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"IN-PLANE" AND "OUT OF PLANE" STABILITY DERIVATIVES OF SLENDER CONES AT MACH 14

Otto Walchner, et al

Aerospace Research Laboratories
Wright-Patterson Air Force Base, Ohio

July 1973

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AEROSPACE RESEARCH LABORATORIES
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FOREWORD

This report was prepared by Mr. Otto Walchner and Mr. Frank M. Sawyer of the Aerospace Research Laboratories, ARL/ LH under Project 7064 entitled, "High Velocity Fluid Mechanics."

Results of this study were presented to SAMSO on the occasion of a review of ARL's research efforts in the area of hypersonic stability problems, 13 February 1973.

The authors acknowledge the assistance of the wind tunnel staff, ARL/ LF.

This manuscript was submitted for publication 30 April 1973.

ABSTRACT

A 10-deg. circular cone with various spherical and conical (45°) nose bluntnesses of 1.7%, 10% and 25% was investigated in ARL's Mach-14 wind tunnel. Test results confirm that the static and dynamic stability coefficients are not equal in pitch and in yaw for nonzero angles of attack, if the pitching moment becomes a nonlinear function of angle of attack due to nose blunting. The inequality of the "in plane" and "out of plane" stability derivatives was found at small angles of attack which are only fractions of the cone half angle.

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NOMENCLATURE

A	Cone base area
C_m	Pitching moment coefficient. pitching moment/ $q_\infty Ad$
C_n	Side-moment coefficient, sidemoment/ $q_\infty Ad$
d	Cone base diameter
L	Model length measured from sharp cone apex
q_∞	Free stream dynamic pressure
q	Pitching velocity
r	Yawing velocity
V_∞	Free stream velocity
$x_{C.G}$	Moment center location, measured from sharp cone apex
α	Angle of attack
β	Angle of sideslip
θ_c	Cone half angle

$C_{m_\alpha} = \partial C_m / \partial \alpha$

$C_{n\beta} = \partial C_n / \partial \beta$

$C_{m_q} + C_{m_{\dot\alpha}} = \partial C_m / \partial(qd/2V_\infty) + \partial C_m / \partial(\dot\alpha d/2V_\infty)$

$C_{n_r} - C_{n_{\dot\beta}} = \partial C_n / \partial(rd/2V_\infty) - \partial C_n / \partial(\dot\beta d/2V_\infty)$

Subscripts

N	Refers to nose
B	Refers to base

SECTION I

INTRODUCTION

Stone et al$^{(1)}$ recently reported a theoretical and experimental investigation of "in plane" and "out of plane" damping derivatives, $C_{m_q} + C_{m_{\dot{\alpha}}}$ and $C_{n_r} - C_{n_{\dot{\beta}}}$ respectively, for a nearly pointed circular cone at various angles of attack. The "in plane" and "out of plane" derivatives were found to be equal for angles of attack up to $\alpha \approx \theta_c$. At larger angles of attack the damping derivatives are unequal. The inequality of the static stability derivatives, $-C_{m_\alpha}$ and C_{n_β}, at large angles of attack was not discussed in Reference (1).

The purpose of the present report is to show that nose blunting of a slender cone at high Mach numbers and the associated nonlinearity of the pitching moment can cause differences between the "in plane" and "out of plane" static and dynamic stability derivatives at small angles of attack which are only fractions of the cone half angle.

With respect to the static stability, the authors are indebted to Dr. C. H. Murphy for pointing out the following relation between the lateral directional stability, C_{n_β}, and the pitching moment, C_m,

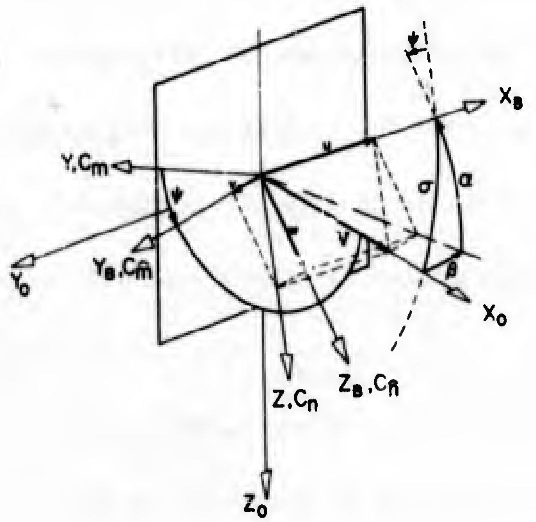
$$C_{n_\beta}(\alpha, \beta = 0) = -(1/\alpha) \int_0^\alpha C_{m_\alpha} d\alpha \tag{1}$$

See also Eq. (35) of Reference (2).

Equation (1) holds for any type of nonlinear pitching moment and is not limited to a cubic static moment. It includes, of course, the linear case.

This is easily verified by inspection of the sketch below, where definitions and nomenclature are the same as used in Reference (3).

Shown in this sketch are three coordinate systems, all having the origin at the vehicle's center of gravity. The system x_o, y_o, z_o does not rotate with respect to inertial space, and x_o is aligned with the velocity vector V.



For convenience the body axes x_B, y_B, z_B are shown as non-rolling. That is, the y_B axis lies in the x_o-y_o plane. The velocity components along the body axes are u, v, w, respectively, and the plane containing v and w is the cross flow plane. The pitching moment and side-moment coefficients referred to the body axes y_B and z_B are denoted $C_{\hat{m}}$ and $C_{\hat{n}}$ respectively. The angle of attack is defined by $\tan \alpha = w/u$ and the angle of sideslip by $\sin \beta = v/V$.

The axes of the aerodynamic coordinate system are x_B, y, z. The z-axis lies in the x_B-V plane, which contains the resultant angle of attack, σ, and is along the intersection of the cross flow plane and the resultant angle of attack plane. The y axis is along the intersection of the cross flow plane and the space fixed y_o-z_o plane. The moment coefficients referred to the aerodynamic axes y and z are denoted C_m and C_n.

The angle ψ in the cross flow plane defines the orientation of the body axes, y_B, z_B, measured from the aerodynamic axes, y, z. Note that $\sin\psi = \sin\beta / \sin\sigma$, $\cos\psi = \tan\alpha / \tan\sigma$ and $\cos\sigma = \cos\alpha \cos\beta$.

The total moment vector in the cross flow plane transfers from the body coordinate system to the aerodynamic system through the following equation,[3]

$$C_{\hat{m}} + i\, C_{\hat{n}} = (C_m + i\, C_n) e^{-i\psi}$$

For a body of revolution in a steady flow, the sidemoment in the aerodynamic coordinate system vanishes, $C_n = 0$. Therefore,

$$C_{\hat{m}} = C_m \cos\psi = C_m \tan\alpha / \tan\sigma$$

$$C_{\hat{n}} = -\, C_m \sin\psi = -C_m \sin\beta / \sin\sigma$$

Let $\beta \longrightarrow 0$; **then**

$$\sigma \longrightarrow \alpha \quad , \qquad C_m \longrightarrow C_{\hat{m}} \quad , \qquad C_{\hat{n}_\beta}(\alpha, \beta = 0) = -\, C_{\hat{m}}(\alpha) / \sin\alpha$$

As pointed out by Murphy in Ref. (2), the derivative C_{n_β} at angles of attack is related to the pitching moment and not its derivative.

It is well known that moderate nose blunting of a slender cone makes the pitching moment a nonlinear function of α, even in the range of small angles of attack, $\alpha < \theta_c$. Depending on the nonlinearity of the pitching moment, appreciable differences between $-C_{m_\alpha}$ and C_{n_β} must be expected at small angles of attack. If, however, the pitching moment is a linear function of α, as in the case of a sharp cone at $\alpha \leq \theta_c$, then the equality of $-C_{m_\alpha}$ and C_{n_β} exists.

The present investigation includes the measurement of the "in plane" derivatives C_{m_α} and $C_{m_q} + C_{m_{\dot{\alpha}}}$ and "out of plane" derivatives C_{n_β} and $C_{n_r} - C_{n_{\dot{\beta}}}$ at several angles of attack. Different types of nonlinear pitching moments are obtained by varying the nose bluntness of the slender circular cone. In addition, the measured values of C_{m_α} are used to compute C_{n_β} according to Equation (1).

SECTION II

TEST PROCEDURE AND MODEL

The experiments were made in ARL's 20-inch Mach 14 hypersonic wind tunnel, which is a free-jet intermittent-blowdown to vacuum type of facility. Typical test conditions are $M_\infty = 14.2$, $\gamma = 1.4$, $p_t = 1500$ psi, $T_t = 2000°R$, $Re_{\infty,Ft} = 5.5 \times 10^5$, $T_w / T_t \approx 0.3$.

The free oscillation technique was used to obtain a small amplitude (~ 1.0 degree) oscillatory planar motion. The model was attached to the sting with a circular cross section beryllium-copper flexure. The reduced oscillation frequency was $\omega d / 2V_\infty \approx .003$.

An Optron tracker provided a voltage proportional to the model motion, and this voltage was digitized and recorded. The motion amplitude and frequency were obtained from a least squares fit of the displacement-time data, and the stability derivatives were computed using the known free stream properties and the model constants.

"In plane" derivatives were measured up to an angle of attack of approximately 12 degrees. The available test setup limited the angle of attack range for the "out of plane" derivatives to $\alpha = 6$ degrees.

The basic model configuration was a circular cone, $\theta_c = 10$ deg., $d = 5.0$ in. The moment center was at the axial station $x_{C.G.}/L = 0.65$, measured from the sharp cone tip. Five interchangeable noses were used as listed in the following table.

Nose #	Bluntness ratio, r_N/r_B	Bluntness Configuration
1	0.017	spherical (nearly pointed)
2	0.100	spherical
3	0.100	conical, 45 deg.
4	0.250	spherical
5	0.250	conical, 45 deg.

A photograph of the model and the different noses is shown in Figure 1.

SECTION III

TEST RESULTS

Figure 2 shows the results obtained with nose 1. As expected for this nearly pointed cone model, the static and dynamic stability derivatives in pitch do not change with α in the investigated range of $\alpha \lesssim \theta_c$. The "in plane" and "out of plane" derivatives are equal, $C_{n_\beta} = -C_{m_\alpha}$ and $C_{n_r} - C_{n_{\dot\beta}} = C_{m_q} + C_{m_{\dot\alpha}}$.

The moderate 10% spherical bluntness of nose 2 makes the pitching moment a nonlinear function of α, as seen in Fig. 3. For $\alpha = 0$, the value of C_{m_α} is 2.1 times the sharp cone value. With increasing angle of attack, C_{m_α} drops toward the sharp cone value. Under these conditions the equality of C_{n_β} and $-C_{m_\alpha}$ exists only for $\alpha = 0$. Appreciable differences are observed for larger angles of attack, e.g., $C_{n_\beta} = 1.5(-C_{m_\alpha})$ for $\alpha = 5$ deg. It is noted that the measured values of C_{n_β} compare well with calculation based on Equation (1). The damping derivatives $C_{m_q} + C_{m_{\dot\alpha}}$ and $C_{n_r} - C_{n_{\dot\beta}}$ are constant and equal for the small angle of attack range from $\alpha = 0$ to $\alpha \approx 4$ deg. However, it appears that the damping derivatives will not be equal for angles of attack greater than 4 degrees and that the damping in pitch exceeds the damping in yaw.

The 10% conical nose bluntness of nose 3, Fig. 4, further increases the static stability in pitch at $\alpha = 0$ to approximately 2.5 times the sharp cone value. Again, C_{m_α} drops toward the sharp cone value when the angle increases. The greater nonlinearity of the pitching moment versus α leads to greater differences between C_{m_α} and C_{n_β} at angles of attack, e. g., $C_{n_\beta} = 1.8\ (-C_{m_\alpha})$ for $\alpha = 5$ deg. The measured damping derivatives for the 10% conical and 10% spherical nose bluntnesses are nearly identical.

Figures 5 and 6 show the test results obtained with the 25% spherical and 25% conical nose bluntnesses. The nonlinearity of the pitching moment versus angle of attack is quite different from what was shown for the more moderately blunted cones. The maximum value of C_{m_α} is found at a nonzero angle of attack. Consequently, the equality of C_{n_β} and $-C_{m_\alpha}$ exists at two angles of attack, and, depending on α, C_{n_β} can be larger or smaller than $-C_{m_\alpha}$. The measurements also show the well known deterioration of the damping derivatives due to large nose bluntness at small angles of attack, and it is seen that $C_{m_q} + C_{m_{\dot\alpha}}$ and $C_{n_r} - C_{n_{\dot\beta}}$ are unequal for angles of attack greater than 3 deg. Again, the damping in pitch exceeds the damping in yaw for $\alpha > 3$ deg.

SECTION IV

CONCLUDING REMARKS

The present experimental study confirms that the static and dynamic stability derivatives are unequal in pitch and in yaw, for a body of revolution at nonzero angles of attack, if the pitching moment is a nonlinear function of α. Moderate nose blunting of a slender cone provides such nonlinearity at high Mach numbers, and the stability derivatives become unequal even at small angles of attack which are less than the cone half angle.

Stone(1) and, earlier, Levy and Tobak(4) did point out that an erroneous Magnus-like moment is obtained from the analysis of a vehicle motion if the inequality of the damping derivatives, such as indicated in this report, is ignored.

The measured values of $C_{n_\beta}(\alpha)$ are shown to compare very well with the relation given by Equation (1). This indicates that the static stability is accurately determined even though the data reduction rests on the very small frequency difference between wind-on and wind-off runs.

Ericsson(5) has theoretically studied the effect of different nose shapes on the stability of slender cones. In his words: "Changing from spherical to conical nose bluntness without a change of nose drag ($\theta_{nose} = 45°$) will increase static stability for moderate nose bluntness and decrease it for large nose bluntness. The effects on dynamic stability are opposite, causing some decrease for small and a substantial increase for large nose bluntness." The present investigation essentially confirms this theoretical prediction.

Relating to the observed decrease of the static stability by changing from large spherical to conical bluntness, it may be worthwhile to recall the results of wind tunnel tests published by Neff.(6) It is shown in this paper that the decrease of the static stability is accompanied by a forward shift of the center of pressure, i.e., by a reduction of the static margin.

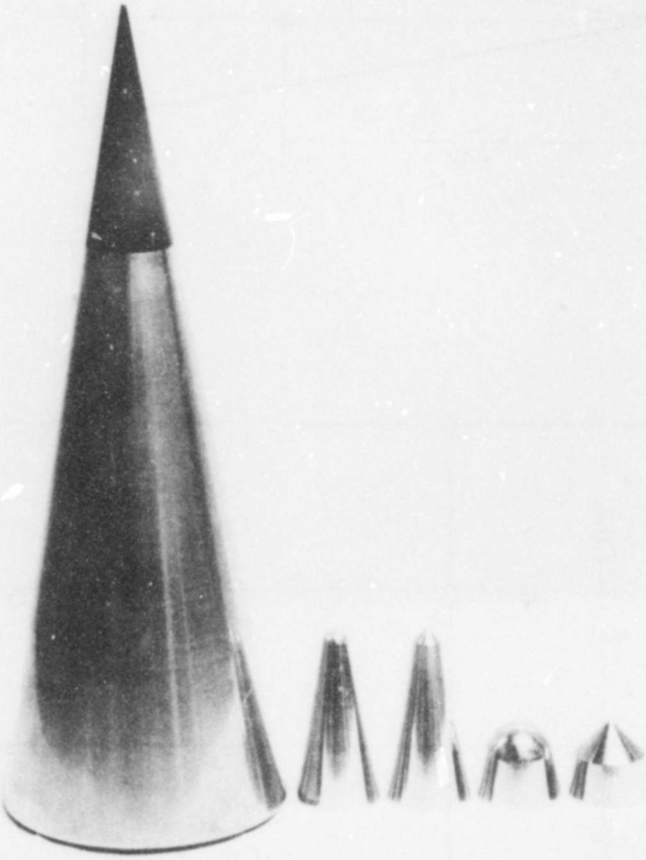


FIGURE 1 10-deg. cone model with interchangeable noses

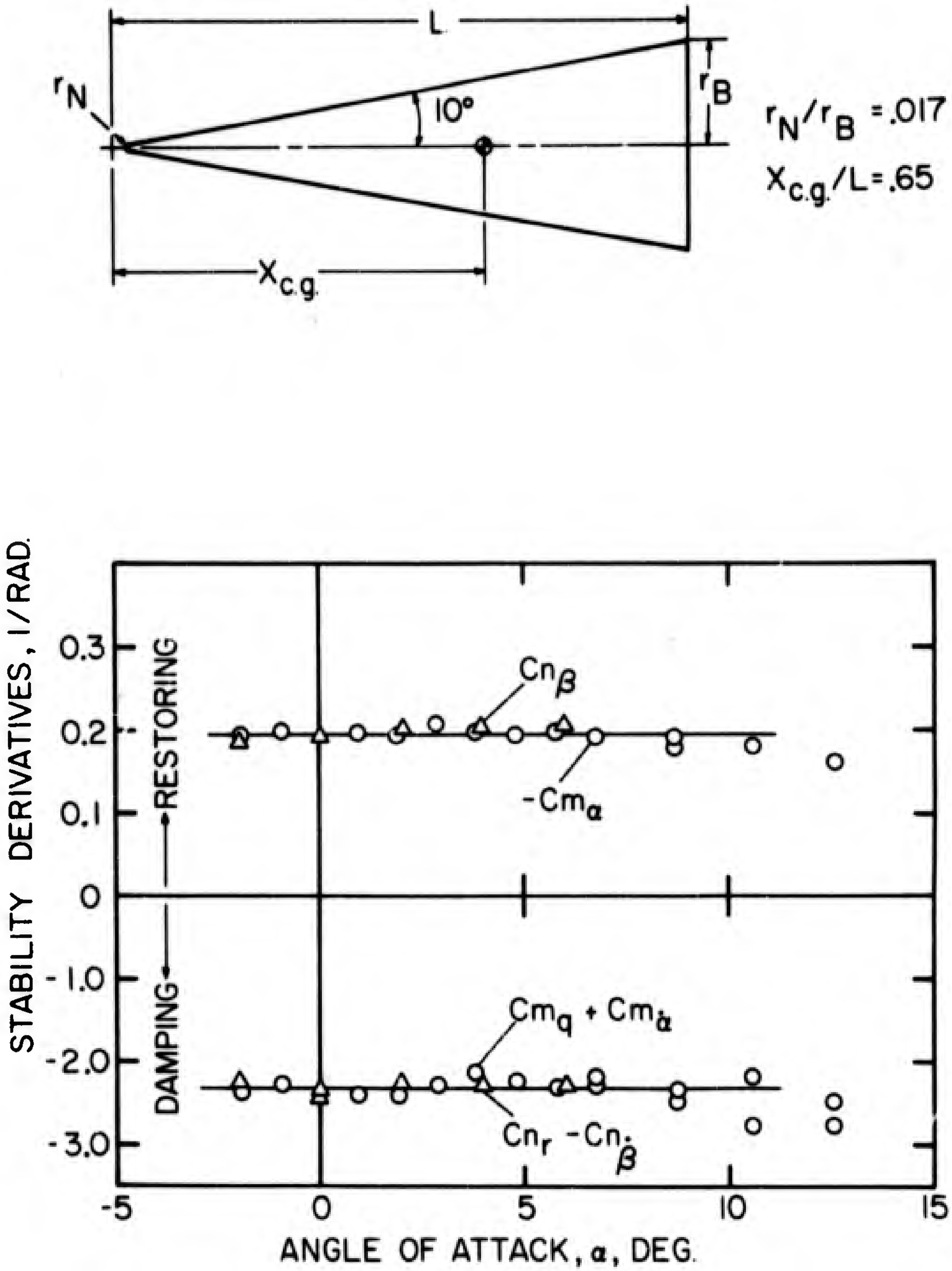


FIGURE 2 Stability derivatives versus angle of attack, $\beta = 0$, $r_N/r_B = .017$ (spherical)

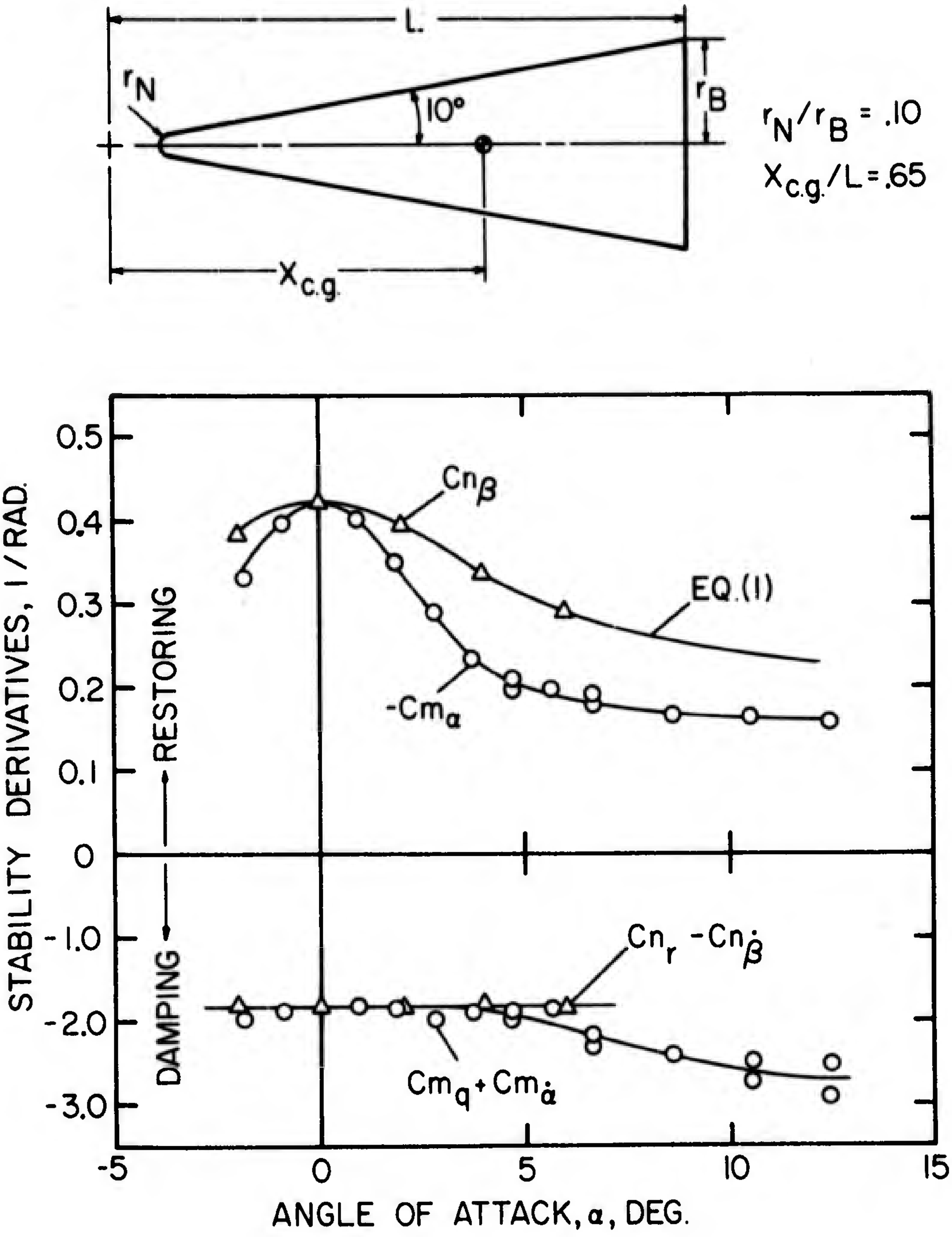


FIGURE 3 Stability derivatives versus angle of attack, $\beta = 0$, $r_N / r_B = 0.10$ (spherical)

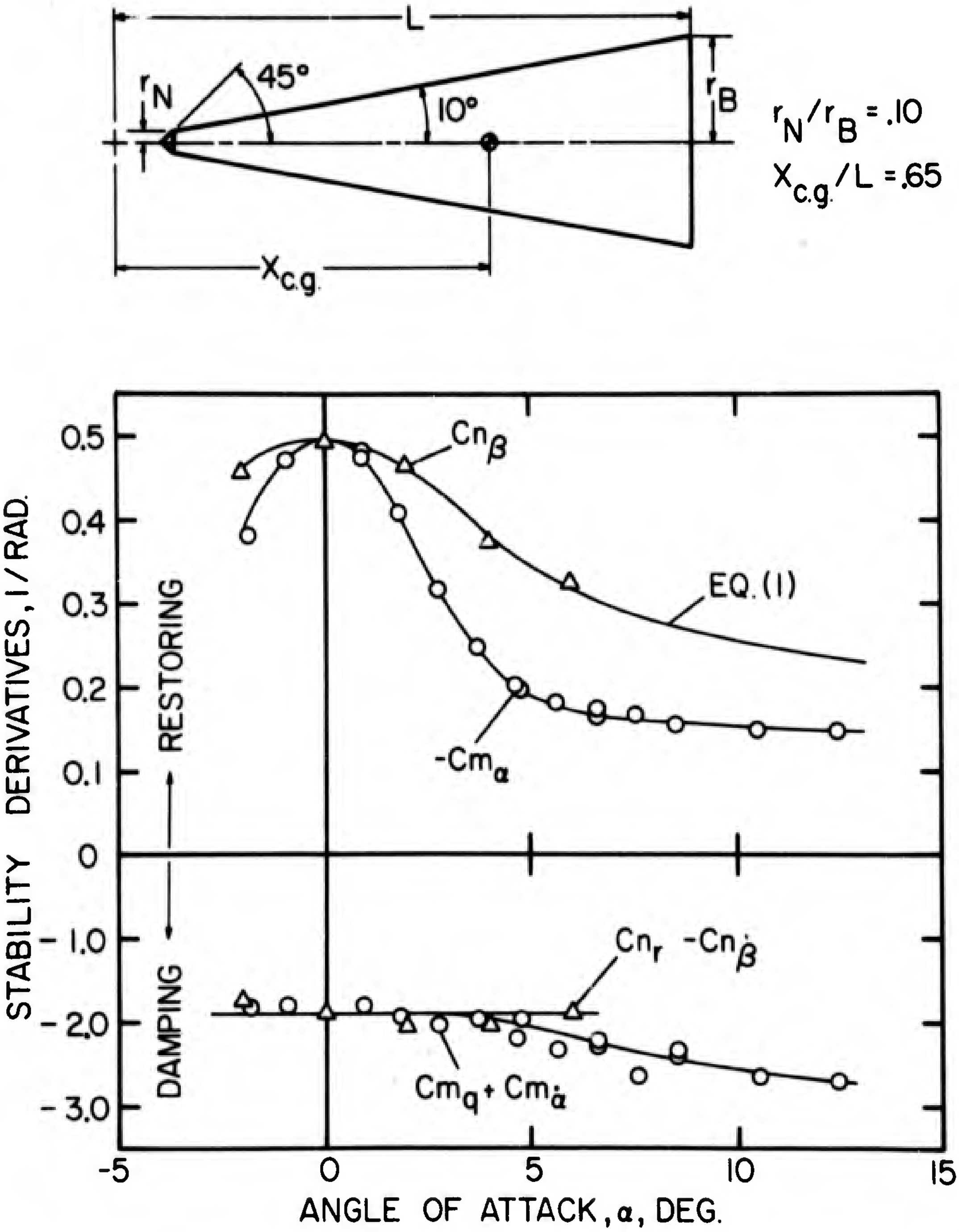


FIGURE 4 Stability derivatives versus angle of attack, $\beta = 0$, $r_N/r_B = 0.10$ (conical)

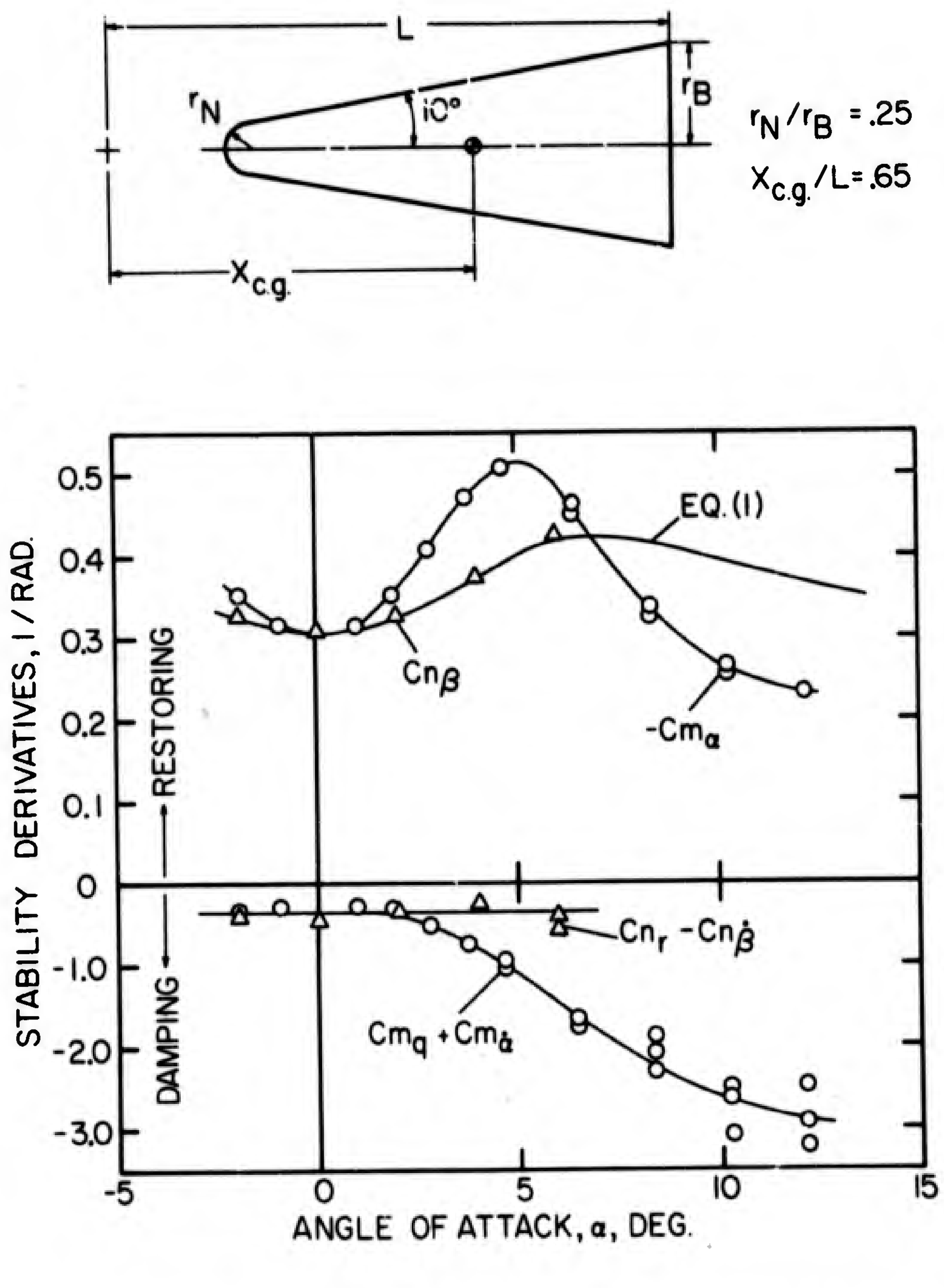


FIGURE 5 Stability derivatives versus angle of attack, $\beta = 0$, $r_N / r_B = 0.25$ (spherical)

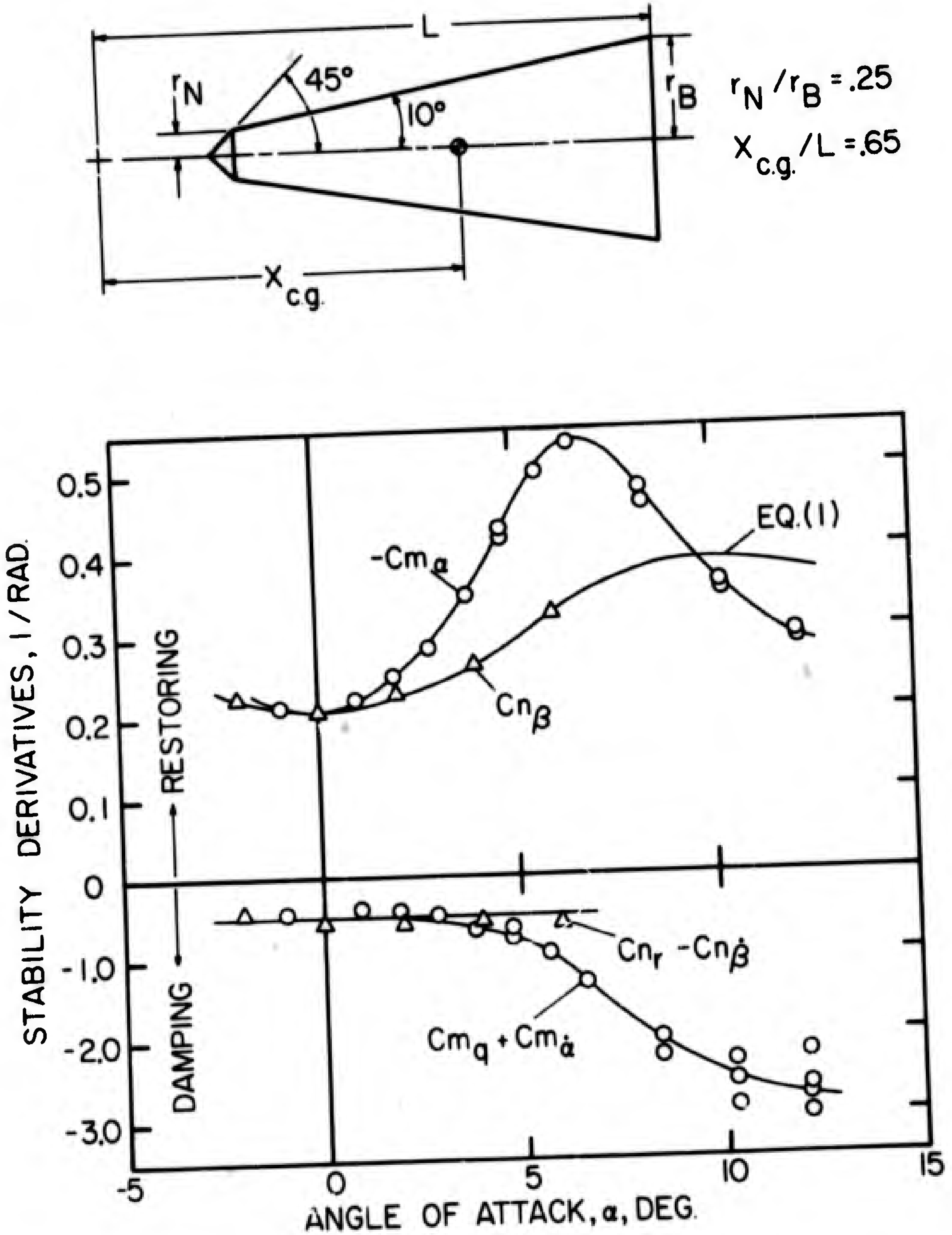


FIGURE 6 Stability derivatives versus angle of attack, $\beta = 0$, $r_N / r_B = 0.25$ (conical)

REFERENCES

1. Stone, G. W. and Clark, E. L., Jr., Sandia Laboratories and Burt, G. E., ARO, Inc., "An Investigation of Nonsymmetrical Aerodynamic Damping Moments," AIAA Paper #72-29.

2. Murphy, Charles H., "Nonlinear Motion of a Missile with Slight Configurational Asymmetries," Journal of Spacecraft and Rockets, Vol 8, No. 3, March 1971, pp 259-263.

3. Tobak, Murray and Schiff, Lewis B., "A Nonlinear Aerodynamic Moment Formulation and Its Implications for Dynamic Stability Testing," NASA Ames Research Center, AIAA Paper #71-275.

4. Levy, L. L., Jr, and Tobak, Murray, "Nonlinear Aerodynamics of Bodies of Revolution in Free Flight," AIAA Journal, Vol 8, No. 12, December 1970, pp 2168-2171.

5. Ericsson, Lars E. and Guenther, Rolf, "Effect on Slender Vehicle Dynamics of Change from Spherical to Conical Nose Bluntness," Journal of Spacecraft and Rockets, Vol 9, No. 6, June 1972, pp 435-440.

6. Neff, Robert S., "Conical Nose Shape Effects on Drag and Static Stability at Mach 10," Journal of Spacecraft and Rockets, Vol 9, No. 2, February 1972, pp 126-128.