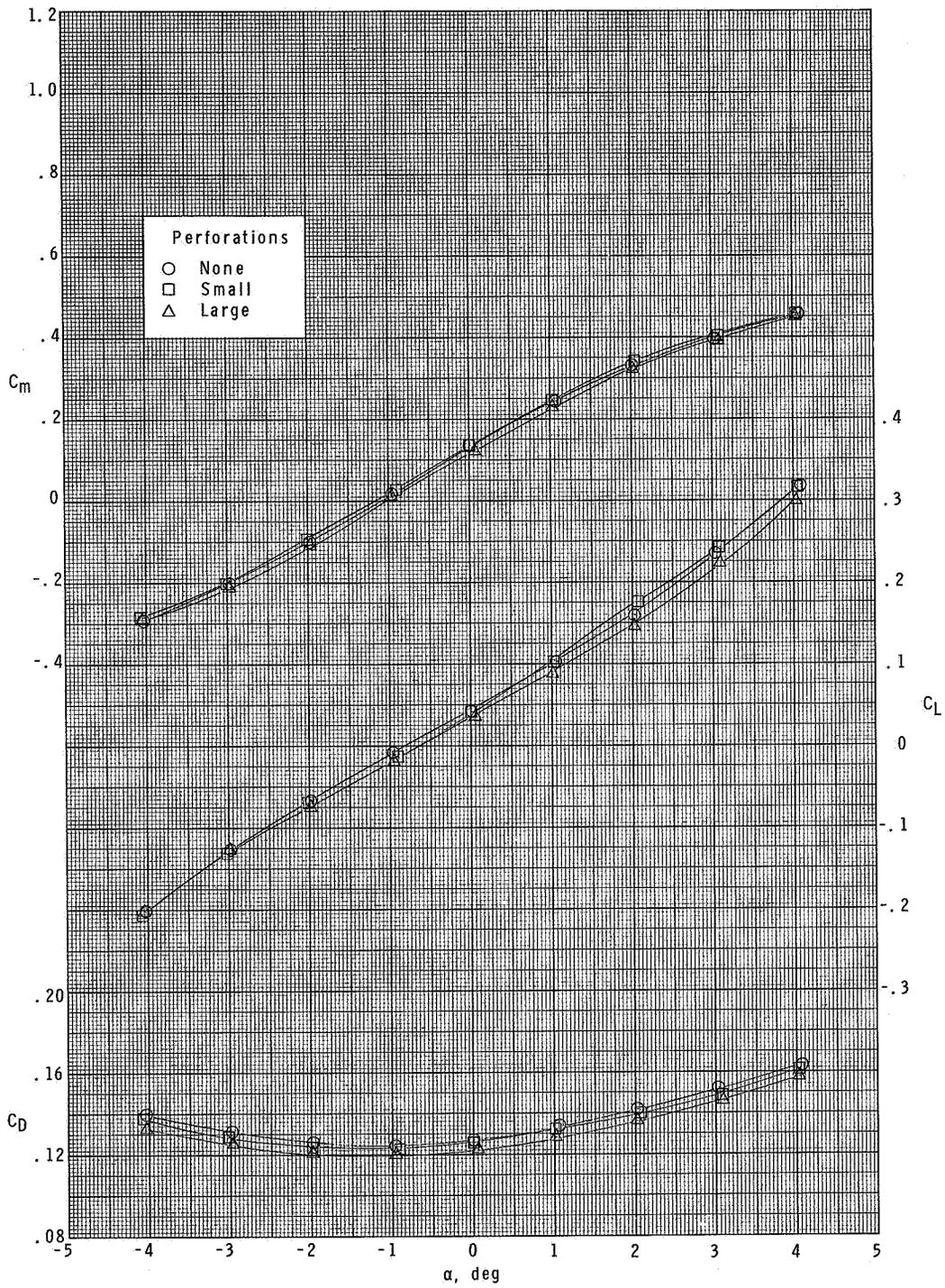
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(f) M = 4.63.

Figure 6.- Continued.
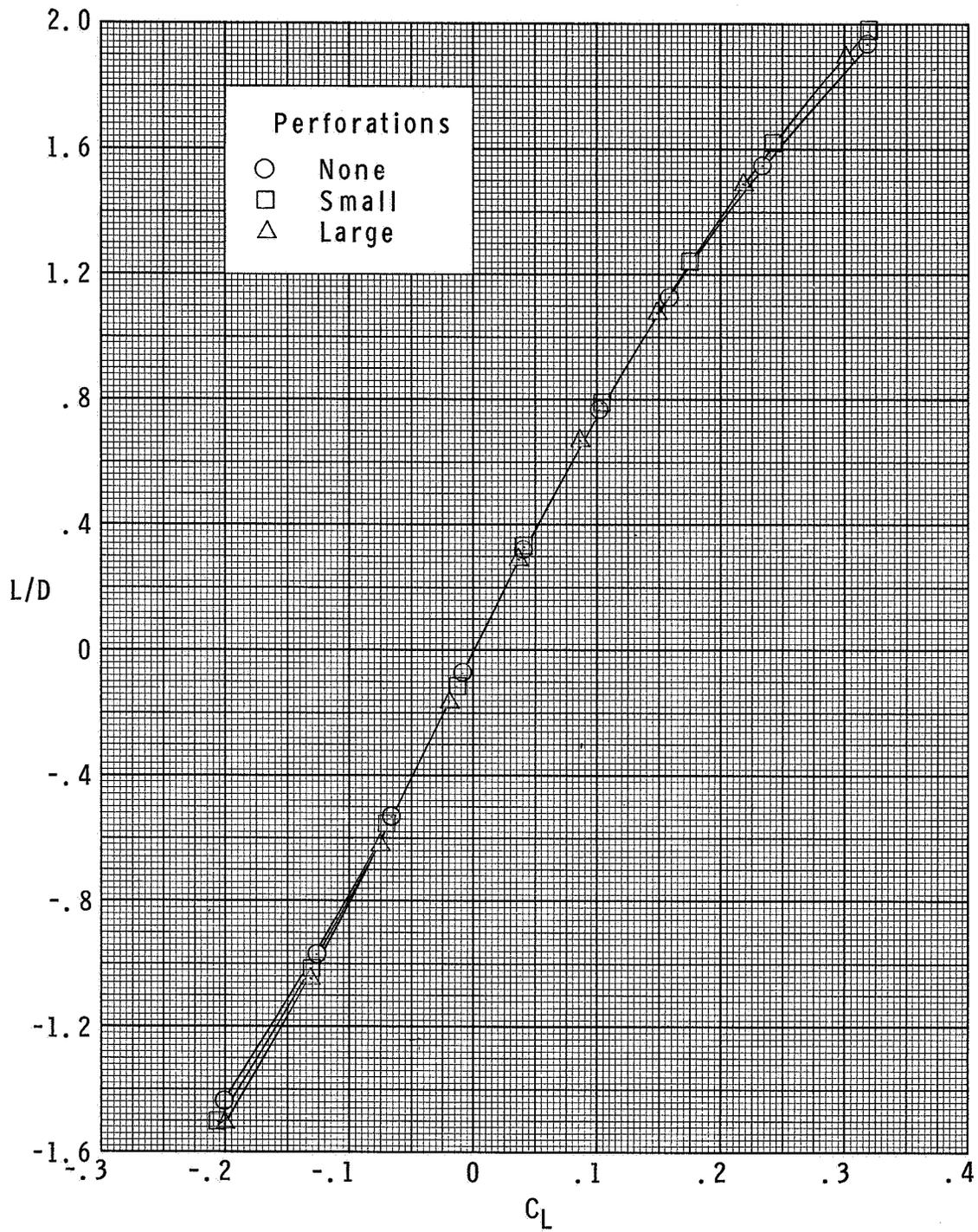
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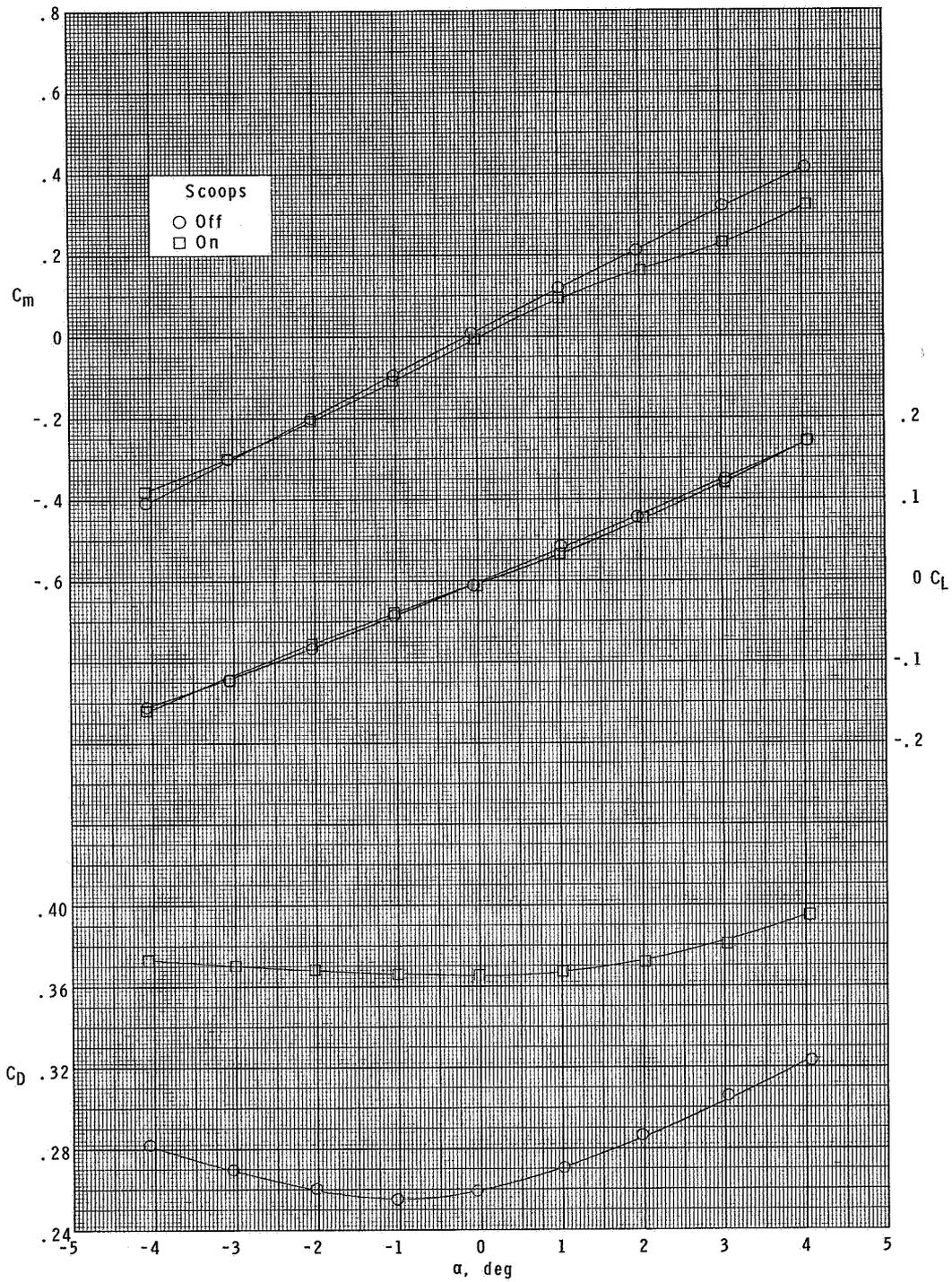
(a) M = 1.57.

Figure 7.- Effect of afterbody scoops on longitudinal aerodynamic characteristics.

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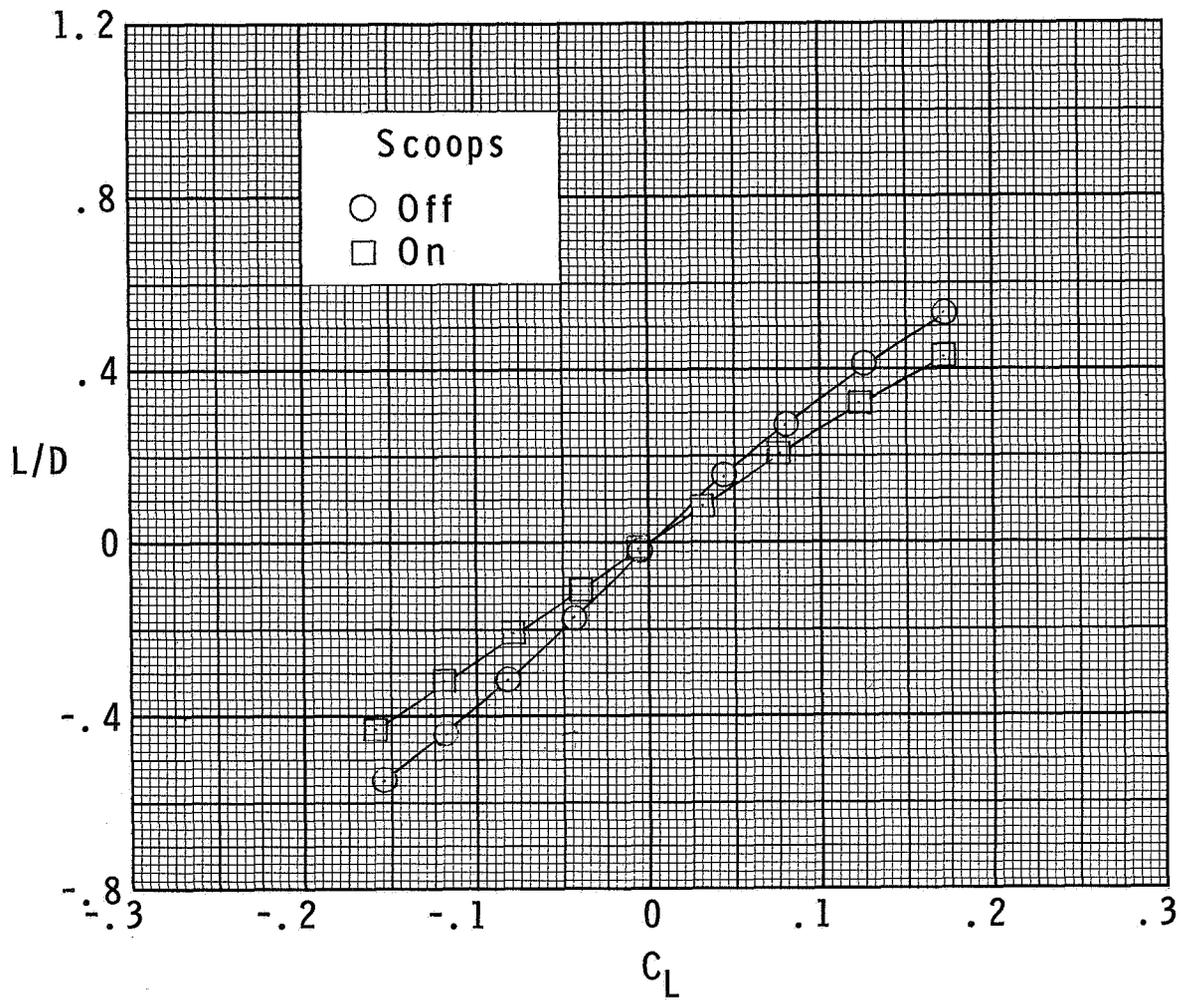
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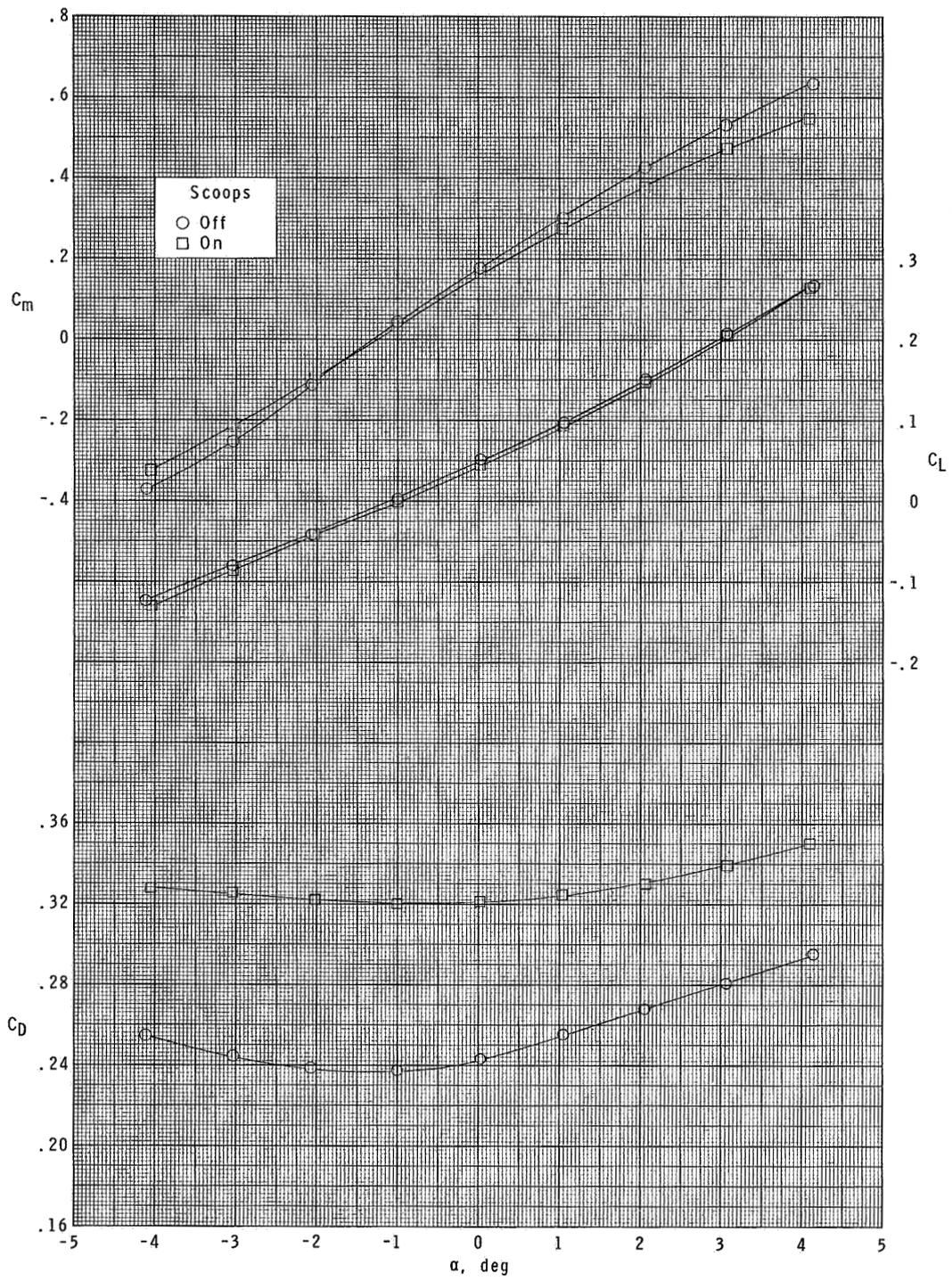
Figure 7.- Continued.

(b) M = 2.16.

Figure 7.- Continued.
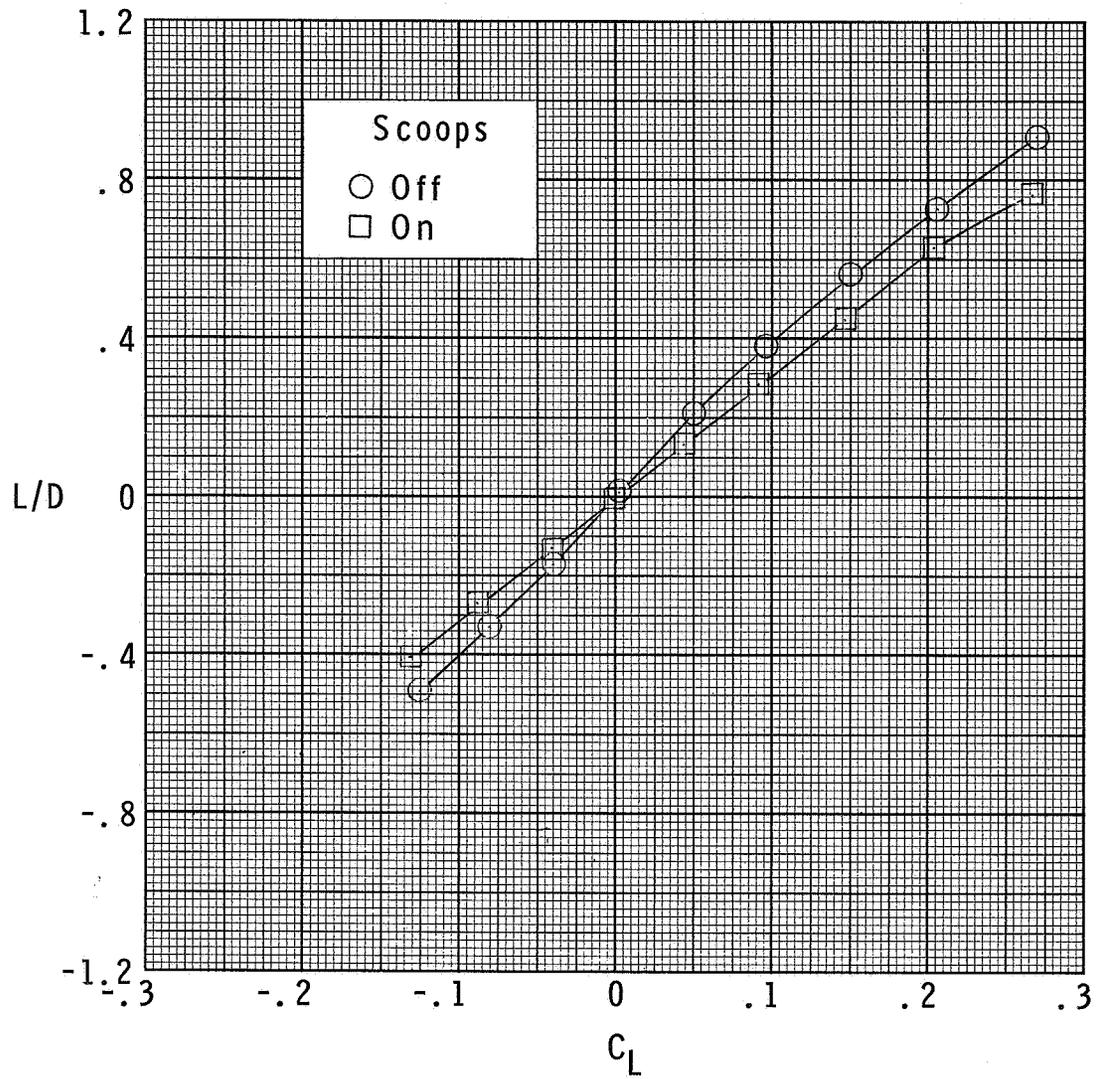
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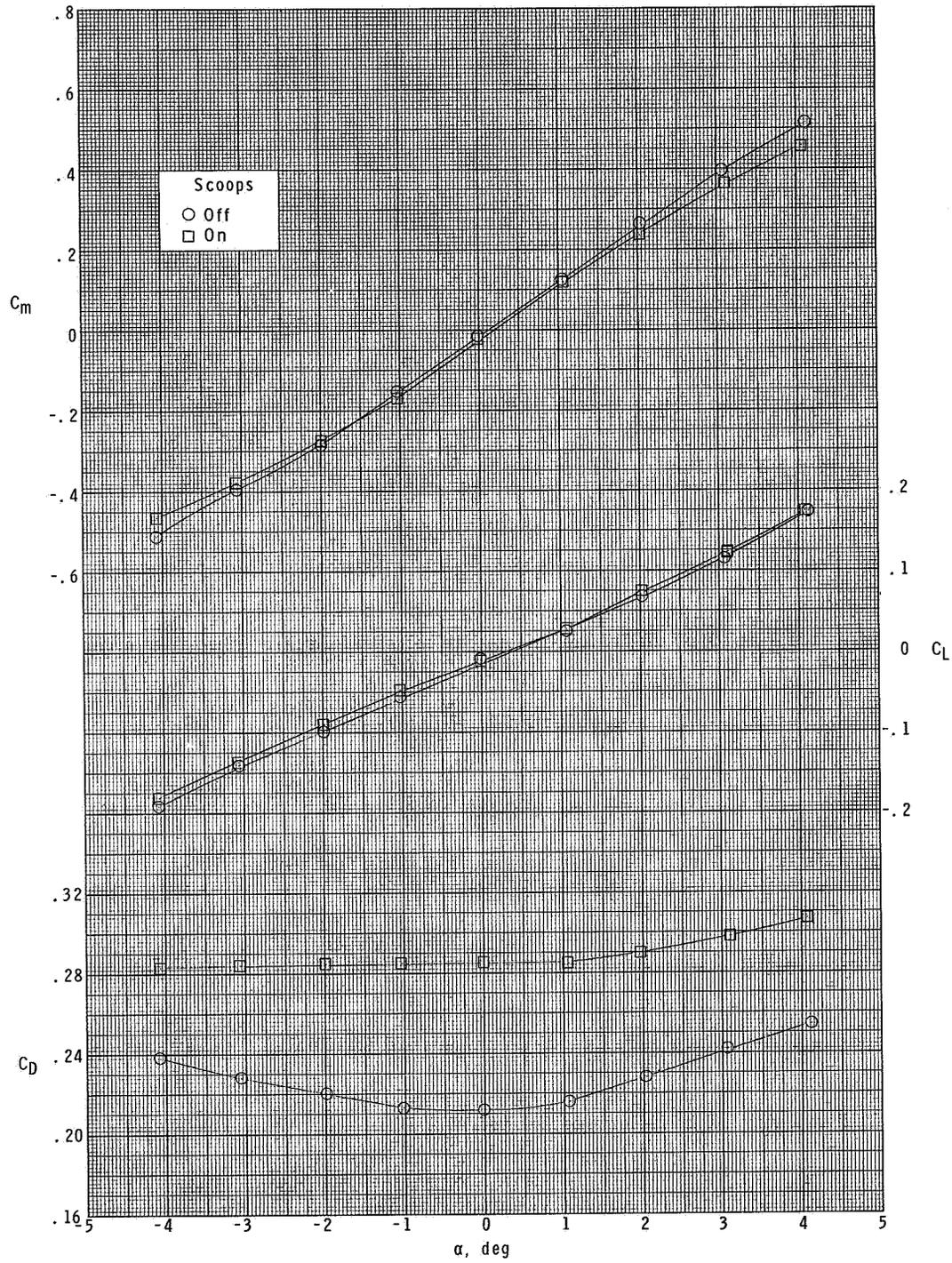
Figure 7.- Continued.

(c) M = 2.50.

Figure 7.- Continued.

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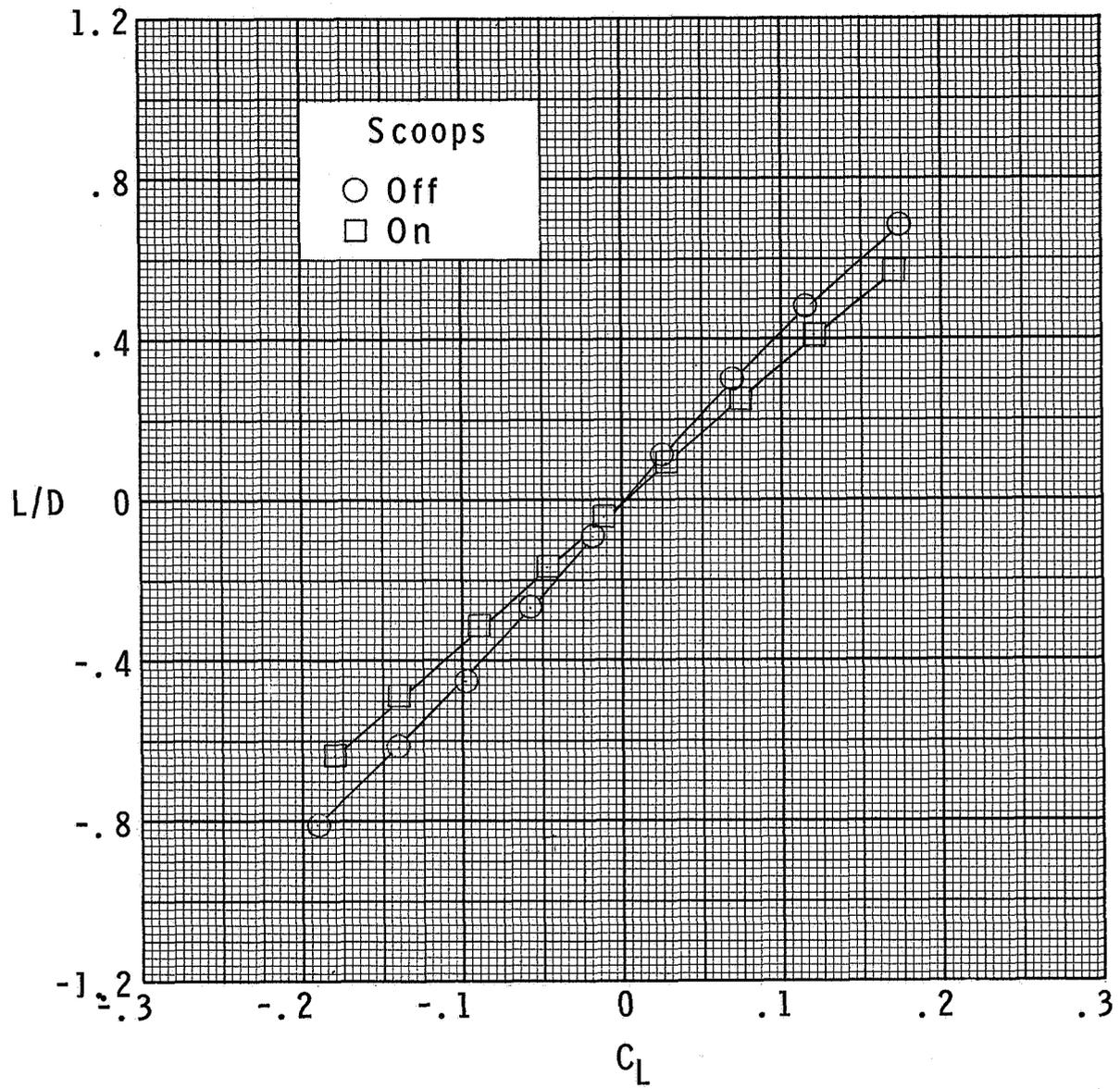
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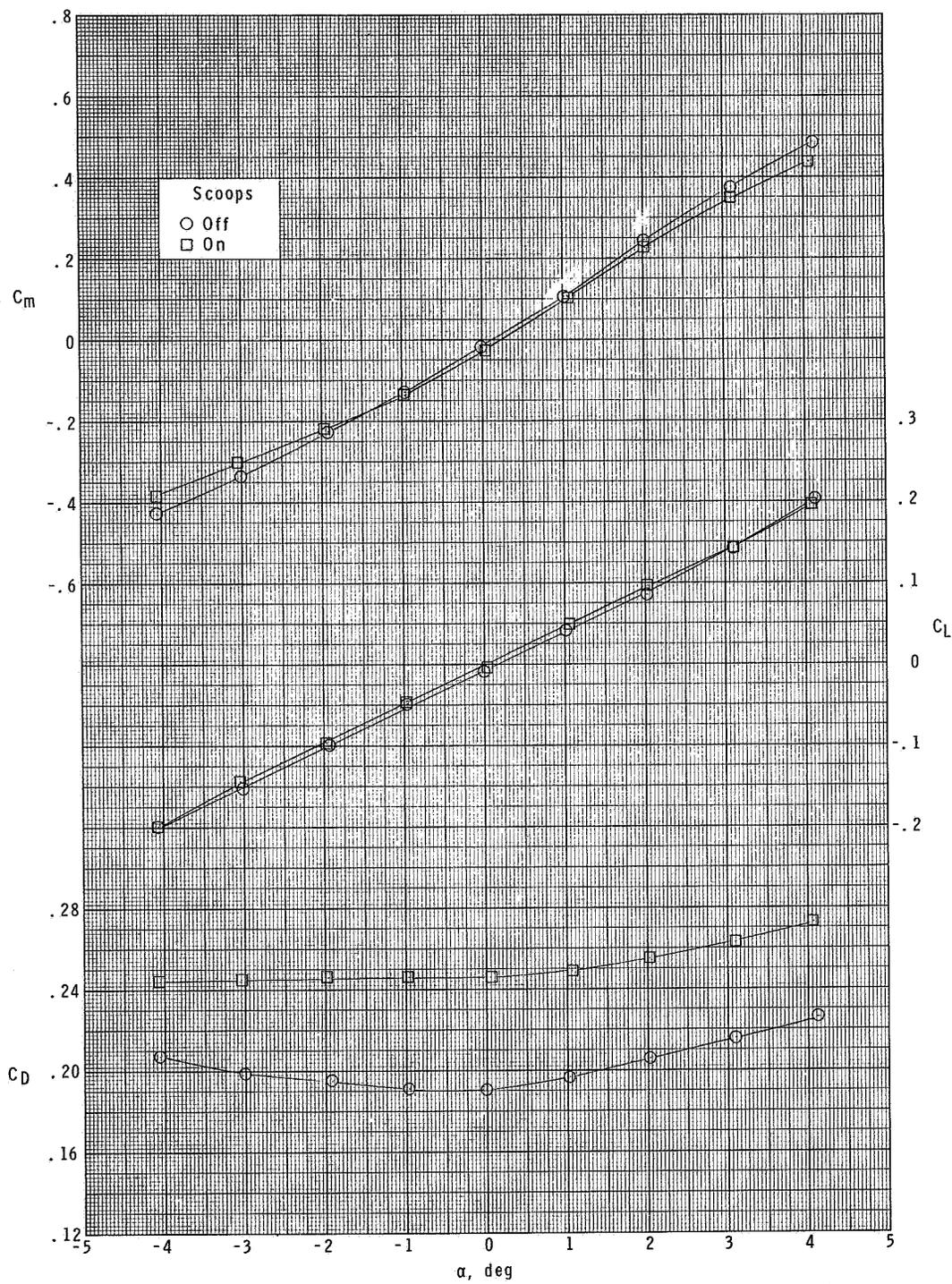
Figure 7.- Continued.

(d) M = 2.96.

Figure 7.- Continued.
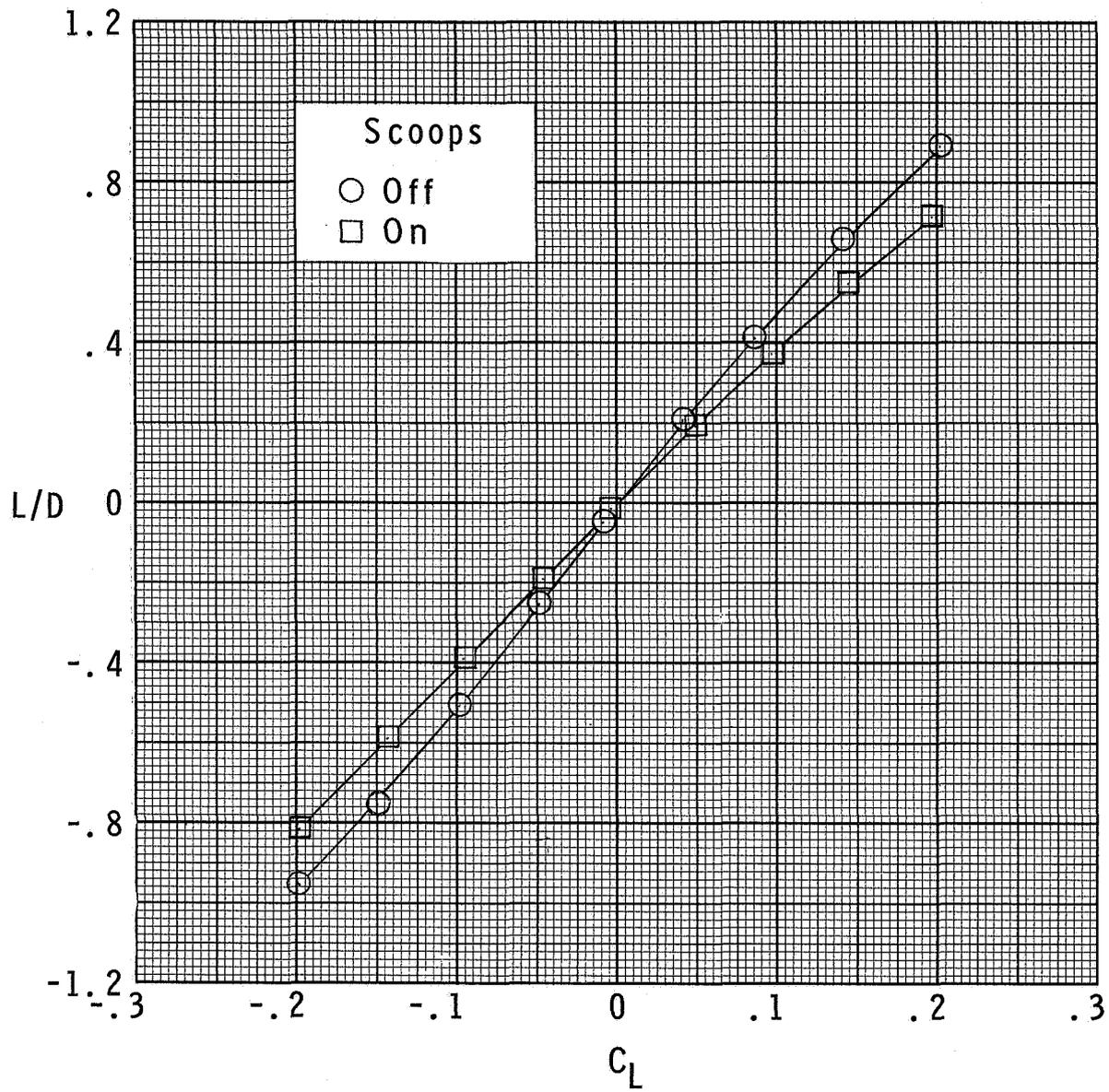
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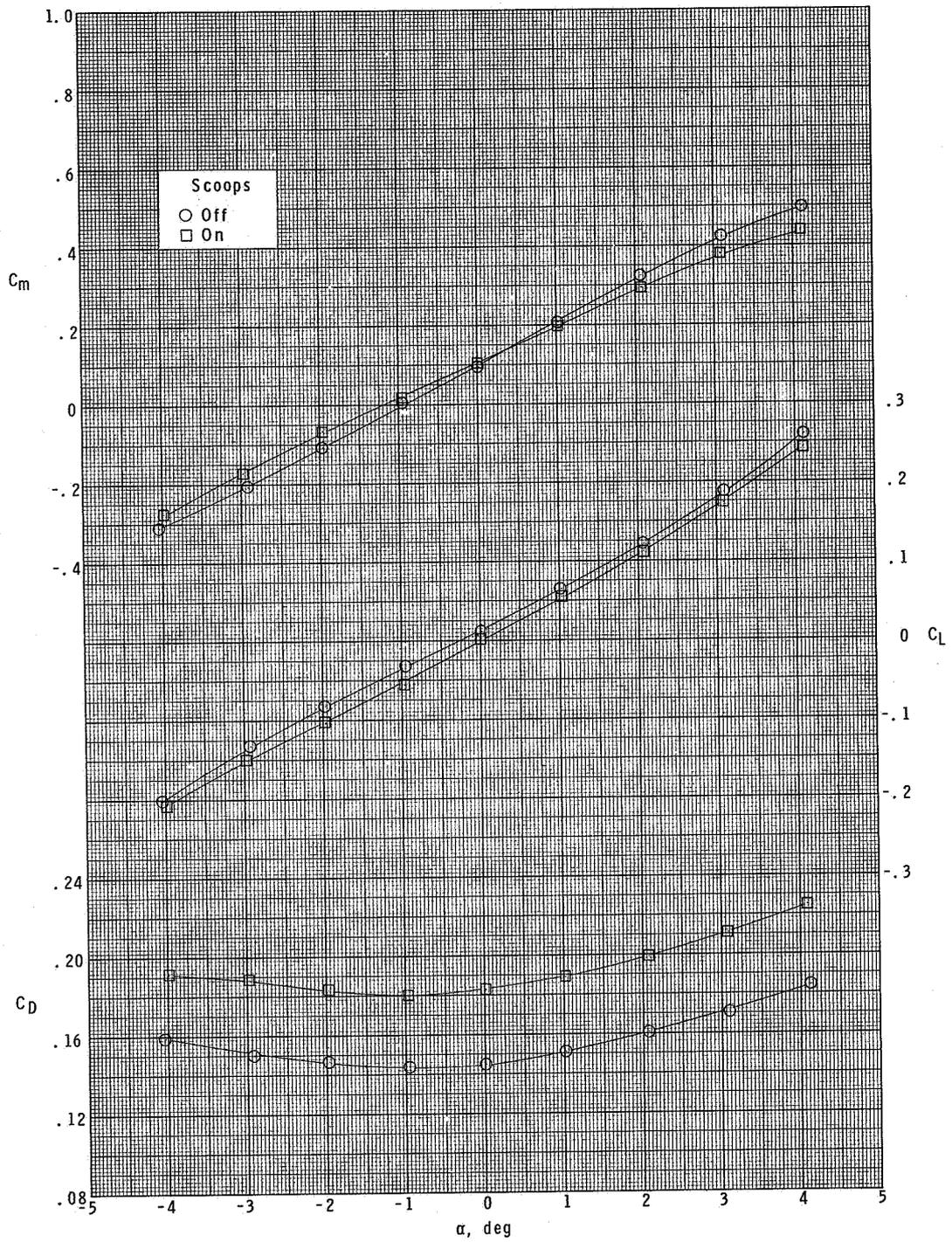
Figure 7.- Continued.

(e) M = 3.95.

Figure 7.- Continued.
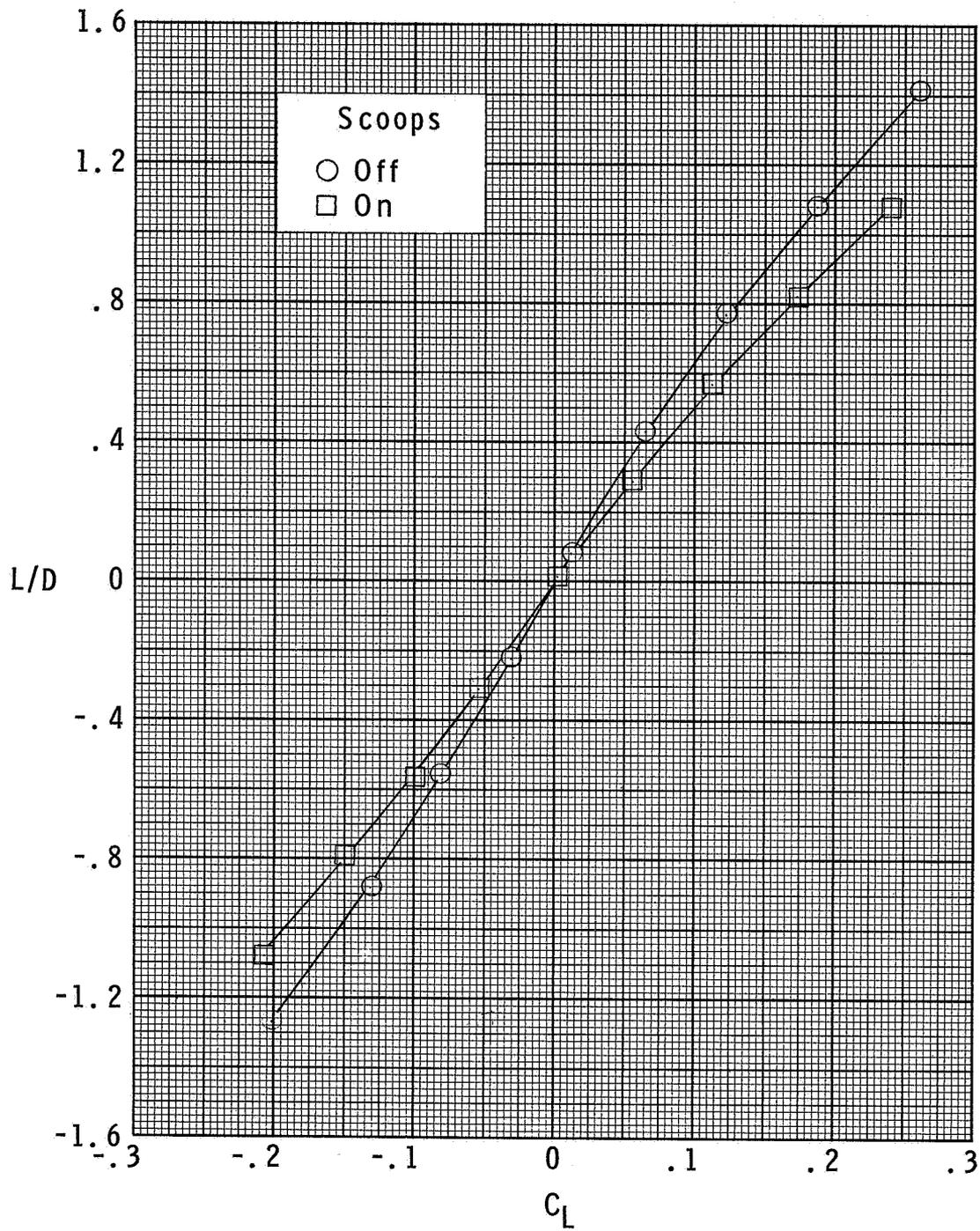
(e) Concluded.
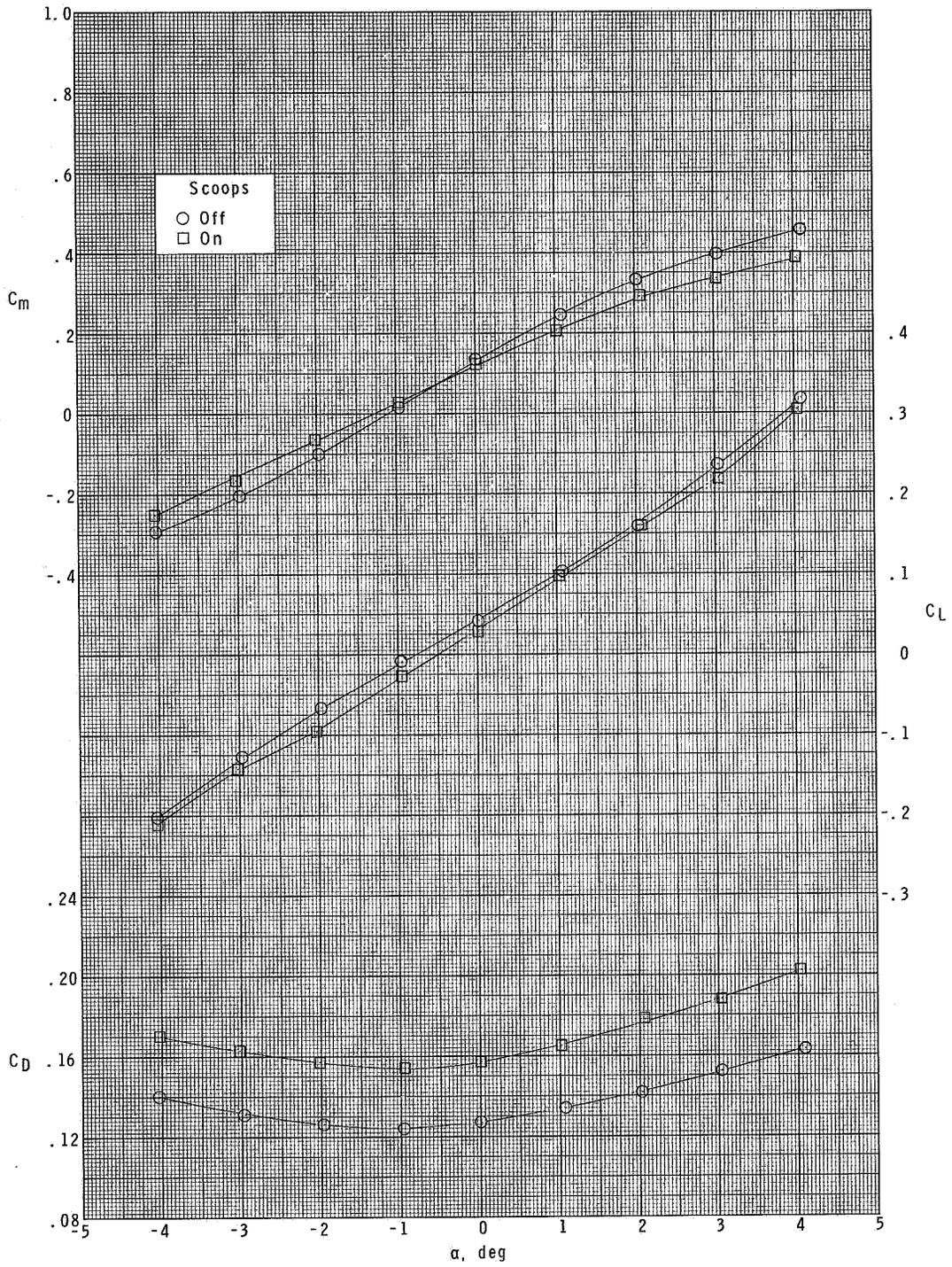
Figure 7.- Continued.

(f) M = 4.63.

Figure 7.- Continued.
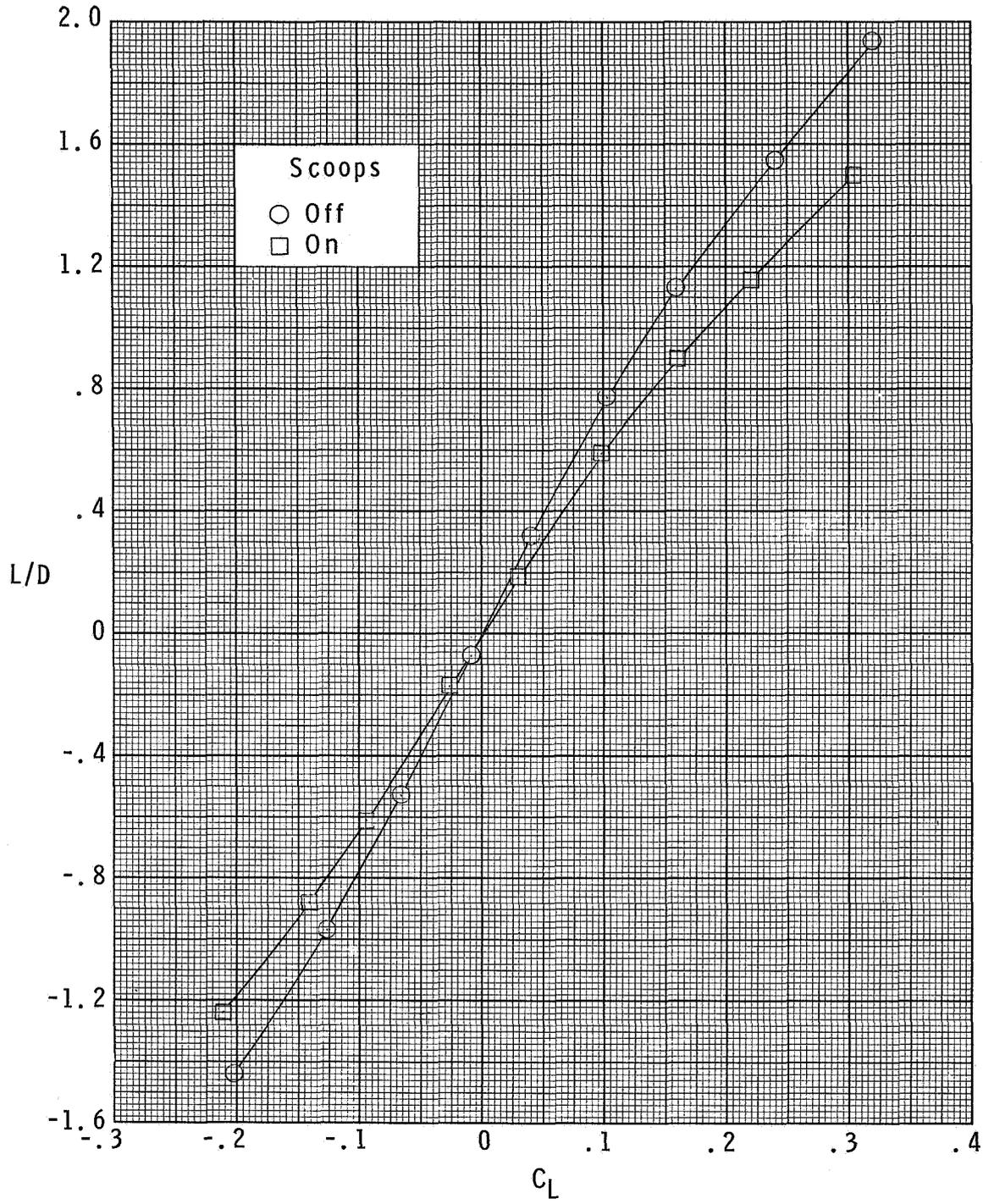
(f) Concluded.

Figure 7.- Concluded.
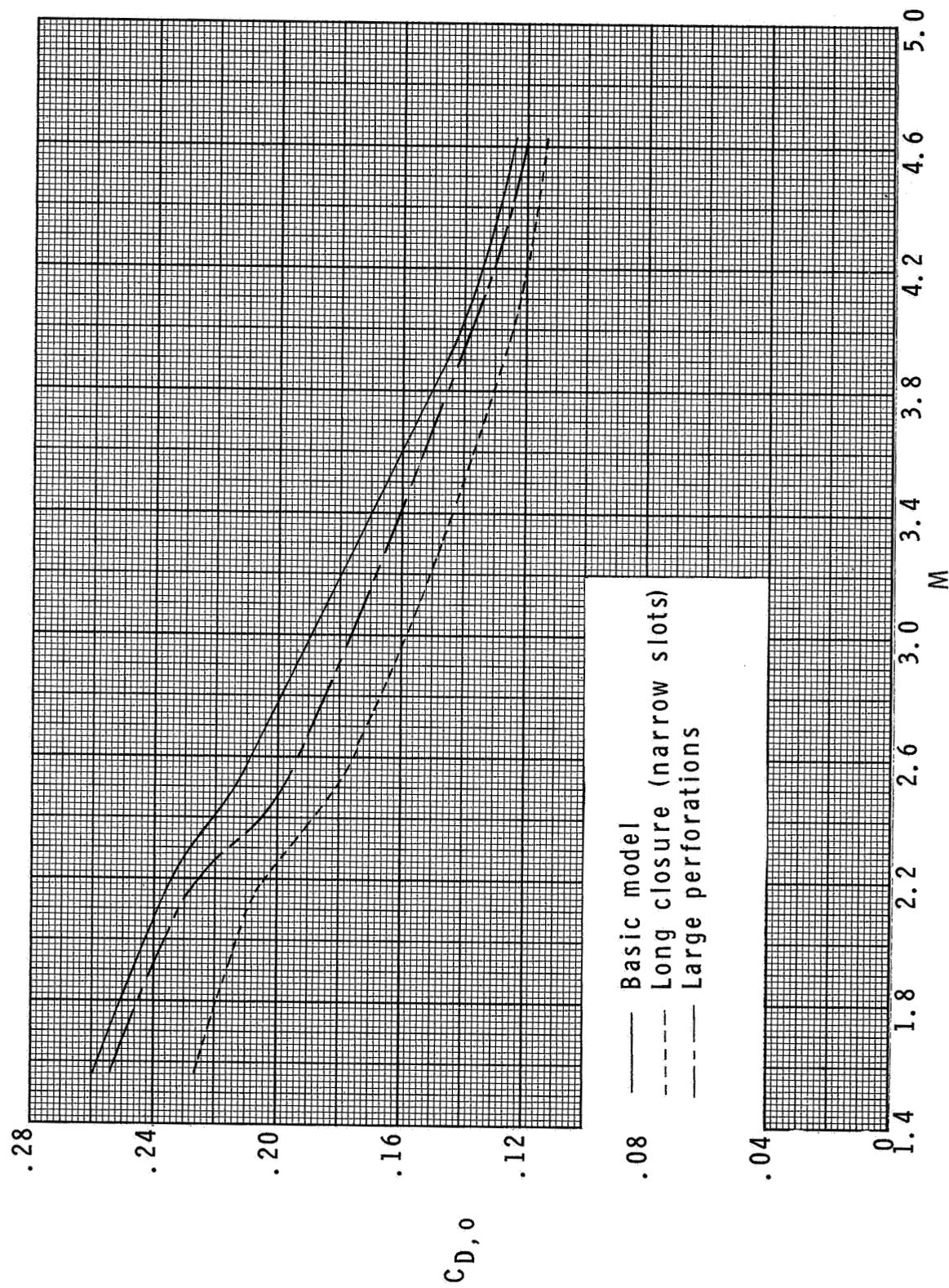
Figure 8.- Effect of afterbody modification on $C_{D,o}$.

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