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AFATL-TR-75-111

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**EFFECT OF THE GBU-15 (CRUCIFORM WING)
AND GBU-15 (PLANAR WING) STORES
ON THE AERODYNAMIC CHARACTERISTICS
OF THE F-4C AIRCRAFT**

**PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE 37389**

November 1975

Final Report for Period April 28 through May 2, 1975

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**AIR FORCE ARMAMENT LABORATORY (AFATL/DLJC)
EGLIN AIR FORCE BASE, FLORIDA 32542**

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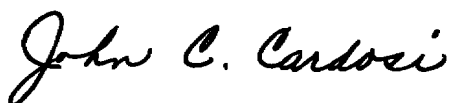
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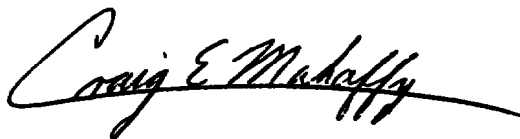
APPROVAL STATEMENT

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



JOHN C. CARDOSI
Lt Colonel, USAF
Chief Air Force Test Director, PWT
Directorate of Test



CRAIG E. MAHAFFY
Colonel, USAF
Director of Test

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PREFACE

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), at the request of the Air Force Armament Laboratory (AFATL/DLGC), AFSC, under Program Element 62602F, Project 2567. The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project No. P41H-02A. The author of this report was Eddie S. Washington, ARO, Inc. The manuscript (ARO Control No. ARO-PWT-TR-75-121) was submitted for publication on July 23, 1975.

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1.0 INTRODUCTION

The primary purpose of the F-4C aircraft is for air-to-air missile combat missions with a secondary purpose of limited tactical missions. However, over the past few years the F-4C role as a tactical fighter-bomber utilizing external carriage of various stores has taken on greater importance. Therefore, the need for more information on the behavior of the F-4C while performing these tactical missions has also taken on greater significance.

The purpose of this investigation was to determine the effect of carriage of the GBU-15 (cruciform wing) and the GBU-15 (planar wing) stores on the longitudinal stability and drag characteristics of the F-4C. These stores belong to the relatively new generation of winged, guided glide bombs. To determine the changes in longitudinal stability and drag characteristics, a wind tunnel test was conducted in the Aerodynamic Wind Tunnel (4T) of the AEDC Propulsion Wind Tunnel Facility (PWT) utilizing 0.05-scale models of the F-4C aircraft and 15 store combinations of interest. Force and moment data were taken over a Mach number range from 0.6 to 1.1 at a constant stagnation pressure of 2,500 psfa. The model attitude was varied in pitch from -4 to 20 deg. The bulk of the data were obtained for a stabilator angle of 0 deg (1-deg incidence angle with respect to the waterline). A limited amount of data for selected configurations was taken at stabilator settings of -2.5 and 5 deg; however, only data for a 0-deg stabilator setting are presented in this report.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel 4T is a closed-loop, continuous flow, variable-density tunnel in which the Mach number can be varied from 0.1 to 1.3. At all Mach numbers, the stagnation pressure can be varied from 300 to 3,700 psfa. The test section is 4 ft square and 12.5 ft long with perforated variable porosity (0.5- to 10-percent open) walls. It is completely enclosed in a plenum chamber from which the air can be evacuated, allowing part of the tunnel airflow to be removed through the perforated walls of the test section.

The tunnel support system for the model consisted of a pitch sector strut and sting attachment which has a pitch angle capability of -9 to 28 deg with respect to the tunnel centerline.

2.2 TEST ARTICLE

The test articles were 0.05-scale models of the F-4C aircraft and the various external stores of interest. The stores included the GBU-15 (planar wing), GBU-15 (cruciform wing), ALQ 119 ECM pod, ALQ 131 ECM pod, 370-gal fuel tank, and 600-gal fuel tank.

Photographs of the F-4C configured with the GBU-15 (cruciform wing) plus 370-gal fuel tanks and the GBU-15 (planar wing) plus 370-gal fuel tanks are presented in Figs. 1 and 2, respectively. Basic dimensions of the F-4C model and its wing panel are presented in Figs. 3 and 4. The details and dimensions of the GBU-15 (cruciform wing), GBU-15 (planar wing), 370- and 600-gal fuel tanks, ALQ 119 and ALQ 131 ECM pods, and the MAU 12B/A inboard pylon are shown in Figs. 5 through 11. A configuration identification key is presented in Fig. 12. All of the configurations tested were symmetric about the model BL 0.000 with the exception of configurations 6 and 15. In these configurations the ECM pods were carried in the left forward missile wells.

2.3 INSTRUMENTATION

Force and moment data for the model were measured using a six-component strain-gage balance. Base pressures for the model were measured using three 5-psid transducers. Electrical signals from the balance, pressure transducers, and standard tunnel instrumentation were processed by the AEDC-PWT data acquisition system and digital computer for online data reduction.

3.0 TEST DESCRIPTION

3.1 TEST PROCEDURES AND TEST CONDITIONS

Aerodynamic data were obtained for various angles of attack at several stabilator angle settings. The angle of attack was varied from -4 to 20 deg at a constant roll angle of 0 deg with horizontal stabilator settings of 0, -2.5, and 5.0 deg. Data were obtained for a constant total pressure of 2,500 psfa over a Mach number range of 0.6 to 1.1. A complete summary of test conditions is given in Table 1.

3.2 DATA REDUCTION AND CORRECTIONS

The force and moment data for the F-4C model were reduced to coefficient form in the stability axis system. Base drag was calculated using the average of pressure readings from three orifices located at the model base. Since only the incremental changes in the F-4C stability and drag characteristics caused by the addition of stores were of interest, only measured coefficients are presented in this report.

Wind tunnel flow angularity corrections in the pitch plane were determined and applied to the data. Corrections for the model weight as a function of angle of attack were also applied to the data. Moment data were referenced to the 33-percent point of the theoretical MAC (Fig. 3).

3.3 PRECISION OF MEASUREMENTS

The precision of the aerodynamic data attributable to errors in the balance measurements and tunnel conditions was determined for a confidence level of 95 percent, and the values are presented in Table 2.

The uncertainty in setting Mach number in the portion of the test section occupied by the model was no greater than ± 0.005 for Mach numbers up to 0.95 and 0.01 for Mach numbers greater than 1.0. The uncertainty in setting angle of attack and roll angle was no greater than ± 0.1 deg.

4.0 RESULTS AND DISCUSSION

4.1 GENERAL

To determine the changes in longitudinal stability and drag characteristics of the F-4C, several external store combinations were compared with the baseline configurations. The baseline configurations were chosen to show the increments in aerodynamic characteristics caused by the GBU-15 (cruciform wing) and the GBU (planar wing) stores and are as follows: configuration number 2 (F-4C with inboard pylons), configuration number 4 (F-4C with inboard pylons and 370-gal fuel tanks outboard), and configuration number 12 (F-4C with centerline 600-gal fuel tank).

The aerodynamic characteristics of the F-4C with various store loadings are presented in Figs. 13 through 24. The data are presented in the following order: (1) lift coefficient (C_L) versus wing chord angle of attack (α_w), (2) C_L versus pitching moment (C_m), (3) drag coefficient (C_D) versus α_w , (4) C_L versus C_D , (5) static margin (XSM) versus free-stream Mach number (M_∞), and (6) C_D versus M_∞ . To maintain compatibility with previous aerodynamic data for the F-4C, XSM and C_D were evaluated by methods found in Ref. 1. Specifically, XSM was determined by curve-fitting the C_m versus C_L curve over the range $0 \leq C_L \leq 0.4$ and is equal to the derivative of this curve at $C_L = 0.2$. Negative values of XSM indicated a stable aircraft. Drag coefficient as a function of Mach number was determined by curve-fitting the C_D versus C_L curve over the range $-0.2 \leq C_L \leq 0.6$ and determining the value of C_D at a $C_L = 0.3$ and 0.1 for $M_\infty < 1.0$ and $M_\infty \geq 1.0$, respectively. The basic aerodynamic characteristics of F-4C configured with the GBU-15 (planar wing) and GBU-15 (cruciform wing) stores plus 370-gal fuel tanks are presented to show the typical variations of the data. However, the variations in stability and drag characteristics for the majority of the configurations tested have been summarized in the plots of XSM versus Mach number and C_D versus Mach number.

The basic aerodynamic data presented in Figs. 13 through 16 indicated that the addition of the stores produced a decrease in longitudinal stability and an increase in the drag coefficient. A detailed discussion of the aerodynamic characteristics is presented in the following sections.

4.2 LONGITUDINAL STABILITY CHARACTERISTICS

The effect of Mach number on XSM is presented in Figs. 17 through 20. These figures show the effects of the GBU-15 (planar wing) and GBU-15 (cruciform wing) stores without and with the 370- and 600-gal fuel tanks and ALQ 119 ECM pod on the stability characteristics of the F-4C aircraft. The data presented in Fig. 17 show a decrease in the F-4C static margin for both stores when compared with the data for baseline configuration number 2. As can be seen from Fig. 17, configuration number 9, GBU-15 (cruciform wing) store, caused the greatest decrease in the static margin of the F-4C without the 370-gal fuel tank for $M_\infty > 0.80$. But for $0.60 \leq M_\infty \leq 0.800$, the values of the static margin were essentially the same. Moreover, the largest decrease in the static margin of the F-4C for both stores occurred at $M_\infty = 0.975$.

Data in Fig. 18 indicate that with the 370-gal fuel tank on the outboard armament stations the greatest decrease in static margin resulted for configuration number 5, GBU-15 (planar wing). Also configuration 7, GBU-15 (cruciform) caused the static margin to increase above that for baseline configuration number 4 (F-4C plus 370-gal fuel tank outboard) for Mach numbers greater than 0.975. While at $M_\infty = 0.975$, baseline configuration numbers 4 and 7 had the same value of static margin. Configuration 5 showed a drop in static margin when compared with both 4 and 7 at $M_\infty = 0.975$.

The results from Fig. 19 indicated that configurations 10 and 11 involving the 600-gal fuel tanks on centerline show the same trends exhibited by the stores without the tank on centerline which were shown in Fig. 17.

The comparison of configurations 6 and 5 presented in Fig. 20 indicates that the GBU-15 (planar wing) store was less destabilizing when the ALQ 119 ECM pod was carried in the left forward missile well.

4.3 DRAG CHARACTERISTICS

The variations in C_D produced by carriage of the GBU-15 (cruciform wing) and GBU-15 (planar wing) stores for various combinations of external stores are presented in Figs. 21 through 24. The data presented indicate that both stores created a large increase in the drag coefficient. The greatest increase was caused by the GBU-15 (cruciform wing store) (Fig. 21). However, the differences in the drag coefficient for the GBU-15 (cruciform

wing) and the GBU-15 (planar wing) stores were very small. The addition of the 370-gal fuel tanks outboard or the 600-gal fuel tank on the centerline when either the GBU-15 (cruciform wing) and GBU-15 (planar wing) stores were carried increased the drag coefficient above that of configurations without the fuel tanks (Figs. 22 and 23). The data also showed that carriage of the GBU-15 (planar wing) store in combination with the ALQ 119 ECM pod increased the drag coefficient slightly above that for the GBU-15 (planar wing) store alone (Fig. 24).

5.0 SUMMARY OF RESULTS

The aerodynamic characteristics of a 0.05-scale model of the F-4C aircraft have been investigated for several combinations of external stores involving the GBU-15 (planar wing) and GBU-15 (cruciform wing) at Mach numbers from 0.60 to 1.10 and angles of attack from -4 to 20 deg. The results of this investigation may be summarized as follows:

1. Both the GBU-15 (planar wing) and GBU-15 (cruciform wing) stores had a destabilizing effect on the aircraft, with the largest decreases in static margin occurring for Mach numbers approaching 1.0.
2. The addition of either of the stores to the aircraft caused a significant increase in the drag coefficient.

REFERENCE

1. Whoric, J. M. "Effect of Various External Stores on the Aerodynamic Characteristics of the F-4C Aircraft." AEDC-TR-74-75 (AD787657), AFATL-TR-74-113, October 1974.

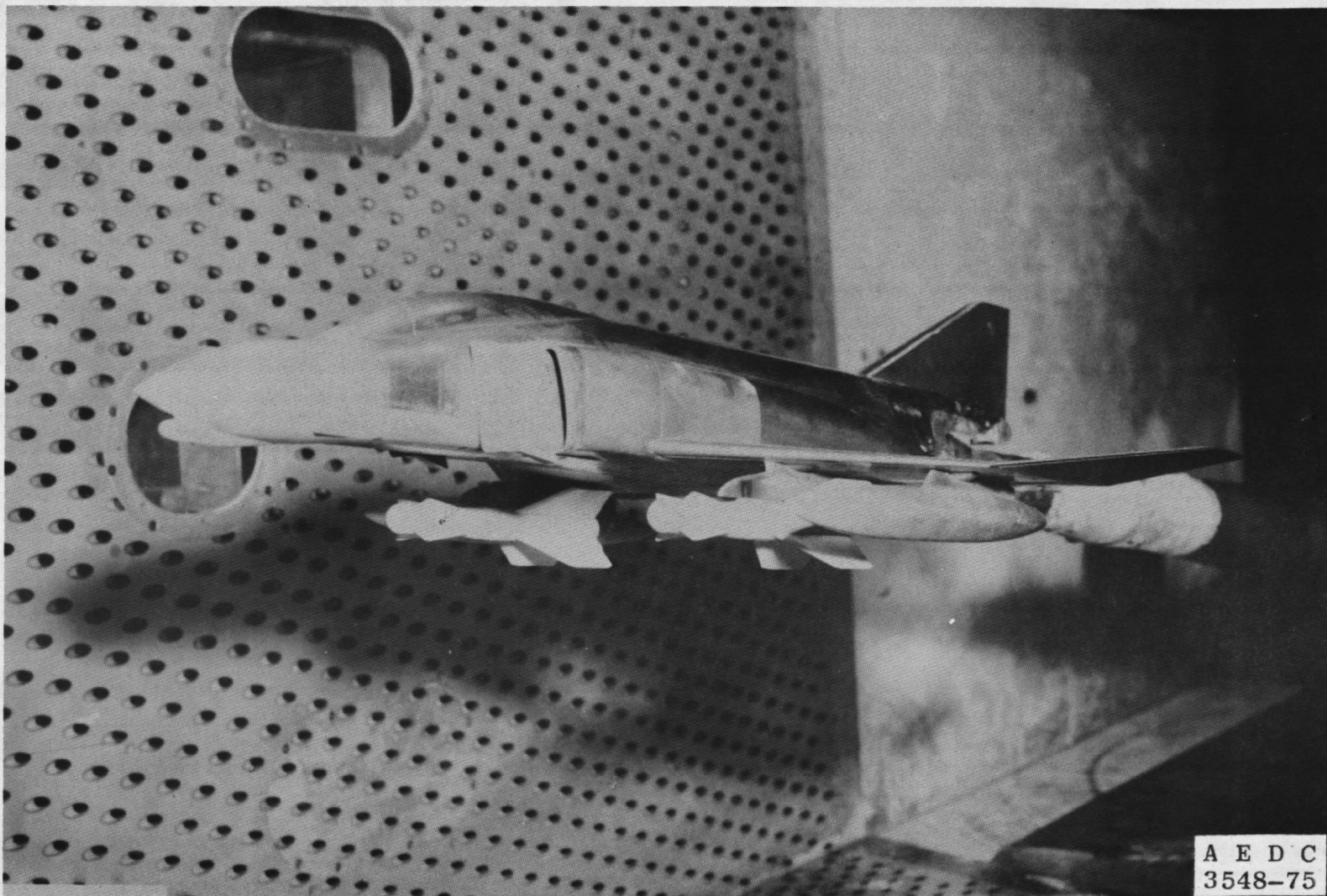


Figure 1. Wind tunnel installation of F-4C with two GBU-15 (cruciform wing) stores and 370-gal fuel tanks.

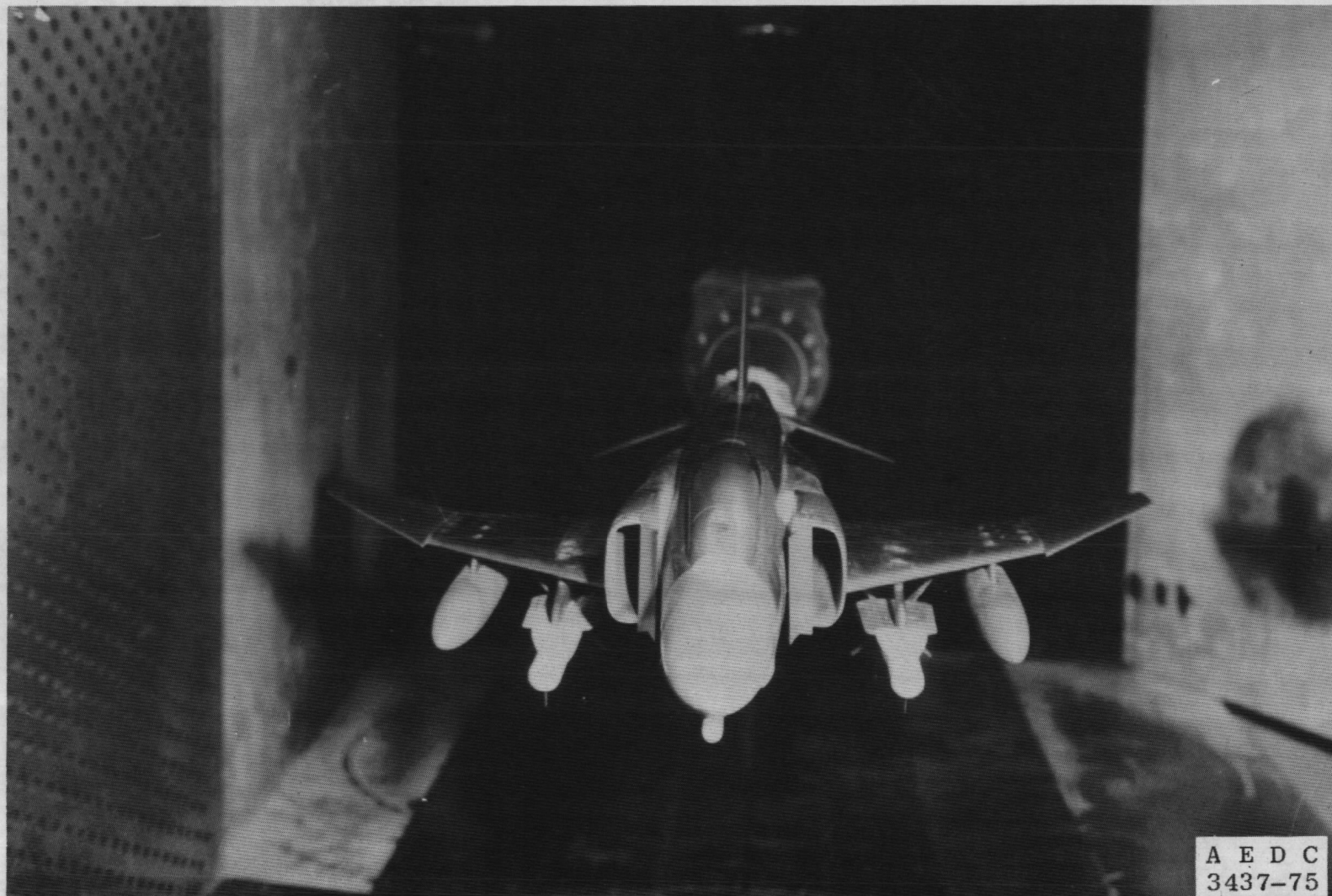


Figure 2. Wind tunnel installation of F-4C with two GBU-15 (planar wing) stores and 370-gal fuel tanks.

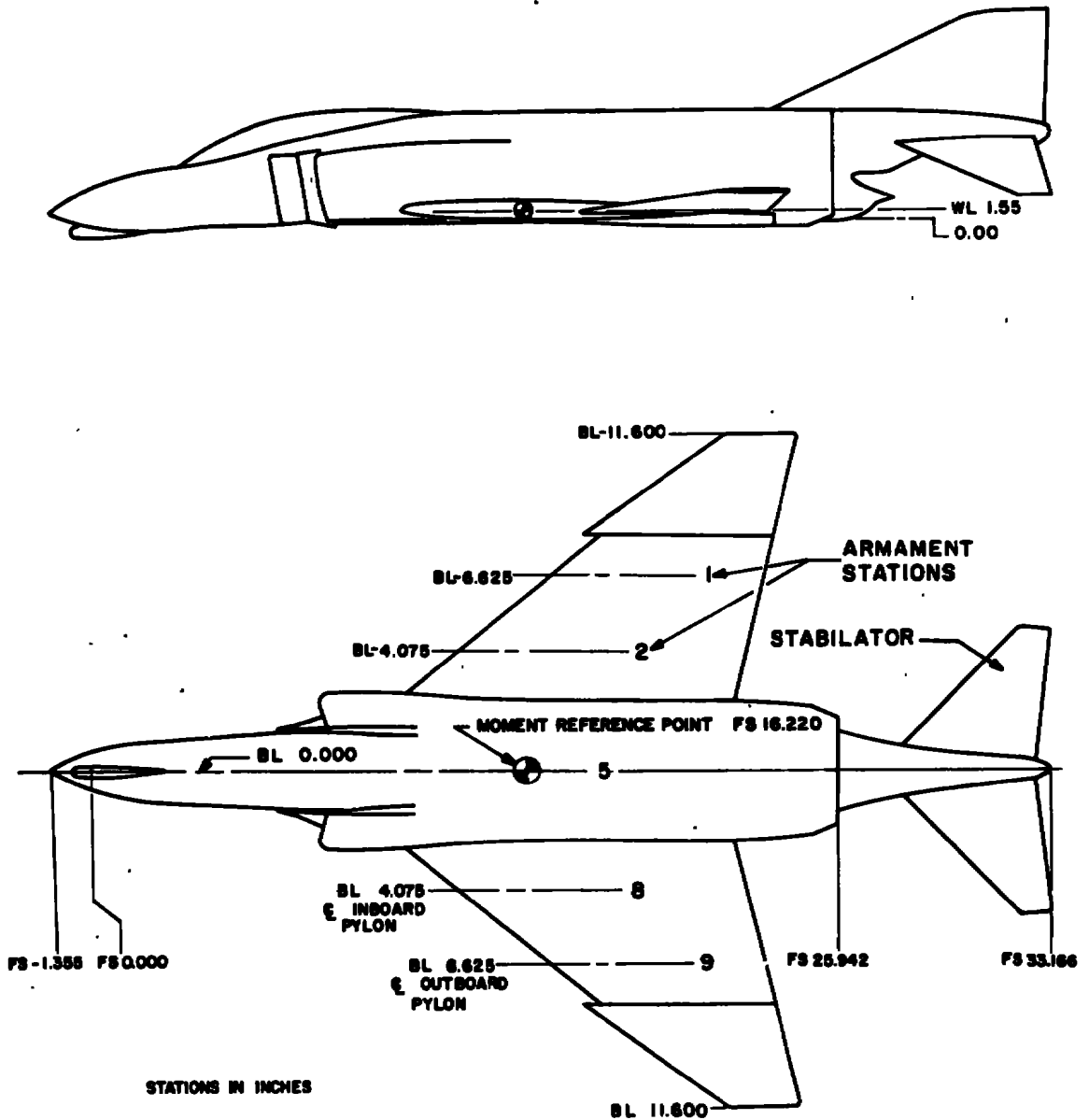


Figure 3. Sketch of 0.05-scale wind tunnel model of the F-4C.

DIMENSIONS IN INCHES

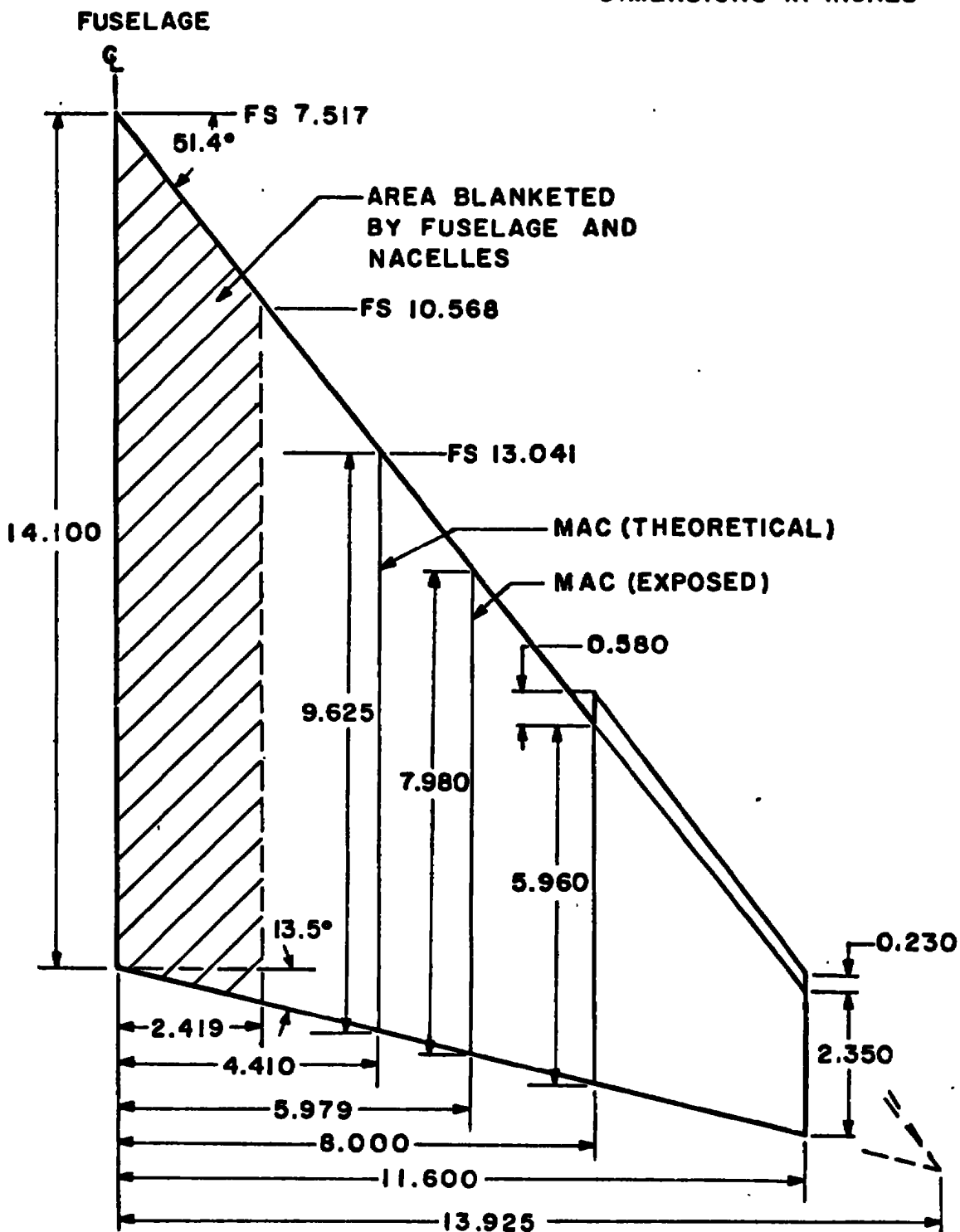


Figure 4. Sketch of F-4C wind tunnel model wing panel.

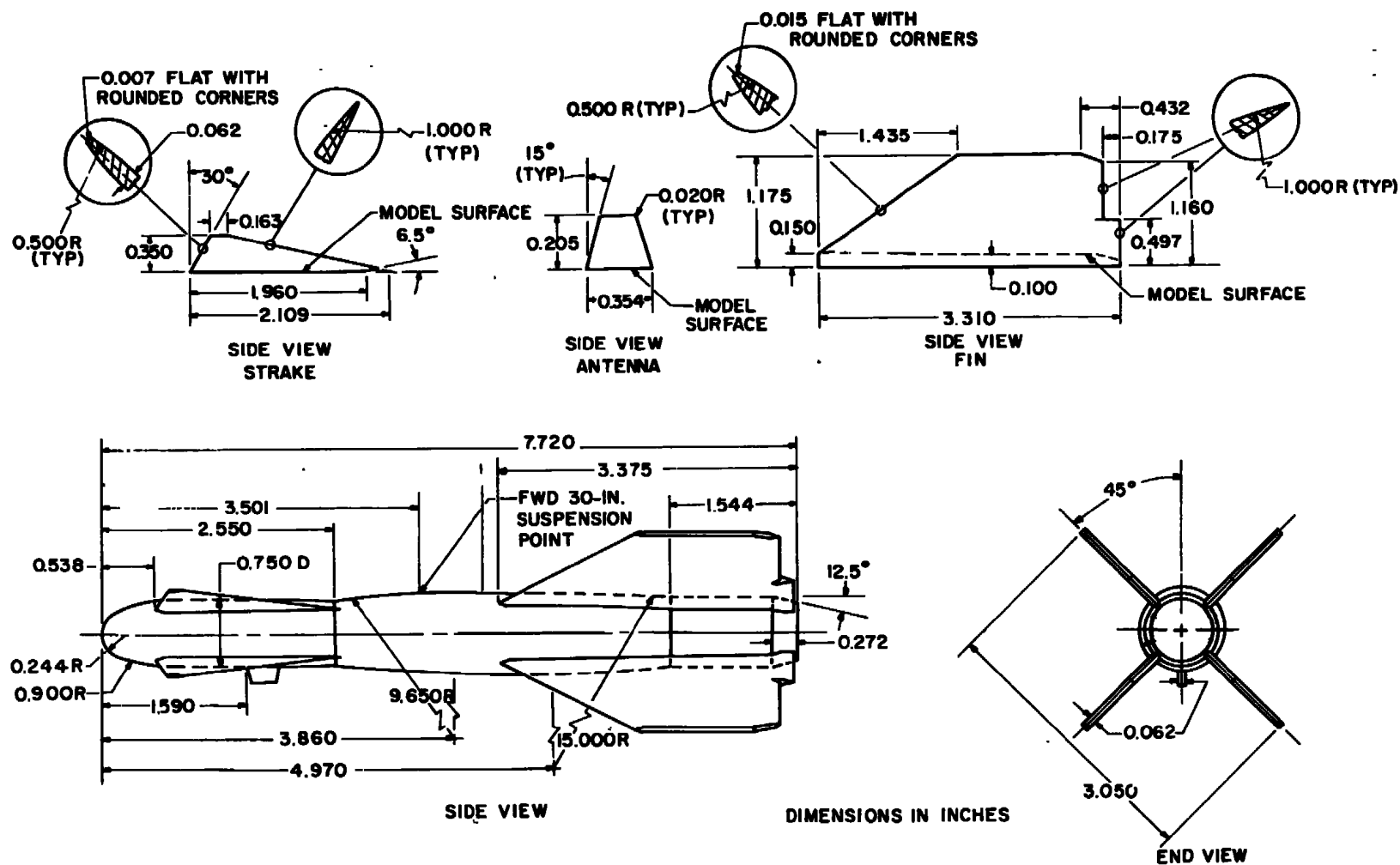


Figure 5. Details and dimensions of the GBU-15 (cruciform wing) tunnel model.

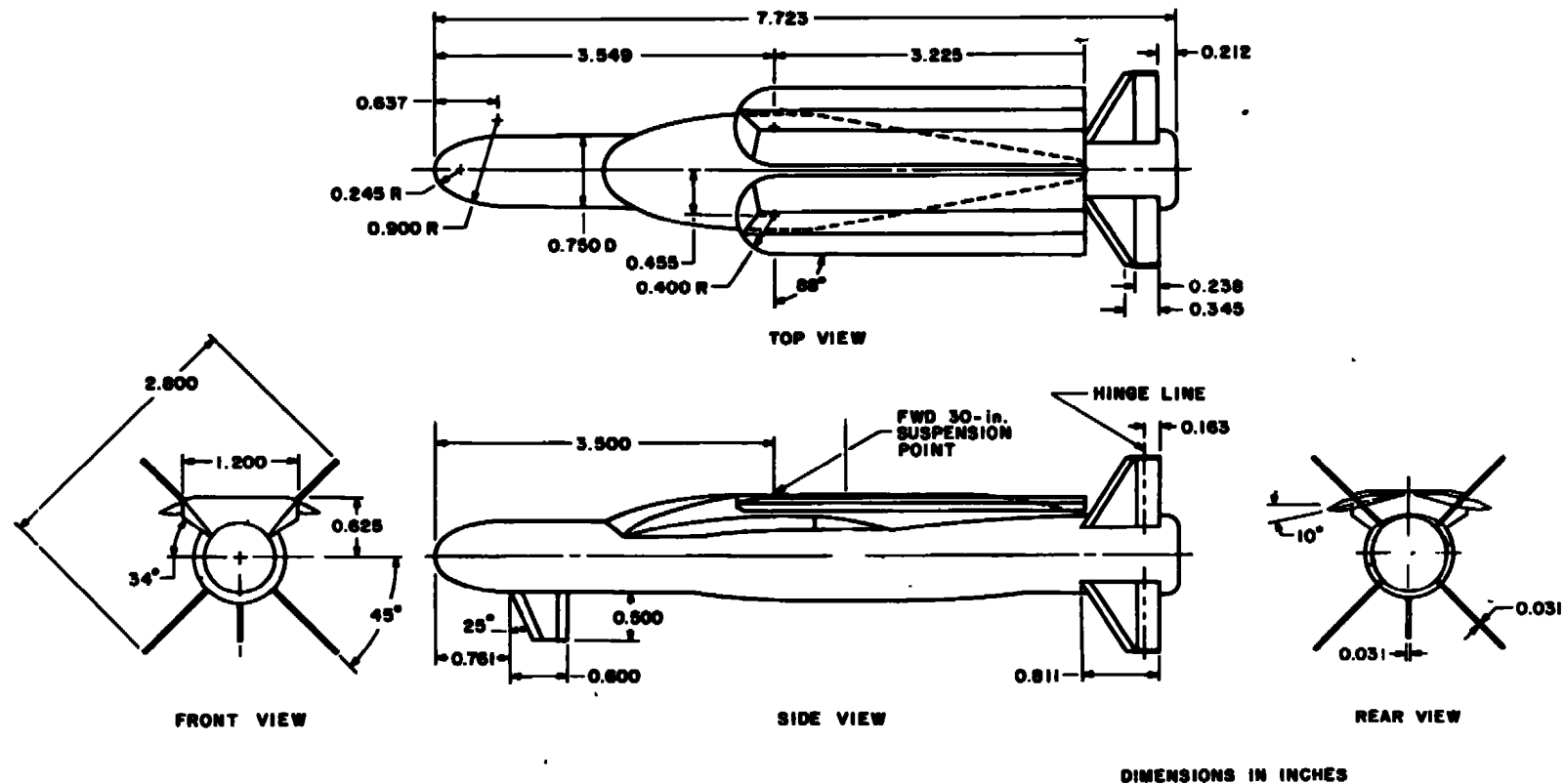
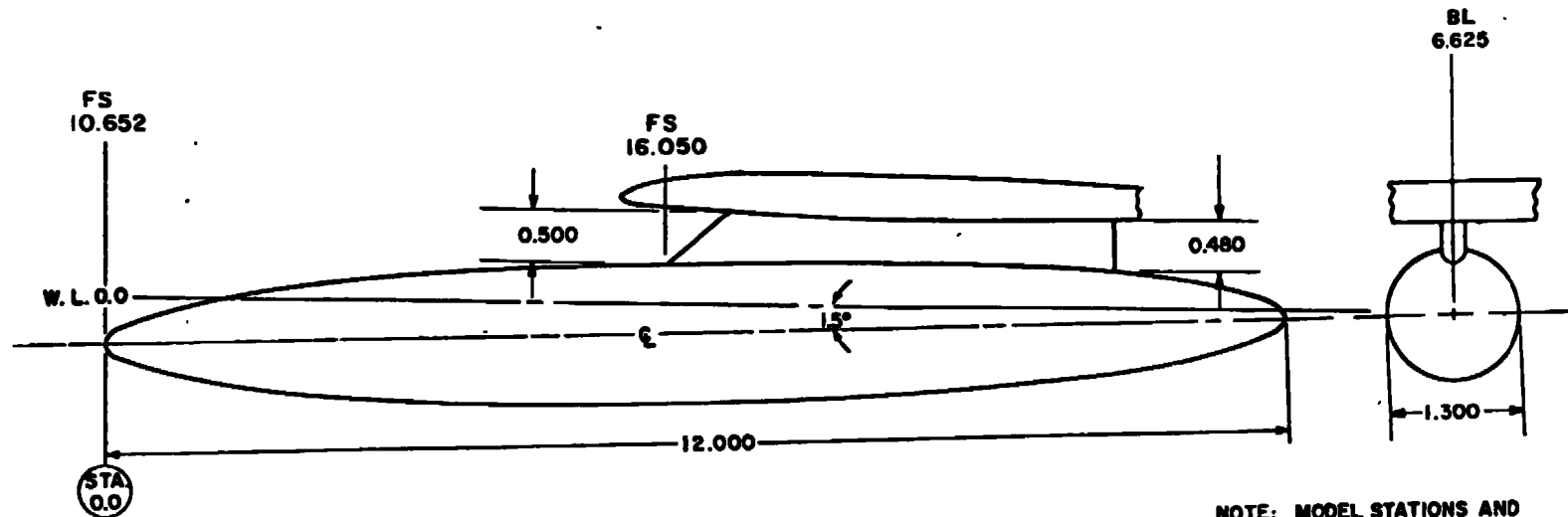


Figure 6. Details and dimensions of the GBU-15 (planar wing) wind tunnel model.



NOTE: MODEL STATIONS AND
DIMENSIONS IN INCHES

BODY CONTOUR, TYPICAL BOTH ENDS

STATION	BODY DIAM	STATION	BODY DIAM
0.000	0.000	2.500	1.116
0.025	0.100	2.750	1.156
0.050	0.144	3.000	1.190
0.150	0.256	3.250	1.218
0.250	0.340	3.500	1.242
0.500	0.498	3.750	1.260
0.750	0.622	4.000	1.274
1.000	0.724	4.250	1.286
1.250	0.812	4.500	1.294
1.500	0.890	4.750	1.298
1.750	0.958	5.000	1.300
2.000	1.016	6.000	1.300
2.250	1.070		

Figure 7. Details and dimensions of the 370-gal fuel tank with suspension equipment.

BODY CONTOUR			
Y	R	Y	R
0.000	0.000	4.250	0.827
0.050	0.049	4.500	0.838
0.100	0.077	4.750	0.847
0.150	0.101	5.000	0.854
0.200	0.122	5.250	0.859
0.250	0.143	5.500	0.860
0.500	0.232	6.250	0.860
0.750	0.308	6.500	0.859
1.000	0.376	6.750	0.856
1.250	0.438	7.000	0.852
1.500	0.494	7.250	0.846
1.750	0.546	7.500	0.839
2.000	0.593	7.750	0.830
2.250	0.637	8.000	0.820
2.500	0.679	8.250	0.809
2.750	0.713	8.500	0.796
3.000	0.740	8.750	0.781
3.250	0.762	9.000	0.765
3.500	0.782	9.250	0.745
3.750	0.799	3.000	0.400
4.000	0.814		

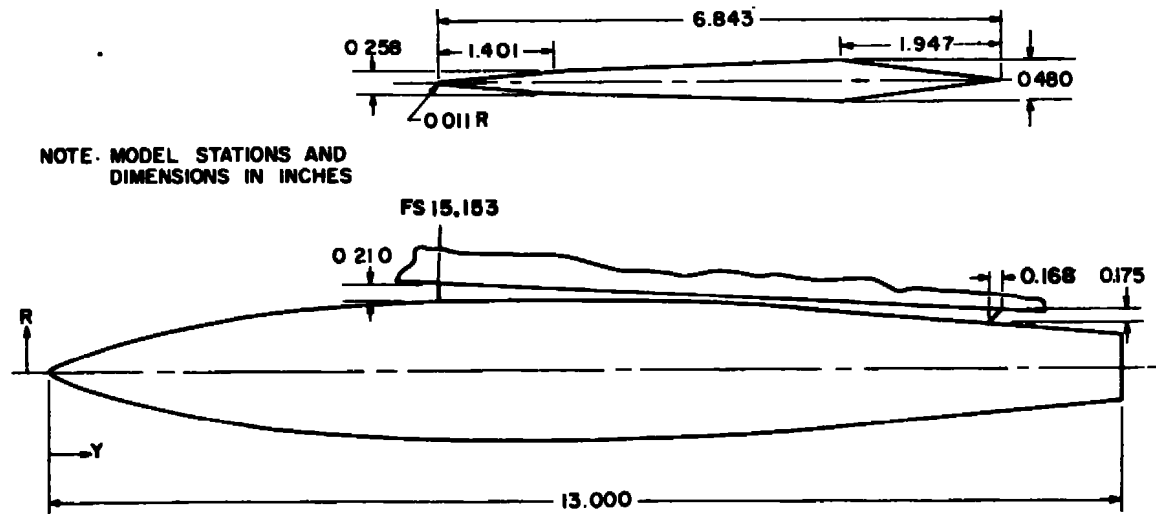
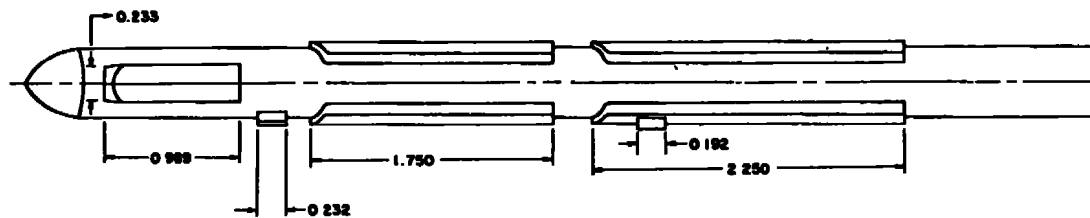
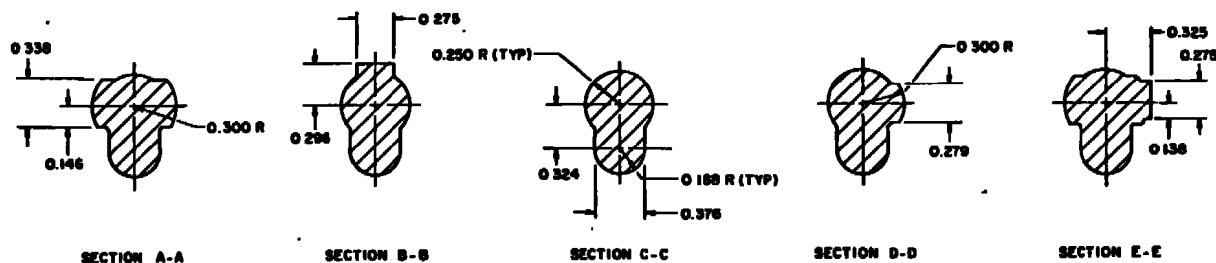
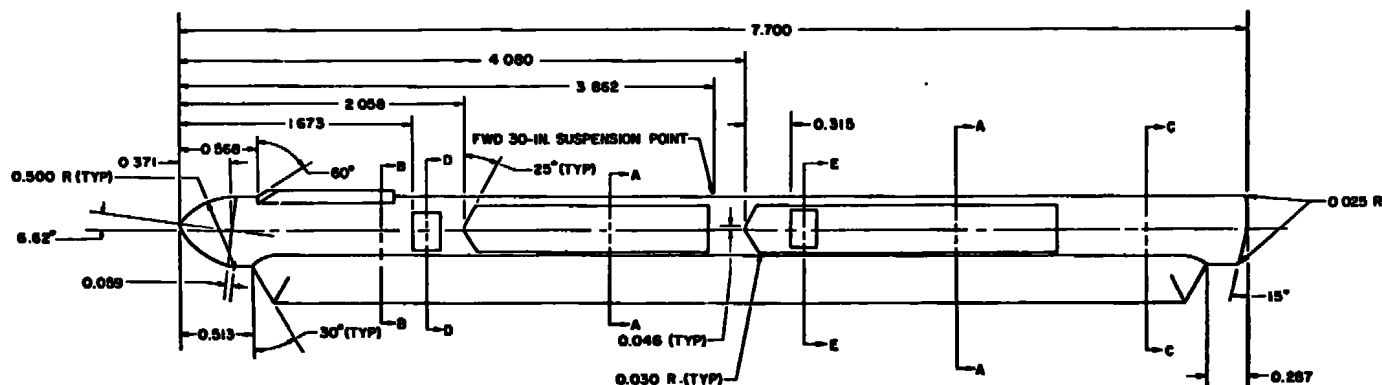


Figure 8. Details and dimensions of the 600-gal fuel tank.



TOP VIEW

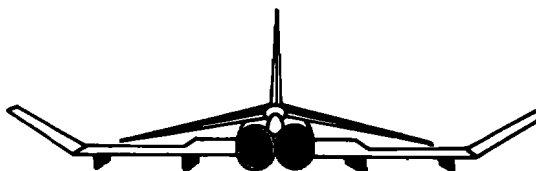


DIMENSIONS IN INCHES

SIDE VIEW

Figure 9. Details and dimensions of the ALQ 119 ECM pod.





CONFIG NO.	EXTERNAL ARMAMENT	ARMAMENT PROFILE	ARMAMENT STATIONS					LEFT FWD MISS WELL
			1	2	5	8	9	
1	NONE		CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	
2	NONE		CLEAN	PYLON	CLEAN	PYLON	CLEAN	
3	370-GAL FUEL TANK			CLEAN	CLEAN	CLEAN		
4	370-GAL FUEL TANK			PYLON	CLEAN	PYLON		
5	370-GAL FUEL TANK GBU-15(PW)				CLEAN			
6	370-GAL FUEL TANK GBU-15(PW)				CLEAN			ALQ 119 ECM POD
7	370-GAL FUEL TANK GBU-15(CW)				CLEAN			
8	GBU-15(PW)		CLEAN		CLEAN		CLEAN	
9	GBU-15(CW)		CLEAN		CLEAN		CLEAN	
10	600-GAL FUEL TANK GBU-15(PW)		CLEAN				CLEAN	
11	600-GAL FUEL TANK GBU-15(CW)		CLEAN				CLEAN	
12	600-GAL FUEL TANK		CLEAN	PYLON		PYLON	CLEAN	
13	600-GAL FUEL TANK		CLEAN	CLEAN		CLEAN	CLEAN	
14	370-GAL FUEL TANK 600-GAL FUEL TANK			CLEAN		CLEAN		
15	370-GAL FUEL TANK GBU-15(CW)				CLEAN			ALQ 131 ECM POD

Figure 12. External store configuration identification key.

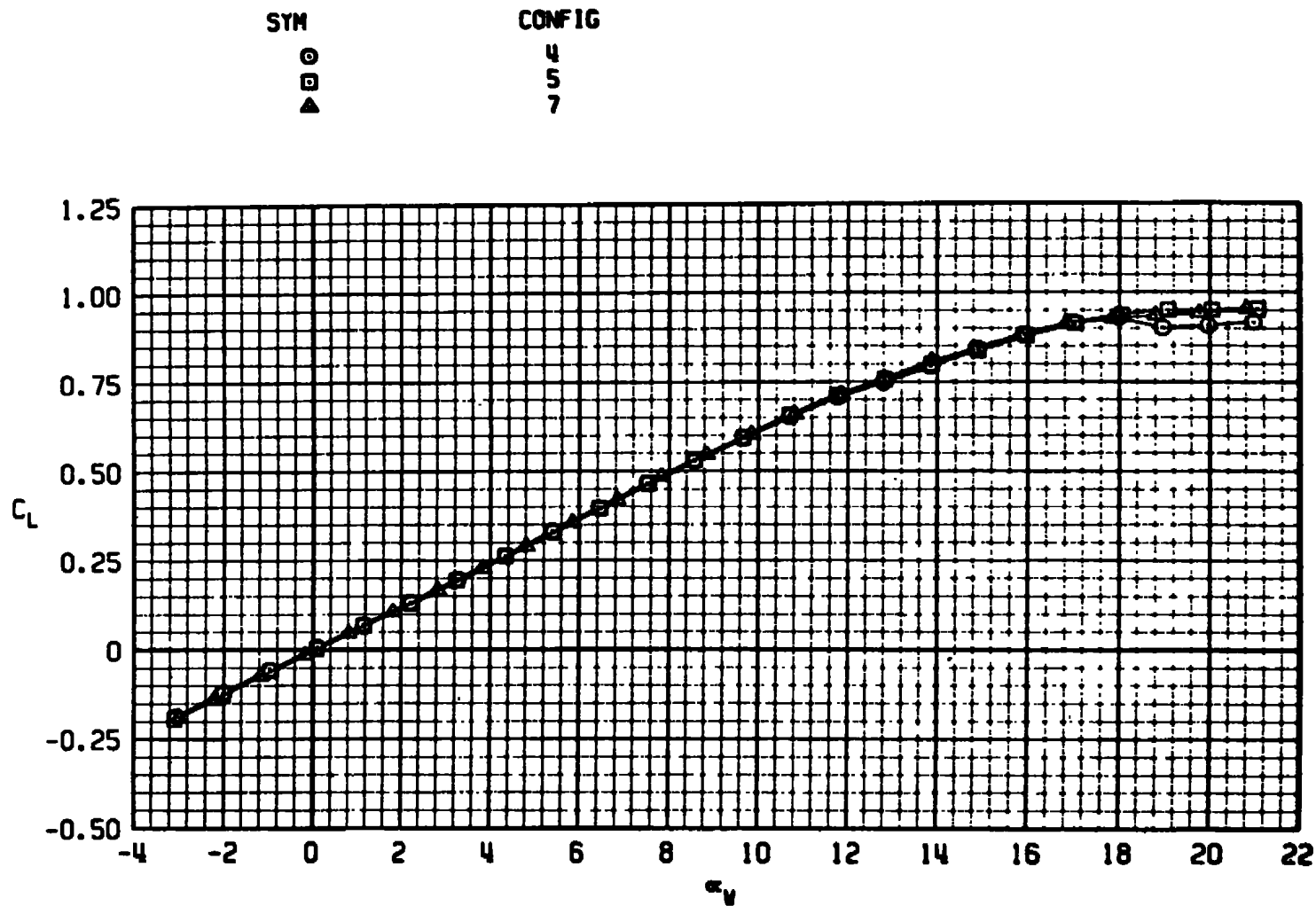
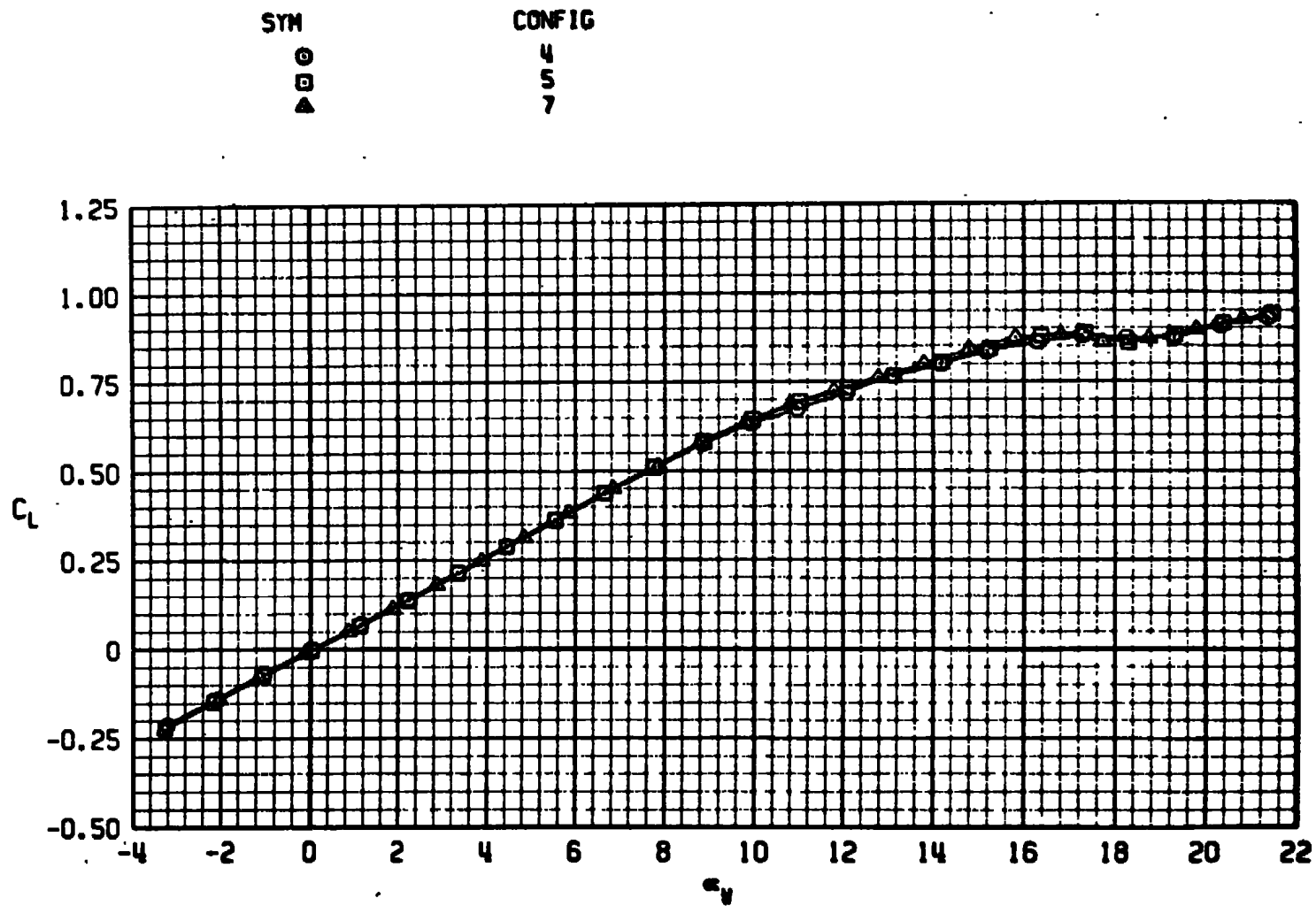
a. $M_\infty = 0.600$

Figure 13. Lift coefficient variation with angle of attack for configurations 4, 5, and 7.



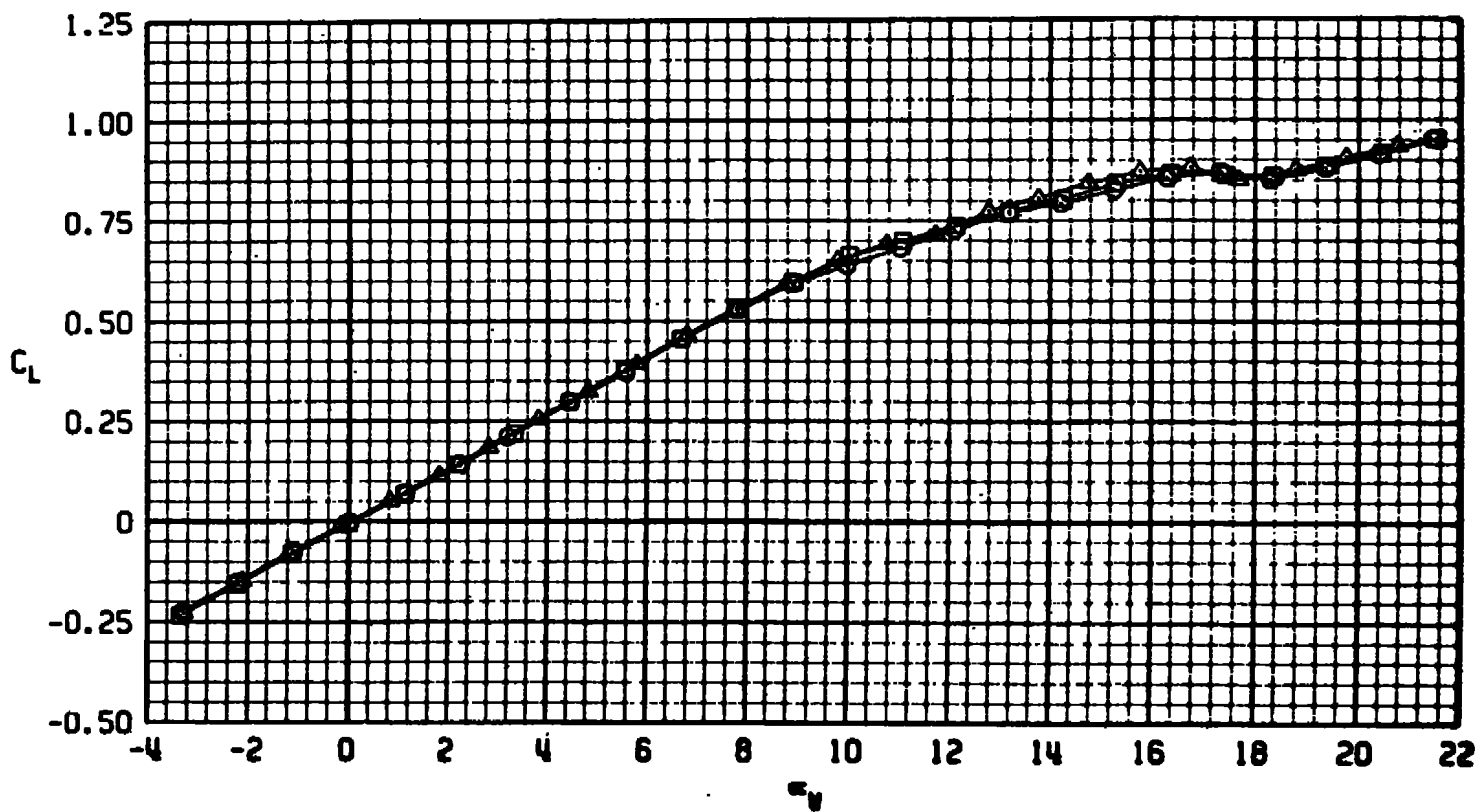
b. $M_\infty = 0.800$
Figure 13. Continued.

SYM

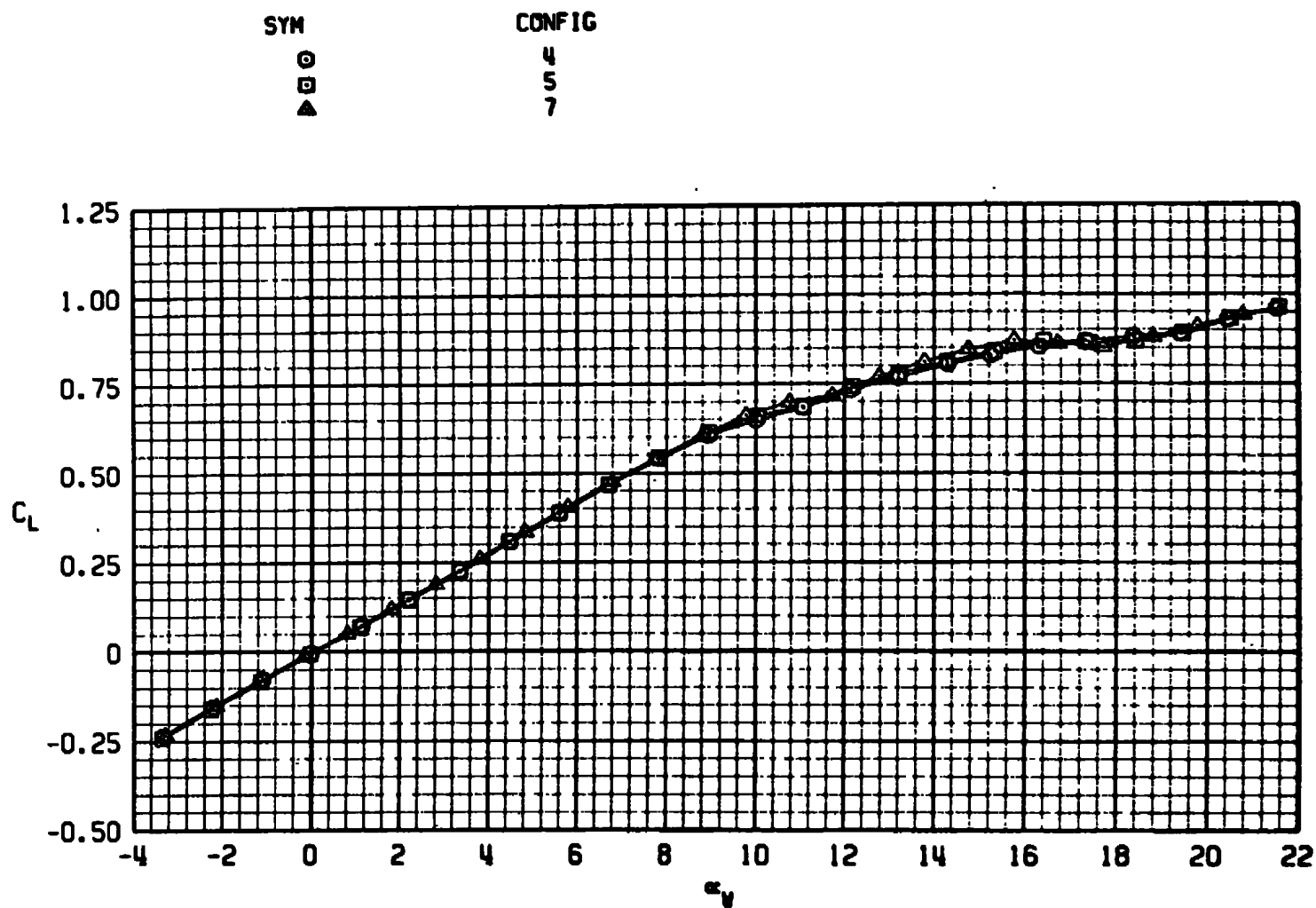
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CONFIG

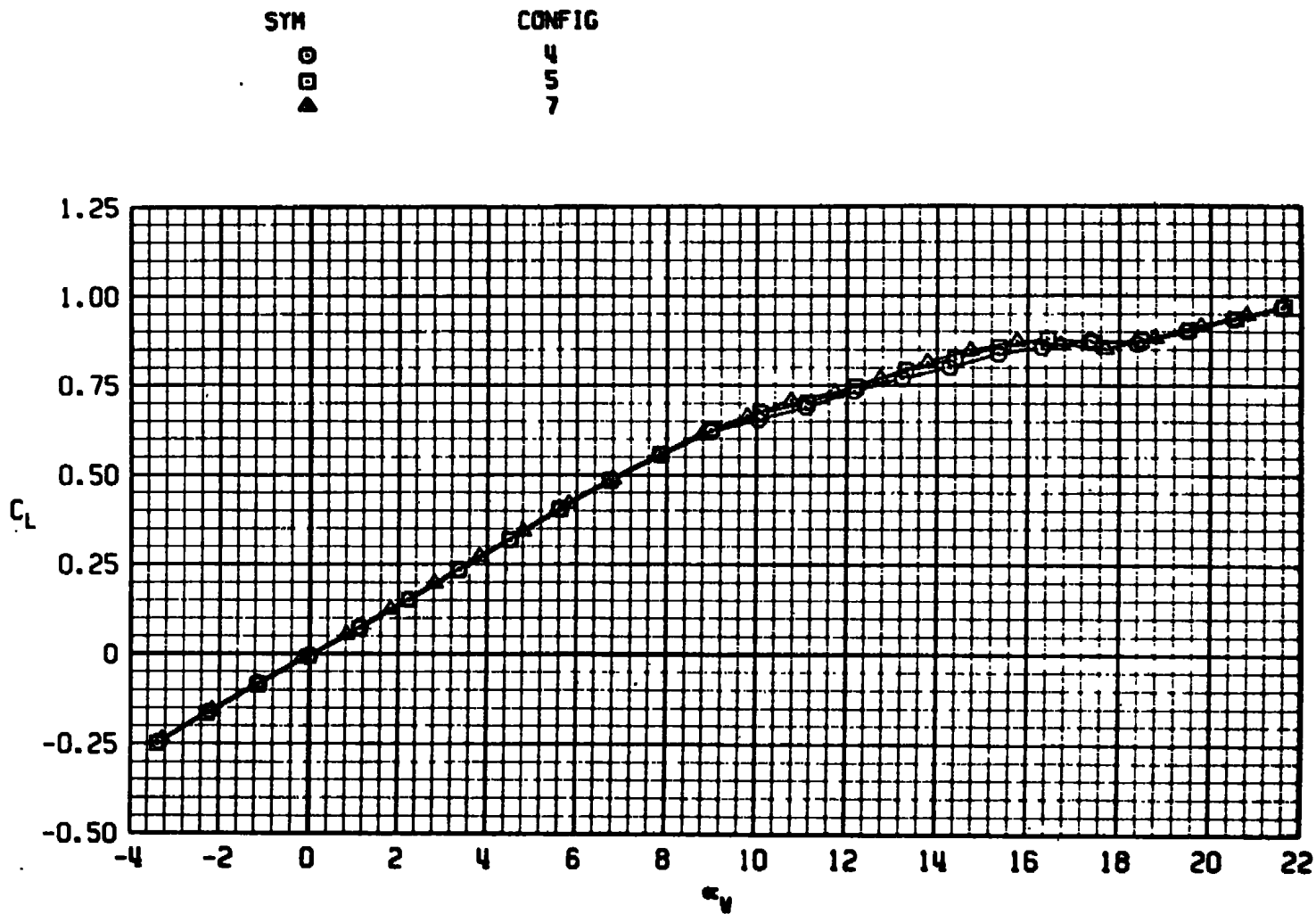
4
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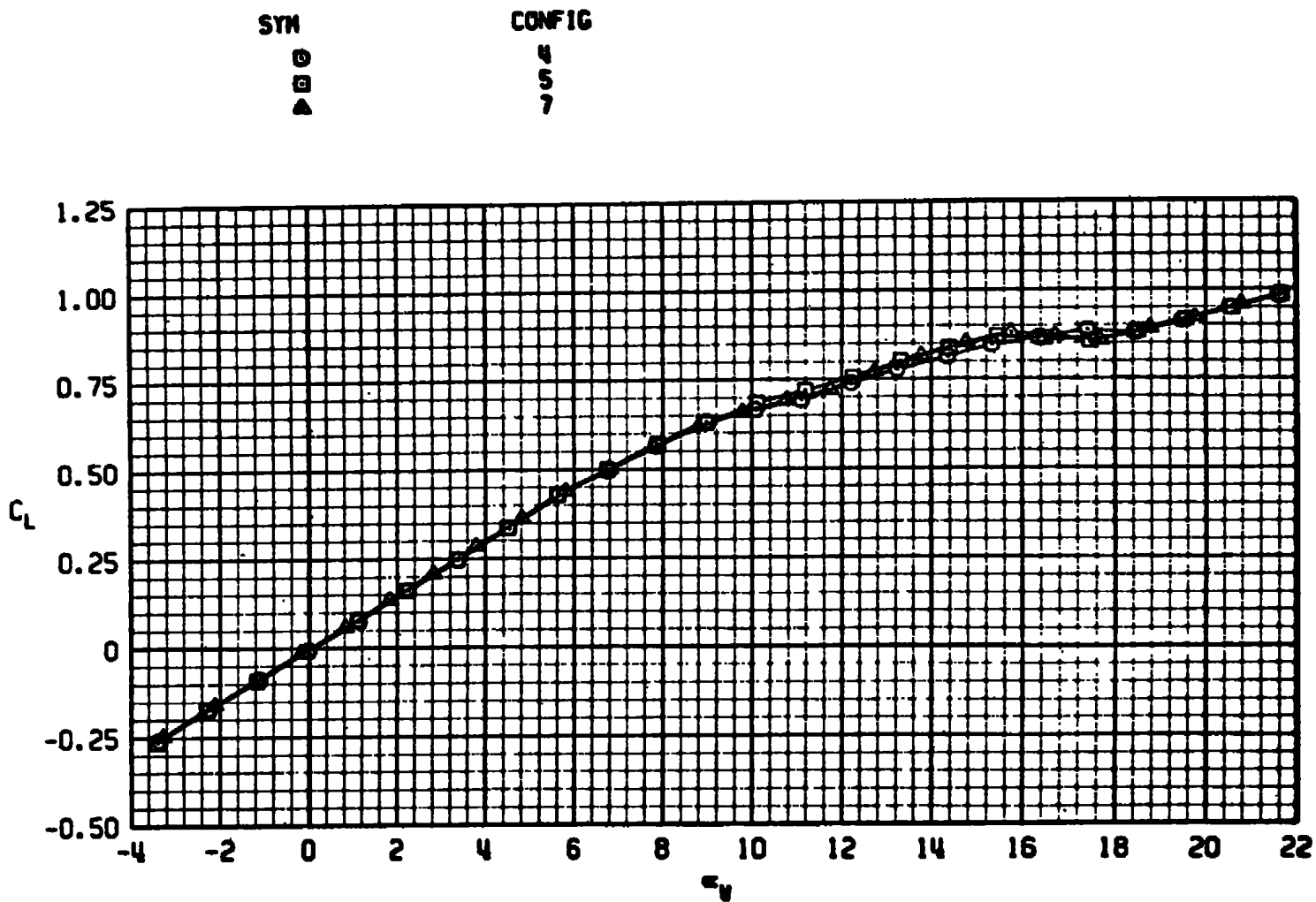
c. $M_\infty = 0.850$
Figure 13. Continued.



d. $M_\infty = 0.875$
 Figure 13. Continued.



e. $M_\infty = 0.900$
Figure 13. Continued.

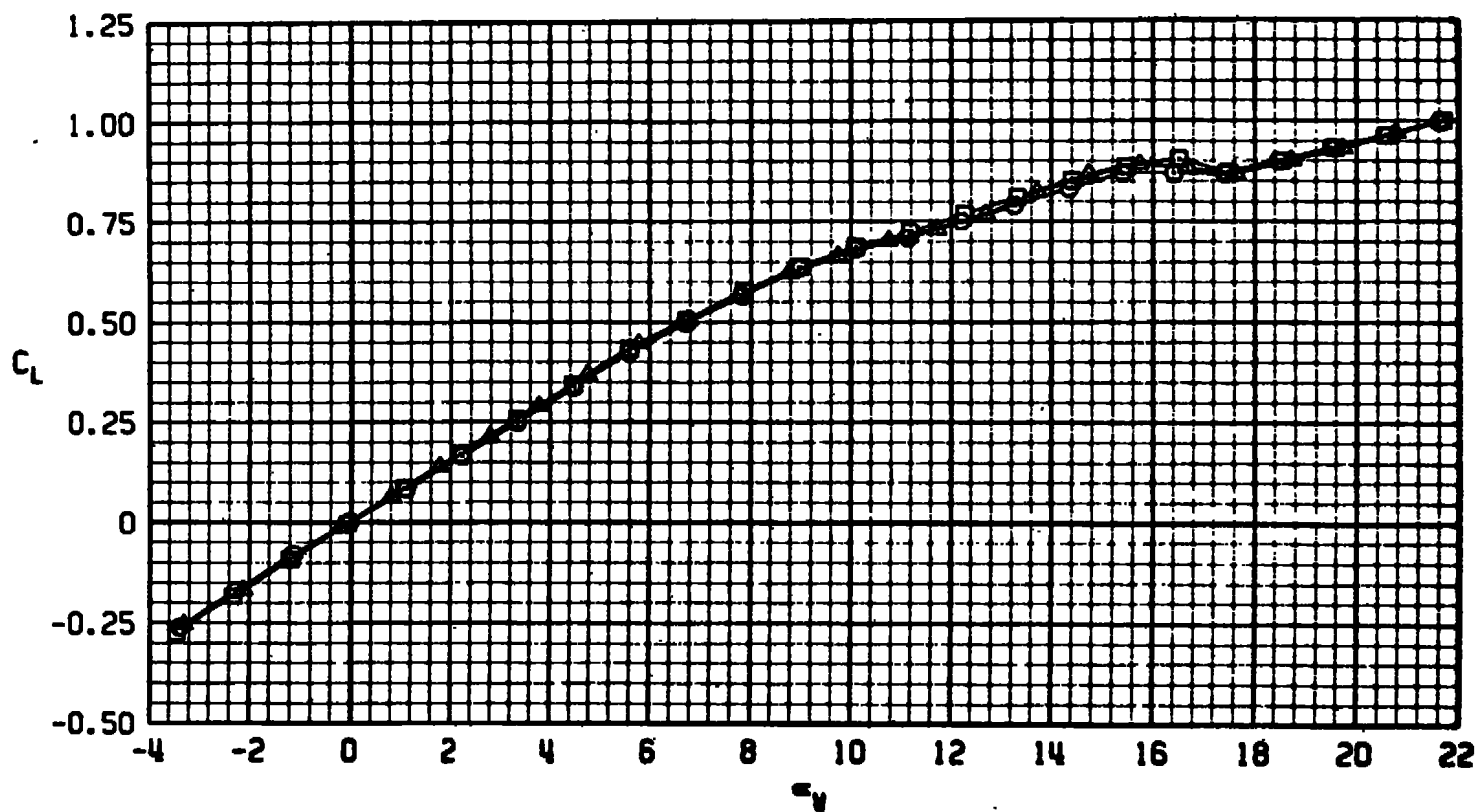


f. $M_\infty = 0.925$
Figure 13. Continued.

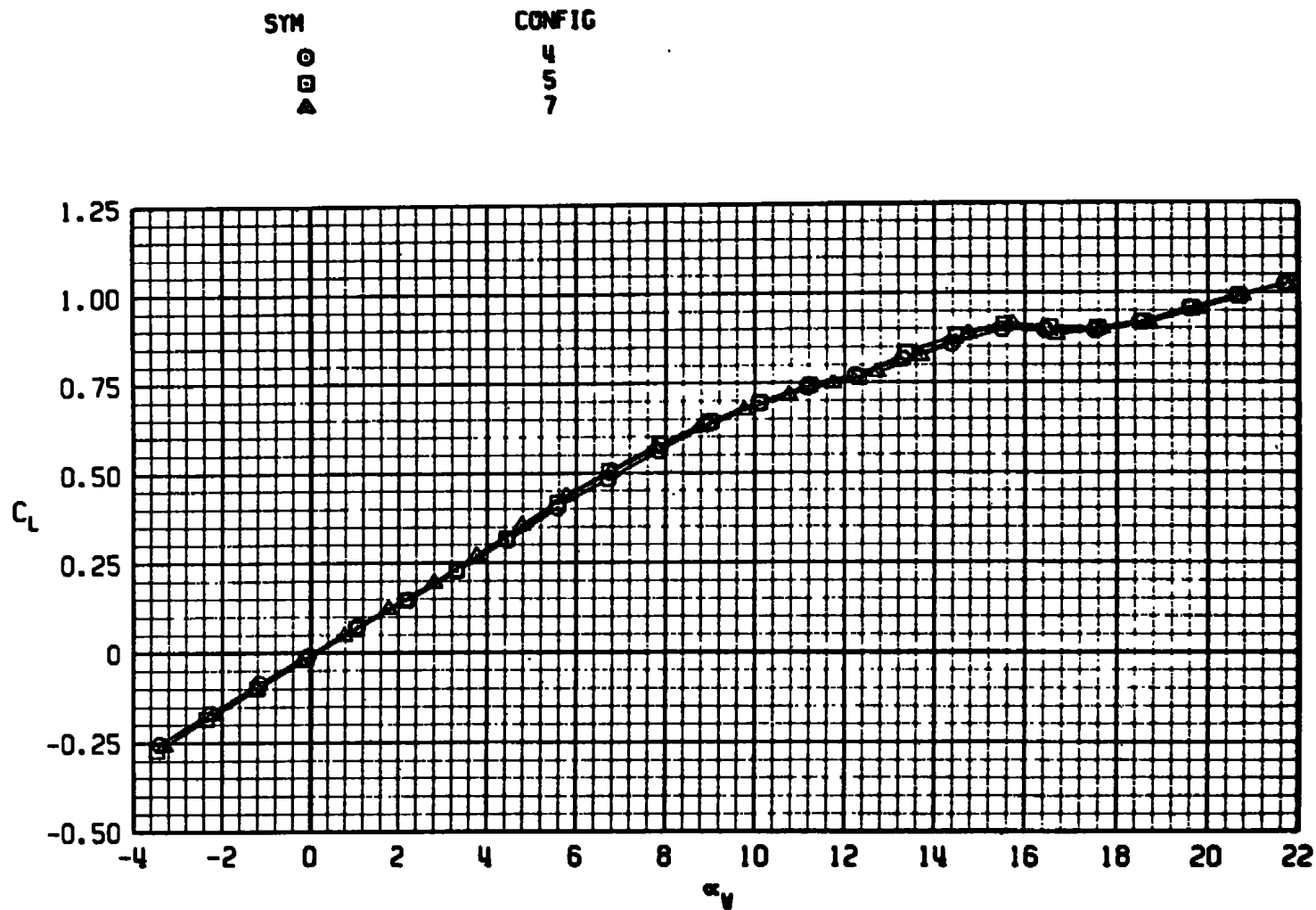
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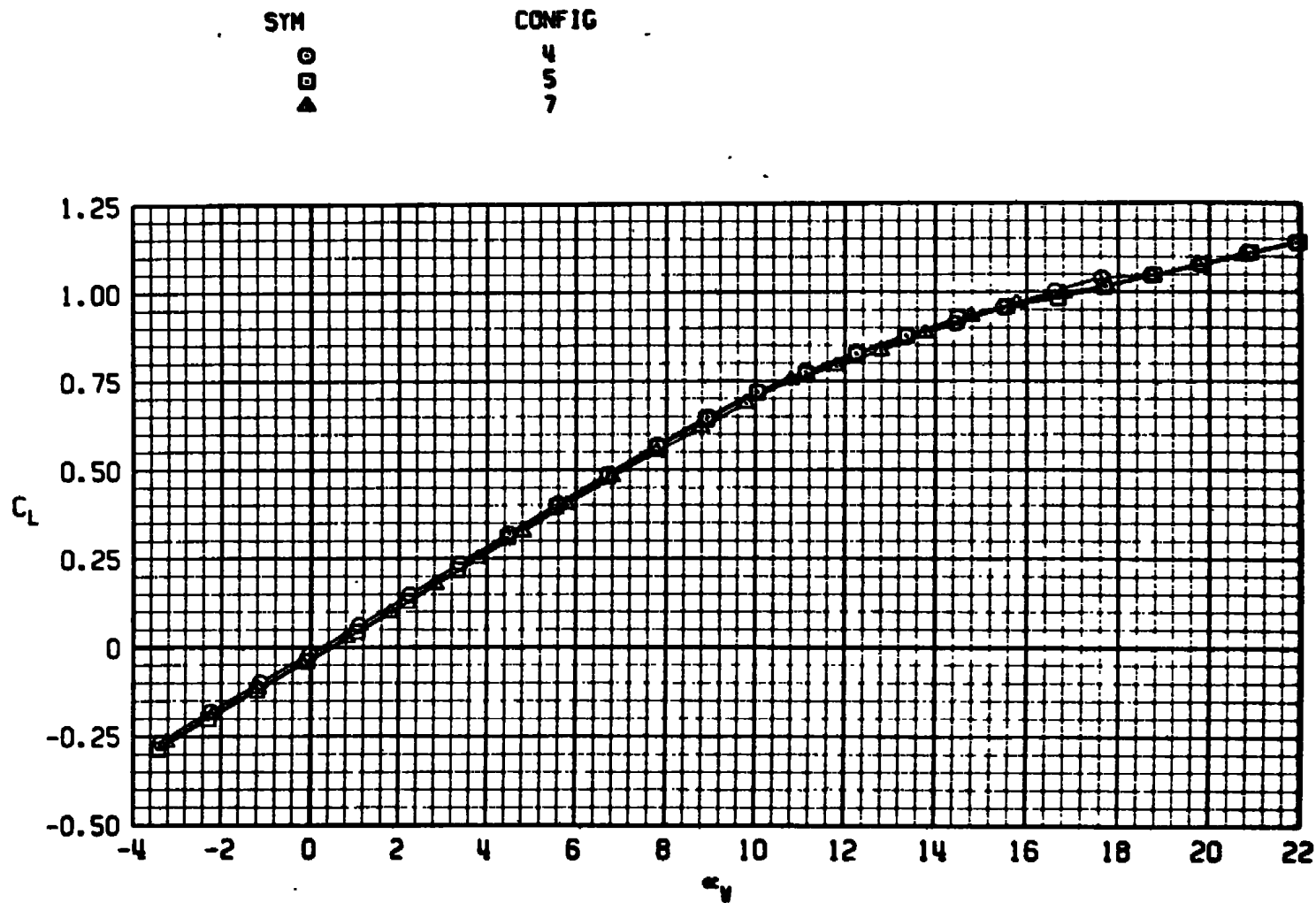
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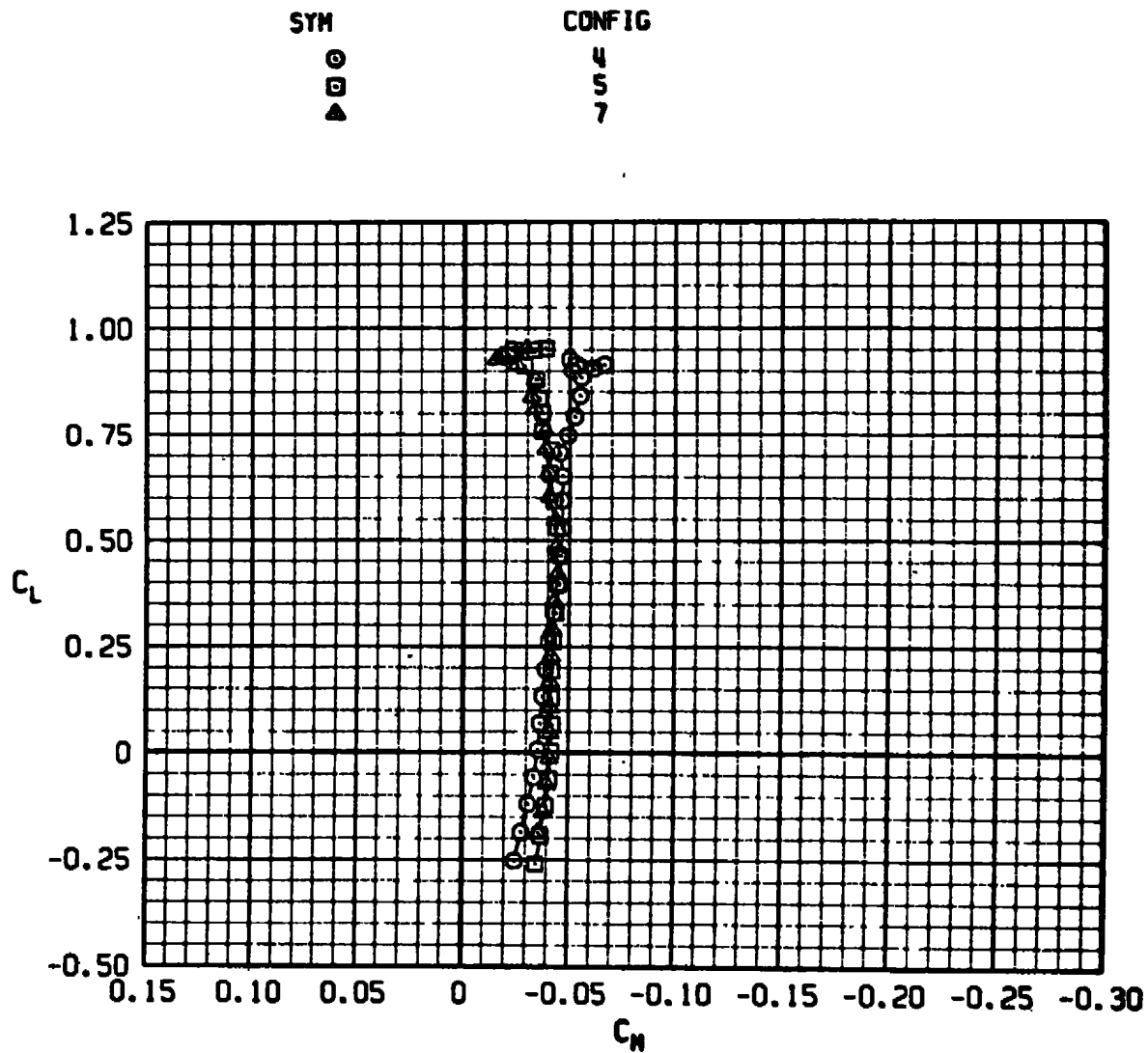
g. $M_\infty = 0.950$
 Figure 13. Continued.



h. $M_\infty = 0.975$
Figure 13. Continued.

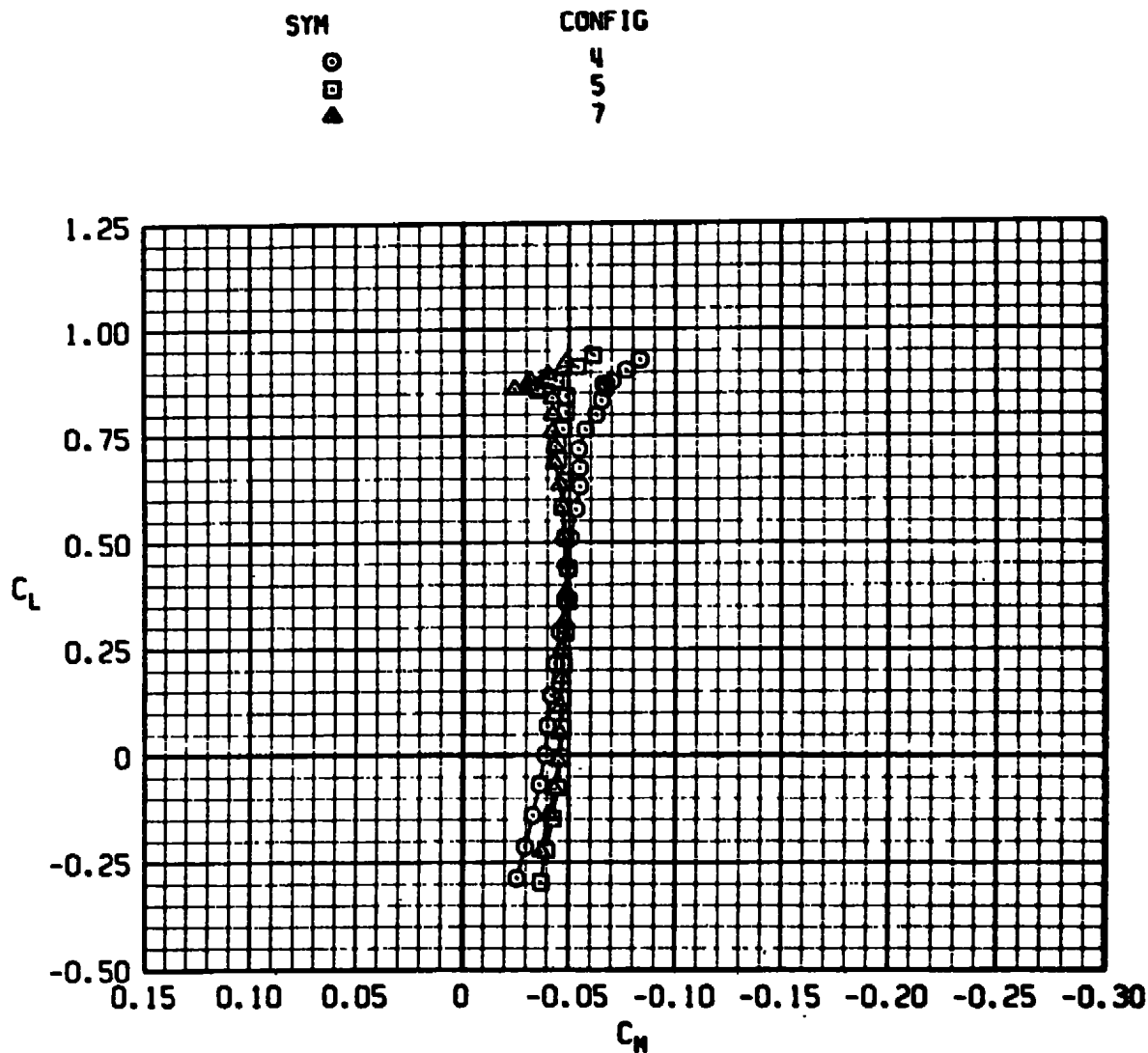


i. $M_\infty = 1.100$
Figure 13. Concluded.

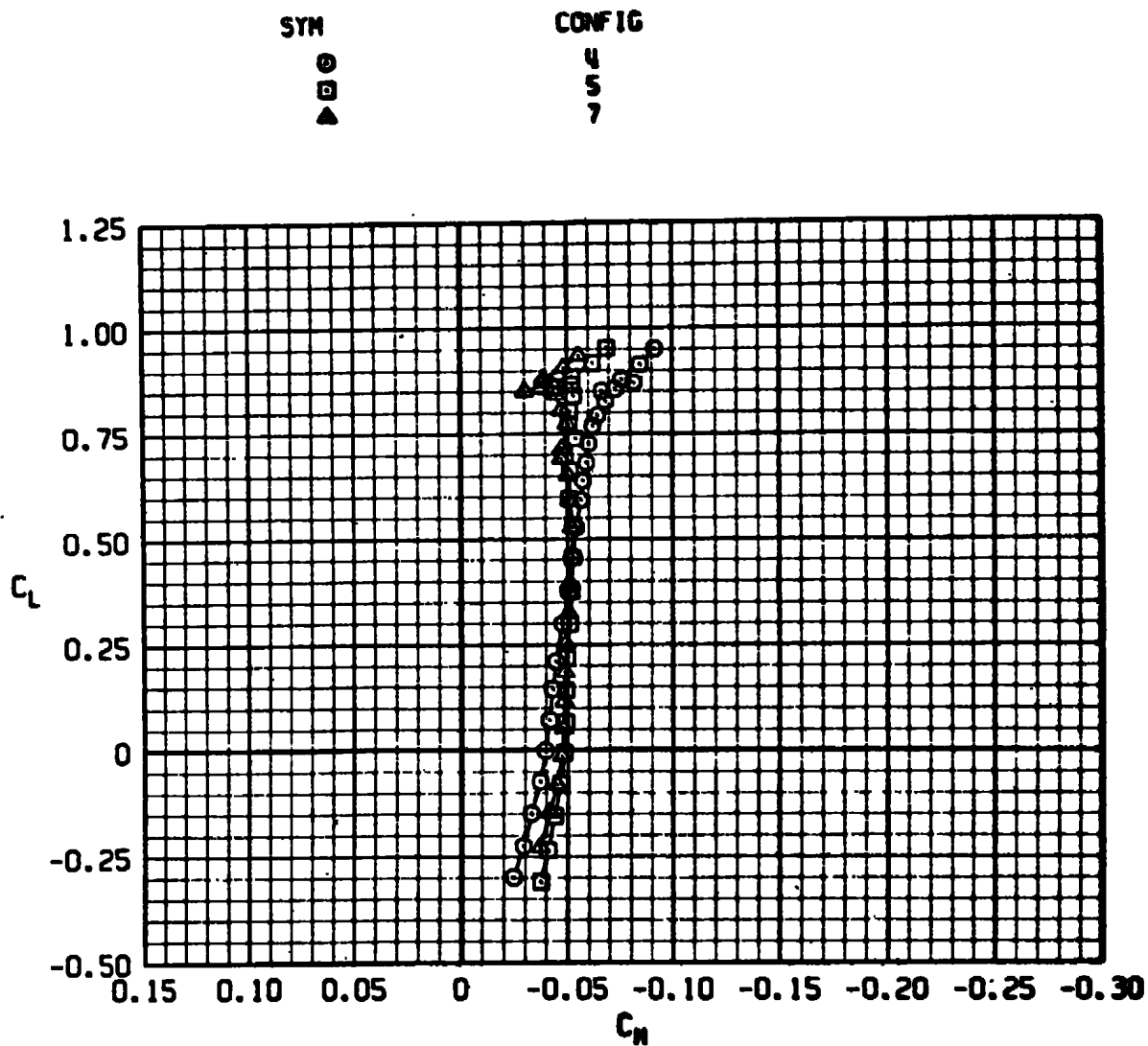


a. $M_\infty = 0.600$

Figure 14. Pitching-moment coefficient variation with lift coefficient for configurations 4, 5, and 7.



b. $M_\infty = 0.800$
 Figure 14. Continued.



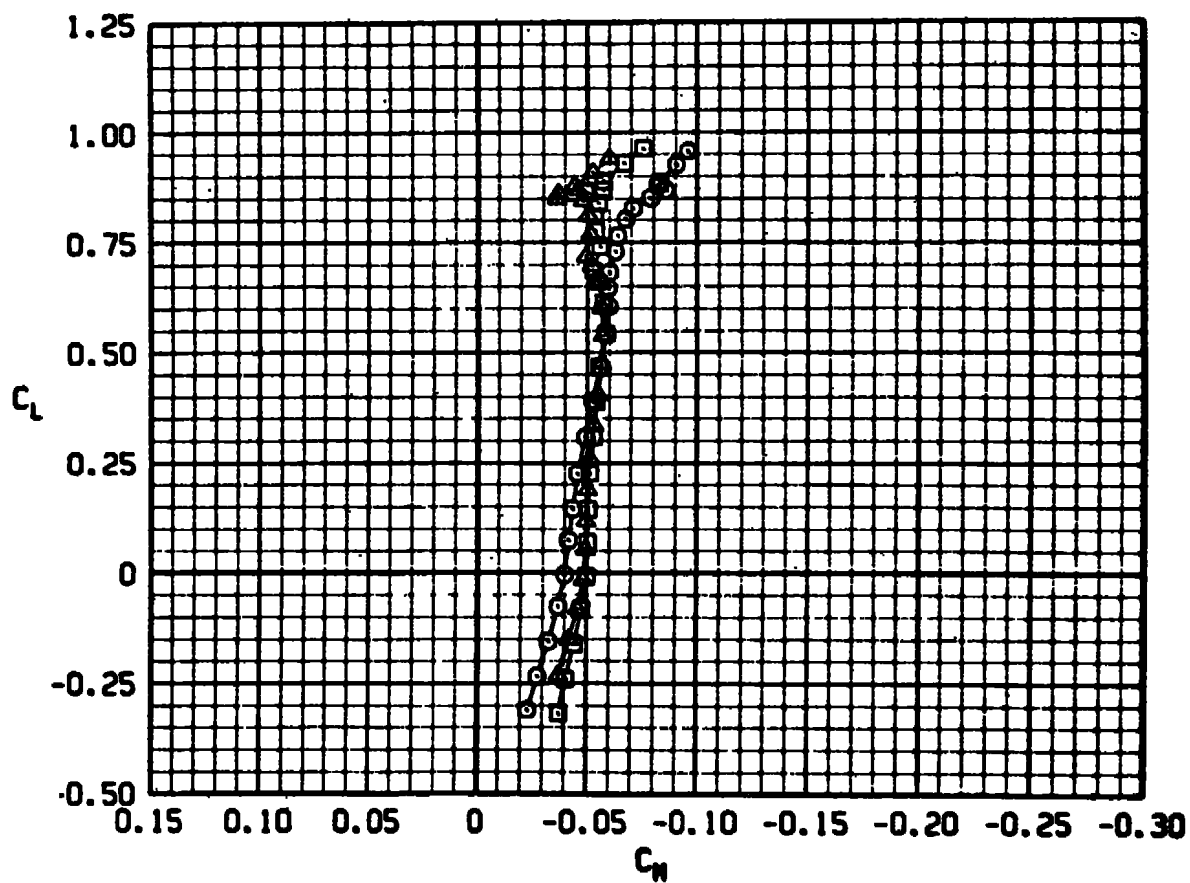
c. $M_\infty = 0.850$
Figure 14. Continued.

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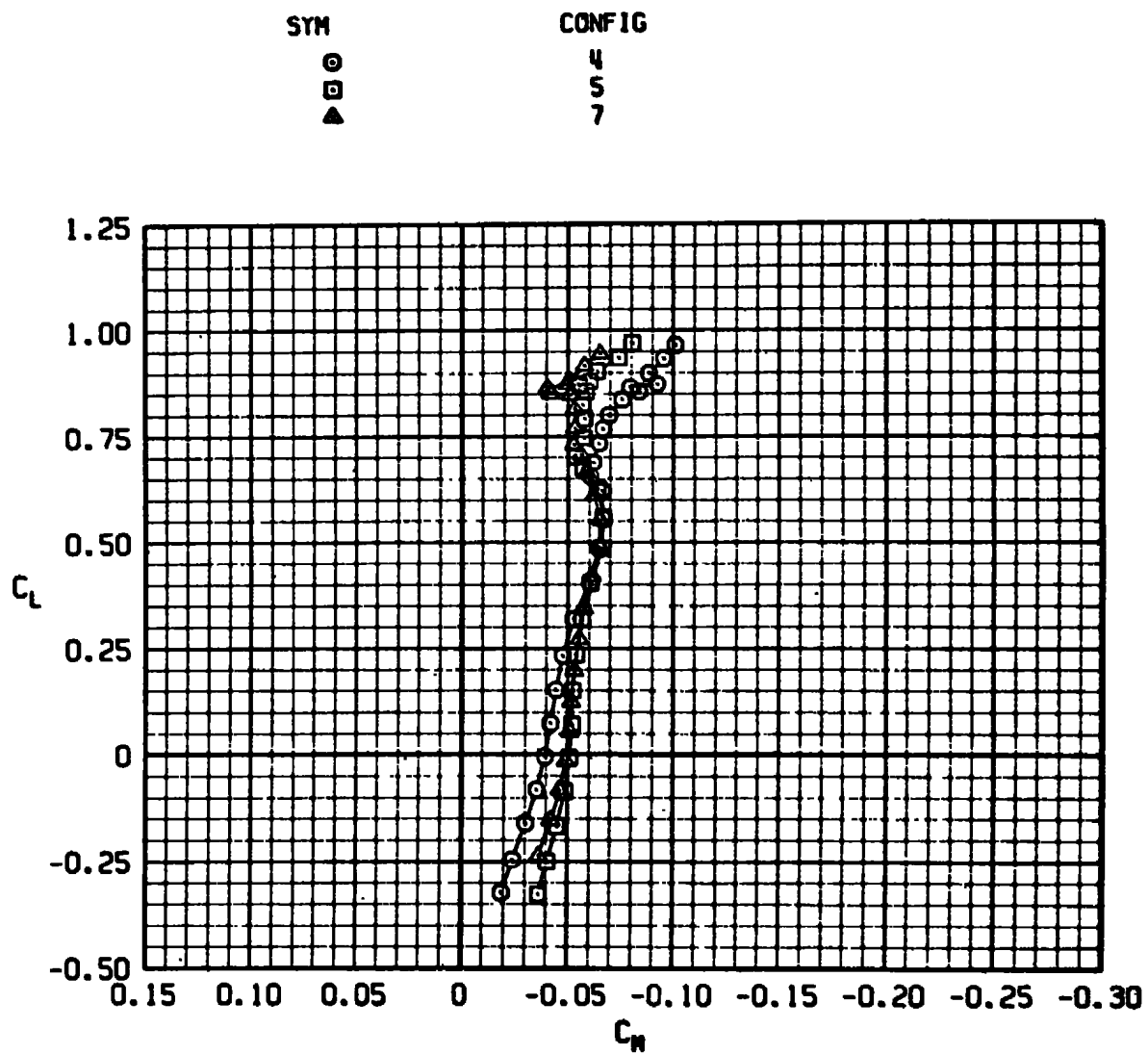
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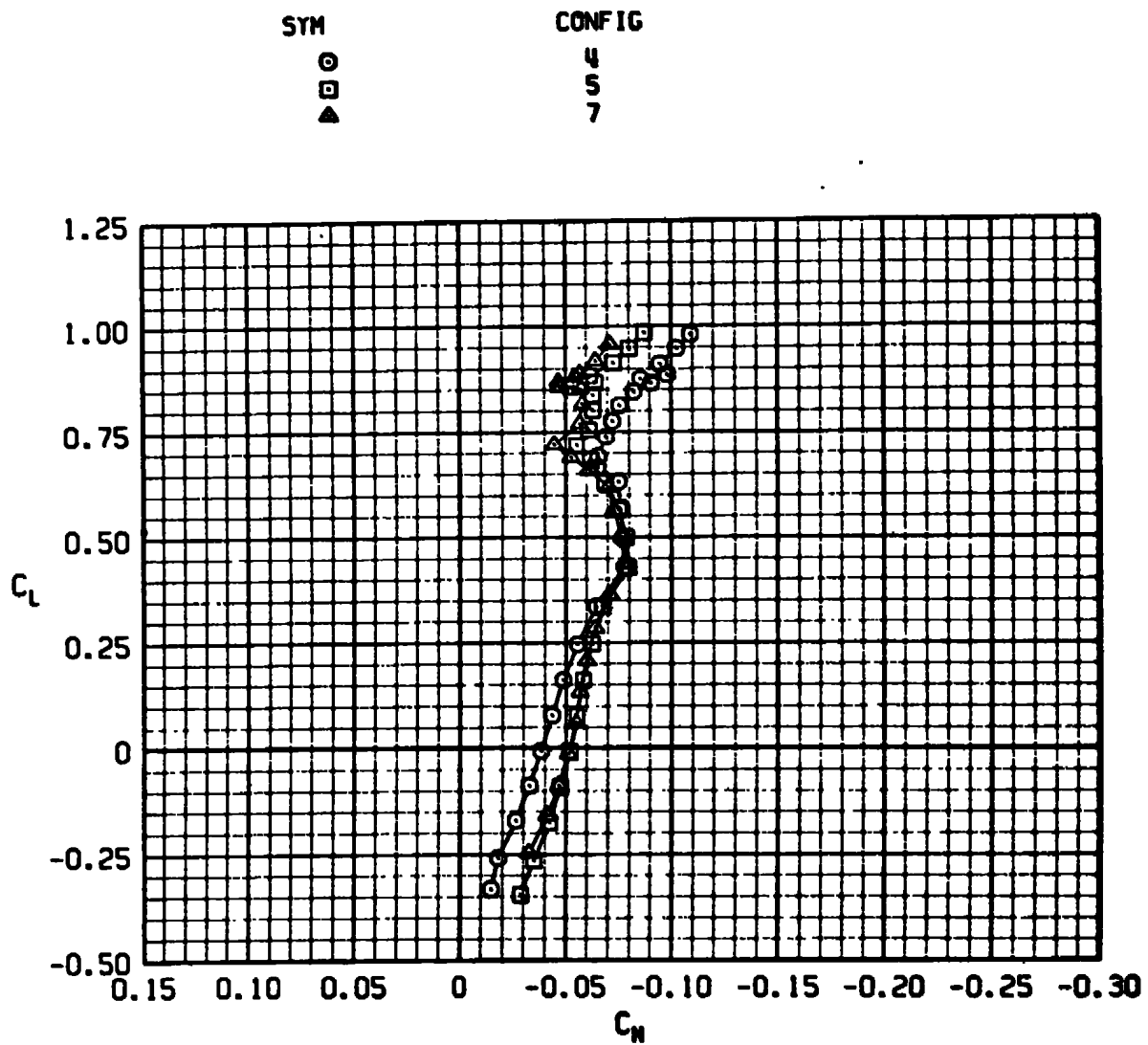
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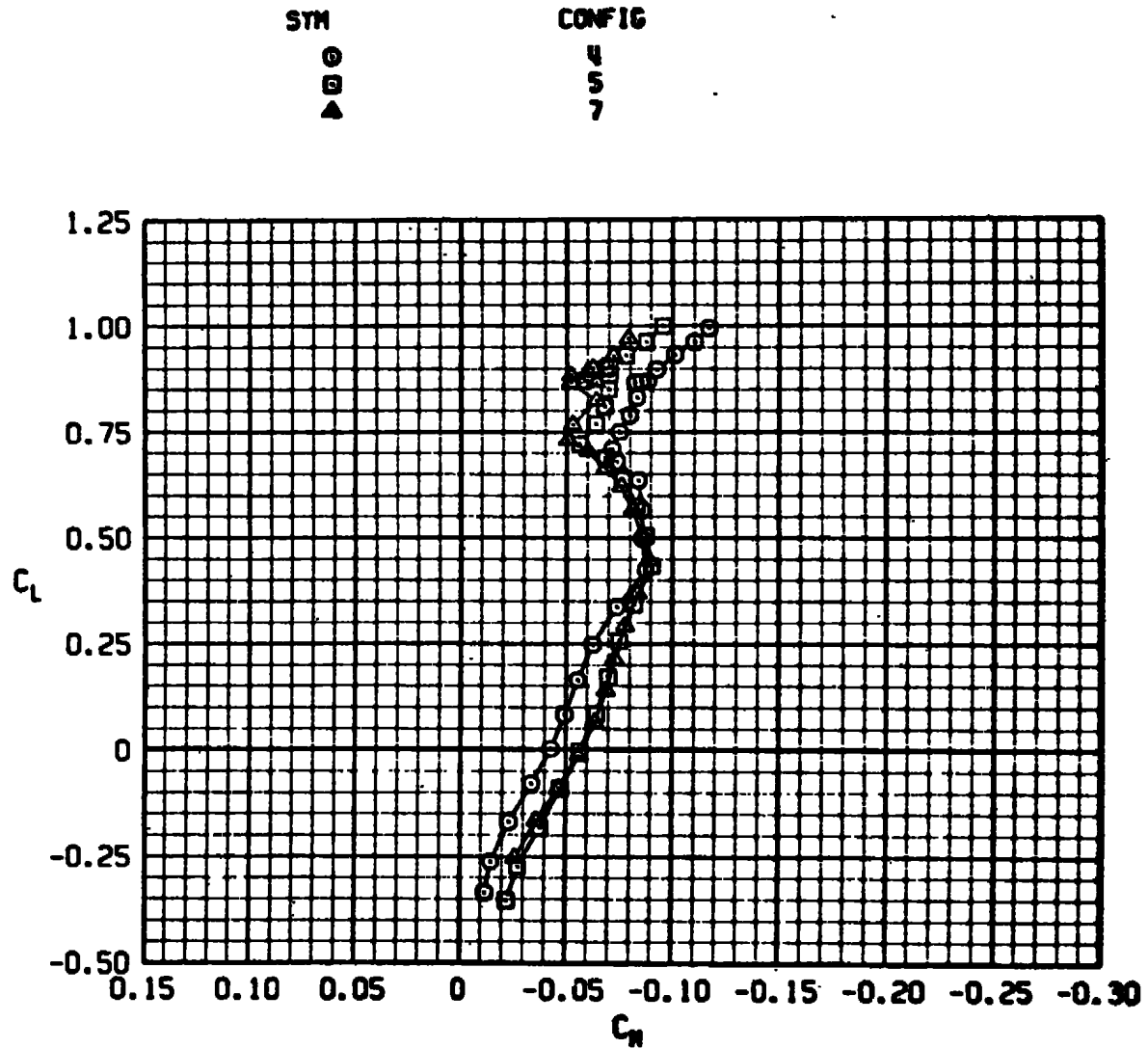
d. $M_\infty = 0.875$
Figure 14. Continued.



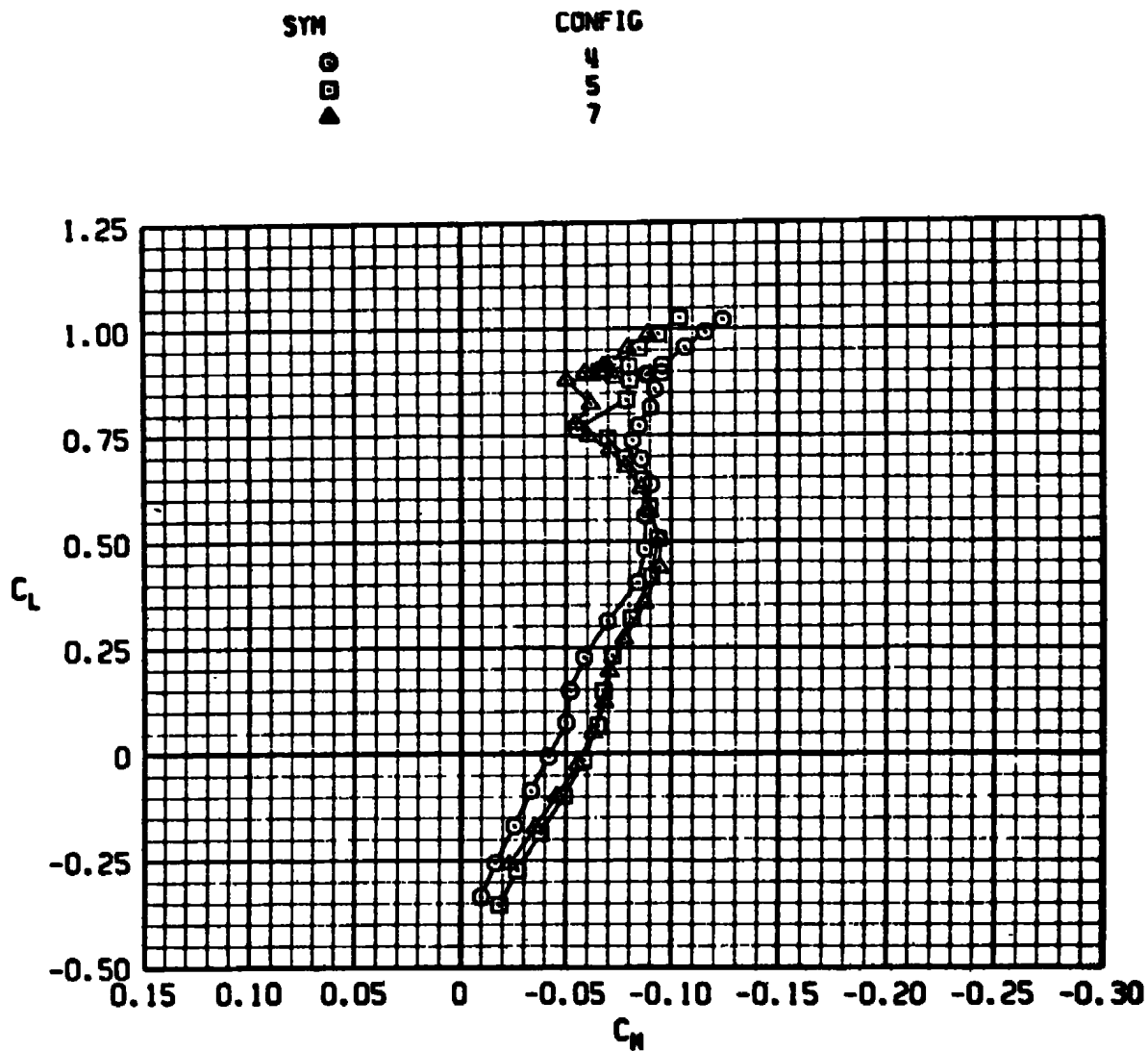
e. $M_\infty = 0.900$
 Figure 14. Continued.



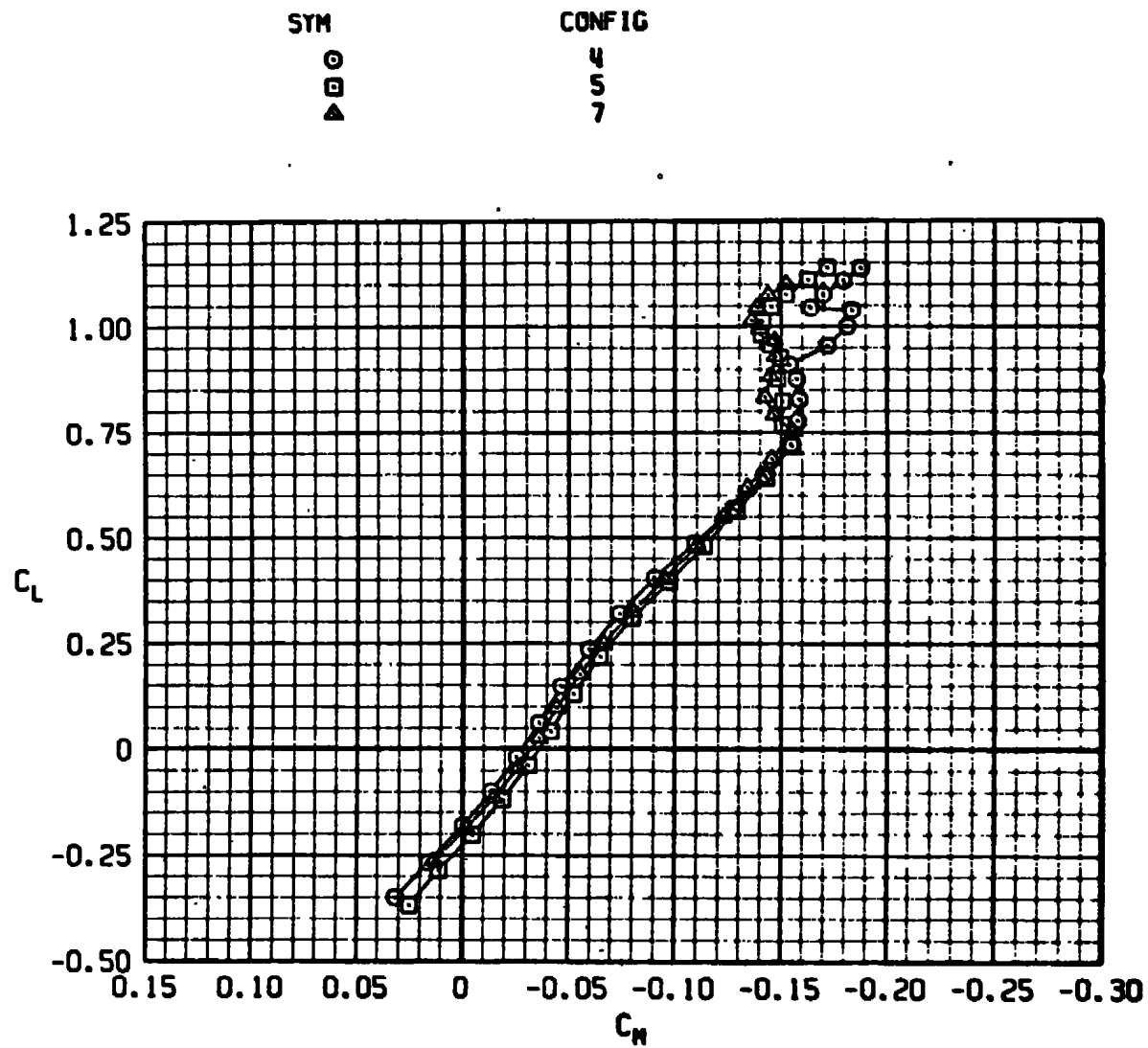
f. $M_\infty = 0.925$
Figure 14. Continued.



$\alpha = 0.950$
Figure 14. Continued.



h. $M_\infty = 0.975$
Figure 14. Continued.



i. $M_\infty = 1.100$
 Figure 14. Concluded.

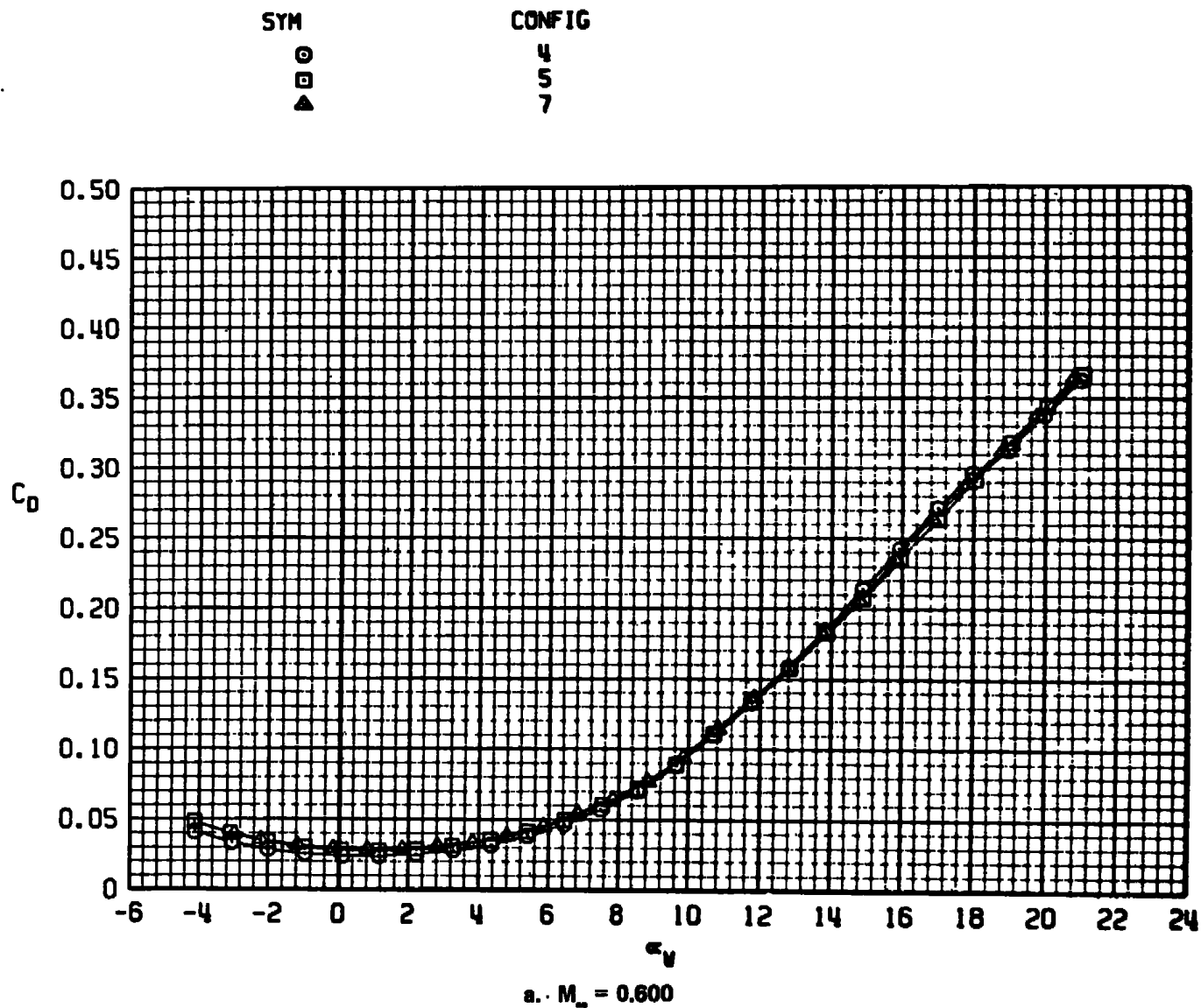


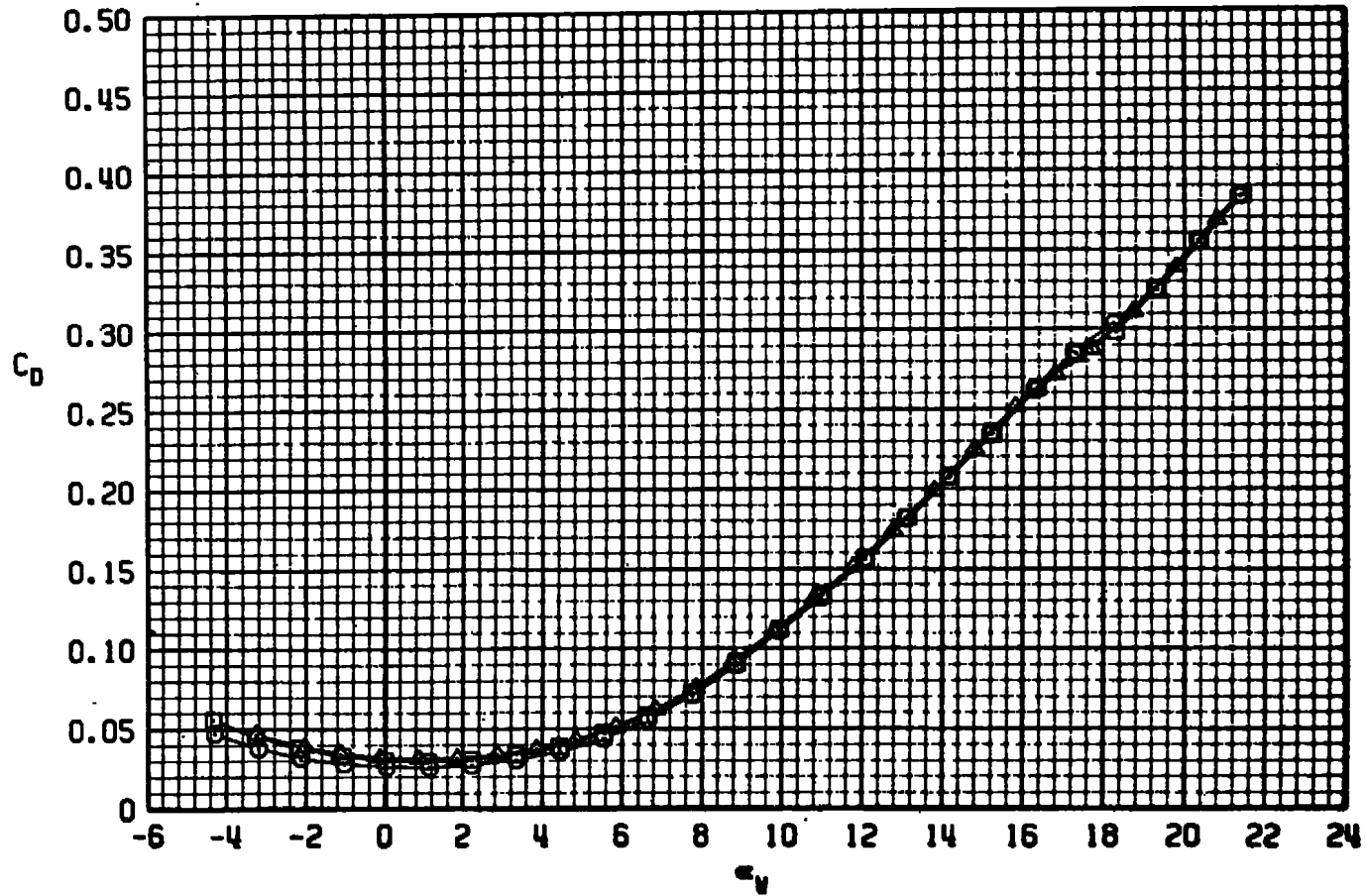
Figure 15. Drag coefficient variation with angle of attack for configurations 4, 5, and 7.

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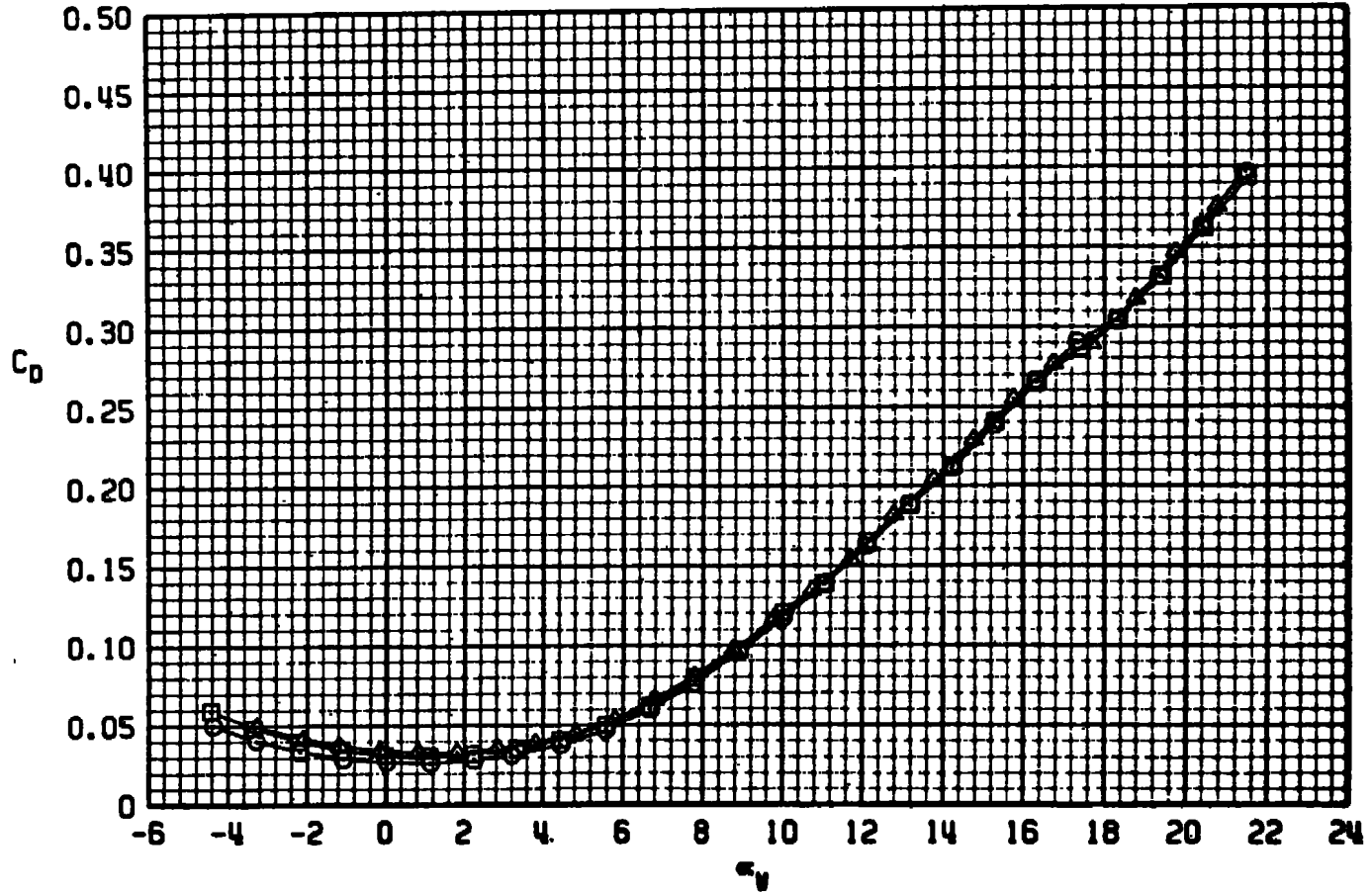
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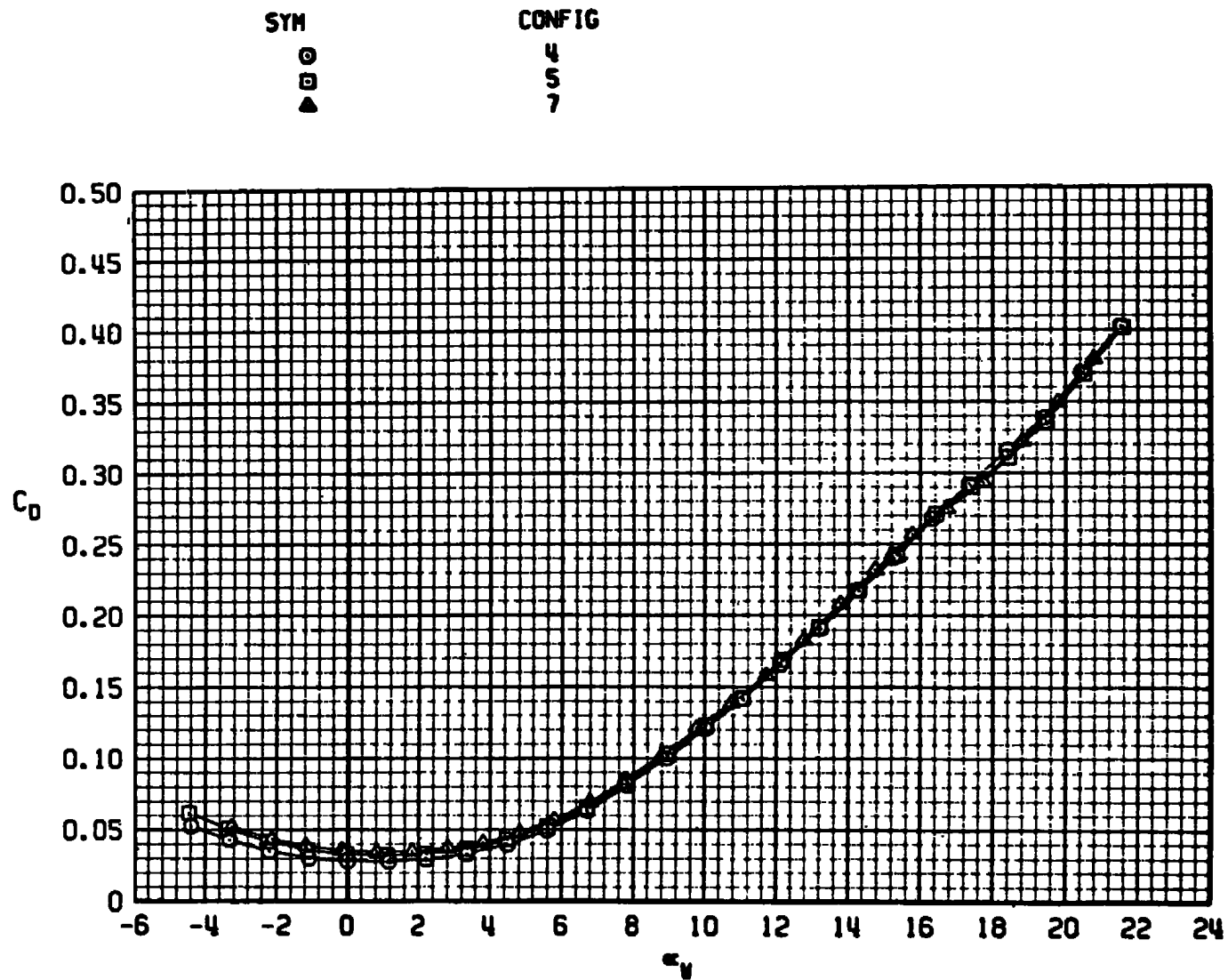
b. $M_\infty = 0.800$
Figure 15. Continued.

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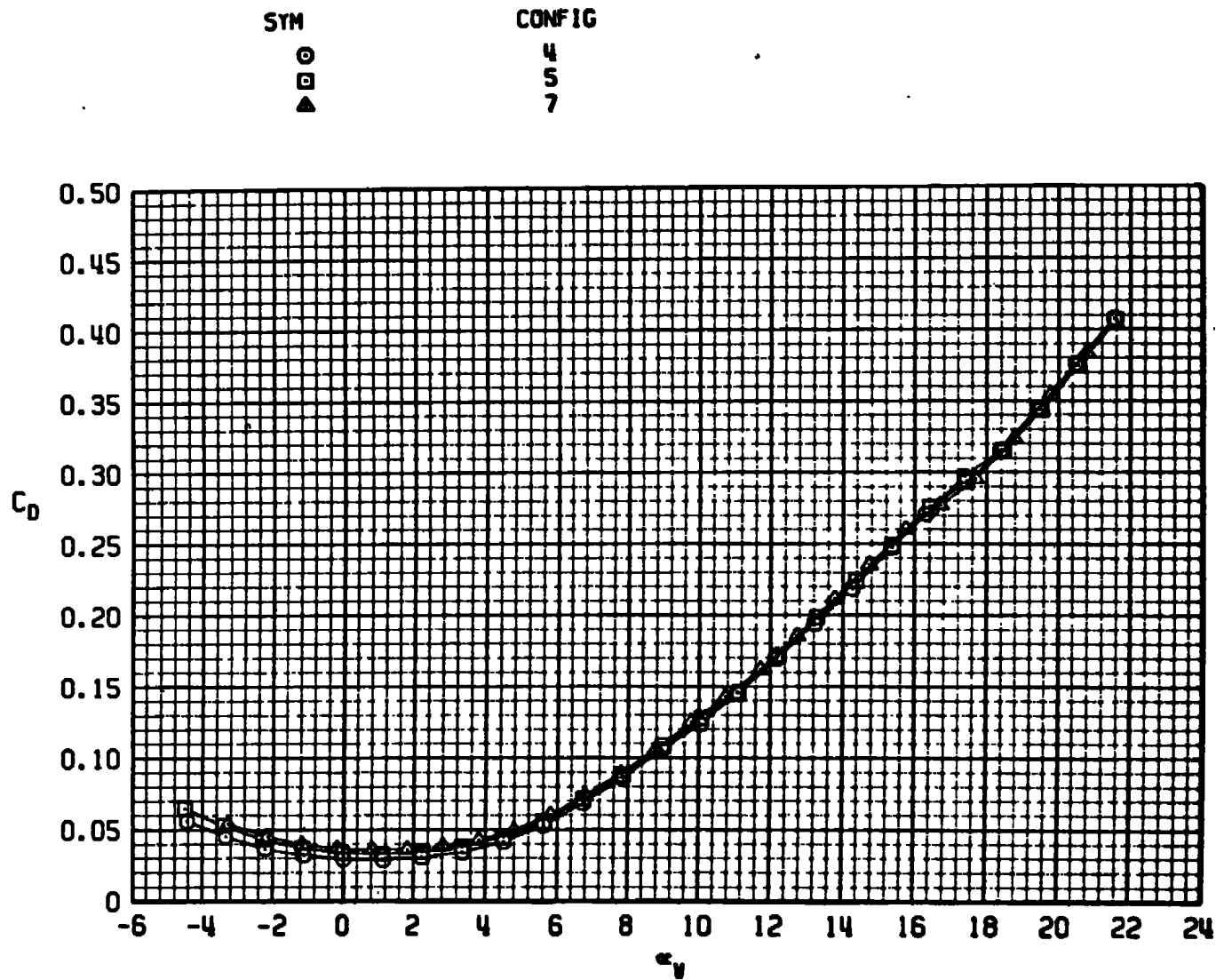
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c. $M_\infty = 0.850$
Figure 15. Continued.

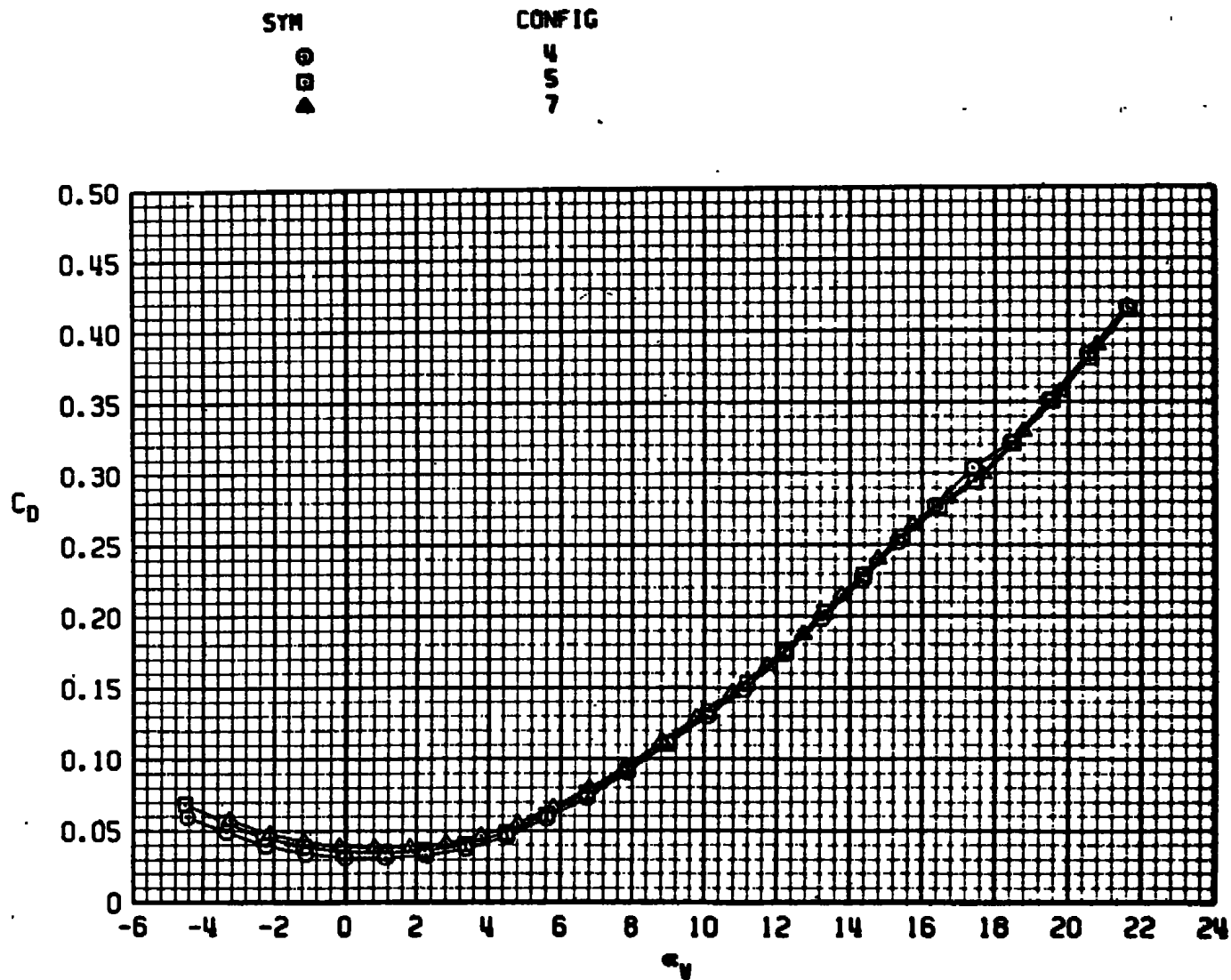


d. $M_\infty = 0.875$
Figure 15. Continued.



α_v

$M_\infty = 0.900$
 Figure 15. Continued.



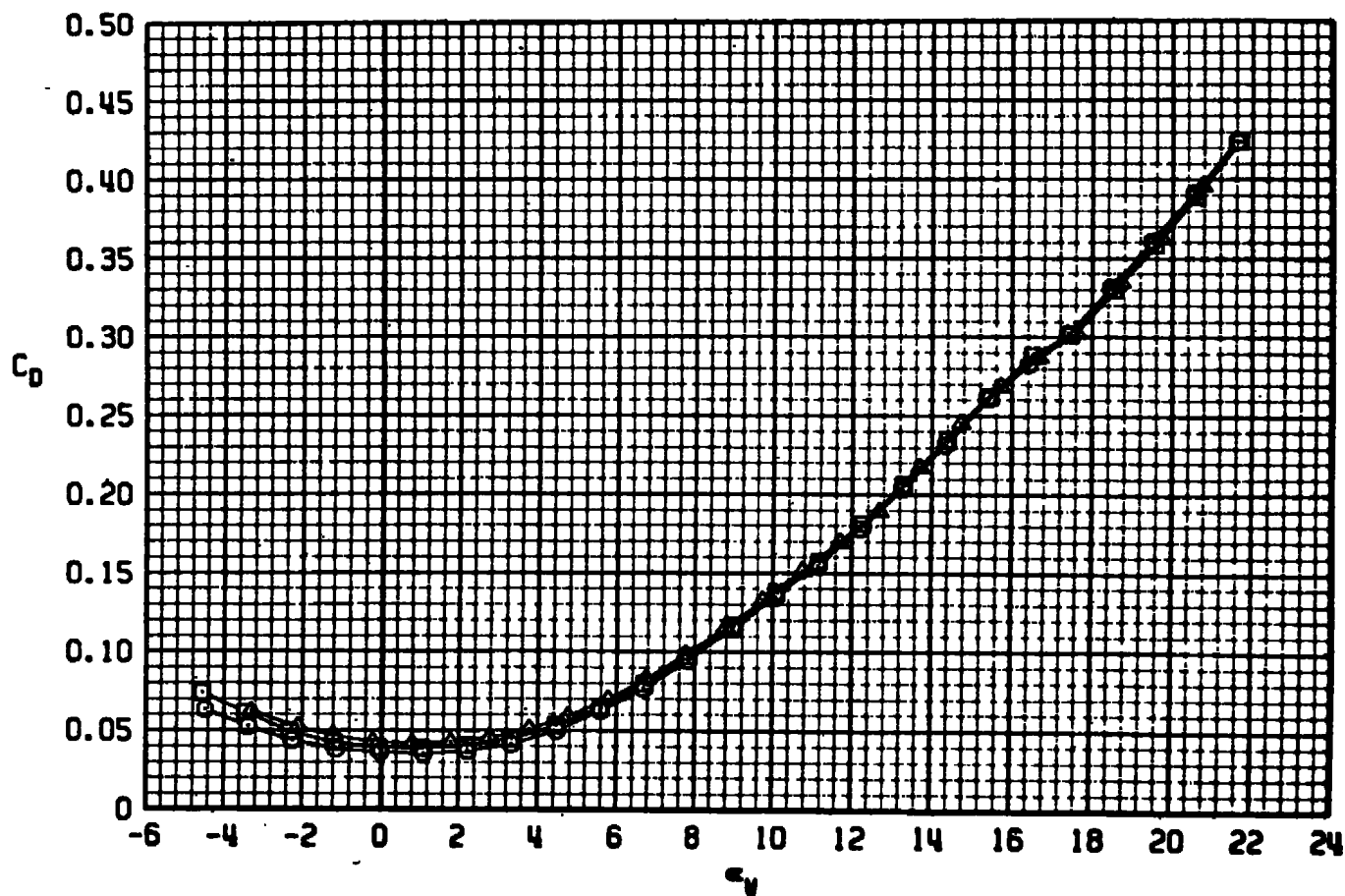
f. $M_\infty = 0.925$
Figure 15. Continued.

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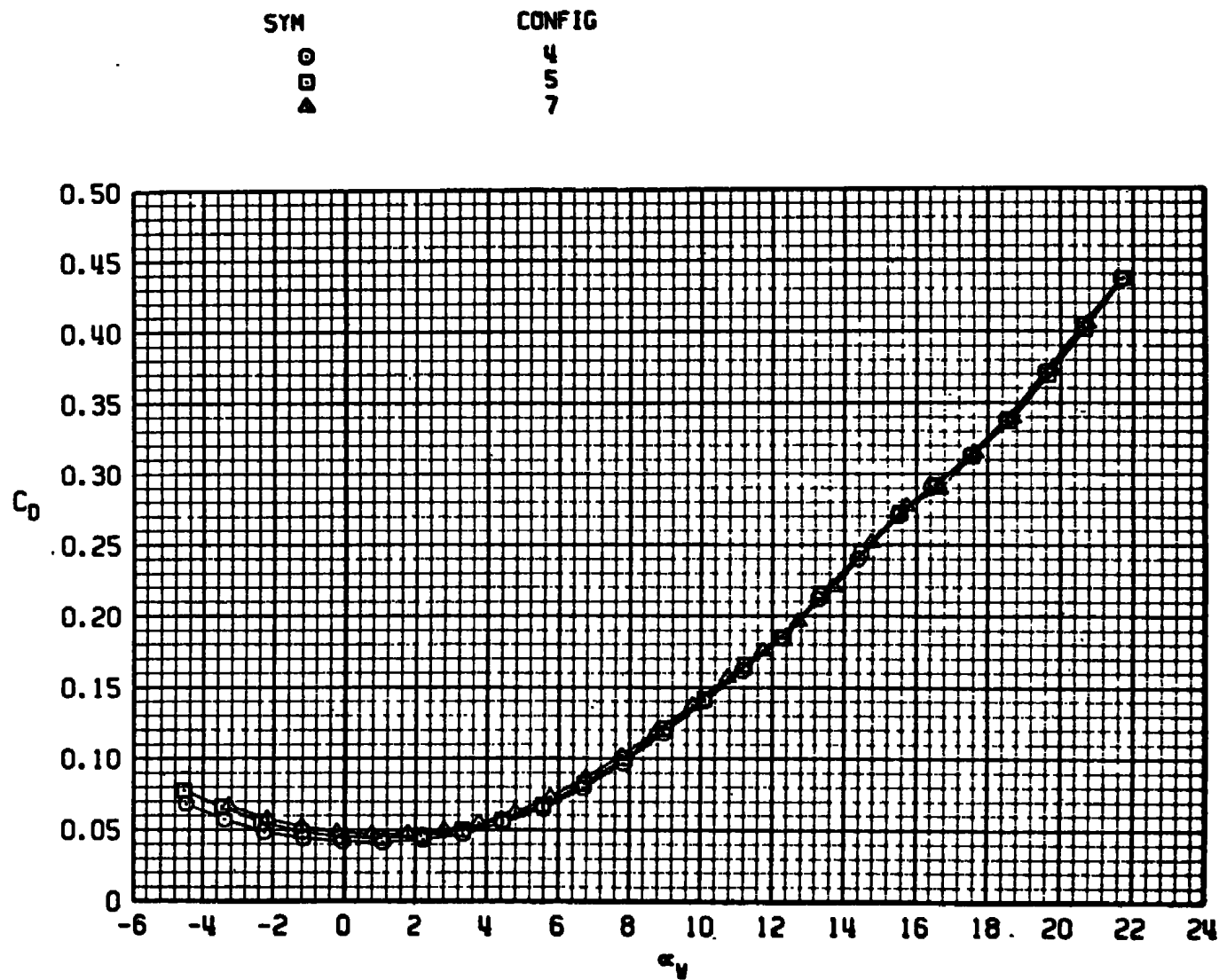
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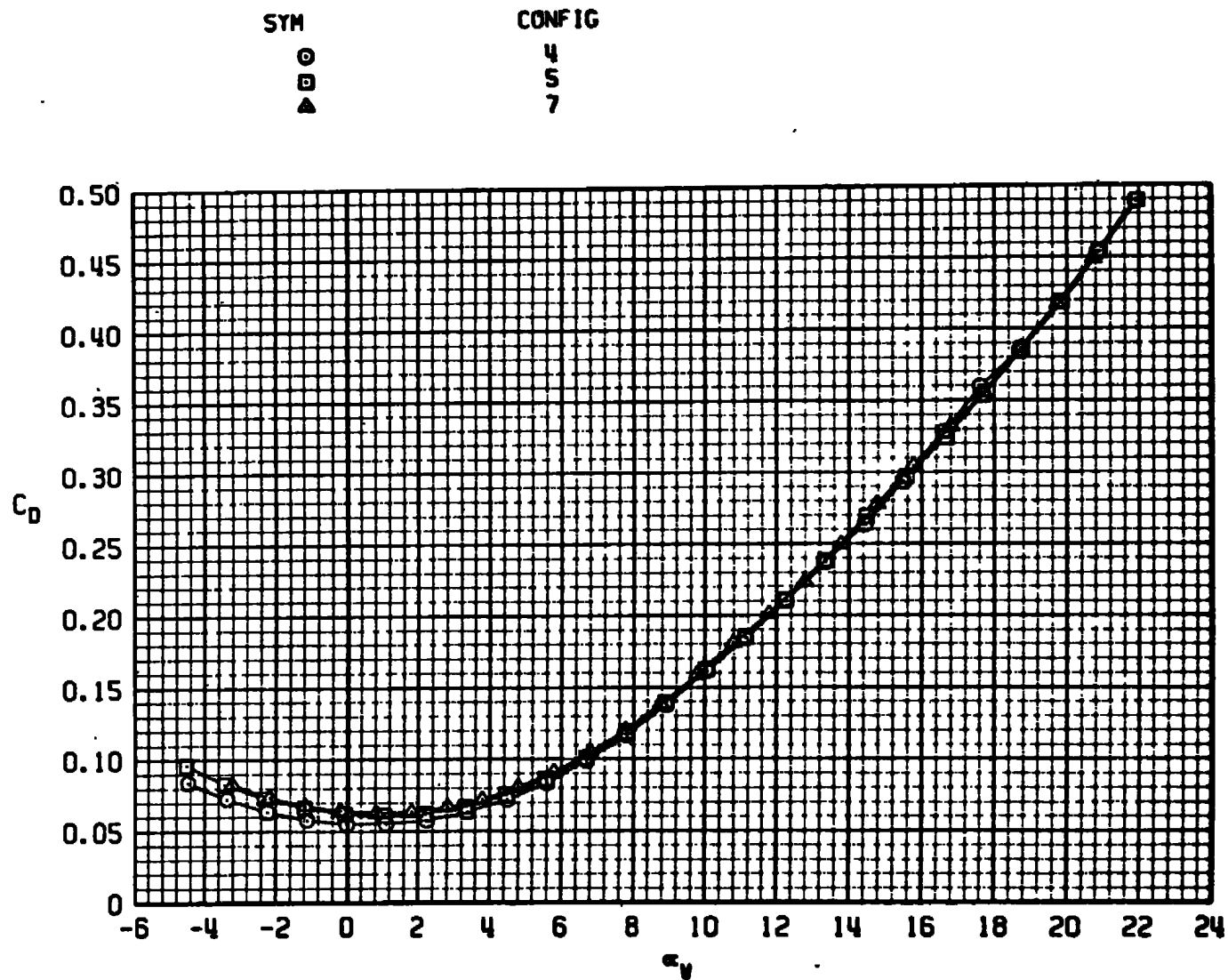
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$g. M_{\infty} = 0.950$
Figure 15. Continued.



h. $M_\infty = 0.975$
Figure 15. Continued.



i. $M_\infty = 1.100$
Figure 15. Concluded.

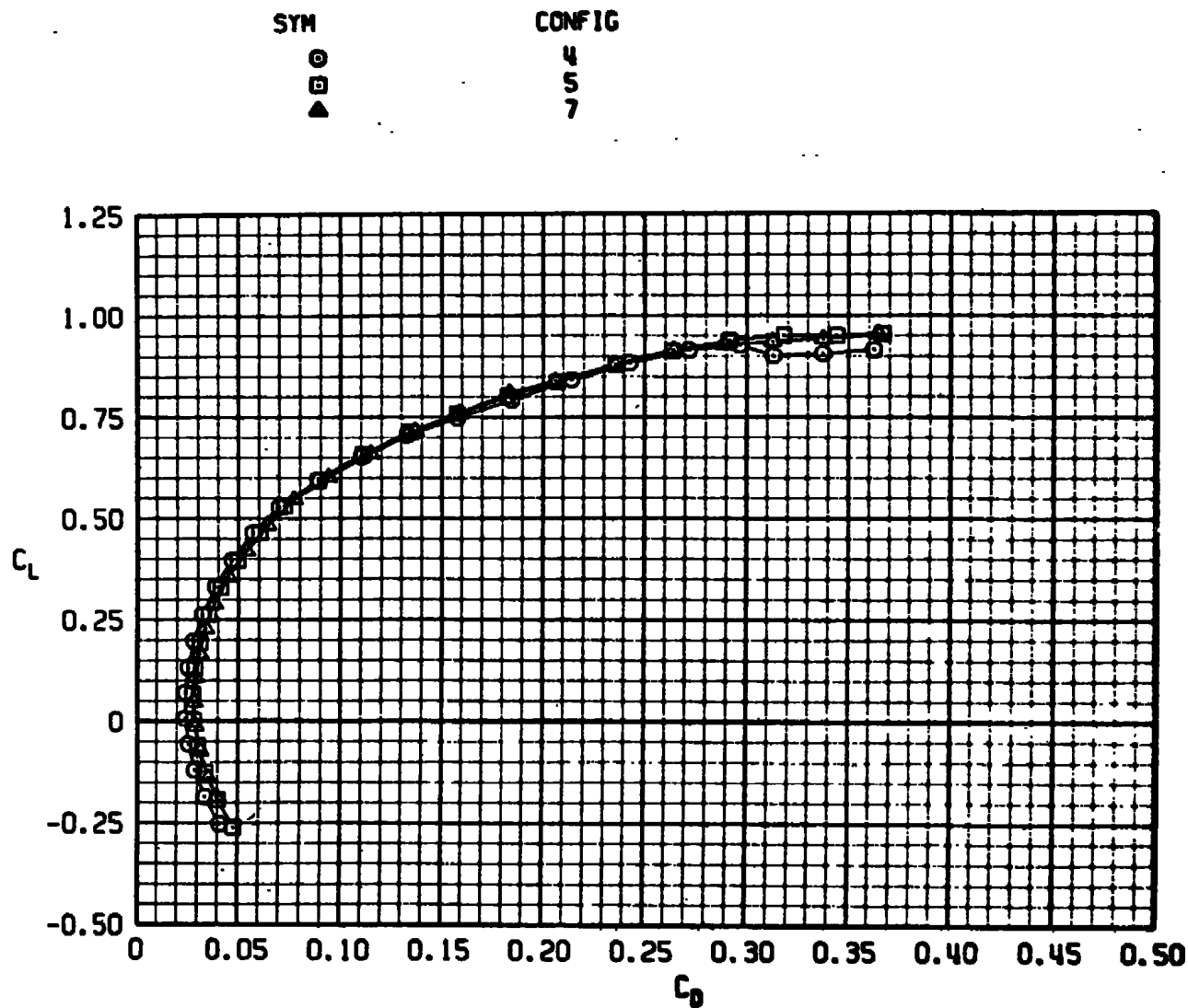
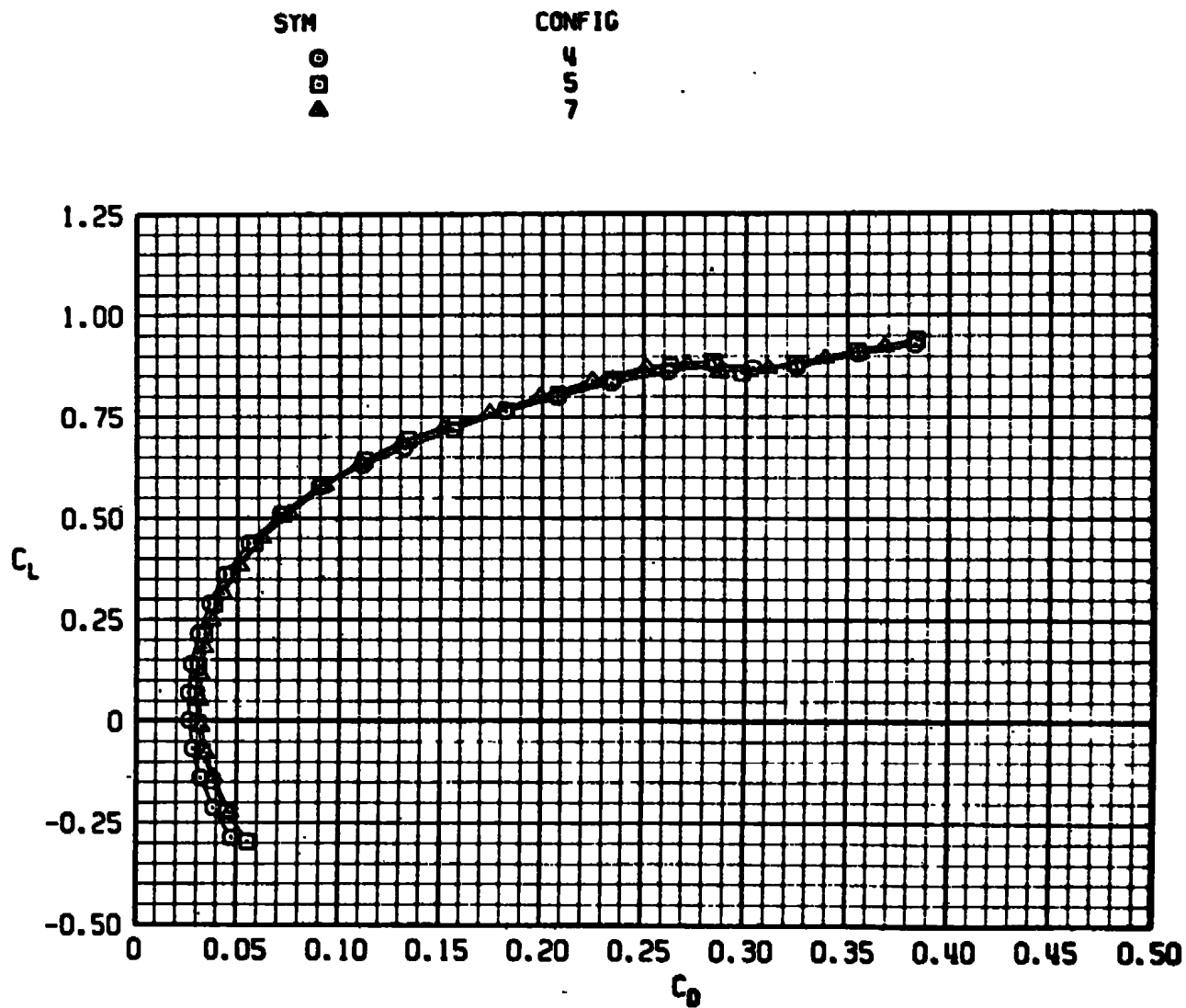
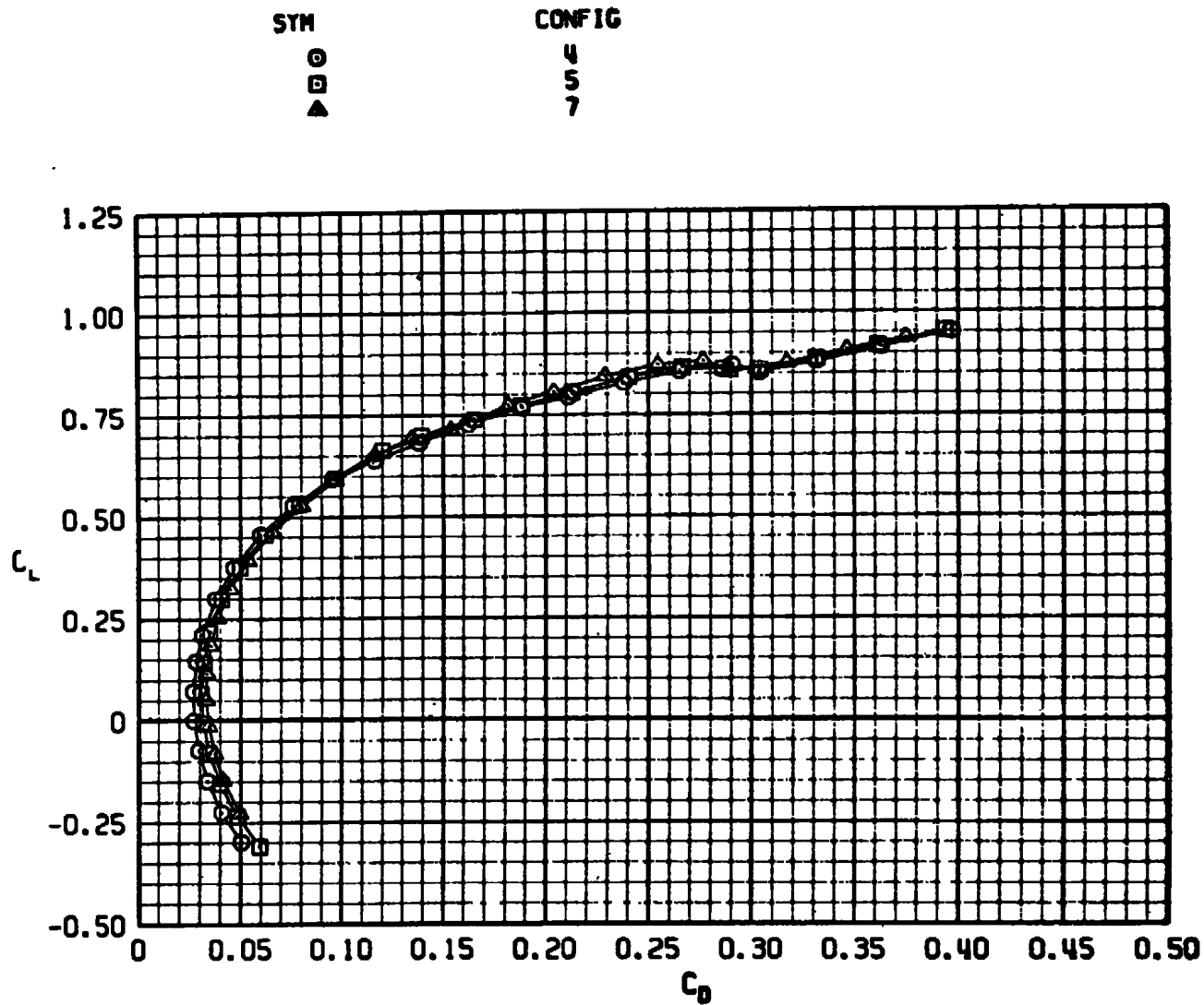


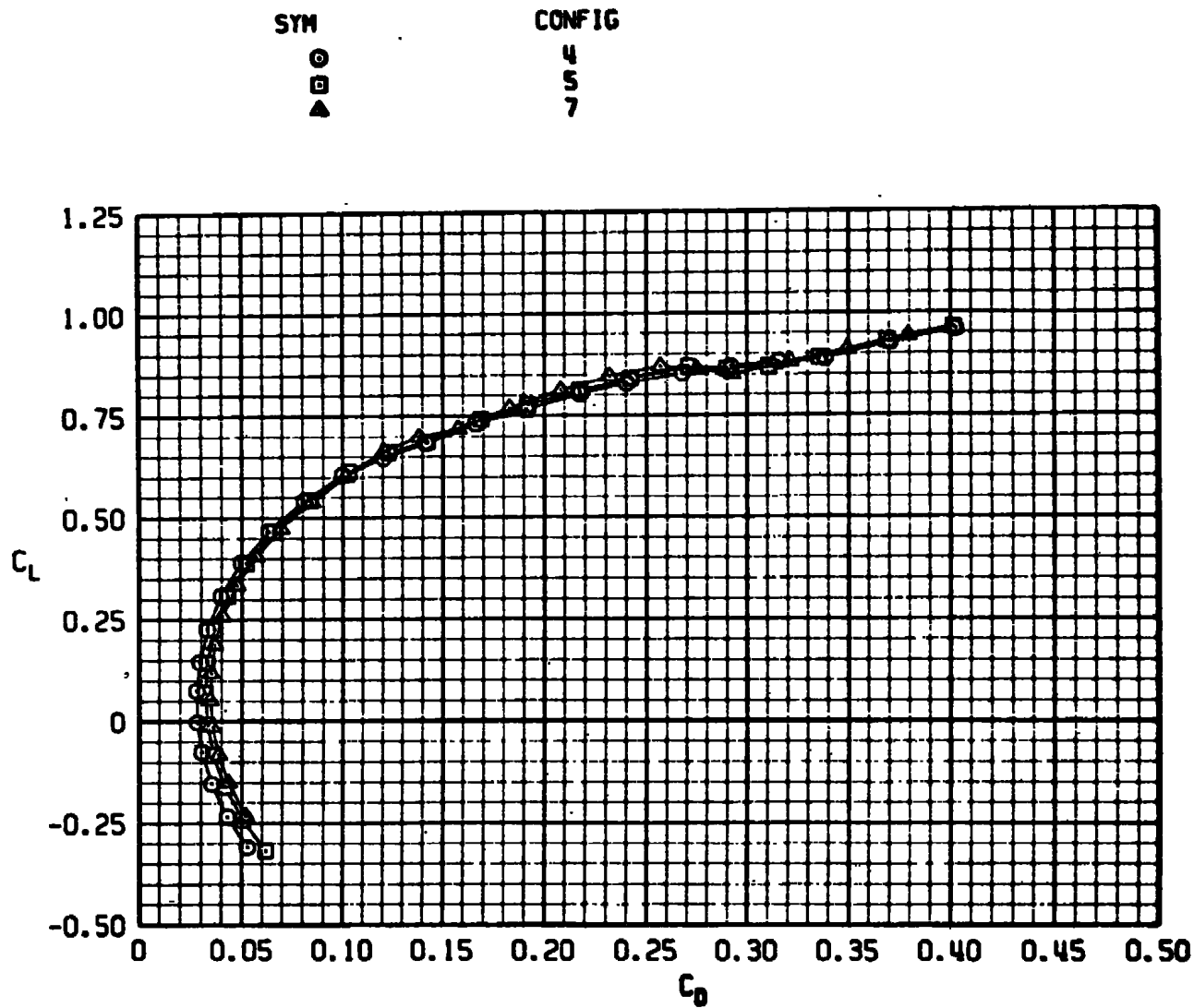
Figure 16. Drag coefficient variation with lift coefficient for configurations 4, 5, and 7.



b. $M_\infty = 0.800$
Figure 16. -Continued.



c. $M_\infty = 0.850$
 Figure 16. Continued.



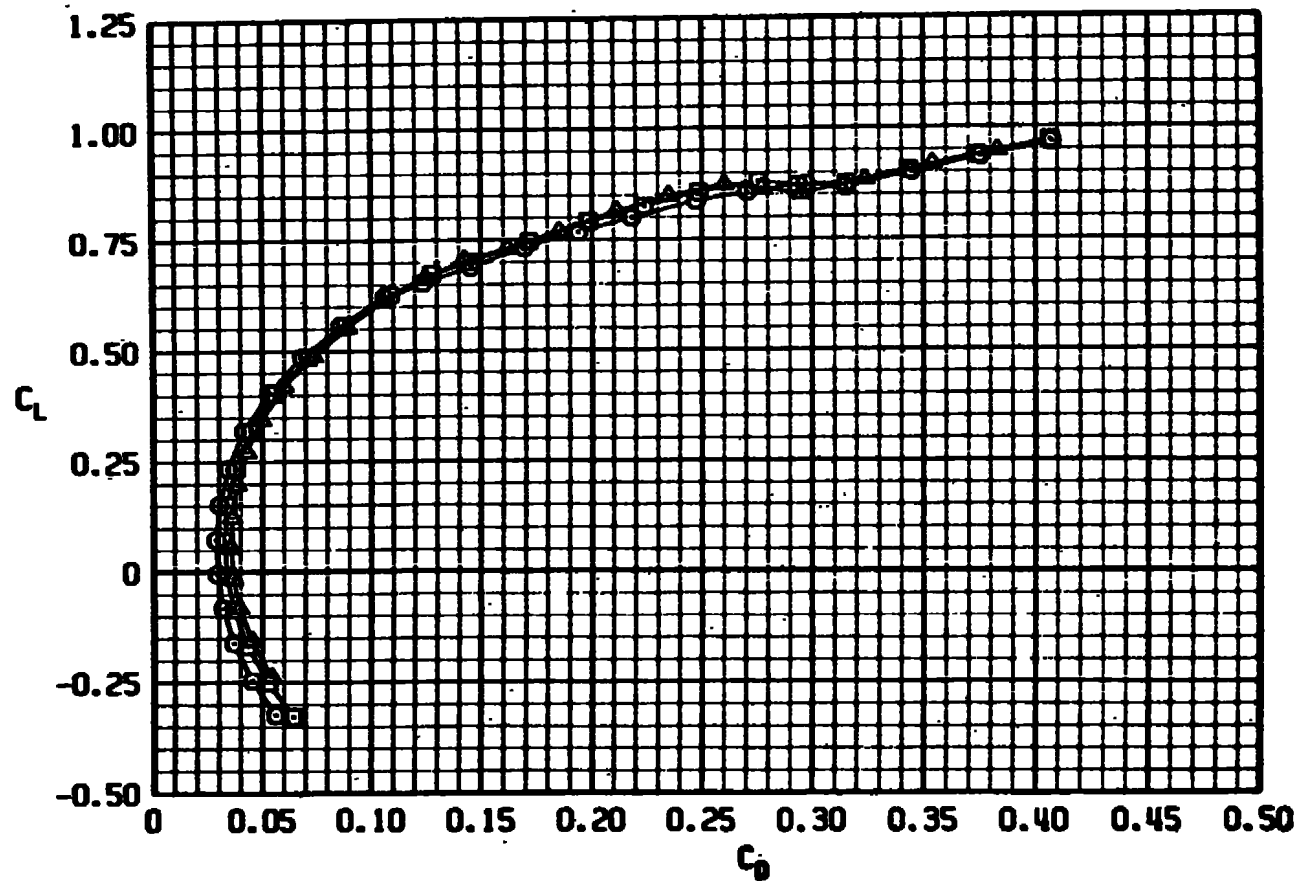
d. $M_\infty = 0.875$
Figure 16. Continued.

SYM

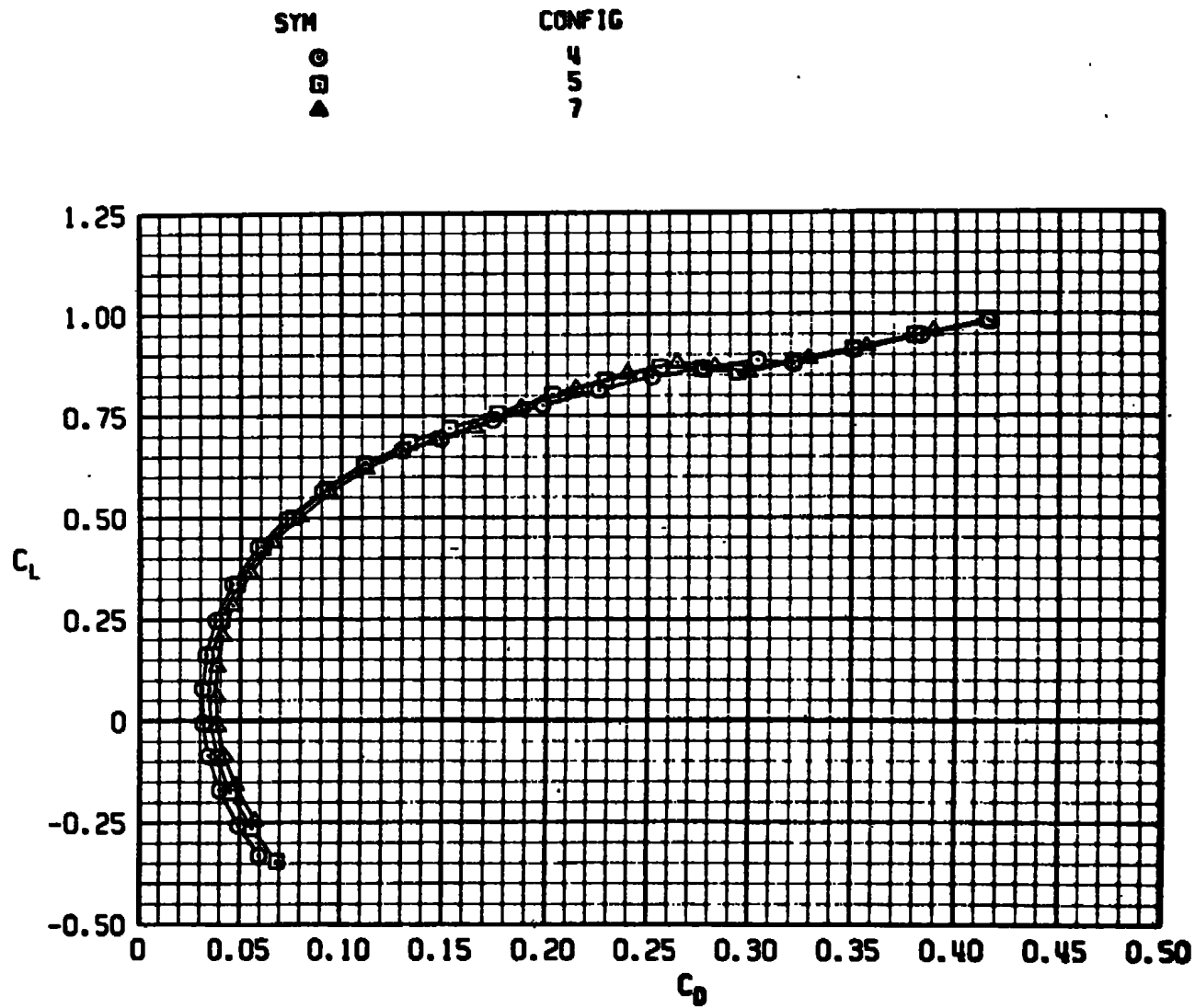
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a. $M_\infty = 0.900$
Figure 16. Continued.



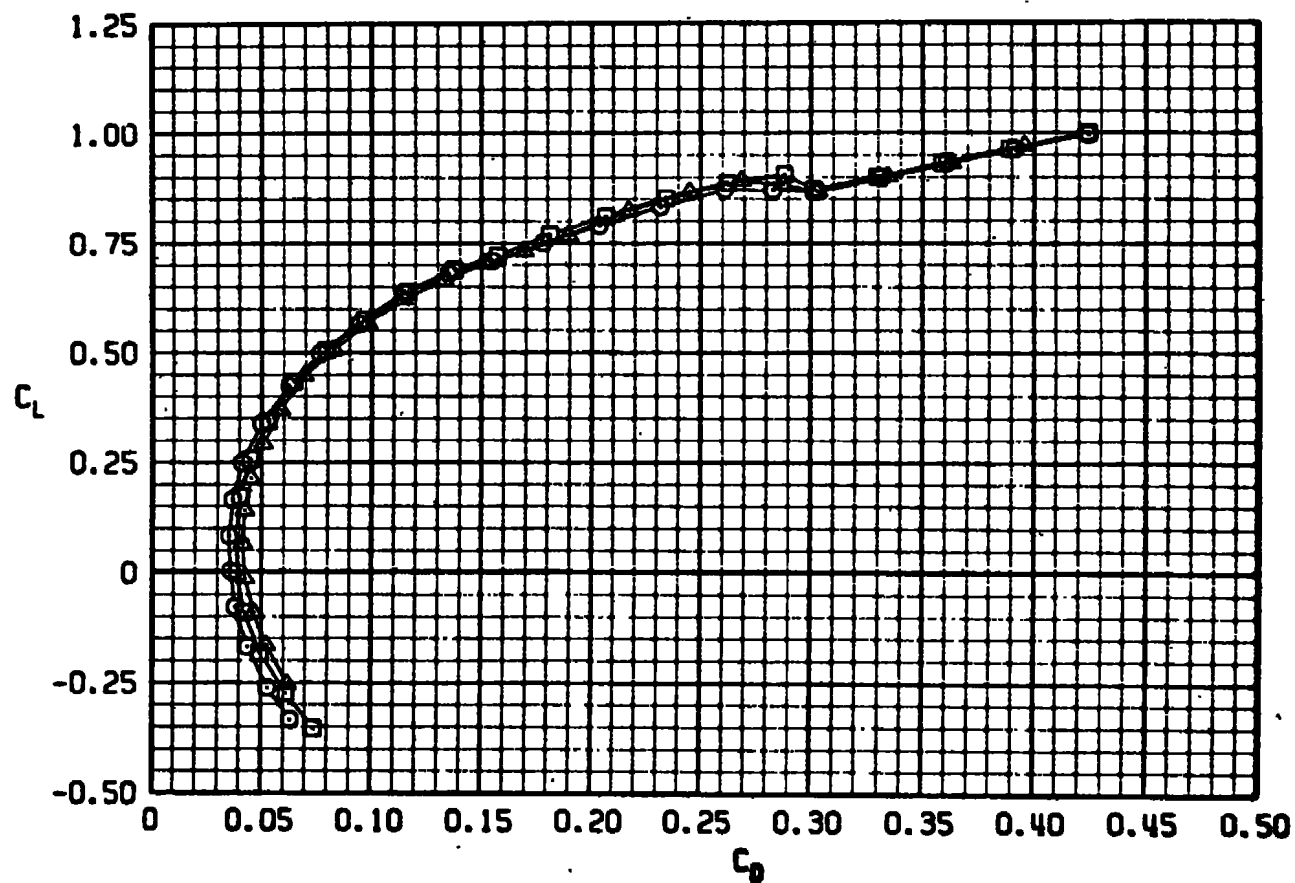
f. $M_\infty = 0.925$
Figure 16. Continued.

SYM

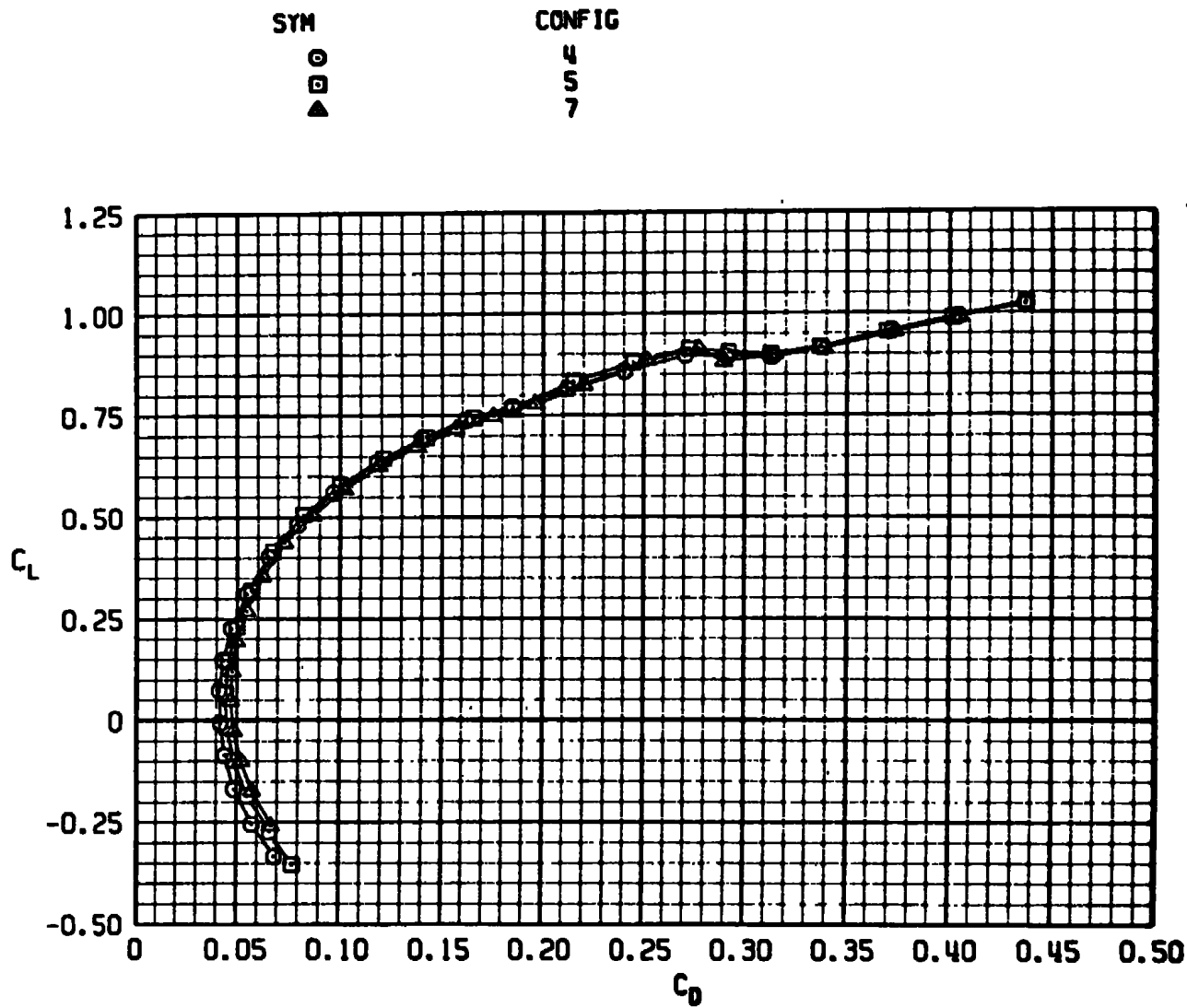
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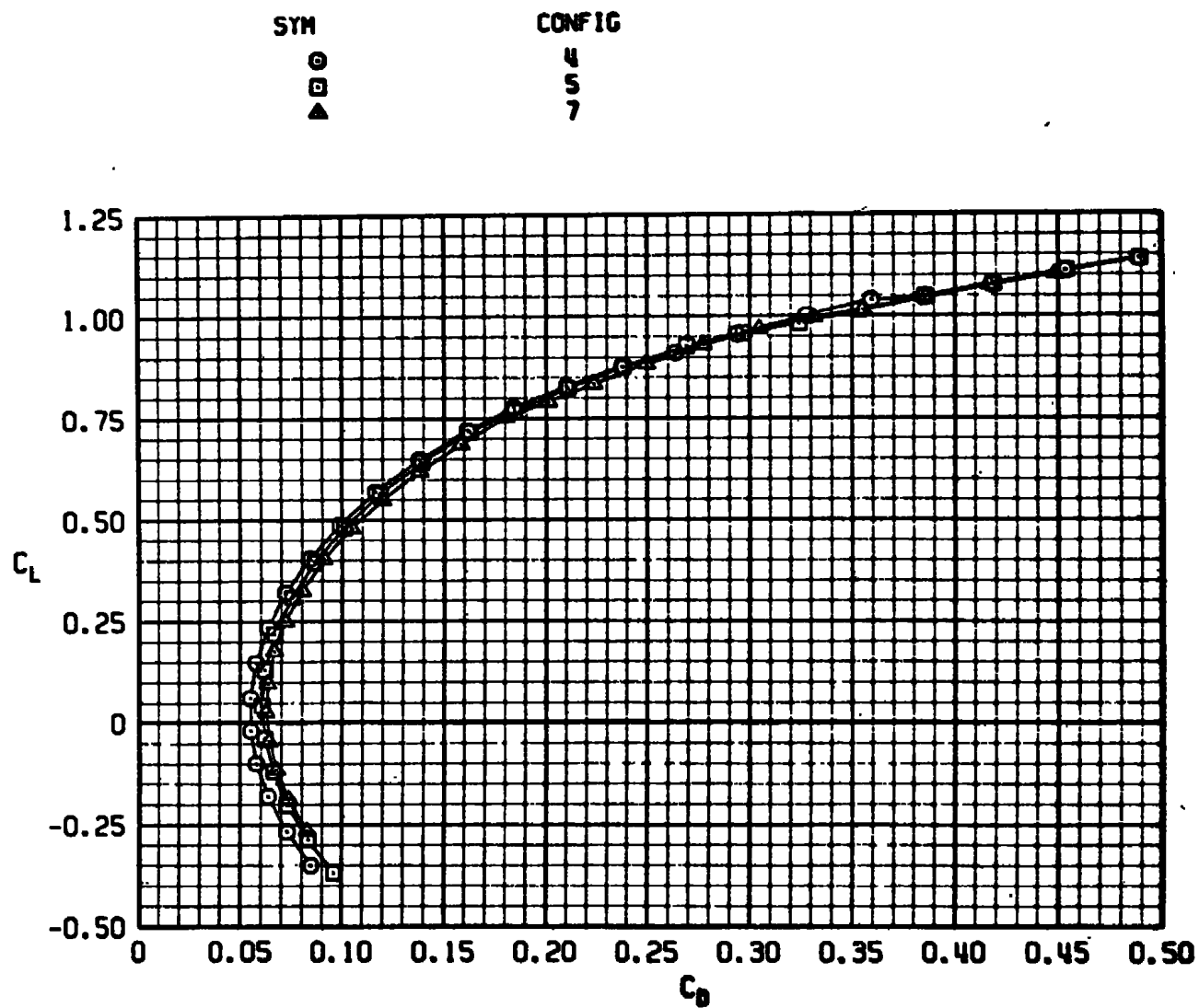
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g. $M_\infty = 0.950$
Figure 16. Continued.



h. $M_\infty = 0.975$
Figure 16. Continued.



i. $M_\infty = 1.100$
Figure 16. Concluded.

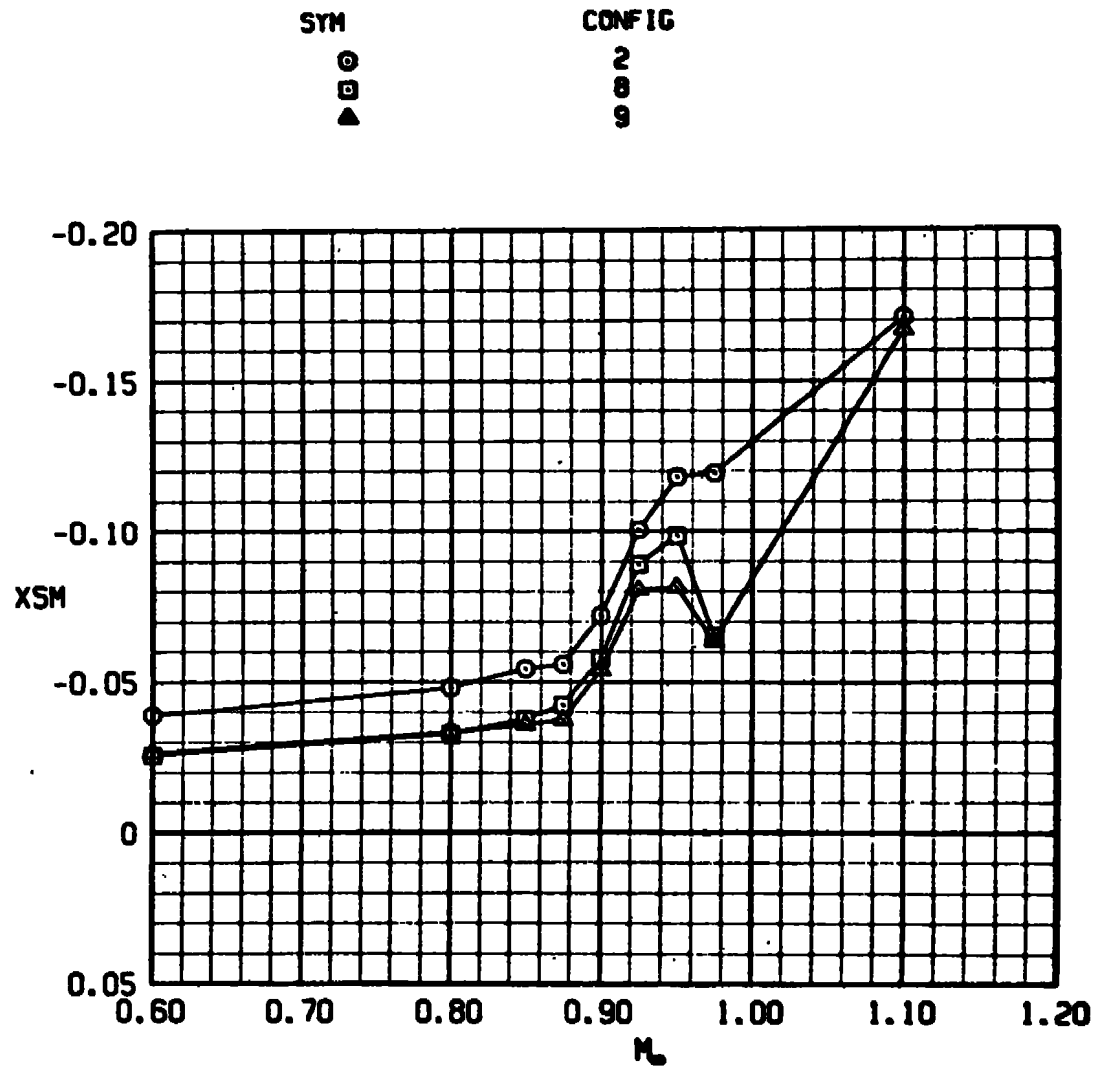


Figure 17. Static margin variation with Mach number for configurations 2, 8, and 9.

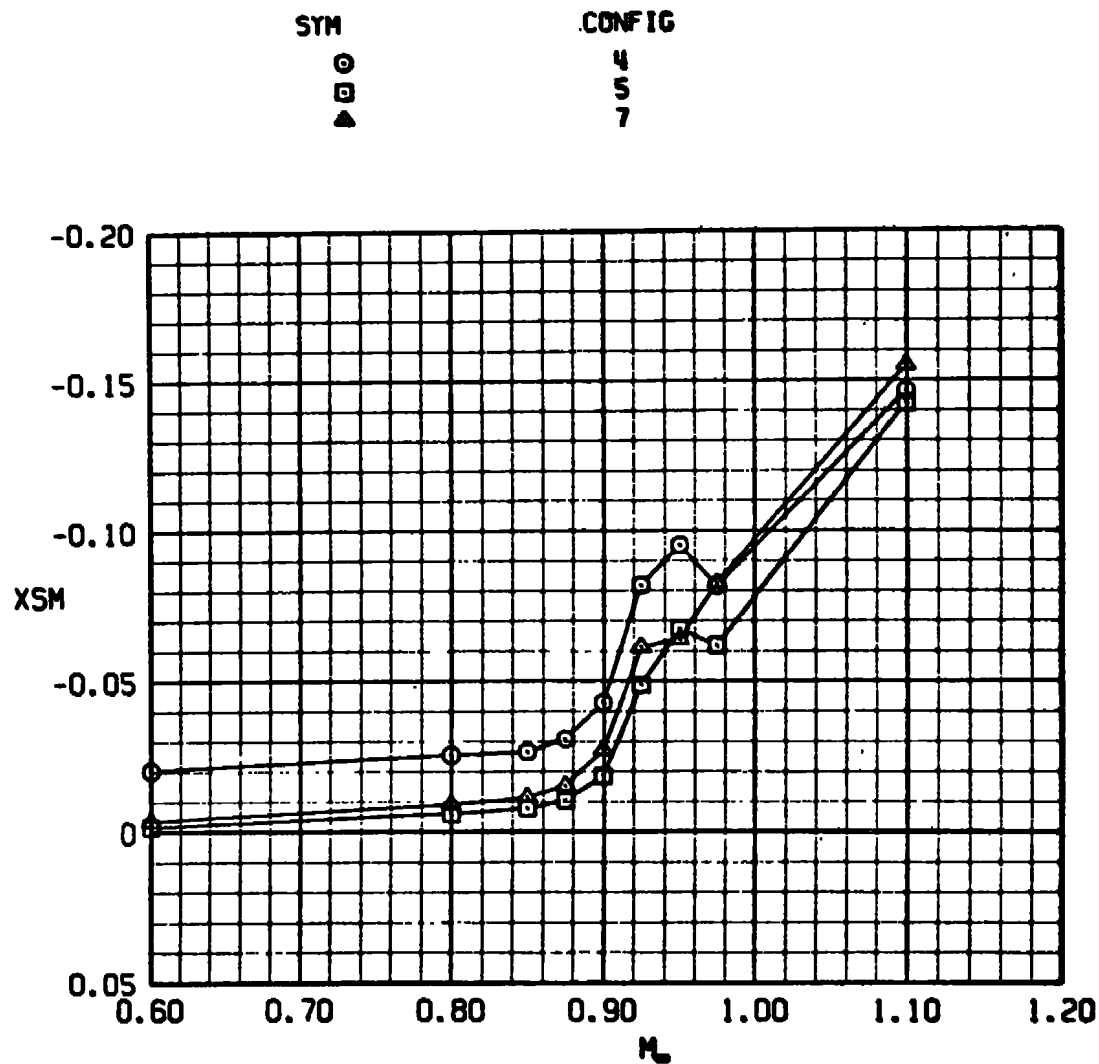


Figure 18. Static margin variation with Mach number for configurations 4, 5, and 7.

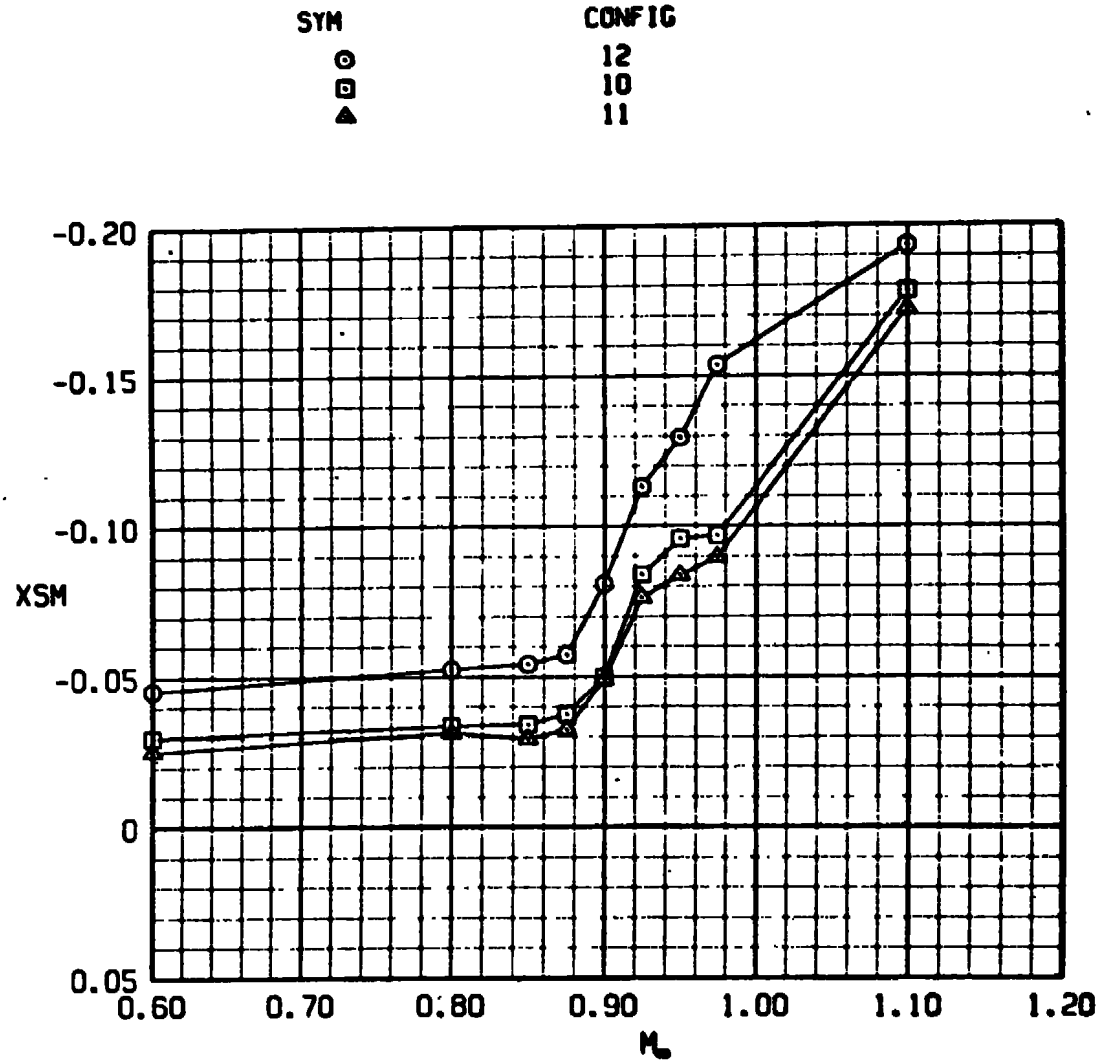


Figure 19. Static margin variation with Mach number for configurations 10, 11, and 12.

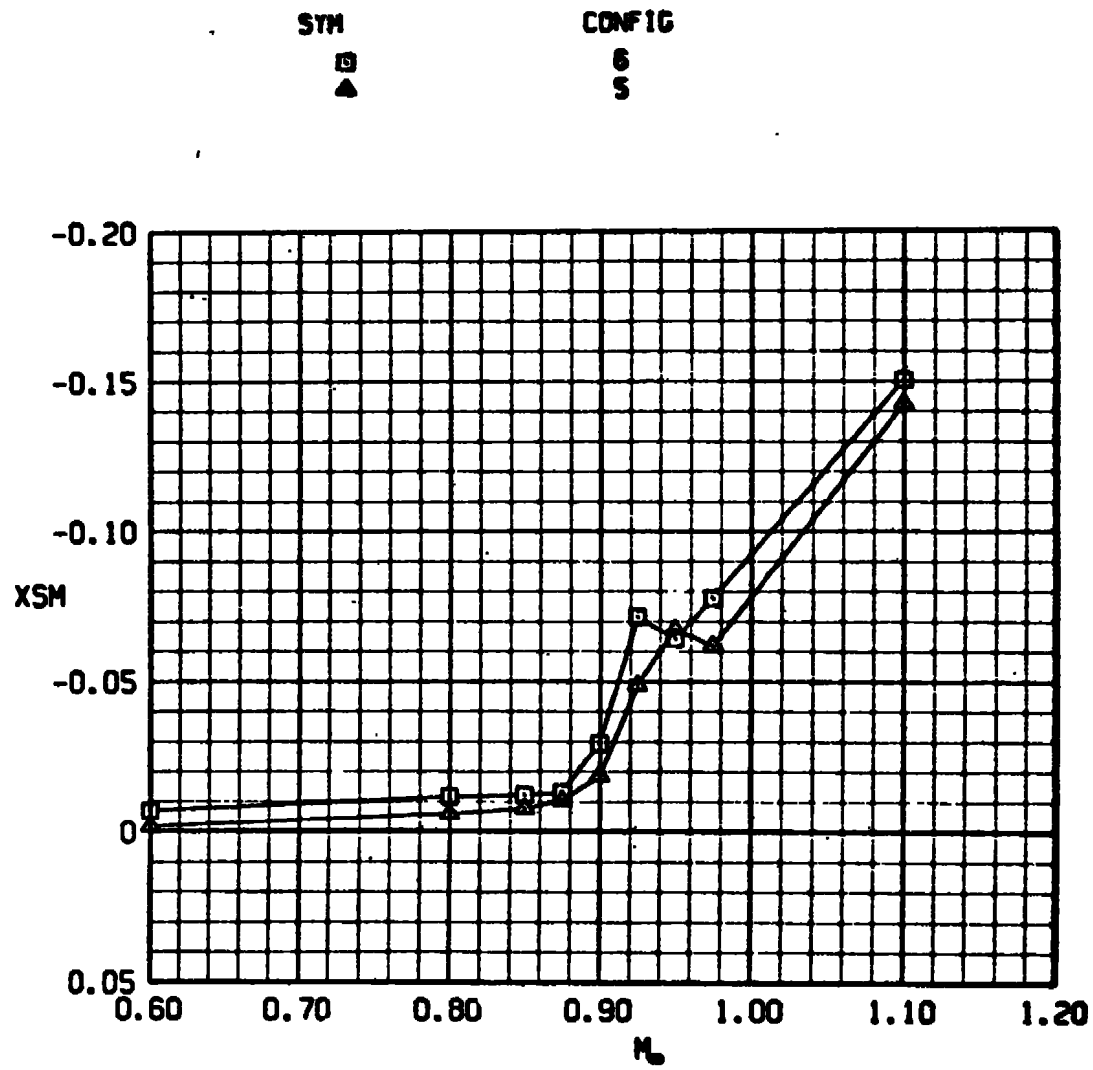


Figure 20. Static margin variation with Mach number for configurations 5 and 6.

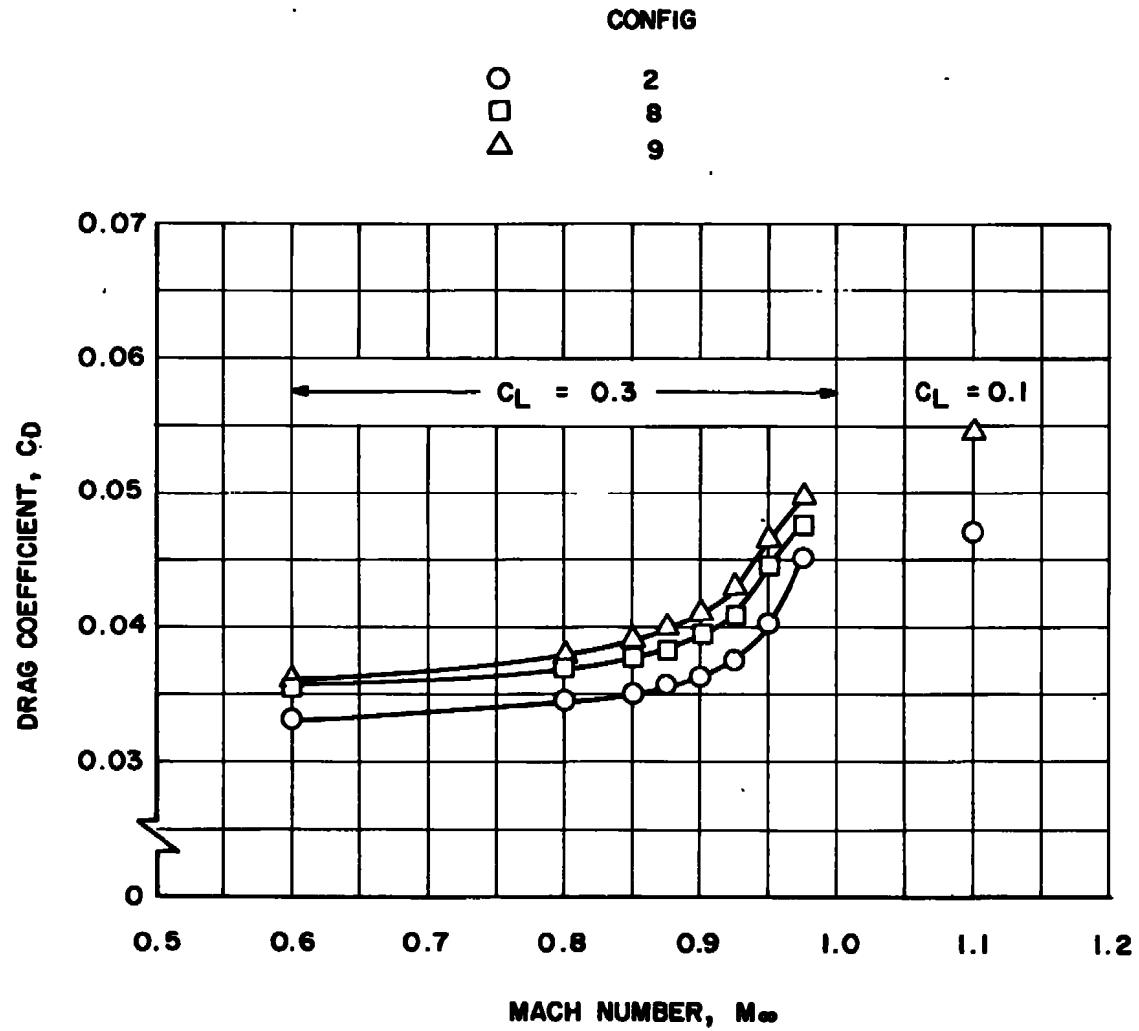


Figure 21. Drag coefficient variation with Mach number for configurations 2, 8, and 9.

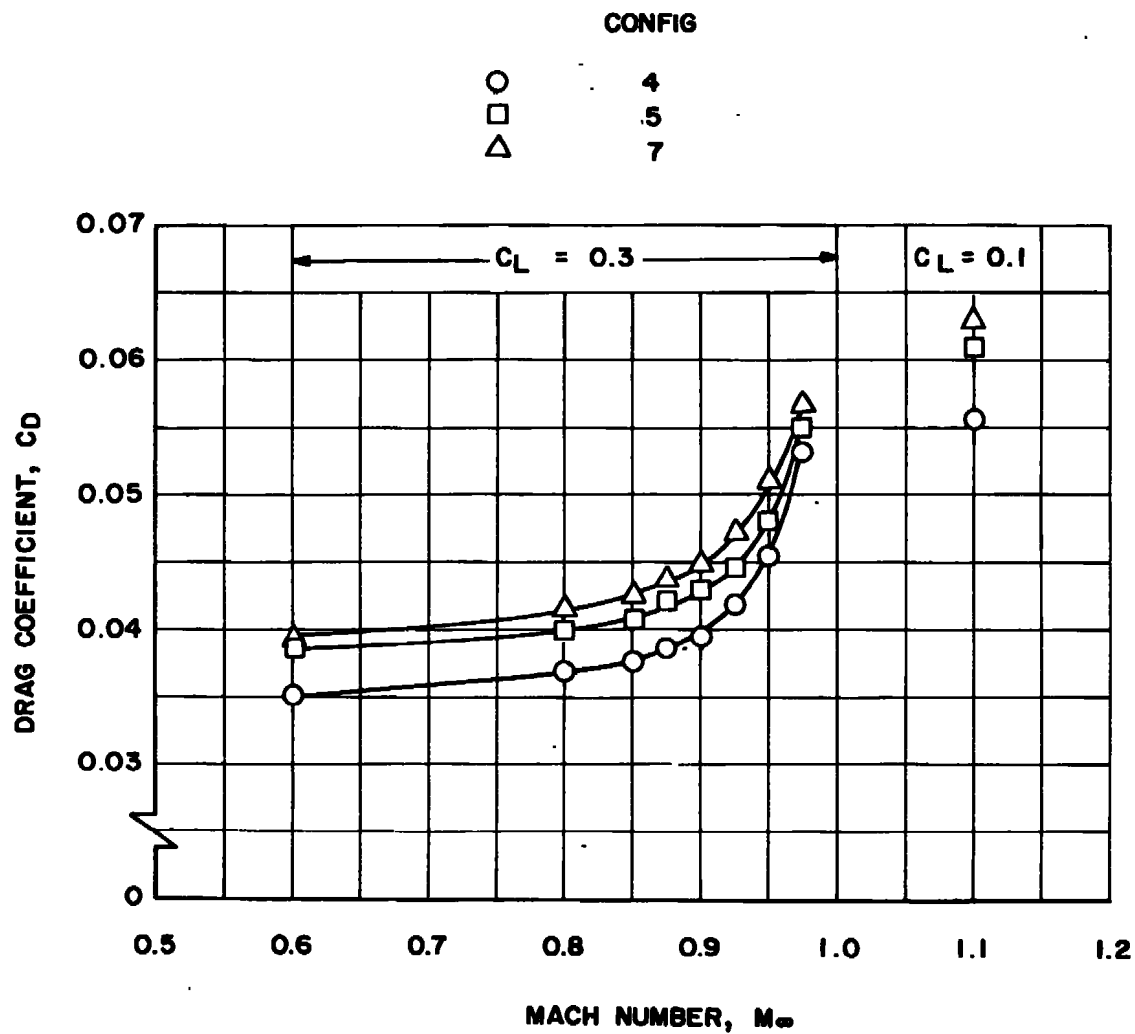


Figure 22. Drag coefficient variation with Mach number for configurations 4, 5, and 7.

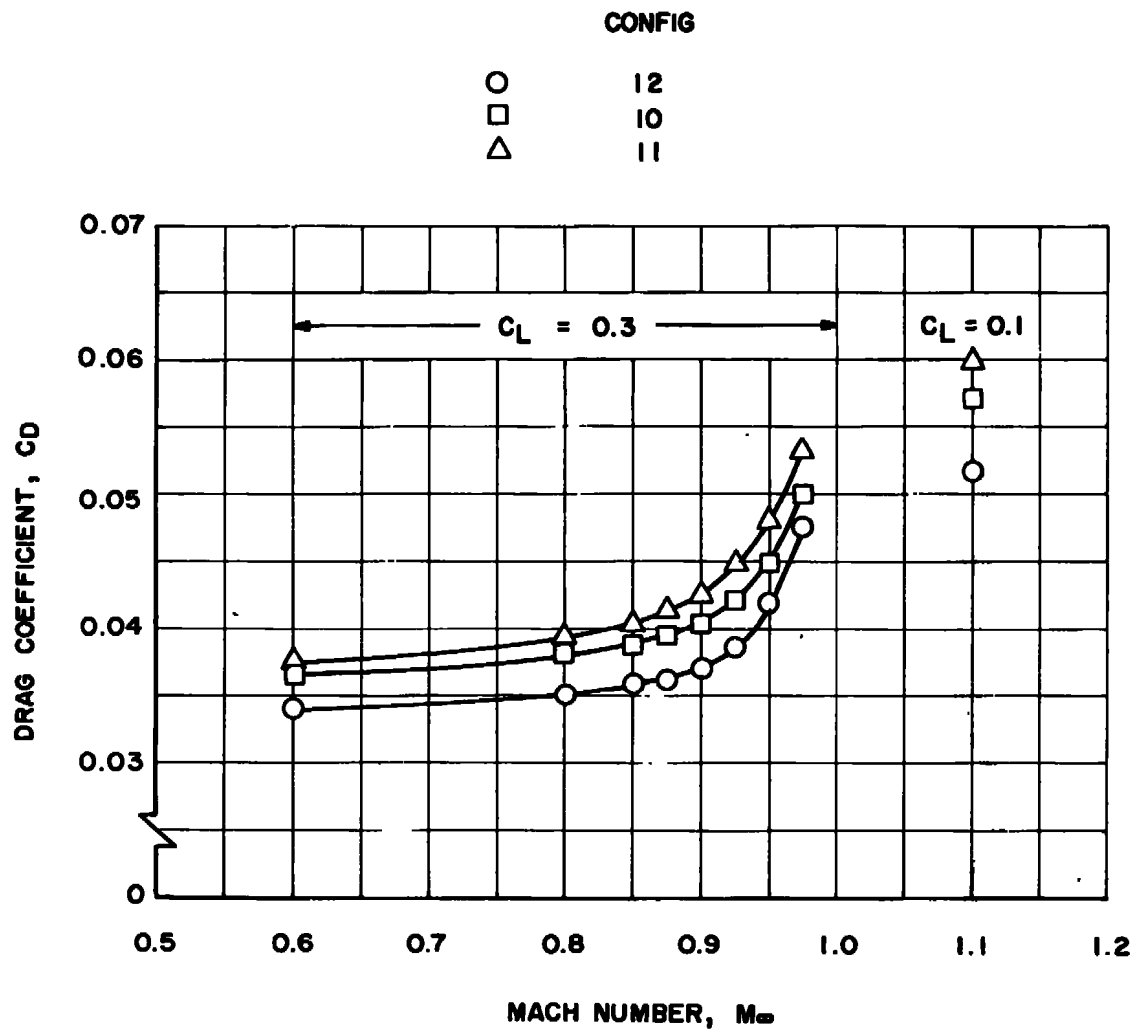


Figure 23. Drag coefficient variation with Mach number for configurations 10, 11, and 12.

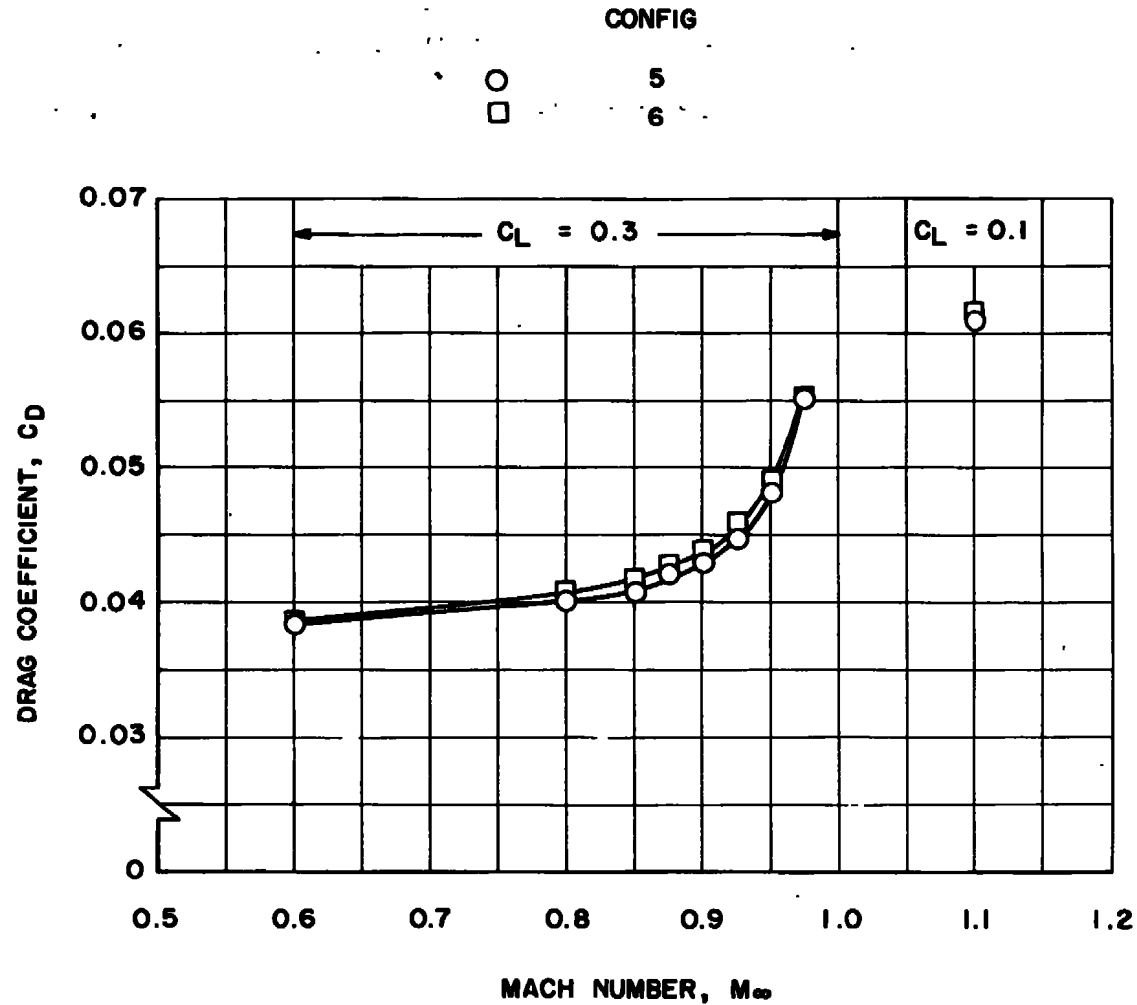


Figure 24. Drag coefficient variation with Mach number for configurations 5 and 6.

Table 1. Nominal Test Conditions

<u>M_∞</u>	<u>P_t, psfa</u>	<u>q_∞, psf</u>	<u>Re x 10⁻⁶ per ft</u>
0.600	2,500	494	3.900
0.800		735	4.600
0.850		788	4.750
0.875		809	4.800
0.900		838	4.900
0.925		856	4.975
0.950		884	5.000
0.975		900	5.100
1.100		992	5.200

Table 2. Aerodynamic Coefficient Precision

<u>M_∞</u>	<u>q_∞, psf</u>	<u>±ΔC_L</u>	<u>±ΔC_D</u>	<u>±ΔC_m</u>
0.600	494	0.0115	0.0021	0.0042
0.800	735	0.0076	0.0017	0.0028
0.850	788	0.0070	0.0016	0.0026
0.875	809	0.0067	0.0016	0.0026
0.900	838	0.0065	0.0016	0.0025
0.925	856	0.0062	0.0016	0.0024
0.950	884	0.0060	0.0016	0.0024
0.975	900	0.0058	0.0015	0.0023
1.100	992	0.0059	0.0016	0.0022

NOMENCLATURE

BL	Buttockline from plane of symmetry, in.
C_D	Drag coefficient, $\text{drag}/q_\infty S$
C_L	Lift coefficient, $\text{lift}/q_\infty S$
C_m	Pitching-moment coefficient referenced to 33 percent of the theoretical mean aerodynamic chord FS 16.22 and WL 1.55, $\text{pitching moment}/q_\infty S c$
c	Theoretical mean aerodynamic chord (MAC) (see Fig. 4), 9.625 in.
FS	Fuselage station from zero reference point, in.
M_∞	Free-stream Mach number
p_t	Wind tunnel free-stream total pressure, psfa
q_∞	Wind tunnel free-stream dynamic pressure, psf
Re	Wind tunnel free-stream unit Reynolds number, per foot
S	Wing reference area, 1.3250 ft ²
WL	Waterline from reference horizontal plane, in.
XSM	Static margin determined at $C_L = 0.2$ and expressed in fraction of chord length from the moment reference point. Negative values indicate that the center of pressure is aft of the selected moment reference point (statically stable condition); $XSM = \left. \frac{dC_m}{dC_L} \right _{C_L=0.20}$
α_w	Wing chord angle of attack, deg. (Note: the wing chord is at 1-deg positive incidence with respect to the model waterline)