A NONLINEAR MATHEMATICAL MODEL OF MOTIONS
OF A PLANING BOAT IN IRREGULAR WAVES

by

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SEPTEMBER 1979

DTNSRDC/SPD-0867-01
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**Planing Boat, Hydrodynamic Impact, Small Boat Seaworthiness, Nonlinear Ship Motions in Waves**

A computer program previously developed to estimate the motions and accelerations of a planing craft in regular waves was modified and extended to compute the corresponding motions in random or irregular waves. Ten regular waves with random phase were combined to represent the random seaway. The amplitudes and frequencies that were selected represent the energy distribution of a Pierson-Moskowitz spectrum for a fully developed sea. A comparison of computed results with experiment indicates that the computer program can predict craft behavior with reasonable quantitative
Accuracy in moderate operating conditions. In severe operating conditions, however, the amplitudes of the computed vertical accelerations, which include impacts, are one-half of the experimental values.
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<tr>
<td>LCG</td>
<td>Longitudinal center of gravity percent of $L$</td>
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<td>$M$</td>
<td>Mass of craft</td>
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\[ V \]
NOTATION (CONT)

\( M_a \)  
Added mass of craft

\( m_a \)  
Sectional (two-dimensional) added mass

\( N \)  
Hydrodynamic force normal to baseline

\( r^- \)  
Ratio of negative maximum to total maximum

\( r \)  
Wave elevation, positive down, feet

\( r_i \)  
Wave amplitude of \( i \)th component

\( U \)  
Relative fluid velocity parallel to baseline

\( V \)  
Relative fluid velocity normal to baseline

\( V/\sqrt{L} \)  
Speed-to-length ratio in knots/ft\(^{1/2}\)

\( W \)  
Weight of craft

\( w_z \)  
Vertical component of wave orbital velocity, positive down

\( x \)  
Fixed longitudinal axis; also the coordinate of a point relative to the origin of body axis.

\( x_{CG} \)  
Surge velocity

\( \ddot{x}_{CG} \)  
Surge acceleration

\( x_{CG} \)  
Longitudinal distance from origin of fixed axis to CG of the body

\( z \)  
Fixed vertical normal axis; also the coordinate of a point relative to the origin of body axis, positive down

\( z_{CG} \)  
Heave acceleration of the CG

\( z_{CG} \)  
Heave displacement of the CG, positive down

\( \beta \)  
Deadrise angle

\( \Delta \)  
Hull displacement \( \Delta \)

\( \zeta \)  
Normal body axis; also the coordinate of a point relative to the origin of body axis

\( \eta \)  
Vertical acceleration (i.e., in direction of \( \zeta \) axis)

\( v_f \)
NOTATION (CONT)

\( \theta \)  
Pitch angle

\( \dot{\theta} \)  
Pitch angular velocity

\( \ddot{\theta} \)  
Pitch angular acceleration

\( \theta_{50} \)  
Pitch crest or trough corresponding to 50% probability point, degrees

\( \theta_{90} \)  
Pitch crest or trough corresponding to 90% probability point, degrees

\( \xi \)  
Longitudinal body axis; also the coordinate of a point relative to the origin of body axis

\( \rho \)  
Density of water

\( \sigma_i \)  
Phase angle of ith component

\( \omega \)  
Wave frequency

\( \omega_p \)  
Peak frequency of wave spectrum

\( \ell \)  
Wetted length

\( \Omega \)  
Nondimensional frequency, \( \omega / \omega_p \)

\( \epsilon \)  
Spectral width parameter
ABSTRACT

A computer program previously developed to estimate the motions and accelerations of a planing craft in regular waves was modified and extended to compute the corresponding motions in random or irregular waves. Ten regular waves with random phase were combined to represent the random seaway. The amplitudes and frequencies that were selected represent the energy distribution of a Pierson-Moskowitz spectrum for a fully developed sea. A comparison of computed results with experiments indicate that the computer program can predict craft behavior with reasonable quantitative accuracy in moderate operating conditions. In severe operating conditions, however, the amplitudes of the computed vertical accelerations, which include impacts, are one-half of the experimental value.

ADMINISTRATIVE INFORMATION

This work has been authorized by the Naval Material Command (08T2); under Program Element 625 43 N, Task Area ZF43-421-001, administered by the Ship Performance Department, High Performance Vehicle Program Office, Code 1512.
INTRODUCTION

In a previous study\(^1\) a computer program was developed to estimate the motions and accelerations of a planing craft in regular waves. As a logical extension of this work, the program was modified to compute the motion of the craft in random or irregular waves.

Since the mathematical model is nonlinear, the computations are made in the time domain. Ten regular waves are combined with random phase to represent the random seaway. The amplitudes and frequencies are adjusted to conform to the energy distribution in a Pierson-Moskowitz fully developed sea.

The mathematical model was developed for a V-shaped prismatic-body with hard chines and constant deadrise planing at constant speed. The thrust and the friction drag forces are assumed to act through the center of gravity. The vertical components of the thrust and fiction drag are also assumed to be negligible in comparison to the hydrodynamic forces.

The mathematical formulation is analogous to low-aspect-ratio wing theory with provisions for including hydrodynamic impact loads, essentially a strip theory. Surface wave generation and forces associated with unsteady circulatory flow are neglected, and the flow is treated as quasi-steady. The mathematical formulation is an empirical synthesis of several theoretically derived flows describing the overall craft hydrodynamics.

MATHEMATICAL FORMULATION

EQUATIONS OF MOTIONS

The equations of motion for a planing craft restricted to pitch \(\theta\), heave \(z_{CG}\), and surge \(x_{CG}\) can be written as
\[ M_{x_{CG}} = T_x - N \sin \theta - D \cos \theta \]
\[ M_{z_{CG}} = T_z - N \cos \theta + D \sin \theta + W \]
\[ I\ddot{\theta} = N_x - D_x + T_x_p \]

where \( M \) is mass of craft
\( I \) is pitch moment of inertia of craft
\( N \) is hydrodynamic normal force
\( D \) is friction drag
\( W \) is weight of craft
\( T_x \) is thrust component in \( x \) direction
\( x_c \) is distance from center of gravity (CG) to center of pressure for normal force, positive forward
\( x_d \) is distance from CG to line of action for friction drag force
\( x_p \) is moment arm of thrust about CG.

Motions are measured relative to a fixed coordinate system with the \( x \) axis located in the undisturbed free surface pointing in the direction of travel and the \( z \) axis pointing downward.

Since the perturbation velocities in the forward direction are small in comparison to the speed of the craft, the equations of motion can be simplified by neglecting them and by setting the forward velocity equal to a constant, i.e.,

\[ \dot{x}_{CG} = \text{CONSTANT} \]

Furthermore, if it is assumed that the vertical components of the thrust and friction drag forces are small in comparison to the hydrodynamic forces
and that the total thrust and friction drag forces are acting through the center of gravity (so as to produce no moments) the equations of motion can be written as

\[
\begin{align*}
\ddot{x}_{CG} &= 0 \\
\ddot{M}_{CG} &= -N \cos \theta + W \\
I \ddot{\theta} &= N \dot{c}
\end{align*}
\]

A so called "strip theory" is used to obtain the hydrodynamic force acting on the body by integrating the 2-D hydrodynamic forces normal to the baseline over the wetted length of the body. A body coordinate system \((\xi, \zeta)\) with its origin at the CG and the \(\xi\) axis pointing forward parallel to the baseline of the body as shown in Figure 1 is used to facilitate this integration.

The normal hydrodynamic force per unit length \(f\), acting at a section, is assumed to be proportional to the rate of change of momentum associated with an added mass term and the cross flow drag, i.e.

\[
f = \frac{D}{dt} (m_a V) + C_{D, c} \rho b V^2
\]

where \(V\) is the velocity in plane of the cross section normal to the baseline.

- \(m_a\) is the added mass associated with the section form
- \(C_{D, c}\) is the crossflow drag coefficient
- \(\rho\) is the density of the fluid
- \(b\) is the half beam

Expanding the momentum term results is

\[
\frac{D}{dt} (m_a V) = m_a \dot{V} + V m_a \dot{\dot{V}} - \frac{\partial}{\partial \zeta} (m_a V) \frac{d \zeta}{dt}
\]

where \(\zeta\) is the body coordinate parallel to the baseline; see Figure 1.
The last term on the right-hand side of the above equation takes into account the variation of the section added mass along the hull. This contribution can be visualized by considering the 2-D flow plane as a substantive surface moving past the body with velocity \( U = -d\zeta/dt \) tangent to the baseline. As the surface moves past the body, the section geometry in the moving surface may change with a resultant change in added mass. This term exists even in steady-state conditions and is the lift-producing factor in low-aspect-ratio theory.

For a V-shaped wedge the 2-D added mass is defined as

\[
m_a = k_a \frac{\pi}{2} b^2 (\zeta, t)
\]

where \( k_a \) is the added mass coefficient (assumed to be 1 in this study) and \( b \) is the wetted half beam. Once the chine becomes wetted the beam is assumed constant regardless of depth of penetration.

Cross-flow drag for a V section with separation at the chine is assumed equal to the drag of a flat plate \( (C_{D,c} = 1.0) \) corrected by the Bobyleff flow coefficient approximated by \( \cos \beta \), i.e.,

\[
C_{D,c} = 1.0 \cos \beta
\]

The Bobyleff flow coefficient is the theoretical ratio of the pressure on a V-section to that experienced by a flat plate for Helmholtz-type flow.

The same approximation is used for estimating the drag coefficient for nonwetted chine sections, using the instantaneous value of the half-beam at the free surface.

An additional force acting on the body is the buoyancy force \( f_B \). This force is assumed here in to act in the vertical direction and to be equal to the static buoyancy force multiplied by a correction factor,
\[ f_B = \alpha g A_R \]

where \( A_R \) is the cross-sectional area of the section, and \( \alpha \) is a correction factor. The full amount of the static buoyancy is not realized because at planing speeds the water separates from the transom and chines, reducing the pressure at these locations to atmospheric or less than the equivalent hydrostatic pressure. A greater reduction is realized in the buoyancy moment because of the corresponding shift in the center of pressure. Shuford\(^2\) in his work on steady-state planing recommended a factor of one-half to obtain the correct buoyancy force. In the following computations, the buoyancy force was corrected by a factor of one-half, i.e., \( \alpha = 1/2 \). The buoyancy moments, computed as the static buoyancy force multiplied by its corresponding moment arm, was corrected by an additional factor of one-half to obtain the proper mean-trim angles.

Integrating the 2-D hydrodynamic force over the wetted length of the craft \( (\xi) \) and taking the component in the \( z \) direction results in

\[
-N \cos \theta = F_z(t) = \int_0^L f(t) \cos \theta d\xi + \int_0^L f_B d\xi
\]

\[
= \left[ \int_0^L \{ m_a(\xi,t) \dot{V}(\xi,t) + \dot{m}_a(\xi,t) V(\xi,t) \}
- U(\xi,t) \frac{\partial}{\partial \xi} [m_a(\xi,t) V(\xi,t)]
+ C_{D,c}(\xi,t) \rho b(\xi,t) V^2(\xi,t) \right] \cos \theta d\xi
+ \alpha g A_R d\xi
\]

Similarly, the hydrodynamic moment about the CG is obtained by integrating the product of the normal force per unit length by the corresponding moment arm.

6
\[ F_\theta = -\int f(\xi,t) d\xi - \int b \cos \theta d\xi \]

\[ = \int \left\{ m_\theta(\xi,t) V(\xi,t) + m_\nu(\xi,t) V(\xi,t) \right\} d\xi \]

\[ - U(\xi,t) \frac{\partial}{\partial \xi} \left( m_\theta(\xi,t) V(\xi,t) \right) + C_{Dc}(\xi,t) \rho b(\xi,t) V^2(\xi,t) \]

\[ + a_{\rho A} \cos \theta \right\} d\xi \]

Wave excitation enters into the above equations through the geometrical properties of the wave, altering the wetted length and draft of the craft, and by the vertical component of the wave orbital velocity at the surface \( w_z \), altering the normal velocity \( V \). Diffraction has been neglected.

The horizontal component of orbital velocity is neglected, since it is assumed small in comparison with the forward speed \( \dot{x}_{CG} \). The velocities \( U \) and \( V \) may then be written as

\[ U = \dot{x}_{CG} \cos \theta - (\dot{z}_{CG} - w_z) \sin \theta \]

\[ V = \dot{x}_{CG} \sin \theta - \dot{\theta} + (\dot{z}_{CG} - w_z) \cos \theta \]

The depth of submergence \( h \) of the body at any point \( P(\xi,\tau) \) may be determined by

\[ h = z_{CG} - \xi \sin \theta + \xi \cos \theta - r \]

where \( r \) is the instantaneous value of the wave elevation directly above the point measured positive downward.

A more detailed derivation of the above integrals for the hydrodynamic force and moment is presented in reference (1). Although the hydrodynamic
forces and moment require integration over the wetted length, which may vary with time, the resulting equations of motion can be integrated in the time domain using numerical method such as the Runge-Kutta-Merson integration routine used in these studies.

**REPRESENTATION OF THE SEAWAY**

The seaway in general can be represented by an infinite sum of sine waves with random phase. In these studies, for the sake of computational economy, the seaway is represented by the discrete sum of ten harmonic waves with random phase

\[ r = \sum_{i=1}^{10} r_i \cos[k_i(x + c_i t) + \sigma_i] \]

where \( r_i \) is the wave amplitude, \( k_i \) is the wave number, \( c_i \) is the wave celerity, and \( \sigma_i \) is the random phase angle of the \( i \)th wave component.

Note that at point \( P(x,z) \) on the craft

\[ x = x_{CG} + \xi \cos \theta + \zeta \sin \theta \]

and

\[ x_{CG} = \int x_{CG} \, dt \]

Each frequency and wave amplitude is weighted in accordance with the energy distribution in a Pierson-Moskowitz spectrum for a fully developed sea. The Pierson-Moskowitz formulation for a continuous spectrum can be written as

\[ S(\omega) = \frac{A g^2}{\omega^5} e^{-B/\omega^4} \]

where \( A = 8.1 \times 10^{-3} \)

\( g \) = gravitational constant

\( B = \frac{4A g^2}{(H T/3)^2} \)

The constant \( B \) is also related to the peak frequency \( (\omega_p) \) of the spectrum.
by

\[ B = \frac{5}{4} \frac{\omega^4}{\omega_p} \]

which can be confirmed by differentiating the spectrum formulation and setting it equal to zero. Normalizing the frequencies by the peak frequency leads to a nondimensional spectrum \( \tilde{S} \) which is related to the dimensional spectrum by

\[ \tilde{S}(\Omega) = \frac{16}{\Omega^2} \frac{\Omega}{\Omega_p}^2 \tilde{S}(\omega=\Omega \omega_p) = \frac{5}{\Omega^5} e^{-5/4 \Omega^4} \]

where \( \Omega = \omega/\omega_p \)

and where

\[ \int_0^{\infty} \tilde{S}(\Omega)d\Omega = 1 \]

The discrete frequencies representing the spectrum varied from \( \Omega = .80 \) to 2.6 in nearly equal increments \( \Delta \Omega = 0.2 \). A slight random perturbation is given to each frequency to avoid precise integer multiple frequencies, thereby increasing the fundamental repetition period of the computed time history. Each discrete amplitude is adjusted so that its energy corresponds to that contained in a bandwidth (\( \Delta \Omega \)) centered about its frequency in the continuous spectrum i.e.,

\[ r_i^2 = \frac{H^2}{8} \frac{1}{\Omega^3} \int_{\Omega_i-\Delta \Omega/2}^{\Omega_i+\Delta \Omega/2} \tilde{S}(\Omega)d\Omega \]

The band widths are equally spaced between frequencies except for the first and last frequencies which lump all of the remaining energy at the beginning and end of the spectrum. Table 1 presents a list of the amplitude for each nondimensional frequency in terms of the significant wave height.

**COMPARISON OF COMPUTED RESULTS WITH EXPERIMENTS**

Computations of pitch and heave motions and bow and CG vertical
accelerations were made using the computer program (see Appendix) for comparison with the model experiments of Fridsma\(^3\). Fridsma tested a series of constant-deadrise models of various lengths in irregular waves to determine the effects of deadrise, trim, load, speed and sea state on the added resistance, heave and pitch motions and vertical accelerations at the bow and CG. Figure 2 shows the lines of the prismatic models. The computations were made with the Centers’ Control Data Corporation 6700 computer system. A listing of the computer program is presented in the Appendix.

Table 2 presents the characteristics of the model craft for those conditions selected for the comparison. The number of computer runs was kept to a minimum for economic reasons. Approximately one minute of central processor time was required for every second of data using model scale dimensions, and approximately 40 seconds of model scale data was required to obtain 100 cycles of amplitude data.

The output of the program is the time histories of the pitch and heave motions and the bow and CG accelerations. Sample plots of the outputs are shown in Figures 3 and 4. Procedures required for processing and analysing the data are not a part of this study. In order to facilitate the comparison, the analysis procedures followed in this report are those used by Fridsma\(^3\) for his experimental data. The amplitudes (maxima or minima) of the pitch and heave motions about the mean are assumed to be described by the so called "Generalized Rayleigh Distribution." i.e.,

\[
p(y) = \frac{1}{\sqrt{2\pi}} e^{-y^2/\epsilon^2} + (1 - \epsilon^2)^{1/2} e^{-y^2/\epsilon^2} \int_{-\infty}^{y(1-\epsilon^2)} e^{-x^2/2} dx
\]

where \(y\) = maximum or minimum (absolute values) normalized by the standard deviation,
\[ \epsilon^2 = 1 - (1 - 2r^-)^2 \]

and \( r^- \) = ratio of negative maxima to total maxima or positive minima to total minima.

To fit the data to this distribution the crests (maxima) and troughs (minima) relative to the mean value are first determined from time histories of the motions. The mean value is defined as halfway between the average crest and average trough value. The crests or trough data \((X_i)\) are sorted in ascending order and grouped into fifteen intervals. At the same time, the proportion \( r^- \) of negative maxima to total maxima or positive minima to total minima is determined. The cumulative frequency and corresponding probability that a crest or trough is less than or equal to the interval value \((X_i)\) is then computed. From the probability and \( r^- \) values, the theoretical value of the normalized amplitude \((y)\) is calculated. A plot of \( X_i \) versus corresponding \( y \) values is compared with a line drawn through \( x = y = 0 \), and the point, \( x = \bar{x}, y = \bar{y} = \sqrt{\pi/2}(1 - 2r^-) \) which is indicative of the fit of the theoretical distribution function to the data. The values \( x \) and \( y \) are the observed average value of the first moment and the theoretical average value (normalized) respectively.

Figures 5 and 6 show typical examples of such plots for the pitch and heave crests and troughs. As can be seen in these figures, the data fit the assumed probability function reasonably well, but it is also quite possible that some other distribution might fit the data better.

The acceleration data were assumed to follow a simple exponential distribution. For this distribution, the probability, \( P \) of the acceleration peak \( n \) being less than a given value is

\[ P(n) = 1 - e^{-n/\bar{n}} \]
where $\overline{a}$ = average peak acceleration.

Only the negative peak accelerations (impact spikes as well as wave induced) were analyzed. The data were sorted and grouped into fifteen intervals similar to the motion data analysis and the probability was plotted with respect to $\eta$ on inverted semilog paper. For a good fit, the data should follow a straight line through the point ($P = 0.368, \eta = \overline{a}$) and the origin. Figure 7 shows a sample of the acceleration data plotted in the above manner. An exponential probability function appears to be a good fit to the data.

Table 3 presents a comparison of the computed motions and accelerations with the corresponding experimental results. The computations were made for a craft with a length to beam ratio ($L/b$) of 5, a deadrise angle ($\beta$) of 20 degrees and a speed length ratio ($V/\sqrt{L}$) of 6 for several sea states with significant wave height to beam ratios ($H_{1/3}/2b$) of .222, .444 and .666 which would correspond to Sea states 2, 3, and 4 respectively for a 50 foot craft. Computations were also made in sea condition with $H_{1/3}/2b$ of .444 for a speed length ratio of 4 at $\beta$ of 10, 20 and 30 degrees deadrise angles.

The tabulated values for the heave and pitch are those with a 50 percent and those with a 90 percent probability of not being exceeded. Heave is nondimensionalized by the beam. The values for the bow and CG accelerations are the average values of the negative peaks.

Other statistical variables such as the $1/3$ or $1/10$ highest values can be computed from the specific probability distribution. For the assumed distribution of the motion amplitudes, the $1/10$ highest value is related to the 90% probability value by the ratio of $y_{1/10}/y_{90}$, which is
approximately 1.33 over the r' value range measured. The 1/10 highest accelerations from the exponential distribution is 3.30 \bar{n}.

Plots of the data in Table 3 are also presented in Figure 8 through 13. Figures 8 through 10 show respectively a comparison between the computed and experimental results of the variation in the 90 percent probability values for the pitch and heave motions, and the average values for the bow and CG accelerations, with significant wave height to beam ratio. Figures 11 through 13 show similar plots for the variation with deadrise angle.

The pitch data in the figures show that while the computed troughs (bow down) are in reasonable agreement with the experiment, the computer crests are lower than the experiment. The heave exhibits the same trend with the computed crests (CG down) being in reasonable agreement with the experiment and troughs being lower than the experiment. Furthermore, the 90 percent probability values for the pitch and heave crests and troughs for the computer model are about equal in magnitude; whereas, the experimental model values in the pitch bow up and heave CG up direction are greater. It appears that the experiment model exhibits more nonlinearity than the computer model.

The computed acceleration data for the bow and CG are generally lower than the corresponding experiment data. Figures 10 and 13 show that the computed accelerations differ by 15 percent to 50 percent of the corresponding experiment values with the largest differences occurring in the more severe conditions where the accelerations are extremely high.

For example, at the ten degree deadrise angle condition presented in Table 2, the average 1/10 highest bow acceleration corresponds to about
24 g's for the experiment and 11 g's for the computed value. It is
doubtful that any operational boat would be driven to such extreme conditions.

The characteristics of the experiment model motions appear to be
slightly different from those of the computer model in very extreme
conditions. The experiment model experienced larger pitch bow up and heave
motion than the computer model, which probably resulted in larger impact
accelerations. This does not completely explain the differences between
the experiment and computed vertical accelerations which may also
reflect a deficiency in the mathematical representation of the impact
phenomenon, and perhaps the seaway as well.

In less severe conditions the agreement between computed and experiment
results is better. Good results can be expected for speed length ratios up
to approximately 6 in a seaway with significant wave height to beam ratio
of 0.222 (State 2 sea for a 50 foot craft). For a significant wave height
to beam ratio of 0.444 (State 3 for a 50 foot craft), the calculations
could probably be used to predict reasonable quantitative results up to a
speed length ratio of 4. In more extreme conditions the computed results are
less accurate quantitatively, but are still indicative of gross trends.

SUMMARY AND CONCLUSIONS

A computer program was developed to compute the motions and accelerations
of simple prismatic planing craft in head irregular waves. This was
achieved by incorporating irregular waves into an existing program for
computing the motions in regular waves. The irregular waves were synthe-
sized by combining ten regular waves with random phase and with frequencies
and amplitudes weighted to represent a Pierson-Moskowitz spectrum for
fully developed seas.
Computations were made for a craft with a length to beam ratio of 5, a deadrise angle of 20 degrees and a speed length ratio of 6 for several sea states, and in a single sea state for a speed length ratio of 4 with 10, 20 and 30 degrees deadrise angles. The results were compared with the experiment results of Fridsma. First the probability distributions of the crests and troughs of the motions and accelerations were examined to determine whether or not they were the same as those obtained by the experiments. It was found that the fit of the pitch and heave crests and troughs to the "Generalized Rayleigh Distribution" which was used in the experiment data analysis, was acceptable for the computed data, but no attempt was made to fit the data to other types of distribution which might have fitted better. The computed acceleration data, fitted an exponential type of distribution.

A comparison of the motions showed that the computed pitch troughs were in good agreement with the experiment, but the crests (bow up) were lower than the experiment values. The heave exhibited the same trend, with the troughs (CG heave up) for the experiment being higher than the computed values while the crests were in good agreement.

Computed vertical accelerations at the bow and CG were, for certain conditions, much lower than the experiment values. At some conditions examined, the computed accelerations were about half of the comparable experiment values. This occurred at the more extreme operating condition where very large accelerations were experienced. For example, a value of 24 g's was obtained for the average of the 1/10 highest bow acceleration from the experiment for a craft with 10 degrees deadrise angle as compared to 11 g's from the computed results. These values were obtained in a seaway
with a significant wave height to beam ratio of 0.666 and a speed length ratio of 6 which represent an operating condition far more severe than that in which the boat would be expected to operate (42 knots in a State 4 sea for a 50 foot craft).

In summary it appears that the computer program can predict craft behavior quantitatively most effectively in moderate operating conditions. In severe operating conditions, probably beyond that in which the craft would be expected to operate, the computed vertical accelerations which include impacts are roughly one half the experiment values; however, despite the deficiency of the computer program in predicting quantitative results, the predictions are still indicative of gross trends.

Additional work is required to improve the prediction of the impact accelerations especially during the more severe conditions. Towards this end, it would be desirable to compare the time histories of experimental motion and acceleration data with the corresponding computed values. It may be possible to modify the hydrodynamic coefficients in the mathematical model on the basis of experimental results, specifically those affecting impact acceleration, and greatly improve the correlation. It is recommended that if additional model experiments are conducted, time histories of the motions and accelerations along with the wave height be made available for the above studies.

ACKNOWLEDGMENT

Acknowledgment is given to Ms. Dana Gentily of ORI, Inc., who prepared the computer programs for statistical analysis of the data.
REFERENCES


<table>
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<th>$\Omega$</th>
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**TABLE 2**

MODEL CHARACTERISTICS AND WAVE CONDITIONS FOR COMPUTATIONS

Model Length = 114.3 cm (3.75 ft)
Length/Beam = 5; $C_\Delta = 0.600$

<table>
<thead>
<tr>
<th>COMPUTER RUN</th>
<th>SYMBOL</th>
<th>$\beta$ DEGREE</th>
<th>LCG PERCENT L</th>
<th>RADIUS OF GYRATION PERCENT L</th>
<th>$V/\sqrt{C}$</th>
<th>$H_{1/3}/2b$</th>
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<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>20</td>
<td>64.0</td>
<td>24.8</td>
<td>6</td>
<td>0.222</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>20</td>
<td>64.0</td>
<td>24.8</td>
<td>6</td>
<td>0.444</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>20</td>
<td>64.0</td>
<td>24.8</td>
<td>6</td>
<td>0.666</td>
</tr>
<tr>
<td>4</td>
<td>O</td>
<td>20</td>
<td>66.8</td>
<td>25.0</td>
<td>4</td>
<td>0.666</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>10</td>
<td>68.0</td>
<td>25.0</td>
<td>6</td>
<td>0.444</td>
</tr>
<tr>
<td>6</td>
<td>G</td>
<td>30</td>
<td>62.1</td>
<td>25.0</td>
<td>6</td>
<td>0.444</td>
</tr>
<tr>
<td></td>
<td>Crest</td>
<td>Trough</td>
<td>Crest</td>
<td>Trough</td>
<td>Crest</td>
<td>Trough</td>
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<tr>
<td>----------------</td>
<td>-------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
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<td>--------</td>
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<tr>
<td><strong>PITCH (DEGREES)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Computed</td>
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<td>1.67</td>
<td>0.108</td>
<td>1.75</td>
<td>0.122</td>
<td>0.060</td>
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<tr>
<td>Experiment</td>
<td>0.155</td>
<td>2.13</td>
<td>0.080</td>
<td>2.20</td>
<td>0.146</td>
<td>0.067</td>
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<tr>
<td>Computed</td>
<td>0.105</td>
<td>3.93</td>
<td>0.139</td>
<td>3.85</td>
<td>0.196</td>
<td>0.213</td>
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<tr>
<td>Experiment</td>
<td>0.182</td>
<td>5.61</td>
<td>0.064</td>
<td>4.34</td>
<td>0.024</td>
<td>0.265</td>
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<tr>
<td>Computed</td>
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<td>5.53</td>
<td>0.151</td>
<td>5.48</td>
<td>0.085</td>
<td>0.414</td>
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<td>Experiment</td>
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<td>6.71</td>
<td>0.200</td>
<td>6.27</td>
<td>0.192</td>
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<tr>
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<td>0.101</td>
<td>8.18</td>
<td>0.500</td>
<td>7.47</td>
<td>0.140</td>
<td>0.447</td>
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<tr>
<td>Experiment</td>
<td>0.126</td>
<td>6.66</td>
<td>0.097</td>
<td>3.63</td>
<td>0.146</td>
<td>0.209</td>
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<tr>
<td>Computed</td>
<td>0.143</td>
<td>3.98</td>
<td>0.134</td>
<td>3.91</td>
<td>0.044</td>
<td>0.226</td>
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<tr>
<td>Experiment</td>
<td>0.121</td>
<td>4.72</td>
<td>0.131</td>
<td>4.70</td>
<td>0.132</td>
<td>0.233</td>
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<tr>
<td>Computed</td>
<td>0.177</td>
<td>5.78</td>
<td>0.094</td>
<td>4.67</td>
<td>0.062</td>
<td>0.259</td>
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</table>
Figure 2 - Lines of Prismatic Models
(From Reference 3)
Figure 3 - Sample of Computed Pitch and Heave Motion
CG ACCELERATION

$\beta = 20^\circ$

$V / \sqrt{C} = 6$

$H_{1/3} / 2b = 0.444$

Figure 4 - Sample of Computed Bow and CG Acceleration
Figure 5 - Example of Pitch Motion Correlation with Generalized Rayleigh Distribution
Figure 6 - Example of Heave Motion Correlation with Generalized Rayleigh Distribution

Figure 7 - Example of Bow and CG Acceleration Correlation with Exponential Distribution
Figure 8 - Comparison of Computed and Experimental Pitch Variation with Significant Wave Height

Figure 9 - Comparison of Computed and Experimental Heave Variation with Significant Wave Height
Figure 10 - Comparison of Computed and Experimental Bow and CG Acceleration Variation with Significant Wave Height

Figure 11 - Comparison of Computed and Experimental Pitch Variation with Deadrise Angle
Figure 12 - Comparison of Computed and Experimental Heave Variation with Deadrise Angle

Figure 13 - Comparison of Computed and Experimental Bow and CG Acceleration Variation with Deadrise Angle
APPENDIX

LISTING OF COMPUTER PROGRAM FOR MOTION COMPUTATIONS
PROGRAM MAIN(INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE3=312, TAPE2=512, TAPE4=512, TAPE4)

REAL MM, MMAX, N, NO, NL, KAR
INTEGER ENO

DIMENSION Y(6), FX(2, 2000)

COMMON /CUST/ MCO1, ECG, PI, DPH, RPU, GHA, VTY, RNH, NUM, MA(120), CO, TA,
H(120), META, R(120), T2, DR, X, DX, X0, M, IT,
1
DELTA, T, EST(120), KAR, MMAX(120), TEST(120),
1
H(120), PTMF
COMMON /SHIF/ MAS5, CINT, OA, CE, CE2, CE3, DMU, EUMU, E3DMU, E3DUMU, B, GM

COMMON /IN/ H(I120), R(I120), VELIN
COMMON/OUT/NPLINT, NPLOT, ENU
COMMON/TEH(5, I1), T2, T3, T4, T5, T6, T7, T8
COMMON/THENS/ START, RISE, RAHM
COMMON /INTER/ II, KTT(110), DIFF(110)
COMMON /INP/ NG(I120), XI, XE, MMAX, H(120), EPS(6)
COMMON /ACC/ SHFP, B#ACL, COACL, BL

CALL INPUT

C COMPUTE INTEGRATION INTERVAL INFORMATION
C
NLESS = NUM-1
I = 1
II = 1
DIFFX = EST(I+1)-EST(I)
KTT(I) = 1
DIFF(I) = DIFF
GO TO 25 IF(II.GT.10) STOP 4
GO TO 25 II = I+1
KTT(I) = 1
DIFF(I) = DIFF
25 CONTINUE
KTT(I) = KTT(II)+1

C * * * CHECK IF NUMBER OF INTERVALS EXCEEDS DIMENSION
IF (II.GT.10) STOP 4

C * * * POINT AT WHICH MULTIPLE RUNS START
B CONTINUE
CALL SEAWAY
CALL TABLE
TIME=EI
COUNT=1
END=END-1
WRITE(6, 39)

3) FORMAT(1H1)
C
C * * * READ IN INITIAL CONDITIONS
C X(I) = VELOCITY* X(2) = Z OUT* X(3) = THEA DOT
C X(4) = X* X(5) = Z* X(6) = THEA
C
C THEA IS =EAU IN DEGREES THEN CONVERTED TO RADIANS IN PROGRAM
READ(5,10) (X(I),I=1,L6)
C DATA: USED IN RAMP FUNCTION, TO TURN ON WAVE
READ(5,10) START,RISE
C
10 FORMAT(1H6.4)
C • • • • • • WRITE OUT THE INPUT VALUES
WRITE(6+19) START,RISE,KAR
19 FORMAT(1H6.4) START = "*F10.4"/"" RISE = "*F10.4"/"" KAR = "*F10.4"
C
C THE IS THE TIME AT WHICH THE INTEGRATION INTERVAL IS
C TO BE CHANGED
C MAX IS THE NEW MAXIMUM INTERVAL SIZE AFTER TIME THE
C MN IS THE NEW MINIMUM INTERVAL SIZE FOR RUNTIME TO SUB-DIVIDE
C THE MAXIMUM INTERVAL UP TO
C IF THIS OPTION IS NOT USED SET THE TO THE STOP TIME OF THE RUN
C
READ(5,10) TIME,MAX,MIN
WRITE(6+11) TIME,MAX,MIN
11 FORMAT(1H6.4) AT TIME = "*F10.4" THE MAXIMUM INTERVAL SIZE FOR INTEGRATION IS
• ON WILL BE CHANGED FROM "*F10.4", TO "*F10.4", +
• AND THE MINIMUM SIZE FOR HALVING CHANGES FROM "*F10.4", +
• TO "*F10.4", +
C ADJUST THE TIME FOR CHANGE OF INTEGRATION INTERVAL
C FOR CHECK AGAINST TIME IN THE INTEGRATION LOOPS
C TM = TIME-(MAX/2.)

C IPT = 0
IF(TIME.EQ.1E) IPT = 1
C
READ(5+10) PE=CAT
ACCL = ECCL*PE+BL
RACCL = ECCL*PE+ACCL
WRITE(6+12) PE,CAT,ACCL
12 FORMAT(1H6.4) THE X USED FOR THE BW AND CG ACCELERATION COMPUTATIONS
.IS EQUAL TO ECG="*F10.4",=H OR =F10.4)
C
WRITE(6+3)
WRITE(6+7)
23 FORMAT(1H5.4)
47 FORMAT(1H6.4) STATION NO.,~X,~DEAD RISE="*F10.4",EST="*F10.4",MIN=
CAN, "*F10.4"

WRITE(6+52) ((L+EST(I)+NO(I)+SM(I))=I=1,NUM)
53 FORMAT(6X125X,F10.4,F10.4,F10.4,F10.4,F10.4)
WRITE(6+3)
WHITE (5+58) (A(I)=1=I=6)
56 FORMAT(1H4.4) VALUES: "*X,~F10.4,~X,~F10.4,~X,~F10.4"
C • • • • • • • WRITE OUT COMMUTED ANGLES
C WRITE(6+7)M=11,PHALF,PI,WHALY
IF(N=1,N,LT续航) UN TO 62
WHITE (6+54) (T(I)=I=1,NUM)
WRITE (6+54) (S(I)=I=1,NUM)
WRITE (6+54) (MAX(I)=I=1,NUM)
WRITE (6+54) (MIN(I)=I=1,NUM)
C
C • • • • • • • WRITE OUT COMMUTED ANGLES
C WRITE(6+7)M=11,PHALF,PI,WHALY
IF(N=1,N,LT续航) UN TO 62
WHITE (6+54) (T(I)=I=1,NUM)
WRITE (6+54) (S(I)=I=1,NUM)
WRITE (6+54) (MAX(I)=I=1,NUM)
WRITE (6+54) (MIN(I)=I=1,NUM)
62 CONTINUE
   WRITE(6,28) (AT(1:1)+DIFF(1:1)=T(1:1))
28 FORMAT(* T=UFF * T=10.4)
51 FORMAT (43 M= 8F10.4,43 I= 8F10.4,43 PI=RMV/2= 8F10.4,43 1 SH PI= 8F10.4,10M GRAVITY= 8F10.4)
   CONTINUE
   WRITE(6,29) (AT(1:1)+DIFF(1:1)=T(1:1))
29 FORMAT(* T=UFF * T=10.4)
   CONTINUE
   WRITE(6,28) (AT(1:1)+DIFF(1:1)=T(1:1))
   MAIN 120
   MAIN 121
   MAIN 122
   MAIN 123
   MAIN 124
   MAIN 125
   MAIN 126
   MAIN 127
   MAIN 128
   MAIN 129
   MAIN 130
   MAIN 131
   MAIN 132
   MAIN 133
   MAIN 134
   MAIN 135
   MAIN 136
   MAIN 137
   MAIN 138
   MAIN 139
   MAIN 140
   MAIN 141
   MAIN 142
   MAIN 143
   MAIN 144
   MAIN 145
   MAIN 146
   MAIN 147
   MAIN 148
   MAIN 149
   MAIN 150
   MAIN 151
   MAIN 152
   MAIN 153
   MAIN 154
   MAIN 155
   MAIN 156
   MAIN 157
   MAIN 158
   MAIN 159
   MAIN 160
   MAIN 161
   MAIN 162
   MAIN 163
   MAIN 164
   MAIN 165
   MAIN 166
   MAIN 167
   MAIN 168
   MAIN 169
   MAIN 170
   MAIN 171
   MAIN 172
   MAIN 173
   MAIN 174
   MAIN 175
   MAIN 176
   MAIN 177
   MAIN 178

C * * * * * WRITE READINGS AND CONDITIONS AT TIME = 0.
   91 FORMAT(11H1,2X,TIME",9X,"DOUTH",9X,"ZDOUT",9X,"THETA DOT",6X,
   * 1MX,YX,1M2+MTHETA+MZ+M1+M2+MTHETA+Z2+M2+CHFL*,
   * 4X*8HMVUZ ACCL=4*7HMVUZ ACCL=1//)
   WRITE(4,92) TIME,(X(I)+=1.0)+NL*FL*WACL*OACL
   WRITE(9) TIME,(X(1)+=4.0)+WACL*OACL
   KOUNT = KOUNT+1
   FX1=FX(1)+=X(5)
   FX2=(X(1)+=X(6)
   IKUTS = (TIME=XX)/HMAX + (X=TIME)/HMAX + .05
   FIRST=0.0
   IKUTS=0
   C
   C START OF INTEGRATION LOOP
   C
   851 CONTINUE
   NPRINT = IPRINT
   C * * * * * CHECK PITCH 6GT .5236 RADIANS
   IF(X(6)+GT .5236) GO TO 853
   C * * * * * PERFORM INTEGRATIONS
   IF(TIME.LT.TM.UT.TME.EQ.TM) GO TO 98
   IF(IPT.EQ.1) GO TO 98
   MMIN = MMN
   MMAX = MMAX
   FIRST = 0.0
   C
   98 CONTINUE
   CALL KUTHRT(NES,TIME,HMAX,X,EPS=,AHMIN,FIRST)
   IKUTS=IKUTS+1
   IF(FIRST.EQ.2) GO TO 96
   IF((KOUNT.NE.1 AND KOUNT.NE.1) GO TO 99
   WRITE(4,91))
   KOUNT=1
   C
   C * * * OUT TIME INTERVAL RESULTS
   99 WRITE(4,92) TIME,(X(1)+=1.0)+NL*FL*WACL*OACL
   WRITE(6,93) (XX=X(I)+=1.0)+NL*FL*WACL*OACL
   WRITE(9) TIME,(X(1)+=4.0)+WACL*OACL
   IF(TIME.LT.TM.UT.TME.EQ.TM) GO TO 96
   IF(IPT.EQ.1) GO TO 20U
   CALL PLOT(I,FAXX*HMAX,1D1,IKUTS)
   IJ=1
   IC=1
   IC=0
   XA = TIME
   FIRST = U0.0
   HMIN = MMIN
   HMAX = MMAX
   20U CONTINUE
SUBROUTINE PLOT2(FMIN,FMAX,NVAR,NFUN,N,NX,NX0,DELA)
C
C PLOT FIRST N POINTS OF UP TO NFUN FUNCTIONS F(X)
C F(1,J) CONTAINS THE VALUE FOR THE JTH POINT OF THE ITH FUNCTION
C FMIN(I) AND FMAX(I) CONTAIN THE MIN AND MAX ORDINATE VALUES FOR
C THE ITH FUNCTION.
C
C NVARI1 AN ARRAY OF INDEXES FOR THE VARIOUS FUNCTIONS
C TO BE PLOTTED AGAINST THE ABSCISSA
C NFUN NUMBER OF FUNCTIONS TO BE PLOTTED - DIMENSION OF
C NVARI1, FMIN, FMAX
C N1 USED ONLY IN F(N1+1) AS PASSED DIMENSION
C N NUMBER OF POINTS IN A SINGLE PLOT FRAME
C XO FIRST ABSCISSA VALUE
C DELA X OSCISSA INCREMENT
C
DIMENSION XST(20),F(N1),FMIN(NFUN),FMAX(NFUN),VLAST(20),
1 VF1-ST(20),READ(6),STEP(26)
INTEGER CH(26),NVARI1,NFUN,OPT,STEP,PLUS,BLANK
INTEGER C, R(101)


C

UATA BLANK,OUT,ASTER,PLUS/IN \ IN+1,IN+1H,IN/

UATA CH(1),CH(2),CH(3),CH(4),CH(5),CH(6),CH(7),CH(8),CH(9),CH(10)

2 / 1K+,1M+,1H+,1M+,IN+1MH+1MH+1MH/ 

UATA CH(11),CH(12),CH(13),CH(14),CH(15),CH(16),CH(17),CH(18)

2 / 1M+,1M+,1H+,1M+,1H+,1H+,1R+1R+1R/ 

UATA CH(19),CH(20),CH(21),CH(22),CH(23),CH(24),CH(25),CH(26)

2 / 1IN+,1T+,1IN+,1IN+,1X+,1T+,1R+1R+1R/ 

C

IF(NFUN.LE.0,UN,N,LE.0) RETURN
C PRINT HEADINGS.
WRITE(6,46)
46 FORMAT (1H1)
   UO 60 I=1,N
30 TENH+ABS(FMAX(I)-FMIN(I))
   EXP=1.
   IF (TENH.EQ.0.) GO TO 2
C BRING TENH TO A VALUE BETWEEN 1 AND 10
   IF(TENH.LT.1.) GO TO 3
   EXP=EXP+10.
   TENH=TENH*10.
   GO TO 3
1 EXP=EXP+1.
   TENH=TENH+10.
   IF(TENH.GT.10.) GO TO 2
   GO TO 1
C SET UP VALUE BETWEEN GRID LINES, RSTEP.
   PSSTEP=5.
   IF(TENH.GE.5.) RSTEP=10.
   IF(TENH.LT.2.) RSTEP=2.
   RSTEP(I)=STEP*EXP(I)
C COMPUTE VALUE OF STARTING LINE, FVINST.
   FIRST=FMIN(I)/RSTEP(I)
   IF(FMIN(I).LT.0.) FIRST=FIRST+1.
   FVINST=FIRST-FINST
   IF(FVINST.LT.0.) GO TO 4
C CHECK END LINE VALUE=VLAST.
   VLAST(I)=FVINST(I)+10*RSTEP(I)
   IF(VLAST(I).LT.0.) GO TO 4
C IF GRAPH IS TOO SMALL TAKE NEXT LARGER STEP.
   A=PSTEM
   IF(AA.LT.1.) PSTEM=5.
   IF(AA.EQ.5.) PSTEM=10.
   IF(AA.LT.10.) GO TO 5
   PSTEM=2.
   EXP=10.*EXP
   GO TO 5
C COMPUTE VALUE BETWEEN POINTS, STEP.
   STEP(I)=-RSTEP(I)+1
   R=0.
   UO 6 KK=1,A
   HEAD(KK)=FVINST(I)+2*RKK*RSTEP(I)
   RKK=RKK*1.
   40 WRITE (6,45) CH(I), NVAR(I), (HEAD(KK),KK=1,6)
   45 FORMAT (1X,I1,1J1,J10=1X,A10,5X,1PE12.4,5(8X,1PE12.4))
   UO 50 J=1,101
   A(J)=BLANK
   IF(MOD(J,10).EQ.1) A(J)=DOT
50 CONTINUE
   WRITE(KK,50) A,A
   59 FORMAT (25X,1U1A1/15X,4MTIME+6X,10A1)
C PLOT EACH POINT
   UO 100 J=1,N
   B=X+FLDAT(J-1)*DELX
   UO 70 K=1,101
   A(K)=BLANK
   IF(MOD(K,10).EQ.1) A(K)=DOT
   IF(MOD(K+1,10).EQ.1) A(K)=DOT
   GO TO 100
C
CONTINUE

UD 60 (L+NU4
LOC=(F1(I,J)-F1ST(I))/STP(I)+1.5)
C=ALOC
A(LOC)=CH(I)
IF(C,ME,BLANK,AND.C,NE.DOT) A(IOC)=ASTER
CONTINUE

IF(MOD(J,10))JLGO TO VS
WRITE(6,85) A

FORMAT (25X+10A1)
GO TO 100

10 FORMAT (12X:+E12.4,1X+10A1)
CONTINUE

RETURN

SUBROUTINE KUTNER(K0,T,M,Y0,EPSE,A,N,MCX,FIRST)
DIMENSION Y0(0),Y1(6),F2(6),F0(6),F1(6),F2(5),EPSE(6),A(6)
COMMON/OUT/NPRINT,NSPLOT,END
COMMON/ACCEL/XACCEL,BWACCEL,EWACCEL
DATA NAME1,NAME2/CH1,2MY2/

NO = NUMBER OF EQUATIONS. NO. OF COMPONENTS OF Y0
T = INDEPENDENT VARIABLE
M = INCREMENT FOR WHICH SOLUTION IS TO BE RETURNED. OR -
Y0 = THE VECTOR OF DEPENDENT VARIABLES. ENTER WITH INITIAL
VALUES AT T AND RETURN WITH VALUES AT T-M
EPSE = RELATIVE ERROR CRITERION FOR COMPONENTS OF YO. LT. ABS(A)
A = ABSOLUTE ERROR CRITERION FOR COMPONENTS OF YO. LT. ABS(A)
NOTE -- EPSE AND A MUST BE SPECIFIED FOR EACH COMPONENT OF THE SYSTEM
MCX = THE SMALLEST STEP SIZE USED IN THE INTEGRATION
FIRST SHOULD BE 0 WHEN KUTNER IS ENTERED FOR THE FIRST TIME
AFTER THAT FIRST IS 1 IF KUTNER IS ENTERED WITH THE SAME M OR
IF IT IS ENTERED WITH A CHANGED M
IF FIRST IS 2 THE ERROR CRITERIA CANNOT BE MEET AND THE STEP SIZE
REDUCED TO 0.1/10.
C
- - - - - - FIRST ENTRY
10 MC = M
             IFLAG = I.
- - - - - - OTHER ENTRY
20 LOC = 0
MC = MC
IF (MC.NE.0) GO TO 30
WRITE(6+10A1)

FORMAT(5X+5MKUTNER ENTERED WITH ZERO INTEGRATION INTERVAL)
FIRST = 2
RETURN
C
- - - - - - CALLS TO DAUX
30 CALL DAUX(T+Y0,F0)
    IF(NPRINT.GT.3)WRITE(6,400)T+Y0,F0

400 FORMAT(0(C8.4,F8.4),4HTIME=25X+10.F4)
    IF(NPRINT.GT.3)WRITE(6,400)MC

3Y UD 60 =1+0
40 Y1(I) = Y1(I)+(MC/1.)*F0(I)
    IF(NPRINT.GT.3)WRITE(6,400)Y1(I)
C

KUTNER 8
KUTNER 9
KUTNER 10
KUTNER 11
KUTNER 12
KUTNER 13
KUTNER 14
KUTNER 15
KUTNER 16
KUTNER 17
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KUTNER 34
KUTNER 35
KUTNER 36
KUTNER 37
KUTNER 38
KUTNER 40
KUTNER 41
KUTNER 42
KUTNER 43
KUTNER 44
CALL DAUX(T+MC/3,Y1,F1)
IF(NPRINT ,F0.3) WRITE(6,400)F1,T
UO 50 I=I+10
50 Y1(I) = Y0(I)+(MC/6)*F0(I)+(MC/6)*F1(I)
IF(NPRINT,F0.3) WRITE(6,400)Y1,T
C
CALL DAUX(T+MC/2,Y1,F2)
IF(NPRINT,F0.3) WRITE(6,400)F2,T
UO 60 I=I+10
60 Y1(I) = Y0(I)+(MC/3)*F0(I)+(2/3)*MC*F2(I)
IF(NPRINT,F0.3) WRITE(6,400)Y1,T
C
CALL DAUX(T+MC/3,Y1,F3)
IF(NPRINT,F0.3) WRITE(6,400)F3,T
UO 70 I=I+10
70 Y1(I) = Y0(I)+(MC/6)*F0(I)+(MC/6)*F1(I)
IF(NPRINT,F0.3) WRITE(6,400)Y1,T

C - - - - - - - CHECK ERROR CRITERIA
UO 110 I=1,NU
Z2 = ABS(Y1(I)) - A(I)
IF (Z2) 85,87,88
C - - - - - - - ABSOLUTE ERROR
85 ERROR = ABS(Y1(I) - Y2(I))
IF (ERROR > 1) 100,100,90
C - - - - - - - RELATIVE ERROR
87 ERROR = ABS(Y1(I) - Y2(I)) / Y1(I)
IF (ERROR > 0.01) 100,100,90
C - - - - - - - SINCE ERROR GT. ERROR CRITERIA CHECK IF MC, GE, HT.
C - - - - - - - IF YES THEN HALVE INTERVAL, OTHERWISE STOP.
90 X = 128.*ABS(MC) - ABS(M)
IF(X) 91,95,96
C - - - - - - - ERROR YOU LARGE
91 WRITE(6,92)I,ERROR,MC
92 FORMAT(1X,'ERROR',1X,'MC')
   ERROR = E15.8,4M IS E15.8,1M STEP SIZE = E15.8
   FIRST = 0.
   RETURN
C - - - - - - - HALVE INTERVAL
95 MC = MC/2.
   PLOC = 2*PLOC
   LOC = 2*LOC
   MCX = MC
   WRITE(2,710)I,ERROR,MC
710 FORMAT(2X,10E13.5)
   13H HAS ERROR = E16.8,1M STEP SIZE NOW = E15.8
   WRITE(2,720)NAM1+(Y2(J)+J)+1,NU)
   WRITE(2,720)NAM1+(Y1(J)+J)+1,NU)
720 FORMAT(2X,1.2 / 3.10E13.5)
UO TO 30
C - - - - - - - TEST IF INTERVAL LENGTH CAN BE DOUBLED
100 IF (ERROR*MC < MSE(I)) 110,114,101
101 INC = 1
DO 20 J=1,10
MT = PTO* (J) + UTIME(J)
ANOX = PTPR,NTA
AS = ANO,1 (ANOX*x2000) = 499.
IS = AS
IC = IS + 500
UX = AS-IS
IF (IS*LT.-1 ± 200) IS = 2002-IS
IF (IC.LE.0) IC = -IC
IF (IC.GT.1000) IC = 2002-IC
UX = DX/PMTAU
AXIN = POINT(IS)
YCOS = POINT(IC)
ASIN = "POINT(IJ)
A940 = POINT(LJ)
CYOS = "POINT(IJ)
AX = PMTAU/AXIN
A940 = PMTAU/AYOS
50 CONTINUE
V1 = AL*V9

C = + + + + + Compute HW submergence of a point and R the wave
C = HW(I) IS IN THE FIXED COORDINATE SYSTEM
HW(I) = X(I) - E(I) + SX6 + N(I)*CXB - R(I)
IF (HW(I).LT.0) GO TO 65
C = Crafts is not submerged
MA(I) = 0.
B(I) = 0.
GO TO 75
65 U(I) = V1*AM
V(I) = HW(I)/(CXB-V(I)*SXB)
C = O(I) IS IN THE BODY AXIS SYSTEM AND IS THE SUBMERGENCE
IF (O(I).LE.0) TEST(I) GO TO 70
C = Crafts is partly submerged
B(I) = O(I)*U(I)*TA*PH
D(I) = O(I)*U(I)*TA*PH
MA(I) = KAR*HALF*O(I)*E(I)
GO TO 75
C = CHINE IS IMMERSLED
C = B1 array is used for the integrals over the portion
C = of the hull for which the CHINE is not immersed
70 MA(I) = MAXI
B(I) = BMI
VI(I) = 0.
75 CONTINUE
IF (NPRII .LE. 1) GO TO 85
WRITE (6,97) TIME
74 FORMAT (910,5E16.9)
WRITE (6,76) (X(I),I=1,10)
WRITE (6,77) (N(I),I=1,10)
WRITE (6,78) (I, I=1,11)
WRITE (6,79) (I, I=1,11)
WRITE (6,80) (I, I=1,11)
WRITE (6,81) (I, I=1,11)
76 FORMAT (X(I),S120)
**C** Computes NL and FL and the associated integrals

**CALL FUNCTION**

```plaintext
C IF(NPRINT.LT.4) GO TO 17
WRITE(6,15) TA,FL,DRAG,TZ,WNL,XX,TT,XP
15 FORMAT(1H144.10,1H106)
C CONTINUE
C IF(NPRINT.LT.3) GO TO 18
WRITE(6,16) (F(I+1),I=1,11)
16 CONTINUE
C Computes the F vector
F(1+1) = TA*FL*SX+DRAG*CX
F(1+2) = TA*FL*SX*DRAG*CX+W
F(3+1) = NL*DRAG*X*X
IF(NPRINT.LT.3) GO TO 18
WRITE(6,17) (F(I+1),I=1,11)
17 CONTINUE
C Computes the A matrix
A(1+1) = MASS*SL*SL
A(1+2) = MASS*SL*SL
A(1+3) = 0,
A(1+4) = 0,
A(1+5) = A(1+2),
A(2+2) = MASS*SL*SL
A(2+3) = -2*SL*SL
A(3+1) = A(1+3),
A(3+2) = A(1+3),
A(3+3) = 1+16,
IF(NPRINT.LT.1) GO TO 25
WRITE(6,18) (A(I+1),I=1,11)
WRITE(6,19) (A(I+1),I=1,11)
WRITE(6,19) (A(I+1),I=1,11)
18 CONTINUE
C Invert the A matrix
29 CALL MATINS(A+3+1,11,30,DETERM=ID,INDEX)
IF(ID.EQ.2) WRITE(0,20)
26 FORMAT(1H144.10,1H106)
C ON RETURN WILL CONTAIN THE INVERSE MATRIX
C ID=2 MATRIX IS SINGULAR
C =1 INVERSE WAS FOUND
C Computes the right hand side
RHS(1) = F(1+1)
RHS(2) = F(2+1)
RHS(3) = F(3+1)
RHS(4) = 0,
RHS(5) = A(1)
RHS(6) = X(2)
10 FORMAT(1H144.10,1H106)
11 FORMAT(1H144.10,1H106)
12 FORMAT(1H144.10,1H106)
13 FORMAT(1H144.10,1H106)
14 FORMAT(1H144.10,1H106)
```

42
30 IF(NPRINT.LT.6) GO TO 40  
WRITE(6,12) (A(I),I=1,3)  
WRITE(6,13) (A(I),I=1,3)  
WRITE(6,14) (A(I),I=1,3)  
WRITE(6,15) (A(I),I=1,3)  
35 FORMAT" RMS(i) *.6(2X,E12.6)"  
40 CONTINUE  
RETURN  
END

SURROUTINE FUNCT(A)
REAL IA,IAA,IPART,KPI,MA,MAS=M
INTEGER EN)
DIMENSION(IPART(I),C(I),C2(I))
IF(NPRINT.LT.6) GO TO 40
WRITE(6,12) (A(I),I=1,3) DAUX 160
WRITE(6,13) (A(I),I=1,3) DAUX 161
WRITE(6,14) (A(I),I=1,3) DAUX 162
WRITE(6,15) (A(I),I=1,3) DAUX 163
FORA4T0 QRI(S(I))',6(2X,0.15)
CONTINUE  
RETURN  
END

COMMON /SHIFPT/ M ASD+CINT+QA+CE+CE2+CE3+DMU*EMU*EMU+ZMU+EMU+BF*BMF

COMMON /CUCAST/ NCO*ECG+P1+PLR+BHP+GRAVITY+RMD+NUM+MA(120)+CD+TA,
B1(120)+BLT&+WM(120)+T2+UMA+XO+X+r+MA+IT
1 DELTA+ST+EST(120)+KAN+MA+MAX(120)+TEST(120)
, K(120)+PHALF
COMMON /H/ HM(120),B(120)+VLIN
CALL/OUT/NPRINT+NEPLOT+END
COMON /WAVE/ LMA+ZMMA+ZMMA+ZMMA+ZMMA+ZMMA+ZMMA+ZMMA+ZMMA+ZMMA
COMMON /WAVE2/ WU(120)+XWPT(120)+ACOSPT(120+20)+CX6+SX6
COMMON /WAVE2/ W(120)+X(120)+X(120)+X(120)+X(120)+X(120)+X(120)+X(120)
1 RO(20)+H(20)+M(20)+P(20)
COMMON /INTER/ II+KT(10)+DIFF(10)
COMMON/TRANS/START,RISE,RAMP
COMMON/TEST/ VMA
COMMON/LEAD/MA

C * * * * * * * * INITIALIZE INTEGRAL SUMS
MASS = 0.0  
QA = 0.0  
IA = 0.0  
CE = 0.0  
CE2 = 0.0  
UMJ = 0.0  
EMU=0.0  
E2MU=0.0  
LJMU=0.0  
BF = 0.0  
MM = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
MA = 0.0  
IPART+Q=+s1N(X(6))X(X(6))

C * * * * SET UP FUNCTIONS FOR INTEGRALS * * * *
DO 90 I=1+NUM
IPART(I)=C(I)*T(I)*MA(I)
QPART(I)=C(I)*MA(I)
ZWOT = 0.0  
90 CONTINUE

C * * * * * * * STOP
UWDT = 0.0
UDT = 0.0
UNDE = 0.0
XNE = X(J) + (N(I) + XE6 - E(I) + SX6)
XMEQ = X(J) - (E(I) + CX6 - N(I) + SXO)
UO 15 J = 1.0
ZWDT = -N0(J) * ASINT(J + 1)
ZWDT = ZWDT + ZWDT
UWDT = -N0(J) * ACOSPT(J + 1)
UDMT = DMT + UDMT
UWDT = -N0(J) * ASINT(J + 1) + (X(I) - XNE)
UWD = DMT + UWD
DMD = -R0(J) * ACUSPT(J + 1)
UWDE = DMD + DMD

IS CONTINUE
ZWD[1] = ZWDT + ZWDT
UNDE = DMD + DMD
UDRT = DMT + DMD
U = X(I) + CX6 + XE6 + ZWD[1] * SX6
IF (VEL + E(I) + U) GO TO 60
IF (X(I) + E(I) + U) GO TO 50
U1[1] = VEL + H1[1] * (X(2) - XNE) - UDMT
GO TO 51
50 U1[1] = U.
51 CONTINUE
C1[1] = VEL + VEL + E(I)
GO TO 61
60 U1[1] = U.
61 CONTINUE
UN[1] = E(I) + U3[1]
PMH = PI/2.
60 CONTINUE
WMO = HM + 2 * GRAVITY
PMH = PI/2.
KPI = KAP * 1

EVALUATE INTEGRALS USING TRAP METHOD
I = 1
INDEX = 1
91 CALL TRAP(I(INDEX) + DIFF(I) + KIT(I) + MASS)
CALL TRAP(I(INDEX) + DIFF(I) + KIT(I) + OA1)
CALL TRAP(C1(INDEX) + DIFF(I) + KIT(I) + LEA)
CALL TRAP(C2(INDEX) + DIFF(I) + KIT(I) + CECA)
CALL TRAP(P1(INDEX) + DIFF(I) + KIT(I) + IAA)
CALL TRAP(I1(INEX), DIFF(I), KTT(I), DMUA)
CALL TRAP(I2(INEX), DIFF(I), KTT(I), EMDUA)
CALL TRAP(I3(INEX), DIFF(I), KTT(I), EZDMUA)
CALL TRAP(I4(INEX), DIFF(I), KTT(I), EMUA)
CALL TRAP(I5(INEX), DIFF(I), KTT(I), DMUA)
CALL TRAP(I6(INEX), DIFF(I), KTT(I), ZMAA)
CALL TRAP(I7(INEX), DIFF(I), KTT(I), ZMMA)
CALL TRAP(I8(INEX), DIFF(I), KTT(I), EMASA)
CALL TRAP(I9(INEX), DIFF(I), KTT(I), ZZMMA)
CALL TRAP(I10(INEX), DIFF(I), KTT(I), ZWZMAA)
CALL TRAP(I11(INEX), DIFF(I), KTT(I), ZZWMAA)
CALL TRAP(I12(INEX), DIFF(I), KTT(I), E2ZMAA)

C 93 CONTINUE
MASS = MASS + TMASS
UA = QA + QA
IA = IA + IAA
CE = CE + CE
CE2 = CE2 + CE2
EDMU = EDMIN + EDMAX
E2DMU = E2DMIN + E2DMAX
E3DMU = E3DMIN + E3DMAX
B = BF + ZMU + BFA
BHM = BMH + BMAX + ZMMA
ZMA = ZMA + ZMAA
ZMAA = ZMAA + ZMAAA
EMAS = EMAS + EMASA
ZZMA = ZZMA + ZZMMA
ZZMMA = ZZMMA + ZZMMAA
ZWEA = ZWEA + ZWEAA
ZWEAA = ZWEAA + ZWEAAA
ZMAZ = ZMAZ + ZMAZA
ZMAZA = ZMAZA + ZMAAA
94 CONTINUE
IF ( I .GE. II ) GO TO 92
INDEX = INEX + KTT(I) - 1
I = I + 1
GO TO 91
92 CONTINUE

C * * * * CALL COMPUT TO FIND THE VALUE OF NL AND FL USING
C THE VALUES OF THE ABOVE INTERVALS
CALL COMPUT(X)

C IF(NPRINT.LT.4) GO TO 111
IF(NPRINT.LT.0) GO TO 108
IF(NPRINT.GT.0) GO TO 109
WRITE(6, 47) (I,PAR(1), I=1,NUM)
WRITE(6, 49) (Q,PAR(1), I=1,NUM)
WRITE(6, 99) (CI(1), I=1,NUM)
WRITE(6, 6100) (C(1), I=1,NUM)
WRITE(6, 6101) (U(1), I=1,NUM)
WRITE(6, 6103) (U2(1), I=1,NUM)
WRITE(6, 6105) (U(1), I=1,NUM)
WRITE(6, 106) U2(1), I=1,NUM)
WRITE(6, 6112) (C0(1), I=1,NUM)
WRITE(6, 6113) (ZL(1), I=1,NUM)
WRITE(6, 6114) (ZC(1), I=1,NUM)
C

\[ \text{CX6 = COS}(x(6)) \]
\[ \text{SX6 = SIN}(x(6)) \]
\[ \text{P1M = P1/2.0} \]
\[ \text{KP1 = KAR*P1} \]
\[ \text{CONS1 = CA6} \]
\[ \text{CONS2} = (\text{KP1} \ast \text{NUM} \ast \text{P1M}/\text{T1})/\text{CX6} \]
\[ \text{CONS3} = \text{CA6} \ast \text{SX6} \]
\[ \text{CONS4 = CX6} \ast \text{SX6} \]
\[ \text{TERM1} = x(1) \ast \text{CX6} \]
\[ \text{TERM2} = x(2) \ast \text{SX6} \]
\[ \text{UVNUM} = (x(1) \ast \text{CX6} - (x(2) - \text{ZDOTT}(\text{NUM})) \ast \text{SX6}) \]
\[ 4 = (x(1) \ast \text{SX6} - x(3) \ast \text{E}(\text{NUM}) \ast (x(2) - \text{ZDOTT}(\text{NUM})) \ast \text{CX6}) \]

C

\[ \text{ZMA} = \text{ZMA} \ast x(3) \ast \text{SX6} \]
\[ \text{Z2WMA} = \text{Z2WMA} \ast x(3) \ast \text{SX6} \]
\[ \text{ZMA} = \text{ZMA} \ast \text{CONS1} \]
\[ \text{EMAS} = \text{EMAS} \ast \text{CONS1} \]
\[ \text{DMU} = \text{DMU} \ast \text{CONS2} \]
\[ \text{EDMU} = \text{DMU} \ast \text{CONS2} \]
\[ \text{CE} = \text{CE} \ast \text{CONS4} \]
\[ \text{E2DMU} = \text{E2DMU} \ast \text{CONS3} \]
\[ \text{E3DMU} = \text{E3DMU} \ast \text{CONS3} \]
\[ \text{ZWEMA} = \text{ZWEMA} \ast \text{CONS4} \]
\[ \text{Z2WMA} = \text{Z2WMA} \ast \text{CONS4} \]

C

\[ T1 = QA \ast x(3) \ast (\text{TERM1} - \text{TERM2}) \]
\[ T1 = T1 + \text{Z2WMA} - \text{EMAS} \]
\[ T2 = \text{EDMU} \]
\[ T3 = \text{CE} \]
\[ T4 = \text{MA(NUM)} \ast \text{E}(\text{NUM}) \ast \text{UVNUM} + \text{EMA2} + \text{E3DMU} = \text{Z2WMA} + \text{BMM} \]
\[ \text{NL} = T1 \ast T2 + T3 + T4 + \text{DMM} \]
\[ T5 = \text{MASS} \ast x(3) \ast (\text{TERM2} - \text{TERM1}) \]
\[ T5 = T5 + \text{ZMA} - \text{MA} \]
\[ T6 = \text{DMU} \]
\[ T7 = \text{CE} \]
\[ T8 = -\text{MA(NUM)} \ast \text{UVNUM} - \text{E2DMU} + \text{ZWEMA} \]
\[ \text{BF} = \text{BF/} \text{CX6} \]

C

\[ \text{FL=T5} \ast T6 \ast T7 \ast T8 \ast \text{BF} \]

C

\[ \text{IF(NPRINT.LT.3)} \text{GO TO 30} \]

25 \text{CONTINUE}

\[ \text{WRITE}(6,10) \text{NL,FL} \]

10 \text{FORMAT}(\text{NL} = *.E12.6, \text{FL} = *.E12.6) \]

30 \text{RETURN}

END

\text{SUBROUTINE INPUT}

C \text{... DEFINITION OF INPUT VARIABLES...}

\text{INPUT 2}

C \text{X0 = INITIAL TIME}

\text{INPUT 3}

C \text{XE = FINAL TIME}

\text{INPUT 4}

C \text{MMIN = MINIMUM STEP SIZE}

\text{INPUT 5}

C \text{MMAK = MAXIMUM STEP SIZE}

\text{INPUT 6}

C \text{EPS = RELATIVE ERROR CRITERION USED FOR VALUES OF Y GT A}

\text{INPUT 7}

C \text{EPS = ERROR CRITERION IN KUTME}

\text{INPUT 8}

C \text{A = ABSOLUTE ERROR CRITERIA USED IN KUTME}

\text{INPUT 9}

C \text{NPRINT = 1 FINAL PRINTOUT}

\text{INPUT 10}

C \text{n = 2 MATRIX INVERSE MATRIX,F COLUMN MATRIX,AND KUTME }

\text{INPUT 11}

C

47
RESULTS

INPUT 13

C 3

INTEGRAL VALUES

INPUT 14

C 4

CALCULATED VALUES=CONSTANT FOR GIVEN INPUT VALUES

INPUT 15

END = NUMBER OF RUNS

INPUT 16

M = MASS OF CRAFT

INPUT 17

W = WEIGHT OF CRAFT

INPUT 18

T = THRUST COMPONENT IN Z DIRECTION

INPUT 19

TA = THRUST COMPONENT IN X DIRECTION

INPUT 20

XCG = DISTANCE FROM CG TO CENTER OF PRESSURE FOR NORMAL FORCE

INPUT 21

XU = DISTANCE FROM CG TO CENTER OF PRESSURE FOR DRAG FORCE

INPUT 22

K = ADDED MASS COEFFICIENT

INPUT 23

AN ARRAY GIVEN THE VALUE KAR WHICH IS READ IN

INPUT 24

WM(I) = EAM AT FREE SURFACE OR AT CHINE

INPUT 25

UWAG = FRICTION DRAG

INPUT 26

K = WAVE NUMBER

INPUT 27

RO = WAVE HEIGHT

INPUT 28

NU = WAVE SLUPE

INPUT 29

NUM = NUMBER OF STATIONS

INPUT 30

BL = BUAT LENGTH

INPUT 31

LAMBD = WAVE LENGTH

INPUT 32

RG = RADIUS OF GENERATION IN FEET

INPUT 33

T = PROPELLE THRUST IN LBS

INPUT 34

GAMMA = PROPELLE THRUST ANGLE IN DEGREES

INPUT 35

VELAS = STATION SPACING IN FEET

INPUT 36

ECG = LONGITUDINAL CENTER OF GRAVITY

INPUT 37

NCG = VERTICAL CG

INPUT 38

BETA(1) = DETA(I)

INPUT 39

NO(1) = HEIGHT OF MEAN BUTTUCK

INPUT 40

RHO = DENSITY OF WATER

INPUT 41

GRAVITY = GRAVITY FT/SEC**2

INPUT 42

DPR = DEGREES PER RADIAN

INPUT 43

PU = W/IA = W/RA DEGREE

INPUT 44

PI = 3.14159265358979

INPUT 45

EST(1) = STATION POSITION

INPUT 46

START = START TIME OF THE RAMP FUNCTION FOR SEA WAVE

INPUT 47

RISE = DURATION OF THE RISE FROM ZERO TO ONE OF THE RAMP

INPUT 48

IC OPTIONS

INPUT 49

IC(1) = 1 USE WAVE 2 DISTANCE IN COMPUTING LIFT COMPONENT

INPUT 50

OF NL AND FL

INPUT 51

REAL IT,k,MMA,MMA,NU,N,NCG,NU,MASS,NL,IA,KAR

INPUT 52

INTEGER EN

INPUT 53

COMMON /CONST/ NCC,ECG,PI*,DPR*,RDP*,GRAVITY*,RHO*,NUM,MA(I20),CD,TA,

INPUT 54

B(I20),BETA,HM(I20),UWAG*,XO*,XP*,MU*,IT,

INPUT 55

Deltas,TA,EST(I20),KAR,MMAX(I20),TEST(I20)

INPUT 56

COMMON /SHIP/ PASS*CMOA.CECE2,CE3*,MOE,EDM*,EDM*,EBM*,BMM,

INPUT 57

NL*,FL*IA,CE(I20)

INPUT 58

COMMON /IN/ HM(I20),B1(I20),VELIN

INPUT 59

COMMON /IN/ NG(I20),X*,X*,MMAX*,MINA(I6),EPSL(I6)

INPUT 60

48
COMMON/OUT/NPRINT,NPLOT*END
COMMON /ACCEL/ XACCEL+ZACCEL+CAACL+CHL
NAMELIST/MSL*/NPRINT,NPLOT*END
NAMELIST/TX,TEX,ECPXXPXR
* ORAG,RT,AMMA,ECG,MCZ,KAR,NBETA,EST
* XAXI,MAXI,MMAXI,EPs,VELIN

INPUT 72
C
DATA A /1.,0001.,0001.,1.,0001.,000001/
DATA NPRINT,NPLOT*END,1,1,1/
DATA WMLTZTAAX.CGPX.XQURAG.RTXGA4NA.
L ECG,MCZ,CW/16,3,7=40,0,4,220,210,0,4
* 2.325,0,0,1,0/
DATA NUM,BETA,EST /77,20,0*
 0.0000,6612,=0.2500,0.9376,1.0500,1.15625,1.1875,0,21875
 0.2500,2812,1.3125,1.4376,1.5625,1.6875,1.8125,1.9375,2,0625
 0.5000,3437,2.0937,2.2500,2.3750,2.5000,2.6250,2.7500,2.8750
 0.7500,3.1437,2.8125,2.9375,3.0625,3.1875,3.3125,3.4375,3.5625
 1.0000,3.9375,3.6250,3.7500,3.8750,4,0000,4,1250,4,2500,4,3750
 1.5625,4.5625,4.6875,4.8125,4.9375,5,0625,5,1875,5,3125,5,4375
 2.0625,2.1250,2.1875,2.2500,2.3125,2.3750,2.4375,2.5000,2.5625
 2.6250,2.6875,2.7500,2.8125,2.8750,3,0937,3.1562,3.2187,3.2812

DATA XAXI,MAXI,MAXI,EPs,VELIN /14,62,
DATA VELIN /14,62,
C
C *** * * * * READ IN AND WRITE OUT KUTHER PARAMETERS AND PROGRAM
C OPTIONS
READ(8,MSL)
WRITE(9,MSL)
DO 10 I=1,7
10 EPSE(I) = FPS
C
C *** * * * SET UP CONSTANTS

PI = 3.14,15926535d4
GRAVITY=32,10
UPR=57,295795130d
NPD=.01745329245
IF (EST(NUM),L2,BL) STOP J
C
C COMPUTE NU ANH .HM ARRAYS
C THIS IS FOR SPECIAL BOX FROM ONLY. CHANGE PROGRAM
C THRU STATEMENT 32 FOR NEW BOX SHAPE
C DO 32 I=1,NUM
1 IF(EST(I),0.6,0,75) GO TO 30
NO(I)=0.46875*(1.0-SQRT(EST(I)/0,75)=EST(I)/0,75)**2,01
DM(I)=3.75*SQRT(1.0-(EST(I)/0,75)**2,0)
DO TO 32
30 NO(I)=0,0
DM(I)=0,375
32 CONTINUE
C
C******* COMPUTE CONSTANTS AND INITIALIZE ARRAYS
HM=GRAVITY
RHO=1,94
ITEM=SERN
PHALF = (PI/2,F)*RHO
C
BETA = WET+31NH
CU = COS(DFTA)

49
TA = TAN(BETA)
DO 60 I=1,NUM
C(I) = ECU-EST(I)
N(I) = NCG-N0(I)
MAX(I) = KAR+HALF*Q(M(I))#Q(M(I))
TEST(I) = (2.*Q(M(I))*TA)/P1
60 CONTINUE
END-END+1
RETURN
END
SUBROUTINE PLOTER (FX,XA,MAX,MB,INT)
C
INPUT:
FX  A TWO DIMENSIONAL ARRray CONTAINING PITCH AND
HEAVE VALUES AT EACH TIME STEP
XA  INITIAL TIME
MAX  TIME INTERVAL, *TIME+MAX = INTERVAL BETWEEN
INT  NUMBER OF FX VALUES
C
REAL ITK,LAMBA,B,MAX,MB,NCG
INTEGER EN
C
DIMENSION FX(2,2000),FMIN(2),FMAX(2),NVAR(2)
C
COMMON /CUST/MAX,ECG,DP,*GRAVITY,NUM,MA(120),CD,TA,
       N(120),HALF
COMMON/OUT/NPINT,NPNTST,E
C
* * * * * * * * * SET UP VALUES FOR PLOT AND CREATE PLOT
IF(EN=2)
C
* * * * * * * * * SET UP MIN AND MAX LIMITS FOR PLOT
FMIN(1)=FX(1,1)
FMIN(2)=FX(2,1)
FMAX(1)=FX(1,1)
FMAX(2)=FX(2,1)
C
DO 200 I=1,100
IF(FX(1,I).LT.FMIN(1))FMIN(1)=FX(1,I)
IF(FX(1,I).GT.FMAX(1))FMAX(1)=FX(1,I)
IF(FX(2,I).LT.FMIN(2))FMIN(2)=FX(2,I)
IF(FX(2,I).GT.FMAX(2))FMAX(2)=FX(2,I)
200 CONTINUE
C
DO 800 I=1,100
NVAR(1)=100 HEAVE
NVAR(2)=100 PITCH
N1=Z
XQ=XG
DELS=MPC
IF(NPLOT.EQ.1)CALL PLOT2(FX,FMIN,FMAX,NVAR,NFUN,N1,XO,DELS)
RETURN
END
SUBROUTINE TRAX(F,UX,NPTS,ANS)
C
INPUT:
C
50
FUNCTION RAMP(T,START,RISE)
C ******* THIS FUNCTION IS USED TO GRADUALLY IMPLEMENT THE WAVE
C
T  CURRENT TIME
C
START  TIME TO START RAMP FROM 0,0 TO 1,0
C
RISE  THE LENGTH OF THE RISE FROM 0,0 TO 1,0
C
M=0,0
IF (T,LT,START) GO TO 99
IF (RISE,GT,0.0) GO TO 80
TOP=T-START
M=1.0
IF (TOP,LT,RISE) M=TOP/RISE
GO TO 99
80 M=0.15
IF (T,LE,START) M=0.5
99 NMAP=M
RETURN
END
SUBROUTINE SEAWAY
REAL K ...
COMMON /WAVE2/ O(20),K(20),C(20),RNM(20),RNQ(20),RH(20)*
* RO(20),AK(20),RMS(20)
C
COMMON /CUST/ MCG,ECG,E10,PH,MH,GRAVITY,RMU,NUM,MA(120),CO,TA,*
* 8(120),ETA,MA(120),T+DNAUGX,KD,DX,KP,IT,
1  DELTAS,TA,EST(120),KAR,MAX(120),TEST(120)*
*  n(120),PMHF
HEAD (5.0) M
WRITE (6,9) M
SEAWAY 90
FORMAT (27H* SIGNIFICANT WAVE HEIGHT = E10.4,2X,SH FEET,//)
SEAWAY 90
MKDOT = SQRT(M)
WN = 2.276*MKDOT
W(1) = 1.5*4**4
W(2) = WN
W(3) = 1.13*WN
W(4) = 1.403*WN
W(5) = 1.601*WN
W(6) = 1.795*WN
W(7) = 2.003*WN
W(8) = 2.194*WN
W(9) = 2.344*WN
W(10) = 2.612*WN
W(1) = 0.136*WN
SEAWAY 100
51
HO(2) = 0.1868*H
HO(3) = 0.1657*H
HO(4) = 0.1302*H
HO(5) = 0.0999*H
HO(6) = 0.0771*H
HO(7) = 0.0604*H
HO(8) = 0.0482*H
RO(9) = 0.0340*H
RO(10) = 0.0626*H
PHS(1) = 0.005
PHS(2) = 2.41
PHS(3) = 5.20
PHS(4) = 4.00
PHS(5) = 0.00
PHS(6) = 1.27
PHS(7) = 3.11
PHS(8) = 2.92
PHS(9) = 3.55
PHS(10) = 0.70
DO 50 J=1,10
   K(J) = WO(J)*U(J)/GRAVITY
   C(J) = GRAVITY*U(J)
   RW0(J) = RO(J)*U(J)
   RW02(J) = RW0(J)*U(J)
   RR(J) = RW02(J)*K(J)
   HK(J) = NO(J)*K(J)
   CONTINUE
   RETURN
END
SUBROUTINE TABLE
COMMON/SINE/,POINT(1000)
UX = 0.003413905
X = 1.57079632
DO 100 J=1,501
   POINT(J) = SIN(X)
   K = 1002-J
   POINT(K) = -POINT(J)
   X = X+DX
100 CONTINUE
   RETURN
END
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