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EFFECT OF UNSYMMETRICAL NOSE-BLUNTNESS ON THE STABILITY DERIVATIVES OF A 10° CONE AT MACH-14

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

FOREWORD

This report was prepared by Otto Walchner, Frank Sawyer and Lt Kevin Yelmgren of the Hypersonic Research Laboratory, Aerospace Research Laboratories, Air Force Systems Command, United States Air Force, under Project 7064, entitled "High Velocity Fluid Mechanics."

The reported wind tunnel tests were performed in ARL's 20-inch Hypersonic Wind Tunnel during the period from 27 May to 4 June 1970.

ABSTRACT

In the analysis of the free flight motion of bodies of revolution, the tricyclic theory assumes that a small configurational asymmetry does not violate the rotational symmetry of the stability derivatives in pitch and yaw but does produce a non-zero trim angle. Tests in ARL's 20-inch Hypersonic Wind Tunnel at Mach 14 show that a small unsymmetric nose bluntness destroys the rotational symmetry of the stability derivatives of a slender cone at hypersonic Mach numbers and therefore severely violates the assumptions of the tricyclic theory. Restoring and damping derivatives in pitch and yaw are reported for a 10° cone with symmetric and unsymmetrically blunted noses. The effect of non-equal stability derivatives on the motion are shown for a simplified case.

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LIST OF FIGURES

NOMENCLATURE
(Also see Figure 1)

A	base area of cone
C_m	pitching moment coefficient, $M/q_\infty Ad$
C_n	yawing moment coefficient, $N/q_\infty Ad$
C_{m_α}	$= \partial C_m/\partial\alpha$
C_{n_β}	$= \partial C_n/\partial_\beta$
C_{m_q}	$= \partial C_m/\partial(qd/2V_\infty)$
C_{n_r}	$= \partial C_n/\partial(rd/2V_\infty)$
$C_{m_{\dot\alpha}}$	$= \partial C_m/\partial(\dot\alpha d/2V_\infty)$
$C_{n_{\dot\beta}}$	$= \partial C_n/\partial(\dot\beta d/2V_\infty)$
d	base diameter of cone
I	moment of inertia
k	flexure spring constant
ℓ	length of sharp cone
M	pitching moment about y axis
M_∞	free stream Mach number
N	yawing moment about z axis
q	angular velocity component about y axis
q_∞	free stream dynamic pressure, $\rho_\infty V_\infty{}^2/2$
r	angular velocity component about z axis
$Re_{\infty,d}$	Reynolds number based on free stream condition and base diameter

r_B	base radius
r_N	nose radius
V_∞	free stream velocity
x_o, y_o, z_o	wind tunnel fixed axes
x, y, z	moving, non-rolling, body fixed axes
α	angle of attack. For rectilinear flight, $\alpha = \Theta$
β	angle of sideslip. For rectilinear flight, $\beta = - \psi$
Θ	angle of pitch
ψ	angle of yaw
ρ_∞	free stream density
σ	complex angle of attack, $\sigma = \beta + i\alpha$
ω	circular frequency
$(\dot{\ })$	d( )/ dt

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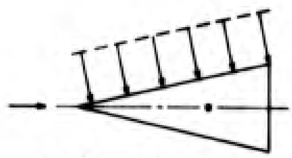
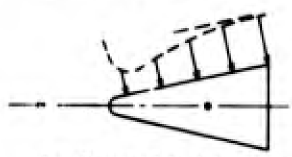
I. INTRODUCTION

The present investigation was motivated by two recent publications[1,2]. In Ref 1, the authors report on a wind tunnel experiment in which a slender cone model was suspended in a Mach 10 flow by a spherical air bearing with freedom to yaw, pitch and roll. A non-zero trim angle was produced by a small configurational asymmetry in the form of a slight nose bevel. The resulting trim force coupled with a small c. g. -offset was expected to provide conditions leading to persistent roll resonance. The observed motion of the cone was section fitted with the tricyclic theory[3,4] and the result indicated that the model did not achieve the expected persistent roll resonance. Further, the authors found that the model trimmed in a direction opposite to the moment resulting from the impact pressure on the nose bevel. In Ref 2, the authors report on ballistic range tests of ablating and non-ablating cones. The observed free flight motion of the non-ablating models could be fitted with the tricyclic theory and the various stability derivatives were extracted. However, the authors note that the motion of several of the ablating models was such that the tricyclic solution could not be fitted to the observed motion and, therefore, was considered as not applicable to those cases.

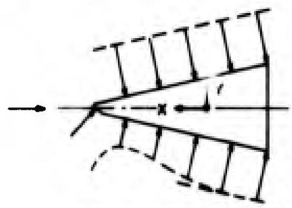
In considering the direction of trim of the beveled cone, the authors of Ref 1 speculated that this could be the result of an "unsymmetrical flow field." A possible explanation of this field is as follows. Disregarding viscosity effects, the pressure distribution along a ray from the apex of a pointed cone is constant. At hypersonic Mach numbers, a small axisymmetric nose bluntness is known to alter the sharp cone pressure distribution many nose diameters downstream of the nose. Sketch (a) and (b) schematically illustrate these two types of pressure distribution. A one-sided nose bevel, Sketch (c), represents an unsymmetric nose blunting. Consequently, the pressure distribution downstream of the nose is expected to lose its rotational symmetry. One may then hypothesize that the pressure distribution has approximately conical flow characteristics over one side and blunt cone characteristics over the other, as indicated in Sketch (c). This unsymmetric pressure distribution would cause the model to trim at a negative yaw angle even though the impact pressure on the nose causes a positive yawing moment.



a. Sharp Cone



b. Symmetric Bluntness



c. Unsymmetric Bluntness

If a small unsymmetric nose should indeed destroy the rotational symmetry of the pressure distribution, then it is conjectured that the stability derivatives in pitch and yaw can no longer have identical values.

This conjecture, if true, leads to serious consequences. The tricyclic theory assumes that a small configuration asymmetry of a body of revolution does not violate the rotational symmetry of the stability derivatives but does produce a non-zero trim angle. Thus, if the stability derivatives are not equal, the tricyclic theory is not applicable for analyzing an observed motion and will give incorrect results if used in such cases. The tricyclic theory would also, of course, fail to correctly predict the flight motions of a vehicle which has an asymmetric nose.

The purpose of the following investigation was to prove or disprove the several conjectures stated above. The restoring and damping derivatives in pitch and yaw of a 10° cone model with symmetric and unsymmetric noses were measured in ARL's 20-inch Hypersonic Wind Tunnel and are reported herein. Pressure measurements are planned and will be reported later.

II. MODEL CONFIGURATION

The basic configuration is a 10° half-angle cone with the center of gravity and moment center at 65% of the sharp cone length downstream of the tip. This basic model was investigated with the four different noses shown in Figure 2. Nose 1 is nearly pointed and has a small spherical nose bluntness. The bluntness ratio, $r_N / r_B = 0.017$, corresponds to the STA standard 10° cone wind tunnel model. Nose 2 has a one-sided 20° nose bevel. The maximum height of the eliptical section is 5.5% of the base diameter. Nose 3 results from Nose 2 by an additional 40° cut which increases the maximum height of the eliptical section to 7.1% of the base diameter. Nose 4 results from Nose 3 by an additional 90° cut.

Note the orientation of the bevels with respect to the y body axis. The flow over the nose is symmetrical at positive and negative angles of attack. This symmetry does not exist with respect to the angle of sideslip.

III. TEST PROCEDURES AND TEST CONDITIONS

The free oscillation technique was used to extract the restoring and damping derivatives from the observed time histories of planar oscillations with small amplitudes of approximately ±1° and from known model constants and free stream properties. The investigated range of angles of attack and sideslip was from -8° to + 8°. The stability derivatives in pitch were measured at $\beta = 0°$ only and the derivatives in yaw at $\alpha = 0°$ only. Unfortunately, the necessary equipment to measure pitch derivatives at non-zero angles of sideslip and yaw derivatives at non-zero angles of attack is not available at this time. A study of a possible frequency effect on the derivatives was not the subject of this investigation and tests were made at one oscillation frequency only.

Typical test conditions are as follows:

Mach Number	M_∞	= 14.24
Total pressure	P_t	= 1500 psia
Total temperature	T_t	= 2000°R
Dynamic pressure	q_∞	= 61.3 psfa
Free stream velocity	V_∞	= 5058 ft/sec
Reynolds number	$Re_{\infty,d}$	= 2.23×10^5
Flexure spring constant	k	= 19.19 ft-lb/rad
Reduced moment of inertia	$I/\rho_\infty Ad^3$	= 62×10^3
Reduced frequency	$\omega d/2V_\infty$	= 3.3×10^{-3}
Model surface temperature ratio	T_w/T_t	= 0.27 to 0.35

IV. RESULTS AND DISCUSSION

In Fig 3, the restoring and damping derivatives for the nearly pointed cone model (Nose 1) are plotted as functions of the angle of attack. It is seen that both derivatives are very nearly constant over the angle of attack range from -8° to + 8°. Because of the rotational symmetry of this model, $C_{n_\beta} = -C_{m_\alpha}$ and $C_{n_r} - C_{n_{\dot{\beta}}} = C_{m_q} + C_{m_{\dot{\alpha}}}$.

In Fig 4, the experimental results are shown for the model with Nose 2. Because of the asymmetry of this nose, the derivatives in pitch and yaw are no longer identical. They differ slightly but distinctly. Also, all derivatives show a slight variation over the investigated α, β range. It was learned from earlier investigations of spherically blunted cones[5,6] that nose blunting, in general, causes a variation of the derivatives with angle of attack. The characteristics of this variation change drastically with cone angle and bluntness ratio.

In the present case, with the orientation of the nose bevel as defined in Fig 2, the pitch derivatives are symmetric at positive and negative angles of attack. However, the yaw derivatives vary unsymmetrically with respect to the angle of sideslip.

No explanation is readily available for the peculiar dips of the pitch damping derivatives at $\alpha \approx \pm 5°$. Similar dips in the pitch damping derivatives appear again and are even more pronounced in the measurements with the Noses 3 and 4, Figures 5 and 6. All the features indicated in the measurements with Nose 2 are amplified by the somewhat larger bluntness of Noses 3 and 4. This is especially true for the variation of the restoring derivatives in pitch and yaw with α and β, respectively, and for the quantitative difference between $-C_{m_\alpha}$ and C_{n_β}. The measurements indicate that the derivatives approach the sharp cone values at large angles of attack or sideslip.

The present investigation shows that a small but unsymmetric nose blunting destroys the rotational symmetry of the restoring and damping stability derivatives in pitch and yaw for a 10° cone at hypersonic Mach numbers. A nose bevel with a maximum height of 7.1% of the base diameter results in a difference between $-C_{m_\alpha}$ and C_{n_β} of nearly 30% for α or $\beta \rightarrow 0$ (see Fig 5). This type of slight configuration asymmetry, therefore, violates the basic assumption of the tricyclic theory. As an illustration, the motion in the α-β plane is shown in Fig 7 for the simple case of a non-rolling body of revolution ($I_y = I_z$) with zero trim and zero damping. The initial conditions are $\alpha_o = \beta_o$ and $\dot{\alpha}_o = \dot{\beta}_o = 0$.

The motion in Fig 7a is for the case where the restoring derivatives in pitch and yaw are of equal magnitude. This motion is correctly described by the tricyclic solution. The nutation and precession arms are equal in magnitude and have angular velocities which are equal in magnitude but opposite in direction. The trim arm is zero and the result is a straight line in the α-β plane. Figures 7b, c and d are for the same initial conditions but with the restoring derivatives in yaw and pitch differing by 10, 20 and

30% respectively. The completion of one yaw cycle requires less time than the completion of one pitch cycle. The results are Lissajou figures. It is believed that this type of motion can probably be fitted with the tricyclic solution but will give incorrect results.

It is expected that results entirely different from the measurements presented in Figs 4 to 6 will be obtained if a cone with a smaller half-angle, say 5° instead of 10°, is equipped with the investigated type of unsymmetric noses.

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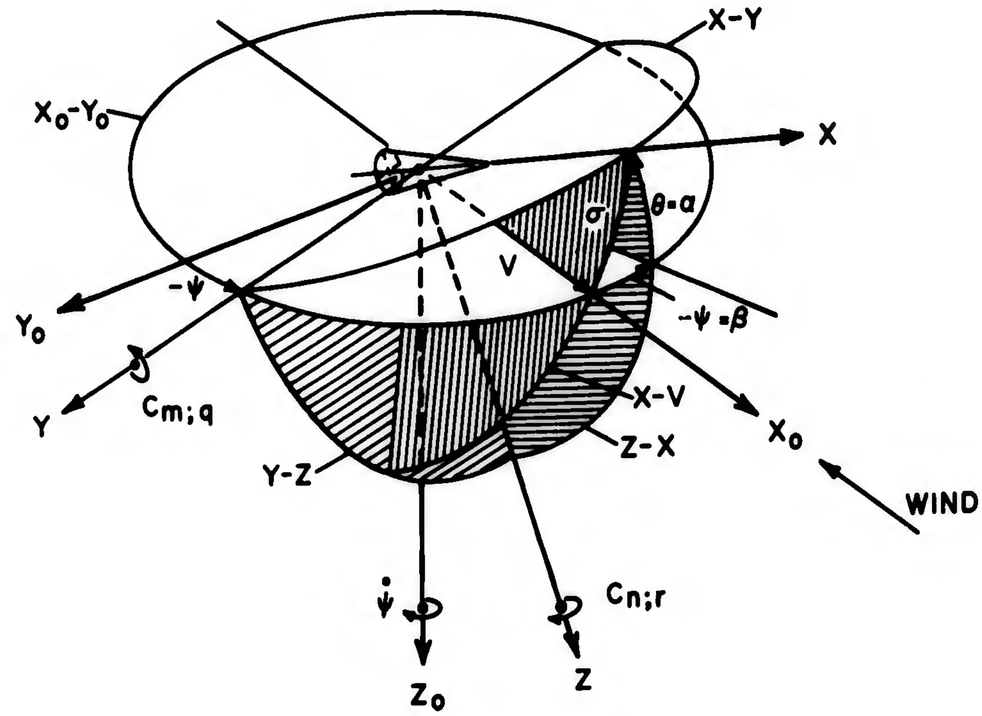

Figure 1 Coordinate System and Nomenclature for Non-Rolling Body in Rectilinear Flight (Wind Tunnel Simulation)

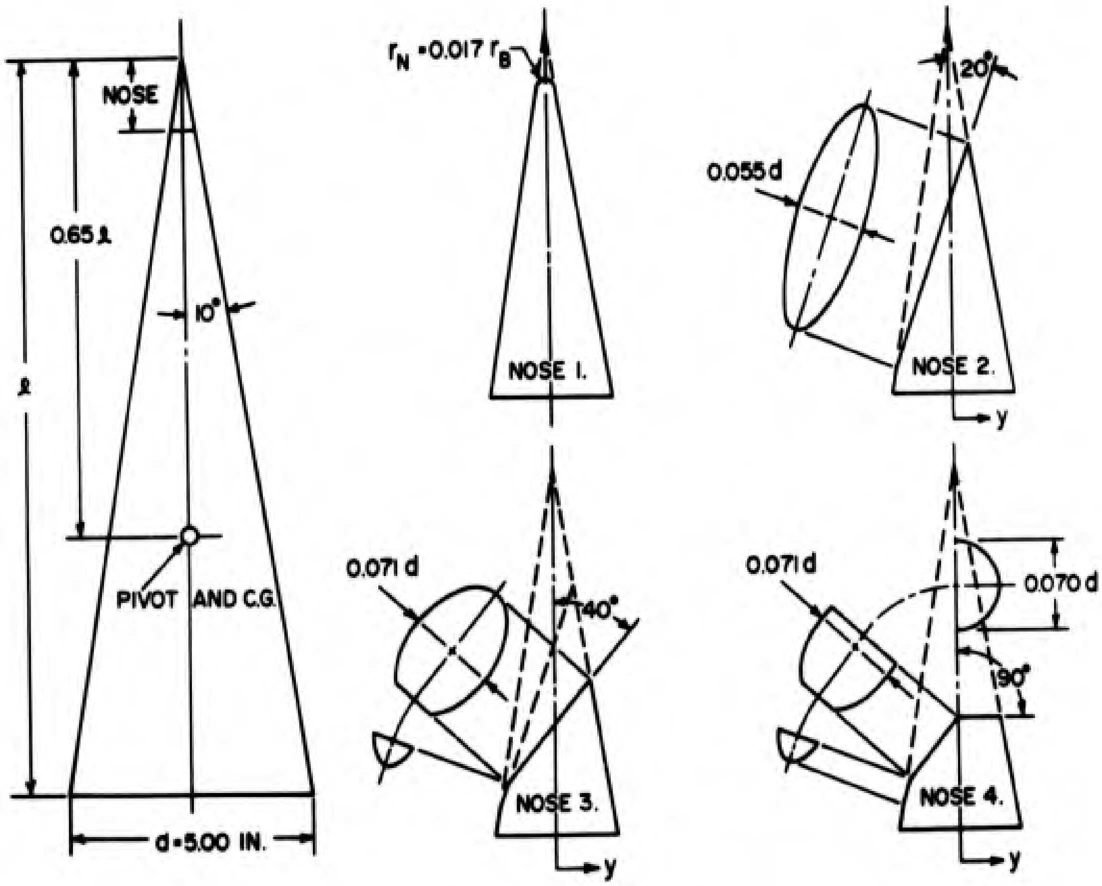

Figure 2 Model Configurations

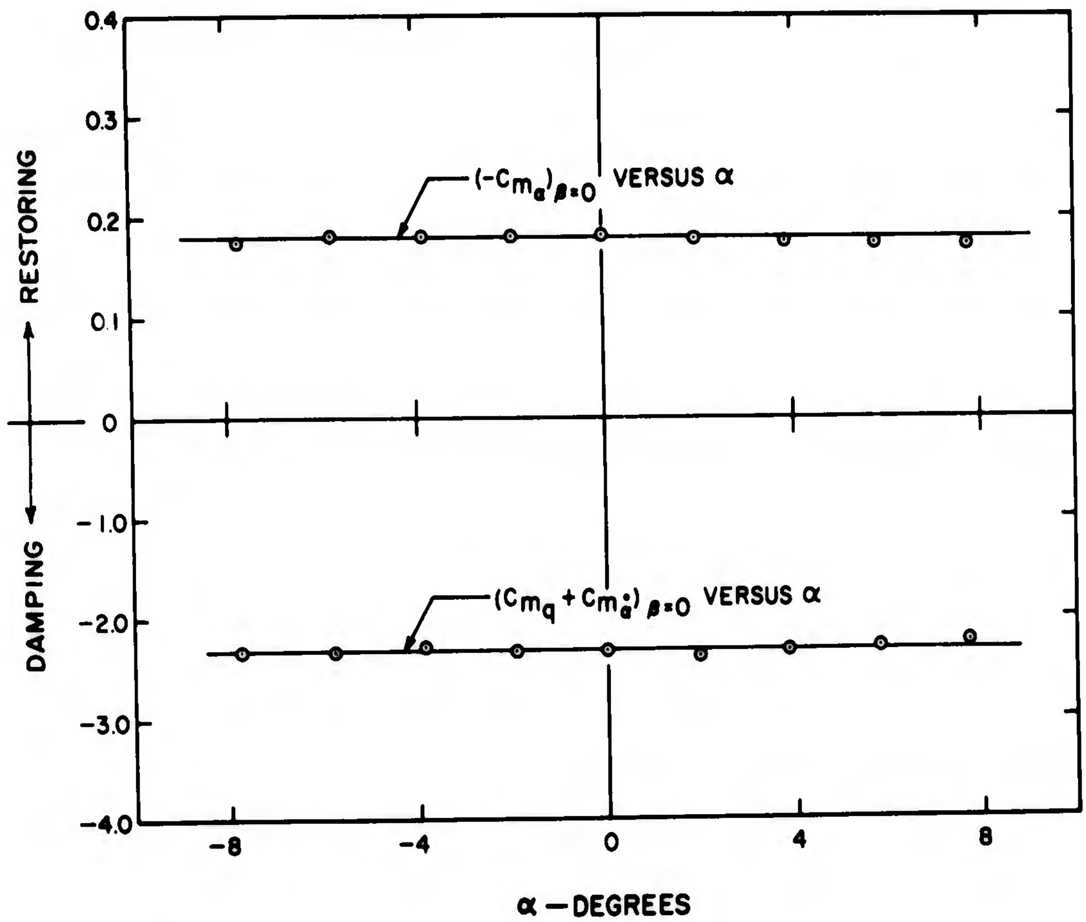

Figure 3 Restoring and Damping Derivatives, Nose 1

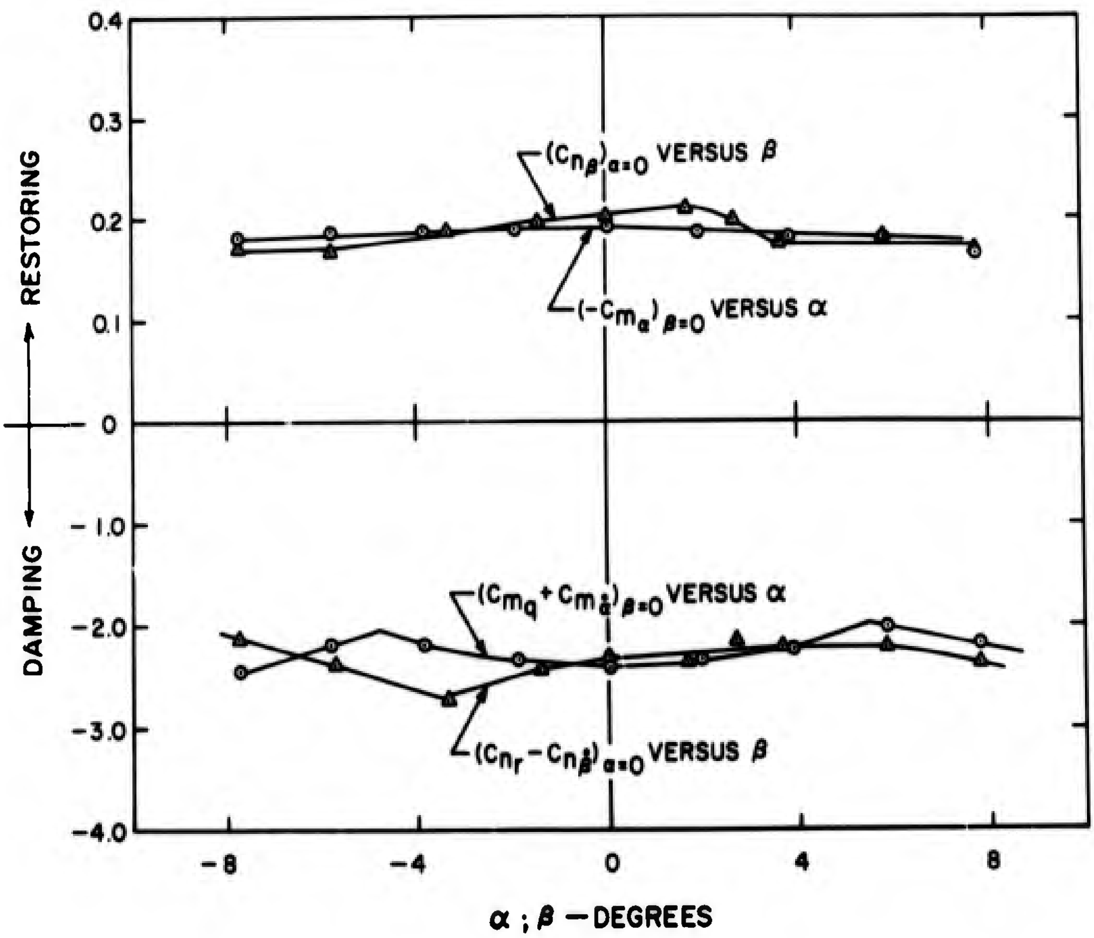

Figure 4 Restoring and Damping Derivatives, Nose 2

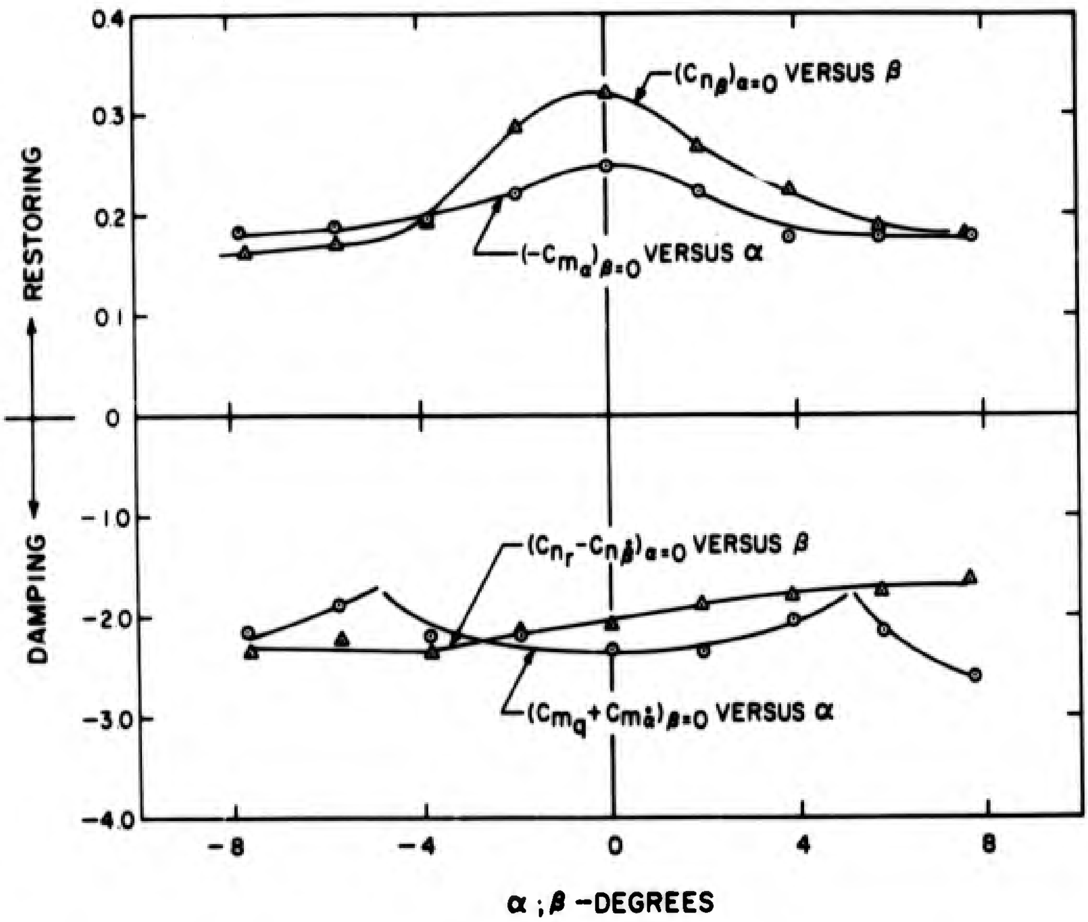

Figure 5 Restoring and Damping Derivatives, Nose 3

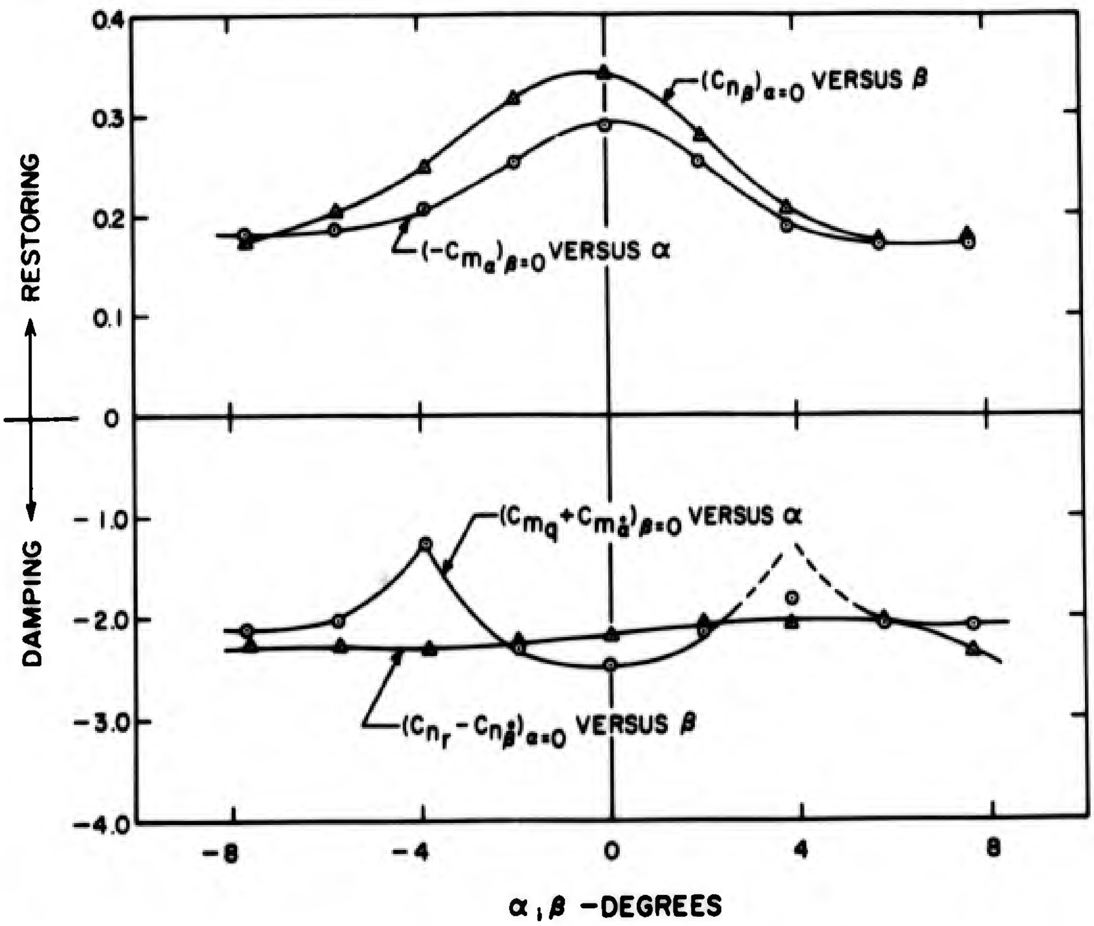

Figure 6 Restoring and Damping Derivatives, Nose 4

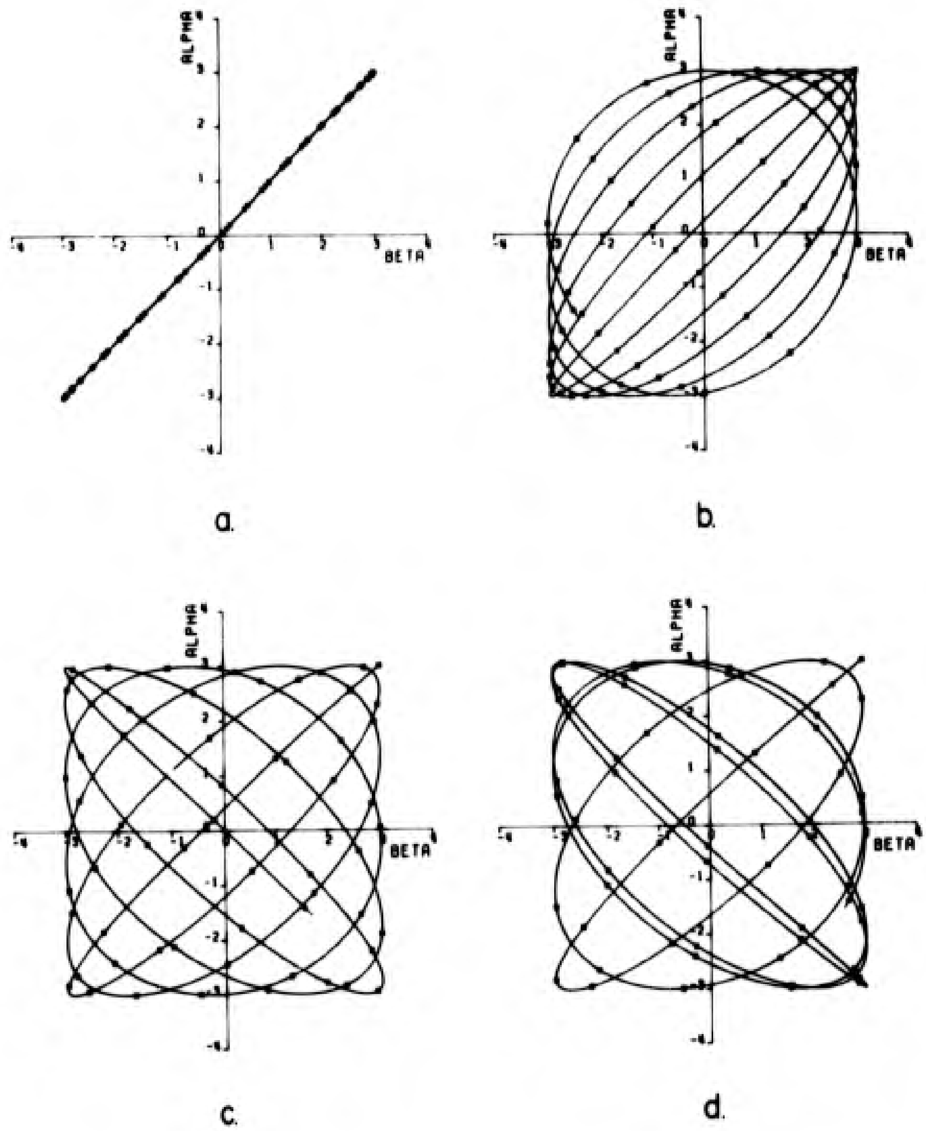

Figure 7 Motion in Pitch and Yaw of a Non-Rolling Body with Different Ratios of $C_{n_\beta} / (-C_{m_\alpha})$

a. $C_{n_\beta} = -C_{m_\alpha}$

b. $C_{n_\beta} = 1.100 (-C_{m_\alpha})$

c. $C_{n_\beta} = 1.200 (-C_{m_\alpha})$

d. $C_{n_\beta} = 1.300 (-C_{m_\alpha})$

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