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WIND TUNNEL TESTS ON A NONAXISYMMETRIC  
PROJECTILE SHAPE AT MACH  
NUMBERS 2.5 TO 6.0

Lyle D. Kayser

September 1983



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND  
BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MARYLAND

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| Projectiles<br>Supersonic<br>Nonaxisymmetric<br>Nonconical Boattails                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                |                                             |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                |                                             |
| <p>Wind tunnel tests on spinning nonaxisymmetric projectile configurations at Mach numbers of 2.5 to 6.0 are reported. The projectile shapes are ogive-cylinder bodies which have been modified by machining three forward facing surfaces and three rearward facing surfaces on the projectile. The machined surfaces are twisted at a rate corresponding to a typical rifling twist. The forward facing surfaces produce a helical or corkscrew type effect and the rearward surfaces form a nonconical boattail and a triangular base. The</p> |                                                                |                                             |

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20. ABSTRACT (Continued)

Objective of the test program was to study shapes which have improved stability characteristics which require less gyroscopic stabilization. A more slender, longer L/d projectile can then be flown which has lower drag and shorter time of flight to a moving target.

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## I. INTRODUCTION

Some studies on the aerodynamic properties of nonaxisymmetric projectiles have been carried out in the Ballistic Research Laboratory in recent years. Figure 1 shows photographs of three such shapes which are designated as semicorkscrew, nonconical boattail, and corkscrew shapes. Platou<sup>1,4</sup> has considered nonaxisymmetric boattail shapes and has demonstrated that the projectile stability can be improved while still retaining the advantage of drag reduction through nonconical boattailing. For spinning projectiles, the boattail surfaces must be twisted at the same rate as the rifling twist. A resulting benefit of this twist is a reduction of the Magnus moment. Platou considered several nonconical configurations such as triangular, square, and cruciform. He concluded that the three-surface triangular boattail has the best aerodynamic properties. Later Platou<sup>5</sup> considered forward facing, and twisted, surfaces which gave the projectile a sharp nose tip and triangular cross sections near the nose; this shape was designated the corkscrew projectile. The general findings for the corkscrew shape were: (1) a low drag coefficient, (2) small Magnus moments, (3) smaller pitching moments than axisymmetric configurations of the same L/d. Platou<sup>6</sup> reports results of a study where he considered aerodynamic and physical properties of projectiles which could decrease projectile time of flight and therefore be more effective against maneuvering targets. Various geometries considered in Reference 5 were: conventional, nonconical boattail, corkscrew, and semicorkscrew shapes. The semicorkscrew shape shown in Figures 1 and 2 was considered by Platou to be a more practical shape than the sharp nose corkscrew shape. The semicorkscrew shape is primarily the subject of this report.

1. Platou, A.S., "An Improved Projectile Boattail," ARBRL-MR-2395, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, July 1974 (AD 785520).
2. Platou, A.S., and Nielson, G.I.T., "An Improved Projectile Boattail. Part II.," BRL R 1866, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, March 1976 (AD A024073).
3. Platou, A.S., "An Improved Projectile Boattail. Part III.," ARBRL-MR-2644, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, July 1976 (AD B012781L).
4. Platou, A.S., "An Improved Projectile Boattail. Part IV.," ARBRL-MR-02826, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, April 1978 (AD B027520L).
5. Platou, A.S., "Aeroballistics of Corkscrew Projectiles," ARBRL-MR-02825, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, April 1978 (AD A054735).
6. Platou, A.S., "Decreasing the Flight Time of Bullets by Improving Its Aerodynamic Characteristics," ARBRL-MR-03103, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, May 1981 (AD B058203L).

Other nonconical boattail results are reported in References 7 to 9. In Reference 7, computations on axisymmetric shapes were compared to experimental results on nonaxisymmetric shapes. The basic finding of Reference 7, for supersonic speeds of  $M = 1.75$  to  $4.0$ , was that the triangular nonconical boattail increased the static stability and in some cases, the stability is greater than that of a straight cylindrical ( $0^\circ$ ) boattail. In Reference 8, Danberg and Tschirschnitz obtained pressure measurements on axisymmetric and nonconical boattails at transonic speeds. Intergration of pressures over the boattails showed that the nonconical boattail reduced total projectile drag by approximately 15% and increased the static stability with respect to the conical (axisymmetric) boattail configuration. Wind tunnel results for a projectile with a cone-caliber triangular boattail are presented in Reference 9 for  $M = 0.91$  and  $3.0$ . The results show improved stability at both Mach numbers. Also presented in Reference 9 are computational results for the nonconical boattail at  $M = 3.0$ ; agreement between computation and experiment is generally good. The computational method used was the parabolized Navier-Stokes solver described in Reference 10.

The above references document desirable aerodynamic characteristics of nonaxisymmetric shapes, but whether or not such shapes can be successfully flown has not been fully determined. Sabot design for the complex semicorkscrew shape is difficult and the launch dynamics are complex. For example, free-flight launchings of the semicorkscrew shape have shown large initial yaw which has overshadowed other desirable aerodynamic characteristics. Currently there is not a major effort in the study of nonaxisymmetric shapes here at the Ballistic Research Laboratory. However, there are currently computational projects involving nonaxisymmetric shapes including finned bodies. The experimental results of the semicorkscrew projectile presented in this report can be of value in providing guidance and verification of the computational effort.

- 
7. Kayser, L.D., and Sturek, W.B., "Aerodynamic Performance of Projectiles with Axisymmetric and Non-Axisymmetric Boattails," ARBRL-MR-03022, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, May 1980 (AD A086091).
  8. Danberg, J.E., and Tschirschnitz, R.H., "Transonic Pressure Distribution and Boundary Layer Characteristics of a Projectile with an Asymmetric Afterbody," Technical Report 243, University of Delaware, June 1981.
  9. Kayser, L.D., and Whiton, F., "Some Aerodynamic Characteristics of a Projectile Shape with a Nonaxisymmetric Boattail at Mach Numbers of 0.91 and 3.02," ARBRL-TR-02525, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, September 1983.
  10. Schiff, L.B., and Sturek, W.B., "Numerical Simulation of Steady Supersonic Flow Over an Ogive Cylinder Boattail Body," ARBRL-TR-02363, U.S. Army Ballistic Research Laboratory, ARRADCOM, Aberdeen Proving Ground, Maryland 21005, September 1981 (AD A106060).

## II. EXPERIMENT

### A. Models and Instrumentation

Details of the model geometry are shown in Figure 2. The three configurations tested had length to diameter ( $L/d$ ) ratios of 6, 7, and 8. The model was equipped with a boundary-layer trip for all test runs and was located 0.8 caliber from the nose tip. The trip was fabricated by spot welding two rows of 30 0.75mm steel balls to a thin ring. The trip ring can be seen in the photograph of Figure 1a. The models were mounted on a center body by means of ball bearing attachments; thus, the model was free to spin as aerodynamic torque was applied. The model was not equipped with the air driven turbine which is generally used for spinning axisymmetric shapes. The center-body was mounted on an internal strain gage balance. A Naval Surface Weapons Center (NSWC) balance capable of measuring normal force, pitching moment, side force, and yawing moment was used for most of the test program. Since this balance did not have a drag measurement capability, a BRL balance was used for a limited number of test runs. The BRL balance had a smaller load capacity and for this reason, the angle-of-attack range and tunnel supply pressure were limited.

### B. Wind Tunnels

The Mach 2.5, 3.5, and 5.0 tests were conducted in the NSWC Wind Tunnel No. 2. Tunnel No. 2 is a 0.41 x 0.41m (16 x 16 inch) cross-section horizontal tunnel with an open jet test section capable of operation over a Mach number range of 0.3 to 5.02 with supply pressures ranging from 0.5 to 15 atmospheres. The tunnel is capable of intermittent (blowdown) or continuous operation with a higher Reynolds number capability for the intermittent mode. Mach number changes are made by replacing the two-dimensional nozzle block units -- each nozzle block provides one distinct Mach number.

The Mach 6 portion of the test program was conducted in the NSWC Wind Tunnel No. 8 which has a Mach number range of 5 to 10. The Mach 6 nozzle is two dimensional and has a nozzle exit size of 0.46 x 0.46 m (18 x 18 inches). A pebble bed heater and an electric resistance heater are used to heat the air so that air liquefaction in the expanding nozzle is avoided. The tunnel is operated only in the intermittent mode but the run time can be substantial for high Mach numbers and low supply pressures. Air is stored in a high pressure bottle field and can be supplied to the tunnel at pressures up to 150 atmospheres.

### C. Test Procedure

Data were acquired at the conditions shown in the test run summary of Table 1. The procedure for acquiring data was to start the tunnel, pitch the model to the desired attitude, let the model spin rate stabilize, and then record the data. At each angle of attack, numerous (approx. 30) sets of data were recorded and then averaged to provide one useful set of data for each angle of attack. Normal force, pitching moment, side force, and yawing moment data were adjusted so that the data curve, as a function of angle of attack, passed through the origin. For the purpose of computing pitching moment and yawing moment data, the center of gravity was assumed to be located at 60% of the model length from the nose.

### III. RESULTS

A tabulation of the coefficient data is provided in the appendix. The dimensionless spin rates for zero angle of attack are shown in Figure 3 along with the "match-spin" rate. There does seem to be some Mach number dependence on spin rate with the spin rate at the lower Mach numbers approaching the "match-spin" rate. Also, the higher Reynolds number flow produces a higher rate than the lower Reynolds flow. The higher Reynolds flow was achieved primarily by increasing the density; therefore, the dynamic pressure is approximately proportional to the Reynolds number. The increase in spin rate could be due to: (1) a Reynolds effect, (2) an increase in dynamic pressure overcoming bearing friction or (3) a combination of 1 and 2. For this reason, the change in spin rate with Reynolds number is believed to be partly the result of bearing friction. In a free flight situation, the spin rate at launch would equal "match-spin" and as the velocity decays, the spin rate would also decay but would always be slightly above "match-spin." To determine the effects of bearing friction, a spin control system, such as an air turbine drive, would be needed so that spin rates could be adjusted both above and below "match-spin."

Static stability characteristics of the semicorkscrew projectile are presented in Figures 4a to 4g. Figures 4a to 4d are normal force and center of pressure plots. The normal force curves show, as expected, that the longer configurations have the larger normal force. The center of pressure data are in calibers from the c.g. which is assumed to be located at 60% of the model length from the nose. The positive values of  $X_{cp}$  show that all configurations are statically unstable and are most unstable at zero angle of attack. The static behavior is summarized in Figures 4e, f, g where  $C_{N_\alpha}$ ,  $C_{m_\alpha}$ , and  $X_{cp}$  are shown as a function Mach number. The slope of the normal force does not show a large variation for the different model lengths. Values of  $C_{m_\alpha}$  show the instability for all configurations over the range of Mach numbers tested. Values of  $C_{m_\alpha}$  and  $X_{cp}$  are relatively constant over the Mach number range and show that instability increases with increasing model length. Reference 7 compares results for a 6.2 caliber nonconical boattail configuration with axisymmetric shapes having the same L/d. The nonconical configuration (of Reference 7) had a conventional axisymmetric forebody and a boattail identical to the semicorkscrew boattail; this configuration was designated "Projectile A." The results of Reference 7 show a substantial increase in stability with the addition of the nonconical boattail. A value of  $C_{m_\alpha}$  of 0.29 at  $M = 5$  is nearly equal to that of the 6-caliber semicorkscrew shape. This comparison suggests that the improvement in stability is primarily a result of the nonconical boattail and not of the forward facing flat (helical) surfaces.

The axial force, excluding base drag, data shown in Figures 5a to 5c are somewhat erratic. Generally, the longer configuration has the larger axial force and the force decreases with increasing Mach number.

A sample of side force and yawing moment data are shown in Figures 6a and 6b. The data are somewhat erratic and the yawing moment is seen to be highly

nonlinear. To the extent possible, slopes of the side force and yawing moment coefficients at zero angle of attack were obtained and are shown in Figures 6c and 6d. The slope of the side force coefficient is negative, which is typical for axisymmetric projectiles, but the slope of the yawing moment coefficient is also negative, which is not typical for axisymmetric projectiles. This indicates that the dominant portion of the side force is forward of the c.g. whereas the typical Magnus center of pressure is aft of the c.g. Since the model spin rate could be varied, the influence of bearing friction could not be determined. If the model is slowed by bearing friction, the twisted surfaces will act similar to canted fins, thus affecting side force and yawing moment data by an unknown amount. However, if there is a canted fin effect, it must be small since the side forces and yawing moments are of the same order of magnitude as those for axisymmetric shapes.

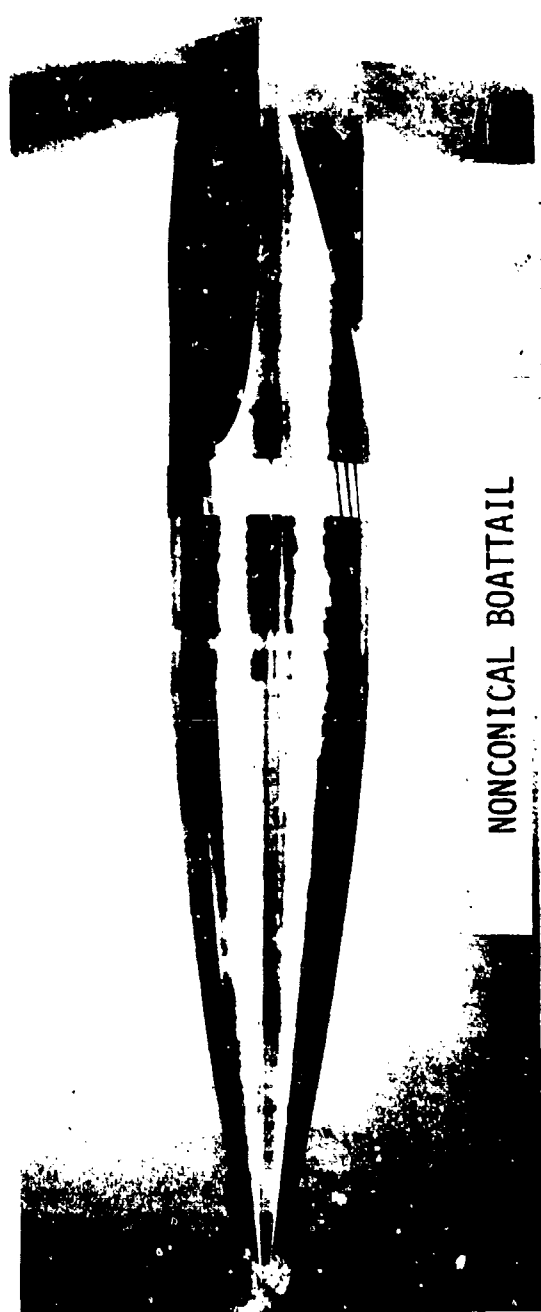
#### IV. CONCLUSIONS

1. The normal force, pitching moment and axial force measurements provide a data base that will be useful in evaluating computational results for nonaxisymmetric projectile shapes.
2. Comparisons of the side force and yawing moment data with computations should be made with reservation due to the unknown effects of bearing friction.
3. The shorter ( $L/d = 6$ ) semicorkscrew shape is considerably more stable than a typical axisymmetric shape but is not noticeably more stable than a nonconical boattail shape of comparable length. Instability of the semicorkscrew shape increases with increasing length.



Figure 1. Projectile Photographs

a. Semicorkcrew Model



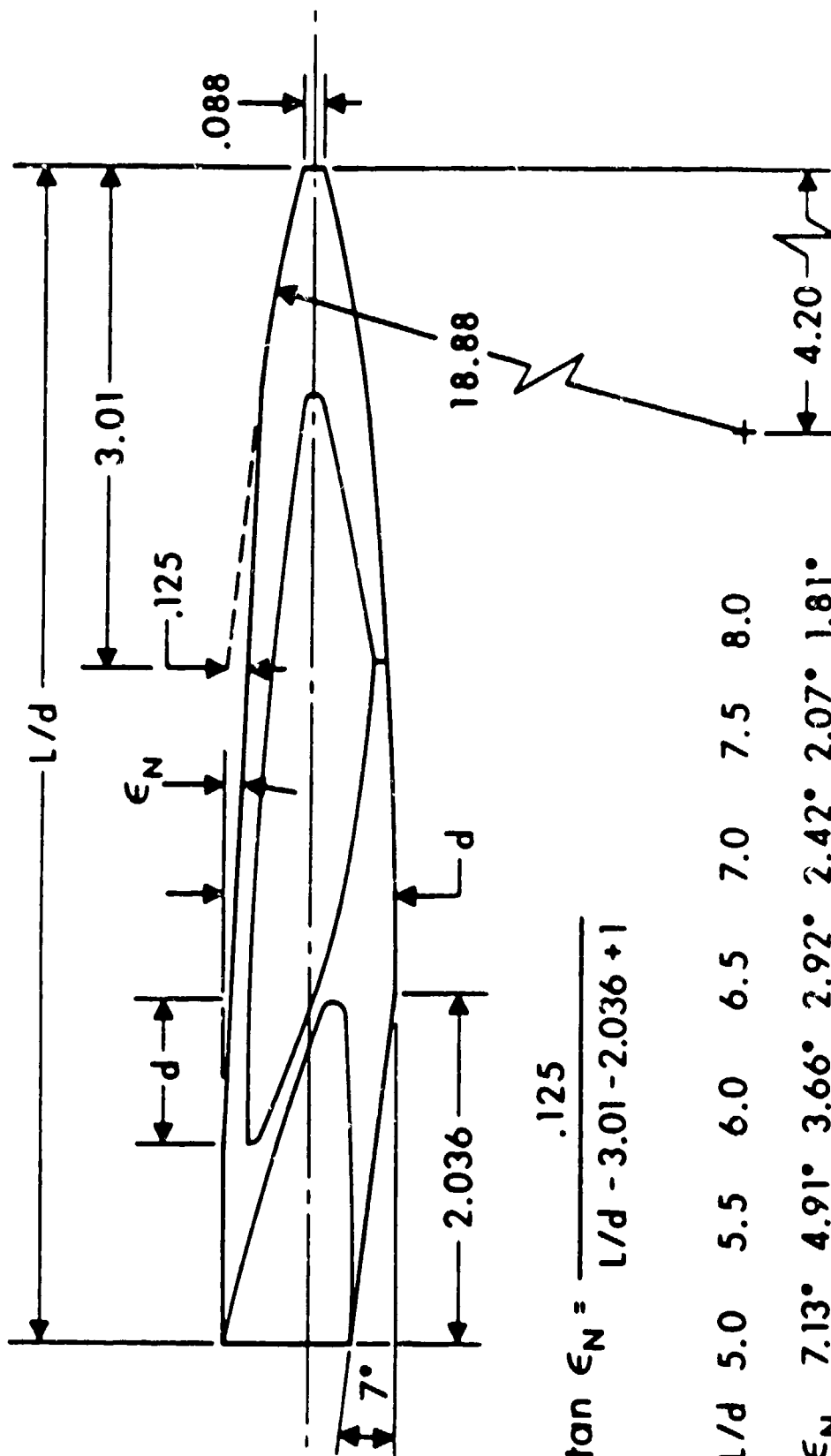
NONCONICAL BOATTAIL



CORKSCREW

Figure 1. Continued

b. Nonconical Boattail and Corkscrew Shapes



$$\tan \epsilon_N = \frac{.125}{L/d - 3.01 - 2.036 + 1}$$

Figure 2. Semicorkscre Geometry

# SEMICORKSCREW

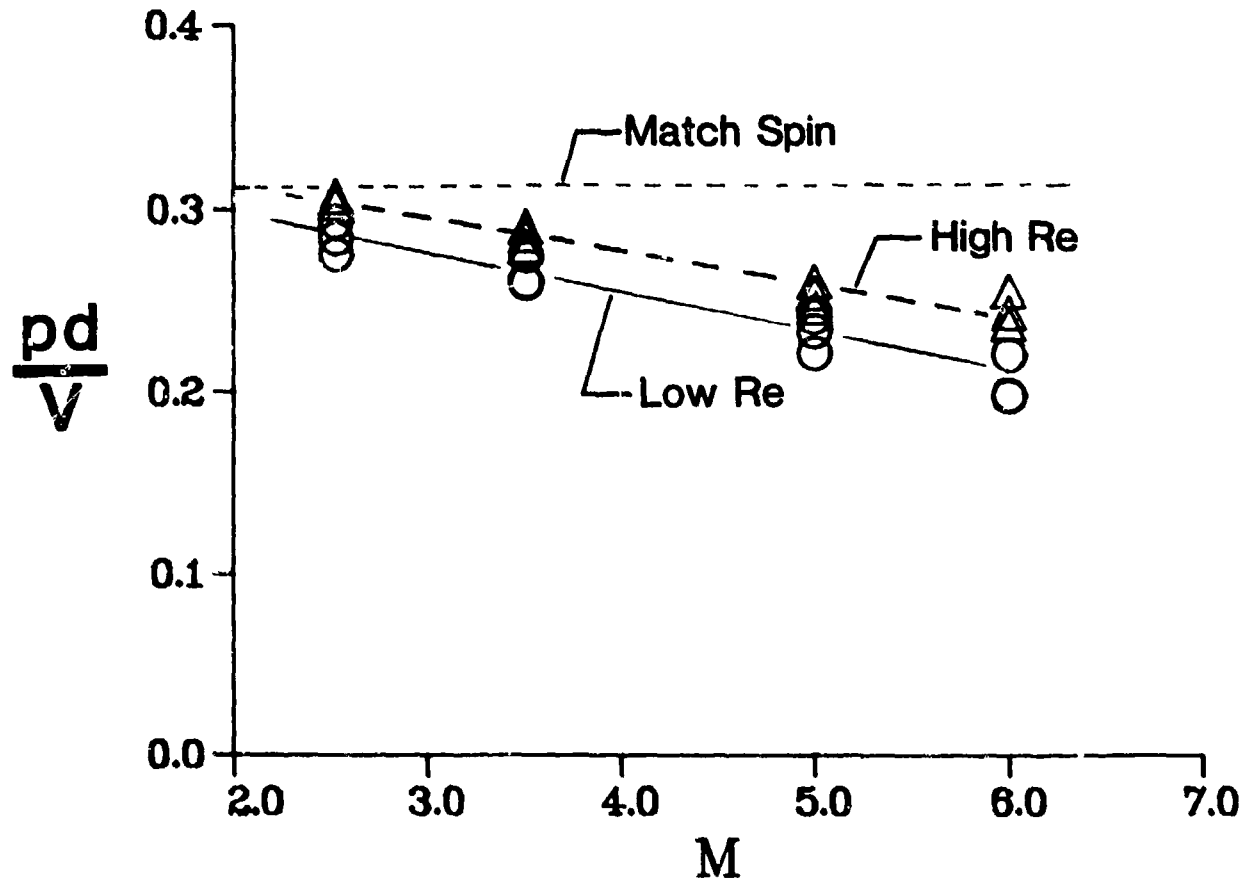


Figure 3. Dimensionless Spin Rate,  $pd/V$ ,  $\alpha = 0$

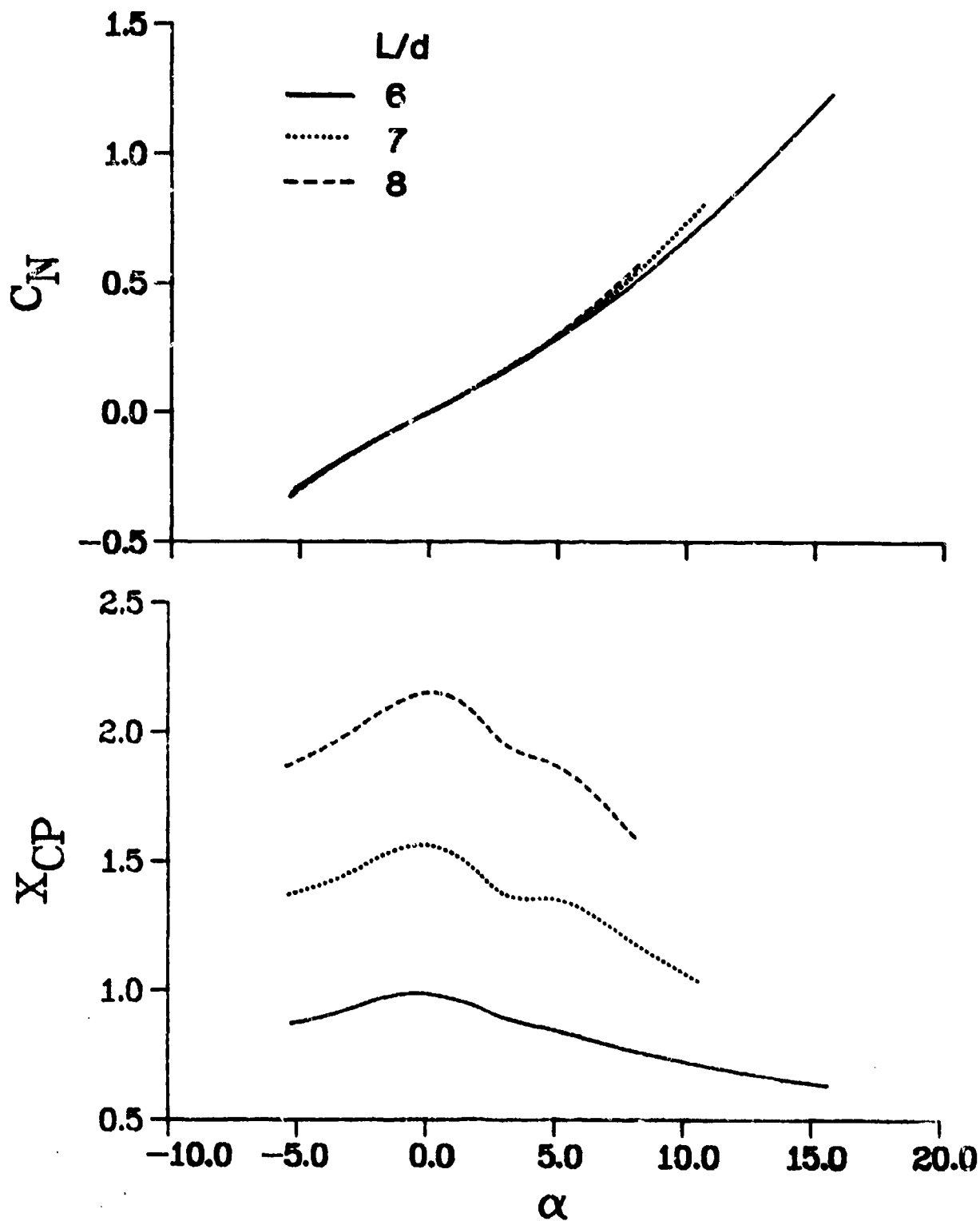


Figure 4. Static Stability

a.  $C_N$  and  $X_{CP}$  vs  $\alpha$ ,  $M = 2.53$ ,  $P_0 = 172$  kPa

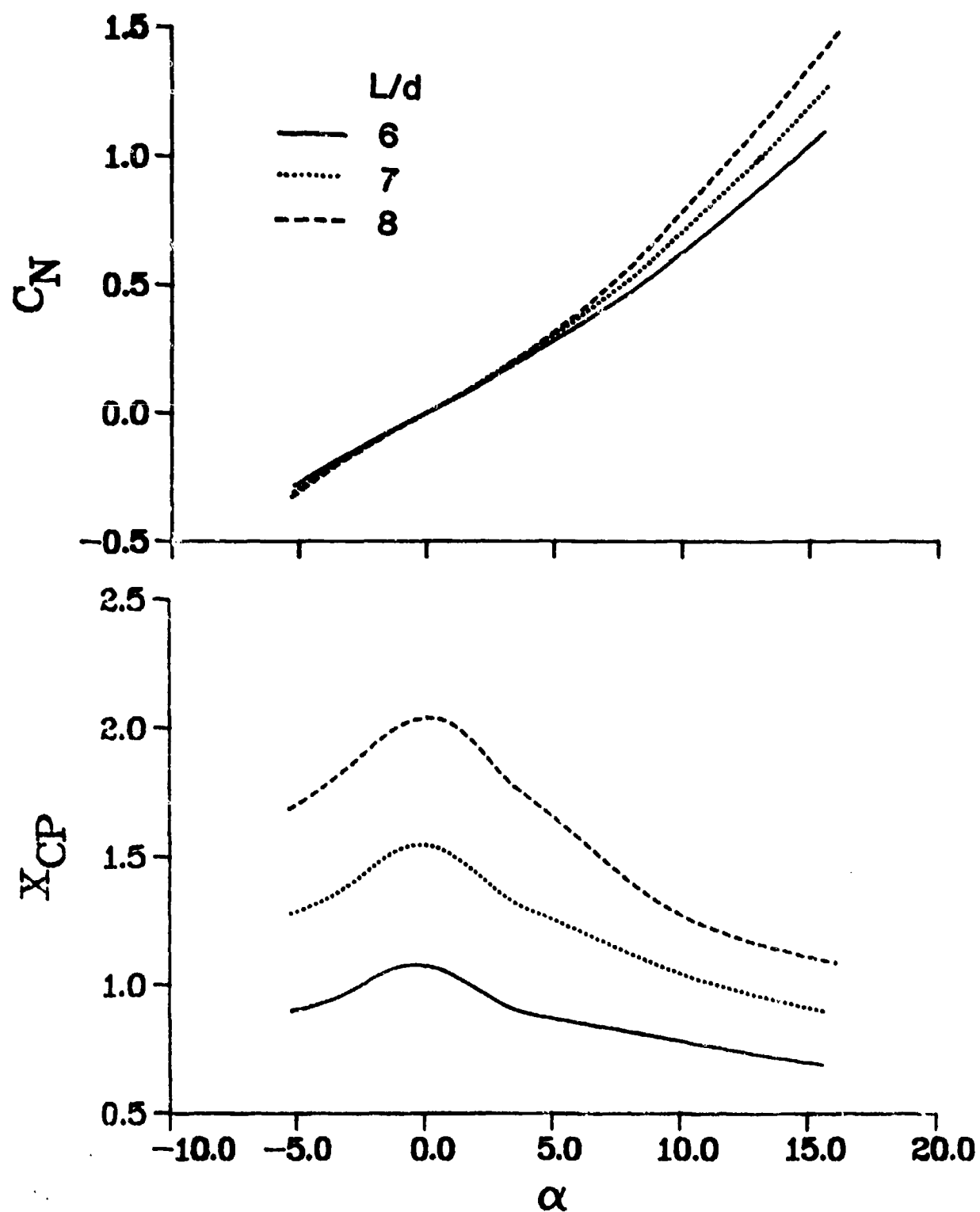


Figure 4. Continued

b.  $C_N$  and  $X_{CP}$  vs  $\alpha$ ,  $M = 3.51$ ,  $P_0 = 276$  kPa

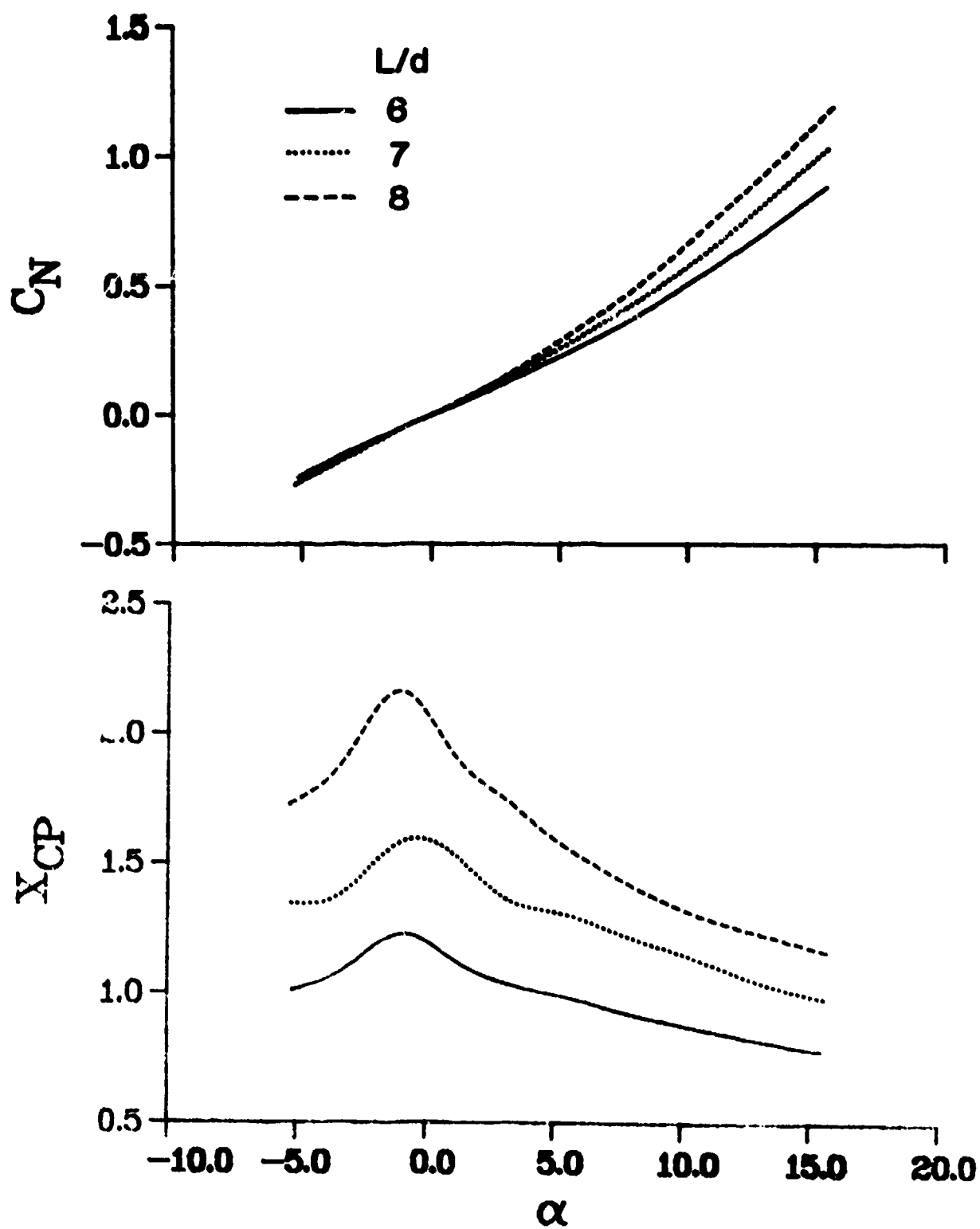


Figure 4. Continued

c.  $C_N$  and  $X_{CP}$  vs  $\alpha$ ,  $M = 5.00$ ,  $P_0 = 827$  kPa

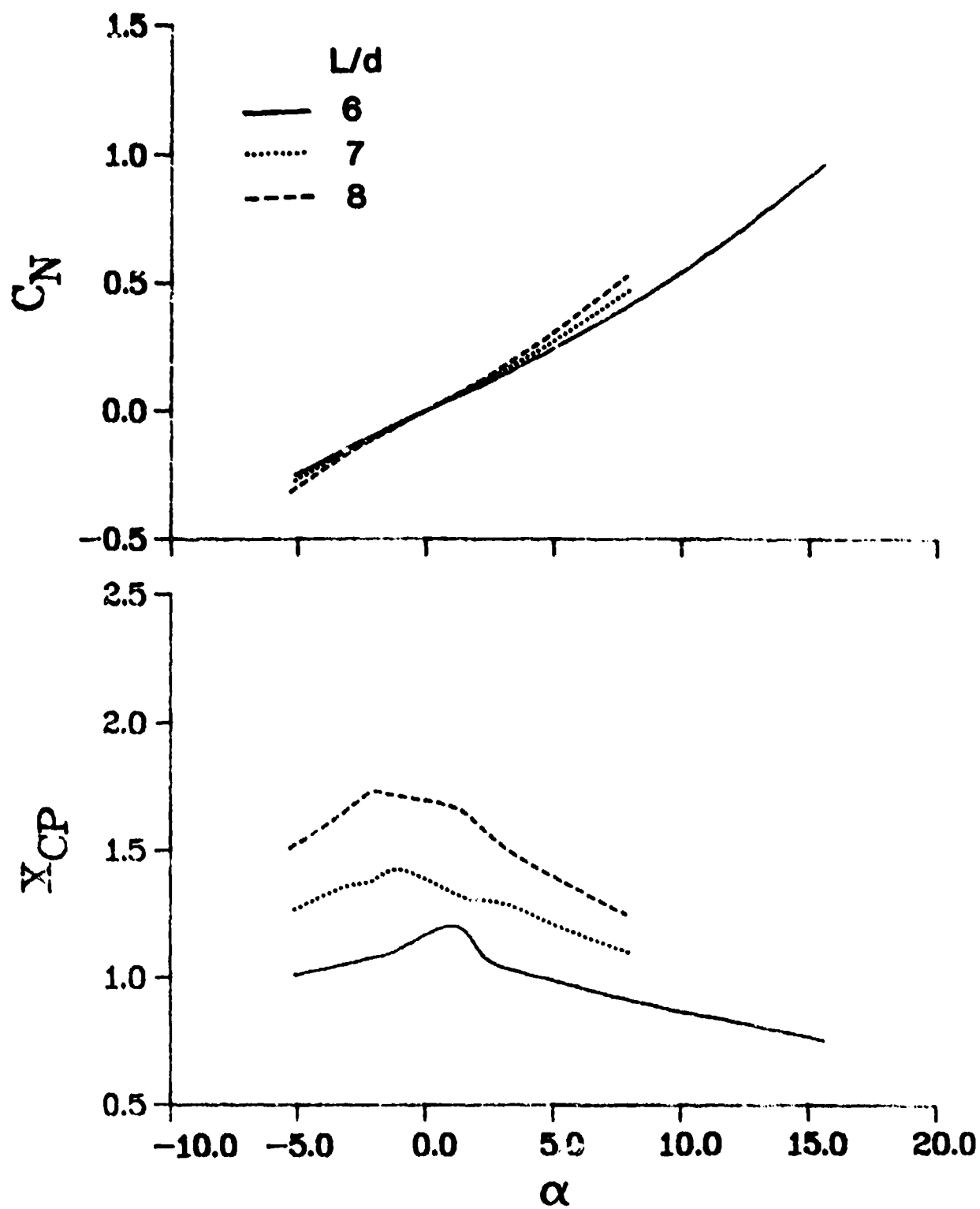


Figure 4. Continued

d.  $C_N$  and  $X_{CP}$  vs  $\alpha$ ,  $M = 6.00$ ,  $P_0 = 1931$  kPa

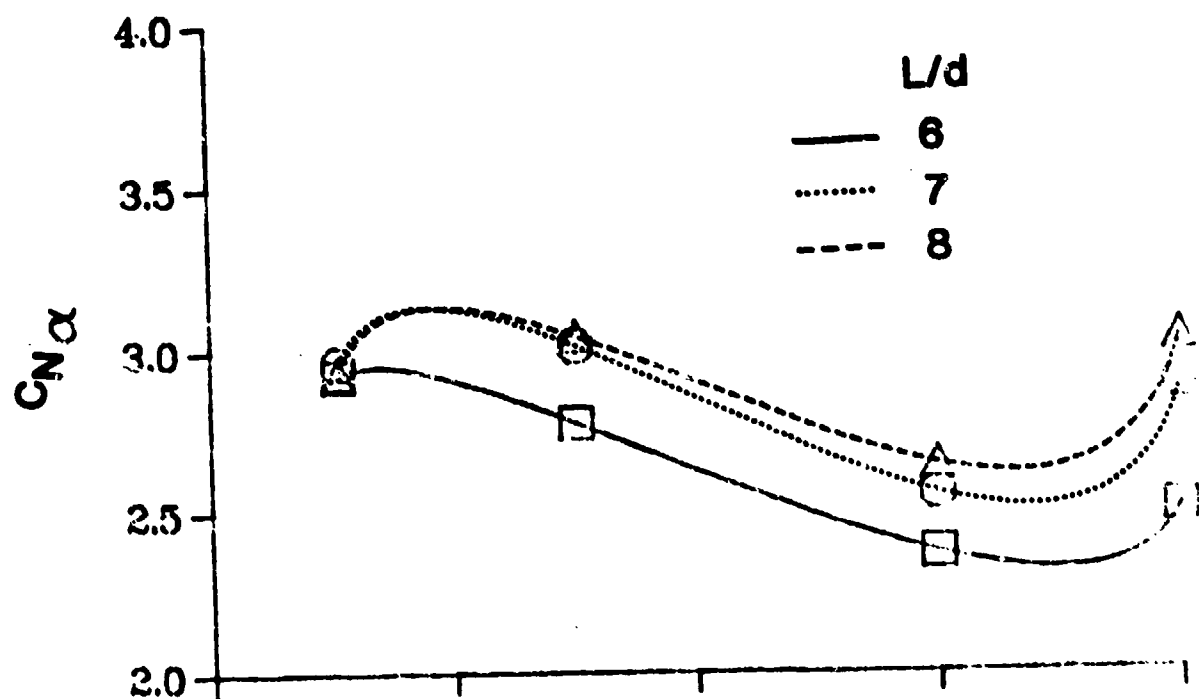


Figure 4. Continued

e.  $C_{N\alpha}$  vs M

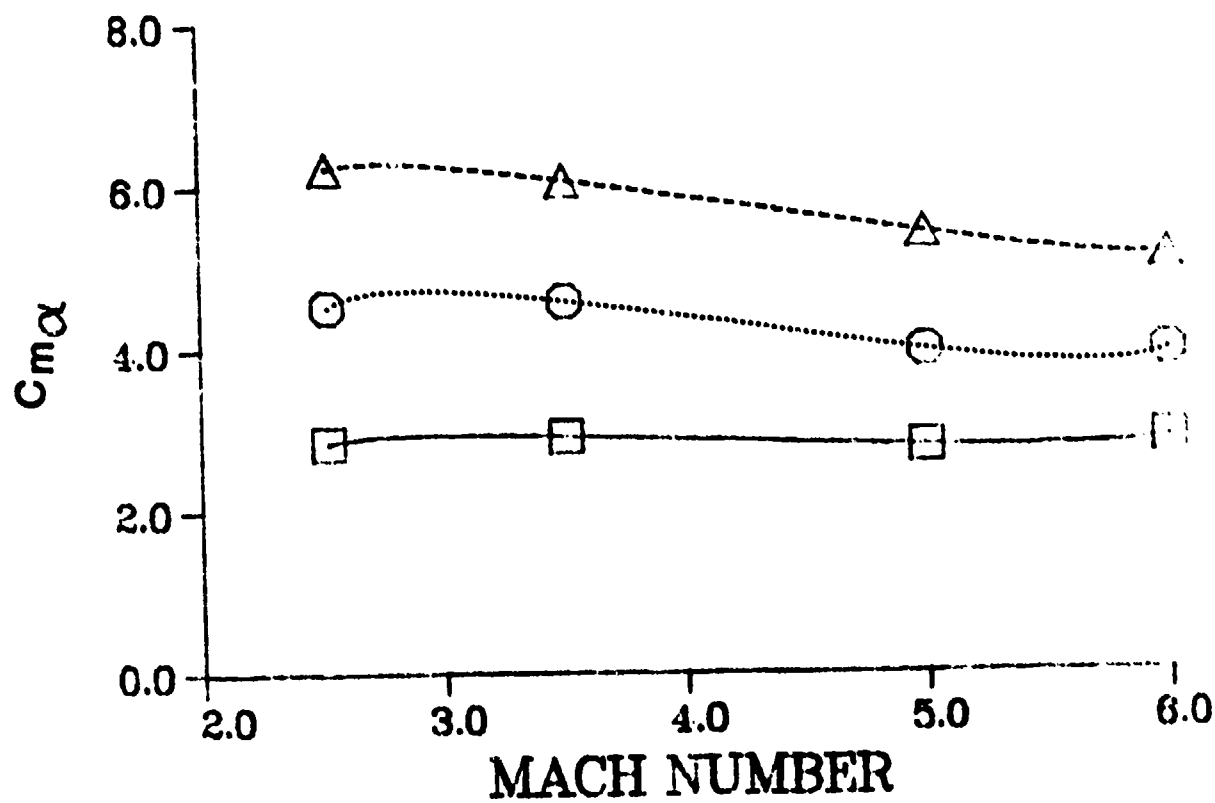


Figure 4. Continued

f.  $C_{m\alpha}$  vs M

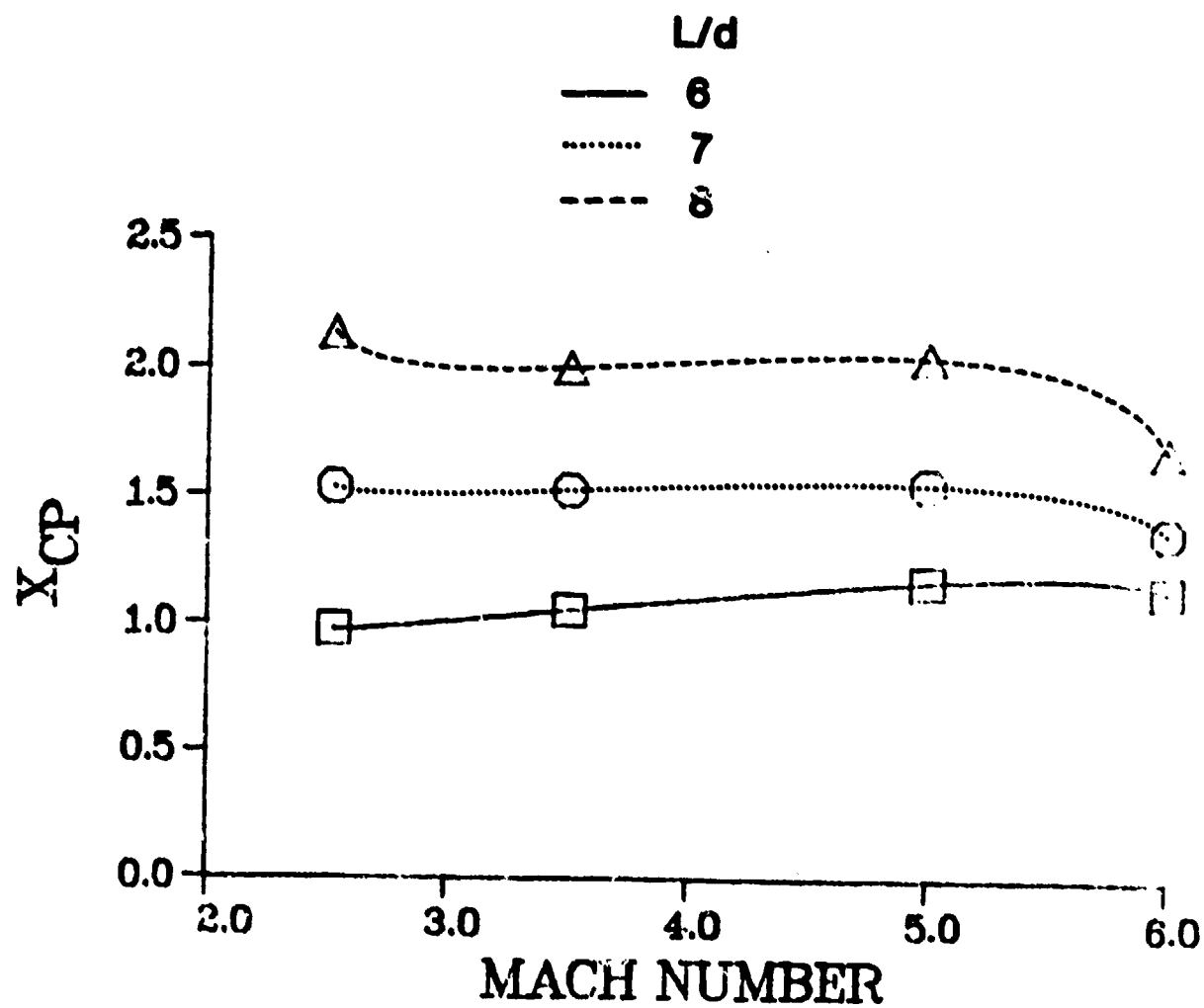


Figure 4. Continued

g.  $X_{cp}$  vs M

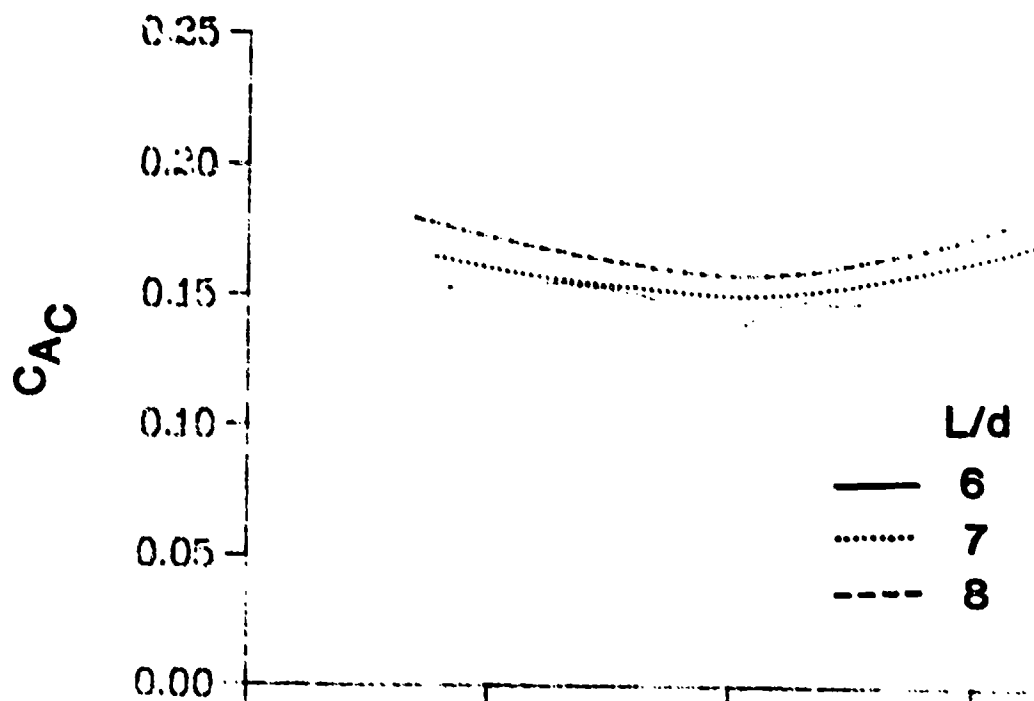


Figure 5. Axial Force  
a.  $M = 2.53$ ,  $P_0 = 172$  kPa

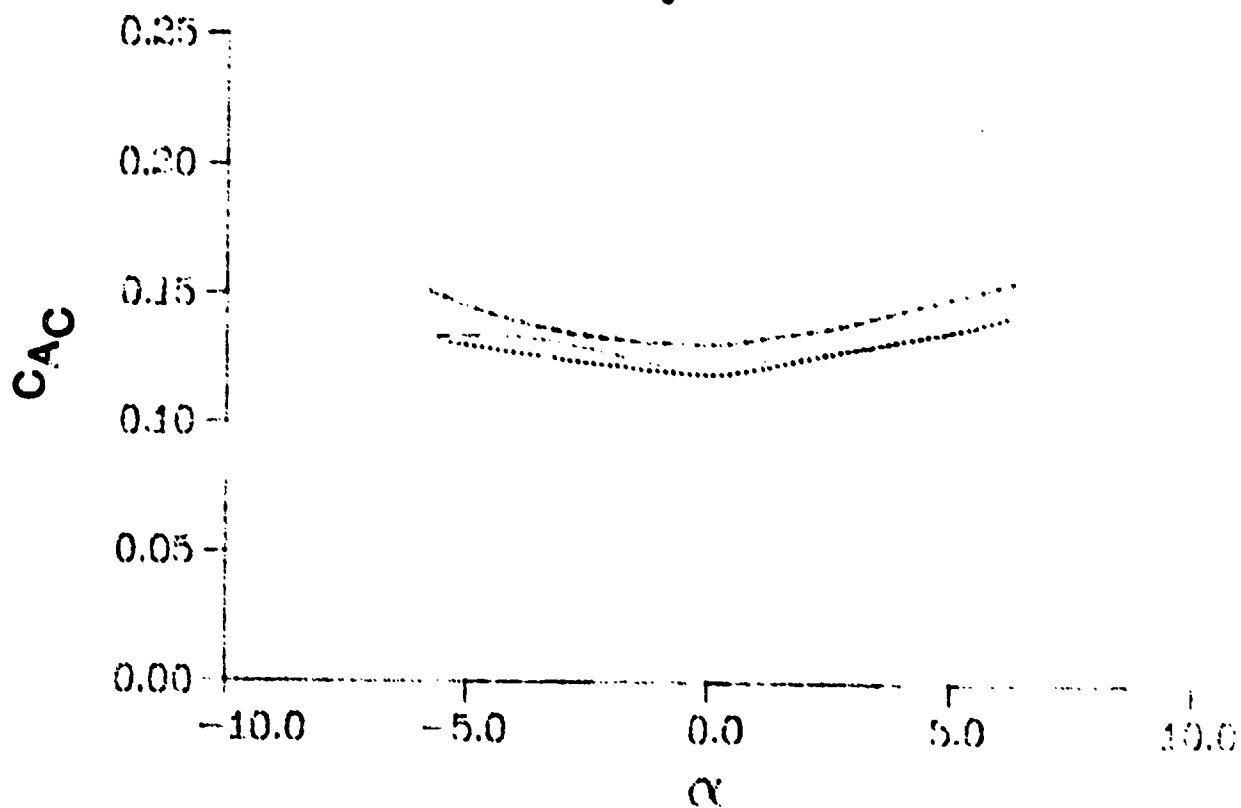


Figure 5. Continued  
b.  $M = 3.51$ ,  $P_0 = 276$  kPa

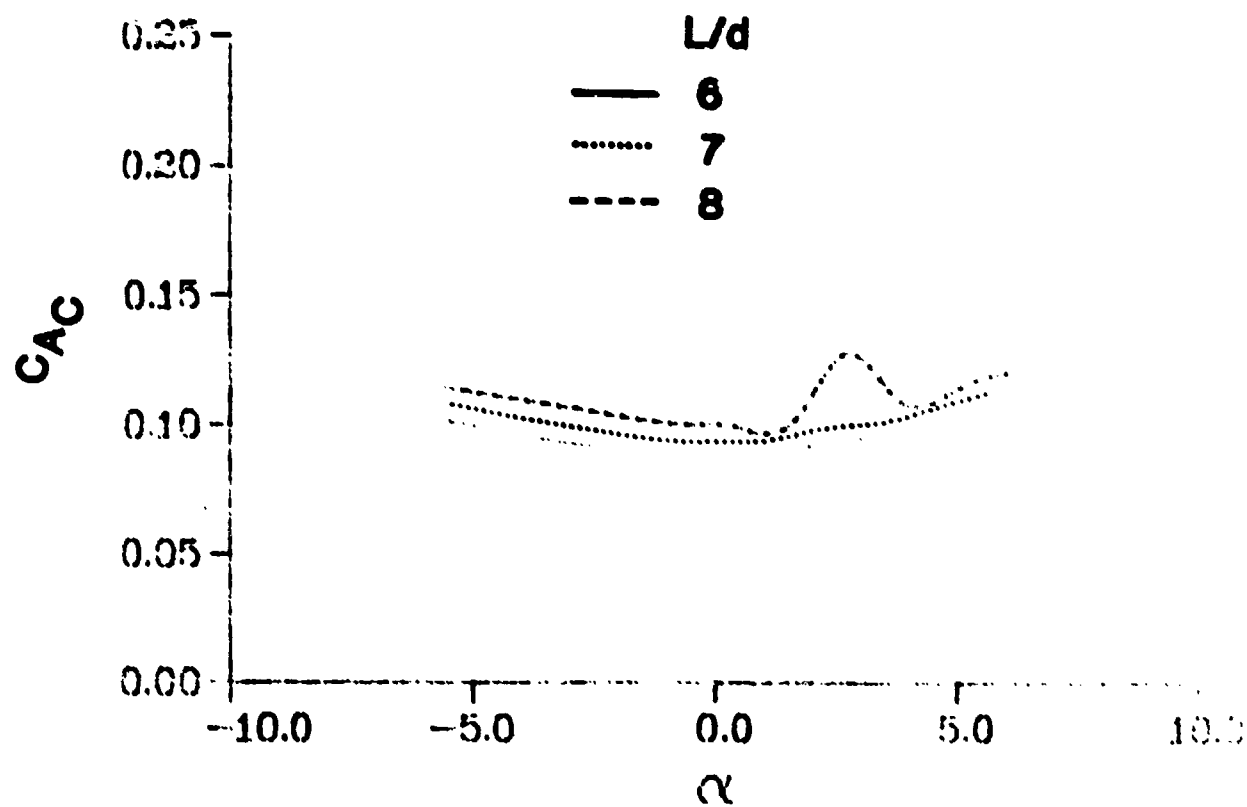


Figure 5. Continued  
c.  $M = 5.00$ ,  $P_0 = 827$  kPa

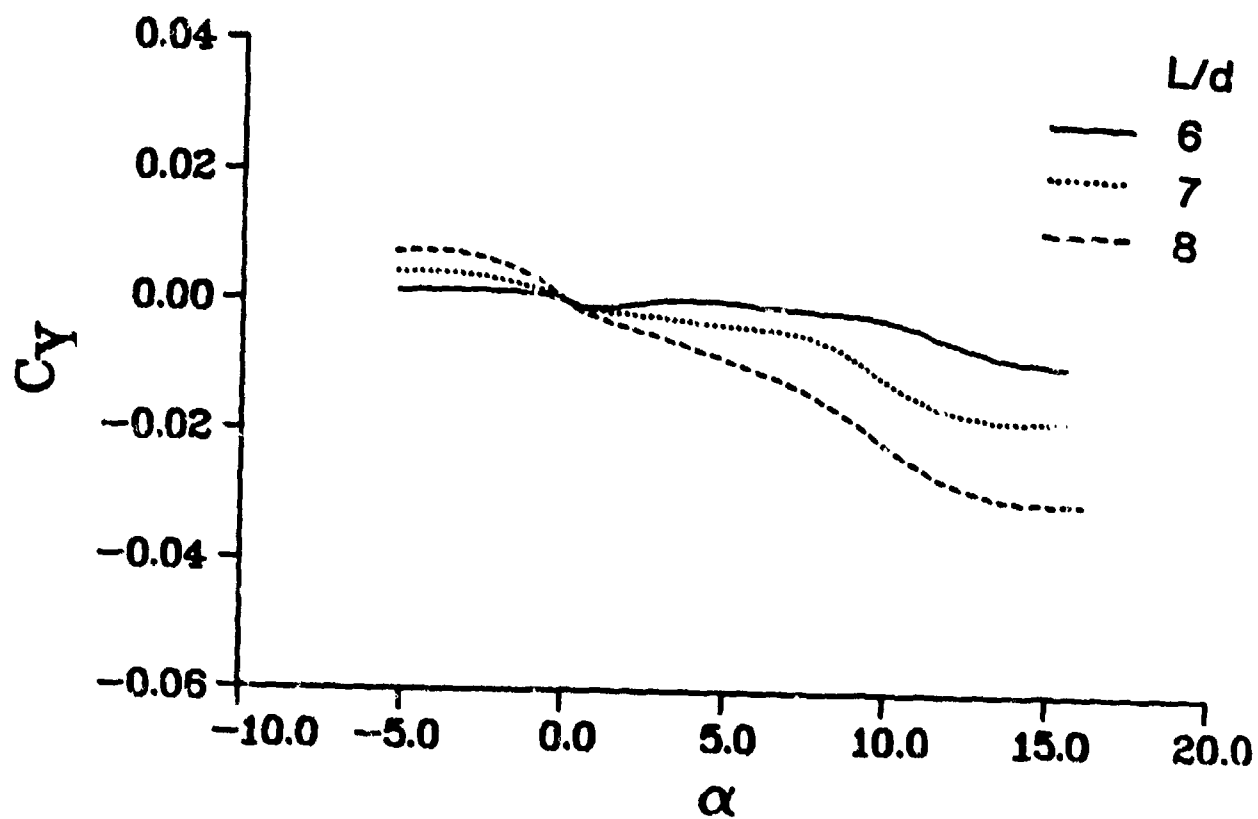


Figure 6. Lateral Forces and Moments

a.  $C_y$  vs  $\alpha$

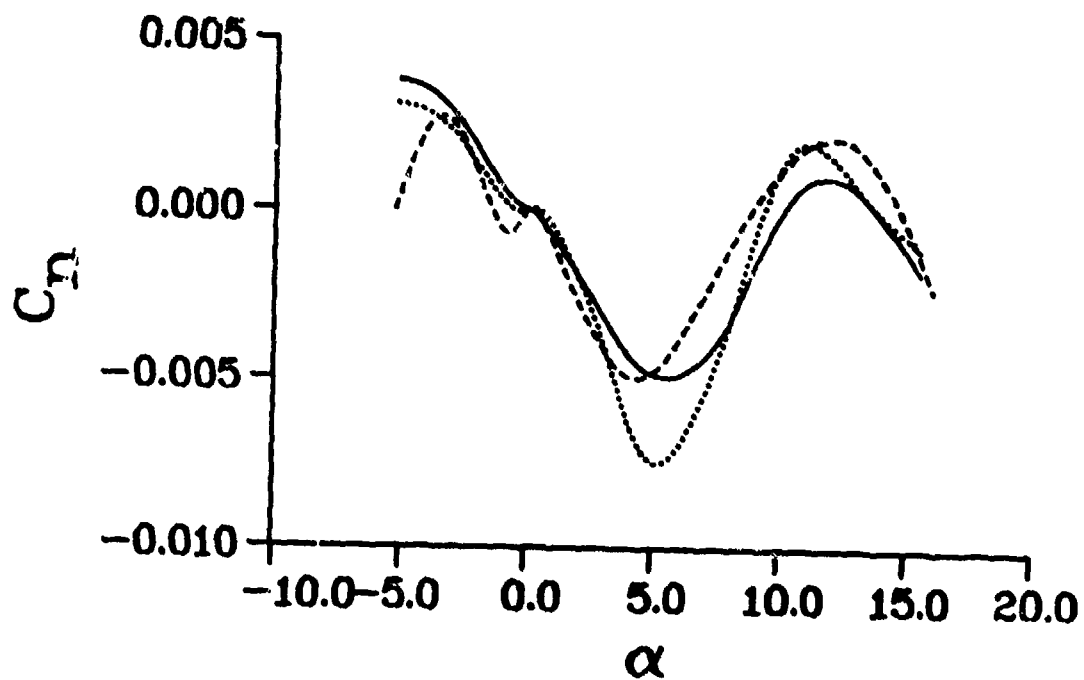


Figure 6. Continued

b.  $C_n$  vs  $\alpha$

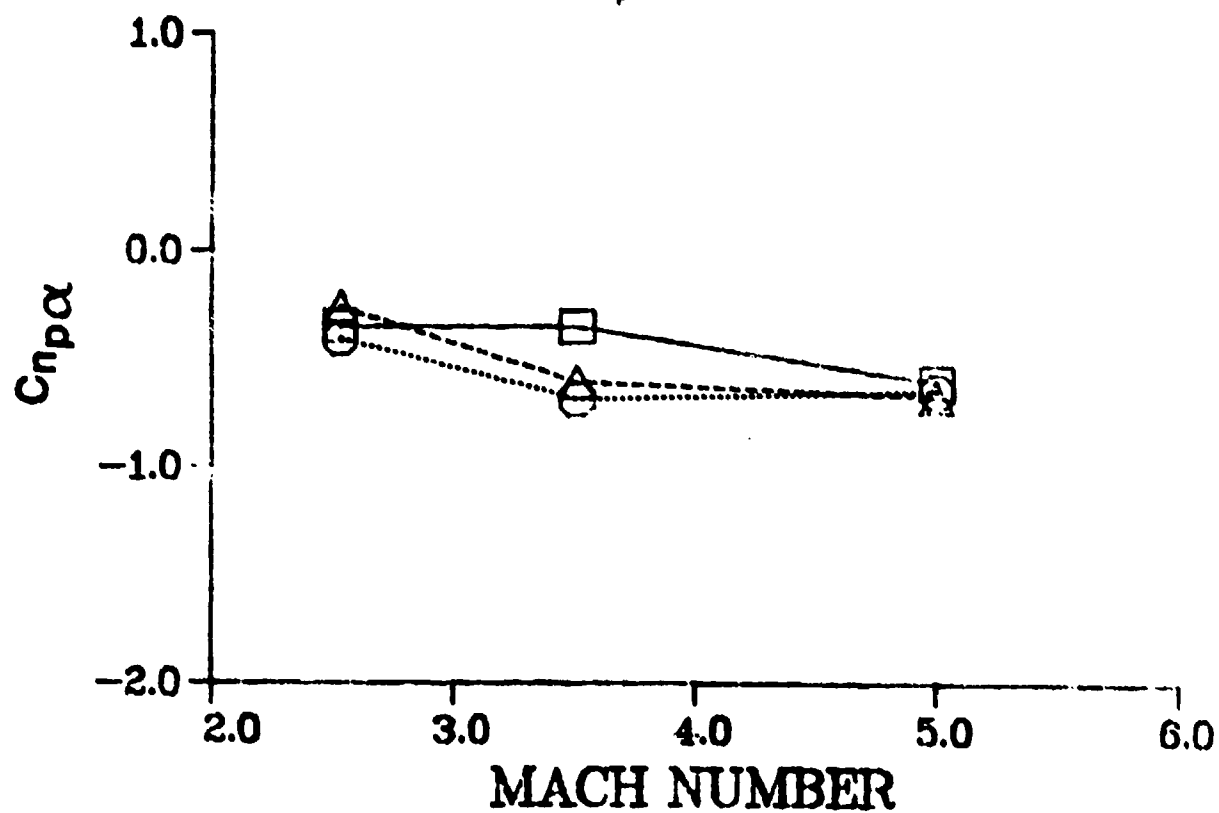
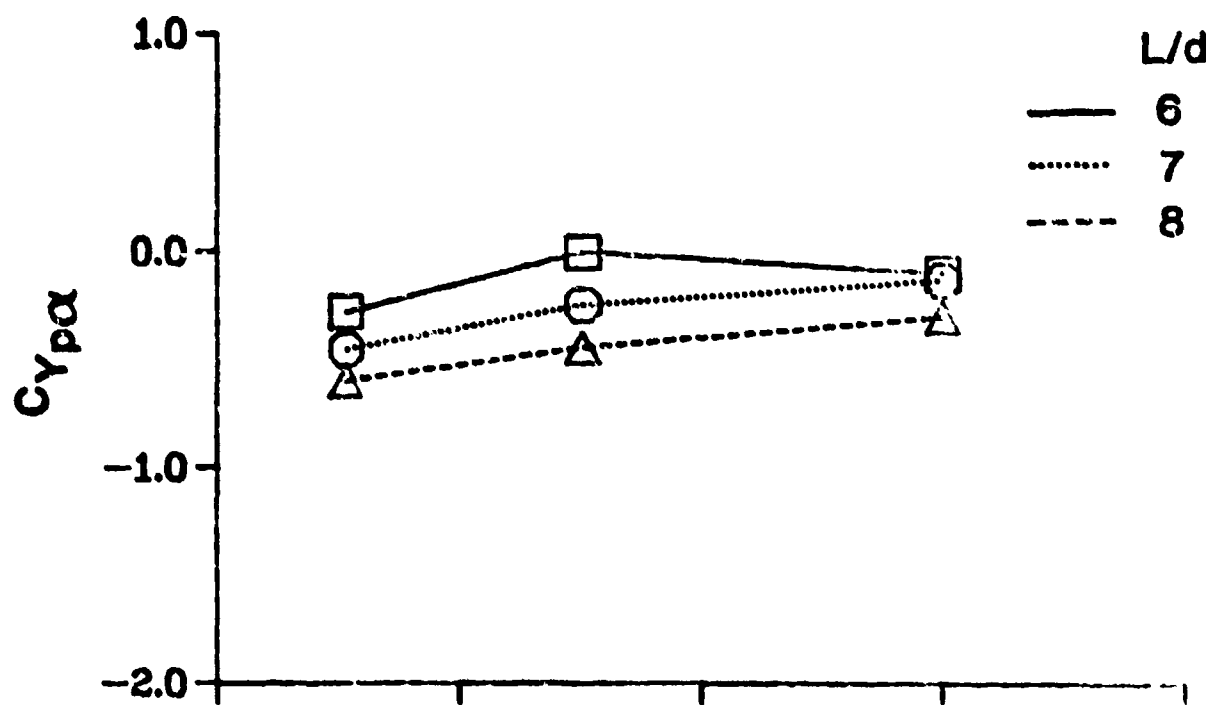


Figure 6. Continued

d.  $C_{n\alpha}$  vs M

TABLE 1. TEST RUN SUMMARY

| M    | L/d | $Re_x \times 10^6$ | $P_{01}$ kPA | $T_{01}$ K | $\alpha$ , deg | balance |
|------|-----|--------------------|--------------|------------|----------------|---------|
| 2.53 | 6   | 6.3                | 172          | 294        | -5 to 15       | NSWC    |
|      | 7   | 7.3                |              |            | -5 to 10       |         |
|      | 8   | 8.3                |              |            | -5 to 8        |         |
| 3.51 | 6   | 6.3                | 276          | 294        | -5 to 15       |         |
|      | 7   | 7.3                |              |            |                |         |
|      | 8   | 8.3                |              |            |                |         |
| 5.00 | 6   | 6.3                | 827          | 367        | -5 to 15       |         |
|      | 7   | 7.3                |              |            |                |         |
|      | 8   | 8.3                |              |            |                |         |
| 6.00 | 6   | 6.3                | 1931         | 478        | -5 to 15       |         |
|      | 7   | 7.3                |              |            | -5 to 7.5      |         |
|      | 8   | 8.3                |              |            | -5 to 7.5      |         |
| 2.53 | 6   | 11.3               | 310          | 294        | -3 to 10       |         |
|      | 7   | 13.1               |              |            | -3 to 9        |         |
|      | 8   | 15.0               |              |            | -3 to 9        |         |
| 3.51 | 6   | 11.3               | 517          | 294        | -5 to 15       |         |
|      | 7   | 13.1               |              |            | -5 to 13       |         |
|      | 8   | 15.0               |              |            | -5 to 10       |         |
| 5.00 | 6   | 11.3               | 1517         | 367        | -5 to 15       |         |
|      | 7   | 13.1               |              |            | -5 to 15       |         |
|      | 8   | 15.0               |              |            | -5 to 10       |         |
| 6.00 | 6   | 11.3               | 3448         | 478        | -5 to 10       |         |
|      | 7   | 13.1               |              |            | -5 to 7.5      |         |
|      | 8   | 15.0               |              |            | -5 to 7.5      |         |
| 2.53 | 6   | 6.3                | 172          | 294        | -5 to 5        | BRL     |
|      | 7   | 7.3                |              |            |                |         |
|      | 8   | 8.3                |              |            |                |         |
| 3.51 | 6   | 6.3                | 276          | 294        | -5 to 5        |         |
|      | 7   | 7.3                |              |            |                |         |
|      | 8   | 8.3                |              |            |                |         |
| 5.00 | 6   | 6.3                | 827          | 367        | -5 to 5        |         |
|      | 7   | 7.3                |              |            |                |         |
|      | 8   | 8.3                |              |            |                |         |

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**APPENDIX A**

**TABULATED DATA**

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|----------------------------------------------|-------------|
| M = 2.53, Low Re.....                        | 32          |
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| L/D | H    | RE-06 | ALPFA | PD/V  | HFC    | PI'C   | SFC     | YIC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 2.53 | 6.25  | -5.20 | 0.281 | -0.293 | -0.256 | 0.0046  | 0.0028  | 0.87 |
| 6   | 2.53 | 6.38  | -3.25 | 0.284 | -0.173 | -0.159 | 0.0036  | 0.0030  | 0.92 |
| 6   | 2.53 | 6.30  | -1.09 | 0.276 | -0.054 | -0.053 | 0.0017  | 0.0012  | 0.98 |
| 3   | 2.53 | 6.38  | 0.01  | 0.275 | 0.001  | 0.001  | 0.0000  | 0.0000  |      |
| 6   | 2.53 | 6.38  | 1.07  | 0.277 | 0.056  | 0.054  | -0.0020 | -0.0013 | 0.97 |
| 6   | 2.53 | 6.50  | 3.17  | 0.284 | 0.171  | 0.153  | -0.0042 | -0.0041 | 0.89 |
| 6   | 2.53 | 6.50  | 5.26  | 0.297 | 0.306  | 0.257  | -0.0050 | -0.0082 | 0.84 |
| 6   | 2.53 | 6.38  | 7.85  | 0.305 | 0.493  | 0.381  | -0.0056 | -0.0106 | 0.77 |
| 6   | 2.53 | 6.38  | 10.48 | 0.305 | 0.717  | 0.514  | -0.0067 | -0.0094 | 0.72 |
| 6   | 2.53 | 6.38  | 13.16 | 0.304 | 0.971  | 0.650  | -0.0109 | -0.0045 | 0.67 |
| 6   | 2.53 | 6.38  | 15.65 | 0.308 | 1.232  | 0.781  | -0.0134 | -0.0052 | 0.63 |
| 7   | 2.53 | 7.58  | -5.30 | 0.292 | -0.309 | -0.424 | 0.0081  | -0.0006 | 1.37 |
| 7   | 2.53 | 7.58  | -3.15 | 0.295 | -0.172 | -0.248 | 0.0062  | 0.0021  | 1.44 |
| 7   | 2.53 | 7.44  | -1.04 | 0.289 | -0.053 | -0.082 | 0.0026  | 0.0005  | 1.55 |
| 7   | 2.53 | 7.58  | 0.04  | 0.284 | 0.002  | 0.003  | -0.0001 | 0.0000  |      |
| 7   | 2.53 | 7.58  | 1.11  | 0.284 | 0.058  | 0.088  | -0.0031 | -0.0008 | 1.53 |
| 7   | 2.53 | 7.58  | 3.18  | 0.286 | 0.180  | 0.246  | -0.0073 | -0.0037 | 1.37 |
| 7   | 2.53 | 7.58  | 5.30  | 0.297 | 0.318  | 0.428  | -0.0107 | -0.0045 | 1.35 |
| 7   | 2.53 | 7.58  | 7.98  | 0.308 | 0.536  | 0.639  | -0.0155 | -0.0036 | 1.19 |
| 7   | 2.53 | 7.58  | 10.64 | 0.310 | 0.803  | 0.831  | -0.0214 | 0.0011  | 1.03 |
| 8   | 2.53 | 8.67  | -5.38 | 0.301 | -0.322 | -0.601 | 0.0134  | -0.0063 | 1.87 |
| 8   | 2.53 | 8.50  | -3.22 | 0.304 | -0.177 | -0.349 | 0.0086  | 0.0003  | 1.96 |
| 8   | 2.53 | 8.67  | -1.07 | 0.299 | -0.055 | -0.116 | 0.0042  | -0.0006 | 2.11 |
| 8   | 2.53 | 8.67  | 0.07  | 0.293 | 0.004  | 0.008  | -0.0003 | 0.0000  |      |
| 8   | 2.53 | 8.67  | 1.10  | 0.294 | 0.056  | 0.120  | -0.0040 | 0.0007  | 2.13 |
| 8   | 2.53 | 8.67  | 3.22  | 0.299 | 0.180  | 0.350  | -0.0100 | -0.0020 | 1.95 |
| 8   | 2.53 | 8.67  | 5.40  | 0.306 | 0.331  | 0.613  | -0.0174 | -0.0039 | 1.85 |
| 8   | 2.53 | 8.67  | 8.23  | 0.316 | 0.582  | 0.922  | -0.0278 | 0.0026  | 1.58 |

| L/D | M    | RE-06 | ALPHA | PD/V  | NFC    | PHC    | SFC     | YIC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 3.51 | 6.50  | -5.15 | 0.291 | -0.279 | -0.252 | 0.0013  | 0.0038  | 0.90 |
| 6   | 3.51 | 6.50  | -3.12 | 0.288 | -0.160 | -0.154 | 0.0015  | 0.0030  | 0.97 |
| 6   | 3.51 | 6.38  | -1.03 | 0.279 | -0.050 | -0.053 | 0.0010  | 0.0007  | 1.07 |
| 6   | 3.51 | 6.50  | 0.03  | 0.275 | 0.001  | 0.002  | 0.0000  | 0.0000  | 1.04 |
| 6   | 3.51 | 6.50  | 1.06  | 0.274 | 0.051  | 0.053  | -0.0011 | -0.0008 | 0.93 |
| 6   | 3.51 | 6.50  | 3.11  | 0.280 | 0.166  | 0.154  | 0.0001  | -0.0032 | 0.87 |
| 6   | 3.51 | 6.50  | 5.18  | 0.287 | 0.292  | 0.254  | -0.0001 | -0.0049 | 0.82 |
| 6   | 3.51 | 6.50  | 7.79  | 0.292 | 0.459  | 0.379  | -0.0012 | -0.0036 | 0.78 |
| 6   | 3.51 | 6.50  | 10.32 | 0.292 | 0.650  | 0.505  | -0.0029 | 0.0003  | 0.73 |
| 6   | 3.51 | 6.50  | 12.95 | 0.292 | 0.864  | 0.633  | -0.0073 | 0.0007  | 0.69 |
| 6   | 3.51 | 6.50  | 15.58 | 0.293 | 1.095  | 0.758  | -0.0094 | -0.0018 |      |
| 7   | 3.51 | 7.44  | -5.20 | 0.272 | -0.305 | -0.390 | 0.0042  | 0.0031  | 1.28 |
| 7   | 3.51 | 7.44  | -3.13 | 0.272 | -0.172 | -0.236 | 0.0039  | 0.0024  | 1.38 |
| 7   | 3.51 | 7.44  | -1.00 | 0.264 | -0.052 | -0.080 | 0.0019  | 0.0003  | 1.53 |
| 7   | 3.51 | 7.58  | 0.04  | 0.259 | 0.002  | 0.003  | -0.0001 | 0.0000  | 1.51 |
| 7   | 3.51 | 7.58  | 1.04  | 0.259 | 0.055  | 0.083  | -0.0015 | -0.0005 | 1.35 |
| 7   | 3.51 | 7.44  | 3.13  | 0.264 | 0.179  | 0.242  | -0.0026 | -0.0041 | 1.25 |
| 7   | 3.51 | 7.58  | 5.24  | 0.273 | 0.320  | 0.399  | -0.0037 | -0.0075 | 1.13 |
| 7   | 3.51 | 7.44  | 7.97  | 0.279 | 0.525  | 0.591  | -0.0058 | -0.0035 | 1.03 |
| 7   | 3.51 | 7.44  | 10.42 | 0.283 | 0.744  | 0.766  | -0.0132 | 0.0018  | 0.96 |
| 7   | 3.51 | 7.44  | 13.08 | 0.286 | 0.995  | 0.953  | -0.0175 | 0.0007  | 0.90 |
| 7   | 3.51 | 7.58  | 15.72 | 0.287 | 1.273  | 1.142  | -0.0177 | -0.0012 |      |
| 8   | 3.51 | 8.17  | -5.27 | 0.261 | -0.325 | -0.549 | 0.0073  | 0.0000  | 1.69 |
| 8   | 3.51 | 8.17  | -3.17 | 0.265 | -0.180 | -0.329 | 0.0071  | 0.0027  | 1.83 |
| 8   | 3.51 | 8.33  | -1.09 | 0.263 | -0.059 | -0.117 | 0.0038  | -0.0005 | 2.00 |
| 8   | 3.51 | 8.33  | -0.03 | 0.260 | -0.002 | -0.003 | 0.0001  | 0.0000  |      |
| 8   | 3.51 | 8.33  | 1.08  | 0.260 | 0.056  | 0.113  | -0.0028 | -0.0011 | 2.02 |
| 8   | 3.51 | 8.33  | 3.13  | 0.265 | 0.181  | 0.328  | -0.0058 | -0.0042 | 1.82 |
| 8   | 3.51 | 8.33  | 5.31  | 0.275 | 0.337  | 0.553  | -0.0094 | -0.0046 | 1.64 |
| 8   | 3.51 | 8.33  | 6.01  | 0.284 | 0.576  | 0.810  | -0.0150 | -0.0011 | 1.41 |
| 8   | 3.51 | 8.50  | 10.61 | 0.291 | 0.840  | 1.05   | -0.0239 | 0.0017  | 1.25 |
| 8   | 3.51 | 8.33  | 13.37 | 0.292 | 1.156  | 1.332  | -0.0296 | 0.0017  | 1.15 |
| 8   | 3.51 | 8.33  | 16.11 | 0.293 | 1.479  | 1.605  | -0.0304 | -0.0023 | 1.09 |

| L/D | M    | RE-06 | ALPHA | PD/V  | NFC    | PMC    | SFC     | YMC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 5.00 | 7.13  | -5.13 | 0.240 | -0.239 | -0.242 | 0.0020  | 0.0029  | 1.01 |
| 6   | 5.00 | 7.25  | -3.10 | 0.242 | -0.137 | -0.150 | 0.0014  | 0.0038  | 1.09 |
| 6   | 5.00 | 7.38  | -1.01 | 0.237 | -0.043 | -0.053 | 0.0006  | 0.0008  | 1.23 |
| 6   | 5.00 | 7.25  | 0.01  | 0.233 | 0.000  | 0.001  | 0.0000  | 0.0000  |      |
| 6   | 5.00 | 7.38  | 1.07  | 0.234 | 0.043  | 0.048  | -0.0009 | -0.0006 | 1.13 |
| 6   | 5.00 | 7.38  | 3.17  | 0.239 | 0.138  | 0.143  | -0.0009 | -0.0021 | 1.03 |
| 6   | 5.00 | 7.38  | 5.15  | 0.243 | 0.231  | 0.230  | -0.0009 | -0.0005 | 0.99 |
| 6   | 5.00 | 7.38  | 7.75  | 0.246 | 0.368  | 0.341  | -0.0046 | 0.0035  | 0.93 |
| 6   | 5.00 | 7.38  | 10.25 | 0.250 | 0.524  | 0.459  | -0.0099 | 0.0063  | 0.88 |
| 6   | 5.00 | 7.25  | 12.85 | 0.258 | 0.697  | 0.575  | -0.0105 | 0.0074  | 0.83 |
| 6   | 5.00 | 7.25  | 15.45 | 0.263 | 0.883  | 0.691  | -0.0113 | 0.0096  | 0.78 |
| 7   | 5.00 | 8.31  | -5.21 | 0.226 | -0.264 | -0.354 | 0.0005  | 0.0021  | 1.34 |
| 7   | 5.00 | 8.31  | -3.22 | 0.228 | -0.160 | -0.222 | 0.0017  | 0.0027  | 1.39 |
| 7   | 5.00 | 8.31  | -1.09 | 0.225 | -0.048 | -0.075 | 0.0012  | -0.0001 | 1.58 |
| 7   | 5.00 | 8.46  | -0.02 | 0.221 | -0.001 | -0.001 | 0.0000  | 0.0000  |      |
| 7   | 5.00 | 8.31  | 1.02  | 0.220 | 0.046  | 0.071  | -0.0010 | 0.0005  | 1.54 |
| 7   | 5.00 | 8.31  | 3.08  | 0.224 | 0.154  | 0.210  | -0.0014 | -0.0061 | 1.37 |
| 7   | 5.00 | 8.17  | 5.15  | 0.22  | 0.264  | 0.347  | -0.0010 | -0.0027 | 1.31 |
| 7   | 5.00 | 8.17  | 7.74  | 0.231 | 0.423  | 0.518  | -0.0058 | 0.0032  | 1.23 |
| 7   | 5.00 | 8.17  | 10.31 | 0.235 | 0.600  | 0.686  | -0.0108 | 0.0116  | 1.14 |
| 7   | 5.00 | 8.17  | 12.96 | 0.240 | 0.813  | 0.853  | -0.0154 | 0.0142  | 1.05 |
| 7   | 5.00 | 8.17  | 15.56 | 0.245 | 1.035  | 1.020  | -0.0154 | 0.0141  | 0.99 |
| 8   | 5.00 | 9.67  | -5.26 | 0.240 | -0.270 | -0.467 | 0.0034  | -0.0005 | 1.73 |
| 8   | 5.00 | 9.67  | -3.17 | 0.244 | -0.152 | -0.288 | 0.0040  | 0.0019  | 1.90 |
| 8   | 5.00 | 9.67  | -1.07 | 0.243 | -0.047 | -0.102 | 0.0015  | -0.0031 | 2.17 |
| 8   | 5.00 | 9.67  | 0.01  | 0.241 | 0.000  | 0.001  | 0.0000  | 0.0000  |      |
| 8   | 5.00 | 9.67  | 1.06  | 0.241 | 0.051  | 0.099  | -0.0024 | 0.0031  | 1.93 |
| 8   | 5.00 | 9.67  | 3.14  | 0.242 | 0.162  | 0.283  | -0.0039 | -0.0009 | 1.75 |
| 8   | 5.00 | 9.50  | 5.25  | 0.247 | 0.302  | 0.478  | -0.0017 | 0.0034  | 1.58 |
| 8   | 5.00 | 9.50  | 7.87  | 0.254 | 0.487  | 0.696  | -0.0049 | 0.0092  | 1.43 |
| 8   | 5.00 | 9.50  | 10.45 | 0.261 | 0.704  | 0.924  | -0.0105 | 0.0146  | 1.31 |
| 8   | 5.00 | 9.50  | 13.19 | 0.266 | 0.947  | 1.168  | -0.0142 | 0.0164  | 1.23 |
| 8   | 5.00 | 9.33  | 15.77 | 0.269 | 1.199  | 1.398  | -0.0164 | 0.0186  | 1.17 |

| L/D | H    | RE-06 | ALPHA | PD/V  | NFC    | PMC    | SFC     | YIC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 6.00 | 7.13  | -5.08 | 0.222 | -0.250 | -0.252 | 0.0170  | -0.0012 | 1.01 |
| 6   | 6.00 | 7.13  | -1.97 | 0.225 | -0.091 | -0.098 | -0.0019 | 0.0116  | 1.08 |
| 6   | 6.00 | 7.13  | -0.95 | 0.222 | -0.041 | -0.045 | -0.0001 | 0.0075  | 1.12 |
| 6   | 6.00 | 7.13  | 0.07  | 0.220 | 0.003  | 0.003  | 0.0000  | -0.0006 |      |
| 6   | 6.00 | 7.13  | 1.11  | 0.221 | 0.049  | 0.058  | -0.0030 | 0.0058  | 1.20 |
| 6   | 6.00 | 7.13  | 2.16  | 0.226 | 0.097  | 0.106  | -0.0191 | 0.0022  | 1.10 |
| 6   | 6.00 | 7.13  | 3.16  | 0.233 | 0.147  | 0.152  | -0.0430 | 0.0045  | 1.04 |
| 6   | 6.00 | 7.13  | 4.17  | 0.239 | 0.199  | 0.201  | -0.0278 | -0.0112 | 1.01 |
| 6   | 6.00 | 7.13  | 5.21  | 0.245 | 0.255  | 0.251  | -0.0274 | -0.0112 | 0.98 |
| 6   | 6.00 | 7.13  | 7.78  | 0.250 | 0.403  | 0.370  | -0.0294 | -0.0073 | 0.92 |
| 6   | 6.00 | 7.13  | 10.37 | 0.255 | 0.568  | 0.490  | -0.0250 | -0.0133 | 0.86 |
| 6   | 6.00 | 7.13  | 12.95 | 0.260 | 0.755  | 0.613  | -0.0280 | -0.0105 | 0.81 |
| 6   | 6.00 | 7.13  | 15.59 | 0.243 | 0.965  | 0.730  | -0.0359 | -0.0054 | 0.76 |
|     |      |       |       |       |        |        |         |         |      |
| 7   | 6.00 | 7.58  | -5.12 | 0.203 | -0.272 | -0.344 | -0.0294 | 0.0220  | 1.27 |
| 7   | 6.00 | 7.58  | -3.04 | 0.202 | -0.152 | -0.206 | -0.0005 | 0.0095  | 1.36 |
| 7   | 6.00 | 7.58  | -2.00 | 0.201 | -0.100 | -0.138 | 0.0031  | 0.0062  | 1.38 |
| 7   | 6.00 | 7.44  | -0.96 | 0.200 | -0.048 | -0.068 | -0.0004 | 0.0034  | 1.42 |
| 7   | 6.00 | 7.44  | 0.09  | 0.198 | 0.004  | 0.006  | 0.0000  | -0.0003 |      |
| 7   | 6.00 | 7.44  | 1.15  | 0.199 | 0.058  | 0.077  | 0.0052  | -0.0024 | 1.33 |
| 7   | 6.00 | 7.44  | 2.21  | 0.201 | 0.112  | 0.145  | 0.0042  | -0.0025 | 1.30 |
| 7   | 6.00 | 7.44  | 3.25  | 0.202 | 0.168  | 0.215  | 0.0028  | -0.0040 | 1.28 |
| 7   | 6.00 | 7.44  | 4.29  | 0.203 | 0.229  | 0.284  | -0.0034 | -0.0065 | 1.24 |
| 7   | 6.00 | 7.44  | 5.37  | 0.203 | 0.296  | 0.353  | -0.0026 | -0.0020 | 1.19 |
| 7   | 6.00 | 7.44  | 7.96  | 0.205 | 0.474  | 0.520  | -0.0054 | -0.0032 | 1.10 |
|     |      |       |       |       |        |        |         |         |      |
| 8   | 6.00 | 8.00  | -5.28 | 0.208 | -0.314 | -0.474 | 0.0162  | -0.0216 | 1.51 |
| 8   | 6.00 | 8.00  | -3.23 | 0.212 | -0.177 | -0.291 | 0.0084  | -0.0222 | 1.65 |
| 8   | 6.00 | 7.83  | -2.16 | 0.206 | -0.114 | -0.196 | 0.0146  | -0.0265 | 1.73 |
| 8   | 6.00 | 7.83  | -1.13 | 0.201 | -0.060 | -0.103 | 0.0165  | -0.0257 | 1.72 |
| 8   | 6.00 | 7.83  | -0.10 | 0.198 | -0.005 | -0.009 | 0.0002  | -0.0001 |      |
| 8   | 6.00 | 7.83  | 0.97  | 0.197 | 0.051  | 0.085  | -0.0022 | 0.0008  | 1.68 |
| 8   | 6.00 | 7.83  | 2.07  | 0.197 | 0.111  | 0.178  | 0.0105  | -0.0220 | 1.60 |
| 8   | 6.00 | 7.83  | 3.11  | 0.200 | 0.179  | 0.270  | 0.0183  | -0.0414 | 1.51 |
| 8   | 6.00 | 7.83  | 4.14  | 0.203 | 0.246  | 0.355  | 0.0135  | -0.0399 | 1.45 |
| 8   | 6.00 | 7.67  | 5.19  | 0.207 | 0.320  | 0.444  | 0.0078  | -0.0365 | 1.39 |
| 8   | 6.00 | 7.67  | 7.85  | 0.218 | 0.529  | 0.660  | -0.0021 | -0.0311 | 1.25 |

| L/D | H    | RE-06 | ALPHA | PD/V  | NFC    | PHC    | SFC     | YMC     | XCP   |
|-----|------|-------|-------|-------|--------|--------|---------|---------|-------|
| 6   | 2.53 | 11.50 | -3.23 | 0.311 | -0.174 | -0.155 | 0.0025  | 0.0031  | 0.89  |
| 6   | 2.53 | 11.63 | 0.01  | 0.307 | 0.001  | 0.001  | 0.0000  | 0.0000  |       |
| 6   | 2.53 | 11.38 | 1.08  | 0.306 | 0.056  | 0.054  | -0.0027 | -0.0007 | 0.97  |
| 6   | 2.53 | 11.63 | 3.26  | 0.310 | 0.175  | 0.157  | -0.0061 | -0.0038 | 0.90  |
| 6   | 2.53 | 11.63 | 5.51  | 0.320 | 0.325  | 0.267  | -0.0081 | -0.0092 | 0.82  |
| 6   | 2.53 | 11.75 | 8.19  | 0.323 | 0.516  | 0.395  | -0.0090 | -0.0121 | 0.77  |
| 6   | 2.53 | 11.75 | 10.91 | 0.320 | 0.749  | 0.533  | -0.0101 | -0.0103 | 0.71  |
| 7   | 2.53 | 13.42 | -3.33 | 0.301 | -0.183 | -0.256 | 0.0044  | 0.0027  | 1.40  |
| 7   | 2.53 | 13.42 | -0.05 | 0.303 | -0.002 | -0.004 | 0.0002  | 0.0000  |       |
| 7   | 2.53 | 13.27 | 1.11  | 0.303 | 0.056  | 0.086  | -0.0035 | 0.0000  | 1.54  |
| 7   | 2.53 | 13.56 | 3.31  | 0.309 | 0.184  | 0.264  | -0.0086 | -0.0040 | 1.43  |
| 7   | 2.53 | 13.56 | 5.54  | 0.319 | 0.333  | 0.448  | -0.0133 | -0.0040 | 1.34  |
| 7   | 2.53 | 13.71 | 8.34  | 0.328 | 0.559  | 0.656  | -0.0193 | -0.0032 | 1.17  |
| 7   | 2.53 | 13.71 | 9.95  | 0.326 | -0.561 | 0.664  | -0.0249 | 0.0020  | -1.18 |
| 8   | 2.53 | 15.50 | -3.44 | 0.310 | -0.191 | -0.368 | 0.0074  | -0.0009 | 1.92  |
| 8   | 2.53 | 15.50 | -0.03 | 0.306 | -0.002 | -0.003 | 0.0001  | 0.0000  |       |
| 8   | 2.53 | 15.67 | 1.29  | 0.306 | 0.066  | 0.141  | -0.0054 | 0.0004  | 2.15  |
| 8   | 2.53 | 15.67 | 3.43  | 0.315 | 0.196  | 0.386  | -0.0134 | -0.0049 | 1.97  |
| 8   | 2.53 | 15.50 | 5.76  | 0.325 | 0.357  | 0.660  | -0.0221 | -0.0047 | 1.85  |
| 8   | 2.53 | 15.83 | 8.83  | 0.332 | 0.633  | 0.982  | -0.0336 | 0.0024  | 1.55  |

| L/D | II   | RE-06 | ALPHA | PD/V  | NFC    | PHC    | SFC     | YHC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 3.51 | 11.50 | -5.21 | 0.309 | -0.280 | -0.258 | 0.0068  | -0.0029 | 0.92 |
| 6   | 3.51 | 11.75 | -3.22 | 0.303 | -0.160 | -0.164 | 0.0081  | -0.0033 | 1.02 |
| 6   | 3.51 | 11.75 | -1.05 | 0.292 | -0.048 | -0.061 | 0.0085  | -0.0039 | 1.27 |
| 6   | 3.51 | 11.75 | 0.00  | 0.290 | 0.002  | -0.007 | 0.0067  | -0.0051 |      |
| 6   | 3.51 | 11.75 | 1.11  | 0.291 | 0.058  | 0.051  | 0.0060  | -0.0060 | 0.89 |
| 6   | 3.51 | 11.88 | 3.19  | 0.300 | 0.173  | 0.150  | 0.0052  | -0.0088 | 0.86 |
| 6   | 3.51 | 11.88 | 5.31  | 0.308 | 0.303  | 0.252  | 0.0043  | -0.0121 | 0.83 |
| 6   | 3.51 | 12.00 | 7.98  | 0.310 | 0.476  | 0.380  | 0.0028  | -0.0117 | 0.80 |
| 6   | 3.51 | 12.00 | 10.61 | 0.307 | 0.674  | 0.510  | -0.0003 | -0.0100 | 0.75 |
| 6   | 3.51 | 12.00 | 13.36 | 0.309 | 0.897  | 0.643  | -0.0037 | -0.0090 | 0.72 |
| 6   | 3.51 | 12.00 | 16.03 | 0.306 | 1.128  | 0.769  | -0.0028 | -0.0121 | 0.68 |
|     |      |       |       |       |        |        |         |         |      |
| 7   | 3.51 | 13.56 | -5.37 | 0.296 | -0.312 | -0.392 | 0.0027  | 0.0049  | 1.26 |
| 7   | 3.51 | 13.71 | -3.23 | 0.292 | -0.175 | -0.239 | 0.0038  | 0.0039  | 1.37 |
| 7   | 3.51 | 13.71 | 0.05  | 0.279 | 0.003  | 0.004  | -0.0001 | -0.0001 |      |
| 7   | 3.51 | 13.71 | 1.13  | 0.277 | 0.059  | 0.089  | -0.0031 | -0.0014 | 1.51 |
| 7   | 3.51 | 13.85 | 3.25  | 0.287 | 0.186  | 0.253  | -0.0059 | -0.0050 | 1.36 |
| 7   | 3.51 | 14.00 | 5.42  | 0.295 | 0.325  | 0.415  | -0.0065 | -0.0053 | 1.28 |
| 7   | 3.51 | 14.00 | 8.15  | 0.297 | 0.530  | 0.604  | -0.0082 | -0.0035 | 1.14 |
| 7   | 3.51 | 14.00 | 10.84 | 0.301 | 0.766  | 0.790  | -0.0114 | -0.0002 | 1.03 |
| 7   | 3.51 | 14.00 | 13.60 | 0.303 | 1.027  | 0.983  | -0.0124 | -0.0032 | 0.96 |
|     |      |       |       |       |        |        |         |         |      |
| 8   | 3.51 | 15.50 | -5.50 | 0.302 | -0.342 | -0.565 | 0.0099  | -0.0015 | 1.65 |
| 8   | 3.51 | 15.67 | -3.31 | 0.301 | -0.187 | -0.342 | 0.0078  | 0.0020  | 1.83 |
| 8   | 3.51 | 15.50 | -1.13 | 0.293 | -0.057 | -0.121 | 0.0033  | -0.0007 | 2.12 |
| 8   | 3.51 | 15.67 | 0.04  | 0.285 | 0.002  | 0.004  | -0.0001 | 0.0000  |      |
| 8   | 3.51 | 15.83 | 3.36  | 0.293 | 0.201  | 0.358  | -0.0090 | -0.0072 | 1.78 |
| 8   | 3.51 | 15.83 | 5.58  | 0.305 | 0.363  | 0.589  | -0.0137 | -0.0084 | 1.62 |
| 8   | 3.51 | 16.00 | 8.39  | 0.310 | 0.605  | 0.854  | -0.0198 | -0.0035 | 1.41 |
| 8   | 3.51 | 16.00 | 11.19 | 0.315 | 0.899  | 1.116  | -0.0258 | -0.0004 | 1.24 |

| L/D | H    | RE-06 | ALPHA | PD/V  | NFC    | PMC    | SFC     | YMC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 5.00 | 10.88 | -5.22 | 0.261 | -0.244 | -0.234 | -0.0055 | -0.0027 | 0.96 |
| 6   | 5.00 | 12.25 | -3.11 | 0.266 | -0.134 | -0.144 | -0.0015 | -0.0008 | 1.07 |
| 6   | 5.00 | 12.50 | -1.04 | 0.259 | -0.042 | -0.052 | 0.0001  | -0.0028 | 1.24 |
| 6   | 5.00 | 12.50 | 0.04  | 0.254 | 0.002  | 0.002  | 0.0000  | 0.0001  |      |
| 6   | 5.00 | 12.50 | 1.08  | 0.255 | 0.046  | 0.048  | -0.0014 | 0.0015  | 1.04 |
| 6   | 5.00 | 13.75 | 3.17  | 0.263 | 0.139  | 0.139  | -0.0030 | -0.0031 | 1.00 |
| 6   | 5.00 | 13.75 | 5.25  | 0.272 | 0.236  | 0.228  | -0.0038 | -0.0022 | 0.97 |
| 6   | 5.00 | 13.75 | 7.86  | 0.276 | 0.371  | 0.341  | -0.0068 | 0.0005  | 0.92 |
| 6   | 5.00 | 13.75 | 10.47 | 0.280 | 0.530  | 0.454  | -0.0097 | 0.0034  | 0.86 |
| 6   | 5.00 | 13.75 | 13.05 | 0.288 | 0.699  | 0.561  | -0.0117 | 0.0032  | 0.80 |
| 6   | 5.00 | 13.75 | 15.77 | 0.289 | 0.892  | 0.674  | -0.0130 | 0.0014  | 0.76 |
| 7   | 5.00 | 14.58 | -5.29 | 0.260 | -0.251 | -0.344 | 0.0059  | 0.0060  | 1.37 |
| 7   | 5.00 | 14.58 | -3.17 | 0.256 | -0.139 | -0.206 | 0.0053  | 0.0048  | 1.48 |
| 7   | 5.00 | 14.58 | -1.12 | 0.249 | -0.047 | -0.082 | 0.0021  | 0.0014  | 1.76 |
| 7   | 5.00 | 14.58 | 0.02  | 0.246 | 0.001  | 0.002  | 0.0000  | 0.0000  |      |
| 7   | 5.00 | 16.04 | 1.02  | 0.248 | 0.044  | 0.071  | 0.0000  | 0.0026  | 1.60 |
| 7   | 5.00 | 16.04 | 3.15  | 0.256 | 0.145  | 0.210  | -0.0008 | -0.0003 | 1.45 |
| 7   | 5.00 | 16.04 | 5.28  | 0.263 | 0.258  | 0.348  | 0.0002  | 0.0014  | 1.35 |
| 7   | 5.00 | 16.04 | 8.04  | 0.267 | 0.424  | 0.518  | -0.0047 | 0.0077  | 1.22 |
| 7   | 5.00 | 16.04 | 10.57 | 0.272 | 0.605  | 0.672  | -0.0077 | 0.0138  | 1.11 |
| 7   | 5.00 | 16.04 | 13.24 | 0.278 | 0.812  | 0.837  | -0.0065 | 0.0127  | 1.03 |
| 7   | 5.00 | 16.04 | 16.01 | 0.283 | 1.042  | 1.003  | -0.0061 | 0.0122  | 0.96 |
| 8   | 5.00 | 18.33 | -5.39 | 0.269 | -0.266 | -0.431 | 0.0017  | -0.0013 | 1.62 |
| 8   | 5.00 | 18.33 | -3.22 | 0.270 | -0.151 | -0.261 | 0.0049  | -0.0006 | 1.73 |
| 8   | 5.00 | 18.33 | -1.05 | 0.266 | -0.049 | -0.090 | 0.0022  | -0.0037 | 1.83 |
| 8   | 5.00 | 18.33 | 0.06  | 0.260 | 0.003  | 0.005  | -0.0001 | 0.0002  |      |
| 8   | 5.00 | 18.33 | 1.06  | 0.260 | 0.044  | 0.097  | -0.0021 | 0.0010  | 2.22 |
| 8   | 5.00 | 18.33 | 3.21  | 0.266 | 0.161  | 0.292  | -0.0038 | -0.0042 | 1.81 |
| 8   | 5.00 | 18.33 | 5.39  | 0.273 | 0.292  | 0.481  | -0.0046 | -0.0040 | 1.65 |
| 8   | 5.00 | 18.33 | 8.27  | 0.280 | 0.488  | 0.721  | -0.0076 | 0.0015  | 1.48 |
| 8   | 5.00 | 18.33 | 10.83 | 0.283 | 0.694  | 0.932  | -0.0081 | 0.0016  | 1.34 |

| L/D | H    | RE-06 | ALPHA | PD/V  | YFC    | PI/C   | SFC     | YFC     | XCP  |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|
| 6   | 6.00 | 11.75 | -5.24 | 0.267 | -0.255 | -0.238 | -0.0109 | 0.0158  | 0.94 |
| 6   | 6.00 | 11.75 | -3.16 | 0.267 | -0.146 | -0.144 | -0.0108 | 0.0157  | 0.99 |
| 6   | 6.00 | 11.75 | -2.12 | 0.262 | -0.095 | -0.099 | -0.0066 | 0.0095  | 1.04 |
| 6   | 6.00 | 11.75 | -1.06 | 0.257 | -0.046 | -0.051 | 0.0020  | -0.0008 | 1.11 |
| 6   | 6.00 | 11.88 | 0.02  | 0.255 | 0.001  | 0.001  | 0.0000  | 0.0000  |      |
| 6   | 6.00 | 11.75 | 1.08  | 0.255 | 0.047  | 0.051  | -0.0023 | 0.0003  | 1.09 |
| 6   | 6.00 | 11.63 | 2.11  | 0.245 | 0.095  | 0.093  | -0.0086 | 0.0042  | 0.98 |
| 6   | 6.00 | 11.63 | 3.18  | 0.238 | 0.150  | 0.141  | -0.0094 | 0.0038  | 0.94 |
| 6   | 6.00 | 11.63 | 4.19  | 0.239 | 0.203  | 0.185  | -0.0113 | 0.0056  | 0.91 |
| 6   | 6.00 | 11.63 | 5.22  | 0.245 | 0.262  | 0.231  | -0.0106 | 0.0061  | 0.88 |
| 6   | 6.00 | 11.75 | 7.85  | 0.252 | 0.414  | 0.349  | -0.0181 | 0.0164  | 0.84 |
| 6   | 6.00 | 11.63 | 10.64 | 0.263 | 0.586  | 0.454  | -0.0158 | 0.0121  | 0.83 |
| 7   | 6.00 | 12.40 | -5.14 | 0.235 | -0.276 | -0.345 | -0.0103 | 0.0200  | 1.25 |
| 7   | 6.00 | 12.40 | -3.04 | 0.249 | -0.151 | -0.203 | -0.0052 | 0.0120  | 1.34 |
| 7   | 6.00 | 12.25 | -1.98 | 0.247 | -0.095 | -0.133 | -0.0038 | 0.0075  | 1.39 |
| 7   | 6.00 | 12.25 | 0.13  | 0.243 | 0.006  | 0.009  | 0.0002  | -0.0005 |      |
| 7   | 6.00 | 12.25 | 1.22  | 0.244 | 0.058  | 0.084  | -0.0010 | -0.0025 | 1.45 |
| 7   | 6.00 | 12.40 | 2.30  | 0.248 | 0.113  | 0.153  | -0.0010 | -0.0073 | 1.36 |
| 7   | 6.00 | 12.10 | 3.32  | 0.246 | 0.171  | 0.218  | -0.0130 | 0.0052  | 1.28 |
| 7   | 6.00 | 12.10 | 4.37  | 0.242 | 0.233  | 0.287  | -0.0093 | 0.0038  | 1.23 |
| 7   | 6.00 | 12.54 | 5.47  | 0.245 | 0.298  | 0.354  | -0.0075 | -0.0003 | 1.19 |
| 7   | 6.00 | 12.25 | 8.12  | 0.250 | 0.479  | 0.527  | -0.0073 | -0.0024 | 1.10 |
| 8   | 6.00 | 14.50 | -5.41 | 0.236 | -0.321 | -0.484 | -0.0083 | 0.0188  | 1.51 |
| 8   | 6.00 | 14.33 | -3.27 | 0.242 | -0.179 | -0.294 | -0.0059 | 0.0157  | 1.64 |
| 8   | 6.00 | 14.33 | -2.18 | 0.242 | -0.111 | -0.198 | -0.0056 | 0.0111  | 1.78 |
| 8   | 6.00 | 14.17 | -1.10 | 0.239 | -0.056 | -0.105 | 0.0001  | 0.0023  | 1.85 |
| 8   | 6.00 | 14.17 | -0.01 | 0.237 | -0.001 | -0.001 | 0.0000  | 0.0000  |      |
| 8   | 6.00 | 14.00 | 1.11  | 0.238 | 0.058  | 0.101  | 0.0010  | -0.0027 | 1.72 |
| 8   | 6.00 | 14.00 | 2.18  | 0.240 | 0.110  | 0.192  | 0.0038  | -0.0058 | 1.65 |
| 8   | 6.00 | 14.00 | 3.25  | 0.245 | 0.184  | 0.285  | 0.0004  | -0.0069 | 1.55 |
| 8   | 6.00 | 14.00 | 4.38  | 0.249 | 0.260  | 0.378  | 0.0006  | -0.0052 | 1.45 |
| 8   | 6.00 | 14.00 | 5.44  | 0.253 | 0.336  | 0.467  | -0.0022 | -0.0015 | 1.39 |
| 8   | 6.00 | 13.83 | 8.20  | 0.258 | 0.536  | 0.679  | -0.0075 | 0.0074  | 1.27 |

| L/D | H    | RE-06 | ALPHA | PD/V  | NFC    | PI/C   | SFC     | Y/C     | XCP  | CA    |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|-------|
| 6   | 2.53 | 6.25  | -5.83 | 0.000 | -0.330 | -0.267 | -0.0012 | 0.0061  | 0.81 | 0.154 |
| 6   | 2.53 | 6.25  | -3.52 | 0.000 | -0.193 | -0.168 | 0.0013  | 0.0040  | 0.87 | 0.155 |
| 6   | 2.53 | 6.25  | -1.12 | 0.000 | -0.056 | -0.052 | 0.0010  | 0.0019  | 0.92 | 0.147 |
| 6   | 2.53 | 6.25  | 0.14  | 0.000 | 0.007  | 0.007  | -0.0001 | -0.0002 |      | 0.140 |
| 6   | 2.53 | 6.25  | 1.18  | 0.000 | 0.062  | 0.057  | -0.0019 | -0.0055 | 0.92 | 0.149 |
| 6   | 2.53 | 6.25  | 2.32  | 0.000 | 0.121  | 0.108  | -0.0037 | -0.0048 | 0.89 | 0.148 |
| 6   | 2.53 | 6.25  | 3.48  | 0.000 | 0.189  | 0.162  | -0.0049 | -0.0061 | 0.86 | 0.153 |
| 6   | 2.53 | 6.25  | 4.61  | 0.000 | 0.258  | 0.215  | -0.0066 | -0.0080 | 0.83 | 0.158 |
| 6   | 2.53 | 6.25  | 5.79  | 0.000 | 0.327  | 0.261  | -0.0073 | -0.0092 | 0.80 | 0.157 |
| 7   | 2.53 | 7.15  | -6.11 | 0.000 | -0.374 | -0.473 | 0.0109  | 0.0084  | 1.26 | 0.165 |
| 7   | 2.53 | 7.00  | -3.56 | 0.000 | -0.201 | -0.272 | 0.0080  | 0.0099  | 1.36 | 0.157 |
| 7   | 2.53 | 7.00  | -1.12 | 0.000 | -0.058 | -0.085 | 0.0033  | 0.0037  | 1.46 | 0.152 |
| 7   | 2.53 | 7.00  | 0.12  | 0.000 | 0.006  | 0.009  | -0.0004 | -0.0004 |      | 0.151 |
| 7   | 2.53 | 7.15  | 1.38  | 0.000 | 0.074  | 0.107  | -0.0052 | -0.0041 | 1.46 | 0.152 |
| 7   | 2.53 | 7.00  | 2.58  | 0.000 | 0.142  | 0.198  | -0.0093 | -0.0089 | 1.39 | 0.155 |
| 7   | 2.53 | 7.00  | 3.78  | 0.000 | 0.217  | 0.292  | -0.0126 | -0.0115 | 1.34 | 0.159 |
| 7   | 2.53 | 7.00  | 5.05  | 0.000 | 0.299  | 0.391  | -0.0166 | -0.0121 | 1.30 | 0.164 |
| 7   | 2.53 | 7.15  | 6.30  | 0.000 | 0.393  | 0.490  | -0.0203 | -0.0130 | 1.25 | 0.171 |
| 8   | 2.53 | 8.00  | -6.53 | 0.000 | -0.423 | -0.705 | 0.0115  | -0.0021 | 1.67 | 0.180 |
| 8   | 2.53 | 8.17  | -3.71 | 0.000 | -0.213 | -0.393 | 0.0094  | 0.0049  | 1.85 | 0.168 |
| 8   | 2.53 | 8.00  | -1.01 | 0.000 | -0.052 | -0.105 | 0.0023  | 0.0029  | 2.03 | 0.160 |
| 8   | 2.53 | 8.00  | 0.31  | 0.000 | 0.016  | 0.032  | -0.0012 | -0.0009 |      | 0.159 |
| 8   | 2.53 | 8.17  | 1.66  | 0.000 | 0.089  | 0.176  | -0.0063 | -0.0057 | 1.99 | 0.160 |
| 8   | 2.53 | 8.00  | 2.96  | 0.000 | 0.167  | 0.317  | -0.0130 | -0.0086 | 1.90 | 0.165 |
| 8   | 2.53 | 8.00  | 4.29  | 0.000 | 0.249  | 0.459  | -0.0171 | -0.0094 | 1.84 | 0.170 |
| 8   | 2.53 | 8.00  | 5.72  | 0.000 | 0.352  | 0.623  | -0.0215 | -0.0059 | 1.77 | 0.179 |

| L/D | N    | RE-06 | ALPHA | PD/V  | HFC    | PHC    | SFC     | YIC     | XCP  | CA    |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|-------|
| 6   | 3.51 | 5.88  | -5.61 | 0.000 | -0.313 | -0.260 | -0.0045 | 0.0080  | 0.83 | 0.134 |
| 6   | 3.51 | 5.88  | -3.32 | 0.000 | -0.169 | -0.155 | 0.0000  | 0.0060  | 0.91 | 0.132 |
| 6   | 3.51 | 5.88  | -1.08 | 0.000 | -0.052 | -0.050 | 0.0013  | 0.0027  | 0.96 | 0.124 |
| 6   | 3.51 | 5.88  | 0.02  | 0.000 | 0.001  | 0.001  | 0.0000  | 0.0000  |      | 0.124 |
| 6   | 3.51 | 5.88  | 1.14  | 0.000 | 0.059  | 0.057  | -0.0003 | -0.0012 | 0.97 | 0.125 |
| 6   | 3.51 | 5.88  | 2.23  | 0.000 | 0.117  | 0.108  | -0.0014 | -0.0031 | 0.92 | 0.128 |
| 6   | 3.51 | 5.88  | 3.30  | 0.000 | 0.180  | 0.157  | -0.0017 | -0.0048 | 0.87 | 0.131 |
| 6   | 3.51 | 5.88  | 4.45  | 0.000 | 0.245  | 0.207  | -0.0014 | -0.0056 | 0.84 | 0.135 |
| 6   | 3.51 | 5.88  | 5.57  | 0.000 | 0.315  | 0.257  | -0.0014 | -0.0062 | 0.82 | 0.138 |
| 7   | 3.51 | 6.71  | -5.37 | 0.000 | -0.317 | -0.367 | -0.0054 | 0.0038  | 1.22 | 0.131 |
| 7   | 3.51 | 6.85  | -3.06 | 0.000 | -0.170 | -0.226 | 0.0001  | 0.0028  | 1.32 | 0.125 |
| 7   | 3.51 | 6.85  | -0.66 | 0.000 | -0.037 | -0.054 | 0.0010  | 0.0025  | 1.46 | 0.120 |
| 7   | 3.51 | 6.71  | 0.45  | 0.000 | 0.025  | 0.037  | -0.0006 | -0.0017 |      | 0.120 |
| 7   | 3.51 | 6.71  | 1.61  | 0.000 | 0.088  | 0.124  | -0.0029 | -0.0027 | 1.41 | 0.124 |
| 7   | 3.51 | 6.85  | 3.90  | 0.000 | 0.233  | 0.295  | -0.0078 | -0.0091 | 1.26 | 0.133 |
| 7   | 3.51 | 6.85  | 5.02  | 0.000 | 0.309  | 0.373  | -0.0091 | -0.0103 | 1.21 | 0.137 |
| 7   | 3.51 | 6.85  | 6.23  | 0.000 | 0.391  | 0.452  | -0.0115 | -0.0124 | 1.16 | 0.143 |
| 8   | 3.51 | 7.50  | -5.79 | 0.000 | -0.377 | -0.592 | -0.0007 | 0.0103  | 1.57 | 0.151 |
| 8   | 3.51 | 7.50  | -3.25 | 0.000 | -0.194 | -0.338 | 0.0006  | 0.0026  | 1.74 | 0.137 |
| 8   | 3.51 | 7.50  | -0.72 | 0.000 | -0.042 | -0.081 | 0.0008  | -0.0003 | 1.93 | 0.132 |
| 8   | 3.51 | 7.50  | 0.43  | 0.000 | 0.025  | 0.048  | -0.0005 | 0.0001  |      | 0.132 |
| 8   | 3.51 | 7.33  | 1.65  | 0.000 | 0.095  | 0.181  | -0.0010 | -0.0047 | 1.90 | 0.135 |
| 8   | 3.51 | 7.50  | 2.85  | 0.000 | 0.169  | 0.305  | -0.0056 | -0.0050 | 1.80 | 0.139 |
| 8   | 3.51 | 7.50  | 4.07  | 0.000 | 0.253  | 0.433  | -0.0064 | -0.0069 | 1.71 | 0.145 |
| 8   | 3.51 | 7.50  | 5.30  | 0.000 | 0.349  | 0.565  | -0.0098 | -0.0062 | 1.62 | 0.151 |
| 8   | 3.51 | 7.67  | 6.57  | 0.000 | 0.452  | 0.684  | -0.0111 | -0.0033 | 1.51 | 0.156 |

| L/D | M    | RE-06 | ALPHA | PD/V  | NFC    | PNC    | SFC     | Y/C     | XCP  | CA    |
|-----|------|-------|-------|-------|--------|--------|---------|---------|------|-------|
| 6   | 5.00 | 6.75  | -5.45 | 0.000 | -0.261 | -0.242 | -0.0045 | 0.0086  | 0.93 | 0.101 |
| 6   | 5.00 | 7.13  | -3.26 | 0.000 | -0.150 | -0.147 | -0.0017 | 0.0082  | 0.98 | 0.093 |
| 6   | 5.00 | 7.13  | -1.06 | 0.000 | -0.047 | -0.050 | 0.0000  | 0.0040  | 2.17 | 0.089 |
| 6   | 5.00 | 7.13  | 0.04  | 0.000 | 0.002  | 0.002  | 0.0000  | -0.0002 |      | 0.089 |
| 6   | 5.00 | 7.13  | 1.14  | 0.000 | 0.051  | 0.055  | 0.0009  | -0.0022 | 1.08 | 0.089 |
| 6   | 5.00 | 7.13  | 2.23  | 0.000 | 0.098  | 0.100  | 0.0017  | -0.0051 | 1.02 | 0.092 |
| 6   | 5.00 | 7.13  | 3.30  | 0.000 | 0.149  | 0.147  | 0.0014  | -0.0064 | 0.98 | 0.095 |
| 6   | 5.00 | 7.13  | 4.35  | 0.000 | 0.204  | 0.193  | 0.0000  | -0.0094 | 1.43 | 0.101 |
| 6   | 5.00 | 7.00  | 5.45  | 0.000 | 0.259  | 0.240  | -0.0001 | -0.0078 | 0.93 | 0.103 |
| 7   | 5.00 | 8.02  | -5.59 | 0.000 | -0.299 | -0.376 | -0.0022 | 0.0118  | 1.25 | 0.108 |
| 7   | 5.00 | 8.31  | -3.35 | 0.000 | -0.170 | -0.229 | -0.0002 | 0.0113  | 1.35 | 0.100 |
| 7   | 5.00 | 8.31  | -1.08 | 0.000 | -0.053 | -0.080 | 0.0014  | 0.0032  | 1.50 | 0.094 |
| 7   | 5.00 | 8.31  | 0.02  | 0.000 | 0.001  | 0.002  | 0.0000  | -0.0001 |      | 0.093 |
| 7   | 5.00 | 8.46  | 1.17  | 0.000 | 0.054  | 0.078  | 0.0015  | -0.0020 | 1.43 | 0.094 |
| 7   | 5.00 | 8.31  | 2.28  | 0.000 | 0.107  | 0.147  | 0.0012  | -0.0044 | 1.37 | 0.099 |
| 7   | 5.00 | 8.31  | 3.41  | 0.000 | 0.168  | 0.225  | 0.0012  | -0.0067 | 1.34 | 0.101 |
| 7   | 5.00 | 8.31  | 4.49  | 0.000 | 0.228  | 0.295  | 0.0004  | -0.0071 | 1.29 | 0.106 |
| 7   | 5.00 | 8.31  | 5.60  | 0.000 | 0.296  | 0.368  | 0.0010  | -0.0022 | 1.24 | 0.112 |
| 8   | 5.00 | 8.83  | -5.54 | 0.000 | -0.322 | -0.489 | -0.0112 | 0.0129  | 1.52 | 0.114 |
| 8   | 5.00 | 9.17  | -3.07 | 0.000 | -0.165 | -0.277 | -0.0025 | 0.0136  | 1.68 | 0.106 |
| 8   | 5.00 | 9.50  | -0.77 | 0.000 | -0.038 | -0.071 | 0.0001  | 0.0032  | 1.87 | 0.100 |
| 8   | 5.00 | 9.50  | 0.40  | 0.000 | 0.020  | 0.037  | -0.0001 | -0.0017 |      | 0.099 |
| 8   | 5.00 | 9.50  | 1.59  | 0.000 | 0.077  | 0.151  | -0.0003 | -0.0013 | 1.96 | 0.100 |
| 8   | 5.00 | 9.50  | 2.73  | 0.000 | 0.142  | 0.260  | -0.0015 | -0.0055 | 1.83 | 0.128 |
| 8   | 5.00 | 9.50  | 3.88  | 0.000 | 0.209  | 0.360  | -0.0021 | -0.0071 | 1.72 | 0.108 |
| 8   | 5.00 | 9.50  | 5.07  | 0.000 | 0.285  | 0.463  | -0.0017 | -0.0039 | 1.63 | 0.115 |
| 8   | 5.00 | 9.50  | 6.04  | 0.000 | 0.352  | 0.546  | -0.0019 | -0.0003 | 1.55 | 0.120 |

APPENDIX A - TABULATED DATA  
LIST OF SYMBOLS

|          |                                                 |
|----------|-------------------------------------------------|
| CA       | axial force coefficient, $C_{A_C}$              |
| L/D      | model length to diameter ratio                  |
| M        | test section Mach number                        |
| NFC      | normal force coefficient                        |
| PD/V     | dimensionless spin rate                         |
| PMC      | pitching moment coefficient                     |
| RE-06    | Reynolds number based on model length, millions |
| SFC      | side force coefficient                          |
| XCP      | center of pressure, calibers from c.g.          |
| YMC      | yawing moment coefficient                       |
| $\alpha$ | angle of attack, deg                            |

# LIST OF SYMBOLS

|                   |                                                        |
|-------------------|--------------------------------------------------------|
| $C_{A_c}$         | axial force coefficient, $C_{A_c} = C_{A_t} - C_{A_b}$ |
| $C_{A_b}$         | base axial force coefficient                           |
| $C_{A_t}$         | total axial force coefficient                          |
| $C_m$             | pitching moment coefficient                            |
| $C_{m_\alpha}$    | slope of the pitching moment coefficient               |
| $C_n$             | yawing moment coefficient                              |
| $C_{n_{p\alpha}}$ | $d/d\alpha (C_n)/(pd/V)$                               |
| $C_N$             | normal force coefficient                               |
| $C_{N_\alpha}$    | slope of the normal force coefficient                  |
| $C_Y$             | side force coefficient                                 |
| $C_{Y_{p\alpha}}$ | $d/d\alpha (C_Y)/(pd/V)$                               |
| c.g.              | center of gravity, 0.6L from projectile nose           |
| d,D               | projectile diameter                                    |
| L                 | projectile length                                      |
| M                 | Mach number                                            |
| p                 | model spin rate, radians/sec                           |
| $P_o$             | tunnel supply pressure, kPa                            |
| $Re_\lambda$      | Reynolds number based on model length                  |
| $T_o$             | Tunnel stagnation temperature, K                       |
| $X_{cp}$          | center of pressure, calibers from c.g.                 |

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