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WIND TUNNEL TESTS OF SUPERSONIC LIFTING BODIES AT MACH NUMBER 1--ETC(U)
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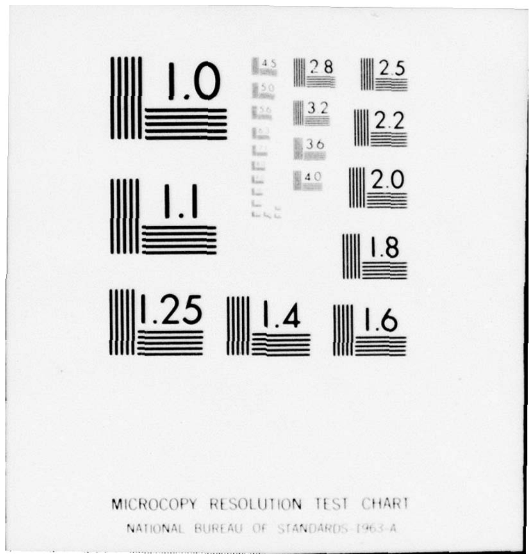
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BRL

MEMORANDUM REPORT NO. 2728

WIND TUNNEL TESTS OF SUPERSONIC LIFTING BODIES AT MACH NUMBER 1.5 TO 4.0

Charles J. Nietubicz

February 1977

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USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (1cb) Wind tunnel tests were conducted on four new wedge shaped configurations, one of which approached that of a wave rider design. Aerodynamic data are presented for Mach numbers 1.5 through 4.0 with angle of attack variation from -10° to +7°. The data are similar to previously reported results with the one exception being the near wave rider configuration. This configuration resulted in lift/drag data being invariant with respect to Mach number. The maximum value of lift/drag reached approximately 3.0.		

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LIST OF ILLUSTRATIONS (Continued)

I. INTRODUCTION

The Weapons Systems Concepts Office, Directorate of Development and Engineering, APG-Edgewood Area, under the direction of Mr. Abraham Flatau, has initiated an investigation of aeroballistic shapes designed to achieve increased range and flattened trajectories. Conceptually, this is obtained by design of a model with low overall drag and sufficient aerodynamic lift to slightly offset the affects of gravity.

Results of an initial experimental study of wedge shaped configurations have been previously reported[1]. The present wind tunnel tests, conducted by the Launch and Flight Division (LFD), U.S. Army Ballistic Research Laboratory (BRL), are a continuation of the Edgewood Wedge Program.

II. EXPERIMENTAL INVESTIGATION

A six component force test was conducted for four wedge shaped configurations in Supersonic Wind Tunnel No. 1[2] of the U.S. Army Ballistic Research Laboratory. Three configurations were designed and fabricated by the Weapons Systems Concepts Office, Directorate of Development and Engineering. The remaining configuration was a BRL design to obtain data on a wave rider[3] shape in supersonic flow. All configurations were tested to obtain lift and drag data. Additionally, roll moment data were obtained. The test conditions covered a Mach number range of 1.5 through 4.0 at a constant Reynolds number of 15.6 x 10^6 per metre. Angle of attack variation was from -10° to +7°.

A. Equipment

The wind tunnel is a continuous, closed circuit, variable throat tunnel with Mach capability from 1.5 through 5.0 calibrated in 0.25 Mach number increments. The supply pressure can be varied from 250 to 5000 mm Hg. The free stream Reynolds number has a range of 1.6 x 10^6

---

1. *C. J. Nietubicz, "Some Aerodynamic Characteristics of Supersonic Lifting Bodies," BRL Memorandum Report No. 2458, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, March 1975. AD A009704.*

2. *J. C. McMullen, "Wind Tunnel Testing Facilities at the Ballistic Research Laboratories," BRL Memorandum Report No. 1292, U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, July 1960. AD 244180.*

3. *L. F. Crabtree and P. A. Treadgeld, "Experiments on Hypersonic Lifting Bodies," International Council of the Aeronautical Sciences Paper No. 66-24, September 1966.*

to 2.8 x 10^6 per metre for a stagnation temperature of 311° Kelvin. The test section is 0.33 metres wide by 0.38 metres high and the standard angle of attack range is from +15° to -10°. An automatic roll head allows the model to be positioned throughout 270° (+180° to -90°) without interruption of air flow.

A six component strain gage balance was used to measure the aerodynamic forces and moments. The maximum allowable normal and side force acting between the gages are 890 Newtons (N) and 445 N respectively. The associated maximum allowable moments are 34 Newton-meter (Nm) and 14 Nm. The balance capacity in axial force is 334 N and the maximum roll moment is 6.8 Nm.

Due to the unique shape of the configurations tested, the balance was mounted external to the models. A sketch of the model assembly is shown in Figure 1. This arrangement, unfortunately, increases the moment arm causing the maximum allowable loads to be decreased.

The models are shown in Figure 2 and are identified as follows.

Model Description	Configuration No.
E-1 Curved Under Surface	1.00
E-1	2.00
F	3.00
BRL M3 Wave Rider	4.00

B. Test Procedure

All configurations were tested at Mach numbers 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0. The angle of attack variation was from -10° to +7° except where loads began to exceed balance capacities. Base pressures were obtained using 1.6 mm diameter pressure probes located near the model base. Roll moment data were determined at $\phi = 45°$. Spark shadowgraphs and schlieren photographs were obtained throughout the test program.

All data were reduced on the BRL Electronic Scientific Computer (BRLESC) using a standard force reduction program. Strut deflections due to aerodynamic loading were subtracted from the data both in the pitch and yaw planes. Flow corrections were applied to the yaw plane data. Due to the configuration's asymmetry with respect to the pitch plane no flow inclination corrections were applied. The coefficients were reduced about a body axis system which was allowed to roll with the model.

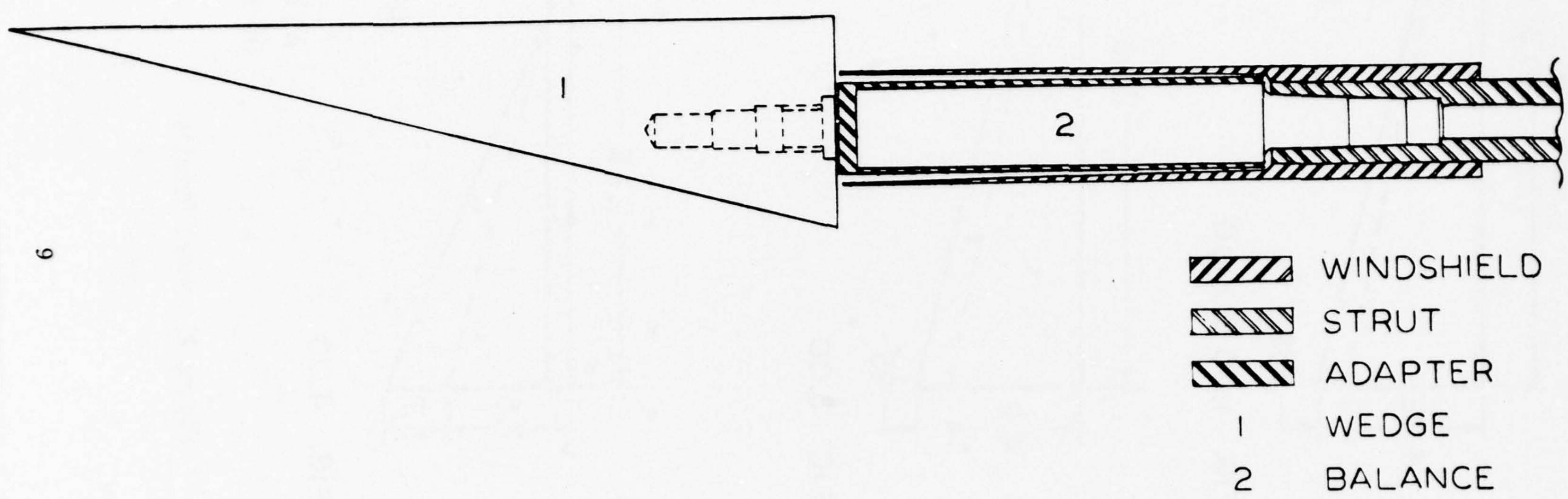

Figure 1. Model-Balance-Strut Assembly

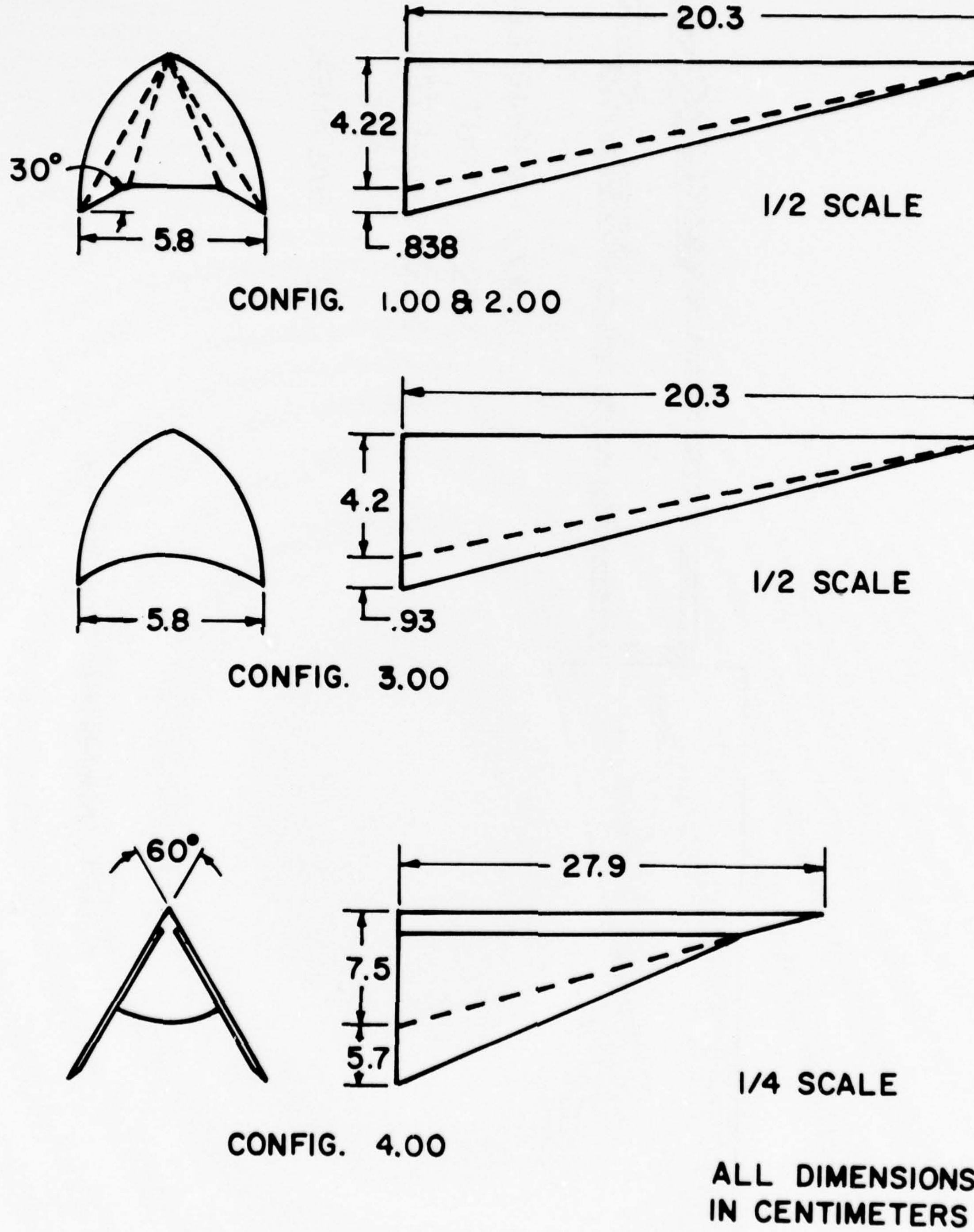

Figure 2. Model Details

C. Presentation of Data

The reduced data in coefficient form are presented in Appendix A. The normal force (C_N), pitching moment (C_M), axial force (C_A), and normal force center of pressure (X_{CP}) are plotted as a function of angle of attack in Figure A1. Figure A2 shows the same coefficients cross plotted with respect to configuration. The side force (C_Y), yawing moment (C_{YM}), and side force center of pressure (Y_{CP}) are plotted in Figure A3. Configurational variations of the same coefficients are presented in Figure A4. Roll moment data at $\phi = 45°$ are shown in Figure A5 for each configuration. The lift (C_L), drag (C_D), and lift/drag ratio (C_L/C_D) are plotted in Figures A6 and A7.

The normal force and pitching moment slopes were calculated about the point where C_N becomes zero and are tabulated in Table I for each configuration.

III. DISCUSSION

The data for configurations 1.00, 2.00, and 3.00 show characteristically similar patterns to that reported previously[1]. The normal force data are nonlinear above $\alpha = 0°$ and are effectively independent of Mach number variation. Configuration 4.00 (Figure A1d), however, shows a strong Mach number dependence above $\alpha = -5°$. Common to all configurations was the expected increase in axial force with decreasing Mach number and the invariance of normal force center of pressure with respect to Mach number and angle of attack. The normal force center of pressure is calculated using the normal force coefficient; therefore, the apparent discontinuity in X_{CP} is due to the normal force going to zero at that point. Figure A2 shows the effect of configuration at each test Mach number. For all Mach numbers, the results for configuration 4.00 show a higher normal force coefficient and lower axial force coefficient in comparison with the other configurations. The difference in normal force and axial force data becomes smaller as the Mach number increases. This can be seen in Figures A2a through A2f. The axial force data at Mach 1.5 was invalid for configuration 4.00 due to unsteady flow conditions caused by the relatively large model size.

The side force data presented in Figures A3 and A4 are symmetrical with respect to $\alpha = 0°$. The side force center of pressure is again invariant with respect to Mach number and angle of attack. The side force data for configuration 4.00 (Figure A3d) shows a slight variation with Mach number. The data scatter of Y_{CP} for configuration 3.00 at Mach number 4.0 is peculiar to that one run and is most probably caused by erroneous raw data.

Roll moment data were obtained for negative angle of attack only, since the important regime for this test series was centered around the trim angle of approximately -7°. A negative roll moment coefficient (counter clockwise direction) is considered as the restoring moment throughout this discussion. The roll moment data for configurations 1.00, 2.00, and 3.00 as seen in Figures A5a through A5c are small and can be considered negligible in terms of a restoring moment. However, it is interesting to note that the roll moment data for all configurations is a restoring type moment whereas the previously reported data showed non-restoring roll moments for $\alpha < 0°$. Since the shapes are not appreciably different, the change in sign for roll moment data is not completely understood. The roll moment data of configuration 4.00, seen in Figure A5d, shows a significant increase in magnitude for roll moment over all previously tested configurations. Although only a few wave rider type shapes have been tested at supersonic speeds, the increased restoring roll moment may be a characteristic.

The data were also reduced to obtain lift and drag coefficients. A comparison of lift/drag for configurations 1.00, 2.00, and 3.00 are shown in Figures A6a through A6c to be dependent on Mach number. A maximum value of approximately 2.5 was attained near $\alpha = 6°$. Conversely, there was no Mach number dependence for configuration 4.00 as can be seen in Figure A6d. The maximum value of lift/drag for this configuration was 3.0 at $\alpha = 1°$. Configuration 4.00 was designed to be consistent with the wave rider theory; however, concessions made during model fabrication introduced the edge discontinuity. It was felt that this change would not significantly alter the planar shock pattern. However, as can be seen in the spark shadowgraph (Figure 3) the shock is slightly below the model.

A comparison of previous configurations with those reported here is presented in Figure 4 in the form of lift/drag data. Configurations 972.00 and 4.00 which are nearest to a wave rider design have the largest magnitudes of lift/drag for all angles and a more negative trim angle. The area of concern is most likely not with large values of lift/drag but most probably with the configuration which produces the largest lift slope (C_{L_α}) near trim since the thought is to fly these shapes near the trim conditions. Table I is a tabulation of summary data which includes $C_{L_{\alpha(trim)}}$. Configuration 4.00 exhibits the highest slope for all Mach numbers with the exception of Mach 4.0.

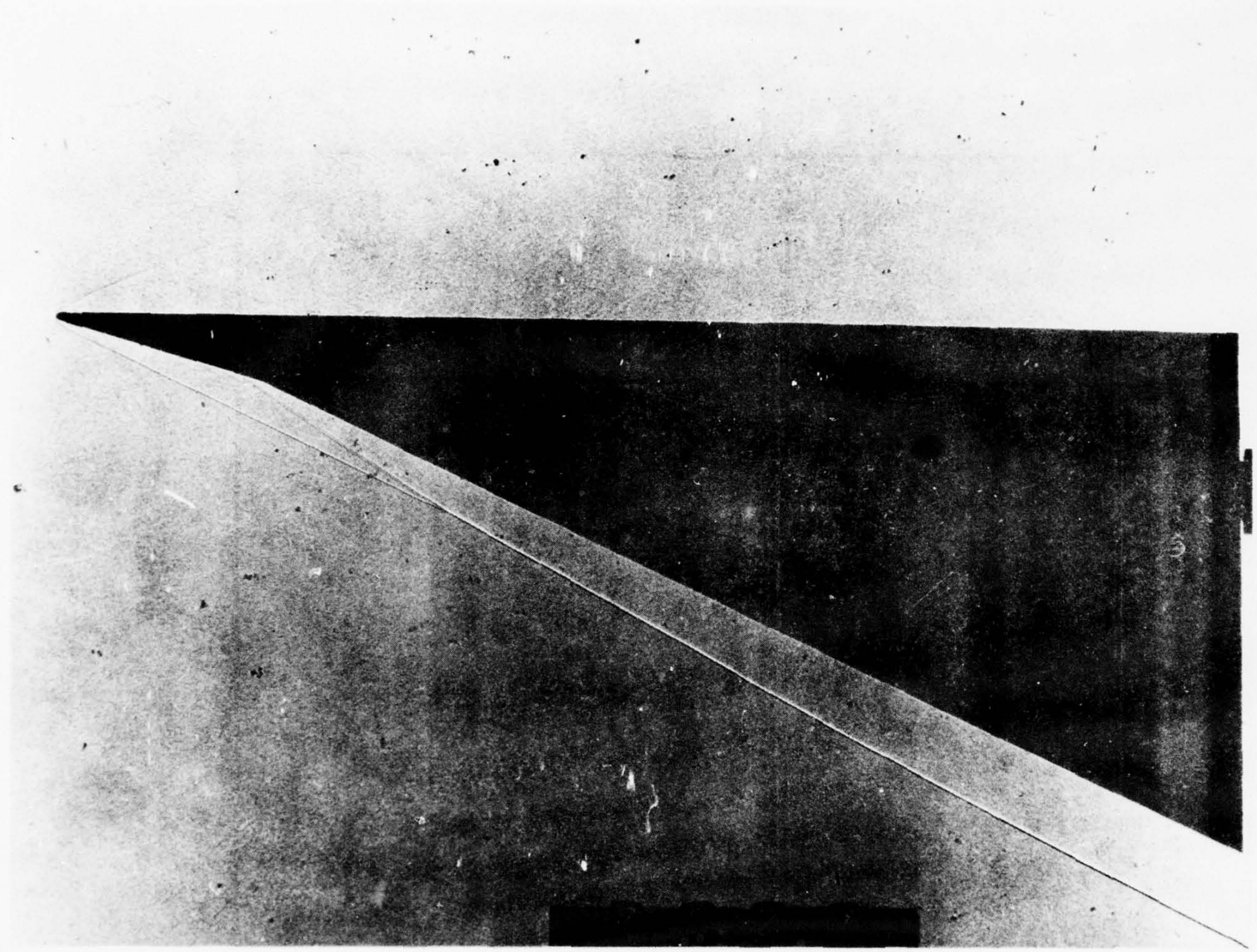

Figure 3. Spark Shadowgraph, $M = 3.0$, $\alpha = 0°$, CONFIG = 4.00

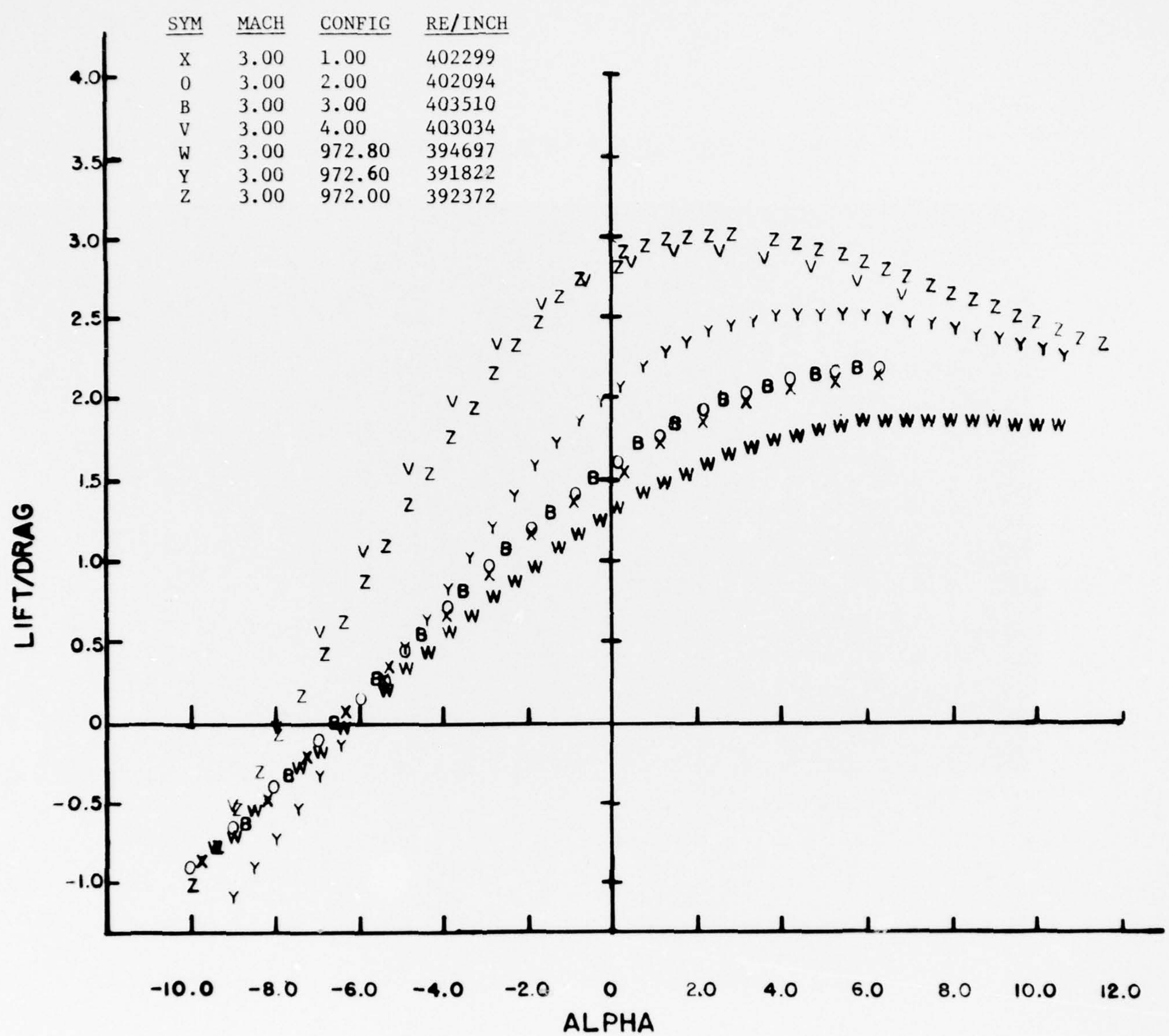

Figure 4. Comparison of Lift/Drag Data for Lifting Bodies

Table I. Summary Data

CONFIG	M	C_{N_α}	C_{M_α}	$C_{L_{\alpha(trim)}}$
1.00	1.5	.0187	.0061	.0167
	2.0	.0180	.0059	.0165
	2.5	.0176	.0057	.0164
	3.0	.0169	.0055	.0159
	3.5	.0161	.0053	.0156
	4.0	.0158	.0051	.0155
2.00	1.5	.0180	.0060	.0157
	2.0	.0183	.0060	.0167
	2.5	.0177	.0058	.0165
	3.0	.0170	.0056	.0161
	3.5	.0165	.0054	.0159
	4.0	.0161	.0052	.0157
3.00	1.5	.0182	.0060	.0164
	2.0	.0180	.0059	.0167
	2.5	.0176	.0057	.0164
	3.0	.0168	.0054	.0159
	3.5	.0165	.0052	.0158
	4.0	.0158	.0051	.0152
4.00	1.5	.0269	.0079	.0268
	2.0	.0243	.0072	.0237
	2.5	.0217	.0065	.0207
	3.0	.0194	.0059	.0192
	3.5	.0175	.0054	.0168
	4.0	.0160	.0054	.0154

IV. CONCLUSIONS

Four additional lifting body configurations have been tested at supersonic speeds. The lift/drag data for three configurations were found to be dependent on Mach number while the wave rider like shape showed no Mach number dependence. For all configurations, the position of the normal force center of pressure was found to be invariant with respect to Mach number and angle of attack. The maximum value of lift/drag was found to be 3.0 for the pseudo wave rider configuration, which also exhibited the largest lift slope near trim.

The roll moment data continues to reveal the problem of an almost non-existent restoring moment for these configurations. The wave rider like shape, however, does show a measurable restoring moment.

APPENDIX A

Aerodynamic Coefficients

SYM.	RUN NUMBER	MACH	CONFIG	RE/INCH	ROLL ANGLE
■	17	1.50	1.00	384964.	0.0
▲	20	2.00	1.00	399703.	0.0
▼	23	2.50	1.00	402894.	0.0
+	26	3.00	1.00	402299.	0.0
×	29	3.50	1.00	398623.	0.0
•	32	4.00	1.00	400570.	0.0

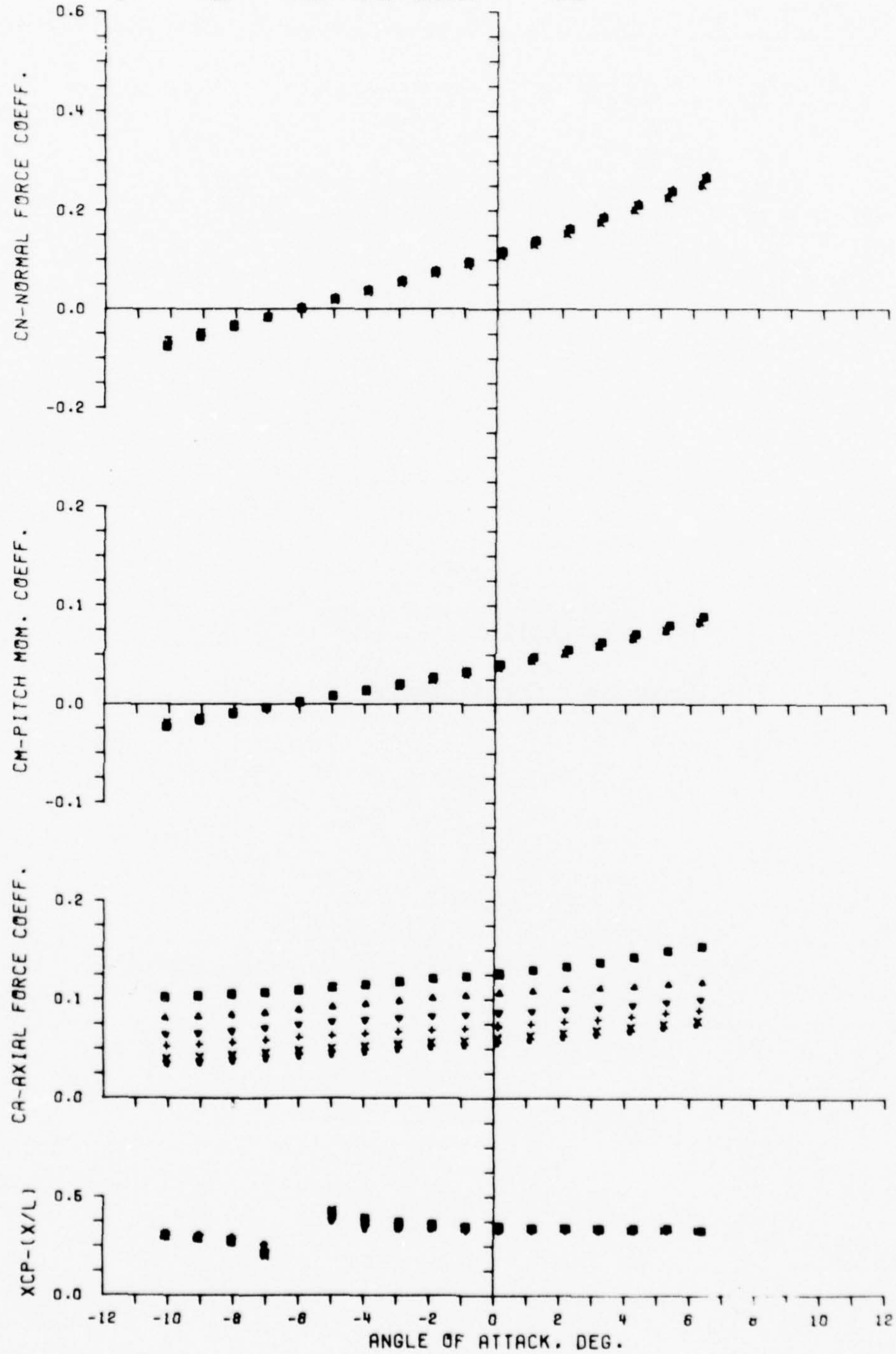

Figure A1. Aerodynamic Coefficients C_N, C_M, C_A, X_{CP}-- Mach Number Variation

a. CONFIG 1.00

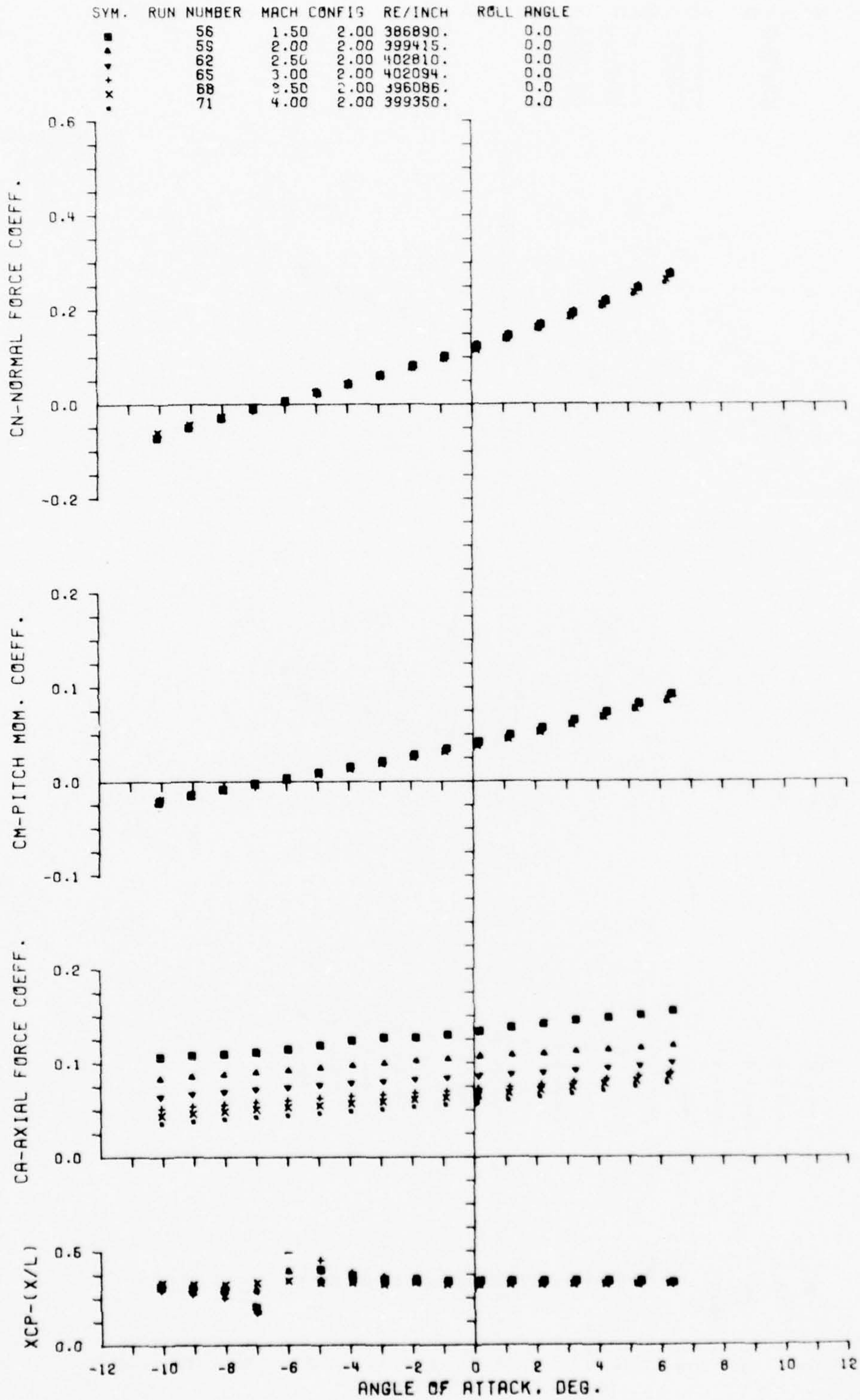

Figure A1. Continued

b. CONFIG 2.00

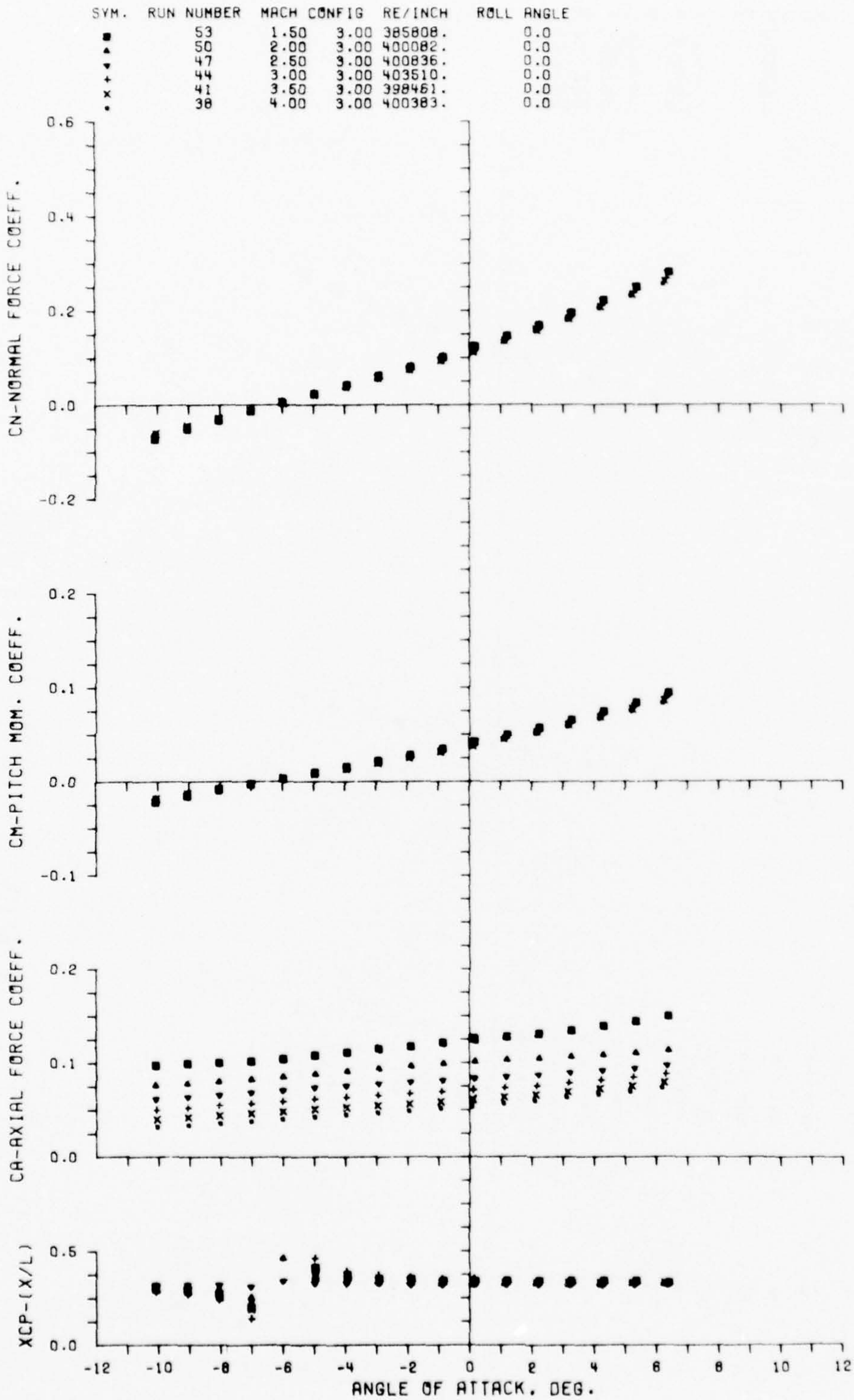

Figure A1. Continued

c. CONFIG 3.00

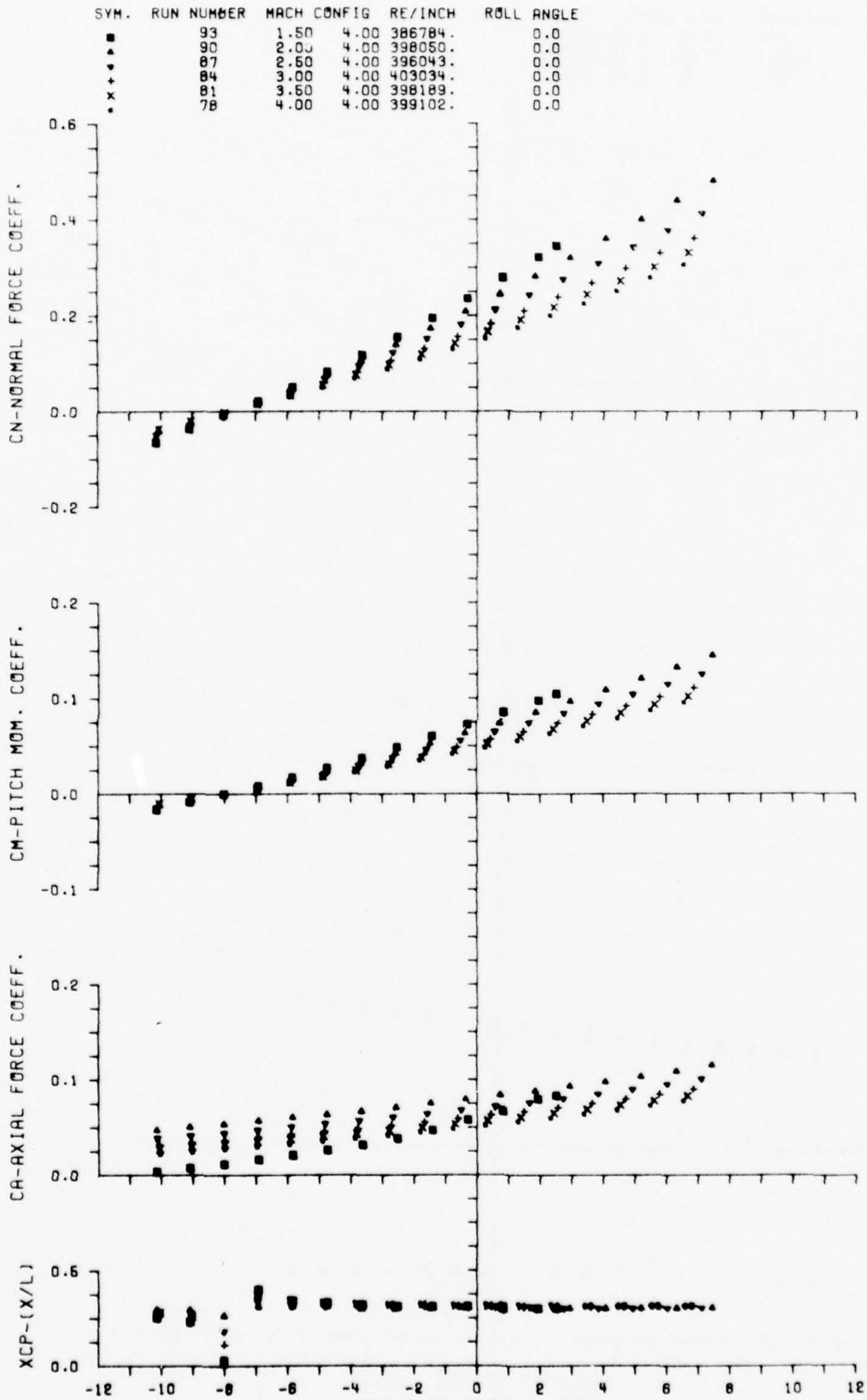

Figure A1. Concluded

d. CONFIG 4.00

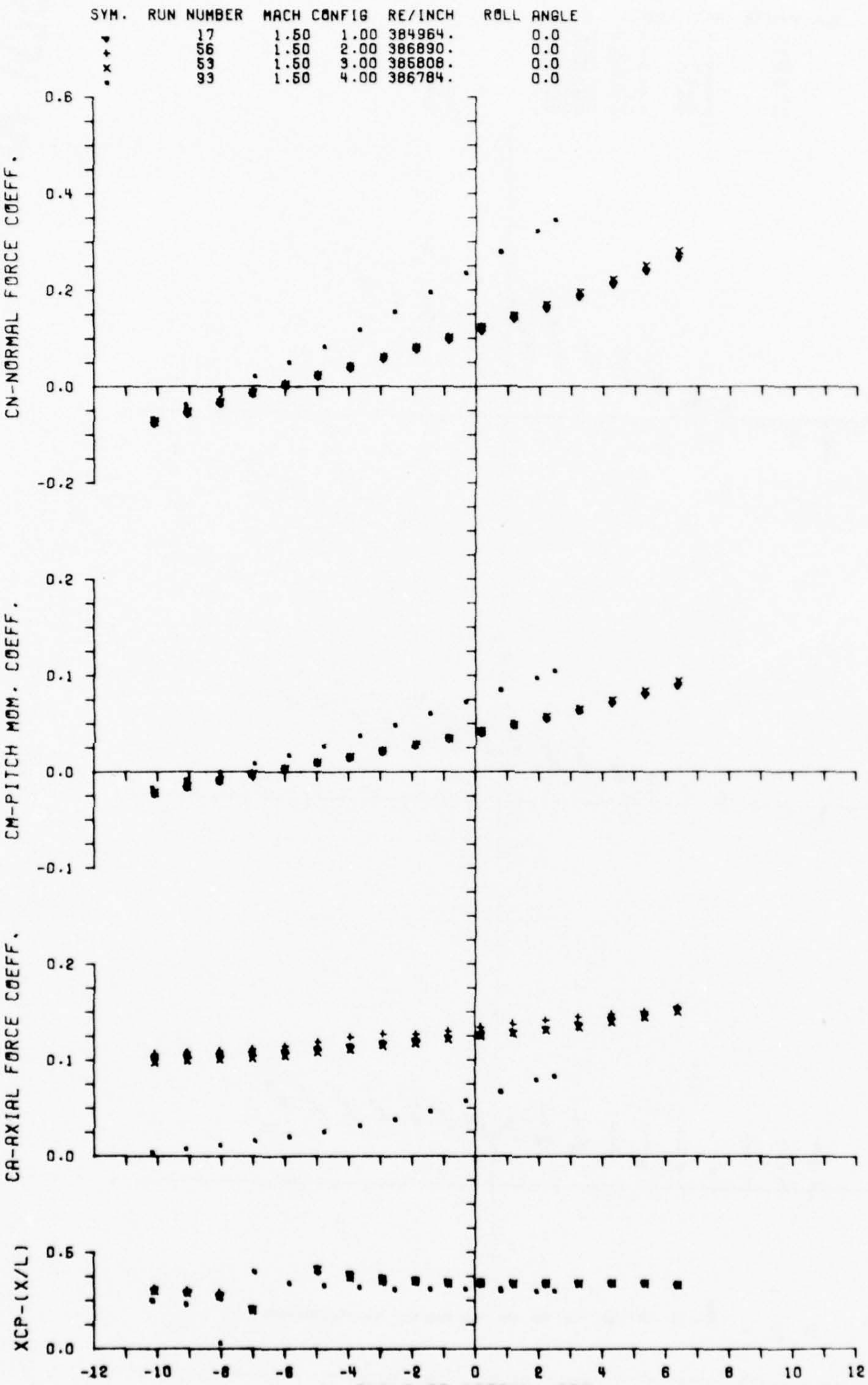

Figure A2. Aerodynamic Coefficients C_N, C_M, C_A, X_{CP}--Configuration Variation

a. MACH 1.5

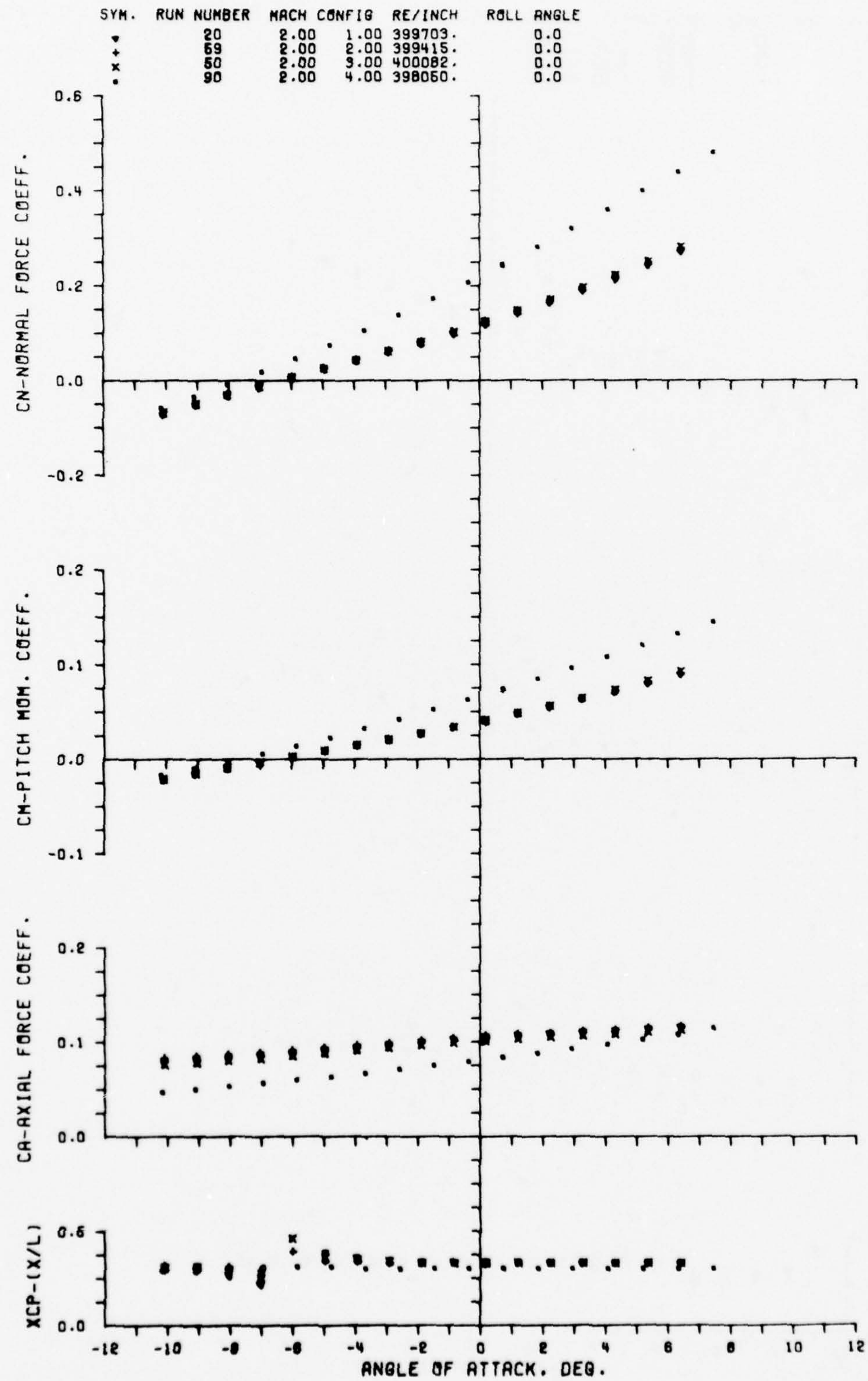

Figure A2. Continued

b. MACH 2.0

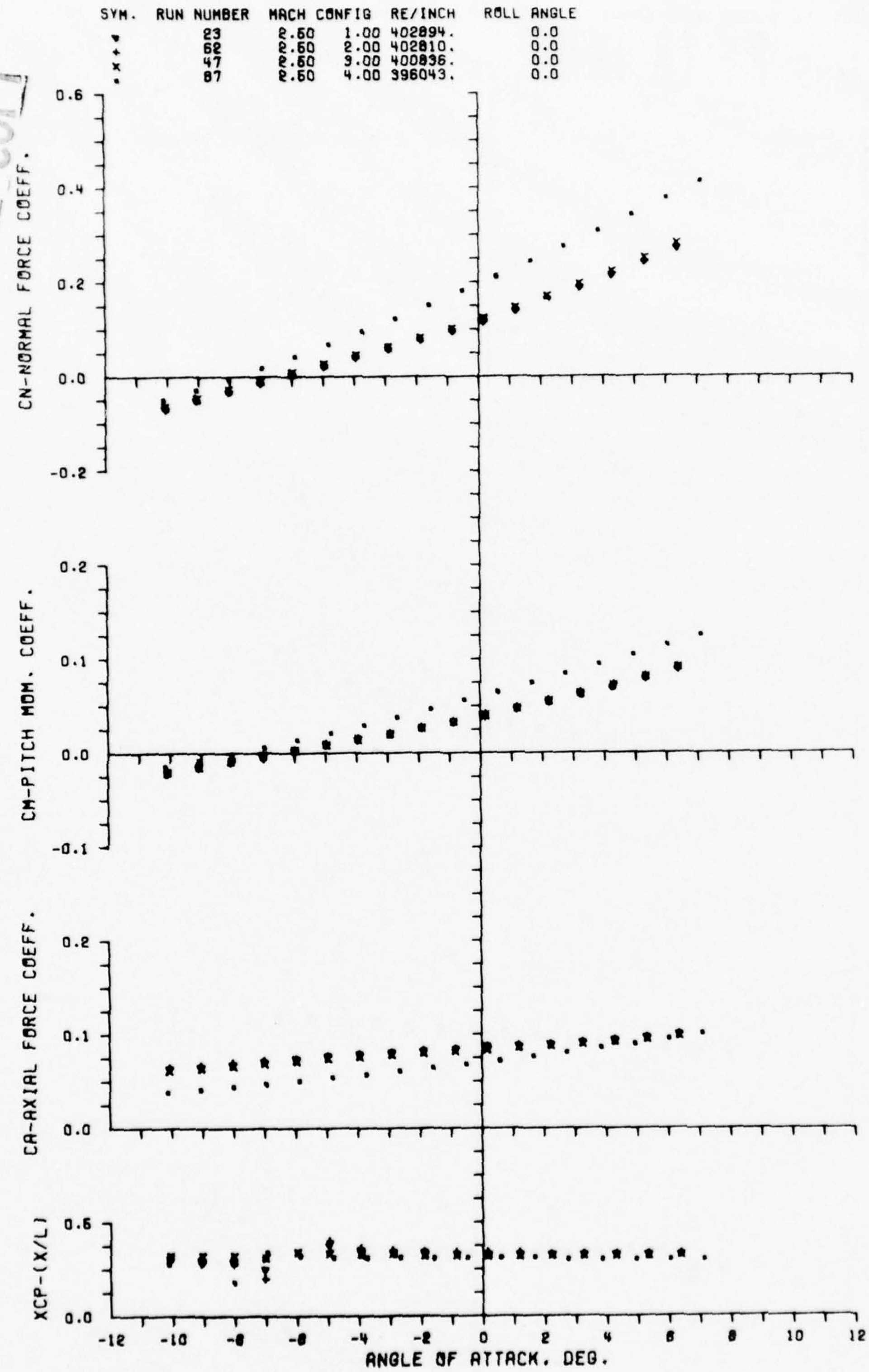

Figure A2. Continued

c. MACH 2.5

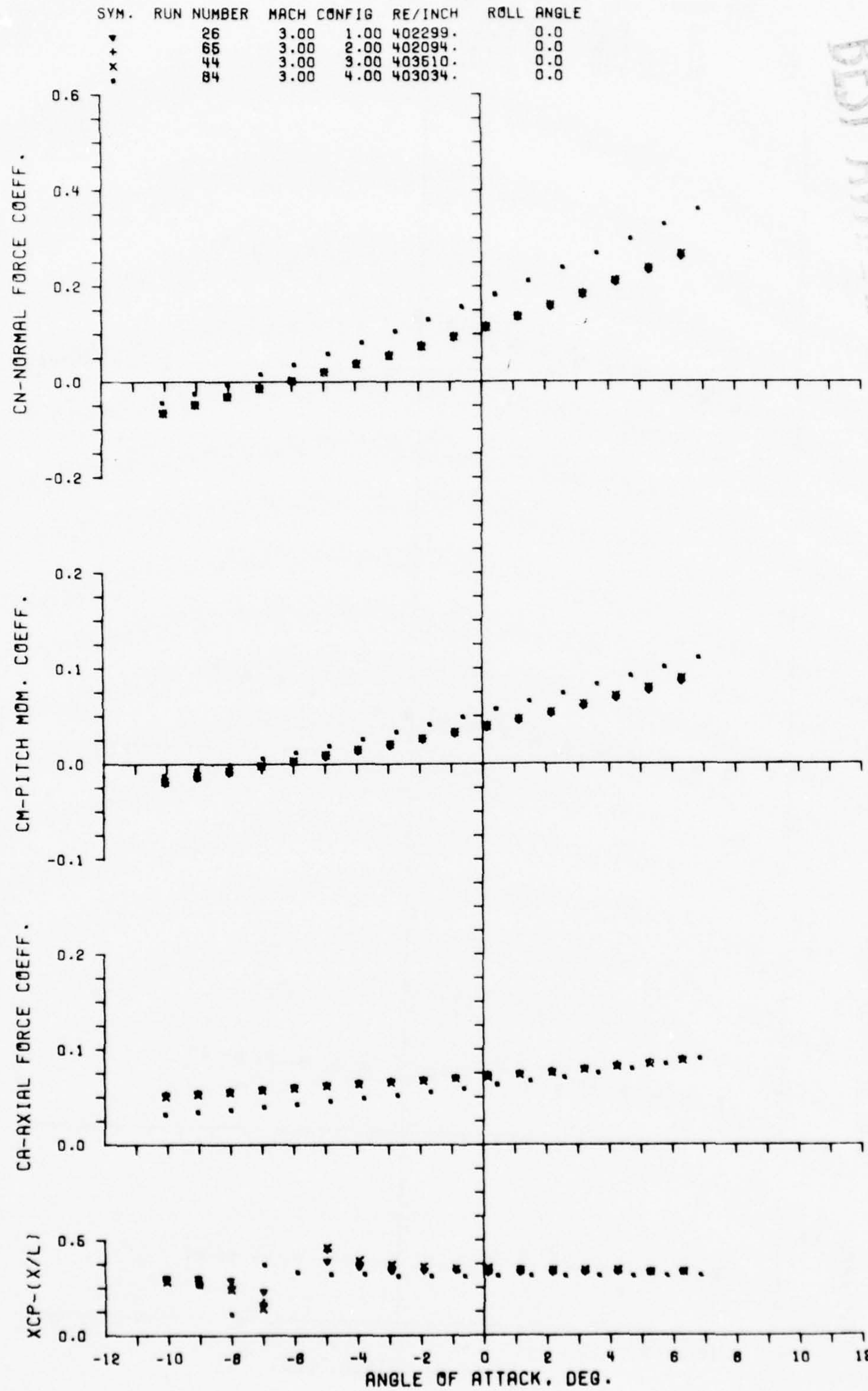

Figure A2. Continued

d. MACH 3.0

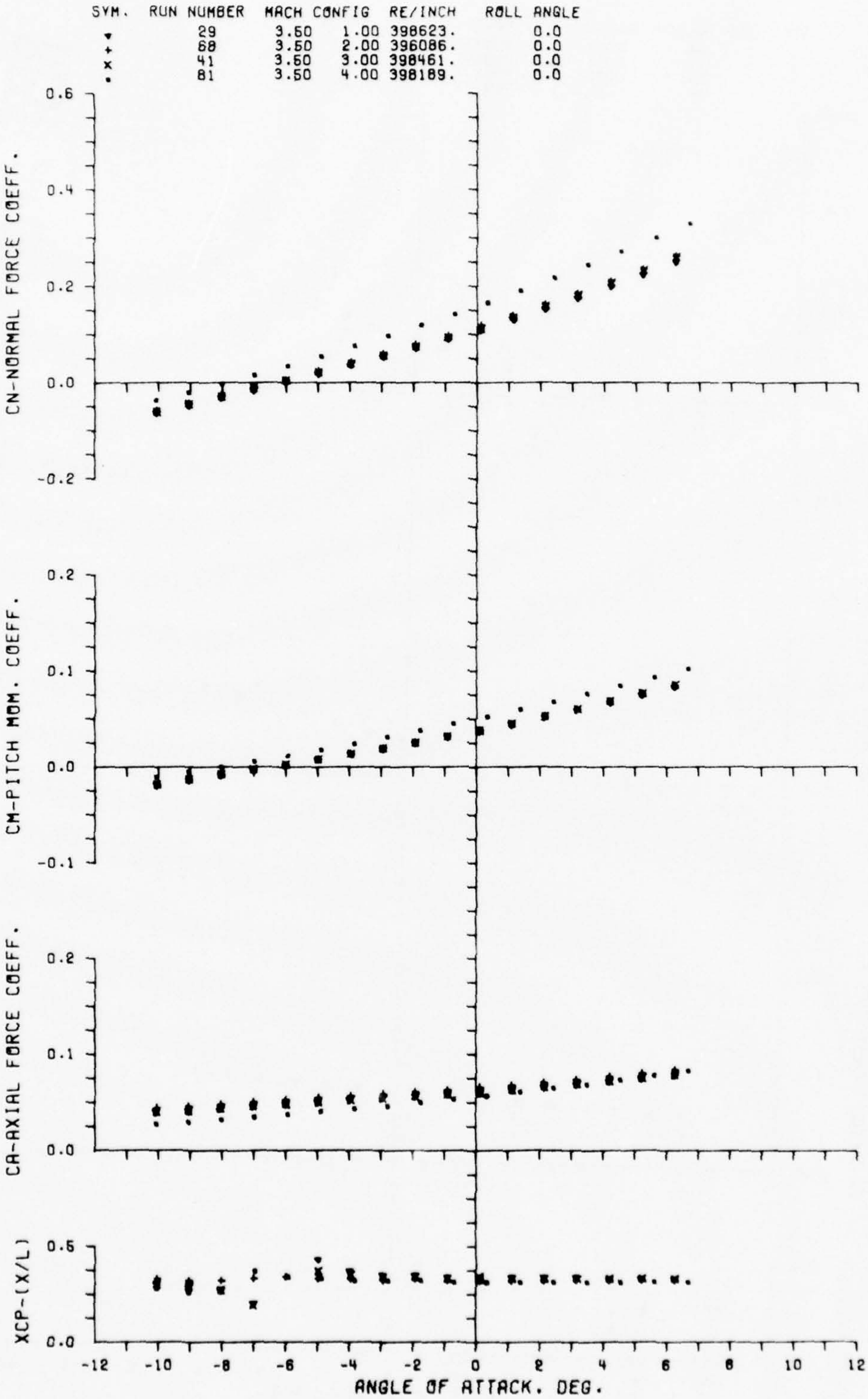

Figure A2. Continued

e. MACH 3.5

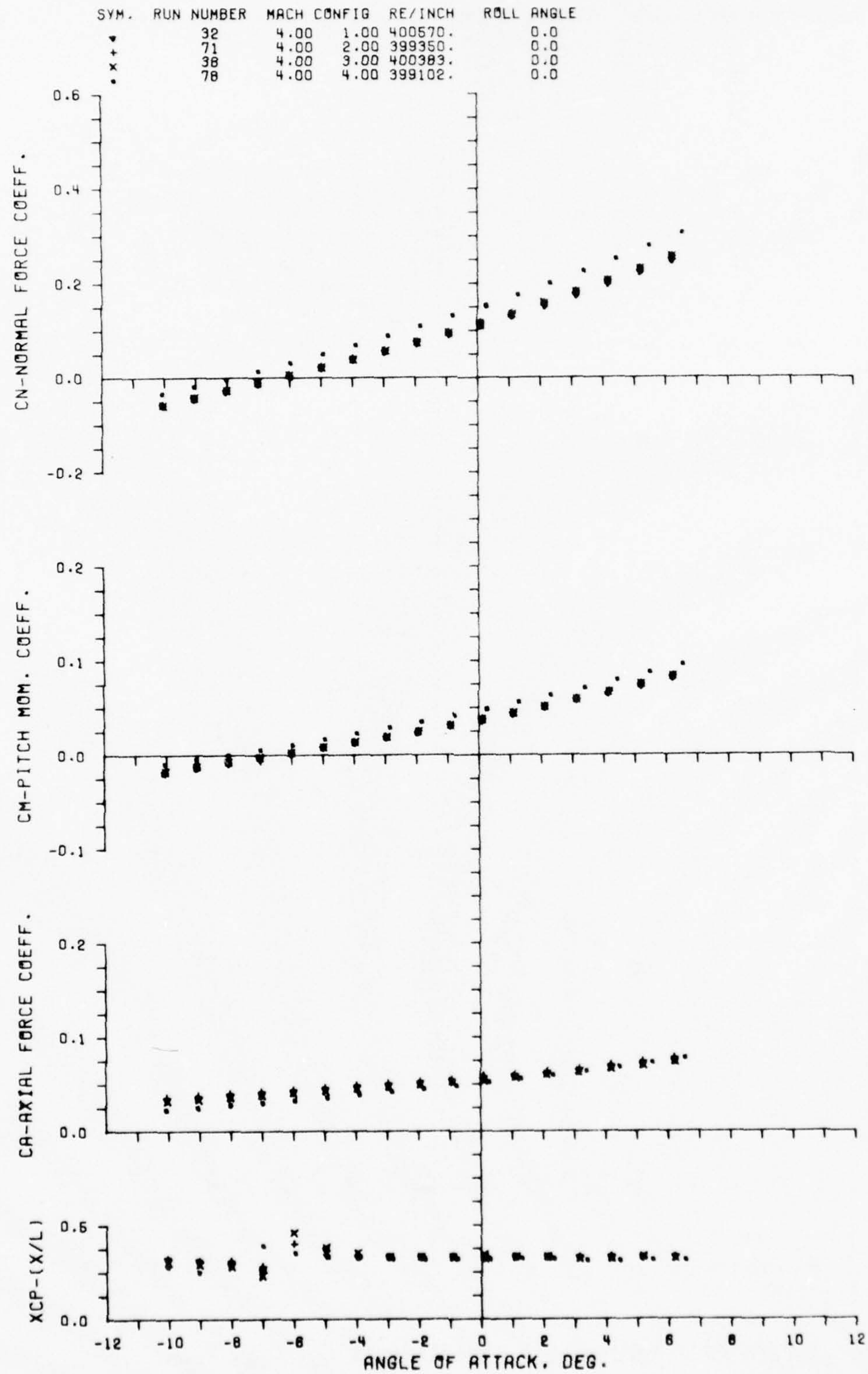

Figure A2. Concluded

f. MACH 4.0

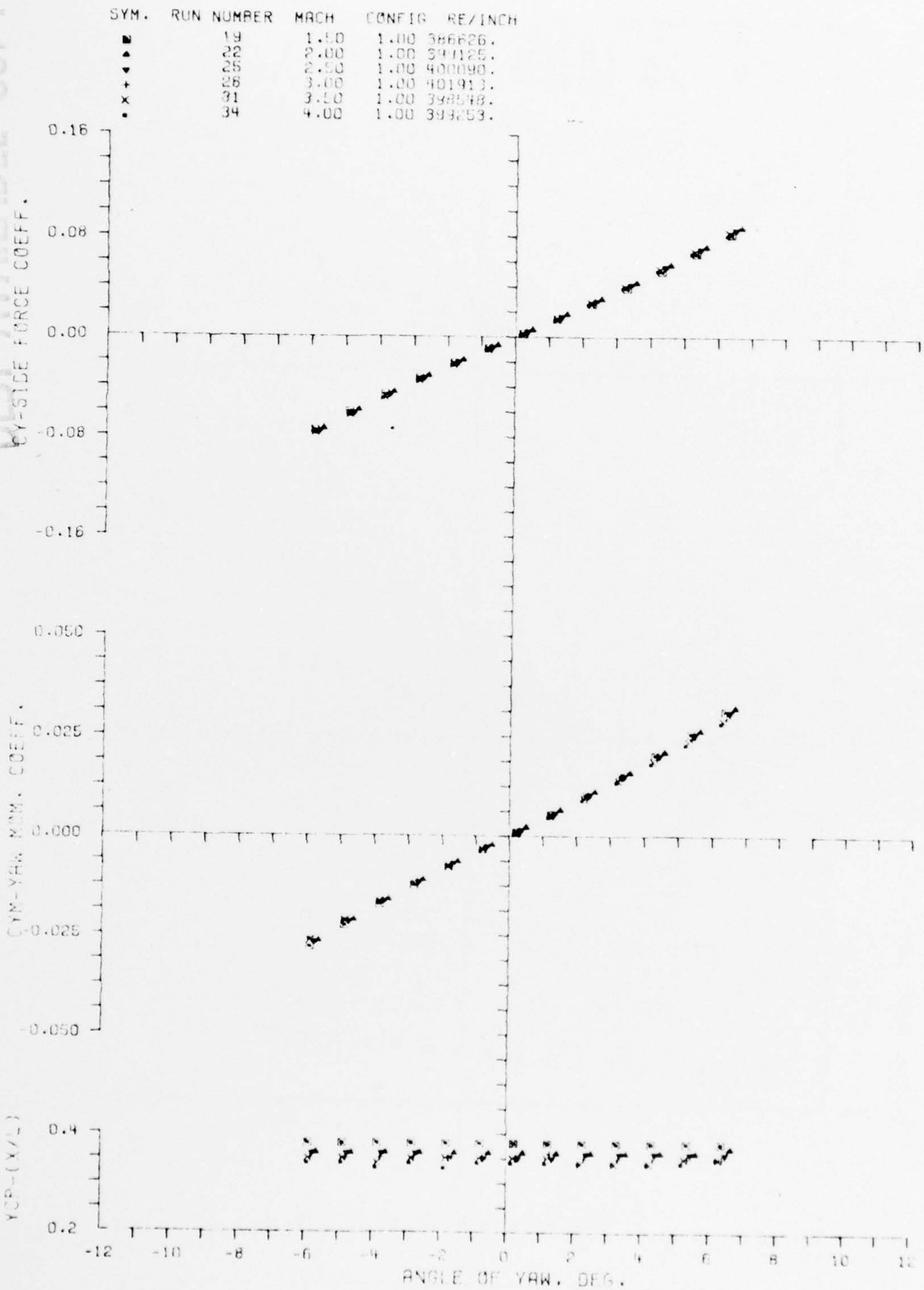

Figure A3. Aerodynamic Coefficients C_Y, C_{YM}, Y_{CP}--Mach Number Variation

a. CONFIG 1.00

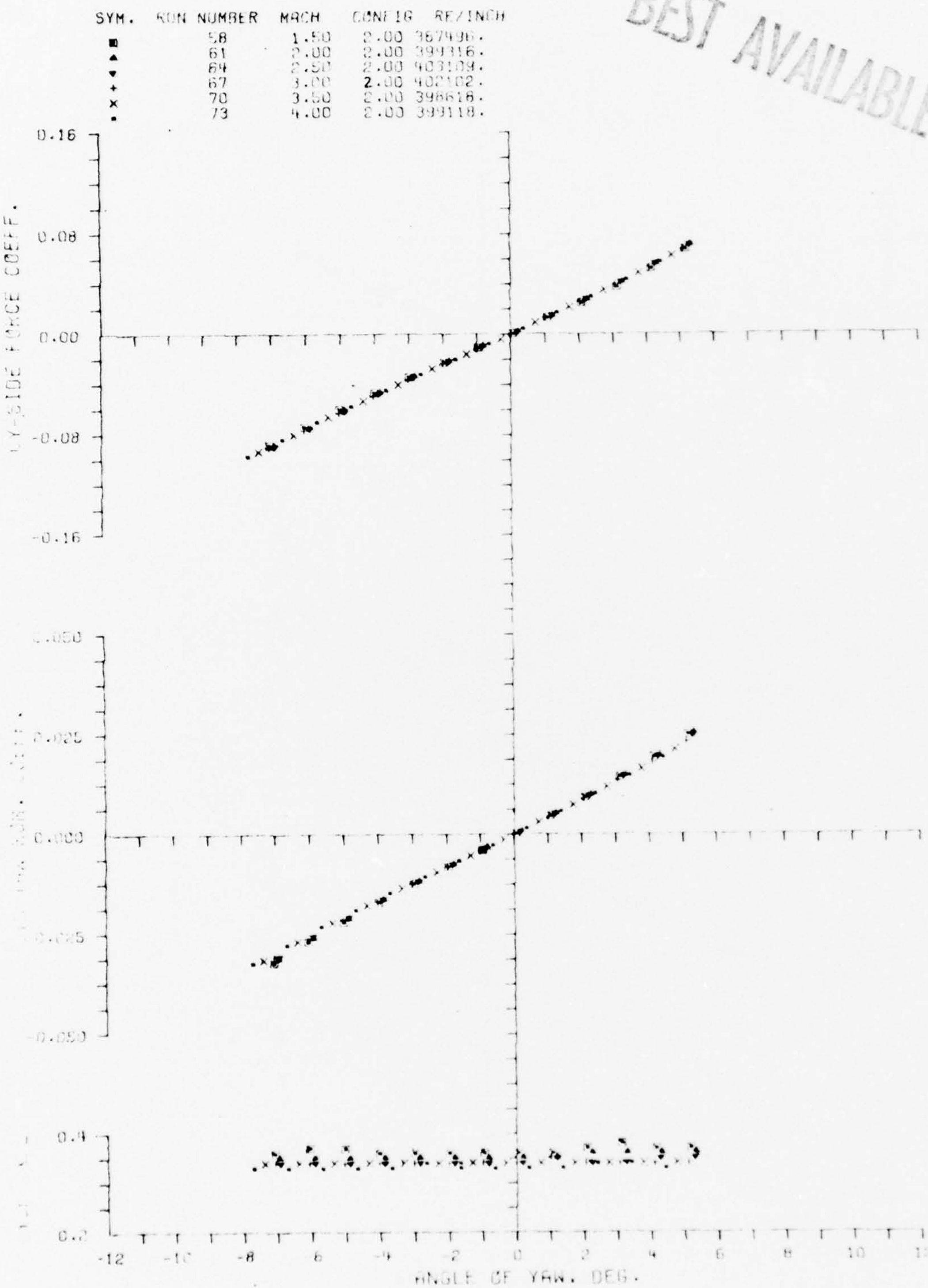

Figure A3. Continued

b. CONFIG 2.00

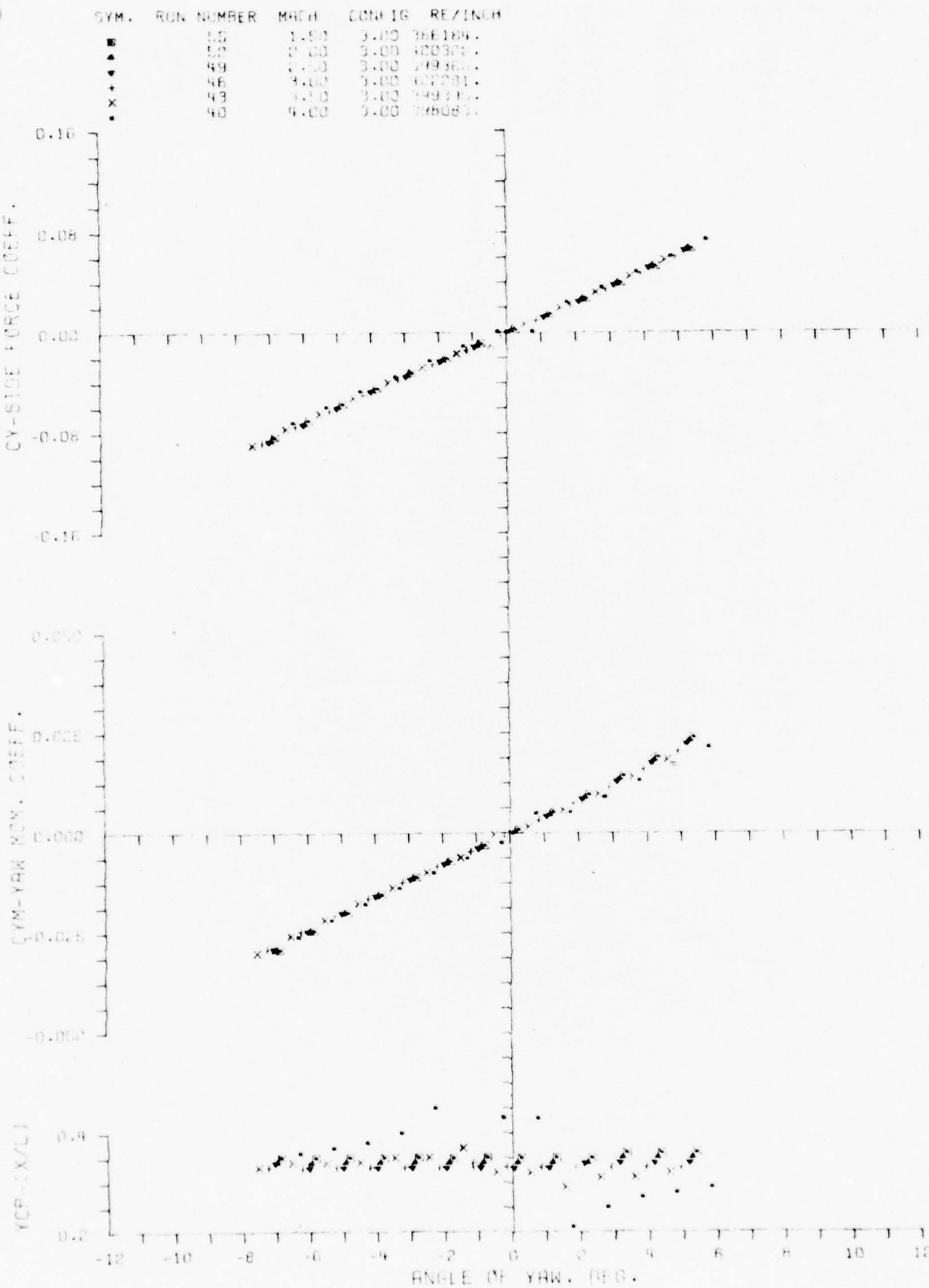

Figure A3. Continued

c. CONFIG 3.00

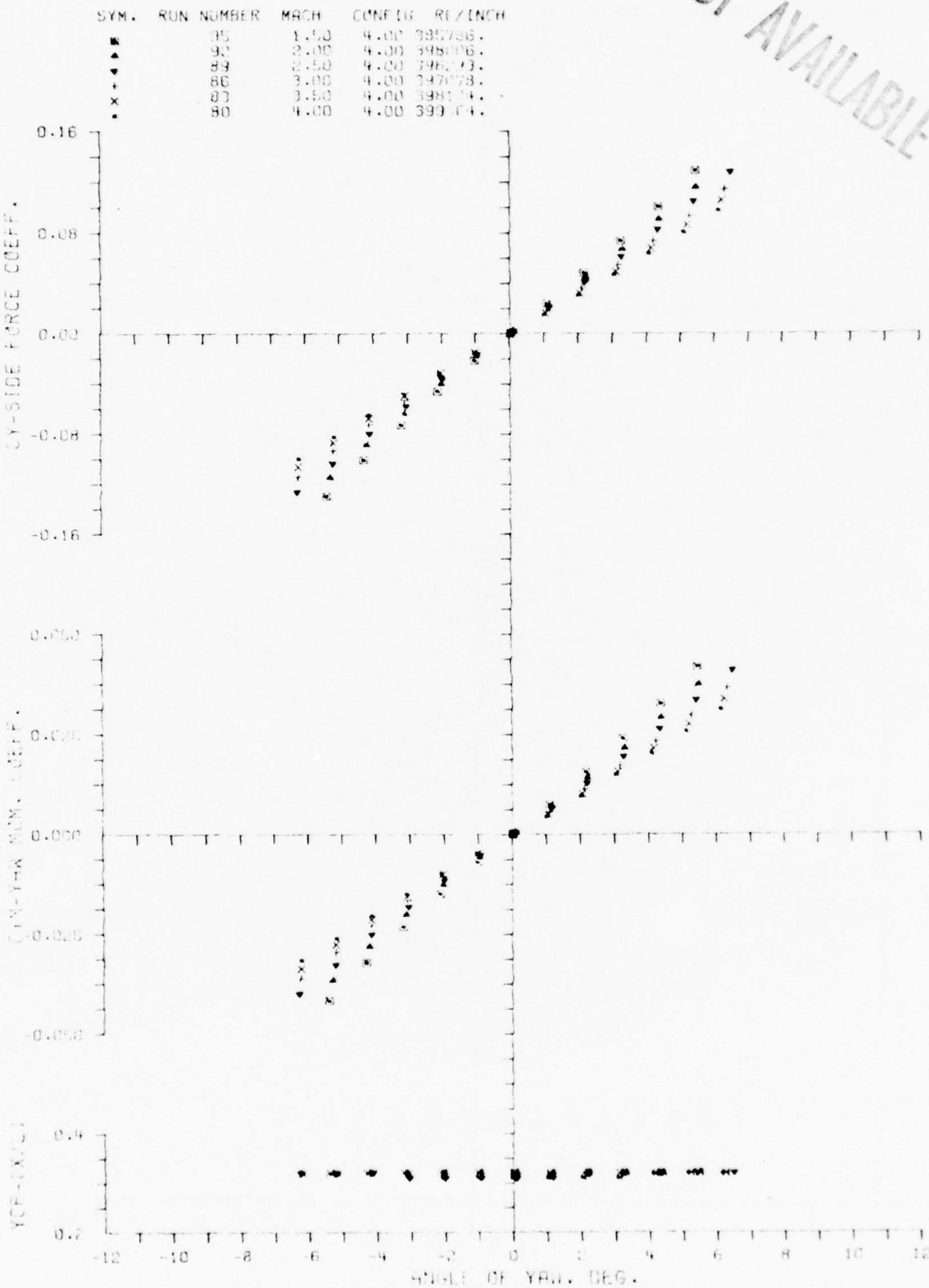

Figure A3. Concluded

d. CONFIG 4.00

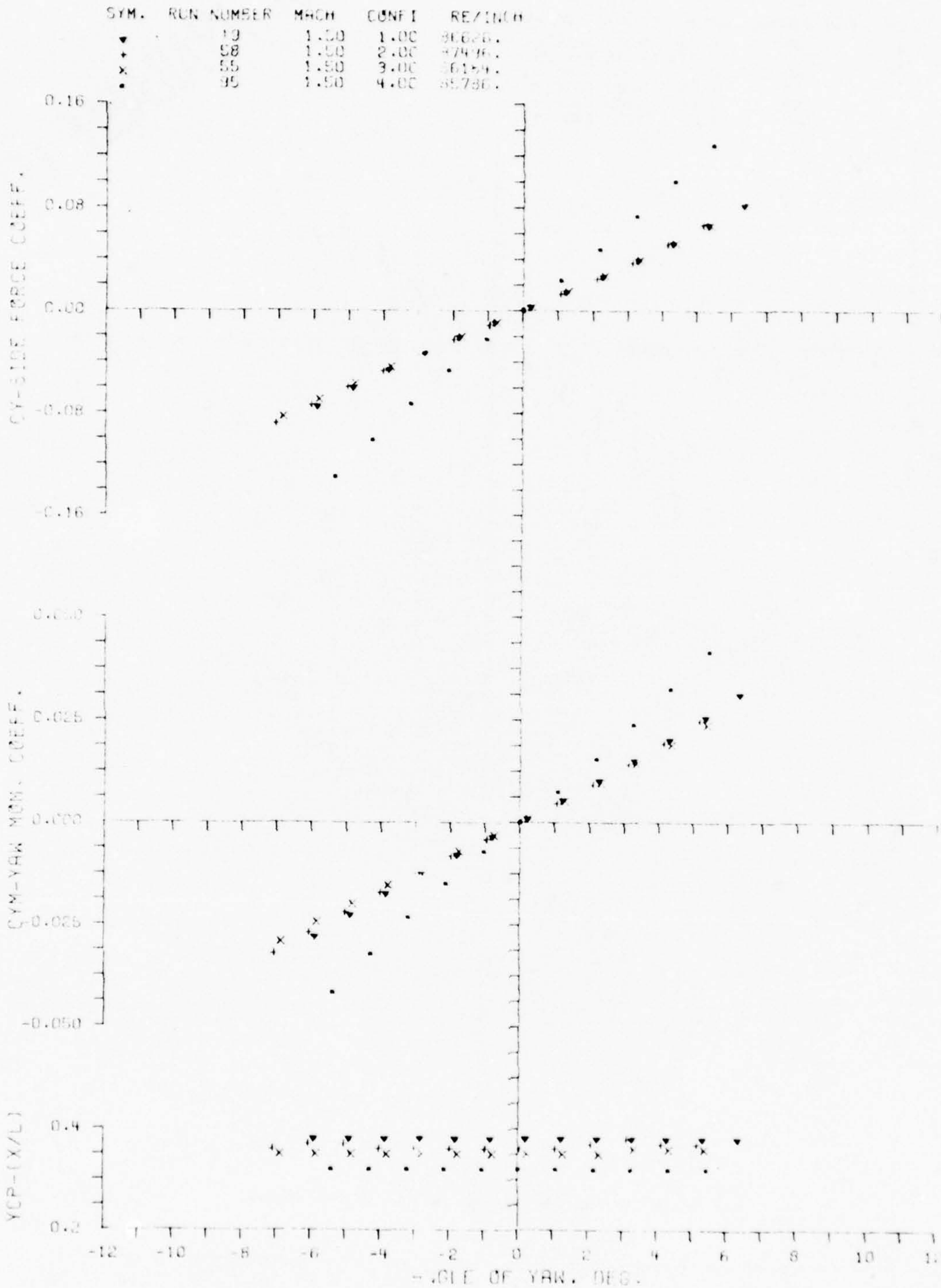

Figure A4. Aerodynamic Coefficients C_Y, C_{YM}, Y_{CP}--
Configuration Variation

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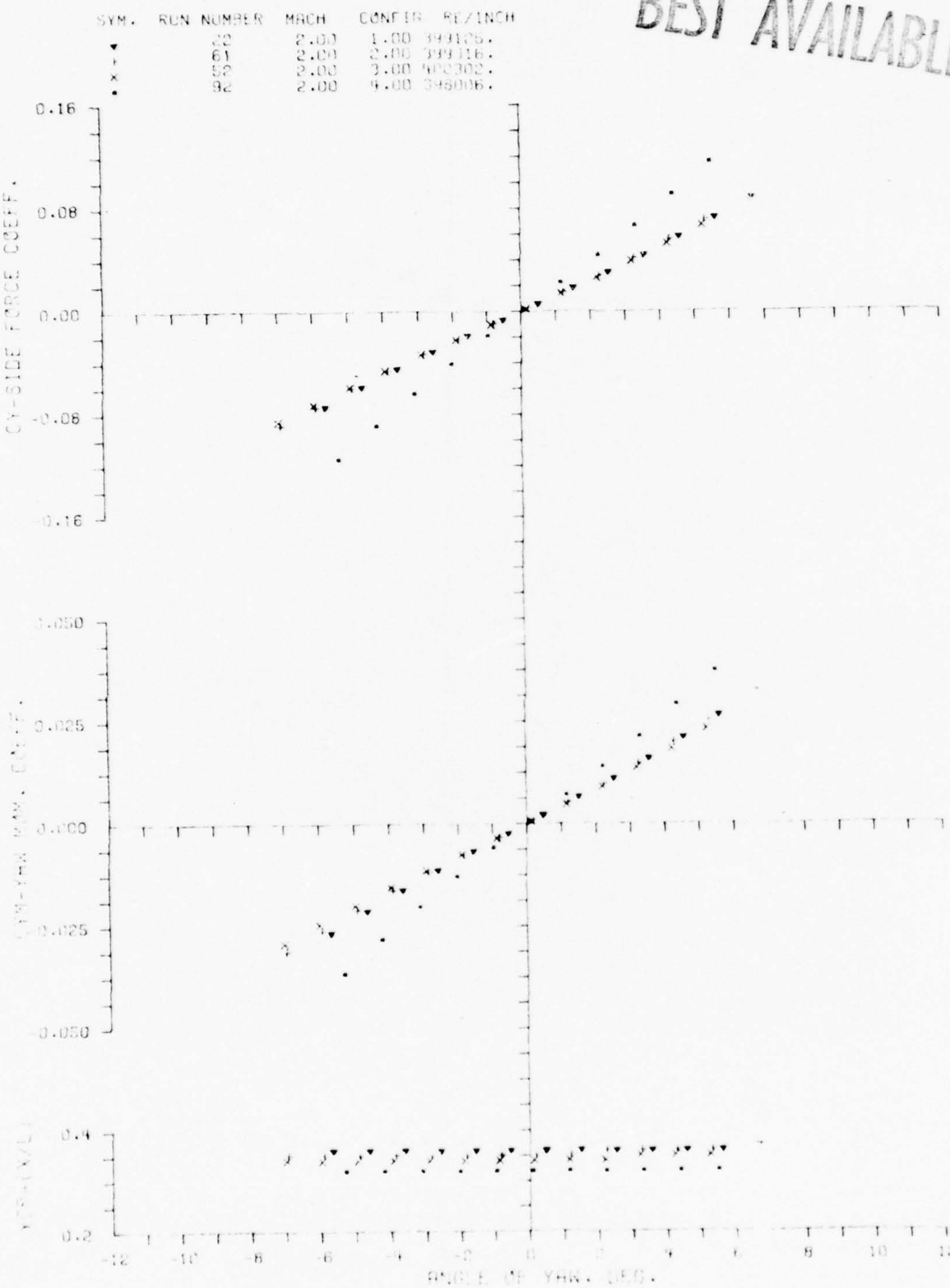


Figure A4. Continued

b. MACH 2.0

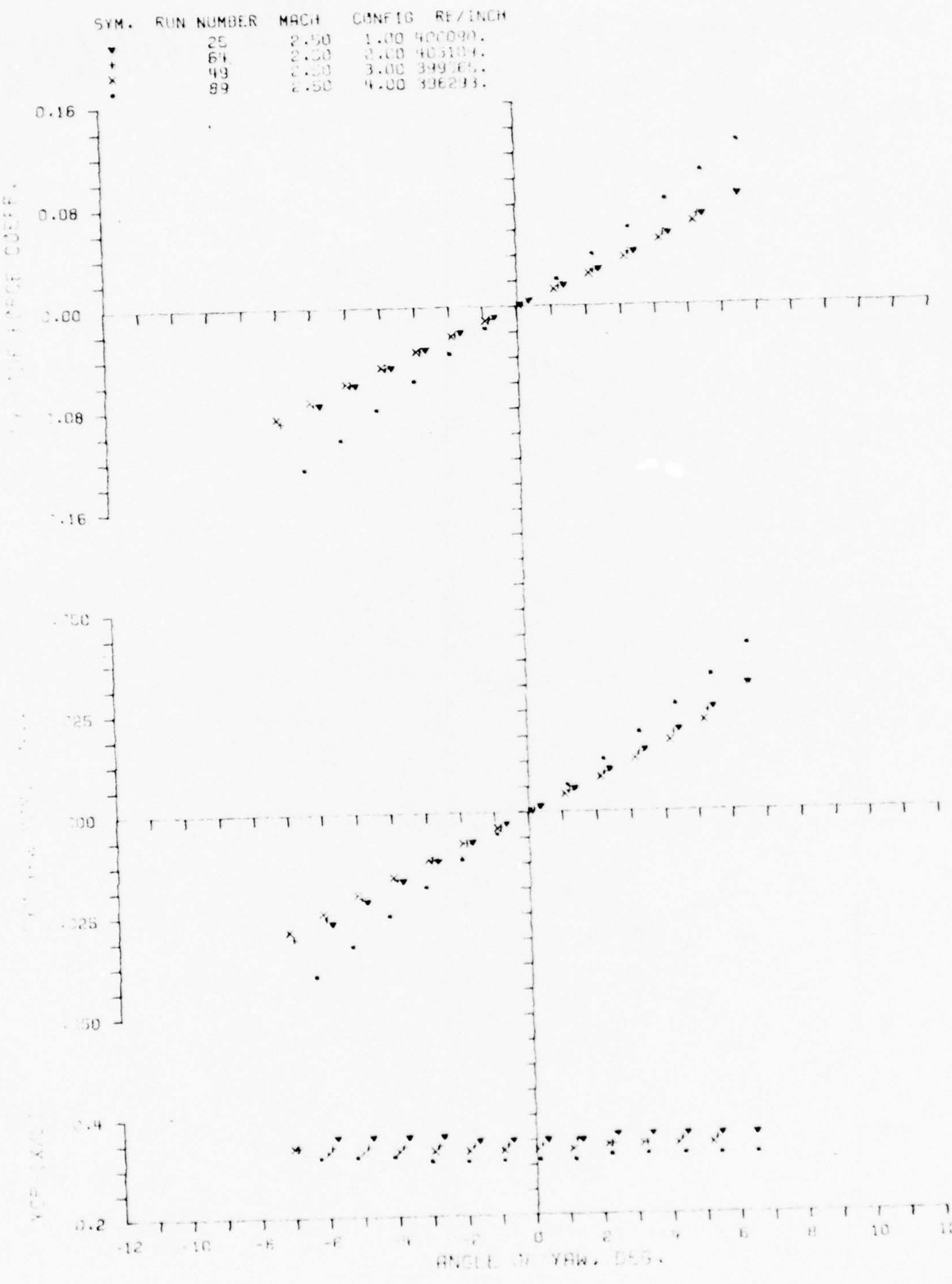
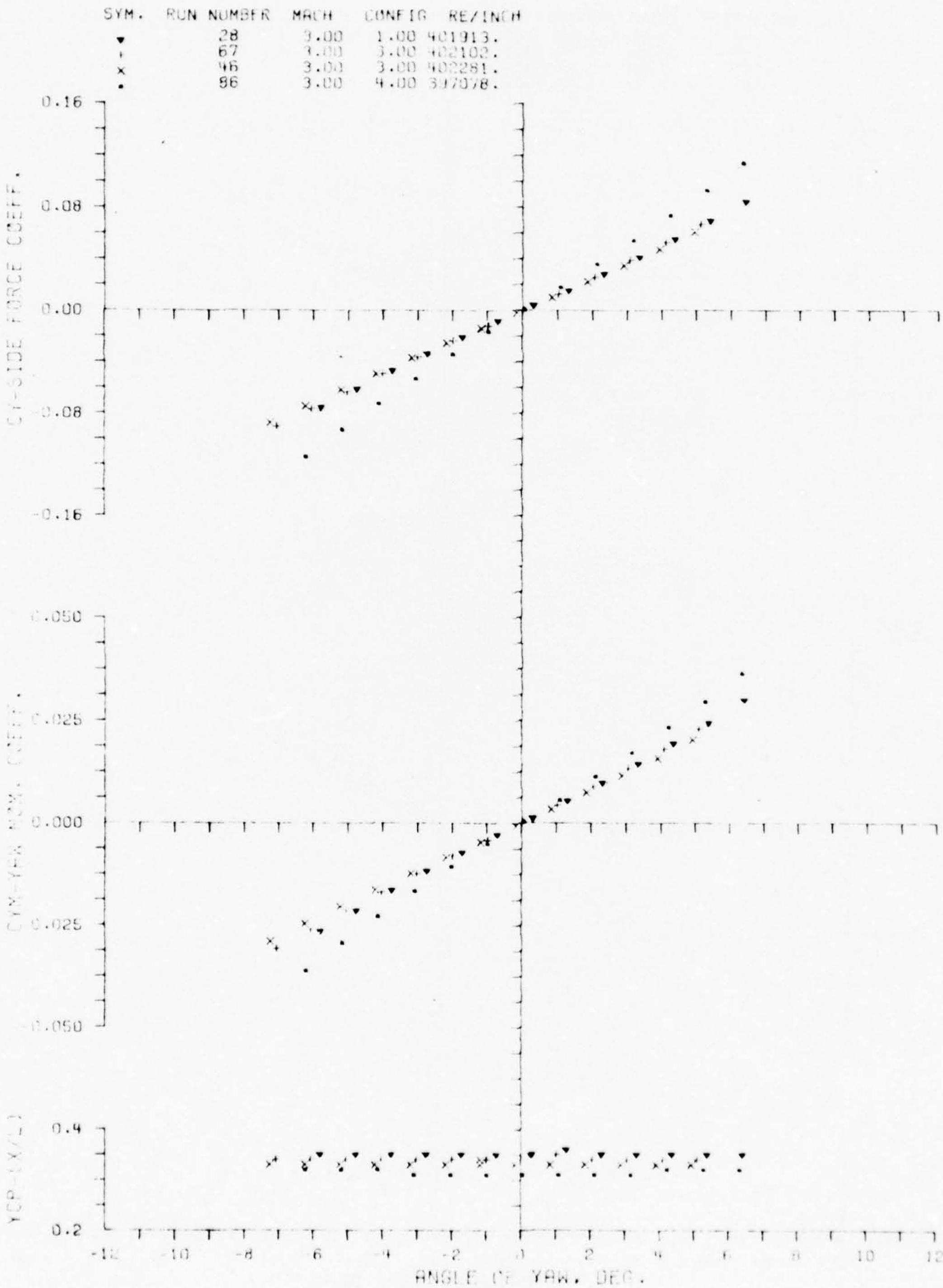


Figure A4. Continued

c. MACH 2.5



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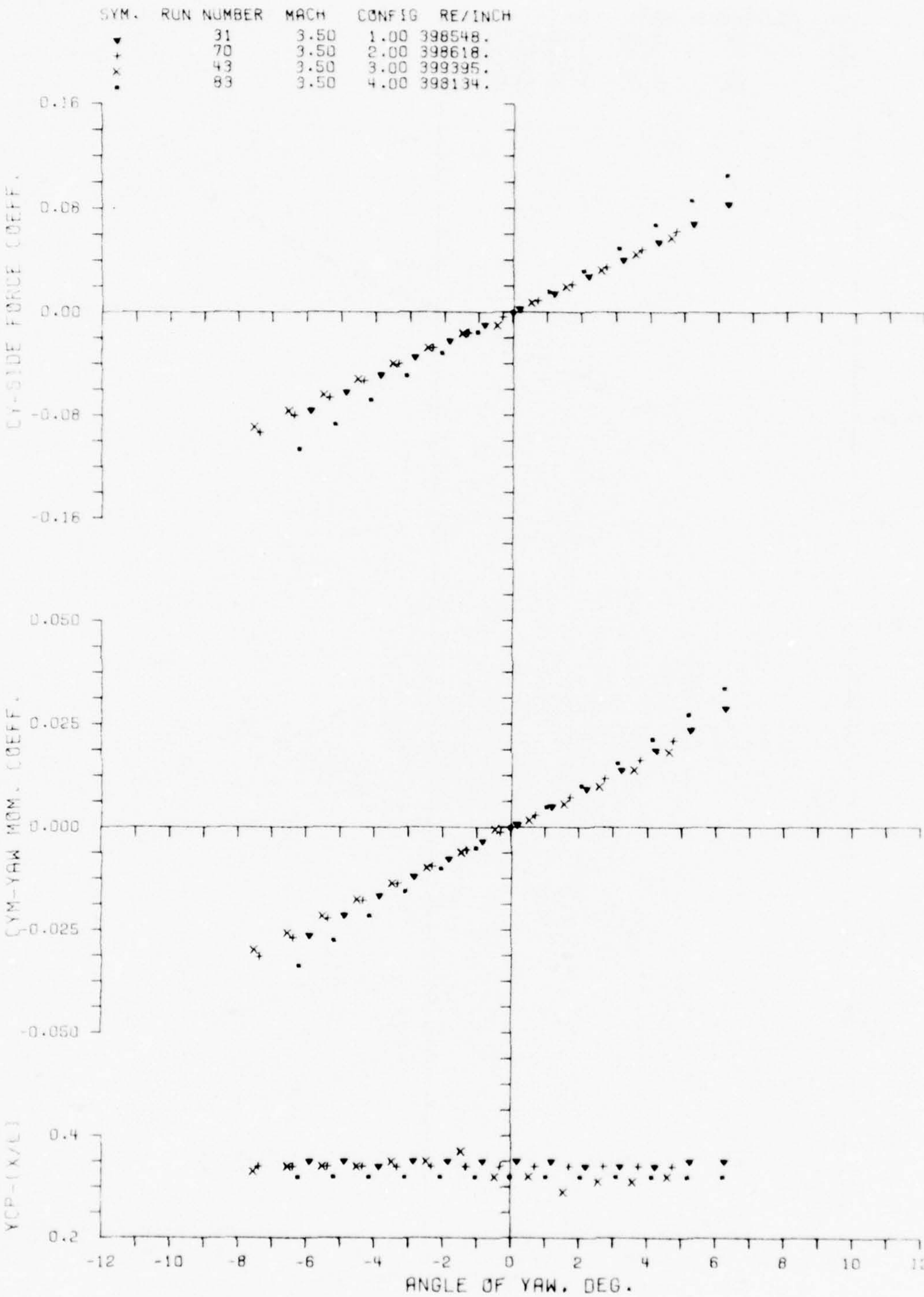

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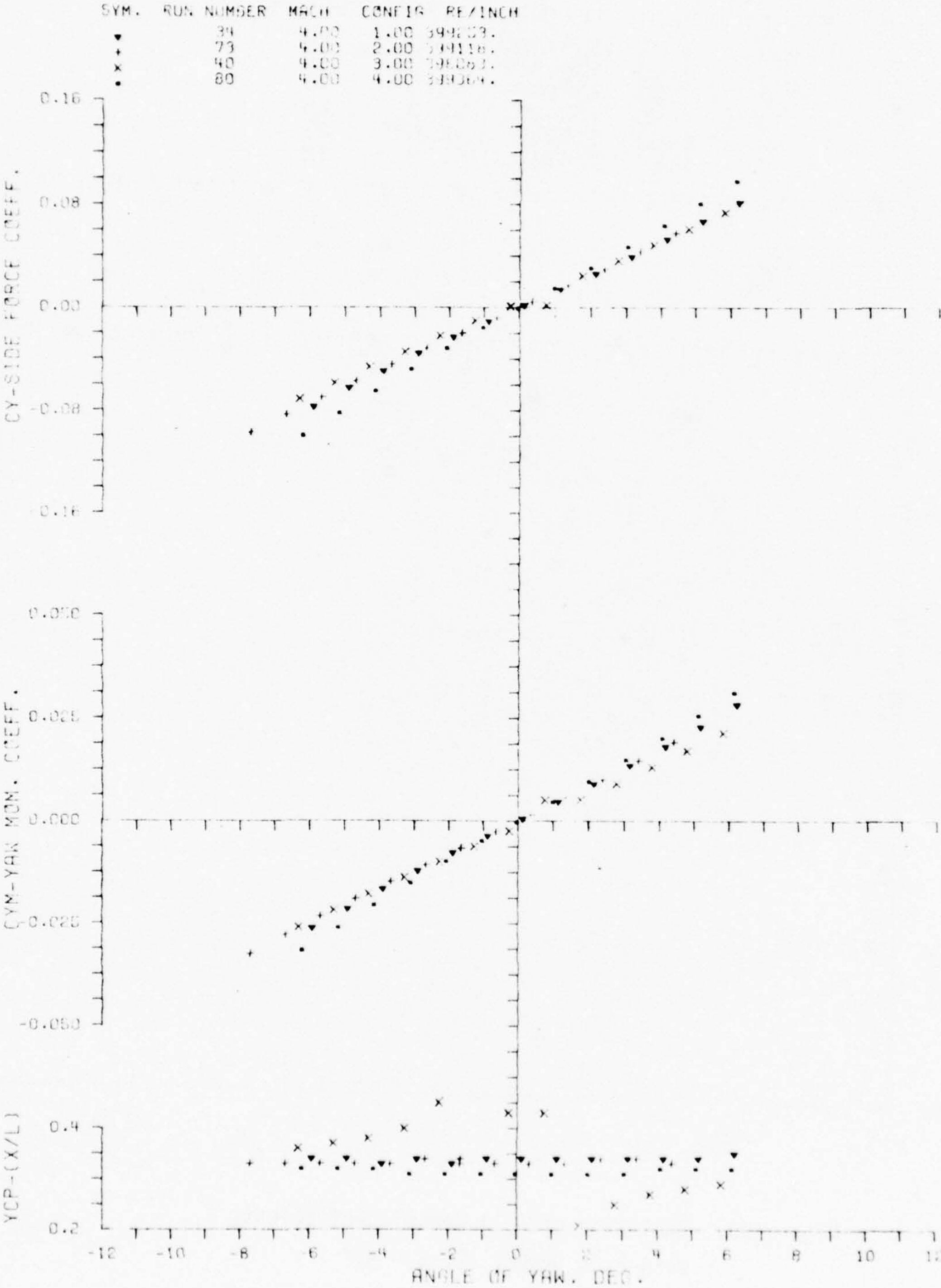

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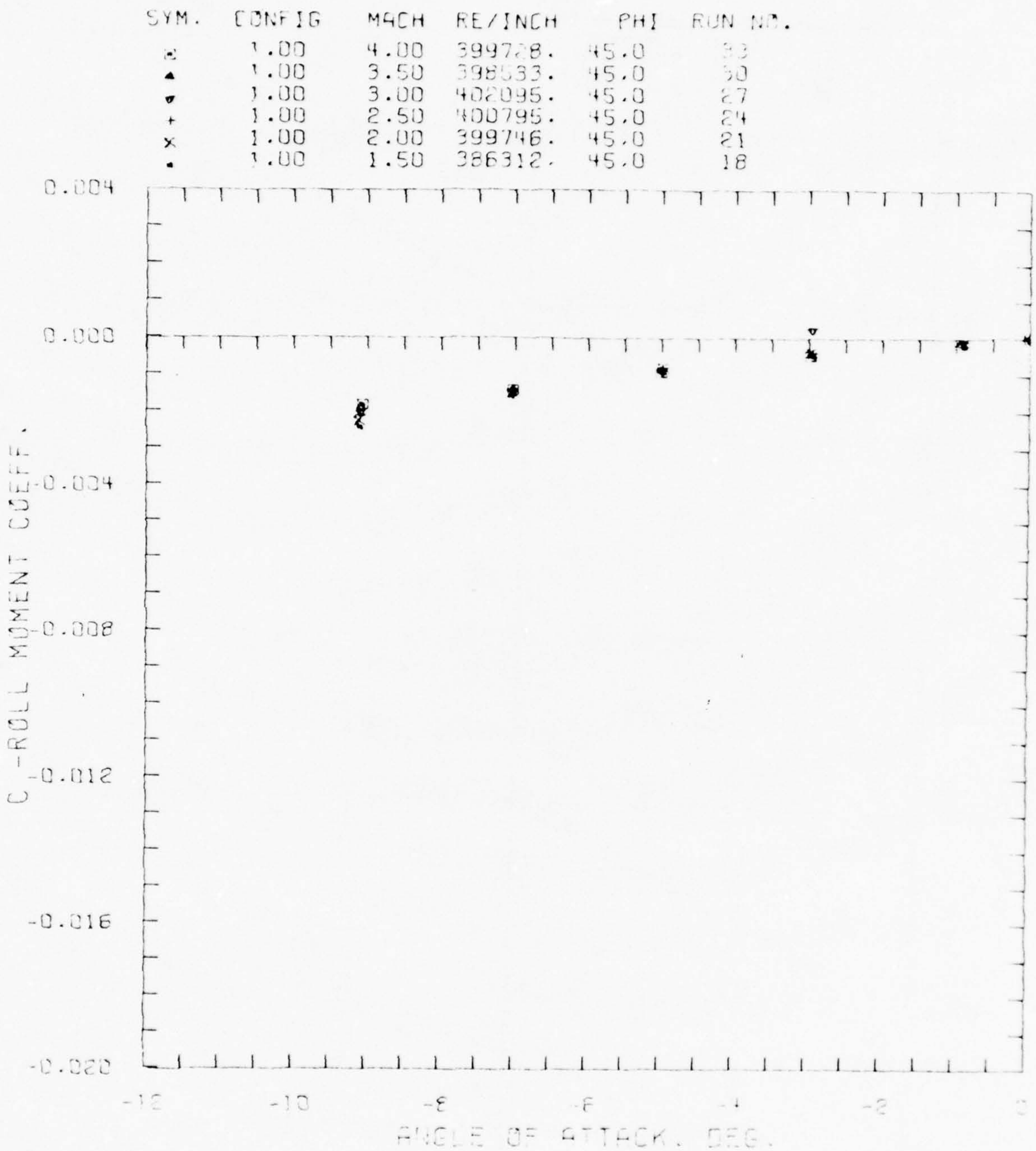


Figure A5. Variation of Roll Moment Coefficient, C_ℓ, With Mach Number for ϕ = 45°

a. CONFIG 1.00

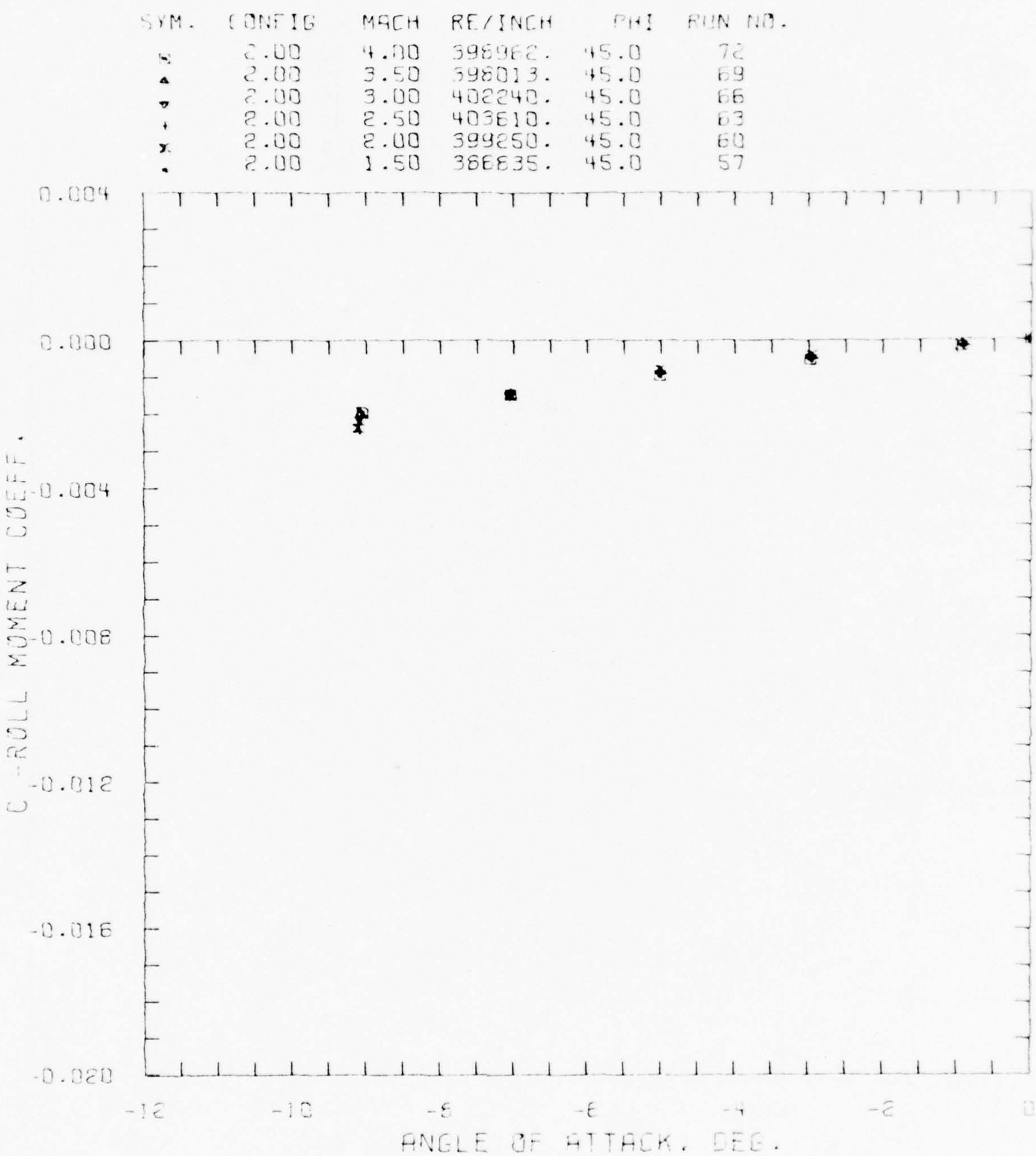
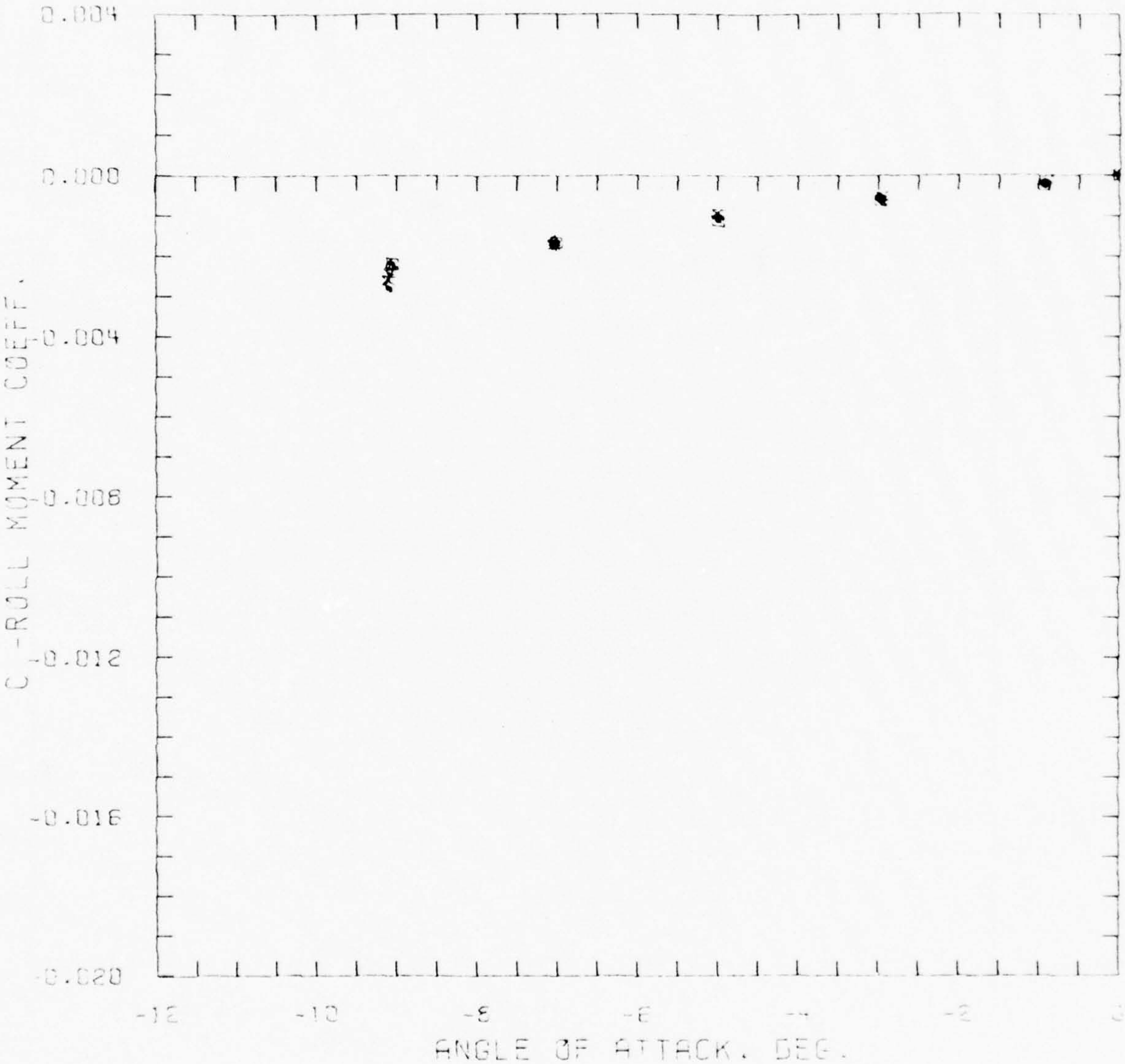


Figure A5. Continued

b. CONFIG 2.00

SYM.	CONFIG	MACH	RE/INCH	PHI	RUN NO.
⊠	3.00	4.00	398995.	45.0	39
▲	3.00	3.50	400493.	45.0	42
▼	3.00	3.00	403542.	45.0	45
+	3.00	2.50	399433.	45.0	48
×	3.00	2.00	399311.	45.0	51
•	3.00	1.50	386039.	45.0	54



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c. CONFIG 3.00

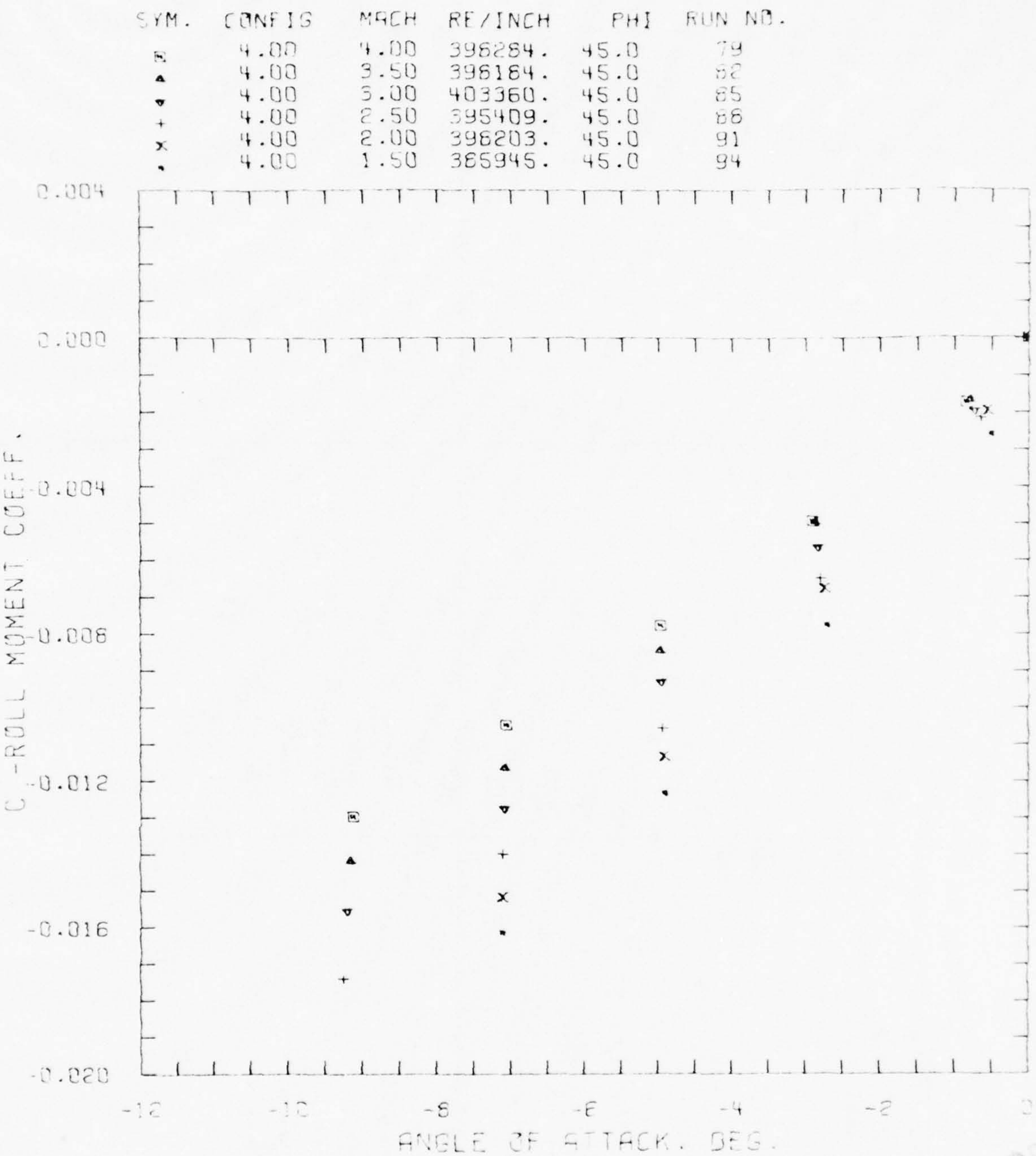

Figure A5. Concluded

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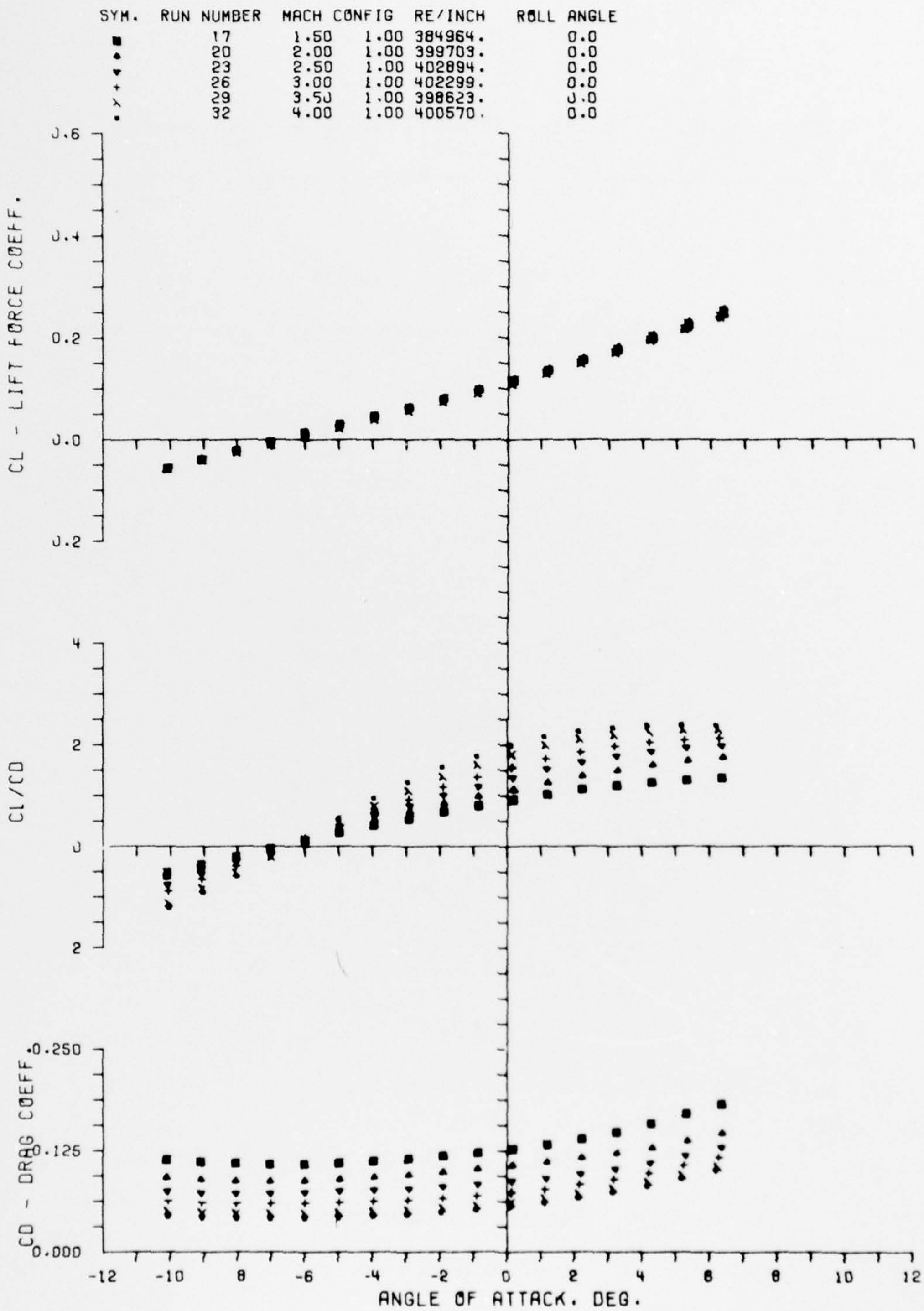
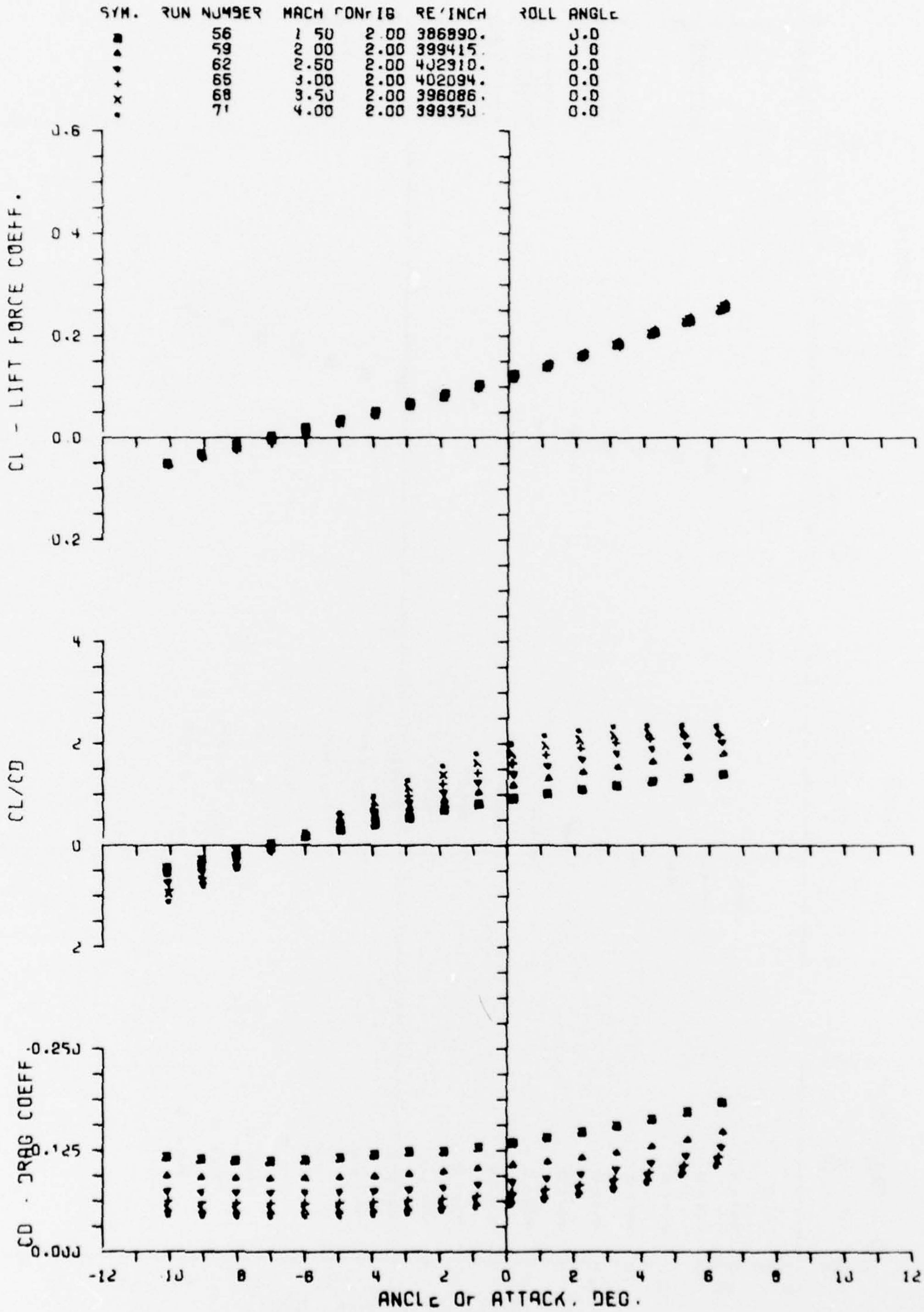


Figure A6. Aerodynamic Coefficients C_L, C_D, C_L/C_D--
Mach Number Variation

a. CONFIG 1.00



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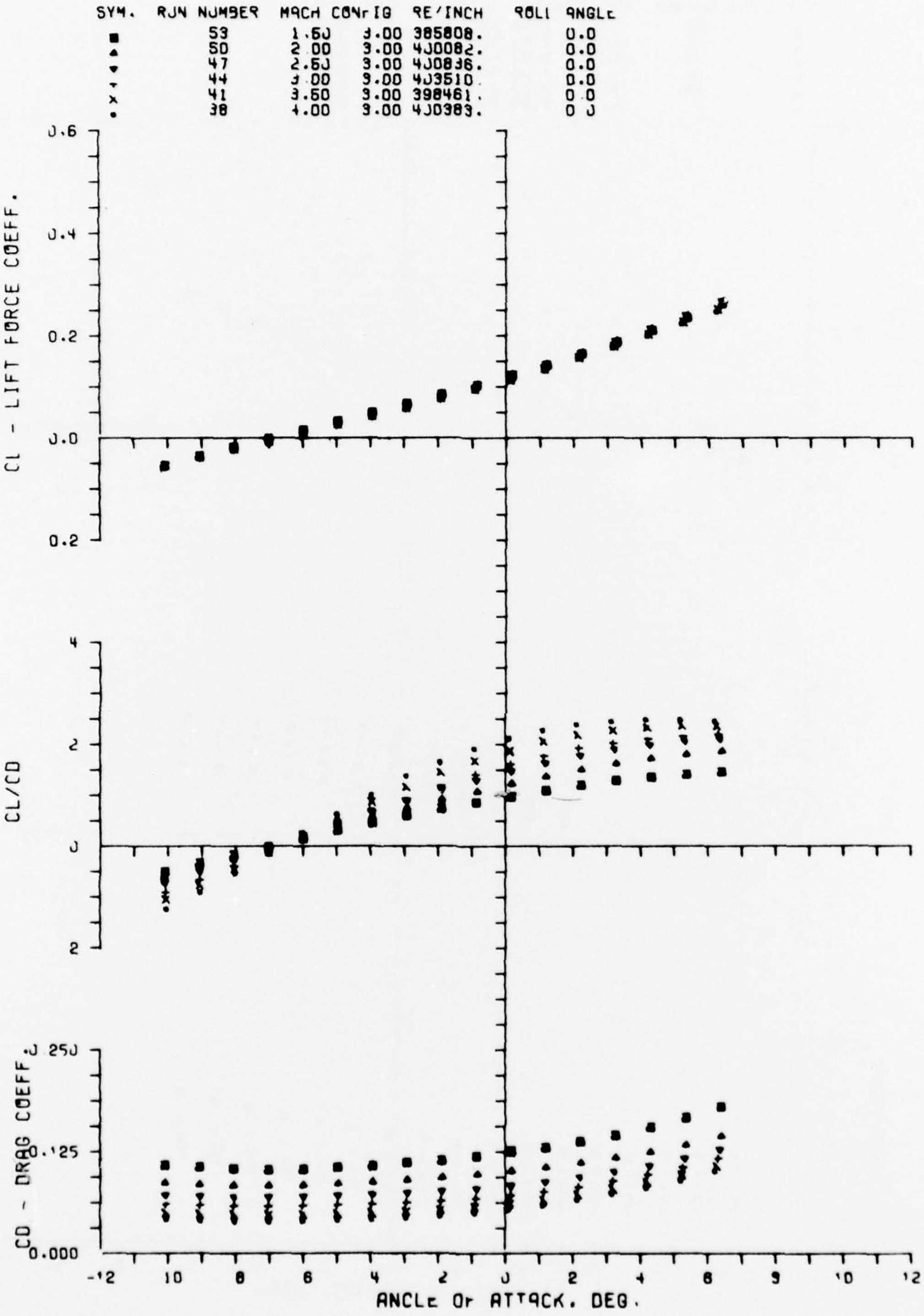

Figure A6. Continued

c. CONFIG 3.00

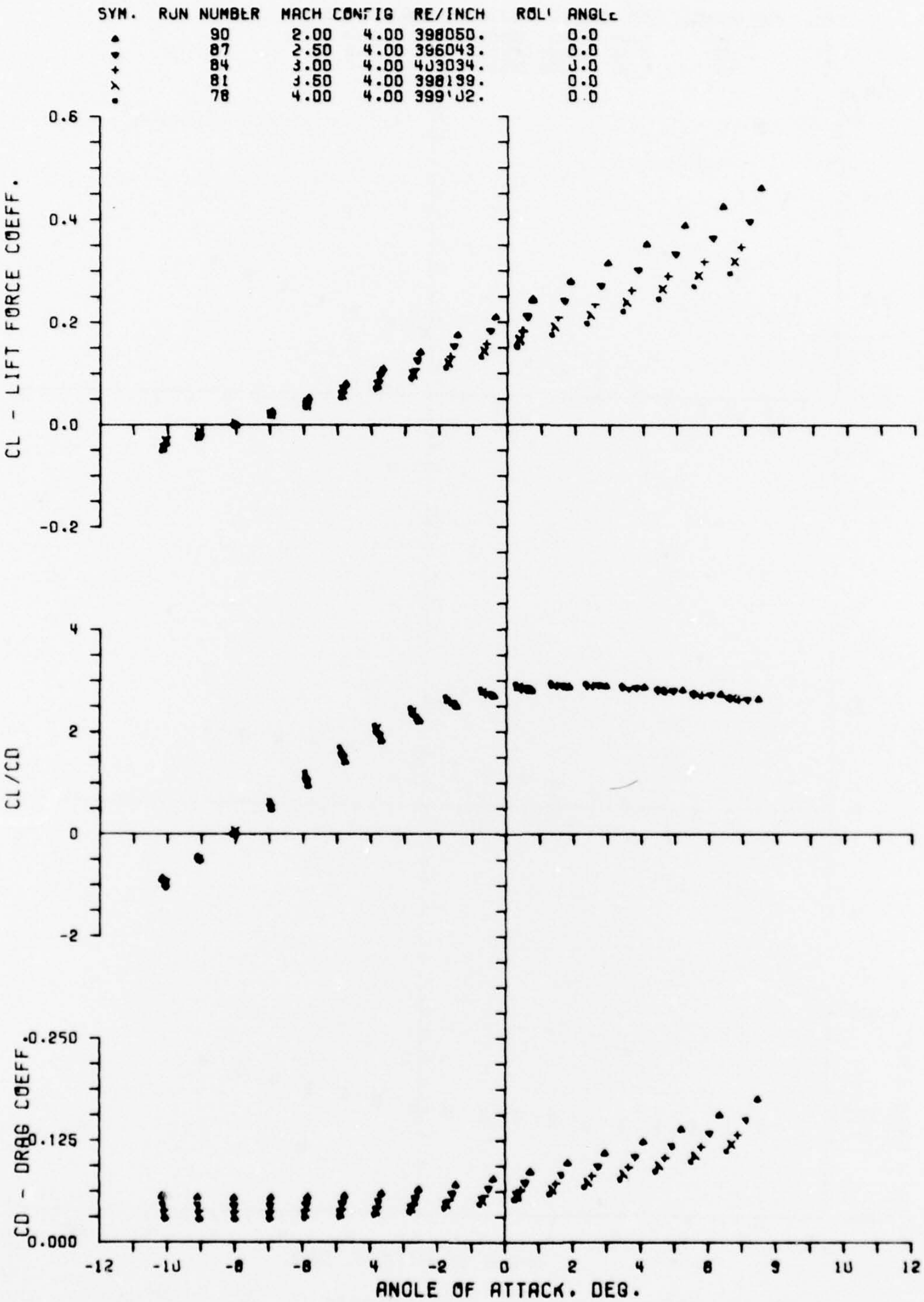

Figure A6. Concluded

d. CONFIG 4.00

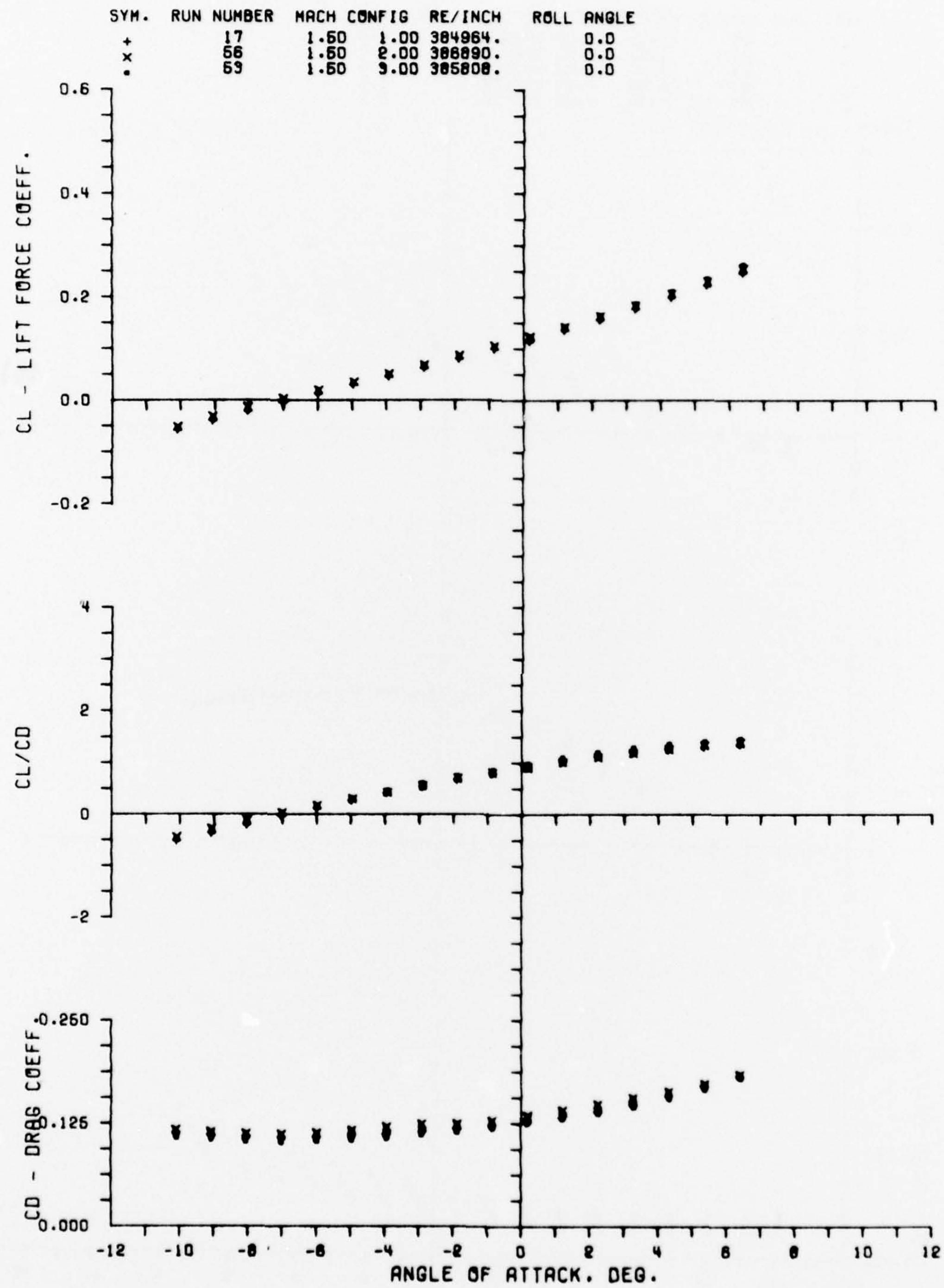

Figure A7. Aerodynamic Coefficients C_L, C_D, C_L/C_D--Configuration Variation

a. MACH 1.5

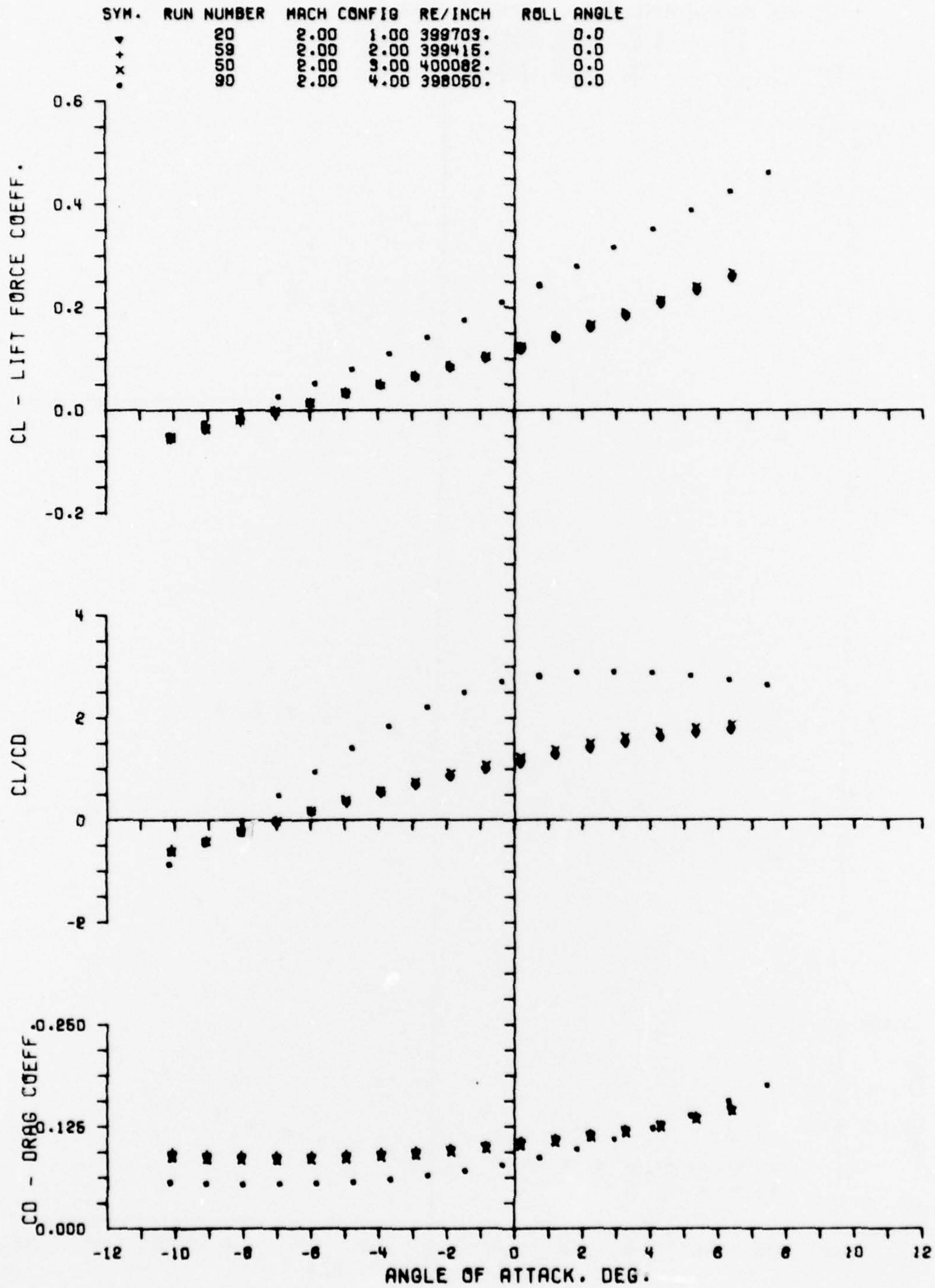

Figure A7. Continued

b. MACH 2.0

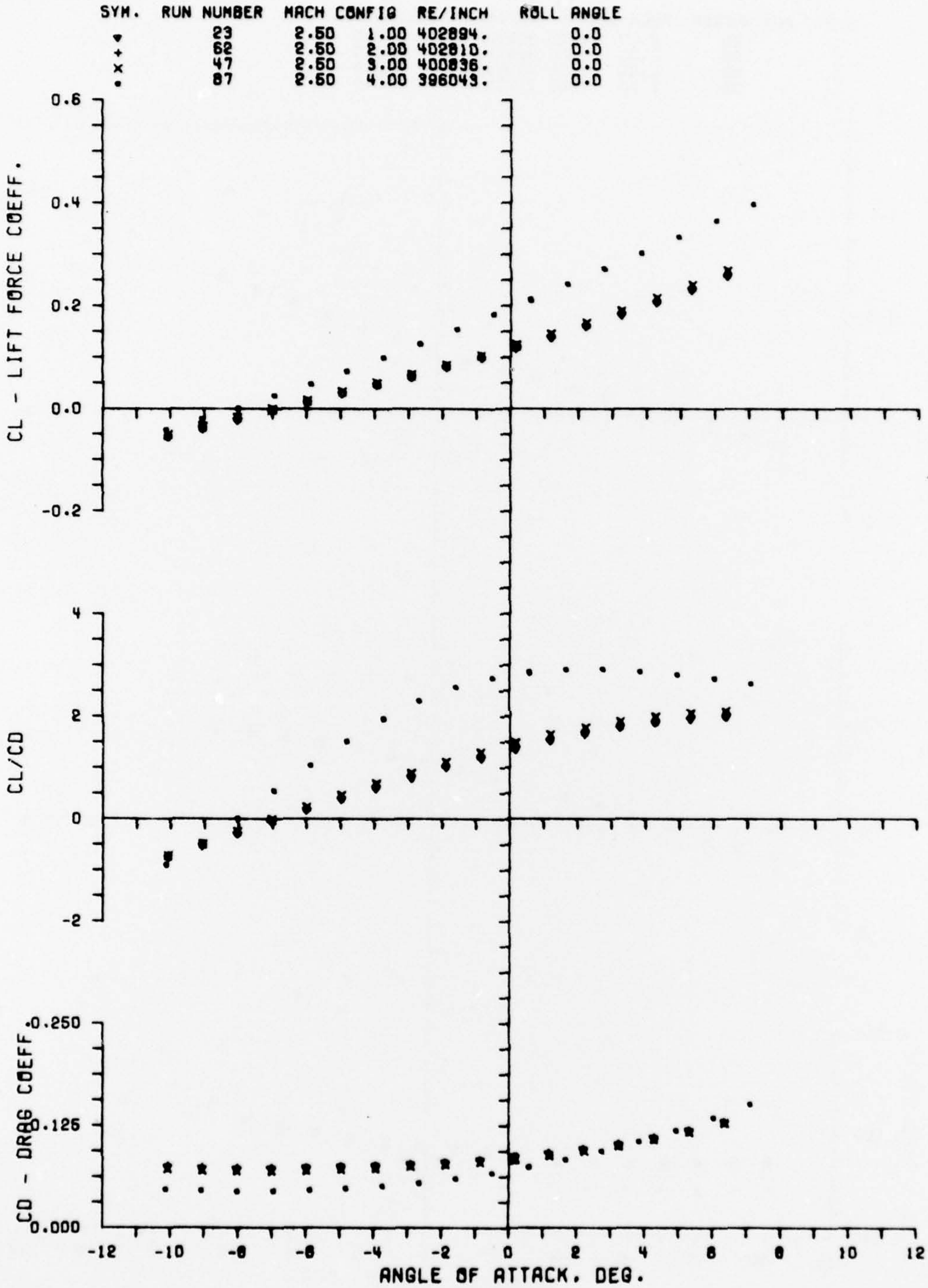

Figure A7. Continued

c. MACH 2.5

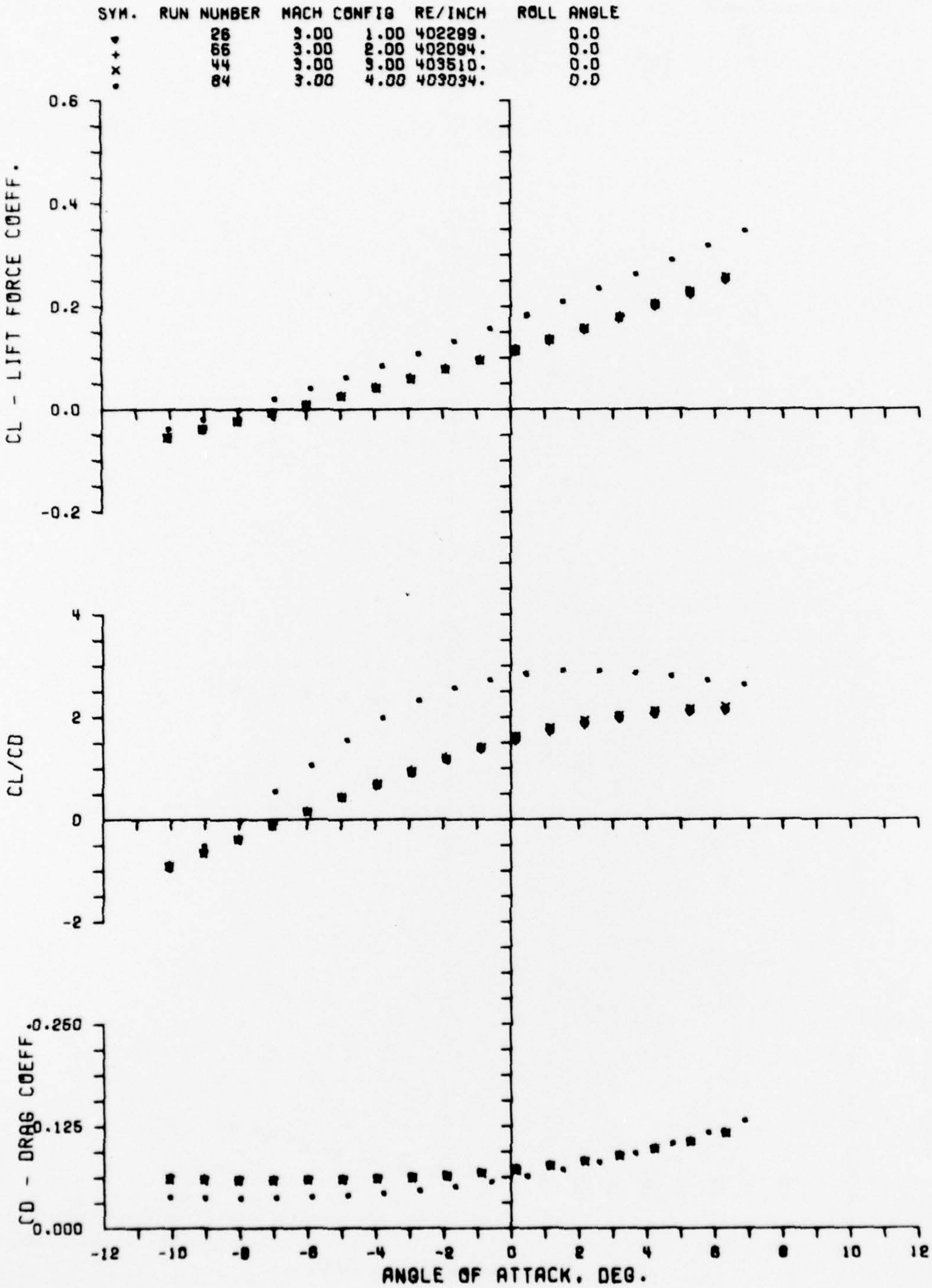

Figure A7. Continued

d. MACH 3.0

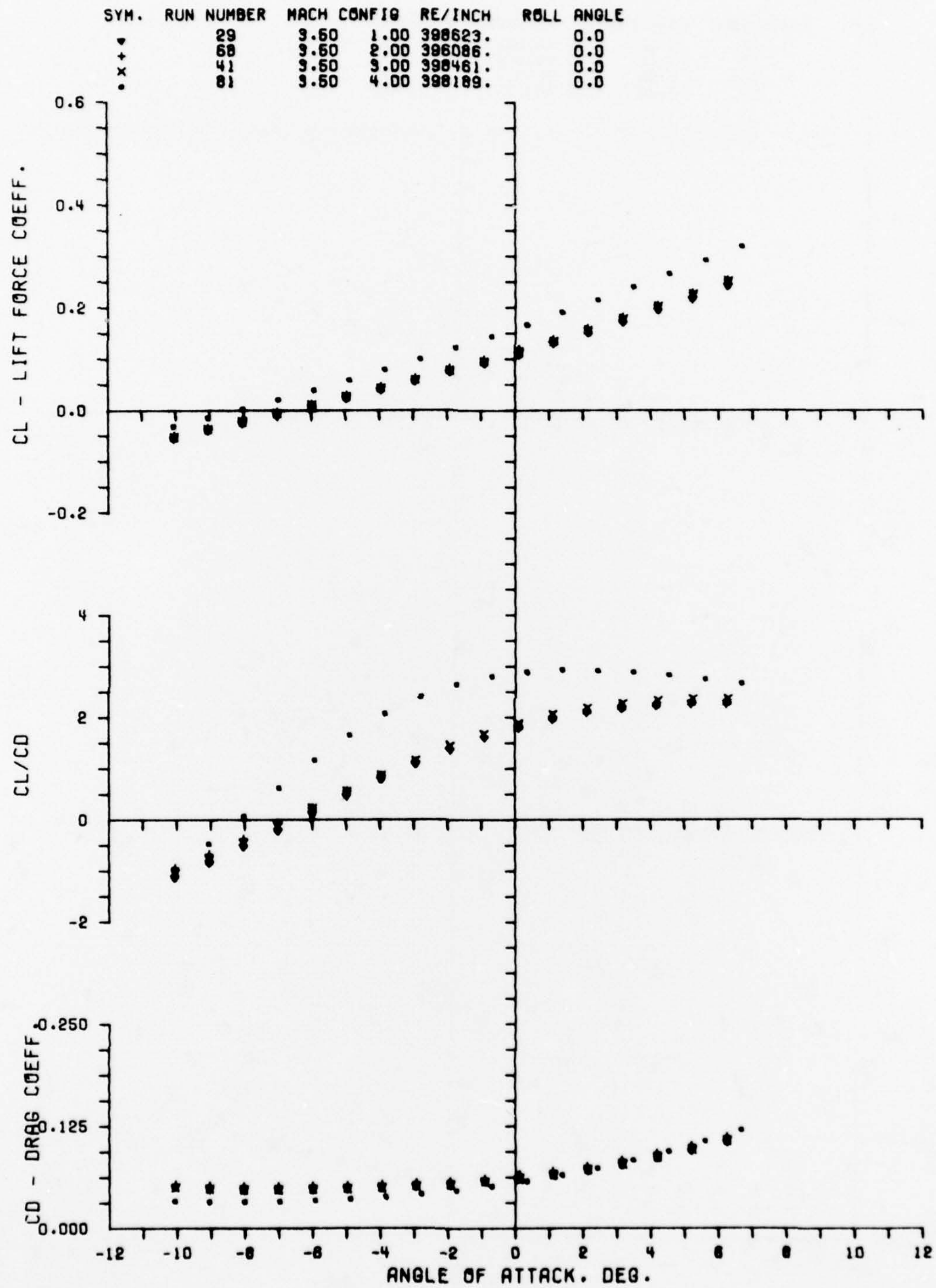

Figure A7. Continued

e. MACH 3.5

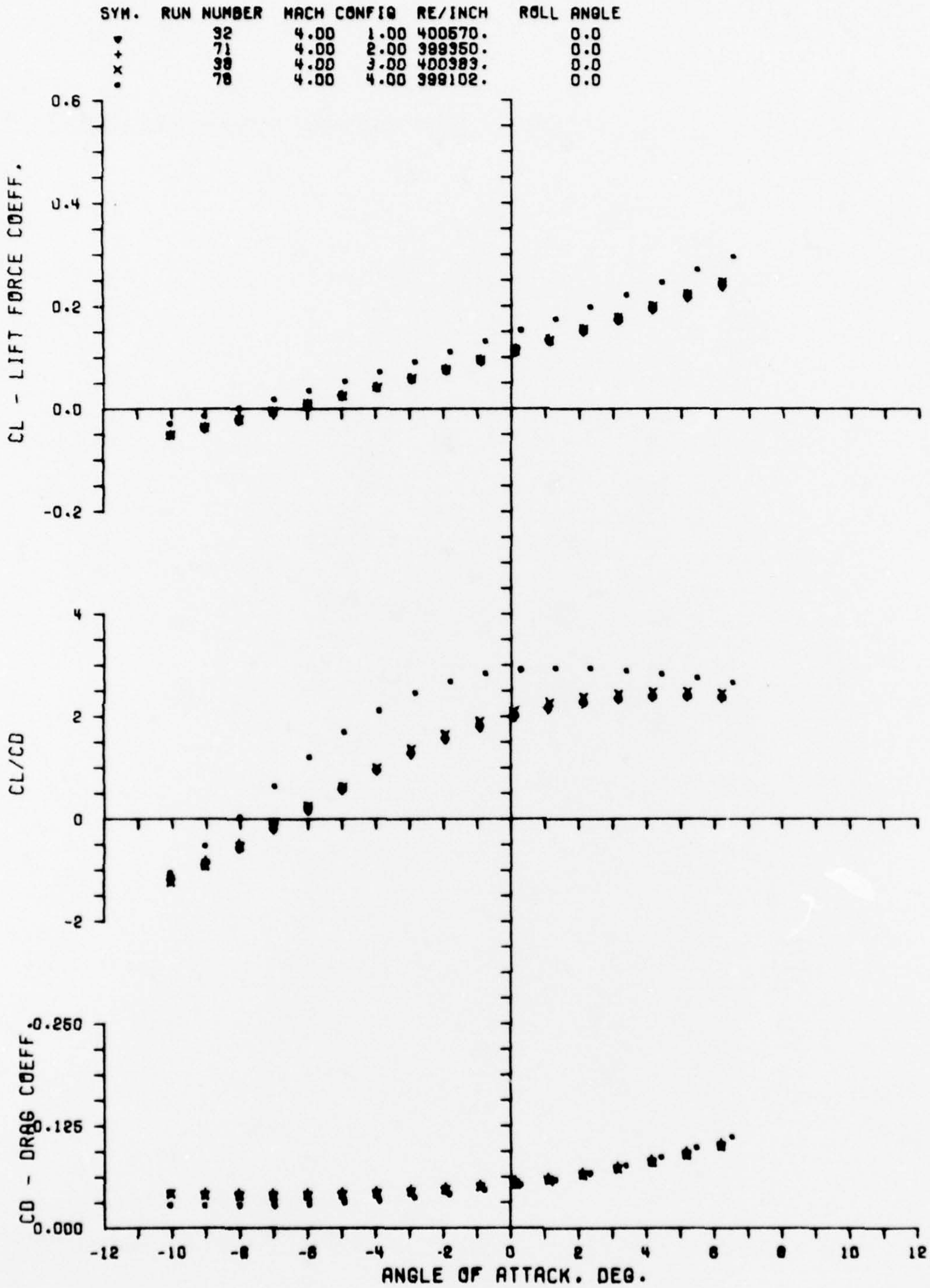

Figure A7. Concluded

f. MACH 4.0

LIST OF SYMBOLS

b	model base width
C_A	axial-force coefficient, $F_A/(qS)$
C_D	drag-force coefficient, $F_D/(qS)$
C_L	lift-force coefficient, $F_L/(qS)$
C_{L_α}	lift-force coefficient slope about trim angle
C_m	pitching-moment coefficient, $m/(qS\ell)$, reference at the model base
C_n	yawing-moment coefficient, $n/(qS\ell)$, reference at the model base
C_N	normal-force coefficient, $F_N/(qS)$
C_Y	side-force coefficient, $F_Y/(qS)$
F_A	axial-force
F_D	drag-force, $F_A \cos \alpha + F_N \sin \alpha$
F_L	lift-force, $F_N \cos \alpha - F_A \sin \alpha$
F_N	normal force
F_Y	side force
ℓ	model length
m	pitching moment
M	Mach number
n	yawing moment
q	free-stream dynamic pressure
Re	Reynolds number, based on free-stream conditions

LIST OF SYMBOLS (Continued)

S	reference planform area, $1/2[b\ell]$
X_{CP}	location of normal-force center of pressure, normalized with respect to model length, ℓ, and referenced at the model base
Y_{CP}	location of side-force center of pressure, normalized with respect to model length, ℓ, and referenced at the model base
α	angle of attack
ψ	angle of yaw

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