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THE LATERAL RESPONSE
OF AN AIRSHIP TO TURBULENCE

by

John J. Wrobleski, Jr.

December 1981

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The Lateral Response of an Airship to Turbulence

by

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ABSTRACT

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NOMENCLATURE

A	hull cross-sectional area
B	total buoyancy force of the airship, $\rho \cdot g \cdot \text{volume}$
BM	hull bending moment about the vertical axis distributed along the hull longitudinal axis
$\bar{c}$	longitudinal characteristic length of the airship
$\bar{c}_s$	mean chord of fin
$\tilde{C}, \tilde{D}$	matrix of coefficients from equation 51
C_Y	nondimensional aerodynamic force in the y- direction, $C_Y = 2Y/\rho U_o^2 S$
$C_{l,n}$	nondimensional aerodynamic rolling and yawing moments respectively, $(C_l, C_n) = 2(L,N)/\rho U_o^2 S \bar{c}$
C_L	nondimensional aerodynamic lift
$(C_L^*)_s$	C_L for the fins alone, no hull interference
C_s	nondimensional shear force $C_s = 2S(1)/\rho U_o^2 S$
C_{BM}, C_{TM}	nondimensional bending and twisting moment respectively, $(C_{BM}, C_{TM}) = 2(BM, TM)/\rho U_o^2 S \bar{c}$
$D()$	nondimensional time derivative, $(c/2U_o) d()/dt$
g	gravitational acceleration
$G_{Y_Y}, G_{l_Y}, G_{n_Y}$	turbulence forcing functions (equation 59)
h	body-fixed coordinate measured normal to the hull centerline (positive up)

h_{cm}	h location of the vehicle's mass center
$(h_{cm})_s$	h location of the empennage-assembly's mass center
$H(k)$	Sears' function corrected for finite aspect ratios by Filotas [Ref. 16]
I_{xx}, I_{zz}	moments of inertia about the x- and z-axes
I_{xz}	product of inertia w.r.t. x- and z-axes
i_{xx}, i_{zz}, i_{xz}	nondimensional moments and product of inertia $i_{xx} = 8I_{xx}/\rho S \bar{c}^3$
i	imaginary operator, $i = \sqrt{-1}$
K	hull potential cross-flow factor from Jones and DeLaurier [Ref. 6]
k_1, k_2	axial and traverse apparent-mass coefficients
k_c	control gain of fin normal force to vehicle azimuth angle
l	axially-aligned body-fixed coordinate originating at the nose
l_b	axial location of the buoyancy center
l_h	axial location of the hull-fin intersection point
l_s	axial location of the fin's aerodynamic center
l_{cm}	axial mass-center location of the entire vehicle
$\tilde{L}$	turbulent scale length
L	rolling moment
m	mass of the entire vehicle, including internal air and gas
m_s	mass of the empennage assembly
N	yawing moment

p	vehicle angular velocity about the x-axis
$\hat{p}$	nondimensional value of p , $\hat{p} = (\bar{c}/2U_0)p$
$\hat{P}$	nondimensional maximum value of $\hat{p}$
r	vehicle angular velocity about the z-axis
$\hat{r}$	nondimensional value of r , $\hat{r} = (\bar{c}/2U_0)r$
$\hat{R}$	nondimensional maximum value of $\hat{r}$
$R(\tau)$	auto-correlation function
S	reference area of airship, (volume) ^{2/3}
$S(1)$	hull shear force, normal to the centerline
S_s	stabilizer reference area (planform area)
t	time
TM	twisting moment, about the hull axis
U_0	reference flight speed
v	perturbation velocity of the vehicle's mass center in the y-direction
$\hat{v}$	nondimensional value of v , $\hat{v} = v/U_0$
$\hat{V}$	nondimensional maximum magnitude of $\hat{v}$
v_g	horizontal velocity of the atmospheric turbulence
x, y, z	body-fixed wind-aligned stability axes (x positive forward, y positive right, z positive down)
x', y', z'	axes fixed in inertial space
Y	force in the y-direction
GREEK SYMBOLS	
α_0	reference aerodynamic relative angle of attack
β	aerodynamic sideslip angle

γ	horizontal nondimensional velocity of the spectral component
Γ	maximum value of γ
η_s	stabilizer efficiency factor, from Jones and DeLaurier [Ref. 6]
μ	nondimensional mass, $\mu = 2m/\rho S \bar{c}$
ξ	axial coordinate, measured from the nose
ρ	atmospheric density
σ	turbulence intensity
$\hat{\sigma}$	nondimensional stability root
ϕ	roll angle
Φ	maximum value of ϕ
$\phi_{jj}(\Omega)$	power-spectral function for turbulence component v_g
ψ	azimuth angle
Ψ	maximum value of ψ
ω	spectral component frequency
Ω	wave number

SUBSCRIPTS

() _{aero}	aerodynamic force or moment terms
() _B	buoyancy terms
() _c	control terms
() _{cm}	mass center terms
() _{emp}	term for entire empennage assembly
() _g	atmospheric-turbulence term

$()_h$	hull term
$()_m$	inertial term
$()_o$	reference equilibrium value
$()_p$	derivative w.r.t. $\hat{p}$
$()_{\dot{p}}$	derivative w.r.t. $D\hat{p}$
$()_r$	derivative w.r.t. $\hat{r}$
$()_{\dot{r}}$	derivative w.r.t. $D\hat{r}$
$()_s$	fin term
$()_T$	thruster-rotor term
$()_v$	derivative w.r.t. $\hat{v}$
$()_{\dot{v}}$	derivative w.r.t. $D\hat{v}$
$()_\beta$	derivative w.r.t. β
$()_{\dot{\beta}}$	derivative w.r.t. $D\beta$

SUPERSCRIPTS

$()^{\wedge}$	nondimensional term
$()^{\cdot}$	derivative w.r.t. time

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I. INTRODUCTION

When a close look is taken of the history of airship flight, it becomes evident that turbulence is a prime cause for concern in the design of lighter-than-air (LTA) craft. The spectacular crashes of the airships Shennandoah, Akron, and Macon are perhaps the most obvious reminders of the powerful effect the wind can have on these fragile vehicles. It is imperative that proper consideration be given to the gust response of an airship, both dynamically and structurally.

At the time the great rigids were built, designers had only a cursory knowledge of turbulence and how to deal with it. Burgess [Ref. 1], for example, dedicates only one page to the subject, and that is mainly a warning that gusts encountered in flight can place larger loads on an airship than any maneuver of which it is capable. He suggests using the standard gust analysis technique of the day--a "fixed-in-space" flight through a ramp shaped gust. This was the method used to evaluate all aircraft at the time, and provided some measure of confidence that the structure would withstand the stresses of flight. Its principal weakness was that it took into account only the direct gust loads.

Since that time, the methods used to analyze response to turbulence have been greatly improved. Over time, the ramp shaped gust gave way to other gust shapes, finally settling

on the (1-cosine) gust as standard [Ref. 2]. By the mid-fifties enough data had been gathered on the nature of the turbulent wind to derive some basic statistical relations. This, in turn, allowed the development of the power spectral method for aircraft load analysis (see, for example, Press and Meadows [Ref. 3]). The spectral method has been applied to many types of aircraft over the last twenty years. At present, both methods are used in analysis of flight structures, the one giving the more conservative structure determining the final design.

While the development of turbulence modeling techniques progressed, applications to airship technology were slower in coming. Because the success of heavier-than-air (HTA) craft made the slower airship economically less attractive, LTA research lagged. In the period between World War II and the Arab Oil Embargo of 1973, the only significant contribution to the study of airships in turbulence was by Calligeros and McDavitt [Ref. 4]. This paper presented a method of analysis that allowed a stable airship to respond dynamically to both sinusoidal and (1-cosine) gusts. Thus, the inertial and aerodynamic reaction forces of gust encounter could be included in the model. Further, by using the sinusoidal representation for gust shape, it was possible to apply spectral methods to the analysis.

The recent interest in LTA brought about by rising fuel costs has increased the research in all aspects of airship

flight. The spectre of the great rigids disintegrating in turbulence makes it imperative that the designer have adequate means to predict an airship's response to gust penetration. Current research is aimed at supplying that means. DeLaurier and Hui [Ref. 5] refined the technique of Calli-geros and McDavitt [Ref. 4], by introducing refinements to the aerodynamic cross-flow model [Ref. 6] and allowing for stability augmentation through pilot control input. The model allows statistical prediction of an airship's dynamic response and operational lifetime for various combinations of speed, altitude and control gain.

DeLaurier and Hui's work (as well as most others dealing with this subject) concentrated only on the longitudinal aerodynamic case. This thesis proposes to apply their model to the lateral case, enabling the response to side-force to be calculated. Bending and shear in the horizontal plane, as well as twisting moment, can then be taken into account when predicting airship life expectancies.

II. THE TURBULENT WIND

The motion of the atmosphere is very complex. Shearing stress between layers of different speeds and at the ground, thermals caused by solar heating, weather fronts, vortex shedding behind obstructions and aircraft, plus many other phenomena, all contribute to a velocity field that is most difficult to describe. Of the methods available, that chosen will depend on the purpose for which it is used. A goal in the design of any flight vehicle is safety, with performance adequate for the mission. This dictates using models giving reasonable estimates for the design parameters, and it may or may not be necessary to closely match the physical reality to do this. In any case, the designer must be familiar with the advantages and limitations of methods available in order to choose wisely. What follows is a brief review of some of the turbulence models currently in use and how they apply to airship analysis.

A. THE DISCRETE GUST

As mentioned in the introduction, the discrete gust model has been used to analyze aircraft for many years. It is especially good when response to the passage through a steady velocity gradient, such as a thermal, mountain updraft, or jet stream, is desired. The method has been improved

steadily until, as Etkin [Ref. 7] points out, it has attained a high degree of sophistication.

Figure 1 shows the shape for a (1-cosine) gust, where W_m and d_m are maximum gust velocity and distance along the flight path of this maximum. By varying these parameters, the gust severity can be controlled. The value for d_m is prescribed by the Federal Aviation Administration (FAA) as

$$2d_m = 25\bar{c}$$

The size of W_m is dependent on airspeed and altitude, and is shown in figure 2 for three values of equivalent airspeed. The $25\bar{c}$ wavelength was chosen because it historically couples with the short period pitch mode of a rigid aircraft to produce the largest load factors. Calligeros and McDavitt [Ref. 4] showed that, for airships, the maximum loads occur when the wavelength is equal to the airship length.

The British dictate (ARB CAR CH D3-3) that the gust parameters be chosen to produce the peak response with aircraft flexibility taken into account. In this way, the model is "tuned" to the aircraft, thus assuring a conservative design.

B. RANDOM TURBULENCE

Extensive measurements of the atmospheric velocity field have been made, and the techniques involved are well established and reliable [Ref. 2]. They show that the velocity vector is best characterized by a random function of space

and time that is, in general, non-homogeneous, non-stationary, and anisotropic. The exact function has not been developed due to its tremendous complexity. Until enough data is collected (if ever) to allow the precise formulation, certain simplifying assumptions must be made to enable flight vehicle analysis.

One assumption that applies everywhere except in the planetary boundary layer (below about 1000 ft), is that the turbulence is 'homogeneous', that is, the statistics of the field do not vary through space. In the boundary layer, scale length and intensity are homogeneous in the horizontal plane, but not vertically. Another assumption made is that the turbulence is 'stationary', or statistically time constant. Over the time periods of interest to flight this approximation is quite adequate. Also, the turbulence is assumed to be isotropic (again, except in the boundary layer), making the statistics invariant with orientation.

One last simplification used to model atmospheric turbulence is the 'frozen field' or Taylor's hypothesis [Ref. 8]. The change in the velocity field perceived by an aircraft as it passes with speed U_0 through the air is given by the substantial derivative

$$\frac{D(\quad)}{Dt} = \frac{\partial(\quad)}{\partial t} + U_0 \frac{\partial(\quad)}{\partial x}$$

Taylor's hypothesis states that for all but the smallest values of U_0 , the second term dominates and the first may be ignored. The result is that the correlations and spectra reduce to three-dimensional functions of space only. Physically, this means the velocity field is 'frozen' in time, and the changes are due only to displacement.

In an effort to specify an acceptable lower limit on U_0 , for which the frozen field applies, Dobrolenskiy [Ref. 9] cites studies comparing records of turbulence spectra gathered by captive balloon and an aircraft flying nearby at the same time. Within the margin of error, the two are statistically quite similar, and he concludes the lower limit on U_0 is comparable to the convection velocity (for all practical purposes, the mean wind speed). Etkin [Ref. 7] points out that the vehicle speed can be as low as one-third the wind speed for good results. Note that the only vehicles capable of less than this velocity are LTA and VTOL craft, and then only when they are convected downwind with the air-mass. In hover, or upwind flight, the hypothesis holds. For that small portion of the flight envelope in which it does not, the forces generated on an airship's structure are small and, therefore, do not present a problem.

The techniques for dealing with isotropic, frozen turbulence are well known [Ref. 8]. For those not familiar with the mathematical background necessary to deal with the

subject in depth, Chapters 2, 3, and 13 of Etkin [Ref. 10] will provide a good primer.

1. Turbulence Organization

Anyone who has seen leaves swirl on an autumn day, or watched someone blow smoke rings, has an intuitive understanding that the motion of the atmosphere is not completely arbitrary. What happens at one location effects conditions at another. Fluiddynamicists characterize this interdependence by using expressions relating the stress and strain in the fluid. The technique has been applied to turbulence [Ref. 11] with some success in predicting the actual velocity field of a boundary layer type flow.

For flight vehicle analysis, a more convenient method of specifying the velocity field is the spectral decomposition of the three-dimensional homogeneous vector field [Ref. 12]. Figure 3 shows an aircraft flying through a (two-dimensional) sinusoidal wave of shearing motion. The velocity change from the mean is given (for the lateral gust component) by

$$\Delta v_g(x', y') = e^{i(\Omega_1 x' + \Omega_2 y')} \Delta c_2 \quad (1)$$

where Ω_1 and Ω_2 are the wave number components in the x' and y' directions respectively, and c_2 is the complex amplitude of the lateral component. If the vehicle penetrates the

field with velocity U_0 , the coordinates become $x' = x + U_0 t$, and $y' = y$ in the body fixed system. Equation (1) then becomes

$$dv_g(x, y) = e^{i\Omega_1 U_0 t} e^{i(\Omega_1 x + \Omega_2 y)} d\Omega_2 \quad (2)$$

The air velocity over the vehicle is then periodic with wavelengths $(2\pi/\Omega_{1,2})$ and frequencies $(\Omega_{1,2} U_0/2)$. The total field is made up of the superposition of these spectral components, much as a Fourier series represents a random scalar.

2. Probability Distribution and Spectra

With the expression for a single spectral component available, the next difficulty is determining the probability distribution of the individual frequencies. The power spectral density of a time varying function, $X(t)$, is defined (in terms of wave number) as

$$\phi(\Omega) = \lim_{\substack{\Delta\Omega \rightarrow 0 \\ T \rightarrow \infty}} \frac{1}{T\Delta\Omega} \int_0^T X(t, \Omega, \Delta\Omega) dt \quad (3)$$

where $\phi(\Omega)$ is expressed in $(\text{ft/sec})^2/(\text{radians/ft})$, and T is the duration over which $X(t)$ is measured. The value is usually computed by taking the autocorrelation function $R(\tau)$ [Ref. 10: Chapter 2], and performing a Fourier transformation, thus

$$\phi(\Omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R(\tau) e^{i\Omega\tau} d\tau \quad (4)$$

Figure 4 [Ref. 2] shows the spectra of three different meteorological conditions. While varying in detail, they all exhibit the same decreasing trend at higher frequency. The vertical dimension is a measure of the intensity of the turbulence at that particular frequency, and the square root of the area under the curve a measure of the overall rms gust velocity [Ref. 13]. As a point of practicality, only the area under the actual measured curve is included, because values of the spectrum at higher frequencies contribute little to the response of an aircraft.

From analyzing large numbers of samples, it is apparent the probability distribution is non-Gaussian [Ref. 14], with very high and very low values of intensity occurring more frequently than predicted by a normal distribution. However, the vast majority of values do fall on a Gaussian curve, so it is reasonable to use this assumption for most applications. This is very beneficial because, whereas Gaussian input to a linear system results in Gaussian output, response to non-Gaussian input is, in general, unknown. In the analysis of flight vehicles, linear system models are used extensively, making the assumption of normal distribution most desirable. In order to account for the large gusts omitted by this type model, the (1-cosine) method can

be employed. This is the practice recommended by many certifying agencies.

Two Gaussian models in current use are the Dryden spectrum

$$\phi_{33}(\Omega) = \frac{\sigma^2 \tilde{L}}{\pi} \frac{1 + 3\tilde{L}^2 \Omega^2}{(1 + \tilde{L}^2 \Omega^2)^2} \quad (5)$$

and the von Kàrmàn spectrum

$$\phi_{33}(\Omega) = \frac{\sigma^2 \tilde{L}}{\pi} \frac{1 + \frac{8}{3}(1.339\tilde{L}\Omega)^2}{[1 + (1.339\tilde{L}\Omega)^2]^{11/10}} \quad (6)$$

The first was developed to define turbulence spectra in wind tunnels. It is the simpler of the two, but not as accurate as the second. For that reason it is not used as much today as in the past, but is mentioned here due to its historical significance and the large number of references to it in the literature.

Today, the von Kàrmàn spectrum is used almost universally. In equation (6), σ is the rms turbulence intensity, and $\tilde{L}$ is the "scale length"--a measure of the average eddy size encountered. Testing has shown that the model is a reasonable fit to all levels of turbulence. Figure 5 is a plot of one set of experimental data along with the predicted turbulence spectra for severe storm conditions using various values for $\tilde{L}$. As can be seen, the agreement is quite good.

The values for σ and $\tilde{L}$ are variable and appear to be functions of altitude. In addition, two standard categories of intensity are defined--"storm" and "non-storm". Table I [Ref. 15] lists values for non-storm (b_1) and storm (b_2) intensities, as well as scale length, currently used by NASA for horizontal atmospheric flight. In this table, the values p_1 and p_2 are the probabilities of encountering non-storm and storm turbulence, respectively, at the altitude specified. Note that the values of $\tilde{L}$ given for flight below 1000 ft are representative values that are probably low, giving conservative (high) numbers of load exceedances per unit length of flight. These values are usable for structural analysis, but inappropriate for control system studies of flight simulation where the vertical inhomogeneity must be taken into account.

Equation (6) is the expression for the transverse spectrum needed to analyze the longitudinal response to vertical gusts. When dealing with lateral aerodynamics, such as the analysis done in Chapter III, it is necessary to use the longitudinal spectrum

$$\phi_{11}(\Omega) = \frac{\sigma^2 \tilde{L}}{\pi} \frac{2}{[1 + (1.339 \tilde{L} \Omega)^2]^{5/6}} \quad (7)$$

where σ and $\tilde{L}$ are the same as in the transverse case. The term "longitudinal" refers to the variation in gust velocity parallel to the direction of the mean wind, whereas

"transverse" refers to the perpendicular direction (both vertically and horizontally), thus

$$\phi_{22} = \phi_{33}$$

It should be obvious from this discussion that flight direction relative to the mean wind becomes important when dealing with lateral aerodynamics.

III. METHOD OF ANALYSIS

A. THE MODEL

The aerodynamic model used in this analysis is the same as used by DeLaurier and Hui [Ref. 5], except that it is applied for the lateral case. The assumptions are as follows:

- i) the vehicle is perfectly rigid, flying at a reference velocity U_0 through a constant density ρ
- ii) the motions are described by the lateral case only
- iii) the control provided by rudder deflection is linearly proportional to the yaw angle (ψ), that is,
 $\Delta C_{Yc} = k_c \psi$

This last assumption is the case for a helmsman using greater control the farther off heading he is perturbed, an assumption in keeping with operational practice.

The turbulence model used is the von Kàrmàn spectra described in Chapter II. It is assumed that the turbulence is composed of horizontal gusts only--either u_g or v_g depending on airship heading relative to the mean wind direction. (v_g is shown in the analysis.)

1. Forces from Turbulence Components

From Jones and DeLaurier [Ref. 6], the normal force on a hull segment of length $d\xi$ is (see figure 6)

$$F_h = \frac{1}{2} \rho U_0^2 \left[K \sin(2\theta) \cos\left(\frac{\theta}{2}\right) \frac{dA}{d\xi} d\xi + (C_{dc})_h \sin\theta \sin|\theta| \frac{1}{2} d\xi \right] \quad (8)$$

where: K is the hull potential cross-flow factor [Ref. 6]
 θ is the angle between the hull centerline and U_0
 r is the radius of the hull segment.

Differentiating with respect to θ to obtain a perturbation equation gives

$$dF_h = \frac{1}{2} \rho U_0^2 \left[\left(-\frac{K}{2} \sin(2\theta) \sin\left(\frac{\theta}{2}\right) + 2K \cos(2\theta) \cos\left(\frac{\theta}{2}\right) \right) d\theta \frac{dA}{d\xi} d\xi + \right. \\ \left. (C_{d_c})_h (\cos\theta \sin|\theta| + \sin\theta \cos|\theta|) d\theta 2r d\xi \right]$$

By limiting the analysis to the lateral aerodynamic case only, (θ) becomes (β) , the sideslip angle, and F_h becomes Y_h , the hull sideforce. Further, if (β_0) , the undisturbed value of sideslip, is assumed to be zero--the usual case--the above expression becomes

$$(dY_g)_h = \frac{1}{2} \rho U_0^2 K \frac{dA}{d\xi} \left[2 \cos(2\beta_0) \cos\left(\frac{\beta_0}{2}\right) \right] d\beta_0 d\xi \\ = \rho U_0^2 K \frac{dA}{d\xi} d\xi d\beta$$

Finally, for small values of v_g ,

$$d\beta = \frac{v_g}{U_0}$$

and

$$(dY_g)_h = \rho U_0^2 K \frac{dA}{d\xi} d\xi \frac{v_g}{U_0} \quad (9)$$

The stabilizer forces are given by

$$(Y_g)_s = \rho \frac{U_o^2}{2} S_s (C_{L\alpha}^*)_s H(k_s) \eta_s \frac{(v_g)_s}{U_o} \quad (10)$$

where: $H(k_s)$ is the generalized Sears function as given by Filotas [Ref. 16]

$k_s = \frac{\omega \bar{c}_s}{2U_o}$, the "reduced frequency" of the fin

$(v_g)_s$ is the gust velocity at the fin mid-chord

The propellers used to drive the airship produce a side force when acted by the turbulence [Ref. 17]. Each thruster contribution adds to the total force and moment produced, and can be described, for the j th thruster-rotor combination by the following:

$$(Y_g)_{T_j} = -\rho \frac{U_o^2}{2} S_{T_j} (C_{Y\beta})_{T_j} \frac{(v_{gT})_j}{U_o} \quad (11)$$

$$(L_g)_{T_j} = (Y_g)_{T_j} (h_{cm} - h_{T_j}) \quad (12)$$

$$(N_g)_{T_j} = (Y_g)_{T_j} (l_{cm} - l_{T_j}) \quad (13)$$

Equations (12) and (13) assume that the rotors are arranged symmetrically about the x - z plane, so that moments due to rotor offset in the y -direction cancel out.

2. Aerodynamic Forces and Moments Due to Airship Motion

$$(dY_w)_h = \rho U_o^2 K \frac{dA}{d\xi} d\xi \frac{v(\xi)}{U_o} + \rho A \left[k_2 \frac{\partial v(\xi)}{\partial t} + U_o r k_1 \right] d\xi \quad (14)$$

where k_2 , k_1 are the horizontal and longitudinal apparent mass coefficients respectively and

$$v(\xi) = v - r[(l_{cm} - \xi)]$$

For the fins we have

$$(Y_w)_s = -\rho \frac{U_o^2}{2} S_s \left[(C_{Y\beta})_s \frac{v_s}{U_o} + (C_{Yr})_s^{ac} \frac{\bar{c}r}{2U_o} + (C_{Y\dot{\beta}})_s \frac{\bar{c}\dot{v}_s}{2U_o^2} \right] \quad (15)$$

where $v_s = v - r(l_{cm} - l_s)$

$$\dot{v}_s = \dot{v} - \dot{r}(l_{cm} - l_s)$$

$$(L_w)_s = (Y_w)_s (h_{cm})_s \quad (16)$$

$$(N_w)_s = \frac{1}{2} \rho U_o^2 S_s \bar{c}_s (C_{nr})_s^{ac} \frac{\bar{c}r}{2U_o} \quad (17)$$

The superscript ac indicates the quantity in parentheses is taken about the fin aerodynamic center.

Thruster forces and moments are given by:

$$(Y_w)_{T_j} = -\rho \frac{U_o^2}{2} S_{T_j} (C_{Y\beta})_{T_j} \frac{(v_T)_{T_j}}{U_o} \quad (18)$$

$$(L_w)_{T_j} = (Y_w)_{T_j} (h_{cm} - h_{T_j}) \quad (19)$$

$$(N_w)_{T_j} = (Y_w)_{T_j} (l_{cm} - l_{T_j}) \quad (20)$$

where

$$(v_T)_j = v - r(l_{cm} - l_{T_j}) - p(h_{cm} - h_{T_j})$$

3. Inertial Reaction of Airship to Aerodynamic Forces and Moments

The "forces" covered here are those arising as reactions to airship motion. They are, in general, the negative of the forces and moments that give rise to the indicated airship translational and angular velocities and accelerations so as to produce a state of dynamic equilibrium ($\bar{F} - m\bar{a} = 0$).

For the hull:

$$(dY_m)_h = -\dot{y}'(\xi)(d_m)_h \quad (21)$$

where $\dot{y}' = \dot{v} + \dot{r}(l_{cm} - \xi) + U_0 r$

$$(dL_m)_h = -dI_{xx}\dot{p} + dI_{xz}\dot{r} \quad (22)$$

$$(dN_m)_h = -dI_{zz}\dot{r} + dI_{xz}\dot{p} \quad (23)$$

For the empennage:

$$(Y_m)_s = -\dot{y}'_s m_s \quad (24)$$

$$(N_m)_s = -(I_{zz})_s \dot{r} + (I_{zx})_s \dot{p} \quad (25)$$

$$(L_m)_s = -(I_{xx})_s \dot{p} + (I_{zx})_s \dot{r} \quad (26)$$

where dI_{xx} , dI_{zz} and dI_{xz} are the moments and product of inertia respectively of the differential element under consideration, including all structure, air and gas contained in the airship.

4. Bouyancy and Control Terms

Referring to figure 7, the force due to bouyancy is given by:

$$(Y_b)_h = -(gdm - \rho g A d\xi) \sin\phi \cos\alpha_0$$

ϕ = roll angle

α_0 = steady state angle of attack

Differentiating to obtain a perturbation equation gives

$$(dY_b)_h = (\rho g A d\xi - gdm) \cos\phi_0 \cos\alpha_0 d\phi$$

and letting $\phi_0 = 0$ results in

$$(dY_b)_h = [\rho g A d\xi - gdm] \cos\alpha_0 d\phi \quad (27)$$

Control force is assumed to come from rudder deflection, and acts through the fin aerodynamic center.

$$\Delta C_{Y_C} = k_C \psi$$

$$(Y_C)_s = \rho \frac{U_0^2}{2} S_s k_C \psi \quad (28)$$

5. Shear Force, Bending and Twisting Moment

The hull's shear force at station (1) is obtained by summing the sideforce values from the nose, up to (1):

$$S(1) = \int_0^1 (dY)_h + \sum_{j=1}^a [(Y_g)_{T_j} + (Y_w)_{T_j}] \quad (29)$$

where $(dY)_h = (dY_g)_h + (dY_w)_h + (dY_m)_h + (dY_b)_h$

and (a) is the number of rotors forward of station (1).

Likewise, the bending moment at (1), measured along the centerline, is

$$BM(1) = \int_0^1 (1 - \xi) (dY)_h + \int_0^1 (dN_m)_h + \sum_{j=1}^a (1 - l_{T_j}) [(Y_g)_{T_j} + (Y_w)_{T_j}] \quad (30)$$

Finally, the twisting moment at station (1) is

$$TM(1) = - \int_0^1 h_{cm}(\xi) (dY)_h + \int_0^1 (dL_m)_h + \int_0^1 (dL_{mg})_h - \sum_{j=1}^a (h_{T_j}) [(Y_g)_{T_j} + (Y_w)_{T_j}] \quad (31)$$

The term $(dL_{mg})_h$ is the torque contribution due to the center of gravity being offset from the central axis (see figure 7).

It is calculated from

$$(dL_{mg})_h = h_{cm} g \, dm \, \phi \, \cos \alpha_0$$

B. FLIGHT DYNAMICS

1. Dynamic Stability

The equations for Lateral Dynamic Stability are taken from DeLaurier et. al. [Ref. 18] and given below:

$$\Delta C_{y_{aero}} + \Delta C_{y_c} - (\hat{B} - \hat{m}g) \cos \alpha_0 \phi = 2\mu (DB + \hat{P}) \quad (32)$$

$$\Delta C_{naero} + \Delta C_{nc} - \hat{x}_b \hat{B} \cos \alpha_0 \phi = I_{zz} D\hat{r} - I_{xz} D\hat{\beta} \quad (33)$$

$$\Delta C_{laero} + \Delta C_{lc} + \hat{z}_b \hat{B} \cos \alpha_0 \phi = I_{xx} D\hat{\beta} - I_{xz} D\hat{r} \quad (34)$$

$$D\phi = \hat{\beta} + \hat{r} \tan \alpha_0 \quad (35)$$

$$D\psi = \hat{r} \sec \alpha_0 \quad (36)$$

$$\Delta C_{yaero} = C_{y\beta} \beta + C_{y\dot{\beta}} D\beta + C_{yr} \hat{r} + C_{y\dot{r}} D\hat{r} + C_{yp} \hat{p} + C_{y\dot{p}} D\hat{p} \quad (37)$$

$$\Delta C_{naero} = C_{n\beta} \beta + C_{n\dot{\beta}} D\beta + C_{nr} \hat{r} + C_{n\dot{r}} D\hat{r} + C_{np} \hat{p} + C_{n\dot{p}} D\hat{p} \quad (38)$$

$$\Delta C_{laero} = C_{l\beta} \beta + C_{l\dot{\beta}} D\beta + C_{lr} \hat{r} + C_{l\dot{r}} D\hat{r} + C_{lp} \hat{p} + C_{l\dot{p}} D\hat{p} \quad (39)$$

$$\Delta C_{yc} = k_c \psi \quad (40)$$

$$\Delta C_{nc} = \frac{[l_s - l_{cm}]}{\bar{c}} \Delta C_{yc} = \frac{[l_s - l_{cm}]}{\bar{c}} k_c \psi \quad (41)$$

$$\Delta C_{lc} = \frac{[h_s - h_{cm}]}{\bar{c}} \Delta C_{yc} = \frac{[h_s - h_{cm}]}{\bar{c}} k_c \psi \quad (42)$$

In this analysis $\beta = \frac{v}{U_0} = \hat{v}$, thus equations (32) to (39) become

$$\Delta C_{yaero} + \Delta C_{yc} - (\hat{B} - \hat{m}g) \cos \alpha_0 \phi = 2\mu (D\hat{v} + \hat{r}) \quad (43)$$

$$\Delta C_{naero} + \Delta C_{nc} - \hat{x}_b \hat{B} \cos \alpha_0 \phi = I_{zz} D\hat{r} - I_{xz} D\hat{\beta} \quad (44)$$

$$\Delta C_{laero} + \Delta C_{lc} - \hat{z}_b \hat{B} \cos \alpha_0 \phi = I_{xx} D\hat{\beta} - I_{xz} D\hat{r} \quad (45)$$

$$D\phi = \hat{\beta} + \hat{r} \tan \alpha_0 \quad (46)$$

$$D\psi = \hat{r} \sec \alpha_0 \quad (47)$$

$$\Delta C_{yaero} = C_{y\beta} \hat{v} + C_{y\beta} D\hat{v} + C_{y_r} \hat{r} + C_{y_r} D\hat{r} + C_{y_p} \hat{p} + C_{y_p} D\hat{p} \quad (48)$$

$$\Delta C_{naero} = C_{n\beta} \hat{v} + C_{n\beta} D\hat{v} + C_{n_r} \hat{r} + C_{n_r} D\hat{r} + C_{n_p} \hat{p} + C_{n_p} D\hat{p} \quad (49)$$

$$\Delta C_{laero} = C_{l\beta} \hat{v} + C_{l\beta} D\hat{v} + C_{l_r} \hat{r} + C_{l_r} D\hat{r} + C_{l_p} \hat{p} + C_{l_p} D\hat{p} \quad (50)$$

These equations are linear, and along with equations (40) through (42) can be written in matrix form as:

$$[\tilde{C}] \begin{bmatrix} \hat{v} \\ \hat{r} \\ \hat{p} \\ \hat{\phi} \\ \hat{\psi} \end{bmatrix} - [\tilde{D}] \begin{bmatrix} D\hat{v} \\ D\hat{r} \\ D\hat{p} \\ D\hat{\phi} \\ D\hat{\psi} \end{bmatrix} = 0$$

where: v is translation in the y -direction

r is the rotation rate about the z -axis

p is the rotation rate about the x -axis

ϕ is the roll angle

ψ is the yaw angle

The matrices $[\tilde{C}]$ and $[\tilde{D}]$ are given by

$$[\tilde{C}] = \begin{bmatrix} C_{y\beta} & (C_{y_r} - 2\mu) & C_{y_p} & (\hat{m}g - \hat{B}) \cos \alpha_0 & -k_c \\ C_{n\beta} & C_{n_r} & C_{n_p} & -\hat{x}_b \hat{B} \cos \alpha_0 & \frac{(1_s - 1_{cm})}{\bar{c}} k_c \\ C_{l\beta} & C_{l_r} & C_{l_p} & -\hat{z}_b \hat{B} \cos \alpha_0 & \frac{+h_{cm}}{\bar{c}} k_c \\ 0 & \tan \alpha_0 & 1 & 0 & 0 \\ 0 & \sec \alpha_0 & 0 & 0 & 0 \end{bmatrix}$$

$$[D] = \begin{bmatrix} (2\mu - C_{Y\dot{\beta}}) & -C_{Y\dot{r}} & -C_{Y\dot{p}} & 0 & 0 \\ -C_{n\dot{\beta}} & (I_{zz} - C_{n\dot{r}}) & -(I_{xz} + C_{n\dot{p}}) & 0 & 0 \\ -C_{l\dot{\beta}} & -(I_{xz} + C_{l\dot{r}}) & (I_{xx} - C_{l\dot{p}}) & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

To solve this system of equations, assume a solution of the form

$$\begin{aligned} \hat{v} &= \hat{v} e^{i\hat{\sigma}\hat{t}}, \quad \hat{p} = \hat{p} e^{i\hat{\sigma}\hat{t}}, \quad \hat{r} = \hat{r} e^{i\hat{\sigma}\hat{t}} \\ \phi &= \phi e^{i\hat{\sigma}\hat{t}}, \quad \psi = \psi e^{i\hat{\sigma}\hat{t}} \end{aligned} \quad (52)$$

which, when substituted into equation (51) becomes

$$[\tilde{C} - i\hat{\sigma}\tilde{D}] \begin{bmatrix} \hat{v} \\ \hat{r} \\ \hat{p} \\ \phi \\ \psi \end{bmatrix} = 0 \quad (53)$$

where $\hat{\sigma}$ is the non-dimensional stability root. This is an eigenvalue problem. A computer solution is performed to find the eigenvalues (stability roots) and eigenvectors (model vectors) for the control gains considered. For the subsequent load-response analysis, dynamically stable cases must be chosen.

2. Turbulence Forcing Functions

As mentioned above, the model chosen for the turbulence is sinusoidal with Gaussian statistics, in particular,

$$\frac{v_g(\xi)}{U_0} = \Gamma \exp \left(i\omega t - i\omega \xi \frac{\cos \alpha_0}{U_0} \right) \quad (54)$$

By using this expression in equation (9), integrating from $\xi = 0$ to $\xi = l_h$ (the hull/fin intersection) and adding the contributions of the fins and thruster-rotor combinations, the complete turbulence forcing functions for the airship can be found. That is,

$$Y_g = \int_0^{l_h} d(Y_g)_h + \sum_{j=1}^a (Y_g)_{T_j} + (Y_g)_s \quad (55)$$

Likewise, the yawing moment about the nose is

$$N_{gnose} = + \int_0^{l_h} \xi d(Y_g)_h + \sum_{j=1}^a [(l_{T_j})(Y_g)_{T_j}] + l_s (Y_g)_s$$

$$\text{and } N_{gcm} = N_{gnose} - l_{cm} Y_g \quad (56)$$

and rolling moment is given by

$$L_g = -h_{cm} Y_g \quad (57)$$

These may be non-dimensionalized according to

$$Y_g = \frac{U_0^2}{2} S G_Y \quad (L_g, N_g) = \frac{U_0^2}{2} S \bar{C} (G_l, G_n) \quad (58)$$

and the non-dimensional equations can be expressed as

$$G_y = G_{y\gamma} \gamma \quad G_l = G_{l\gamma} \gamma \quad G_n = G_{n\gamma} \gamma \quad (59)$$

$$\text{where } \gamma = \Gamma \exp(i\omega t) = \Gamma \exp(ik\hat{t}) \quad (60)$$

$$k = \frac{\bar{\omega}}{2U_0}$$

$G_{y\gamma}$, $G_{l\gamma}$ and $G_{n\gamma}$ are the turbulent forcing functions for the vehicle.

3. Motion Response Transfer Functions

Using the functions of equation (59) as forcing functions on the right-hand side of equation (53), and dividing through by γ gives

$$[\tilde{C} - ik\tilde{D}] \begin{bmatrix} \hat{V}/\Gamma \\ R/\Gamma \\ P/\Gamma \\ \phi/\Gamma \\ \psi/\Gamma \end{bmatrix} = \begin{bmatrix} G_{y\gamma} \\ G_{n\gamma} \\ G_{l\gamma} \\ 0 \\ 0 \end{bmatrix} \quad (61)$$

Solution of this expression for specific reduced frequencies (k), or spectral wave numbers (Ω), and fixed stable control gains (k_c), allows calculation of the expressions necessary for the solution of distributed force loadings and moments, by means of the following expressions.

$$\begin{aligned}\hat{v} &= \frac{v}{U_0} = \frac{\hat{v}}{\Gamma} \exp(ik\hat{t}), & \frac{\bar{c}p}{2U_0} &= \frac{\hat{p}}{\Gamma} \exp(ik\hat{t}) \\ \frac{\bar{c}r}{2U_0} &= \frac{\hat{R}}{\Gamma} \exp(ik\hat{t}), & \phi &= \frac{\hat{\phi}}{\Gamma} \exp(ik\hat{t})\end{aligned}\quad (62)$$

$$\psi = \frac{\hat{\psi}}{\Gamma} \exp(ik\hat{t})$$

C. LOAD RESPONSE TRANSFER FUNCTIONS

Once the motion response of the airship is known, the load response transfer functions can be calculated.

1. Turbulence Loading

These may be obtained by substituting equation 54 into equations (9) through (13) and dividing by γ (equation (60)). This gives, for example, for equation (9):

$$\frac{(dy_g)_h}{\Gamma} = \frac{U_0^2}{2} \kappa \frac{dA}{d\xi} \exp(-i\Omega\xi \cos\alpha_0) d\xi \quad (63)$$

$$\text{where } \Omega = \frac{\omega}{U_0} = \frac{2k}{c}$$

Table II gives the complete list of load response transfer functions.

2. Motion Response Loading

The aerodynamic-reaction loading may be obtained by replacing the motion variables, $\left[\frac{v}{U_0}\right]$, $\left[\frac{\bar{c}p}{2U_0}\right]$, etc., in equations (14) through (20) with the corresponding motion-response transfer functions in equations (62). For example, equation (14) becomes

$$\begin{aligned} \frac{(dy_w)_h}{\Gamma} &= \left\{ \rho \frac{U_o^2}{2} K \frac{dA}{d\xi} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} (1_{cm} - \xi) \frac{\hat{R}}{\Gamma} \right] \right. \\ &\quad \left. + \rho U_o^2 A \left\{ i\Omega \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} \frac{\hat{R}}{\Gamma} (1_{cm} - \xi) \right] k_2 + \frac{2}{c} \frac{\hat{R}}{\Gamma} k_1 \right\} \right\} d\xi \end{aligned} \quad (64)$$

The Inertial-Reaction, and Bouyancy loading transfer functions are similarly obtained from equations (21) through (27). For example, equation (21) becomes

$$\frac{(dy_m)_h}{\Gamma} = \left\{ - \frac{2U_o^2}{c} \frac{\hat{R}}{\Gamma} + i\Omega U_o^2 \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} \frac{\hat{R}}{\Gamma} (1_{cm} - \xi) \right] \right\} dm \quad (65)$$

and equation (27) becomes

$$\frac{(dy_B)_h}{\Gamma} = [\rho g A d\xi - g dm] \cos \alpha_o \frac{\phi}{\Gamma} \quad (66)$$

3. Shear Force, Bending and Twisting Moment Transfer Functions

The shear force loading transfer function is obtained using equation (29):

$$\frac{S(1)}{\Gamma} = \int_0^1 \frac{dy}{\Gamma} + \sum_{j=1}^a \frac{(Y_T)_j}{\Gamma} \quad (67)$$

where:

$$\frac{dy}{\Gamma} = \frac{(dy_g)_h}{\Gamma} + \frac{(dy_w)_h}{\Gamma} + \frac{(dy_m)_h}{\Gamma} + \frac{(dy_B)_h}{\Gamma}$$

and

$$\frac{(Y_T)_j}{\Gamma} = \frac{(Y_g)_j}{\Gamma} + \frac{(Y_w)_j}{\Gamma}$$

The bending-moment transfer function comes from equation (30)

$$\frac{BM(1)}{\Gamma} = \int_0^1 (1_{cm} - \xi) \frac{(dY)_h}{\Gamma} + \int_0^1 \frac{(dN_m)_h}{\Gamma} + \sum_{j=1}^a (1 - 1_{Tj}) \left[\frac{(Y_g)_{Tj}}{\Gamma} + \frac{(Y_w)_{Tj}}{\Gamma} \right] \quad (68)$$

and finally the twisting-moment transfer function, from equation (31), is:

$$\begin{aligned} \frac{TM(1)}{\Gamma} = & - \int_0^1 h_{cm}(\xi) (dY)_h + \int_0^1 \frac{(dL_m)_h}{\Gamma} + \int_0^1 \frac{(dL_{mg})_h}{\Gamma} \\ & - \sum_{j=1}^a h_{Tj} \left[\frac{(Y_g)_{Tj}}{\Gamma} + \frac{(Y_w)_{Tj}}{\Gamma} \right] \end{aligned} \quad (69)$$

An important check on the analytical model is obtained by ensuring the net Shear Force, and Bending and Twisting Moments equal zero.

$$\frac{S(1)_h}{\Gamma} + \frac{(Y_g)_s}{\Gamma} + \frac{(Y_w)_s}{\Gamma} + \frac{(Y_m)_s}{\Gamma} + \frac{(Y_c)_s}{\Gamma} = 0 \quad (70)$$

The moments are evaluated to the empennage assembly's mass center, $(1_{cm})_s$, so that

$$\begin{aligned} \frac{BM(1_{cm})_s}{\Gamma} + [(1_{cm})_s - 1_s] \left[\frac{(Y_g)_s}{\Gamma} + \frac{(Y_w)_s}{\Gamma} + \frac{(Y_c)_s}{\Gamma} \right] \\ + \frac{(N_w)_s}{\Gamma} + \frac{(N_m)_s}{\Gamma} = 0 \end{aligned} \quad (71)$$

$$\frac{TM(l_{cm})s}{\Gamma} + \frac{(L_w)s}{\Gamma} + \frac{(L_m)s}{\Gamma} + (h_{cm})s \left[\frac{(Y_g)s}{\Gamma} + \frac{(Y_w)s}{\Gamma} + \frac{(Y_c)s}{\Gamma} \right] = 0 \quad (72)$$

These equations may be non-dimensionalized as follows:

$$\frac{C_s(1)}{\Gamma} = \frac{2}{\rho U_o^2 s} \frac{S(1)}{\Gamma} \quad (73)$$

$$\frac{C_{BM}(1)}{\Gamma} = \frac{2}{\rho U_o^2 s \bar{c}} \frac{BM(1)}{\Gamma} \quad (74)$$

$$\frac{C_{TM}(1)}{\Gamma} = \frac{2}{\rho U_o^2 s \bar{c}} \frac{TM(1)}{\Gamma} \quad (75)$$

D. RESPONSE TO ATMOSPHERIC TURBULENCE

Once the force and moment transfer function coefficients are known, the turbulence statistics can be applied to obtain estimates of airship lifetime and failure probability. When dealing with the lateral aerodynamic case, two different spectra must be considered-- ϕ_{11} and ϕ_{22} . This analysis will use the von Kàrmàn spectra as given by equations (7) and (6) respectively. As explained in Chapter II, the first is used when the flight direction is perpendicular to the mean wind, and the second when the direction is parallel.

1. Root-Mean-Square Responses

The root-mean-square response to turbulence of any system parameter can be obtained using its transfer function

multiplied by the spectrum (provided, of course, the spectrum is Gaussian). For example, the rms shear force coefficient is

$$\frac{(C_s)_{rms}}{c} = \left[\frac{2}{U_0^2} \int_0^\infty \left| \frac{C_s}{r} \right|^2 \frac{\phi_{11}}{\sigma^2} d\Omega \right]^{1/2} \quad (76)$$

Response to various conditions can be evaluated using appropriate values for σ and L in the equations for ϕ_{11} , and choosing either ϕ_{11} or ϕ_{22} according to desired flight direction.

2. Mission Analysis Method

The mission analysis method is a technique for estimating a flight vehicle's probable lifetime. The method is based on the probability distribution of encountering turbulence in representative flight operations [Refs. 7 and 15]. It is assumed the total flight is a sum of Gaussian patches [Ref. 2]. The formula for calculating the number of exceedences is

$$N(x) = \sum t N_0 \left[p_1 \exp \left(\frac{-|x - x_{ref}|}{b_1 \bar{A}} \right) + p_2 \exp \left(\frac{-|x - x_{ref}|}{b_2 \bar{A}} \right) \right] \quad (77)$$

where: x = maximum structural value of bending, moment coefficient at a given station,

x_{ref} = value of x in one-g level flight,

$N(x)$ = average number of exceedences of the indicated value of x per unit time

N_0 = number of zero crossings of x per unit time
 $\bar{A}$ = $[(C_{BM})_{rms}/\sigma]/\gamma_{rms}$
 t = fraction of time in mission segment
 p_1, p_2 = probability values from Table I
 b_1, b_2 = intensity levels from Table I

also

$$N_0 = \left[\frac{1}{2\pi} \frac{(\dot{B}M)_{ms}}{(BM)_{ms}} \right]^{1/2}$$

where

$$(BM)_{ms} = \left(\frac{\rho U_0^2 S \bar{C}}{2} \right)^2 \int_0^\infty \left| \frac{C_{BM}}{\Gamma} \right| \phi_{11} d\Omega \quad (78)$$

$$(\dot{B}M)_{ms} = \left(\frac{\rho U_0^2 S \bar{C}}{2} \right)^2 \int_0^\infty \left| \frac{C_{BM}}{\Gamma} \right| \Omega \phi_{11} d\Omega \quad (79)$$

The probable lifetime is then $[N(x)]^{-1}$

Shear force and twisting moment are analyzed in the same fashion using the appropriate transfer functions.

3. Other Methods

DeLaurier and Hui [Ref. 5] also include Failure-Probability analysis [Ref. 3] and "Mil-Spec Storm" analysis in their paper. There are others in existence, such as the Design Envelope Analysis [Ref. 7] that have been used for HTA flight, and are well documented. Because of this, they will not be included here, as techniques for using them are

the same once the transfer functions of response are known.
The exact method used is up to the designer, based on his
needs.

IV. NUMERICAL EXAMPLE

In order to illustrate the lateral aerodynamic case developed in Chapter III, an example using the USS AKRON (ZR-4) is presented. The flight conditions chosen are:

$$U_0 = 123 \text{ ft/sec}$$

$$\text{Alt} = 1000 \text{ ft}$$

The velocity represents the maximum for the vehicle, and the altitude is typical of its operational range. In addition, a condition of neutral buoyancy ($B - mg = 0.0$) was selected. The geometry was taken from Freeman [Ref. 19] and the weight distribution from Woodward [Ref. 20]. With this information available, the inertial properties of the AKRON could be calculated using the method of Scholaert and DeLaurier [Ref. 21] (see Appendix). The values obtained are shown in Table III. The Hull cross-flow and stabilizer efficiency factors are calculated using the method given in reference 6, and are:

$$K = 0.93225$$

$$\eta_s = 0.2600$$

The apparent-mass coefficients are from Munk [Ref. 22].

The stability derivatives are taken from DeLaurier and Schenck [Ref. 18], and shown in Table IV. With these, the control gain, and the inertial and geometrical properties,

equation 53 can be solved to find the stable roots. This was done in reference 18 and the results are shown in figure 8. Mode 4 (indicated in the figure) is characterized by roll, yaw, and sideslip of equal magnitudes not unlike the dutch roll mode of a fixed wing aircraft. Mode 5 is one of equal and opposite β and ψ motions with small ϕ perturbations. Mode 6 is a relatively high-frequency rolling motion, little affected by control gain. Modes 1, 2, and 3 refer to longitudinal aerodynamic modes [Ref. 18]. From this analysis, a control gain of 0.2 was found to provide the minimum stable condition.

The forcing functions were next obtained using equations 54 through 60, and are plotted in figure 9. The peaks in all the curves occur at a wave number of about .008. This corresponds to a wavelength equal to the length of the airship. $|G_{1\gamma}|$ is significantly smaller than the others, as expected, due to the smaller moment arm through which the sideforce works in producing roll.

With the turbulence forcing functions, equation 61 was solved to obtain the motion response transfer functions. These are shown in figures 10 through 14. Control gains of 0.2, 1.0, and 2.0 were used to illustrate the effect of its variation. The most significant feature of these responses is the peak at a wave number of .008. This corresponds, as in the forcing functions, to a condition where the spectral component wavelength exactly equals the airship length. This

is the result predicted by Calligeros and McDavitt [Ref. 4] for the longitudinal case. DeLaurier and Hui [Ref. 5] also obtained this result, but only for cases of higher control gain. For the lateral case, the control gain does not significantly change this peak, although, for yaw and yaw rate (ψ and $\dot{\psi}$), and to a lesser extent roll (ϕ), the response at lower wave numbers is reduced.

Finally, the load response transfer functions were calculated. The results are shown in figures 15 through 17 for a wave number of .009, and a control gain of 0.2. Complete results are given in the appendix. For the most part, the results yield no surprises. The magnitudes of the load response follow the general trend of the combined motion responses, thus the peak loads occur at wave numbers near .008. The location along the axis of the peak load varies as the magnitude of the motions increases, shifting aft in the case of shear and twisting moment, and to the center for bending moment. Again, the lack of significant change with control gain is apparent.

V. CONCLUSIONS AND RECOMMENDATIONS

The analysis presented is an extension of the work by DeLaurier and Hui [Ref. 5], and is subject to the same restrictions. That is, it is limited to small perturbations in order to allow a linear analysis usable with power spectral methods, and its ability to make precise predictions of the loading when used with one of the methods that accounts for severe turbulence is questionable. Nonetheless, it is a valuable tool in understanding the response to an initial disturbance, and when employed as the aerodynamic input to the various statistical methods discussed earlier, it can yield important design and operational insight.

The limited effectiveness of the simple control model employed, which is typical of someone cuing his response to a compass, was demonstrated. It is suggested that an examination of the effects of roll control and yaw rate feedback be made. This would allow a decision as to the feasibility of using control to provide gust alleviation. As discussed by DeLaurier and Hui, control gain made a large difference in the expected lifetime of an airship when considering only longitudinal aerodynamics. Undoubtedly, for the lateral case, even the yaw control used in this analysis will contribute to increased survivability due to the reduction of loads at low wave numbers. Thus, the next step is to employ

the statistical methods to discover how much change is realized.

The case of combined longitudinal and lateral motion needs to be studied. No aircraft ever built has ever managed to fly through turbulence that is strictly one dimensional, as is assumed for this analysis. Coupling the two cases would give a much better idea of the true action of an airship in turbulence.

Finally, some means must be found to establish the veracity of this model, as well as that for the longitudinal case. To the author's knowledge, no investigation of the actual response of an airship to conditions of known turbulence has ever been made. This is, of course, a difficult project, considering the limited number of airships currently available if full scale tests are to be carried out. Wind tunnel investigations, made in the various oscillating flow tunnels available, would be helpful. Until some tests are done, however, this type of analysis must be considered only for its qualitative aspects as opposed to its quantitative predictions.

COMPUTER OUTPUT FOR THE NUMERICAL EXAMPLE

CCNTRCL GAIN = 0.20
WAVE NUMBER = .10000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY .61066E+00 .66185E+00 .29296E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19540E+01 .15717E-01 .54070E-03 .12302E+00 .40043E+01 YAW
CTM

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS 0.652803 0.237232 0.000000
78.500000 1.081468 0.283407 0.015538
157.000000 1.204353 0.151262 0.020323
235.000000 1.209334 0.064002 0.018993
314.000000 1.156551 0.065707 0.014817
392.000000 0.940412 0.220875 0.002184
470.000000 0.572192 0.244691 0.015983
548.000000
626.000000
705.000000

CCNTRCL GAIN = 0.20
WAVE NUMBER = .20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY .61056E+00 .66184E+00 .29291E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19538E+01 .31421E-01 .10971E-02 .12528E+00 .40027E+01 YAW
CTM

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS 0.653393 0.237455 0.000000
78.500000 1.082489 0.283722 0.015564
157.000000 1.205780 0.151651 0.020402
235.000000 1.211145 0.064651 0.019150
314.000000 1.158874 0.065860 0.015139
392.000000 0.943718 0.220797 0.004343
470.000000 0.577579 0.244644 0.020353
548.000000
626.000000
705.000000

CONTROL GAIN = 0.20
 WAVE NUMBER = .30000E-04

THE FORCING FLACIICN MAGNITUDES ARE:
 GY
 .61046E+00 .66184E+00 .29287E-01

THE MOTICN RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19535E+01 .47101E-01 .16843E-02 .12894E+00 .40001E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATION
 78.500000
 157.000000
 235.500000
 314.000000
 392.500000
 510.250000
 605.559561

CS
 0.654447
 1.084311
 1.208291
 1.214296
 1.162869
 0.949313
 0.586508

CBM
 0.237852
 0.234278
 0.152318
 0.065726
 0.066119
 0.220692
 0.244593

CTM
 0.000000
 0.015608
 0.020535
 0.019412
 0.015661
 0.006504
 0.020944

53

CONTROL GAIN = 0.20
 WAVE NUMBER = .40000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
 GY
 .61036E+00 .66182E+00 .29282E-01

THE MOTICN RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19531E+01 .62746E-01 .23157E-02 .12388E+00 .39966E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATION
 78.500000
 157.000000
 235.500000
 314.000000
 392.500000
 510.250000
 605.559561

CS
 0.655960
 1.086925
 1.211873
 1.218767
 1.168507
 0.957137
 0.558789

CBM
 0.238421
 0.285072
 0.192360
 0.067202
 0.066482
 0.220558
 0.244538

CTM
 0.000000
 0.015670
 0.020720
 0.019774
 0.016363
 0.008660
 0.021742

CONTROL GAIN = 0.20
 WAVE NUMBER = .50000E-04
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GN GL
 .61026E+00 .66185E+00 .29277E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL YAW
 .19526E+01 .78343E-01 .30025E-02 .13995E+00 .39920E+01
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC
 78.500000 CS CBM
 157.000000 0.657923 0.239159
 235.500000 1.090310 0.286098
 314.000000 1.216497 0.194467
 352.500000 1.224521 0.069048
 510.250000 1.175735 0.065944
 605.559561 0.967100 0.220397
 0.614170 0.244475

CONTROL GAIN = 0.20
 WAVE NUMBER = .60000E-04
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GN GL
 .61015E+00 .66194E+00 .29272E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL YAW
 .19521E+01 .93881E-01 .37551E-02 .14695E+00 .39865E+01
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC
 78.500000 CS CBM
 157.000000 0.660323 0.240060
 235.500000 1.094449 0.287350
 314.000000 1.222136 0.195931
 352.500000 1.231519 0.071226
 510.250000 1.184502 0.067502
 605.559561 0.979101 0.220209
 0.632365 0.244416


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CCNTRL GAIN = 0.20
WAVE NUMBER = .50000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
      GN      .6053E+00 .6621E+00 .2925E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      SIDLIP  YAW RATE  ROLL RATE  ROLL      YAW      .3964E+01
      .1950E+01 .1400E+00 .6467E-02 .1724E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
      STATION  CS      CPM      CTH
      7E-500000 0.669578 0.24368E 0.000000
      157.500000 1.111086 0.25236E 0.01623E
      235.500000 1.244714 0.20173E 0.02234E
      314.000000 1.259421 0.07938E 0.02280E
      352.500000 1.219241 0.06970E 0.02172E
      510.250000 1.026006 0.21948E 0.01929E
      605.5595E1 0.700730 0.24420E 0.02795E

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[illegible]

CONTROL GAIN = 0.20
WAVE NUMBER = .20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60855E+00 .66422E+00 .29195E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.19396E+01 .25570E+00 .22914E-01 .28566E+00 .38178E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.727811	0.26536E	0.000000
157.000000	1.210469	0.322141	0.018487
235.500000	1.378057	0.234921	0.028313
314.000000	1.422005	0.118367	0.032822
392.500000	1.417681	0.082189	0.036798
510.250000	1.281152	0.215064	0.040642
605.559561	1.029990	0.243208	0.046034

CONTROL GAIN = 0.20
WAVE NUMBER = .30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60734E+00 .66763E+00 .29137E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.15255E+01 .42633E+00 .45602E-01 .38288E+00 .36207E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
76.500000	0.789513	0.288476	0.000001
157.000000	1.316072	0.353618	0.020810
235.500000	1.518108	0.268751	0.034044
314.000000	1.590379	0.142318	0.041716
392.500000	1.618807	0.095028	0.049075
510.250000	1.527111	0.269325	0.056514
605.559561	1.316590	0.242043	0.061165

CONTROL GAIN = 0.20
 WAVE NUMBER = .4000E-03
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY .6061E+00 .67245E+00 .29078E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL YAW
 .15087E+01 .53291E+00 .73201E-01 .46283E+00 .33943E+01
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.840595 0.307626 0.000001
 157.000000 1.403069 0.379664 0.022717
 235.500000 1.633134 0.256545 0.038635
 314.000000 1.728057 0.178735 0.048663
 392.500000 1.781960 0.105961 0.058465
 510.250000 1.722820 0.202840 0.068494
 605.559561 1.536736 0.240689 0.073059

CONTROL GAIN = 0.20
 WAVE NUMBER = .5000E-03
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY .60451E+00 .67875E+00 .29020E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL YAW
 .18898E+01 .62081E+00 .10357E+00 .52488E+00 .31634E+01
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.873510 0.320029 0.000002
 157.000000 1.458610 0.356683 0.023977
 235.500000 1.707350 0.215360 0.041745
 314.000000 1.817780 0.156917 0.053408
 392.500000 1.889241 0.113952 0.064909
 510.250000 1.852855 0.196245 0.076836
 605.559561 1.683661 0.239225 0.081617

CONTROL GAIN = 0.20
WAVE NUMBER = .6000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60375E+00 .68635E+00 .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.18654E+01 .69318E+00 .13524E+00 .57175E+00 .29435E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.888033	0.325615	0.000004
157.000000	1.740728	0.404643	0.024602
233.500000	1.860188	0.325507	0.043496
314.000000	1.942540	0.207907	0.056206
392.500000	1.921973	0.119234	0.068839
510.250000	1.766445	0.189938	0.082156
605.959561		0.237748	0.087329

CONTROL GAIN = 0.20
WAVE NUMBER = .7000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60266E+00 .69521E+00 .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.18478E+01 .75345E+00 .16742E+00 .60702E+00 .27423E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.887216	0.325521	0.000006
157.000000	1.479346	0.405048	0.024697
233.500000	1.739551	0.328543	0.044133
314.000000	1.863228	0.213262	0.057460
392.500000	1.951330	0.122217	0.070810
510.250000	1.941836	0.184104	0.085158
605.959561	1.798752	0.236359	0.090837

CONTROL GAIN = 0.20
WAVE NUMBER = .80000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GI
.60166E+00 .70527E+00 .28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.18251E+01 .80462E+00 .19978E+00 .63402E+00 .25625E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CEN CTM
7E-500000 0.874949 0.321186 0.000008
157.000000 1.456253 0.399770 0.024388
235.500000 1.713269 0.326251 0.043937
314.000000 1.836377 0.214491 0.057567
392.500000 1.926462 0.123539 0.071345
510.250000 1.924844 0.178798 0.086482
605.559561 1.793912 0.235136 0.092751

CONTROL GAIN = 0.20
WAVE NUMBER = .50000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GI
.60075E+00 .71644E+00 .28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.18015E+01 .84505E+00 .23233E+00 .65550E+00 .24035E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CEN CTM
7E-500000 0.854832 0.313945 0.000010
157.000000 1.419082 0.390524 0.023789
235.500000 1.668203 0.320211 0.043145
314.000000 1.788183 0.212848 0.056866
392.500000 1.877569 0.123736 0.070879
510.250000 1.881737 0.174014 0.086654
605.959561 1.763109 0.234134 0.093574

CONTROL GAIN = 0.20
WAVE NUMBER = .10000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.59957E+00 .72864E+00 .28783E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.17765E+01 .88846E+00 .26523E+00 .67357E+00 .22636E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.829797	0.304882	0.000013
157.000000	1.372738	0.378694	0.022990
235.500000	1.610818	0.311679	0.041945
314.000000	1.725497	0.209305	0.055622
392.500000	1.812331	0.123233	0.069755
510.250000	1.820993	0.169710	0.086085
605.559561	1.715072	0.233374	0.093695

CONTROL GAIN = 0.20
WAVE NUMBER = .20000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60042E+00 .88883E+00 .28805E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.14750E+01 .11447E+01 .67587E+00 .85850E+00 .14582E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.586978	0.216714	0.000065
157.000000	0.865587	0.248165	0.012625
235.500000	0.924737	0.205288	0.026839
314.000000	0.944674	0.157462	0.041608
392.500000	0.993928	0.120533	0.058528
510.250000	1.073725	0.145733	0.081325
605.559561	1.146722	0.232768	0.094352

CCNTRCL GAIN = 0.20
 WAVE NUMBER = .30000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GN
 .61712E+00 .10700E+01 .29600E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SICESLIP YAW RATE ROLL RATE ROLL
 .11000E+01 .12024E+01 .13867E+01 .11755E+01 .10212E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS CBM
 78.500000 0.497046 0.184123
 157.000000 0.538568 0.165723
 235.500000 0.367343 0.125053
 314.000000 0.419372 0.132322
 392.500000 0.689627 0.149338
 510.250000 1.089929 0.151987
 605.959561 1.358668 0.217797

CTM
 0.000200
 0.005468
 0.025085
 0.055028
 0.081781
 0.113898
 0.125510

CCNTRCL GAIN = 0.20
 WAVE NUMBER = .40000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GN
 .64440E+00 .12258E+01 .30919E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SICESLIP YAW RATE ROLL RATE ROLL
 .67565E+00 .10358E+01 .25474E+01 .16211E+01 .65974E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS CBM
 78.500000 0.434833 0.160260
 157.000000 0.292965 0.092671
 235.500000 0.240585 0.081765
 314.000000 0.836513 0.169587
 392.500000 1.437812 0.221642
 510.250000 2.141464 0.186965
 605.959561 2.478434 0.186207

CTM
 0.000491
 0.008731
 0.045973
 0.086100
 0.127013
 0.175656
 0.190058

CONTROL GAIN = 0.20
WAVE NUMBER = .50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
GY GA GL
.67258E+00 .13310E+01 .32267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.24526E+00 .67855E+00 .43425E+01 .22125E+01 .34576E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CIM
78.500000 0.266768 0.094702 0.001046
157.000000 0.189725 0.024270 0.014957
235.500000 0.863461 0.209193 0.064239
314.000000 1.753875 0.341996 0.120351
392.500000 2.703362 0.387143 0.180007
510.250000 3.844154 0.246157 0.257894
605.559561 4.324980 0.071187 0.290179

CONTROL GAIN = 0.20
WAVE NUMBER = .60000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
GY GA GL
.6521E+00 .13725E+01 .3320E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.38654E+00 .71525E+00 .72023E+01 .30592E+01 .30372E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CIM
78.500000 0.184072 0.069484 0.002081
157.000000 0.778218 0.025075 0.020584
235.500000 1.828513 0.523120 0.080676
314.000000 3.118036 0.718689 0.155355
392.500000 4.585062 0.741300 0.240635
510.250000 6.445200 0.355100 0.368677
605.559561 7.238190 0.165356 0.445685

CONTRCL GAIN = 0.20
 WAVE NUMBER = .70000E-02
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GA GL
 .69712E+00 .13477E+01 .33444E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .11008E+01 .20505E+01 .12345E+02 .44961E+01 .76104E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 1.149822 0.438929 0.004162
 157.000000 2.162449 0.736564 0.026533
 235.500000 3.621204 1.172613 0.097797
 314.000000 5.498711 1.457783 0.197320
 352.500000 7.808969 1.457262 0.321883
 510.250000 10.938520 0.614341 0.541721
 605.559561 12.396368 0.558990 0.719025

CONTRCL GAIN = 0.20
 WAVE NUMBER = .80000E-02
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GA GL
 .68515E+00 .12592E+01 .32872E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .22778E+01 .50536E+01 .22118E+02 .70498E+01 .16222E+01
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 3.452179 1.305918 0.008521
 157.000000 5.377102 1.840727 0.036940
 235.500000 7.396248 2.571503 0.125860
 314.000000 10.074638 3.136181 0.257785
 352.500000 13.690218 3.110294 0.436685
 510.250000 15.039459 1.250182 0.819951
 605.559561 21.936630 1.387006 1.220056

CCNTRCL GAIN = 0.20
 WAVE NUMBER = .90000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .65745E+00 .11188E+01 .31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .22280E+01 .58179E+01 .21336E+02 .60455E+01 .16470E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS 4.577765 1.719222 C1M 0.009247
 STATION 6.748293 2.279095 0.040418
 157.000000 2.532747 0.121645
 235.500000 10.067587 0.217082
 314.000000 12.753042 0.328918
 352.500000 17.369659 0.645486
 510.250000 20.566772 1.111805
 605.559561

CCNTRCL GAIN = 0.20
 WAVE NUMBER = .10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .61780E+00 .94575E+00 .25635E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .11555E+01 .35247E+01 .11758E+02 .29989E+01 .89803E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS 3.132074 1.167065 C1M 0.005662
 STATION 4.656887 1.532093 0.036617
 157.000000 5.339117 0.093290
 235.500000 7.927462 0.150272
 314.000000 6.762783 0.181123
 352.500000 8.673275 0.282001
 510.250000 10.728956 0.571219
 605.559561

[illegible]

CCNTRCL GAIN = 0.20
WAVE NUMBER = .30CCOE-01

THE FORCING FUNCTION MAGNITUDES ARE:
GA .10561E+00 .74178E+00 .52583E-02
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.71773E-01 .46384E+00 .11081E+01 .94253E-01 .39393E-01
YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
CS CEM
STATIC C.7493360 0.250370
78.500000 0.102953
157.000000 0.519041
135.500000 0.584548
314.000000 0.557267
352.500000 0.154667
51C.559561 0.224975
603.559561 0.049563
CYM
0.001601
0.077025
0.020930
0.052577
0.109876
0.065140
0.049563

0-001338
0-0075660
0-0057990
0-0084400
0-0074062
0-0050662
0-0027899

0-20760E
0-42526E
0-129982
0-353697
0-349055
0-242864
0-050750

9472300-0
4271540-0
116850-0
804390-0
822060-0
335950-0
901100-0
M13

CONTROL GAIN = 0.20
WAVE NUMBER = .60000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.51347E+00 .45648E+00 .24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.24128E-01 .13655E+00 .31873E+00 .13556E-01 .58151E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICCS
78.500000 0.643571
157.000000 1.160521
235.500000 1.550056
314.000000 1.145030
392.500000 1.010427
510.250000 0.337443
605.959561 0.558483

CIM
0.223922
0.337170
0.437335
0.256267
0.366862
0.314961
0.026738

CIM
0.000921
0.048571
0.079754
0.071790
0.068022
0.033967
0.035750

CONTROL GAIN = 0.20
WAVE NUMBER = .70000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.65821E+00 .35145E+00 .31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.22010E-01 .97028E-01 .21375E+00 .77927E-02 .35315E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICCS
78.500000 0.672918
157.000000 1.041965
235.500000 1.340559
314.000000 1.740253
392.500000 1.999074
510.250000 1.334963
605.959561 0.910286

CIM
0.236757
0.221562
0.249585
0.331336
0.242040
0.277302
0.058236

CIM
0.000721
0.037318
0.079496
0.107676
0.116080
0.090895
0.083215

CCNTRCL GAIN = 0.20
WAVE NUMBER = .800C0E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY .701C5E+00 .40424E+00 .33632E-01
GA

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SICESLIP YAW RATE ROLL
.20873E-01 .85286E-01 .17442E+00 .55645E-02 .27161E-02 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC
78.500000 0.710734 0.255827 0.000672
157.000000 1.119813 0.286351 0.016939
235.500000 1.157440 0.231112 0.019265
314.000000 1.079324 0.271900 0.014292
392.500000 0.967588 0.333952 0.007460
510.250000 2.056246 0.174401 0.157102
605.559561 1.063324 0.109365 0.126323

CCNTRCL GAIN = 0.20
WAVE NUMBER = .500C0E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY .83025E+00 .53478E+00 .39831E-01
GA

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SICESLIP YAW RATE ROLL
.23686E-01 .99234E-01 .19241E+00 .54571E-02 .28092E-02 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC
78.500000 0.768450 0.286531 0.000834
157.000000 1.375266 0.444614 0.028224
235.500000 1.737722 0.457728 0.073297
314.000000 1.772990 0.438384 0.107678
392.500000 1.406926 0.428248 0.115724
510.250000 2.505047 0.053959 0.097379
605.559561 1.279762 0.154907 0.054535

CONTROL GAIN = 0.20
WAVE NUMBER = .10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:

GY .12155E+01 .85551E+00 .58500E-01

THE ACTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.32743E-01 .14375E+00 .27641E+00 .70559E-02 .36635E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CPM	CTM
78.500000	1.807979	0.313998	0.001331
157.000000	1.177783	0.391707	0.054202
235.500000	0.618283	0.264058	0.100733
314.000000	1.561124	0.636597	0.082167
392.500000	2.850967	0.620091	0.054767
510.250000	2.842363	0.231886	0.080716
605.559561	2.087214	0.308157	0.115052

CONTROL GAIN = 1.00
WAVE NUMBER = .10000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY .61066E+00 .66185E+00 .29296E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.19540E+01 .31438E-02 .49158E-03 .12228E+00 .80097E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652587	0.237151	0.000000
157.000000	1.081090	0.283293	0.015525
235.500000	1.203835	0.151128	0.020297
314.000000	1.208692	0.063794	0.018941
352.500000	1.155750	0.065660	0.014713
510.250000	0.939320	0.220889	0.000619
605.559561	0.570484	0.244693	0.015877

CONTROL GAIN = 1.00
WAVE NUMBER = .20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY .61056E+00 .66184E+00 .29291E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.15538E+01 .62877E-02 .98355E-03 .12233E+00 .80099E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652520	0.237127	0.000000
157.000000	1.080968	0.283263	0.015527
235.500000	1.203700	0.191115	0.020295
314.000000	1.208565	0.063822	0.018942
352.500000	1.155663	0.065672	0.014724
510.250000	0.939347	0.220851	0.001149
605.559561	0.570771	0.244652	0.019909

CONTROL GAIN = 1.00
WAVE NUMBER = .3000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.61046E+00 .66184E+00 .29287E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL

.19535E+01 .94321E-02 .14764E-02 .12242E+00 .80103E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652479	0.237113	0.000000
157.000000	1.080882	0.283245	0.015526
1335.500000	1.203603	0.191114	0.020294
314.000000	1.208486	0.063877	0.018947
352.500000	1.155644	0.065697	0.014744
510.250000	0.939501	0.220812	0.001696
605.959561	0.571319	0.244610	0.015963

CONTROL GAIN = 1.00
WAVE NUMBER = .4000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.61036E+00 .66186E+00 .29282E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL

.19531E+01 .12577E-01 .19705E-02 .12255E+00 .80110E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652464	0.237108	0.000000
157.000000	1.080831	0.283236	0.015524
1335.500000	1.203547	0.191126	0.020295
314.000000	1.208454	0.063958	0.018955
352.500000	1.155696	0.065737	0.014774
510.250000	0.939781	0.220771	0.002247
605.959561	0.572125	0.244566	0.020038

CONTRCL GAIN = 1.00
 WAVE NUMBER = .50000E-04
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY .61026E+00
 GL .66185E+00
 .29277E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19526E+01 .15723E-01 .24664E-02 .12271E+00 .80118E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATICN
 78.500000
 157.000000
 235.500000
 314.000000
 392.500000
 510.250000
 605.959561
 CS 0.652472
 CEN 0.237112
 0.283238
 0.191149
 0.064066
 0.065790
 0.220727
 0.244521
 CTM 0.000000
 0.015523
 0.020296
 0.018966
 0.014814
 0.002800
 0.020135

CONTRCL GAIN = 1.00
 WAVE NUMBER = .60000E-04
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY .61015E+00
 GL .66194E+00
 .29272E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19521E+01 .18870E-01 .29645E-02 .12292E+00 .80129E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATICN
 78.500000
 157.000000
 235.500000
 314.000000
 392.500000
 510.250000
 605.959561
 CS 0.652505
 CEN 0.237125
 0.283250
 0.191184
 0.064195
 0.065856
 0.220682
 0.244474
 CTM 0.000000
 0.015523
 0.020299
 0.018981
 0.014862
 0.003353
 0.020253

CONTROL GAIN = 1.00
WAVE NUMBER = .70000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY
CG
GL
.61005E+00 .66201E+00 .29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.19516E+01 .22019E-01 .34653E-02 .12316E+00 .80143E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652563	0.237148	0.000000
157.000000	1.080874	0.283273	0.015523
235.500000	1.203606	0.191232	0.020303
314.000000	1.208636	0.064358	0.018999
392.500000	1.156256	0.065936	0.014919
510.250000	0.941358	0.220634	0.003906
605.559561	0.576067	0.244425	0.020392

CONTROL GAIN = 1.00
WAVE NUMBER = .80000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY
CG
GL
.60954E+00 .66208E+00 .29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.19503E+01 .25169E-01 .39692E-02 .12344E+00 .80158E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.652642	0.237178	0.000000
157.000000	1.080952	0.283304	0.015523
235.500000	1.203695	0.191289	0.020308
314.000000	1.208783	0.064541	0.019020
392.500000	1.156572	0.066030	0.014986
510.250000	0.942124	0.220583	0.004458
605.559561	0.577875	0.244374	0.020550

CCNTRCL GAIN = 1.00
 WAVE NUMBER = .90000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
 GN
 .60983E+00 .66218E+00 .29256E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19502E+01 .28322E-01 .44766E-02 .12376E+00 .80176E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 78.500000 0.652746 0.237218
 157.000000 1.081063 0.283347
 235.500000 1.203826 0.151360
 314.000000 1.208977 0.064745
 352.500000 1.156957 0.066135
 510.250000 0.943009 0.220530
 605.559561 0.579925 0.244321

CTM
 0.000000
 0.015523
 0.020314
 0.019044
 0.015061
 0.005010
 0.020728

CCNTRCL GAIN = 1.00
 WAVE NUMBER = .10000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
 GN
 .60972E+00 .66225E+00 .29251E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19455E+01 .31477E-01 .49879E-02 .12412E+00 .80196E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 78.500000 0.652873 0.237266
 157.000000 1.081205 0.283398
 235.500000 1.203990 0.191441
 314.000000 1.209214 0.064982
 352.500000 1.157404 0.066254
 510.250000 0.944012 0.220475
 605.559561 0.582209 0.244267

CTM
 0.000000
 0.015524
 0.020322
 0.019072
 0.015144
 0.005561
 0.020925

CONTROL GAIN = 1.00
WAVE NUMBER = .20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60855E+00	.66422E+00	.29195E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19385E+01	.63203E-01	.10407E-01	.12961E+00	.80514E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

CS	CBM	CTM
0.655331	0.238192	0.000000
1.084228	0.284409	0.015546
1.207438	0.192826	0.020448
1.213758	0.068485	0.019505
1.165116	0.068099	0.016393
0.959976	0.219805	0.011000
0.616645	0.243634	0.023769

CONTROL GAIN = 1.00
WAVE NUMBER = .30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60734E+00	.66763E+00	.29137E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.19219E+01	.95409E-01	.16626E-01	.13822E+00	.81028E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

CS	CBM	CTM
0.655582	0.239786	0.000000
1.089580	0.266146	0.015588
1.221343	0.195057	0.020651
1.221411	0.073607	0.020178
1.177546	0.070917	0.018206
0.984723	0.218920	0.016262
0.666981	0.242840	0.027707

CONTRCL GAIN = 1.00
 WAVE NUMBER = .40000E-03
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GN GL
 .60611E+00 .67245E+00 .29078E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19002E+01 .12828E+00 .23921E-01 .14936E+00 .81705E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM
 78.500000 6.664992 0.241812
 157.000000 1.096274 0.288312
 235.500000 1.220762 0.157788
 314.000000 1.230692 0.079556
 352.500000 1.192676 0.074354
 510.250000 1.014871 0.217840
 605.559561 0.725697 0.241906

CONTRCL GAIN = 1.00
 WAVE NUMBER = .50000E-03
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GA GL
 .60451E+00 .67875E+00 .29020E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .18744E+01 .16192E+00 .32492E-01 .16253E+00 .82506E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM
 78.500000 6.670868 0.244010
 157.000000 1.103226 0.250583
 235.500000 1.228059 0.200653
 314.000000 1.239993 0.085651
 352.500000 1.208345 0.078059
 510.250000 1.046979 0.216585
 605.559561 0.786528 0.240857

CCNTRCL GAIN = 1.00
 WAVE NUMBER = .60000E-03

THE FCRCING FUNCTION MAGNITUDES ARE:
 GN
 .60375E+00 .68635E+00 .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 YAW RATE ROLL
 Sideslip .18452E+01 .19637E+00 .42495E-01 .17739E+00 .83386E+00 YAW

THE FERCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 STATIC
 76.500000 0.676571 0.246143
 157.000000 1.109435 0.292660
 235.500000 1.234082 0.203316
 314.000000 1.222612 0.091398
 352.500000 1.078109 0.081735
 510.250000 1.078109 0.215178
 605.559561 0.845046 0.239721

CIM
 0.000001
 0.015676
 0.021365
 0.022853
 0.024827
 0.030519
 0.041318

CCNTRCL GAIN = 1.00
 WAVE NUMBER = .70000E-03

THE FCRCING FUNCTION MAGNITUDES ARE:
 GN
 .60266E+00 .69521E+00 .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 YAW RATE ROLL
 Sideslip .18135E+01 .23162E+00 .54096E-01 .15378E+00 .84303E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 STATIC
 78.500000 C.681585 0.248018
 157.000000 1.114085 0.294300
 235.500000 1.237824 0.205511
 314.000000 1.253041 0.096473
 352.500000 1.233947 0.085158
 510.250000 1.106068 0.213641
 605.559561 0.898493 0.238530

CIM
 0.000002
 0.015645
 0.021536
 0.023767
 0.027024
 0.034715
 0.045700

CCNTRCL GAIN = 1.00
WAVE NUMBER = .80000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL
.60166E+00 .70527E+00 .28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.17759E+01 .26757E+00 .67443E-01 .21164E+00 .85215E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
CS CTM
78.500000 0.685551 0.249501 0.000003
157.000000 1.116611 0.255337 0.015570
235.500000 1.238585 0.207054 0.021647
314.000000 1.254781 0.100690 0.024645
392.500000 1.241320 0.088178 0.029145
510.250000 1.129460 0.211994 0.038656
605.959561 0.945418 0.237305 0.049866

CCNTRCL GAIN = 1.00
WAVE NUMBER = .50000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL
.60075E+00 .71644E+00 .28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.17451E+01 .30410E+00 .82722E-01 .23099E+00 .86086E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
CS CTM
78.500000 0.688266 0.250518 0.000004
157.000000 1.116686 0.255673 0.015445
235.500000 1.235962 0.207838 0.021697
314.000000 1.252598 0.103967 0.025490
392.500000 1.244175 0.050704 0.031196
510.250000 1.147586 0.210251 0.042378
605.959561 0.985304 0.236081 0.053804

CONTROL GAIN = 1.00
WAVE NUMBER = .1000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

THE ACTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:	
SIDESLIP	ROLL RATE
.17056E+01	.10013E+00
.34102E+00	.25185E+00

YAH
-86884E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

AND MOMENT	COEFFICIENT	MAGNITUDES	ARE:	CRM	CTM
18-15000000	0.614923	658	0.251043	0.00005	0.00005
18-5000000	1.124813	8	0.255275	0.015273	0.015273
18-5000000	1.124633	138	0.207823	0.026315	0.026315
18-5000000	1.124235	17	0.106269	0.033197	0.033197
18-5000000	1.124287	1	0.208427	0.045923	0.045923
18-5000000	1.124182	67	0.234364	0.051526	0.051526

CTM
0.000005
0.015273
0.021693
0.026315
0.033197
0.045923
0.057526

CENTRL GAIN = 1.00
WAVE NUMBER = .2000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

THE MOTION RESPONSE		TRANSFER FUNCTION MAGNITUDES ARE:	
SIDESLIP	YAW RATE	ROLL RATE	ROLL
.1354E+01	.68749E+00	.43080E+00	.54589E+00

00-352528-
NY

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE: C_{PM}

AND MOMENT STATION	COEFFICIENT	MAGNITUDES ARE:	CEM	CTH
7E-500000	0.656477	0.238788	0.000041	0.000041
157-500000	0.988779	0.262610	0.012100	0.012100
1235-500000	1.026686	0.174078	0.022943	0.022943
2314-500000	1.027188	0.050419	0.038534	0.038534
352-500000	1.062360	0.050308	0.056385	0.056385
51C-500000	1.123013	0.188221	0.080001	0.080001
60E-559561	1.149684	0.223255	0.089738	0.089738

0-000041
0-012100
0-022943
0-038534
0-056385
0-080001
0-089738

THE FORCE AND MOMENT STATISTICS	COEFFICIENT	MAGNITUDES ARE:	
	CS	CM	CTM
18.500000	0.609183	0.221343	0.000164
157.000000	0.807094	0.212946	0.010436
1235.000000	0.750821	0.113441	0.033560
3314.000000	0.815568	0.056161	0.061885
252.500000	1.018828	0.100347	0.090681
3510.250000	1.332452	0.176517	0.123681
60.2559561	1.502719	0.202710	0.129761

THE FORCE AND MOMENT STATICA	COEFFICIENT	MAGNITUDES ARE:	CTH
78-500000	0.539106	0.154994	0.00445
157-500000	0.602973	0.150004	0.012275
1235-500000	0.586367	0.058770	0.048647
314-500000	0.988963	0.120194	0.090035
352-500000	1.528344	0.181610	0.131892
510-250000	2.178324	0.155134	0.180129
603-559561	2.463434	0.155134	0.189209

CCNTRCL GAIN = 1.00
WAVE NUMBER = .50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.67258E+00 .13310E+01 .32267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.22627E+00 .59599E+00 .41715E+01 .21251E+01 .30369E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION
78.500000
157.000000
235.500000
314.000000
352.500000
510.250000
605.959561
CS
0.364403
0.364024
0.822711
1.663159
2.583288
3.687246
4.143902
CPM
0.128290
0.059585
0.174830
0.306992
0.356857
0.240926
0.063612
CTM
0.001004
0.015405
0.063140
0.118708
0.177415
0.252619
0.280690

CCNTRCL GAIN = 1.00
WAVE NUMBER = .60000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.69215E+00 .13729E+01 .33206E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.32372E+00 .66510E+00 .7211CE+01 .30628E+01 .28242E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION
78.500000
157.000000
235.500000
314.000000
352.500000
510.250000
605.959561
CS
0.089675
0.619974
1.635498
2.899204
4.335018
6.161600
6.947445
CPM
0.034778
0.206831
0.479715
0.677553
0.708205
0.347508
0.147206
CTM
0.002084
0.018375
0.075633
0.147766
0.230148
0.353578
0.426636

CENTRCL GAIN = 1.00
WAVE NUMBER = .70000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN
.65712E+00 .13477E+01 .33444E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.10355E+01 .20496E+01 .12865E+02 .46851E+01 .74601E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICN	CS	CBM	CTM
78.500000	1.078175	0.415664	0.004337
157.000000	2.011559	0.705057	0.021714
235.500000	3.432062	1.139404	0.088807
314.000000	5.265799	1.463589	0.183479
392.500000	7.539106	1.471949	0.303272
510.250000	10.656343	0.613297	0.518561
605.959561	12.141193	0.543728	0.694464

CENTRCL GAIN = 1.00
WAVE NUMBER = .80000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN
.68515E+00 .12592E+01 .32872E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.21492E+01 .45915E+01 .22818E+02 .72727E+01 .15898E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICN	CS	CBM	CTM
78.500000	3.398520	1.288068	0.008790
157.000000	5.237886	1.808050	0.029149
235.500000	7.127623	2.503336	0.112733
314.000000	9.602432	3.034832	0.230361
392.500000	12.984966	3.014273	0.391142
510.250000	18.118134	1.230213	0.752460
605.959561	21.009048	1.346717	1.143815

CONTROL GAIN = 1.00
WAVE NUMBER = .50000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.65745E+00 .11188E+01 .31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.18131E+01 .45385E+01 .18925E+02 .53626E+01 .13980E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	3.942038	1.480221	0.008202
157.000000	5.791830	1.954727	0.032453
235.500000	6.972773	2.478195	0.106049
314.000000	8.352362	2.860790	0.182158
392.500000	10.387287	2.824291	0.258819
510.250000	14.054478	1.222084	0.498265
605.559561	16.787857	1.363981	0.883849

CONTROL GAIN = 1.00
WAVE NUMBER = .10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.61780E+00 .94575E+00 .29635E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL YAW
.95681E+00 .30623E+01 .10617E+02 .27078E+01 .78021E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	2.764446	1.029070	0.005113
157.000000	4.115517	1.347707	0.032463
235.500000	5.671564	1.619152	0.085946
314.000000	5.085283	1.777737	0.138997
392.500000	5.630541	1.734595	0.162331
510.250000	7.039822	0.825724	0.216180
605.559561	8.828053	0.868258	0.456969

STATION	CS	CBM	CH
127-500000	0.746151	0.289295	0.001589
128-500000	0.820849	0.106886	0.077070
129-500000	1.718292	0.512115	0.080923
130-500000	1.714957	0.575279	0.052645
131-500000	0.507745	0.57583	0.110879
132-500000	2.346483	0.154464	0.063739
133-500000	0.66339	0.220805	0.046188

CONTROL GAIN = 1.00
WAVE NUMBER = .40000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL
.24458E+00 .63635E+00 .11734E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.42791E-01 .29151E+00 .69200E+00 .44145E-01 .18567E-01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CTM
78.500000 0.577479 0.218872 0.001333
157.000000 1.283806 0.331974 0.075648
235.500000 1.408186 0.440645 0.058007
314.000000 1.231693 0.409548 0.084582
392.500000 1.844090 0.429575 0.074097
510.250000 2.016289 0.109567 0.049761
605.559561 0.334192 0.149185 0.026307

CONTROL GAIN = 1.00
WAVE NUMBER = .50000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL
.36215E+00 .52871E+00 .17374E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.28806E-01 .19294E+00 .45815E+00 .23381E-01 .98313E-02 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CTM
78.500000 0.587817 0.207938 0.001103
157.000000 1.309130 0.424355 0.056520
235.500000 1.109384 0.128790 0.090783
314.000000 1.597287 0.351502 0.063433
392.500000 1.537951 0.346731 0.058937
510.250000 1.180824 0.242600 0.049153
605.559561 0.282871 0.089903 0.007541

CCNTRL GAIN = 1.00
 WAVE NUMBER = .60C00E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .51347E+00 .45648E+00 .24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .24027E-01 .13653E+00 .31816E+00 .13531E-01 .57977E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 STATICA
 78.500000 0.6433871 0.224073 0.000919
 157.000000 1.160705 0.337057 0.048572
 235.500000 1.548003 0.436300 0.079713
 314.000000 1.144318 0.294887 0.071796
 392.500000 1.014178 0.365458 0.068160
 510.250000 0.342652 0.314417 0.034207
 605.959561 0.559238 0.026384 0.035332

CCNTRL GAIN = 1.00
 WAVE NUMBER = .70C00E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .65821E+00 .39145E+00 .31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .21951E-01 .56815E-01 .21346E+00 .77820E-02 .35238E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS
 STATICA
 78.500000 0.672964 0.236792 0.000720
 157.000000 1.042583 0.21872 0.037322
 235.500000 1.341129 0.249397 0.079499
 314.000000 1.739594 0.330595 0.107653
 392.500000 1.996907 0.241195 0.116011
 510.250000 1.335586 0.276931 0.090908
 605.959561 0.910171 0.058437 0.083063

CONTROL GAIN = 1.00
 WAVE NUMBER = .80000E-01
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GN GL
 .70105E+00 .40424E+00 .33632E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .20828E-01 .85142E-01 .17422E+00 .55582E-02 .27115E-02
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.710651 0.255797 0.000671
 157.000000 1.119725 0.286292 0.016938
 235.500000 1.157343 0.230762 0.019276
 314.000000 1.079087 0.271257 0.014323
 352.500000 0.966950 0.333328 0.007527
 510.250000 2.054621 0.174318 0.157054
 605.559561 1.062377 0.109415 0.126236

CONTROL GAIN = 1.00
 WAVE NUMBER = .50000E-01
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GN GL
 .83025E+00 .5347E+00 .39831E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .23639E-01 .99102E-01 .19222E+00 .54519E-02 .28055E-02
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.768290 0.286460 0.000833
 157.000000 1.374752 0.444364 0.028223
 235.500000 1.756910 0.457258 0.073291
 314.000000 1.772249 0.437751 0.107683
 352.500000 1.408672 0.437562 0.115757
 510.250000 2.502272 0.059268 0.097271
 605.559561 1.277543 0.154797 0.094419

CONTROL GAIN = 1.00
WAVE NUMBER = .10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:
CY .1215E+01 .8555E+00 .5850E-01

THE ACTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SLIP YAW RATE ROLL RATE ROLL
.3268E-01 .1436E+00 .2762E+00 .7050E-02 .3659E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS
18.500000 0.807783
157.000000 1.177675
1235.500000 0.619539
314.000000 1.559916
352.500000 1.848248
510.250000 2.838743
605.559561 2.083281

CTM
0.001330
0.054205
0.100758
0.082192
0.054678
0.080567
0.114761

CONTROL GAIN = 2.00
 WAVE NUMBER = .10000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .61066E+00 .66185E+00 .29296E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19540E+01 .15719E-02 .48586E-03 .12230E+00 .40049E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS 0.652624 0.237165
 STATICN 1.081154 0.283312
 78.500000 1.203919 0.191147
 157.000000 1.208793 0.063820
 235.500000 1.155873 0.065667
 314.000000 0.939482 0.220889
 392.500000 0.570731 0.244694
 510.250000
 605.959561

CTM
 0.000000
 0.015531
 0.020300
 0.018947
 0.014725
 0.000940
 0.019590

CONTROL GAIN = 2.00
 WAVE NUMBER = .20000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .61056E+00 .66184E+00 .29291E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19538E+01 .31440E-02 .97271E-03 .12243E+00 .40051E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 CS 0.652671 0.237183
 STATICN 1.081226 0.283337
 78.500000 1.204036 0.191191
 157.000000 1.208967 0.063927
 235.500000 1.156153 0.065702
 314.000000 0.940090 0.220854
 392.500000 0.571761 0.244655
 510.250000
 605.959561

CTM
 0.000000
 0.015533
 0.020308
 0.018966
 0.014771
 0.001821
 0.019961

CONTROL GAIN = 2.00
WAVE NUMBER = .30000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.61046E+00 .66184E+00 .29287E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.19535E+01 .47165E-02 .14616E-02 .12265E+00 .40056E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICN	CS	CBM	CTM
78.500000	0.652818	0.237238	0.000000
157.000000	1.081465	0.283411	0.015537
235.500000	1.204360	0.191285	0.020324
314.000000	1.209392	0.064112	0.019001
352.500000	1.156748	0.065766	0.014851
510.250000	0.940967	0.020819	0.002713
605.959561	0.573540	0.244617	0.020080

CONTROL GAIN = 2.00
WAVE NUMBER = .40000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.61036E+00 .66186E+00 .29282E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.19531E+01 .62898E-02 .19536E-02 .12295E+00 .40063E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATICN	CS	CBM	CTM
78.500000	0.653063	0.237330	0.000000
157.000000	1.081861	0.283531	0.015545
235.500000	1.204888	0.191427	0.020347
314.000000	1.210060	0.064374	0.019052
352.500000	1.157653	0.065859	0.014963
510.250000	0.942379	0.022078	0.003608
605.959561	0.576056	0.244575	0.020246

CTM
0.000000
0.015555
0.020378
0.019117
0.015107
0.004504
0.020458

CTM
0-000000
0-015569
0-020416
0-019197
0-015281
0-005399
0-020713

CONTROL GAIN = 2.00
WAVE NUMBER = .70000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.61005E+00 .66201E+00 .29267E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19513E+01 .11016E-01 .34582E-02 .12440E+00 .40095E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM

78.500000 0.654384 0.237822
157.000000 1.084010 0.284167
235.500000 1.207680 0.192147
314.000000 1.213512 0.065610
352.500000 1.162201 0.066310
510.250000 0.949239 0.220669
605.559561 0.587895 0.244461

CIM
0.000000
0.015585
0.020462
0.019292
0.015484
0.006294
0.021011

CONTROL GAIN = 2.00
WAVE NUMBER = .80000E-04

THE FORCING FUNCTION MAGNITUDES ARE:
GY GN GL

.60954E+00 .66208E+00 .29261E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19508E+01 .12594E-01 .39726E-02 .12505E+00 .40110E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM

78.500000 0.655014 0.238057
157.000000 1.085037 0.284469
235.500000 1.209004 0.192482
314.000000 1.215137 0.066165
352.500000 1.164316 0.066516
510.250000 0.952381 0.220630
605.559561 0.593210 0.244421

CIM
0.000000
0.015604
0.020515
0.019401
0.015715
0.007187
0.021349

CONTROL GAIN = 2.00
WAVE NUMBER = .9000E-04

THE FORCING FUNCTION MAGNITUDES ARE:

60983E+00
 66218E+00
 29256E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:	
SIDESLIP	YAW RATE
.15501E+01	.14175E-01
	ROLL RATE
	.44950E-02
	ROLL
	.12579E+00

	YAH	KULL	RATE	YAH
.1550E+01	.1417E-01	.44950E-02	.12579E+00	.40127E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	COLLECTOR	MAGNITUDE	ARE.	CBM	CTM
78	5000000	0.655739	0.238326	0.000000	0.000000
157	5000000	1.066219	0.288177	0.015625	0.015625
1235	5000000	1.215226	0.152865	0.020575	0.020575
2314	5000000	1.216995	0.066789	0.019524	0.019524
3532	5000000	1.196727	0.067509	0.015972	0.015972
510	250000	1.955940	0.220589	0.008080	0.008080
605	359561	0.599175	0.244380	0.021725	0.021725

CTRL GAIN = 2.00
 WAVE NUMBER = 10000E-03

THE FORCING FUNCTION MAGNITUDES ARE:

-6097E+00

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:		
SIDESLIP	YAW RATE	ROLL
.19493E+01	.15757E-01	.50263E-02
		.12660E+00

YAH	ROLL	ROLL RATE
.40146E+00	.12660E+00	.50263E-02
		.15757E-01
		.19493E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATION	COEFFICIENT	MAGNITUDES	CPM	CTN
18-500000	0.656558	0.238631	0.00000	0.00000
157-000000	1.087554	0.285208	0.015650	0.015650
155-500000	1.212238	0.193293	0.020642	0.020642
125-500000	1.219084	0.067479	0.016660	0.016660
392-500000	1.169428	0.067010	0.016255	0.016255
310-500000	0.959908	0.220547	0.008971	0.008971
165-559561	0.605764	0.244339	0.022138	0.022138

CONTROL GAIN = 2.00
WAVE NUMBER = .20000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY .60855E+00 .66422E+00 .29195E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19379E+01 .31753E-01 .10997E-01 .13869E+00 .40450E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CIM
78.500000 0.6695553 0.243458 0.000000
157.000000 1.108755 0.291394 0.016033
235.500000 1.239287 0.199927 0.021669
314.000000 1.251801 0.077395 0.021679
392.500000 1.211231 0.070974 0.020151
510.250000 1.019936 0.220081 0.017796
605.959561 0.700148 0.243895 0.027781

CONTROL GAIN = 2.00
WAVE NUMBER = .30000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY .60734E+00 .66763E+00 .29137E-01
GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL
.19203E+01 .48214E-01 .18544E-01 .15613E+00 .40946E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATIC CS CBM CIM
78.500000 0.690015 0.251050 0.000000
157.000000 1.142143 0.301083 0.016631
235.500000 1.281615 0.210092 0.023219
314.000000 1.302605 0.090927 0.024569
392.500000 1.275225 0.076915 0.025169
510.250000 1.108882 0.219520 0.026386
605.959561 0.828241 0.243384 0.035007

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .40CCOE-03

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .60611E+00 .67249E+00 .29078E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL
 .18972E+01 .65337E-01 .27934E-01 .17660E+00 .41616E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CIM
 78.500000 0.715768 0.260595 0.000001
 157.000000 1.184151 0.313220 0.017375
 235.500000 1.334583 0.222578 0.025099
 314.000000 1.365805 0.105947 0.027921
 352.500000 1.353838 0.084098 0.030568
 510.250000 1.214911 0.218871 0.034655
 605.959561 0.970067 0.242774 0.042784

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .50CCOE-03

THE FORCING FUNCTION MAGNITUDES ARE:
 GN .60491E+00 .67875E+00 .29020E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL
 .18655E+01 .83280E-01 .39194E-01 .19840E+00 .42436E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CIM
 78.500000 0.744517 0.271239 0.000001
 157.000000 1.230999 0.326701 0.018198
 235.500000 1.393380 0.236209 0.027136
 314.000000 1.435636 0.121115 0.031440
 352.500000 1.439771 0.091878 0.035979
 510.250000 1.327995 0.218140 0.042540
 605.959561 1.113428 0.242051 0.050612

CCNTRCL GAIN = 2.00
WAVE NUMBER = .60000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY .60375E+00 .68635E+00 .28965E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL YAW
.18375E+01 .10216E+00 .52227E-01 .22044E+00 .43378E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATICN CS CBM CTM
78.500000 0.774198 0.282217 0.000002
157.000000 1.279286 0.340544 0.019040
235.500000 1.453721 0.250004 0.029198
314.000000 1.507099 0.135642 0.034937
392.500000 1.527005 0.059770 0.041218
510.250000 1.440807 0.217337 0.049998
605.959561 1.251355 0.241201 0.058246

CCNTRCL GAIN = 2.00
WAVE NUMBER = .70000E-03

THE FORCING FUNCTION MAGNITUDES ARE:
GY .60266E+00 .69521E+00 .28912E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
SIDESLIP YAW RATE ROLL RATE ROLL YAW
.18034E+01 .12203E+00 .66899E-01 .24212E+00 .44416E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
STATICN CS CBM CTM
78.500000 0.803134 0.292908 0.000002
157.000000 1.326241 0.353960 0.019853
235.500000 1.512183 0.263224 0.031191
314.000000 1.576289 0.149072 0.038298
392.500000 1.611066 0.107432 0.046192
510.250000 1.548426 0.216474 0.057008
605.959561 1.379966 0.240219 0.065557

CONTRCL GAIN = 2.00
WAVE NUMBER = .80C00E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60166E+00 .70527E+00 .28864E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.17666E+01 .14293E+00 .83083E-01 .26317E+00 .45519E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CPM	CTM
78.500000	0.830094	0.302857	0.000003
157.000000	1.369819	0.366374	0.020603
235.500000	1.566272	0.275361	0.033057
314.000000	1.640429	0.161157	0.041463
392.500000	1.688923	0.114641	0.050858
510.250000	1.647837	0.215560	0.063568
605.959561	1.497267	0.239109	0.072482

CONTRCL GAIN = 2.00
WAVE NUMBER = .50C00E-03

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.60075E+00 .71644E+00 .28821E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.17283E+01 .16483E+00 .10068E+00 .28354E+00 .46663E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CPM	CTM
78.500000	0.854249	0.311760	0.000004
157.000000	1.408638	0.377404	0.021270
235.500000	1.614327	0.286098	0.034762
314.000000	1.697717	0.171781	0.044402
392.500000	1.758718	0.121257	0.055205
510.250000	1.737387	0.214606	0.069692
605.959561	1.602442	0.237878	0.078997

CONTROL GAIN = 2.00
 WAVE NUMBER = .10000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.59957E+00	.72864E+00	.28783E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.16891E+01	.18769E+00	.11966E+00	.30332E+00	.47820E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.875116	0.319439	0.000006
157.000000	1.441879	0.386826	0.021841
235.500000	1.655387	0.255262	0.036292
314.000000	1.747139	0.180914	0.047108
392.500000	1.819495	0.127205	0.059241
510.250000	1.816387	0.213616	0.075405
605.959561	1.695441	0.236541	0.085102

CONTROL GAIN = 2.00
 WAVE NUMBER = .20000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.60042E+00	.8883E+00	.28805E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.13045E+01	.44266E+00	.40965E+00	.51982E+00	.56390E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.914618	0.233503	0.000039
157.000000	1.481856	0.357810	0.022794
235.500000	1.702482	0.308223	0.044185
314.000000	1.842920	0.205594	0.065503
392.500000	1.995697	0.151700	0.088706
510.250000	2.139095	0.202347	0.117918
605.959561	2.129992	0.219566	0.129290

CONTROL GAIN = 2.00
 WAVE NUMBER = .30000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .61712E+00 .10700E+01 .29606E-01
 GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .95552E+00 .64362E+00 .10244E+01 .86810E+00 .54660E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS
 78.500000 0.804209 0.292035
 157.000000 1.239575 0.328300
 235.500000 1.398894 0.242813
 314.000000 1.589475 0.169390
 392.500000 1.851178 0.147635
 510.250000 2.170668 0.192481
 605.559561 2.274214 0.194651 CBM

CTM
 0.000148
 0.020030
 0.048821
 0.081069
 0.114373
 0.153343
 0.162380

CONTROL GAIN = 2.00
 WAVE NUMBER = .40000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .6444E+00 .1225E+01 .30915E-01
 GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .60835E+00 .67731E+00 .21445E+01 .13648E+01 .43141E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS
 78.500000 0.663383 0.239121
 157.000000 0.925644 0.234900
 235.500000 1.050351 0.160683
 314.000000 1.417698 0.159436
 392.500000 1.922850 0.188756
 510.250000 2.538595 0.198717
 605.559561 2.777395 0.148928 CBM

CTM
 0.000413
 0.017891
 0.056018
 0.099714
 0.144142
 0.195497
 0.205683

CONTRCL GAIN = 2.00
 WAVE NUMBER = .50000E-02
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GL
 .67258E+00 .13310E+01 .32267E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .23363E+00 .51131E+00 .40051E+01 .20403E+01 YAW .26054E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CIM
 78.500000 0.456905 0.161028 0.000964
 157.000000 0.559799 0.116394 0.016971
 235.500000 0.902206 0.168855 0.063951
 314.000000 1.677668 0.289674 0.119623
 352.500000 2.567989 0.338292 0.178215
 510.250000 3.639133 0.237832 0.252218
 605.559561 4.070953 0.061514 0.277598

CONTRCL GAIN = 2.00
 WAVE NUMBER = .60000E-02
 THE FORCING FUNCTION MAGNITUDES ARE:
 GY GL
 .65215E+00 .13725E+01 .33206E-01
 THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .25511E+00 .60545E+00 .71795E+01 .30493E+01 YAW .25709E+00
 THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CIM
 78.500000 0.037478 0.003586 0.002074
 157.000000 0.454871 0.158499 0.016368
 235.500000 1.427497 0.430645 0.070389
 314.000000 2.658466 0.630644 0.139807
 352.500000 4.057806 0.670002 0.215032
 510.250000 5.843296 0.338461 0.337201
 605.559561 6.617575 0.126528 0.405529

CONTROL GAIN = 2.00
 WAVE NUMBER = .70000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GN GL
 .69712E+00 .13477E+01 .33444E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .94956E+00 .15692E+01 .13300E+02 .48435E+01 .71673E+00 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATION CS CBM
 78.500000 0.990999 0.386760
 157.000000 1.817941 0.660521
 235.500000 3.161425 1.082881
 314.000000 4.910086 1.400835
 392.500000 7.105391 1.420348
 510.250000 10.165751 0.604229
 605.559561 11.662699 0.517211
 0.004483
 0.015726
 0.076846
 0.164414
 0.276938
 0.483844
 0.655407

CONTROL GAIN = 2.00
 WAVE NUMBER = .80000E-02

THE FORCING FUNCTION MAGNITUDES ARE:
 GN GL
 .68515E+00 .12592E+01 .32872E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL RATE ROLL
 .19088E+01 .46280E+01 .22496E+02 .71696E+01 .14739E+01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATION CS CBM
 78.500000 3.177864 1.206850
 157.000000 4.845032 1.685754
 235.500000 6.495617 2.303188
 314.000000 8.607545 2.768852
 392.500000 11.545469 2.755655
 510.250000 16.170893 1.148131
 605.559561 18.912399 1.234204
 0.008666
 0.020133
 0.095661
 0.190768
 0.321689
 0.638637
 1.000337

CONTRCL GAIN = 2.00
WAVE NUMBER = .90000E-02

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.65745E+00 .11188E+01 .31543E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.14224E+01 .40702E+01 .16442E+02 .46588E+01 YAW
.11522E+01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	3.307787	1.241728	0.007126
157.000000	4.846958	1.633014	0.026030
235.500000	5.746975	2.031952	0.093563
314.000000	6.709463	2.308107	0.154535
392.500000	8.129591	2.273863	0.201162
510.250000	10.875336	1.008864	0.358588
605.559561	13.144466	1.109520	0.667025

CONTRCL GAIN = 2.00
WAVE NUMBER = .10000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.61780E+00 .54575E+00 .29635E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.7728 +00 .26211E+01 .95183E+01 .24275E+01 YAW
.66779E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	2.412622	0.857061	0.004584
157.000000	3.597662	1.171357	0.028642
235.500000	4.038742	1.381890	0.079553
314.000000	4.298811	1.487326	0.130244
392.500000	4.578722	1.443144	0.150225
510.250000	5.499517	0.709948	0.159573
605.559561	7.028250	0.730363	0.349401

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .20000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.29319E+00	.88392E+00	.14066E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.14167E+00	.82556E+00	.21006E+01	.26798E+00	.10517E+00

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	1.114007	0.420709	0.002023
157.000000	1.017117	0.407246	0.045883
235.500000	0.476656	0.310316	0.114601
314.000000	1.533462	0.636330	0.107860
352.500000	2.638281	0.636358	0.026232
510.250000	1.981400	0.373381	0.092132
605.959561	1.397262	0.331174	0.045663

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .30000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GN	GL
.10561E+00	.74178E+00	.52583E-02

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE	ROLL	YAW
.67613E-01	.45150E+00	.10901E+01	.92722E-01	.38345E-01

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.743482	0.287993	0.001575
157.000000	0.830583	0.111672	0.077125
235.500000	1.703632	0.503706	0.080916
314.000000	1.698411	0.564004	0.052737
352.500000	0.532746	0.575804	0.112101
510.250000	2.301491	0.154395	0.062072
605.959561	0.606895	0.215734	0.042087

CONTROL GAIN = 2.00
WAVE NUMBER = .40000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.24458E+00 .63635E+00 .11734E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.42022E-01 .28907E+00 .6853E+00 .43923E-01 .18412E-01 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.578510	0.219122	0.001326
157.000000	1.281893	0.330991	0.075632
235.500000	1.405575	0.437231	0.058027
314.000000	1.229513	0.404051	0.084807
392.500000	1.834221	0.423927	0.074144
510.250000	1.992366	0.111295	0.048653
605.959561	0.310158	0.146867	0.024347

CONTROL GAIN = 2.00
WAVE NUMBER = .50000E-01

THE FORCING FUNCTION MAGNITUDES ARE:

GY GN GL
.36215E+00 .52871E+00 .17374E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP YAW RATE ROLL RATE ROLL
.28506E-01 .15190E+00 .45665E+00 .23307E-01 .97785E-02 YAW

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CBM	CTM
78.500000	0.588809	0.208348	0.001100
157.000000	1.306915	0.423235	0.056505
235.500000	1.111964	0.127333	0.090850
314.000000	1.595331	0.388788	0.063465
392.500000	1.530070	0.343851	0.058896
510.250000	1.170894	0.242278	0.049195
605.959561	0.282030	0.088861	0.006664

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .60000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 CY GN .51347E+00 .45648E+00 .24634E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL
 .23889E-01 .13602E+00 .31745E+00 .13501E-01 .57760E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.644243 0.224260 0.000917
 157.000000 1.160934 0.336918 0.048574
 235.500000 1.545453 0.435014 0.075563
 314.000000 1.143443 0.293173 0.071804
 392.500000 1.018844 0.363716 0.068332
 510.250000 0.349154 0.313741 0.034506
 605.959561 0.560294 0.025959 0.034816

CCNTRCL GAIN = 2.00
 WAVE NUMBER = .70000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 CY GN .65821E+00 .35145E+00 .31577E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 SIDESLIP YAW RATE ROLL
 .21878E-01 .96545E-01 .21305E+00 .77687E-02 .35141E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC CS CBM CTM
 78.500000 0.673021 0.236835 0.000718
 157.000000 1.043350 0.222257 0.037326
 235.500000 1.341840 0.249165 0.079503
 314.000000 1.738777 0.329683 0.107624
 392.500000 1.994212 0.240145 0.115925
 510.250000 1.336372 0.276469 0.090925
 605.959561 0.910056 0.058689 0.082875

CONTROL GAIN = 2.00
 WAVE NUMBER = .80000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .70105E+00 .40424E+00 .33632E-01
 GN .20772E-01 .84963E-01 .17397E+00 .55504E-02 .27058E-02
 GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 YAW RATE .20772E-01 .84963E-01 .17397E+00 .55504E-02 .27058E-02
 ROLL .20772E-01 .84963E-01 .17397E+00 .55504E-02 .27058E-02
 CTM

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC
 CS 0.710547 0.255760
 76.500000 0.286218
 157.000000 0.230327
 235.500000 0.270456
 314.000000 0.222551
 392.500000 0.174217
 510.250000 0.109473
 605.959561 1.061211

CONTROL GAIN = 2.00
 WAVE NUMBER = .90000E-01

THE FORCING FUNCTION MAGNITUDES ARE:
 GY .83025E+00 .53478E+00 .39831E-01
 GN .23581E-01 .58537E-01 .19206E+00 .54455E-02 .28008E-02
 GL

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
 YAW RATE .23581E-01 .58537E-01 .19206E+00 .54455E-02 .28008E-02
 ROLL .23581E-01 .58537E-01 .19206E+00 .54455E-02 .28008E-02
 CTM

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
 STATIC
 CS 0.768090 0.286371
 76.500000 0.444054
 157.000000 0.456672
 235.500000 0.436963
 314.000000 0.436707
 392.500000 0.059652
 510.250000 0.154661
 605.959561 1.274786

CCNTROL GAIN = 2.00
WAVE NUMBER = .10000E+00

THE FORCING FUNCTION MAGNITUDES ARE:

GY	GL
.1215E+01	.85951E+00
	.58506E-01

THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:

SIDESLIP	YAW RATE	ROLL RATE
.32615E-01	.14344E+00	.27593E+00
		.70436E-02

YAW
.36546E-02

THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:

STATIC	CS	CPM	CTM
78.500000	0.807538	0.313782	0.001329
157.000000	1.177540	0.351286	0.054208
235.000000	0.621107	0.262626	0.100790
314.000000	1.558413	0.634651	0.082223
352.500000	1.844856	0.618087	0.054568
510.250000	2.834230	0.231392	0.080382
605.959561	2.078382	0.307479	0.114399

COMPUTER PROGRAM--NUMERICAL EXAMPLE

```

REAL K,KC,KK,KX,IXX,IZZ,IXZ,LCC,LS,K1,K2
COMPLEX YG,AG,LG,DYG,DIG,DIG,YGS,NES,YGT,NGT,DYGT,E(23),GY,GN,GL,
+ C(5,5),D(5,5),R(5,5),W(5,5),W(5,5),DAE(7),DAIE(7),
+ DSHR(7),CBENC(7),DTHST(7),SHEAR(7),BENC(7),WIST(7),SEARS
+ DIMENSION RMAG(5),RPHASE(5),X(23),Y(23),A(23),DIXZ(8),DFCG(8),
+ XENG(8),ZENG(8),CA(7),DAX(7),DAX2(7),DIZZ(8),
+ CSSMAG(7),CBMAG(7),CfMAG(7),DIZZ(8),
DATA KK/.53225/,ETA/.2600/,SS/16866./,LS/665.84/,
+ STK/209.44/,CLAS/1.8310/,CYBT/.14/2/5/37914./,CBAR/785./,CS/100./,
+ PI/3.141593/,G/32.1747/K1/.0440/K2/.9140/
KC=2.0 Q02308
RHC=.002308
U0=123.
C=.5*RC*U0**2
BUOY=548642.
HCG=-37.66
LCG=364.24
ALPHA=.0037
COSA=CCS(ALFFA)
TANA=TAN(ALFFA)
SECA=1./COSA
XB=363.01
ZB=(-HCG+(LCG-XB)*TANA)*COSA

      READ IN AIRSHIP GEOMETRY
      READ (5,800) (X(I),I=1,23)
      READ (5,800) (Y(I),I=1,23)
      READ (5,800) (XENG(I),I=1,8)
      READ (5,800) (ZENG(I),I=1,8)
      FORMAT (F15.5)
      DO 1 I=1,8
      READ (5,810) DM(I),DIXX(I),DIZZ(I),DIXZ(I),DFCG(I)
      FORMAT (5(F10.6))
      CONTINUE
      READ (5,800) CMEGA
      IF (CMEGA.LT.0.1) GO TO 50

      CALCULATE FORCING FUNCTIONS
      DO 5 I=1,23
      A(I)=PI*Y(I)**2
      E(I)=CEXP(C*PLX(0.,-CMEGA*X(I)*COSA))
      CONTINUE
      K=CMEGA*CBAR/2.
      YG=CEXP(C*PLX(0.,-CMEGA*X(17)*COSA))*A(17)
      NG=YG*X(17)

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THE00490
THE00500
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10  DYG={0.,0.,0.}
    DNG={0.,0.,0.}
    DO 10 I=1,3
      DYG=DYG+(E(I)+1)*A(I+1)*E(I)/2.*(X(I+1)-X(I))
      DNG=DNG+(E(I)+1)*OMEGA)*CCCSA*X(I+1)*E(I+1)*A(I+1)
      $+(E(I)-CMPLX(0.,CMEGA)*CCSA*X(I)*E(I))/2.*(X(I+1)-X(I))
    CONTINUE
    YG=2.*(YG+DYG*CMPLX(0.,OMEGA)*CCSA)*KK
    NG=2.*(NG+DNG)
    CALL SFARFN(KS,SEARS)
    YGS=YGS+CLAS*SEARS*ETA*CEXP(CMPLX(0.,-OMEGA*LS*CCSA))
    NGT={0.,0.,0.}
    YGT={0.,0.,0.}
    DO 20 I=1,8
      DYG=STK*CYBT*CEXP(CMPLX(0.,-OMEGA*XENG(I))*CCSA))
      YGT=YGT+DYG
      NGT=NGT+DYG*XENG(I)
    CONTINUE
    YG=YG+YG*YGT
    NG=NG+NG*YGT-LCG*YG
    LG=HCG*YG
    GN=NG/S/CBAR
    GL=LG/S/CBAR
    BEGIN DYNAMICS CALCULATIONS
    MASS=17038.6
    IXX=39585100.
    IZZ=471759000.
    Ixz=102129000.
    DO 25 I=1,5
      DO 22 J=1,5
        C(I,J)={0.,0.}
      CONTINUE
      C(1,1)={-7224,0.}
      C(1,3)={-0648,0.}
      C(1,2)={CMPLX(-.3418-4.*MASS/(RHO*S*CBAR),0.)}
      C(1,5)={CMPLX(-KC,0.)}
      C(2,1)={-1710,0.}
      C(2,3)={-0150,0.}
      C(2,2)={-232,0.}
      C(2,4)={CMPLX(-XB/CBAR*EUOV/(Q*S),0.)*CCSA
      C(2,5)={CMPLX(1.350624*KC),0.}
      C(3,1)={-0322,0.}

```



```

905 WRITE(6,505) THE MOTION RESPONSE TRANSFER FUNCTION MAGNITUDES ARE:
      FORMAT(//,SIDESLIP,4X,YAW RATE,4X,ROLL RATE,5X,ROLL,9X,YAW,1)
915 WRITE(6,515){RPA(1),I=1,5)
      FORMAT(5X,5(2X,E10.5))

C      CALCULATE THE LOADING TRANSFER FUNCTIONS

NDIV(1)=1
NDIV(2)=4
NDIV(3)=6
NDIV(4)=8
NDIV(5)=12
NDIV(6)=13
NDIV(7)=15
NDIV(8)=18
NDIV(9)=23
DO 80 I=1,7
  DA(I)=0
  DAE(I)=10.,0.)
  DATE(I)=(0.,0.)
  DAX2(I)=0.
  J1=NDIV(I)
  J2=NDIV(I+1)-1
  CO 70 J=J1,J2
  DKE=(X(J+1)+A(J))*E(J))/2.*DX
  DAE(I)=DAE(I)+A(J+1)+A(J))*X(J))/2.*DX
  DAX(I)=DAX(I)+A(J+1)+A(J))*X(J))/2.*DX
  DATE(I)=DATE(I)+(X(J+1)+X(J))*2*A(J))/2.*DX
  DAX2(I)=DAX2(I)+X(J+1)+X(J))*2*A(J))/2.*DX
CONTINUE

70
C      SHEAR CALCULATIONS
C
GSHR(I)=(A(NDIV(I+1))*E(NDIV(I))-A(NDIV(I)))+(0.,1.)*
$OMEGA*CGSA*CAE(I))/2.*C*KK
GSHR(I)=DSHR(I)+2.*Q*KK*(1.1)*A(NDIV(I+1))-A(NDIV(I))
CSHR(I)=DSHR(I)-Q*KK*4./CBAR*(2.1)*A(NDIV(I+1))*{LCG-
$X(NDIV(I+1)))-A(NDIV(I)))-DA(I))
GSHR(I)=DSHR(I)+2.*Q*(0.,1.)*CMEGA*R(1,1)*DA(I)*K2
DSHR(I)=CSHR(I)-C*4./CBAR*K2*(0.,1.)*OMEGA*(LCG*(DA(I)
$-DAX(I)))*R(2,1))
DSHR(I)=DSHR(I)+C*4./CBAR*(2,1)*K1*DA(I)
DSHR(I)=DSHR(I)+CGSA*RFQ*G*DA(I)*R(4,1)
DSHR(I)=DSHR(I)+(-UO**2*(0.,1.)*OMEGA*R(1,1))-2./CBAR*(0.,1.1)
$OMEGA*R(2,1))*{LCG-(X(NDIV(I+1)))/2.-2.*UO**2/CBAR

```

```

C C
      $R(2,1)-G*CCCSA*R(4,1))*DM(1)
      BENDING CALCULATIONS
      CBEND(1)=LCG*DSR(1)
      CBEND(1)=CBEND(1)-(X(NDIV(I+1))*A(NDIV(I+1))*E(NDIV(I+1))-X(NDIV(I+1))
      $)*A(NDIV(I+1))-DAE(1))*2.*Q*KK
      CBEND(1)=DBEND(1)-2.*C*KK*R(1,1)*X(NDIV(I+1))*A(NDIV(I+1))-
      $X(NDIV(I+1))*A(NDIV(I+1))-CA(1)
      CBEND(1)=CBEND(1)+4./CBAR*Q*KK*R(2,1)*LCG*(X(NDIV(I+1))*2.*A(NDIV(I+1))
      $*X(NDIV(I+1))-X(NDIV(I+1))*A(NDIV(I+1))+2.*DAX(1))
      CBEND(1)=CBEND(1)-2.*Q*(0.,1.)*GMEGA*R(1,1)*CAX(1)*K2
      CBEND(1)=CBEND(1)+C*(0.,1.)*OMEGA*4./CBAR*R(2,1)*K2*(LCG*DAX(1)
      $-DAX2(1))
      CBEND(1)=EBEND(1)-4./CEAR*Q*R(2,1)*K1*CAX(1)
      CBEND(1)=DBEND(1)-CGSA*R(4,1)*RHO*G*DAX(1)
      CBEND(1)=CBEND(1)+UO**2*(0.,1.)*OMEGA*R(1,1)*(X(NDIV(I+1))
      $*X(NDIV(I+1)))/2.*CH(1)
      CBEND(1)=CBEND(1)+2./CEAR*UO**2*(0.,1.)*OMEGA*R(2,1)*X(NDIV(I+1))
      $/2.*DM(1)
      CBEND(1)=DBEND(1)+G*CCCSA*R(4,1)*(X(NDIV(I+1))*X(NDIV(I+1)))/2.*DM(1)
      CBEND(1)=CBEND(1)+2./CBAR*UO**2*R(2,1)*(X(NDIV(I+1))*X(NDIV(I+1))
      $/2.*CP(1)
      CBEND(1)=EBEND(1)+(0.,1.)*OMEGA*2./CBAR*(DIXZ(1)*R(3,1)-DIZZ(1)
      $*R(2,1))
      TWISTING CALCULATIONS
      GTWIST(1)=(-CHCE(1))*CSHR(1)+(G.,1.)*OMEGA*2./CBAR*UO**2*(DIXZ(1)
      $*R(2,1)-DIXX(1)*R(3,1))+DHCG(1)*G*CP(1)*CGSA*R(4,1)
      CONTINUE
      DO 110 L=1,7
      SHEAR(L)=(0.,0.)
      BEND(L)=(0.,0.)
      TWIST(L)=(0.,0.)
      DO 50 I=1,L
      SHEAR(L)=SHEAR(L)+CSHR(I)
      BEND(L)=BEND(L)+CBEND(I)
      TWIST(L)=TWIST(L)+DTWIST(I)
      CONTINUE
      DO 100 J=1,6
      IF (XENG(J)).GE. X(NDIV(L+1)) GO TO 100
      YI=0*STK*CYET*(CEXF(CPFLX(0.))-CMEGA*XENG(J))*COSA)*R(1,1)
      $-2./CBAR*R(2,1)*(LCG-XENG(J))-2.*CBAR*R(3,1)*(HCG-ZENG(J))
      SHEAR(L)=SHEAR(L)-YI
      BEND(L)=BEND(L)+(X(NDIV(L+1))-XENG(J))*YI

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THE01930
THE01940
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THE01970
THE01980
THE01990
THE02000
THE02010
THE02020
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THE02100
THE02110
THE02120
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THE02390
THE02400

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100 TWIST(I)=TWIST(I)-ZENG(J)*Y
    CONTINUE
    CSSMAG(I)=CABS(SPEAR(I)*2./(Q*S))
    CBMMAG(I)=CABS(BEND(I)*2./(Q*S*CBAR))
    CTMMAG(I)=CABS(TWIST(I)*2./(Q*S*CBAR))
    CONTINUE
110 WRITE(6,950)
    FORMAT(//,' THE FORCE AND MOMENT COEFFICIENT MAGNITUDES ARE:
    $1//,12X,'STATIC',11X,'CS',12X,'CB',13X,'CTH')
950 DO 120 I=1,7
    WRITE(6,960) XINCLV(I+1),CSSMAG(I),CBMMAG(I),CTMMAG(I)
960 FORMAT(5X,4(5X,F10.6))
120 CONTINUE
    GO TO 1
50 CONTINUE
    STOP
    END
    SUBROUTINE SFARFA (RFFIN,SEARS)
    THIS SUBROUTINE CALCULATES THE SEARS FUNCTION CORRECTED FOR
    ASPECT RATIO
    C
    C
    C
    IMPLICIT REAL*8 (A-H,C-Z)
    COMPLEX*16 SEARSC,ENUK,GKAR,GAPHAT,FILGEN
    COMPLEX*16 DCMPLX
    COMPLEX SEARS
    IF (RFFIN) 72,72,73
    SEARS=DCMPLX(1,0,0,0.0C0)
    GO TO 71
72 RFI=RFFIN/3.C
    BESSJ0=1.0-2.250*(RFI**2)+1.26562*(RFI**4)-.31639*(RFI**6)
    $+.04445*(RFI**8)-.00394*(RFI**10)
    BESSJ1=RFFIN*(1.50-.56250*(RFI**2)+.21094*(RFI**4)-.03945*(RFI**6)
    $+.00443*(RFI**8))
    BESSY0=.63662*DLCG(.5*RFFIN)*BESSJ0+.36747+.60559*(RFI**2)
    $-.74350*(RFI**4)+.25300*(RFI**6)-.04261*(RFI**8)
    BESSY1=.63662*DLCG(.5*RFFIN)*BESSJ1-(1.0/RFFIN)*(-.63662
    $-.22121*(RFI**2)-2.16827*(RFI**4)+1.31648*(RFI**6)
    $-.31240*(RFI**8))
    AR=1.87
    RF2=RFFIN*AR/3.75
    BESS11=RFFIN*AR*(1.50+.87891*(RF2**2)+.51499*(RF2**4)
    $+.15085*(RF2**6)+.02655*(RF2**8))
    RF3=RFFIN*AR/2.0
    BESSK1=DLOG(RF3)*BESS11+(1.0/(RFFIN*AR))*(1.0+.15443*(RF3**2)
    $-.67275*(RF3**4)-.18157*(RF3**6)-.01919*(RF3**8)
    $-.0011C*(RF3**10))
    RF4=RFFIN*AR

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THE02890
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THE02980

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STRUL1=63662*(.33333*(RF4**2)+.02222*(RF4**4)
$+.00000000071188*(RF4**12)+.0000001018*(RF4**10)
$+.00000000071188*(RF4**12)+.0000001018*(RF4**10)
SEARSD=2.0/(3.14159*RF4**12)*CMPLX(BESSJ0-BESSY1,-BESSJ1-BESSY0)
SEARSD=5*SEARSD*CMPLX(BESSJ0-BESSY1,-BESSJ1-BESSY0)
EMUK=CMPLX(BESSK1-(1.0-1.57080*(STRUL1-BESSI1)))
GKHAT=1.0/(1.0+4.0*RF4**12)*CMPLX(BESSK1-(1.0-1.57080*(STRUL1-BESSI1)))
SEARSD=SEARSD*GKHAT
RETURN
END

```

71

AKR000010
AKR000020
AKR000030
AKR000040
AKR000050
AKR000060
AKR000070
AKR000080
AKR000090
AKR000100
AKR000110
AKR000120
AKR000130
AKR000140
AKR000150
AKR000160
AKR000170
AKR000180
AKR000190
AKR000200
AKR000210
AKR000220
AKR000230
AKR000240
AKR000250
AKR000260
AKR000270
AKR000280
AKR000290
AKR000300
AKR000310
AKR000320
AKR000330
AKR000340
AKR000350
AKR000360
AKR000370
AKR000380
AKR000390
AKR000400
AKR000410
AKR000420
AKR000430
AKR000440
AKR000450
AKR000460
AKR000470
AKR000480

005

UUUU

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C      SUM3=SUM3+PI*DELTAX*(X(I)*Y(I)**2+X(I+1)*Y(I+1)**2)/2.
C      SUM4=SUM4+(Z(I)*Y(I)+X(I+1)*Y(I+1))*DELTAX
C
THE NEXT 4 VARIABLES ARE USED LATER IN THE INERTIA CALCULATIONS
C
    HAIR(I)=0.
    DAIR(I)=0.
    CHEL(I)=PI/2.*(V(I)**2+Y(I+1)**2)*DELTAX
    HHEL(I)=0.
    CONTINALE=SUM1
    VOL(J)=SUM1
    APROJ(J)=SUM2
    ASURF(J)=PI*SUM2
    VCENIR(J)=SUM3/VCL(J)
    CAPRCJ(J)=SLF4/APRCJ(J)
    CONTINUE
    DO 30 J=1,M
    SUM5=0.
    SUM6=0.
    SUM7=C.
    K1=NDIV(J)
    K2=NDIV(J)+1-1
    DO 40 I=K1,K2
    DELTAA=X(I)-VCENIR(J)
    DX1=X(I+1)-VCENIR(J)
    DX2=X(I+1)-VCENIR(J)
    SUM5=SUM5+(DX1+DX2)/2.*DELTAA
    SUM6=SUM6+PI*DELTAX*(CX1**2+CX2**2)/2.*DELTAA
    SUM7=SUM7+(CX1**2+CX2**2)/2.*DELTAA
    I3(J)=SUM5
    MQDQ(J)=SUM6
    MQI(J)=SUM7
    CONTINALE
    WRITE(6,201)
    WRITE(6,202)
    WRITE(6,203)
    WRITE(6,204)
    WRITE(6,205)
    WRITE(6,206)
    WRITE(6,207)
    WRITE(6,208)
    WRITE(6,209)
    FORMATT(//,3.//,57X,'AKRCA',12X,.04,12X,.05,12X,16,12X,'1',12X,
+2.,12X,'3.',12X,'4.',12X,'5.',12X,'6.',12X,'7.',12X,'8.',12X,'9.',12X,
FORMAT(//,2X,'SLRFACE AREA',2X,8(1X,E12.6))
FORMAT(//,2X,'SEGMENT NUMBER',6X,'1',12X,
201
202
203

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204204000970
205000980
206000990
207001000
208001010
209001020
20001030
201001040
202001050
203001060
204001070
205001080
206001090
207001100
208001110
209001120
20001130
201001140
202001150
203001160
204001170
205001180
206001190
207001200
208001210
209001220
20001230
201001240
202001250
203001260
204001270
205001280
206001290
207001300
208001310
209001320
20001330
201001340
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207001400
208001410
209001420
20001430
201001440
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204001470
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207001500
208001510
209001520
20001530
201001540
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205001580
206001590
207001600
208001610
209001620
20001630
201001640
202001650
203001660
204001670
205001680
206001690
207001700
208001710
209001720
20001730
201001740
202001750
203001760
204001770
205001780
206001790
207001800
208001810
209001820
20001830
201001840
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203001860
204001870
205001880
206001890
207001900
208001910
209001920
20001930
201001940
202001950
203001960
204001970
205001980
206001990
207002000
208002010
209002020
20002030
201002040
202002050
203002060
204002070
205002080
206002090
207002100
208002110
209002120
20002130
201002140
202002150
203002160
204002170
205002180
206002190
207002200
208002210
209002220
20002230
201002240
202002250
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204002270
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207002300
208002310
209002320
20002330
201002340
202002350
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208002410
209002420
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209002520
20002530
201002540
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207002600
208002610
209002620
20002630
201002640
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206002690
207002700
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209002720
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201002740
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207002800
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209002820
20002830
201002840
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204002870
205002880
206002890
207002900
208002910
209002920
20002930
201002940
202002950
203002960
204002970
205002980
206002990
207003000
208003010
209003020
20003030
201003040
202003050
203003060
204003070
205003080
206003090
207003100
208003110
209003120
20003130
201003140
202003150
203003160
204003170
205003180
206003190
207003200
208003210
209003220
20003230
201003240
202003250
203003260
204003270
205003280
206003290
207003300
208003310
209003320
20003330
201003340
202003350
203003360
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205003380
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207003400
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209003420
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209003520
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205003580
206003590
207003600
208003610
209003620
20003630
201003640
202003650
203003660
204003670
205003680
206003690
207003700
208003710
209003720
20003730
201003740
202003750
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209003820
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206003990
207004000
208004010
209004020
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207004100
208004110
209004120
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201004140
202004150
203004160
204004170
205004180
206004190
207004200
208004210
209004220
20004230
201004240
202004250
203004260
204004270
205004280
206004290
207004300
208004310
209004320
20004330
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203004360
204004370
205004380
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204004470
205004480
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205004980
206004990
207005000
208005010
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201005040
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AKRC1450
AKRC1460
AKRC1470
AKRC1480
AKRC1490
AKRC1500
AKRC1510
AKRC1520
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AKRC1550
AKRC1560
AKRC1570
AKRC1580
AKRC1590
AKRC1600
AKRC1610
AKRC1620
AKRC1630
AKRC1640
AKRC1650
AKRC1660
AKRC1670
AKRC1680
AKRC1690
AKRC1700
AKRC1710
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AKRC1790
AKRC1800
AKRC1810
AKRC1820
AKRC1830
AKRC1840
AKRC1850
AKRC1860
AKRC1870
AKRC1880
AKRC1890
AKRC1900
AKRC1910
AKRC1920

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C      VAIR(I)=VOLUME OF AIR IN THE I*TH SEGMENT
C      XBARA(I)=DISTANCE FROM NCSE FO CG OF AIR IN THE I*TH SEGMENT
C      ZBARA(I)=DISTANCE FROM CENTER LINE TC AIR CG
C      SIMILAR CONVENTION FOR HELIUM

DO 100 J=1,N
  SUM5=0.
  SUM10=0.
  SUM11=0.
  K1=NGIV(J)
  K2=NDIV(J+1)-1
  CO 110 I=K1,K2
  IF (Y(I)-LT.D)GG TC 110
  IF (Y(I+1)-LT.D)GG TC 110
  ALPHA1=ARCCOS(D/Y(I))
  ALPHA2=ARCCOS(D/Y(I+1))
  A1=Y(I)**2/2.*(2.*ALPHA1-SIN(2.*ALPHA1))
  A2=Y(I+1)**2/2.*(2.*ALPHA2-SIN(2.*ALPHA2))
  DELTAX=X(I+1)-X(I)
  B1=2./3.*(Y(I)*SIN(ALPHA1))**3
  B2=2./3.*(Y(I+1)*SIN(ALPHA2))**3
  SUM5=SUM5+(A1+A2)/2.*DELTAX
  SUM10=SUM10+(B1+B2)/2.*DELTAX
  SUM11=SUM11+(X(I+1)*A1+X(I+1)*A2)/2.*DELTAX

C      STORE THE AMOUNT OF HELIUM AND AIR IN EACH SETION FOR LATER USE
C      IN THE INERTIA CALCULATIONS.
C
  DAIR(I)=(A1+A2)/2.*DELTAX
  DHEL(I)=PI*(Y(I)**2+Y(I+1)**2)/2.*DELTAX-DAIR(I)
  HAIR(I)=(B1+B2)/2.*DELTAX/DAIR(I)
  HHEL(I)=-DAIR(I)*HAIR(I)/DHEL(I)
  CONTINUE
  VAIR(J)=SUM5
  VHDL(J)=VEL(J)-VAIR(J)
  IF (VAIR(J).EQ.0)GG TC 111
  ZBARA(J)=SUM10/VAIR(J)
  ZBARH(J)=VAIR(J)*ZBARA(J)/(VAIR(J)-VEL(J))
  XBARA(J)=SUM11/VAIR(J)
  XBARH(J)=(VEL(J)+VCENTR(J)-XBARA(J)*VAIR(J))/VHDL(J)
  GO TO 100
CONTINUE
XBARA(J)=0.
XBARH(J)=VCENTR(J)
ZBARA(J)=0.
ZBARH(J)=0.
CONTINUE
WRITE(6,211) D

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211 WRITE(6,212) (VAIR(J),J=1,M)
212 WRITE(6,213) (VHEL(J),J=1,M)
213 WRITE(6,214) (XBARA(J),J=1,M)
214 WRITE(6,215) (XBARF(J),J=1,M)
215 WRITE(6,216) (ZBARA(J),J=1,M)
216 WRITE(6,217) (ZBARH(J),J=1,M)
217 FORMAT(//,10X, 'DISTANCE FROM CENTER LINE TO TOP OF AIR LAYER =',
+ F5.2, ' FT. ')
218 FORMAT(//,2X, 'AIR VOLUME', 4X, 8(1X, E12.6))
219 FORMAT(//,2X, 'HEL VOLUME', 4X, 8(1X, E12.6))
220 FORMAT(//,2X, 'XBAR AIR', 6X, 8(1X, E12.6))
221 FORMAT(//,2X, 'XBAR HEL', 6X, 8(1X, E12.6))
222 FORMAT(//,2X, 'ZBAR AIR', 6X, 8(1X, E12.6))
223 FORMAT(//,2X, 'ZBAR HEL', 6X, 8(1X, E12.5))
224
225 NOW FIND THE ENGINE HEIGHT IN EACH SEGMENT
226
227 XENG(1)=322.5
228 XENG(2)=322.5
229 XENG(3)=475.2
230 XENG(4)=475.2
231 YENG(1)=62.6
232 YENG(2)=60.6
233 YENG(3)=60.6
234 YENG(4)=60.6
235 ZENG(1)=47.2
236 ZENG(2)=47.2
237 ZENG(3)=46.6
238 ZENG(4)=46.6
239 DO 170 J=1,4
240 IF (J.EQ.1) THEN
241   VE(J,X)=0.
242   ZE(J,K)=0.
243   WE(J,K)=0.
244   CONTINUE
245 DO 180 J=1,4
246   NE=0
247   DO 180 K=1,4
248     IF ((XENG(K).LT.X(NDIV(J))) .OR. (XENG(K).GT.X(NDIV(J+1)))) GO TO 180
249     NE=NE+1
250     XE(NE,J)=XENG(K)
251     YE(NE,J)=YENG(K)
252     ZE(NE,J)=ZENG(K)
253     WE(NE,J)=WENG(K)
254     CONTINUE
255
256 THE FRAME MASS IS ASSUMED TO BE CONCENTRATED IN THE SHELL AND SO
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C      THE MOMENT ON INERTIA CAN BE CALCULATED USING THE SHELL DENSITY SDENAKR02410
C      SDEN=HFRAME/32.2/SURFACAKR02420
C      DO 120 J=1,M AKR02430
C      HFRAME(J)=SDEN*ASURF(J) AKR02440
C      XBARF(J)=CAPROJ(J) AKR02450
C      CONTINUE AKR02460
C      AKR02470
C      AKR02480
C      AKR02490
C      AKR02500
C      AKR02510
C      AKR02520
C      AKR02530
C      AKR02540
C      AKR02550
C      AKR02560
C      AKR02570
C      AKR02580
C      AKR02590
C      AKR02600
C      AKR02610
C      AKR02620
C      AKR02630
C      AKR02640
C      AKR02650
C      AKR02660
C      AKR02670
C      AKR02680
C      AKR02690
C      AKR02700
C      AKR02710
C      AKR02720
C      AKR02730
C      AKR02740
C      AKR02750
C      AKR02760
C      AKR02770
C      AKR02780
C      AKR02790
C      AKR02800
C      AKR02810
C      AKR02820
C      AKR02830
C      AKR02840
C      AKR02850
C      AKR02860
C      AKR02870
C      AKR02880

120  C      CALCULATE THE BUOYANT FORCES
C      BSUM=0.
C      CBX=0.
C      DO 320 I=1,M
C      BUOY(I)=RHOAIR*VCL(I)*32.2
C      BSUM=BSUM+BUOY(I)
C      CBX=CBX+BLOY(I)*VCENTR(I)
C      CONTINUE
C      CBX=CBX/BSUM

320  C      SOLVES FOR THE POSITION OF THE KEEL CC THAT THE CG LIES UNDER THE
C      CENTER OF BUOYANCY
C      XCEG=0.
C      EMTOT=0.
C      DO 312 I=1,M
C      CMHEL=VHEL(I)*RH*CHEL
C      CHAIR=VAIR(I)*RH*CAIR
C      CMFRAM=HFRAME(I)
C      CMENG=0.
C      DO 325 J=1,4
C      CMENG=CMENG+WE(J,I)/32.2
C      CMENG=CMENG+WE(J,I)*XE(J,I)/32.2
C      EMTOT=CMHEL+CHAIR+CMFRAM+CMENG
C      XCEG=XCEG+CMHEL*XBARH(I)+CHAIR*XBARA(I)+CMFRAM*XBARF(I)+EMXE
C      EMTOT=EMTOT+CMHEL+CHAIR+CMFRAM+CMENG
C      CONTINUE
C      XCEG=XCEG+MFINS/32.2*XFINS
C      EMTOT=EMTOT+MFINS/32.2
C      CKEEL=((EMTOT*WKEEL/32.2)*CBX-XCEG)/(WKEEL/32.2)

325  C      NEXT FIND THE PORTION OF THE KEEL IN EACH SEGMENT
312  C      LENGTH OF KEEL = TWICE THE DISTANCE FROM THE CONTROL CAR TO THE CB
C      LK=466.07
C      ZKEEL=66.
C      SKEEL=CKEEL-LK/2.
C      FKEEL=CKEEL+LK/2.

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AKR02890
AKR02900
AKR02910
AKR02920
AKR02930
AKR02940
AKR02950
AKR02960
AKR02970
AKR02980
AKR02990
AKR03000
AKR03010
AKR03020
AKR03030
AKR03040
AKR03050
AKR03060
AKR03070
AKR03080
AKR03090
AKR03100
AKR03110
AKR03120
AKR03130
AKR03140
AKR03150
AKR03160
AKR03170
AKR03180
AKR03190
AKR03200
AKR03210
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AKR03230
AKR03240
AKR03250
AKR03260
AKR03270
AKR03280
AKR03290
AKR03300
AKR03310
AKR03320
AKR03330
AKR03340
AKR03350
AKR03360

IFLAG=0
DO 160 K=1,M
X1=X(NCIV(K+1)) GC TC 153
IF (IFLAG.EQ.1) GC TC 153
IF ((X1-LT.SKEEL).AND.(X2-LT.SKEEL)) GO TO 153
IF ((X1-LT.SKEEL).AND.(X2-GT.SKEEL)) GO TO 151
IF ((X1-LT.FKEEL).AND.(X2-GT.FKEEL)) GC TC 152
LKEEL(K)=X2-X1
XKEEL(K)=(X1+X2)/2.
GO TO 160
LKEEL(K)=X2-SKEEL
XKEEL(K)=(X2+SKEEL)/2.
GO TO 160
LKEEL(K)=FKEEL-X1
XKEEL(K)=(FKEEL+X1)/2.
IFLAG=1
GO TO 160
LKEEL(K)=0.
XKEEL(K)=0.
CONTINUE
DO 150 J=1,M
WK(J)=LKEEL(J)/LK*SKEEL
CONTINUE

151

152

153

160

150

C CALCULATES THE CG

CGX=0.
CGH=0.
DO 190 I=1,M
CMHEL=VHEL(I)*RH*CHEL
CHAIR=VAIR(I)*RH*CAIR
CFRAM=FRAME(I)
CMKEEL=WK(I)/32.2
EMZE=0.
EMXE=0.
CMENG=0.
DO 320 J=1,4
CMENG=CMENG+WE(J,I)/32.2
EMXE=EMXE+WE(J,I)*ZE(J,I)/32.2
EMZE=EMZE+WE(J,I)*ZE(J,I)/32.2
CMTOT(I)=CMHEL+CHAIR+CMFRAM+CMKEEL+CMENG
CMTOT(I)=CMTOT(I)+CMTOT(I)*32.2
WTOT=WTOT+(CMHEL+CHAIR)*32.2
XCG(I)=(CMHEL*XBARH(I)+CHAIR*XEARA(I)+CFRAM*XBARF(I)+CMKEEL*XKEEL
*(I)+EMXE)/CMTOT
YCG(I)=0.
ZCG(I)=(CMHEL*ZBARH(I)+CHAIR*ZBARA(I)+CMKEEL*ZKEEL+EMZE)/CMTOT

326

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190      CGX=CGX+XCG(I)*CMICI
        CGH=CGH+ZCG(I)*CMICI
        CONTINUE
        CGX=(CGX+WFINS/32.2*XFINS)/WTOT*32.2
        CGH=(CGH*32.2/WTOT)

C      FRAME CONTRIBUTION TO MOMENTS OF INERTIA
C
      DO 130 J=1,N
        IXXF(J)=0.
        IYVF(J)=0.
        IZZF(J)=0.
        IXZ(J)=0.
        K1=NDIV(J)-1
        K2=NDIV(J)+1
      DO 140 I=K1,K2
        THETA=ATAN(ABS((Y(I+1)-Y(I))/(X(I+1)-X(I))))
        A=(Y(I+1)-Y(I))/(X(I+1)-X(I))
        B=Y(I)-A*X(I)
        IXXF(J)=IXXF(J)+(FUNC2(A,B,X(I+1),ZCG(J))-FUNC2(A,B,X(I),ZCG(J)))
        +PI*SDEN*PI/COS(THETA)
        IYVF(J)=IYVF(J)+(FUNC1(A,B,X(I+1),XCG(J),ZCG(J))-
        +FUNC1(A,B,X(I),XCG(J),ZCG(J)))+PI*SDEN/CCS(THETA)
        IZZF(J)=IZZF(J)+(FUNC1(A,B,X(I+1),XCG(J),0.)-
        +FUNC1(A,B,X(I),XCG(J),0.))-FUNC1(A,B,X(I),XCG(J))
        +0.)*PI*SDEN/CCS(THETA)
        IXZ(J)=IXZ(J)+(FUNC3(A,B,X(I+1),XCG(J))-FUNC3(A,B,X(I),XCG(J)))*2.
        +PI*SDEN*ZCG(J)/COS(THETA)
      CONTINUE
      CONTINUE

140      ENGINE CONTRIBUTIONS
130      CONTINUE
C
C
      DO 300 I=1,N
        SIXXE(I)=0.
        SIYVE(I)=0.
        SIIZE(I)=0.
        DO 300 J=1,N
          SIXXE(I)=SIXXE(I)+XE(I)*YE(J,I)/32.2*(YE(J,I)**2+(ZE(J,I)-ZCG(I))**2)
          SIYVE(I)=SIYVE(I)+YE(J,I)/(32.2*(XE(J,I)-XCG(I))**2+
          +ZE(J,I)-ZCG(I))**2)
          SIIZE(I)=SIIZE(I)+YE(J,I)/32.2*(XE(J,I)-XCG(I))**2+YE(J,I)**2)
          IXZ(I)=IXZ(I)+XE(J,I)/32.2*(XCG(I)-XE(J,I))*(ZE(J,I)-ZCG(I))
        CONTINUE
      CONTINUE

300      AIR AND HELIUM CONTRIBUTION
C
C
      DO 410 J=1,N
        K1=NDIV(J)

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410
C
C
K2=NOIV(J+1)-1
IXX(J)=IXXF(J)+WK(J)/32.2*(ZKEEL-ZCG(J))*2
IYY(J)=IYVF(J)+SIVVE(J)+WK(J)/32.2*(LKEEL(J))*2/12.+(XKEEL(J)-
+XCG(J))*2+(ZKEEL-ZCG(J))*2
IZZ(J)=IZZF(J)+WK(J)/32.2*(LKEEL(J))*2/12.+(XKEEL(J)-
+XCG(J))*2
IXZ(J)=IXZF(J)+WK(J)/32.2*(XCG(J)-XKEEL(J))*(ZKEEL-ZCG(J))
DO 410 I=K1,K2
IXX(J)=IXX(J)+DAIR(I)*RHOAIR*(ZCG(J)-HAIR(I))*2+DHEL(I)*RHOHEL*
+ZCG(J)-DHEL(I))*2
IYY(J)=IYY(J)+DAIR(I)*RHOAIR*(X(I)-XCG(J))*2+(HAIR(I)-ZCG(J))*2
+DHEL(I)*RHOHEL*(X(I)-XCG(J))*2
IZZ(J)=IZZ(J)+DAIR(I)*RHOAIR*(X(I)-XCG(J))*2+DHEL(I)*RHOHEL*
+X(I)-XCG(J))*2
IXZ(J)=IXZ(J)+DAIR(I)*RHOAIR*(XCG(J)-X(I))*(HAIR(I)-ZCG(J))+
+DHEL(I)*RHOHEL*(XCG(J)-X(I))*(HHEL(I)-ZCG(J))
CONTINUE
410
C
C
FIN CONTRIBUTION
CIXX=12751.
CIYY=34756.5
CIZZ=47547.2
CIXZ=1336.2
FM=WFINS/32.2/4.
ZF=35.268
XF=667.48
IXXFIN=2.*(CIXX+FM*(ZF**2+CGH**2))+ (CIXX+FM*(ZF+CGH))*2)+
+ (CIXX+FM*(ZF-CGH))*2
IYYFIN=2.*(CIYY+FM*(CGH**2+(XF-CGX)**2))+ (CIYZ+FM*(ZF+CGH
+I**2+(XF-CGX)**2))+ (CIZZ+FM*(ZF-CGH))*2+(XF-CGX)**2)
IZZFIN=2.*(CIZZ+FM*(XF-CGX)**2+ZF**2))+2.*(CIYY+FM*(XF-CGX)**2)
IXZFIN=4.*FM*CGH*(XF-CGX)+2.*CIXZ
SUM UP COMPONENT PARTS TO GET IXX,IYY,IZZ, AT THE AIRSHIP CG
C
C
C
IXXIGI=0.0
IYYIGI=0.0
IZZIGI=0.0
IXZIGI=0.0
DO 411 I=1,M
IXXIGI=IXXIGI+IXX(I)+C*IGI(I)/32.2*(CGH-ZCG(I))*2
IYYIGI=IYYIGI+IYY(I)+C*IGI(I)/32.2*(CGH-XCG(I))*2+(CGH-ZCG(I))*2
+2)
IZZIGI=IZZIGI+IZZ(I)+C*IGI(I)/32.2*(CGH-XCG(I))*2
IXZIGI=IXZIGI+IXZ(I)+C*IGI(I)/32.2*(CGH-XCG(I))*(ZCG(I)-CGH)
CONTINUE
411
C
C
IXXICT=IXXICT+IXXFIN

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AKR04810
AKR04820
AKR04830
AKR04840
AKR04850
AKR04860
AKR04870
AKR04880
AKR04890
AKR04900
AKR04910
AKR04920
AKR04930
AKR04940
AKR04950
AKR04960
AKR04970
AKR04980
AKR04990
AKR05000
AKR05010

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RETURN
END
FUNCTION F(C)
REAL*8 F,D
DIMENSION X(100),Y(100)
COMMON/AIR/X,Y,VCLAIR,K
SUM8=0.
L=N-1
DO 60 I=1,L
  X=X(I)-X(I)
  DELTA=X(I)-X(I+1)
  IF(Y(I) .LT. Y(I+1)) .L.Y.DIGC TO 60
  THETA1=DARCCS(D/Y(I+1))
  THETA2=Y(I)*((THETA1+Y(I+1))-D*SIN(THETA1))
  AREA2=Y(I+1)*((THETA2+Y(I+1))-D*SIN(THETA2))
  AREA2=SUM8+((AREA1+AREA2)/2.*DELTA)
  SUM8=SUM8+AREA2
CONTINUE
F=DBLE(SUM8-VCLAIR)
RETURN
END

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TABLE I
PARAMETERS FOR TURBULENCE

Altitude (ft)	Mission Segment*	Turbulence Component**	P ₁ (unitless)	b ₁ (ft/sec)	P ₂ (unitless)	b ₂ (ft/sec)	L (ft)
0 - 1,000	Low Level Contour (rough terrain)	V	1.00	2.7	10 ⁻⁵	10.65	500
0 - 1,000	Low Level Contour (rough terrain)	L, L	1.00	3.1	10 ⁻⁵	14.06	500
0 - 1,000	C, C, D	V, L, L	1.00	2.51	0.005	5.04	500
1,000 - 2,500	C, C, D	V, L, L	0.42	3.02	0.0033	5.94	1750
2,500 - 5,000	C, C, D	V, L, L	0.30	3.42	0.0020	8.17	2500
5,000 - 10,000	C, C, D	V, L, L	0.15	3.59	0.00095	9.22	2500
10,000 - 20,000	C, C, D	V, L, L	0.062	3.27	0.00028	10.52	2500
20,000 - 30,000	C, C, D	V, L, L	0.025	3.15	0.00011	11.88	2500
30,000 - 40,000	C, C, D	V, L, L	0.011	2.93	0.000095	5.84	2500
40,000 - 50,000	C, C, D	V, L, L	0.0046	3.28	0.000115	8.81	2500
50,000 - 60,000	C, C, D	V, L, L	0.0020	3.82	0.000078	7.04	2500
60,000 - 70,000	C, C, D	V, L, L	0.00088	2.93	0.000057	4.33	2500
70,000 - 80,000	C, C, D	V, L, L	0.00038	2.80	0.000044	1.80	2500
above 80,000	C, C, D	V, L, L	0.00025	2.50	0	0	2500

*Climb, cruise, and descent (C, C, D)

**Vertical, lateral, and longitudinal (V, L, L)

TABLE II

LOAD RESPONSE TRANSFER FUNCTIONS

$$\frac{(dY_g)_h}{\Gamma} = \rho U_o^2 K \frac{dA}{d\xi} \exp(-i\Omega \xi \cos \alpha_o) d\xi$$

$$\frac{(Y_g)_s}{\Gamma} = -\rho \frac{U_o^2}{2} S_s [(C_{Y\beta})_s H(k_s) \eta_s] \exp(-i\Omega l_s \cos \alpha_o)$$

$$\frac{(Y_g)_{T_k}}{\Gamma} = -\rho \frac{U_o^2}{2} S_{T_k} (C_{Y\beta})_{T_k} \exp(-i\Omega l_{T_k} \cos \alpha_o)$$

$$\frac{(N_g)_{T_k}}{\Gamma} = \frac{(Y_g)_{T_k}}{\Gamma} (l_{cm} - l_{T_k})$$

$$\frac{(L_g)_{T_k}}{\Gamma} = \frac{(Y_g)_{T_k}}{\Gamma} (h_{cm} - h_{T_k})$$

$$\begin{aligned} \frac{(dY_w)_h}{\Gamma} = & \left\{ \rho U_o^2 K \frac{dA}{d\xi} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} (l_{cm} - \xi) \frac{\hat{R}}{\Gamma} \right] \right. \\ & \left. + \rho U_o^2 A \left\{ l\Omega \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) \right] k_2 + \frac{2}{c} \frac{\hat{R}}{\Gamma} k_1 \right\} \right\} d\xi \end{aligned}$$

$$\begin{aligned} \frac{(Y_w)_s}{\Gamma} = & -\rho \frac{U_o^2}{2} S_s \left\{ (C_{Y\beta})_s \left[\frac{\hat{V}}{\Gamma} - \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) \right] + (C_{Yr})_s^{ac} \frac{\hat{R}}{\Gamma} \right. \\ & \left. + \frac{ik}{2} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) \right] \right\} \end{aligned}$$

$$\frac{(N_w)_s}{\Gamma} = \rho \frac{U_o^2}{2} S_s \bar{c}_s (C_{nr})_s^{ac} \frac{\hat{R}}{\Gamma}$$

$$\frac{(L_w)_s}{\Gamma} = \frac{(Y_w)_s}{\Gamma} (h_{cm})_s$$

$$\frac{(Y_w)_{T_k}}{\Gamma} = -\rho \frac{U_o^2}{2} S_{T_k} (C_{Y_\beta})_{T_k} \left[\frac{\hat{V}}{\Gamma} - \frac{2}{c} \frac{\hat{R}}{\Gamma} (l_{cm} - l_{T_k}) - \frac{2}{c} \frac{\hat{P}}{\Gamma} (h_{cm} - h_{T_k}) \right]$$

$$\frac{(L_w)_{T_k}}{\Gamma} = \frac{(Y_w)_{T_k}}{\Gamma} (h_{cm} - h_{T_k})$$

$$\frac{(N_w)_{T_k}}{\Gamma} = \frac{(Y_w)_{T_k}}{\Gamma} (l_{cm} - l_{T_k})$$

$$\frac{(dY_m)_h}{\Gamma} = - \left[U_o^2 i \Omega \frac{\hat{V}}{\Gamma} + \frac{2}{c} U_o^2 i \Omega \frac{\hat{R}}{\Gamma} (l_{cm} - \xi) + \frac{2U_o^2}{c} \frac{\hat{R}}{\Gamma} \right] (dm)_h$$

$$\frac{(dL_m)_h}{\Gamma} = i \Omega \frac{2}{c} U_o^2 (-dI_{xx} \frac{\hat{P}}{\Gamma} + dI_{xz} \frac{\hat{R}}{\Gamma})$$

$$\frac{(dN_m)_h}{\Gamma} = i \Omega \frac{2}{c} U_o^2 (-dI_{zz} \frac{\hat{R}}{\Gamma} + dI_{xz} \frac{\hat{P}}{\Gamma})$$

$$\frac{(Y_m)_s}{\Gamma} = - \left[U_o^2 i \Omega \frac{\hat{V}}{\Gamma} + \frac{2}{c} U_o^2 i \Omega \frac{\hat{R}}{\Gamma} (l_{cm} - l_s) + \frac{2U_o^2}{c} \frac{\hat{R}}{\Gamma} \right] m_s$$

$$\frac{(L_m)_s}{\Gamma} = i \Omega \frac{2}{c} U_o^2 \left[-(dI_{xx})_s \frac{\hat{P}}{\Gamma} + (dI_{xz})_s \frac{\hat{R}}{\Gamma} \right]$$

$$\frac{(N_m)_s}{\Gamma} = i \Omega \frac{2}{c} U_o^2 \left[-(dI_{zz})_s \frac{\hat{R}}{\Gamma} + (dI_{xz})_s \frac{\hat{P}}{\Gamma} \right]$$

$$\frac{(dY_b)_h}{\Gamma} = (\rho g A d \xi - g d m) \cos \alpha_o \frac{\hat{\phi}}{\Gamma}$$

$$\frac{(Y_c)_s}{\Gamma} = -\rho \frac{U_o^2}{2} S_s K_c \frac{\hat{\psi}}{\Gamma}$$

$$\frac{(dL_{mg})_h}{\Gamma} = h_{cm} g d m \cos \alpha_o \frac{\hat{\phi}}{\Gamma}$$

TABLE III
GEOMETRICAL AND INERTIAL PROPERTIES
OF THE USS AKRON (ZR-4)

total volume = 7,382,400 ft³

$\bar{c}$ = 785.0 ft

s = 37,914 ft²

l_{cm} = 364.24 ft

h_{cm} = -37.66 ft

l_b = 363.01 ft

mass = 17,039 slugs

buoyancy = 548,642 lb

I_{xx} = 38,685,100 slug-ft²

I_{zz} = 471,799,000 slug-ft²

I_{xz} = 102,129,000 slug-ft²

TABLE IV

STABILITY DERIVATIVES OF THE USS AKRON (ZR-4)neutral buoyancy, $U_0 = 123$ ft/sec, ALT = 1000 ft

$C_{Y\beta} = -0.7224$	$C_{Y\dot{\beta}} = -0.9863$
$C_{Yr} = -0.3418$	$C_{Y\dot{r}} = 0.0586$
$C_{Yp} = -0.0648$	$C_{Y\dot{p}} = -0.0913$
$C_{n\beta} = -0.1710$	$C_{n\dot{\beta}} = 0.0293$
$C_{nr} = -0.2352$	$C_{n\dot{r}} = -0.0991$
$C_{np} = -0.0150$	$C_{n\dot{p}} = 0.0028$
$C_{l\beta} = -0.0322$	$C_{l\dot{\beta}} = -0.0456$
$C_{lr} = -0.0153$	$C_{l\dot{r}} = 0.0028$
$C_{lp} = -0.0066$	$C_{l\dot{p}} = -0.0042$

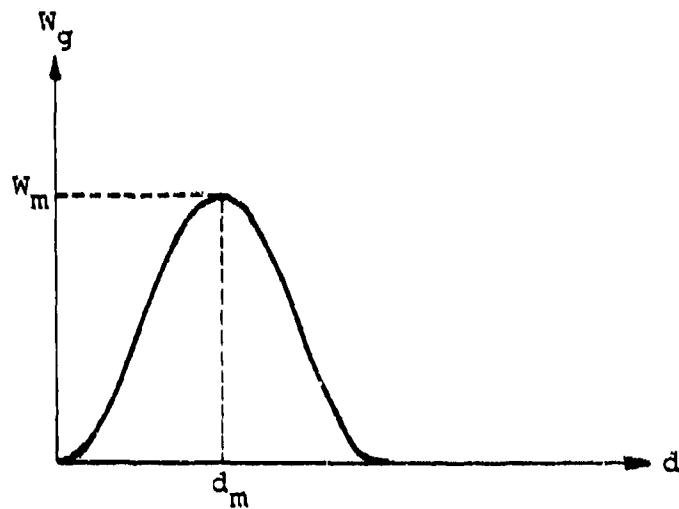


Figure 1. The (1-Cosine) Gust Shape

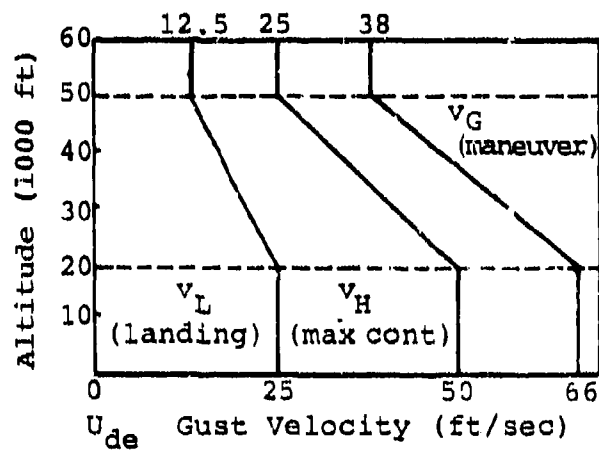


Figure 2. Derived Gust Velocity for Gust Loads Formula

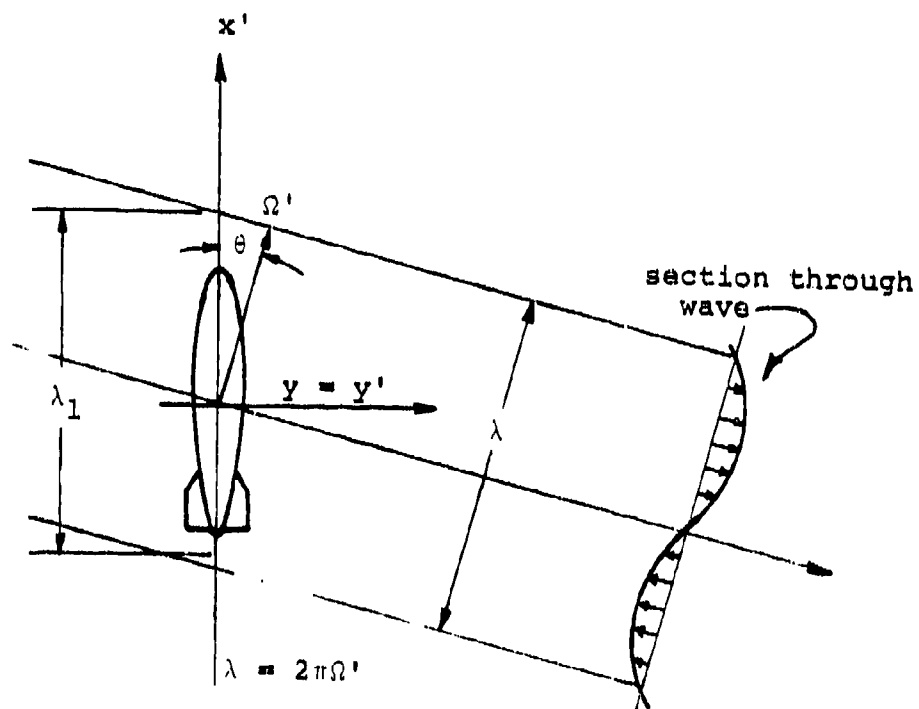


Figure 3. Elementary Spectral Components in Two Dimensions

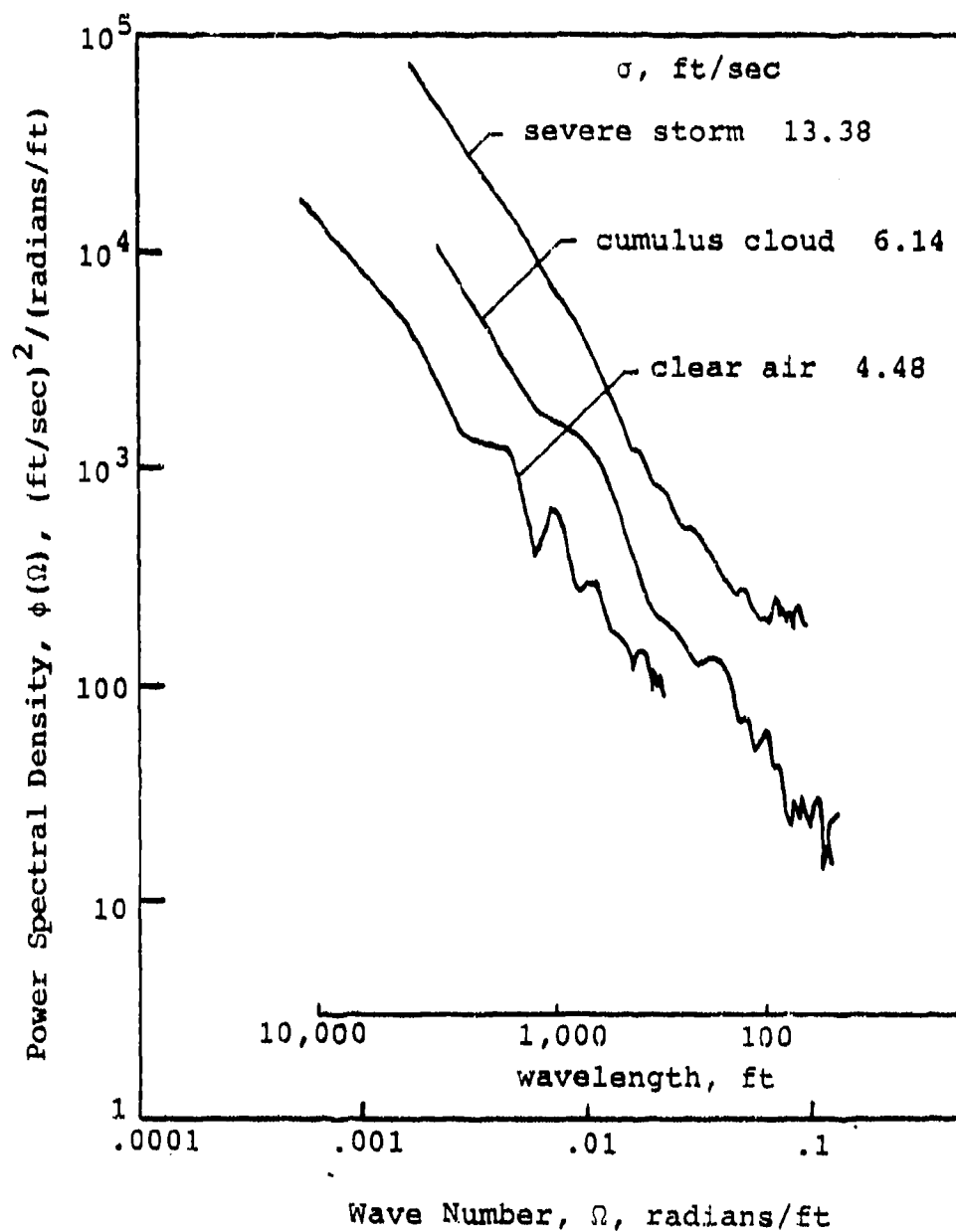


Figure 4. Typical Power Spectra of Vertical Gust Velocity

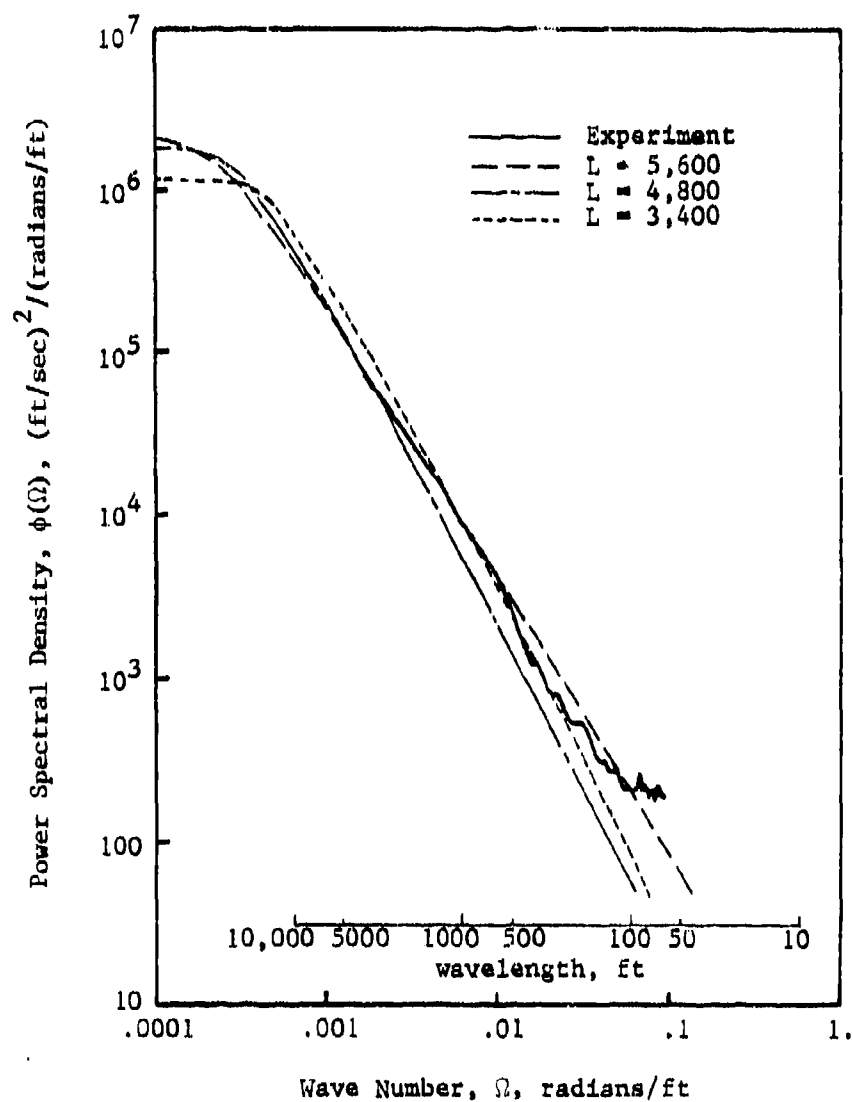


Figure 5. Measured and Fitted von Kármán Spectra of Vertical Gust Velocity from Severe Storm

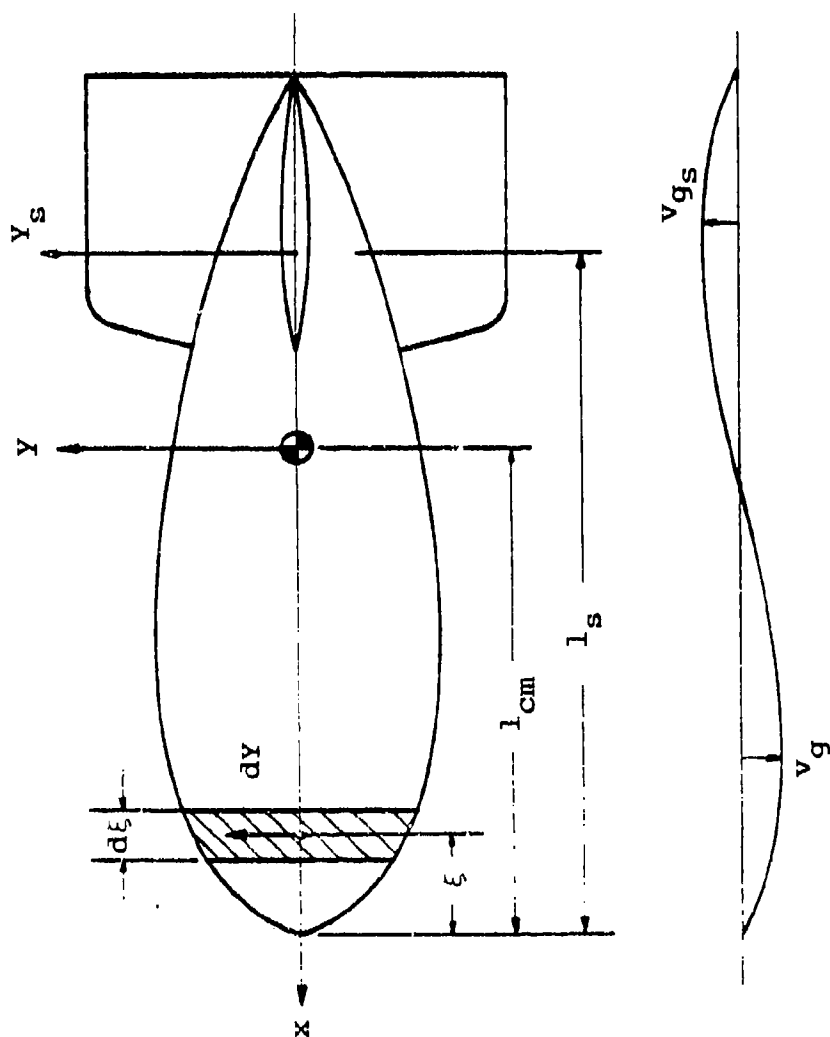


Figure 6. Schematic of Airship Loads from Turbulence

Y_B shown in positive sense

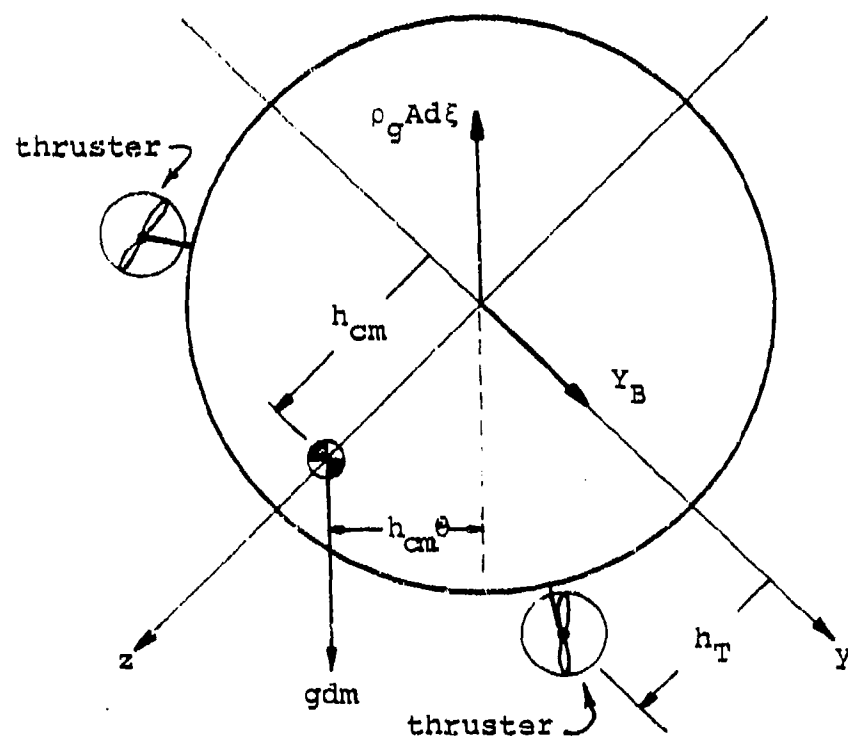


Figure 7. Schematic of Buoyancy Forces and Moments

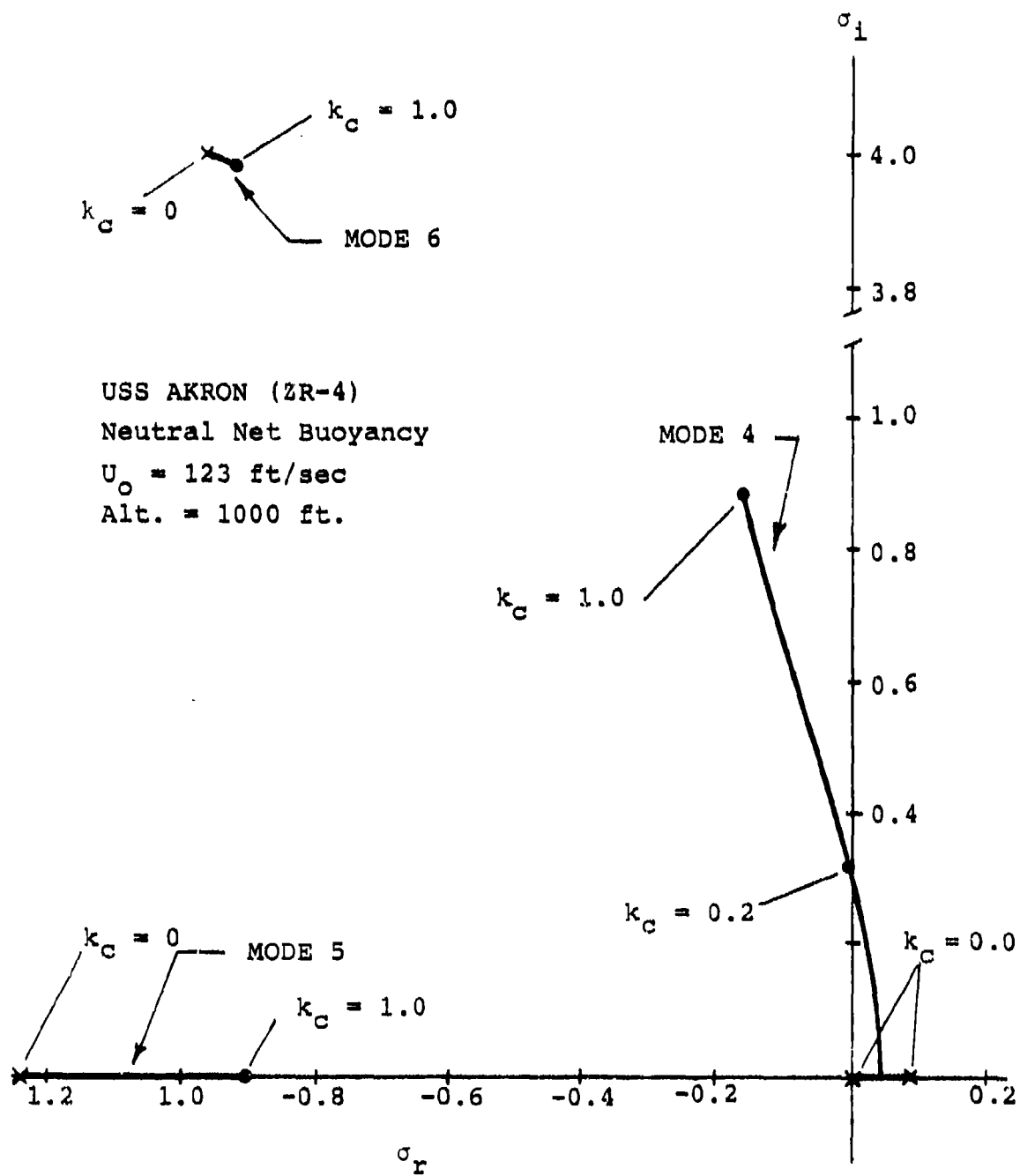


Figure 8. Lateral Root-Locus of the USS AKRON (ZR-4)

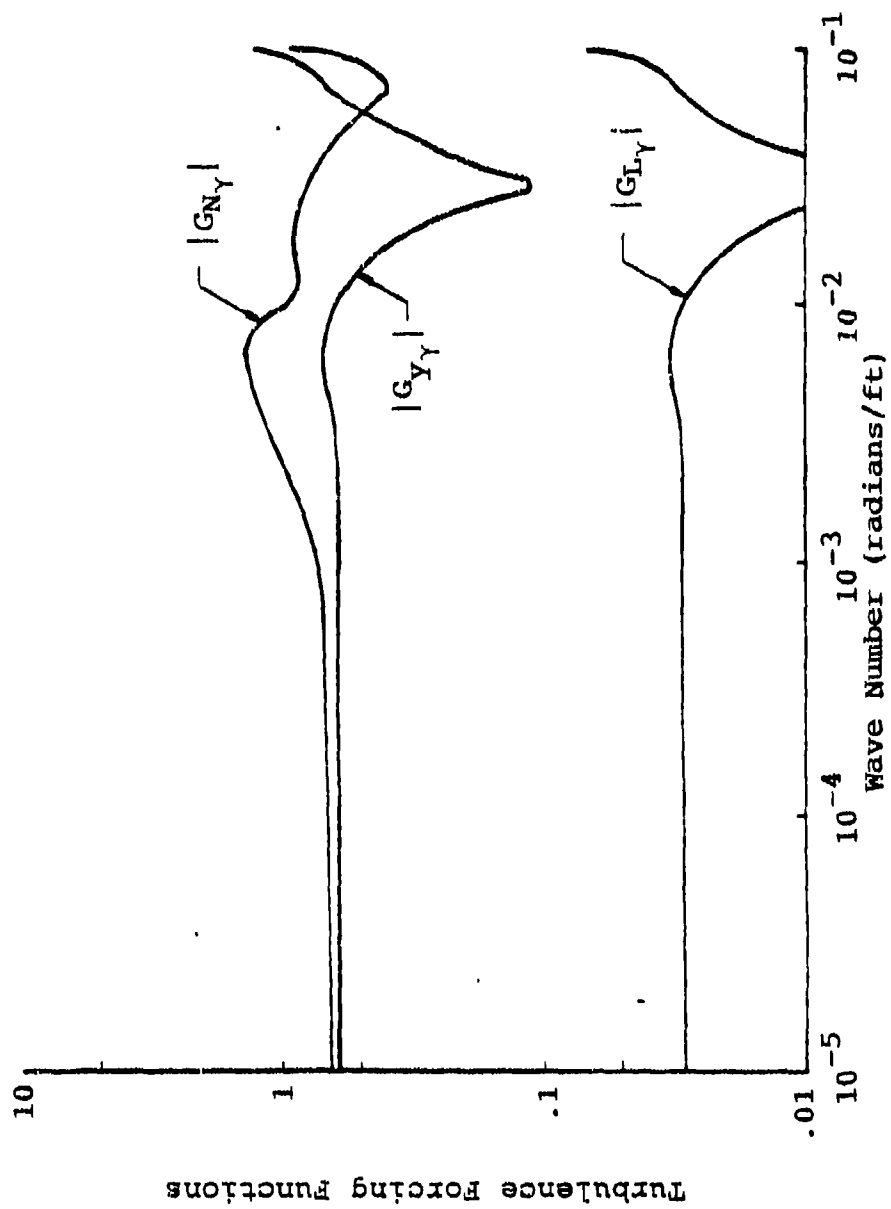


Figure 9. Turbulence Forcing Functions

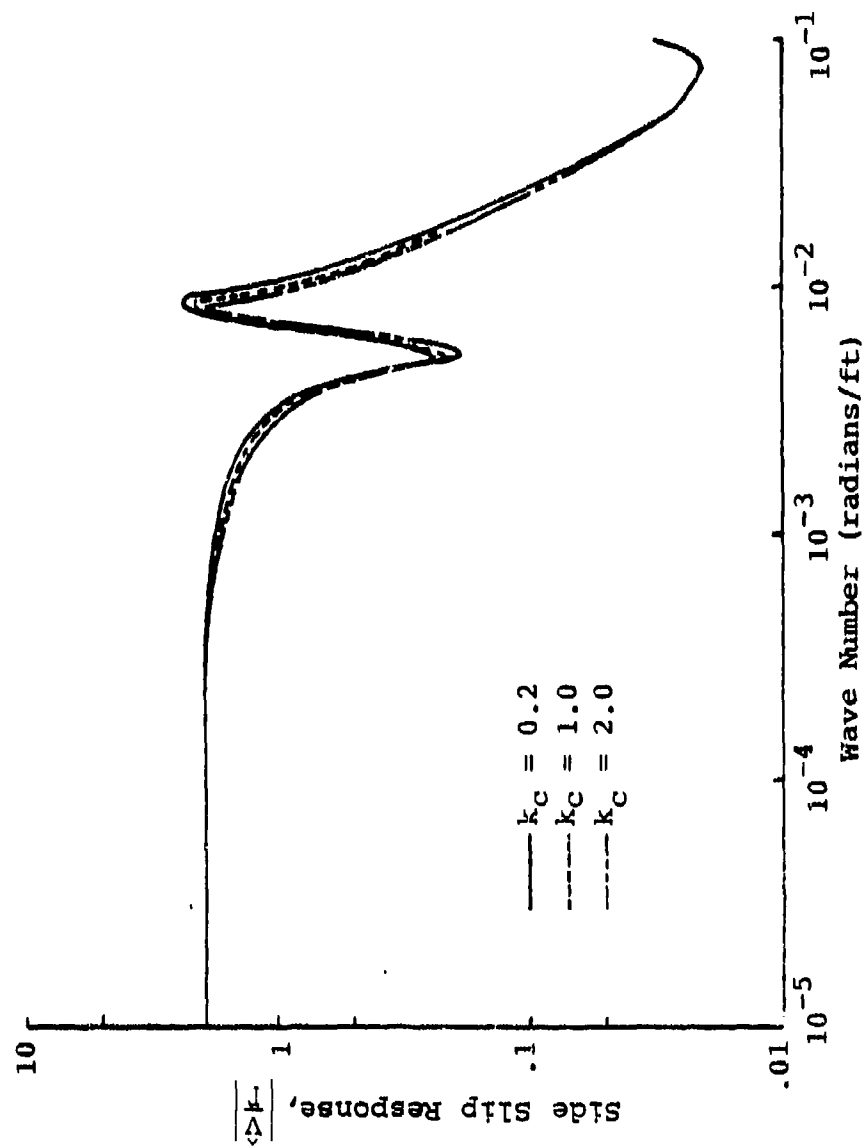


Figure 10. Side Slip Response

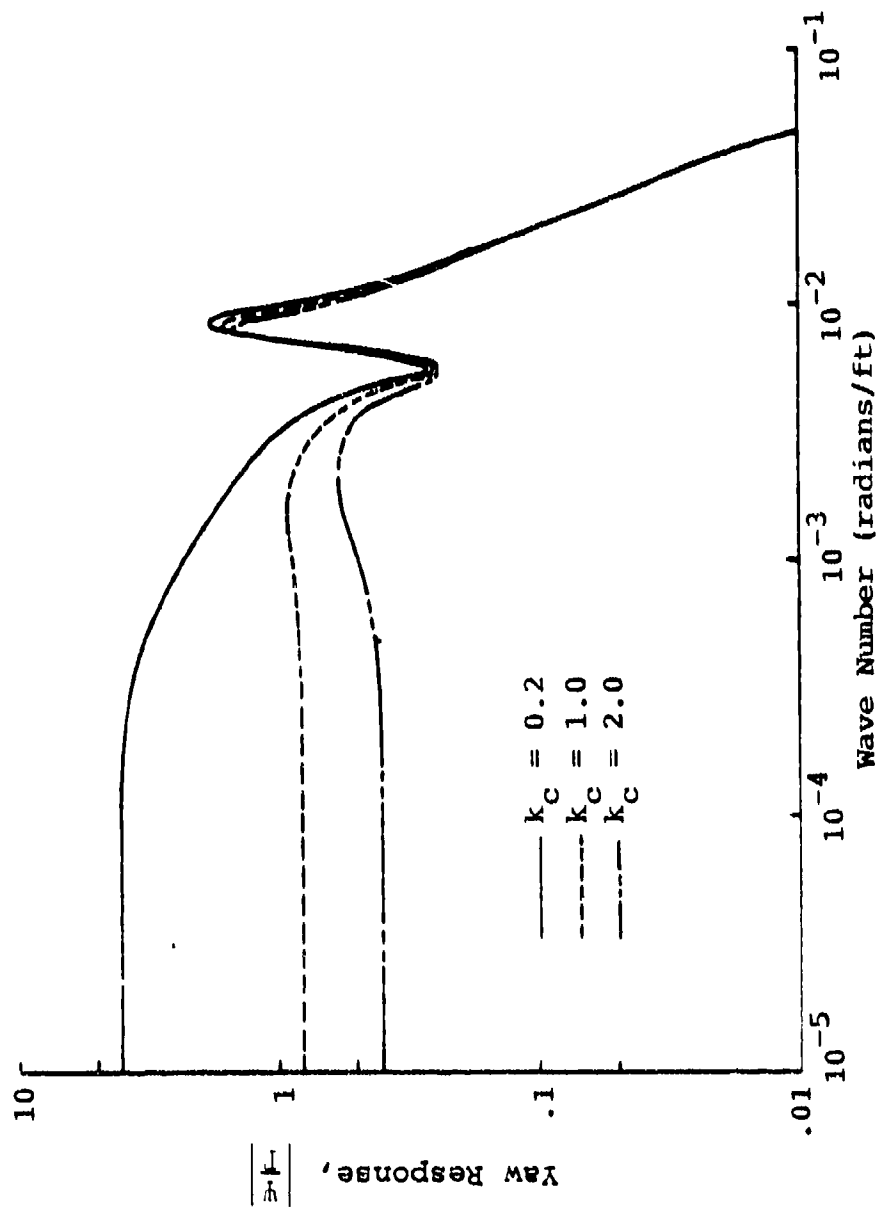


Figure 11. Yaw Response

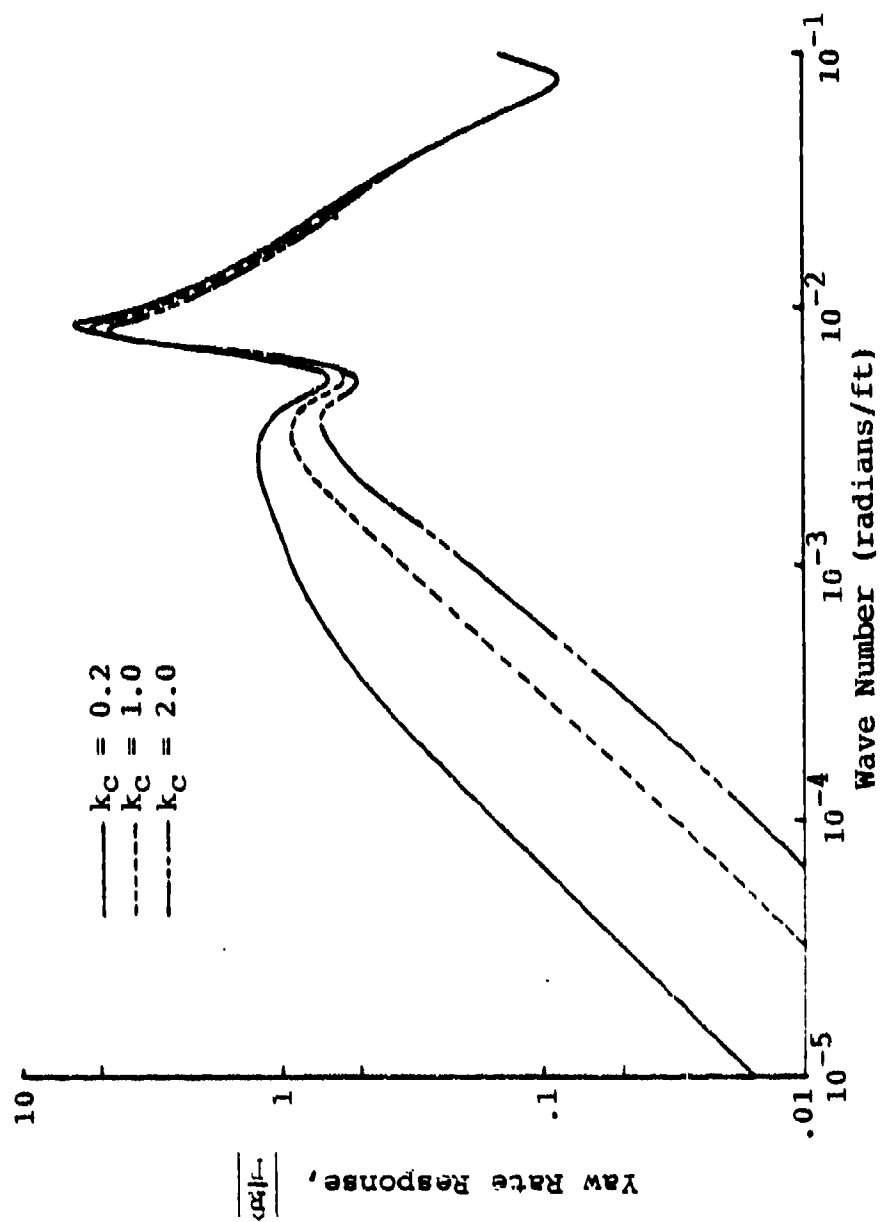


Figure 12. Yaw Rate Response

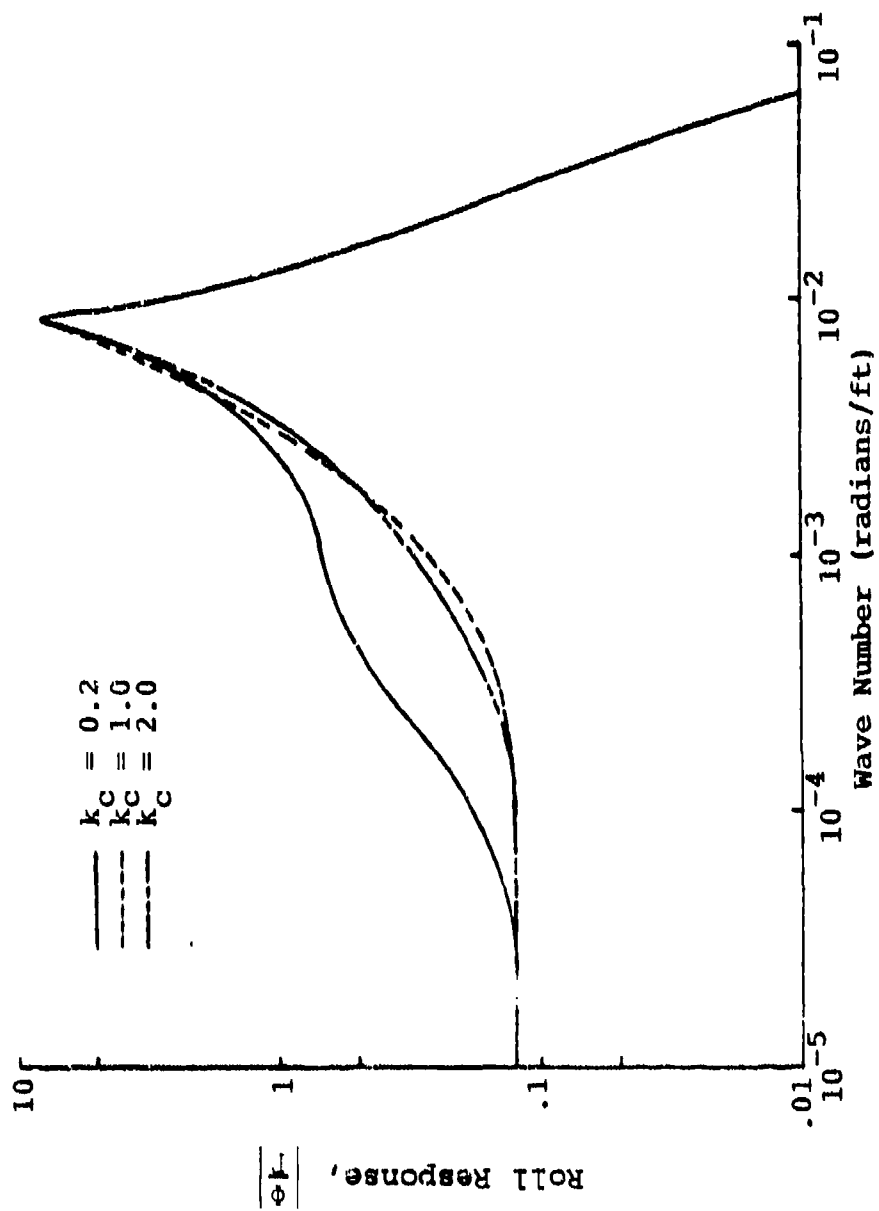


Figure 13. Roll Response

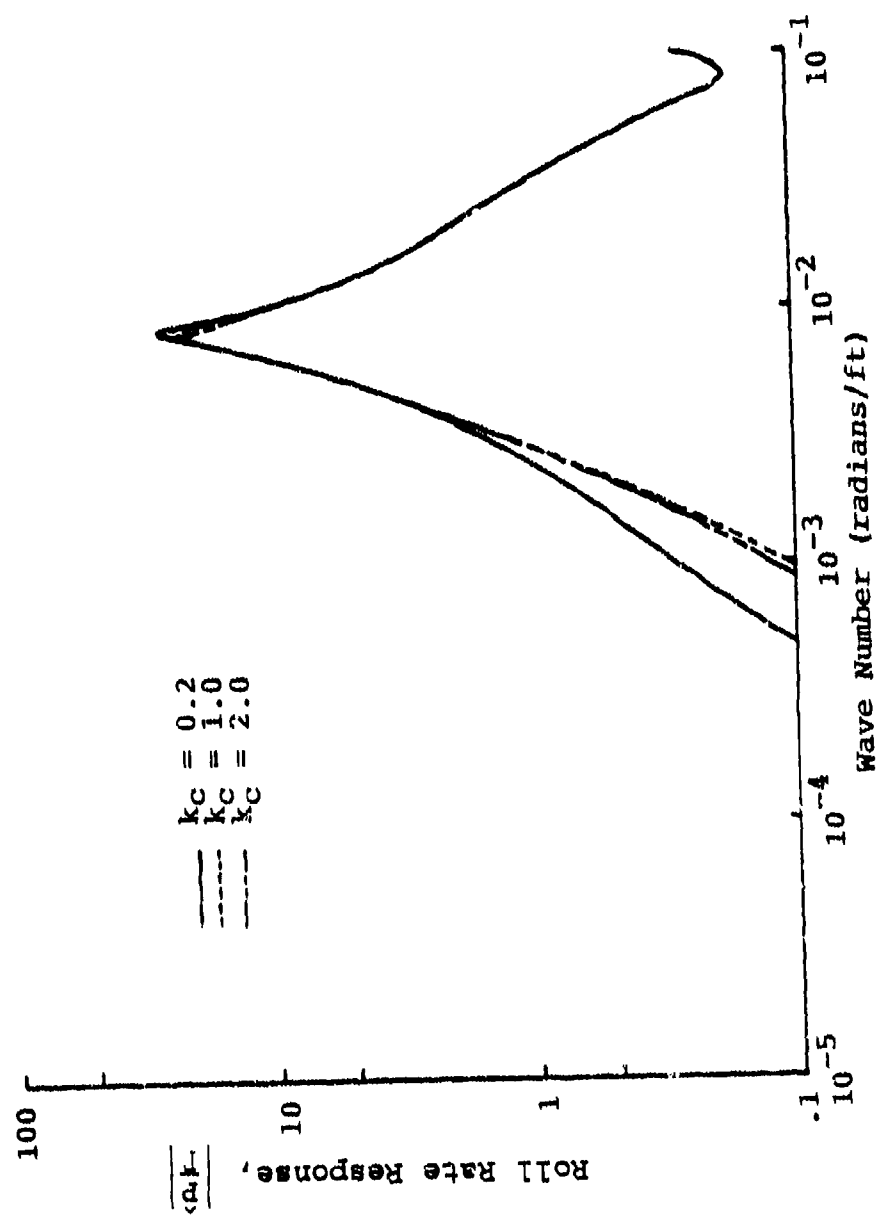


Figure 14. Roll Rate Response

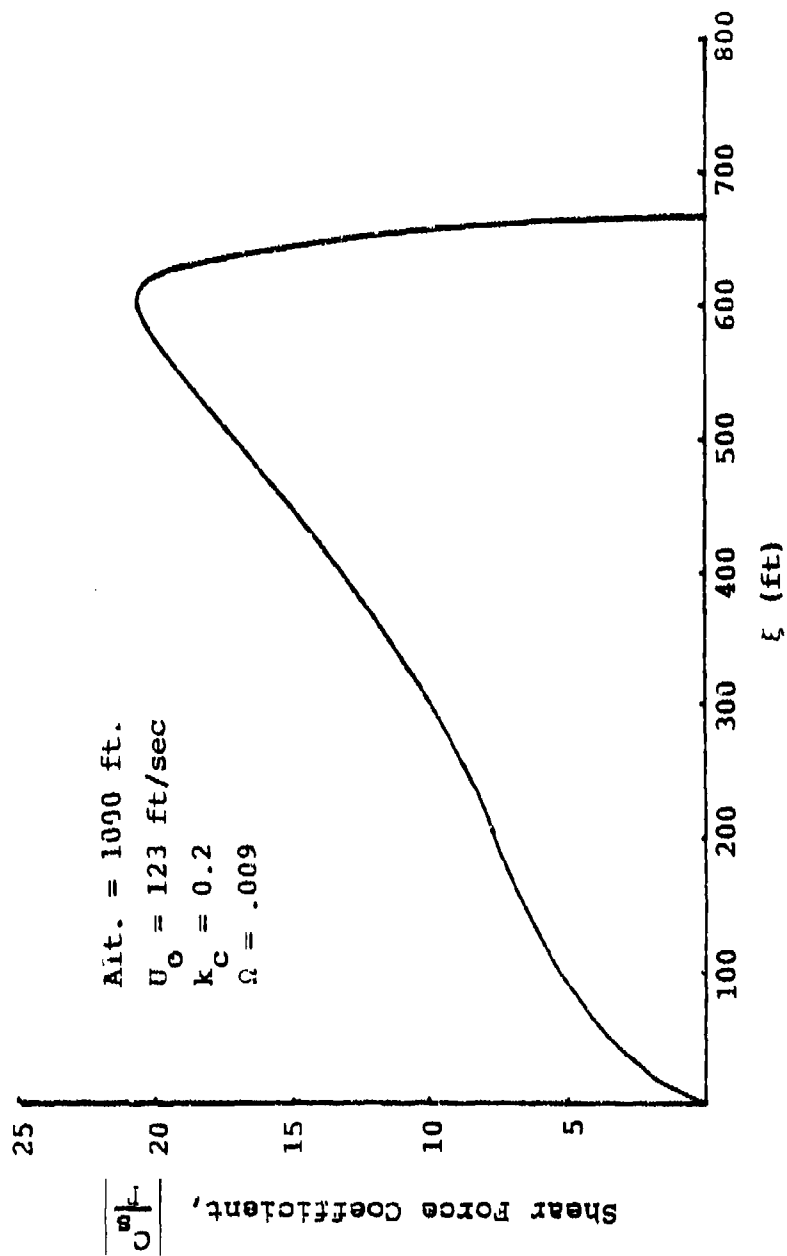


Figure 15. Shear Force Coefficient

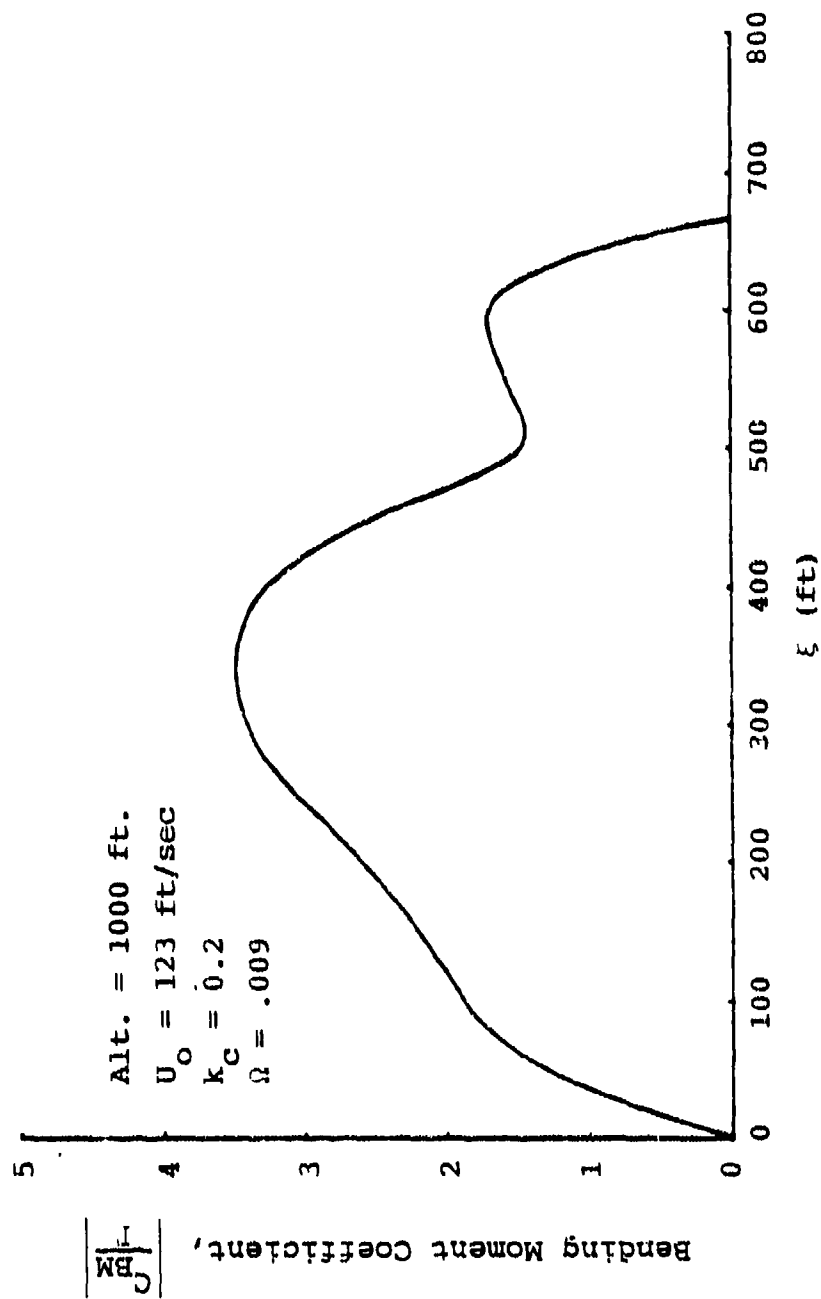


Figure 16. Bending Moment Coefficient

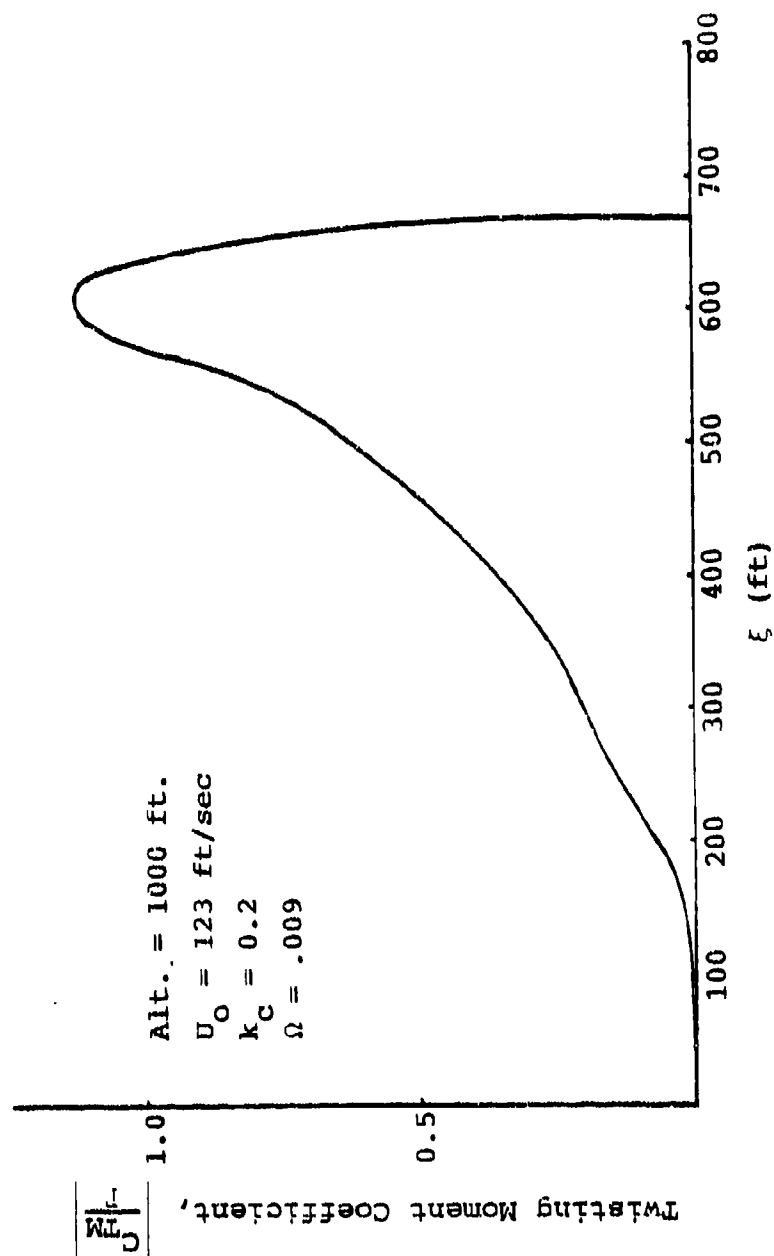


Figure 17. Twisting Moment Coefficient

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