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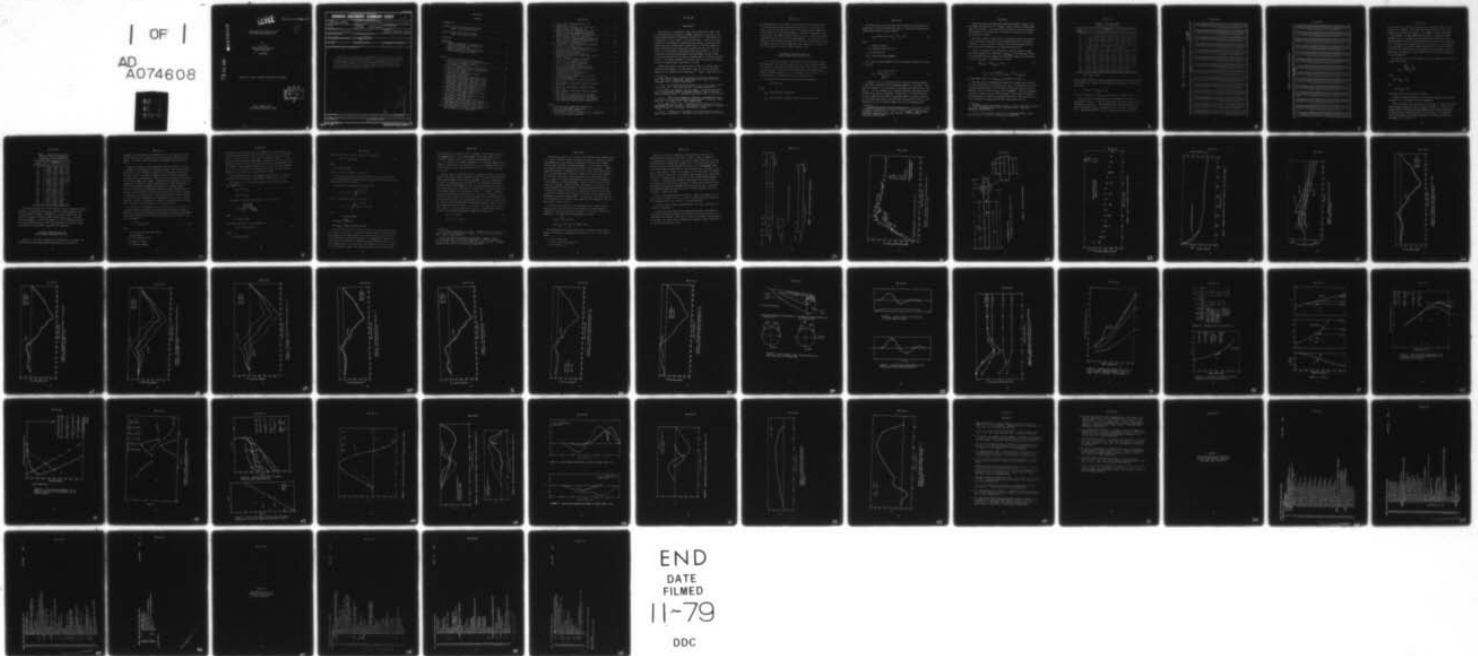
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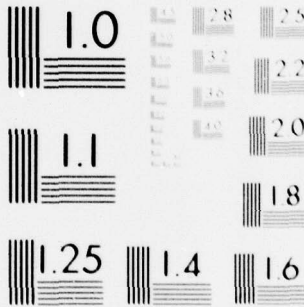
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6 AERODYNAMIC COEFFICIENTS FOR THE SIX-INCH TVC (TVC6) MISSILE

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by

10 W.H. Clark
Weapon Synthesis Division
Weapons Department

11 June 1978

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This report is a final report documenting the predictions of the static aerodynamic coefficients (normal and side force and pitch and yaw moments) used in computer simulations of the Navy's 6-inch-diameter thrust vector controlled ASRAAM candidate. Although the predictions described are for a specific missile configuration, the techniques used are sufficiently general to be applicable to a variety of slender bodies of revolution that are expected to fly at high angles of attack.

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INTRODUCTION

The validity of the subsonic normal force coefficients used in the air intercept missile evaluation (AIMVAL) simulation of the Navy's "D" concept missile was first questioned in April 1977.¹ (This missile will be referred to in this report as the TVC6 missile.) Errors were found to exist in the aerodynamic coefficients and action to recalculate the normal force and pitching moment coefficients for TVC6 was suggested.² These coefficients were recalculated during fiscal year 1977; the new values of the aerodynamic coefficients have been included in the simulation models currently being used by NWC and Hughes Aircraft Company in the short-range air-to-air missile (SRAAM) generic airframe evaluation efforts. This report documents the methods used to estimate the normal force and pitching moment coefficients for TVC6.

Symmetrical bodies of revolution such as TVC6, at certain angles of attack and Mach numbers, can experience large side forces and yawing moments due to asymmetric flow separation.³⁻⁶ Indeed, these side forces

¹Naval Weapons Center. Need for Review of Simulation Employed at ACM(I) (U), by W.F. Cartwright. China Lake, Calif., NWC 20 April 1977. (Reg. Memo 015/14, document UNCLASSIFIED.)

²———. 6" TVC Normal Force Coefficient (U), by W.H. Clark. China Lake, Calif., NWC. (Reg. Memo 3914-93-77, document UNCLASSIFIED.)

³W.H. Clark, J.R. Peoples, and M.M. Briggs. "Occurrence and Inhibition of Large Yawing Moments During High-Incidence Flight of Slender Missile Configurations," *J. Spacecraft and Rockets*, Vol. 10, No. 8 (1973).

⁴———. "Body Vortex Formation on Missiles in Incompressible Flow," presented at the AIAA 4th Atmospheric Flight Mechanics Conference, Hollywood, Fla., 8-10 August 1977. Paper UNCLASSIFIED.

⁵P.J. Lamont and B.L. Hunt. "Pressure and Force Distributions on a Sharp-Nosed Circular Cylinder at Large Angles of Inclination to a Uniform, Subsonic Stream," *J. Fluid Mech.*, Vol 76, Part 3 (1976).

⁶———. "Prediction of Aerodynamic Out-of-Plane Forces on Ogive-Nosed Circular Cylinders," *J. Spacecraft and Rockets*, Vol. 14, No.1 (1977).

and yawing moments, which tend to move the missile body perpendicular to the plane containing the missile axis and the free stream velocity vector, for some configurations can be of the same order of magnitude as the normal force and pitching moment. A realistic evaluation of the TVC6 missile's performance should include a study of sensitivity in performance to these side forces and yawing moments. For this reason, efforts also were undertaken during fiscal year 1977 to estimate the forces and moments associated with asymmetrical flow separation for inclusion in the six degree-of-freedom computer models of TVC6.

ESTIMATE OF THE NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS FOR TVC6

In arriving at the values of the normal force coefficient (C_N) and pitching moment coefficient (C_M) given in this report, maximum possible use was made of existing Agile wind tunnel data. The problem in scaling the coefficients from Agile to TVC6 is that Agile was designed with a length-to-diameter ratio (l/d) of 12.5 and the ratio for TVC6 l/d is 20. The method used to perform the scaling is outlined below.

The normal force coefficient for TVC6 can be expressed as

$$C_N = C_{N_B} + C_{N_F} \quad (1)$$

where

C_{N_B} = the body alone coefficient

C_{N_F} = the effective contribution due to the six tail fins.

The body alone force coefficient can be scaled from the Agile wind tunnel data by using the method described in a National Aeronautics and Space Administration technical report.⁷

$$C_{N_B} = \sin 2\alpha \cos \alpha / 2 + \eta C_{D_c} \frac{A_p}{A_r} \sin^2 \alpha \quad (2)$$

where

α = angle of attack

A_r = reference area ($\equiv \pi d^2/4$)

A_p = planform area

ηC_{D_c} = cross flow drag parameter.

The cross flow drag parameter can be determined from measured values of C_{N_B} from

$$\eta C_{D_c} = \frac{C_{N_B} - \sin 2\alpha \cos^3 \alpha / 2}{\frac{A_p}{A_r} \sin^2 \alpha} \quad (3)$$

In general, ηC_{D_c} is a function of both the cross flow Mach number, M_c ($\equiv M_\infty \sin \alpha$), and the cross flow Reynolds number, R_x ($\equiv R_\infty \sin \alpha$). (However, see Footnote 4 for a discussion concerning the correlation of ηC_{D_c} with R_x .) For our purposes, R_x is usually large and only supercritical values of ηC_{D_c} need be considered. Because ηC_{D_c} is a "weak" function of R_x for supercritical values of Reynolds number, and because there is not sufficient Agile data to perform useful extrapolations with R_x , the dependence of ηC_{D_c} on Reynolds number will not be considered here.

⁷ National Aeronautics and Space Administration. *Prediction of Static Aerodynamic Characteristics for Space - Shuttle - Like and Other Bodies at Angles of Attack From 0° to 180°*, by L.H. Jorgensen. Ames Research Laboratory, Sunnyvale, Calif. NASA, Jan 1973. (NASA TN-D-6996, publication UNCLASSIFIED.)

Contractor reports provide wind tunnel measurements of C_{NB} for several Agile configurations.^{8,9} (Figure 1 shows the Agile configurations used in this study.) From these data the value of ηC_{Dc} was calculated (from Equation 3) and plotted as a function of cross flow Mach number, M_c , as shown in Figure 2.

The data of Figure 2 shows that ηC_{Dc} versus M_c follows two distinct curves, depending on whether the free stream Mach number is subsonic or supersonic. The solid lines in Figure 2 were faired through the data points and used to compute the C_N values described below.

Given the values for ηC_{Dc} from Figure 2 and the values for Agile body alone normal force coefficient, $(C_{NB})_{\text{Agile}}$, from Footnotes 8 and 9 it is straightforward to compute the body alone normal force coefficient for TVC6, $(C_{NB})_{\text{TVC6}}$. From Equation 2 we have

$$(C_{NB})_{\text{TVC6}} = (C_{NB})_{\text{Agile}} + \Delta C_{NB} \quad (4)$$

where

$$\Delta C_{NB} = \eta C_{Dc} \sin^2 \alpha \left((C_{p/A_r})_{\text{TVC6}} - (C_{p/A_r})_{\text{Agile}} \right)$$

The estimated values for $(C_{NB})_{\text{TVC6}}$ are tabulated in Table 1.

The final step in computing the normal force coefficient for TVC6 is to obtain the effective fin normal force, C_{NF} . The appropriate values for C_{NF} were obtained directly from Footnote 8, using the values of the configuration that utilized the "C_{62F}" fin arrangement. (This configuration is shown in Figure 1 at the top of the page.) The values for C_{NF} were obtained simply by taking the difference between the values of C_N for the full configuration (C_{NB+F}) and the body alone values; that is,

⁸ McDonnell Douglas Astronautics Co.-West. *Agile Configuration Development Test*. Huntington Beach, Calif., MDC, April 1974. (MDC G51J6 publication UNCLASSIFIED.)

⁹ *Agile External Geometry Test*. Huntington Beach, Calif., MDC, June 1973. (MDC G4027, publication UNCLASSIFIED.)

TABLE 1. TVC6 Body Alone
Normal Force Coefficient.

Angle of attack	Mach no.							
	0.6	0.8	0.95	1.1	1.2	1.6	2.0	3.0
0	0	0	0	0	0	0	0	0
5	0.22	0.33	0.32	0.32	0.24	0.39	0.24	0.36
10	0.74	0.85	0.87	0.89	0.79	0.95	0.99	1.29
15	1.36	1.74	1.69	1.87	1.79	2.31	2.66	3.0
20	2.46	3.04	3.76	3.46	3.54	4.66	5.01	5.17
25	4.06	4.89	5.11	5.73	6.16	7.76	7.89	7.34
30	6.09	6.96	7.52	9.07	9.45	11.23	10.7	9.63
35	8.49	9.21	...	12.8	...	14.8
40	11.0	11.6	13.2	16.6	16.8	17.7	16.0	14.6
45	13.22	14.3	16.2	20.5	20.4	20.5	18.6	17.1
50	15.1	17.2	19.3	24.3	23.6	23.2	21.3	19.5
55	16.5	20.1	22.3	27.5	26.4	25.8	23.8	22.0
60	18.8	22.7	24.3	29.9	28.8	28.6	26.3	24.3
65	20.4	25.4	25.8	31.9	31.0	31.1	28.6	26.4
70	23.1	26.9	27.1	33.5	33.4	33.0	30.5	28.3
75	24.9	28.4	28.2	35.3	35.6	34.2	32.0	29.9
80	26.2	28.9	29.4	37.6	37.4	35.3	33.2	...
85	27.1	29.1	30.3	39.0	38.4	36.0	33.9	...
90	26.9	29.4	31.3	39.2	38.5	36.4	34.3	...

$$C_{NF} = C_{NB+F} - C_{NB} \tag{5}$$

By scaling the values for C_{NF} thus obtained from the 8-inch Agile diameter to the 6-inch TVC6 diameter we can simply add the values of C_{NF} and C_{NB} , as follows:

$$(C_N)_{TVC6} = (C_{NB})_{TVC6} + C_{NF} \tag{6}$$

The final estimates for $(C_N)_{TVC6}$ are tabulated in Tables 2 and 3.

The procedure for estimating the pitching moment coefficient is illustrated in Figure 3. As this figure shows, we require two additional parameters to obtain C_M . These parameters are the body normal force center of pressure, X_{CPB}/λ , and the effective fin center of pressure, \bar{X}/C_r . These parameters also can be obtained from Footnotes 8 and 9.

TABLE 2. TVC6 Pitching Moment Coefficients.

$A_T = 0.1963$
 $X_T = 59.31$

a	Mach No.												
	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	3.0
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5.000	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310	-0.310
10.000	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390	-0.390
15.000	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700	-1.700
20.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000
25.000	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600	-6.600
30.000	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190	-4.190
35.000	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910	-6.910
40.000	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910	-3.910
45.000	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010	-3.010
50.000	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070	-6.070
55.000	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260	-0.260
60.000	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720	6.720
65.000	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070	1.070
70.000	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570	-3.570
75.000	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160	-3.160
80.000	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530	-16.530
85.000	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120	-14.120
90.000	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920	-18.920
95.000	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020	-23.020
100.000	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070	-26.070
105.000	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370	-31.370
110.000	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500	-34.500
115.000	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260	-33.260
120.000	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270	-34.270
125.000	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250	-30.250
130.000	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110	-26.110
135.000	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690	-25.690
140.000	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660	-24.660
145.000	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060	-18.060
150.000	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150	-14.150
155.000	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070	-9.070
160.000	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720	-6.720
165.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000
170.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000
175.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000	-6.000
180.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values for X_{cp}/ℓ are shown in Figure 4 for angles of attack in the region 0 to 90 degrees. The solid curve shown in Figure 5 was faired through the data points of Figure 4. For angles of attack, 90 degrees $\leq \alpha \leq 160$ degrees, it was assumed that the center of pressure followed the same curve. For angles of attack approaching 180 degrees it was assumed that the center of pressure moved to the blunt end at the nozzle exit. Although this assumption is arbitrary and certain to be complicated by the presence of the rocket plume further efforts were not considered justified. The TVC6 missile is not expected to fly at angles of attack approaching 180 degrees, and performance studies will not be compromised by this assumption.

The effective fin center of pressure, \bar{X}/C_r , is obtained from Footnote 8 through the relation

$$\bar{X}/C_r = \frac{\frac{-\Delta C_M}{\Delta C_N} d - \ell_{FLE}}{C_r} \quad (7)$$

where

$$\Delta C_M = C_{M_{B+F}} - C_{M_B}$$

and

$$\Delta C_N = C_{N_{B+F}} - C_{N_B}$$

The values of \bar{X}/C_r are tabulated in Table 4.

A computer program was written to perform the computations indicated in Figure 3. This program is given in Appendix A.

The fin location, X_{FLE} , was varied in an attempt to "match" the Agile static stability margin at launch, as shown in Figure 6. Although the present model for the TVC6 pitching moment estimate does not duplicate the Agile stability margin exactly, a value of $X_{FLE} = 110$ inches was selected as giving a reasonable compromise over launch Mach numbers in the range of $0.7 \leq \text{Mach} \leq 1.2$.

TABLE 4. Effective Fin Center of Pressure, X/C_r , Configuration B₆ N₂₁ C_{62F} A₉ (See Footnote 8).

Angle of attack	Mach no.			
	0.8	1.1	1.6	2.0
0	6.52	1.86	1.42	5.2
5	6.52	1.86	1.42	5.2
10	1.48	0.19	-0.81	0.91
15	2.39	2.39	0.52	2.0
20	1.52	1.02	2.52	0.66
25	1.13	0.65	1.57	0.32
30	0.42	0.97	0.08	-0.42
35	-0.19	0.43	1.69	-0.81
40	0.81	0.64	0.13	...
45	1.19	0.16	0.66	...
50	1.76	-0.14	0.65	...
55	1.97	0.08	1.13	...
60	1.13	-1.09	-0.2	...
65	2.6	-0.91	0.52	...
70	1.27	-0.81	1.41	...
75	2.08	0.32	0.39	...
80	5.32	1.41	0.96	...
85	1.19	1.36	1.19	...
90	1.1	1.19	1.86	...

The final estimates for the TVC6 values of C_M are tabulated in Table 2. Finally, the sensitivity to C_N , X_{cp} , and \bar{X}/C_r of the estimated values of C_M are shown in Figures 7 through 14. As these figures show, the center of pressure of the body alone normal force, X_{cpB} , is the most critical parameter. If the TVC6 missile is to be considered seriously as a future SRAAM candidate, then a thorough study of missile overall performance to the parameter X_{cpB} should be undertaken.

ESTIMATE OF THE SIDE FORCE AND YAWING MOMENT COEFFICIENTS FOR TVC6

This part of the report summarizes the method used to estimate the TVC6 side force and yawing moment coefficients that arise due to

asymmetric flow separation on the missile body. The reader is advised that the method used is based on an (as yet) unproven, semi-empirical method. The results should be used for preliminary planning purposes only.

Figure 15 defines the "out-of-plane" or side force that occurs due to asymmetric flow separation on the missile body. The prediction technique used for the estimates is based on the information contained in Footnotes 5 and 6. The work of Lamont and Hunt is strictly applicable to conditions of incompressible, laminar flow over cylindrical afterbodies with pointed tangent ogive noses. Although these conditions are not representative of realistic flight conditions such as those experienced by TVC6, this technique nonetheless was selected for several reasons. First the flow structure observed by Lamont and Hunt is believed by the author to be qualitatively the same as that which exists under conditions of compressible, turbulent flow. Second, the method of Lamont and Hunt is simple and easily implemented for preliminary calculations. Attempts were made to correct the method for effects of compressibility and higher Reynolds numbers. These attempts will be described later.

In Footnote 5, it was shown that the "out-of-plane" or side force on the missile body was typically distributed along the body, as shown in Figure 16. This force distribution was obtained via pressure measurements around the circumference of the body at different axial locations. The force coefficient

$$C_F = F / \frac{1}{2} \rho V_\infty^2 \sin^2 \alpha D \quad (8)$$

where

- F = the side force per unit length
- ρ = air density
- V_∞ = free stream velocity
- α = angle of attack
- D = cylinder diameter

was shown to correlate well with the parameter $\bar{t} = X \tan \alpha / R$, where X is the axial station measured from the missile nose and R is the cylinder radius. A typical curve of C_F versus \bar{t} is shown in Figure 17. This curve, with the appropriate magnitudes, completely defines the side force and distribution from which the total side force and yawing moment can be obtained. Lamont and Hunt showed that the values for the parameters \bar{t}_A , \bar{t}_C , \bar{t}_E , \bar{t}_G correlated well with angle of attack and nose fineness ratio, $F_N \equiv L_N/D$, where L_N is the total nose length.

Also the maximum value of the parameter C_{F_B} at point B on Figure 17 was shown to be a function of the parameter \bar{X} , where $\bar{X} \equiv 2 F_N \tan \alpha$.

The values of C_F at the points D and F on the curve were given approximately by

$$C_{F_D} = -0.6 C_{F_B} \quad (9)$$

$$C_{F_F} = 0.3 C_{F_B} \quad (10)$$

The shape of the curve from points A to C is given by

$$C_F = C_{F_B} \left(e^{\frac{\chi_B - \chi}{\tan \chi_B}} \right) \frac{\sin \chi}{\sin \chi_B} \quad (11)$$

where

$$\chi = \bar{t} (\bar{t} - \bar{t}_A) / (\bar{t}_C - \bar{t}_A)$$

The curve from point C to E is defined by

$$C_F = -0.6 C_{F_B} \sin \pi \xi_1 \quad (12)$$

where

$$\xi_1 = (\bar{t} - \bar{t}_C) / (\bar{t}_E - \bar{t}_C)$$

while from point E to point G the curve is defined by

$$C_F = 0.3 C_{F_B} \sin \pi \xi_2 \quad (13)$$

where

$$\xi_2 = (\bar{e} - \bar{e}_E) / (\bar{e}_G - \bar{e}_E)$$

For $\bar{e} > \bar{e}_G$ the out-of-plane force, $C_F = 0$.

With the out-of-plane force distribution defined as outlined above it is straightforward to obtain the total side force coefficient, C_Y , and the yawing moment coefficient, C_{η} .

The side force coefficient is obtained from

$$C_Y = 2/\pi \sin \alpha \cos \alpha \int_0^{\bar{e} = \ell/R \tan \alpha} C_F(\bar{e}) d\bar{e} \quad (14)$$

and the corresponding moment coefficient is

$$C_{\eta} = 1/\pi \cos^2 \alpha \int_0^{\bar{e} = \ell/R \tan \alpha} (\bar{e}_{REF} - \bar{e}) C_F(\bar{e}) d\bar{e} \quad (15)$$

where

ℓ = missile length

$$\text{and } \bar{e}_{REF} = \frac{X_{REF}}{R} \tan \alpha$$

with X_{REF} = moment reference station

The above description is a brief outline of the method discussed in more detail in Footnote 6. Using this technique Lamont and Hunt obtained good agreement with experimental data obtained under the conditions for which the theory is strictly applicable. As regards TVC6, one of the major areas of concern was to establish how the increase in missile overall fineness ratio, ℓ/D , would affect the magnitude of the out-of-plane forces and moments. Hence, the prediction method was applied directly

and the results of Figures 18 and 19 obtained. These figures show how the maximum side force and yawing moment coefficients depend on ℓ/D . The theory predicts that C_Y is essentially independent of ℓ/D for $\ell/D > 12$. However, the moment coefficient, C_η , increases rapidly with ℓ/D . Figure 19 shows that C_η more than doubles as ℓ/D increases from 12 to 20. The reader will recall that Agile had an $\ell/D = 12.5$ and that TVC6 had an $\ell/D = 20$.

The next step in this analysis was to compare the theory with experimental data obtained under conditions for which both compressibility and high Reynolds number effects would be present. For these comparisons the work of Deffenbaugh was utilized.^{10,11} Deffenbaugh's experiments included pressure measurements on the configurations shown in Figure 20. From these data direct comparison can be made with the generalized curve from Lamont and Hunt that was shown in Figure 17. Figure 21 compares the predicted values of the points A, B, C, E, and G of Figure 17 from Lamont and Hunt's method to those values obtained from Deffenbaugh's data. The spacing values $\bar{\epsilon}_E - \bar{\epsilon}_C$ and $\bar{\epsilon}_B$ shown on Figures 21 and 22, respectively, are in reasonable agreement with the prediction method, despite the higher Mach number and Reynolds number. The values for $\bar{\epsilon}_A$ and $\bar{\epsilon}_C$ do not agree well, however. For the prediction of C_Y and C_η for TVC6 the values for $\bar{\epsilon}_A$ and $\bar{\epsilon}_C$ for supercritical Reynolds numbers were modified to

$$\bar{\epsilon}_A = 1.0 + 0.05\alpha \quad (16)$$

$$\bar{\epsilon}_C = 9.5 + 4.7 \tan\alpha \quad (17)$$

¹⁰F.D. Deffenbaugh and W.G. Koerner. "Asymmetric Vortex Wake Development on Missiles at High Angles of Attack," *J. Spacecraft and Rockets*, Vol. 14, No. 3 (March 1977).

¹¹U.S. Army Missile Research and Development Command. Summary of the 4th Meeting of the DoD/NASA High Angle of Attack Working Group, 16-17 Feb 1977. Huntsville, Ala., Redstone Arsenal, Feb 1977. (Internal Technical Note TDK-77-1, publication UNCLASSIFIED.)

With the node points (A, C, E and G) and the maximum and minimum points (B, D, and F) determined only three features remain to complete the model. The maximum value, C_{FB} , must be corrected for the effects of compressibility, nose bluntness, and Reynolds number. To study those effects the reports referenced on Figures 22 through 26 were consulted. Figure 22 shows the variation of maximum side force, C_Y , with nose fineness ratio, F_n , for sharp-nosed ogive cylinders. Figure 23 presents some experimental data that indicates how nose bluntness affects the maximum value of C_Y . Figure 24 presents experimental data indicating the dependence of the maximum C_Y on Reynolds number. Figures 23 and 24 indicate that there is no apparent consistent trend, with respect to the effects of nose bluntness, or Reynolds number. The theoretical method does seem to bound the maximum values of C_Y for sharp-nosed bodies, as indicated in Figure 22. Figures 25 and 26 show the effects of Mach number on both maximum side force and yawing moment. In this case it is clear that the values decrease with increasing Mach number and are essentially zero for Mach numbers greater than 1.6.

In view of the above data it was decided that no attempt would be made to correct the theory for nose bluntness. The simple approach suggested in Footnote 6 was used to account for turbulent boundary layer separation. This approach was implemented as follows:

$$\text{if } R_D \equiv \frac{U_\infty D}{\nu} \geq 200,000$$

$$\text{then } C_{FB} = 0.8 C_{FB}' \text{ (for laminar flow)}$$

The compressibility effects were grossly included by simply multiplying the theoretical incompressible values of C_Y and C_η by a factor, f , where

$$f = 1.0 \text{ for } M_\infty \leq 0.6$$

$$f = 1.6 - M_\infty \text{ for } 0.6 \leq M_\infty \leq 1.6$$

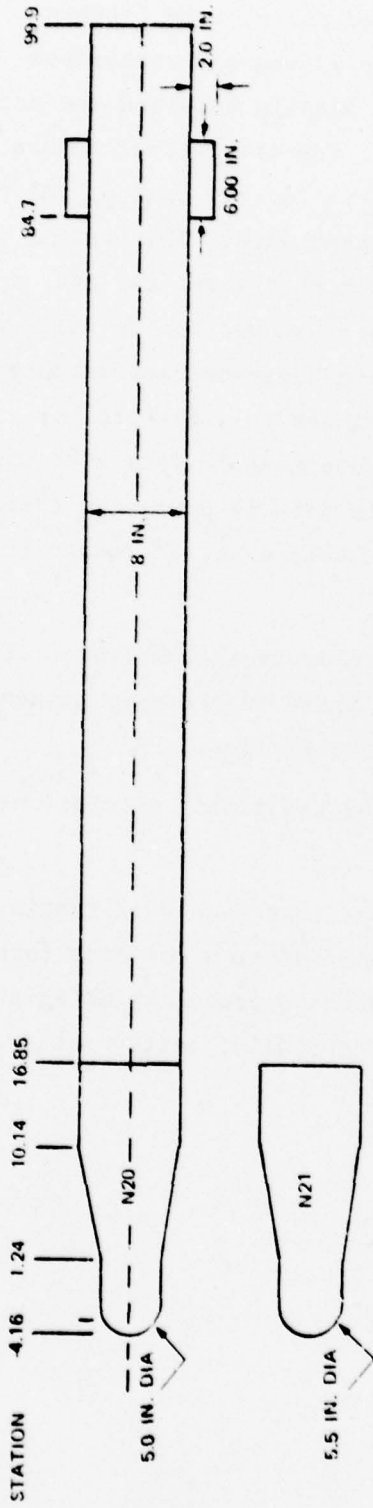
$$f = 0.0 \text{ for } M_\infty > 1.6$$

Next, with the method modified as described above, some further comparisons were made with other data. Figure 27 shows a comparison of the theoretical distribution of C_F along a missile body and the actual measured values of Deffenbaugh (Footnote 10). The theoretical values are higher as may be expected, because the theory is for the maximum values and the experimental values are for time-averaged data. The overall value of C_Y versus angle of attack, α , is shown for both theoretical and experimental values in Figure 28. The original theory showed the C_Y value going to zero at 70 degrees angle of attack; the data suggested approximately 50 degrees. The theory was revised to approximate this feature better and Figures 29 through 32 were obtained to compare Agile data with theory. Although the quantitative agreement with Agile data is poor, the theory does generally bound the data and, hence, could be expected to provide estimates of worst-case data.

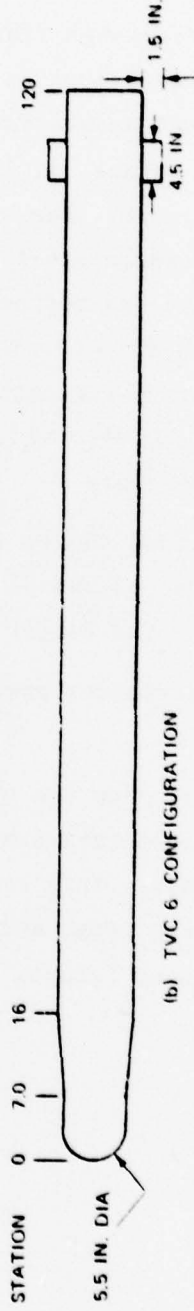
Finally, the modified theory was used to compute the estimates of C_Y and C_n shown in Figures 33 and 34 for TVC6. These values were adjusted for compressibility by the factor, f , discussed earlier.

A listing of the computer program used for the final calculations is included in Appendix B.

It should be clear from the above analyses that much work remains to be accomplished before accurate and reliable predictions of side forces and moments can be made. This area of research is presently being pursued by the Navy, Air Force, Army, and NASA and, hopefully, better methods will be available in the near future.



(a) AGILE CONFIGURATIONS (6 FIXED SEXTA-FORM FINS)



(b) TVC 6 CONFIGURATION

FIGURE 1. Agile and TVC6 Missile Configurations.

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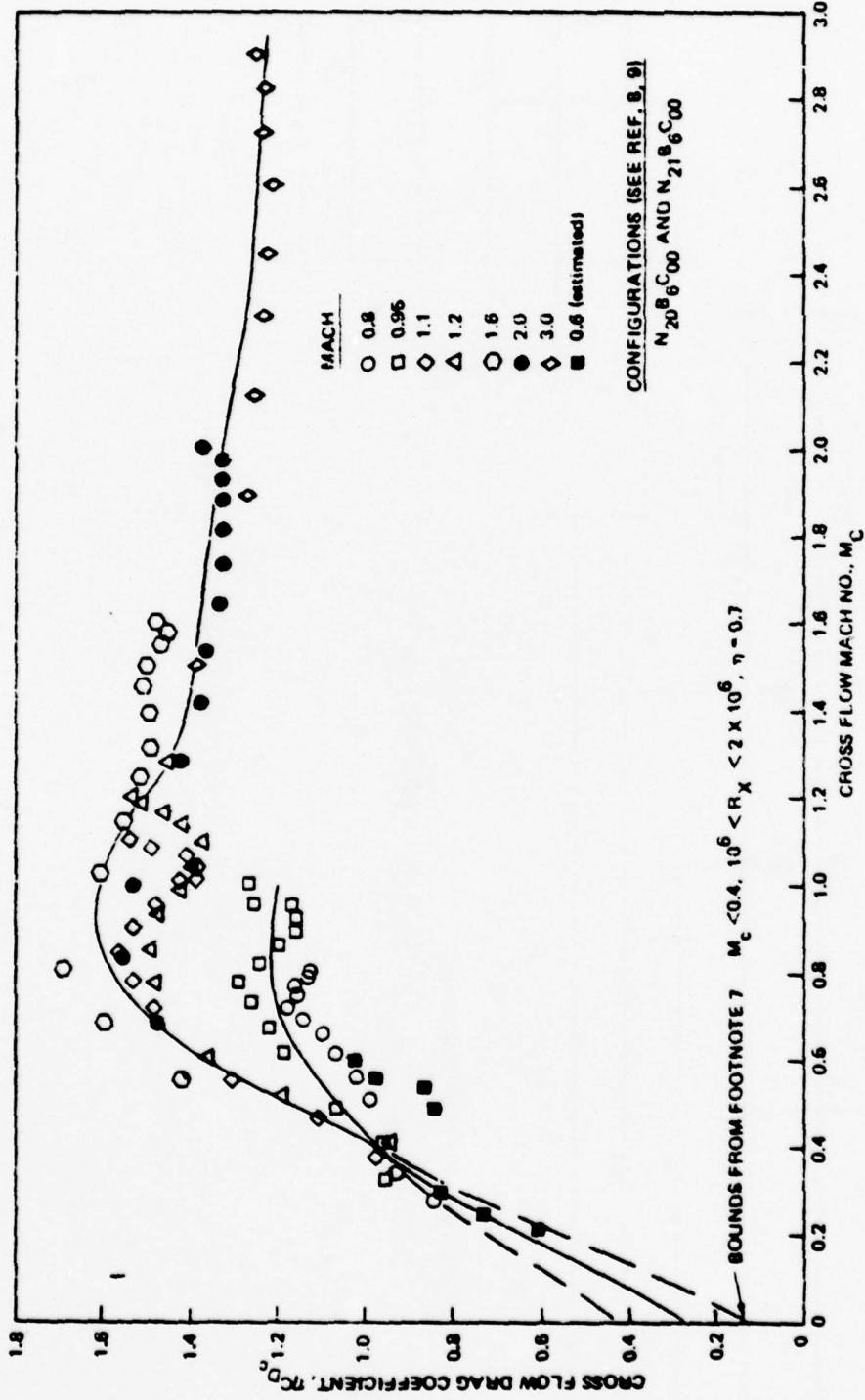
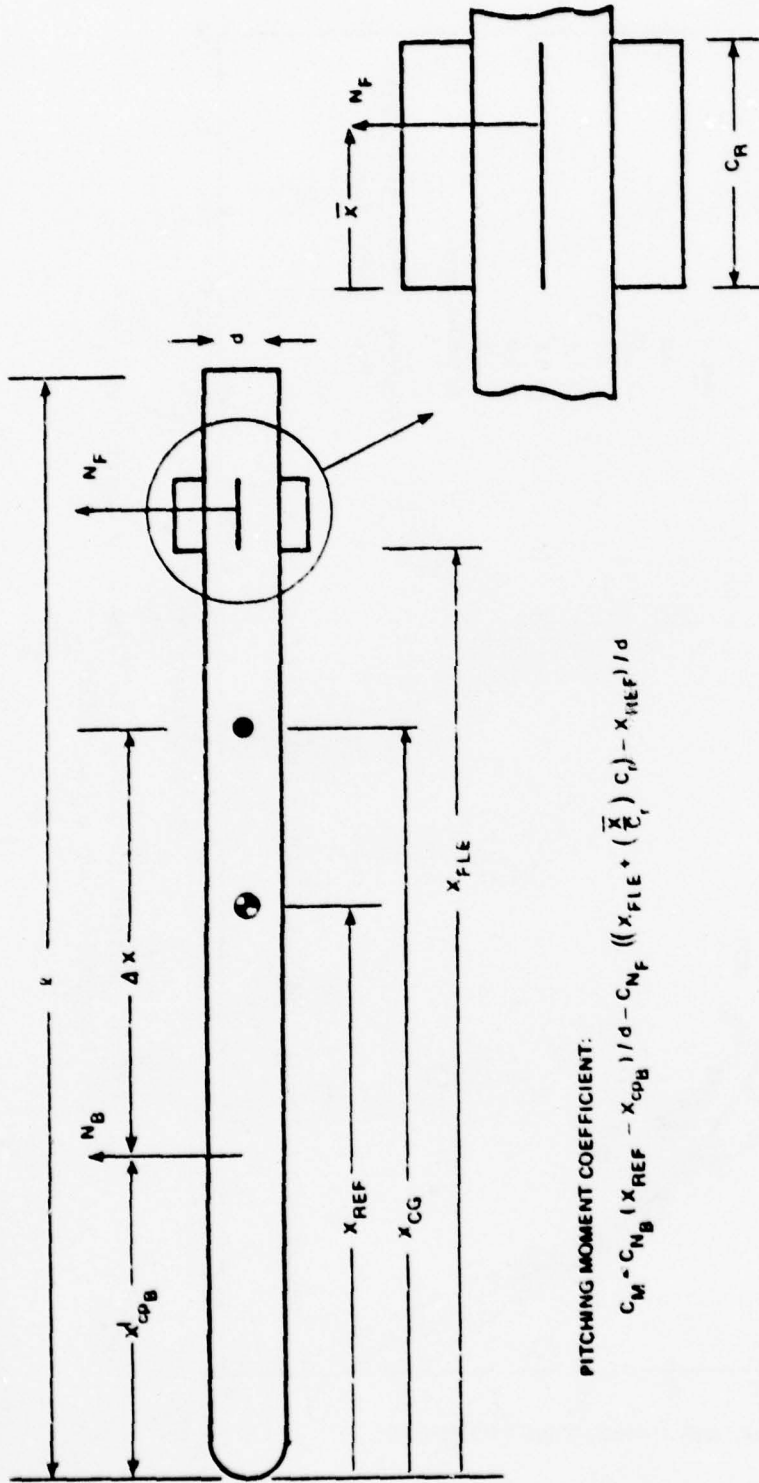


FIGURE 2. Correlation of Cross Flow Drag Coefficient vs Cross Flow Mach Number for Agile.

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PITCHING MOMENT COEFFICIENT:

$$C_M = C_N (x_{REF} - x_{cpB}) / d - C_{N_F} ((x_{FLE} + (\bar{x} / C_r) C_r) - x_{REF}) / d$$

FIGURE 3. TVC6 Moment Calculations.

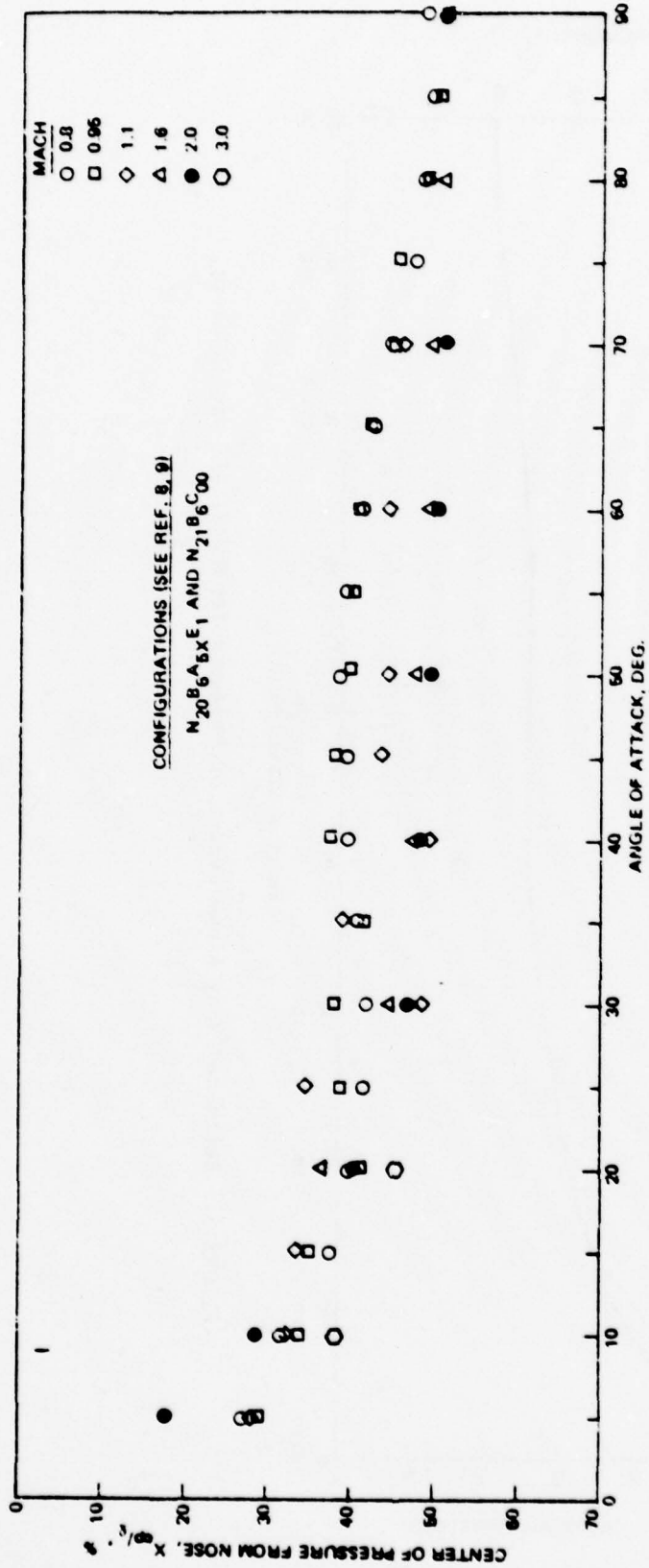


FIGURE 4. Center of Pressure for Agile Configurations.

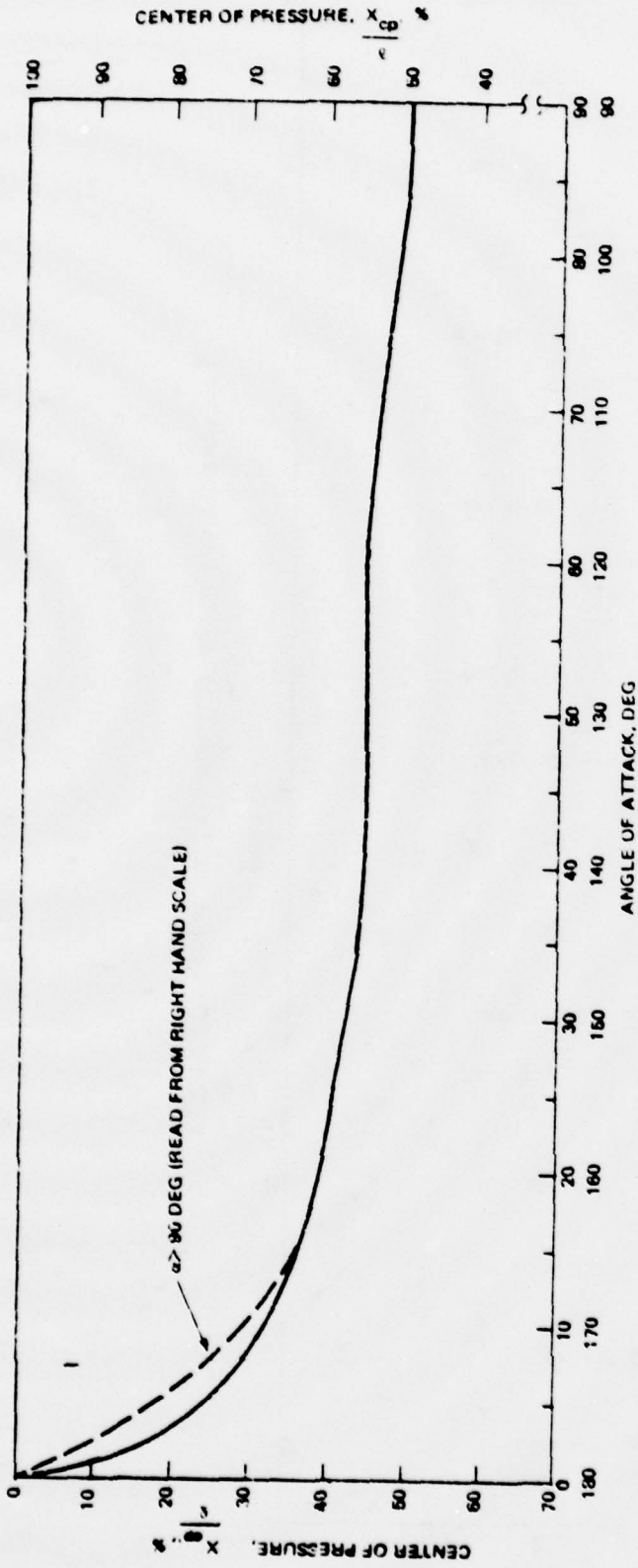


FIGURE 5. Estimated Body Alone Center of Pressure for TVC6, All Mach Numbers.

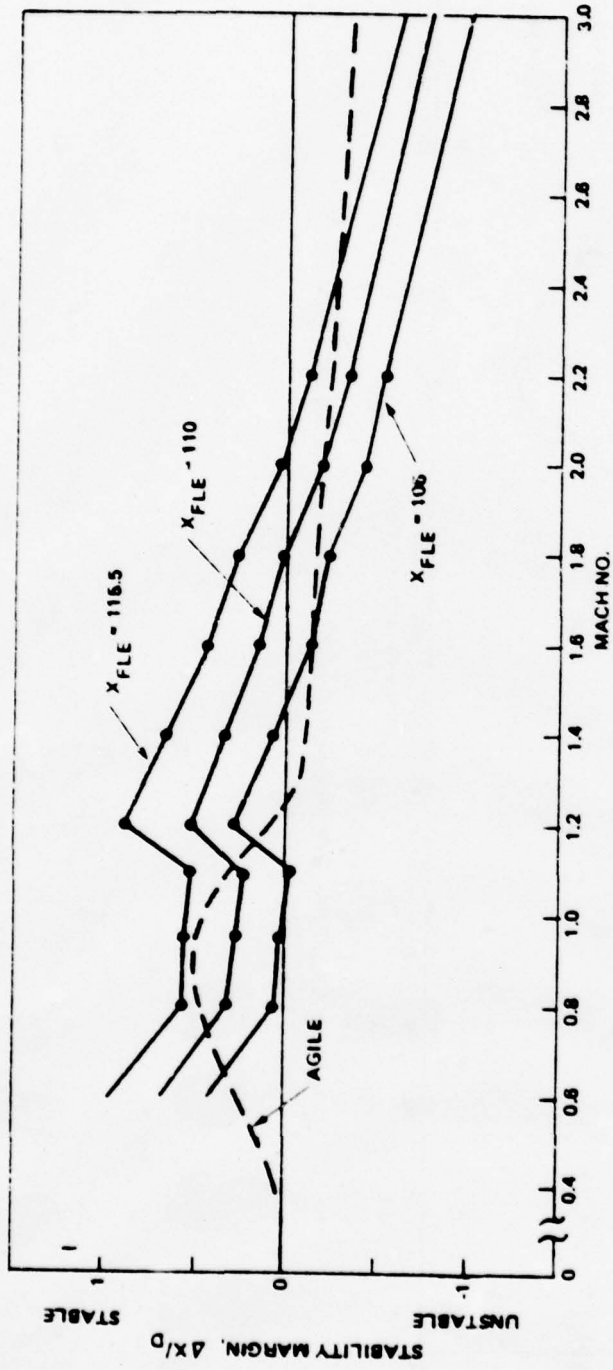


FIGURE 6. Comparison of Agile and TVC6 Launch Static Stability Margins.

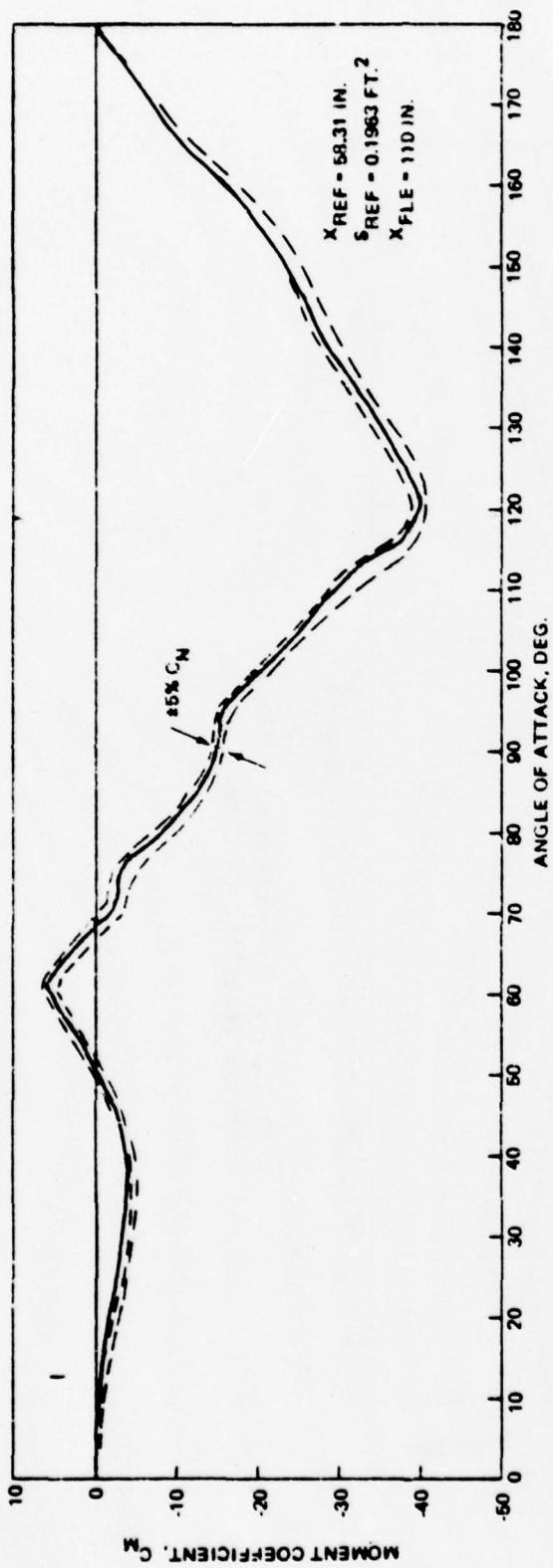


FIGURE 7. TVC6 Moment Coefficient Sensitivity to Body Normal Force Coefficient, C_{NB} (Mach = 0.8).

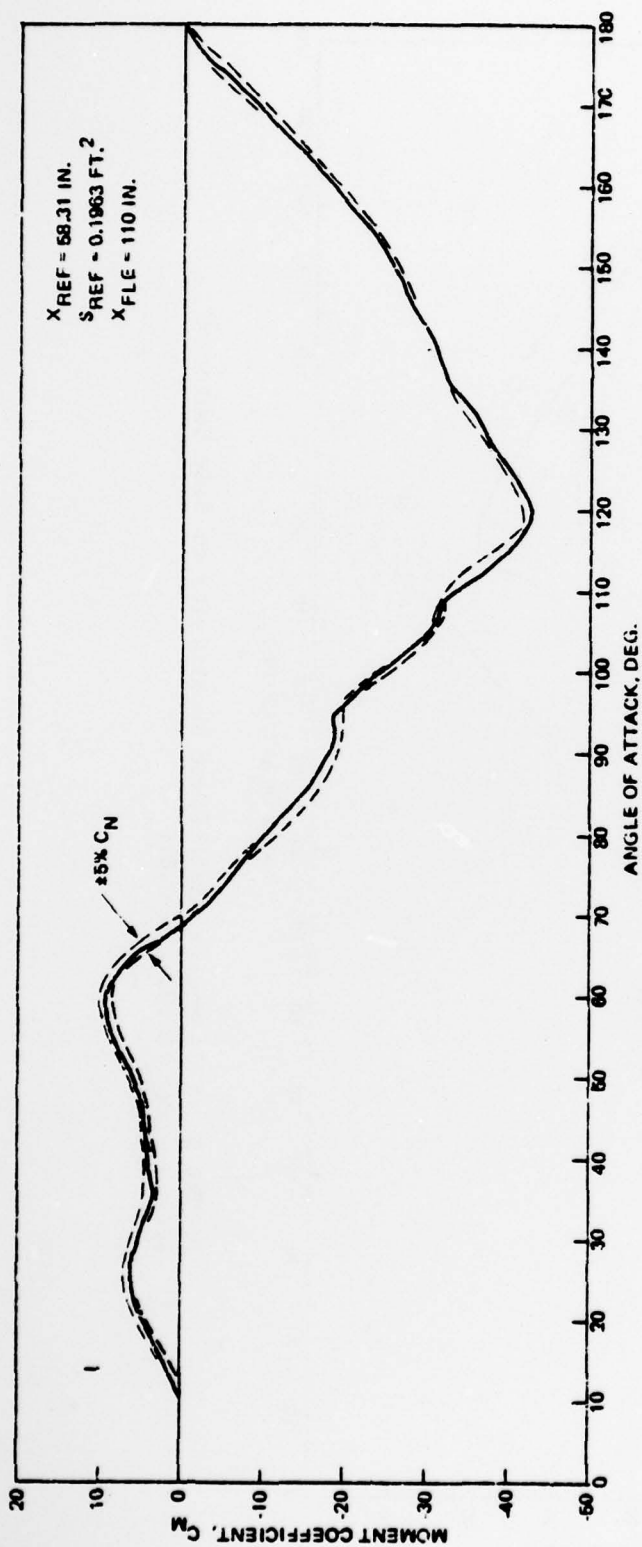


FIGURE 8. TVC6 Moment Coefficient Sensitivity to Body Normal Force Coefficient, C_N (Mach = 2.0).

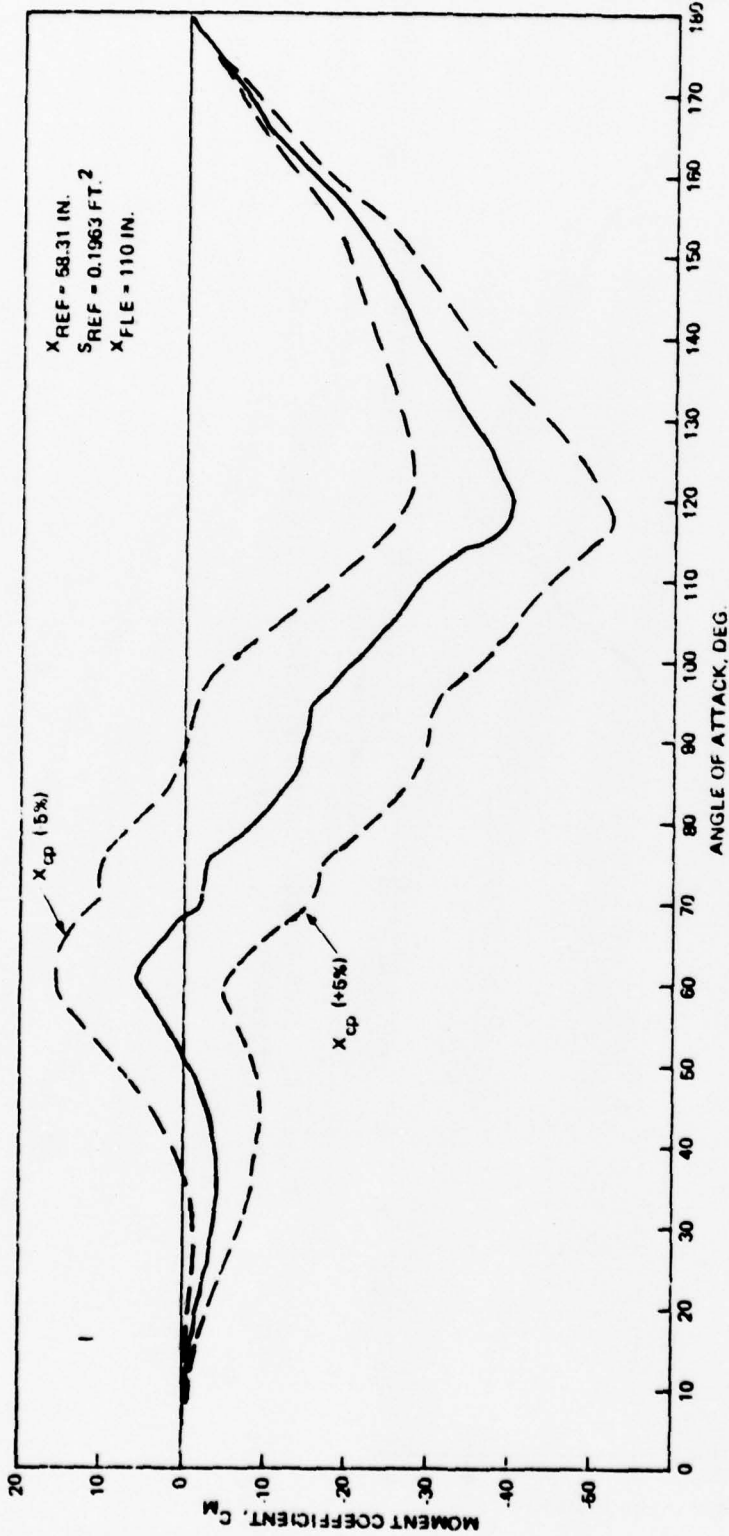


FIGURE 9. TVC6 Moment Coefficient Sensitivity to Body Center of Pressure, X_{cp}/l (Mach = 0.8).

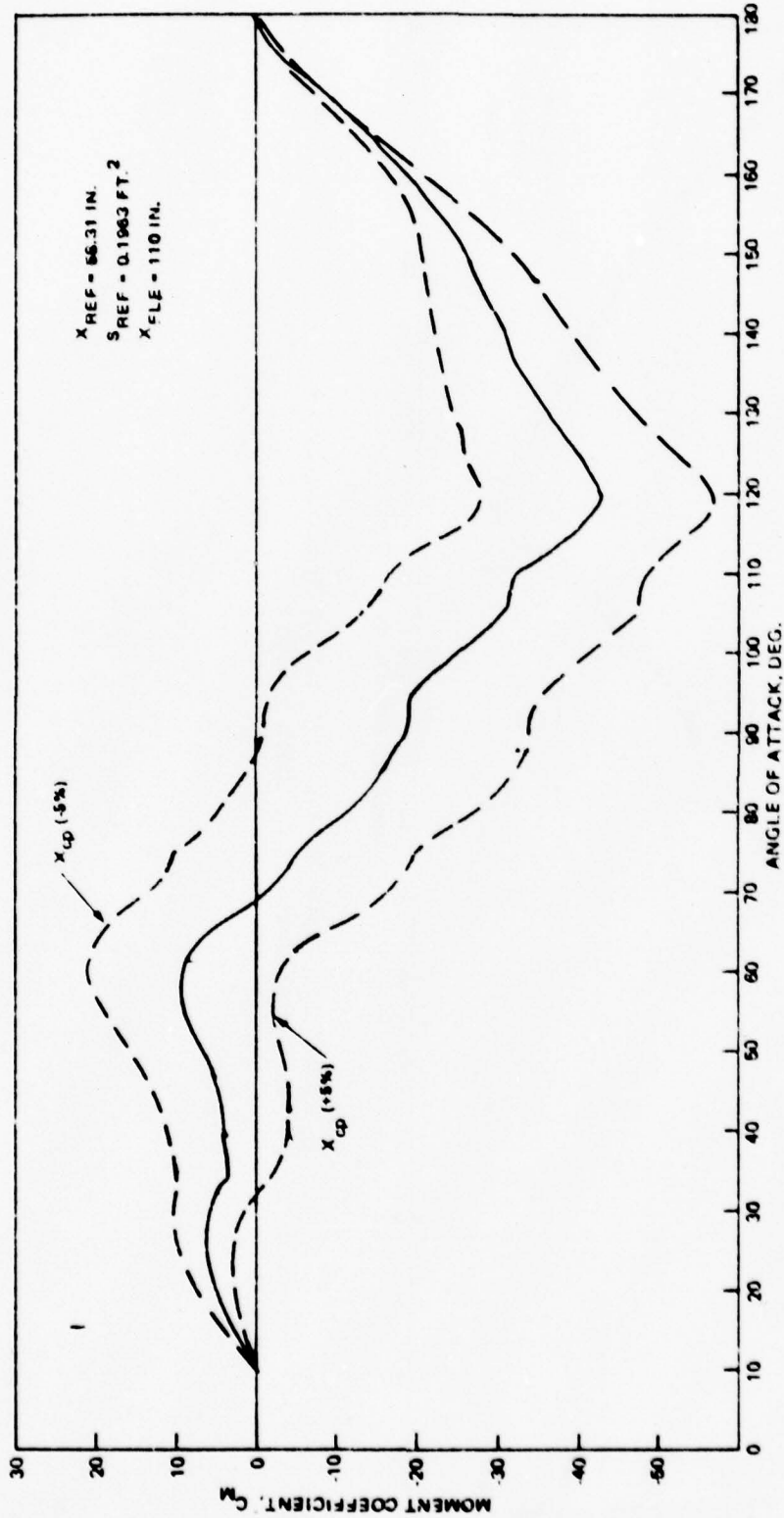


FIGURE 10. TVC6 Moment Coefficient Sensitivity to Body Center of Pressure, X_{cp} / λ (Mach = 2.0).

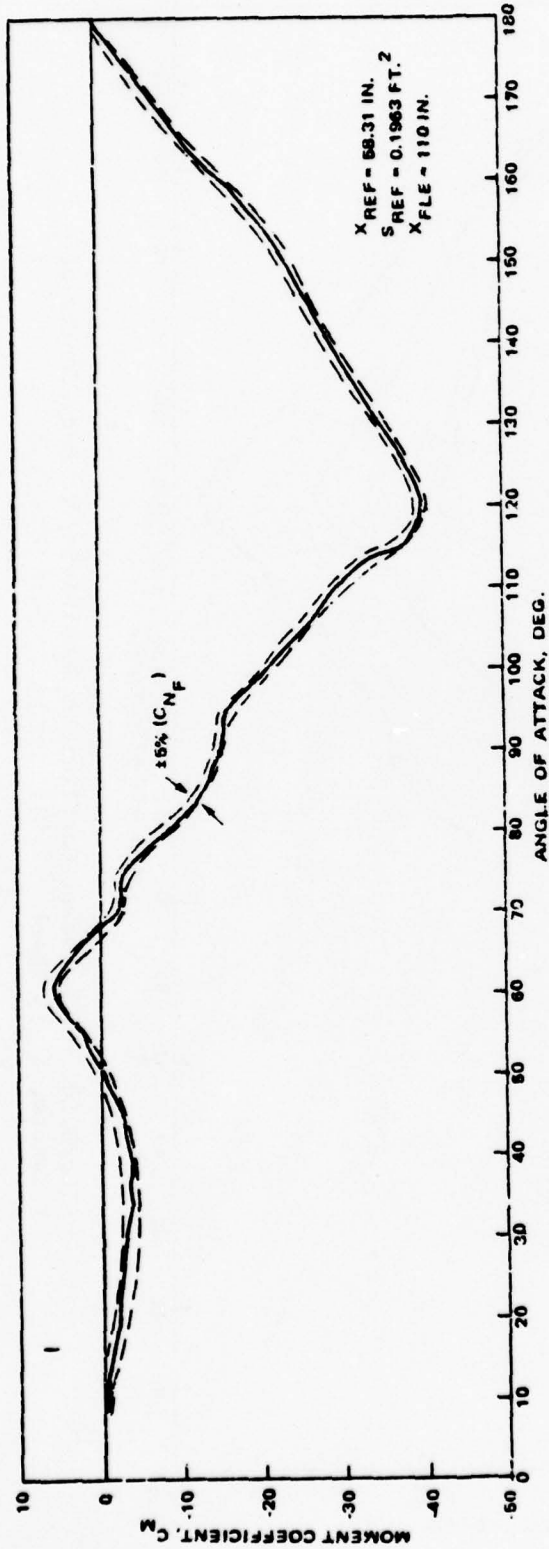


FIGURE 11. TVC6 Moment Coefficient Sensitivity to Fin Normal Force, C_{N_f} (Mach = 0.8).

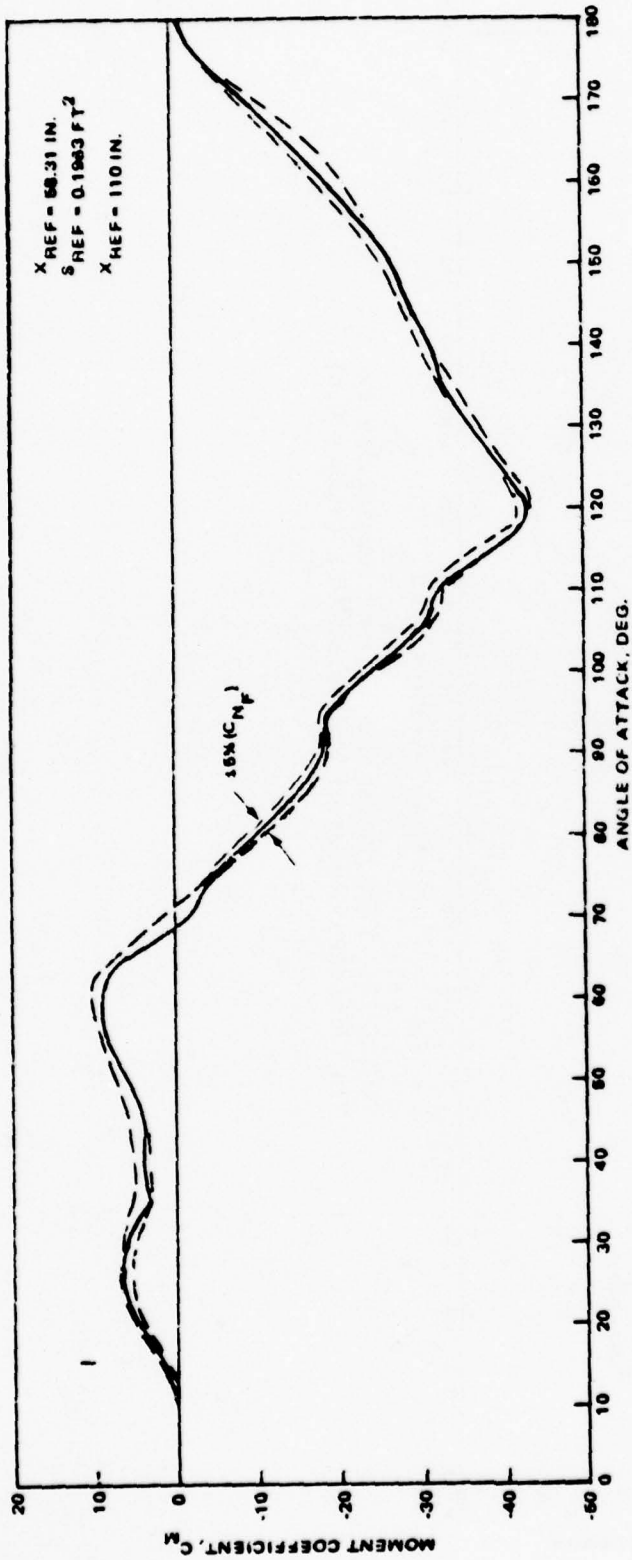


FIGURE 12. TVC6 Moment Coefficient Sensitivity to Fin Normal Force, C_{NF} (Mach 2.0).

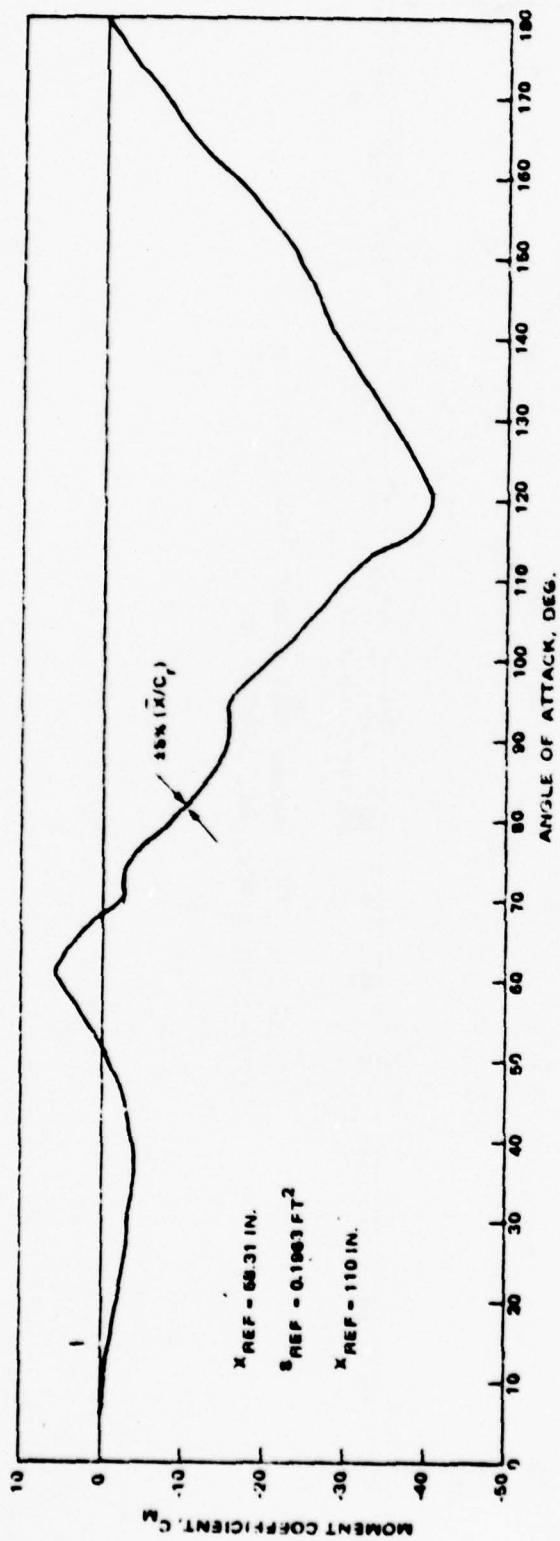


FIGURE 13. TVC6 Moment Coefficient Sensitivity to Fin Effective Center of Pressure, \bar{x}/c_p (Mach = 0.8).

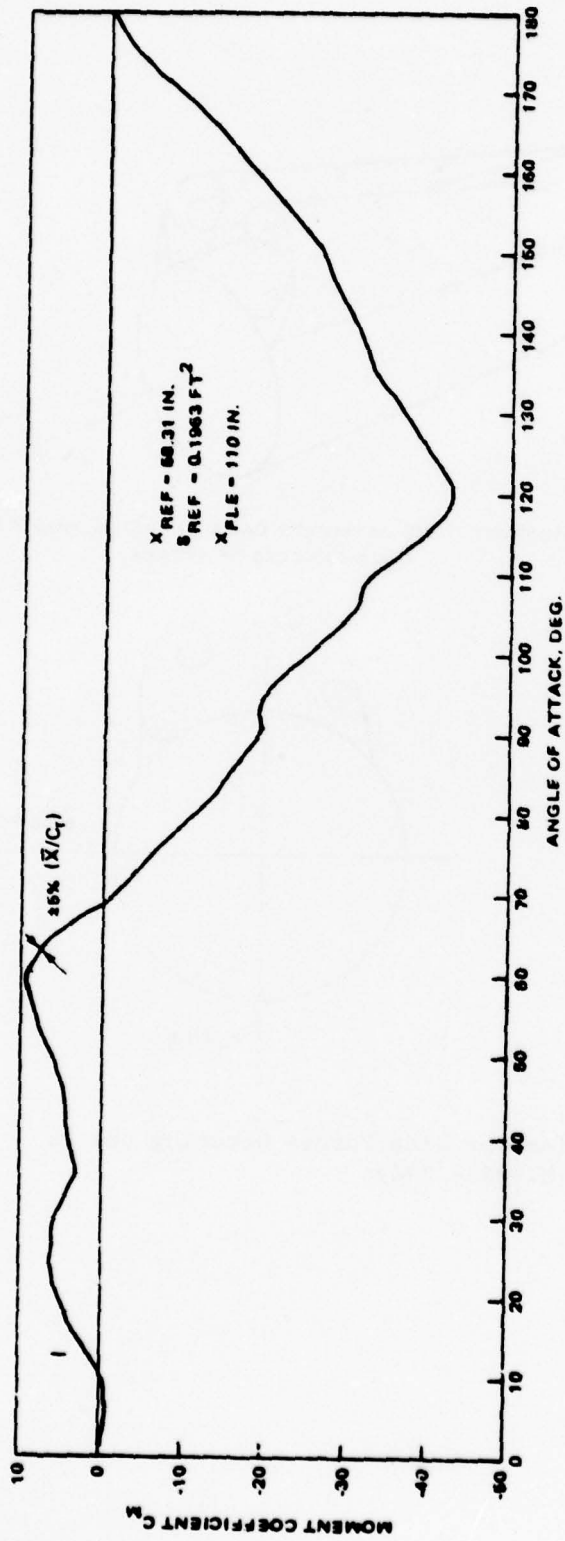


FIGURE 14. TVC6 Moment Coefficient Sensitivity to Pin Effective Center of Pressure, \bar{X}/C_r (Mach = 2.0).

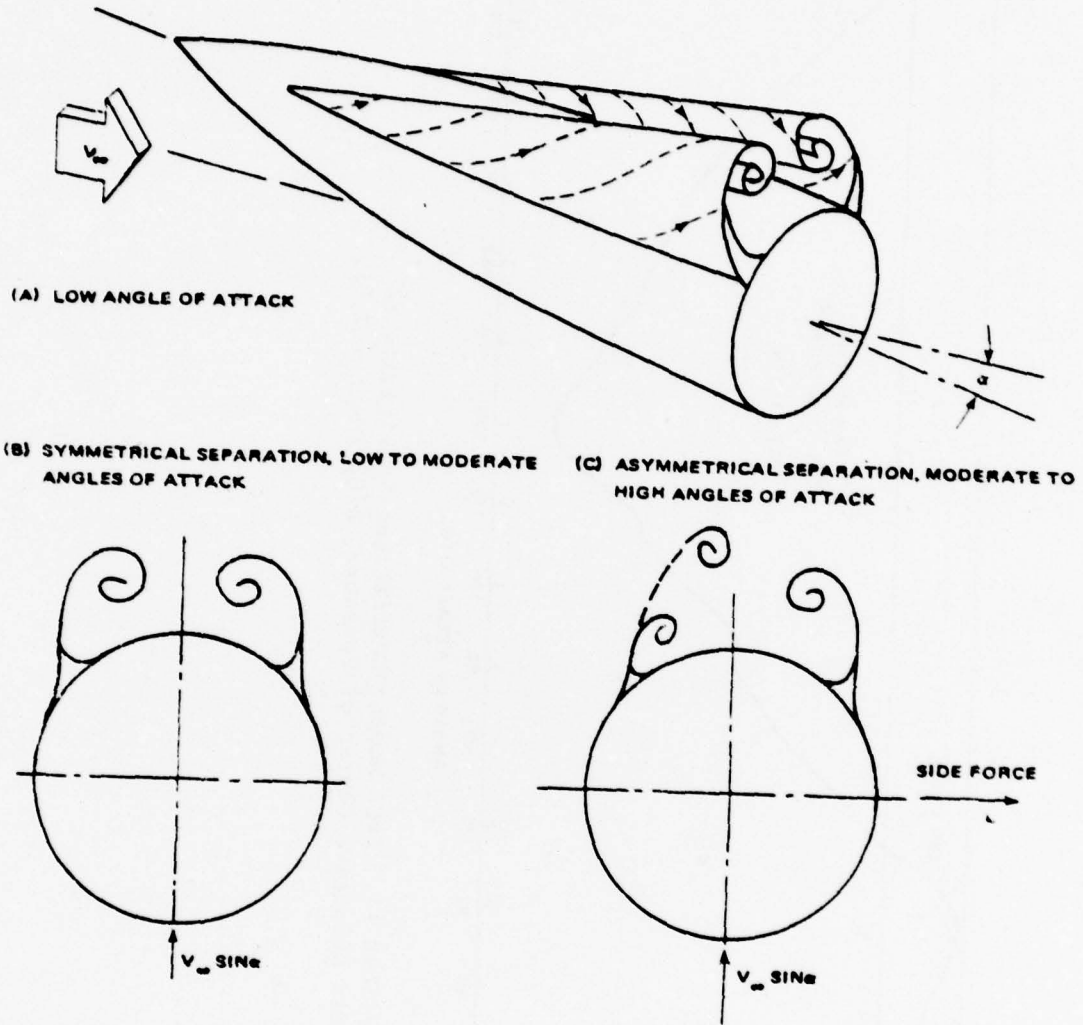


FIGURE 15. Out-of-Plane or Side Forces Occuring Due to Flow Separation on a Missile Body.

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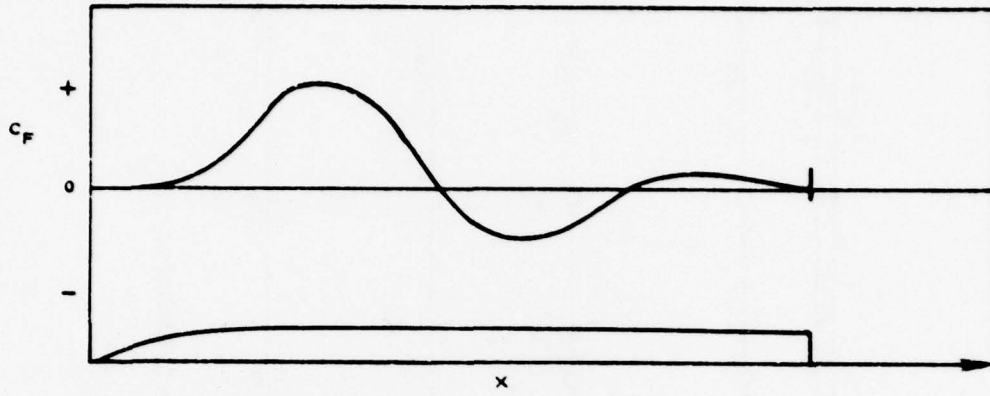


FIGURE 16. Typical Side Force Distribution at a Fixed Angle of Attack.

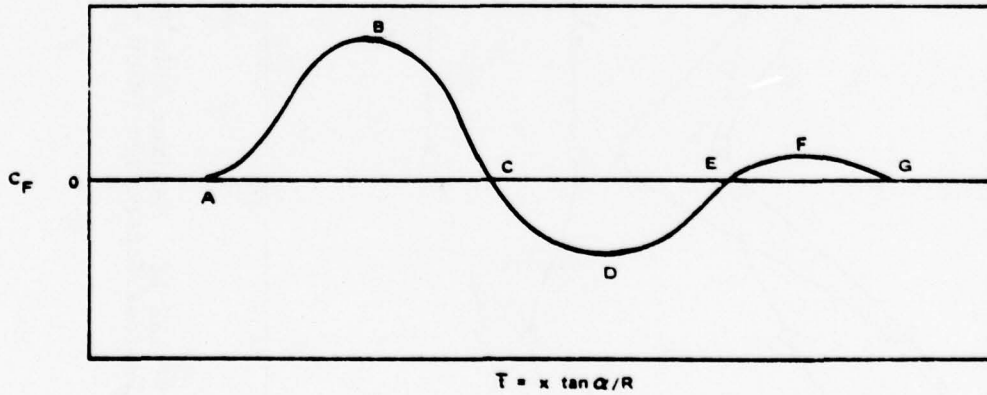


FIGURE 17. Characteristic Distribution of Side Force Along the Body (From Reference 6).

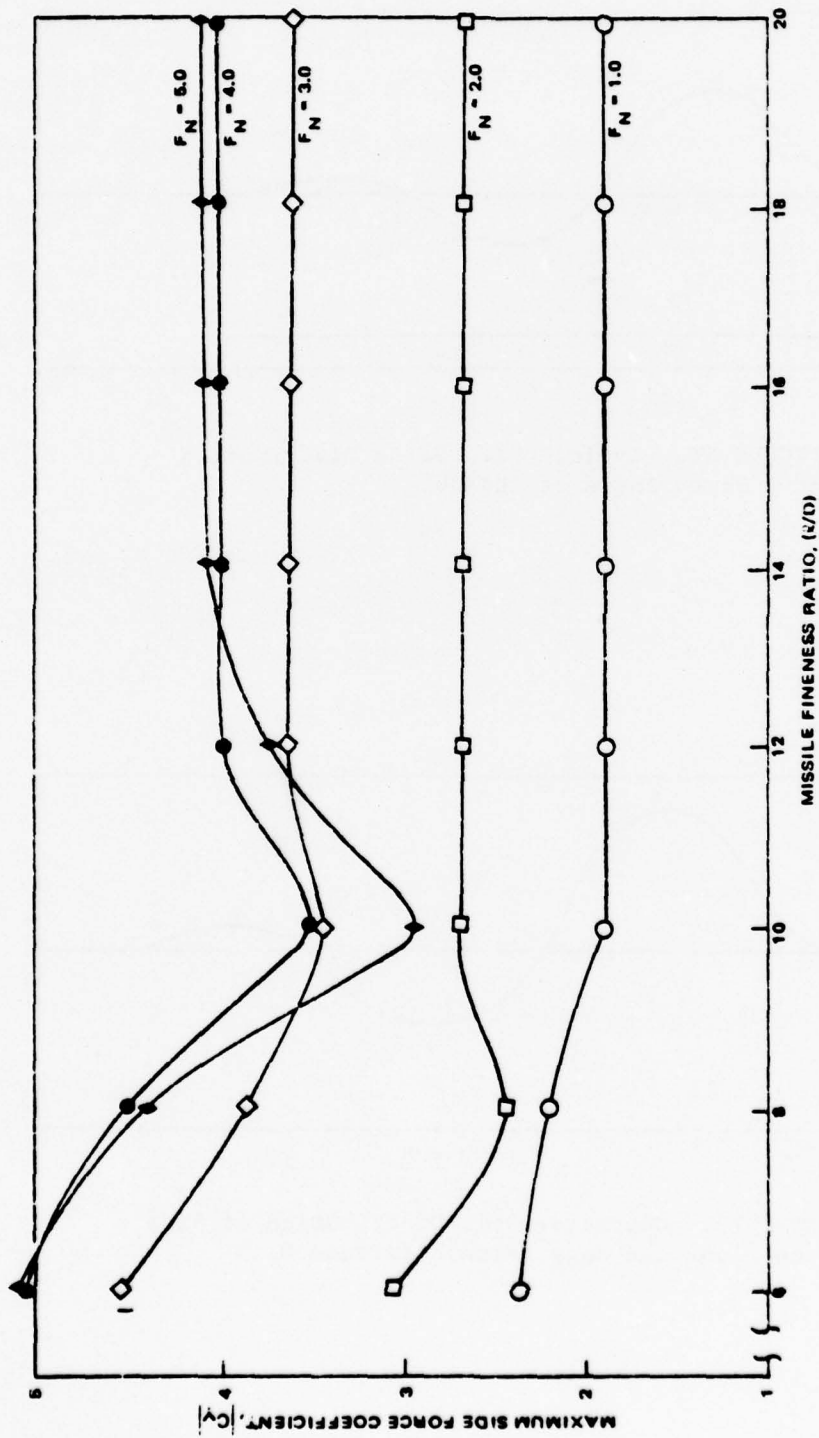
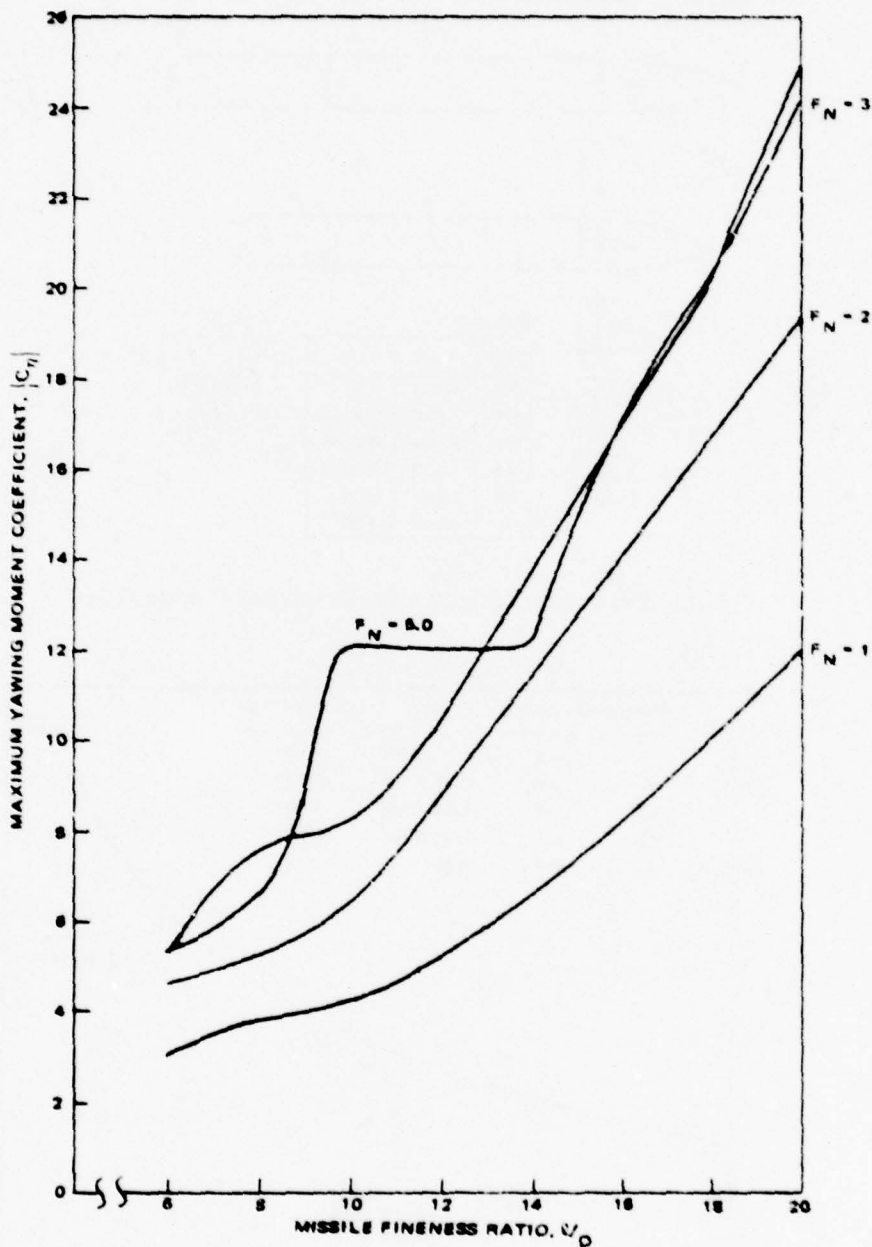


FIGURE 18. Maximum Side Force Coefficient for Ogive Cylinders, Laminar Separation ($Mach = 0$) (From Reference 6).



- FIGURE 19. Maximum Yawing Moment Coefficient for Ogive Cylinders, Laminar Separation (Mach = 0; Moment Center at Mid-Body) (From Reference 6).

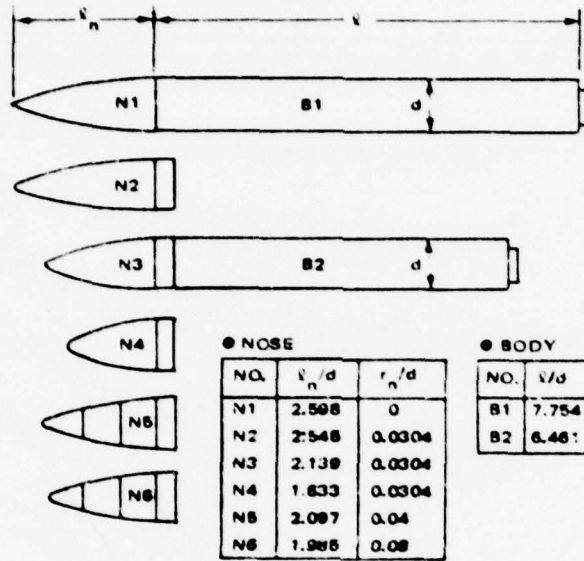


FIGURE 20. Configurations From Reference 10.

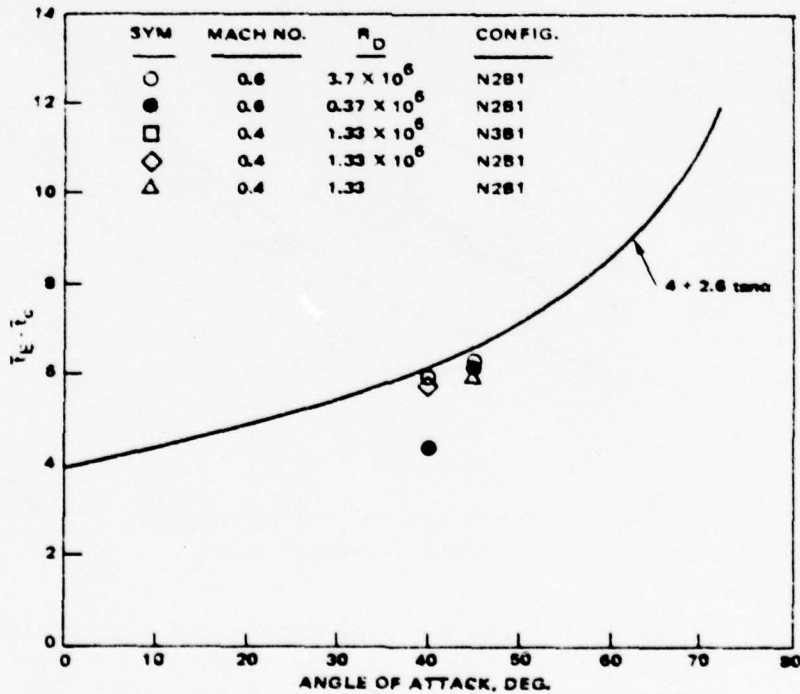


FIGURE 21. Comparison of Theoretical Spacing Parameters with Data From Reference 10.

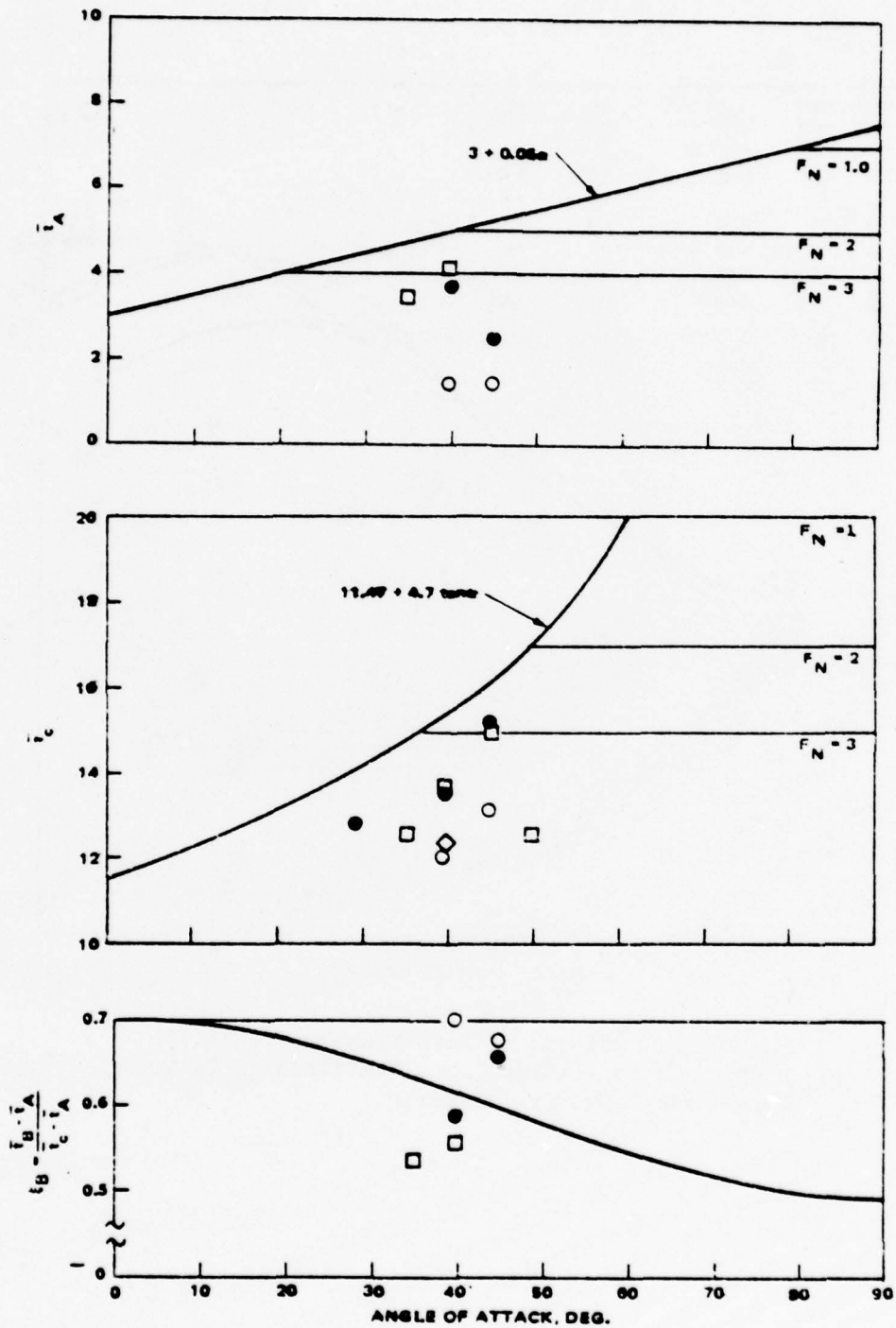


FIGURE 21. (Contd.)

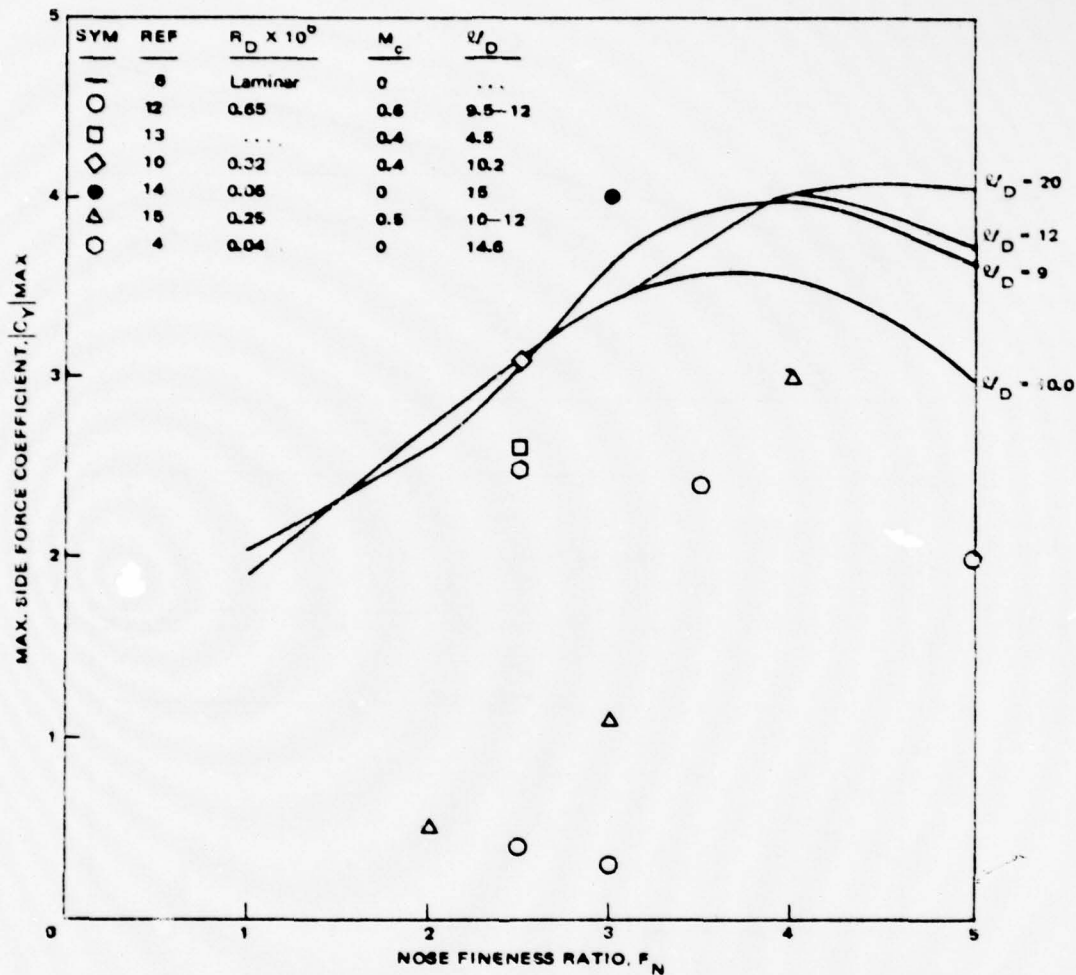
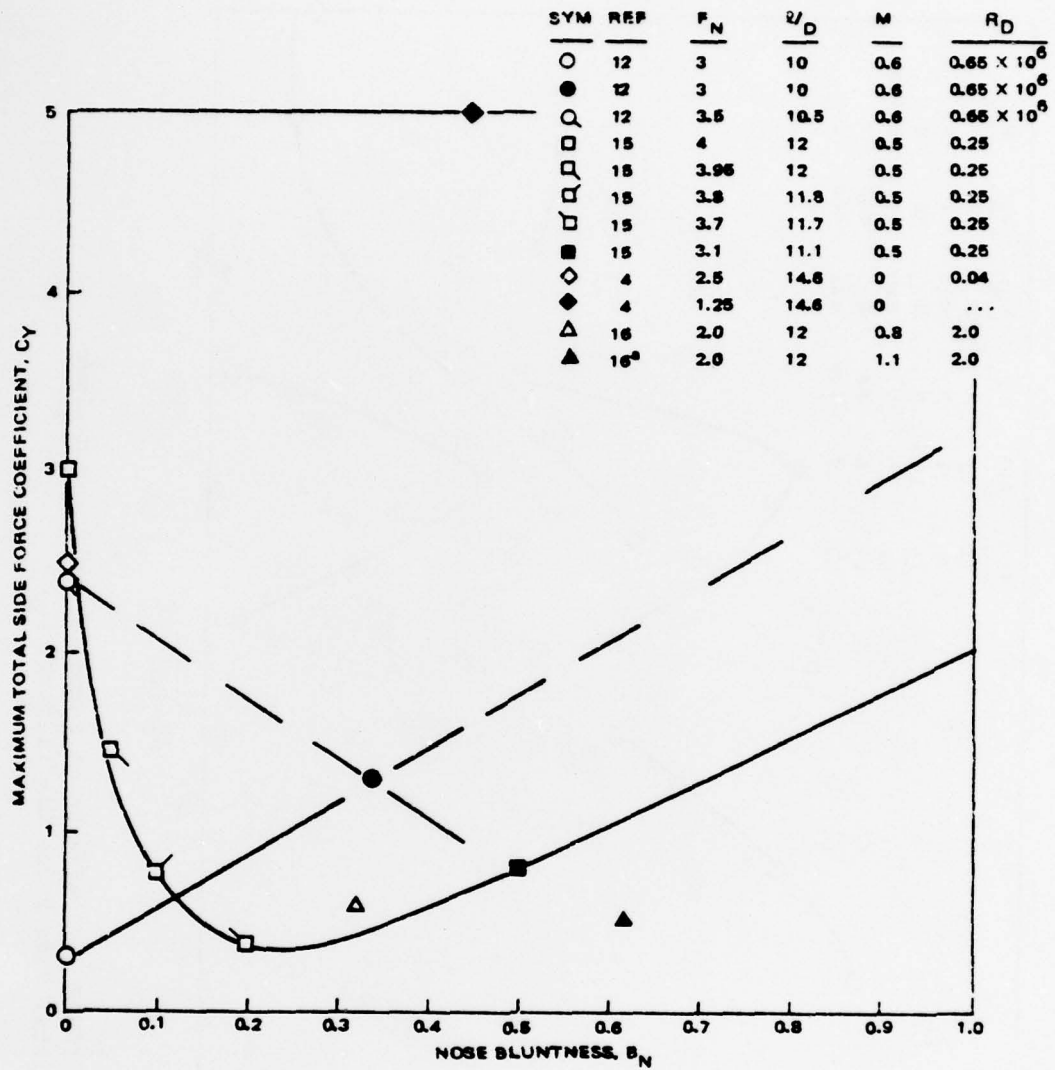


FIGURE 22. Effects of Nose Fineness Ratio, F_N , on Maximum Total Side Force Coefficient, C_y For Sharp-Nose Ogive Cylinders.



^a SPECIAL NOSE SHAPE. N_8

FIGURE 23. Effects of Nose Bluntness, B_N , on Maximum Total Side Force Coefficient, C_y , For Ogive Cylinders.

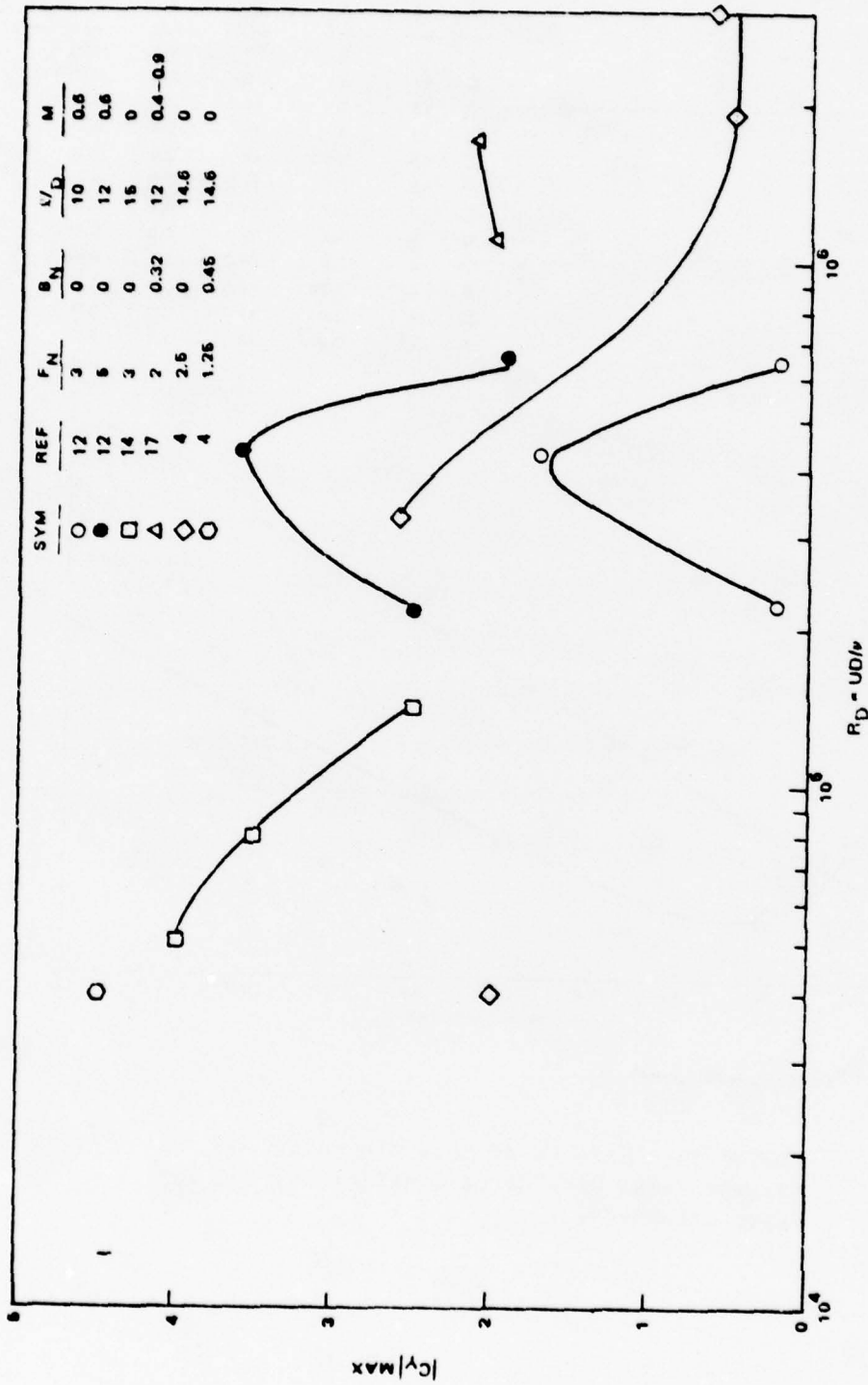


FIGURE 24. Effects of Reynolds Number on Maximum Total Side Force Coefficient, C_y .

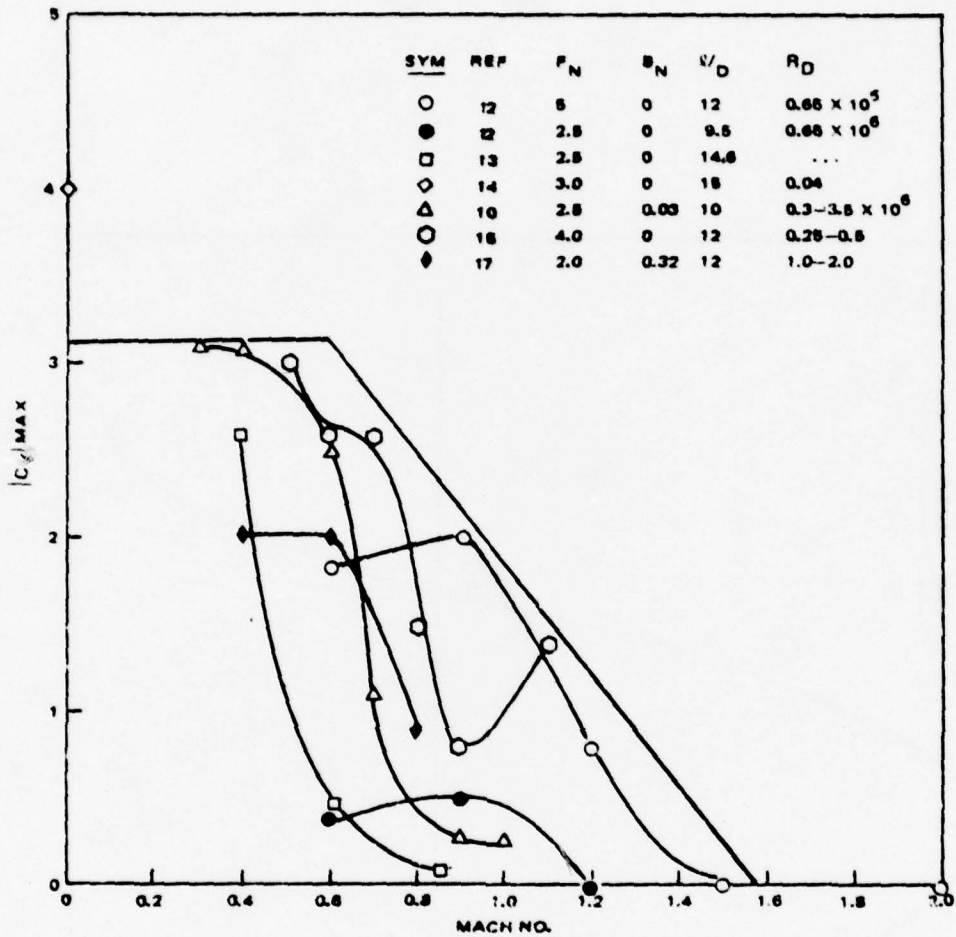


FIGURE 25. Effects of Mach Number on Maximum Total Side Force Coefficient, C_y .

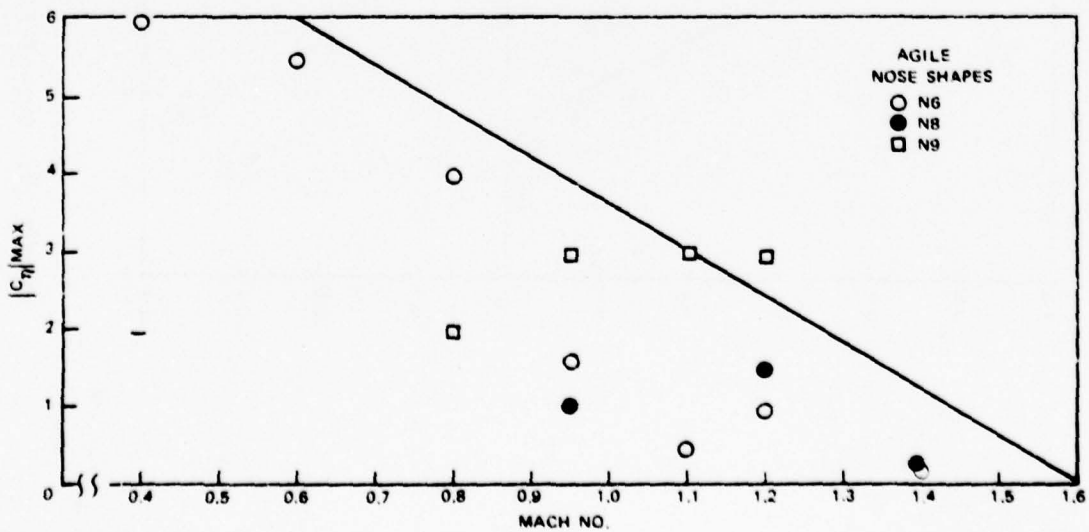


FIGURE 26. Effect of Mach Number and Nose Shape on Maximum Yawing Moment Coefficient, Agile (See References 16 and 17).

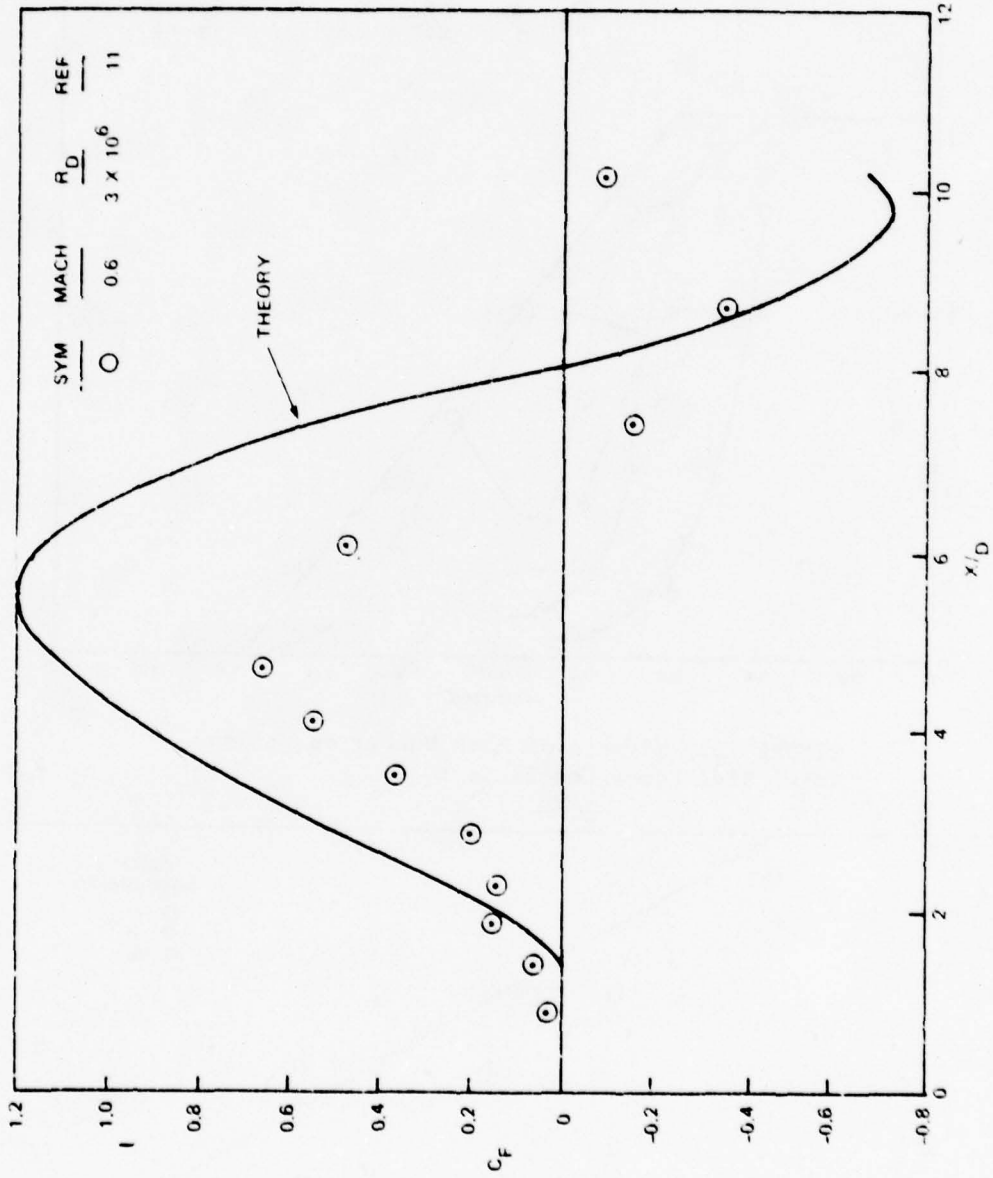


FIGURE 27. Out-of-Plane Force Distribution at 40-Degree Angle of Attack.

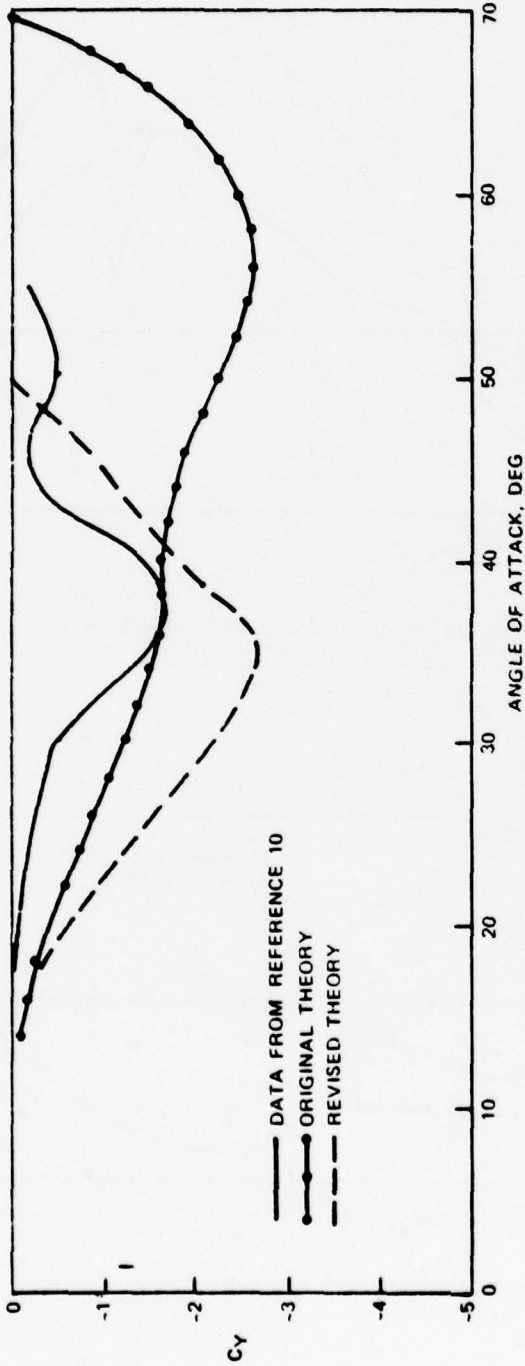


FIGURE 28. Side Force Coefficient vs Angle of Attack, Data From Reference 10.

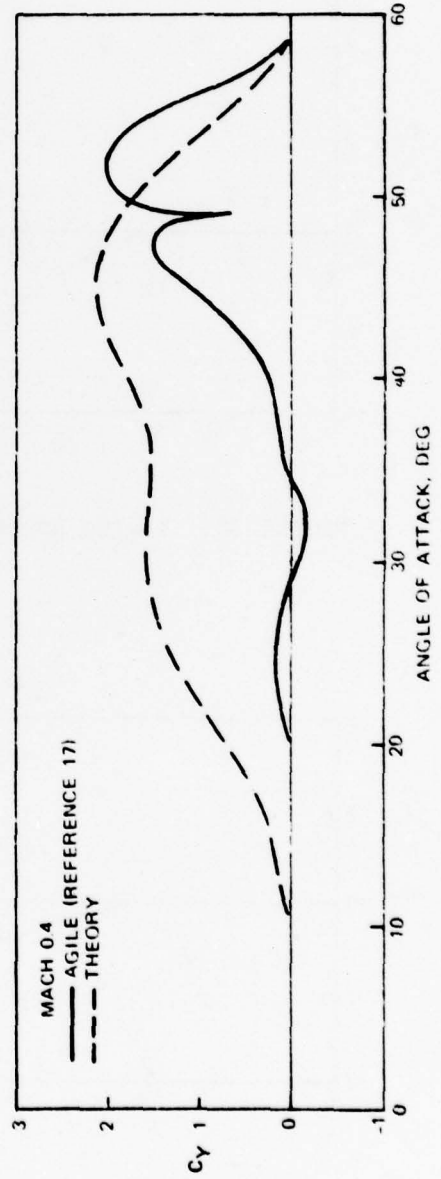


FIGURE 29. Side Force Coefficient vs Angle of Attack, Mach = 0.4.

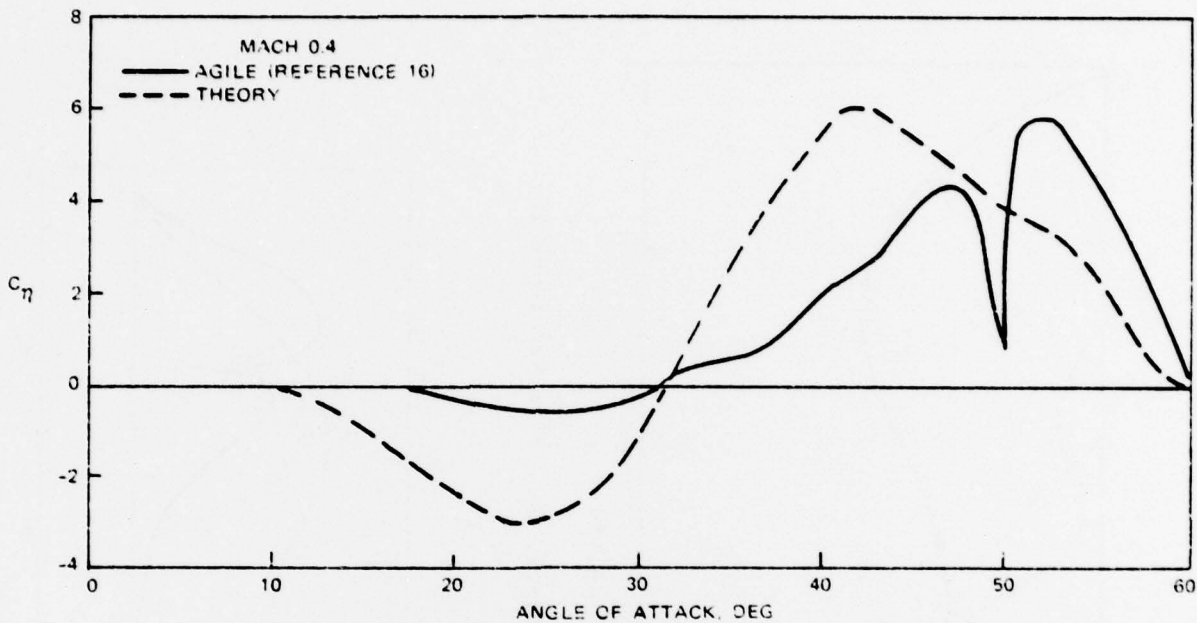


FIGURE 30. Yawing Moment Coefficient vs Angle of Attack, Mach = 0.4.

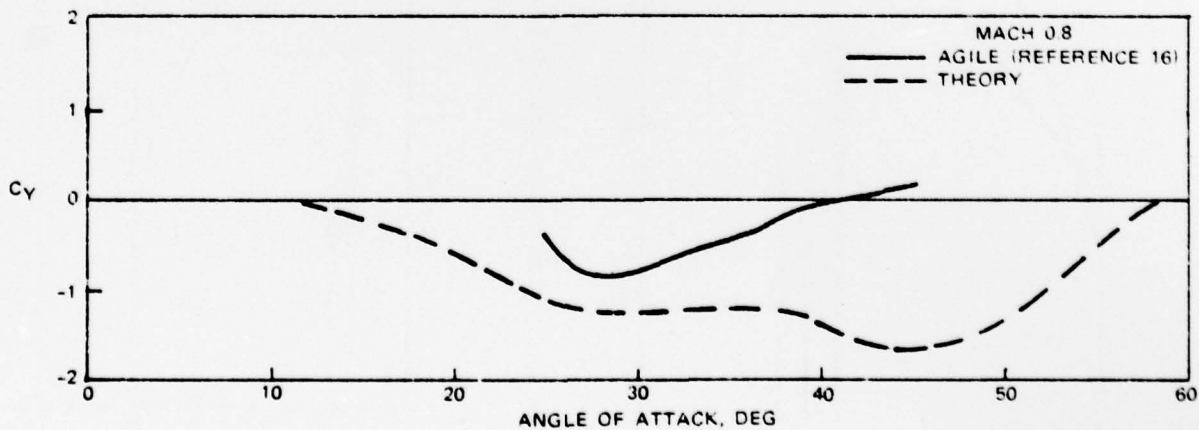


FIGURE 31. Side Force Coefficient vs Angle of Attack, Mach = 0.8.

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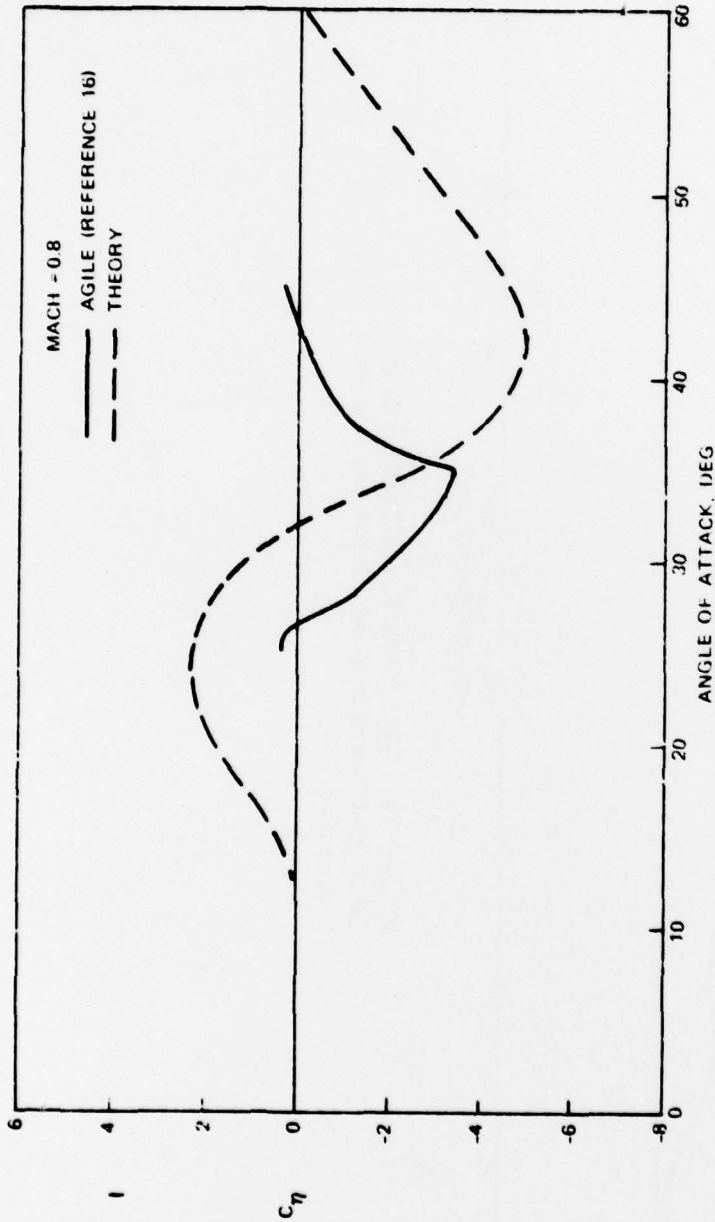


FIGURE 32. Yawing Moment Coefficient vs Angle of Attack, Mach = 0.8.

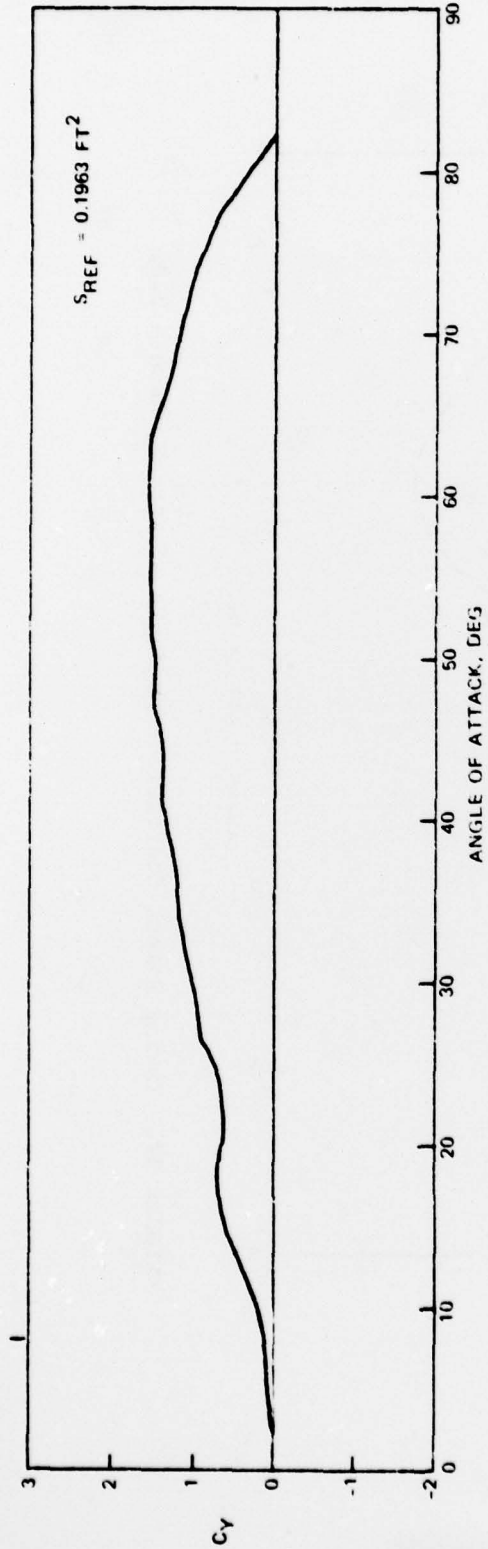


FIGURE 33. TVC6 Side Force Coefficient, C_y , Estimated Using Method of Lamont and Hunt (Reference 6).

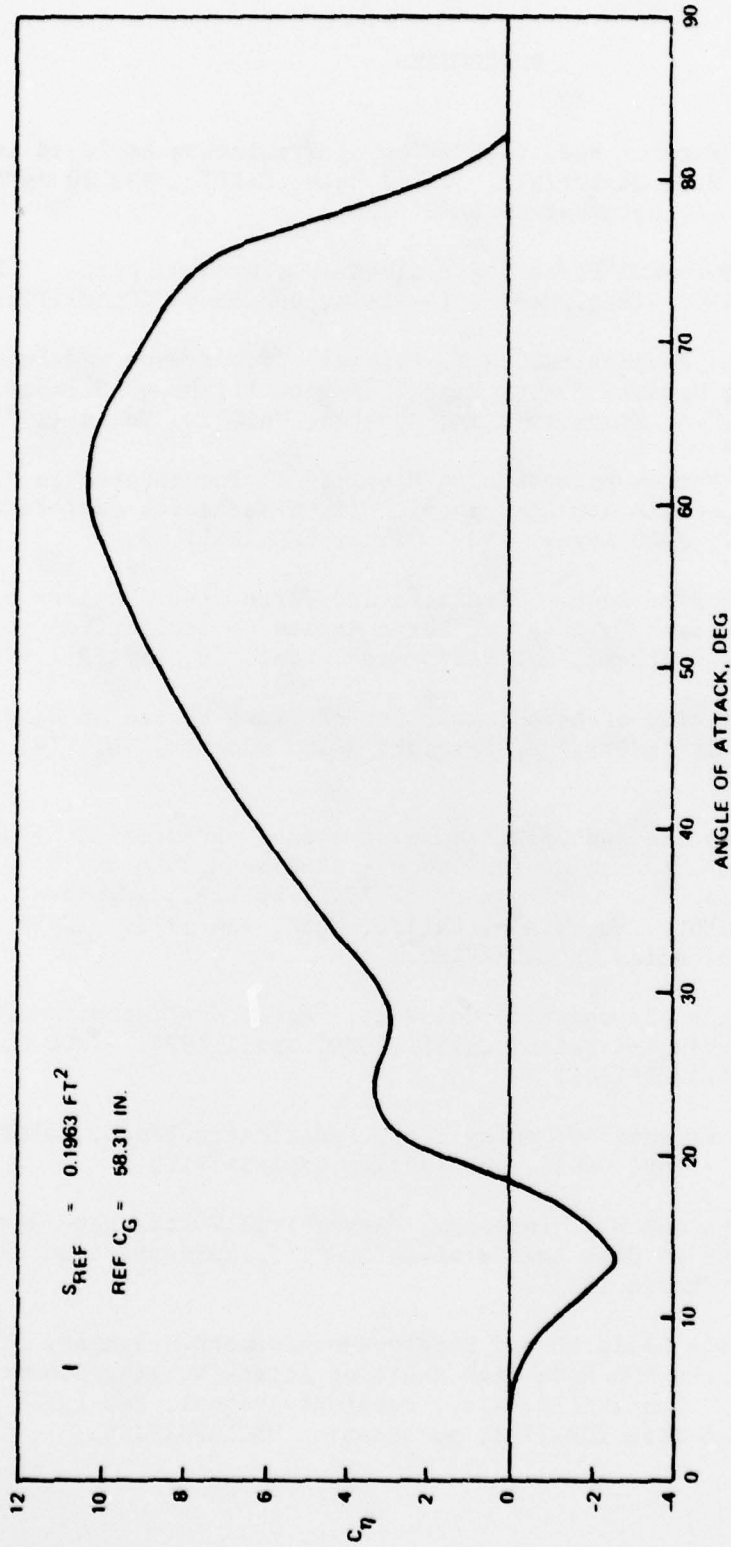


FIGURE 34. TVC6 Yawing Moment Coefficient, C_{η} , Estimated Using Method of Lamont and Hunt (Reference 6).

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Appendix A

COMPUTER PROGRAM FOR THE COMPUTATION
OF TVC6 PITCHING MOMENT COEFFICIENT
AND NORMAL FORCE COEFFICIENT

NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS

```

3914633*SRAAM(1),TVC6ARO
1  COMPILER(DIAG=3)
2  PROGRAM TVC6ARO...
3  COMPUTES CN AND CM FOR TVC6 MISSILE...
4  DATA IS EXTRAPOLATED FROM AGILE WIND TUNNEL DATA...
5  ESTIMATED BODY ALONE CM FOR TVC 6...
6  DATA IS TABULATED FOR MACH#S 6.8 95.1.1.2.1.6.2.3.
7  FOR ANGLES OF ATTACK 0 TO 90 IN 5 DEG INCREMENTS...
8  DIMENSION CNB(19,8) CMACH(8)
9  DATA CMACH/ 6.8 95.1.1.1.2.1.6.2.3./
10 DATA (CNB(1,1))=1.191/
11 A 0.28 74.1 36.2 46.4 4.06
12 B 6.09 8.49 11.13 22.15 1.16 5.26 9.1
13 C 16.8 20.4 23.1 24.9 26.2 27.1 26.9/
14 DATA (CNB(1,2))=1.191/
15 A 0.33 85.1 14.3 04.4 89.
16 B 6.9 21.1 6.14 3.17 2.20 1.29 4/
17 C 22.7 25.4 26.9 28.4 28.9 29.1 29.4/
18 DATA (CNB(1,3))=1.191/
19 A 0.32 87.1 69.3 76.5 11.
20 B 7.52 10.3 13.2 16.2 19.3 22.3 31.3/
21 C 24.3 25.8 27.1 28.2 29.4 30.3 31.3/
22 DATA (CNB(1,4))=1.191/
23 A 0.32 89.1 87.3 46.5 73.
24 B 9.07 12.8 16.6 39.5 24.3 27.5
25 C 29.9 31.9 32.5 35.3 37.6 39.2/
26 DATA (CNB(1,5))=1.191/
27 A 0.24 79.1 79.3 54.6 16.
28 B 9.45 13.1 16.9 30.4 23.5 26.4
29 C 28.8 31.3 33.4 35.6 37.4 38.4 38.5/
30 DATA (CNB(1,6))=1.191/
31 A 0.33 14.8 17.2 20.3 23.3 25.8
32 B 11.23 14.8 17.2 20.3 23.3 25.8
33 C 28.6 31.1 33.4 34.2 35.3 36.4/
34 DATA (CNB(1,7))=1.191/
35 A 0.24 59.2 66.5 01.7 89
36 B 10.7 13.3 16.8 6.21 3.23 8
37 C 26.3 28.6 30.5 32.3 33.9 34.3/
38 DATA (CNB(1,8))=1.191/
39 A 0.36 12.2 14.6 17.1 19.5 22.
40 B 9.63 12.2 14.6 17.1 19.5 22.
41 C 24.3 26.4 28.3 29.9 30.3 30.7/
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
C...INPUT BODY ALONE CP/L ESTIMATE FROM ALPHA=0 TO 180. (SDEG INCR)
DIMENSION XCP(37)
DATA XCP/2.5 25.32 3.36 38.5 41.42 5.44
A 41.5 45.45 45.45 45.45 46.47 5.48 49.49.5.
B 50.5 50.5 51.52 52.5 54.55 55.55.55.
C 55.5 56.57 59.61 5.65 71.81 5.100./
C...DATA FOR FIN EFFECTIVENESS FOR C62F CONFIGURATION...
C...MACH NOS OF 8 1 1 6 2 ...
DIMENSION FMACH(4) DCNF(19.4)
DATA FMACH/ 8 1 1 1 1.6 2 /
DATA (DCNF(1,1))=1.191/
A 0 5.1 4.1 4.1 3.1 1.1 1.3.
B 9.9 6.5 8.7 9.9 6.5 8.7/

```

NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS

```

57 DATA (DCNF(I,2),I=1,19)/
58 A 0.15,4.5,8.1,1.1,2.
59 B 1.4,1.1,1.1,1.2,1.4.
60 C 1.3,1.4,1.3,9.8,1.7.
61 DATA (DCNF(I,3),I=1,19)/
62 A 0.15,4.5,6.6,7.9.
63 B 1.4,1.1,1.1,1.1,1.1.
64 C 1.3,1.4,1.3,9.8,1.7.
65 DATA (DCNF(I,4),I=1,19)/
66 A 0.1,35.45,5.65,85.1,05.11*1./
67 C**DATA FOR FIN EFFECTIVE CP:
68 C**FOR REGIONS WITH MISSING DATA A VALUE OF X/CR=.5 IS USED**
69 DIMENSION XCPF(19,4)
70 DATA (XCPF(I,1),I=1,19)/
71 A 6.5,6.52,1.48,2.39,1.52,1.13,.42.
72 B -19.81,1.19,1.76,1.97,1.13.
73 C 2.6,1.27,2.08,5.32,1.19,1.17.
74 DATA (XCPF(I,2),I=1,19)/
75 A 1.86,1.86,19.2,39.1,02.65,.97.
76 B .43,64.16,14.08,-1.09.
77 C -.91,81.32,1.41,1.36,1.19/
78 DATA (XCPF(I,3),I=1,19)/
79 A 1.42,1.42,-81.52,2.52,1.57,.08.
80 B 1.69,1.13,66.65,1.13,-2.
81 C .52,1.41,39.96,1.19,1.86/
82 DATA (XCPF(I,4),I=1,19)/
83 A 5.2,5.2,91.2,66.32,-.42.
84 B -.81,11.5/
85 DIMENSION MACH(20),CNTAB(37,11),CNTAB(37,11)
86 REAL MACH
87 DATA JM/1, JM/1/
88 C*****
89 WRITE(6,100)
90 FORMAT(IX,'HOW MANY MACH #S?')
91 READ(5,101)NMACH
92 FORMAT(I)
93 WRITE(6,102)
94 FORMAT(IX,'INPUT MACH#S')
95 READ(5,101)(MACH(I),I=1,MMACH)
96 WRITE(6,103)
97 FORMAT(IX,'WHAT IS MAX. ALPHA?')
98 READ(5,101)ALFMAX
99 WRITE(6,104)
100 FORMAT(IX,'INPUT MOMENT REF. FIN LEADING EDGE AND CENTER FO GRAVITY
101 LOCATION IN INCHES FROM NOSE')
102 READ(5,101)(XREF,XFLE,XCG
103 DIA=6
104 ALPHA=0.
105 CR=4.5
106 XL=120.
107 DO 1 I=1,MMACH
108 ALPHA=0.
109 DO 2 J=1,37
110 **INTERPOLATE WITH RESPECT TO MACH NO**
111 **DETERMINE BODY ALONE CN**
112 CN=MACH(I)
113 IF (MACH(I).LT..6)XM=.6

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NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS

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114 IF(MACH(I),GT,3.)XM=3.
115 CALL VLOOK(XM,8,BHACH,JM,IM)
116 JJ=J
117 YE(J,GT,19)JJ=28-J
118 DEL=(XM-BHACH(IM-1))/(BMACH(IM)-BMACH(IM-1))
119 CN1=CNB(JJ,IM-1)*DEL*(CNB(JJ,IM)-CNB(JJ,IM-1))
120 XM=MACH(I)
121 IF(XM,LI,8)XM=8
122 IF(XM,GT,2)XM=2
123 CALL VLOOK(XM,4,FMACH,JM1,IM1)
124 FORMAT(2I3)
125 DEL=(XM-FMACH(IM1-1))/(FMACH(IM1)-FMACH(IM1-1))
126 DCNF1=DCNF(JJ,IM1-1)*DEL*(DCNF(JJ,IM1)-DCNF(JJ,IM1-1))
127 CPM=XCPF(JJ,IM1-1)*DEL*(XCPF(JJ,IM1)-XCPF(JJ,IM1-1))
128 C**COMPUTE FIN CP DISTANCE FROM NOSE
129 XFIN=XFLE*CPEN*CR
130 CMB=CN1*(XREF-XCP(JJ)*.91*XL)/DIA
131 CMF=DCNF1*(XFIN-XREF)/DIA
132 CM=CMB-CMF
133 CN=CN1-DCNF1
134 C**COMPUTE STATIC STABILITY MARGIN**
135 XX=XCG-XREF
136 XBAR=CM/CN-XX/DIA
137 WRITE(6,105)MACH(I),ALPHA,CN,CM,CMB,CMF,XBAR
138 CNTAB(J,1)=CN
139 CNTAB(J,1)=CM
140 FOPAT(1A,10(F8.2,1X))
141 ALPHA=ALPHA*5.
142 IF(ALPHA,GT,ALFMAX) GO TO 1
143 CONTINUE
144 CONTINUE
145 CONTINUE
146 WRITE(6,110)
147 FOPAT(1X)
148 FOPAT(1X)
149 FOPAT(1X)
150 FOPAT(1X)
151 FOPAT(1X)
152 ALPHA=0.
153 DO 4 I=1,37.2
154 WRITE(6,109)ALPHA (CNTAB(I,J),J=1,11)
155 WRITE(14,199)(CNTAB(I,J),J=1,11)
156 ALPHA=ALPHA*5.
157 WRITE(6,111)
158 FOPAT(1X)
159 WRITE(6,107)
160 ALPHA=0.
161 DO 5 I=1,37.2
162 WRITE(6,109)ALPHA (CNTAB(I,J),J=1,11)
163 WRITE(13,199)(CNTAB(I,J),J=1,11)
164 FOPAT(12F6.2)
165 FOPAT(1X)
166 FOPAT(1X)
167 ALPHA=ALPHA*5.
168 STOP
169 SUBROUTINE VLOOK(VAR,LNTH,ARRAY,JLST,INDEX)
170 DIMENSION ARRAY(LNTH)
171 LOGICAL L1,L2

```

NORMAL FORCE AND PITCHING MOMENT COEFFICIENTS

```

171 L1=VAR GE ARRAY(JLST)
172 L2=VAR LE ARRAY(JLST*1)
173 IF(L1.AND.L2)GO TO 30
174 IF(.NOT.L1)JLST=JLST-1
175 IF(L1)JLST=JLST+1
176 IF(JLST.GT.0.AND.JLST.LT.LNTH)GO TO 20
177 WRITE(6,100)
100 FORMAT('X',VARIABLE OUTSIDE ALLOWABLE LIMITS')
178 RETURN
179 INDEX=JLST*1
180 END
181

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Appendix B

COMPUTER PROGRAM FOR THE
COMPUTATION OF OUT-OF-PLANE
FORCES AND MOMENTS

OUT OF PLANE FORCE AND MOMENT CALCULATIONS

```

3914933*SRAAM(1),YAH5
C**PROGRAM YAH5**
C***COMPUTE OUT OF PLANE FORCES AND MOMENTS ON OSIVE-
C***CYLINDERS USING METHODS OF LAHONT AND HUNT(J) SPACECRAFT
C****V 14,NO 1 JAN 1977)
REAL L,REF,MACH,MU
DATA R1,257.2253,R1/3,1415926/
DIMENSION T(51),CF(51)
DIMENSION VS(11),RH(11),TMU(11)
DATA VS,1117.1059,1076,1058,1037,1017,
.995,973,971,971,971,971,971,
DATA RH,002279,002049,001756,001497,001267,
.001066,000689,000737,000585,00046,000562/
DATA TMU,3.719,3.618,3.515,3.411,3.305,3.196,
.3,036,2.574,2.961,2.961,2.961/
R=5
WRITE(5,108)
FORMAT(IX)INPUT FN,L,REF,MACH,ALT,DIA*)
READ(5,100)FN,L,REF,MACH,ALT,DIA
ALPHA=10
WRITE(6,109)
DO 13 JJ=1,37
FORMAT(IX)INPUT ALPHA*)
READ(5,100)ALPHA
FORMAT(1)
C***COMPUTE REYNOLDS ***
RALT=ALT/5+.1
I=ALT-RALT
DIFF=I-RALT-IALT
VSNDE=VS(IALT)*DIFF*(VS(IALT+1))-VS(IALT)
PHO=PH(IALT)*DIFF*(PH(IALT+1))-RH(IALT)
MU=TMU(IALT)*DIFF*(TMU(IALT+1))-THU(IALT)
V=MACH*VSNDE
DIA=DIA/12
REYD=PHO*V*DIA/MU
RETD=REYD*.1*DE07
ALP=ALPHA/RTD
TA=3+.05*ALPHA
FACE7=.5*FN
IF(TA.GT.FACE)TA=FACE
IF(RET.D.LT.200000.)GO TO 16
FACE2=.2*FN
IF(TC.GT.FACE)TC=FACE
IF(RET.D.LT.200000.)GO TO 16
FACE5=.5*FN
IF(CTA.GT.FACE)TA=FACE
IF(CTA.GT.FACE)TA=FACE
FACE15=.2*FN
IF(TC.GT.FACE)TC=FACE
CONTINUE
CONTINUE
TB=(.6+.1*COS(2.*ALP))*(TC-TA)+TA
TE=TC-.4*.2*ATAN(ALP)
TE=TE+.4*.2*ATAN(ALP)
CBMX=1+.4*FN
XM=8*.6*TA
XC=TC-TA

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OUT OF PLANE FORCE AND MOMENT CALCULATIONS

```

57 X=4.6*FN*TAN(ALP)-TA
58 IF(X.GE.0.)GO TO 1
59 CB=1
60 GO TO 3
61 IF(X.GE.XC)GO TO 2
62 IF(X.GT.XM)GO TO 17
63 CB=1.-(CBMX-1.)*X/XM
64 GO TO 3
65 CB=CBMX-CBMX*(X-XM)/(XC-XM)
66 GO TO 3
67 CB=0.
68 CONTINUE
69 IF(REFD.GE.200000)CB=CB*.8
70 IF(MACH.LT..6)FMACH=1.-(MACH-.6)
71 IF(MACH.GE..6)FMACH=1.-(MACH-.6)
72 IF(MACH.GT.1.6)FMACH=0.
73 CB=CB*FMACH
74 TMAX=L*TAN(ALP)/R
75 H=TMAX/50.
76 T=0.
77 DO 4 I=1,51
78 T J(I)=T.TA)GO TO 5
79 IF(T.GT.TA)GO TO 5
80 CF(I)=0.
81 GO TO 9.
82 IF(T.GT.TC)GO TO 6
83 X=PI*(T-TA)/(TC-TA)
84 XB=PI*(TB-TA)/(TC-TA)
85 CF(I)=CB*EXP((XB-X)/TAN(XB))*SIN(X)/SIN(XB)
86 GO TO 9.
87 IF(T.GT.TE)GO TO 7
88 XI1=(T-TC)*PI/(TE-TC)
89 CF(I)=-.8*CB*SIN(XI1)
90 GO TO 9.
91 IF(T.GT.TC)GO TO 8
92 XI2=PI*(T-TE)/(TC-TE)
93 CF(I)=3*CB*SIN(XI2)
94 GO TO 9.
95 CF(I)=0
96 CONTINUE
97 T=T+H
98
99 C**COMPUTE SIDE FORCER USING SIMPSONS RULE FOR INTEG**
100 SUM=0.
101 DO 10 I=2,50
102 SUM=SUM*CF(I)
103 XINT=.5*H*(CF(1)+2*SUM+CF(51))
104 CT=2.*SIN(ALP)*COS(ALP)*XINT/PI
105 C**COMPUTE MOMENT COEFF**
106 TREF=LREF*TAN(ALP)/R
107 SUM=0.
108 DO 11 I=2,50
109 SUM=SUM*(TREF-T(I))*CF(I)
110 XINT=.5*H*(TREF*CF(1)+2*SUM+(TREF-TMAX)*CF(51))
111 CETA=(COS(ALP))*2*XINT/PI
112 DIA=DIA*.12.

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