TECHNICAL REPORT ARBRL-TR-02525

SOME AERODYNAMIC CHARACTERISTICS OF A PROJECTILE SHAPE WITH A NONAXISYMMETRIC BOATTAIL AT MACH NUMBERS OF 0.91 AND 3.02

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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Some aerodynamic properties of a projectile shape with a nonaxisymmetric boattail are presented. The boattail is formed by machining three flat surfaces which are equally spaced and inclined seven degrees to the model axis. Aerodynamic forces obtained by strain-gage balance measurements are presented for angles of attack up to 15° and for various roll orientations of the model. Because the effect of roll orientation on coefficient data is quite small, coefficients are presented in incremental form so that the effect of roll can be graphically amplified. A limited quantity of the data is compared to

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20. ABSTRACT (Continued)

computational results for Mach 3.02. The results of this study support previous studies which show that nonaxisymmetric boattail shapes can improve the static stability of projectiles.

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I. INTRODUCTION

The objective of the wind tunnel test program was to obtain data on a nonaxisymmetric projectile shape which could be used for comparison with computation. Most of the computational effort within the Aerodynamics Research Branch of the Launch and Flight Division has been directed toward axisymmetric projectile shapes; however, recent efforts have been in the direction of increasing the computational capability for nonaxisymmetric shapes, including finned bodies. The specific projectile shape with a nonaxisymmetric boattail, as shown in Figures 1 and 2, was chosen for the experiment as a result of our past experience with this nonconical projectile shape. The aerodynamic characteristics of nonaxisymmetric boattail shapes have been examined to some degree at the BRL since 1974. The terms nonaxisymmetric, nonconical, and unconventional are used interchangeably in this report. The nonaxisymmetric boattail is usually formed by a number of flat surfaces inclined to the model axis as opposed to the conventional axisymmetric conical boattail. For example, three surfaces of sufficient length would develop into a triangular base (Figure 2), or four flat surfaces would develop into a square base. All data for this report are for the one-caliber seven-degree triangular boattail shown in Figure 2. Platou[1-4] has examined several nonconical boattail configurations in recent years including triangular, square, cruciform, and modified square and triangular boattails with added lifting surfaces. The general findings of Platou are that nonconical boattails reduce drag and increase the static stability of projectiles when compared to conical boattails. For spinning projectiles, the boattail surfaces must be twisted at the same rate as the rifling twist to avoid an excessive despinning moment. Zumwalt's[5] trough-like base region has similarities to the cruciform configuration of Platou. Zumwalt found that the effect of adding the trough to the base was to increase the base pressure by a factor of two at Mach 2

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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. *Zumwalt, G.W., "Experiments on Three-Dimensional Separating-and-Reattaching Flows," AIAA Paper No. 81-0259, AIAA 19th Aerospace Sciences Meeting, January 1981.*

and a factor of four at Mach 3. Reference 6 compares measured pressures on a nonconical boattail with pressures obtained by inviscid computation. Qualitatively, the inviscid computation predicted the correct trends; however, the quantitative agreement was generally poor. More recent computations by Sturek[7] using a parabolized Navier-Stokes code showed a much improved agreement in comparison of pressure distributions over the nonconical boattail. Reference 6 also reports comparisons of experimental nonconical static stability results with computational results for axisymmetric shapes having similar moments of inertia characteristics. The results show that the nonconical boattail increases the static stability and in some cases the stability is greater than that of a straight cylindrical (0°) boattail. Danberg and Tschirschnitz[8] obtained pressure measurements in the boattail region of axisymmetric and nonaxisymmetric configurations at transonic speeds. Integration of pressures over the boattails showed that the nonaxisymmetric (triangular) boattail reduced total projectile drag by approximately 15% and increased the static stability with respect to the conical boattail configuration. The static stability for the nonconical shape was, however, not as good as the high drag straight cylindrical configuration. Platou[9] has extended the concept of the nonconical boattail to forward facing flats on the model, which gives the model corkscrew-like characteristics. Reference 9 describes a study of corkscrew configurations which have the potential of further decreasing projectile drag.

II. EXPERIMENTS

The wind tunnel tests were conducted in the Supersonic Wind Tunnel No. 2 of the Naval Surface Weapons Center (NSWC), White Oak Laboratory, at Mach Numbers of 0.91 and 3.02. Data were acquired at angles of attack of -5 to 15 degrees for M = 0.91, and -5 to 12.5° for M = 3.02. The procedure of acquiring the data was to fix the roll orientation to one of the positions shown in

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6. *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, Maryland 21005, May 1980 (AD A086091).*

7. *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).*

8. *Danberg, J.E., and Tschirschnitz, R.H., "Transonic Pressure Distribution and Boundary Layer Characteristic of a Projectile with an Asymmetric Afterbody," Technical Report 243, University of Delaware, June 1981.*

9. *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).*

Figure 4, and then pitch the model through the angle-of-attack range. Aerodynamic force and moment measurements were obtained by means of an internal strain-gage balance. The following forces and moments were measured: normal force, pitching moment, side force, yawing moment, and rolling moment. Supply pressure and temperature for the M = 3.02 runs were 221 kPa (32 psia) and 322° K, respectively, which yielded a model-length Reynolds number of 5.0×10^6. The supply pressure and temperature for the M = 0.91 runs were 101 kPa (14.7 psia) and 322 K, which gave a model-length Reynolds Number of 4.5×10^6.

III. DATA PROCESSING

Data were supplied by the NSWC with the usual bias corrections for flow angularity; for example, it is assumed that normal force and pitching moments must be zero at zero angle of attack for appropriate configurations. An initial examination of the data showed that the effects of varying the roll attitude of the model were very small; for this reason, the data were further processed with the hope that the effects of roll could be adequately extracted. The pitch plane data, for a given roll orientation, was fitted with a cubic spline; Figure 4 is an example of such a curve fit. When all data had been curve fitted, incremental coefficient values were computed by subtracting coefficient values at zero roll angle from coefficient values at positive angles of roll. Figures 5a, b, c are examples of some results. Some of the results are reasonably good (Figure 5a) and other results are rather poor (Figures 5b and c). Conditions of symmetry dictate, theoretically, that C_N and C_m are symmetrical about $\phi = 60°$ and that C_Y, C_n, and C_ℓ have odd symmetry about $\phi = 60°$. Therefore, in an attempt to further improve the quality of results, conditions of symmetry were forced upon the data by appropriate averaging.

IV. ERROR ANALYSIS

Initially, it was considered that the order of magnitude of the error could be estimated by assuming a measurement accuracy of one percent of the full-scale measuring capacity. Table 1 shows this error in percent of the maximum coefficient value measured. For normal force and pitching moment coefficients, the 1% criterion would indicate good quality data. The 1% criterion for incremental coefficient values at Mach 3.02 gives large errors which are in the range of 94 to 500%, but at Mach 0.91, the 1% criterion is not so severe although it still suggests moderate to large errors of 9 to 52%. It may be difficult to show by conventional error analysis that measurement errors are substantially less than one percent; however, experience has sometimes shown that when bias errors are removed from the data, considerable improvements are exhibited.

Because of symmetry, as indicated above, many comparisons of data repeatability could be made. If it is "assumed" that the correct data value is the average of all repeated measurements, then an indication of the error is the difference between the average value and the measured value. For each coefficient, approximately 10 errors were computed for the angle-of-attack range and a standard deviation computed for each coefficient. These values are tabulated in Table 1 and are believed to be reasonably good indication of error magnitude. The normal force and pitching moment errors vary from 0.1 to 0.3%, which is considered very good. The incremental coefficient values, due to change in roll orientation, vary from good to poor in quality. The standard deviations for Mach 3.02 are seen to be much smaller than the error determined by the one-percent criterion, which indicates that the balance and measuring systems were functioning well. It is surprising to note that the standard deviations for side force and yawing moment at Mach 0.91 are larger than 1% errors. This situation may indicate that some unexplained flow phenomena have existed at the transonic Mach number.

V. COMPUTATIONS

Recently, Sturek[7] has been using the thin-layer parabolized Navier-Stokes (PNS) code to compute flow over various projectile shapes. The PNS code used is that reported by Schiff and Steger. (Details of the notation, the PNS assumption, derivation of the algorithm, the associated stability analysis, and application of the boundary conditions may be found in Reference 10.) PNS computations were carried out for the nonconical shape at Mach 3 and angles of attack of 4, 6, and 10°. For each angle of attack, a solution was obtained over the axisymmetric portion of the projectile shape; then the solution was picked up and marched over the nonaxisymmetric boattail for boattail orientations of 0 to 60° (see Figure 3) in 10° increments. Generally, 36 circumferential points are used for axisymmetric shapes; however, for this computation the number of points was increased to 72. At each of the 72 points, in the circumferential direction, were 50 points normal to the surface. Thus, at each computational plane normal to the axis of the model there were 3600 points. It should be noted that the spacing of the points was not constant in the normal direction, but the spacing in the circumferential direction was constant at 5° intervals. The total number of computational planes over the entire model was approximately 700 with 120 (of the 700) being placed over the boattail section of the model. The spacing of the points along the longitudinal direction was constant.

VI. RESULTS

Tabulated results of the experimental data are presented in Appendix A. The tables include normal force and pitching moment coefficient data and incremental coefficient data for normal force, pitching moment, side force, yawing moment, and rolling moment. The incremental coefficient values are referenced to the $\phi = 0°$ roll orientation; therefore, for side force, yawing moment, and rolling moment, there is no difference between the actual coefficient values and the incemental values.

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10. *Schiff, L.B., and Steger, J.L., "Numerical Simulation of Steady Supersonic Flow," AIAA Journal, Vol. 18, No. 12, December 1980, pp. 1421-1430.*

Normal force and pitching moment data at zero roll are presented in Figures 6a and 6b. Mach 3 computations at 4, 6, and 10 degrees angle of attack are included and the agreement between computation and experiment is very encouraging. Similar plots at other roll positions are not included because the effect of roll, as will be shown, is very small. Figures 7a and 7b provide a summary of the static force and moment data for the nonconical boattail (SOCBT-NC) configuration along with data for two axisymmetric configurations -- an ogive cylinder (SOC) and and ogive cylinder with a 7° conical boattail (SOCBT). Coefficients for the axisymmetric SOC and SOCBT shapes are independent of roll orientation and are therefore shown as constant values in Figure 7. At Mach 0.91, we see that the static moment for the nonconical shape does not vary significantly with roll orientation. Also, it is seen that the static moment for the nonconical shape is smaller (more stable) than that of the SOCBT shape, but it is still larger than that of the high drag SOC. Danberg[8] made similar comparisons at Mach 0.94 for the following three afterbody shapes: (1) 1.44 caliber, 7° triangular boattail; (2) 1.44 caliber straight cylindrical boattail; (3) 1.46 caliber axisymmetric boattail (0.96 caliber cylinder + 0.5 caliber, 7° conical). Their findings are similar to the above results and show that even in the most unfavorable orientation, the triangular afterbody is more stable than the conventional conical boattail shape but not as stable as the high drag cylinder. Although no drag results were obtained in this investigation, Danberg found the boattail drag of the triangular shape to be only 48% of the drag of the conventional boattail, which resulted in an estimated overall drag reduction of 15.5%. At Mach 3, Figure 7b, computational results are compared to experiment; the agreement with $C_{N\alpha}$ is very good but the agreement with $C_{m\alpha}$ is not quite as good. Both computation and experiment show only slight variations with roll orientation. Again, the nonconical boattail is seen to decrease the static moment with respect to the conical boattail, and at this Mach number (3.0) the static moment is approximately equal to that of the cylindrical boattail shape (SOC).

The small variation of normal force with roll is illustrated, computationally, in Figure 8a where normal force coefficient is plotted on a highly expanded scale and data for all roll positions fall within a rather narrow band. The normal force is seen to increase with distance along the boattail which, acting on the aft end of the model, provides a restoring moment or increased stability; this trend is opposite of that typically observed on conical boattails. The longitudinal variation in side force is shown in Figure 8b. The side force is seen to increase to a maximum at Z/D values of approximately 5.6; then the side force decreases over the remainder of the boattail. This unexpected behavior also occurred at 4° and 6° angles of attack. The final values of side force are seen to be very small and the variation with roll is nearly an order of magnitude smaller than normal force variations. These small values of side force coefficient make it impossible to get a reasonable comparison with experiment.

Incremental coefficient values for the five components of measurement are presented in Figures 9 and 10. Coefficient values at -5° angle of attack would not be expected to equal values at +5° angle of attack. Conditions of symmetry permitted adjustment to the -5° data so that, theoretically, it should equal the +5° data. The difference between the -5° and +5° data is, therefore, an indication of the data quality. The Mach 0.91 normal force and pitching moment data of Figure 9a and b show a good consistency with angle of attack and are believed to be good quality data. The side force, yawing moment, and rolling moment show a fair degree of consistency and should indicate, qualitatively, the variation of coefficient values with roll. The incremental coefficient values at Mach 3.02, Figures 10 a-e, do not show as good a consistency as the Mach 0.91 data but, nevertheless, the data appear to be of sufficient quality for making qualitative comparisons to computational data. Incremental values of normal force coefficient for computation and experiment are compared in Figure 11. The magnitude and trends of the data compare reasonably well although there is some difference in the overall shape of the curves. The agreement is considered to be fairly good considering the accuracy of the experimental data and the small values being compared.

VII. CONCLUSIONS

1. The ogive-cylinder model with a 7° nonconical boattail exhibits a smaller static moment (greater static stability) both transonically and supersonically than a similar body with a conventional conical boattail.

2. The variation of $C_{N\alpha}$ and $C_{m\alpha}$ are nearly independent of roll orientation for the nonconical shape (SOCBT-NC).

3. The accuracy of the coefficient data are not as good as desired but the data are of sufficient quality to help evaluate computational codes for nonaxisymmetric bodies.

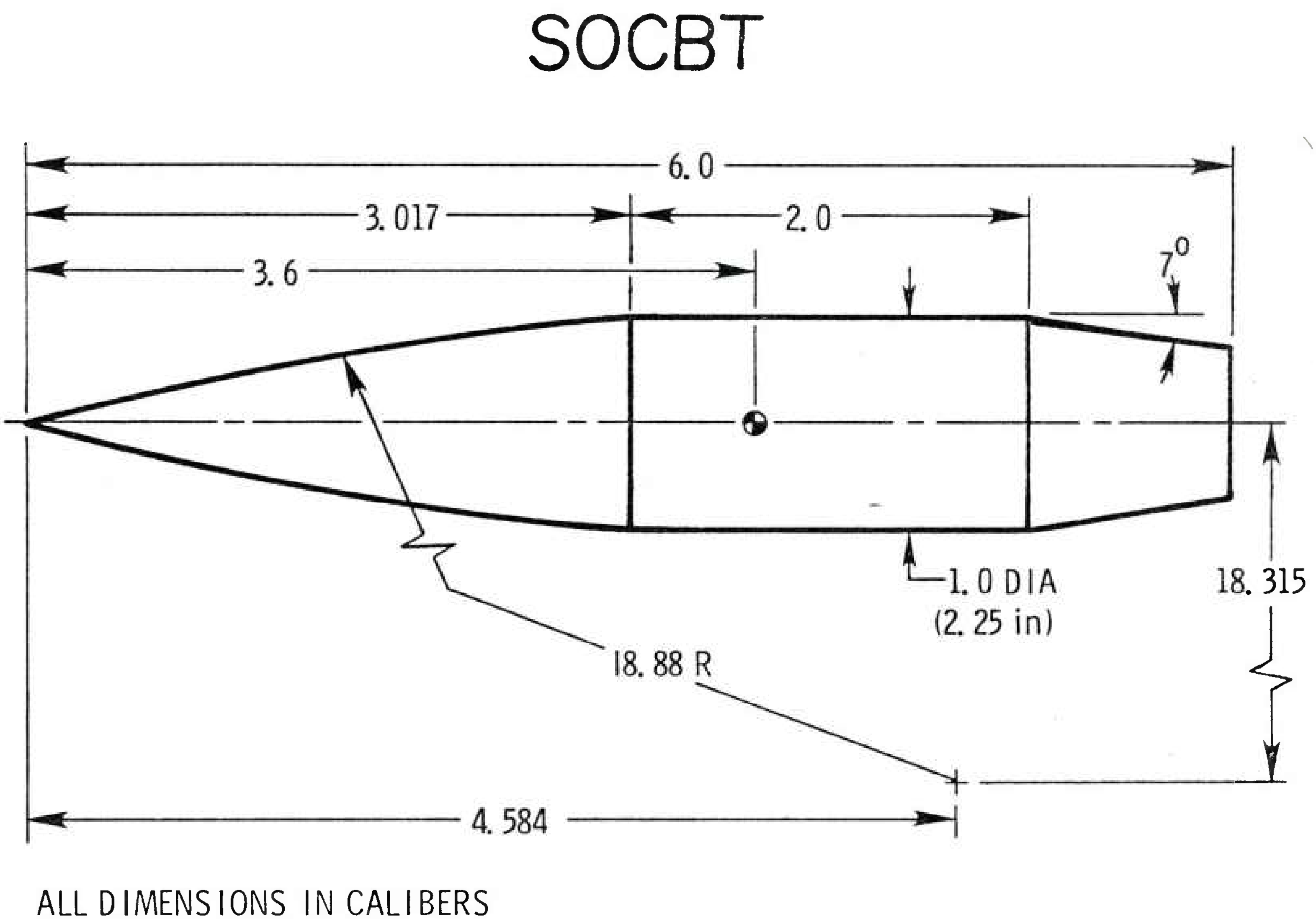

Figure 1. Model Geometry, SOCBT Axisymmetric Shape

SOCBT-NC

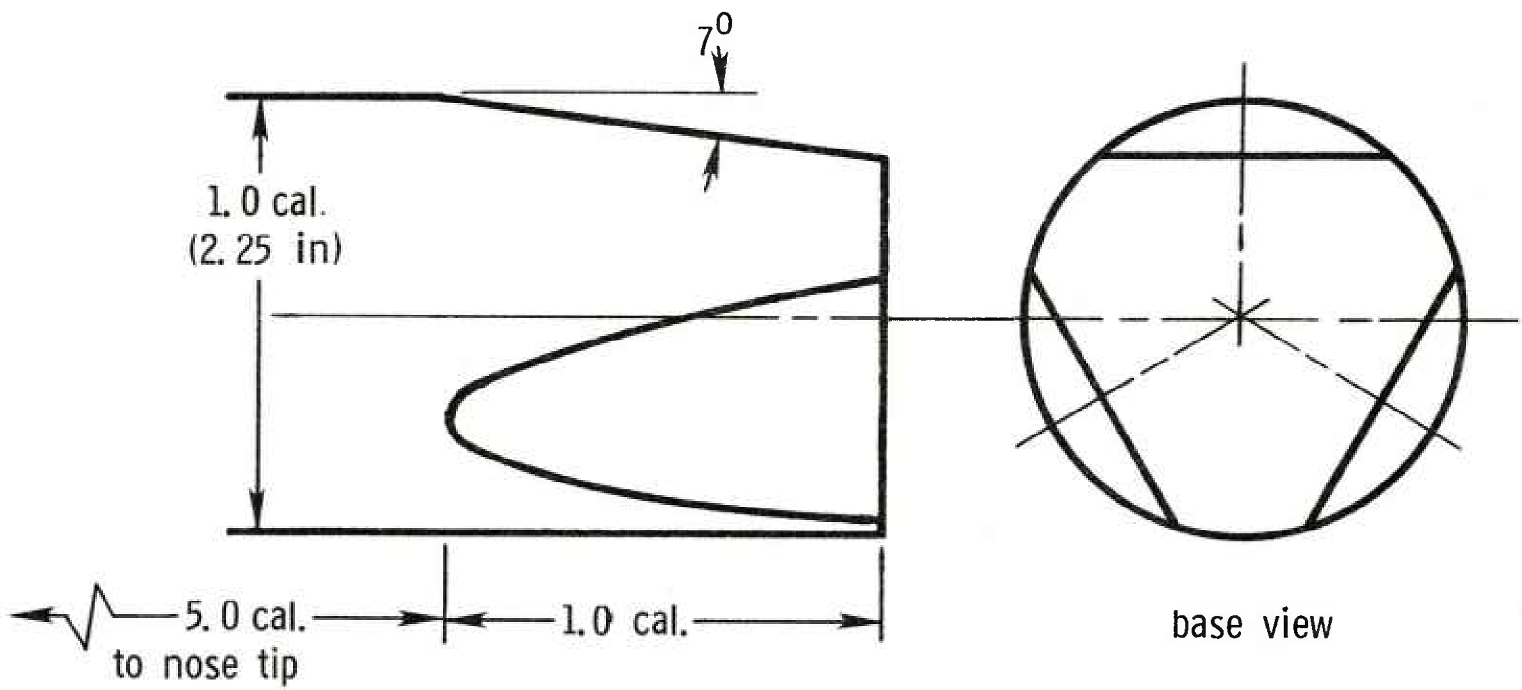

Figure 2. Nonconical Boattail Geometry

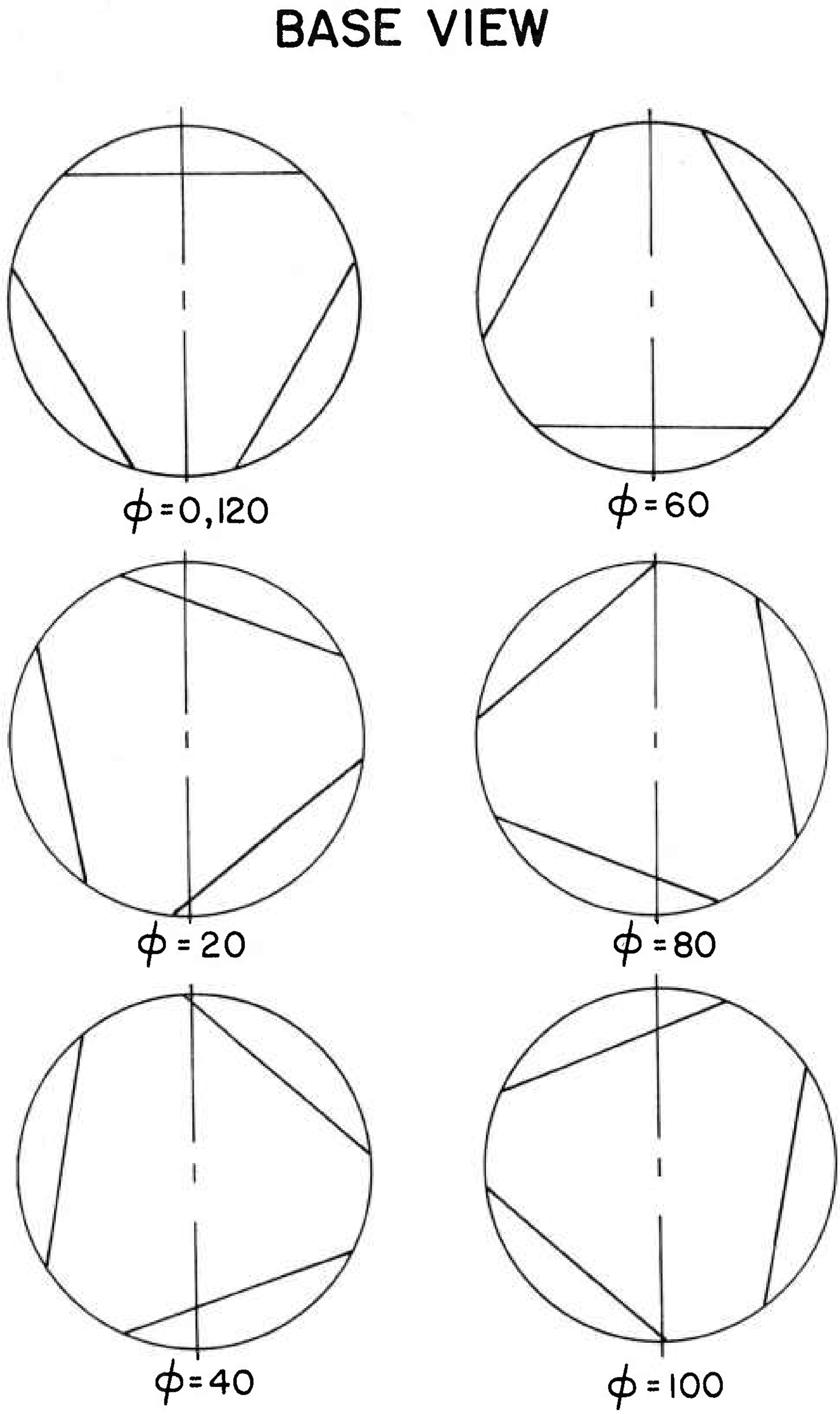

Figure 3. Model Roll Orientation

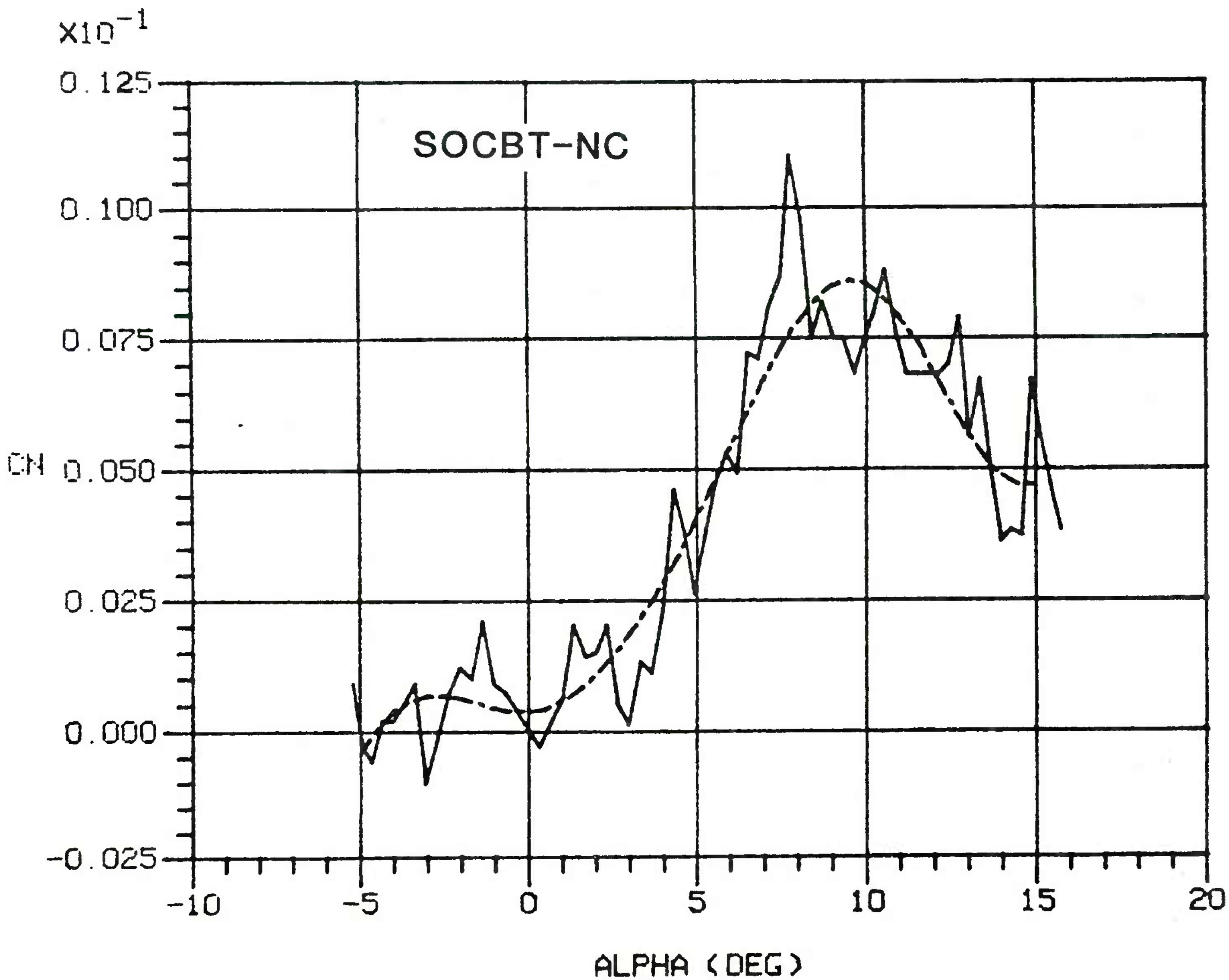

Figure 4. Cubic Spline Curve Fit, $M_\infty = 0.91$, $\phi = 20°$

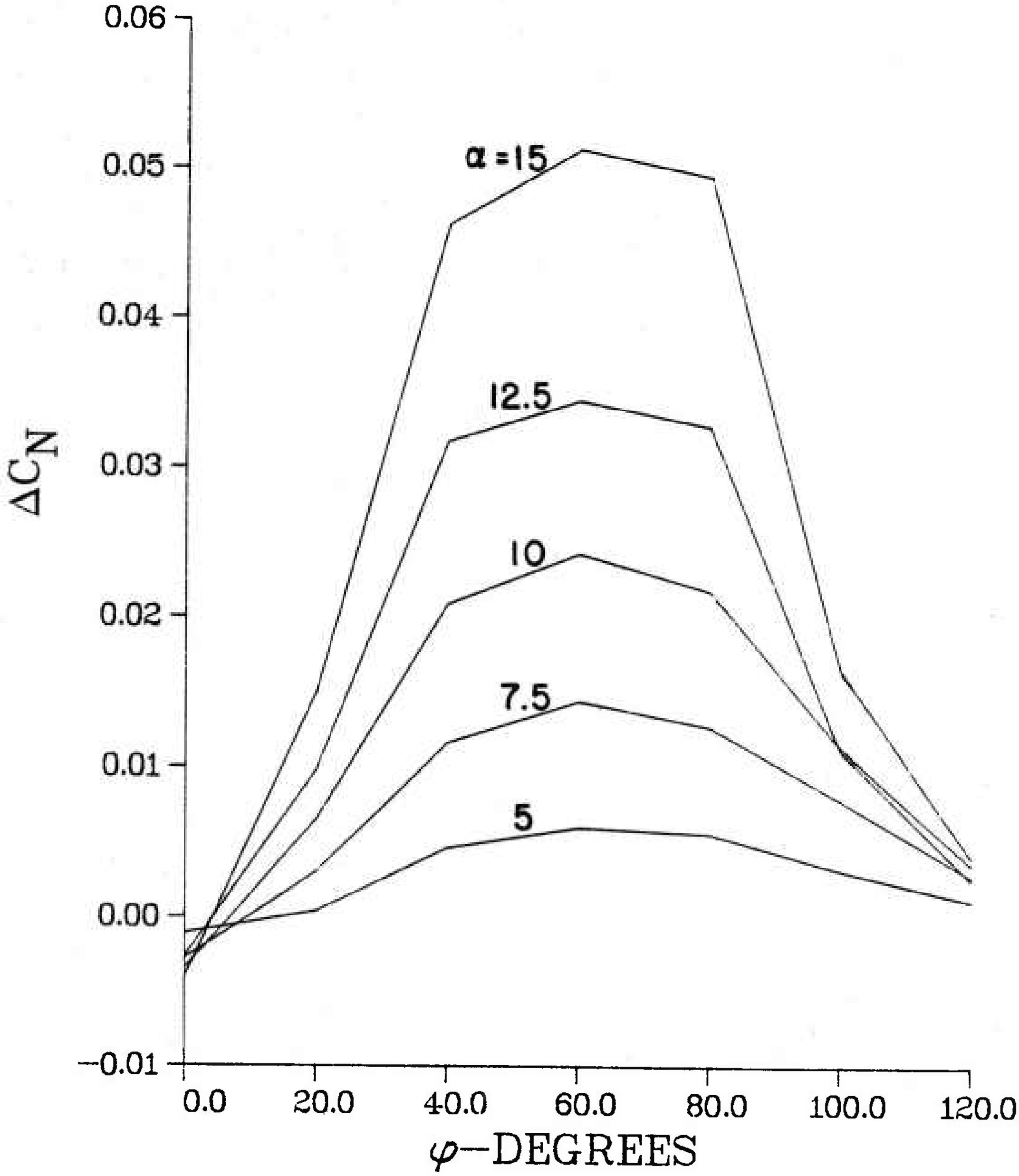

Figure 5. Uncorrected Incremental Coefficient Data, SOCBT-NC

a. ΔC_N vs ϕ, $M_\infty = 0.91$

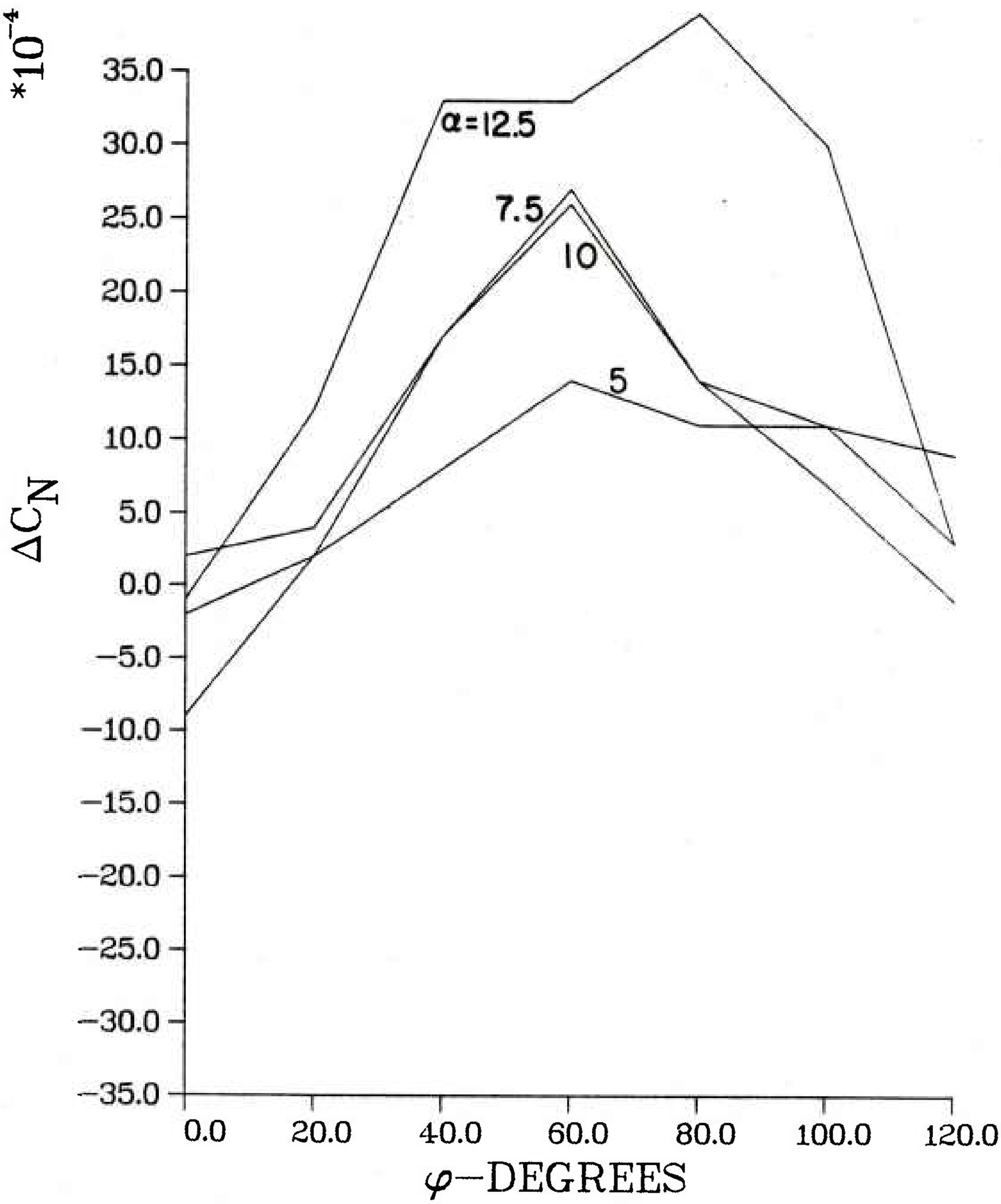

Figure 5. Continued

b. ΔC_N vs ϕ, $M_\infty = 3.02$

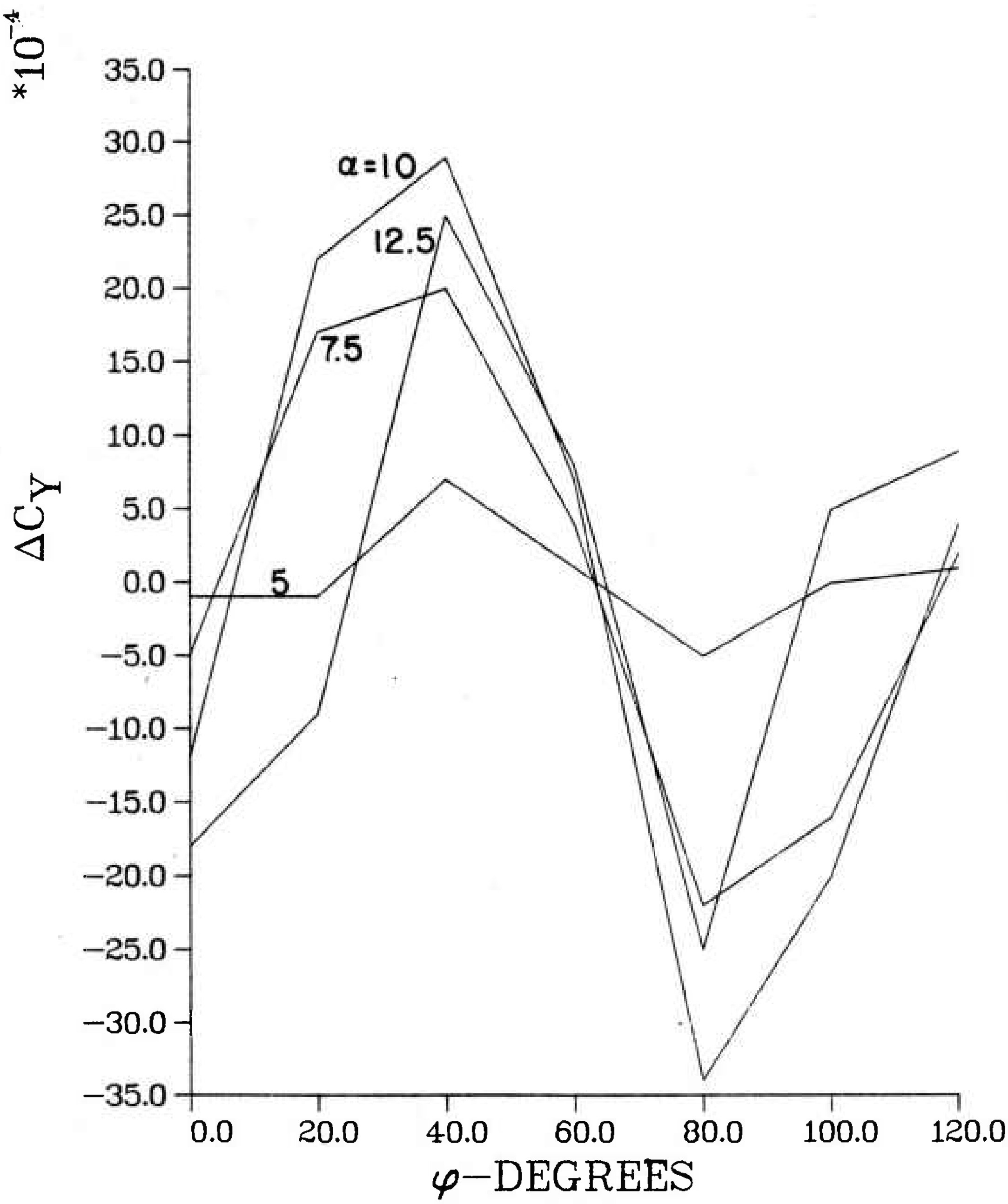

Figure 5. Continued

c. ΔC_Y vs ϕ, $M_\infty = 3.02$

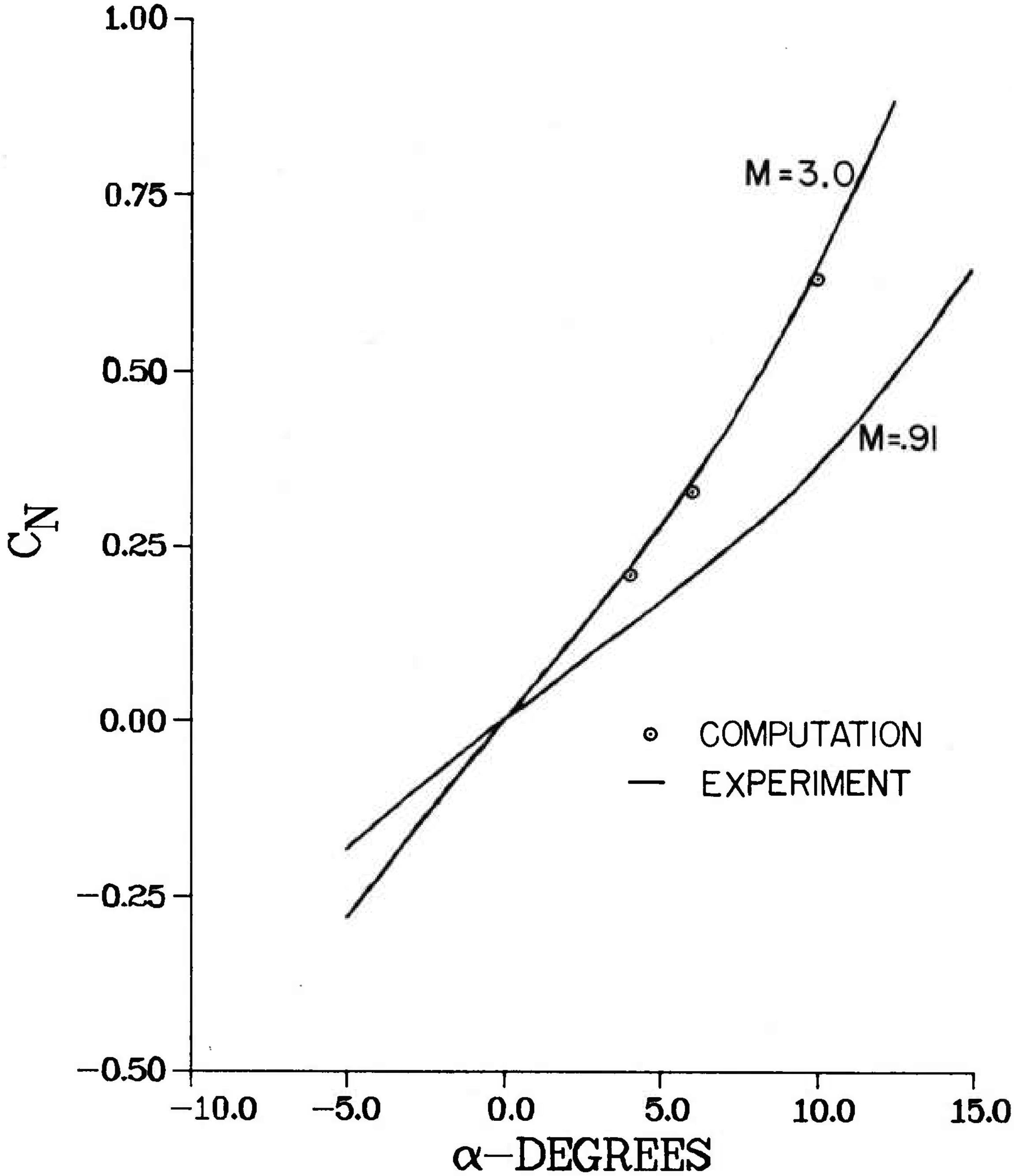

Figure 6. Comparison of Computation and Experiment, SOCBT-NC, ϕ = 0°

a. C_N vs α

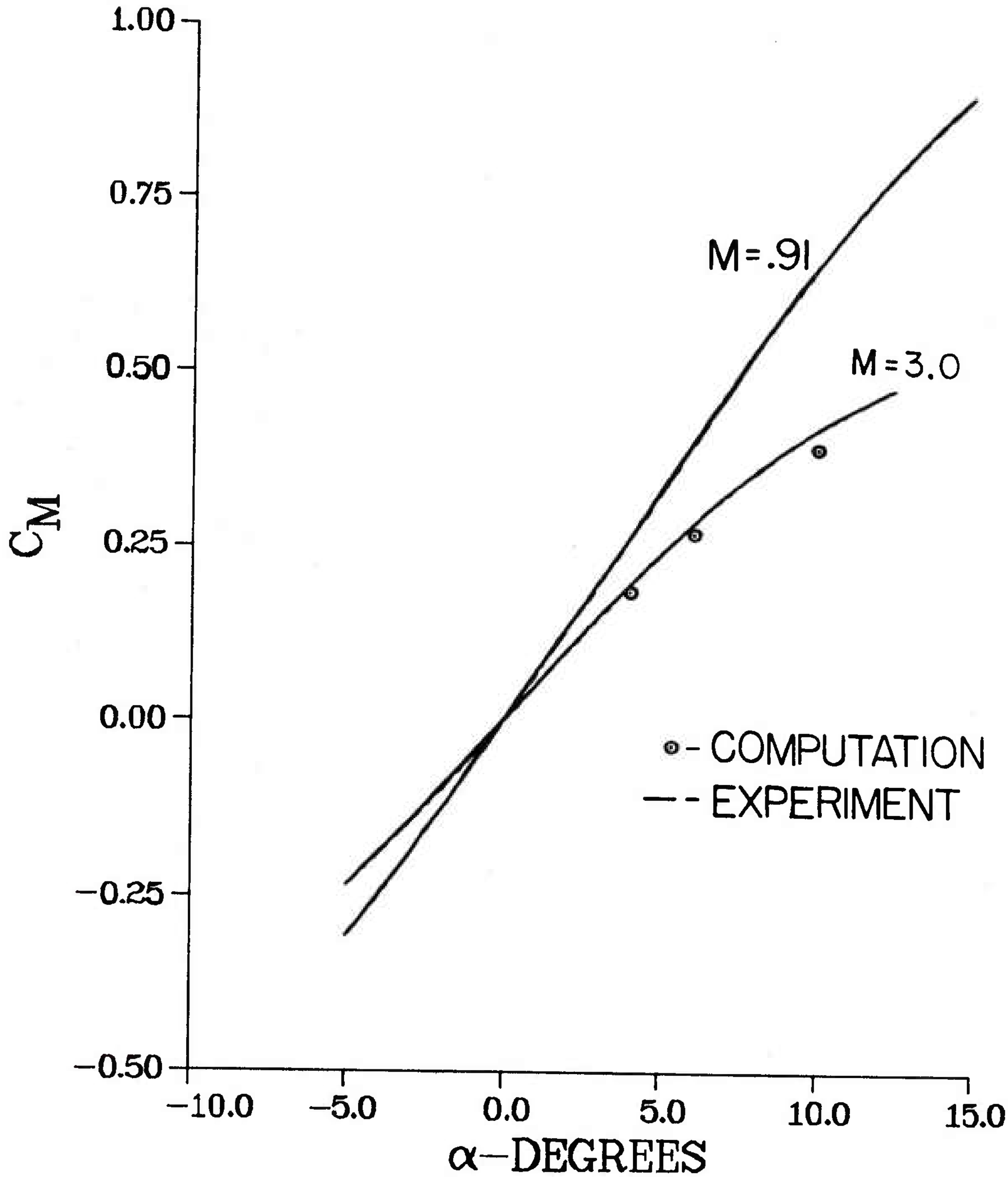

Figure 6. Continued

b. C_m vs α

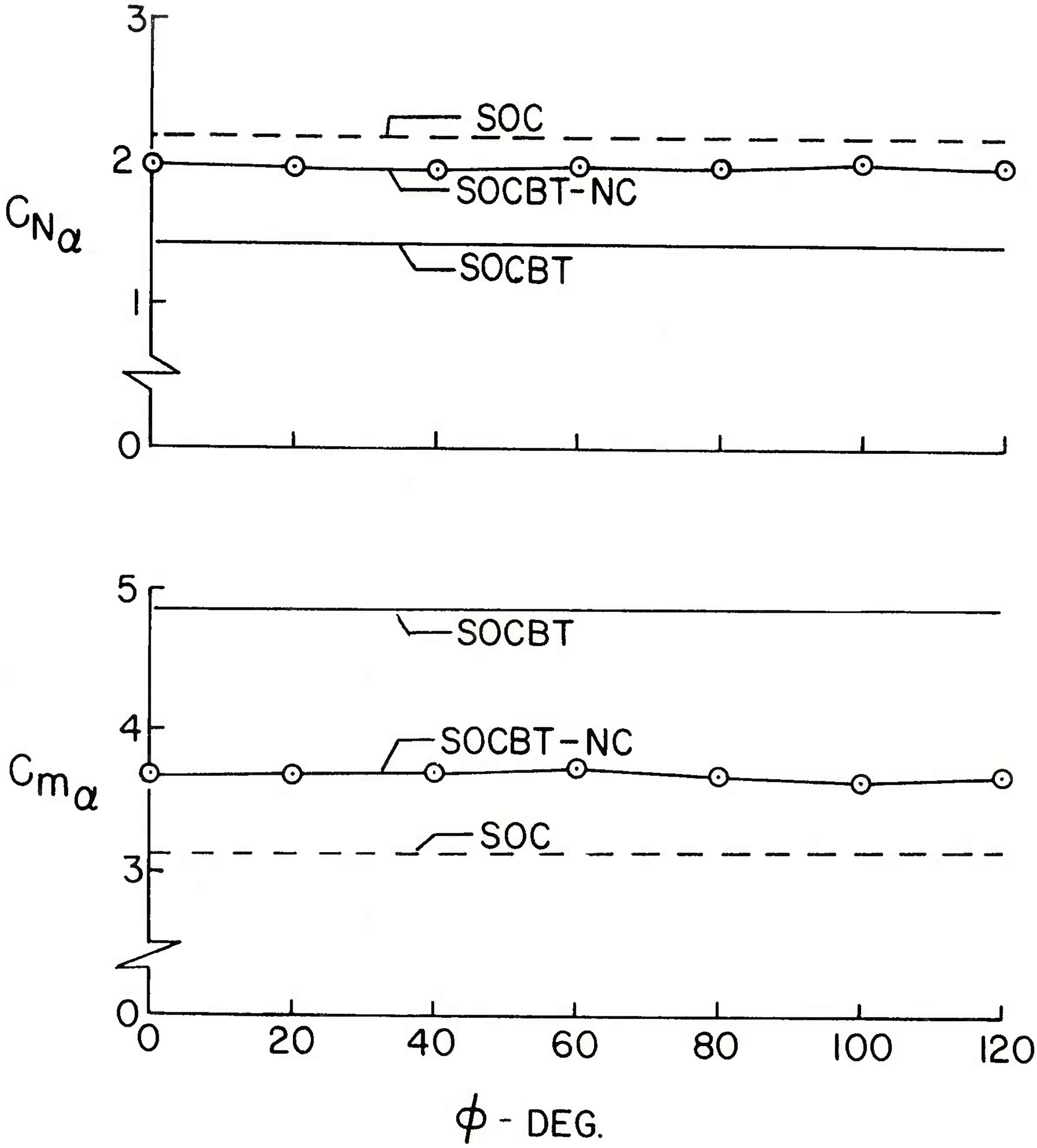

Figure 7. Comparison of Nonconical and Axisymmetric Shapes

a. $C_{N\alpha}$ and $C_{m\alpha}$ vs ϕ, $M_\infty = 0.91$

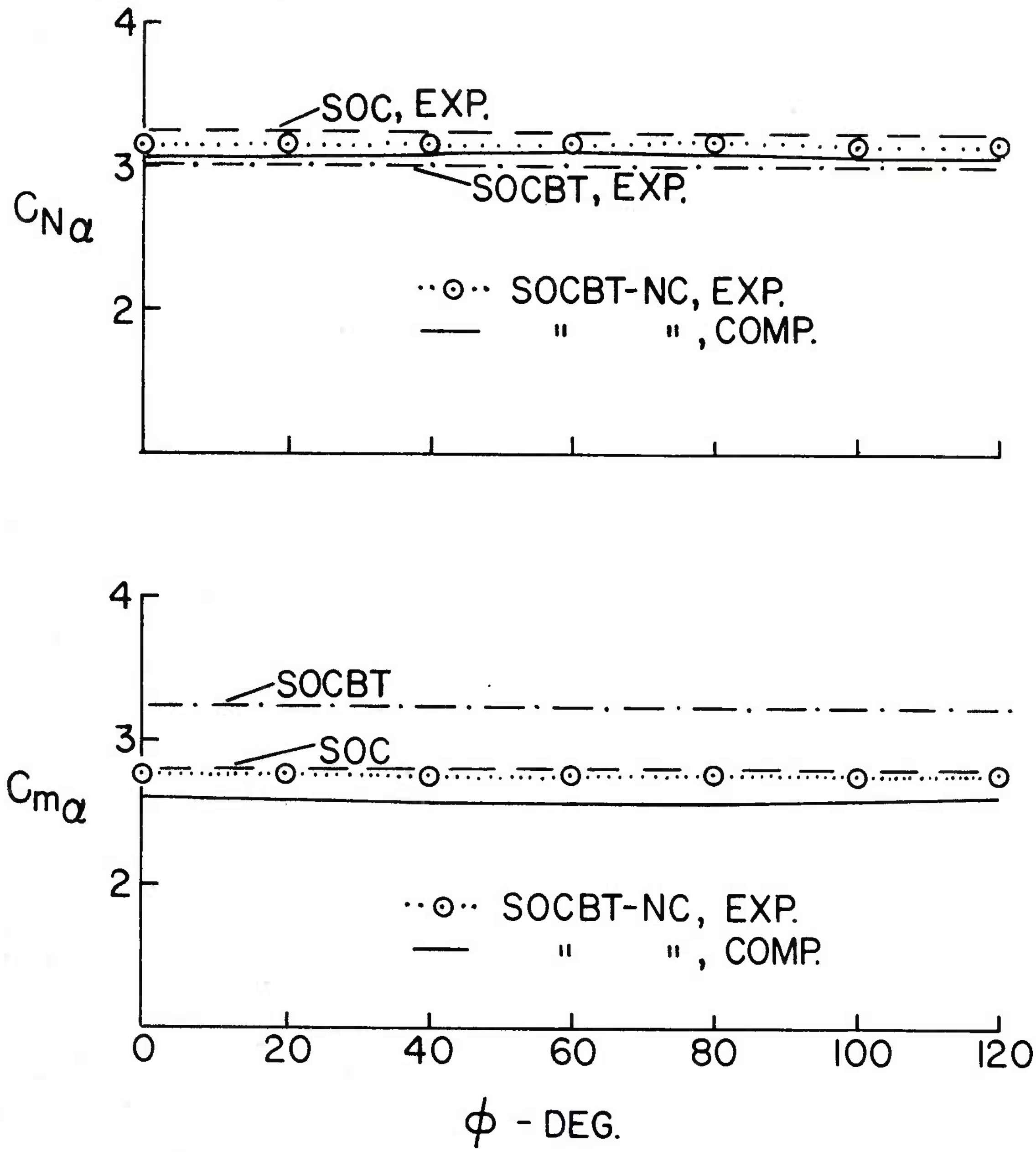

Figure 7. Continued

b. $C_{N\alpha}$ and $C_{m\alpha}$ vs ϕ, $M_{\infty} = 3.02$

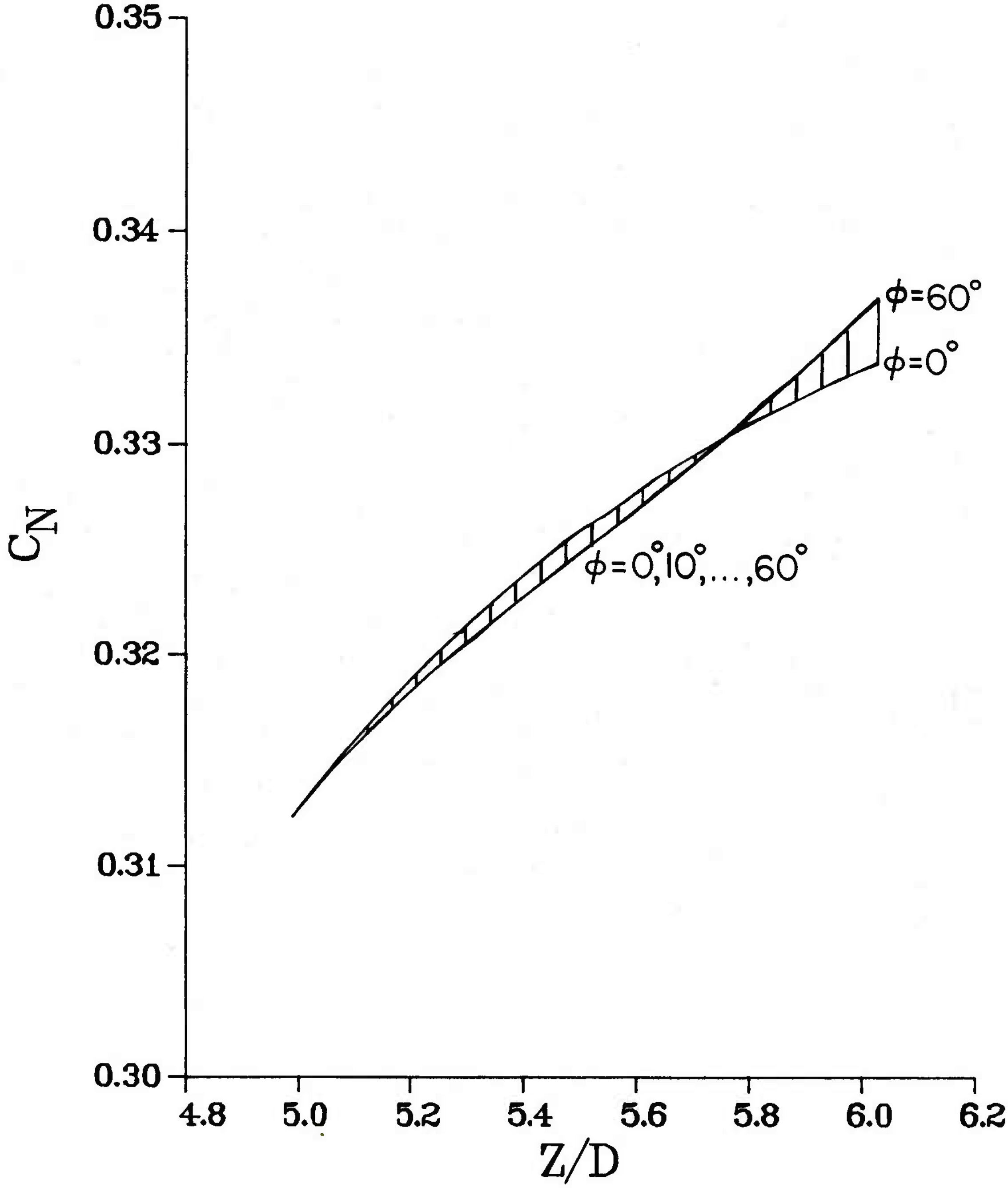

Figure 8. Computational Results, SOCBT-NC, $M_\infty = 3.02$

a. C_N vs Z/D, $\alpha = 6°$

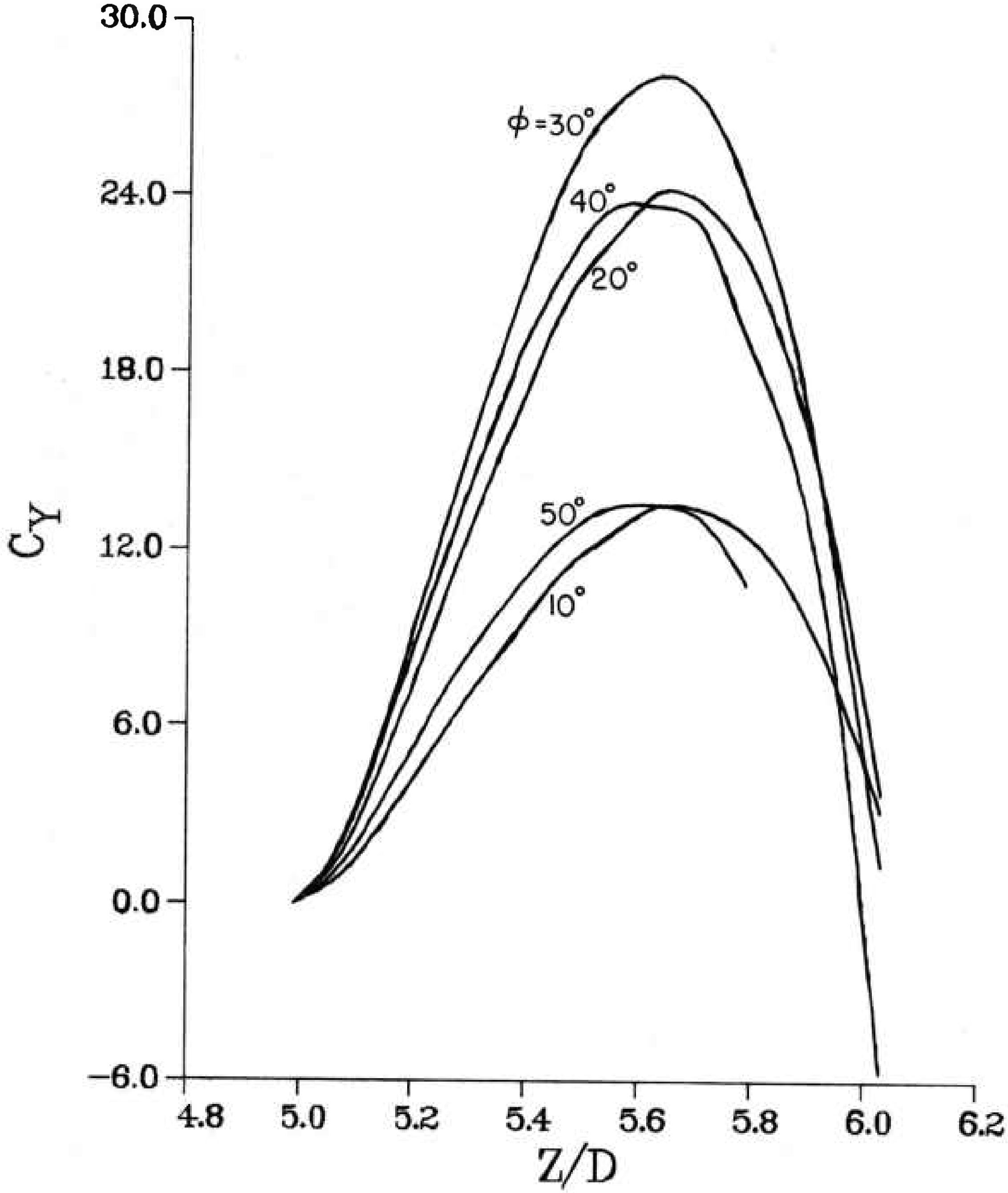

Figure 8. Continued

b. C_Y vs Z/D, $\alpha = 10°$

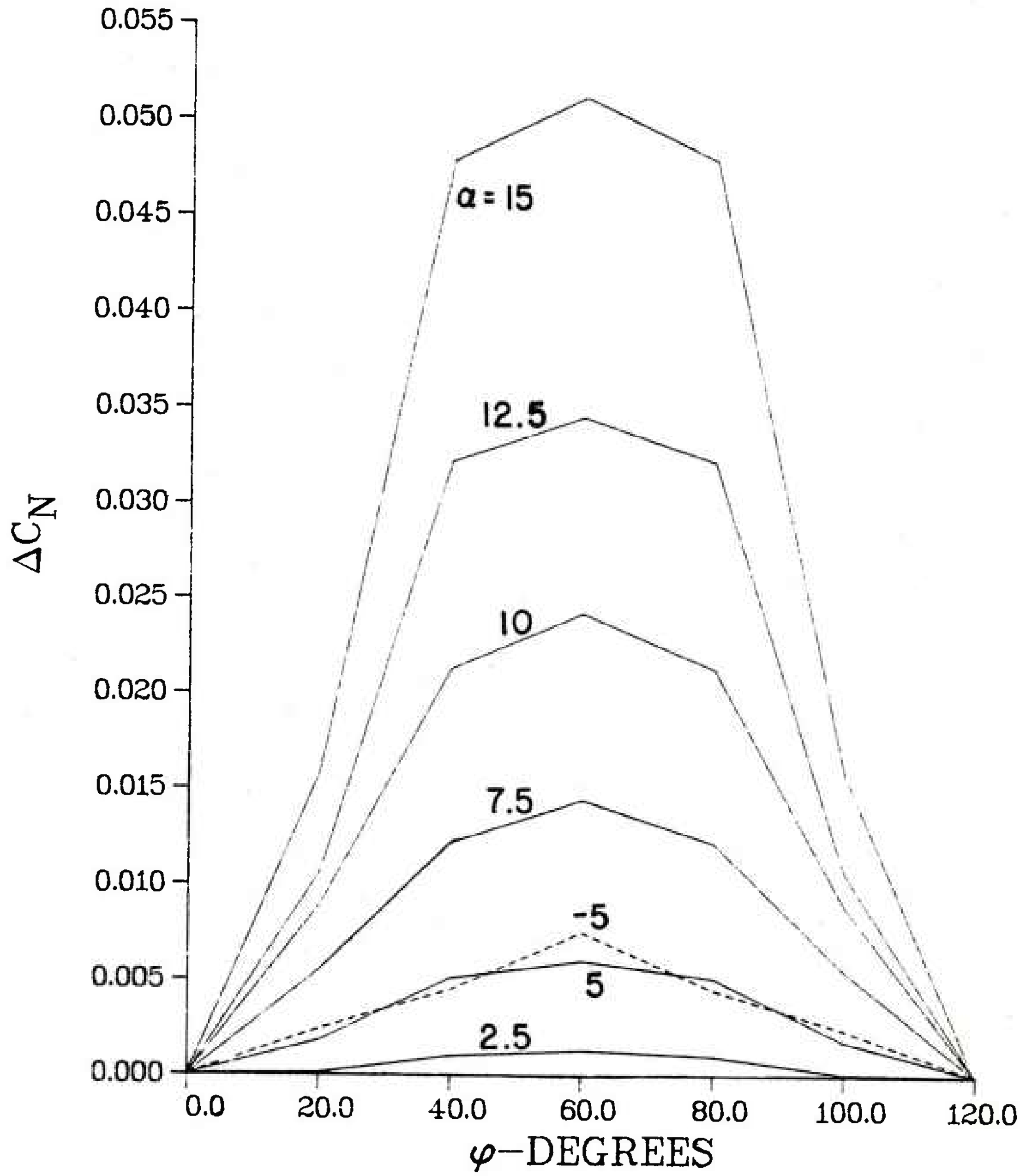

Figure 9. Incremental Coefficient Values, SOCBT-NC

a. ΔC_N vs ϕ, $M_\infty = 0.91$

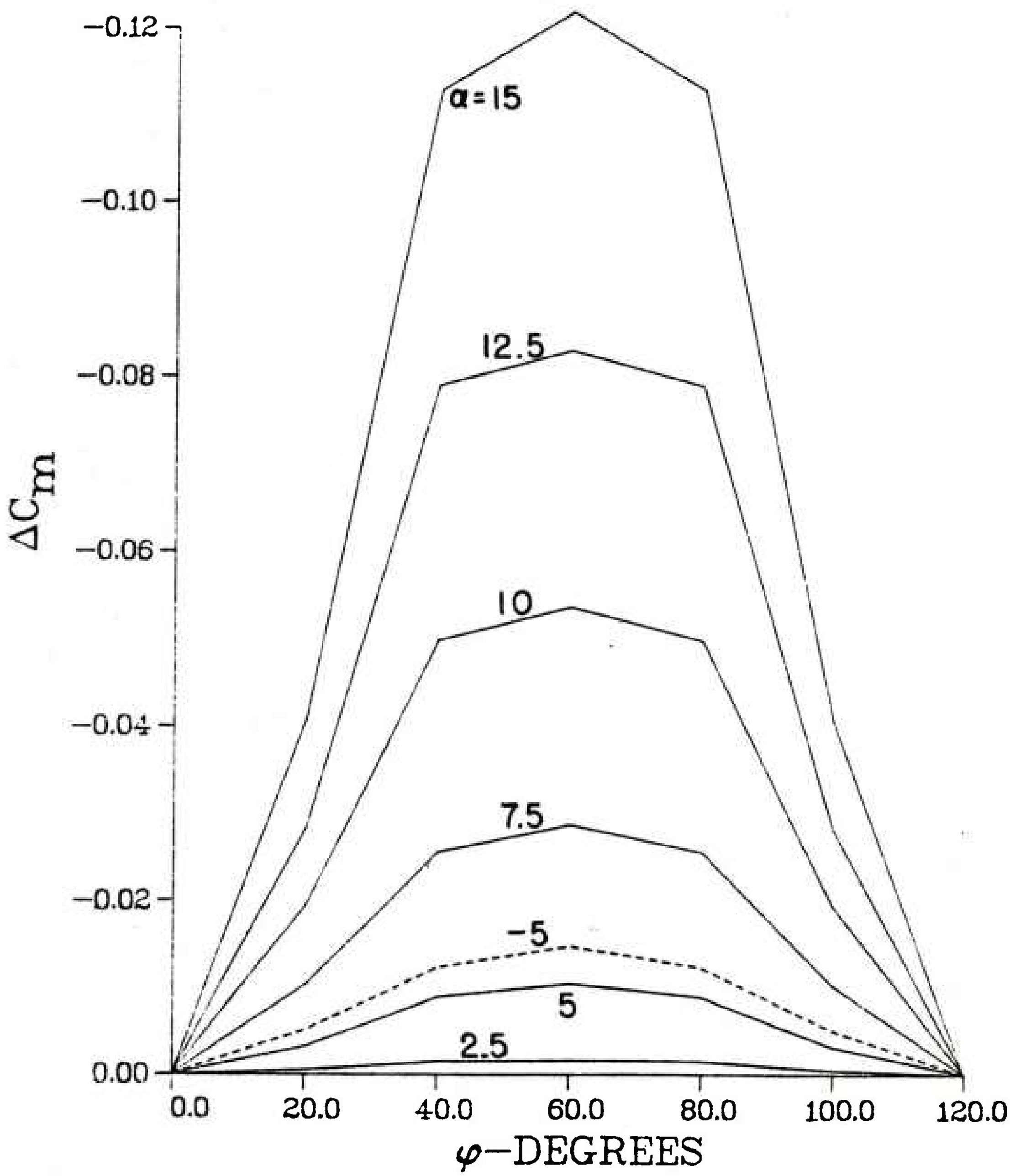

Figure 9. Continued

b. ΔC_m vs ϕ, $M_\infty = 0.91$

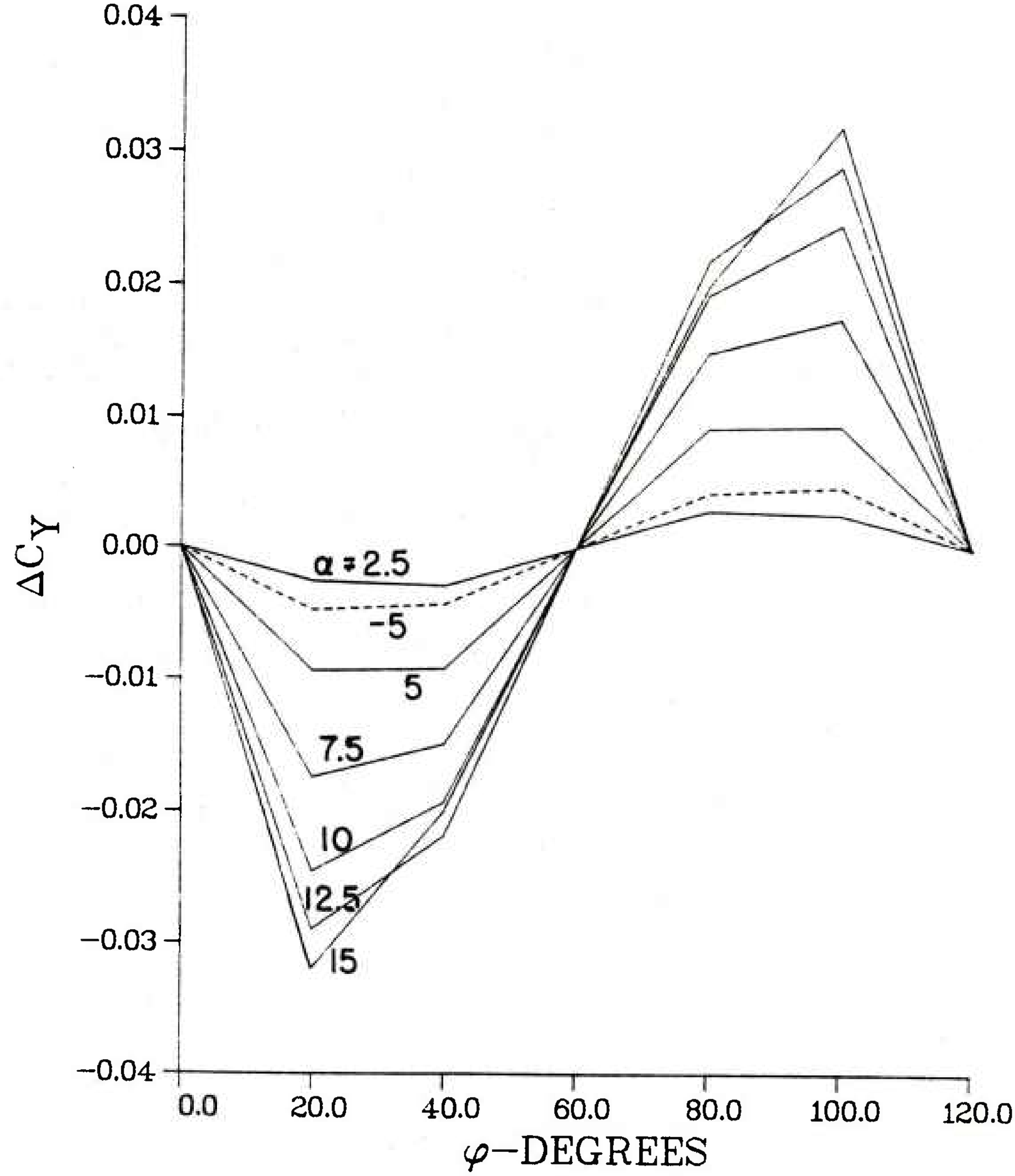

Figure 9. Continued

c. $\Delta\ C_Y$ vs ϕ, $M_\infty = 0.91$

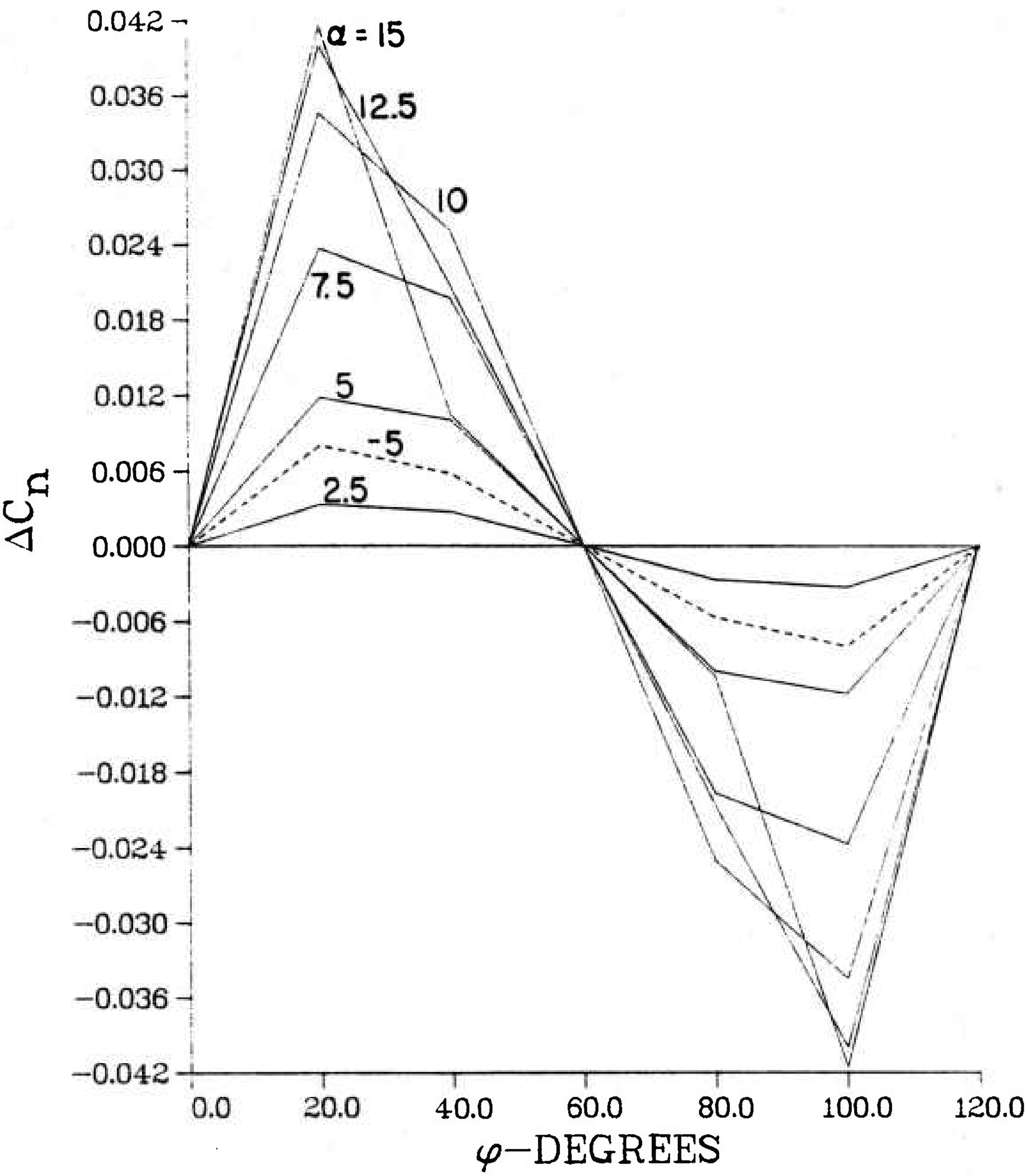

Figure 9. Continued

d. ΔC_n vs ϕ, $M_\infty = 0.91$

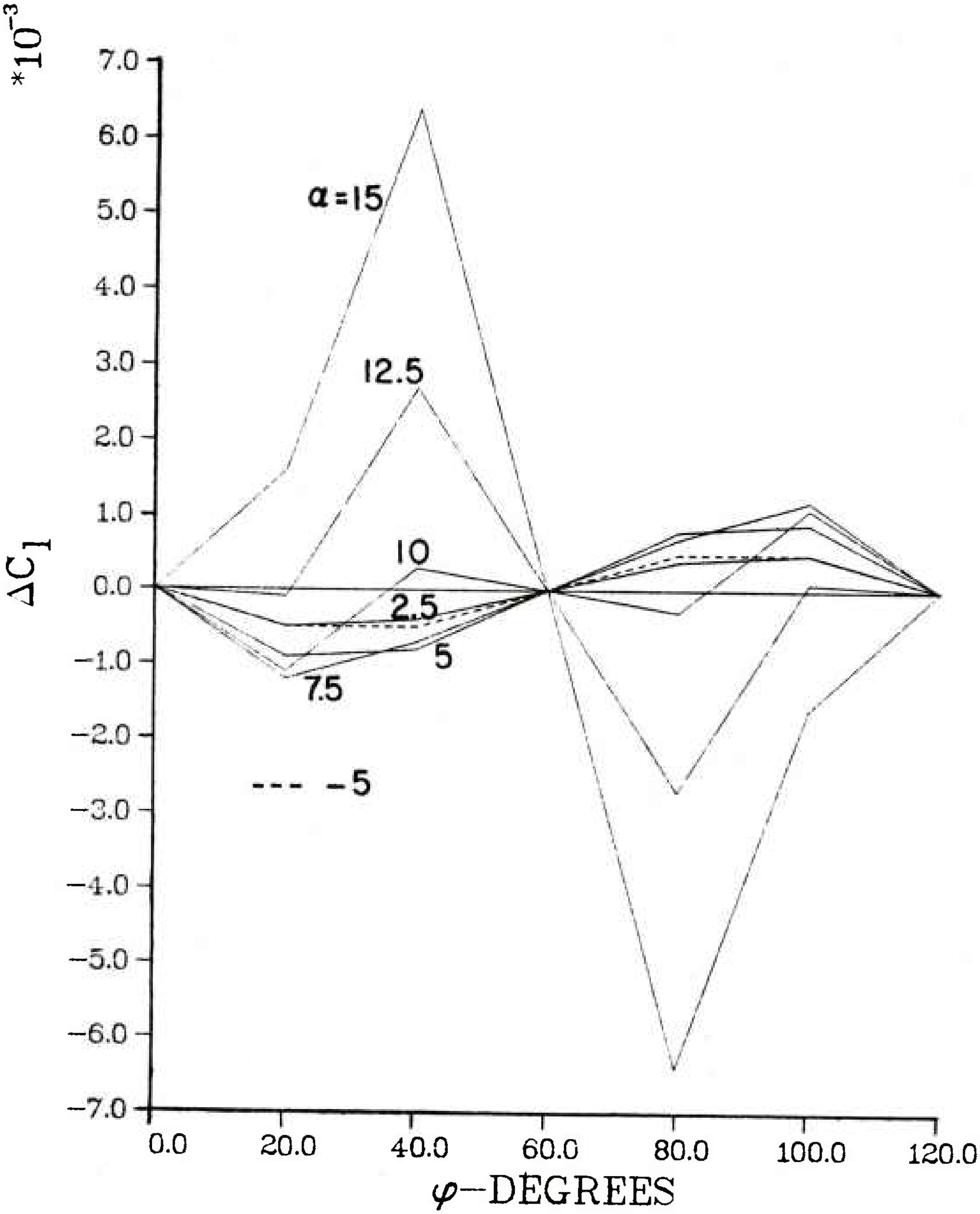

Figure 9. Continued

e. ΔC_ℓ vs ϕ, $M_\infty = 0.91$

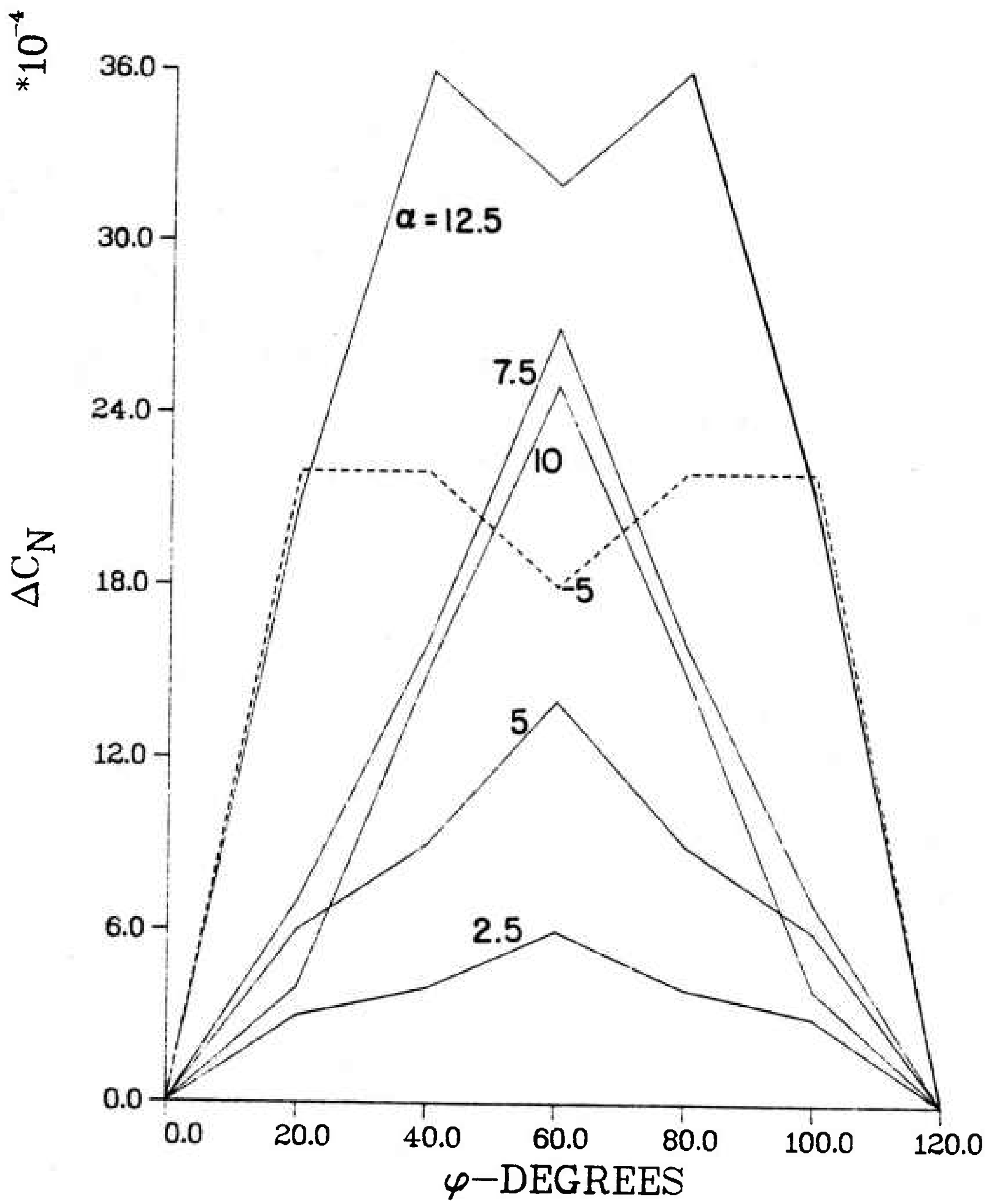

Figure 10. Incremental Coefficient Values, SOCBT-NC

a. $\Delta\ C_N$ vs ϕ, $M_\infty = 3.02$

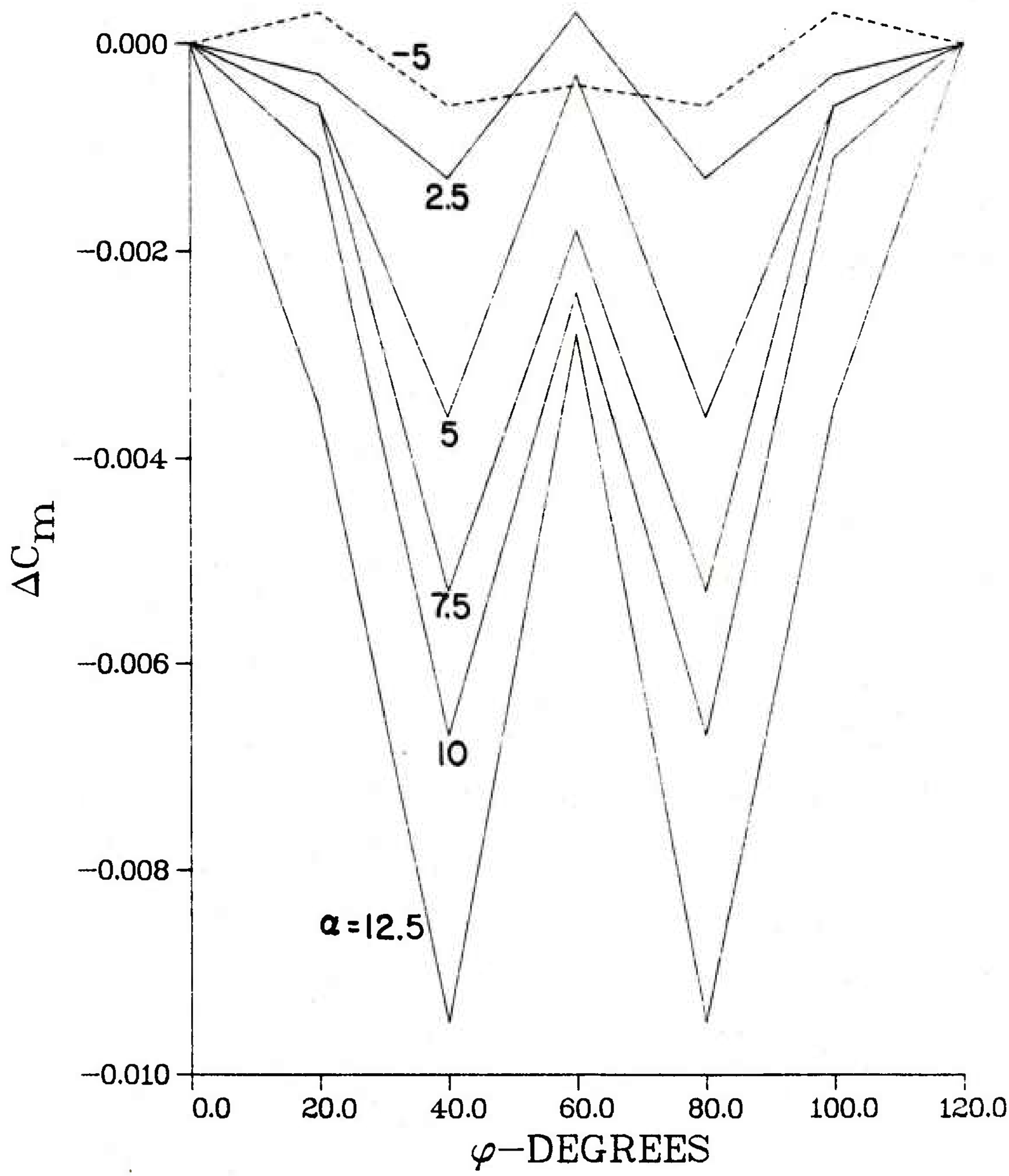

Figure 10. Continued

b. ΔC_m vs ϕ, M_∞ = 3.02

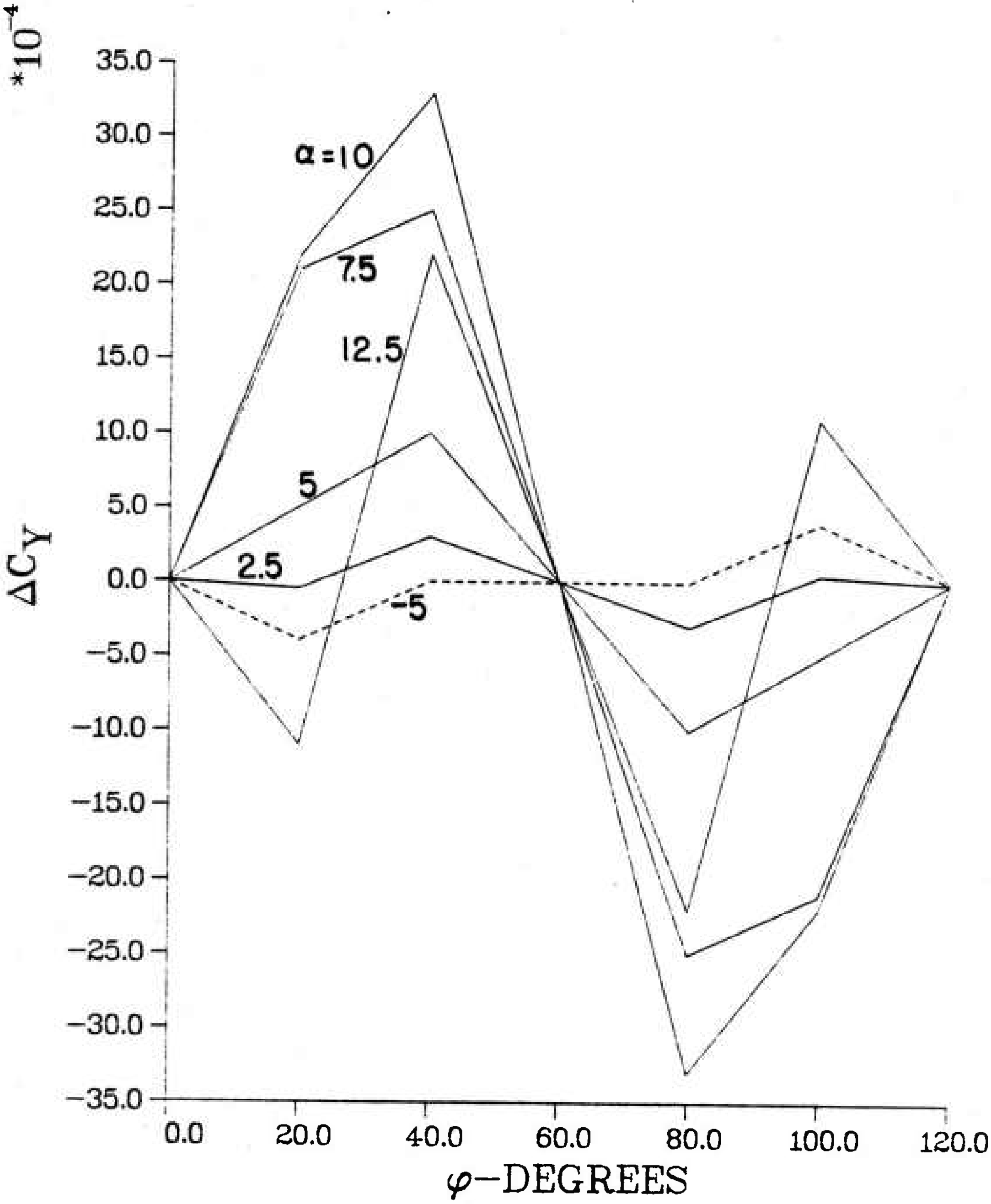

Figure 10. Continued

c. ΔC_Y vs ϕ, $M_\infty = 3.02$

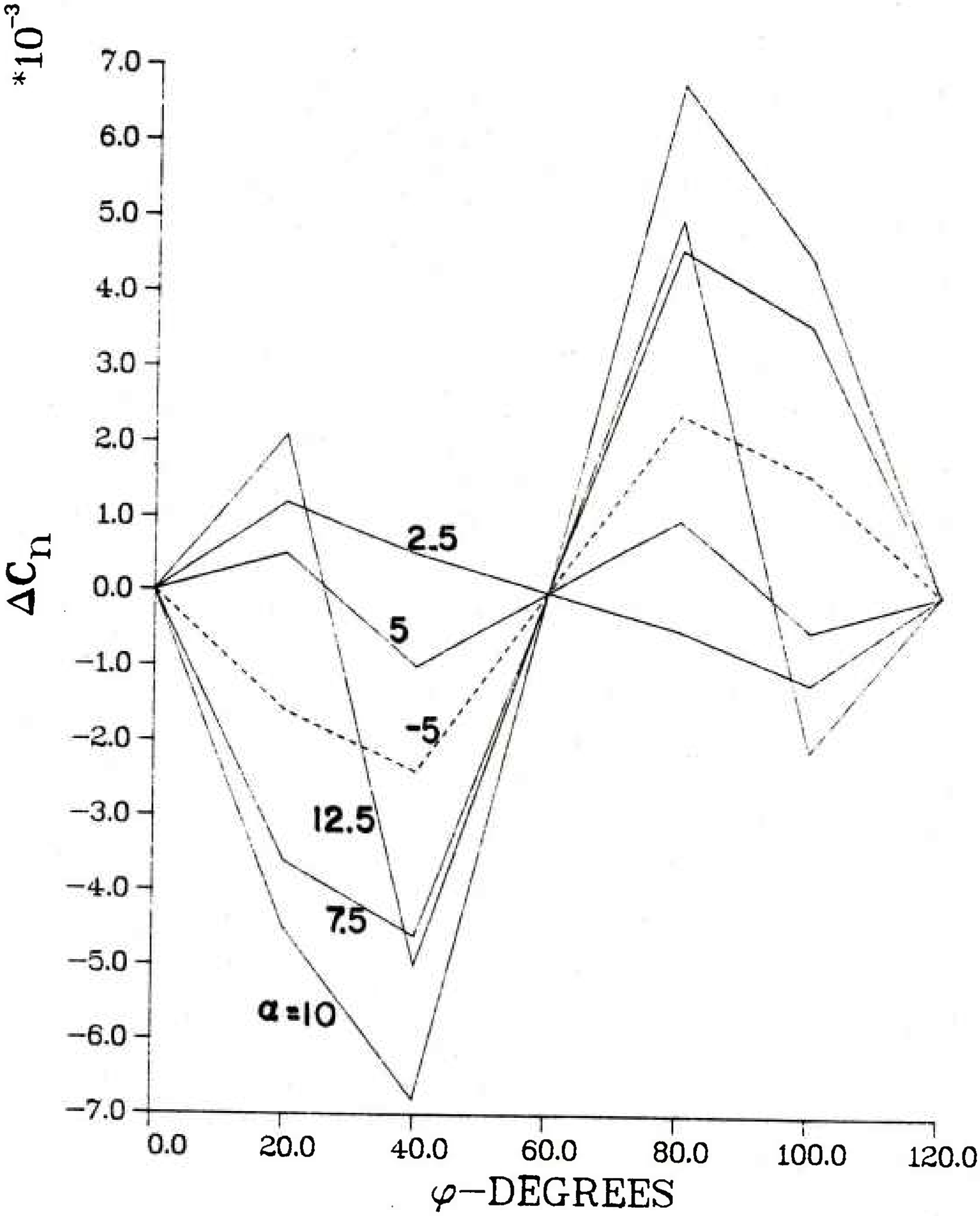

Figure 10. Continued

d. ΔC_n vs ϕ, $M_\infty = 3.02$

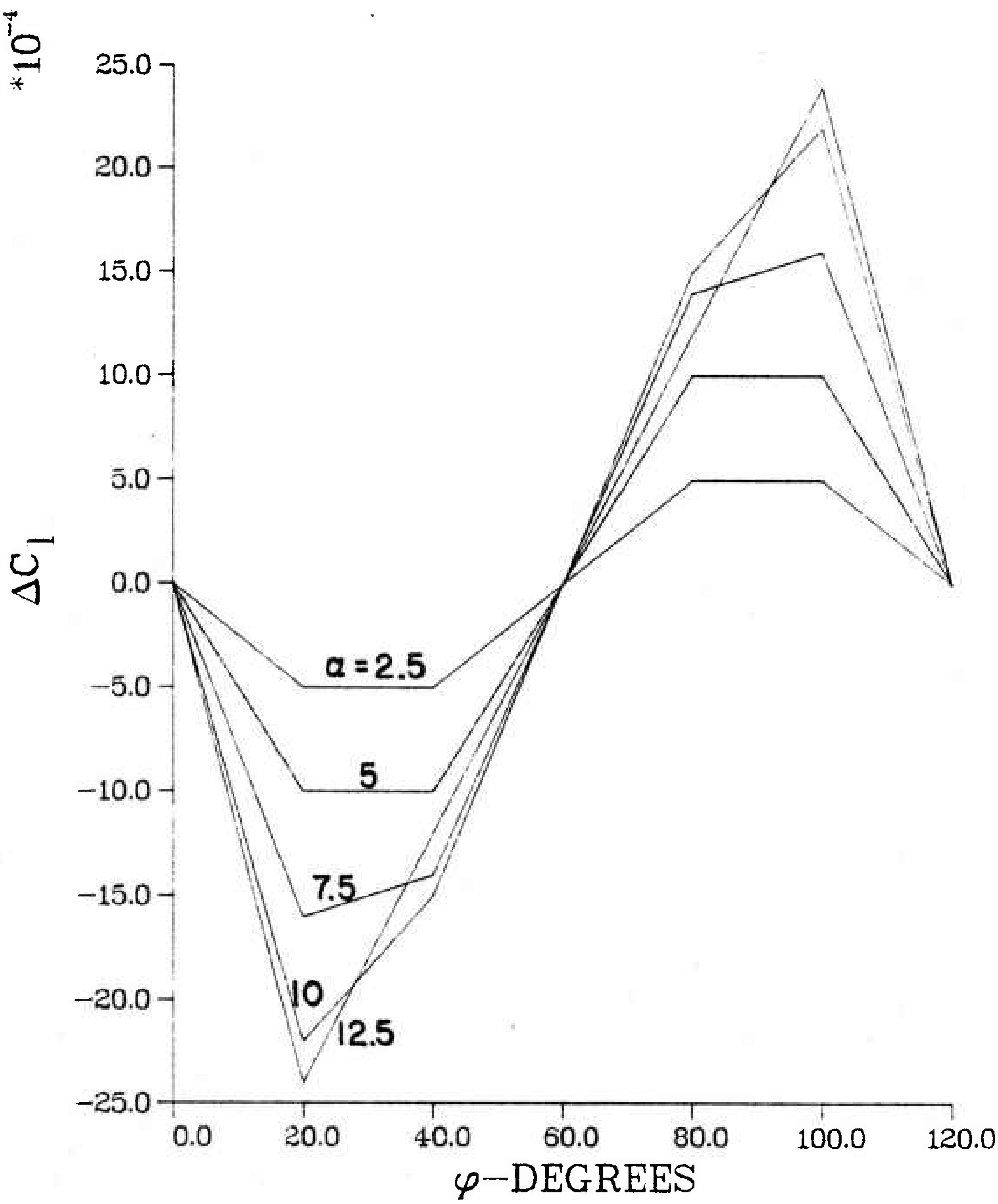

Figure 10. Continued

e. ΔC_ℓ vs ϕ, M_∞ = 3.02

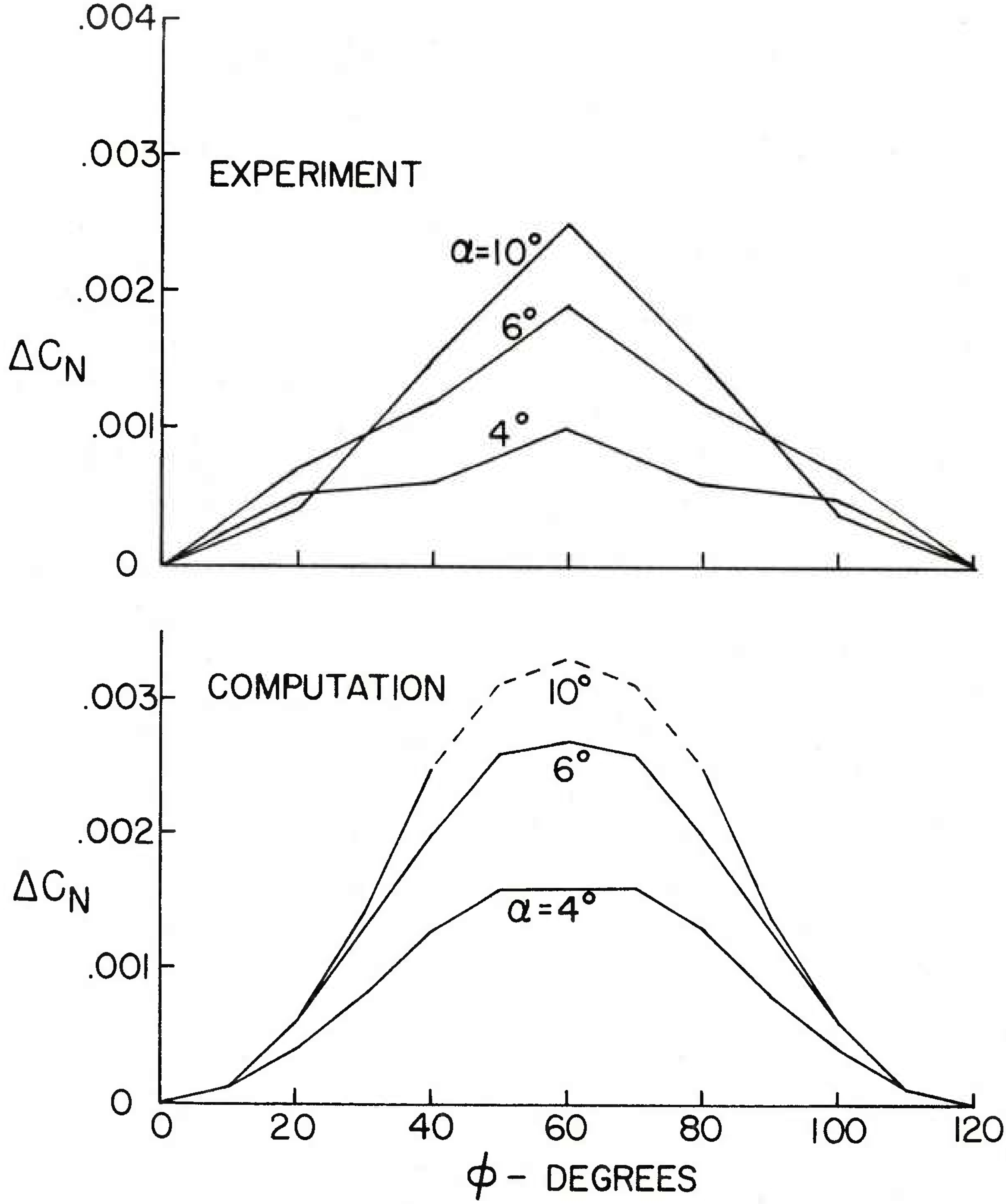

Figure 11. Incremental Normal Force Coefficients, Computation and Experiment, $M_\infty = 3.02$

TABLE 1. ESTIMATED ERRORS

	M = 0.91		M = 3.02	
	SD	1%*	SD	1%
C_N	0.2	2.0	0.1	2.1
ΔC_N	3.1	29	27	500
C_m	0.3	0.8	0.3	1.7
ΔC_m	2.0	6.2	19.0	100
ΔC_Y	35	23	18	400
ΔC_n	29	9	40	70
ΔC_ℓ	44	52	63	170

Errors - percent

$$SD = \frac{\text{Standard Deviation}}{\text{Max. Measurement}} \times 100$$

$$*1^\circ \text{ Criterion} = \frac{.01 \text{ (Full Scale)}}{\text{Max. Measurement}} \times 100$$

REFERENCES

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. Zumwalt, G.W., "Experiments on Three-Dimensional Separating-and-Reattaching Flows," AIAA Paper No.81-0259, AIAA 19th Aerospace Sciences Meeting, January 1981.

6. 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).

7. 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).

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. 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).

10. Schiff, L.B. and Steger, J.L., "Numerical Simulation of Steady Supersonic Flow," AIAA Journal, Vol. 18, No. 12, December 1980, pp. 1421-1430.

APPENDIX A. TABULATED DATA

MACH=0.91 NORMAL FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	-.1831	-.1802	-.1768	-.1749	-.1779	-.1786	-.1818
-2.5	-.0887	-.0872	-.0864	-.0869	-.0870	-.0886	-.0881
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0852	.0848	.0860	.0867	.0867	.0862	.0855
5.0	.1699	.1714	.1756	.1770	.1766	.1742	.1722
7.5	.2592	.2650	.2736	.2764	.2747	.2699	.2658
10.0	.3646	.3746	.3890	.3924	.3899	.3795	.3717
12.5	.4957	.5082	.5301	.5328	.5311	.5096	.5010
15.0	.6476	.6667	.6980	.7030	.7012	.6683	.6558

MACH=0.91 PITCHING MOMENT COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	-.3083	-.3124	-.3184	-.3234	-.3183	-.3100	-.3090
-2.5	-.1604	-.1607	-.1614	-.1633	-.1584	-.1504	-.1593
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.1620	.1616	.1607	.1604	.1605	.1615	.1620
5.0	.3265	.3229	.3175	.3155	.3165	.3225	.3254
7.5	.4938	.4823	.4666	.4623	.4543	.4791	.4663
10.0	.6517	.6303	.5993	.5935	.5956	.6254	.6428
12.5	.7876	.7568	.7076	.7008	.7022	.7543	.7802
15.0	.9007	.8591	.7910	.7767	.7800	.8516	.8958

MACH=0.91 DELTA NORMAL FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	.0024	.0045	.0075	.0045	.0024	.0000
-2.5	.0000	-.0002	.0010	.0015	.0010	-.0002	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	.0001	.0010	.0013	.0010	.0001	.0000
5.0	.0000	.0018	.0051	.0060	.0051	.0018	.0000
7.5	.0000	.0055	.0122	.0144	.0122	.0055	.0000
10.0	.0000	.0089	.0213	.0242	.0213	.0089	.0000
12.5	.0000	.0106	.0322	.0345	.0322	.0106	.0000
15.0	.0000	.0158	.0479	.0512	.0479	.0158	.0000

MACH=0.91 DELTA PITCHING MOMENT COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	-.0051	-.0123	-.0148	-.0123	-.0051	.0000
-2.5	.0000	-.0018	-.0038	-.0034	-.0038	-.0018	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	-.0005	-.0015	-.0016	-.0015	-.0005	.0000
5.0	.0000	-.0032	-.0089	-.0105	-.0089	-.0032	.0000
7.5	.0000	-.0103	-.0256	-.0288	-.0256	-.0103	.0000
10.0	.0000	-.0194	-.0498	-.0537	-.0498	-.0194	.0000
12.5	.0000	-.0283	-.0790	-.0830	-.0790	-.0283	.0000
15.0	.0000	-.0407	-.1130	-.1219	-.1130	-.0407	.0000

MACH=0.91 DELTA SIDE FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	-.0048	-.0043	.0000	.0043	.0048	.0000
-2.5	.0000	-.0029	-.0026	.0000	.0026	.0029	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	-.0026	-.0029	.0000	.0029	.0026	.0000
5.0	.0000	-.0094	-.0092	.0000	.0092	.0094	.0000
7.5	.0000	-.0175	-.0149	.0000	.0149	.0175	.0000
10.0	.0000	-.0246	-.0193	.0000	.0193	.0246	.0000
12.5	.0000	-.0290	-.0219	.0000	.0219	.0290	.0000
15.0	.0000	-.0320	-.0200	.0000	.0200	.0320	.0000

MACH=0.91 DELTA YAWING MOMENT COEFFICIENT

-5.0	.0000	.0080	.0057	.0000	-.0057	-.0080	.0000
-2.5	.0000	.0025	.0021	.0000	-.0021	-.0025	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	.0033	.0027	.0000	-.0027	-.0033	.0000
5.0	.0000	.0118	.0100	.0000	-.0100	-.0118	.0000
7.5	.0000	.0237	.0197	.0000	-.0197	-.0237	.0000
10.0	.0000	.0345	.0251	.0000	-.0251	-.0345	.0000
12.5	.0000	.0400	.0207	.0000	-.0207	-.0400	.0000
15.0	.0000	.0416	.0104	.0000	-.0104	-.0416	.0000

MACH=0.91 DELTA ROLLING MOMENT COEFFICIENT

-5.0	.0000	-.0005	-.0005	.0000	.0005	.0005	.0000
-2.5	.0000	-.0004	-.0004	.0000	.0004	.0004	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	-.0005	-.0004	.0000	.0004	.0005	.0000
5.0	.0000	-.0009	-.0008	.0000	.0008	.0009	.0000
7.5	.0000	-.0012	-.0007	.0000	.0007	.0012	.0000
10.0	.0000	-.0011	.0003	.0000	-.0003	.0011	.0000
12.5	.0000	-.0001	.0027	.0000	-.0027	.0001	.0000
15.0	.0000	.0016	.0064	.0000	-.0064	-.0016	.0000

MACH=3.02 NORMAL FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	-.2811	-.2819	-.2814	-.2806	-.2840	-.2836	-.2836
-2.5	-.1361	-.1364	-.1367	-.1371	-.1370	-.1368	-.1368
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.1352	.1354	.1355	.1359	.1358	.1358	.1353
5.0	.2800	.2804	.2810	.2816	.2813	.2813	.2805
7.5	.4459	.4470	.4485	.4495	.4482	.4479	.4477
10.0	.6482	.6484	.6497	.6506	.6494	.6457	.6479
12.5	.8866	.8879	.8900	.8900	.8906	.8897	.8869

MACH=3.02 PITCHING MOMENT COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	-.2332	-.2328	-.2330	-.2340	-.2356	-.2330	-.2340
-2.5	-.1222	-.1224	-.1229	-.1228	-.1233	-.1224	-.1225
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.1232	.1234	.1217	.1240	.1231	.1235	.1242
5.0	.2391	.2393	.2343	.2397	.2386	.2395	.2410
7.5	.3399	.3401	.3315	.3389	.3394	.3403	.3415
10.0	.4186	.4183	.4081	.4172	.4178	.4189	.4207
12.5	.4781	.4753	.4659	.4766	.4740	.4765	.4808

MACH=3.02 DELTA NORMAL FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	.0022	.0022	.0018	.0022	.0022	.0000
-2.5	.0000	-.0003	-.0005	-.0006	-.0005	-.0003	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	.0003	.0004	.0006	.0004	.0003	.0000
5.0	.0000	.0006	.0009	.0014	.0009	.0006	.0000
7.5	.0000	.0007	.0016	.0027	.0016	.0007	.0000
10.0	.0000	.0004	.0015	.0025	.0015	.0004	.0000
12.5	.0000	.0021	.0036	.0032	.0036	.0021	.0000

MACH=3.02 DELTA PITCHING MOMENT COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	.0003	-.0006	-.0004	-.0006	.0003	.0000
-2.5	.0000	.0003	-.0004	-.0004	-.0004	.0003	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	-.0003	-.0013	.0003	-.0013	-.0003	.0000
5.0	.0000	-.0006	-.0036	-.0003	-.0036	-.0006	.0000
7.5	.0000	-.0006	-.0053	-.0018	-.0053	-.0006	.0000
10.0	.0000	-.0011	-.0067	-.0024	-.0067	-.0011	.0000
12.5	.0000	-.0035	-.0095	-.0028	-.0095	-.0035	.0000

MACH=3.02 DELTA SIDE FORCE COEFFICIENT

ALPHA	PHI=0	20	40	60	80	100	120
-5.0	.0000	-.0004	.0000	.0000	.0000	.0004	.0000
-2.5	.0000	-.0004	-.0004	.0000	.0004	.0004	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	.0000	.0003	.0000	-.0003	.0000	.0000
5.0	.0000	.0005	.0010	.0000	-.0010	-.0005	.0000
7.5	.0000	.0021	.0025	.0000	-.0025	-.0021	.0000
10.0	.0000	.0022	.0033	.0000	-.0033	-.0022	.0000
12.5	.0000	-.0011	.0022	.0000	-.0022	.0011	.0000

MACH=3.02 DELTA YAWING MOMENT COEFFICIENT

-5.0	.0000	-.0016	-.0024	.0000	.0024	.0016	.0000
-2.5	.0000	-.0011	-.0006	.0000	.0006	.0011	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	.0012	.0005	.0000	-.0005	-.0012	.0000
5.0	.0000	.0005	-.0010	.0000	.0010	-.0005	.0000
7.5	.0000	-.0036	-.0046	.0000	.0046	.0036	.0000
10.0	.0000	-.0045	-.0068	.0000	.0068	.0045	.0000
12.5	.0000	.0021	-.0050	.0000	.0050	-.0021	.0000

MACH=3.02 DELTA ROLLING MOMENT COEFFICIENT

-5.0	.0000	-.0010	-.0010	.0000	.0010	.0010	.0000
-2.5	.0000	-.0005	-.0005	.0000	.0005	.0005	.0000
0.0	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2.5	.0000	-.0005	-.0005	.0000	.0005	.0005	.0000
5.0	.0000	-.0010	-.0010	.0000	.0010	.0010	.0000
7.5	.0000	-.0016	-.0014	.0000	.0014	.0016	.0000
10.0	.0000	-.0022	-.0015	.0000	.0015	.0022	.0000
12.5	.0000	-.0024	-.0012	.0000	.0012	.0024	.0000

LIST OF SYMBOLS

C_ℓ	rolling moment coefficient
C_m	pitching moment coefficient
$C_{m\alpha}$	slope of the pitching moment coefficient at $\alpha = 0$
C_n	yawing moment coefficient
C_N	normal force coefficient
$C_{N\alpha}$	slope of the normal force coefficient at $\alpha = 0$
C_Y	side force coefficient
M_∞	free-stream Mach number
SOC	figure 1 geometry with zero degree boattail angle
SOCBT	figure 1 geometry
SOCBT-NC	ogive-cylinder geometry of figure 1 with the boattail geometry of figure 2
α	angle of attack, degrees
$\Delta C_{(\ )}$	incremental coefficient values, for example, $\Delta C_N = C_N)_{\phi = A} - C_N)_{\phi = 0}$; $A \neq 0°$
ϕ	roll orientation of model, see figure 3

NOTE: The model diameter (d), model cross section area ($\pi d^2/4$), and the free-stream dynamic pressure were used to nondimensionalize forces and moments.

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