NASA Technical Memorandum 81791

Effect of Conventional and Square Stores on the Longitudinal Aerodynamic Characteristics of a Fighter Aircraft Model at Supersonic Speeds

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Effect of Conventional and Square Stores on the Longitudinal Aerodynamic Characteristics of a Fighter Aircraft Model at Supersonic Speeds

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and Space Administration

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SUMMARY

An investigation has been conducted to determine the effect of conventional and square stores on the longitudinal aerodynamic characteristics of a fighter aircraft configuration at Mach numbers of 1.6, 1.8, and 2.0. Five conventional-store configurations and six arrangements of a square-store configuration were studied. Tests were conducted for angles of attack ranging from -3° to 20° at a Reynolds number of 6.56×10^{6} per meter.

All configurations of the stores produced small, positive increments in the pitching moment throughout the angle-of-attack range, but the configuration with area-ruled wing tanks also had a slight decrease in stability at the higher angles of attack. There were some small changes in lift coefficient because of the addition of the stores, causing the drag increment to vary with lift coefficient (C_L) above $C_L \approx 0.25$. As a result, there were corresponding changes in the increments of the maximum lift-drag ratios. The store-drag coefficient based on the cross-sectional area of the stores ranged from a maximum of 1.1 for the configuration with three Maverick missiles to a minimum of about 0.40 for the two MK-84 bombs and the arrangements with four square stores touching or two square stores in tandem. Square stores located side by side yielded, (at a Mach number of 1.6), about 0.50 in the aft position compared to 0.74 in the forward position.

INTRODUCTION

The National Aeronautics and Space Administration (NASA) has maintained a continuing research program in missile aerodynamics. In an effort to focus the program on areas of interest and to provide support to industry and the Department of Defense (DOD), NASA initiated a study on carriage effects of stores mounted externally on fighter aircraft configurations at supersonic speeds. The investigation was conducted using a model of a General Dynamics F-16A fighter utilizing three types of store configurations: conventional (circular), elliptical, and square cross sections. Test results for the tangentially mounted elliptical stores were reported in reference 1, which also evaluated the wave-drag prediction methods. Results for the conventional and square stores are presented in this paper.

The results presented herein are based on a slightly modified version of the F-16A model of reference 1. Six arrangements of conventional-store configurations and six arrangements of the square-store configuration were utilized with this model. The conventional stores represented bombs, missiles, wing tanks, and electronic countermeasures (ECM) pod. The square store represented an air-to-ground missile having a deployable wing and folding tails and was tested in the following tangent-mount arrangements: two tandem, two forward (side by side), two aft, four touching (with and without a nose fairing), and four with lateral separation. The tests were conducted at Mach numbers ranging from 1.6 to 2.0 with a Reynolds number of 6.56×10^6 per meter and an angle-of-attack range of -3° to 20°.

SYMBOLS

The force and moment coefficients are referenced to the stability axis system. The moment reference point is located at fuselage station 54.298 cm which corresponds to $0.35\bar{c}$. Measurements and calculations were made in U.S. Customary Units and were converted to the International System of Units (SI) for the report by using factors found in reference 2.

A_s	maximum cross-sectional area of store, cm^2
AR	aspect ratio
b	wing span, cm
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
$C_{D,o}$	drag coefficient at zero lift
$\Delta C_{D,o}$	difference in zero-lift drag coefficient with and without store
$C_{D,s}$	effective store-drag coefficient based on frontal area, $(\Delta C_{D,o})\frac{S}{N \cdot A_s}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$\bar{c}$	wing mean geometric chord, cm
L/D	lift-drag ratio
M	free-stream Mach number
N	number of stores
q	free-stream dynamic pressure, Pa
S	reference area of wing including fuselage intercept, cm^2

Sta longitudinal distance from nose along centerline of store, positive rearward, cm

w width of body of square store, cm

x longitudinal distance, cm

y lateral distance, cm

z vertical distance, cm

α angle of attack, deg

Γ dihedral angle, deg

Λ leading-edge sweep angle, deg

DESCRIPTION OF MODEL

A three-view drawing of the 1/15-scale model is shown in figure 1, and the stores and installations are shown in figures 2 to 7. The fighter aircraft configuration was a model of the General Dynamics F-16A modified by the addition to the fuselage of lower surface fairings, which provide a flatter surface more suitable for some types of store installations, and by the addition of wheel fairings under the wings at the body junction. The model otherwise consisted of the same components as the unmodified configuration of reference 1 which represented a fuselage with a single engine, a clipped delta wing with leading-edge extension, a horizontal tail, a vertical tail, and wing-tip mounted AIM-9J Sidewinder missiles. Ventral fins were omitted, as in reference 1, from the configurations having square stores; but, they were retained for the configurations employing conventional stores. Geometric characteristics of the aircraft model are presented in table I.

A series of six square-store arrangements and six conventional-store arrangements were tested. The square store (fig. 2) represented a conceptual guided weapon with deployable wing and folding tails and was tested in the following arrangements: (a) forward pair touching, (b) aft pair touching, (c) four touching, (d) four touching with nose fairing, (e) four with lateral separation, and (f) tandem pair on body centerline. The conventional-store test configurations were two MK-84 low drag bombs, two area-ruled wing tanks, three Maverick missiles, a conceptual FLIR/ECM (forward looking infrared radar/electronic countermeasures) pod, and two or three modified SUU-51 dispenser stores. Pylon mounting was used for the Maverick missiles, the SUU-51 stores, and the area-ruled wing tanks. Tangent mounting was used for all other stores.

TESTS AND CONDITIONS

The tests were conducted in the Langley Unitary Plan Wind Tunnel at the following conditions:

Mach number	Reynolds number per meter	Stagnation pressure, kPa	Stagnation temperature, K
1.60	6.56×10^6	54.63	339
1.80	6.56	58.46	339
2.00	6.56	63.54	339

The dew point was maintained sufficiently low to prevent measurable condensation effects in the test section. Sized by the method of reference 3, boundary-layer transition strips of No. 60 grit were cemented to the model in 0.16-cm-wide strips at 3.05 cm aft of the body nose and 1.02 cm streamwise from the leading edges of the wings, tails, ventral fins, and external inlet surface. Tests were made over an angle-of-attack range of -3° to 20°.

Aerodynamic forces and moments were measured by means of a six-component strain-gage balance which was housed within the model. The balance was attached to a sting which, in turn, was rigidly fastened to the model support system of the tunnel. Static pressures in the balance chamber were measured with pressure tubes located in the vicinity of the balance. The conditions of the internal flow ducted through the model were measured using a pressure rake in the annular duct exit at the model base to determine momentum loss with respect to the free stream. The rake, consisting of 18 total-pressure tubes and 6 static-pressure tubes, was removed for all the force-measurement tests. The drag data presented herein have been corrected for internal drag and have also been corrected to the condition of free-stream static pressure in the balance chamber. Corrections to the model angles of attack have been made for both tunnel-airflow misalignment (determined from upright and inverted runs) and deflection of the balance and sting under load.

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

RESULTS AND DISCUSSION

The effects of external stores on the longitudinal aerodynamic characteristics of the model are presented in figures 8 to 11 for the square stores and in figures 12 and 13 for the conventional stores. All store test configurations produced small, positive increments in the pitching moment throughout the angle-of-attack range, but the configuration with area-ruled wing tanks also had a decrease in stability at the higher angles of attack. There were small changes in lift due to the addition of the stores: the area-ruled wing tanks and the square stores, except for the aft-mounted pair, produced changes ranging from zero to slightly negative, whereas the other conventional-store test configurations ranged from zero to slightly positive. As expected for every store test configuration, there was an increase in C_D and a decrease in L/D. For the square stores, the drag increments (figs. 8 to 11) generally increased with lift coefficient for $C_L > 0.25$, whereas for the conventional stores (figs. 12 and 13), ΔC_D decreased with an increase in C_L. Examination of the axial-force data (which are not presented in the figures) reveals that the axial-force increments increase with angle of attack for all square-store test configurations except the tandem and decrease for the area-ruled wing tanks. It is roughly constant for the other conventional stores and for the tandem square stores. For all conventional stores except the area-ruled wing tanks, the observed decrease in drag increment at the higher lift coefficients occurred as a result only of positive increments in C_L.

A summary of the results for $(L/D)_{max}$, $\Delta C_{D,o}$, and $\Delta C_{D,o}/C_{D,o}$ are presented with expanded scales in figure 14. Results for square stores (fig. 14(a)) indicate a 6- to 8-percent increase in drag increment due to lateral separation for four stores. The addition of a fairing on the fuselage ahead of the group of four touching square stores showed a small decrease in drag increment at $M = 2$ as expected; but at $M = 1.6$, a slight increase in drag increment resulted. The increment for the forward pair of stores is almost 90 percent of that for the four touching stores, whereas for the aft pair, it is only about 62 percent. The tandem pair of stores had slightly less than half the drag increment of the four touching stores. The maximum reduction in $(L/D)_{max}$ is only about 9 percent for the four square stores with lateral separation which corresponds to a 17-percent increase in $C_{D,o}$.

The results for the conventional stores are presented in figure 14(b). The three SUU-51 stores had the highest drag increment level of the group, with 28 percent of the basic airplane value, but produced only a 10-percent reduction in $(L/D)_{max}$. The drag increment for the two area-ruled wing tanks is almost as high, but those for the three Maverick missiles and the two SUU-51 are somewhat lower. For the FLIR/ECM pod and the two MK-84 low-drag bombs, the increment in minimum drag was only about 9 or 10 percent, with about 4 percent reduction in $(L/D)_{max}$.

Comparison of the drag increments for the stores can be made on the basis of drag per unit of store maximum cross-sectional area (fig. 15) where $C_{D,s} = (\Delta C_{D,o})\dfrac{S}{N \cdot A_s}$. The highest values of $C_{D,s}$, about 1.1, were obtained for the installation with three Maverick missiles. This is not surprising because of the hemispherically blunted nose and the fairly large pylons. The lowest values were about 0.40 and were obtained on three test configurations: four square stores touching, two square stores in tandem, and two MK-84 low-drag bombs. The two area-ruled wing tanks resulted in a value for $C_{D,s}$ of about 0.53, which is slightly below the level for the FLIR/ECM pod. The side-by-side touching pair of square stores yields, at $M = 1.6$, about 0.50 in the aft position and about 0.74 for the forward position. SUU-51 stores installed as an outboard pair resulted in a value $C_{D,s}$ of about 0.90, while the addition of a third store beneath the aircraft centerline increases the coefficient to about 1.0, presumably due to mutual interference between the stores.

SUMMARY OF RESULTS

An investigation has been conducted to determine the effect of conventional and square stores on the longitudinal aerodynamic characteristics of a fighter aircraft configuration at Mach numbers of 1.6, 1.8, and 2.0. Five conventional-store configurations and six arrangements of a square-store configuration were studied. Tests were conducted for angles of attack ranging from -3° to 20° at a Reynolds number of 6.56×10^{6} per meter.

All configurations of the stores produced small, positive increments in the pitching moment throughout the angle-of-attack range, but the configuration with area-ruled wing tanks also had a slight decrease in stability at the higher angles of attack. There were some small changes in lift coefficient because of the addition of the stores, causing the drag increment to vary with lift coefficient (C_L) above $C_L \approx 0.25$. As a result, there were corresponding changes in the increments of the maximum lift-drag ratios. The store-drag coefficient based on the cross-sectional area of the stores ranged from a maximum of 1.1 for the configuration with three Maverick missiles to a minimum of about 0.40 for the two MK-84 bombs and the arrangements with four square stores touching or two square stores in tandem. Square stores located side by side yielded, at a Mach number of 1.6, about 0.50 in the aft position compared to 0.74 in the forward position.

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April 18, 1980

REFERENCES

1. Dollyhigh, Samuel M.; Sangiorgio, Giuliana; and Monta, William J.: Effect of Stores on Longitudinal Aerodynamic Characteristics of a Fighter at Supersonic Speeds. NASA TP-1175, 1978.

2. Mechtly, E. A.: The International System of Units - Fundamental Constants and Conversion Factors. Stipes Pub. Co., c.1977.

3. Braslow, Albert L.; Hicks, Raymond M.; and Harris, Roy V., Jr.: Use of Grit-Type Boundary-Layer-Transition Trips on Wind-Tunnel Models. Conference on Aircraft Aerodynamics, NASA SP-124, 1966, pp. 19-36. (Also available as NASA TN D-3579.)

TABLE I.- GEOMETRIC CHARACTERISTICS

Wing:	
$A\!\!\!/$	3.0
Λ, deg	40
Γ, deg	0
b (without wing-tip missiles), cm	60.96
$\bar{c}$, cm	23.002
S, cm^2	1238.71
Taper ratio	0.2275
Root chord (theoretical), cm	33.108
Airfoil	NACA 64A204
Incidence, deg	0
Twist, deg, at -	
$\frac{y}{b/2} = 0.30$	0
$\frac{y}{b/2} = 1.0$	3
Horizontal tail (each):	
Area, cm^2	101.16
$A\!\!\!/$	1.299
Taper ratio	0.3
Λ, deg	40
Γ, deg	-10
Airfoil -	
At root	6% biconvex
At tip	3.5% biconvex
Vertical tail:	
$A\!\!\!/$	1.294
Area, cm^2	226.06
Taper ratio	0.437
Λ, deg	47.5
Airfoil -	
At root	5.3% biconvex
At tip	3% biconvex

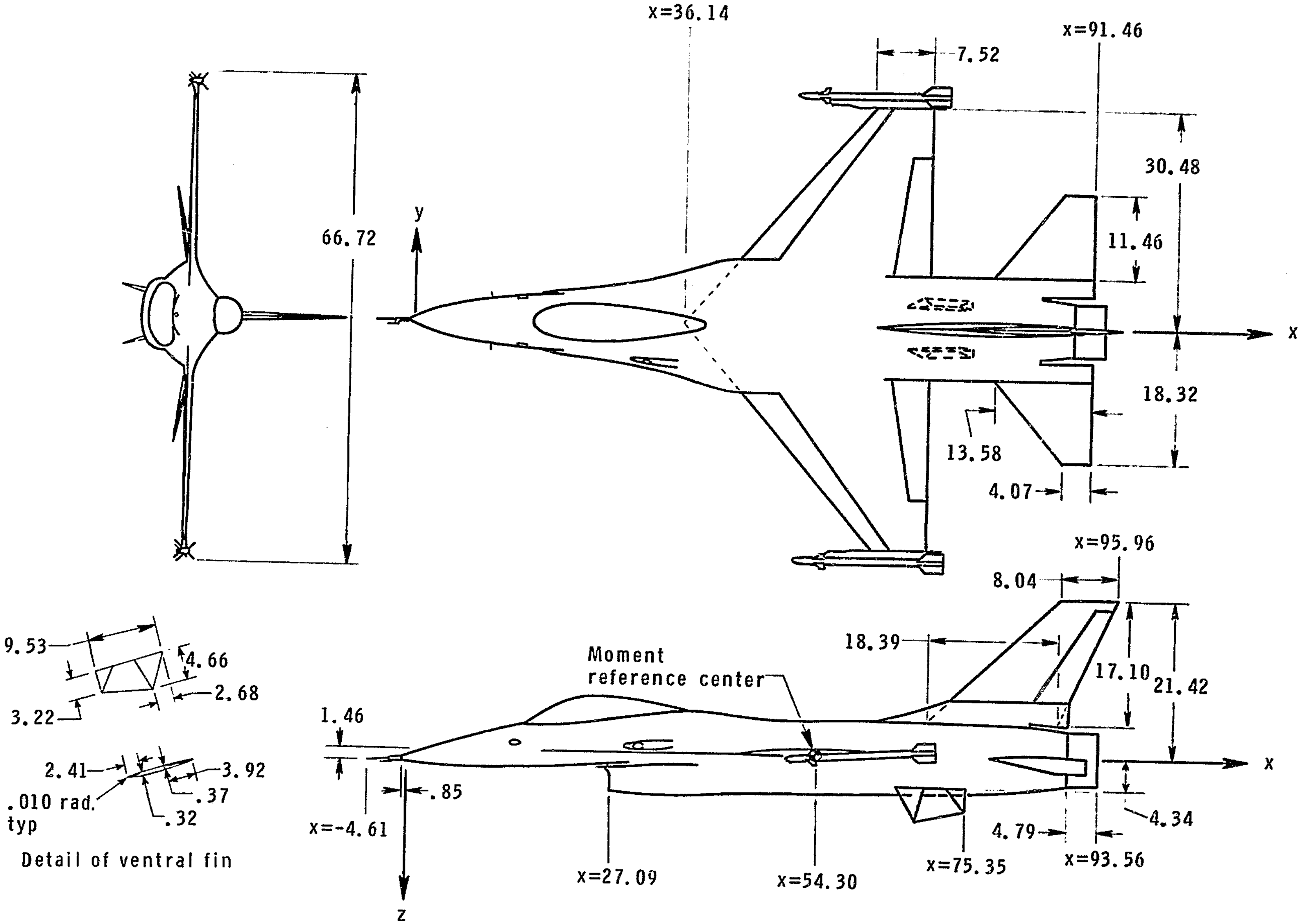
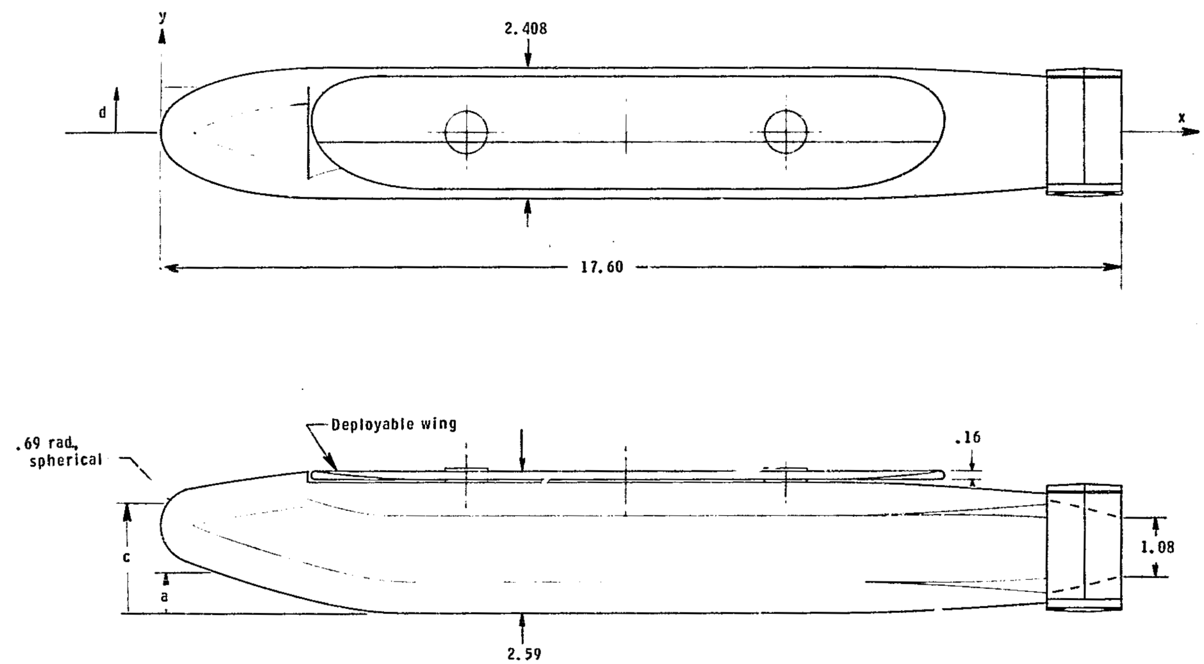
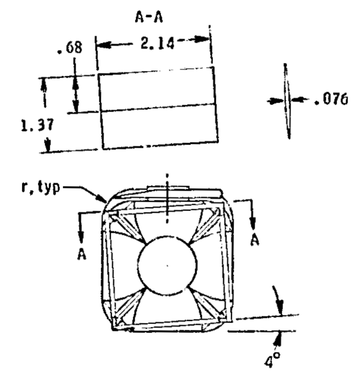


Figure 1.- Drawing of 1/15-scale fighter aircraft model. Dimensions are in centimeters, except as noted.



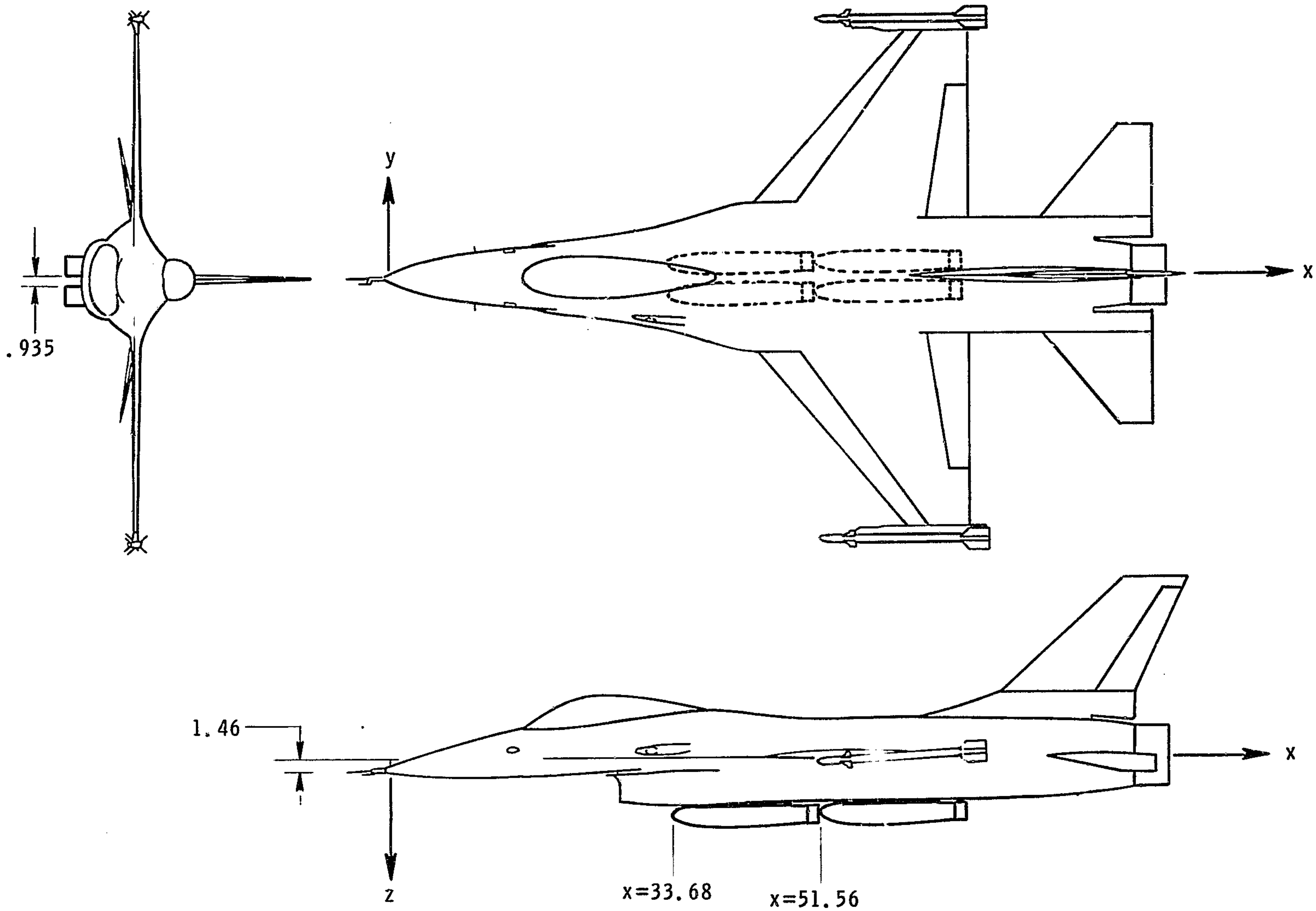
Body coordinates

x, cm	a, cm	c, cm	d, cm	r, cm	
0.000	1.620		0.000		
.808	.838	2.339	.815	0.688	
1.554	.594	2.464	1.011	.668	
2.677	.269	2.591	1.146	.637	
2.677		2.408	1.146	.317	upper geom. only
3.426		2.408	1.191	.508	upper geom. only
4.173	.000	2.408	1.204	.597	
Constant section					
12.700	0.000	2.468	1.204	0.597	
13.548	.030	2.377	1.173	.597	
14.361	.099	2.309	1.105	.597	
15.166	.183	2.225	1.021	.597	
15.987	.295	2.113	.909	.577	
16.794	.460	1.948	.744	.559	
17.602	.663	1.745	.541	.541	



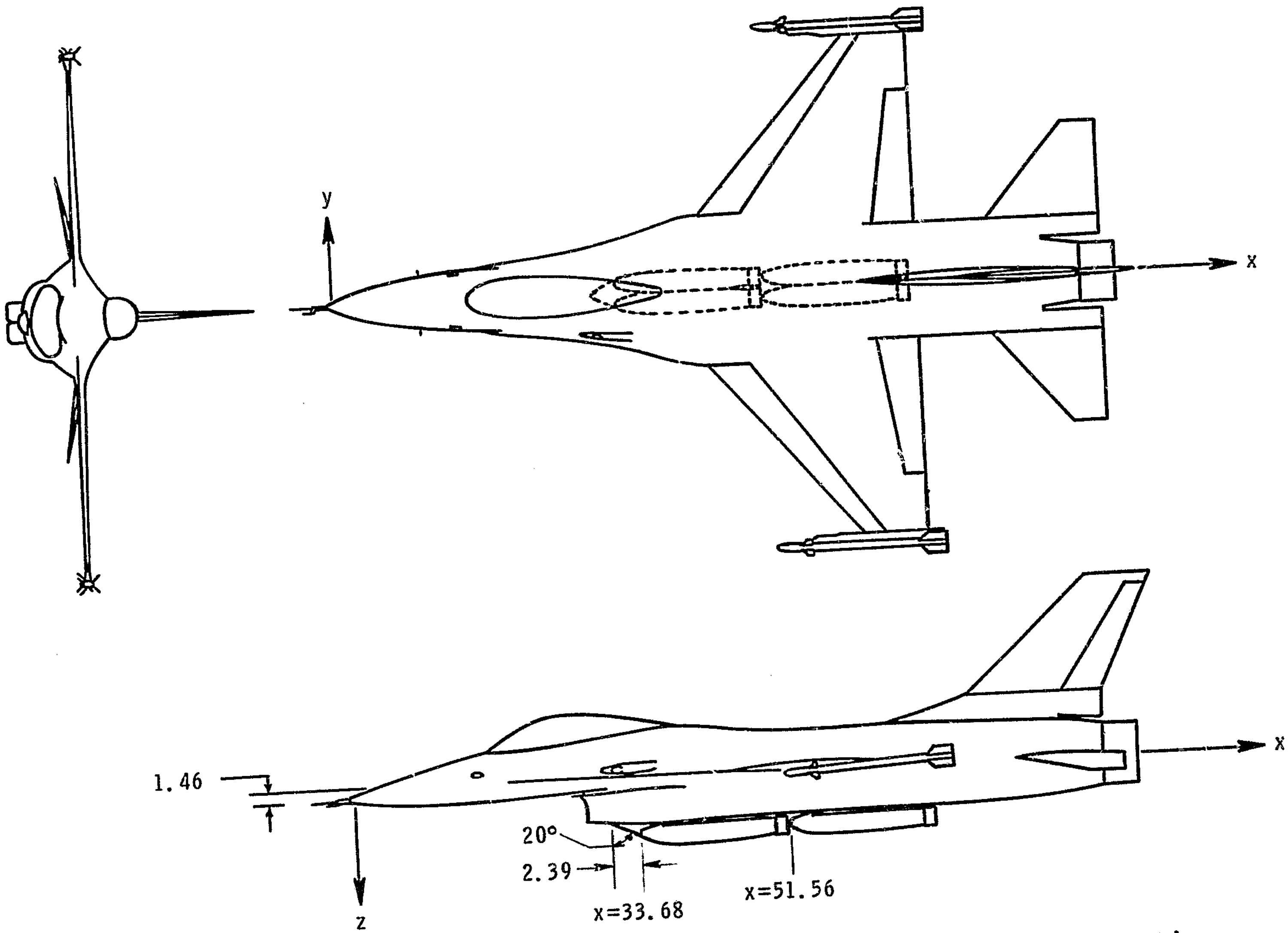
(a) Square store.

Figure 2.- Model and installations of square store.



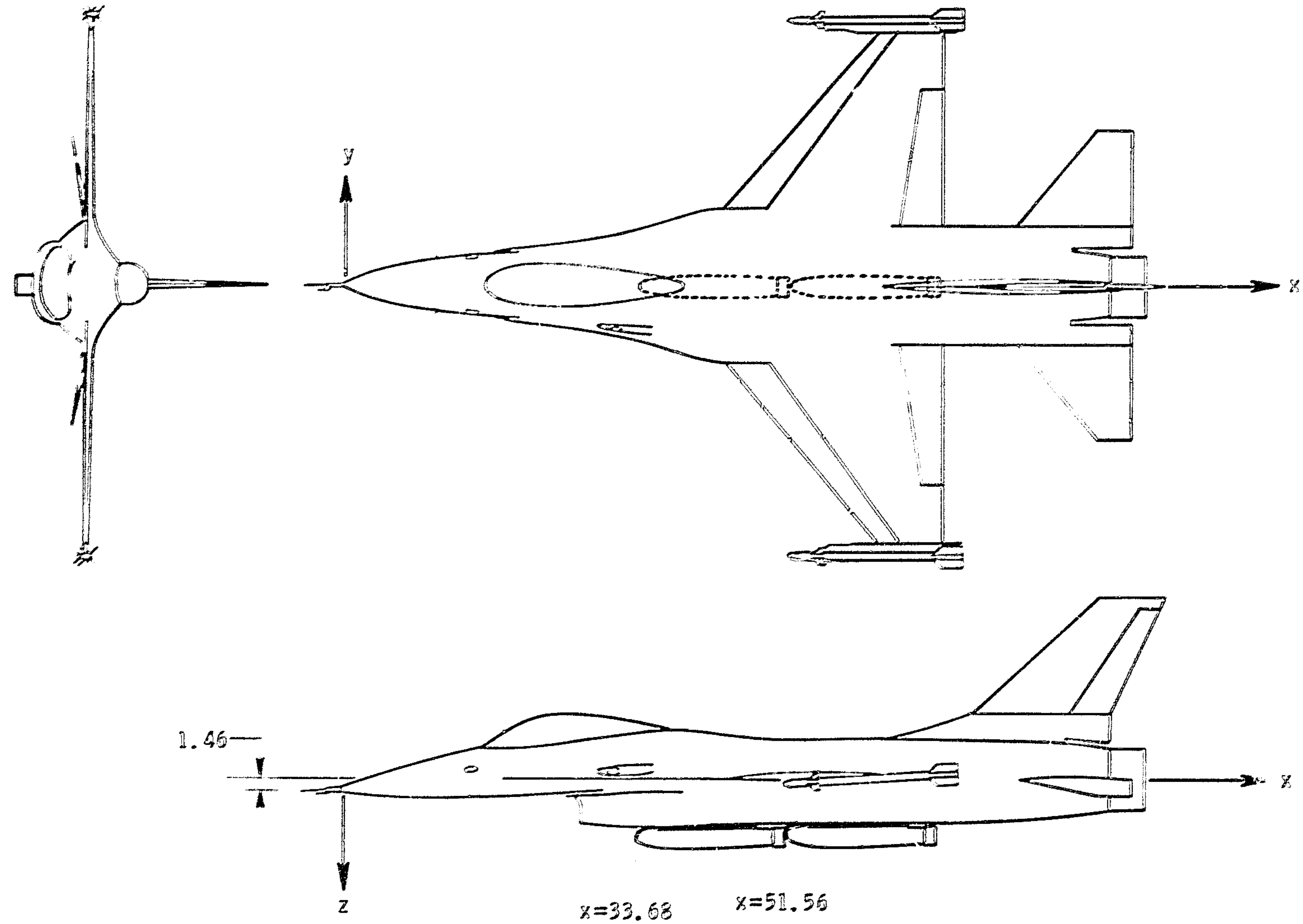
(b) Installation of four square stores having lateral separation on fighter configuration (ventral fins removed).

Figure 2.- Continued.



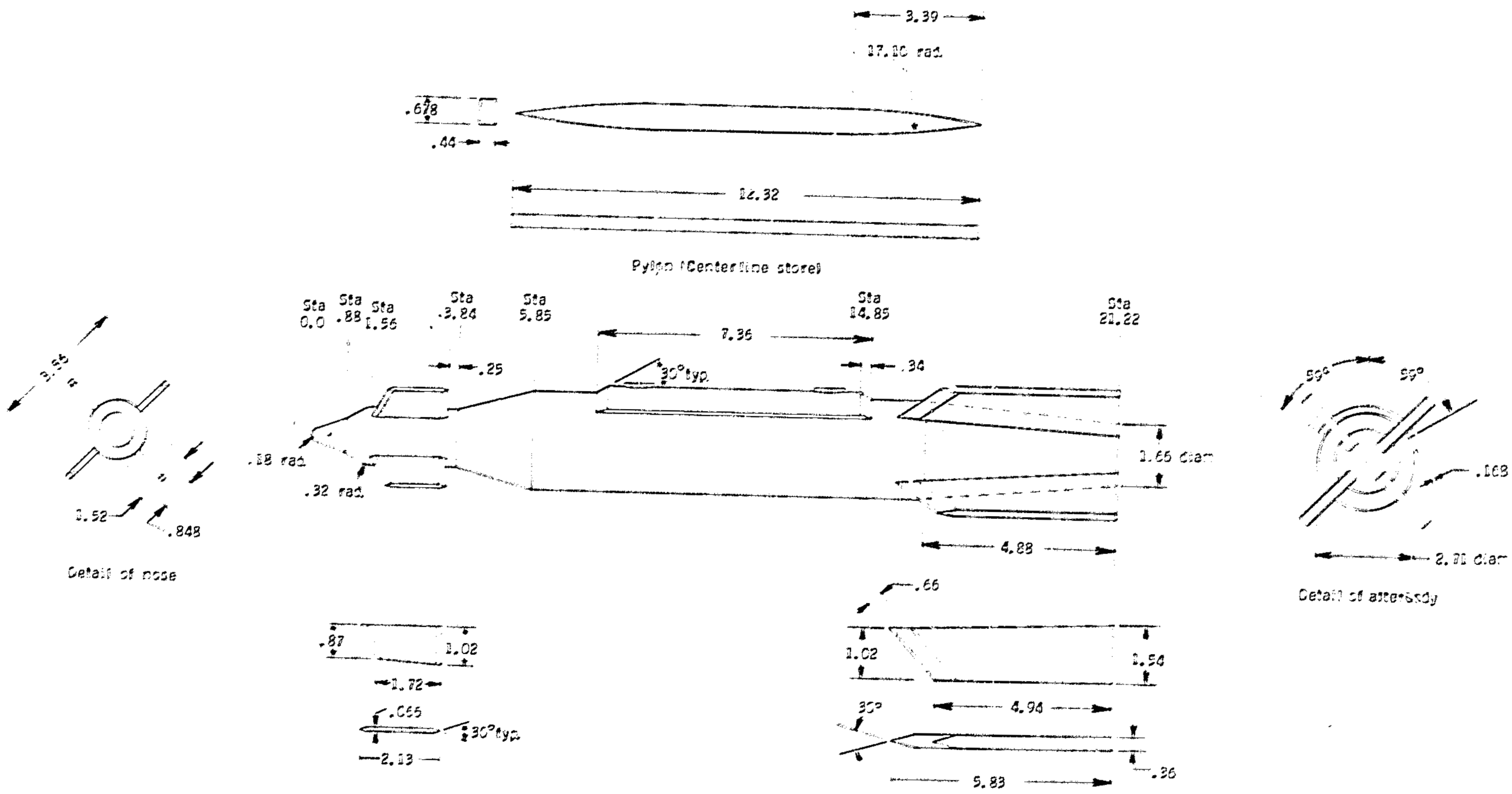
(c) Installation of four square stores and nose fairing on fighter configuration (ventral fins removed).

Figure 2.- Continued.



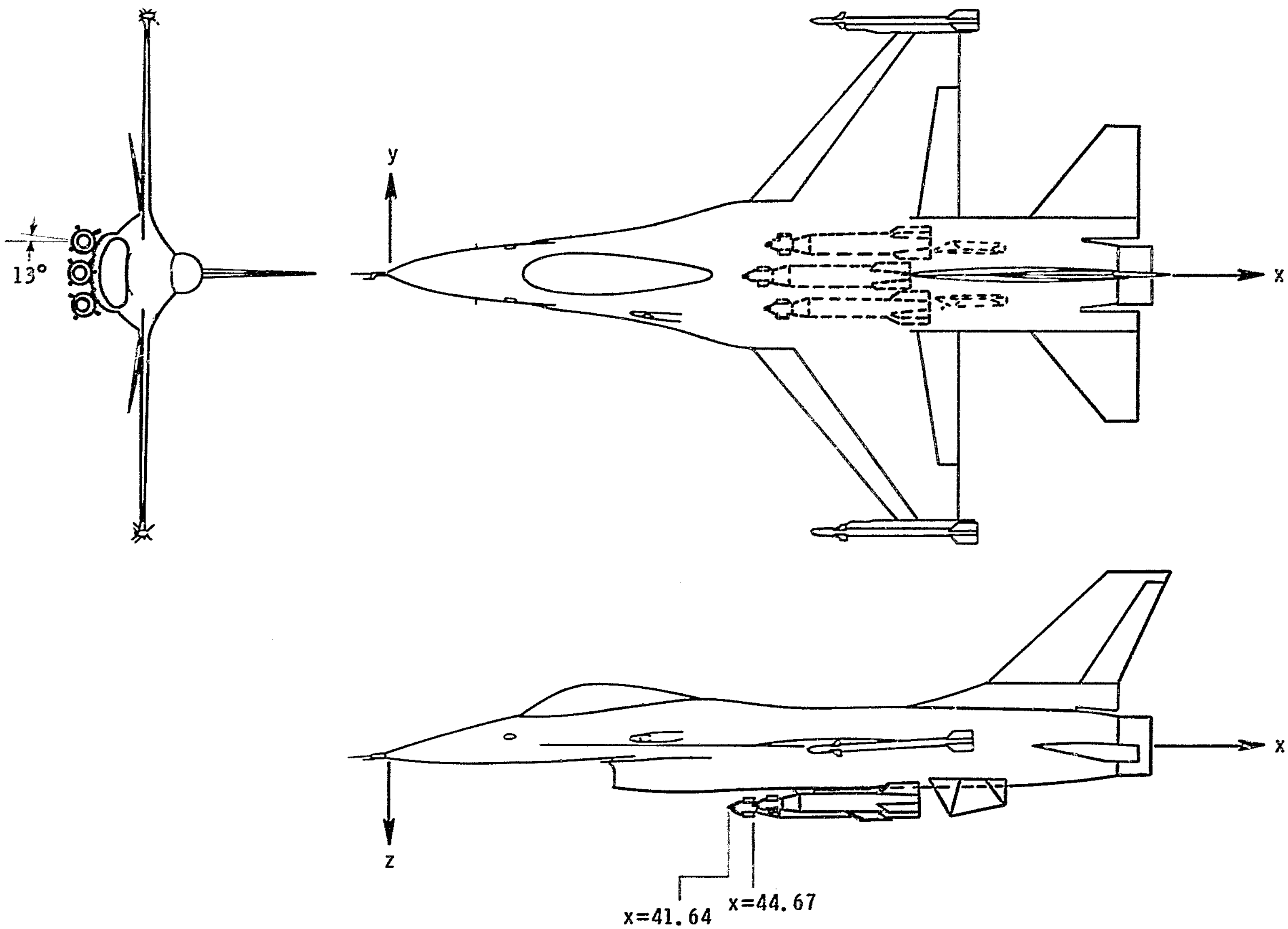
(d) Installation of two square stores in tandem on fighter configuration.

Figure 2.- Concluded.



(a) Modified SUU-51 store.

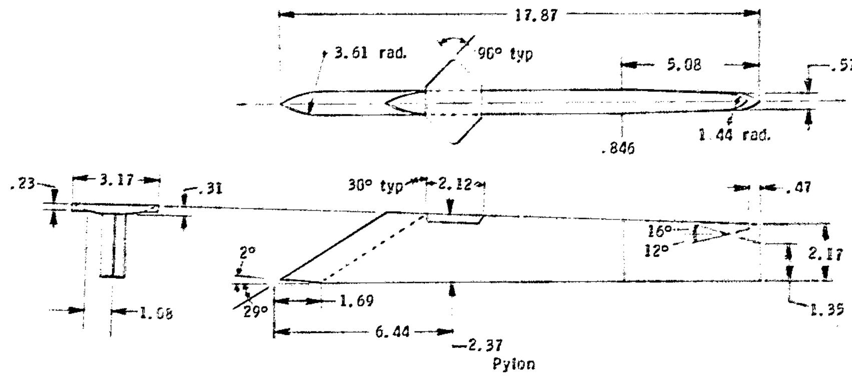
Figure 3.- Model and installation of modified SUU-51 store.

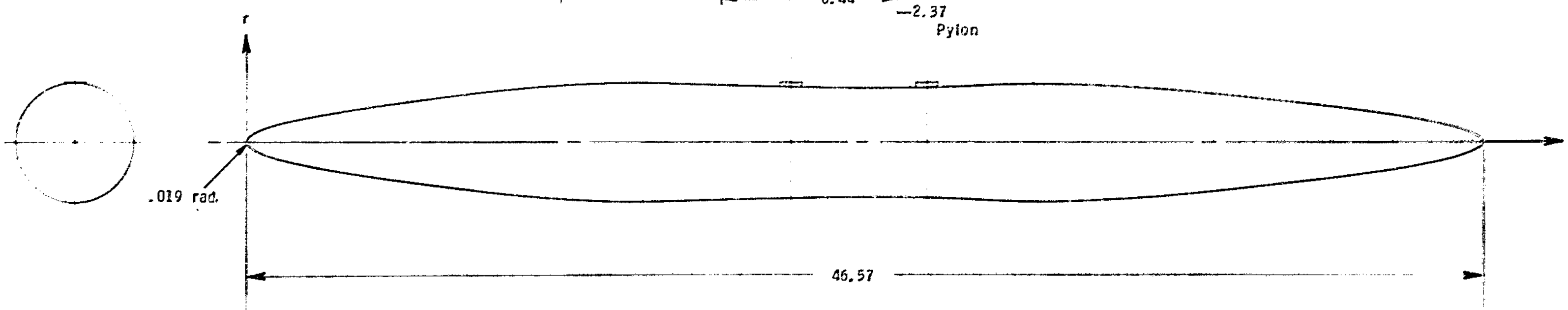


(b) Installation of three modified SUU-51 stores on fighter configuration.

Figure 3.- Concluded.

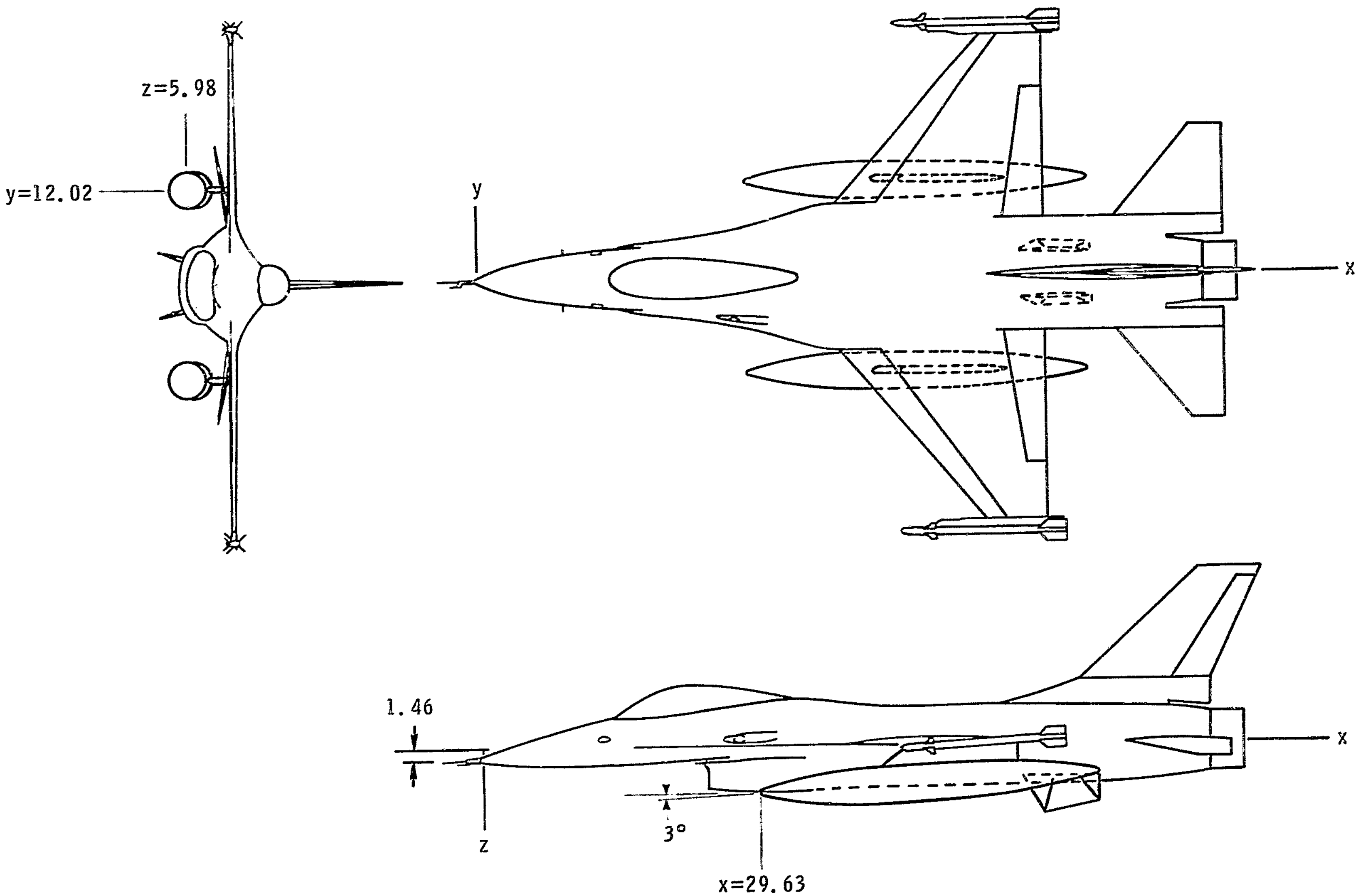
Body coordinates			
x, cm	r, cm	x, cm	r, cm
0	0	24.554	2.037
.170	.223	26.245	2.070
.424	.371	27.940	2.126
.846	.531	29.634	2.189
1.694	.765	31.326	2.177
2.540	.940	33.020	2.078
3.386	1.092	34.714	1.943
4.234	1.224	36.406	1.796
5.926	1.458	38.100	1.633
7.620	1.669	39.794	1.453
9.314	1.862	41.486	1.252
11.006	2.024	42.334	1.140
12.700	2.151	43.180	1.016
14.394	2.197	44.026	.876
16.086	2.189	44.874	.714
17.780	2.144	45.720	.505
19.474	2.085	46.144	.358
21.166	2.050	46.398	.221
22.860	2.032	46.566	0





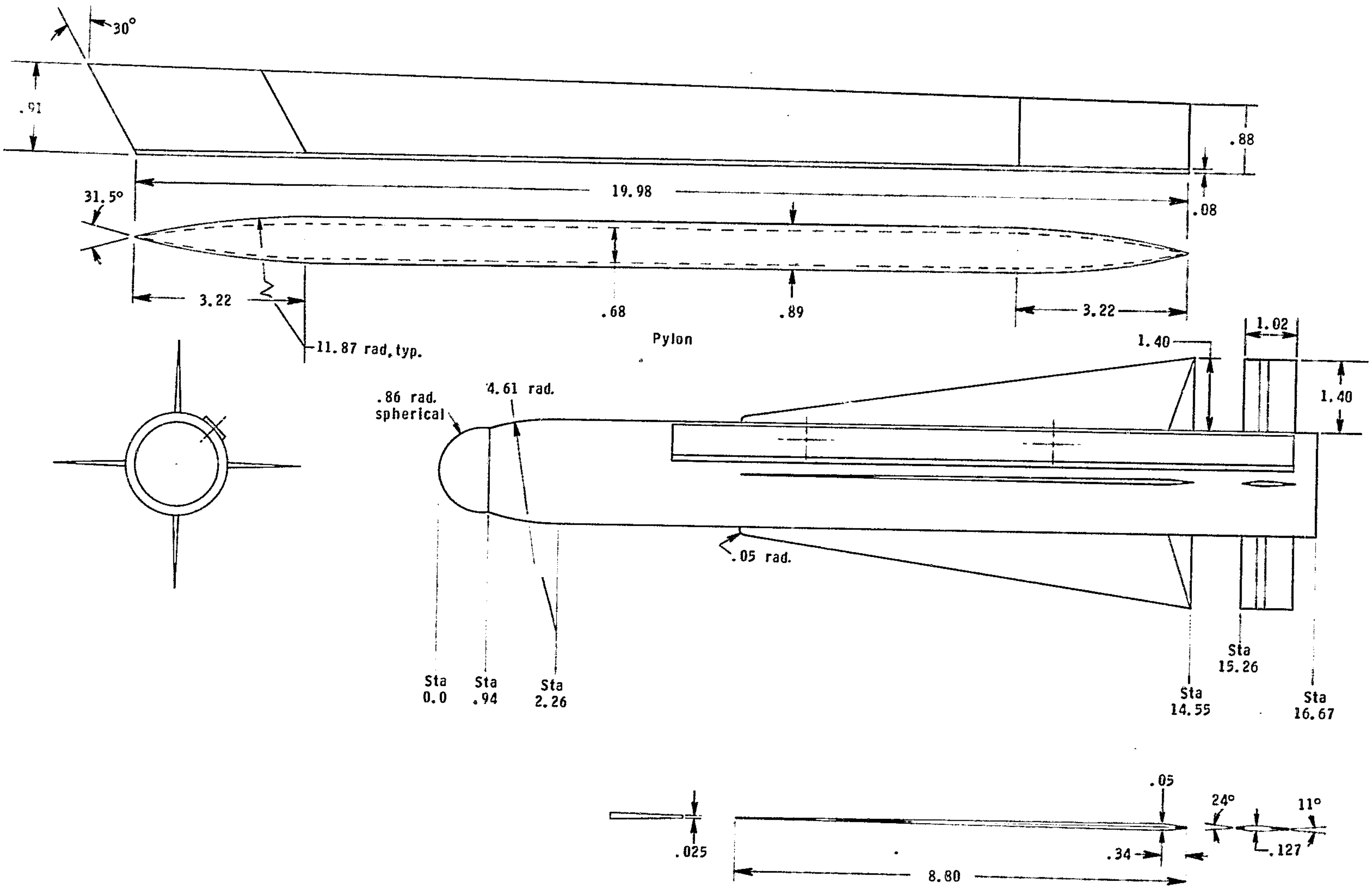
(a) Area-ruled wing tank.

Figure 4.- Model and installation of area-ruled wing tank.



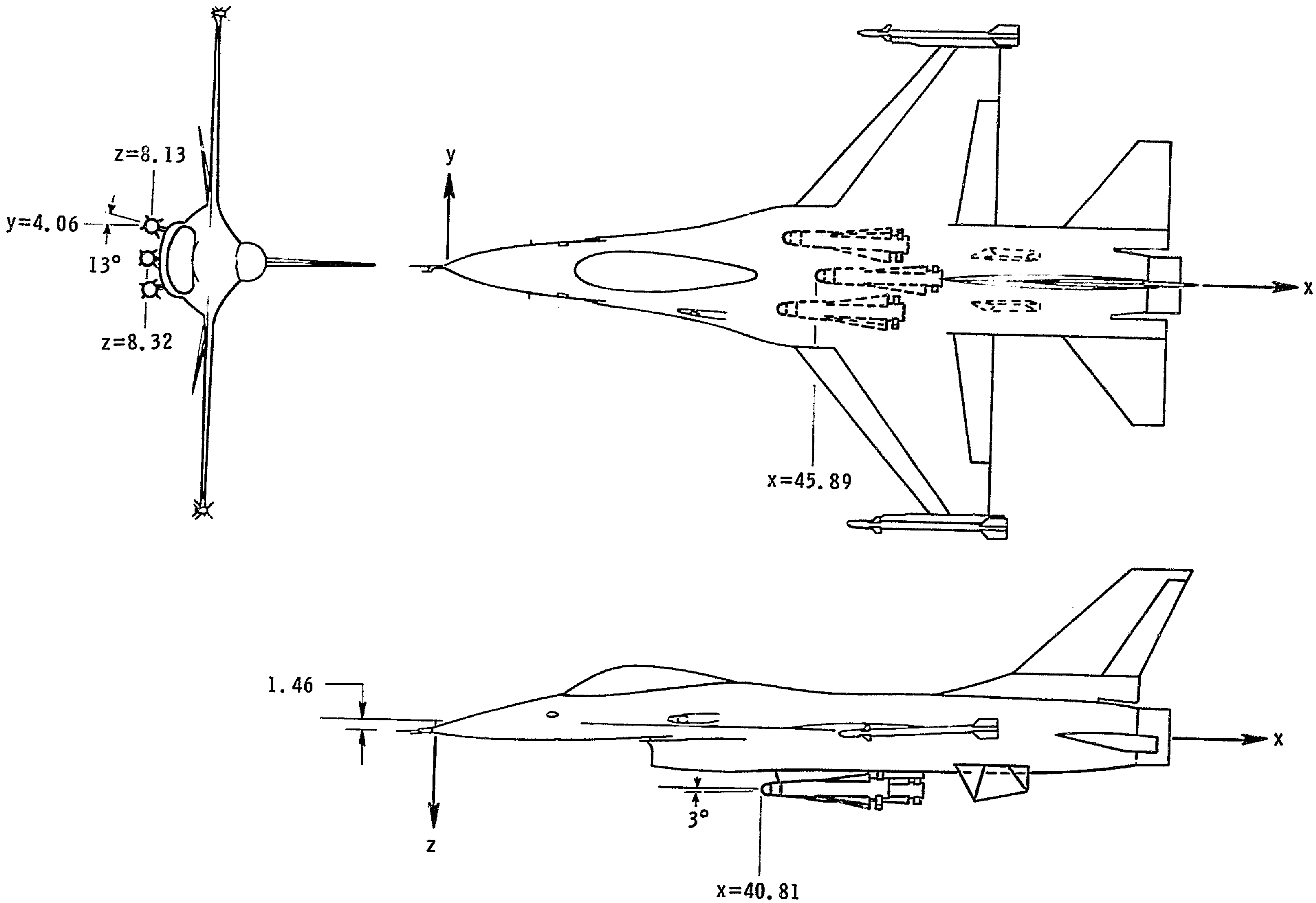
(b) Installation of two area-ruled wing tanks on fighter configuration.

Figure 4.- Concluded.



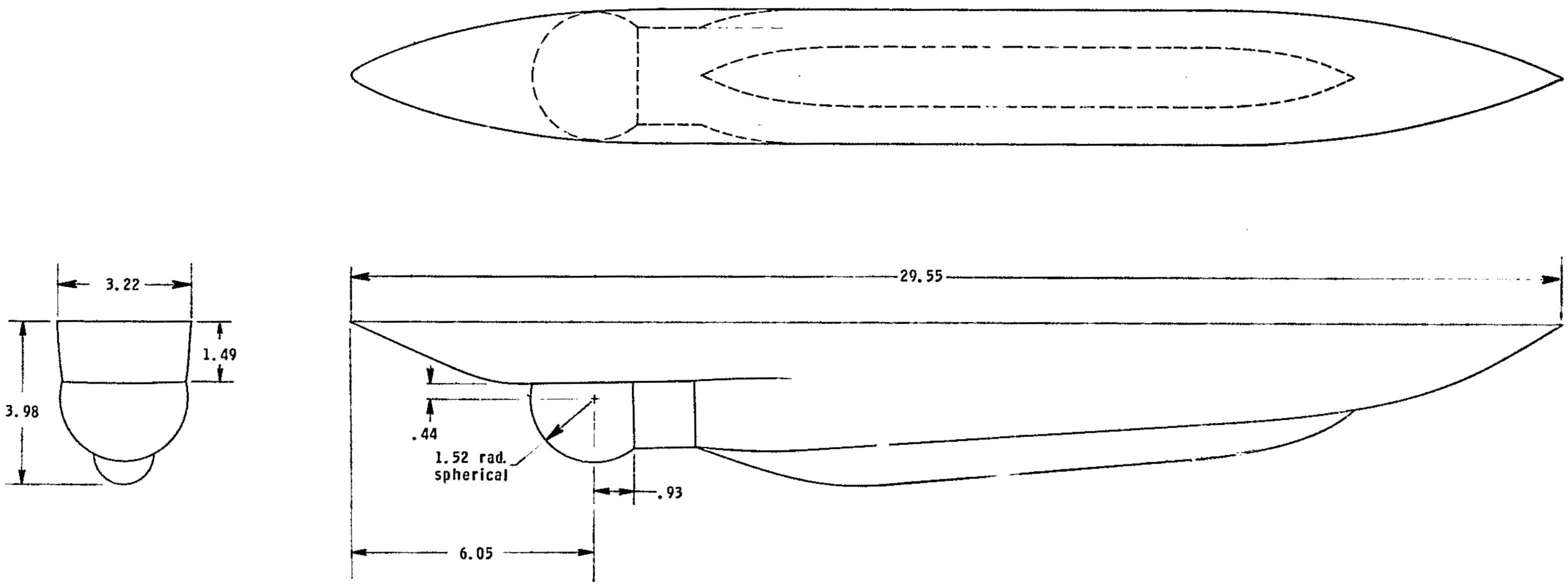
(a) Maverick missile.

Figure 5.- Model and installation of Maverick missile.



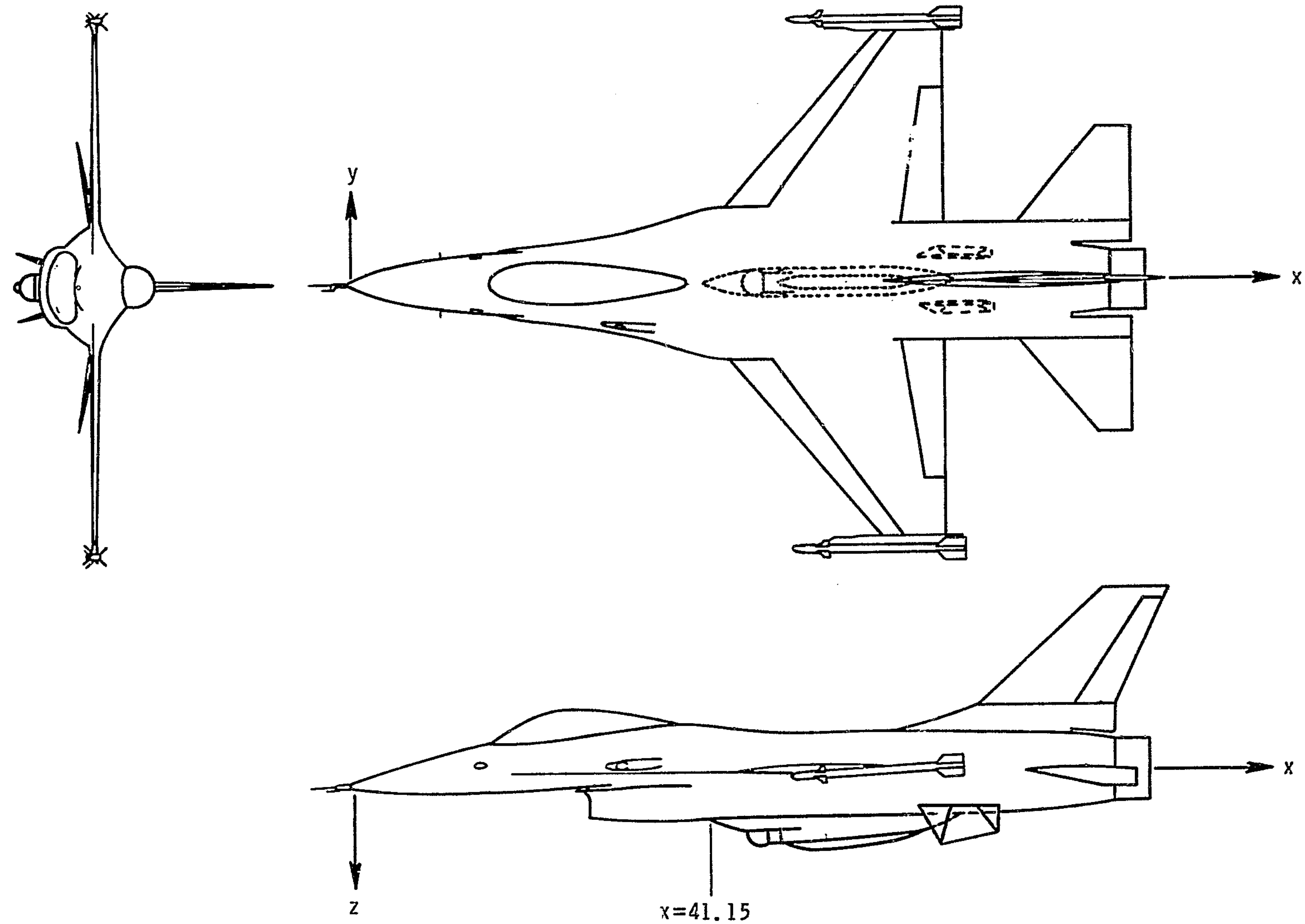
(b) Installation of three Maverick missiles on fighter configuration.

Figure 5.- Concluded.



(a) Conceptual FLIR/ECM pod.

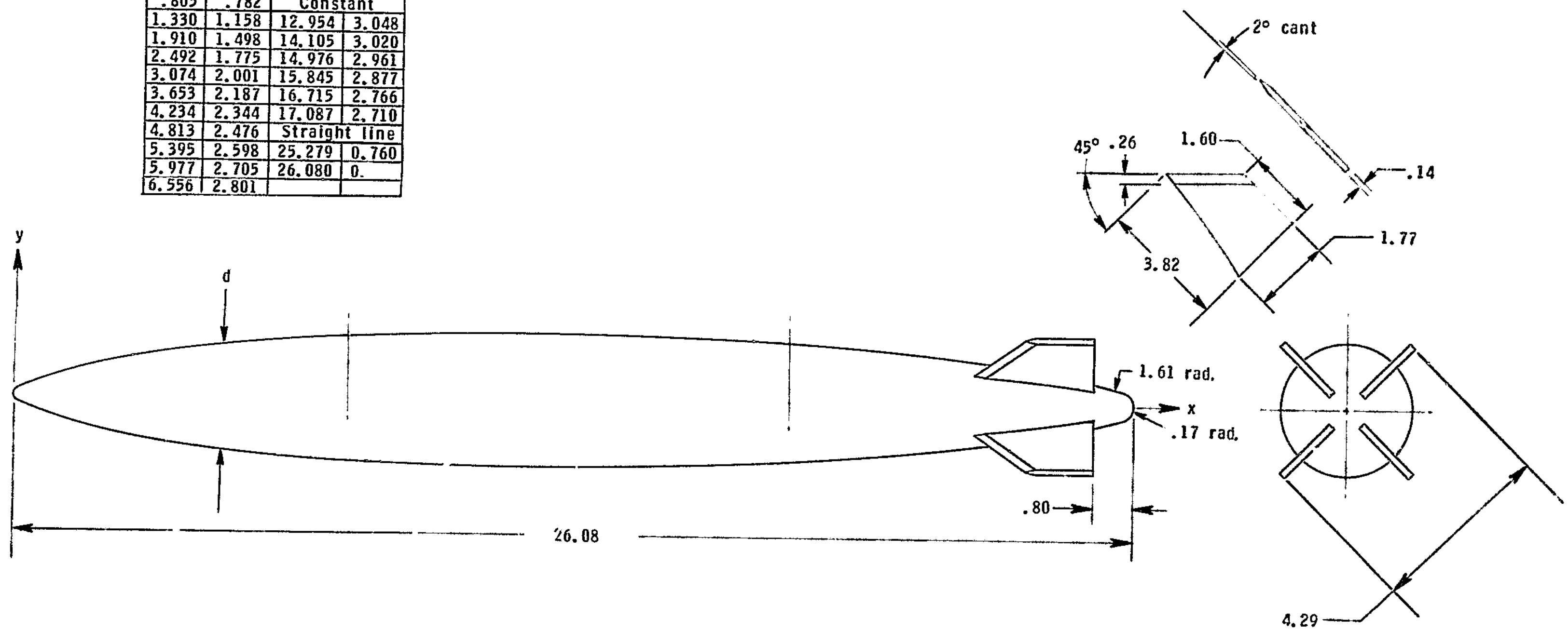
Figure 6.- Model and installation of conceptual FLIR/ECM pod.



(b) Installation of conceptual FLIR/ECM pod on fighter configuration.

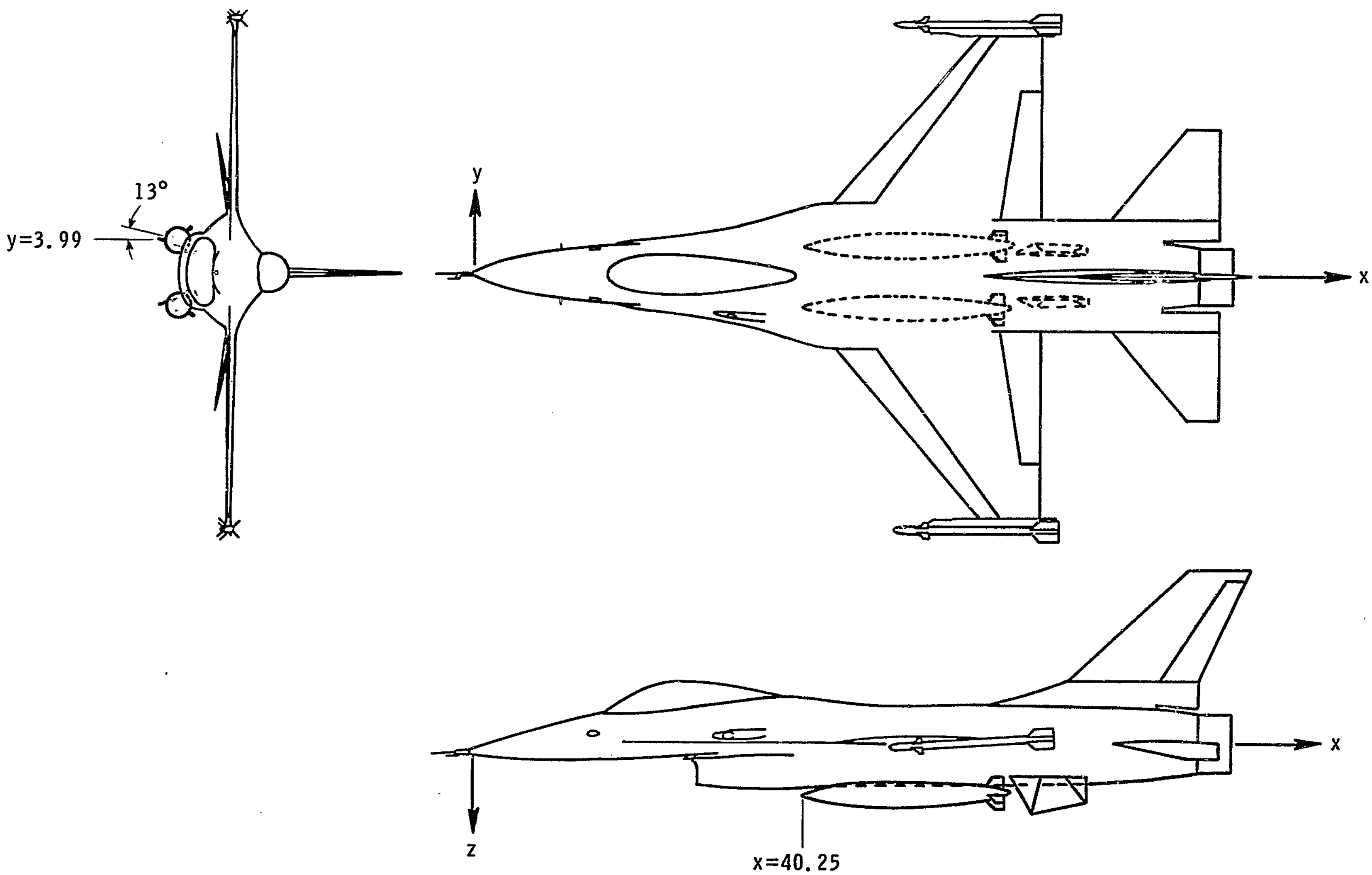
Figure 6.- Concluded.

body			
x, cm	d, cm	x, cm	d, cm
0.	0.	7.137	2.876
.171	.224	8.009	2.987
.460	.495	9.170	3.048
.805	.782	Constant	
1.330	1.158	12.954	3.048
1.910	1.498	14.105	3.020
2.492	1.775	14.976	2.961
3.074	2.001	15.845	2.877
3.653	2.187	16.715	2.766
4.234	2.344	17.087	2.710
4.813	2.476	Straight line	
5.395	2.598	25.279	0.760
5.977	2.705	26.080	0.
6.556	2.801		



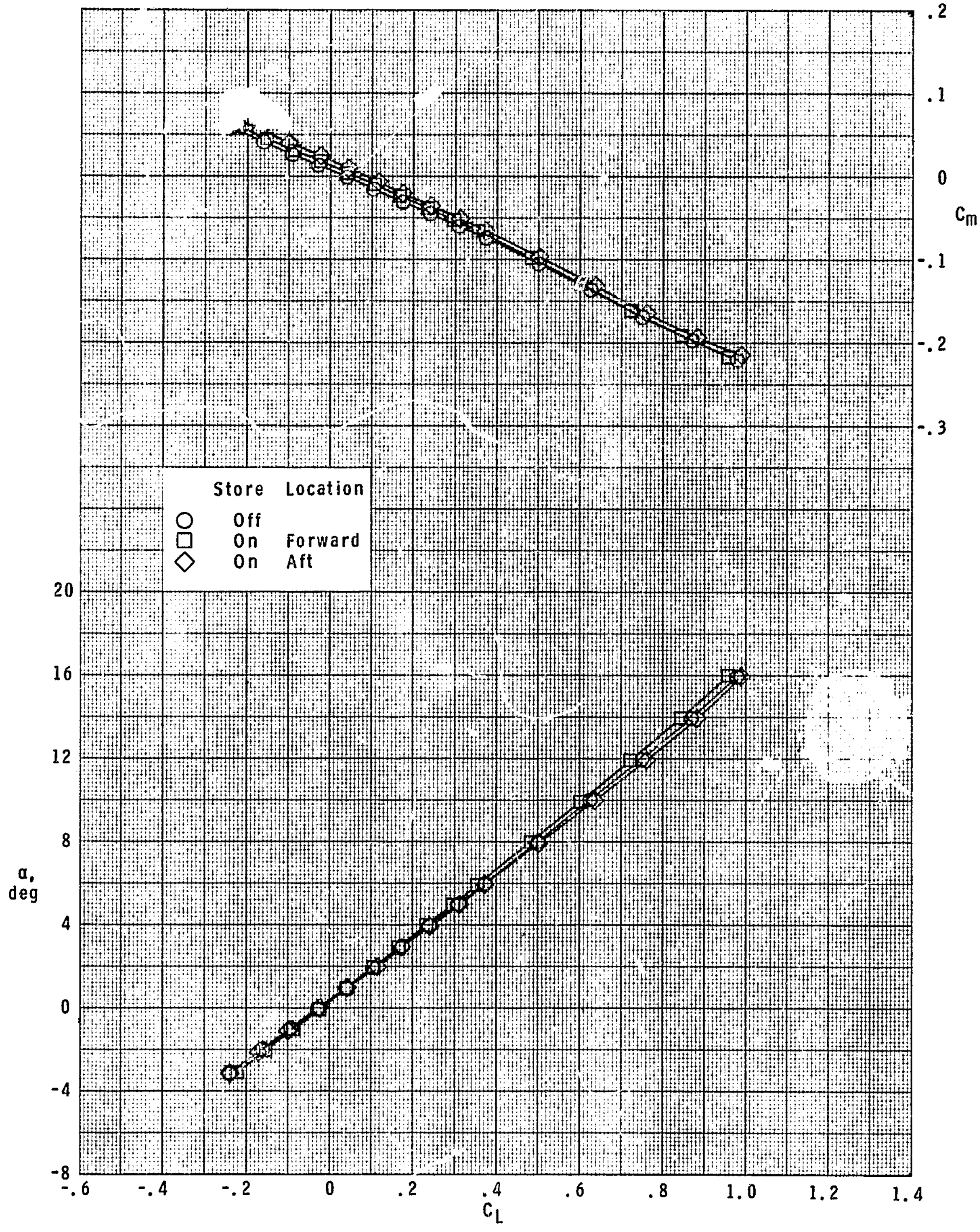
(a) MK-84 low drag bomb.

Figure 7.- Model and installation of MK-84 low drag bomb.



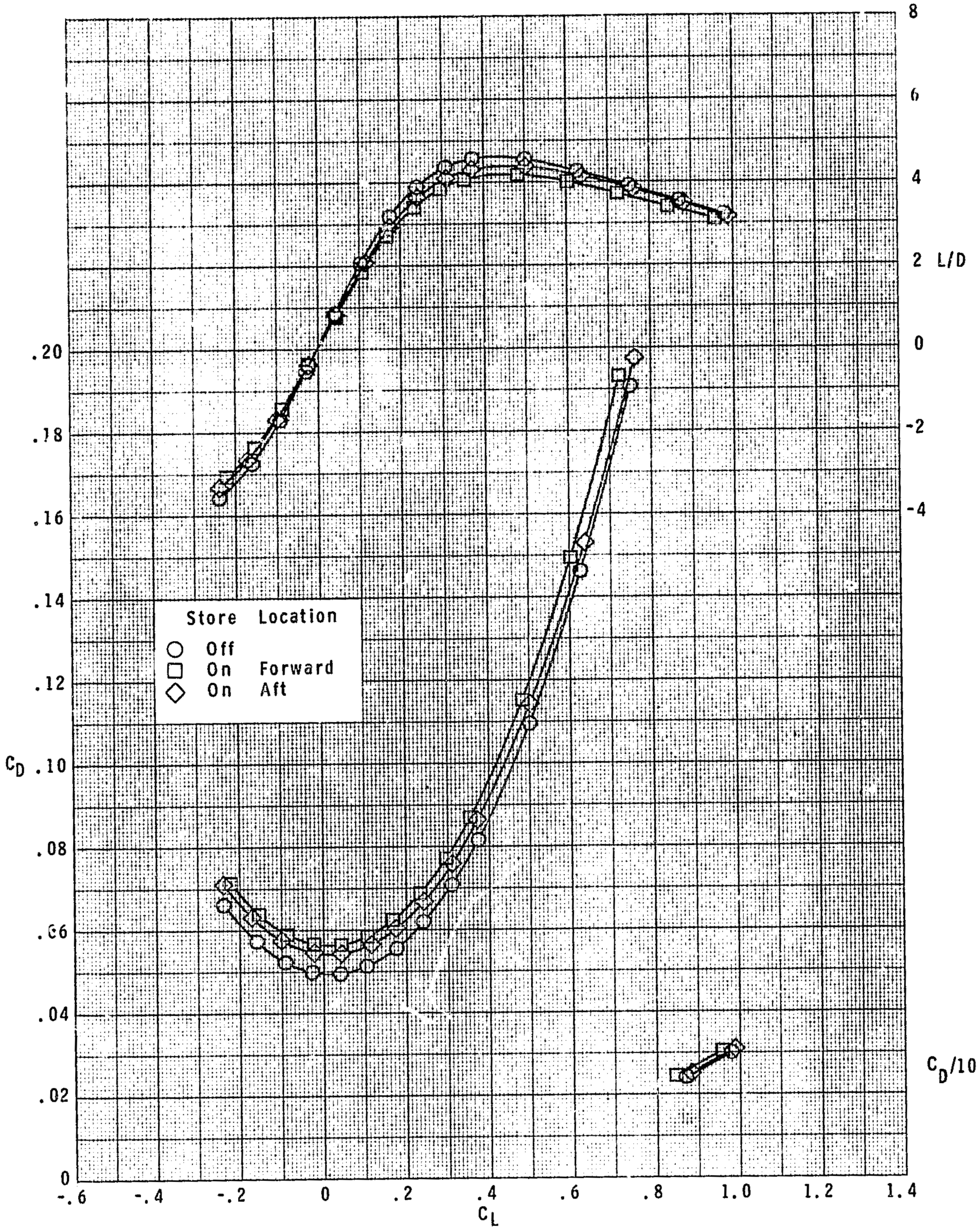
(b) Installation of two MK-84 low drag bombs on fighter configuration.

Figure 7.- Concluded.



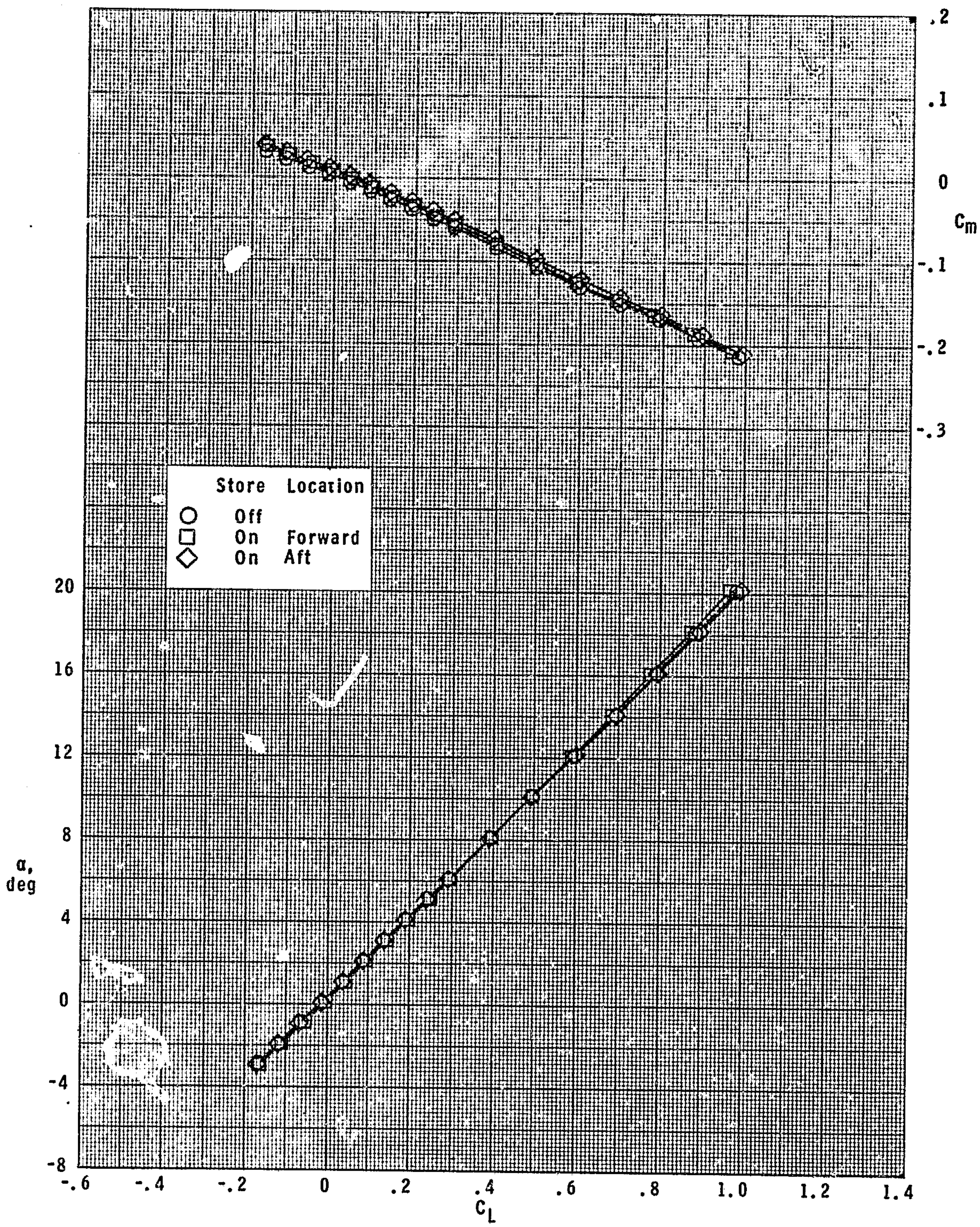
(a) M = 1.60.

Figure 8.- Effect of longitudinal location of pair of side-by-side square stores with sides touching on longitudinal characteristics; modified F-16A, ventral fins removed.



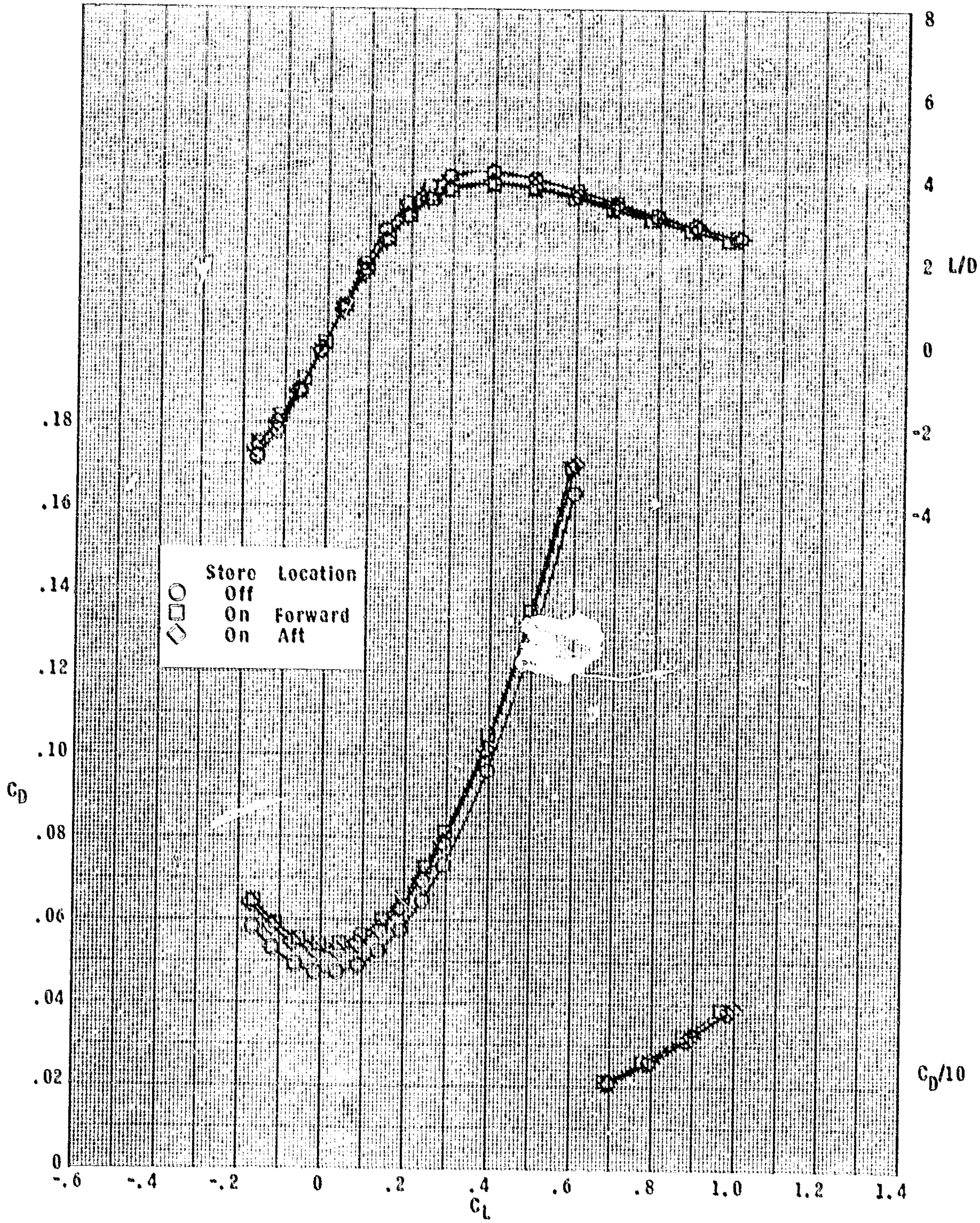
(a) Concluded.

Figure 8.- Continued.



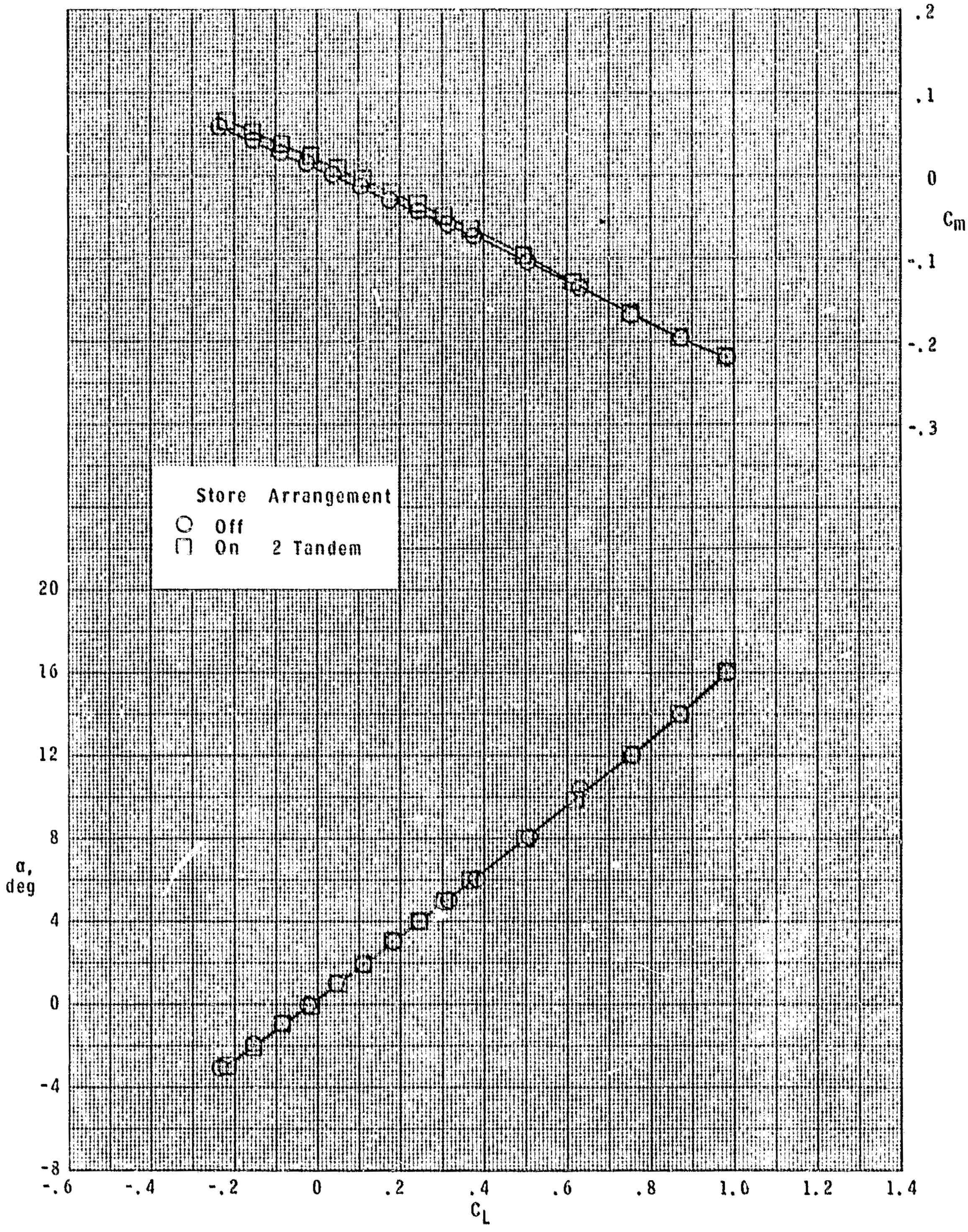
(b) M = 2.00.

Figure 8.- Continued.



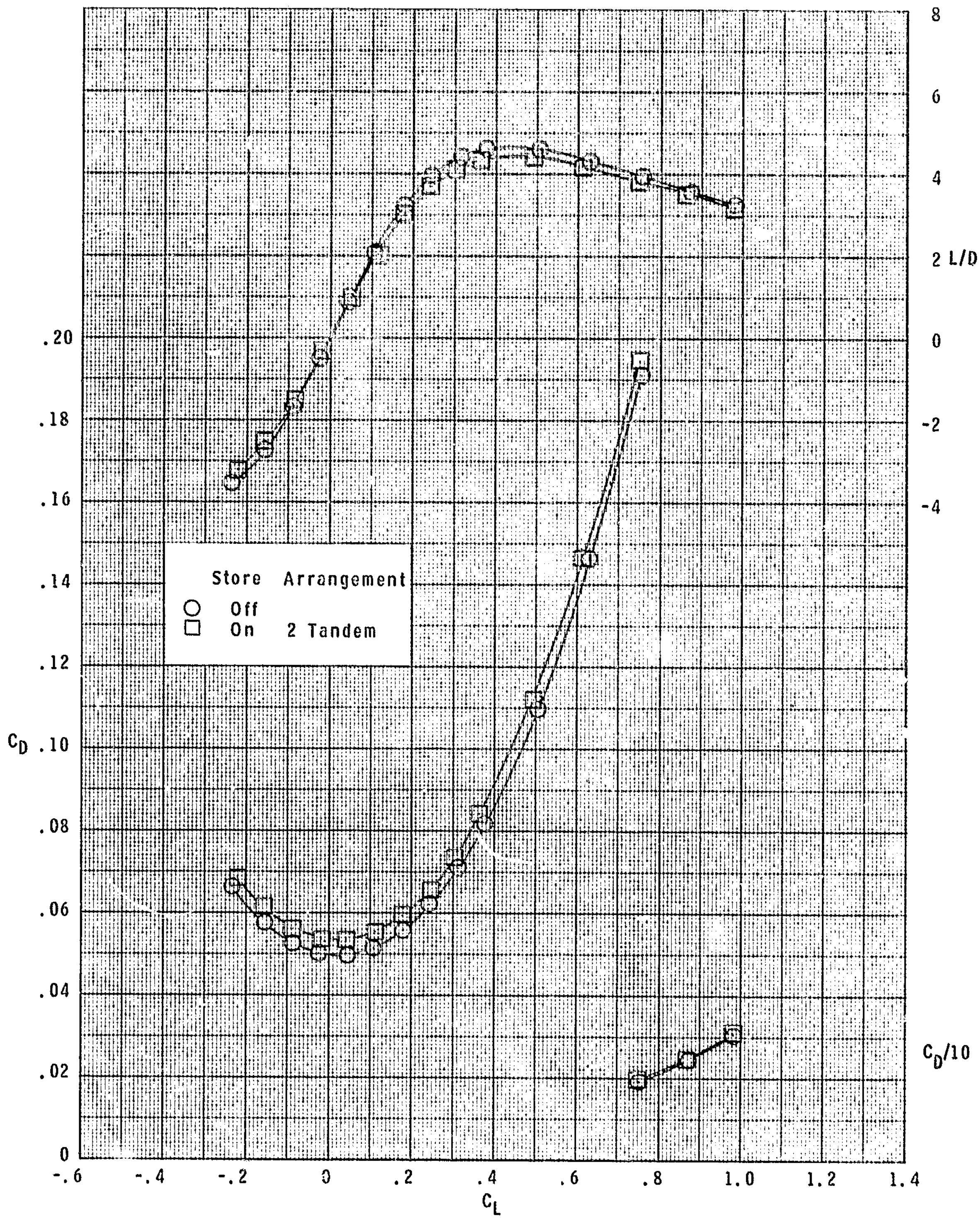
(b) Concluded.

Figure 8.- Concluded.



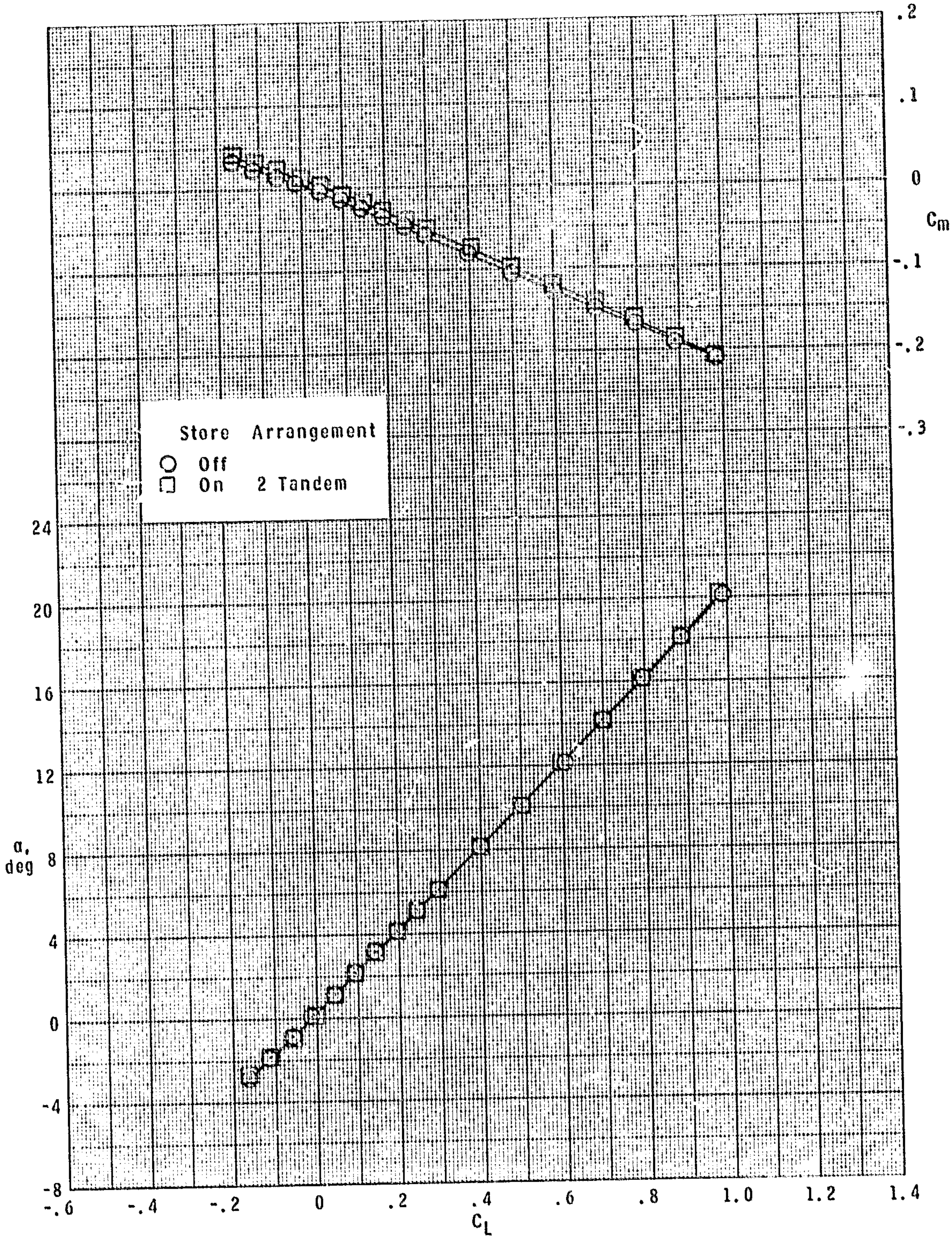
(a) M = 1.60.

Figure 9.- Effect of pair of square stores in tandem arrangement on longitudinal characteristics; modified F-16A, ventral fins removed.



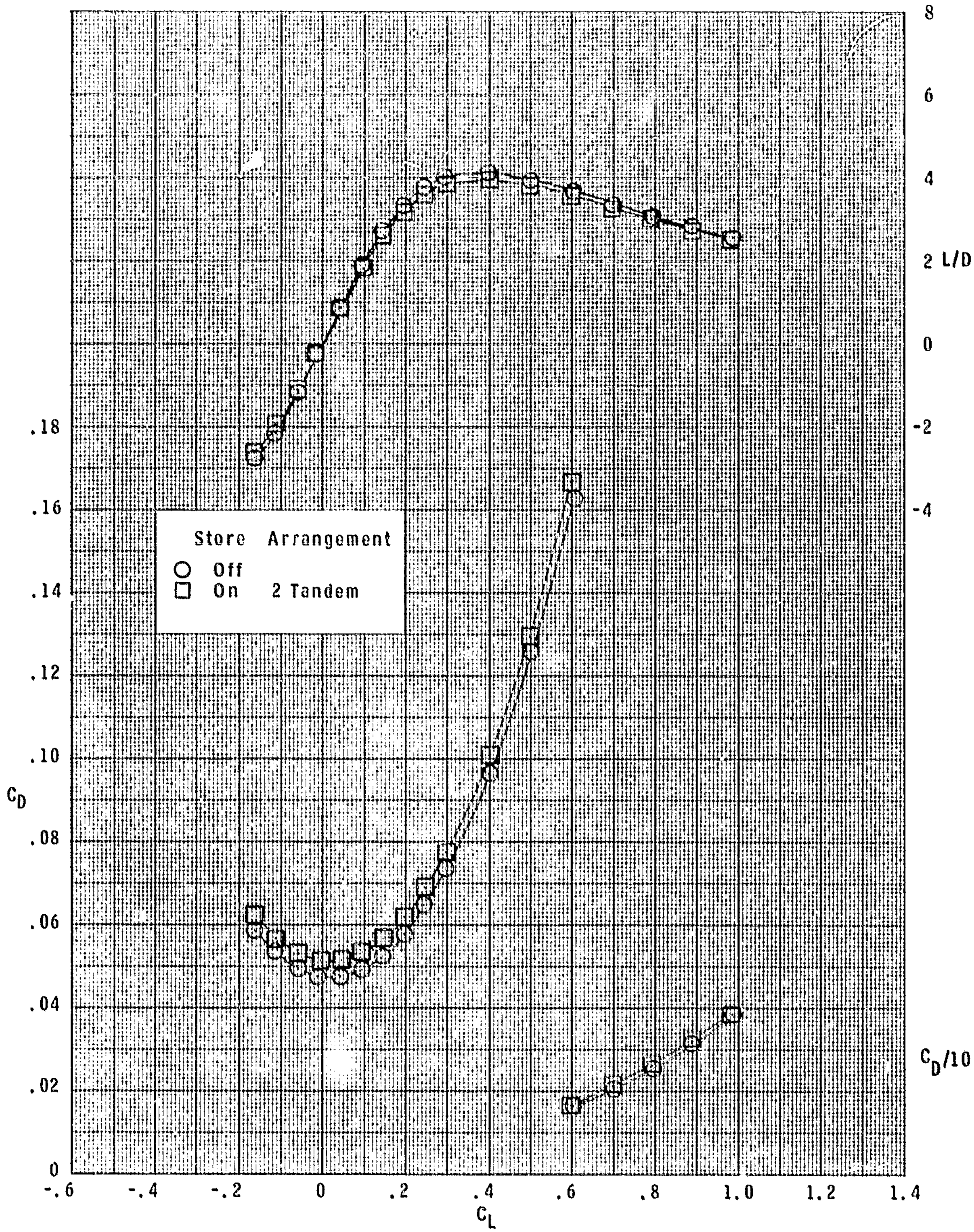
(a) Concluded.

Figure 9.- Continued.



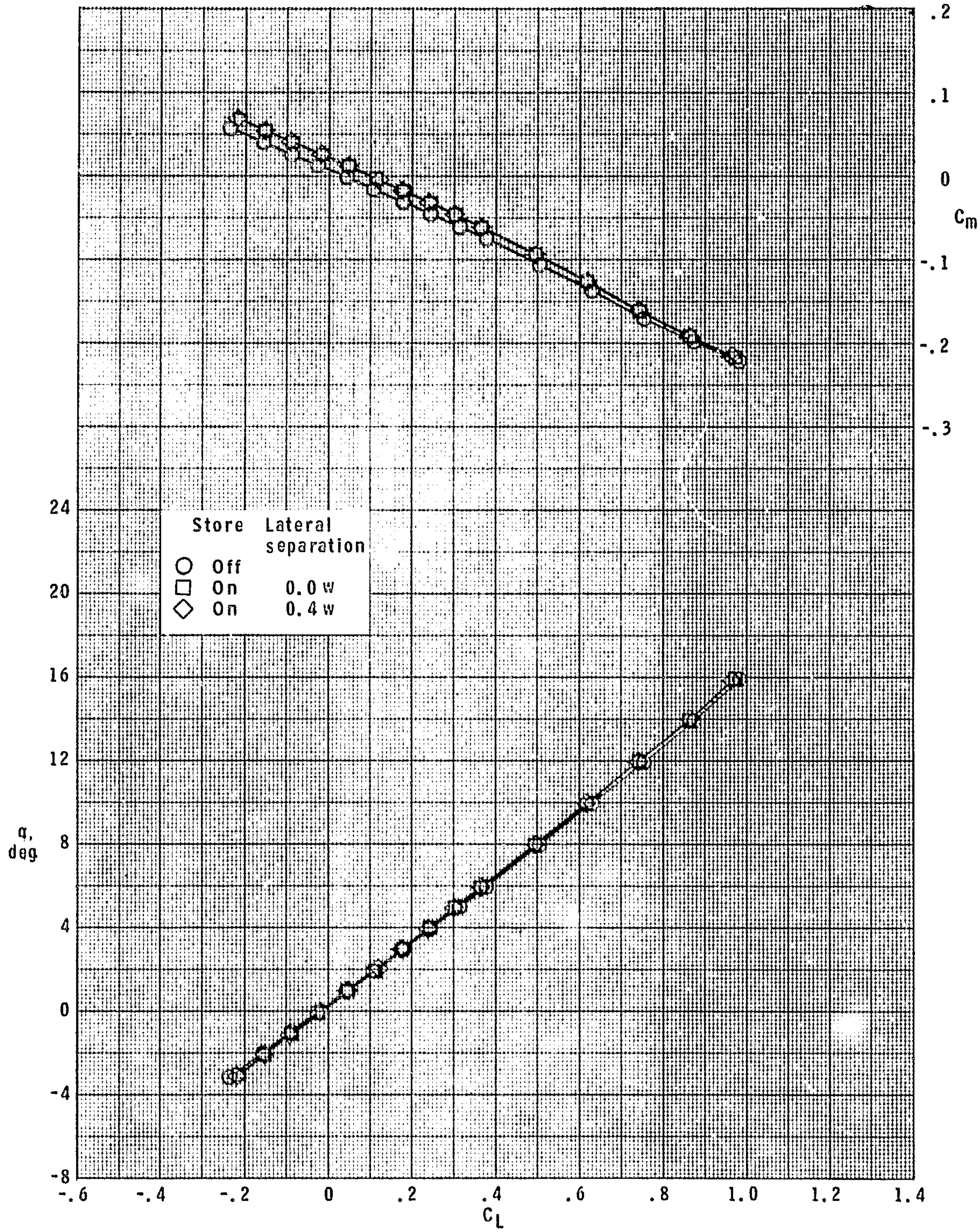
(b) M = 2.00.

Figure 9.- Continued.



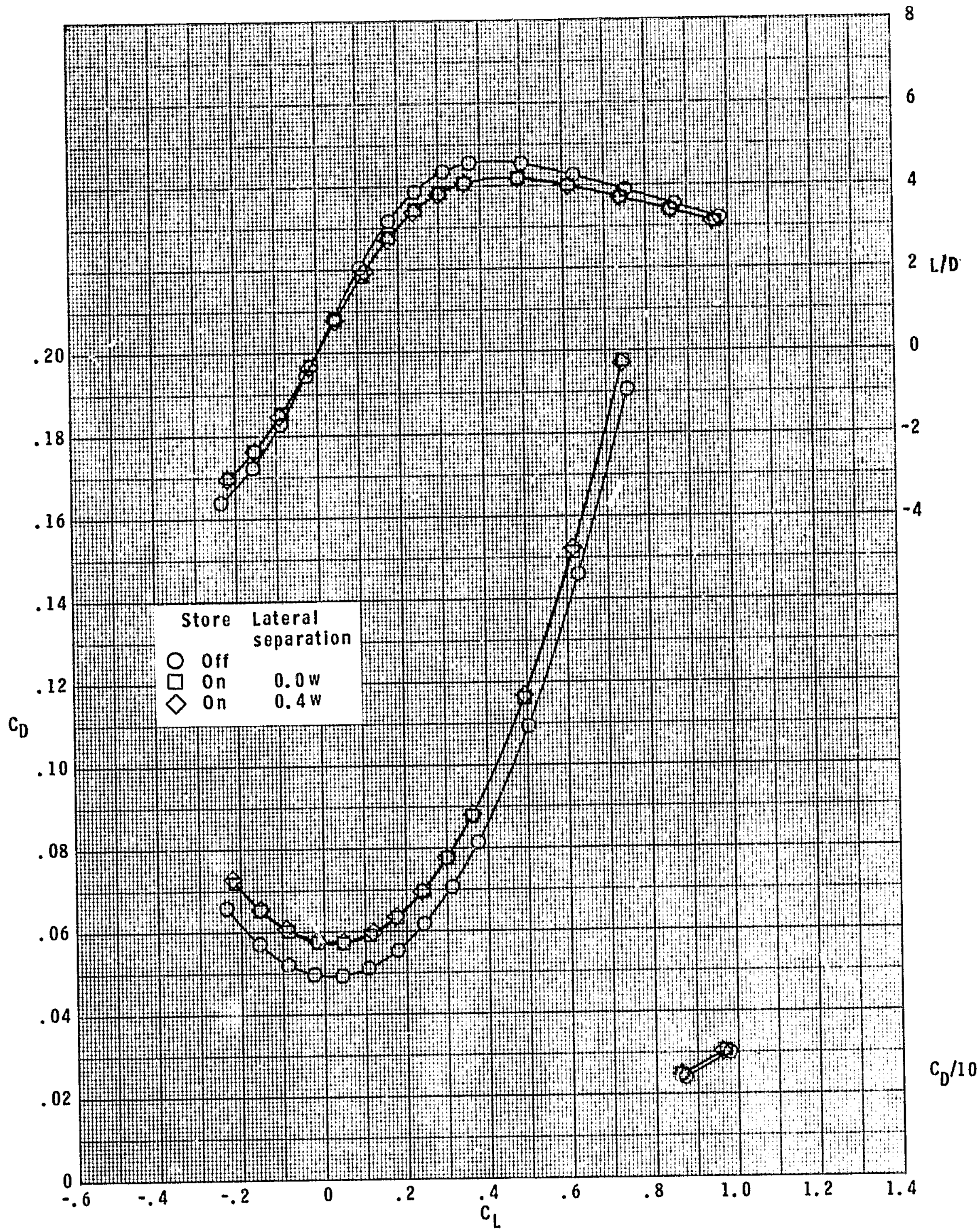
(b) Concluded.

Figure 9.- Concluded.



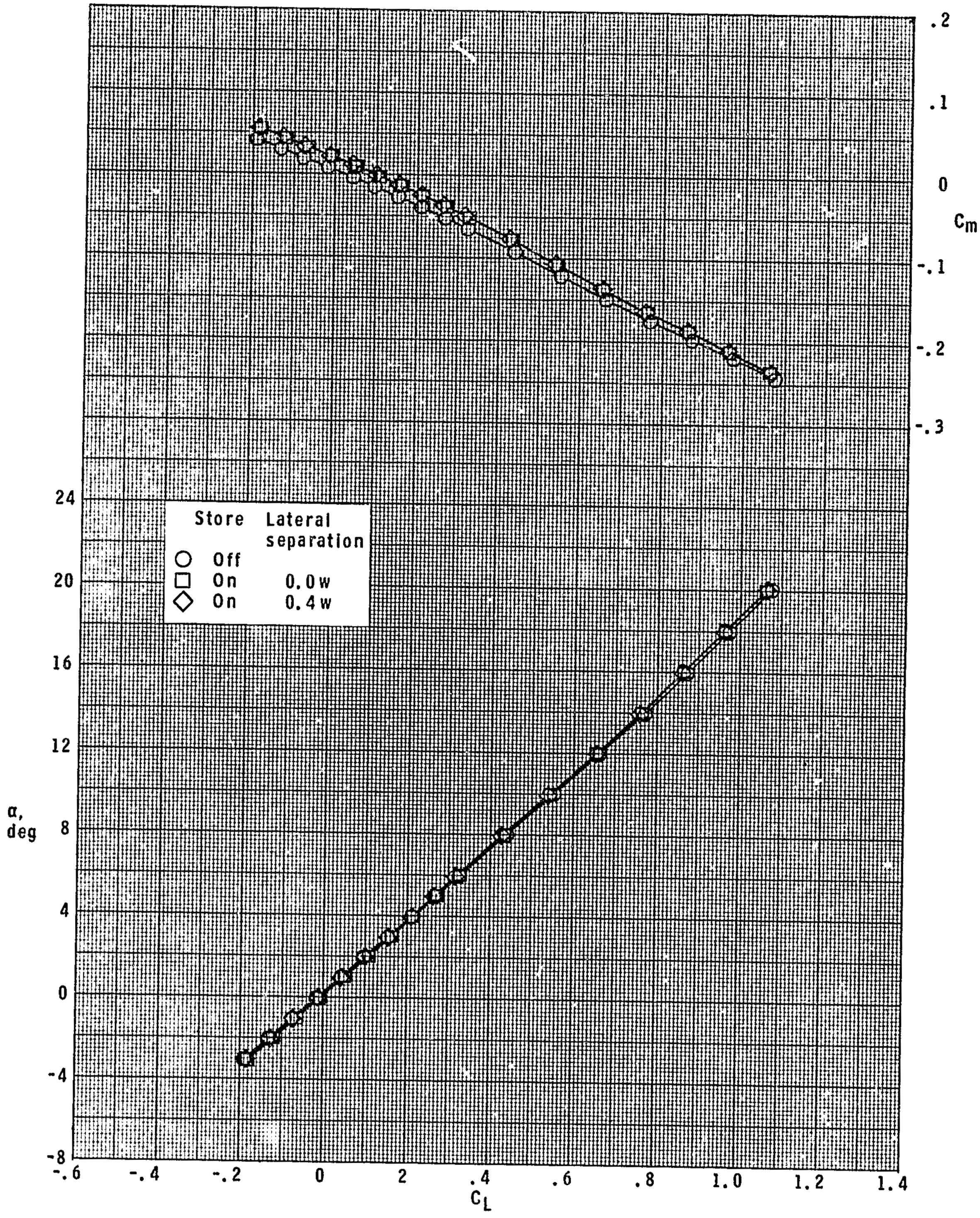
(a) M = 1.60.

Figure 10.- Effect of lateral separation of four square stores on longitudinal characteristics; modified F-16A, ventral fins removed.



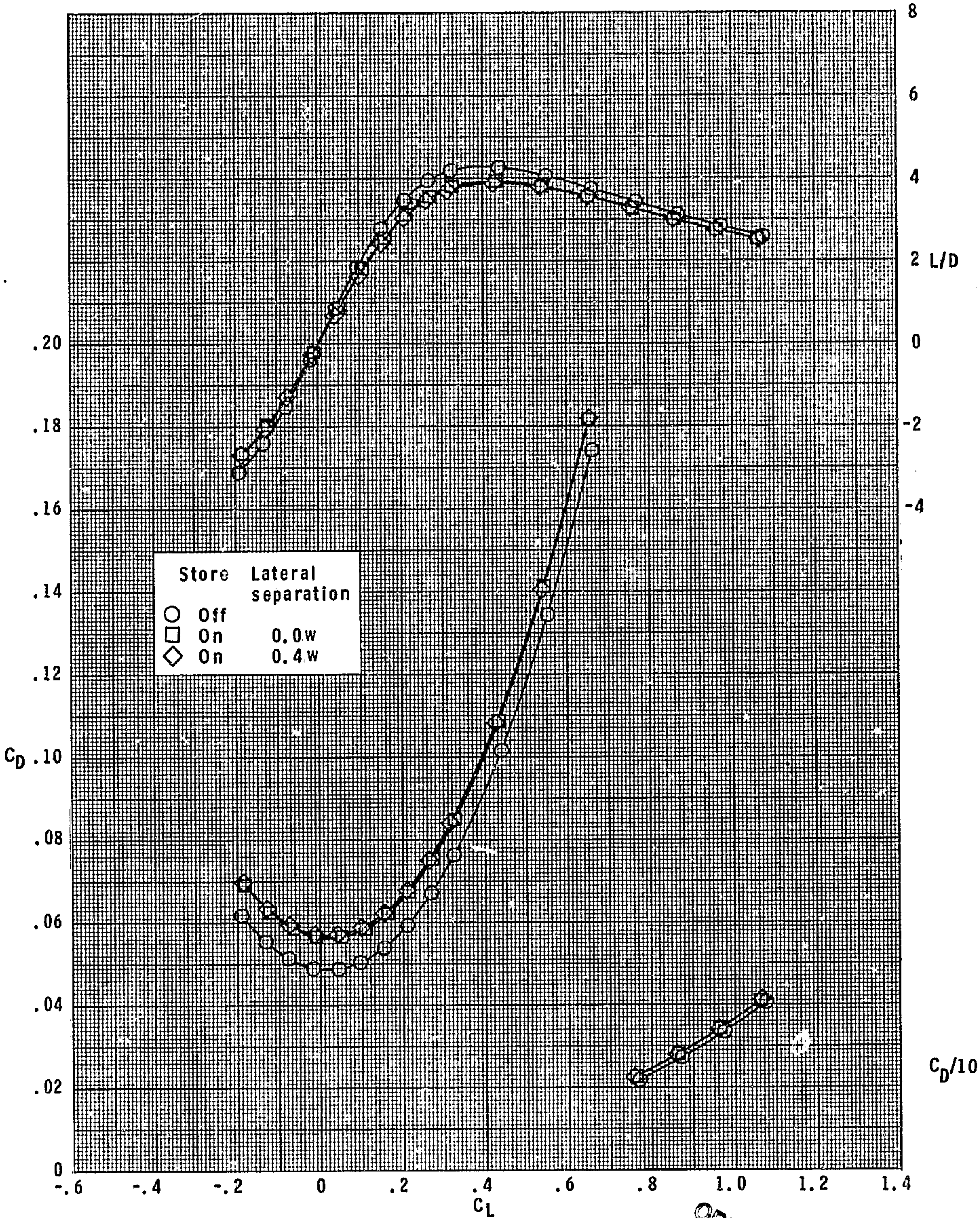
(a) Concluded.

Figure 10.- Continued.



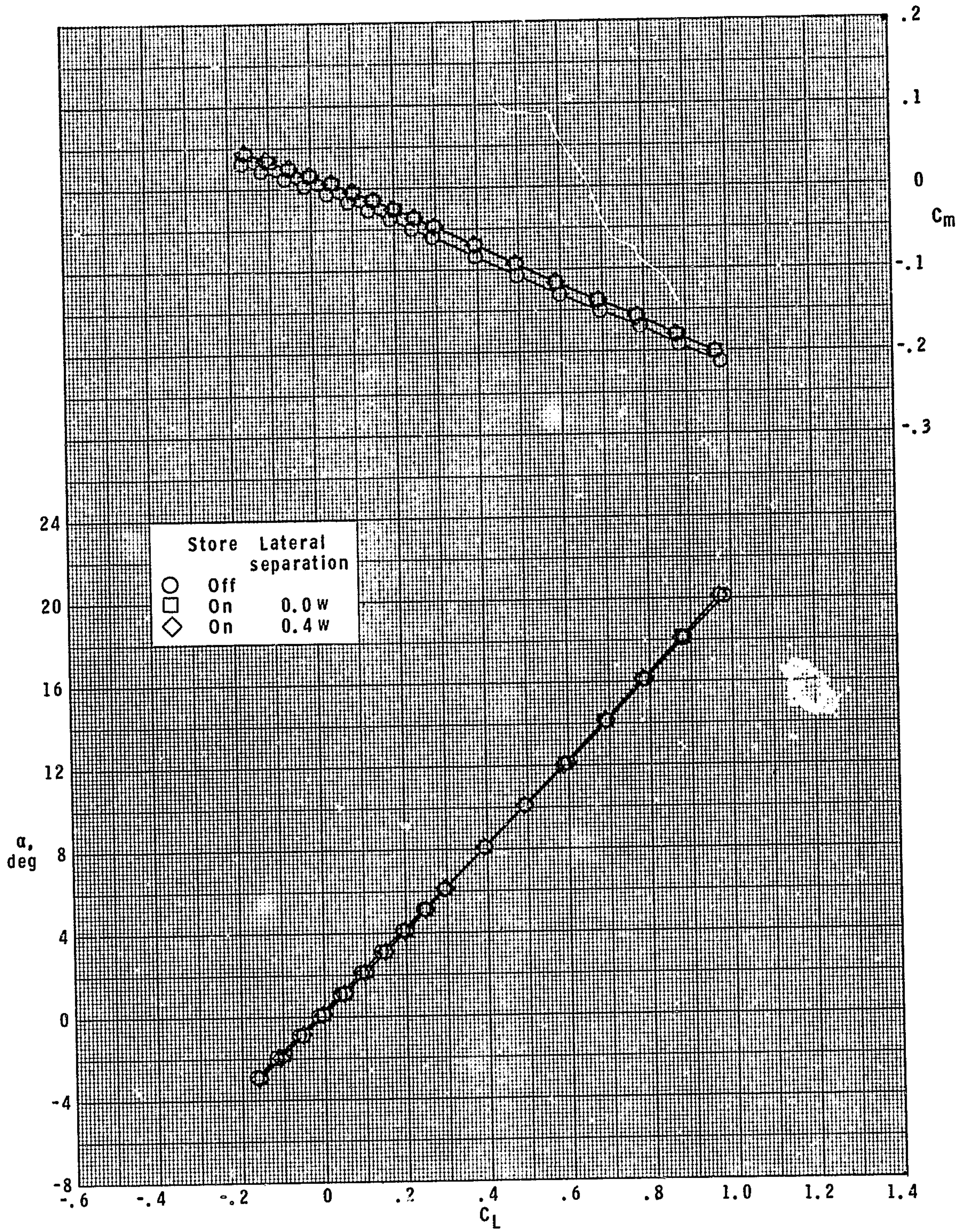
(b) M = 1.80.

Figure 10.- Continued.



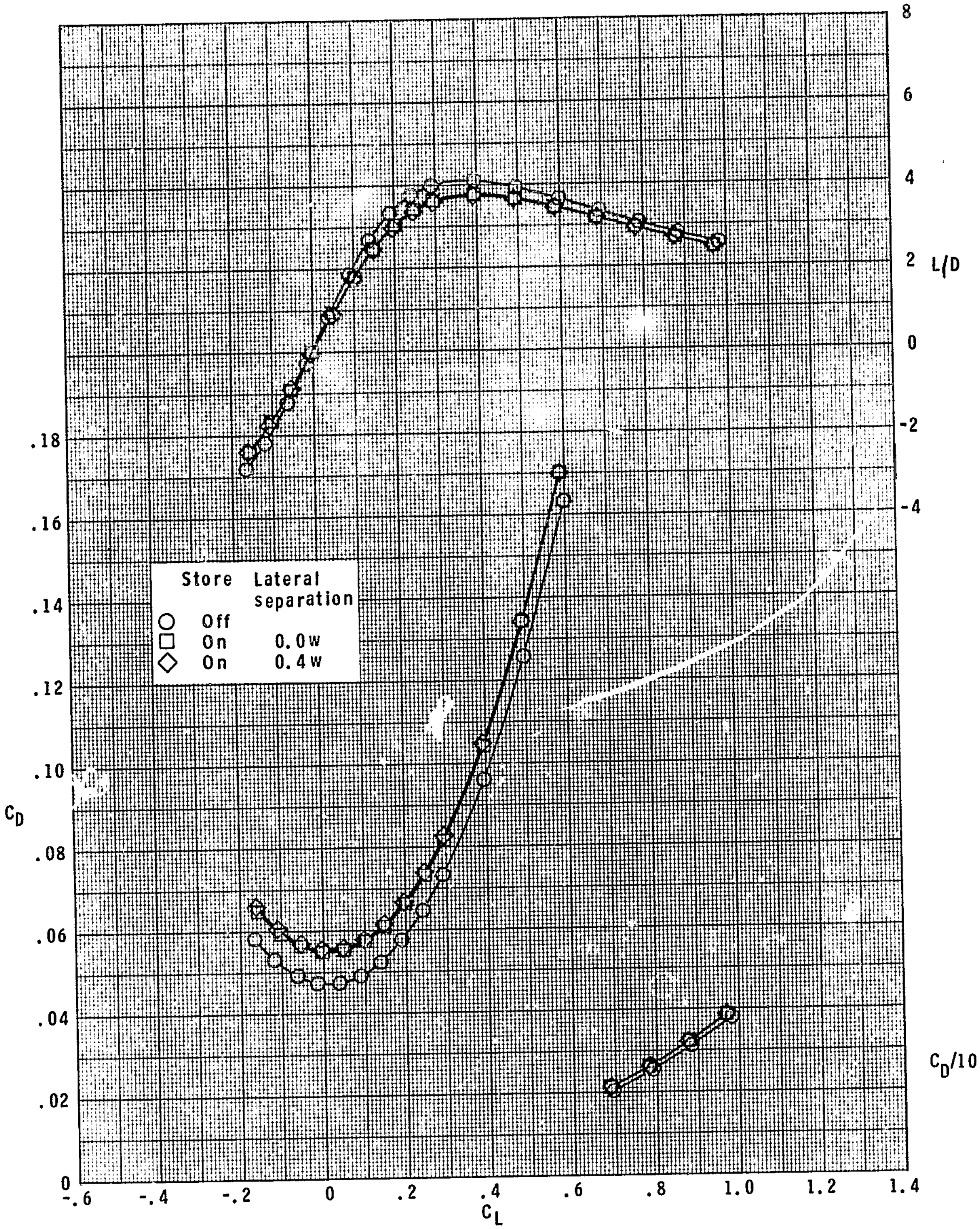
(b) Concluded.

Figure 10.- Continued.



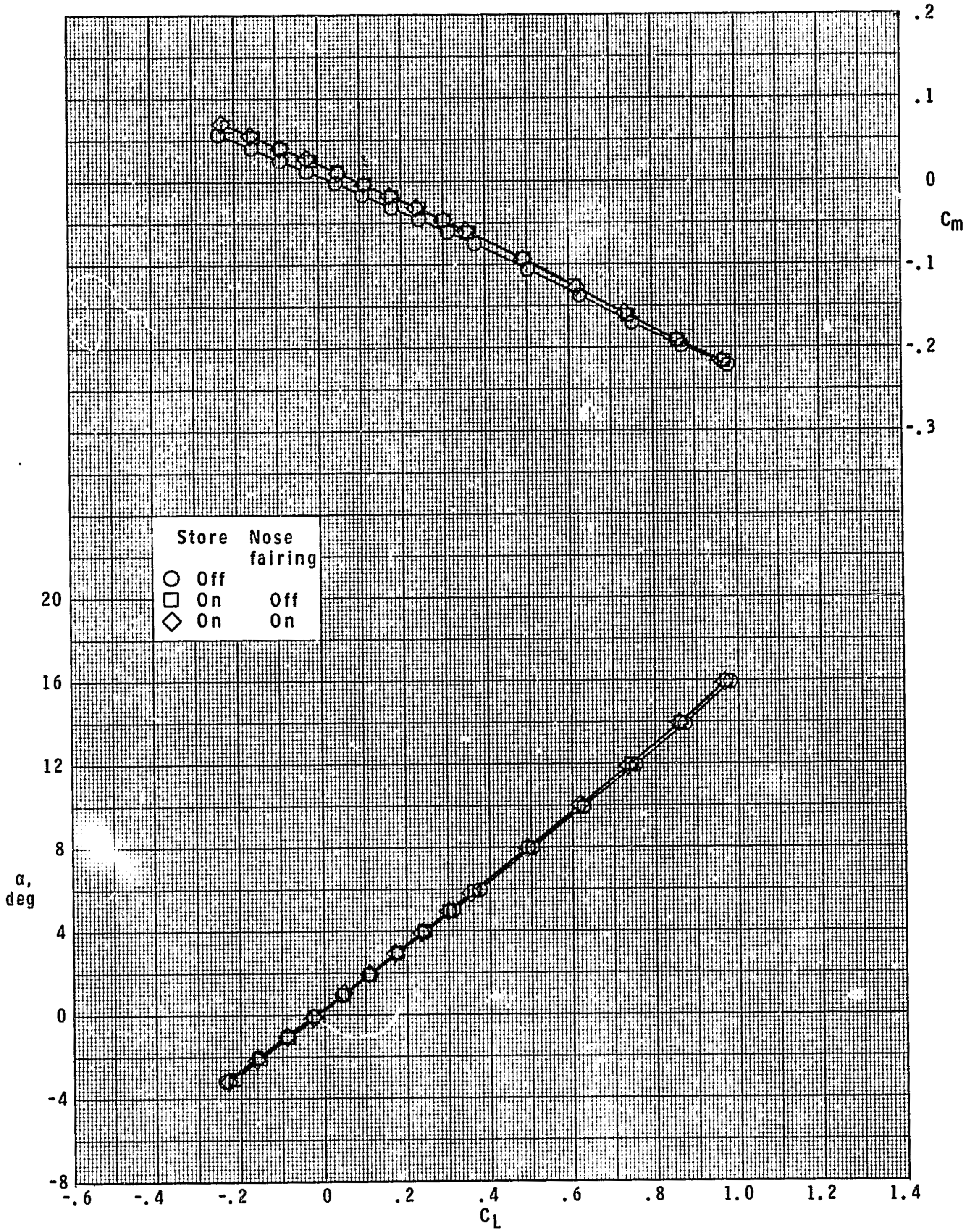
(c) M = 2.00.

Figure 10.- Continued.



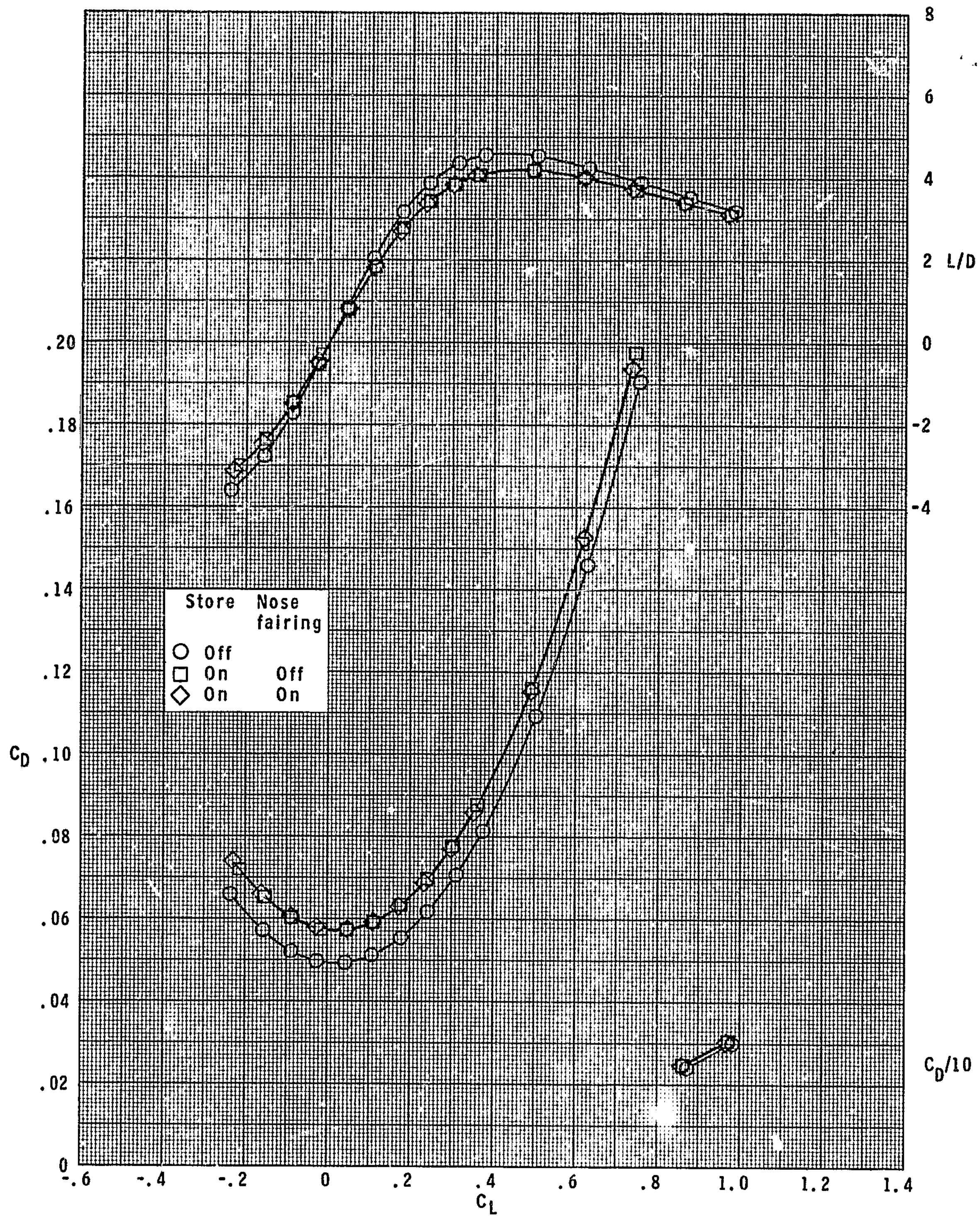
(c) Concluded.

Figure 10.- Concluded.



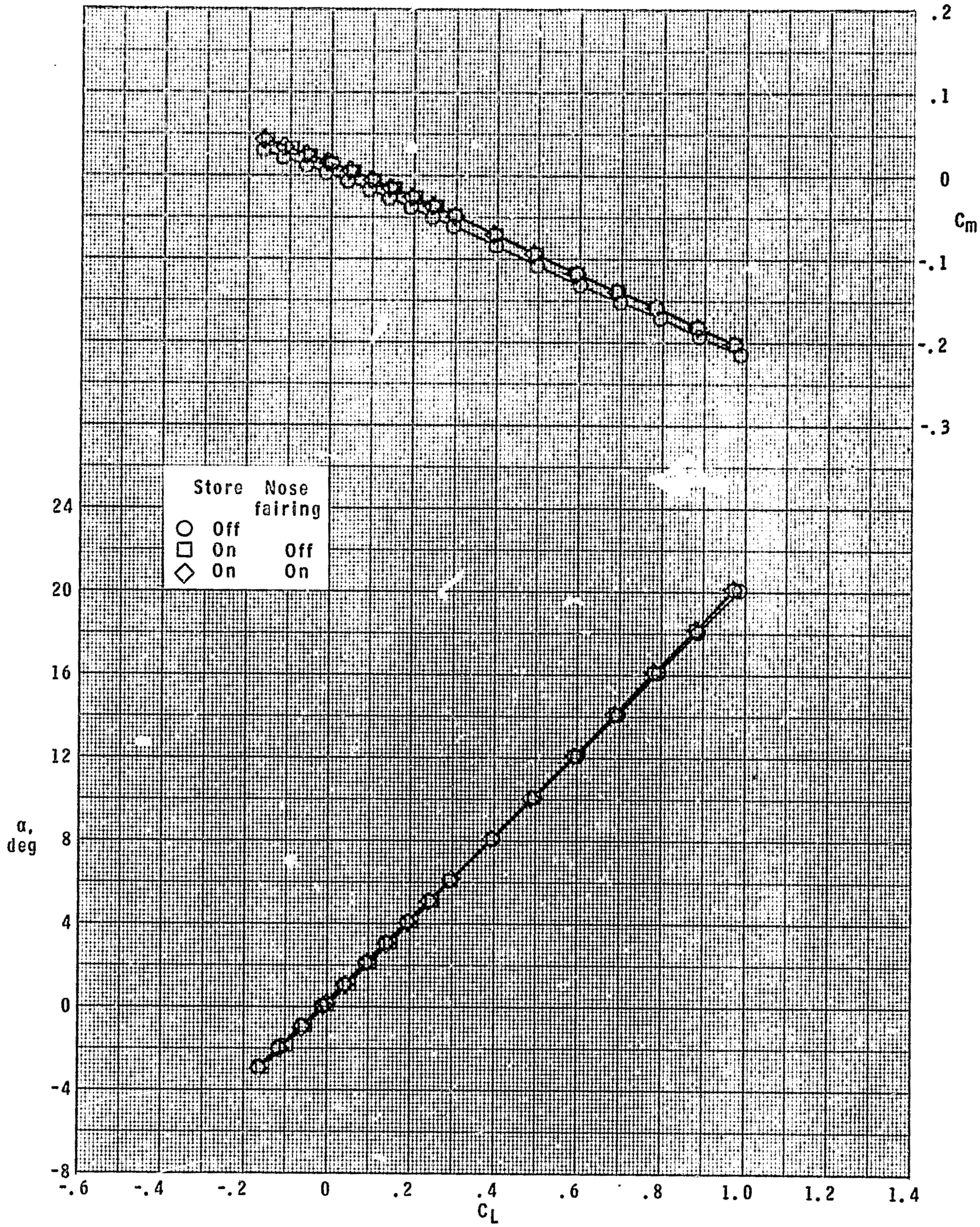
(a) M = 1.60.

Figure 11.- Effect of four square stores, sides touching on longitudinal characteristics; modified F-16A, ventral fins removed.



(a) Concluded.

Figure 11.- Continued.



(b) M = 2.00.

Figure 11.- Continued.

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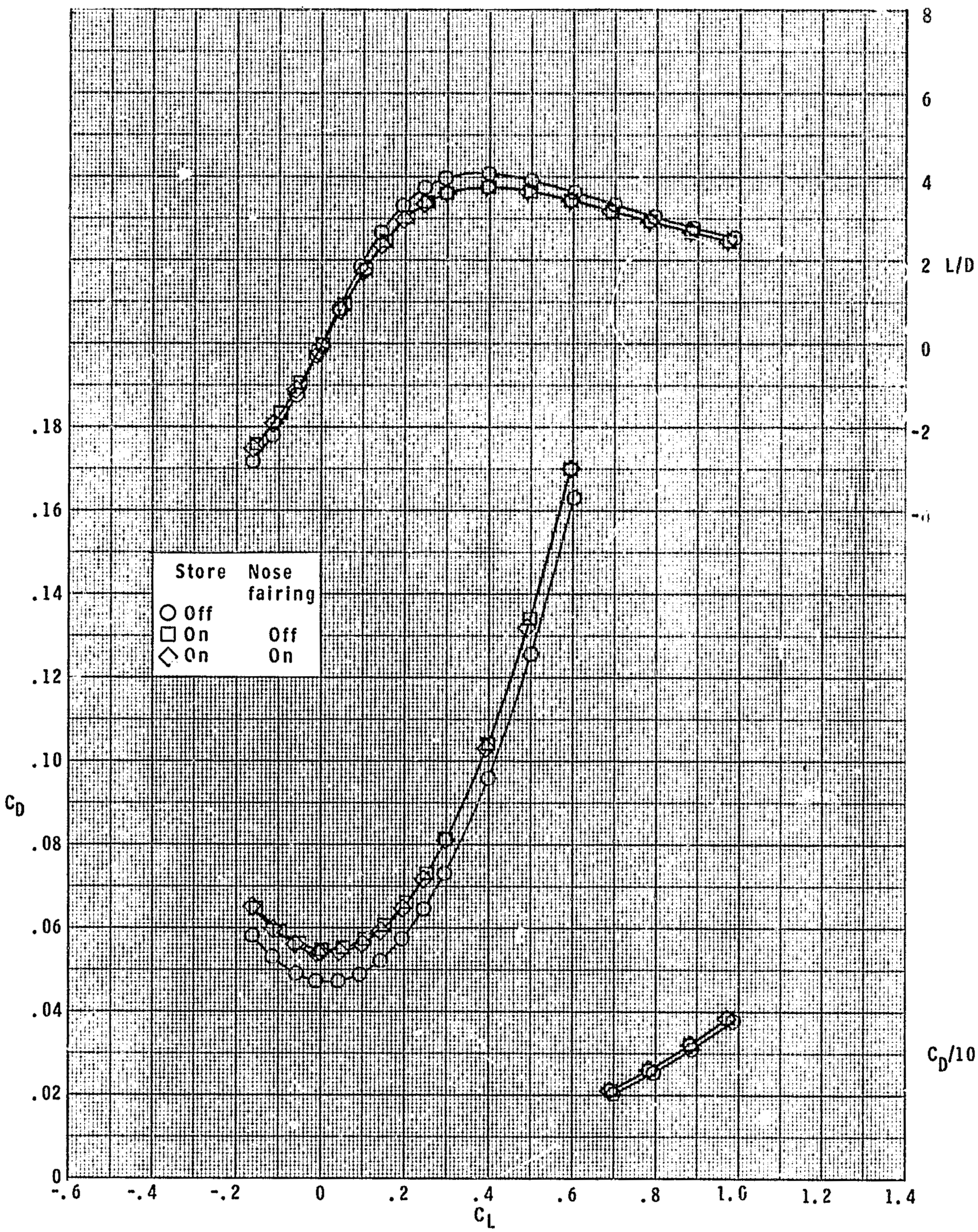
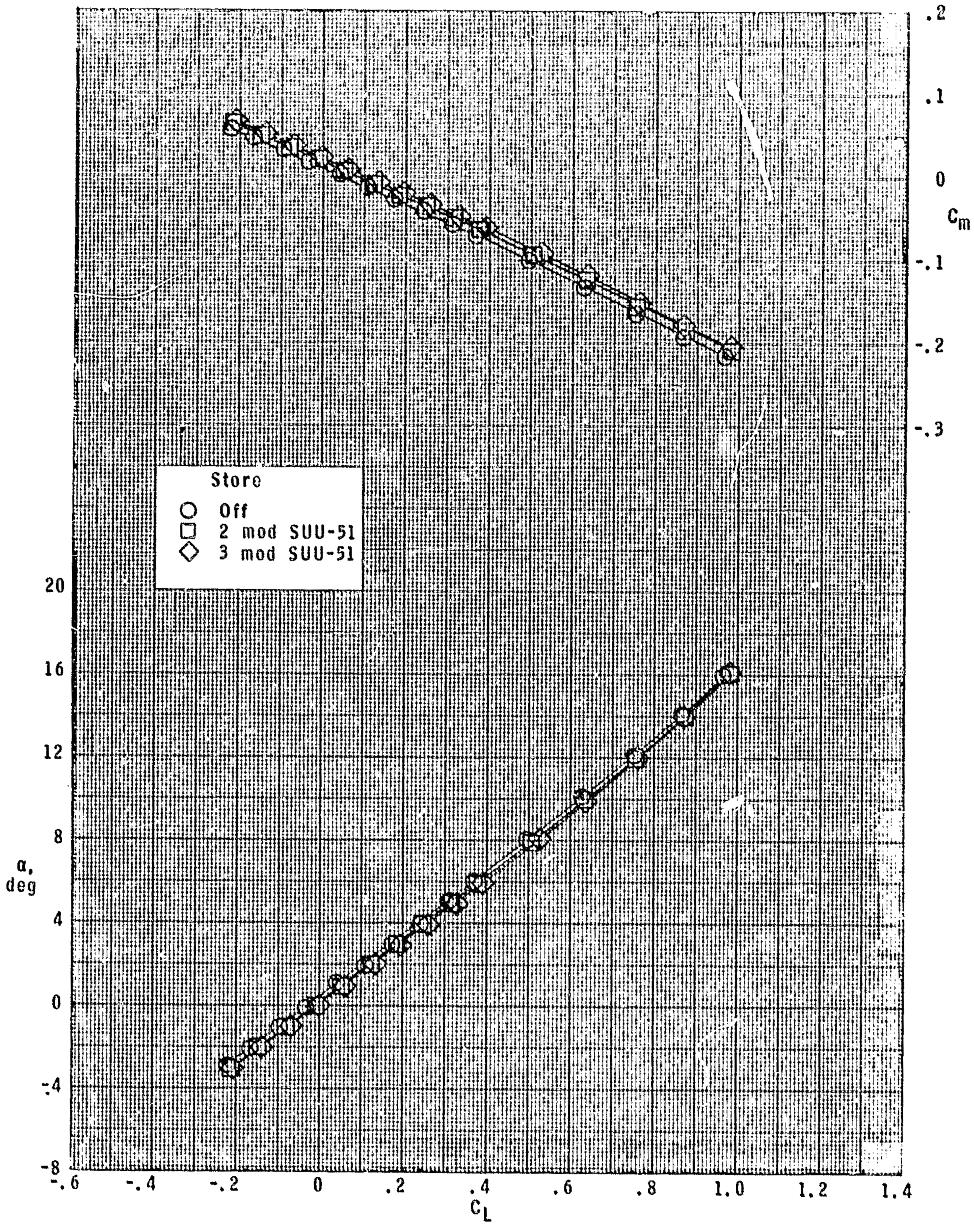


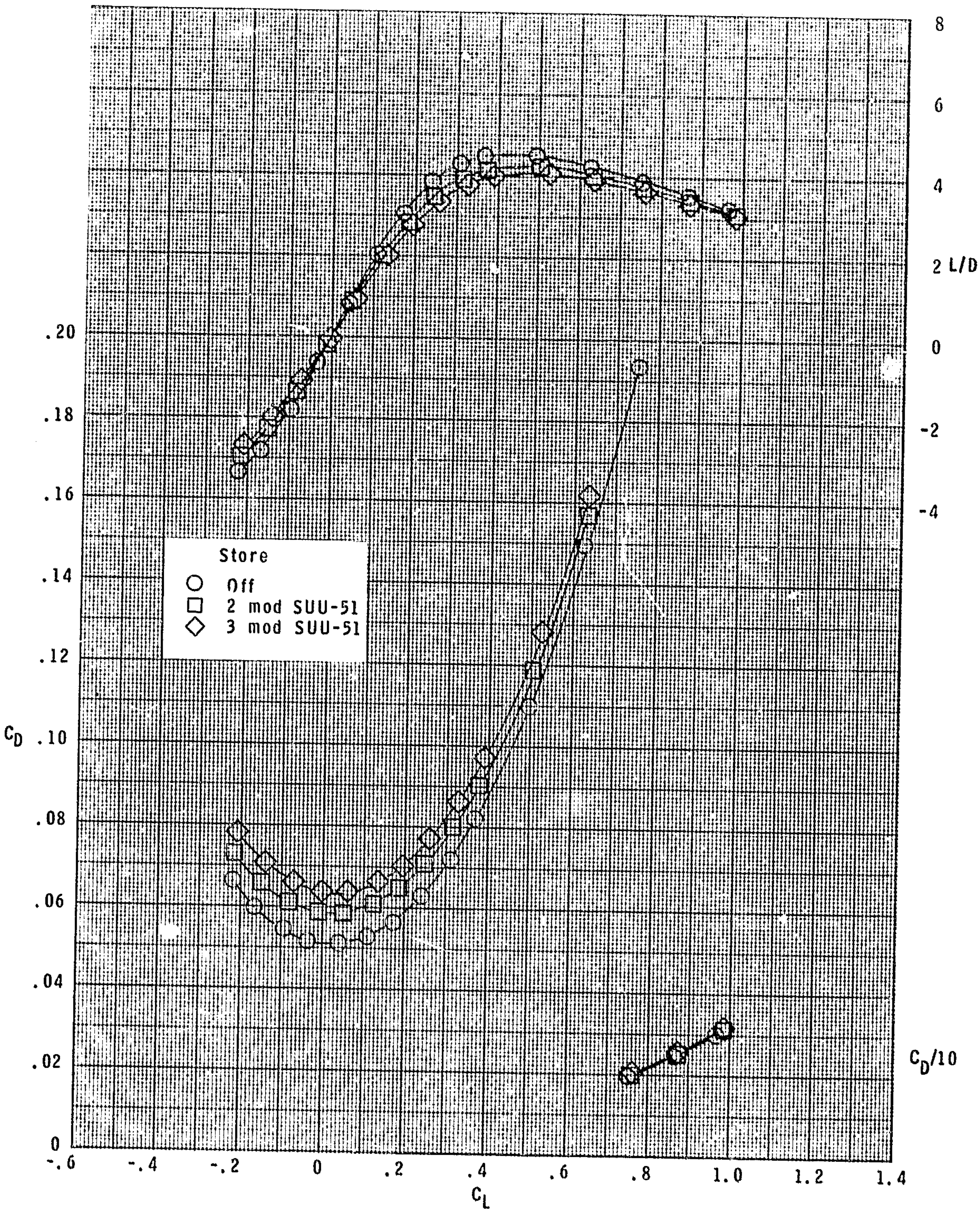
(c) Concluded.

Figure 11.- Concluded.



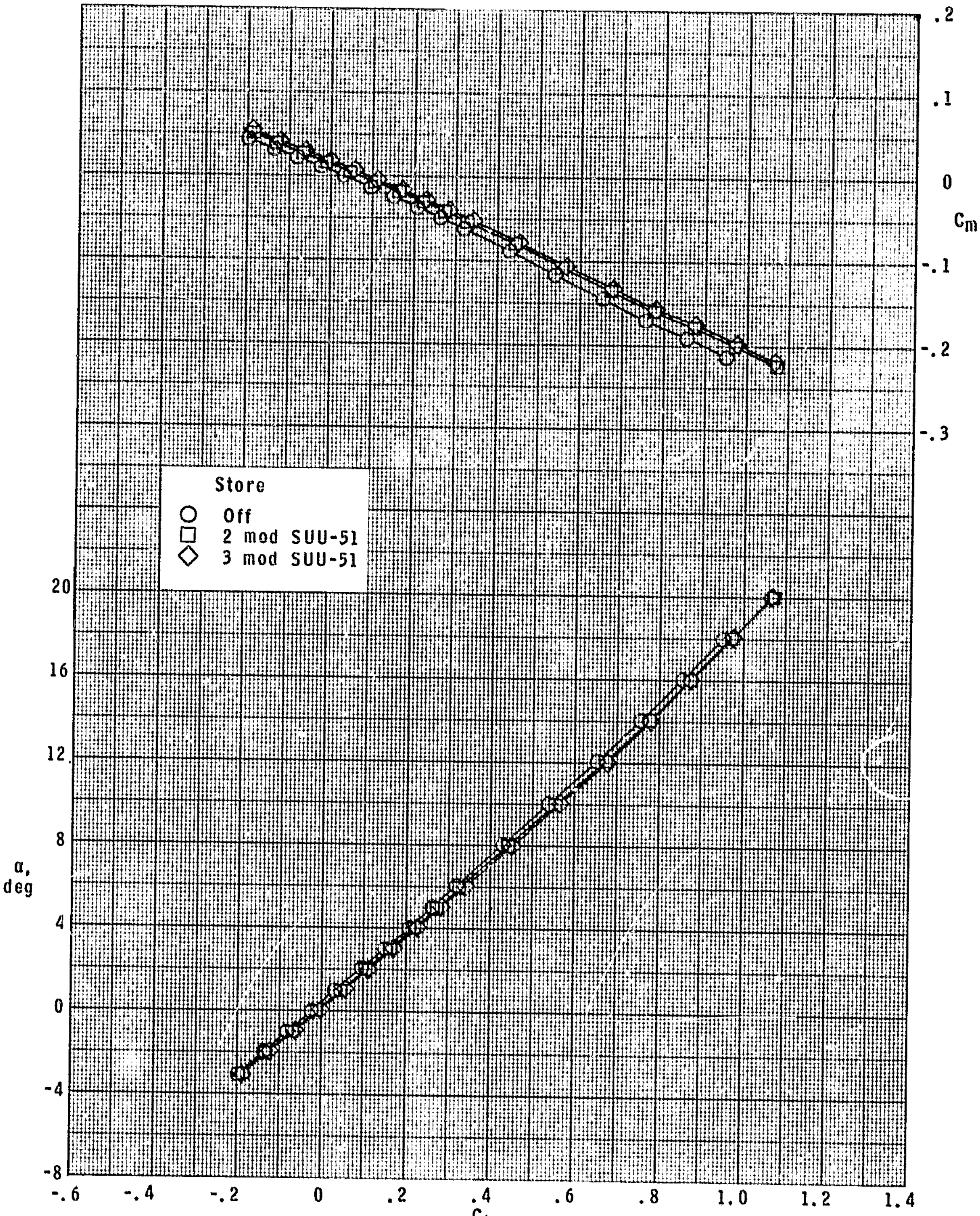
(a) M = 1.60.

Figure 12.- Effect of two- and three-store arrangements of modified SUU-51 on longitudinal characteristics; modified F-16A.



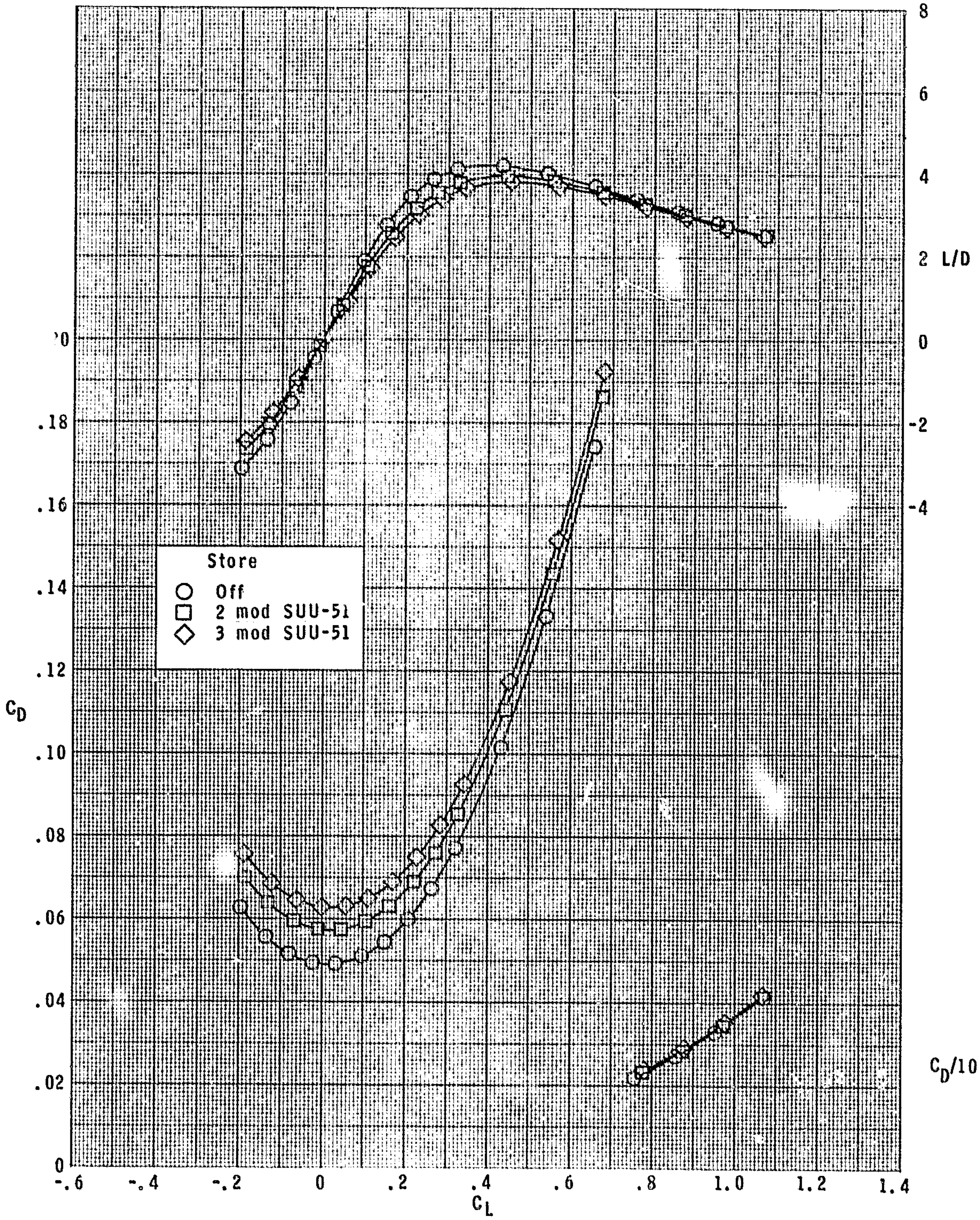
(a) Concluded.

Figure 12.- Continued.



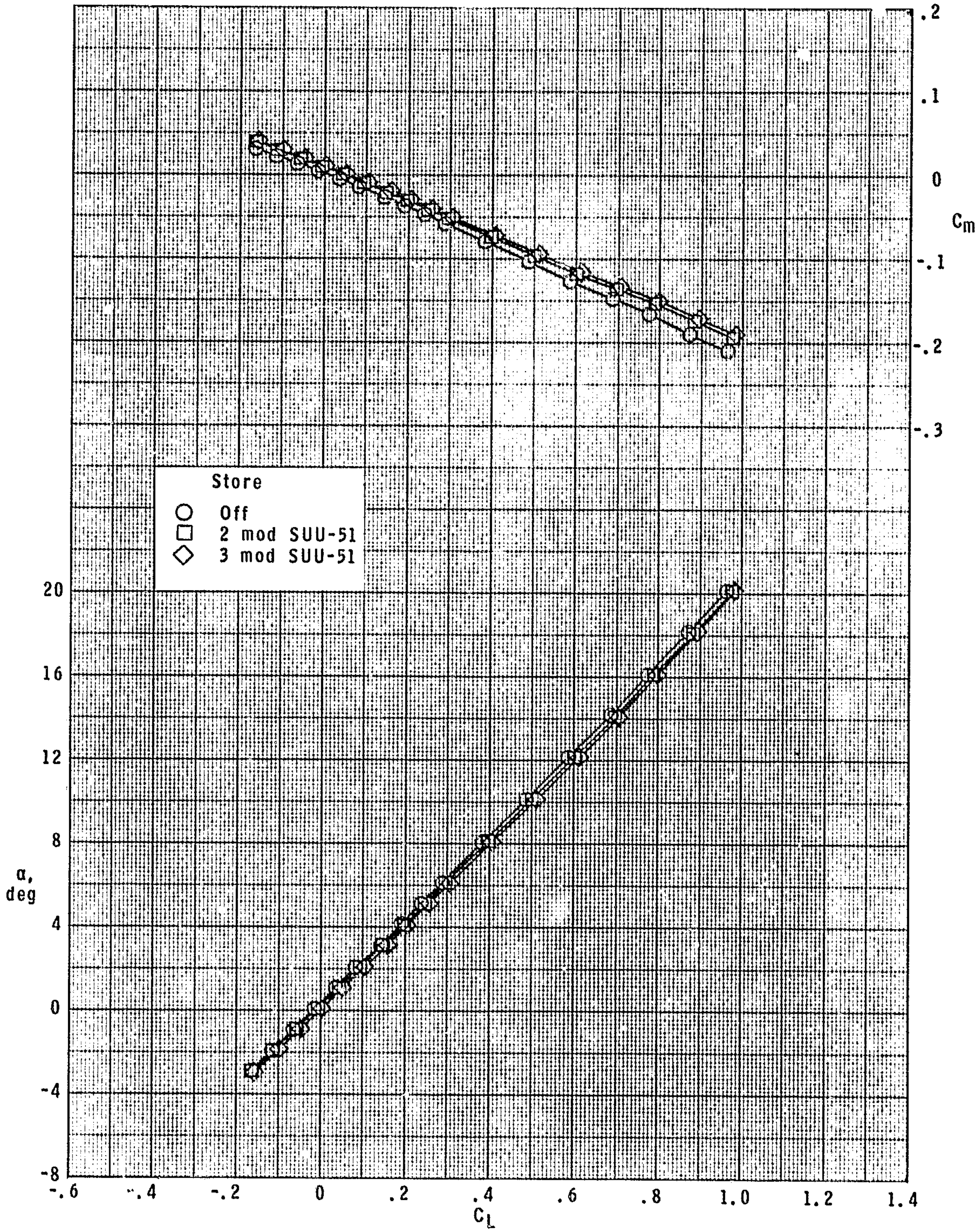
(b) M = 1.80.

Figure 12.- Continued.



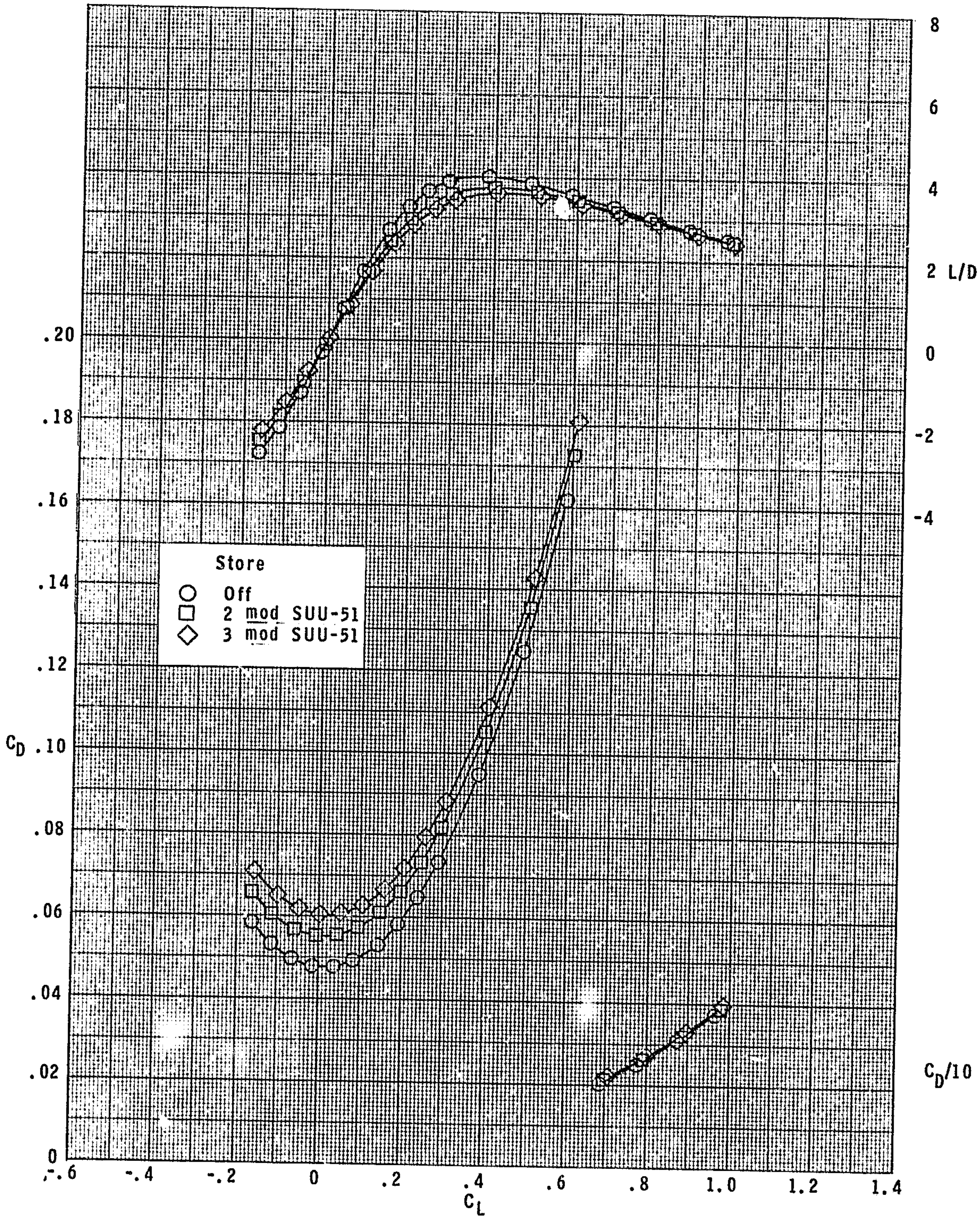
(b) Concluded.

Figure 12.- Continued.



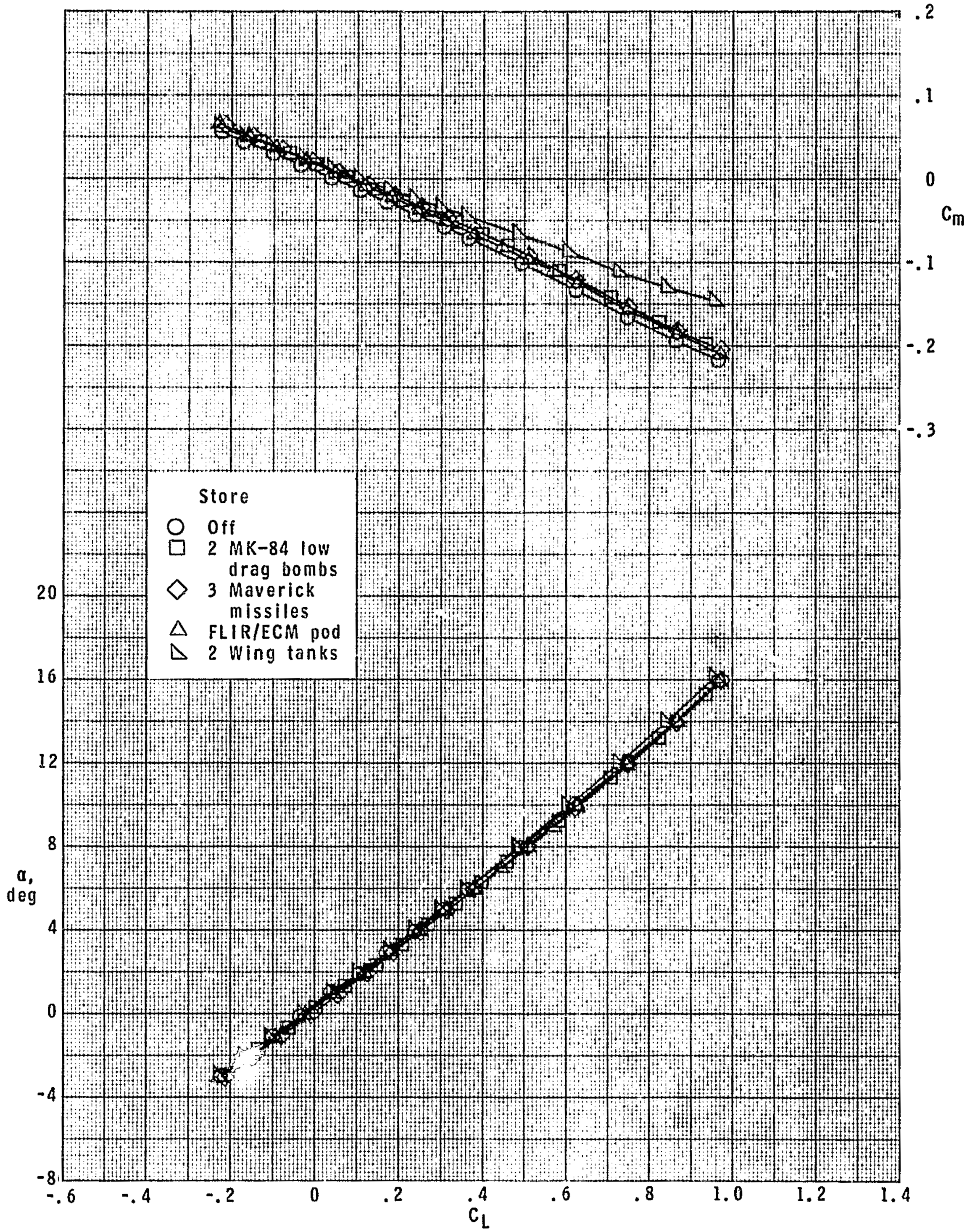
(c) M = 2.00.

Figure 12.- Continued.



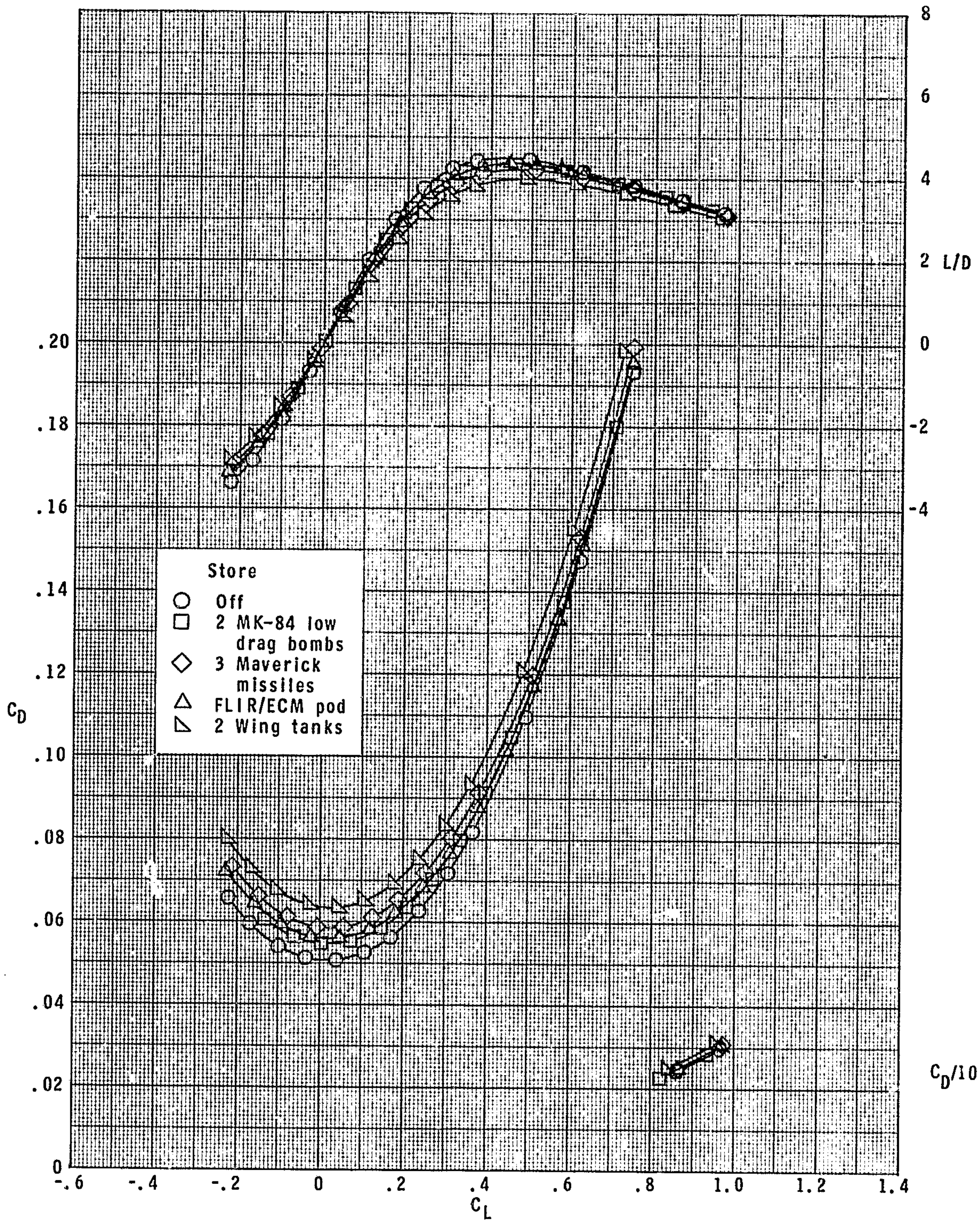
(c) Concluded.

Figure 12.- Concluded.



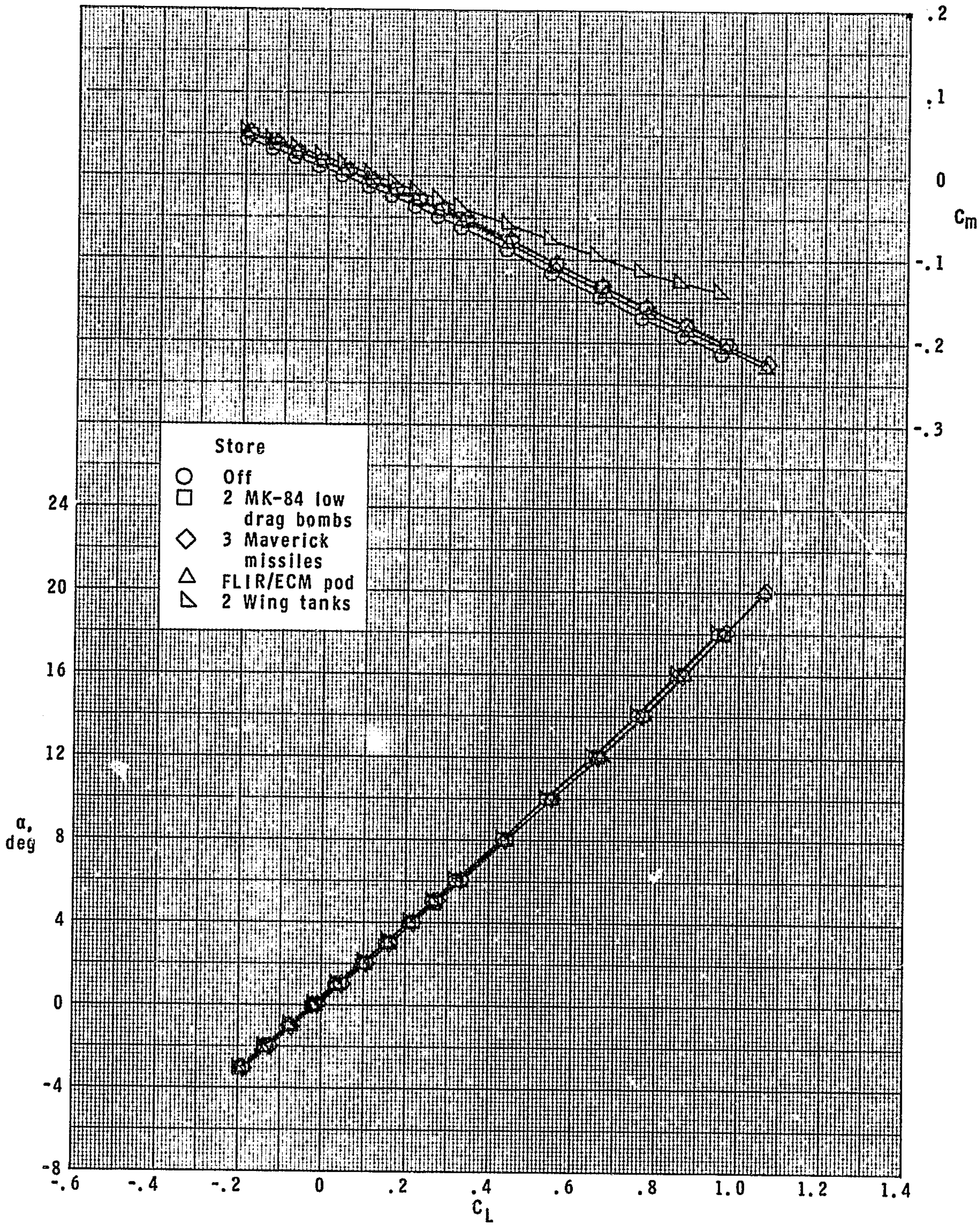
(a) M = 1.60.

Figure 13.- Effect of several conventional stores on longitudinal characteristics; modified F-16A.



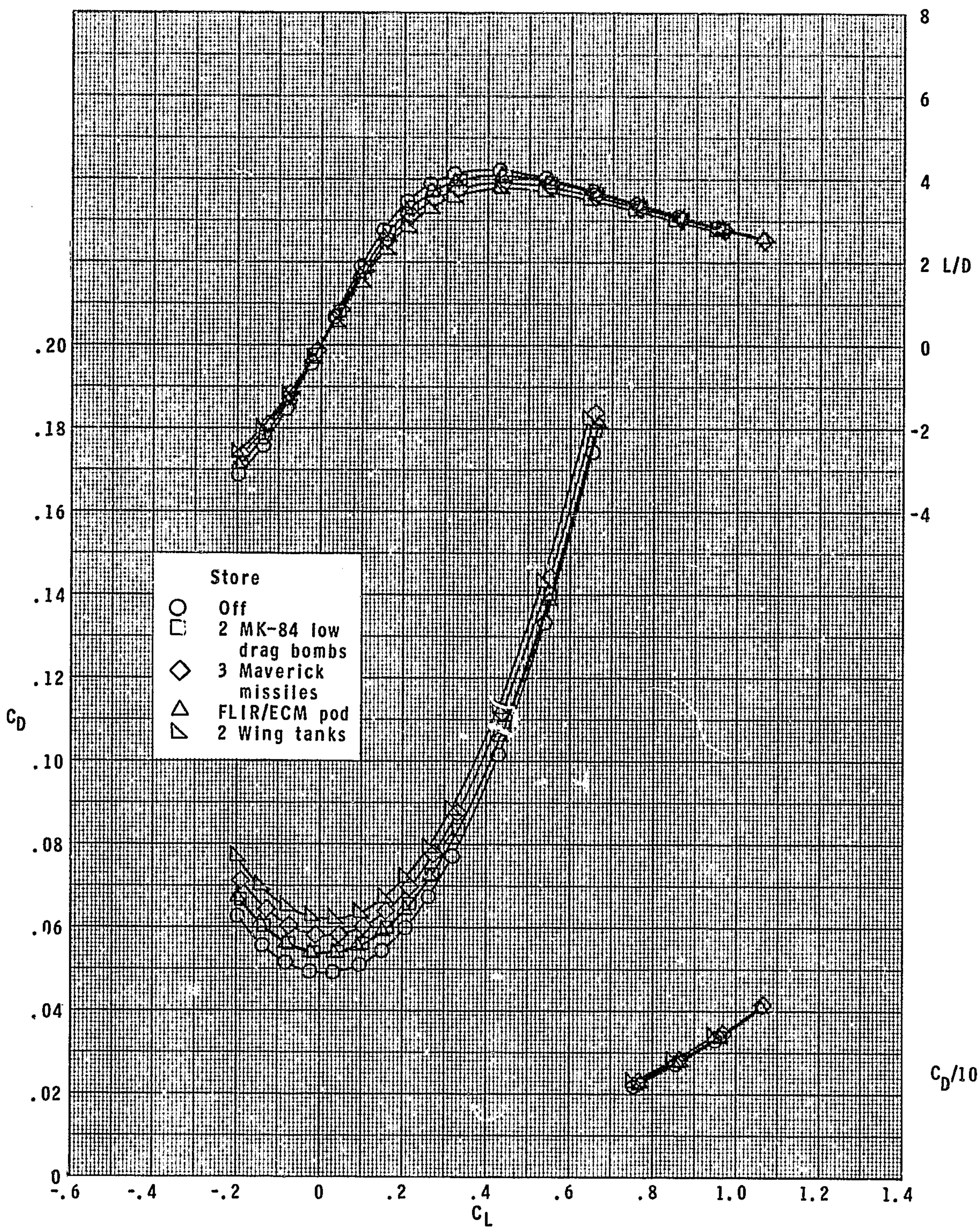
(a) Concluded.

Figure 13.- Continued.



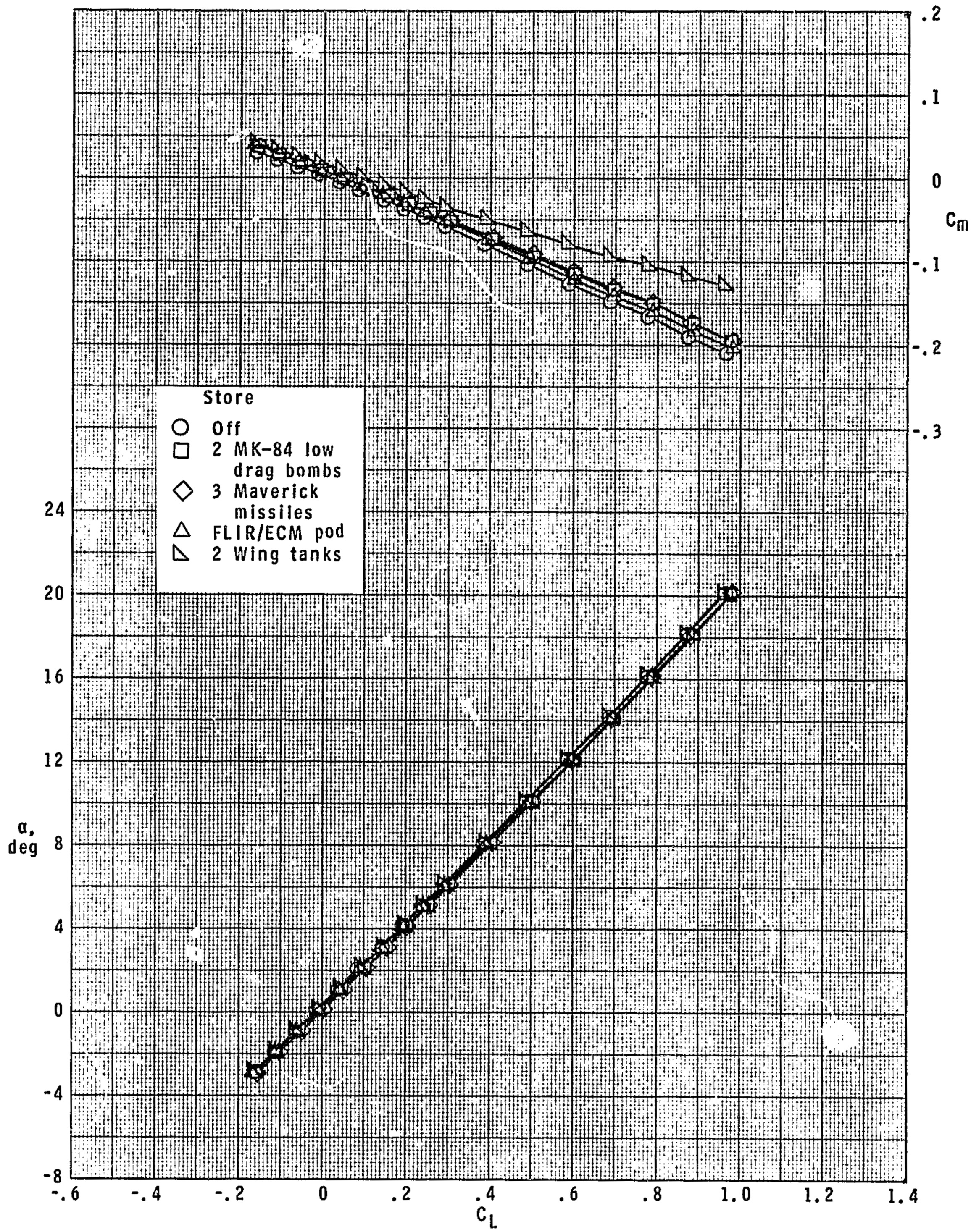
(b) M = 1.80.

Figure 13.- Continued.



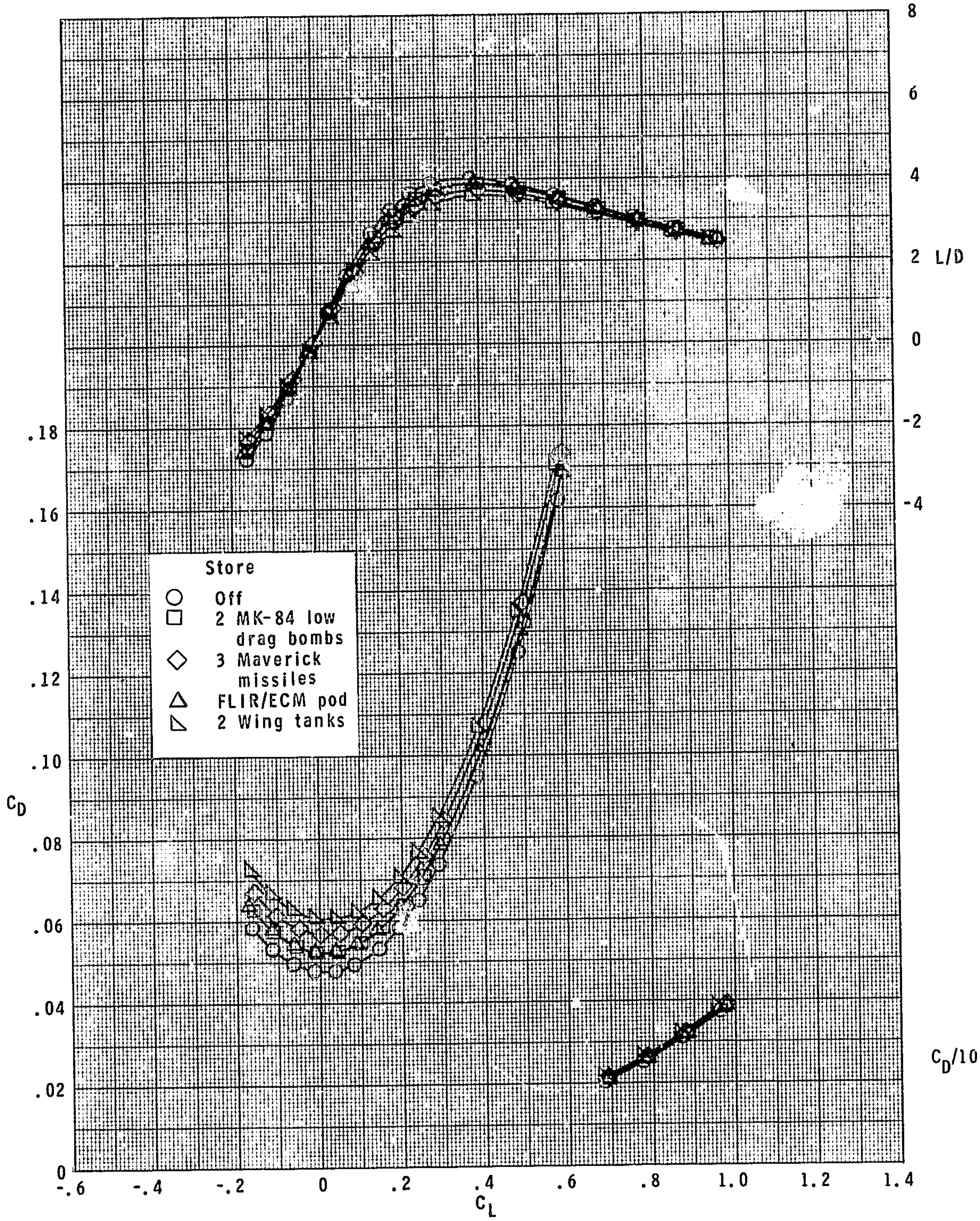
(b) Concluded.

Figure 13.- Continued.



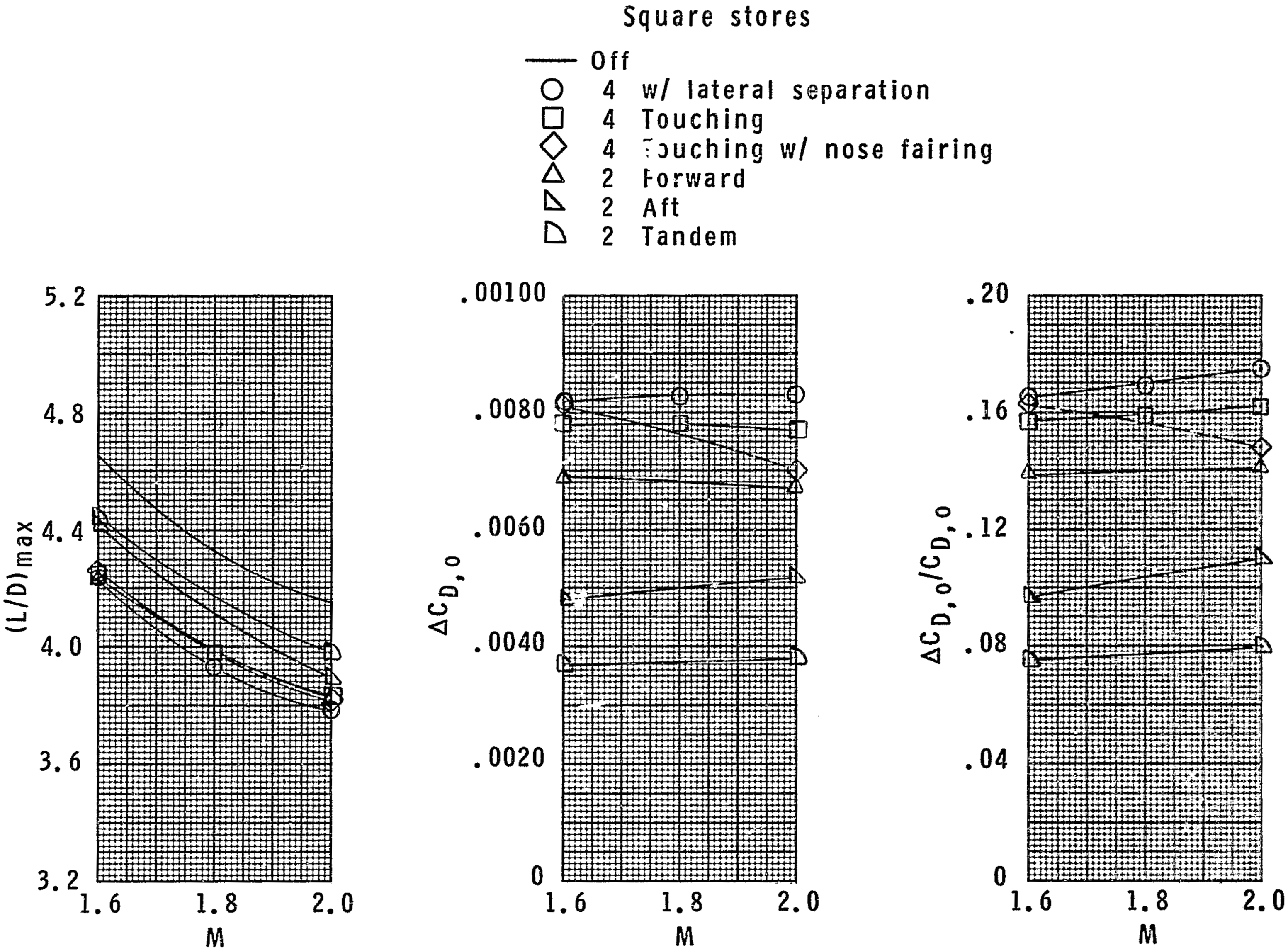
(c) M = 2.00.

Figure 13.- Continued.



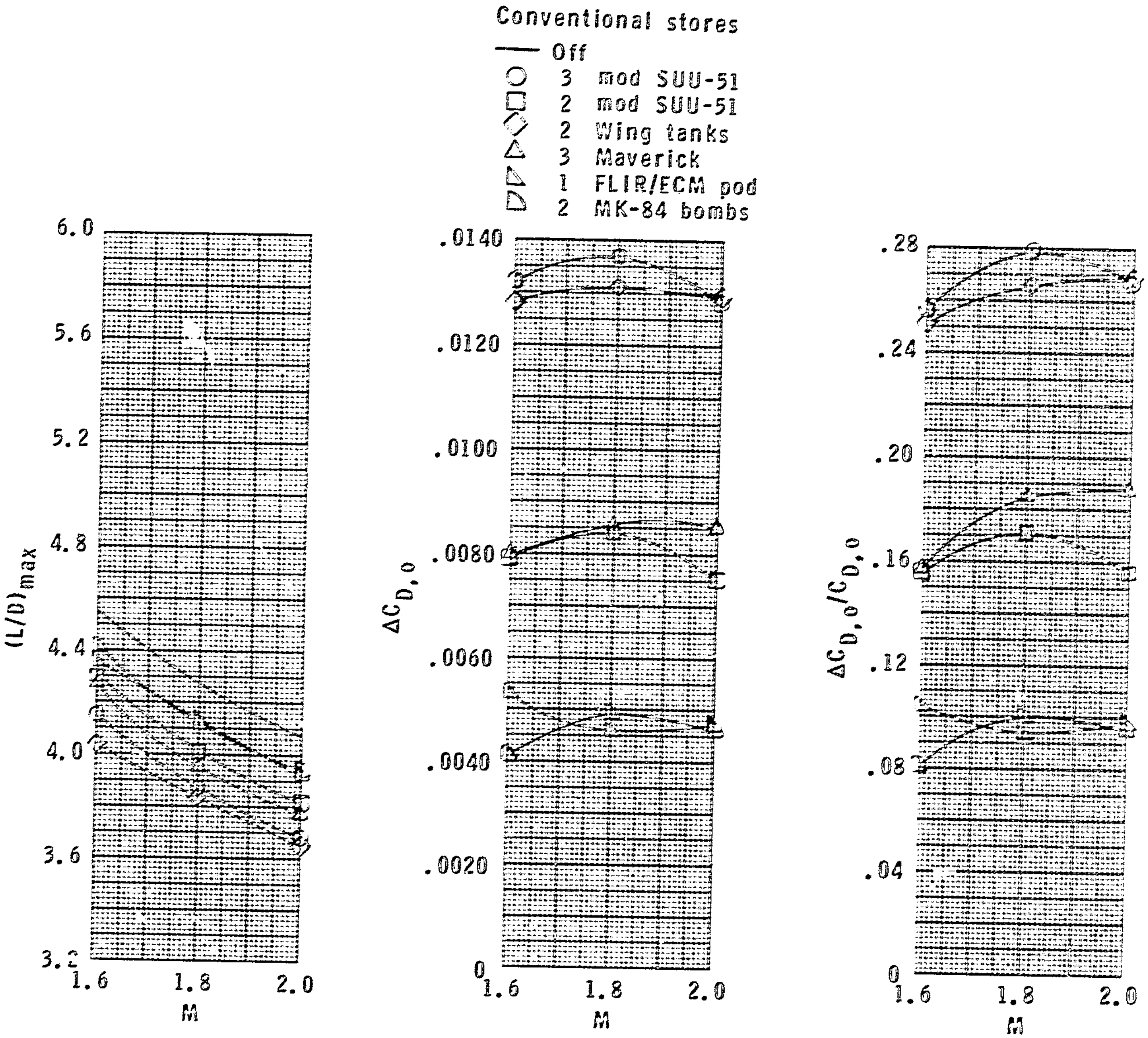
(c) Concluded.

Figure 13.- Concluded.



(a) Square stores.

Figure 14.- Comparison of $(L/D)_{max}$, $\Delta C_{D,o}$, and $\Delta C_{D,o}/C_{D,o}$ for various store configurations.



(b) Conventional stores.

Figure 14.- Concluded.

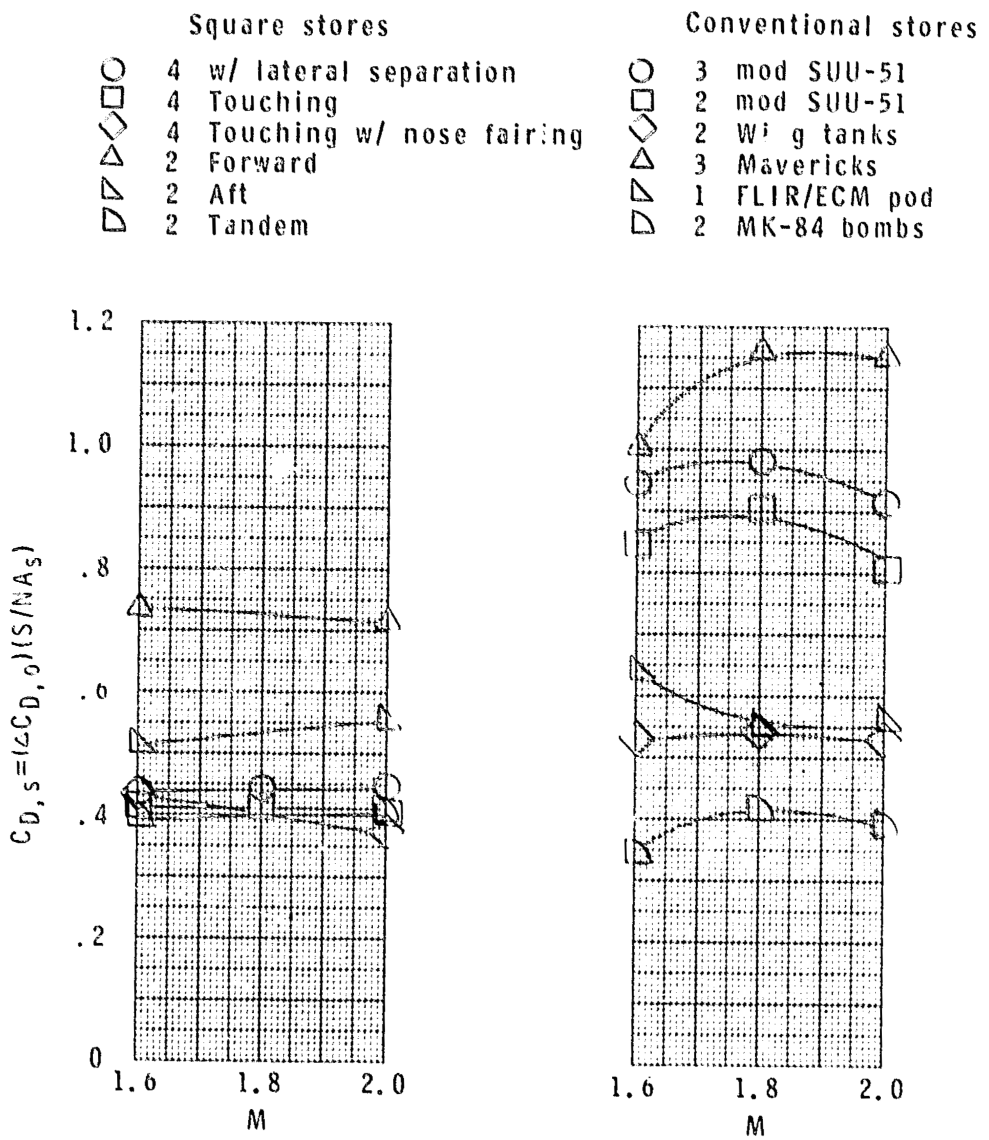


Figure 15.- Comparison of $C_{D,s}$ for various store configurations.