

Member Agencies:

United States Coast Guard
Naval Sea Systems Command
Maritime Administration
American Bureau of Shipping
Military Sealift Command



Ship Structure Committee

An Interagency Advisory Committee
Dedicated to the Improvement of Marine Structures

August 2, 1990

Address Correspondence to:

Secretary, Ship Structure Committee
U.S. Coast Guard (G-MTH)
2100 Second Street S.W.
Washington, D.C. 20593-0001
PH: (202) 267-0003
FAX: (202) 267-0025

SSC-333
SR-1277

ADVANCED METHODS FOR SHIP MOTION AND WAVE LOAD PREDICTION

Advanced numerical methods are needed by ship designers to better predict and simulate ship motions and hull girder loads. Complex structural loading problems such as bottom slamming, bow flare impact, and green water on deck cannot be satisfactorily analyzed using linear strip theory.

This report provides a numerical method for predicting transient three-dimensional hydrodynamic pressures and resulting loads. This work is based on an initial level of investigation and development, and will require further testing, validation, and refinement of the numerical methods and computer programs.



J. D. SIPES

Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee



Accession For	
NTIS	CRA&I ☒
DTIC	TAR ☐
Unannounced	☐
Justification	
By	
Distribution /	
Availability Codes	
Dist	Availability for Special
A-1	

1. Report No. SSC-333	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle ADVANCED METHODS FOR SHIP MOTION AND WAVE LOAD PREDICTION		5. Report Date February 1985	
		6. Performing Organization Code SHIP STRUCTURE COMMITTEE	
7. Author(s) JAMES C. OLIVER		8. Performing Organization Report No. SR-1277	
9. Performing Organization Name and Address GIANNOTTI & ASSOCIATES INC. 703 Giddings Avenue, Suite U-3 Annapolis, Maryland 21401		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTCG23-80-C-20032	
12. Sponsoring Agency Name and Address U.S. COAST GUARD (G-M) WASHINGTON, D.C. 20593		13. Type of Report and Period Covered FINAL REPORT 10/80 - 2/85	
		14. Sponsoring Agency Code G-M	
15. Supplementary Notes CONTRACT MONITORED BY: SHIP STRUCTURE COMMITTEE NATIONAL ACADEMY OF SCIENCES, WASHINGTON, D.C.			
16. Abstract A numerical method for the simulation of ship motions, hull girder loads and transient three-dimensional hydrodynamic pressure is developed. A time-step intergration of the equations of motion is performed with sectional hydrodynamic forces computed using strip theory and buoyancy forces evaluated over the instantaneous immersed hull. In addition to hydrostatic and dynamic buoyancy forces, ship motion induced and wave diffraction forces, the method can also account for "flare" force and quadratic damping forces. The numerical model also has several features which may provide for more realistic simulations. Linear wave theory is assumed for the representation of the incident wave field, and regular and irregular, unidirectional or multidirectional wave systems can be generated. A method for the prediction of transient three-dimensional hydrodynamic pressures extending the technique developed by R. B. Chapman is presented. Initial and boundary values for the pressure simulation are simultaneously generated from the solution of the equations of motion using sectional force computations. An option exists in the program to substitute the three-dimensional pressures for the two-dimensional hydrodynamic forces. The work presented herein represents an initial level of investigation and development. The numerical methods and computer programs require further testing, validation and improvement.			
17. Key Words Ship Motions Numerical Method Hydrodynamics simulation Computer		18. Distribution Statement Available from: National Technical Information Service Springfield, VA 22151 or Marine Technical Information Facility National Maritime Research Center Kings Point, NY 10024-1699	
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 196	22. Price

METRIC CONVERSION FACTORS

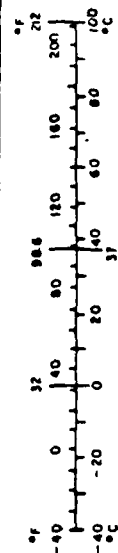
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
m	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
m ²	square inches	0.6	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
ac	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	29	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2000 lb)			
VOLUME				
l	liters	1	liters	l
fl oz	fluid ounces	30	milliliters	ml
cup	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m ³
yds ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 m = 2.54 inches. For unit exact conversions and more detailed tables, see NIST Basic Table 286, Units of Length and Mass, Price \$2.25, SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	yards	yd
		0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.6	square miles	mi ²
ha	hectares (10,000 m ²)	2.6	acres	ac
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
		1.06	quarts	qt
		0.26	gallons	gal
m ³	cubic meters	36	cubic feet	ft ³
		1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

TABLE OF CONTENTS

VOLUME 1 - THEORETICAL MODEL AND NUMERICAL RESULTS

1.0	<u>INTRODUCTION</u>	1-1
1.1	Background	1-2
2.0	<u>THEORETICAL MODEL</u>	2-1
2.1	General Formulation of Equations of Motion	2-1
2.2	Evaluation of External Forces and Moments	2-5
2.3	Froude-Krylov Forces	2-11
2.4	Sectional Hydrodynamic Forces	2-13
2.5	Three-Dimensional Dynamic Pressures and Forces	2-17
2.6	Hull Girder Loads	2-33
2.7	Numerical Aspects	2-34
3.0	<u>NUMERICAL RESULTS</u>	3-1
3.1	Two-Dimensional Hydrodynamic Coefficients	3-1
3.2	Motion Response and Hull Girder Loads in Small Amplitude Regular Waves	3-1
3.3	Irregular Waves	3-5
3.4	Non-Linear Response in Larger Waves	3-8
3.5	Influence of Draft-Dependent Hydrodynamic Coefficients	3-13
3.6	Force Prediction Using the Three-Dimensional Approach	3-13
3.7	Limitations, Run Times, and Computational Requirements	3-20
4.0	<u>SUMMARY AND RECOMMENDATIONS</u>	4-1
5.0	<u>REFERENCES</u>	5-1
	APPENDIX A - Numerical Simulator Test Program	A-1

VOLUME 2 - COMPUTER PROGRAM USER'S MANUAL

1.0	INTRODUCTION	1-1
2.0	GENERAL STRUCTURE AND COMPUTATIONAL OVERVIEW	2-1
3.0	GENERAL SOFTWARE APPLICATIONS	3-1
4.0	RUN PROCEDURES	4-1
5.0	SAMPLE CASE	5-1
	APPENDIX A - Program Listing for HYDREX2, HYDREX3 and SSX	A-1

LIST OF TABLES

	<u>Page</u>
Table 1 Comparison of Statistical Responses, SSX vs. MIT.....	3-7
Table 2 Comparison of Statistical Responses, SSX vs. MIT.....	3-7
Table 3 Numerical Parameters.....	3-14
Table 4 Representative Run Times.....	3-21

LIST OF FIGURES

	<u>Page</u>
Figure 1a	Axes for Solution of Equations of Motion.....2-2
Figure 1b	Sign Convention for Translational and Rotational Motions.....2-2
Figure 2	Diagram of Computational Scheme.....2-6
Figure 3	Quadrilateral panels and source representation of semisubmerged sphere.....2-24
Figure 4	Added mass and damping coefficients.....3-2
Figure 5	Calculated and measured amplitude and phase characteristics for heave and pitch.....3-3
Figure 6	Calculated and measured amplitudes of heave and pitch.....3-4
Figure 7	Midship dynamic vertical bending moment for SL-7 containership.....3-6
Figure 8	Midship vertical, horizontal wave bending and pitch.....3-6
Figure 9	Heave amplitude/wave amplitude vs. wave amplitude.....3-9
Figure 10	Pitch amplitude/wave amplitude vs. wave amplitude.....3-9
Figure 11	Midship vertical bending moment, SL-7 containership, 25 knots, head seas (effect of flare on sagging shown).....3-10
Figure 12	Heave amplitude vs. wavelength/shiplength.....3-11
Figure 13	Pitch amplitude vs. wavelength/shiplength.....3-11
Figure 14	SL-7 containership in head seas at 25 knots ($\lambda/L=1.5$) 3-12
Figure 15	SL-7 containership in head seas at 25 knots ($\lambda/L=1.75$).....3-12
Figure 16	Added mass and damping coefficients for semisubmerged sphere.....3-16
Figure 17	Radiated waves vertically oscillating sphere at $k=1.0$ 3-17
Figure 18	Wave excitation forces for semisubmerged sphere.....3-18
Figure 19	Diffracted waves from semisubmerged sphere, regular unidirectional waves, $k=1.4$ 3-19

NOMENCLATURE

Equations of Motion and Strip Theory

A_{jk}	= components of added mass matrix
B_{km}	= transformation matrix for Eulerian angles
$BM_y(x_0)$	= vertical bending moment at x_0
$BM_z(x_0)$	= horizontal bending moment at x_0
F_j	= external forces
I_{jk}	= components of moment and product of inertia matrix
K	= roll moment
M	= pitch moment
M_{jk}	= components of mass matrix
M_s	= ship's mass
N	= yaw moment
R_G	= vector position of ship c.g. in space system
$SF_y(x_0)$	= vertical shear force at x_0
$SF_z(x_0)$	= horizontal shear force at x_0

NOMENCLATURE (Continued)

S_i, C_i	= sine and cosine components of force fluctuation for wave component i , the relative magnitudes of which provide the proper phase relationship of all wave-related forces
T_j	= external moments
$TM_x(x_0)$	= torsional moment at x_0
U	= ship's speed
V_{G_k}	= translational velocities of center of mass in space fixed system
	= $\frac{d}{dt} (R_G)$
X	= longitudinal force
Y	= vertical force
Z	= lateral force
$x_b^s \dots m_b^s$	= hydrostatic force components of the Froude-Krylov force
$x_{3D} \dots m_{3D}$	= force components calculated from the three-dimensional pressure computations
a_i	= amplitude of i^{th} wave component
a_{22}	= heave added mass
a_{33}	= sway added mass

NOMENCLATURE (Continued)

a_{34}	= section roll added mass moment of inertia due to sway motion
a_{44}	= sectional roll added mass moment of inertia
b_{22}	= heave damping coefficient
b_{33}	= sway damping coefficient
b_{34}	= sectional roll damping moment coefficient due to sway motion
b_{44}	= sectional roll damping coefficient
b	= Froude-Krylov force subscript
$\frac{dY_h}{dx}, \frac{dZ_h}{dx}, \frac{dK_h}{dx}$	= sectional ship motion-induced hydrodynamic force in heave sway and roll
$\frac{dY_w}{dx}, \frac{dZ_w}{dx}, \frac{dK_w}{dx}$	= sectional diffraction force in heave, sway and roll
f	= "flare" force subscript
h	= ship motion-induced force subscript
h_{cg}	= vertical distance from waterline to ship c.g. (+ up).
i, N	= wave index, total number of wave components
i_x	= local section's mass moment of inertia
k_i	= horizontal vector wave number

NOMENCLATURE (Continued)

$\vec{k}_i \vec{x}_i$	= $xk_i \cos\beta - zk_i \sin\beta$
$\hat{k}_i$	= projection of the wave number onto the x-axis of ship
q	= quadratic damping force subscript
t	= total force
w	= wave diffraction force subscript
x	= longitudinal distance to section from ship's c.g.
$\vec{x}_i$	= horizontal cartesian coordinates
$\bar{y}$	= local section's center of gravity relative to ship c.g. (positive up).
y_G, z_G	= heave and sway velocity of center of mass of ship
β	= direction of wave propogation
ω_i	= circular frequency
ϵ_i	= phase angle
ω_k	= rotational velocities = $B_{km} \frac{d\alpha_m}{dt}$
$\psi, \dot{\psi}$	= Eulerian pitch angle and velocity in ship system
$\phi, \dot{\phi}$	= Eulerian yaw angle and velocity in ship system

NOMENCLATURE (Continued)

$\theta, \dot{\theta}$	= Eulerian roll angle and roll velocity in ship system
$\xi_i, \dot{\xi}_i$	= average vertical water velocity, acceleration
$\zeta_i, \dot{\zeta}_i$	= average lateral water velocity, acceleration
$\kappa_i, \dot{\kappa}_i$	= average roll water velocity, acceleration
$\xi_i, \dot{\xi}_i$	= average vertical water velocity, acceleration
$\zeta_i, \dot{\zeta}_i$	= average lateral water velocity, acceleration
$\kappa_i, \dot{\kappa}_i$	= average roll water velocity, acceleration
μ	= vertical sectional added mass gradient

Three-dimensional Analysis

A_{nm}, B_{nm}	= complex functions of wave numbers and time
A_{nm}^*, B_{nm}^*	= complex conjugates
$A_i(t)$	= area of panel i
E_{ij}	= source - velocity influence matrix
L_x, L_y, l_x, l_y, T	= parameters for computing spectral free-surface representation wave numbers and spacing
$\hat{P}_{ij}$	= source - potential influence matrix

NOMENCLATURE (Continued)

p_T, p_B, p_{FS}, p_A = pressure at panel center, total, body, free-surface, ambient

X_{ij} = source - x velocity influence matrix

a_T, a_B, a_{FS}, a_A = acceleration vector

k_{nm} = $k_{nm}^2 = kx_n^2 + ky_m^2$

kx_n, ky_m = wave numbers in x and y; e.g., $\frac{\omega_n^2}{g}$

$s_i(t)$ = strength of source at panel i

v_T, v_B, v_{FS}, v_A = velocities vector at panel centers, total, body-induced, free-surface and ambient wave

v_X, v_Z, a_X, a_Z = x and z components of ambient wave-induced velocity and acceleration at panel center

ϕ_T = total time varying potential

ϕ_B = instantaneous effect on the body

ϕ_{FS} = free surface disturbance due to previously radiated and diffracted waves

ϕ_A = ambient wave potential

σ_i = source density of panel i

$\Delta kx_n, \Delta ky_m$ = wave number spacing; e.g., $\Delta kx_n = kx_{n+1} - kx_n$

NOMENCLATURE (Continued)

$$\omega_{nm}^2 = \omega_{nm}^2 = g [k_{x_n}^2 + k_{y_m}^2]^{1/2}$$

$$\Delta A_{nm}^{BODY}, \Delta A_{nm}^{BODY*}, \Delta B_{nm}^{BODY}, \Delta B_{nm}^{BODY*}$$

= influence of body on free surface spectral component

**ADVANCED METHODS FOR
SHIP MOTION AND WAVE
LOAD PREDICTION**

VOLUME 1

1.0 INTRODUCTION

While the established ship motion and loading methods currently used in design practice remain indispensable, there is need for a more advanced tool that can carry the ship designer a step closer toward a fully rational ship design procedure. Although the application of linear strip theory in the frequency and probabilistic domains has met with remarkable success, there are a number of practical seakeeping and structural loading problems not satisfactorily analyzed by such techniques. Green water, bow flare impact and bottom slamming are particularly obvious examples. Reported large differences in dynamic sagging and hogging moments in some type of ships is a consequence of nonlinear loading [1,2]. The accurate prediction of rolling amplitudes requires the use of a nonlinear restoring moment at a large angle and nonlinear viscous damping estimates. These examples tend to highlight the generally nonlinear character of the ship motion and loads problem. An equally important part of the problem is its three-dimensionality. For example, the prediction of hydrodynamic pressures on the ship's hull below the mean waterline using linear two- and three-dimensional methods is not at a consistent level of accuracy. Clearly, there are a number of areas where improvements can be made in ship motion and loading prediction.

Based on an extensive review of the reported advanced methods in body-wave hydrodynamics and ship motion/loads prediction, a time-domain simulation of ship motion, hull girder loads and hydrodynamic pressures has been developed. Strip theory with certain nonlinear enhancements is used to predict sectional hydrodynamic forces for motion and hull girder loading prediction, and a three-dimensional source distribution of the hull, combined with a spectral representation of the free surface is used for the evaluation of hydrodynamic hull pressures. Linear wave theory is used and some optional numerical features have been included that may improve the predictions in some cases. The time-domain numerical simulation technique using strip theory-derived forces expands upon the capsizing simulation work of Oakley, Paulling, Wood and others [3]. In that method, the hydrodynamic forces from ship motion and diffraction are assumed to be small due to low encounter frequency in following and quartering waves -- allowing for approximate formulations. On the other hand, the Froude-Krylov forces (hydrostatic and dynamic buoyancy) are computed very accurately for the instantaneous immersed hull. In the present model, this accurate approach to Froude-Krylov forces has been used, while the ship motion and diffraction-induced forces are formulated according to standard strip theory equations [4].

Three-dimensional hull pressures and resultant loads are computed by a separate method based on Chapman's techniques for the simulation of arbitrary linearized motions of a floating body [5,6]. The present method extends Chapman's formulation to include ambient wave field and associated diffraction effects. Although the three-dimensional technique can be generalized to include a time-dependent hull shape, the computational method has been developed here in as simple a form as possible. Thus, as presently established, the hull is specified by surface panels describing the hull portion directly beneath the static-waterline only. The computational method can be easily expanded to include the entire hull; however, at present the computational effort to run a program with such an extension would be prohibitively expensive.

Several optional features have been incorporated into the numerical simulation procedures. Sectional added mass and damping coefficients may be evaluated for the instantaneous average sectional draft at each time step. Also the frequencies at which the added mass and damping coefficients are evaluated (for ship motion-induced forces) can be selected to correspond to either (a) the peak frequencies of motion response spectra, or (b) allowed to vary based on the measured response of the vessel during the previous two cycles of motion. Additionally, a vertical velocity-squared term is included in the strip formulations to partially account for the effect of flare impact loading. Finally, the simulation can incorporate the effects of velocity-squared damping using quadratic damping coefficients selected by the user.

It should be pointed out that because the majority of the testing and validation efforts described in this report use regular waves, the reader may tend to form the impression that the method is limited to regular waves. This is not the case. The incident wave system may be irregular and multidirectional. It is constructed from the superposition of regular waves, the amplitudes, frequencies, directions and phases of which may be specified by the user. They can thus be selected to represent the time history associated with any given sea spectrum.

This document (Volume I) describes the method and presents some test and validation results. Several computer programs were written to implement the approach and a user's manual (Volume II) is provided as a companion report.

1.1 BACKGROUND

In recent years, a number of impressive advances have been made in body-wave hydrodynamics. In particular, the fast-growing field of numerical ship hydrodynamics is producing a wide range of promising techniques with the potential to handle difficult nonlinear three-dimensional hydrodynamic phenomena. It is enlightening to follow the progress made by various investigators as presented in the First, Second and Third International Conferences on Numerical Ship Hydrodynamics in 1975, 1977 and 1981, respectively. Some of those efforts and others pertinent to the ship motion problem will be noted.

Efforts towards quasi-analytical solutions to Laplace's equation using singularity distributions for the ship motion problem have been reported by Chapman [6] and Chang [7]. M.S. Chang represents the ship hull by source/dipole distributions and solves the fluid domain and free surface equations using a mean hull boundary condition. It is a frequency-domain solution and appears to be an excellent way to find the correct linear wave excitation load distribution along the ship for any heading, speed and wave length. Solutions in the frequency domain assume that the response of the body to excitations of varied frequency content may be represented as the linear summation of responses to a series of discrete frequencies. Thus the equations of motion need to be solved only for the component frequencies. In contrast, in a time-domain solution, a time-history of the excitation is decomposed into a series of time steps with the time history of the response constructed by re-solving the equations of motion at each time step. R.B. Chapman's method is a time-domain computation somewhat analogous to Chang's approach. However, it does

not use Green's functions representing solutions of the free surface equations for oscillating singularities moving with uniform speed as does Chang. Simple sources and their image are used to represent the hull. Although the problem is linearized, the method is theoretically capable of accounting for a time-dependent hull shape. It thus provides the flexibility of arbitrary motions.

Another effort using singularity distributions includes that of Pettersen [8]. Pettersen's work is particularly interesting. As the problem is now formulated, he solves the integral equation at zero frequency for three-dimensional sources over the bow and stern and two-dimensional sources using strip theory for the middlebody. The approach has applications for ship maneuvering analysis but some work is being done for $\omega \neq 0$. Methods of finite difference potential field solutions to a free surface and wave problems have been reported by von Kerczek [9] and McCormick and J.W. Thomas [10], to mention only a few.

Bai [11] has continued to develop a finite element method applied to a three-dimensional harmonic ship-motion problem. The computational domain is reduced to a very small local domain using an eight-node three-dimensional element. The work is a direct extension of the earlier work by Bai and Yeung [12]. Other studies of finite element method applied to time harmonic ship motion problems have been presented by Chen and Mei [13], Seto and Yamamoto [14], Yue, Chen and Mei [15] and Chowdbury [16]. Emphasis in these cases is on the solution of regular harmonic motions, although finite element techniques have also been applied to transient problems by J.T. Beale [17] and C. Licht [18]. A. Jami and M. Lenoir [19] present a method for coupling finite elements and an integral representation.

Limited improvements to strip theory in the area of wave excitation and diffraction effects have been reported by S.O. Skjoldal [20], and Troesch [21].

Research in the area of incompressible viscous flow has yielded several interesting techniques. Bourianoff and Penumalli [22] have developed a three-dimensional time-dependent ship motion simulation using a method they call the Inertial Marker Particle (IMP) technique. It is a Eulerian approach. A Eulerian approach uses a space-fixed reference system through which the fluid flows. In the alternate Lagrangian description, the reference frame moves with the fluid. A Lagrangian approach to transient-free surface flows was reported by Fritts and Boris [23]. Nichols and Hirt [24] report on progress being made with variants and improvements of the original Marker-and-Cell method in free-surface computations.

In the area of ship motion and loads prediction, the more advanced methods incorporate a time-simulation approach using some form of strip theory. The primary motivation for the development of this class of simulation programs is to account for nonlinearities from various sources. Paulling, Oakley and Wood [3] were interested in the capsizing problem with emphasis on accurate computation of buoyancy forces. Chang [25] developed a motion simulator emphasizing non-rigid body structural response to regular head seas. Meyerhoff and Schlacter [26] emphasized the dynamic whipping response due to bottom and flare impact in unidirectional irregular head seas. Borresen and

Telsgard [27] emphasized the nonlinear effects of bow flare on motions and rigid body hull girder loads. In the last three references, the relative motion hypothesis is employed in each case, and the frequencies at which the hydrodynamic coefficients are evaluated are usually the frequency of encounter (ω_e) or infinite frequency (ω_∞). Also, the methods in the last three references treat only pitch and heave in unidirectional regular waves.

In view of these reported successes with the time-step solution to the equations of motion and the method's general capability of incorporating loads of a nonlinear character, this approach will be used as the basis of the present model. It is also intended that some type of three-dimensional hydrodynamic formulation cast as an initial value problem would be integrated with the motion simulator from which initial and boundary values would be specified. As noted before, a finite difference solution to the Euler equation was initially chosen based on the reported successes of Bourianoff and Penumalli [22]. The technique developed to apply this finite difference solution is described in [28]. The fundamental difficulty with using this technique for ship motion and transient-free surface simulation was the conflicting demands of numerical stability vs. realistic fluid dynamics. The finite difference Euler equation solution method was abandoned after it became apparent that some of the numerical difficulties could not be overcome within the scope of this project. Alternative methods were investigated, and the technique developed by R.B. Chapman reported in [6] was selected because of its ability to predict three-dimensional flow and handle arbitrary motions and time-dependent hull shapes. Its principal disadvantage is the fact that it is computationally demanding, requiring long run times.* Nevertheless, in view of the ever-increasing capabilities of modern computational hardware, the use of the Chapman method and others like it should become practical in the near future.

* Prescribed motion of a 120-panel body requires 7 CPU minutes per time step ($0.1 \text{ sec} < t < 0.25 \text{ sec}$) on a DEC VAX 11/750 or roughly 20-25 CPU secs on a so-called supercomputer (e.g., CRAY or CDC STAR).

2.0 THEORETICAL MODEL

2.1 GENERAL FORMULATION OF EQUATIONS OF MOTION

The equations of motion for the ship can be derived from Newton's second law and formulated as four first-order ordinary differential equations, the solution of which gives translational and rotational displacements and velocities. Solution is accomplished in a time-step fashion using a fourth-order Runge-Kutta integration scheme. The external forces and moments called for in the equations of motion are calculated using an extension of basic strip theory to derive ship motion-induced and diffraction forces. Froude-Krylov forces are computed using a volume integral approach over the instantaneous immersed hull. The incident wave system is represented by one or more linear waves of arbitrary amplitude, direction, frequency and phase relationship.

The ship is considered to be advancing with forward speed with an arbitrary heading in a system of sinusoidal waves of various amplitudes, frequencies and directions. Let (x,y,z) be a Cartesian coordinate system fixed in space. Let (x',y',z') be a Cartesian coordinate system fixed with respect to the ship, whose axes coincide with the principal axes of inertia of the ship and whose origin corresponds to the ship's center of mass. The direction of the axes are illustrated in Figure 1a.

The position of the ship in space is completely characterized by the position of the ship's mass center and the angular displacement of the ship. Eulerian angles will be used to describe angular displacement. Figure 1b shows the convention for the Eulerian angles.

The motion of the ship in an inertial frame of reference, according to Newton's second law, can be formulated using subscript notation as

$$\frac{d}{dt} M_{jk} V_{G_k} = F_j \quad (j = 1,2,3) \quad (1)$$

$$\frac{d}{dt} I_{jk} \omega_k = T_j \quad (j = 1,2,3) \quad (2)$$

in which

M_{jk} = components of mass matrix

I_{jk} = components of moment and product of inertia matrix

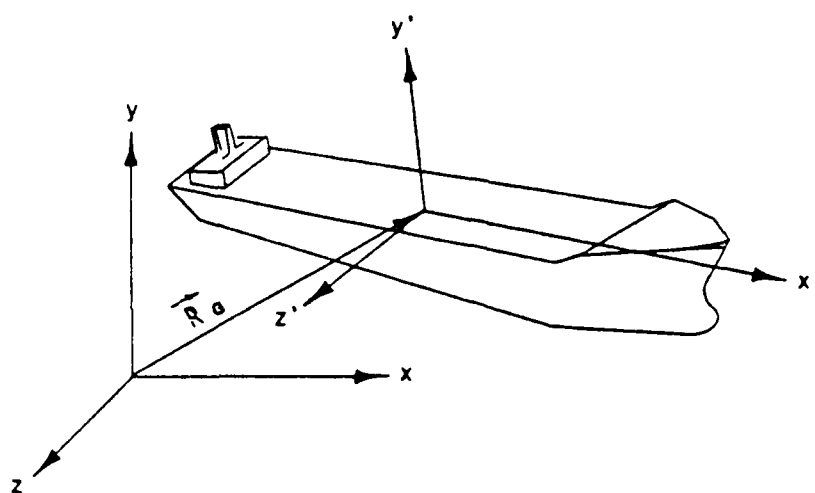


Figure 1a Axes for Solution of Equations of Motion

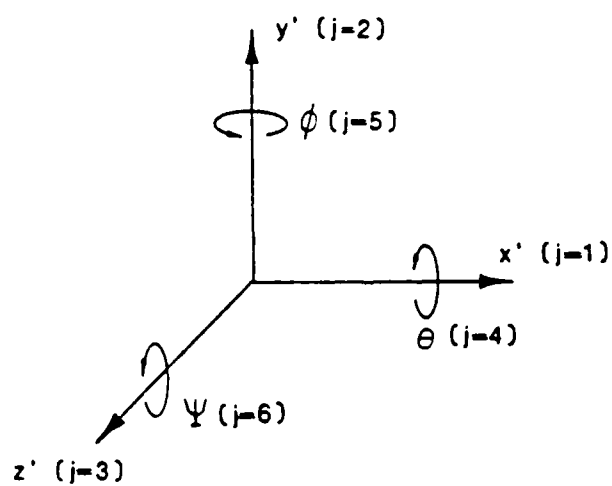


Figure 1b Sign Convention for Translational and Rotational Motions

$$\begin{aligned} V_{G_k} &= \text{translational velocities of center of mass in space fixed system} \\ &= \frac{d}{dt} R_G \end{aligned}$$

$$\begin{aligned} \omega_k &= \text{rotational velocities} \\ &= B_{km} \frac{d\alpha_m}{dt} \end{aligned}$$

and

$$B_{km} = \begin{bmatrix} 1 & \sin \psi & \theta \\ 0 & \cos \theta \cos \psi & \sin \theta \\ 0 & -\sin \theta \cos \psi & \cos \theta \end{bmatrix}$$

$$\alpha_m = \{ \theta, \phi, \psi \}$$

θ = Eulerian roll angle

ϕ = Eulerian yaw angle

ψ = Eulerian pitch angle

F_j = external forces

T_j = external moments

In the ship coordinate system, the left side of equation (2) takes the following form:

$$\frac{d}{dt} (I_{jk} \omega_k) = I_{jk} \frac{d}{dt} \omega_k + \omega_k \times I_{jk} \omega_k \quad (3)$$

This is the Eulerian equation of motion whose application makes possible the use of constant moments and products of inertia. In the inertial frame of reference, these values are continuously changing.

Equations (1), (2) and (3) can be manipulated to yield the following two sets of two first-order ordinary differential equations:

$$\frac{d}{dt} X_{G_k} = V_{G_k} \quad (k = 1, 2, 3) \quad (4)$$

$$\frac{d}{dt} V_{G_k} = (M_{jk})^{-1} F_j \quad (k = 1, 2, 3) \quad (5)$$

$$\frac{d}{dt} \alpha_m = (B_{km})^{-1} \omega_k \quad (m = 1, 2, 3) \quad (6)$$

$$\frac{d}{dt} \omega_k = (I_{jk})^{-1} \{ T_j - \omega_k \times I_{jk} \omega_k \} \quad (k = 1, 2, 3) \quad (7)$$

Assuming that the ship has lateral symmetry, the mass matrix is given by

$$M_{jk} = \begin{bmatrix} M_s & 0 & 0 \\ 0 & M_s & 0 \\ 0 & 0 & M_s \end{bmatrix} + A_{jk} \quad (j = 1, 2, 3) \quad (8)$$

where A_{jk} represents added mass. The ship's mass is shown as M_s within the brackets.

The moment and product of inertia matrix is given as

$$I_{jk} = \begin{bmatrix} I_{11} & I_{21} & I_{31} \\ I_{12} & I_{22} & I_{32} \\ I_{13} & I_{23} & I_{33} \end{bmatrix} + A_{mn} \quad \begin{matrix} (j = 1, 2, 3) \\ (m = 4, 5, 6) \end{matrix} \quad (9)$$

where A_{mn} represents added mass coefficients, and the values within the brackets represent ship moment and products of inertia.

If we can evaluate the external forces (F_j) and moments (T_j) required by expressions (5) and (7), we can solve for the ship translational (V_G) and rotational (ω) velocities. These, in turn, are used in equations (4) and (6) to yield the ship translational (X_G) and rotational (α) displacements. The integration of these four first-order ordinary differential equations is performed numerically with the fourth-order Runge-Kutta scheme.

Thus, the prediction of ship motions by this method then becomes a matter of predicting the external forces and moments. The various types of forces and moments which comprise the total force and moment used in equations (5) and (7) are outlined in the following section.

2.2 EVALUATION OF EXTERNAL FORCES AND MOMENTS

The basic method used to evaluate the external forces will be based on strip theory. This approach is used to evaluate forces throughout the simulation of ship motions and loads. An additional and important feature is the prediction of pressures on the hull using a three-dimensional hull source representation. The resultant force on the ship from these pressures can be substituted for the hydrodynamic forces predicted from the strip approach into the equations of motion for a selected interval of time. The interval of time for which this force substitution may be made must be limited in order to minimize the considerable computing effort associated with a three-dimensional solution in the time domain. Figure 2 depicts this procedure. It should be emphasized that the formulations for the two methods (strip and three-dimensional) are separate and distinct and each can provide force information for the solution of the equations of motion.

A brief outline of the force components that comprise the total force used in the ship motion equations follows. We first examine the strip method followed by a brief discussion of the three-dimensional method.

2.2.1 Strip Approach Forces

Following strip theory, we will assume that the hydrodynamic force acting on the ship can be decomposed into three parts:

- (a) Froude-Krylov Force - The resultant force from the pressure in the waves which acts on the hull surface with the assumption that the pressure field is not affected by the presence of the ship.
- (b) Diffraction Force - A correction to the Froude-Krylov force that accounts for the disturbance of the ambient wave field by the presence of the ship.

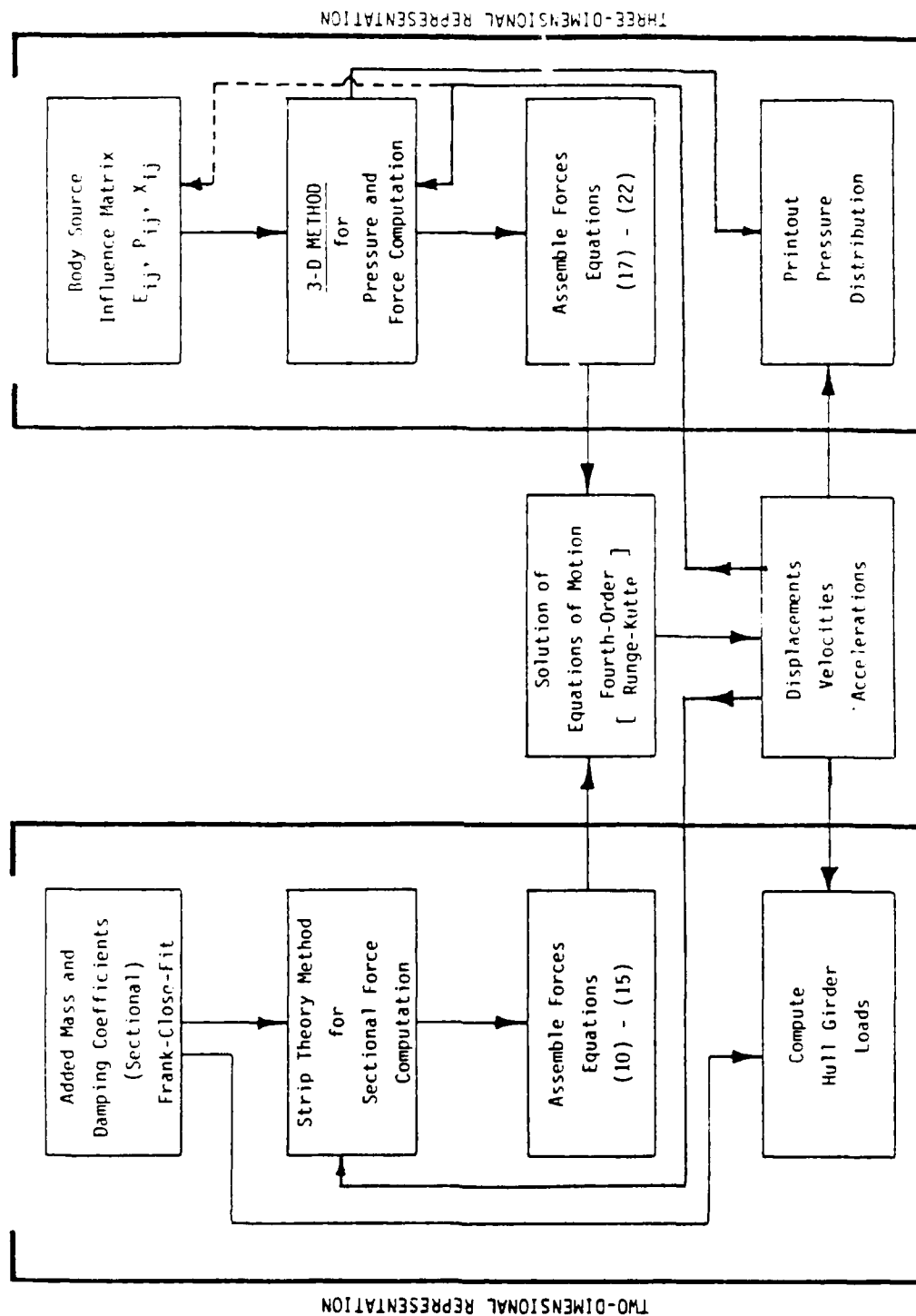


Figure 2 Diagram of Computational Scheme

- (c) Ship Motion-Induced Force - The force resulting from the motion of the ship with the assumption that it undergoes this motion in calm water.

The evaluation of the Froude-Krylov forces is obtained by integrating the pressure existing in the undisturbed waves over the wetted surface of the hull. The evaluation of the diffraction force and ship motion-induced force will generally be according to the elementary strip theory (see Raff [4]). Linear wave theory is employed and it will be assumed that the Froude-Krylov pressure and diffraction force evaluated in an irregular wave system is equivalent to the summation of the pressures and forces from the individual waves that comprise the irregular system.

The calculation of added mass and damping coefficients used in the evaluation of diffraction and ship motion-induced forces is by the Frank close-fit method. Because these coefficients are frequency dependent, a problem exists as to which frequency to use in the ship motion-induced force calculations since the ship motion may be irregular (non-harmonic). One approach taken by several investigators [26, 27] is to select a constant set of coefficients associated with one frequency.

We propose two other approaches and briefly examine the effect of each in Section 3.3. The first and simpler method is for a user-specified fixed value associated with the highest peak of the response spectra obtained from a frequency domain analysis or sea spectrum. The second approach is based on a scheme that samples the previous two zero-crossing periods of motion in sway, heave and roll. The two values are averaged, and three characteristic frequencies are derived for evaluation of the sectional hydrodynamic coefficients. The sway-roll or roll-sway coefficients are (arbitrarily) linked to the sway characteristic frequency.

In frequency domain strip theory formulations, the added mass and damping coefficients are evaluated at the still waterline. In the present formulation, at each time step, two-dimensional hydrodynamic coefficients can be evaluated for each section at either the mean still water draft or at the instantaneous depth of immersion. When it is desired that the hydrodynamic coefficients be draft dependent, the coefficients are obtained by linear interpolation from an array of six values corresponding to six drafts covering a range from near the baseline to the deck edge. Since the hydrodynamic coefficients are also frequency dependent, they are selected using linear interpolation from an array of twelve values associated with a range of twelve frequencies specified by the user. Thus, when the two-dimensional sectional coefficients are to be both draft and frequency dependent, two-dimensional linear interpolation is performed.

One of the advantages of the time domain approach is that it provides the capability to predict the ship motion and loads response to virtually any force for which there is an evaluation method. The force may be an arbitrary function of space and time, or a function of absolute or relative ship position or velocity. Assuming there is an acceptable method of predicting the associated force and moment, we could incorporate into the present method such

phenomena as bottom slamming, flare slamming, and the shipping of green water; as well as wind forces, mooring forces, rudder and propeller forces, viscous and appendage related damping, etc. The incorporation of methods to evaluate most of these forces will be left as the subject of subsequent investigations. We will, however, include here a flare force prediction method and also the means to incorporate a quadratic damping force. For flare impact force, we will use the approach described by Meyerhoff [26].

2.2.2 Three-Dimensional Pressure and Forces

The ship hull is modeled by quadrilateral panels. At the center of each panel, the pressure is evaluated, and resultant forces may be obtained. The pressure computed by this method includes the Froude-Krylov pressure (excluding the hydrostatic part), the diffraction pressure and the ship motion-induced pressure. Further description of this method will be left to Section 2.5, where it is discussed in detail.

2.2.3 Total Force Equations

The total force equations are given using the notation shown below. The force for each degree of freedom is indicated by:

X = longitudinal force
Y = vertical force
Z = lateral force
K = roll moment
N = yaw moment
M = pitch moment

Subscripts to these force symbols specify the type of force according to:

b = Froude-Krylov
h = ship motion-induced
w = wave diffraction
f = "flare" force
q = quadratic damping force
t = total force

Two sets of equations will be given; the first showing the force components normally used during the simulation, and the second showing the force components when the three-dimensional method is invoked. The external forces (F) and moments (M) used in the equations of motion (5) and (7) can be assembled from various sectional force components according to:

$$F_1 = \int \frac{X_b}{dx} dx \quad (10)$$

$$F_2 = \int \frac{dY_h}{dx} dx + \int \frac{dY_w}{dx} dx + \int \frac{dY_f}{dx} dx + \int \frac{dY_b}{dx} dx + Y_q \quad (11)$$

$$F_3 = \int \frac{dZ_h}{dx} dx + \int \frac{dZ_w}{dx} dx + \int \frac{dZ_b}{dx} dx + Z_q \quad (12)$$

$$T_1 = \int \frac{dK_h}{dx} dx + \int \frac{dK_w}{dx} dx + \int \frac{dK_b}{dx} dx + K_q \quad (13)$$

$$T_2 = \int x \frac{dZ_h}{dx} dx + \int x \frac{dZ_w}{dx} dx + \int \frac{dN_b}{dx} dx + N_q \quad (14)$$

$$T_3 = \int x \frac{dY_h}{dx} dx + \int x \frac{dY_w}{dx} dx + \int x \frac{dY_f}{dx} dx + \int \frac{dM_b}{dx} dx + M_q \quad (15)$$

All integrations are performed over the length of the ship. The strip theory equations used to evaluate the sectional forces are given in Section 2.4. As will be seen in that section, in the equations for the sectional ship motion-induced forces there is a part related to acceleration. These acceleration-related forces cannot be computed directly at any particular time step, since the acceleration values at that time are not a priori known. Consequently, the acceleration force terms in those equations are extracted and transferred to the mass moment and product of inertia matrices as the second terms in the right-hand side of expressions (8) and (9) given earlier. These matrices are assembled according to the following expressions:

$$A_{22} = \int a_{22} dx$$

$$A_{33} = \int a_{33} dx$$

$$A_{43} = \int a_{34} dx$$

$$A_{44} = \int a_{44} dx \quad (16)$$

$$A_{45} = \int x a_{34} dx$$

$$A_{53} = \int x a_{33} dx$$

$$A_{55} = \int x^2 a_{33} dx$$

$$A_{62} = \int x a_{22} dx$$

$$A_{66} = \int x^2 a_{22} dx$$

with the remaining values of $A_{jk} = 0$. All integrations are over the length of the ship.

When the three-dimensional pressure calculational procedure is run concurrently with the stripwise force calculations, three-dimensional pressure forces may be substituted for the stripwise hydrodynamic forces. During such an interval, the force expressions (10) - (15) would instead appear as:

$$X_T = X_{3D} + X_b^S + X_q \quad (17)$$

$$Y_T = Y_{3D} + Y_b^S + \int \frac{dY_f}{dx} dx + Y_q \quad (18)$$

$$Z_T = Z_{3D} + Z_b^S + Y_q \quad (19)$$

$$K_T = K_{3D} + K_b^S + K_q \quad (20)$$

$$N_T = N_{3D} + N_b^S + N_q \quad (21)$$

$$M_T = M_{3D} + M_b^S + \int x \frac{dY_f}{dx} dx + M_q \quad (22)$$

where $X_b^S \dots M_b^S$ are the hydrostatic force components of the Froude-Krylov forces, and $X_{3D} \dots M_{3D}$ are the force components calculated from the three-dimensional pressure computations.

This completes the formulation of the equations of motion and the force equations. The next several sections will present the computation of the Froude-Krylov force, the sectional diffraction and ship motion-induced forces, the flare impact force, and the three-dimensional pressures and resultant forces.

2.3 FROUDE-KRYLOV FORCES

We will assume that the elevation of the sea surface $\eta(\vec{x}, t)$ can be described as the superposition of a number of sinusoids of the form:

$$\eta(\vec{x}, t) = \sum_{i=1}^N a_i \cos(\vec{k}_i \cdot \vec{x} - \omega_i t + \epsilon_i) = \sum_{i=1}^N \eta_i \quad (23)$$

The expression for hydrostatic and dynamic pressure can be derived from Bernoulli's equation and the definition of velocity potential for the incident wave field. If we include only the linear terms, and consider only deep water, the expression for pressure may be given as

$$p(t, x, y, z) = -\rho g \left[y - \sum_{i=1}^N e^{k_i y} \eta_i \right] \quad (24)$$

The Froude-Krylov force may be obtained by integrating the pressure over the immersed surface of the ship. This surface integral may be replaced by a volume integral,* so that the expressions for total Froude-Krylov forces and moments can be given by the integral of the pressure gradients. Sectional forces can be evaluated according to:

$$\frac{dX_b}{dx} = - \iint \frac{\partial p}{\partial x} dy dz$$

* Gauss Theorem -

$$F = \iint \eta p dA = \iiint \nabla p dV$$

$$\frac{dY_b}{dx} = - \iint \frac{\partial p}{\partial y} dydz$$

$$\frac{dZ_b}{dx} = - \iint \frac{\partial p}{\partial z} dydz$$

$$\frac{dK_b}{dx} = \iint (z \frac{\partial p}{\partial y} - y \frac{\partial p}{\partial z}) dydz$$

$$\frac{dN_b}{dx} = \iint (x \frac{\partial p}{\partial z} - z \frac{\partial p}{\partial x}) dydz \quad (25)$$

$$\frac{dM_b}{dx} = \iint (y \frac{\partial p}{\partial x} - x \frac{\partial p}{\partial y}) dydz$$

For each section, vertical integration extends to the wave surface rather than the mean water level. This fact necessitates some sort of approximation to evaluate pressures in the free surface zone since linear wave theory implies infinitesimal amplitudes which do not extend measurably above or below the mean water level.

From a review of the relevant literature, there appear to be three basic approaches for approximating the velocities and pressures in the free surface zone:

- (a) Unmodified Formula - Use the same formulas (for pressure) above mean sea level that apply below sea level. (Eq. 26 with no restrictions on y .)
- (b) Stretching Correction - Stretch the still water level in the formula to the sea surface.
- (c) Hydrostatic - Assume the pressure in the wave above the mean water level is hydrostatic.

There is not sufficient experimental data to support the use of one scheme over the next. The CAPSIZE program [29] uses the unmodified formula. There are also some limited experimental data obtained by Chakrabarti [30] to indicate that a hydrostatic pressure assumption is accurate in regular waves. If we select the hydrostatic assumption, the pressure equation may then be written as

$$p(t,x,y,z) = -\rho g \left[y - \sum_{i=1}^N e^{k_i y} n_i \right] \quad y < 0 \quad (26)$$

$$p(t,x,y,z) = -\rho g \left(y - \sum_{i=1}^N \eta_i \right) \quad y > 0 \quad (27)$$

The differences in ship response as a result of using the unmodified pressure formula above the mean waterline were investigated. Comparisons for heave and pitch response of the SL-7 containership in 15-foot waves indicated that the differences were negligible. In any event, both methods are approximations. Their use, however, is necessitated by the employment of linear wave theory, and we therefore cannot escape the use of such simplifications. The computer code, as presently written, allows the user to select either approximation.

2.4 SECTIONAL HYDRODYNAMIC FORCES

Following elementary strip theory, local sectional hydrodynamic forces induced by the ship's motion and by diffraction force for heave, sway and roll are given in this section. The equations given below are equivalent to the basic equations given by Raff [4] in SSC-230. Flare impact force and quadratic roll damping are also discussed.

Vertical Sectional Ship Motion-Induced Force

$$\begin{aligned} \frac{dY_h}{dx} = & -a_{22} (\ddot{y}_G + x\ddot{\psi} - 2U\dot{\psi}) \\ & - b_{22} (\dot{y}_G + x\dot{\psi} - U\psi) \\ & + U \frac{da_{22}}{dx} (\dot{y}_G + x\dot{\psi} - U\psi) \end{aligned} \quad (28)$$

Vertical Sectional Diffraction Force

$$\frac{dy_w}{dx} = \sum_{i=1}^N \left[\dot{\xi}_i a_{22} + \epsilon_i (b_{22} - U \frac{da_{22}}{dx}) \right] \quad (29)$$

Lateral Sectional Ship Motion-Induced Force

$$\begin{aligned}
 \frac{dZ_h}{dx} = & -a_{33} (\ddot{z} - x \ddot{\phi} + 2U \dot{\phi}) \\
 & + \left(U \frac{da_{33}}{dx} - b_{33} \right) (\dot{z} - x \dot{\phi} + U \phi) \\
 & + (a_{43} + h_{cg} a_{33}) \ddot{\theta} \\
 & + [b_{43} + h_{cg} b_{33} - U \left(\frac{da_{43}}{dx} + h_{cg} \frac{da_{33}}{dx} \right)] \dot{\theta}
 \end{aligned} \tag{30}$$

Lateral Sectional Diffraction Force

$$\begin{aligned}
 \frac{dZ_w}{dx} = & \sum_{i=1}^N \{ [\dot{\zeta}_i a_{33} - \zeta_i \left(U \frac{da_{33}}{dx} - b_{33} \right)] \\
 & - [\dot{\kappa}_i h_{cg} a_{34} - \kappa_i h_{cg} \left(U \frac{da_{34}}{dx} - b_{34} \right)] \}
 \end{aligned} \tag{31}$$

Roll Sectional Ship Motion-Induced Moment

$$\begin{aligned}
 \frac{dK_h}{dx} = & - (a_{44} + h_{cg} a_{34}) \ddot{\theta} \\
 & - [b_{44} + h_{cg} b_{34} - U \left(\frac{da_{44}}{dx} + h_{cg} \frac{da_{34}}{dx} \right)] \dot{\theta} \\
 & + a_{34} (\ddot{z} - x \ddot{\phi} + 2U \dot{\phi}) \\
 & + (b_{34} - U \frac{da_{34}}{dx}) (\dot{z} - x \dot{\phi} + U \phi) - h_{cg} \frac{dZ_h}{dx}
 \end{aligned} \tag{32}$$

Roll Sectional Diffraction Force

$$\begin{aligned} \frac{dK_w}{dx} = & \sum_{i=1}^N \{ \dot{\kappa}_i a_{44} - \kappa_i (U \frac{da_{44}}{dx} - b_{44}) \} \\ & - [\dot{\zeta}_i h_{cg} a_{34} - \zeta_i (U \frac{da_{34}}{dx} + b_{34})] - h_{cg} \frac{dZ_w}{dx} . \end{aligned} \quad (33)$$

Following the procedure used in the program CAPSIZE [29], each ship section is defined as a closed polygon made up of straight line segments between offsets. The integrals of vertical, horizontal and "roll" wave velocities and accelerations, as well as pressure gradients over each section, are evaluated exactly at each time step. Longitudinal integrations of sectional diffraction forces and Froude-Krylov forces (excluding hydrostatic component) are performed assuming the sectional forces are functions of the following form:

$$f(x) = \sum_{i=1}^N [C_i \cos(k'_i x) + S_i \sin(k'_i x)]$$

where

S_i, C_i = sine and cosine components of force fluctuation for wave component i , the relative magnitudes of which provide the proper phase relationship of all wave-related forces.

k'_i = projection of the wave number onto the x-axis of ship.

Longitudinal integrations are performed assuming C_i and S_i vary linearly along the ship's length.

Flare Force

The approach for evaluating flare force is actually an extension of the strip theory expressions. Its incorporation into the present methodology serves to highlight the capability of the time domain method to account for the effects of the above-waterline hull on motions and loads. Furthermore, earlier work by Kaplan [31], Borreson and Tellsgaard [27], and Meyerhoff [22] have already provided the basic method to compute flare forces.

Following the approach described by Meyerhoff, the time derivative of the relative wave elevation for any strip may be given as

$$\dot{\eta}_r = \frac{\omega_0}{\omega_e} \dot{\eta} - \dot{y}_G - x\dot{\psi} + \psi U \quad (34)$$

where $\dot{\eta}$ denotes the time-derivative of the wave elevation relative to the ship-fixed coordinate system, ω_0 is wave frequency and ω_e is frequency of encounter. The convective derivative of relative velocity is accounted for by the factor ω_0 / ω_e . In the derivation of the expression for hydrodynamic inertia forces in the strip method, it can be shown that a nonlinear term results which represents an impact term. It contains the square of the relative velocity, and according to Meyerhoff [26] appears as:

$$\frac{dY_f}{dx} = \mu (\dot{\eta}_r)^2$$

where

$$\begin{aligned} \mu &= \left\{ \frac{\partial a_{22}(\infty)}{\partial \eta_r} \right\} & \text{if } \dot{\eta}_r > 0 \\ &= 0 & \text{if } \dot{\eta}_r \leq 0 \end{aligned}$$

The limiting value of added mass at infinite frequency is used in accordance with the theory of normal-symmetric impact upon a calm water surface. (It should also be pointed out that this formulation does not account for diffracted free surface motion, and the name "Froude-Krylov flare force" might more accurately represent the effect.)

Quadratic Damping

The expressions for total forces and moments (10) - (15) and (17) - (22) each contain a term which represents a force or moment which is proportional to velocity-squared. The user of the computer program may specify, as input, his own values for quadratic damping coefficients. Accurate roll prediction often requires some quadratic roll damping. The damping moment associated with roll, for example, may be written in the form

$$K_q = B_{44}^* |\dot{\theta}| \dot{\theta}$$

where B_{44}^* is the quadratic roll damping coefficient for the ship, and $\dot{\theta}$ is roll angle velocity.

2.5 THREE-DIMENSIONAL DYNAMIC PRESSURES AND FORCES

2.5.1 Introduction

A numerical method for calculating the transient three-dimensional flow induced by the motion in waves of a floating body of arbitrary shape with forward speed is presented in this section. Dynamic pressures and the resultant forces and moments acting on the hull surface can be evaluated in the time domain using this technique. The solution is generated in terms of a source distribution representation of the body and a spectral representation of the free surface. The approach presented here expands upon the work of R.B. Chapman [5,6]. Although Chapman had provided the basic method to solve the problem of ship motions in waves, his formulation did not explicitly include the ambient wave field effects and associated diffraction flow.

Following Chapman, the general formulation is linearized, assuming that the individual potentials and their derivatives associated with forward speed, body motion, free surface disturbance caused by radiated and diffracted waves, and the ambient wave flow are each sufficiently small to ignore higher order terms and cross-products. The free surface equations are also linearized. The formulation partially accounts for the "exact" hull boundary by evaluating hydrodynamic pressures on the actual immersed portion of the body surface at each time step below the still waterline. Thus, the effect of large-amplitude motions is included to some extent.

It should be emphasized that this three-dimensional approach is a separate procedure quite distinct from the strip formulation and equations of motion solution techniques that form the basic framework. It is best viewed as a "parallel process," interfacing with the main solution procedures in the following ways:

- (a) It requires, as input, the specification of body position and velocities at each time step.
- (b) It provides as output forces and moments on the hull, as well as additional information regarding distributed dynamic pressures.

In the formulation that follows, for the convenience of the reader who wishes to refer to Chapman's work, we will use Chapman's coordinate system throughout Section 2.5.

2.5.2 Formulation

A Cartesian coordinate system is fixed in space with the x-axis in the direction of the ship's forward advance, positive forward; the z-axis positive

downward and y-axis positive to starboard. The still mean water level corresponds to $z=0$. The free surface elevation is specified by (x,y,t) and the ship's hull is defined by $S(x,y,z,t) = 0$ for $z > 0$. If the fluid is assumed to be inviscid, incompressible and homogeneous and the flow irrotational, then the fluid velocity $\vec{v}(\vec{x}, t)$ can be represented by the gradient of the velocity potential $\phi(\vec{x}, t)$. If we linearize the free surface equations, the velocity potential must satisfy the following conditions:

$$\nabla^2 \phi = 0 \quad z > 0 \quad (35)$$

$$\frac{\partial \phi}{\partial t} = -g \eta \quad z = 0 \quad (36)$$

$$\frac{\partial \phi}{\partial z} = \frac{\partial \eta}{\partial t} \quad z = 0 \quad (37)$$

$$\frac{\partial \phi}{\partial \vec{n}} - \vec{V}_S \cdot \vec{n} = 0 \quad - \text{ on } S(x,y,z,t) = 0 \quad (38)$$

where $\vec{V}_S$ is the velocity at any point on the hull surface S , and $\vec{n}$ is the unit normal to the boundary surface at the point, pointing outward. The velocity potential can be decomposed into two parts:

$$\phi(x,y,z,t) = [-Ux + \phi_S(x,y,z) + \phi_T(x,y,z,t)] \quad (39)$$

where $-Ux + \phi_S$ is the steady part and U is the forward speed of the ship, and $\phi_T(x,y,z,t)$ is the time-varying potential. In the present formulation, we will neglect the steady part and consider only the time-varying potential.

Separating the time-varying potential into three parts, we obtain

$$\phi_T = \phi_B + \phi_{FS} + \phi_A \quad (40)$$

where ϕ_B represents the instantaneous effect of the body, ϕ_{FS} represents the existing free surface disturbance due to previously radiated and diffracted waves, and ϕ_A is the ambient wave potential.

The body potential will be represented by a distribution of simple sources over the wetted hull and its negative image. A spectral representation of the free surface potential will be used so that the diffracted and radiated wave fields are represented by two series, harmonic in space and time. The potential for the ambient wave system will be given according to linear theory for progressive waves. It should be noted that, although the method can be extended to include sources distributed over the entire body, the present procedure only distributes sources over the body below the mean waterline.

The objective of this analysis is to compute the hydrodynamic pressure on the hull, as determined from the potential field $\phi_T(x,y,z,t)$. The dynamic pressure can be obtained from Bernoulli's equation applied to $\phi_T(x,y,z,t)$. If the flow is assumed to be slow enough that the non-linear term can be neglected, Bernoulli's equation is:

$$p_T = -\rho \frac{\partial \phi_T}{\partial t} = -\rho \frac{\partial}{\partial t} [\phi_B + \phi_{FS} + \phi_A] \quad (41)$$

By linearizing the problem, we can evaluate the total pressure at any time or point as the sum of the individual pressure components, as given by:

$$p_B(x,y,z,t) = -\rho \left[\frac{\partial \phi_B}{\partial t} - \vec{V}_s \cdot \vec{\nabla} \phi_B \right] \quad (42)$$

$$p_{FS}(x,y,z,t) = -\rho \frac{\partial \phi_{FS}}{\partial t} \quad (43)$$

$$p_A(x,y,z,t) = -\rho \frac{\partial \phi_A}{\partial t} \quad (44)$$

The convective derivative for the body pressure expression is included because the Bernoulli equation given here is for fixed points in space, yet the body potential is associated with the moving hull surface. We will assume, however, that products of the body velocity and potential gradients are negligible with the exception of $U \frac{\partial \phi_B}{\partial x}$. Equation (42) then becomes:

$$p_B(x,y,z,t) = -\rho \left[\frac{\partial \phi_B}{\partial t} - U \frac{\partial \phi_B}{\partial x} \right]. \quad (45)$$

Prior to describing the individual potential representations in detail, it will be advantageous to first describe the numerical solution procedure on a step-by-step basis.

2.5.3 Solution Procedure

This is an initial value problem that ideally should start from a condition at rest. Prior to starting the simulation, the following arrays relating to the body source representation are calculated:

- (a) E_{ij} - gives the normal velocity component at the center point of panel i induced by a uniform source distributed over panel j and its image. (As will be explained, the hull surface is modeled by quadrilateral panels; at the center of each is a simple source.)
- (b) $\hat{P}_{ij}$ - gives the potential at the center of panel i induced by uniform source density of unit strength acting over panel j .
- (c) X_{ij} - gives the x-direction velocity component at the center point of panel i induced by a uniform source distributed over panel j and its image.

The simulation progresses by a series of small time steps, according to the following sequence:

Step 1.

As we begin each time step, we will have already computed the velocities, accelerations and pressures induced by the free-surface disturbance and ambient wave field at the center of each panel. (These will be known from steps (5) and (6) of the previous time cycle.) The body velocity and acceleration will have been obtained from the solution to the equations of motion.

First, for time $t = t_n$, compute the resultant total normal velocity $(\vec{v}_T \cdot \vec{n})^*$ at the center of each panel.* This resultant velocity represents the sum of the velocity from the body motion, the velocity induced by the existing free surface disturbance, and the velocity induced by the ambient wave field:

$$\vec{v}_T \cdot \vec{n} = (\vec{v}_B + \vec{v}_{FS} + \vec{v}_A) \cdot \vec{n} \text{ at panel centers.} \quad (46)$$

According to Chapman [6], it is more convenient to use accelerations instead of velocities. Equation (46) can then be expressed as:

$$\vec{a}_T \cdot \vec{n} = (\vec{a}_B + \vec{a}_{FS} - U \frac{\partial}{\partial x} \vec{v}_{FS} + \vec{a}_A - U \frac{\partial}{\partial x} \vec{v}_A) \cdot \vec{n}. \quad (47)$$

(The convective derivatives are required in this case for $\vec{a}_{FS}$ and $\vec{a}_A$ because we are in a hull-fixed system when computing the resultant normal acceleration on the body.)

Step 2.

Knowing $\vec{a}_T$ from step (1) and having precalculated E_{ij} , determine the time derivative of the source strengths $\dot{\sigma}_j$ according to

$$\sum_{j=1}^{N_B} E_{ij} \dot{\sigma}_j = \vec{a}_T \cdot \vec{n} \text{ at } t = t_n. \quad (48)$$

Step 3.

Calculate the body-induced component of pressure at the center point of each panel induced by the computed time derivative of the source strength in a hull fixed system according to

* In the equations that follow, it is understood that all normal vectors, areas, positions or coordinates on the hull are functions of time, even though they may not be so specified.

$$p_B = -\rho \frac{\partial \phi_B}{\partial t} + \rho U \frac{\partial \phi_B}{\partial x} \quad (49)$$

or

$$p_B = -\rho \sum_{j=1}^{N_B} \hat{p}_{ij} \dot{\sigma}_j(t_n) + \rho U x_{ij} \sigma_j(t_n) \quad (50)$$

Step 4.

Compute total pressure at each panel

$$p_T(t_n) = p_B(t_n) + p_{FS}(t_n) + p_A(t_n) .$$

Step 5.

Update the source strengths for this time step (t_n) according to

$$\sigma_i(t_n) = \sigma_i(t_n - \Delta t) + \Delta t \dot{\sigma}_i(t_n) \quad (51)$$

Step 6.

As described in Section 2.5.5, update the free surface representations. Modify the free surface to account for the effect of the hull source strengths on the free surface. Calculate acceleration induced by the free surface at the center of each panel $\vec{a}_{FS}(t_n + \Delta t)$ and the pressure induced by the free surface disturbance at the center of each panel $p_{FS}(t_n + \Delta t)$.

Step 7.

Update the ambient wave field. Calculate the acceleration $\vec{a}_A(t_n + \Delta t)$ and pressure $p_A(t_n + \Delta t)$ induced by the ambient wave field at the center of each panel.

Step 8.

Go to Step 1 with the new $\vec{a}_{FS}$, $\vec{a}_A$ and newly prescribed $\vec{a}_B$.

2.5.4 Body Representation

As shown in Figure 3, the hull is modeled by a set of N_B quadrilateral panels. A simple source and its image is distributed over each panel. The expression for the body potential can then be expressed as:

$$\phi_B(x,y,z) = \sum_{i=1}^{N_B} \sigma_i \iint_{S_i} G(x,y,z,x',y',z') dS' \quad (53)$$

in which

$$G(x,y,z,x',y',z') = \left[\frac{(x-x')^2 + (y-y')^2 + (z-z')^2}{4} \right]^{-1/2} - \left[\frac{(x-x')^2 + (y-y')^2 + (z+z')^2}{4} \right]^{-1/2} \quad (54)$$

σ_i is the strength on the i^{th} source panel

S_i is the i^{th} panel surface.

Panel source strengths are evaluated at each time step using a linear system of equations relating resulting total normal velocities $(\vec{v}_T \cdot \vec{n})$ at each panel center to the source strength σ_j at every other panel j center and by the satisfaction of the hull boundary condition at the center of each panel. The exact method of Hess and Smith [32] is used here to determine the normal velocity component at the center point of panel i induced by a plane quadrilateral source element with a unit value of source density at the center point of panel j . A body coefficient scalar matrix E_{ij} is thus computed which can be used to determine unknown source densities when given panel center normal velocities, according to

$$\vec{v}_T \cdot \vec{n}_i = \sum_{j=1}^{N_B} E_{ij} \sigma_j \quad (55)$$

As was shown in equation (46), the panel center total normal velocity is the sum of components from the hull motion and induced velocities from radiated and diffracted free surface disturbances and ambient wave field.

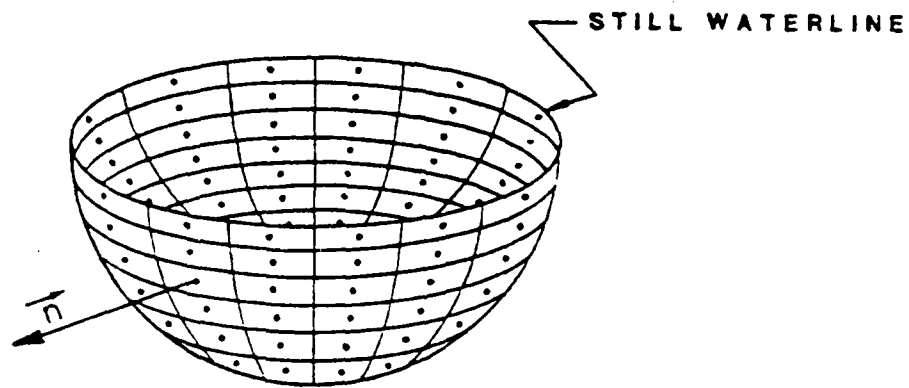


Figure 3 Quadrilateral panels and source representation of semisubmerged sphere.

Also, in Step 3 of the computational sequence, equations (49) and (50) show that the calculation of body-induced pressure at panel centers requires the use of two other arrays $\hat{p}_{ij}$ and X_{ij} . The X_{ij} array gives the x-direction velocity component at the center point of panel i induced by a uniform source (of unit strength) distributed over panel j and its image. It is thus very similar to the E_{ij} array, relating the x-component instead of the normal component of panel velocities. In practice, it is evaluated directly from the information used to evaluate E_{ij} .

The $\hat{p}_{ij}$ array gives the potential at the center of panel i induced by a uniform source (of unit strength) distributed over panel j and its image, or

$$\phi_{B_i} = \sum_{j=1}^{N_B} \hat{p}_{ij} \sigma_j \quad (56)$$

Looking back at equation (53) for a moment, it can be seen the $\hat{p}_{ij}$ can be computed by relating each panel center to every other panel center using the expression for $G(x,y,z,x',y',z')$, or in the indexed notation,

$$\begin{aligned} \hat{p}_{ij} = \iint_{S_i} dS_i \{ & [(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2]^{-1/2} \\ & - [(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j + z_i)^2]^{-1/2} \} \end{aligned} \quad (57)$$

These integrals are evaluated numerically by dividing the surface S_i into many small elements and evaluating the above integrand at the center of each smaller element.

2.5.5 Free Surface Representation

A spectral representation of the free surface will be used. Let the free surface elevation and velocity potential be represented by $\eta(x,y,t)$ and $\phi_{FS}(x,y,z,t)$, respectively. The elevation and potential satisfy the dynamic and kinematic linearized free-surface conditions at $z = 0$.

$$\frac{\partial}{\partial t} \phi(x,y,0,t) = -g \eta(x,y,t) \quad (58)$$

$$\frac{\partial \phi}{\partial z} \eta(x,y,t) = - \frac{\partial \eta}{\partial t} (x,y,0,t) \quad (59)$$

Now assume that both the elevation and deep water potential can be represented by the real part of a finite summation of harmonics in the following forms:

$$\eta(x,y,t) = \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m [A_{nm}(t) e^{i(kx_n \cdot x + ky_m \cdot y)} + A_{nm}^*(t) e^{i(kx_n \cdot x - ky_m \cdot y)}] \quad (60)$$

$$\phi_{FS}(x,y,z,t) = \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m [B_{nm}(t) \omega_{nm} k_{nm}^{-1} e^{i(kx_n \cdot x + ky_m \cdot y)} + B_{nm}^*(t) \omega_{nm} k_{nm}^{-1} e^{i(kx_n \cdot x - ky_m \cdot y)}] e^{-k_{nm} \cdot z} \quad (61)$$

where

A_{nm}, B_{nm} - complex functions of wave numbers and time
(to be further defined below)

A_{nm}^*, B_{nm}^* - complex conjugates

kx_n, ky_m - wave numbers in x and y; e.g., $\frac{\omega_n^2}{g}$

$\Delta kx_n, \Delta ky_m$ - wave number spacing; e.g., $\Delta kx_n = kx_{n+1} - kx_n$

k_{nm} - $k_{nm}^2 = kx_n^2 + ky_m^2$

ω_{nm} - $\omega_{nm}^2 = g [kx_n^2 + ky_m^2]^{1/2}$

Substitution of equations (60) and (61) into the free surface equations (58) and (59) would confirm that the above elevation and potential expressions do indeed satisfy the linearized free surface conditions. We would also obtain, from those substitutions, the following relationships between the complex amplitude functions:

$$\frac{d}{dt} A_{nm}(t) = \omega_{nm} B_{nm}(t) \quad (62)$$

$$\frac{d}{dt} B_{nm}(t) = -\omega_{nm} A_{nm}(t) \quad (63)$$

(The complex conjugates are described by identical expressions).

As part of the free surface elevation representation, we further define the complex amplitude function A_{nm} as

$$A_{nm}(t) = a_{nm} \cos \omega_{nm} t + b_{nm} \sin \omega_{nm} t \quad (64)$$

where a_{nm} and b_{nm} are complex constants. Substitution of (64) into (62) yields the expression for $B_{nm}(t)$.

$$B_{nm}(t) = b_{nm} \cos \omega_{nm} t - a_{nm} \sin \omega_{nm} t \quad (65)$$

Similar expressions also describe the complex conjugates.

Updating the Free Surface

Equations (62), (63), (64) and (65) allow us to develop the expressions for the time evolution of $A_{nm}(t)$ and $B_{nm}(t)$. Consider $A_{nm}(t)$ first. If we increment the time in equation (64) by Δt , we obtain

$$A_{nm}(t + \Delta t) = a_{nm} \cos \omega_{nm} (t + \Delta t) + b_{nm} \sin \omega_{nm} (t + \Delta t) \quad (66)$$

Using the following trigonometric identities,

$$\cos (x \pm y) = \cos x \cos y \mp \sin x \sin y \quad (67)$$

$$\sin (x \pm y) = \sin x \cos y \pm \cos x \sin y$$

we can rewrite (66) as

$$\begin{aligned} A_{nm}(t + \Delta t) = & a_{nm} \cos \omega_{nm} t \cos \omega_{nm}(\Delta t) - a_{nm} \sin \omega_{nm} t \sin \omega_{nm}(\Delta t) \\ & + b_{nm} \sin \omega_{nm} t \cos \omega_{nm}(\Delta t) + b_{nm} \cos \omega_{nm} t \sin \omega_{nm}(\Delta t) \end{aligned} \quad (68)$$

Rearranging (68), we can write

$$\begin{aligned} A_{nm}(t + \Delta t) = & [a_{nm} \cos \omega_{nm} t + b_{nm} \sin \omega_{nm} t] \cos \omega_{nm}(\Delta t) \\ & + [b_{nm} \cos \omega_{nm} t - a_{nm} \sin \omega_{nm} t] \sin \omega_{nm}(\Delta t) \end{aligned} \quad (69)$$

It can be seen that the quantities in the brackets are equivalent to the right-hand sides of equations (64) and (65), so that we can now obtain

$$A_{nm}(t + \Delta t) = A_{nm}(t) \cos \omega_{nm}(\Delta t) + B_{nm}(t) \sin \omega_{nm}(\Delta t) \quad (70)$$

The expression for $B_{nm}(t)$ can be similarly obtained and is given as

$$B_{nm}(t + \Delta t) = B_{nm}(t) \cos \omega_{nm}(\Delta t) - A_{nm}(t) \sin \omega_{nm}(\Delta t) \quad (71)$$

Identical expressions are used for updating $A_{nm}^*(t)$ and $B_{nm}^*(t)$. Thus, expressions (70) and (71) provide the means to update the coefficients which define the wave field. To these updated values must be added any contribution to the wave field from the body motion between times t and $t + \Delta t$, as described next.

Body Effect on the Free Surface

Next we consider the effect of the body source distribution on the wave elevation field over the time interval Δt . Assume that the change in $A_{nm}(t)$ induced by the body between t_n and $t_n + \Delta t$ is expressed by the sum of the effects of the individual sources and their images. For convenience, we will first replace a uniform source density acting over a panel of area A_i by a single point source with strength

$$s_i(t) = A_i [\sigma_i(t_n) + (t - t_n) \dot{\sigma}(t_n)] \quad (72)$$

which is located at the panel center. The time, t , is defined to be $t = t_n + 1/2\Delta t$, the midpoint of the time interval.

At any given point on the mean water level plane $(x, y, 0)$, the vertical velocity induced by the source points and their images is given by

$$\frac{\partial \phi_B(t)}{\partial z} = - \sum_{i=1}^{N_B} \frac{2z_i s_i(t)}{[(x-x_i)^2 + (y-y_i)^2 + z_i^2]^{3/2}} \quad (73)$$

According to Chapman [6], equation (73) can also be expressed in an integral form given as

$$\begin{aligned} \frac{\partial \phi_B(t)}{\partial z} = & \frac{2}{\pi} \sum_{i=1}^{N_B} s_i(t) \int_0^{\infty} dkx e^{ikx(x-x_i)} \int_{-\infty}^{\infty} dky \cos ky(y-y_i) \\ & \cdot e^{-(kx^2 + ky^2)z_i} \end{aligned} \quad (74)$$

Substituting (74) into the linearized kinematic free surface condition (59), and integrating over the time interval Δt , we can rewrite (74) to show how the elevation changes over Δt due to the body,

$$\Delta \eta_B(x,y) = \frac{2}{\pi} \int_{t_n}^{t_n + \Delta t} dt \sum_{i=1}^{N_B} s_i(t) \int_0^{\infty} dk_x e^{ik_x(x-x_i)} \int_{-\infty}^{\infty} dk_y \cos ky(y-y_i) e^{-(k_x^2 + k_y^2)z_i} \quad (75)$$

We may also write $\Delta \eta_B(x,y)$ in a different form, following the same form of the original expression (60) defining the free surface elevation. In that form, we can write

$$\Delta \eta_B(x,y) = \sum_{n=1}^{N_{kx}} \Delta k_{x_n} \sum_{m=1}^{N_{ky}} \Delta k_{y_m} [\Delta A_{nm}^{BODY}(t) e^{i(k_{x_n} \cdot x + k_{y_m} \cdot y)} + \Delta A_{nm}^{BODY*}(t) e^{i(k_{x_n} \cdot x - k_{y_m} \cdot y)}] \quad (76)$$

Then, if we represent the wave number integrals in (75) numerically by a finite summation, and also evaluate the time integral, it should be evident by direct comparison with (76) that the A_{nm} coefficient increments can be written as

$$\Delta A_{nm}^{BODY} = 2 \frac{\Delta t}{\pi} \sum_{i=1}^{N_B} s_i(t_n + 1/2 \Delta t) e^{-i(k_{x_n} \cdot x_i + k_{y_m} \cdot y_i)} e^{-k_{nm} z_i} \quad (77)$$

$$\Delta A_{nm}^{BODY*} = 2 \frac{\Delta t}{\pi} \sum_{i=1}^{N_B} s_i(t_n + 1/2 \Delta t) e^{-i(k_{x_n} \cdot x_i - k_{y_m} \cdot y_i)} e^{-k_{nm} z_i} \quad (78)$$

The changes in B_{nm} induced by the body can be derived from (78) and (79) using the relationship between $A_{nm}(t)$ and $B_{nm}(t)$ given in (63). Multiplying both sides of (63) by Δt and then integrating both sides over time, we obtain

$$\Delta B_{nm}^{BODY} = -1/2 \frac{\partial}{\partial t} A_{nm}^{BODY}(t) \omega_{nm} (\Delta t)^2 \quad (79)$$

or

$$\Delta B_{nm}^{BODY} = - \frac{(\Delta t)^2}{\pi} \sum_{i=1}^{N_B} s_i(t_n) e^{-i(kx_n \cdot x_i + ky_m \cdot y_i)} e^{-k_{nm} z_i} \omega_{nm} \quad (80)$$

with a similar expression for ΔB_{nm}^{BODY*} .

The effect of the body on the free surface can now be easily included by adding ΔA_{nm}^{BODY} , ΔA_{nm}^{BODY*} , ΔB_{nm}^{BODY} , and ΔB_{nm}^{BODY*} to the time evolution equations given earlier as (70) and (71) and the corresponding (complex conjugate) expressions.

Free Surface-Induced Pressure and Acceleration

Finally, we need to evaluate the pressure and acceleration induced by the free surface disturbance at the center of each panel. These two quantities are required in steps (4) and (1), respectively, of the simulation procedure. The pressure at any point (x,y,z) is given by

$$\begin{aligned} p_{FS} &= -\rho \frac{\partial \phi_{FS}}{\partial t} \\ &= \rho \sum_{n=1}^{N_{kx}} \Delta k x_n \sum_{m=1}^{N_{ky}} \Delta k y_m e^{(ikx_n \cdot x - k_{nm} \cdot z)} \\ &\quad [A_{nm}(t) e^{iky_m \cdot y} + A_{nm}^*(t) e^{-iky_m \cdot y}] \end{aligned} \quad (81)$$

the acceleration at any point (x,y,z) coincident with a unit normal vector (n_x, n_y, n_z) may be written as

$$\vec{a}_{FS} \cdot \vec{n} = -g \sum_{n=1}^{N_{kx}} \Delta k x_n \sum_{m=1}^{N_{ky}} \Delta k y_m e^{(ikx_n \cdot x - k_{nm} \cdot z)}$$

$$\begin{aligned}
& [A_{nm}(t) \cdot e^{iky_m \cdot y} (iky_n \cdot n_x + iky_n \cdot n_y - k_{nm} \cdot n_z) \\
& + A_{nm}^*(t) \cdot e^{-iky_m \cdot y} \cdot (ikx_n \cdot n_x - iky_m \cdot n_y - k_{nm} \cdot n_z)] \quad (82)
\end{aligned}$$

2.5.6 Ambient Wave Field Representation

The ambient wave field is represented by a linear wave system of amplitude A . Consider unidirectional, regular waves and define the velocity potential as

$$\phi_A(x, z, t) = -\frac{Ag}{\omega} e^{-kz} \sin(kx - \omega t) \quad (83)$$

The x and z components of velocity can then be expressed as

$$v_x(t) = -\frac{\partial \phi_A}{\partial x} = \frac{Agk}{\omega} e^{-kz} \cos(kx - \omega t) \quad (84)$$

$$v_z(t) = -\frac{\partial \phi_A}{\partial z} = -\frac{Agk}{\omega} e^{-kz} \sin(kx - \omega t) \quad (85)$$

The x and z components of acceleration can be given as

$$a_x(t) = \frac{\partial v_x}{\partial t} = Agk e^{-kz} \sin(kx - \omega t) \quad (86)$$

$$a_z(t) = \frac{\partial v_z}{\partial t} = Agk e^{-kz} \cos(kx - \omega t) \quad (87)$$

The dynamic pressure may be expressed as

$$p_A(t) = -\rho \frac{\partial \phi_A}{\partial t} = -Ae^{-kz} \cos(kx - \omega t) \quad (88)$$

We can now evaluate the normal acceleration and pressure induced at the center of each panel by the ambient wave field. These quantities are used in Steps 1 and 4 of the simulation procedure. The pressure is given in (88) and the normal acceleration is simply

$$\vec{a}_A \cdot \vec{n} = \vec{a}_x \cdot \vec{n}_x + \vec{a}_z \cdot \vec{n}_z \quad (89)$$

where the velocity components are given in (84) and (85). We will assume that in an irregular wave system, the total velocity, acceleration and pressure components can be described as the superposition of individual single frequency components.

2.6 HULL GIRDER LOADS

Hull girder loads are computed in the conventional manner of strip theory where the dynamic shear force at a cross section is the difference between the inertia force and the sum of external forces acting on the portion of the hull forward of the section. The vertical shear force and bending moment at any location x_0 along the ship's length is, in the original coordinate system,

$$SF_y(x_0) = \int_{x_0} \frac{df_y}{dx} dx \quad (90)$$

and

$$BM_y(x_0) = \int_{x_0} (x-x_0) \frac{df_y}{dx} dx \quad (91)$$

where

$$\frac{df_y}{dx} = -\delta m (\ddot{y} - x \ddot{\psi}) + \frac{dY_h}{dx} + \frac{dY_w}{dx} + \frac{dY_f}{dx} + \frac{dY_b}{dx} + y_q \quad (92)$$

and δm = local sectional mass. Integrations are performed from the location x_0 forward to the bow.

The lateral shear force, bending moment and torsional moment are given as

$$SF_z(x_0) = \int_{x_0}^{\text{bow}} \frac{df}{dx} z dx \quad (93)$$

$$BM_z(x_0) = \int_{x_0}^{\text{bow}} (x-x_0) \frac{df}{dx} z dx \quad (94)$$

$$TM_x(x_0) = \int_{x_0}^{\text{bow}} \frac{dm}{dx} x dx \quad (95)$$

where

$$\begin{aligned} \frac{df}{dx} z &= -\delta m (\ddot{z} - x\ddot{\phi} - \bar{y} \ddot{\theta}) \\ &\quad + \frac{dZ_h}{dx} + \frac{dZ_w}{dx} + \frac{dZ_b}{dx} + Z_q \end{aligned} \quad (96)$$

$$\begin{aligned} \frac{dm}{dx} x &= -i_x \ddot{\theta} - \delta m \bar{y} (\ddot{z} - x\ddot{\phi}) \\ &\quad + \frac{dK_h}{dx} + \frac{dK_w}{dx} + \frac{dK_b}{dx} + K_q \end{aligned} \quad (97)$$

and $\bar{y}$ = local section's center of gravity relative to ship c.g. (positive up).

i_x = local section's mass moment of inertia.

2.7 NUMERICAL ASPECTS

2.7.1 Solution Procedures - Two-Dimensional Approach

The equations of motion as represented by expressions (4) - (7) are numerically integrated for each time to yield velocities and displacements. The fourth-order Runge-Kutta scheme is used for this purpose. At each time step, two-dimensional hydrodynamic coefficients are evaluated for each section for either the still water draft or at the instantaneous depth of immersion, at the option of the user. When it is desired that the hydrodynamic coefficients be draft dependent, the coefficients are obtained by linear interpolation from an array of six values corresponding to six drafts which cover a

range specified by the user in the input data. Since the hydrodynamic coefficients are also frequency dependent, they are selected using linear interpolation from an array of twelve values associated with a range of twelve frequencies specified by the user. Thus, when the two-dimensional sectional coefficients are to be both draft and frequency dependent, two-dimensional linear interpolation is performed.

There are two methods for the selection of frequencies at which to evaluate the hydrodynamic coefficients. One is based on a scheme that samples the previous two zero-crossing periods of sectional motion in sway, heave and roll. The two values are averaged, and three characteristic frequencies are derived for evaluation of the sectional hydrodynamic coefficients. The sway-roll or roll-sway coefficients are (arbitrarily) linked to the sway characteristic frequency. The other allows the user to specify a frequency, such as the peaks of the response spectra or peak of the wave energy spectrum.

The sectional hydrodynamic coefficients are computed using the Frank close-fit method. Spatial derivatives of added mass and damping coefficients in the x-direction are approximated by center-space finite differences. In the calculation of the derivative of added mass with respect to the relative wave elevation used in the computation of vertical flare force, the added mass is evaluated at each time step at the instantaneous immersed draft of the section. For each time step interval Δt , the change in added mass is computed and divided by the change in instantaneous draft of the section. During water exit, the calculation of the impact term is not performed and the sectional flare force is set to zero.

2.7.2 Solution Procedures - Three-Dimensional Analysis

Specification of Parameters for Free Surface Harmonics

There are three parameters which must be chosen. These parameters dictate the wave numbers and wave number spacing for the free surface representation. The following parameters are to be specified for the three-dimensional transient analysis:

- L_x, L_y - maximum distances in $\pm x$ and $\pm y$ from body origin defining the physical region over which the wave field is required.
- T - maximum time interval for transient simulation.
- l_x, l_y - minimum half-wavelength related to the smallest scale of disturbance or physical feature of the hull that needs to be represented.

There are no set rules for the selection of these parameters, and their choice must be based on an understanding of the problem. There are, however, some

guidelines which generally seem to work well. The values of L_x and L_y should be 2 to 2.5 times the length and beam of the body, respectively. The values of l_x , l_y should be on the order of the average dimensions of the hull panels. The parameter T can be set to about 60% of the actual time for which a transient analysis is desired.

The wave numbers and wave number spacing are then specified according to the following relations:

(a) Maximum step sizes for kx_n and ky_m are:

$$\begin{aligned} kx_{n+1} - kx_n &\leq \frac{2\pi}{L_x} \\ ky_{m+1} - ky_m &\leq \frac{2\pi}{L_y} \end{aligned} \quad (98)$$

(b) The minimum upper bounds of kx and ky are:

$$\begin{aligned} kx_{N_{kx}} &> \frac{2\pi}{l_x} \\ ky_{N_{ky}} &> \frac{2\pi}{l_y} \end{aligned} \quad (99)$$

(c) Another set of conditions for wave number spacing is:

$$\begin{aligned} \sqrt{kx_{n+1}} - \sqrt{kx_n} &\leq \frac{2\pi}{(T\sqrt{g})} \\ \sqrt{ky_{m+1}} - \sqrt{ky_m} &\leq \frac{2\pi}{(T\sqrt{g})} \end{aligned} \quad (100)$$

A physical interpretation of the wave number spacing required by the above conditions has been pointed out by Chapman [5]. The wave numbers defined by (98), (99), and (100) correspond in the physical domain to "vertical walls"

which must be placed sufficiently far away from the body so that the free surface disturbances generated near the body do not reflect back over the time interval. Associated with the faster propagating, longer wavelengths are vertical walls placed further away - the shorter wavelength walls are nearer. The result is that the time interval for each wave to reflect is equal. For further discussion of the reasoning behind this method of wave number spacing and selection criteria, see [5].

Integration with Equations of Motion

At a time specified by the user, the three-dimensional transient analysis can start, using accelerations and velocities generated by the solution of the equations of motion at that time step. Then, data generated (pressures and loads) from the three-dimensional analysis is not used for a period of time specified by the user, so-called "start-up" time. This allows the free surface disturbance to fully develop since, initially, there exist no radiated or diffracted waves within the three-dimensional simulation. Based on the present level of experience with the program, the minimum start-up time for ship forms has not been fully defined; however, for a sphere, two full cycles of motion appear sufficient.

(THIS PAGE INTENTIONALLY LEFT BLANK)

3.0 NUMERICAL RESULTS

Several computer codes have been developed according to the predictive techniques discussed in the previous sections. The main program is entitled SSX (Ship Simulator, Experimental). It performs the simulation of ship motions, hull girder loads and hull pressures. There are two preprocessing programs - HYDREX2 and HYDREX3. The program HYDREX2 computes sectional added mass and damping coefficients for an array of twelve frequencies and six drafts using the Frank close-fit technique. The program also calculates general hydrostatic data for each of the six drafts. The program HYDREX3 computes areas, normals and panel center coordinates for the panel (either quadrilateral or triangular) representation of the hull. It also evaluates three computationally demanding arrays used for the simulation of hull pressures. For further information about these programs, refer to Volume II (Program Manual).

Because the debugging and testing of SSX or any time simulation program, for that matter, is an extremely time-consuming process, the extent of the validation effort has been limited to the minimum number of cases needed to test the capabilities of the computer programs and verify the basic theory and numerical techniques when possible.

3.1 TWO-DIMENSIONAL HYDRODYNAMIC COEFFICIENTS

Sectional added mass and damping coefficients computed by Program HYDREX2 for the SL-7 containership were checked against values generated by a conformal mapping method, as given by Zielinski [33]. Agreement was excellent in most cases. As an example, Figure 4 compares added mass and damping coefficients for heave and sway at midships with a draft of 32.8 feet.

3.2 MOTION RESPONSE AND HULL GIRDER LOADS IN SMALL AMPLITUDE REGULAR WAVES

A few comparisons between computed and experimental values for heave and pitch motions in one-foot regular waves will first be presented to check the time-domain solution methods using strip theory computed forces where the added mass and damping coefficients are calculated for the mean still water sectional drafts. Figure 5 shows the heave and pitch amplitudes and phases for the Series 60 standard hull form with block coefficient 0.70 at Froude numbers 0.15 and 0.20. The points in the figures represent experimental results by Gerritsma and Beukelman [34]; the solid line is computed by the present method, and the broken line by modified strip theory (frequency domain) of Gerritsma and Beukelman. Note that the pitch amplitude is scaled by wave slope. It is seen that agreement is generally good with the exception of heave amplitude in the vicinity of $\lambda/L = 1.0$. The reason for this disagreement has not been identified.

Figure 6 gives the theoretical and experimental pitch and heave values for the SL-7 containership at 25 knots in a full load condition. The experimental values shown are by Dalzell [35]; the solid line represents the present

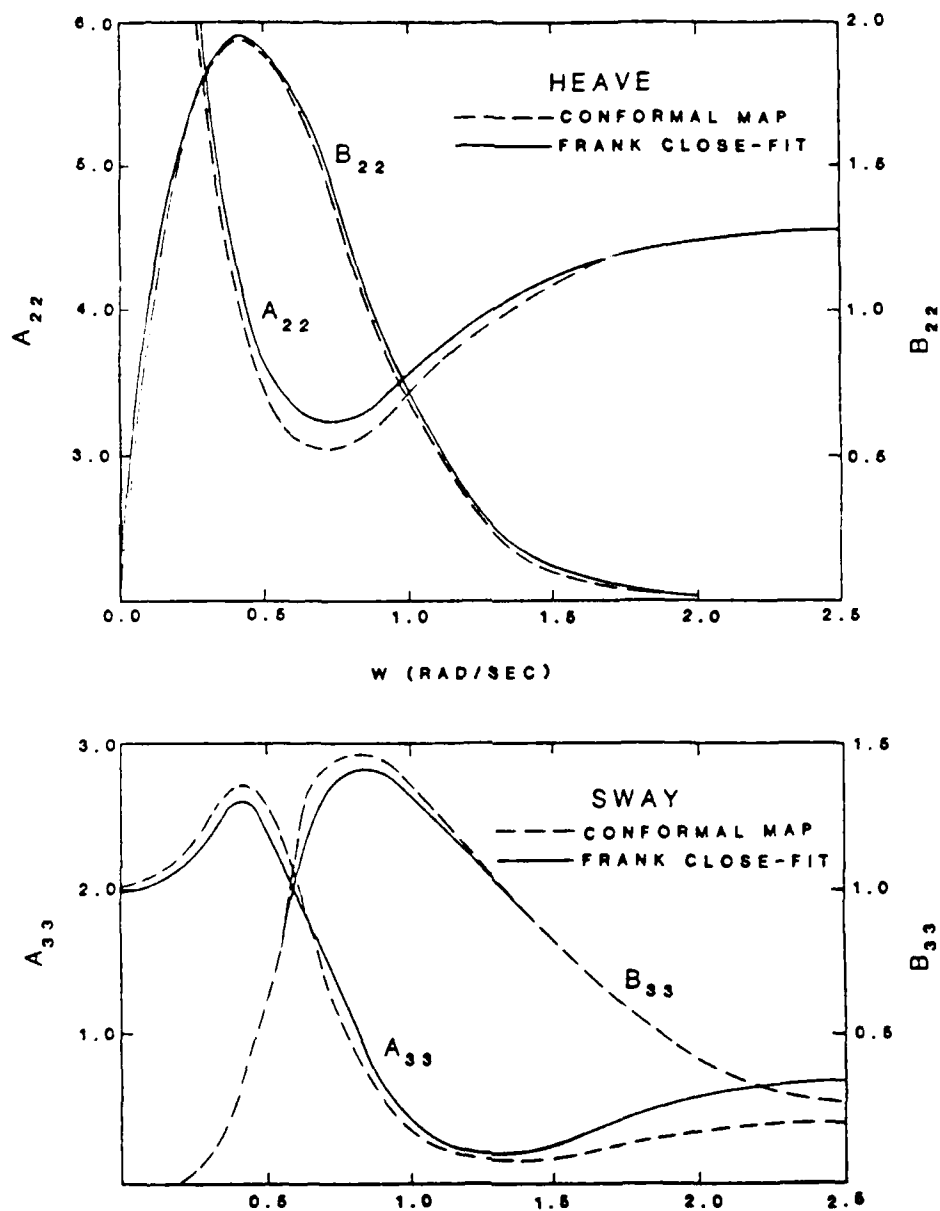


Figure 4 Added mass and damping coefficients. Comparison of HYDREX2 (Frank close-fit) with CGSCORES (Conformal Mapping). SL-7 Containerships, Midships section.

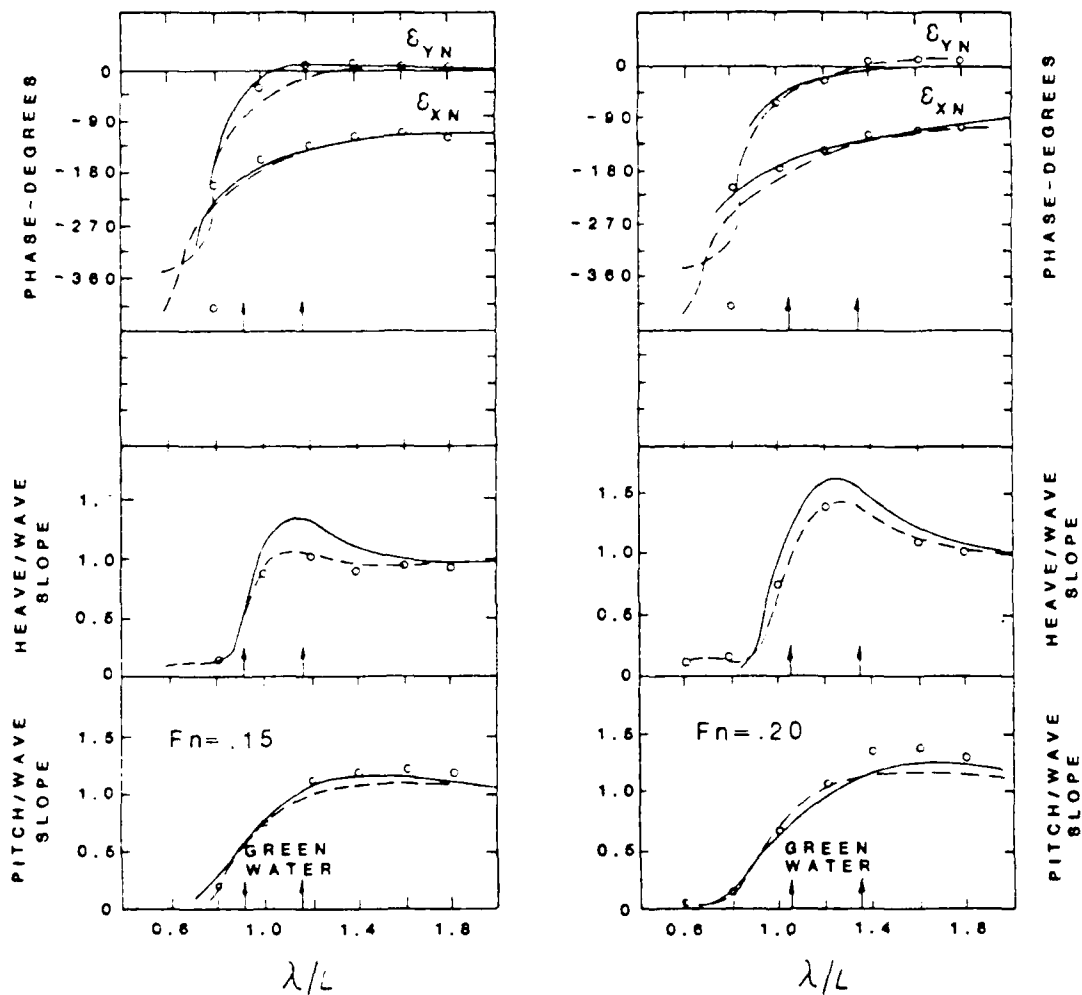


Figure 5 Calculated and measured amplitude and phase characteristics for heave and pitch. Series 60. Block coefficient 0.70. Froude Numbers 0.15 and 0.20.

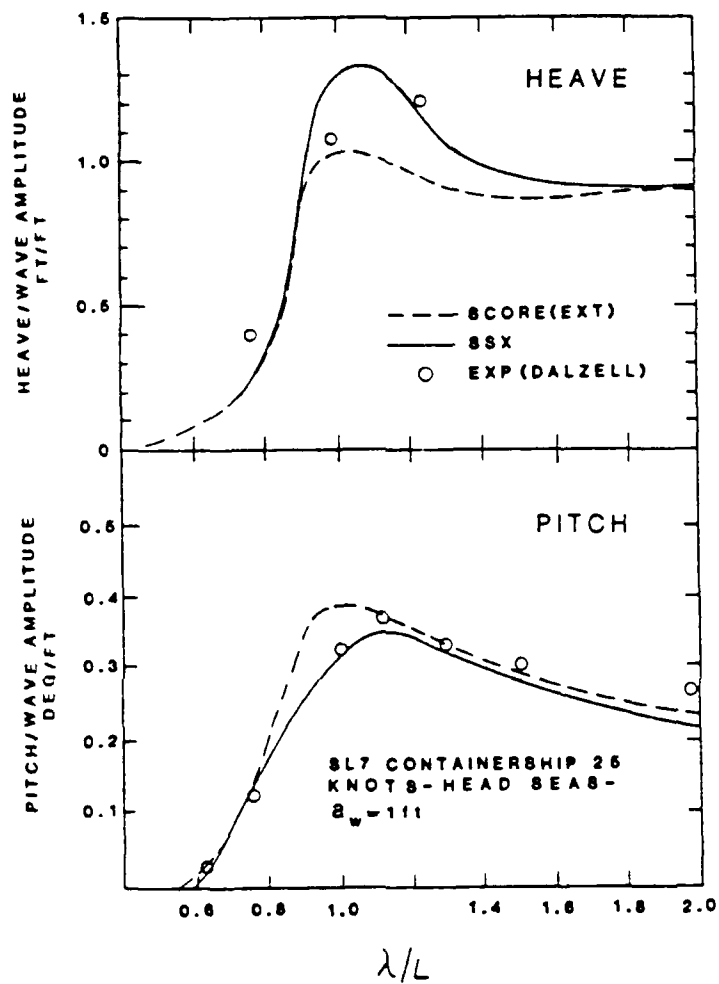


Figure 6 Calculated and measured amplitudes of heave and pitch. SL-7 Containership. 25 knots, head seas.

method, and the broken lines are strip theory results from the SCORES Program [4]. Note that the experimental values for heave at longer wave lengths have not been included because it has been suggested [35] that they were too large and are in error. (The short wavelength experimental values are assumed to be correct.) It is seen that pitch values predicted by SSX agree well with the other values. Heave response, like before, is too high around $\lambda/L = 1.0$.

The routine to compute hull girder loads in the present version of SSX is still in a premature stage. The computation of moment arms and sectional inertial forces essentially assumes a lumped mass model. There is no attempt to account for "trapezoidal" sections of the weight curve. Also, weight segments must correspond to the segment between adjacent stations. However, the routine, as written, does provide the means to evaluate the effect of including various forces or different techniques by which to evaluate such forces.

A comparison between computed and experimental midships bending moment amplitudes for the SL-7 containership at 25 knots in a full load condition is shown in Figure 7. The experimental data is from Dalzell [35]; the present theory is represented by the solid line, the broken line shows predictions from SCORES [4]. Agreement is shown to be very good.

Finally, comparison between theory and experiments for midships horizontal and vertical bending moments and pitch angle are shown in Figure 8 for the SL-7 in oblique waves (210°). Agreement is satisfactory with the exception of vertical bending moment. Further investigation is needed to identify the causes of disagreement.

3.3 IRREGULAR WAVES

A test case was run to check the program's ability to predict motion and loads response in an irregular sea. The SL-7 was subjected to an irregular head sea wave system approximately representing a Bretschneider spectral formulation with $H_s = 10.8$ ft and $T_0 = 8$ secs, where H_s is significant height and T_0 is the period associated with the peak of the sea spectrum. Forward speed was 5 knots. The frequency at which hydrodynamic coefficients used for ship motion-induced forces were to be calculated was set to .8217 - the encounter frequency associated with the peak of the sea spectrum. The sea spectrum was decomposed into ten components. Randomly generated phase angles were used to generate the irregular sea, superimposing the ten regular wave components. A real time simulation of 20 minutes was carried out. Statistics were acquired for heave, pitch and midship's vertical bending moment. Table 1 compares the statistical results of the simulation with predictions from the strip theory frequency domain program developed at MIT and described by Loukakis [36].

As can be seen, the SSX motion values are slightly higher than the MIT program values. The vertical bending moments compare very well. The measured significant RMS wave height from the SSX simulation was close to the desired value of 5.33, providing some assurance that the irregular wave spectrum is correctly being broken down into wave components.

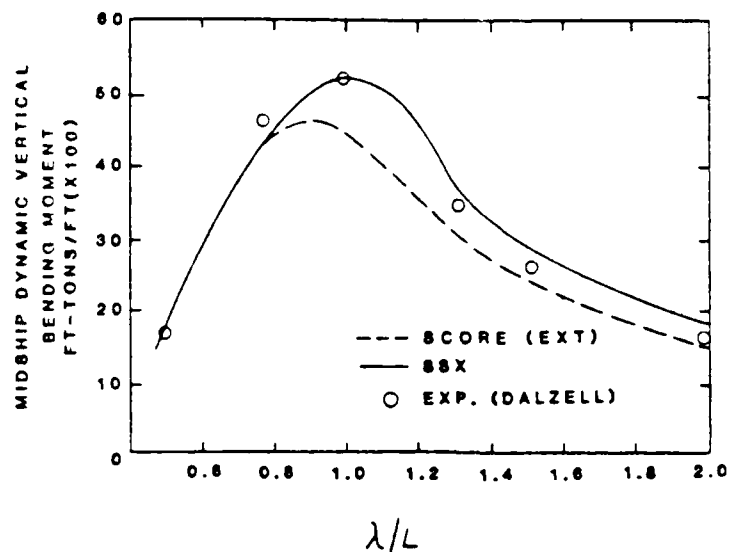


Figure 7 Midship Dynamic Vertical Bending Moment for SL-7 Containership. 25 knots, head seas, full load, regular waves, ampl. = 1 ft.

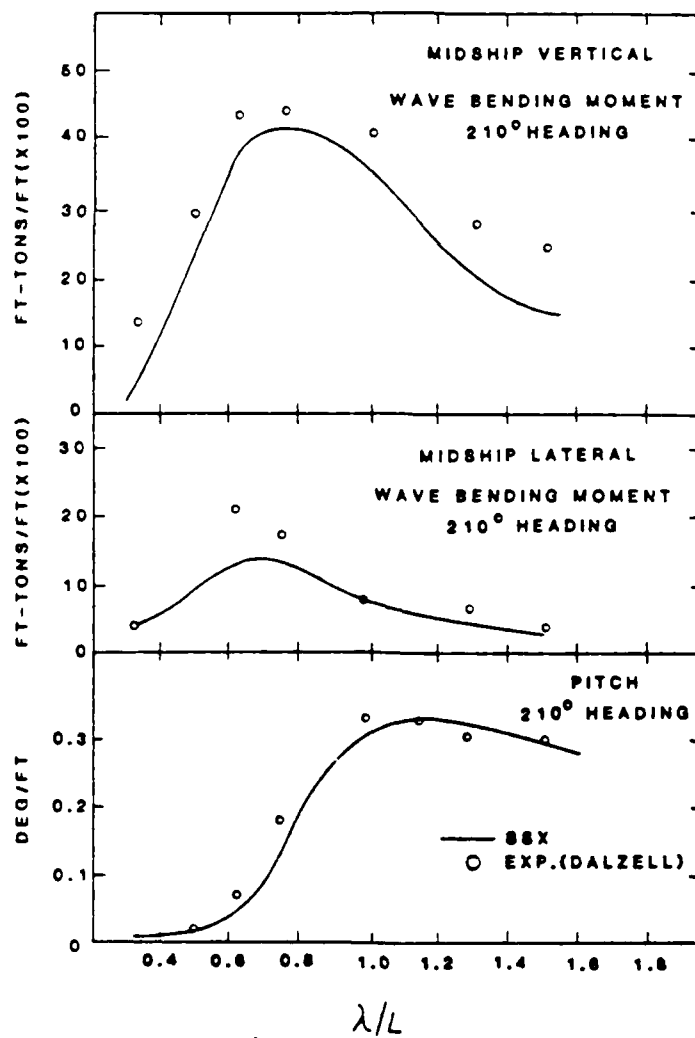


Figure 8 Midship Vertical, Horizontal Wave Bending and Pitch. SL-7 Containership, 25 knots, 210° heading.

Table 1

	SSX	MITA
RMS Pitch (deg)	.2644	.2606
RMS Heave (ft)	.5560	.5308
RMS V.B.M. (ft-tons)	56844	56415
RMS Wave Height	5.23	5.33

One feature of the SSX program is the scheme to average the two most recent zero-crossing periods and derive a "characteristic" frequency at which sectional hydrodynamic coefficients are calculated. This feature was applied to the same test case as before. The results are shown in Table 2.

Table 2

	SSX	
	with f (freq)	without f (freq)
RMS Pitch (deg)	.2619	.2644
RMS Heave (ft)	.5507	.5560
RMS V.B.M. (ft.-tons)	55432	56844

The effect of invoking the characteristic frequency feature is to reduce the SSX values. The calculated sectional characteristic heave frequency during the course of the simulation generally ranged between $\omega = .35$ and $.49$. This reflects the actual response of the ship and is significantly different from the $.8217$ value used in the previous simulation. There is still relatively little difference between the RMS values of the two test cases.

3.4 NONLINEAR RESPONSE IN LARGER WAVES

As part of many model-test programs, a so-called linearity check is performed where the same test runs are made with increasing wave amplitudes to determine if responses are linearly proportional to wave amplitude. Similar experiments have been performed using SSX. The runs were made at 25 knots in head seas with wave amplitudes of 5, 10 and 15 feet. Added mass and damping coefficients were computed at the mean still water draft. Plots showing peak heave, pitch and midship's vertical bending moment are provided in Figures 9, 10 and 11, respectively.

Note that in Figures 9 and 10, the heave and pitch response has been divided by wave amplitude. In both of these figures, nonlinear behavior is exhibited; that is, normalized response is reduced at higher amplitudes, with the exception of the pitch "bow-down" response. It appears quite linear. In Figure 11, the midship's vertical wave bending moment is shown for various wave lengths and wave heights. Note that in this plot, the response has not been normalized by wave amplitude. In general, response is linear with respect to wave amplitude, with the exception of slight nonlinearities shown for hogging at 15 feet wave amplitude for $\lambda/L = 0.75, 1.0, 1.25$.

Also shown in Figure 11 is the effect of including the flare impact force. The broken lines show the bending moment when flare is included. The effect is only measurable in sagging. The values for hogging were so close to the non-flare values that, if drawn, they would be coincident with the lines shown already. (For hogging, a slight reduction in the magnitude of bending moment was the effect of including flare forces.)

The effect of including flare forces on the heave and pitch response is rather minor except around $\lambda/L = 1$, as shown in Figures 12 and 13, respectively. The heave and pitch response is shown for a ten-foot regular wave over a range of wave lengths. As shown in Figures 12 and 13, the effect of flare force inclusion is to reduce the amplitudes in both directions (heave up and down, pitch bow-up and bow-down) between $\lambda/L = 1.0$ and 1.25 . It can also be seen in these figures that for this wave amplitude, the SL-7 containership pitches bow-down more than bow-up, and heave-down more than heave-up over the range of wavelengths.

Linearity checks were performed up to regular wave amplitudes of 15 feet because, at 20 feet and above, inconsistent results were sometimes obtained from the program. A check of what was physically occurring at these greater wave amplitudes was performed graphically. Figures 14 and 15 show the motion of the SL-7 containership at 25 knots for $\lambda/L = 1.5$ and 1.75 , respectively. It can be seen that for $\lambda/L = 1.5$, bow submergence and emergence are quite extreme. For $\lambda/L = 1.0$ and $\lambda/L = 1.25$, behavior was equally extreme.

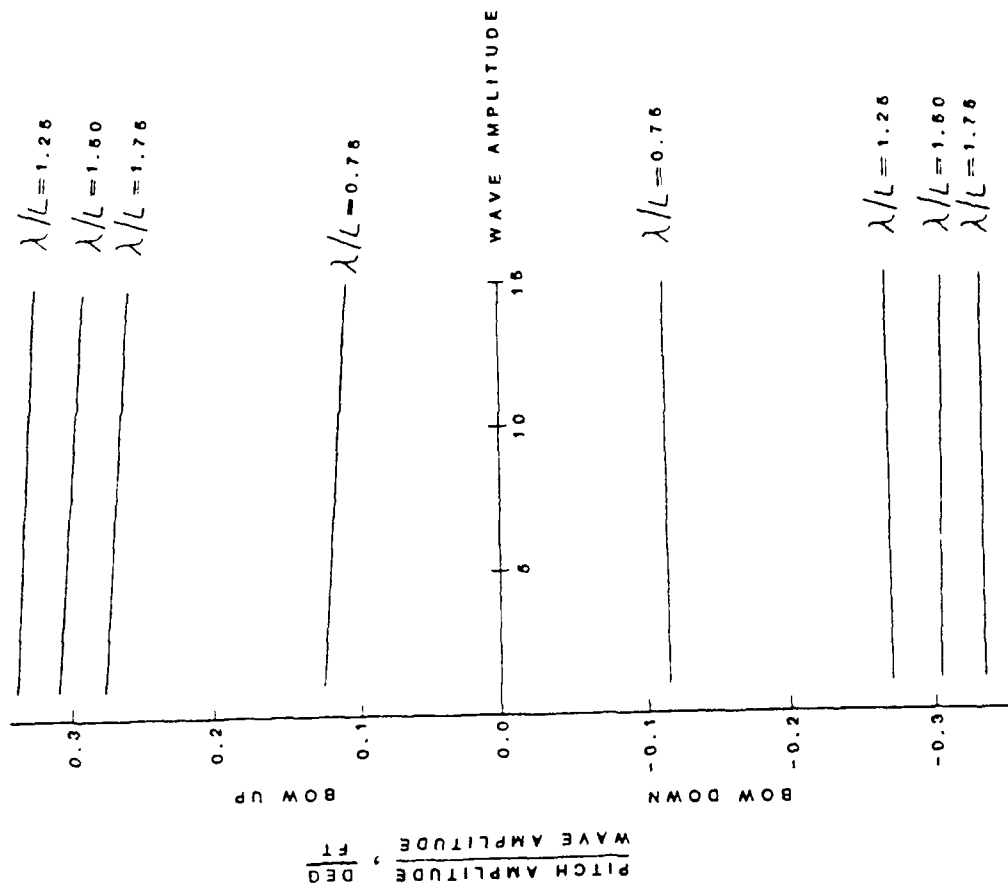


Figure 10 Pitch Amplitude/Wave Amplitude vs. Wave Amplitude. SL-7 Containership, Full Load, Head Seas, 25 knots.

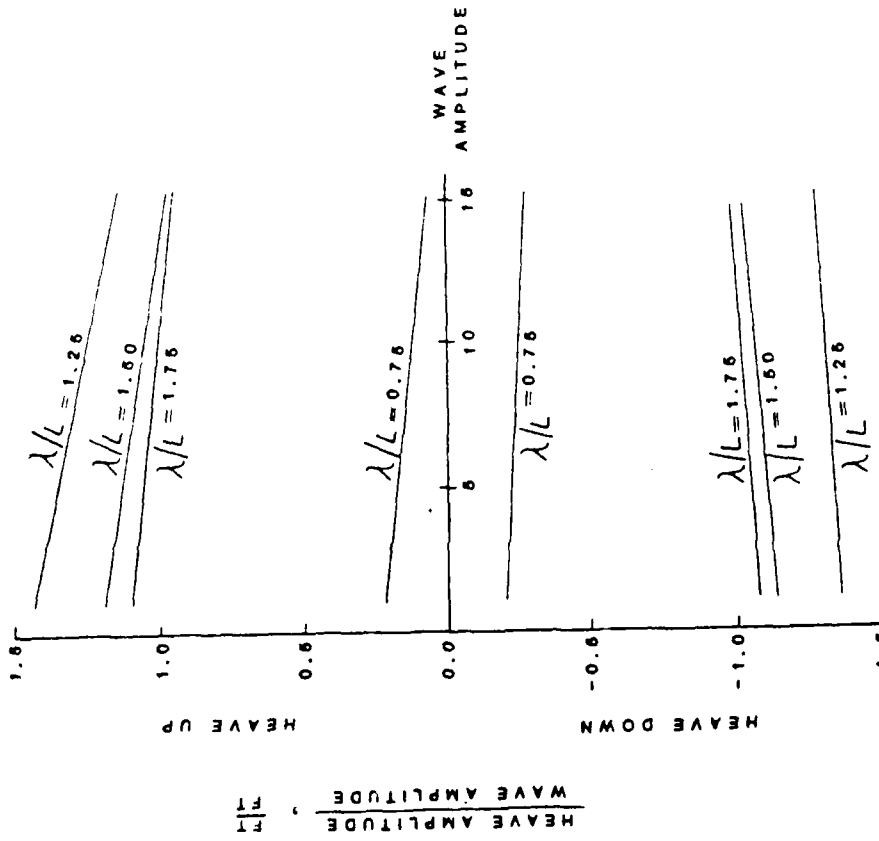


Figure 9 Heave Amplitude/Wave Amplitude vs. Wave Amplitude. SL-7 Containership, 25 knots, full load condition, Head Seas.

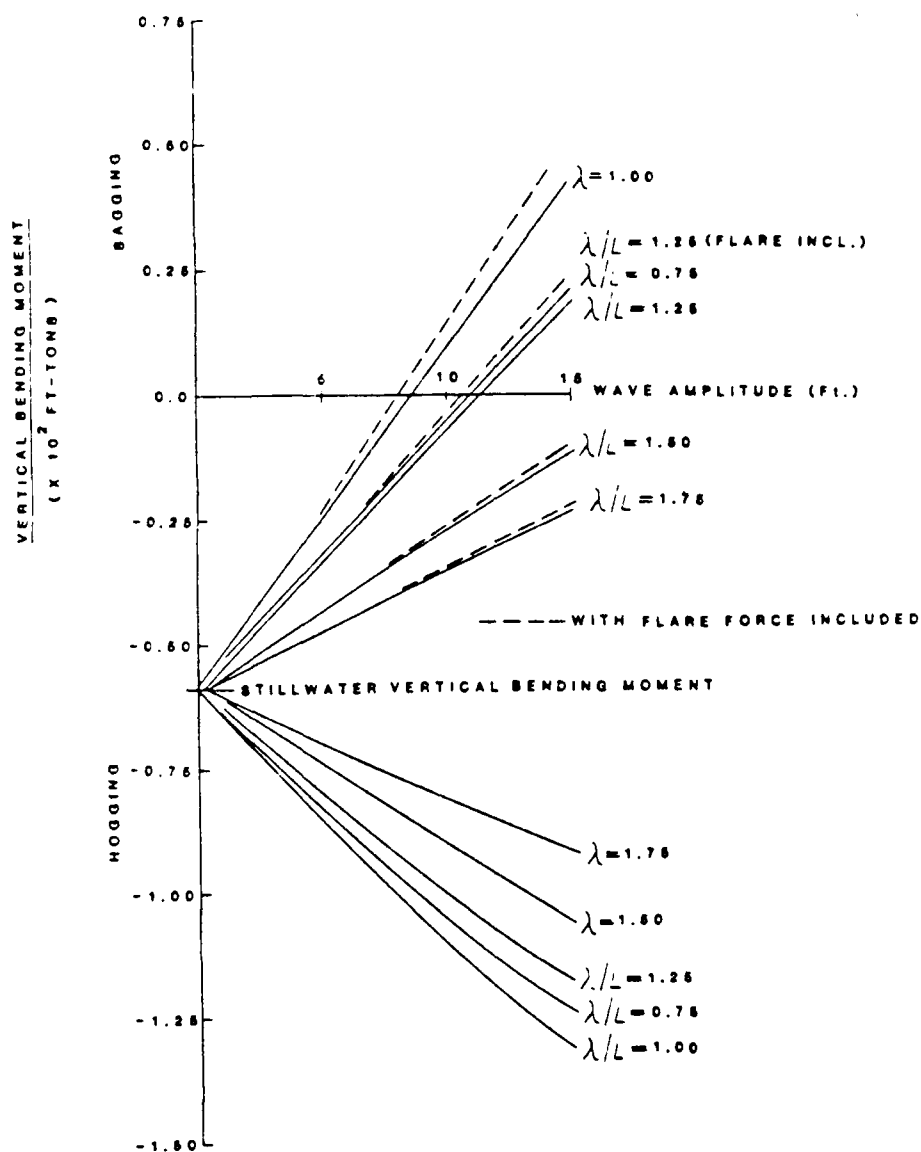


Figure 11 Midship Vertical Bending Moment, SL-7 Containership, 25 knots, head seas (effect of flare on sagging shown).

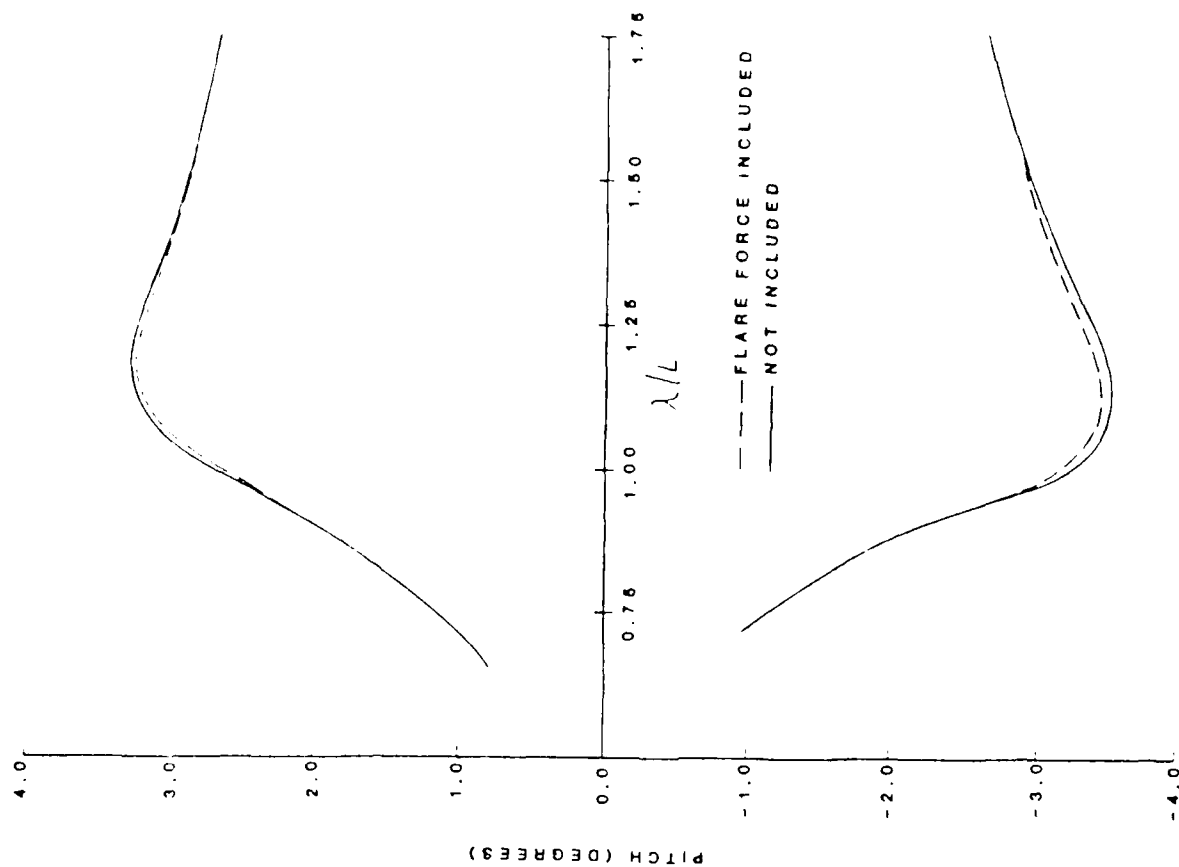


Figure 13 Pitch Amplitude vs. Wavelength/Shiplength.
Comparison of Theoretical Prediction with
and without flare force included.

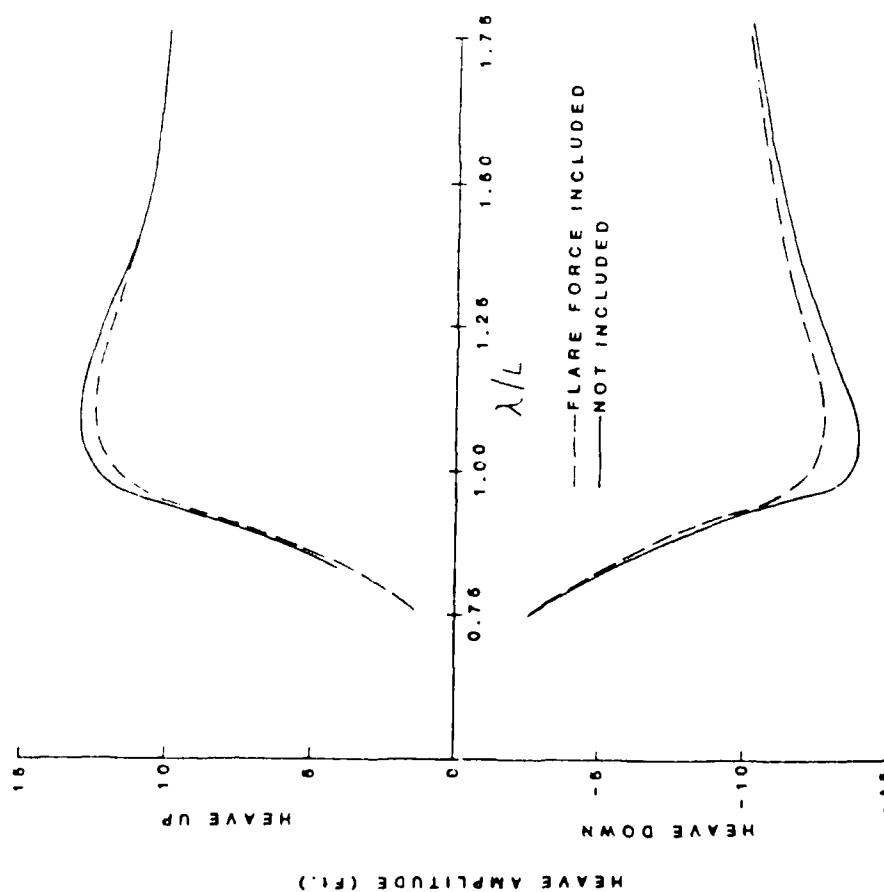


Figure 12 Heave Amplitude vs. Wavelength/Shiplength.
Comparison of Theoretical Prediction with
and without flare force included

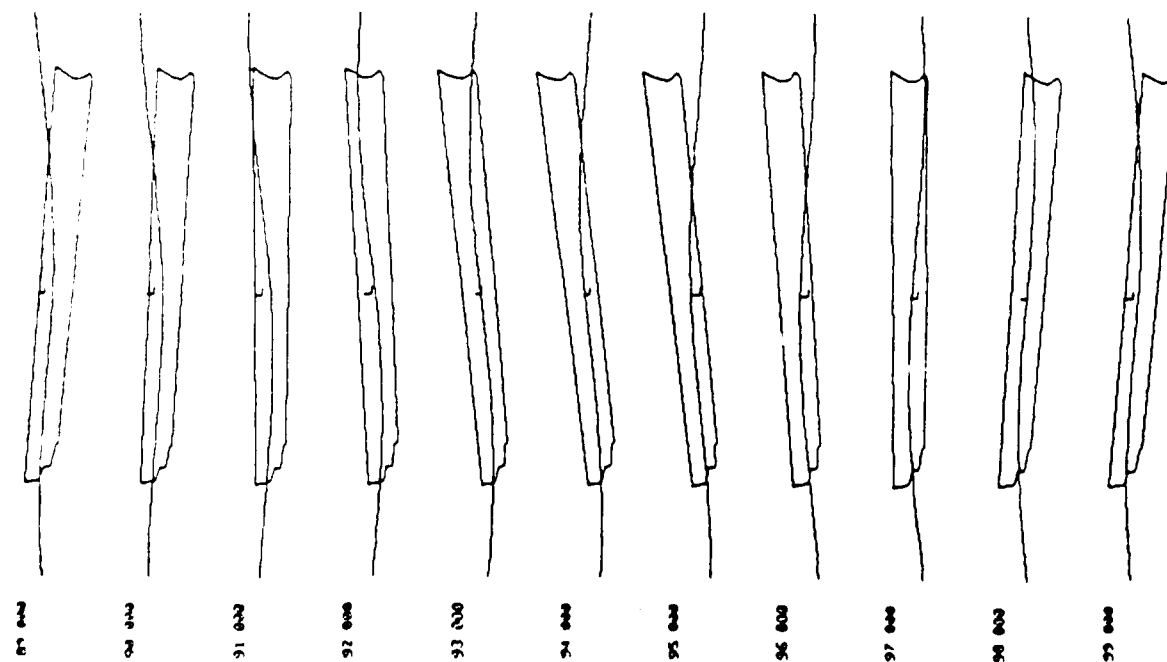


Figure 14 SL-7 Containership in Head Seas at 25 knots. Wavelength/Shiplength = 1.5.

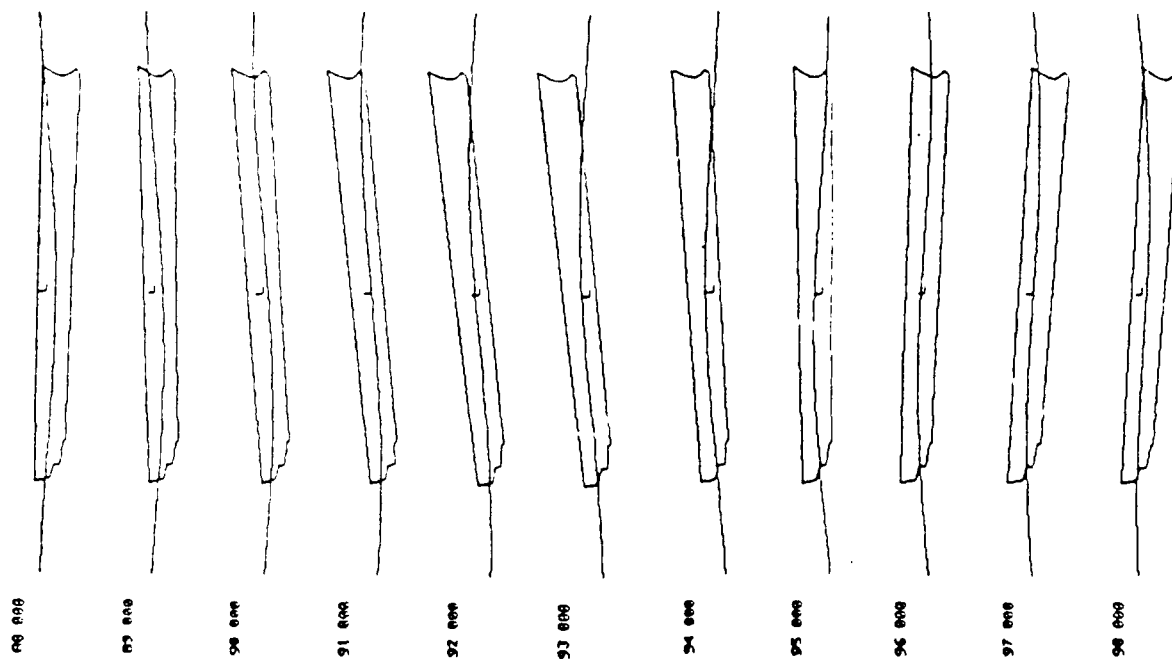


Figure 15 SL-7 Containership in Head Seas at 25 knots. Wave Amplitude = 20 ft, Wavelength/Shiplength = 1.75.

3.5 INFLUENCE OF DRAFT-DEPENDENT HYDRODYNAMIC COEFFICIENTS

In order to evaluate the influence of calculating the sectional added mass and damping coefficients at the actual draft (average) at each station for each instant, a series of runs were made at 25 knots in head seas, $\lambda/L = 2.0$. Flare forces were not included in these runs. Wave amplitudes were 5, 10 and 20 feet. It was found that within this range of conditions, the use of draft-dependent coefficients had negligible effect on pitch and heave motions and vertical wave bending moment.

3.6 FORCE PREDICTION USING THE THREE-DIMENSIONAL APPROACH

The ability of Chapman's method for the prediction of transient motions of a floating body is demonstrated in [5] with the forced oscillation and free oscillation of a two-dimensional rectangle and wedge. Chapman extends the two-dimensional model to three dimensions as reported in [6]. The technique used by Chapman to check the three-dimensional model was to subject a semi-submerged sphere represented by 60 panels to vertical impulse - a unit step in heave velocity. The heave response time history that results is used to derive added mass and damping coefficients. These coefficients are compared with classical results of Havelock [37] and results of Kim [38] with very good correlation.

The basic ability of the three-dimensional method developed here to accurately predict hydrodynamic forces will be verified by two simple tests using a semisubmerged sphere at zero speed. A more comprehensive set of tests is recommended in the future. The two tests presented here should, however, clearly demonstrate that this method has considerable possibilities.

In the first test, the sphere will be subjected to forced vertical oscillations of unit amplitude at various frequencies in otherwise calm water. From the measured pressures, the total vertical time-varying force on the sphere will be calculated, which is then used to derive added mass and damping coefficients. The added mass and damping coefficients can then be compared to the results of Havelock [37].

In the second test, the sphere will be restrained and subjected to regular unidirectional waves of various frequencies and unit amplitude. Wave exciting forces in heave and surge can be measured and compared with analytical predictions given by Garrison [39].

The numerical particulars for both tests are given in Table 3.

Forced Vertical Motions of Sphere

In the first simulation, the semisubmerged sphere is subjected to vertical oscillations of unit amplitude at wave numbers

$$k = \frac{\omega^2}{g} = 0.4, 0.8, 1.0, 1.2, 1.6 \text{ and } 2.0.$$

The total vertical force was measured over two to three full cycles, depending on the frequency, up to about 20 seconds of simulation time with time steps of 0.2 seconds. The last cycle of the simulation was evaluated to derive added mass and damping coefficients using the method described below.

Table 3
Numerical Parameters

NPAN	= number of panels	= 72
L_x	= maximum length scale in X	= 0.25
l_x	= minimum length scale in X	= 2.5
L_y	= maximum length scale in y	= 0.25
l_y	= minimum length scale in y	= 2.5
T	= maximum time scale	= 12 sec.
g	= gravitational acceleration	= 1.0
ρ	= fluid density	= 1.0
a	= sphere radius	= 1.0
Δt	= time step size	= 0.1

The vertical displacement of the sphere from its mean position is given by

$$y = A \sin \omega t.$$

The linearized equation of motion for the sphere in forced heave is

$$(m + a) \ddot{y} + b \dot{y} + c y = Y_T.$$

where

m	= mass of the cylinder,
a	= hydrodynamic or "added" mass in heave,
b	= damping coefficient against vertical motion,
c	= hydrostatic restoring coefficient against vertical displacement, and
Y_T	= external driving force.

The total hydrodynamic force acting on the body in the vertical direction is

$$Y_h(t) = a \ddot{y} - b \dot{y}.$$

Assuming this hydrodynamic force is a harmonic function in time and can be written as

$$Y_h(t) = \gamma \sin(\omega t - \epsilon),$$

the hydrodynamic coefficients are obtained by equating these two expressions for Y_h ,

$$a = \frac{\gamma \cos \epsilon}{\omega A}$$

and

$$b = \frac{\gamma \sin \epsilon}{\omega A}.$$

The amplitude γ and phase shift ϵ are obtained by comparing plots of the displacement and dynamic pressure force Y_h acting on the sphere as functions of time and measuring the shift in phase. A comparison of the results obtained with Havelock's results is shown in Figure 16. The solid line is Havelock's results. The numerical predictions are shown as circles. As can be seen from Figure 16, agreement is excellent.

Figure 17 shows a time sequence of the free surface disturbance induced by the vertical motion of the sphere. The circle represents the mean still waterline of the sphere. The radius of the sphere is 1.0 and the dimensions of the free surface area shown are 8 x 8. The wave number for the sequence is $k = 1.0$. The internal standing waves inside of the sphere are shown. (These internal standing waves should produce no net pressure.)

Wave Excitation Forces on Semisubmerged Sphere

The purpose of the second simulation was to investigate forces on the sphere when subjected to regular waves of different frequencies. Figure 18 shows the comparison between analytical predictions from Garrison [38] for the heave and surge wave exciting forces on a semisubmerged sphere. The agreement is excellent.

Figure 19 shows the diffraction wave system that develops from regular waves ($h = 1.4$) imposed on the sphere. The ambient wave amplitudes have been subtracted out of the free surface plot to more clearly exhibit the diffracted waves.

Other Tests

Attempts were also made to: (a) test a semisubmerged sphere in forced vertical oscillations at a uniform forward speed; and (b) to conduct forced oscillation tests for ellipsoids with L/B ratios of 8:1 and 4:1. In each of these cases, forces quickly increase to unrealistic levels, clearly indicating

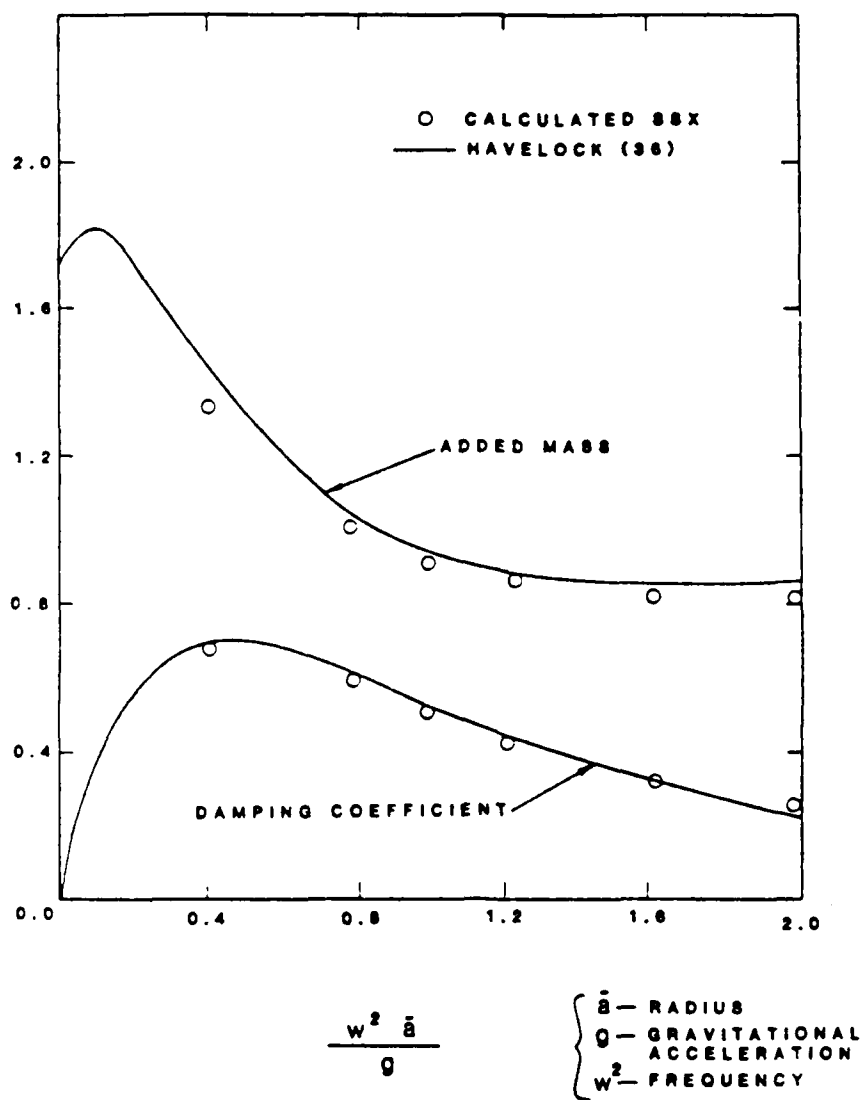


Figure 16 Added Mass and Damping Coefficients for semisubmerged sphere.

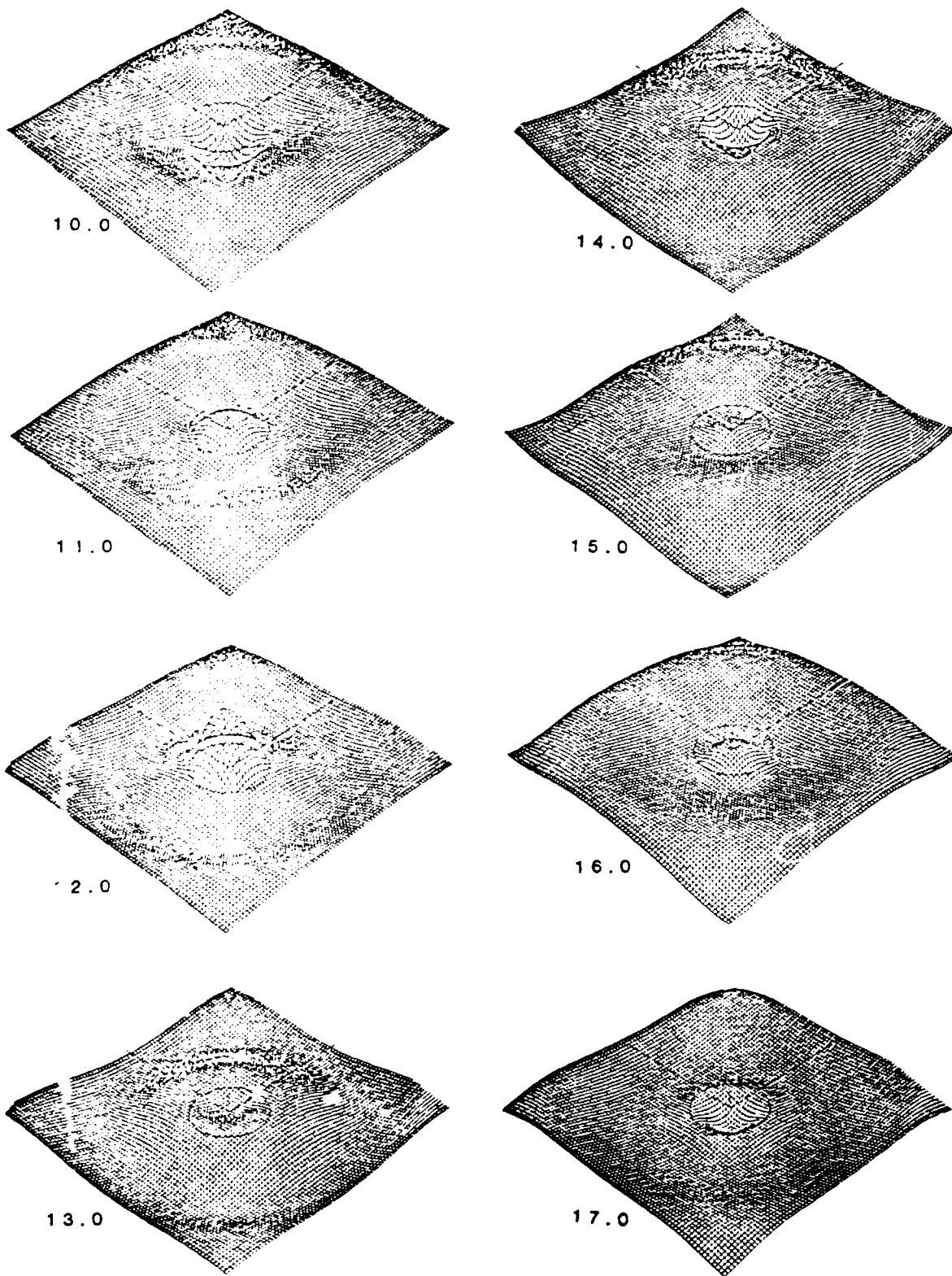


Figure 17 Radiated waves from vertically oscillating sphere at $k = 1.0$.
Time = 10 - 17 secs after startup.

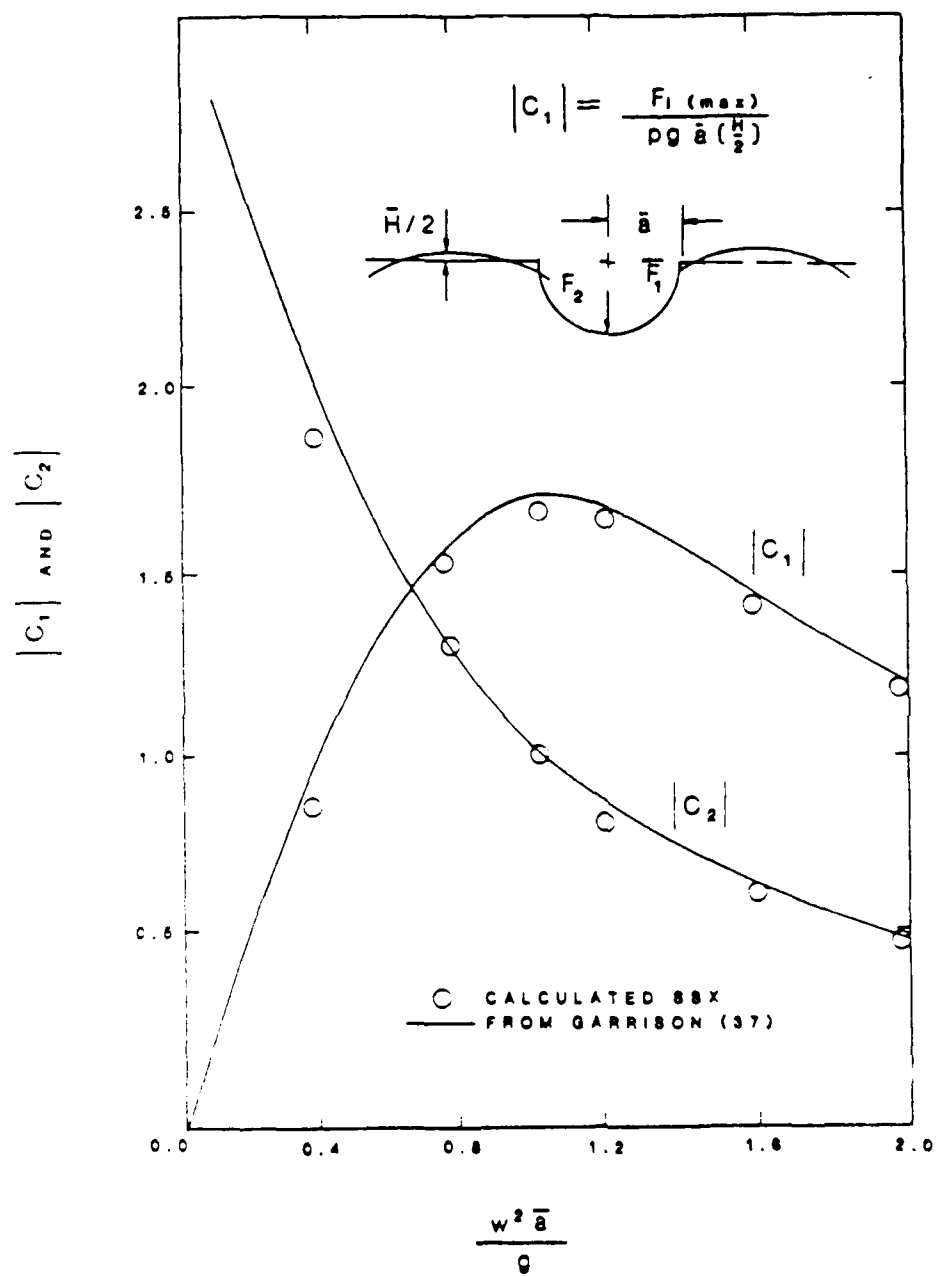


Figure 18 wave excitation forces for semisubmerged sphere.

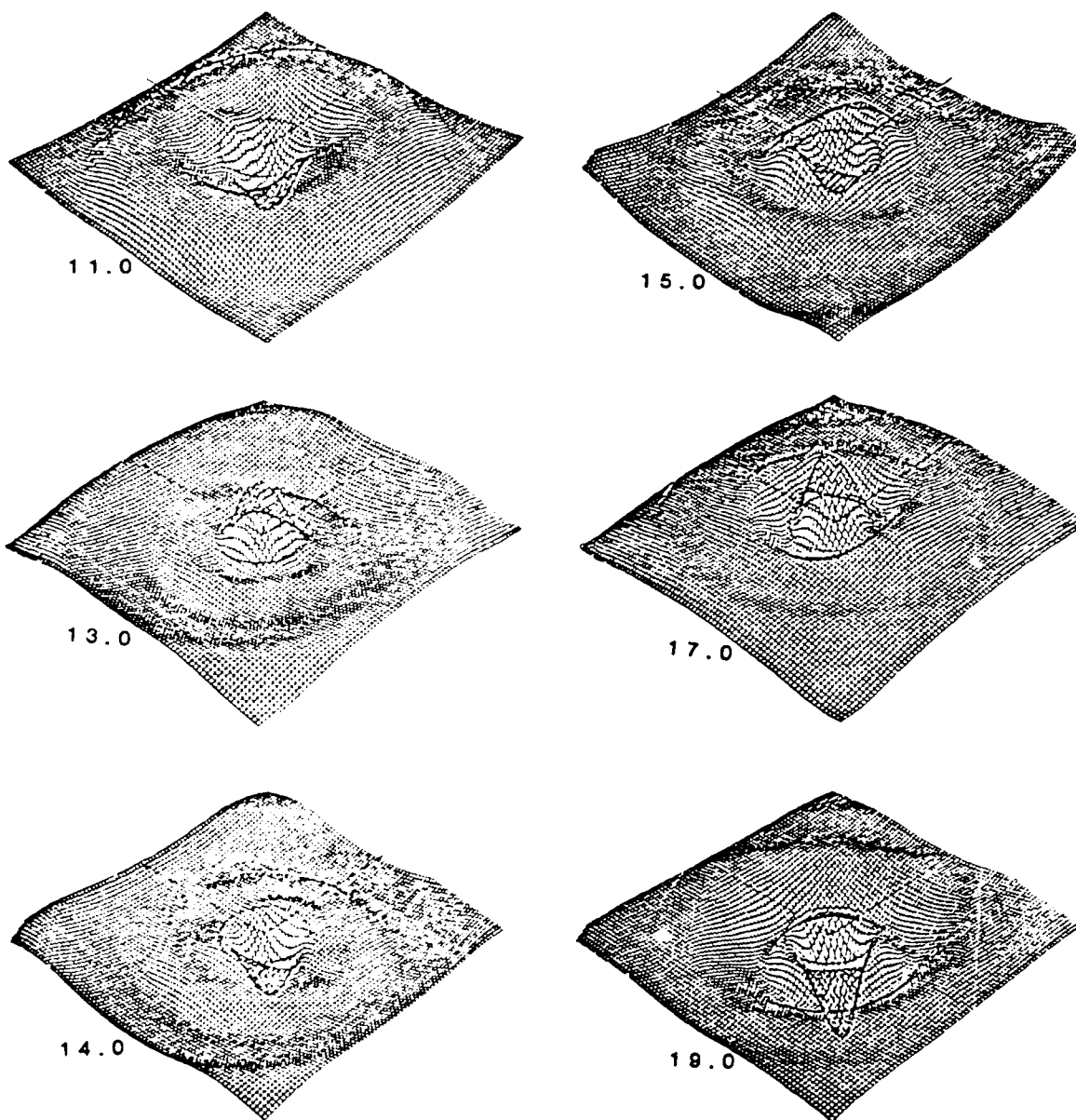


Figure 19 Diffracted waves from semisubmerged sphere,
regular unidirectional waves, $k=1.4$.
 $T=11-19$ seconds.

that there is some problem associated with both forward speed and cases with shapes more closely representing a slender ship. The reasons for these "blow-ups" could not be readily identified.

3.7 LIMITATIONS, RUN TIMES AND COMPUTATIONAL REQUIREMENTS

Theoretical and Numerical Limitations

- (1) The limitations of strip theory generally apply.
- (2) The limitations of linear wave theory apply.
- (3) The limitations of linearized hydrodynamic formulations (linearized free surface, separation of potentials, linearized Bernoulli equation, etc.) apply.
- (4) Strip theory formulations here do not include terms related to the spatial derivative of damping coefficients (as found in "extended" SCORES).
- (5) Flare force is computed using the relative free surface velocity in contrast to using a component of average subsurface wave velocity. Furthermore, free surface distortion effects are not included (diffractions, "pile-up," etc.).
- (6) The ambient wave system for the three-dimensional analysis is formulated for unidirectional waves only.
- (7) The P, E and X source influences matrices are computed only for the mean hull position in the present formulation. Details of the computation are presented in Volume II of this report.
- (8) The use of either a pre-selected or time-varying estimate of added mass and damping coefficients for the ship motion-induced forces in irregular waves is an approximation.
- (9) Pitch angle must not become large enough to cause the intersection of a station plane and the sea surface so that multiple regions or a closed contour in the station plane is defined [3].

Run Times

Typical run times for several simulations with strip theory derived forces and three-dimensionally derived forces are shown in Table 4 for a VAX 11/750 without a floating point processor.

It is estimated that reductions in run time by a factor of 5-10 would occur with any of the large mainframe CDC machines; and a reduction by a factor of 15-20 would occur with a supercomputer (CRAY or similar). It should be emphasized that the program is expensive to run, regardless of the type of machine on which it is installed.

Table 4

SIMULATION OF	VAX 11/750 CPU TIME
Motion and Hull Girder Response of 25-station ship in one regular wave. Steady state evaluated after 2 minutes real time with $\Delta t = 0.5$ sec.	1200 CPU seconds
Motion and Hull Girder Response of 25 station ship in irregular wave system of 10 components evaluated after 10 minutes of real time simulation. $\Delta t = 0.5$ sec.	16 CPU hours
Pressure prediction only of 120 panel body for 15 seconds real time $\Delta t = 0.1$ sec.	17 CPU hours

Computational Requirements

The computer programs were developed on a DEC VAX 11/750. The peak working set size was 250. The memory requirement for the completely integrated program (2D plus 3D) is 650K bytes. When the 3D subroutines are not used and only 2D simulations are used, the memory requirement is 250K bytes.

(THIS PAGE INTENTIONALLY LEFT BLANK)

4.0 CONCLUSIONS AND RECOMMENDATIONS

A numerical method for the simulation of ship motions, hull girder loads and transient three-dimensional hydrodynamic pressures has been developed. The result is a computer program that is capable of evaluating nonlinear responses of surface ships associated with large amplitude motions. The fundamental limitation of the approach is the use of linear wave theory. The restrictions on the severity of the sea conditions that this limitation imposes is not yet known, although it is believed that the method would be appropriate for evaluating motions and hull girder loads in moderately severe sea states.

Furthermore, the three-dimensional technique developed is capable of predicting transient hydrodynamic pressures on time-varying hull shapes moving with arbitrary motions and forward speed. Further effort is required to fully realize these capabilities. An outline of the suggested work is given in the next section.

Although the method presented here and the associated computer program need additional attention to advance them from the investigative and developmental stage at which they now are, some progress has been made toward a more advanced method for ship motion and wave load prediction. There presently exists no other program for the time domain simulation of ship motions and loads in six degrees of freedom for a full range of headings. Nor is there any other program capable of predicting three-dimensional distributed hydrodynamic pressures in the time domain for arbitrary ship motions in waves.

The CAPSIZE program [3,29] and the NSUP program [6] which were used as starting points for the present method have been extended or modified in the following principal ways:

- Actual strip theory formulation used for hydrodynamic forces instead of simplified and approximate methods for added mass, damping and wave exciting forces
- Hull girder loading prediction added, including "flare force" effect
- The addition of the incident wave potential into the three-dimensional formulation
- A number of computational and numerical changes associated with the calculation of two-dimensional hydrodynamic coefficients, the evaluation of two-dimensional hydrodynamic forces, and the evaluation of pressure in the wave above the still water level.

The bulk of the effort in this project was committed to the concept development of a suitable method and the development and testing of the computer code. Because of the particularly time-consuming nature of debugging and testing simulation programs, the extent of the validation effort has been limited to the minimum number of runs needed to verify the capabilities of the

computer programs and evaluate the basic theory and numerical techniques when possible. A full and extensive validation of the methods and codes would require the type of test program typically associated with actual (physical) model testing, with a level of effort representative of a major project in itself. An outline of a simulator test program is provided in Appendix A as a possible basis for the same type of studies reported in SSC-246* [40] and SSC-271** [41] to validate and further investigate SCORES after its initial development.

Recommendations

The work presented herein represents an initial level of investigation and development. The numerical methods and computer programs require further testing, validation and improvement. The following list of recommendations indicates areas where further effort is required or desirable in the near-term, mid-term or far-term.

Near-Term

1. A comprehensive test and validation program is required, an outline of which is given in Appendix A for the two-dimensional method.
2. The method or program coding for the computation of Froude-Krylov forces or strip-theory derived forces should be corrected or improved to provide better predictions, specifically heave motion.
3. The numerical methods and coding associated with the three-dimensional technique should be improved. Specifically, the following areas will be investigated and modified or improved:
 - (a) Investigate the method used for computing the source panel velocity array and the source potential influence array. The so-called exact method of Smith and Hess might be improved. More efficient methods might also be incorporated. There may be reason to suspect that the problems with the ellipsoid tests attempted are due to numerical problems in this area.
 - (b) Investigate the theoretical formulations that include some forward speed effects. Investigate the numerical/computational representation of the theory. Check the coding dealing with forward speed aspects. Identify any deficiencies and make the appropriate changes and additions.

* Kaplan, P., et al, "Theoretical Estimates of Wave Loads on the SL-7 Containership in Regular and Irregular Waves," SSC-246, 1974.

** Kaplan, P., et al, "A Correlation Study of SL-7 Containership Loads and Motions - Model Tests and Computer Simulations," SSC-271, 1977.

- (c) Examine the feasibility and necessity of applying a different free-surface condition interior to the hull. As Chapman suggested in [5], instead of using the linearized free-surface condition over the entire free surface, the surface elevation interior to the hull can be constrained to be uniformly zero by placing surface panels over this region. This would suppress standing waves which are excited in the hull interior as a by-product of the potential flow method of simulation.
- (d) Investigate more efficient ways of computing. For example, if we can assume that motions are sufficiently small, then certain values which are functions, sums and products of the various source influence arrays might be precomputed and stored, rather than computing them inside computational loops over k_x and k_y wave numbers for each panel.
- (e) Demonstrate the accuracy and capabilities of the program by comparing numerical results with predictions from theory or other programs for various shapes at zero speed (sphere, ellipsoids, barge shape, ship shape) and for those shapes with forward speed. The basis for these comparisons would be added mass, damping and wave excitation coefficients.
- (f) Carry out sufficient testing to develop an experience base for setting the parameters for the spectral wave representation.
- (g) Investigate and demonstrate the ability of the method to properly predict the distributed hydrodynamic loads on the underwater hull.
- (h) Examine the feasibility and identify the numerical techniques that would allow for the underwater hull form to change with time.

Mid-Term

- 4. Appropriate specific methods to predict slamming loads and green water loads should be investigated and incorporated in the present program.
- 5. An advanced statistical processing routine should be incorporated in the program to derive frequency response spectra, as well as probability density functions and cumulative distributions of maxima and minima.
- 6. A method should be investigated and appropriate subroutines incorporated to structurally model the ship hull girder in order to predict transient non-rigid body response.
- 7. Improved coding for the computation of sectional mass distribution properties should be written.
- 8. Coding for the computation of appendage damping should be written.

Far-Term

9. Linear wave theory was assumed for the present model and is consistent with the linearized free-surface formulations associated with strip theory and the three-dimensional method. It may be worthwhile, however, to pursue the use of a nonlinear wave theory to generate large amplitude deterministic unidirectional waves. Although the nonlinear wave could not be applied, in a strict sense, within the hydrodynamic formulations as they exist in the two- and three-dimensional formulations, they could be accounted for in an approximate way. Hydrostatic and dynamic buoyancy forces could be accounted for "exactly." Ship motion-induced hydrodynamic forces could be approximated as they are in the present version. Diffraction forces could be possibly estimated by using the same method as now exists but representing the nonlinear wave in the vicinity of the ship with a similarly proportioned linear wave. For the transient pressure simulation, the exact nonlinear wave kinematics could be used to prescribe part of the body boundary condition at the center of each panel.
10. The use of the impulse response function and convolution integral to predict ship motion-induced damping forces should be investigated and appropriate subroutine(s) included in the present version. This would be a partial alternative for the "characteristic frequency" scheme now in place.

The efforts listed under each of the above categories can be grouped into the three separate projects with the following approximate level of effort suggested:

Near-Term Project	3000 manhours
Mid-Term Project	2000 manhours
Far-Term Project	2000 manhours

The near-term project should be considered a necessary requirement in order that the methods and computer programs initiated here are sufficiently developed and proven for practical use.

REFERENCES

1. Smith, C.S., "Measurement of Service Stresses in Warships," Conference on Stresses in Service, Inst. of Civ. Engrs., March 1966.
2. Meek, M., et al., "The Structural Design of the O.C.L. Container Ships," Trans. RINA, Vol. 114, 1972.
3. Oakley, O.H., Paulling, J.P. and Wood, P.D., "Ship Motions and Capsizing in Astern Seas," Tenth Symposium on Naval Hydrodynamics, MIT, Cambridge, pp. 297-350, ONR Report ACR-204, June 1974.
4. Raff, A.I., "Program SCORES - Ships Structural Response in Waves," SSC-230, 1972. NTIS AD 752568.
5. Chapman, R., "Large Amplitude Transient Motion of Two-Dimensional Floating Bodies," Journal of Ship Research, Volume 23, No. 1, March 1979.
6. Chapman, R., "Time Domain Method for Computing Forces and Moments Acting on Three-Dimensional Surface Piercing Ship Hulls with Forward Speed," SAI Report No. 461-80-560-CJ, September 1980.
7. Chang, M.S., "Computations of Three-Dimensional Ship Motions with Forward Speed," Proceedings, Second International Conference on Numerical Ship Hydrodynamics, Berkeley, California, September 1977.
8. Pettersen, B., "Calculation of Potential Flow About Three-Dimensional Bodies in Shallow Water with Particular Application to Ship Maneuvering," Norwegian Institute of Technology, Trondheim, Norway, (Unpublished), 1981.
9. von Kerczek, C., "Numerical Solution of Naval Free Surface Hydrodynamics Problems," First International Conference on Numerical Ship Hydrodynamics, Bethesda, October 1975.
10. McCormick, S. and Thomas, J.W., "Multigrid Methods Applied to Water Wave Problems," Third International Conference on Numerical Ship Hydrodynamics, Paris, June 1981.
11. Bai, K.J., "A Localized Finite Element Method for Three-Dimensional Ship Motion Problems," Third International Conference on Numerical Ship Hydrodynamics, Paris, June 1981.
12. Bai, K.J. and Yeung, R.W., "Numerical Solutions to Free Surface Flow Problems," The Tenth Symposium on Naval Hydrodynamics, Office of Naval Research held at MIT, Cambridge, 1974.
13. Chen, H.S. and Mei, C.C., "Oscillations and Wave Forces in a Man-Made Harbor in the Open Sea," The Tenth Symposium on Naval Hydrodynamics, Office of Naval Research held at MIT, Cambridge, 1974.

REFERENCES (continued)

14. Seto, H. and Yamamoto, Y., "Finite Element Analysis of Surface Wave Problems by a Method of Superposition," The First International Conference on Numerical Ship Hydrodynamics, DTNSDPC, Bethesda, pp. 49-70, (1975).
15. Yue, D.K.P., Chen, H.S. and Mei, C.C., "Three Dimensional Calculations of Wave Forces by a Hybrid Element Method," The Eleventh Symposium on Naval Hydrodynamics, Office of Naval Research, pp. 325-332, (1976).
16. Chowdbury, P.C., "Fluid Finite Elements for Added-Mass Calculations," International Shipbuilding Progress, Volume 19, No. 217, pp. 302-309, (1972).
17. Beale, J.T., "Eigenfunction Expansions for Objects Floating in an Open Sea," Communications on Pure and Applied Mathematics, Volume 30, pp. 283-313, (1977).
18. Licht, C., "Time-Dependent Behavior of Floating Bodies," Third International Conference on Numerical Ship Hydrodynamics, Paris, June 1981.
19. Jami, A., "Numerical Solving of Transient Linear Hydrodynamics Problems by Coupling Finite Elements and Integral Representation," Third International Conference on Numerical Ship Hydrodynamics, Paris, June 1981.
20. Skjoldal, S.O., "A Rational Strip Theory Approach for the Evaluation of Springing," Norwegian Institute of Technology, Trondheim, January 1978.
21. Troesch, A.W., "The Diffraction Potential for a Slender Ship Moving Through Oblique Waves," Department of Naval Architecture and Marine Engineering, The University of Michigan, Report No. 17, 1976.
22. Bourianoff, G.I. and Penumalli, B.R., "Final Report on Computational Prediction of Ship Motion in Confined Waters Using Inertial Marker Particles," MARAD Report MA-RD-940-77084A, November 1978.
23. Fritts, K.J. and Boris, J.P., "Transient Free-Surface Hydrodynamics," Second International Conference on Numerical Ship Hydrodynamics, Berkeley, September 1977.
24. Nichols, B.D. and Hirt, C.W., "Nonlinear Hydrodynamic Forces on Floating Bodies," Second International Conference on Numerical Ship Hydrodynamics, Berkeley, September 1977.
25. Chuang, S., Schroeder, A.E. and Wybranice, S., "Structural Seaworthiness Digital Computer Program (ROSAS)," DTNSRDC Report No. 77-0001, May 1977.
26. Meyerhoff, W.K. and Schlacter, G., "An Approach for Determination of Hull-Girder Loads in a Seaway Including Hydrodynamic Effects," Ocean Engineering, Volume 7, No. 2, 1980.

REFERENCES (continued)

27. Borresen, R. and Tellsga, R., "Nonlinear Response of Vertical Motions and Loads in Regular Head Waves, Part I (Text) and Part II (Figures)," DNV Report 79-1097, December 1979.
28. Oliver, J.C., "Development of an Advanced Method for Ship Motion and Wave Load Prediction - Phase I Report," Giannotti & Associates, Inc. Report No. 80-083-001, January 1982.
29. Fallen, W.J., Hwang, Y.L., Liquori, J.L., Paulling, J.R., Viseneau, G. and Wood, P.D., "Model Tests and Numerical Simulation of Ship Capsizing in Following Seas," USCG Report No. CG-D-08-81.
30. Chakrabarti, S.K., "Laboratory Generated Waves and Wave Theories," Journal of Waterway, Port Coastal and Ocean Engineering, Volume 106, August 1980.
31. Kaplan, P. and Sargent, T.P., "Further Studies of Computer Simulation of Slamming and Other Wave-Induced Vibratory Structural Loadings on Ships in Waves," SSC Report 231, 1972.
32. Hess, J.L. and Smith, A.M.O., "Calculation of Non-Lifting Potential Flow About Arbitrary Three-Dimensional Bodies," Douglas Aircraft Company, Report No. E.S. 40622, March 1962.
33. Zielinski, T.E., "User Manual for Program SCORES, Second Part of the USCG Ship Motion Program," HMC Report CG-M-8-80, July 1980.
34. Gerritsma, J. and Beukelman, W., "Analysis of the Modified Strip Theory for the Calculations of Ship Motions and Wave Bending Moments," International Shipbuilding Progress, Volume 14, August 1967.
35. Dalzell, T.F. and Chiocco, K.J., "Wave Loads in a Model of the SL-7 Containership Running on Oblique Headings in Regular Waves," SSC-239, 1973.
36. Loukakis, T.A., "Computer-Aided Prediction of Seakeeping Performance in Ship Design," MIT Report No. 70-3, August 1970.
37. Havelock, T., "Waves Due to a Floating Sphere Making Heaving Oscillations," Proceedings Royal Society of Architects, 231, 1955, pp. 1-7.
38. Kim, W.P., "On the Harmonic Oscillations of a Rigid Body on a Free Surface," Journal of Fluid Mechanics, 1964.
39. Garrison, C.J., "Hydrodynamics of Large Objects in the Sea, Part I - Hydrodynamic Analysis," Journal of Hydronautics, Vol. 8, January 1974, pp. 5-12.

(THIS PAGE INTENTIONALLY LEFT BLANK)

APPENDIX A

NUMERICAL SIMULATOR TEST PROGRAM

1.0 OBJECTIVE

The objective is to fully exercise the computer program SSX, using as a test vehicle a ship for which model tests have been carried out for a range of headings, speeds and wave heights, with emphasis on lower speeds and higher wave heights.

2.0 TEST SERIES

2.1 TEST SERIES A - REGULAR WAVE TESTS

The ship is subjected to unit amplitude unidirectional regular waves at five headings, four Froude numbers, and at six frequencies corresponding to various wavelength/ship-length ratios. The critical parameters are:

<u>Wavelength Parameters</u> (λ/L) at $\beta = 0$ 180°	0.5, 0.75, 1.0, 1.25, 1.5, 2.0 (or equivalent at other headings)
<u>Froude Numbers</u> (F_n)	0.0, 0.05, 0.10, 0.15
<u>Headings</u> (β)	180, 135, 90, 45, 0
<u>Measurements</u>	- (a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces Including Hydrostatic, Froude-Krylov, Wave Exciting and Ship Motion Induced Forces
<u>Total Number of Runs</u>	120

2.2 TEST SERIES B - LINEARITY CHECKS (NO FLARE FORCE)

The ship is subjected to unidirectional regular waves of four different heights, six frequencies, two speeds and five headings. The critical parameters are:

<u>Wave Height</u> (H_w)	0.2D, 0.4D, 0.6D, 0.8D (Where D is Ship Depth)
<u>Wavelength Parameters</u> (λ/L)	0.5, 0.75, 1.0, 1.25, 1.5 (With the Constraint $H/\lambda < .1$)

<u>Froude Numbers (F_n)</u>	0.0, 0.10
<u>Headings</u>	180, 135, 90, 45, 0
<u>Measurements</u>	(a) C.G. Motions (b) Midships Hull Girder Loads
<u>Total Number of Runs</u>	200

2.3 TEST SERIES C - LINEARITY CHECK WITH FLARE FORCE INCLUDED

The ship is subjected to unidirectional regular waves in head and following directions, three speeds and five frequencies and four wave heights. The critical parameters are:

<u>Wavelength Parameters (λ/L)</u>	0.5, 0.75, 1.0, 1.25, 1.5
<u>Froude Numbers (F_n)</u>	0.0, 0.10, 0.15
<u>Headings</u>	180, 0
<u>Wave Heights</u>	0.2D, 0.4D, 0.6D, 0.8D
<u>Measurements Taken</u>	(a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces
<u>Total Number of Runs</u>	120

2.4 TEST SERIES D - LINEARITY CHECK WITH DRAFT-DEPENDENT HYDRODYNAMIC COEFFICIENT SELECTION

The ship is subjected to unidirectional regular waves of four different heights, six frequencies, two speeds and three headings. The critical parameters are:

<u>Wave Height</u>	0.2D, 0.4D, 0.6D, 0.8D
<u>Wavelength Parameters</u>	0.5, 0.75, 1.0, 1.25, 1.5, 2.0
<u>Froude Numbers</u>	0.0, 0.10
<u>Headings</u>	180, 135, 90
<u>Measurements</u>	(a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces
<u>Total Number of Runs</u>	144

2.5 TEST SERIES E - IRREGULAR WAVE TESTS

The ship is subjected to four unidirectional irregular systems with frequency spectra corresponding to a two-parameter Bretschneider formulation, one speed, five headings. The critical parameters are:

<u>Significant Wave Heights (H_s)</u>	10, 20, 30, 40 ft.
<u>Spectral Modal Frequencies</u>	Most Probable
<u>Headings</u>	180, 135, 90, 45, 0
<u>Froude Number</u>	0.10
<u>Measurements Taken</u>	(a) C.G. Motion Statistics (b) Midship Hull Girder Load Statistics
<u>Total Number of Runs</u>	20

In Test Series E, the frequency at which the 2-D hydrodynamic coefficients are selected is fixed according to the peak of the response spectra obtained from a linear frequency domain analysis.

2.6 TEST SERIES F - IRREGULAR WAVE TESTS WITH DRAFT-DEPENDENT HYDRO-DYNAMIC COEFFICIENT SELECTION

The ship is subjected to three unidirectional wave systems, one speed, three headings. Two-dimensional coefficients are selected as a function of instantaneous sectional draft. The critical parameters are:

<u>Significant Wave Heights (H_s)</u>	20, 30, 40
<u>Headings</u>	180, 135, 90
<u>Froude Number</u>	0.10
<u>Measurements Taken</u>	(a) C.G. Motion Statistics (b) Midship Hull Girder Load Statistics
<u>Total Number of Runs</u>	6

For Test Series F, the ship motion hydrodynamic coefficients are selected as with Test Series E.

2.7 TEST SERIES G - IRREGULAR WAVE TEST: (WITH VARYING FREQUENCY)

Same as Test Series D, except the 2-D hydrodynamic coefficients associated with ship motion-induced forces are selected according to the most recent measured zero crossing periods of motion.

Additional Measurement Taken

Automatically - Selected
Frequencies Used for Heave,
Sway and Roll 2-D Coefficients

Total Number of Runs

20

3.0 SCOPE OF WORK

The following table is used to estimate computer costs using a VAX 11/750 with below average rates:

<u>Test Series</u>	<u>No. Runs</u>	<u>CPU Hours Per Run</u>	<u>Subtotal Hours</u>
A	120	1	120
B	200	1	200
C	120	1	120
D	144	1	144
E	20	32	640
F	6	32	192
G	20	32	640
			<u>2056 CPU HOURS</u>

If we assume a rate for CPU time on a commercial VAX 11/750 is at least \$60/CPU Hour, the total computer charge would be at least \$123,360.00. There are also a significant amount of manhours involved in preparing the input data. Analyses and evaluation of the resultant data would also require at least 1000 manhours.

Even if the number of runs could be reduced by half, a full set of validation runs for SSX requires a surprisingly large amount of effort and computational resources.

**ADVANCED METHODS FOR
SHIP MOTION AND WAVE
LOAD PREDICTION**

VOLUME 2

TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION.....	1-1
2. GENERAL STRIUCTURE AND COMPUTATIONAL OVERVIEW.....	2-1
3. GENERAL SOFTWARE SPECIFICATIONS.....	3-1
4. RUN PROCEDURES.....	4-1
4.1 PROGRAM HYDREX2.....	4-1
4.2 PROGRAM HYDREX3.....	4-5
4.3 PROGRAM SSX.....	4-7
5. SAMPLE CASE.....	5-1
APPENDIX A	

1. INTRODUCTION

Program SSC performs a time-domain simulation of ship motions, hull girder loads and distributed pressures. Two preprocessing programs - HYDREX2 and HYDREX3 - perform certain calculations in preparation for a simulation. Program HYDREX2 computes two-dimensional sectional hydrodynamic coefficients and HYDREX3 calculates several arrays associated with the three-dimensional source representation of the hull. Program input includes a description of the ship's hull by sectional offsets, representation of the hull by quadrilateral or triangular panels, ship geometric and inertial particulars, operational and environmental specifications, and simulation parameters and job options. Output includes a time history plus statistical summaries of heave, pitch, sway, roll, yaw, vertical and horizontal shear and bending moments, torsional moments and dynamic pressures at centers of hull surface panels. The present version of the program contains several features to facilitate experiments with alternative techniques. The program SSX can be run in a batch or interactive mode. The three programs are written in FORTRAN 77 and developed on a DEC VAX 11/750 computer.

This volume (Volume II) provides instructions to the user for performing computations with SSX, HYDREX2 and HYDREX3. A technical description of the model formulation and solution procedures are provided in Volume I.

Program structure and computational overview is first given in Section 2. Program software specifications are described in Section 3. Run procedures are given in Section 4 with input and output variable descriptions. A sample case in Section 5 illustrates code application. Program listings are contained in Appendix A.

(THIS PAGE INTENTIONALLY LEFT BLANK)

2. GENERAL STRUCTURE AND COMPUTATIONAL OVERVIEW

A simplified schematic of the basic flow of information is provided in Figure 1. It shows the major sequence of information processing. Three data files are initially required. The basic information file [BIF] contains basic geometric and mass properties of the ship, operational and environmental parameters, and calculation specifications, simulation parameters and job options. The ship offset file [OFF] gives station offset data. The hull panel file [PAN] contains nodal points and connectivity relationships to represent the hull surface by quadrilateral and/or triangular panels.

Program HYDREX2 uses the [BIF] file and [OFF] file to calculate two-dimensional hydrodynamic added mass and damping coefficients using the Frank Close-Fit method. HYDREX2 places the results of its computation in a two-dimensional coefficient file [COF]. It also provides a printout of its results.

Program HYDREX3 uses the [PAN] file to compute panel center coordinates, areas, normals, source density matrix [E], panel pressure matrix [PP] and forward velocity pressure matrix [PX]. The results are placed in a data file [MAT]. HYDREX3 need not be run if it is anticipated that distributed pressures will not be required.

Program SSX uses the [BIF] data file, the [COF] data file, the [MAT] data file (if a pressure distribution is desired), and the [OFF] data file. SSX output includes an input data summary, time domain results and response statistics.

A simplified flow schematic of the SSX program is given in Figure 2. The main program routine SSX initially asks for the names of the [BIF], [OFF], [COF] and [MAT] data files. Subroutine READIN is called to load the necessary variables and arrays using data read in from the four data files.

At this point all data has been entered, and subroutine PREPARE is called to initialize certain arrays and perform some computations in preparation for the simulation. Next, subroutine COFFEE is called to load a set of arrays that contain the initial set of two-dimensional hydrodynamic coefficients associated with the mean still water draft, the frequencies of encounter of the wave components and the predicted characteristic frequencies of ship motion.

The program then calls FOLIO1 to display the basic input data and some computed preparatory information. At the option of the user, subroutine OUTCOF can be called to display the initial set of two-dimensional hydrodynamic characteristics.

Now the actual simulation is ready to begin. At each time step, the subroutine FOLIO2 is called to display motion and loads response values for that time. Thus FOLIO2 is initially called at $t = 0$. The program then proceeds with the simulation. Within the time step loop in the main program, three subroutines are called - RK4, HULL and PRESSURE. The subroutine RK4 sets up and solves the equations of motions, the subroutine HULL evaluates hull girder loads, and the subroutine PRESSURE evaluates dynamic pressure at the center of each hull surface panel. PRESSURE is only called for a user-selected period of time within the simulation. Both the RK4 and PRESSURE subroutines lead into the large number of subroutines which will be described in the next two paragraphs. At the end of each time step, the time is compared to the user specified stop time. The loop is updated if the stop time has not been reached. If it has been, the simulation stops, and subroutine FINI is called to provide summary statistics.

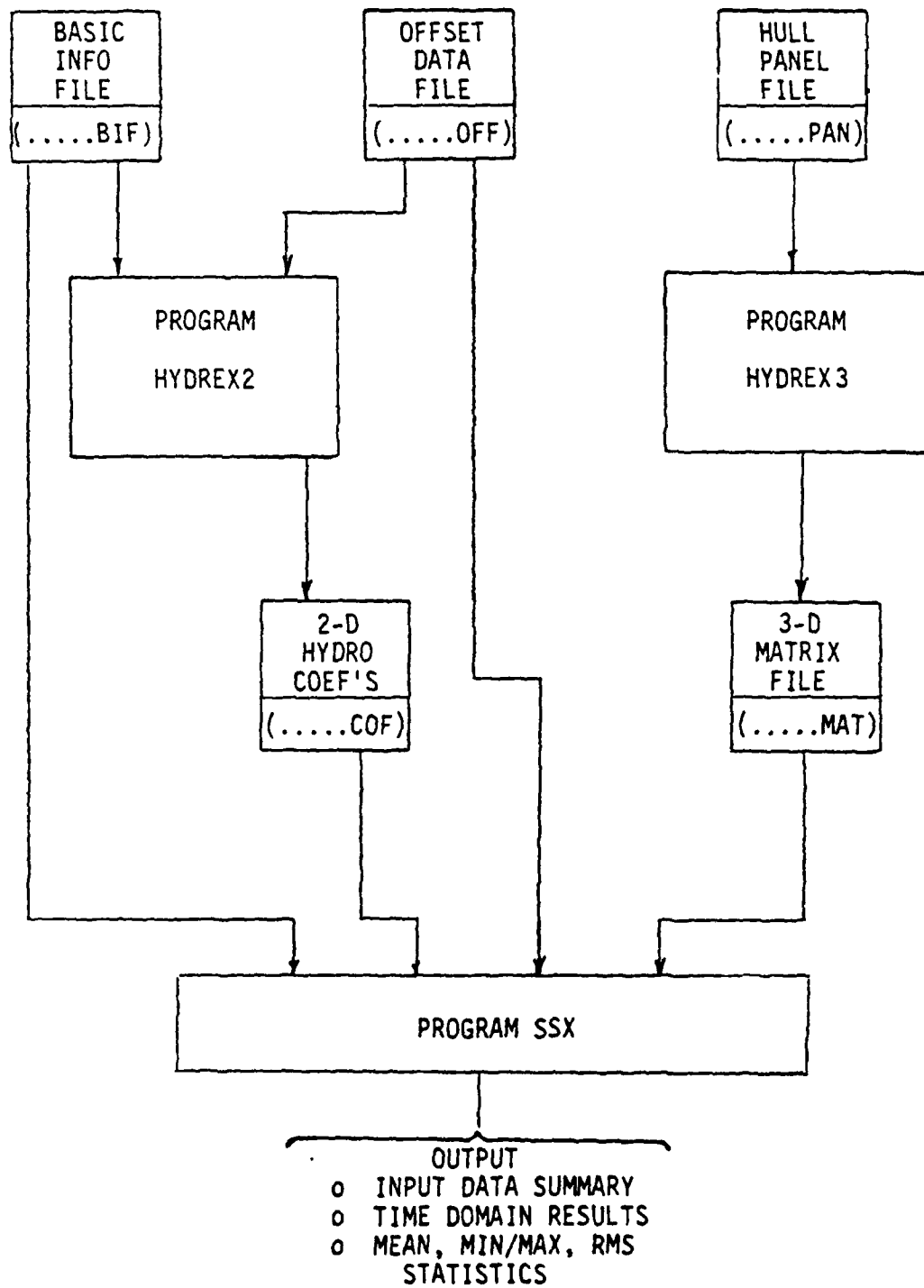
Figure 3 provides a simplified representation of the computational process associated with the solution of the equations of motion. The subroutine RK4 calls DERIV four times for each time step according to the fourth order Runge-Kutta scheme. The subroutine DERIV sets up the equations of motion in the form of four first order ordinary differential equations. It evaluates the derivatives to be integrated by RK4. The subroutine DERIV calls subroutine FORTIS to evaluate external forces and moments, which include hydrostatic and hydrodynamic forces calculated by subroutine AQUA2D. The

subroutine AQUA2D calls a number of other supporting subroutines and functions. MOCHA evaluates 2-D hydrodynamic coefficients when they are to be a function of sectional draft and/or ship motion characteristic frequencies. KRYLOV evaluates ponential and trigonometric integrals for each section. Functions ETAF and ETABAR evaluate the wave surface elevation.

The computational process associated with hull surface pressure calculations is provided in Figure 4. Subroutine PRESSURE calls ACPTR which computes the pressures and normal acceleration at panel centers induced by the free surface. Next subroutine ZBLACN determines the relative normal acceleration at each panel by subtracting the free surface induced accelerations and incident wave field accelerations from the hull kinematical acceleration. The time derivative of panel source strengths are also evaluated in ZBLACN. Next, subroutine POTB is called to obtain body-induced pressures. The body-induced pressure is added to the free-surface-induced pressure at each panel. The final subroutine is CFSR which advances the free surface representation in preparation for the next time step.

If subroutines to evaluate bottom slamming and green water loads were to be included in later modifications to the program SSX, they should be called from the subroutine AQUA2D. Any force as a function of time, displacement velocity and position on the ship can be evaluated from the information available at any instant within AQUA2D.

FIGURE 1
BASIC INFORMATION FLOW



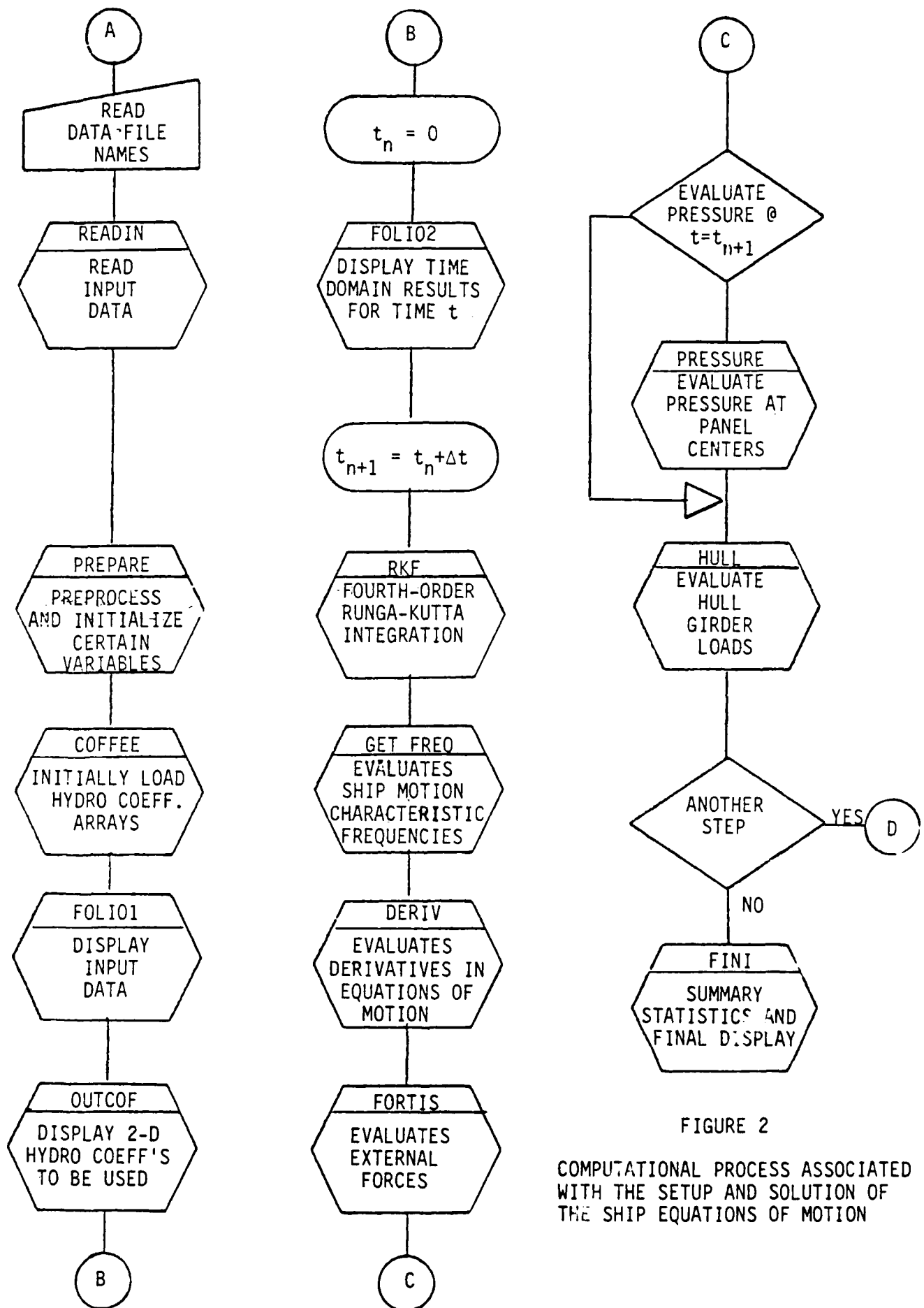


FIGURE 2
COMPUTATIONAL PROCESS ASSOCIATED
WITH THE SETUP AND SOLUTION OF
THE SHIP EQUATIONS OF MOTION

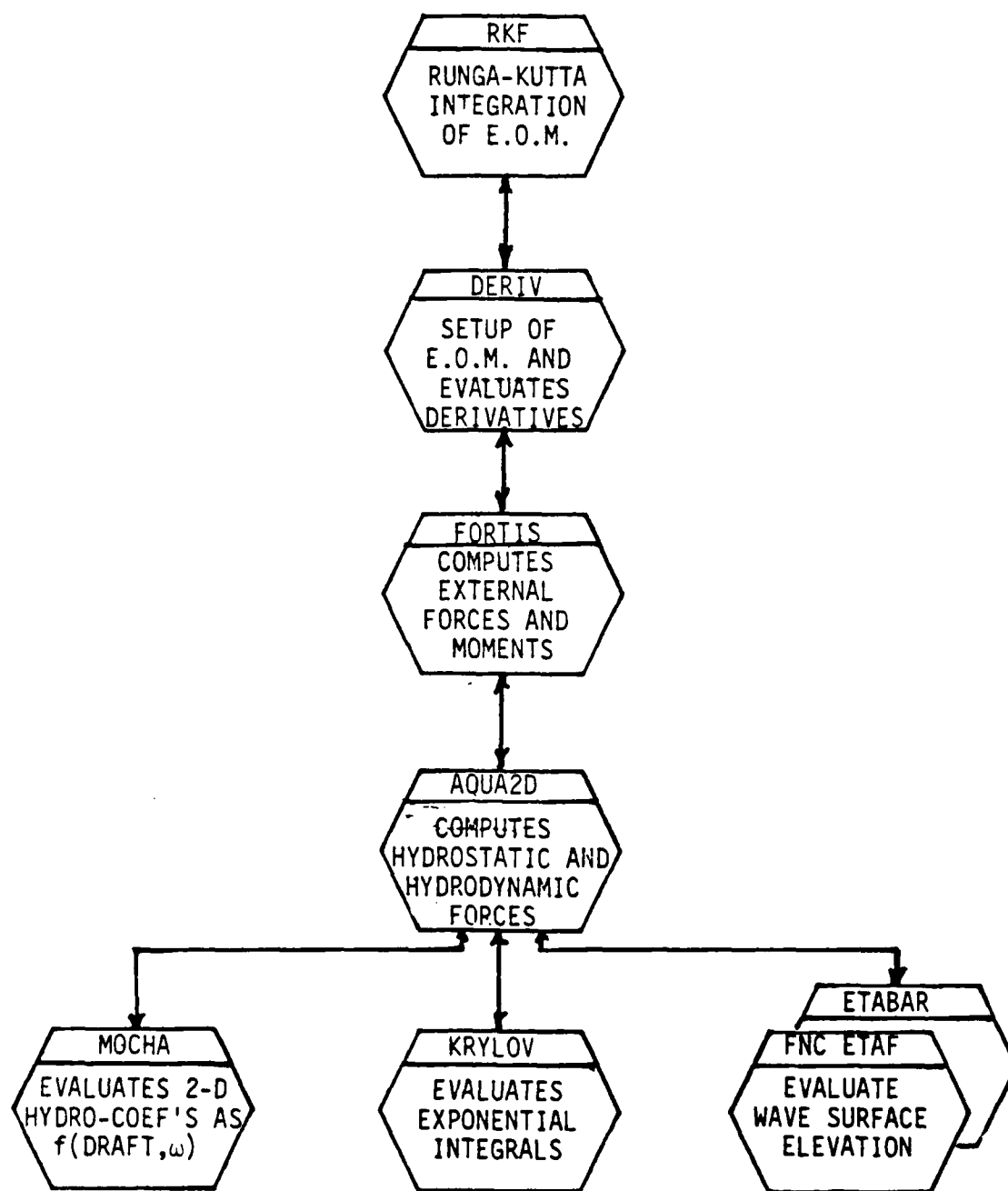


FIGURE 3

COMPUTATIONAL PROCESS ASSOCIATED WITH
THE SETUP AND SOLUTION OF THE SHIP
EQUATIONS OF MOTION

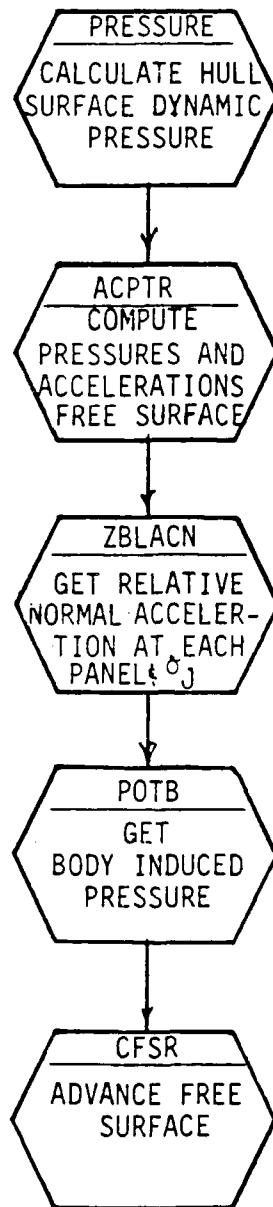


FIGURE 4
COMPUTATIONAL PROCESS ASSOCIATED WITH HULL
PRESSURE CALCULATIONS

(THIS PAGE INTENTIONALLY LEFT BLANK)

3. GENERAL SOFTWARE SPECIFICATIONS

The three codes conform to ANSI X3.9-1978 FORTRAN 77. They were developed on a Digital Equipment Corporation VAX 11/750 computer with a working set size of 250 pages. The only obvious machine depending coding are OPEN statements to open and assign files.

Rather than completely developing new codes, two previously developed and tested codes were used as a basis for the present three codes. The CAPSIZE program written at the University of California, Berkeley by Paul Wood was used as a starting point. The basic variable assignments used in that program were retained, as was the basic computational scheme for the equations of motion. For the three dimensional pressure computations, a program developed by R.B. Chapman entitled NSUP was used as a starting point. Some of the subroutines contained in NSUP and CAPSIZE were adopted directly, while others were completely rewritten. A number of new subroutines were written as well.

SSX Subroutines

The following is a list of subroutines and functions used in the SSX. Short descriptions are given here and the more complicated subroutines should be sufficiently well documented internally to clearly illustrate the computational process.

MAIN	The purpose of the main program is to accept data file names, open the appropriate files, read input data, call several subroutines to prepare data for the simulation, and then execute the time step loop which calls the several subroutines which perform the simulation of motion, hull girder loads and hull dynamic pressures. Calls READIN, SETUP, PREPARE, COFFEE, FOLIO1, OUTCOF, FOLIO2, RK4, HULL, PRESSURE and FINI.
READIN	Reads data from the basic information file [BIF], the ship offset file [OFF], the sectional hydrodynamic coefficient file [COF] and the panel pressure matrices file [MAT]. Prints an echo of data read from [BIF]. Called from MAIN.
PREPARE	Performs computations in preparation for simulation, including (a) from given offsets on the port side, assigns symmetrical offsets on starboard side, (b) recomputes offset coordinates relative to center of mass, (c) consolidates fore and aft profile coordinates into a single pair of arrays, (d) loads certain sectional mass arrays and generalized mass matrix. (e) computes wave numbers, (f) converts initial data in degrees to radians, (g) converts initial linear velocities from ship coordinates to fixed coordinates, and (h) divides all sectional hydrodynamic coefficients by fluid density, (i) initializes special free surface representation for pressure calculations. Calls AFSR. Called from MAIN.

ROTATE	Sets up coordinate system rotation matrices. Called from PREPARE, FORTIS.
FOLI01	Displays ship motion response and hull girder loading response values for each time step. Also accumulates data for post simulation statistical analysis. Called from MAIN.
DERIV	Evaluates the right hand side of the equations of motion. These values are the ones integrated by the integration scheme. Causes external forces to be calculated, combined with inertial properties to yield translational and angular momentum in the appropriate coordinate systems for solution using Newton's second law. Called from RK4. Calls FORTIS.
FINI	Prints final execution and response value statistics - including mean, rms, maximum and minimum.
RK4	Fourth-order Runge-Kutta integration subroutine. Integrates an array YYDOT containing rotational and translational velocities and accelerations to yield array YY which contains new displacements and velocities. Called from MAIN. Calls DERIV.
ERROR	Subroutine to display a limited amount of diagnostics in the event of a runtime error, principally due to data input errors.
KRYLOV	Evaluates two-dimensional exponential and trigonometric integrals over each station of the ship. Called from AQUA2D.
COFFEE	Performs two-dimensional linear interpolation in the table of sectional hydrodynamic coefficients. Coefficients are selected for the mean design draft, and at encounter

frequencies associated with each wave component and at "characteristic" frequencies of ship motion initially assumed to be the modal frequency of the sea spectrum if irregular waves are imposed.

FXIF Provides an index (IT) and a multiplier (TX) for linear interpolation for draft in the table of sectional hydrodynamic coefficients.

TXIT Provides an index (TX) and a multiplier (IT) for linear interpolation for frequency in the table of sectional hydrodynamic coefficients.

FUNCTION COX Performs the two-way linear interpolation in the table of sectional hydrodynamic coefficients using IF, FX, IT, TX obtained through FXIF and TXIT.

FUNCTION COXDXP Same as COXDX except it uses sectional hydrodynamic coefficients that have not been divided by sectional area, and determines the x-spatial derivative.

FUNCTION ETABAR Provides the wave elevation in fixed coordinate system above a given point of the ship's centerline along hull, stern and transom.

FUNCTION ETAF Provides the coordinate of the water surface in yawed and pitched coordinates given a section number, distance off the centerline and relative displacement of the section.

GETFREQ Evaluates the average of the two most recent zero crossing periods and calculates characteristic frequencies of ship motion in heave, sway and roll. Called from RK4.

OUTCOF Prints the temporary sectional hydrodynamic coefficients currently in arrays in COMMON/COEFFX/. Normally done only at the beginning of the simulation. Called from MAIN.

FOLIO1	Displays or prints a summary of basic input data. Called from MAIN.
FOLIO2	Displays or prints ship motion and hull girder response. Called from MAIN.
FOLIO3	Displays or prints ship hull pressure response. Called from MAIN.
TBAR	Provides the average depth of immersion of a given section.
SPECTRA	Provides the amplitude and frequency of ten wave components derived from a two parameter Bretschneider spectrum. Called from SETUP.
PRESSURE	Provides values of dynamic pressure at the center of each hull panel for a particular instant of time. Called from MAIN. Calls ACPTR, ZBLACN, POTB and CFSR.
ZBLACN	In the pressure computations, applies the specified body accelerations for the six degrees of freedom to compute the resulting normal accelerations at the panel centers. The free-surface induced normal accelerations ACNW(J) are subtracted to obtain the net normal acceleration at each panel center, ACN(J), of the body relative to the fluid. These accelerations must be cancelled by the time derivative of the body source density distribution, ST(K). The ACN(J) vector is multiplied by the E matrix to get the necessary net rate of change of the panel source densities, ST(K). The total source strength densities are accumulated in STOLD(K). Called by PRESSURE.

ACPTR	In the pressure computations computes free-surface induced accelerations ACNW(J) and pressures PRFS(T) at panel centers. Called by PRESSURL.
POTB	In the pressure computations this subroutine is used to compute the generalized body-induced pressure BPRES generated by a known source strength distribution and its time derivative. The matrix P(J,K) is multiplied by a vector, ST(K), representing the time derivative of source densities of the panels. Similarly the term proportional to forward speed is computed from the matrix PX and a vector representing the accumulated source densities, STOLD(K). Called by PRESSURE.
CFSR	In the pressure computations advances free-surface by one time increment. Moves body relative to the free surface. Adds the changes in free-surface elevation induced by the body sources acting over the time increment to the free-surface representation. Second order effects in time are included.
AFSR	In the pressure computations sets up and initializes the free-surface representation called by PREPARE.

HYDREX2 Subroutines

The following is a list of subroutines in HYDREX2.

MAIN	Accepts data file names, opens the appropriate files, reads input data, loops over six drafts, calling FLOAT and HYDRO within the loops. Also calls INDATA to read in data from files.
------	--

FLOAT	"Floats" the ship at the specified draft. Creates a set of "wet" offsets to be used for hydrostatic calculations and for the computation of sectional hydrodynamic coefficients.
HYDRO	Applies the Frank Close-fit method to "wet" offsets. Adopted from CAPSIZE which adopted it with some modifications from the original NSRDC code. HYDRO calls GIRL, BEER, WINE and STATN.
STATN	Revises the station offsets by inserting additional points in order to optimize the hydrodynamic computations and to suppress anomolous behaviour which sometimes occurs at certain "singular frequencies". INSERT is called by STATN as part of this process.
GIRL	Computes certain frequency-independent coefficients which are used in the two-dimensional hydrodynamic computations.
BEER	Computes the two-dimensional hydrodynamic coefficients for the special cases of zero or infinite frequency. It calls the simultaneous linear equation solver LINEQT.
WINE	Performs the computation of the two-dimensional hydrodynamic coefficients for finite nonzero frequencies, calling several subroutines for special operations. WOMEN computes some of the interaction between segments of the section. SONG performs the integration of pressures around the section. ROMEO evaluates the exponential integral with complex argument. JULIET is a simultaneous linear equation solver for certain sets of equations in HYDRO.

HYDREX3 Subroutines

The following routines are contained in the program HYDREX3.

MAIN Reads input data and calls subroutines EBD and POTST.

EBD This subroutine reads in the (x,y,z) coordinates of each of the four corner points into a set of arrays XPT(N), YPT(N), ZPT(N). Panels are identified by a set of four integers giving the array positions of the four corner points of each panel. Panel areas, normals and center point coordinates are then computed. Finally, the E matrix giving the source time derivative distribution for a set of prescribed normal accelerations is computed. The inverse of E is computed first by the subroutine GE which gives the acceleration induced at any panel center point, J, by a uniformly distributed time derivative of source strength density of unit magnitude acting over any surface of panel, JL. Subroutine MATIN inverts E to obtain the desired form. Simultaneously, the matrix PX which gives the x component of velocity at the center of panel J induced by a source strength of unit magnitude distributed over a panel, JL, is computed.

POTST Calculates the matrix P(N,J) giving the net force or moment for the Jth degree of freedom induced by a unit time derivative of source strength over panel N. Fundamental to this is the need to compute the potential integrated over each panel area due to a uniform source density over every other panel. For panels which are far apart relative to their dimensions this value is, for unit source density, simply proportional to the product of their areas divided by the distance between centers. The method used here is to divide each panel into a large number of small subpanels and then calculate the results numerically, adding the contributions of each subpanel

under the assumption that their separations are large relative to their dimensions.

SELF This subroutine is called POTST to compute diagonal terms in the P matrix.

MATIN The matrix inversion routine used by subroutine EBD to invert matrix E.

GE A subroutine called by EBD to compute the elements of matrix E prior to inversion. It computes the velocity (acceleration) at field point (XF, YF, ZF) induced by a source density (time rate of change of source strength) of value unity distributed uniformly over panel J.

GO A subroutine called by GE.

SOLID Also called by subroutine GE to compute the solid angle of a panel relative to the field point.

PREP Prepares all panels for the GE subroutine. It is called by EDB prior to using GE.

(THIS PAGE INTENTIONALLY LEFT BLANK)

4. RUN PROCEDURES

This section presents the procedures involved with running HYDREX2, HYDREX3 and SSX. It also gives input data description and formats.

4.1 PROGRAM HYDREX2

HYDREX2 calculates two-dimensional sectional added mass and damping coefficients using the Frank Close-fit method. Two data files are required - a [BIF] file which contains basic ship and program run information and the [OFF] file which contains the ship's offsets. The program will create a third file [COF] into which it will write the results of its calculations.

When HYDREX2 is run, the only required input is the following three files names:

<u>File Name</u>	<u>Format</u>
Basic Input File	(A)*
Ship Offset File	(A)
2-D Coefficient File	(A)

Descriptions of the [BIF] and [OFF] file are given in the next two sections.

Basic Information File [BIF]

The basic information file is used for programs HYDREX3 and SSX as well as HYDREX2. The full [BIF] file will contain more information than that which is described below. However, to run HYDREX2, only the first part of the [BIF] file need be created. The remainder can be created at some other time prior to running SSX. Table 1 below summarizes the input data variables and the associated format.

* (A) format is alphanumeric string variable

TABLE 1

BASIC INFORMATION FILE (PARTIAL)		
Data Set No.	Variables	Line Format
1	TITLE	(A)
2	TF, TA	6F10.0
3	XCG, YCG	6F10.0
4	(DRAFT (I), I=1,6)	6F10.0
5	(OM(I), I=1,12)	6F10.0
6	YMAX, ZMAX, WMAX, NWL	3F10.0, I15
7	NFWD	I5
8	(YFWD(I), XFWD(I), I=1,NFWD)	2F10.0
9	NAFT	I5
10	(YAFT(I), XAFT(I), I=1,NAFT)	2F10.0
:		
:		

A description of the variables contained in Table 1 is provided below:

- TITLE - Any user-specified alphanumeric string up to 81 characters in length. This is displayed at the beginning of certain pages of output.
- XCG - Distance aft of the forward perpendicular of the ship's center of gravity (ft).
- YCG - Height above baseline of ship's center of gravity (ft)
- TF,TA - Ships forward and after draft at FP and AP.
- DRAFT(I) - An array of six drafts at which hydrodynamic coefficients are calculated. The specified drafts should cover a range beginning at approximately the height above the baseline of the top of the turn of the bilge and ending at the minimum hull depth. One of the drafts should be near the mean design draft for the displacement under consideration.
- OM(I) - An array of twelve frequencies at which hydrodynamic coefficients are calculated.

- YMAX,
ZMAX - Specifies the maximum desired vertical (YMAX) and horizontal separation between adjacent offset points for calculation of two-dimensional hydrodynamic coefficients. If both YMAX and ZMAX are positive values, interpolated offset points (straight line) will be added before computing coefficients using the method developed by W. Frank (1967).
- WMAX - A "deck" on the interior waterline has been added to the geometry of each station which is surface piercing to avoid "irregular" frequencies. The default is to use only one segment for this, but a positive WMAX will allow multiple segments each with a maximum length of WMAX.
- NWL - Specifies the number of interior waterline segments to be used to avoid "irregular" frequencies. The default is to use one segment, and this is selected if NWL is zero. A negative value (not recommended) will suppress the modification to Frank's procedure which eliminates irregular frequencies.
- NFWD - Number of forward profile points. This is restricted to $0 \leq \text{NFWD} \leq 25$. These points are numbered by the control variable I in a counterclockwise direction when viewed from the starboard side.
- YFWD(I) - Height of point I of the forward profile measured forward of the first station.
- XFWD(I) - Distance of point I of the forward profile measured forward of the first station. If NFWD=1, XFWD(1) is defined to be the forward most point of the submerged hull.
- NAFT - Number of after profile points. This is restricted to $0 \leq \text{NAFT} \leq 25$. These points are numbered by the control variable I in a clockwise direction when viewed from the starboard side.
- YAFT(I) - Height of point I of the after profile.
- XAFT(I) - Distance of point I of the after profile measured aft of the last (MSTA) station. If NAFT=1, XAFT(1) is defined to be the after most point of the submerged hull.

The offset file [OFF] contains the ship's offsets in the SHCP* format. An actual SHCP data can be used for the [OFF] file. HYDREX2 will read only what it needs. Table 2 below summarizes the input data variables and associated formats.

TABLE 2

SHIP OFFSET FILE		
Data Set Number	Variables	Line Format
1	SHCP Card A <u>or</u> (blank)	(A)
2	SHCP Card B <u>or</u> (blank)	(A)
3	SHCP Card C <u>or</u> space	F10.3, (A)
4	SHCP Card D - STATN, Y1 Z1, JTEST	F6.3, 2F7.0,I6

A description of the variables contained in Table 2 is provided below.

SHCP CARD A - This can be left blank, or if it is an actual SHCP data file, leave it intact.

SHCP CARD B - Blank or actual SHCP Card B

SHCP CARD C - This can be the actual SHCP Card C or simply one variable SPACE, where SPACE is the station spacing. It is actually a multiplier of the x-values of the stations given in the next card set.

STATN - The real distance from the station to the F.P. is the product of STATN and SPACE. The STATN values must be the same for all offsets on the same station.

* Ship Hull Characteristic File (U.S. Navy)

- Y1 - The half breadth of the offset point. The offsets for each station should be ordered from the bottom toward the uppermost parts of the station.
- Z1 - The height of the offset point.
- JTEST - The "breakpoint" indicator 77777 is ignored. The last offset on each station is signified by JTEST = 88888. The last offset on the last station is signified by JTEST = 99999. JTEST values other than zero (or blank) 77777, 88888 or 99999 are illegal.

For HYDREX2, the maximum number of offset points per station is 25. However, for SSX, the maximum number of offset points is 12. It is recommended that as many offset point (up to 25) as possible are used for HYDREX2 to increase the accuracy of the close-fit calculations. However, prior to running SSX, the [OFF] file must be edited to delete extra offset points in order to reduce the total number per station down to 12. The number of stations must be limited to 25.

An example of the actual input and output of HYDREX2 will be provided in Section 5 with a sample case illustration.

4.2 PROGRAM HYDREX3

HYDREX3 calculates coordinates of hull surface panel center, areas and normal vectors of panels, body source density influence matrix [E], a body panel pressure influence matrix [PP], and a forward velocity source density influence matrix [PX].

When HYDREX3 is run, the only required input is the following two file names:

<u>File Name</u>	<u>Format</u>
Panel Description File [PAN]	(A)
Matrix and Geometry File [MAT]	(A)

Table 3 summarizes the input variables and formats for the data for the panel description file [PAN].

TABLE 3

PANEL DESCRIPTION FILE		
Data Set	Variables	Format
1	NPT, NPAN	4I5
2	XPT(N), YPT(N), ZPT(N) N=1, NPT	3F10.0
3	KK(M,1), KK(M,2), KK(M3,) KK(M,4), M=1, NPAN	4I5

The variables and their use are further described below.

NPT - Number of nodal points used to specify coordinates of panel corners. Not to exceed 150.

NPAN - Number of quadrilateral or triangular panels. Not to exceed 120.

XPT(N)
YPT(N)
ZPT(N) - The coordinates of the nodal points used as corner points for the panels. The coordinate system used here has Z positive downwards, X positive forward and Y positive starboard. The origin is at midships at the mean design water line.

KK(M,1) - These are four integers which identify which nodal points are used to define the corners of the panels. The convention for the sequencing of the aft panel corners is to go around the panel clockwise when viewed from outside of the ship hull along the panel normal.

4.3 PROGRAM SSX

Program SSX performs a time domain simulation of ship motions, calculating hull girder loads and distributed pressures (optional). A prerequisite of executing SSX is to have run HYDREX2 and HYDREX3 in order to perform some "preprocessing". SSX requires four data files.

- (1) Basic Information Data File [BIF]
- (2) Ship Offset Data File [OFF]
- (3) 2-D Hydrodynamic Coefficient Data File [COF]
- (4) 3-D Geometry/Matrix File [MAT]

The program initially asks for the names of these four files in the above order. It then reads the data. If the [MAT] file name is 'NONE', then no pressure computations will be performed, and data sets 21 and 22 in the [BIF] file are skipped. The first eight data groups in the [BIF] file were given in Table 1. The variable and format list for the remainder of the [BIF] file is given in Table 4.

TABLE 4

BASIC INFORMATION FILE (PARTIAL)		
Data Set	Variables	Format
9	DISPL	8F10.0
10	(RADII(I), I=1,6)	8F10.0
11	SPEED	8F10.0
12	(DAMPL(I), I=1,6)	8F10.0
13	(DAMPQ(I), I=1,6)	8F10.0
14	IXWAVE IXWAVE = 1 → Include Set 14A IXWAVE ≠ 1 → Include Set 14B	I2
14A-1	NWAVES	4F10.0
14A-2	WVAMP(N), WVFRE(N), WVDIR(N), WVPHA(N), N=1, NWAVES	4F10.0
14B-1	H13, PKFRE, HEAD	8F10.0
15	(POSIT(I), I=1,6)	8F10.0
16	(VELOC(I), I=1,6)	8F10.0
17	TSTART, TSTOP, TOUTPT, TSTEP	8F10.0
18A	(JOBFO(10), I=1,10)	10I1
18B	(JOBPO(10), I=1,10)	10I1

⋮

TABLE 4 (Cont.)

BASIC INFORMATION FILE (PARTIAL)		
Data Set	Variables	Format
18C	JOB CO	I1
19	NWTSTA	I2
20	SEGWT(I), SEGMOX(I), YBAR(I) I=1, NWTSTA	3F10.0
21	TPSTART, TPSTOP, TPRAMP	8F10.0
22	BGX, SMX, BGY, SMY, TSCALE	8F10.0

The variables and their use are further described below.

- DISPL - Ship displacement (long tons). It is best to enter the displacement calculated in HYDREX2 for the design draft and printed in the hydrostatic section of the HYDREX2 printout.
- RADII(1) - Radius of gyration for roll, ρ_{xx} .
- RADII(2) - Radius of gyration for yaw, ρ_{yy} .
- RADII(3) - Radius of gyration for pitch, ρ_{zz} .
- RADII(4) - Radius of gyration, ρ_{xy} . The products of inertia are computed as:
- $$I_{xy} = I_{yx} = \rho_{xy} \cdot |\rho_{xy}| \cdot m$$
- where m is the mass of the ship
- RADII(5) - Radius of gyration, ρ_{xz}
- RADII(6) - Radius of gyration, ρ_{yz}
- SPEED - Intended speed of the ship (feet/sec)
- DAMPL(1) - Linear surge damping
- DAMPL(2) - Linear heave damping
- DAMPL(3) - Linear sway damping
- DAMPL(4) - Linear roll damping
- DAMPL(5) - Linear yaw damping
- DAMPL(6) - Linear pitch damping
- DAMPQ(1) - Quadratic surge damping
- DAMPQ(2) - Quadratic heave damping
- DAMPQ(3) - Quadratic sway damping
- DAMPQ(4) - Quadratic roll damping
- DAMPQ(5) - Quadratic yaw damping
- DAMPQ(6) - Quadratic pitch damping

IXWAVE	- Flag to indicate how the user wants to specify the wave system. IXWAVE=1 means the user will specify the amplitude, frequency, direction and phase angle of N WAVE wave components. IXWAVE $\neq$ 1 means the user will specify the significant height and modal frequency to be used for a two-parameter (Bretschneider) unidirectional sea spectral formulation from which 10 wave components will be calculated with random phase angles.
N WAVES	- Number of sinusoidal waves. This is restricted to $0 < \text{N WAVES} < 20$.
WVAMP(I)	- Amplitude of wave component I (ft)
WVFRE(I)	- Circular frequency of wave component I
WVPHA(I)	- Phase angle in degrees at time equal zero of wave component
H13	- Significant wave height in feet to be used in two-parameter Bretschneider unidirectional sea spectral formulation
PKFRE	- Modal frequency in cycles/sec for Bretschneider formulation
POSIT(1)	- Initial X-coordinate of mass center
POSIT(2)	- Initial Y-coordinate of mass center
POSIT(3)	- Initial Z-coordinate of mass center
POSIT(4)	- Initial roll angle in degrees
POSIT(5)	- Initial yaw angle in degrees
POSIT(6)	- Initial pitch angle in degrees
VELOC(1)	- Initial speed (ft./sec.)
VELOC(2)	- Initial heave velocity

- VELOC(3) - Initial sway velocity
- VELOC(4) - Initial roll rate
- VELOC(5) - Initial yaw rate
- VELOC(6) - Initial pitch rate

The position values are specified with respect to the wave coordinate system fixed on the earth. The velocities are with respect to the ship coordinate system. Positions are in feet; velocities in feet/sec.

- TSTART - Time at which the actual simulation is to start. All forces are multiplied by a ramp function that increases linearly in time from a value of zero at $t=0$ to one at TSTART. This ramp is used to avoid transients caused by arbitrary initial conditions.
- TSTOP - Time at which the simulation is to end
- TOUTPT - Interval at which the ship position and velocity are to be output.
- TSTEP - Integration time step
- JOBCO - Option for selection of different techniques used to select the sectional hydrodynamic coefficients. The sectional coefficients may be calculated for any combination of fixed or varying draft and frequency dependence, according to the following table:

<u>JOBCO</u>	<u>Frequency</u>	<u>Draft</u>
1	Fix	Fix
2	Float	Fix
3	Fix	Float
4	Float	Float

The selection of fixed draft means the mean still waterline draft is always used for coefficient selection. Fixed frequency means the encounter frequency associated with the peak of the sea spectrum (for irregular waves) or the frequency of encounter for a regular wave is always used.

Floating frequency means the computed "characteristic" frequencies of motion as the simulation progresses are used. Floating draft means the actual instantaneous mean sectional draft is used at each time step.

- JOBFO(10) - Option array for which terms to include in the calculation of hydrodynamic forces. In the present version only JOBFO(2) and JOBFO(3) are used. If JOBFO(2)=1 then forward speed terms are included. If JOBFO(3)=1 then flare force is included. If JOBFO(4)=1, pressures in the wave above still water are assumed to be hydrostatic.

- JOBPO(10) - Printout option array. Only JOBFO(1) is used in present version. A value of 1 for JOBPO(1) will cause the initially selected values for hydrodynamic coefficients to be printed.

- NWTSTA - Number of weight stations. In present version of SSX, NWTSTA must equal number of hydrodynamic stations or strips.

- SEGWT(I) - Weight of weight station I (long-tons)

- SEGMOX(I) - Sectional roll gyradius (ft)

- YBAR(I) - Distance from section c.g. and waterline, positive up.

- TPZERO - Time at which to begin 3-D hull pressure computations

- TPSTART - Time at which 3-D hull pressure evaluation actually begins. Between time TPZERO and TPSTART, the exciting normal accelerations are multiplied by a ramp function that increases linearly in time from a value of zero at $t = TPZERO$ to a value of one at $t = TPSTART$

- TPSTOP - Time at which 3-D hull pressure evaluation ends

- BGX - Maximum longitudinal length scale. Corresponds to L_x in eq. (72) of Volume I. Try $2.5 p_{pp}$

- SMX - Minimum longitudinal length scale corresponds to l_x in eq. (73) of Volume I. Try station spacing of ship

- BGY - Maximum transverse length scale. Corresponds to L_y in eq. (72) of Volume I. Try 5R
- SMY - Minimum transverse length scale. Correspondence to l_y in eq. (73) in Volume I. Try 0.1R
- TSCALE - Maximum time scale. Trade off between accuracy and computational effort. Try 0.6 (TPSTOP-TPZERO)

An example of actual input and output is shown in the next section with a sample run.

5. SAMPLE CASE

This example is for the SL-7 containership. An example of the [BIF], [OFF] and [PAN] data files are given. The [BIF] file is in free format. An example of the output for HYDREX2, HYDREX3 and SSX is given.

The sample case shows the full load SL-7 containership at 25 knots in head seas in a one-foot regular wave of $\omega = 0.34$. The basic information file [BIF] is shown in Figure 5. The offset [OFF] file is provided as Figure 6 and the panel file [PAN] is given as Figure 7. An example of the output of HYDREX2 is shown in Figure 8. An example of output of HYDREX3 is given in Figure 9. An example of output of SSX is given in Figure 10. Pressure data output is shown in Figure 11.

SL7 CONTAINERSHIP
 32.8, 32.8
 -478.05, 42.3005
 5., 10., 20., 32.8, 40., 50.
 0., 0., 60., 2
 9
 0., 0.
 1.5, 9.6
 8.25, 16.88
 18.0, 7.04
 30., 0.
 42., 1.92
 56., 7.92
 72., 17.12
 81.75, 23.44
 6
 0., -71.12
 6.0, -67.68
 10.75, -19.44
 25.0, -19.44
 33.0, 12.24
 64.83, 17.92
 47760.
 47., 219., 219., 0., 0., 0.
 16.89
 0., 0., 0., 0., 0., 0.
 0., 0., 0., 0., 0., 0.
 1
 1
 1., 2, 180., 0.
 0., 9.4118, 0., 0., 0.
 16.89, 0., 0., 0., 0., 0.
 30., 100., 5., 5
 25
 094.5500, 37.31, 9.5145
 294.5500, 37.31, 9.5145
 296.2025, 37.31, 9.5145
 496.2025, 37.31, 9.5145
 1143.8223, 37.31, 9.5145
 1134.9353, 37.31, 9.5145
 1681.7071, 37.31, 9.5145
 2040.0422, 37.31, 9.5145
 2508.4206, 37.31, 9.5145
 2578.8111, 37.31, 9.5145
 3053.3377, 37.31, 9.5145
 3591.3250, 37.31, 9.5145
 3530.8231, 37.31, 9.5145
 3175.7759, 37.31, 9.5145
 3725.5737, 37.31, 9.5145
 3530.6277, 37.31, 9.5145
 2595.3904, 37.31, 9.5145
 3151.4265, 37.31, 9.5145
 2534.0626, 37.31, 9.5145
 1915.6687, 37.31, 9.5145
 1761.7387, 37.31, 9.5145
 715.4792, 37.31, 9.5145
 715.4792, 37.31, 9.5145
 747.0264, 37.31, 9.5145
 747.0264, 37.31, 9.5145
 0., 0., 0., 0.
 0., 0., 0., 0.

SL7 CONTAINERSHIP

```

44 0250,0,0,0,0,0
00.00000.000000.0000
00.00004.480101.6404
00.00007.081508.2021
00.00003.815316.4042
00.00000.289026.2467
00.00001.011639.3701
00.00004.277852.4934
00.00008.237765.124788888
00.50000.000000.0000
00.50003.324000.8202
00.50006.358903.2808
00.50006.301113.1234
00.50003.324019.6850
00.50001.300729.5276
00.50002.861539.3701
00.50007.717452.4934
00.50013.353764.993488888
01.00000.000000.0000
01.00005.202701.6404
01.00007.659604.9213
01.00008.237708.2021
01.00007.804111.4829
01.00005.838616.4042
01.00003.179522.9659
01.00005.058239.3701
01.00018.007364.960688888
01.50000.000000.0000
01.50004.191100.8202
01.50007.399503.2808
01.50008.671206.5617
01.50008.815809.8425
01.50008.093213.1234
01.50005.347319.6850
01.50004.133326.2467
01.50007.601839.3701
01.50011.908552.4934
01.50022.545264.895088888
02.00000.000000.0000
02.00004.624700.8202
02.00008.035303.2808
02.00009.480506.5617
02.00009.682909.8425
02.00008.960313.1234
02.00006.937019.6850
02.00006.214426.2467
02.00008.006432.8084
02.00014.452145.9318
02.00023.065559.0551
02.00027.112164.796688888
03.00000.000000.0000
03.00002.890400.0656
03.00007.226001.6404
03.00010.058604.9213
03.00010.752308.2021
03.00011.330411.4829
03.00011.128116.4042
03.00011.330422.9659
03.00013.151429.5276
03.00018.094039.3701
03.00026.302752.4934
03.00034.974064.632588888
04.00000.000000.0000
04.00004.335600.1312
04.00008.757901.6404
04.00011.908504.9213
04.00013.584908.2021
04.00014.741111.4829
04.00016.330816.4042
04.00018.354122.9659
04.00021.042229.5276
04.00025.782539.3701
04.00033.528852.4934
04.00041.911064.534188888
05.00000.0000
05.00004.335
05.00010.839
05.00015.319
05.00018.151
05.00020.232911.4829
05.00023.036616.4042
05.00026.013722.9659
05.00028.904129.5276

```

Figure 6. Offset File [OFF]
Partial Listing

```

05.00040.118952.4934
05.00046.969264.370188888
06.00000.000000.0000
06.00007.226000.2625
06.00014.741101.6404
06.00020.666404.9213
06.00024.279508.2021
06.00030.002516.4042
06.00033.297522.9659
06.00036.187929.5276
06.00040.176739.3701
06.00045.379552.4934
06.00050.351064.337388888
07.00000.000000.0000
07.00011.561600.3281
07.00020.232901.6404
07.00027.025304.9213
07.00031.216408.2021
07.00034.106811.4829
07.00037.488616.4042
07.00040.407922.9659
07.00042.720329.5276
07.00045.697439.3701
07.00049.223752.4934
07.00052.027464.304588888
08.00000.000000.0000
08.00019.365800.3937
08.00027.314401.6404
08.00033.962304.9213
08.00038.297908.2021
08.00041.043811.4829
08.00043.934216.4042
08.00046.246622.9659
08.00047.836329.5276
08.00049.715139.3701
08.00051.564952.4934
08.00052.547764.304588888
09.00000.000000.0000
09.00026.302700.5906
09.00033.962301.6404
09.00040.610304.9213
09.00044.310008.2021
09.00046.477811.4829
09.00048.703416.4042
09.00050.351022.9659
09.00051.304829.5276
09.00052.027439.3701
09.00052.605552.4934
09.00052.750064.304588888
10.00000.000000.0000
10.00032.661600.6562
10.00039.309601.6404
10.00045.379504.9213
10.00048.558908.2021
10.00050.293211.4829
10.00051.911816.4042
10.00052.605522.9659
10.00052.721129.5276
10.00052.750064.304588888
11.00032.751400.6562
11.00035.649700.8202
11.00044.634603.2808
11.00048.692306.5617
17.00033.778832.4834
198968.897688888
100026.2467
757826.2467
190732.8084
346245.9318
20.00032.084854.6260
20.00032.084868.897699999

```

120, 112

450.00	0.00	30.00	225.00	-24.48	12.00
450.00	7.04	24.00	225.00	-30.01	0.00
450.00	6.00	18.00	135.00	0.00	30.00
450.00	3.20	12.00	135.00	-13.12	29.75
450.00	0.88	6.00	135.00	-29.92	24.00
450.00	0.00	0.00	135.00	-38.50	12.00
360.00	0.00	30.00	135.00	-43.14	0.00
360.00	1.76	30.00	0.00	0.00	30.00
360.00	7.60	27.00	0.00	-26.40	29.50
360.00	9.20	24.00	0.00	-43.36	27.00
360.00	9.28	18.00	0.00	-47.20	24.00
360.00	7.52	12.00	0.00	-52.24	12.00
360.00	6.40	6.00	0.00	-52.38	0.00
360.00	7.20	7.20	-90.00	0.00	30.00
450.00	3.50	27.00	-90.00	-26.40	29.50
290.00	0.00	30.00	-90.00	-41.44	27.00
290.00	3.44	30.00	-90.00	-51.56	24.00
290.00	9.69	27.00	-90.00	-52.80	12.00
290.00	11.76	24.00	-90.00	-52.80	0.00
290.00	14.48	12.00	-180.00	0.00	30.00
290.00	18.32	0.00	-180.00	-28.00	27.00
225.00	0.00	30.00	-180.00	-43.68	24.00
225.00	5.04	30.00	-180.00	-48.32	12.00
225.00	13.52	27.00	-180.00	-52.16	0.00
225.00	16.88	24.00	-270.00	0.00	30.00
225.00	24.48	12.00	-270.00	-35.60	12.00
225.00	30.01	0.00	-270.00	-43.28	0.00
135.00	0.00	30.00	-360.00	0.00	30.00
135.00	13.12	29.75	-360.00	-14.00	12.00
135.00	29.92	24.00	-427.50	0.00	29.50
135.00	38.50	12.00	-427.50	-1.50	29.50
135.00	43.14	0.00	-427.50	-2.72	3.50
0.00	0.00	30.00	-427.50	-6.91	0.00
0.00	26.40	29.50	-450.00	0.00	0.00
0.00	43.36	27.00			
0.00	47.20	24.00			
0.00	52.24	12.00			
0.00	52.38	0.00			
-90.00	0.00	30.00	1	7	8
-90.00	26.40	29.50	15	9	10
-90.00	41.44	27.00	2	10	11
-90.00	51.56	24.00	3	11	12
-90.00	52.80	12.00	4	12	13
-90.00	52.80	0.00	5	13	14
-180.00	0.00	30.00	7	16	17
-180.00	28.00	27.00	8	17	18
-180.00	43.68	24.00	9	18	19
-180.00	48.32	12.00	10	19	11
-180.00	52.16	0.00	11	19	20
-270.00	0.00	30.00	12	20	21
-270.00	35.60	12.00	16	22	23
-270.00	43.28	0.00	17	23	24
-360.00	0.00	30.00	18	24	25
-360.00	14.00	12.00	19	25	26
-360.00	25.54	0.00	20	26	27
-427.50	0.00	29.50	22	28	29
-427.50	1.50	29.50	23	29	24
-427.50	2.72	3.50	24	29	30
-427.50	6.91	0.00	24	30	25
-450.00	0.00	0.00	25	30	31
450.00	0.00	30.00	26	31	32
450.00	-7.04	24.00	28	33	34
450.00	-6.00	18.00	29	34	35
450.00	-3.20	12.00	30	35	36
450.00	-0.88	6.00	30	35	36
450.00	0.00	0.00	30	36	37
360.00	0.00	30.00	31	37	38
360.00	-1.76	30.00	33	39	40
360.00	-7.60	27.00	34	40	41
360.00	-9.20	24.00	35	41	36
360.00	-9.28	18.00			
360.00	-7.52	12.00			
360.00	-6.40	6.00	116	113	111
360.00	-7.20	7.20	114	117	113
450.00	-3.50	27.00	118	117	114
290.00	0.00	30.00	115	118	114
290.00	-3.44	30.00	116	118	115
290.00	-9.69	27.00	116	118	116
290.00	-11.76	24.00	120	118	0
290.00	-14.48	12.00			
290.00	-18.32	0.00			
225.00	0.00	30.00			
225.00	-5.04	30.00			
225.00	-13.52	27.00			

Figure 7. Panel Description File
[PAN] Partial Listing

=====

SL7 CONTAINERSHIP ADDED MASS/DAMPING COEFFICIENTS PROGRAM HYDREX

=====

Station 12

Dist. from F.P.	-396.23	Area	3031.365
DRAFT (fwd)	32.80	Roll Ctr abv WL	0.088
DRAFT (aft)	32.80		

F eq.	-----HEAVE-----		-----SWAY-----		-----ROLL-----		--SWAY-ROLL--	
	A22	B22	A33	B33	A44	B44	A34	B34
0.00	99.0000	0.0000	2.2896	0.0000	949.04	0.00	34.4	0.0
0.10	11.6174	0.8778	1.9201	0.0002	547.86	0.03	20.1	0.0
0.20	7.2671	1.4760	2.0412	0.0072	561.35	1.07	21.3	0.1
0.30	5.1586	1.8017	2.2434	0.0544	581.59	7.57	23.3	0.6
0.40	3.9867	1.9286	2.4304	0.2150	593.28	27.55	24.8	2.4
0.50	3.3206	1.9089	2.3837	0.5407	571.59	62.45	23.5	5.8
0.60	2.9645	1.7834	1.9918	0.9268	515.09	94.63	18.7	9.4
0.70	2.8127	1.5879	1.4567	1.1956	456.55	106.05	13.0	11.3
0.80	2.8677	1.1182	0.6952	1.3047	401.19	83.61	6.3	10.4
1.00	3.3945	0.4073	0.2841	0.9812	408.22	29.37	4.9	5.4
1.20	3.6990	0.1707	0.2848	0.7194	423.20	11.92	6.0	2.9
2.00	7.4603	0.0000	0.7945	0.0000	748.80	0.00	15.4	0.0

-----STATION OFFSETS-----

Height above Baseline	Half BREADth	Submerged Offsets	
		-Y-	-Z-
0.000	0.000	-32.800	0.000
0.591	26.303	-32.209	26.303
0.820	30.060	-31.980	30.060
1.640	33.962	-31.160	33.962
3.281	38.298	-29.519	38.298
4.921	40.610	-27.879	40.610
6.562	42.778	-26.238	42.778
8.202	44.310	-24.598	44.310
9.842	45.524	-22.958	45.524
11.483	46.478	-21.317	46.478
13.123	47.345	-19.677	47.345
16.404	48.703	-16.396	48.703
19.685	49.715	-13.115	49.715
26.247	50.929	-6.553	50.929
29.528	51.305	-3.272	51.305
		WATERLINE	51.593
32.808	51.594		
39.370	52.027		
52.493	52.605		
64.304	52.750		

Figure 8. Output of HYDREX2
Partial Listing

	NX	NY	NZ	XP	YP	ZP	AREA
1	0.0000	0.0000	1.0000	390.0000	0.5867	30.0000	79.2000
2	0.0176	0.5404	0.8412	405.0000	3.2150	28.5000	499.6292
3	0.0264	0.7592	0.6504	405.0000	6.8350	25.5000	355.6513
4	0.0301	0.9964	-0.0797	405.0000	7.8800	21.0000	541.9710
5	0.0394	0.9341	-0.3549	405.0000	6.5000	15.0000	578.1236
6	0.0525	0.9600	-0.2752	405.0000	4.5000	9.0000	562.5251
7	0.0698	0.9974	-0.0166	405.0000	3.6200	4.8000	216.5585
8	0.0000	0.0000	1.0000	325.0000	1.3000	30.0000	182.0000
9	0.0120	0.4445	0.8957	325.0000	5.6225	28.5000	472.4277
10	0.0283	0.8527	0.5216	325.0000	9.5625	25.5000	246.2683
11	0.0365	0.9992	0.0133	336.6667	10.0800	22.0000	210.1590
12	0.0694	0.9962	0.0531	325.0000	10.7600	16.5000	632.4223
13	0.1151	0.9722	0.2037	325.0000	11.8800	7.8000	604.7363
14	0.0000	0.0000	1.0000	257.5000	2.1200	30.0000	275.6000
15	0.0158	0.3772	0.9260	257.5000	7.9225	28.5000	516.9807
16	0.0510	0.7405	0.6701	257.5000	12.9625	25.5000	263.3413
17		0.9135	0.3928	257.5000	16.9000	18.0000	853.8872
18		0.9205	0.3594	257.5000	21.8225	6.0000	847.3912
19	0.	0.0138	0.9999	180.0000	4.5400	29.9375	817.2777
20	0.0000	0.0000	0.9424	195.0000	10.5600	28.9167	404.9271
21	0.0125		0.9458	165.0000	18.8533	26.9167	799.3557
22	0.0532		0.7425	195.0000	20.1067	25.0000	203.6294
23	0.0786	-0.6156	0.547	180.0000	27.4450	18.0000	1312.5692
24	0.1172	-0.9156		180.0000	34.0325	6.0000	1.34.2212
25	0.1012	-0.9948		67.5000	9.8800	29.8125	2668.0806
26	0.0000	-0.0189	0.	0000	27.6267	28.7300	1157.2611
27	0.0000	-0.1640	0.986	70	28.8000	26.9167	1200.2803
28	-0.0131	-0.6156	0.7880		40.1600	25.0000	329.7435
29	0.0138	-0.2842	0.9587	-60.0000	11.9650	18.0000	1871.9629
30	0.0481	-0.9936	0.1027	-60.0000	6.0000	6.0000	1657.5626
31	0.0062	-1.0000	0.0000	-60.0000	29.7500	29.7500	2376.4260
32	0.0000	-0.0189	0.9998	-120.0000	28.2500	0000	1457.4741
33	-0.0257	-0.1065	0.9940	-150.0000	-16.	0000	219.3015
34	-0.0281	-0.1878	0.9818	-150.0000	-37.700	00	475.0337
35	-0.0249	-0.2841	0.9585	-120.0000	-45.5600		1116.7516
36	-0.0814	-0.9296	0.3594	-150.0000	-47.8533		70.0344
37	-0.0474	-0.9514	0.3044	-150.0000	-51.0933	8.0	0130
38	0.0000	-0.1361	0.9907	-210.0000	-14.5600	28.0000	
39	-0.1575	-0.4456	0.8813	-240.0000	-26.4267	22.0000	
40	-0.1307	-0.9247	0.3576	-210.0000	-42.5333	16.0000	585.
41	-0.1182	-0.8364	0.5353	-240.0000	-42.4000	8.0000	645.650
42	0.0000	-0.7894	0.6139	-330.0000	-4.6667	24.0000	1026.1578
43	-0.1077	-0.4486	0.8872	-300.0000	-16.5333	18.0000	1805.6287
44	-0.1705	-0.7102	0.6830	-330.0000	-25.0467	8.0000	760.3083
45	0.1558	0.8949	-0.4183	-352.5000	-20.3800	13.8333	1936.0449
46	0.0130	-0.7893	0.6139	-382.5000	-5.1667	23.8333	769.6833
47	-0.1703	-0.9843	0.0462	-405.0000	-6.0733	15.0000	891.4889
48	-0.2034	-0.7057	0.6787	-382.5000	-14.0867	5.1667	573.8820
49	0.3141	0.9442	-0.0988	-405.0000	-9.4200	11.0000	929.3218
50	-1.0000	0.0000	0.0000	-427.5000	-3.2100	11.0000	49.7100
51	-0.1932	-0.6290	0.7530	-435.0000	-3.2100	1.1667	62.5984

Figure 9. Output of HYDREX3.
Partial Listing

-----WAVE COMPONENTS-----

WAVE	AMPLITUDE	FREQUENCY	DIRECTION	PHASE
1	1.00	0.34	180.00	0.00

-----SECTIONAL WEIGHT PROPERTIES-----

SECTION	WEIGHT	Kxx	Centroid
1	94.550	37.31	9.51
2	294.550	37.31	9.51
3	296.203	37.31	9.51
4	496.203	37.31	9.51
5	1143.822	37.31	9.51
6	1134.935	37.31	9.51
7	1681.707	37.31	9.51
8	2040.042	37.31	9.51
9	2508.421	37.31	9.51
10	2578.811	37.31	9.51
11	3053.338	37.31	9.51
12	3591.325	37.31	9.51
13	3530.823	37.31	9.51
14	3175.776	37.31	9.51
15	3725.574	37.31	9.51
16	3530.628	37.31	9.51
17	2595.390	37.31	9.51
18	3151.427	37.31	9.51
19	2534.063	37.31	9.51
20	1915.669	37.31	9.51
21	1761.739	37.31	9.51
22	715.479	37.31	9.51
23	715.479	37.31	9.51
24	747.026	37.31	9.51
25	747.026	37.31	9.51

Figure 10. Part of Output of SSX
Partial Listing

-----Inertial Characteristics-----

WEIGHT 47760.00 L. TONS
 XCG -478.050 ft
 YCG 42.300 ft
 ZCG 0.000 ft

-----GYRADII-----
 Kxx 47.000 ft
 Kyy 219.000 ft
 Kzz 219.000 ft
 Kxy 0.000 ft
 Kxz 0.000 ft
 Kyz 0.000 ft

-----DAMPING COEFFICIENTS-----
(user specified)

MOTION	LINEAR	QUADRATIC
SURGE	0.0000E+00	0.0000E+00
HEAVE	0.0000E+00	0.0000E+00
SWAY	0.0000E+00	0.0000E+00
ROLL	0.0000E+00	0.0000E+00
YAW	0.0000E+00	0.0000E+00
PITCH	0.0000E+00	0.0000E+00

-----OPS DATA-----

SPEED 42.23

-----Initial Conditions-----

-----POSITION-----
 X(CG) 0.000 ft
 Y(CG) 9.412 ft
 Z(CG) 0.000 ft
 ROLL 0.000 deg
 YAW 0.000 deg
 PITCH 0.000 deg

-----VELOCITY-----
 SPEED 42.230 ft/sec
 HEAVE 0.000 ft/sec
 SWAY 0.000 ft/sec
 ROLL 0.000 deg/sec
 YAW 0.000 deg/sec
 PITCH 0.000 deg/sec

-----Run Parameters-----

SIMULATION PARAMETERS
 TIME(START) 30.00
 TIME(END) 100.00
 OUTPUT DT 0.50
 INTEG. DT 0.50

-----JOB OPTIONS-----

-----MISCELLANEOUS VALUES-----

RHO 0.000889
 G 32.169998
 JOBCO 1
 JOBFO 1 1 0

Figure 10. Part of Output of SSX
 Partial Listing

TIME	WAVE	POSITION OF CENTER OF GRAVITY		
		X	Y	Z
0. 0000	1. 0000	0. 0000	0. 0000	0. 0000
0. 5000	0. 9702	21. 1150	0. 0002	0. 0000
1. 0000	0. 8825	42. 2301	0. 0016	0. 0000
1. 5000	0. 7422	63. 3456	0. 0048	0. 0000
2. 0000	0. 5576	84. 4618	0. 0101	0. 0000
2. 5000	0. 3397	105. 5792	0. 0169	0. 0000
3. 0000	0. 1016	126. 6983	0. 0238	0. 0000
3. 5000	-0. 1426	147. 8197	0. 0285	0. 0000
4. 0000	-0. 3783	168. 9435	0. 0284	0. 0000
4. 5000	-0. 5914	190. 0700	0. 0202	0. 0000
5. 0000	-0. 7693	211. 1992	0. 0009	0. 0000
5. 5000	-0. 9012	232. 3307	-0. 0322	0. 0000
6. 0000	-0. 9794	253. 4639	-0. 0808	0. 0000
6. 5000	-0. 9991	274. 5980	-0. 1451	0. 0000
7. 0000	-0. 9592	295. 7319	-0. 2235	0. 0000
7. 5000	-0. 8621	316. 8644	-0. 3120	0. 0000
8. 0000	-0. 7135	337. 9943	-0. 4046	0. 0000
8. 5000	-0. 5224	359. 1200	-0. 4931	0. 0000
9. 0000	-0. 3001	380. 2405	-0. 5676	0. 0000
88. 0000	0. 6254	3715. 1992	0. 9302	0. 0000
88. 5000	0. 7957	3736. 2339	1. 0866	0. 0000
89. 0000	0. 9187	3757. 2551	1. 1782	0. 0000
89. 5000	0. 9870	3778. 2671	1. 1995	0. 0000
90. 0000	0. 9966	3799. 2751	1. 1492	0. 0000
90. 5000	0. 9469	3820. 2847	1. 0303	0. 0000
91. 0000	0. 8409	3841. 3008	0. 8500	0. 0000
91. 5000	0. 6849	3862. 3284	0. 6189	0. 0000
92. 0000	0. 4881	3883. 3718	0. 3509	0. 0000
92. 5000	0. 2621	3904. 4341	0. 0621	0. 0000
93. 0000	0. 0205	3925. 5173	-0. 2304	0. 0000
93. 5000	-0. 2224	3946. 6223	-0. 5090	0. 0000
94. 0000	-0. 4521	3967. 7488	-0. 7573	0. 0000
94. 5000	-0. 6549	3988. 8945	-0. 9603	0. 0000
95. 0000	-0. 8187	4010. 0569	-1. 1060	0. 0000
95. 5000	-0. 9335	4031. 2317	-1. 1858	0. 0000
96. 0000	-0. 9926	4052. 4143	-1. 1949	0. 0000
96. 5000	-0. 9924	4073. 5996	-1. 1329	0. 0000
97. 0000	-0. 9328	4094. 7822	-1. 0034	0. 0000
97. 5000	-0. 8176	4115. 9570	-0. 8141	0. 0000
98. 0000	-0. 6535	4137. 1196	-0. 5763	0. 0000
98. 5000	-0. 4504	4158. 2656	-0. 3041	0. 0000
99. 0000	-0. 2205	4179. 3926	-0. 0138	0. 0000
99. 5000	0. 0225	4200. 4980	0. 2774	0. 0000
100. 0000	0. 2640	4221. 5815	0. 5521	0. 0000
RMS	0. 7112	304. 5160	0. 8489	0. 0000
MEAN	-0. 0134	3704. 3413	-0. 0220	0. 0000
MAX	1. 0000	4221. 5815	1. 2009	0. 0000
MIN	-0. 9991	0. 0000	-1. 1991	0. 0000

- Figure 10. Left side of 132 character width printout of SSX (partial)

ROTATIONS IN DEGREES		PITCH	MIDS. VERT	SPEED
ROLL	YAW			
0. 0000	0. 0000	0. 0000	0. 00000E+00	42. 2300
0. 0000	0. 0000	0. 0000	-0. 57850E+06	42. 2301
0. 0000	0. 0000	-0. 0002	-0. 60541E+06	42. 2305
0. 0000	0. 0000	-0. 0008	-0. 63125E+06	42. 2315
0. 0000	0. 0000	-0. 0021	-0. 65431E+06	42. 2335
0. 0000	0. 0000	-0. 0047	-0. 67303E+06	42. 2364
0. 0000	0. 0000	-0. 0088	-0. 68603E+06	42. 2403
0. 0000	0. 0000	-0. 0148	-0. 69229E+06	42. 2451
0. 0000	0. 0000	-0. 0227	-0. 69116E+06	42. 2503
0. 0000	0. 0000	-0. 0323	-0. 68247E+06	42. 2557
0. 0000	0. 0000	-0. 0433	-0. 66658E+06	42. 2608
0. 0000	0. 0000	-0. 0548	-0. 64439E+06	42. 2649
0. 0000	0. 0000	-0. 0656	-0. 61136E+06	42. 2676
0. 0000	0. 0000	-0. 0745	-0. 58740E+06	42. 2684
0. 0000	0. 0000	-0. 0800	-0. 55632E+06	42. 2669
0. 0000	0. 0000	-0. 0806	-0. 52814E+06	42. 2626
0. 0000	0. 0000	-0. 0751	-0. 50389E+06	42. 2560
0. 0000	0. 0000	-0. 0626	-0. 48633E+06	42. 2466
0. 0000	0. 0000	-0. 0427	-0. 47728E+06	42. 2366
0. 0000	0. 0000	0. 2165	-0. 62122E+06	42. 0858
0. 0000	0. 0000	0. 1917	-0. 62237E+06	42. 0545
0. 0000	0. 0000	0. 1554	-0. 62240E+06	42. 0315
0. 0000	0. 0000	0. 1099	-0. 62129E+06	42. 0183
0. 0000	0. 0000	0. 0577	-0. 61914E+06	42. 0157
0. 0000	0. 0000	0. 0021	-0. 61605E+06	42. 0238
0. 0000	0. 0000	-0. 0537	-0. 61218E+06	42. 0422
0. 0000	0. 0000	-0. 1062	-0. 60782E+06	42. 0697
0. 0000	0. 0000	-0. 1523	-0. 60310E+06	42. 1047
0. 0000	0. 0000	-0. 1893	-0. 59842E+06	42. 1451
0. 0000	0. 0000	-0. 2149	-0. 59400E+06	42. 1883
0. 0000	0. 0000	-0. 2275	-0. 59013E+06	42. 2318
0. 0000	0. 0000	-0. 2265	-0. 58704E+06	42. 2730
0. 0000	0. 0000	-0. 2118	-0. 58496E+06	42. 3092
0. 0000	0. 0000	-0. 1846	-0. 58401E+06	42. 3385
0. 0000	0. 0000	-0. 1463	-0. 58419E+06	42. 3591
0. 0000	0. 0000	-0. 0993	-0. 58556E+06	42. 3697
0. 0000	0. 0000	-0. 0465	-0. 58798E+06	42. 3697
0. 0000	0. 0000	0. 0091	-0. 59137E+06	42. 3593
0. 0000	0. 0000	0. 0641	-0. 59538E+06	42. 3399
0. 0000	0. 0000	0. 1154	-0. 59986E+06	42. 3098
0. 0000	0. 0000	0. 1598	-0. 60459E+06	42. 2737
0. 0000	0. 0000	0. 1948	-0. 60915E+06	42. 2327
0. 0000	0. 0000	0. 2183	-0. 61340E+06	42. 1891
0. 0000	0. 0000	0. 2289	-0. 61708E+06	42. 1456
0. 0000	0. 0000	0. 1599	0. 13537E+05	0. 1269
0. 0000	0. 0000	-0. 0053	-0. 60289E+06	42. 1984
0. 0000	0. 0000	0. 2289	0. 00000E+00	42. 3768
0. 0000	0. 0000	-0. 2282	-0. 62252E+06	0. 0000

Figure 10. Right side of 132 character
width printout of SSX (partial)

PR SURES

0. 38415968	0. 24316231	0. 23651379	0. 22607508	0. 21061255
0. 19246852	0. 17776074	1. 14601755	1. 16095650	1. 15
1. 05791485	1. 29189086	1. 40567327	2. 06866050	
2. 15990114	2. 33326197	2. 64962888	3. 077	
3. 24160838	2. 96586731	3. 32186317		
4. 04283953	3. 78925920	3. 97277		
4. 74622965	4. 53059387			
5. 02411795	5. 234955			
5. 02339220	-			
5. 83894557				

-----TOTAL PRESSURES-----

-1. 46834481	-0. 83654284	-0. 78719705	-1. 71809840	0. 00665942
0. 23063746	1. 18806934	-0. 45587230	-0. 17283618	0. 3525
17. 64413261	2. 48809695	1. 18732226	0. 37171781	
1. 17200983	1. 83491194	2. 47403312	0. 9994507	
1. 39725995	1. 88052142	2. 80034971		
1. 43834829	1. 74238777	2. 93543975		
2. 78261328	2. 71100593	3. 5		
56. 71600723	3. 11889052			
8. 52794075	7. 5015			

B DY INDUCED PRESSURES

-1. 85250449	-1. 07970667	-1. 02371085	-1. 94417346	-0. 20395313
0. 03816893	1. 01030862	-1. 60188985	-1. 33379269	-0. 83561438
16. 58621788	1. 19620597	-0. 21835098	-1. 69694269	-1. 50451446
-0. 98789138	-0. 49835002	-0. 17559581	-2. 02371120	-1. 95836079
-1. 84434843	-1. 08536589	-0. 52151340	-0. 05880385	-2. 24148512
-2. 60449123	-2. 04687142	-1. 03688288	0. 02363856	1. 00506485
-1. 96361649	-1. 81958807	-0. 79081982	-1. 89128637	2. 57368040
51. 69189072	-2. 11605954	-1. 65408003	-1. 66934085	-1. 67518842
3. 50454855	1. 93148851	-1. 43030024	-0. 60449553	1. 84978557
0. 40260637	-0. 62282950	-0. 58973241	-0. 03671409	2. 83566427
-0. 41253781	0. 83666974	-0. 10891942	0. 55786502	0. 00000000
0. 03906842	-2. 58687186	-1. 62076259	-0. 77843022	7. 79187298
-0. 35989502	-0. 11869927	-0. 31951666	-1. 83989894	-1. 40328050
-0. 73166758	11. 49159718	-0. 16707416	-0. 29368657	-1. 92022955
-1. 52942920	-1. 04738855	-0. 60960990	-0. 22613873	-2. 24740911
-1. 75089848	-1. 78046894	-0. 91861057	-0. 41995618	0. 12429215
-2. 62914538	-2. 34276557	-1. 72142696	-1. 22348630	1. 35021770
30. 93821144	-2. 01162410	-1. 54072320	-0. 79989606	-1. 55071521
10. 87392330	0. 00000000	-2. 08891344	-1. 69489515	-1. 51071918
-1. 30158806	2. 16383004	1. 18314898	-1. 51980424	-0. 68915701
1. 78912711	0. 56204945	-0. 96726221	-0. 71865982	-0. 38488629
0. 34184885	-0. 67282838	-0. 67956263	-0. 36257684	0. 79844165
0. 00000000	-0. 03861484			

- Figure 11. Pressure output of SSX
(partial listing for one time step) -

(THIS PAGE INTENTIONALLY LEFT BLANK)

APPENDIX A

Program Listings

HYDREX2

HYDREX3

SSX

PROGRAM SSX

```

C CHARACTER*25 OFFIL,BIFIL,COFIL,MATFIL
C CHARACTER*30 TITLE
COMMON/HEAD/TITLE
COMMON/IOFILE/ OFFIL,BIFIL,COFIL,MATFIL
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF,MAT
INTEGER OUTPUT,BIF,OFF,COF
COMMON /COEFF4 / COEFF4(6,12,8,25),AREAN(25,6)
COMMON/OPTION/JOBCO,JOBFO(10),JOBPO(10)
COMMON/JOBP/JOBP
COMMON /JOBB/ IJOB,IFORCE,IAXIS,IWANT
COMMON / / NWAVES,WVSUM,
1 WVAMP(20),WVFRE(20),WVDIR(20),WVPHA(20),
2 WN(20),WNX(20),WNZ(20),
3 CSK(20),CKK(20),CXK(20),
4 CYK(20),CZK(20),XW(20)
COMMON / / MSTA,NPROF,NFWD,NAFT,LPTS(25),
1 XOFF(25),YOFF(25,25),ZOFF(25,25),
2 XPROF(51),YPROF(51)
COMMON /DAMP / DAMPL(6),DAMPQ(6)
COMMON /LHS / Y(13)
COMMON /MASS / RHO,G,GAMMA
COMMON /MASS / DISPL,SMASS,XCG,YCG,ZCG,
1 AMX,AMY,AMZ,RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /RESIST/ SPEED
COMMON /TIME / TIME,RAMP
COMMON /TIME / TO,TSTART,TSTOP,TOUTPT,TSTEP,ERR
COMMON/PREXIN/TPSTART,TPSTOP,TPRAMP,BGX,SMX,BGY,SMY,TSCALE
COMMON/DRFT1/ DRAFT1(6)
COMMON /SIGMA / NK,SIGMA(24),SIGMAO,ERRO,OM(12)
COMMON /STATS / NRHS(4),DELTA,HSUM,HMIN,HMAX,TT0,TT1
DATA TO /0.0/
DATA NEGS /12/
LOGICAL WL,ADJUST,INTERACT
DATA RHO /0.00088861607142/
DATA ERRO/1.0E-37/
DATA INPUT/5/,OUTPUT/6/,BIF/1/,OFF/2/,COF/9/
DATA MAT/3/

```

*** 1.0 Get DATA file names and assign/open files

```

C TYPE 902
C ACCEPT 901,BIFIL
C TYPE 903
C ACCEPT 901,OFFIL
C TYPE 904
C ACCEPT 901,COFIL
C TYPE 905
C ACCEPT 901,MATFIL

```

```

C OPEN(UNIT=BIF,STATUS='OLD',FILE=BIFIL)
C OPEN(UNIT=OFF,STATUS='OLD',FILE=OFFIL)
C OPEN(UNIT=COF,STATUS='OLD',FORM='UNFORMATTED',FILE=COFIL)
C IF(MATFIL.NE.'NONE') OPEN(UNIT=MAT,STATUS='OLD',FORM='UNFOR
1 MATTED',FILE=MATFIL)

```

*** 2.0 Read in data from [BIF],[OFF] and [COF] files

```

C CALL READIN

```

*** 3.0 Perform preparatory computations

```

C CALL PREPARE

```

```

C CALL COFFEE
C CALL FOLIO1
C IF(JOBPO(1).EQ.1) CALL OUTCOF

```

```

C *** 5.0 Simulation
C
C      WRITE (OUTPUT,130)
C      TSTEP=-ABS(TSTEP)
C      TIME=TO
C      TTO=TO
C      TT1=TO
110 CALL FOLIO2                                !Show time zero condition
C      TNEXT=TIME+TOUTPT
C *** Fourth-order Runge-Kutta integration
C      CALL RKF (TIME,Y,TNEXT,ERR,NEGS,TSTEP)
C *** Get hull girder loads
C      CALL HULL
C *** Get panel pressures
C      TP=TIME-TPSTART
C      IF (TP. GE. 0. .AND. TP. LE. TPSTART) CALL PRESSURE(TP)
C
C      TIME=TNEXT
C      IF (TIME. LT. TSTOP) GO TO 110
120 CALL FOLIO2
C      CALL FINI
C      STOP
C
C 130 FORMAT (1H1,27X,29HPOSITION OF CENTER OF GRAVITY,
C      $      9X,20HROTATIONS IN DEGREES,27X,19HHORIZONTAL VELOCITY/
C      $      4X,4HTIME,8X,4HWAVE,8X,1HX,11X,1HY,11X,1HZ,13X,
C      $      4HROLL,9X,3HYAW,7X,5HPITCH,6X,6HRUDDER,
C      $      7X,5HSPEED,5X,9HSWAY RATE/)
C
C 901 FORMAT(A)
C 902 FORMAT(' Name of Basic INPUT File [BIF] ? > ')
C 903 FORMAT(' Name of Offset File [OFF] ? > ')
C 904 FORMAT(' Name of Coefficient File [COF] ? > ')
C 905 FORMAT(' Name of 3-D Matrix File [MAT] ? > ')
C
C      END

```

SUBROUTINE READIN

```

C
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF, MAT
INTEGER OUTPUT, BIF, OFF, COF
INTEGER ECHO
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON/DRFT1/DRAFT1(6)
COMMON/IOFILE/ OFFIL, BIFIL, COFIL, MATFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/COEFF4/COEFF4(6,12,8,25), AREAN(25,6)
COMMON/OPTION/JOBCO, JOBFO(10), JOBPO(10)
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON /DAMP / DAMPL(6), DAMPG(6)
COMMON /LHS / Y(13)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /RESIST/ SPEED
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOM(26),
* STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
REAL XAFT(25), YAFT(25), XFWD(25), YFWD(25)
EQUIVALENCE (XFWD(1), XPROF(1)), (YFWD(1), YPROF(1)),
$ (XAFT(1), XPROF(26)), (YAFT(1), YPROF(26))
COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREAP(120),
* ST(120), ACN(120), ACNW(120), AN(120,3), E(120), P(120,6),
* PRFS(120), STOLD(120), PX(120,6)
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
COMMON/SOURCE/ EE(120,120)
REAL POSIT(6), VELOC(6)
COMMON/DISPLAY/TARE(6)
EQUIVALENCE (POSIT(1), Y(1)), (VELOC(1), Y(7))
DATA MAXSTA/25/
DATA MAXPTS/25/
DATA MAXFWD/25/
DATA MAXAFT/25/
DATA MAXWVS/20/
DATA TPSTOP/0./
DATA ERRMIN/1.0E-10/
CHARACTER*81 CARDID
DATA DEGREE/0.01745 32925 19943/
DATA G /32.17/
DATA NWL/1/
DATA ECHO/4/
C *** OPEN DATA FILE ECHO PRINTOUT FILE
OPEN(UNIT=ECHO, TYPE='NEW', NAME='ECHO.DAT')
C
WRITE(ECHO,197)
C *** TITLE
READ (BIF,199) TITLE
WRITE(ECHO,196) TITLE
C *** DRAFT (fwd), DRAFT (aft), long. loc's of DRAFT marks
READ (BIF,200) TF, TA, XFPERP, XAPERP
WRITE(ECHO,200) TF, TA, XFPERP, XAPERP
C *** Center of Gravity (XCG aft of FP, YCG above BL)
READ (BIF,200) XCG, YCG, ZCG
WRITE(ECHO,200) XCG, YCG, ZCG
C *** Six DRAFTs at which hydro. coeffs are computed
READ(BIF,200) (DRAFT1(I), I=1,6)
WRITE(ECHO,200) (DRAFT1(I), I=1,6)
C *** Minimum segment lengths for Frank Close Fit
READ (BIF,201) YMAX, ZMAX, WMAX, NWL
WRITE(ECHO,201) YMAX, ZMAX, WMAX, NWL
ADJUST=ZMAX. GT. 0. 0. AND. YMAX. GT. 0. 0

```



```

C      SUBROUTINE AFSR
      INITIALIZES FREE SURFACE
      COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
*      ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
*      STOLD(120), PX(120,6)
      COMMON/FS/AKZ(100,100), SS(100,100), CC(100,100),
*      DKX(100), DKY(100), AKX(100), AKY(100)
      COMMON/FS1/A(100,100), B(100,100), AS(100,100), BS(100,100)
      COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
      COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
      COMPLEX A,B,AS,BS,EYE
      DKTT=1.0/(GEE*TSCALE*TSCALE)
      NBX=0.5/(BGX*DKTT)
      NBY=0.5/(BGY*DKTT)
      AMX=1.0/SMX
      AMY=1.0/SMY
      N=0
      M=0
      AOLD=0.0
1      IF(N.GE.NBX) GO TO 2
      N=N+1
      AKX(N)=N*N*DKTT
      AOLD=AKX(N)
      IF(AOLD.GE.AMX) NBX=N
      GO TO 1
2      N=N+1
      AKX(N)=AOLD+1.0/BGX
      AOLD=AKX(N)
      IF(AOLD.LE.AMX) GO TO 2
      NKX=N
      AKX(NKX+1)=AOLD+1.0/BGX
      AOLD=0.00
11     IF(M.GE.NBY) GO TO 22
      M=M+1
      AKY(M)=M*M*DKTT
      AOLD=AKY(M)
      IF(AOLD.GE.AMY) NBY=M
      GO TO 11
22     M=M+1
      AKY(M)=AOLD+1.0/BGY
      AOLD=AKY(M)
      IF(AOLD.LE.AMY) GO TO 22
      NKY=M
      AKY(M+1)=AKY(M)+1.0/BGY
      AFF=0.000
      DO 17 N=1,NKX
      AF=(AKX(N+1)+AKX(N))*0.50
      DKX(N)=AF-AFF
      AFF=AF
      BFF=0.00
      DO 18 N=1,NKY
      BF=(AKY(N+1)+AKY(N))*0.50
      DKY(N)=BF-BFF
      BFF=BF
18     DO 100 N=1,NKX
      DO 100 M=1,NKY
      A(N,M)=(0.0,0.0)
      B(N,M)=(0.0,0.0)
      AS(N,M)=(0.0,0.0)
      BS(N,M)=(0.0,0.0)
      AKZ(N,M)=SQRT(AKX(N)**2+AKY(M)**2)
      SIG=SQRT(GEE*AKZ(N,M))
      SS(N,M)=SIN(SIG*DT)
      CC(N,M)=COS(SIG*DT)
100    CONTINUE
      RETURN
      END

```

SUBROUTINE PRESSURE(TP)

```

COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF, MAT
INTEGER OUTPUT, BIF, OFF, COF
INTEGER ECHO
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON/DRFT1/DRAFT1(6)
COMMON/IOFILE/ OFFIL, BIFIL, COFIL, MATFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2 XPROF(51), YPROF(51)
COMMON /DAMP / DAMPL(6), DAMPG(6)
COMMON /LHS / Y(13)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3, 3)
COMMON /RESIST/ SPEED
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMDM(26),
* STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
REAL XAFT(25), YAFT(25), XFWD(25), YFWD(25)
EQUIVALENCE (XFWD(1), XPROF(1)), (YFWD(1), YPROF(1)),
$ (XAFT(1), XPROF(26)), (YAFT(1), YPROF(26))
COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120),
* ST(120), ACN(120), ACNW(120), AN(120, 3), E(120), P(120, 6),
* PRFS(120), STOLD(120), PX(120, 6)
COMMON/FS/AKZ(100, 100), SS(100, 100), CC(100, 100),
* DKX(100), DKY(100), AKX(100), AKY(100)
COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150),
* WRFR(150), KK(150, 4)
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
REAL POSIT(6), VELOC(6)
COMMON/SOURCE/EE(120, 120), BPRES(120), PT(6)
COMMON/DISPLAY/TARE(6)

```

```

C-----
C
C TIM=TP
C UFWD=YY(7)
C *** Get free surface induce component of normal acceleration
C at panel centers ACNW(J) and pressure force array PF.
C
C CALL ACPTR
C
C *** Get exciting normal acceleration at panel centers
C
C CALL XNA(AXMT, AYMT, AZMT, ARLMT, APMT, AYWMT)
C
C *** Compute panel source strengths
C
C CALL ZBLACN(AXMT, AYMT, AZMT, ARLMT, APMT, AYWMT)
C
C *** Compute body induced forces and pressures
C
C CALL POTB
C
C *** Advance free surface for single time step
C
C CALL CFSR
C
C *** Forces and moments
C
C CALL PRFR(PT)
C
C RETURN
C END

```

```

C      SUBROUTINE ACPTR
C      Computes wave induced accelerations and pressures at
      panel centers
      COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
*      ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
*      STOLD(120),PX(120,6)
      COMMON/FS/AKZ(100,100),SS(100,100),CC(100,100),
*      DKX(100),DKY(100),AKX(100),AKY(100)
      COMMON/FS1/A(100,100),B(100,100),AS(100,100),BS(100,100)
      COMMON/A/NPAN,NPT,GEE,RHQP,NKX,NKY,EYE,DT,TIM,UFW
      COMPLEX EYE,SC,BX,CX,BY,CY,BYCON,SCON,SK,SKON,
*      B1,B2,C1,C2
      COMPLEX A,B,AS,BS
      DIMENSION BX(100),CX(100),PF(6),DX(100)
      DO 1500 J=1,NPAN
      AX=AN(J,1)
      AY=AN(J,2)
      AZ=AN(J,3)
      X=XPAN(J)
      Y=YPAN(J)
      Z=ZPAN(J)
      ACT=0.00
      PRT=0.00
      DVDZ=0.00
      DO 16 N=1,NKX
      CCXX=AKX(N)*X
      S=SIN(CCXX)
      C=COS(CCXX)
      BX(N)=CMPLX(C,S)*DKX(N)
      DX(N)=-AKX(N)*AKX(N)*AX
16      CX(N)=AKX(N)*AX*EYE
      DO 163 M=1,NKY
      CCYY=AKY(M)*Y
      S=SIN(CCYY)
      C=COS(CCYY)
      BY=CMPLX(C,S)*DKY(M)
      BYCON=CONJG(BY)
      CY=AKY(M)*AY*EYE
      DO 163 N=1,NKX
      ARGZ=AKZ(N,M)*Z
      DEP=EXP(-ARGZ)
      B1=DEP*BY*BX(N)
      B2=DEP*BYCON*BX(N)
      CZ=AKZ(N,M)*AZ
      SC=B1*A(N,M)
      SCON=B2*AS(N,M)
      SK=B1*B(N,M)
      SKON=B2*BS(N,M)
      C1=CX(N)+CY-CZ
      C2=CX(N)-CY-CZ
      ACT=ACT-C1*SC-C2*SCON
      DVZ=DVZ+EYE*AKX(N)*(C1*SK+C2*SKON)/SQRT(AKZ(N,M))
      PRT=PRT+SC+SCON
163      CONTINUE
C      NORMAL ACCELERATION INDUCED BY FREE SURFACE
      DVDZ=DVZ*UFW*SQRT(GEE)
      ACNW(J)=ACT*GEE+DVDZ
C      PRESSURE INDUCED BY FREE SURFACE
      PRFS(J)=PRT*GEE*RHQP
1500      CONTINUE
      60      FORMAT(' FREE SURFACE INDUCE PRESSURES')
1070      FORMAT(1X,5F16.8)
      TYPE 60
      TYPE 1070,(PRFS(J),J=1,NPAN)
      RETURN
      END

```

```

SUBROUTINE CFSR
C *** Advance free surface wave spectra in time
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
* ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/FS/AKZ(100,100),SS(100,100),CC(100,100),
* DKX(100),DKY(100),AKX(100),AKY(100)
COMMON/FS1/A(100,100),B(100,100),AS(100,100),BS(100,100)
COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
DIMENSION CX(100)
COMPLEX EYE,AT,ATS,CX,CY,CXY1,CXYS,A,B,AS,BS,DFWD
DO 100 N=1,NKX
CXX=AKX(N)*UFWD*DT
S=SIN(CXX)
C=COS(CXX)
DFWD=CMPLX(C,-S)
DO 100 M=1,NKY
CT=CC(N,M)
STT=SS(N,M)
AT=A(N,M)*CT+B(N,M)*STT
ATS=AS(N,M)*CT+BS(N,M)*STT
B(N,M)=B(N,M)*CT-A(N,M)*STT
BS(N,M)=BS(N,M)*CT-AS(N,M)*STT
A(N,M)=AT
AS(N,M)=ATS
C MOVE FREE SURFACE RELATIVE TO BODY WITH FWD SPEED
A(N,M)=A(N,M)*DFWD
B(N,M)=B(N,M)*DFWD
AS(N,M)=AS(N,M)*DFWD
BS(N,M)=BS(N,M)*DFWD
100 CONTINUE
6 CONTINUE
C *** Add effects of source panels acting over one time step
DO 1500 J=1,NPAN
C ST IS TIME RATE OF CHANGE OF SOURCE STRENGTH
C STOLD IS SOURCE STRENGTH AT START OF TIME STEP
C STAR IS AVERAGE VALUE OF STRENGTH OVER THE TIME STEP
STAR=(ST(J)*0.50*DT+STOLD(J))*DT
STAR2=STOLD(J)*DT
STAR=STAR*AREA(J)*0.6366197724
STAR2=STAR2*AREA(J)*0.31831
X=XPAN(J)
IF(JTM.GT.0) X=X-UFWD*DT*.5
Y=YPAN(J)
Z=ZPAN(J)
DO 93 N=1,NKX
CXX=AKX(N)*X
S=SIN(CXX)
C=COS(CXX)
93 CX(N)=CMPLX(C,-S)
DO 94 M=1,NKY
CYY=AKY(M)*Y
S=SIN(CYY)
C=COS(CYY)
CY=CMPLX(C,-S)
DO 94 N=1,NKX
ARGZ=AKZ(N,M)*Z
DEP=EXP(-ARGZ)
CXY1=CX(N)*CY*DEP
CXYS=CX(N)*DEP*CONJG(CY)
A(N,M)=A(N,M)+STAR*CXY1
AS(N,M)=AS(N,M)+STAR*CXYS
C B(N,M) AND BS(N,M) INCREMENTED NEGLECTING CHANGES IN
C SOURCE STRENGTHS
C OVER TIME INTERVAL ARE SECOND ORDER IN DT
B(N,M)=B(N,M)-STAR2*CXY1*SS(N,M)
BS(N,M)=BS(N,M)-STAR2*CXYS*SS(N,M)
94 CONTINUE
1500 CONTINUE
RETURN
END

```

```

SUBROUTINE POTB
C *** Pressures induced by time rate of change of source
C strength of panel J in space fixed coordinates
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
* ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
* STOLD(120), PX(120,6)
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
COMMON/SOURCE/EE(120,120), BPRES(120)
COMPLEX EYE
DIMENSION PP(6)
PP(1)=0.00
PP(2)=0.00
PP(3)=0.00
PP(4)=0.00
PP(5)=0.00
PP(6)=0.00
DO 1500 J=1, NPAN
C ST(J) IS TIME RATE OF CHANGE IN HULL FIXED SYSTEM OF SOURCE STRENGTH
C OF PANEL J
C STAV IS AVERAGE SOURCE STRENGTH OVER TIME STEP AT CENTER OF PANEL J
STAV=STOLD(J)+0.5*DT*ST(J)
C TIME DERIVATIVE IN SPACE FIXED SYSTEM
DO 1200 K=1,6
PP(K)=PP(K)+(ST(J)*P(J,K)-STAV*UFWD*PX(J,K))*RHOP
1200 CONTINUE
1500 CONTINUE
DO 1800 J=1, NPAN
BPRES(J)=(ST(J)*P(J,3)-STAV*UFWD*PX(J,3))*RHOP
DENOM=AN(J,3)*AREA(J)
IF(DENOM.EQ.0.) THEN
BPRES(J)=0.
ELSE
BPRES(J)=BPRES(J)/DENOM
ENDIF
1800 CONTINUE
TYPE *, ' BODY INDUCED PRESSURES '
TYPE 1070, (BPRES(J), J=1, NPAN)
1070 FORMAT(1X, 5F16.8)
TYPE *
TYPE 1870
1870 FORMAT(' BODY INDUCED FORCES=' )
TYPE 2020, PP(1), PP(2), PP(3), PP(4), PP(5), PP(6)
2020 FORMAT(3X, 3F20.6)
RETURN
END

```

```

C
C *** SUBROUTINE PRFR(PT)
      Computes forces and moments
      COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
      * ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
      * STOLD(120),PX(120,6)
      COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
      DIMENSION PF(6)
      COMMON/SOURCE/EE(120,120),BPRES(120)
      COMMON/MASS/RHO,G,GAMMA,DISPL,SMASS,XCG,YCG,ZCG
      COMMON / / MSTA,NPROF,NFWD,NAFT,LPTS(25),
      1 XOFF(25),YOFF(25,25),ZOFF(25,25),
      2 XPROF(51),YPROF(51)

      COMPLEX EYE
      COMMON/DISPLAY/TARE(6)
      X1=0.0
      X2=0.0
      X3=0.0
      X4=0.0
      X5=0.0
      X6=0.0
      XCGAM=XCG-(.5*(XOFF(1)-XOFF(MSTA)))
      DO 725 J=1,NPAN
      TPRES=BPRES(J)+PRFS(J)
      PRS=TPRES(J)*AREA(J)
      FRX=-AN(J,1)*PRS
      FRY=-AN(J,2)*PRS
      FRZ=-AN(J,3)*PRS
      XF=XPAN(J)+XCGAM
      YF=YPAN(J)
      ZF=ZPAN(J)+TARE(2)
      X1=X1+FRX
      X2=X2+FRY
      X3=X3+FRZ
      X4=X4+YF*FRZ-ZF*FRY
      X5=X5+ZF*FRX-XF*FRZ
      X6=X6+XF*FRY-YF*FRX
725  CONTINUE
      TYPE 80
80  FORMAT(' PRESSURE INDUCED FORCES---')
      TYPE 40,X1,X2,X3,X4,X5,X6
      PT(1)=X1
      PT(2)=X2
      PT(3)=X3
      PT(4)=X4
      PT(5)=X5
      PT(6)=X6
40  FORMAT(5X,3F15.7)
      RETURN
      END

```

```

SUBROUTINE ZBLACN(ACBX,ACBY,ACBZ,ACBRL,ACBP,ACBYW)
C *** Computes source strengths satisfying body b.c.
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120)
*, ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFW
COMMON/SOURCE/EE(120,120),BPRES(120)
COMPLEX EYE
DO 1800 J=1,NPAN
X=XPAN(J)
Y=YPAN(J)
Z=ZPAN(J)
ACX=ACBX+ACBP*Z-ACBYW*Y
ACY=ACBY+ACBYW*X-ACBRL*Z
ACZ=ACBZ+ACBRL*Y-ACBP*X
C *** Dot product of body acc. + nrml free-surface included
C normal acceleration
ACN(J)=-ACNW(J)+ACX*AN(J,1)+ACY*AN(J,2)+ACZ*AN(J,3)
C *** Integrate time derivative for total source strenght
C at start of time step
STOLD(J)=STOLD(J)+DT*ST(J)
ST(J)=0.00
1800 CONTINUE
DO 1500 J=1,NPAN
AC=ACN(J)
DO 1400 K=1,NPAN
ST(K)=ST(K)+EE(J,K)*AC
1400 CONTINUE
1500 CONTINUE
RETURN
END

```



```

      *'PROGRAM SSX'//,B1(1H*)//,33(1H-),
      *'[BIF] DATA FILE',32(1H-)/)
198 FORMAT(1H1//,B1(1H*)//, ' INPUT DATA ECHO ',T64,
      *'PROGRAM SSX'//,B1(1H*)//,33(1H-),
      *'[OFF] DATA FILE',32(1H-)/)
196 FORMAT(1X,A)
199 FORMAT(A)
200 FORMAT (6F10.2)
201 FORMAT (3F10.2,I5)
202 FORMAT (8F10.0)
203 FORMAT (I2)
210 FORMAT (F10.2,I5,5X,F10.2)
C
410 FORMAT (A)
412 FORMAT (4F10.3,13X,I2,4X,I1)
414 FORMAT (5X,I5,5X,'INPUT OF SHCP TYPE D OFFSET DATA')
416 FORMAT (F6.3,2F7.0,I6)
417 FORMAT (F7.3,2F10.2,I6)
420 FORMAT (2I5,F10.2)
430 FORMAT (2F10.2)
C
      END

```

```

      SUBROUTINE FINI
C
      COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
      INTEGER OUTPUT,BIF,OFF,COF
      COMMON /STATS / NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
      COMMON /TIME / TIME, RAMP
      COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
      COMMON/SUMMARY/ NT,YYBAR(10),YYRMS(10),YYMAX(10),YYMIN(10)
      IF (TT1.LE.TTO) GO TO 100
      DELTA=TT1-TTO
      NRHS(1)=NRHS(1)+1
      HMIN=AMIN1(DELTA,HMIN)
      HMAX=AMAX1(DELTA,HMAX)
      HSUM=HSUM/FLOAT(NRHS(1))
C *** Print execution statistics
      WRITE (OUTPUT,110) NRHS,DELTA,HMIN,HSUM,HMAX,TSTEP,ERR
C *** Compute response statistics
      DO 200 I=1,10
      YYBAR(I)=YYBAR(I)/FLOAT(NT)
      ARG1=(YYRMS(I)/FLOAT(NT)-YYBAR(I)**2)
      IF(ARG1.LT.0) YYRMS(I)=0.
      IF(ARG1.GE.0) YYRMS(I)=SQRT(ARG1)
C
      YYRMS(I)=SQRT(YYRMS(I)/NT-YYBAR(I)**2)
C 200 CONTINUE
C *** Print response statistics
      WRITE(OUTPUT,201) ' RMS ' ,YYRMS
      WRITE(OUTPUT,201) ' MEAN ' ,YYBAR
      WRITE(OUTPUT,201) ' MAX ' ,YYMAX
      WRITE(OUTPUT,201) ' MIN ' ,YYMIN
C
      RETURN
C
110 FORMAT (76H0*** TIME INCREMENT : FWD NO STE
      $P BACK TOTAL/
      $ 36H *** NUMBER OF COMPUTATIONS OF RHS :,4I10/36H *** FINAL V
      1ALUE OF TIME INCREMENT :,1PG13.4/38H *** MINIMUM VALUE OF TIME INC
      2REMENT :,G13.4/38H *** AVERAGE VALUE OF TIME INCREMENT :,G13.4/38H
      3 *** MAXIMUM VALUE OF TIME INCREMENT :,G13.4/42H *** FLAG VALUE, F
      4I, (PLUS 1.0 EXPECTED) :,G13.4/33H *** FINAL VALUE OF ERROR LIMIT
      5:,G13.4)
C
C
201 FORMAT(A8,4X,4(1X,F11.4),3F12.4,2X,E15.5,2X,F12.4)
C
      END

```

SUBROUTINE PREPARE

```

C-----
COMMON /C / C(3,3)
COMMON /IO/ INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON /COEFF4/ COEFF4(6,12,8,25), AREAN(25,6)
COMMON /FORCE / XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /LHS / Y(13)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /RESIST/ SPEED
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON /V / VX, VY, VZ
COMMON /PREXIN/ TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
REAL XAFT(25), YAFT(25), XFWD(25), YFWD(25)
EQUIVALENCE (XFWD(1), XPROF(1)), (YFWD(1), YPROF(1))
EQUIVALENCE (XAFT(1), XPROF(26)), (YAFT(1), YPROF(26))
EQUIVALENCE (XXFWD, XPROF(51)), (XXAFT, YPROF(51))
COMMON /SXPROP/ SEGMAS(26), SEGMDX(26), STRMAS(26), STRMOM(26),
* STRMOX(26), XBAR(26), YBAR(26),
* SEGWT(26), NWTSTA
DATA MAXSTA/25/
DATA MAXPTS/25/
DATA AMX/O. /, AMY/O. /, AMZ/O. /
DATA RAD /O.01745 32925 19943/
GAMMA=RHO*G
SMASS=DISPL/G
DISPL=DISPL/GAMMA
RAMP=TSTART-TO
AMX=1.0+AMX
AMY=1.0+AMY
AMZ=1.0+AMZ
C-----
C *** From given offsets on port side, assign symmetrical
C offsets on starboard side
DO 10 J=1, MSTA
N=LPTS(J)
NP=N
DO 50 I=1, N
NP=NP+1
NM=N-I+1
YOFF(NP, J)=YOFF(NM, J)
ZOFF(NP, J)=-ZOFF(NM, J)
50 CONTINUE
60 IF (ZOFF(NP, J).NE. ZOFF(1, J)) GO TO 70
IF (YOFF(NP, J).EQ. YOFF(1, J)) GO TO 80
70 NP=NP+1
YOFF(NP, J)=YOFF(1, J)
ZOFF(NP, J)=ZOFF(1, J)
80 IF (NP.GT. MAXPTS) GO TO 90
IF (NP.GT. 1) GO TO 20
90 CONTINUE
STOP 'ERROR'
20 LPTS(J)=NP
10 CONTINUE
C
C *** Recompute offset coordinates relative to the center of mass
DO 130 J=1, MSTA
XOFF(J)=-XOFF(J)-XCG
N=LPTS(J)
DO 120 I=1, N
YOFF(I, J)=YOFF(I, J)-YCG
ZOFF(I, J)=ZOFF(I, J)-ZCG
120 CONTINUE
130 CONTINUE

```

```

C *** Consolidate fore & aft profile coordinates into a single
C pair of arrays
  NPROF=NFW
  IF (NFW.EQ.0) GO TO 150
  X=XOFF(1)
  DO 140 I=1,NFW
    XFWD(I)=XFWD(I)+X
    YFWD(I)=YFWD(I)-YCG
  140 CONTINUE
  IF (NFW.NE.1) GO TO 150
  NPROF=0
  XXFWD=XFWD(1)
  150 IF (NAFT.EQ.0) GO TO 190
  X=XOFF(MSTA)
  XXAFT=X-XAFT(1)
  IF (NAFT.EQ.1) GO TO 190
  J=1
  IF (NPROF.EQ.0) GO TO 160
  IF (XXAFT.NE.XFWD(NPROF)) GO TO 160
  IF (YPROF(NPROF).EQ.(YAFT(1)-YCG)) J=2
  160 DO 170 I=J,NAFT
    NPROF=NPROF+1
    XPROF(NPROF)=X-XAFT(I)
    YPROF(NPROF)=YAFT(I)-YCG
  170 CONTINUE
  IF (XFWD(1).NE.XFWD(NPROF)) GO TO 180
  IF (YFWD(1).EQ.YFWD(NPROF)) GO TO 190
  180 NPROF=NPROF+1
  XFWD(NPROF)=XFWD(1)
  YFWD(NPROF)=YFWD(1)
  190 CONTINUE

C *** This section loads certain strip-associated mass and inertial
C arrays using mass/inertial data from segment-associated arrays
C *** Load strip & segment associated inertial arrays
  DO 106 I=1,NWTSTA
    SEGMAS(I)=SEGWT(I)/G
  106 CONTINUE
  VX=SPEED

C *** Load the inertia matrix
  PMI(1,1)=SMASS*RADII(1)**2
  PMI(2,2)=SMASS*RADII(2)**2
  PMI(3,3)=SMASS*RADII(3)**2
  PMI(2,1)=-ABS(RADII(4))*RADII(4)*SMASS
  PMI(1,2)=PMI(2,1)
  PMI(3,1)=-ABS(RADII(5))*RADII(5)*SMASS
  PMI(1,3)=PMI(3,1)
  PMI(2,3)=-ABS(RADII(6))*RADII(6)*SMASS
  PMI(3,2)=PMI(2,3)

C *** Compute wave no's and max wave amplitude
  WVSUM=0.0
  IF (NWAVES.EQ.0) GO TO 260
  DO 250 K=1,NWAVES
    WVPHA(K)=RAD*WVPHA(K)
    WN(K)=WVFRE(K)**2/G
    ARG=WVDIR(K)*RAD
    WNX(K)=WN(K)*COS(ARG)
    WNZ(K)=WN(K)*SIN(ARG)
    WVSUM=WVSUM+ABS(WVAMP(K))
  250 CONTINUE
  260 CONTINUE

C *** Convert degrees to radians
  DO 270 I=4,6
    Y(I)=Y(I)*RAD
    Y(I+6)=Y(I+6)*RAD
  270 CONTINUE

C *** Convert initial linear velocities from ship coordinates
C fixed coordinates.
  CALL ROTATE (Y)
  VX=Y(7)
  VY=Y(8)
  VZ=Y(9)
  Y(7)=C(1,1)*VX+C(2,1)*VY+C(3,1)*VZ
  Y(8)=C(1,2)*VX+C(2,2)*VY+C(3,2)*VZ
  Y(9)=C(1,3)*VX+C(2,3)*VY+C(3,3)*VZ

```

```
C *** Divide all 2-D hydro. coeffs by RHO
DO 110 L=1,MSTA
DO 110 K=1,6
DO 110 J=1,12
DO 110 I=1,8
CDEFF4(K,J,I,L)=CDEFF4(K,J,I,L)/RHO
110 CONTINUE
```

```
C *** Initialize the free surface for special pressure
C computations
C IF(TPSTOP.GT.5.) CALL AFSR
C
RETURN
END
```

```

SUBROUTINE CUPFEE
CCC
COMMON/MASS/RHO, G, GAMMA
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
* AMX, AMY, AMZ, RADII(6)
COMMON/LHS/Y(13)
C5 WAVE PROPERTIES..
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)

C5
C5
C5 TABLE OF OFFSETS..
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON/RESIST/SPEED
COMMON/SIGMA / NK, SIGMA(24), SIGMA0, ERRO, OM(12)

C
C
COMMON/COEFF4/COEFF4(6,12,8,25), AREAN(25,6)
COMMON/COEFFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),
* THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
* THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
* TRACX(25,21), TCACX(25,21), THVCY(25,21),
* ITP(25), TXP(25), IFP(21), FXP(21)
COMMON/OPTION/JOBCO, JOBFO(10)
COMMON/SXOMEG/OMEGAX(3)
COMMON/DRFT1/ DRAFT1(6)

C
DIMENSION LIX(21), FMUX(21)
DATA DEGREE/0.01745 32925/

C
CCC
CCC (Future revision here... no trim now, but in
CCC next revision, the options should include
CCC specifying trim [Y(6)] in addition to draft
CCC as an initial condition)
CCC

      TAVG=YCG-Y(2)                                !Draft
      TYPE *, 'TAVG=', TAVG
      DO 20 JSTA=1, MSTA                             !Loop over stations

      CALL TXIT(TAVG, IT, TX)                         !Get index & mult.
      ITP(JSTA)=IT
      TXP(JSTA)=TX
      TYPE *, 'IT, TX', IT, TX

CCC
CCC
CCC DO 10 K=1, NWAVES
      FREX=ABS((1.0-COS(WVDIR(K)*DEGREE)*SPEED
* WVFRE(K)/G)*WVFRE(K)) !Encounter freq.
      TYPE *, 'Encounter freq=', FREX

C
C-----
C
C
C NOTE: We are using the wave frequency here-- not the
C frequency of encounter.

```

```

C
C
C      FREX=WVFRE(K)
C-----
CCC      CALL FXIF(FREX, IF, FX)                                !Get index & mult.
C
C      IFP(K)=IF
C      FXP(K)=FX
C      THAH(JSTA,K)=COX(IT, TX, IF, FX, 1, JSTA)
C      TSAS(JSTA,K)=COX(IT, TX, IF, FX, 2, JSTA)
C      TRAR(JSTA,K)=COX(IT, TX, IF, FX, 3, JSTA)
C      TCCA(JSTA,K)=COX(IT, TX, IF, FX, 4, JSTA)
C
C      THVH(JSTA,K)=COX(IT, TX, IF, FX, 5, JSTA)
C      TSVS(JSTA,K)=COX(IT, TX, IF, FX, 6, JSTA)
C      TRVR(JSTA,K)=COX(IT, TX, IF, FX, 7, JSTA)
C      TCCV(JSTA,K)=COX(IT, TX, IF, FX, 8, JSTA)
C
C
C      Spatial derivatives in x-direction
C
C      THACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 1, JSTA)
C      TSACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 2, JSTA)
C      TRACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 3, JSTA)
C      TCACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 4, JSTA)
C
C      THVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 5, JSTA)
C      TSVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 6, JSTA)
C      TRVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 7, JSTA)
C      TCVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 8, JSTA)
C
C      10      CONTINUE
C      20      CONTINUE
C
C
CCC      For ship motion related hydro coef's, we will
CCC      us, as a default frequency the frequency associated
CCC      with the first wave [wvfre(1)].
CCC
CCC      Future revision: the default frequencies should
CCC      be the natural period in heave, sway, and roll.
C
C
C      *      FRSI=ABS((1.0-COS(WVDIR(1)*DEGREE)*SPEED
C              *WVFRE(1)/G)*WVFRE(1))      !Encounter freq.
C      OMEGAX(1)=FRSI
C      OMEGAX(2)=FRSI
C      OMEGAX(3)=FRSI
C
C      CALL FXIF(FRSI, IF, FX)
C
C      DO 30 JSTA=1, MSTA
C
C      FXP(21)=FX
C      IFP(21)=IF
C      TXP(21)=TX
C      ITP(21)=IT
C
C      THAH(JSTA, 21)=COX(IT, TX, IF, FX, 1, JSTA)
C      TSAS(JSTA, 21)=COX(IT, TX, IF, FX, 2, JSTA)
C      TRAR(JSTA, 21)=COX(IT, TX, IF, FX, 3, JSTA)

```

```

C      TCCA(JSTA,21)=COX(IT,TX,IF,FX,4,JSTA)
C      THVH(JSTA,21)=COX(IT,TX,IF,FX,5,JSTA)
C      TSVS(JSTA,21)=COX(IT,TX,IF,FX,6,JSTA)
C      TRVR(JSTA,21)=COX(IT,TX,IF,FX,7,JSTA)
C      TCCV(JSTA,21)=COX(IT,TX,IF,FX,8,JSTA)
C      THACX(JSTA,21)=COXDXP(IT,TX,IF,FX,1,JSTA)
C      TSACX(JSTA,21)=COXDXP(IT,TX,IF,FX,2,JSTA)
C      THVCX(JSTA,21)=COXDXP(IT,TX,IF,FX,5,JSTA)
C      TSVCX(JSTA,21)=COXDXP(IT,TX,IF,FX,6,JSTA)
30  CONTINUE
    RETURN
    END
    FUNCTION COX(IT,TX,IF,FX,ITYPE,JSTA)
CCC  This function subprogram returns the 2-D hydrodynamic
CCC  coefficient of a particular TYPE (1 thru 8 where 1 is
CCC  HAH, 2 is SAS, and so on) keyed on ITYPE, for a par-
CCC  ticular station, keyed on ISTA. Provided to the function
CCC  is the draft index (IT) and draft interpolation multi-
CCC  plier, the frequency index (IF) and the frequency inter-
CCC  polation multiplier (FX).
CCC  This function performs a two-dim linear interpolation
CCC  using four values from the big 2-D coefficient array
CCC  COEFF4( , , , )...
CCC  COMMON /COEFF4/ COEFF4(6,12,8,25),AREAN(25,6)
CCC  A1=COEFF4(IT , IF , ITYPE, JSTA)
CCC  A2=COEFF4(IT+1, IF , ITYPE, JSTA)
CCC  A3=COEFF4(IT , IF+1, ITYPE, JSTA)
CCC  A4=COEFF4(IT+1, IF+1, ITYPE, JSTA)
CCC  B12=A1+(TX*(A2-A1))
CCC  B34=A3+(TX*(A4-A3))
CCC  COX=B12+(FX*(B34-B12))
CCC  RETURN
CCC  END
CCC  SUBROUTINE TXIT(TAVG,IT,TX)
CCC  This routine determines the draft index (IT)
CCC  and draft interpolation multiplier (TX) given
CCC  a value for draft (TAVG).
CCC  COMMON/DRFT1/ DRAFT1(6)
CCC  IF (TAVG.GT.DRAFT1(6)) THEN          !Section immersed
CCC  IT=5
CCC  TX=1.0
CCC  ELSE IF (TAVG.LT.DRAFT1(1)) THEN    !Emerged section
CCC  IT=1
CCC  TX=0.0
CCC  ELSE
CCC  DO 10 JJ=2,6
CCC  IF(TAVG-DRAFT1(JJ)) 12,11,10
11  CONTINUE

```

```

      IT=JJ
      GO TO 13
      CONTINUE
      TX=(TAVG-DRAFT1(JJ-1))/(DRAFT1(JJ)-DRAFT1(JJ-1))
      IT=JJ-1
      GO TO 13
      CONTINUE
      CONTINUE
END IF
RETURN
END
SUBROUTINE FXIF(FREX, IF, FX)

  This routine determines the freq. index (IF)
  and freq. interpolation multiplier (FX) given
  a value for frequency (FREX).

  COMMON /SIGMA/ NK, SIGMA(24), SIGMAO, ERROR OM(12)

  IF (FREX.GT.OM(11)) THEN
    IF=11
    FX=1.0
  ELSE
    DO 10 JJ=2, 12
      IF(FREX-OM(JJ)) 12, 11, 10
      CONTINUE
    FX=0.0
    IF=JJ
    GO TO 13
    CONTINUE
    FX=(FREX-OM(JJ-1))/(OM(JJ)-OM(JJ-1))
    IF=JJ-1
    GO TO 13
    CONTINUE
    CONTINUE
  END IF
  RETURN
END
FUNCTION COXDX(IT, TX, IF, FX, L, J)

  COMMON /      /      NWAVES, WVSUM,
1      WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2      WN(20), WNX(20), WNZ(20),
3      CSK(20), CCK(20), CXK(20),
4      CYK(20), CZK(20), XW(20)
  COMMON /      /      MSTA, NPROF, NFWD, NAFT, LPTS(25),
1      XOFF(25), YOFF(25,25), ZOFF(25,25),
2      XPROF(51), YPROF(51)
  COMMON/OPTION/JOBCO, JOBFO(10)
  COMMON/ETA/YC, XK(20)
  COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)

-----

  IF(J.EQ.1) THEN
    CF=0.
  ELSE
    CF=COX(IT, TX, IF, FX, L, J-1)
    AF=ARX(IT, TX, J-1)

```

CF=CF*AF
END IF

CM=COX(IT, TX, IF, FX, L, J)
AM=ARX(IT, TX, J)
CM=CM*AM

IF(J.EQ.MSTA) THEN
CA=0.
ELSE
CA=COX(IT, TX, IF, FX, L, J+1)
AA=ARX(IT, TX, J+1)
CA=CA*AA
END IF

C1=(CM-CF)/DXFWD
C2=(CA-CM)/DXAFT

COXDX=(.5/AM)*(C1+C2)

RETURN
END
FUNCTION COXDXP(IT, TX, IF, FX, L, J)

COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)

IF(J.EQ.1) THEN
CF=0.
DXFWD=XOFF(J+1)-XOFF(J)
ELSE
CF=COX(IT, TX, IF, FX, L, J-1)
AF=ARX(IT, TX, J-1)
CF=CF*AF
DXFWD=XOFF(J)-XOFF(J-1)
END IF

CM=COX(IT, TX, IF, FX, L, J)
AM=ARX(IT, TX, J)
CM=CM*AM

IF(J.EQ.MSTA) THEN
CA=0.
DXAFT=XOFF(J)-XOFF(J-1)
ELSE
CA=COX(IT, TX, IF, FX, L, J+1)
AA=ARX(IT, TX, J+1)
CA=CA*AA
DXAFT=XOFF(J+1)-XOFF(J)
END IF

C1=(CM-CF)/DXFWD

```

C      C2=(CA-CM)/DXAFT
C      COXDXP=(.5/AM)*(C1+C2)
      TDX=DXFWD+DXAFT
      DCX=CA-CF
      COXDXP=(DCX/TDX)/AM
C
      RETURN
      END
      FUNCTION ARX(IT,TX,J)
CCC     COMMON /CDEFF4/ CDEFF4(6,12,8,25),AREAN(25,6)
CCC
CCC
CCC
      B2=AREAN(J,IT+1)
      B1=AREAN(J,IT)
      ARX=B1+(TX*(B2-B1))
CCC
      RETURN
      END

```

```

C      FUNCTION ETABAR(I)
C1     ETABAR RETURNS THE WAVE ELEVATION (ABSOLUTE COORDINATES) ABOVE
C1     A POINT IN THE SHIP COORDINATE SYSTEM.
C2     POINT IS ON THE SHIP CENTERPLANE.
C2     THE COORDINATES OF THE POINT ON THE SHIP ARE..
C2     ( XPROF(I), YPROF(I), -ZCG )
C5
C5     PHYSICAL CONSTANTS..
C5     COMMON /MASS /   RHO, G, GAMMA
C5
C5     SHIP MASS PARAMETERS..
C5     COMMON /MASS /   DISPL, SMASS, XCG, YCG, ZCG,
1      AMX, AMY, AMZ, RADII(6)
C5
C5     ROTATIONAL INERTIA MATRIX FOR FIXED MASS..
C5     COMMON /MASS /   PMI(3,3)
C5
C5     COMMON /TRIG /   CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
C5
C5     WAVE PROPERTIES..
C5     COMMON /           /   NWAVES, WVSUM,
1      WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2      WN(20), WNX(20), WNZ(20),
3      CSK(20), CCK(20), CXK(20),
4      CYK(20), CZK(20), XW(20)
C5
C5     TABLE OF OFFSETS..
C5     COMMON /           /   MSTA, NPROF, NFWD, NAFT, LPTS(25),
1      XOFF(25), YOFF(25,25), ZOFF(25,25),
2      XPROF(51), YPROF(51)
C5
C3     ETABAR=0.0
      IF (NWAVES.EQ.0) RETURN
      X1=XPROF(I)
      Y1=YPROF(I)*CTHETA+ZCG*STHETA
      Z1=YPROF(I)*STHETA-ZCG*CTHETA
      DO 110 K=1,NWAVES
        ARG=(X1-XW(K))*CXK(K)+Y1*CYK(K)+Z1*CZK(K)
        ETABAR=COS(ARG)*WVAMP(K)+ETABAR
110    CONTINUE
      RETURN
C
C      END
C      FUNCTION ETAF (ZT)
C1
C1     FIND COORDINATE OF WAVE SURFACE.
C5
C5     WAVE PROPERTIES..
C5     COMMON /           /   NWAVES, WVSUM,
1      WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2      WN(20), WNX(20), WNZ(20),
3      CSK(20), CCK(20), CXK(20),
4      CYK(20), CZK(20), XW(20)
C5
C5

```

C5 DATA FOR THE COMPUTATION OF THE WAVE SURFACE ELAVATION..
COMMON /ETA / YC, XK(20)

C5
COMMON /CT / CT(3,3)

C3
A=-YC
B=CT(2,2)
IF (NWAVES.EQ.0) GO TO 120
DO 110 K=1,NWAVES
ARG=ZT*CZK(K)+XK(K)
A=COS(ARG)*WVAMP(K)+A
B=SIN(ARG)*WVAMP(K)*CYK(K)+B
110 CONTINUE
120 ETAF=A/B
RETURN

C
END
FUNCTION ETAY(J,K)
COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAF-T, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
ETAY=0.
IF (NWAVES.EQ.0) RETURN
X1=XOFF(J)
Y1=0.
Z1=0.
ARG=(X1-XW(K))*CXK(K)+Y1*CYK(K)+Z1*CZK(K)
ETAY=COS(ARG)*WVAMP(K)
RETURN
C
END

SUBROUTINE FOLIO1

```

COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON/DRFT1/DRAFT1(6)
COMMON/IOFILE/ OFFIL, BIFIL, COFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/COEFF4/COEFF4(6,12,8,25), AREAN(25,6)
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON /DAMP / DAMPL(6), DAMPG(6)
COMMON /LHS / Y(13)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /RESIST/ SPEED
COMMON/OPTION/JOBEO, JOBFO(10)
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOD(26),
* STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
REAL POSIT(6), VELOC(6)
EQUIVALENCE (POSIT(1), Y(1)), (VELOC(1), Y(7))

```

```

C
WEIGHT=SMASS*G
WRITE(OUTPUT,100) TITLE
WRITE(OUTPUT,110) WEIGHT, RADII(1), RADII(2), XCG, RADII(3),
* YCG, RADII(4), ZCG, RADII(5), RADII(6)
WRITE(OUTPUT,120) DAMPL(1), DAMPG(1), SPEED,
* (DAMPL(I), DAMPG(I), I=2,6)
WRITE(OUTPUT,130) (POSIT(I), VELOC(I), I=1,6)
WRITE(OUTPUT,140) TSTART, TSTOP, TOUTPT, TSTEP
WRITE(OUTPUT,160) RHO, G
WRITE(OUTPUT,165) JOBO, (JOBFO(I), I=1,3)
WRITE(OUTPUT,100) TITLE
WRITE(OUTPUT,150)
DO 10 I=1, NWAVES
10 WRITE(OUTPUT,155) I, WVAMP(I), WVFRE(I), WVDIR(I), WVPHA(I)
CONTINUE
WRITE(OUTPUT,170)
DO 20 I=1, NWTSTA
20 WRITE(OUTPUT,175) I, SEGWT(I), SEGMOX(I), YBAR(I)
CONTINUE
WRITE(OUTPUT,100) TITLE

```

```

C
100 FORMAT(1H1, 80(1H=) //, 1X, A, T55, 'PROGRAM SSX (Version 1.0)' //,
* 81(1H=) //)
110 FORMAT(28(1H-), 'Inertial Characteristics', 29(1H-)//,
* T48, 9(1H-), 'GYRADII', 8(1H-)//,
* T5, 'WEIGHT', F15.2, 2X, 'L. TONS', T48, 'Kxx', 4X, F10.3, 5X, 'ft' //,
* T48, 'Kyy', 4X, F10.3, 5X, 'ft' //,
* T5, 'XCG', 10X, F10.3, 4X, 'ft', T48, 'Kzz', 4X, F10.3, 5X, 'ft' //,

```

```

      *T5, 'YCG', 10X, F10.3, 4X, 'ft', T48, 'Kxy', 4X, F10.3, 5X, 'ft',//,
      *T5, 'ZCG', 10X, F10.3, 4X, 'ft', T48, 'Kxz', 4X, F10.3, 5X, 'ft',//,
      * T48, 'Kyz', 4X, F10.3, 5X, 'ft'//, 40(2H -)//)
120  FORMAT(T5, 8(1H-), 'DAMPING COEFFICIENTS', 8(1H-), T48,
      * '-----OPS DATA-----',//,
      *13X, '(user specified)'//,
      *T5, 'MOTION', 7X, 'LINEAR', 7X, 'QUADRATIC'//,
      *T5, '-----', 4X, '-----', 5X, '-----'//,
      *T5, 'SURGE', 2(5X, E10.4), T48, 'SPEED', 5X, F6.2//,
      *T5, 'HEAVE', 2(5X, E10.4)//,
      *T5, 'SWAY', 2(5X, E10.4)//,
      *T5, 'ROLL', 2(5X, E10.4)//,
      *T5, 'YAW', 2(5X, E10.4)//,
      *T5, 'PITCH', 2(5X, E10.4)//)
130  FORMAT(32(1H-), 'Initial Conditions', 31(1H-)//,
      *T5, 11(1H-), 'POSITION', 11(1H-), T48, 10(1H-), 'VELOCITY', 10(1H-)//,
      *T5, 'X(CG)', 11X, F10.3, 2X, 'ft', T48, 'SPEED', 5X, F10.3, 2X, 'ft/sec'//,
      *T5, 'Y(CG)', 11X, F10.3, 2X, 'ft', T48, 'HEAVE', 5X, F10.3, 2X, 'ft/sec'//,
      *T5, 'Z(CG)', 11X, F10.3, 2X, 'ft', T48, 'SWAY', 5X, F10.3, 2X, 'ft/sec'//,
      *T5, 'ROLL', 11X, F10.3, 1X, 'deg', T48, 'ROLL', 6X, F10.3, 2X, 'deg/sec'//,
      *T5, 'YAW', 11X, F10.3, 1X, 'deg', T48, 'YAW', 7X, F10.3, 2X, 'deg/sec'//,
      *T5, 'PITCH', 11X, F10.3, 1X, 'deg', T48, 'PITCH', 5X, F10.3, 2X,
      * 'deg/sec'//)
140  FORMAT(34(1H-), 'Run Parameters', 33(1H-)//,
      *T5, 'SIMULATION PARAMETERS', T48, 'JOB OPTIONS'//,
      *T5, 21(1H-), T48, 11(1H-)//,
      *T5, 'TIME(START)', 3X, F8.2//,
      *T5, 'TIME(END)', 5X, F8.2//,
      *T5, 'OUTPUT DT', 5X, F8.2//,
      *T5, 'INTEG. DT', 5X, F8.2//, 81(1H-)//)
150  FORMAT(33(1H-), 'WAVE COMPONENTS', 33(1H-)//,
      *T5, 'WAVE', 5X, 'AMPLITUDE', 5X, 'FREQUENCY', 5X, 'DIRECTION',
      *5X, 'PHASE'//,
      *T5, '-----', 5X, '-----', 5X, '-----', 5X, '-----',
      *5X, '-----')
155  FORMAT(T7, I2, T16, F6.2, T30, F6.2, T44, F7.2, T55, F7.2)
160  FORMAT(/31(1H-), 'MISCELLANEOUS VALUES', 30(1H-)//,
      *T5, 'RHO', 5X, F10.6//, T5, 'G', 5X, F10.6)
165  FORMAT(T5, 'JOB CD', I2//, T5, 'JOB FD', 4I4//)
170  FORMAT(27(1H-), 'SECTIONAL WEIGHT PROPERTIES', 27(1H-)//,
      *T5, 'SECTION', 5X, 'WEIGHT', 5X, 'Kxx', 5X, 'Centroid'//,
      *T5, '-----', 5X, '-----', 5X, '-----', 5X, '-----'//)
175  FORMAT(T5, 3X, I2, T13, F10.3, T26, F8.2, T39, F8.2)
      RETURN
      END

```

```

SUBROUTINE RKF (TIME,Y,TNEXT,ERR,NEQS,STEP)
C
C RUNGE-KUTTA INTEGRATION FOR CAPSIZE.
C
REAL Y(1)
REAL YY(13), YA(13), YB(13)
C-----
REAL YC(13)
DATA YC(13)/0.0/
C
DATA YY(13)/0.0/
DATA YA(13)/0.0/
DATA YB(13)/0.0/
C
STEP=ABS(STEP)
NSTEP=(TNEXT-TIME)/STEP+0.5
IF (NSTEP.LT.1) NSTEP=1
TSTEP=(TNEXT-TIME)/FLOAT(NSTEP)
HALF=TSTEP/2.0
FACT=TSTEP/6.0
110 CALL DERIV (TIME,Y,YA)
DO 120 I=1,NEQS
    YY(I)=HALF*YA(I)+Y(I)
120 CONTINUE
    TIME=HALF+TIME
    CALL DERIV (TIME,YY,YB)
    DO 130 I=1,NEQS
        YA(I)=2.0*YB(I)+YA(I)
        YY(I)=HALF*YB(I)+Y(I)
130 CONTINUE
    CALL DERIV (TIME,YY,YB)
    DO 140 I=1,NEQS
        YA(I)=2.0*YB(I)+YA(I)
        YY(I)=TSTEP*YB(I)+Y(I)
140 CONTINUE
    TIME=HALF+TIME
    CALL DERIV (TIME,YY,YB)
    DO 150 I=1,NEQS
        Y(I)=(YA(I)+YB(I))*FACT+Y(I)
150 CONTINUE
C-----
C This call to DERIV is to get actual acceleration for the
C new TIME. By calling RHS this time we are loading the
C acceleration array ACC( ) in COMMON ACCEL with correct
C accelerations, rather than accel. computed as dictated
C by the fourth-order RUNGE-KUTTA scheme.
C
CALL DERIV(TIME,Y,YC)
CALL GETFREQ
C-----
IF (TIME+HALF.LT.TNEXT) GO TO 110
TIME=TNEXT
RETURN
END

```

SUBROUTINE DERIV (TT, YY, YYDOT)
Evaluates derivatives in equations of motion

TT -- TIME, THE INDEPENDENT VARIABLE

YY -- DEPENDENT VARIABLE ARRAY.

YY(1) = X-COORDINATE OF MASS CENTER
YY(2) = Y-COORDINATE OF MASS CENTER
YY(3) = Z-COORDINATE OF MASS CENTER
YY(4) = THETA ROTATION (ROLL ANGLE)
YY(5) = PHI ROTATION (YAW ANGLE)
YY(6) = PSI ROTATION (PITCH ANGLE)
YY(7) = X-COMPONENT OF LINEAR VELOCITY
YY(8) = Y-COMPONENT OF LINEAR VELOCITY
YY(9) = Z-COMPONENT OF LINEAR VELOCITY
YY(10) = ANGULAR VELOCITY ABOUT X-AXIS (ROLL RATE)
YY(11) = ANGULAR VELOCITY ABOUT Y-AXIS (YAW RATE)
YY(12) = ANGULAR VELOCITY ABOUT Z-AXIS (PITCH RATE)
YY(13) = TIME INTEGRAL OF YAW ANGLE (EVALUATED ONLY
WHEN REQUIRED BY THE AUTOPILOT)

YYDOT -- DERIVATIVES OF YY.

TT AND YY ARE SUPPLIED TO THIS SUBROUTINE WHENEVER THE EQUATION SOLVING ROUTINE REQUIRES THE VALUES OF THE DERIVATIVE OF YY--YYDOT. YYDOT IS COMPUTED BY EVALUATING THE RIGHT HAND SIDE OF THE EQUATIONS OF MOTION FOR THE GIVEN TT AND YY AND THE PRE-DEFINED GEOMETRY OF THE SHIP AND EQUATIONS OF THE WAVES.

REAL YY(13), YYDOT(13)
COMMON /A / A(6,6)
COMMON /C / C(3,3)
COMMON /CT / CT(3,3)
COMMON /FORCE / XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1),XF)
COMMON /H / H(3)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /STATS / NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /Z / SCR(6)
COMMON/ACCEL/ACC(6)
NRHS(4)=NRHS(4)+1
IF (TT.GT.TT1) GO TO 90
IF (TT.EQ.TT1) GO TO 80
C *** Previous time step rejected
NRHS(3)=NRHS(3)+1
TTO=AMIN1(TT,TTO)
TT1=TTO
GO TO 100
C *** Previous time step repeated
80 NRHS(2)=NRHS(2)+1
GO TO 100
C
C *** Previous time step accepted
90 DELTA=TT1-TTO
TTO=TT1
TT1=TT

```

      IF (DELTA.LE.0.0) GO TO 100
      NRHS(1)=NRHS(1)+1
      HSUM=HSUM+DELTA
      HMIN=AMIN1(HMIN, DELTA)
      HMAX=AMAX1(HMAX, DELTA)
100  CONTINUE
C *** Compute forces on ship
      CALL FORTIS (TT,YY)
C *** Set the values of the derivatives
C *** Set up the H vector (angular momentum)
      H(1)=PMI(1,1)*YY(10)+PMI(1,2)*YY(11)+PMI(1,3)*YY(12)
      H(2)=PMI(2,1)*YY(10)+PMI(2,2)*YY(11)+PMI(2,3)*YY(12)
      H(3)=PMI(3,1)*YY(10)+PMI(3,2)*YY(11)+PMI(3,3)*YY(12)
C *** Set derivatives of position and rotation
      DO 110 I=1,3
         YYDOT(I)=YY(I+6)
110  CONTINUE
      YYDOT(5)=(YY(11)*CTHETA-YY(12)*STHETA)/CPSI
      YYDOT(4)=YY(10)-YYDOT(5)*SPSI
      YYDOT(6)=YY(11)*STHETA+YY(12)*CTHETA
C *** Solve for derivatives of linear and angular velocity
      YYDOT(7)=XF/SMASS
      YYDOT(8)=YF
      YYDOT(9)=ZF
      YYDOT(10)=XM-YY(11)*H(3)+YY(12)*H(2)
      YYDOT(11)=YM-YY(12)*H(1)+YY(10)*H(3)
      YYDOT(12)=ZM-YY(10)*H(2)+YY(11)*H(1)
      DET=0.0
      L=LNEGF(6,5,1,A(2,2),YYDOT(8),DET,SCR)
      IF (L.NE.1) STOP 1
C *** Load the acceleration array ACC [ship coordinates]
      ACC(1)=YYDOT(7)
      ACC(2)=YYDOT(8)
      ACC(3)=YYDOT(9)
      ACC(4)=YYDOT(10)
      ACC(5)=YYDOT(11)
      ACC(6)=YYDOT(12)
C
C *** Resolve linear accelerations into fixed coordinates.
      SCR(1)=YYDOT(7)
      SCR(2)=YYDOT(8)
      SCR(3)=YYDOT(9)
      YYDOT(7)=C(1,1)*SCR(1)+C(2,1)*SCR(2)+C(3,1)*SCR(3)
      YYDOT(8)=C(1,2)*SCR(1)+C(2,2)*SCR(2)+C(3,2)*SCR(3)
      YYDOT(9)=C(1,3)*SCR(1)+C(2,3)*SCR(2)+C(3,3)*SCR(3)
      YYDOT(13)=YY(5)
      RETURN
      END

```

```

SUBROUTINE ROTATE (YY)
C
C1 SET UP COORDINATE ROTATION MATRICES CT AND C .
C1 RESOLVE VELOCITY INTO SHIP COORDINATES.
C1
REAL YY(13)
COMMON /C / C(3,3)
COMMON /CT / CT(3,3)
COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /V / VX, VY, VZ
CTHETA=COS(YY(4))
STHETA=SIN(YY(4))
CPHI=COS(YY(5))
SPHI=SIN(YY(5))
CPSI=COS(YY(6))
SPSI=SIN(YY(6))
C3
C3 SET UP THE CT MATRIX..
C3
CT(1,1)=CPHI*CPSI
CT(1,2)=SPSI
CT(1,3)=-SPHI*CPSI
CT(2,1)=-CPHI*SPSI
CT(2,2)=CPSI
CT(2,3)=SPHI*SPSI
CT(3,1)=SPHI
CT(3,2)=0
CT(3,3)=CPHI
C3
C3 SET UP THE C MATRIX..
C3
C(1,1)=CT(1,1)
C(1,2)=CT(1,2)
C(1,3)=CT(1,3)
C(2,1)=CTHETA*CT(2,1)+STHETA*CT(3,1)
C(2,2)=CTHETA*CT(2,2)
C(2,3)=CTHETA*CT(2,3)+STHETA*CT(3,3)
C(3,1)=CTHETA*CT(3,1)-STHETA*CT(2,1)
C(3,2)=-STHETA*CT(2,2)
C(3,3)=CTHETA*CT(3,3)-STHETA*CT(2,3)
C3
C3 RESOLVE THE LINEAR VELOCITY INTO SHIP COORDINATES..
C3
VX=C(1,1)*YY(7)+C(1,2)*YY(8)+C(1,3)*YY(9)
VY=C(2,1)*YY(7)+C(2,2)*YY(8)+C(2,3)*YY(9)
VZ=C(3,1)*YY(7)+C(3,2)*YY(8)+C(3,3)*YY(9)
C3
C RETURN
C
END

```

SUBROUTINE GETFREQ

```

C *****
C
C Evaluates frequency of accelerations of each
C strip in heave, sway and roll using recent
C history. The routine finds the last several
C peaks or troughs in the response history. Evaluates
C the time difference and calculates the frequency
C (rad/sec) and loads the OMEGAX( , ) array.
C *****
C
C5 WAVE PROPERTIES.
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
C5
C5 TABLE OF OFFSETS.
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON/ACCEL/ ACC(6)
COMMON/SXGEOM/AREAS(25), DXS(25), DX1S(25), DX2S(25),
* YOMS(25), ZOMS(25), ISTA, LSTA
COMMON/SXOMEG/OMEGAX(3)
COMMON/HIST/AHIST(3,30), TIMTK(30)
COMMON/TIME/TIME, RAMP
COMMON/TIME/TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
REAL TPK(10)
C
C -----
C SECTION 1.0 - Move values up one index in the AHIST
C array
C
DO 100 J=30,2,-1
JM1=J-1
AHIST(1,J)=AHIST(1,JM1)
AHIST(2,J)=AHIST(2,JM1)
AHIST(3,J)=AHIST(3,JM1)
100 CONTINUE
C
DO 110 I=30,2,-1
IM=I-1
TIMTK(I)=TIMTK(IM)
110 CONTINUE
C
C -----
C SECTION 2.0 - Calculate acceleration of a strip J in
C heave, sway and roll using the ACC(I)
C array giving ship accelerations in ship
C coordinate system.
C
XDUM=10. !Arbitrary moment arm to get better
C defined history
AH=ACC(2)+ACC(6)*XDUM
AS=ACC(3)-ACC(5)*XDUM

```

```

      AR=ACC(4)
C
      AHIST(1,1)=AH
      AHIST(2,1)=AS
      AHIST(3,1)=AR
C
200  CONTINUE
C
      TIMTK(1)=TIME
C
      IF(TIME.LE.RAMP) GO TO 400
C-----
C
C      SECTION 3.0 - Find peaks and troughs, evaluate freq.
C      [Note: Here we are evaluating frequency
C      using only the last quarter of a "cycle".
C      If we wanted to use a half cycle, we
C      would get out of the GOTO310 loop when
C      KNT=3 instead of KNT=2 and change
C      the 'TQ=...' line to
C      TQ=TPK(3)-TPK(1) followed by
C      OMEGAX(I)=2.*PI/(2.*TQ)
C-----
C
      DO 300 I=1,3
      L=0
      KNT=0
      TSIGN=1.
310  CONTINUE
      L=L+1
      IF(L.EQ.30) GO TO 325
      TSIGN2=TSIGN
      DIF=AHIST(I,L)-AHIST(I,L+1)
      TSIGN=SIGN(1.,DIF)
      IF(L.EQ.1) GO TO 310
      IF(TSIGN2.EQ.TSIGN) GO TO 310
      KNT=KNT+1
      TPK(KNT)=TIMTK(L)
      IF(KNT.EQ.2) GO TO 320
      GO TO 310
C
C320  CONTINUE
      TQ=TPK(1)-TPK(2)
      OMEGAX(I)=6.2831853/(4.*TQ)
      GO TO 300
C320  OMEGAX(I)=0.
C
C300  CONTINUE
C
C400  CONTINUE
      RETURN
      END

```

```

SUBROUTINE OUTCOF
CCC
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON/MASS/RHO, G, GAMMA
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
*          AMX, AMY, AMZ, RADII(6)
COMMON/LHS/Y(13)
COMMON /      /      NWAVES, WVSUM,
1              WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2              WN(20), WNX(20), WNZ(20),
3              CSK(20), CCK(20), CXK(20),
4              CYK(20), CZK(20), XW(20)
COMMON /      /      MSTA, NPROF, NFWD, NAFT, LPTS(25),
1              XOFF(25), YOFF(25,25), ZOFF(25,25),
2              XPROF(51), YPROF(51)
COMMON/RESIST/SPEED
COMMON/SIGMA / NK, SIGMA(24), SIGMA0, ERRO, DM(12)

C
C
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON/COEFFX/THAH(25, 21), TSAS(25, 21), TRAR(25, 21), TCCA(25, 21),
*          THVH(25, 21), TSVS(25, 21), TRVR(25, 21), TCCV(25, 21),
*          THACX(25, 21), THVCX(25, 21), TSACX(25, 21), TSVCX(25, 21),
*          TRACX(25, 21), TCACX(25, 21), THVCY(25, 21),
*          ITP(25), TXP(25), IFP(21), FXP(21)
COMMON/OPTION/JOBCO, JOBFQ(10)
COMMON/SXOMEG/OMEGAX(3)
COMMON/DRFT1/ DRAFT1(6)

C
DATA DEGREE/0.01745 32925/

C-----
C      WRITE(OUTPUT, 2)
C
C      WRITE(OUTPUT, 3)
C      DO 10 J=1, MSTA
C      WRITE(OUTPUT, 1) J, THAH(J, 21), TSAS(J, 21), TRAR(J, 21), TCCA(J, 21)
10      CONTINUE
C
C      WRITE(OUTPUT, 4)
C      DO 20 J=1, MSTA
C      WRITE(OUTPUT, 1) J, THVH(J, 21), TSVS(J, 21), TRVR(J, 21), TCCV(J, 21)
20      CONTINUE
C
C      WRITE(OUTPUT, 5)
C      DO 30 J=1, MSTA
C      WRITE(OUTPUT, 1) J, THACX(J, 21), TSACX(J, 21), THVCX(J, 21),
30      * TSVCX(J, 21)
C      CONTINUE
C
C      DO 40 K=1, NWAVES
C      WRITE(OUTPUT, 6) K
C      WRITE(OUTPUT, 3)
C      DO 110 J=1, MSTA
C      WRITE(OUTPUT, 1) J, THAH(J, K), TSAS(J, K), TRAR(J, K), TCCA(J, K)
110      CONTINUE
C
C      WRITE(OUTPUT, 4)
C      DO 120 J=1, MSTA
C      WRITE(OUTPUT, 1) J, THVH(J, K), TSVS(J, K), TRVR(J, K), TCCV(J, K)

```

```

120      CONTINUE
C
      WRITE(OUTPUT,5)
      DO 130 J=1,MSTA
      WRITE(OUTPUT,1) J, THACX(J,K), TSACX(J,K), THVCX(J,K), TSVCX(J,K)
130      CONTINUE
40      CONTINUE
1      FORMAT(1X,I2,5X,4E15.5)
2      FORMAT(/'*****TEMPORARY HYDRODYNAMIC COEFFICIENTS*****'//)
3      FORMAT(1X,'STA',4X,'HAH',12X,'SAS',12X,'RAR',12X,'CCA'//)
4      FORMAT(1X,'STA',4X,'HVV',12X,'SVS',12X,'RVR',12X,'CCV'//)
5      FORMAT(1X,'STA',4X,'HACX',11X,'SACX',11X,'HVCX',11X,'SVCX',/)
6      FORMAT(/1X,'WAVE NO. - ',I2/)
      RETURN
      END

```

```

SUBROUTINE FOLIO2
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
COMMON /LHS / Y(13)
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON/SUMMARY/ NT,YYBAR(10),YYRMS(10),YYMAX(10),YYMIN(10)
COMMON/LOADS/ SIN2(25),SIN3(25),SIN4(25),SIN5(25),SIN6(25),
1 V2(25),V3(25),V4(25),V5(25),V6(25),
2 RED(6,25)
COMMON/DISPLAY/TARE(10)
REAL YS(10)
EQUIVALENCE (ETA,YS(1))
DATA RAD /0.01745 32925 19943/
ETA=0.0
IF (NWAVES.EQ.0) GO TO 120
C *** Wave amplitude @ c.g.
DO 110 K=1,NWAVES
ARG=Y(1)*WNX(K)-Y(3)*WNZ(K)-TIME*WVFRE(K)+WVPHA(K)
ETA=COS(ARG)*WVAMP(K)+ETA
110 CONTINUE
C *** Position vector
120 DO 130 I=1,3
YS(I+1)=Y(I)
YS(I+4)=Y(I+3)/RAD
130 CONTINUE
C *** Display relative heave -- subtract c.g. height
C above baseline to bring mean value to zero.
YS(3)=YS(3)-TARE(2)
C *** Speed and sway rate
CPHI=COS(Y(5))
SPHI=SIN(Y(5))
YS(8)=0.
!NO RUDDER
YS(8)=V6(14) !BENDING MOMENT AT STATION J=14
YS(9)=Y(7)*CPHI - Y(9)*SPHI
YS(10)=Y(9)*CPHI+ Y(7)*SPHI
C *** Load mean and rms information
TINIT=.75*TSTOP
IF(TIME.LE.TINIT) GO TO 199
NT=NT+1
IF(NT.NE.1) GO TO 198
DO 184 I=1,10
YYMAX(I)=0.0
YYMIN(I)=0.0
YYBAR(I)=0.
YYRMS(I)=0.
184 CONTINUE
C
198 CONTINUE
C
DO 185 I=1,10
IF(YS(I).GT.YYMAX(I)) YYMAX(I)=YS(I)
IF(YS(I).LT.YYMIN(I)) YYMIN(I)=YS(I)
C
YYBAR(I)=YYBAR(I)+YS(I)
YYRMS(I)=YYRMS(I)+YS(I)**2

185 CONTINUE
C
199 CONTINUE
C *** Write to history file
WRITE(10) YS(1),YS(3),YS(7),YS(5),YS(6),YS(4)
C *** Print YS vector
WRITE (OUTPUT,190) TIME,(YS(I),I=1,9)
C
RETURN
C
190 FORMAT(5(1X,F11.4),3F12.4,2X,E15.5,2X,F12.4)
END

```

SUBROUTINE FORTIS (TT, YY)

TT -- TIME, THE INDEPENDENT VARIABLE

YY -- DEPENDENT VARIABLE ARRAY.

YY(1) = X-COORDINATE OF MASS CENTER
YY(2) = Y-COORDINATE OF MASS CENTER
YY(3) = Z-COORDINATE OF MASS CENTER
YY(4) = THETA ROTATION (ROLL ANGLE)
YY(5) = PHI ROTATION (YAW ANGLE)
YY(6) = PSI ROTATION (PITCH ANGLE)
YY(7) = X-COMPONENT OF LINEAR VELOCITY
YY(8) = Y-COMPONENT OF LINEAR VELOCITY
YY(9) = Z-COMPONENT OF LINEAR VELOCITY
YY(10) = ANGULAR VELOCITY ABOUT X-AXIS (ROLL RATE)
YY(11) = ANGULAR VELOCITY ABOUT Y-AXIS (YAW RATE)
YY(12) = ANGULAR VELOCITY ABOUT Z-AXIS (PITCH RATE)

REAL YY(12)

COMMON /C / C(3,3)

COMMON /DAMP / DAMPL(6), DAMPG(6)

COMMON /FORCE / XF, YF, ZF, XM, YM, ZM

REAL FORCE(6)

EQUIVALENCE (FORCE(1), XF)

COMMON /MASS / RHO, G, GAMMA

COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,

1 AMX, AMY, AMZ, RADII(6)

COMMON /MASS / PMI(3,3)

COMMON /STATS / NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1

COMMON /TIME / TIME, RAMP

COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR

COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI

COMMON /V / VX, VY, VZ

C *** Load rotational transform matrices - transform velocity
C into ship coordinates

CALL ROTATE (YY)

C *** Initialize force vector

DO 110 I=1,6
FORCE(I)=0.0

110 CONTINUE

C *** Ensure constant speed for version SSX
C VX=SPEED

C *** Compute hydrodynamic and inertial forces on ship
CALL AQUA2D (TT, YY)

C *** Add damping forces/moments in ship coordinate system

XF=XF-(DAMPL(1)+ABS(VX)*DAMPQ(1))*VX
YF=YF-(DAMPL(2)+ABS(VY)*DAMPQ(2))*VY
ZF=ZF-(DAMPL(3)+ABS(VZ)*DAMPQ(3))*VZ
XM=XM-(DAMPL(4)+ABS(YY(10))*DAMPQ(4))*YY(10)
YM=YM-(DAMPL(5)+ABS(YY(11))*DAMPQ(5))*YY(11)
ZM=ZM-(DAMPL(6)+ABS(YY(12))*DAMPQ(6))*YY(12)

C *** Fixed added mass coefficients - not normally used except
C perhaps for surge.

XF=XF/AMX
YF=YF/AMY
ZF=ZF/AMZ

C *** Ramp function applied to force
C IF (TT.GT.TSTART) GO TO 130
IF (RAMP.EQ.0.0) GO TO 130
R=(TT-TO)/RAMP

DO 120 I=1,6
FORCE(I)=FORCE(I)*R

120 CONTINUE

130 CONTINUE

C RETURN
END

```

SUBROUTINE SPECTRA(PFRQ, TRWH13, OMGBEG, OMGEND, WAMP, PER)
DIMENSION WAMP(10), PER(10), OMEGA(10)
DIMENSION OMG2(101), SPEC(101)
IC1=-8
IC2=0
IC3=-7
IC4=-1
IC5=-9
IC6=1
IW=0
OMG2(1)=OMGBEG
OMG2(101)=OMGEND
1 DELFRQ=(OMG2(101)-OMG2(1))/101.
DO 5 I=2, 101
J=I-1
5 OMG2(I)=OMG2(1)+J*DELFREQ
DO 6 I=1, 101
6 OMG2(I)=OMG2(I)/(2.*3.14159)
DO 7 I=1, 101
7 SPEC(I)=5.*(25*TRWH13)**2*PFRQ*(OMG2(I)*PFRQ)**(-5)*EXP(
10 1 (-5./4.)*(OMG2(I)*PFRQ)**(-4))
ODD=0.
EVEN=0.
DO 20 I=1, 50, 2
20 EVEN=EVEN+SPEC(I)
DO 30 I=3, 99, 2
30 ODD=ODD+SPEC(I)
TAREA=(OMG2(2)-OMG2(1))/3.*(SPEC(1)+4.*EVEN+2.*ODD+SPEC(101))
40 IC1=IC1+10
IC2=IC2+10
IC3=IC3+10
IC4=IC4+10
IC5=IC5+10
IC6=IC6+10
ODD=0.
EVEN=0.
IW=IW+1
DO 50 I=IC1, IC2, 2
50 EVEN=EVEN+SPEC(I)
DO 60 I=IC3, IC4, 2
60 ODD=ODD+SPEC(I)
WAMP(IW)=(OMG2(2)-OMG2(1))/3.*(SPEC(IC5)+4.*EVEN+2.*
1 ODD+SPEC(IC6))
WAMP(IW)=1.414*SQRT(WAMP(IW))
PER(IW)=(OMG2(IC6)+OMG2(IC5))/2.
OMEGA(IW)=2.*3.14159*PER(IW)
PER(IW)=1./PER(IW)
IF(IW.LT.10) GO TO 40
PRINT 500, TRWH13, PFRQ, OMEGA, PER, WAMP
RMS=4.*SQRT(TAREA)
PRINT 1010, TAREA, RMS
500 1 FORMAT(15X, 'H1/3=', F10.2, 2X, 'PEAK FREQ=', F10.4, '//, 2X,
1 2 'OMG', 3X, 10F6.3, '//, 2X, 'PER', 3X, 10F6.2, '//, 2X, 'WAMP', 2X,
1010 10F6.2)
FORMAT(2X, 'TOTAL AREA=', F10.2, 5X, 'RMS=', F10.2)
RETURN
END
SUBROUTINE LINEAR(X, Y, TRWPER, Y2)
DIMENSION X(50), Y(50), Y2(10)
DIMENSION TRWPER(10)
J=0

```

```

140      RA=SQRT((X-XF)**2+(Y-YF)**2+(Z-ZF)**2)
      FRA=ARM/RA
1380     RB=SQRT((X-XF)**2+(Y-YF)**2+(Z+ZF)**2)
      FRA=FRA-ARM/RB
      FRX=-AN(MJ, 1)*FRA
      FRY=-AN(MJ, 2)*FRA
      FRZ=-AN(MJ, 3)*FRA
      P1=P1+FRX
      P2=P2+FRY
      P3=P3+FRZ
      P4=P4+YF*FRZ-ZF*FRY
      P5=P5+ZF*FRX-XF*FRZ
      P6=P6+XF*FRY-YF*FRX
      PBB(NJ, MJ)=PBB(NJ, MJ)+FRA*ARN
138     CONTINUE
      P(NJ, 1)=P(NJ, 1)+P1*ARN
      P(NJ, 2)=P(NJ, 2)+P2*ARN
      P(NJ, 3)=P(NJ, 3)+P3*ARN
      P(NJ, 4)=P(NJ, 4)+P4*ARN
      P(NJ, 5)=P(NJ, 5)+P5*ARN
      P(NJ, 6)=P(NJ, 6)+P6*ARN
128     CONTINUE
127     CONTINUE
      DO 554 KQ=1, 6
554     WRITE(3) (P(NJ, KQ), NJ=1, NPAN)
      RETURN
      END

```

```

      TOPI=2.*3.14159
      DO 20 II=1,10
      IF(II.GT.1) GO TO 69
      J=J+1
      IF(TOPI/TRWPER(II)-X(J))112,111,110
      GOTO 50
      Y2(II)=Y(J)
      GOTO 20
      Y2(II)=Y(J-1)+(Y(J)-Y(J-1))/(X(J)-X(J-1))*
      (TOPI/TRWPER(II)-X(J-1))
20      1  CONTINUE
      RETURN
      END

```

```

      SUBROUTINE TBAR(TT,YY)
CCC
      EXTERNAL ETAF
CCC
      COMMON/MASS/RHO,G,GAMMA
      COMMON/MASS/DISPL,SMASS,XCG,YCG,ZCG,
*      AMX,AMY,AMZ,RADII(6)
      COMMON /      /      NWAVES, WVSUM,
1      WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2      WN(20), WNX(20), WNZ(20),
3      CSK(20), CCK(20), CXK(20),
4      CYK(20), CZK(20), XW(20)
      COMMON /      /      MSTA, NPROF, NFWD, NAFT, LPTS(25),
1      XOFF(25), YOFF(25,25), ZOFF(25,25),
2      XPROF(51), YPROF(51)
      COMMON/ETA/YC,XK(20)
      COMMON/CT/CT(3,3)
      COMMON/TEMPSTA/DXFWD,DXAFT,TSTA(25)
      COMMON/DISPLAY/TARE(6)
      REAL YY(1)

      DATA DEGREE/0.01745 32925/
      SECTION 1.0      Compute average draft at each station
      TSTA(J).

      DO 2 K=1,NWAVES
      CXK(K)=CT(1,1)*WNX(K)-CT(1,3)*WN(K)
      XW(K)=(TT*WVFRE(K)-WVPHA(K)+YY(3)*WNZ(K)-YY(1)*WNX(K))/CXK(K)
2      CONTINUE
C
      DO 5 J=1,MSTA
      XXSTA=XOFF(J)
      IF(NWAVES.EQ.0) GO TO 11
      DO 10 K=1,NWAVES
      XK(K)=(XXSTA-XW(K))*CXK(K)
10      CONTINUE
11      YC=CT(1,2)*XXSTA+YY(2)
      YKEEL=YCG-TARE(2)-YC
      ETA1=ETAF(0.)
      TSTA(J)=ETA1-YKEEL
5      CONTINUE
C
C
C
C
CCC
      RETURN
      END

```

SUBROUTINE MOCHA

Purpose: For JOBCO=2,3 or 4 ... this subroutine will load the COMMON/COEFFX/ arrays for use in subroutine FROUDE.

COMMON/MASS/RHO, G, GAMMA
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
* AMX, AMY, AMZ, RADII(6)

* COMMON/LHS/Y(13)

WAVE PROPERTIES..

COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)

TABLE OF OFFSETS..

COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)

COMMON/RESIST/SPEED

COMMON/SIGMA / NK, SIGMA(24), SIGMA0, ERRO, OM(12)

COMMON/COEFF4/COEFF4(6,12,8,25), AREAN(25,6)

COMMON/COEFFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),

* THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
* THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
* TRACX(25,21), TCACX(25,21), THVCY(25,21),
* ITP(25), TXP(25), IFP(21), FXP(21)

COMMON/OPTION/JOBCO, JOBFO(10)

COMMON/ETA/YC, XK(20)

COMMON/CT/CT(3,3)

COMMON/SXOMEG/OMEGAX(3)

COMMON/DRFT1/ DRAFT1(6)

COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)

DATA DEGREE/O. 01745 32925/

SECTION 1.0 Compute average draft at each station
TSTA(J).

No longer required here. Now done in FROUDE right
before the call to MOCHA

SECTION 2.0 Computations for Coefficients used
in Wave Exciting/Diffraction Force
Calculations

DO 10 J=1, MSTA
DO 10 K=1, NWAVES

IF (JOBCO.EQ.2.OR.JOBCO.EQ.4) THEN

IF=IFP(K)

FX=FXP(K)

CALL TXIT(TSTA(J), IT, TX)

ELSE IF (JOBCO.EQ.3) THEN

IT=ITP(J)

```

      TX=TXP(J)
      IF=IFP(K)
      FX=FXP(K)
END IF

      THAH(J,K)=COX(IT,TX,IF,FX,1,J)
      TSAS(J,K)=COX(IT,TX,IF,FX,2,J)
      TRAR(J,K)=COX(IT,TX,IF,FX,3,J)
      TCCA(J,K)=COX(IT,TX,IF,FX,4,J)

      THVH(J,K)=COX(IT,TX,IF,FX,5,J)
      TSVS(J,K)=COX(IT,TX,IF,FX,6,J)
      TRVR(J,K)=COX(IT,TX,IF,FX,7,J)
      TCCV(J,K)=COX(IT,TX,IF,FX,8,J)

      Spatial derivatives in x-direction

      THACX(J,K)=COXDX(IT,TX,IF,FX,1,J)
      TSACX(J,K)=COXDX(IT,TX,IF,FX,2,J)
      TRACX(J,K)=COXDX(IT,TX,IF,FX,3,J)
      TCACX(J,K)=COXDX(IT,TX,IF,FX,4,J)

      CONTINUE

SECTION 3.0 - This section computes coefficients
              for ship motion related force
              computations, using OMEGAX( ) as
              the frequency at which computations
              are performed. OMEGAX(1) - HEAVE,
              OMEGAX(2) - SWAY, OMEGAX(3) - ROLL.
              These are computed in Subroutine
              GETFREQ.

DO 20 J=1,MSTA
  IF(JOBCO.EQ.2) THEN
    IF=IFP(21)
    FX=FXP(21)
    IFH=IF
    IFS=IF
    IFR=IF
    FXH=FX
    FXS=FX
    FXR=FX
    CALL TXIT(TSTA(J),IT,TX)
  ELSE IF(JOBCO.EQ.3) THEN
    IT=ITP(J)
    TX=TXP(J)
    CALL FXIF(OMEGAX(1),IFH,FXH)
    CALL FXIF(OMEGAX(2),IFS,FXS)
    CALL FXIF(OMEGAX(3),IFR,FXR)
  ELSE IF(JOBCO.EQ.4) THEN
    CALL TXIT(TSTA(J),IT,TX)
    CALL FXIF(OMEGAX(1),IFH,FXH)
    CALL FXIF(OMEGAX(2),IFS,FXS)
    CALL FXIF(OMEGAX(3),IFR,FXR)
  END IF

```

```
THAH(J,21)=COX(IT,TX,IFH,FXH,1,J)
TSAS(J,21)=COX(IT,TX,IFS,FXS,2,J)
TRAR(J,21)=COX(IT,TX,IFR,FXR,3,J)
TCCA(J,21)=COX(IT,TX,IFS,FXS,4,J)
```

C

```
THVH(J,21)=COX(IT,TX,IFH,FXH,5,J)
TSVS(J,21)=COX(IT,TX,IFS,FXS,6,J)
TRVR(J,21)=COX(IT,TX,IFR,FXR,7,J)
TCCV(J,21)=COX(IT,TX,IFS,FXS,8,J)
```

C

C

C

C

Spatial Derivatives in x-directin

```
THACX(J,21)=COXDX(IT,TX,IFH,FXH,1,J)
TSACX(J,21)=COXDX(IT,TX,IFS,FXS,2,J)
THVCX(J,21)=COXDX(IT,TX,IFH,FXH,5,J)
TSVCX(J,21)=COXDX(IT,TX,IFS,FXS,6,J)
```

C

20

C

C

C

C

C

CONTINUE

[Note: Vertical derivative of added mass computed
in SUBROUTINE FROUDE or COFFEE.]

RETURN
END

SUBROUTINE AQUA2D (TT,YY)

CALCULATES SHIP-MOTION INDUCED FORCES, WAVE INDUCED FORCES,
AND OTHER HYDRODYNAMIC FORCES ON THE SHIP.

SECTION	DESCRIPTION
1.0	INITIALIZATION
2.0	FIND WET OFFSET POINTS/ENDS OF HULL
3.0	INITIALIZATION
4.0	CALCULATE VARIOUS 2-D INTEGRALS/GEOMETRIC INFO. FC
5.0	CALCULATE FORCES THAT ARE SHIP-MOTION RELATED
6.0	CALCULATE FORCES THAT ARE WAVE-INDUCED
7.0	CALCULATE OTHER FORCES
8.0	INTEGRATE FORCES OVER LENGTH
9.0	ADD UP FORCES AND LOAD FORCE ARRAY
10.0	LOAD MASS/INERTIA MATRIX A(I,J)

NOTE: The hydrodynamic coefficients were divided by sectional area in COEFS part of this program. They were also divided by RHO in this subroutine. Thus, quantities are multiplied by DVOL when they would normally be multiplied by DX, and there are several places where a coefficient is divided by G operate to make sure that all the units are consistent from force to force. At any point in the force calculations, one must multiply by GAMMA to obtain force in lbs.

```

C1
REAL YY(1)
COMMON /A / A(6,6)
COMMON /AM / YFYA, ZFZA, XMZA, XMXR, XMYR,
1 YMZA, YMYR, ZMYA, ZMZR
COMMON/RESIST/SPEED
REAL VT(6), AM(9)
EQUIVALENCE (AM(1), YFYA)
COMMON /C / C(3,3)
COMMON /CT / CT(3,3)
COMMON /ETA / YC, XK(20)
COMMON /FORCE / XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /V / VX, VY, VZ
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON / / INPTS(25), IPOINT(25), YWET(25,25), ETA(25,25),
1 ZLAST(25,25), ZWET(25,25), ZNEXT(25,25)

```

```

COMMON /      /      ZC0(20), ZS0(20), ZCY(20), ZSY(20),
1             ZCZ(20), ZSZ(20)
COMMON /      /      DZK(20)
COMMON /      /      JSAVE(20), COSJ(20), SINJ(20),
$             COSJJ(20), SINJJ(20),
1             DWC(20), DWS(20), XCI(20), XSI(20)
COMMON /AREA /      AREA, YMOM, ZMOM
EQUIVALENCE (FWD,XPROF(51)), (AFT,YPROF(51))
COMMON/SXFOR/ FBUOY(6,25), FDAMP(6,25), FADMA(6,25), FWVEX(6,25),
*             UDAMP(6,25), UADMA(6,25), UWVEX(6,25), FFLAR(6,25)
COMMON/SXGEOM/AREAS(25), DXS(25), DX1S(25), DX2S(25),
*             YMOMS(25), ZMOMS(25), ISTA, LSTA
COMMON/SXOMEG/OMEGAX(3)
COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)
COMMON/OPTION/JOBCO, JOBFO(10)
DIMENSION COLD(25), CNEW(25), TOLD(25), TNEW(25)
DIMENSION TTOLD(25), TTNEW(25)
REAL ZEROF(1200)
EQUIVALENCE (ZEROF(1), FBUOY(1,1))
COMMON/FCOMP/XFB, YFB, ZFB, XMB, YMB, ZMB
1             XFD, YFD, ZFD, XMD, YMD, ZMD,
2             XFX, YFX, ZFX, XMX, YMX, ZMX,
3             XFN, YFN, ZFN, XMN, YMN, ZMN,
4             XFU, YFU, ZFU, XMU, YMU, ZMU,
5             YFF, ZMF
REAL ZEROC(32)
EQUIVALENCE (ZEROC(1), XFB)
COMMON/COEFFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),
*             THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
*             THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
*             TRACX(25,21), TCACX(25,21), THVCY(25,21),
*             ITP(25), TXP(25), IFP(21), FXP(21)

```

```

C *** Initialization
  IF (NWAVER.EQ.0) GO TO 120

```

SECTION 1.0 - INITIATION

Project wave numbers into calculation coordinate system
(yaw and pitch but not roll). Compute x-coord of wave
crest.

```

DO 110 K=1,NWAVER
  CSK(K)=CT(1,2)*WN(K)
  CCK(K)=CT(2,2)*WN(K)
  CXK(K)=CT(1,1)*WNX(K)-CT(1,3)*WNZ(K)
  CYK(K)=CT(2,1)*WNX(K)-CT(2,3)*WNZ(K)
  CZK(K)=CT(3,1)*WNX(K)-CT(3,3)*WNZ(K)
  DZK(K)=2.0/CZK(K)
  XW(K)=(TT*WVFRE(K)-WVPHA(K)+YY(3)*WNZ(K)-YY(1)*WNX(K))/CXK(K)
  JSAVE(K)=0
110 CONTINUE
120 CONTINUE

```

1.1 Zero the acceleration force coefficients AM(I) and
zero the sectional force arrays in common SXFOR.

```

      DO 130 I=1,9
        AM(I)=0.0
130  CONTINUE
C*
      DO 131 I=1,1200
        ZEROF(I)=0.0      ! Equivalenced with COMMON/SXFOR/
131  CONTINUE
C*
C
      DO 800 I = 1,32
        ZEROC(I)=0.      !ZEROC is EQUIVALENCED with COMMON/FCOMP/
800  CONTINUE
C
C*
C-----
C
C      1.2 Load COMMON/COEFFX/ if JOBCO=2,3 or 4
C-----
C
      CALL TBAR(TT,YY)      !Get average draft at every sta.
      TYPE 1000, (TSTA(J),J=1,MSTA)
1000  FORMAT(1X,25F5.1)
      DO 1000 J=1,MSTA
        TSTA(J)=32.8
C1000 CONTINUE
C
      IF(JOBCO.NE.1.AND.TT.GT.0.) CALL MOCHA
C
      ISTA=0
C-----
C
C      SECTION 2.0 - FIND WET OFFSET POINTS AND HULL ENDS
C-----
C
C3
C3
C3      FIND WET OFFSET POINTS.
C3
C3      ETA(L)   = Y-COORDINATE OF WAVE SURFACE,
C3      YWET(L)  = Y-COORDINATE OF WET OFFSET POINT.
C3      ZWET(L)  = Z-COORDINATE OF WET OFFSET POINT.
C3      ZLAST(L) = Z-COORDINATE OF EITHER THE PREVIOUS WET OFFSET
C3                POINT OR THE Z-COORDINATE OF THE WATER SURFACE,
C3      ZNEXT(L) = Z-COORDINATE OF EITHER THE NEXT WET OFFSET POINT
C3                OR THE Z-COORDINATE OF THE WATER SURFACE.
C3
C4
C4      KEY INDICATES THE STATUS OF THE SEARCH:
C4
C4      KEY = 1  -- THE FIRST OFFSET POINT IS BEING TESTED,
C4      KEY = 2  -- THE LAST OFFSET POINT WAS WET,
C4      KEY = 3  -- THE LAST OFFSET POINT WAS DRY (ETA COMPUTED),
C4      KEY = 4  -- THE LAST OFFSET POINT WAS DRY AND ETAMAX WAS
C4                USED (ETA WAS NOT COMPUTED).
C4
C-----
C
      DO 260 J=1,MSTA
        KEY=1

```

```

I=1
L=0
LWET=0
N=LPTS(J)
XXSTA=XOFF(J)
IF (NWAVES.EQ.0) GO TO 150
DO 140 K=1,NWAVES
    XK(K)=(XXSTA-XW(K))*CXK(K)
140 CONTINUE
150 YC=CT(1,2)*XXSTA+YY(2)
    ETAMAX=(WVSUM-YC)/CT(2,2)
160 Y1=YOFF(I,J)*CTHETA-ZOFF(I,J)*STHETA
    Z1=ZOFF(I,J)*CTHETA+YOFF(I,J)*STHETA
    IF (KEY.LT.3) GO TO 170

C5 THE PREVIOUS OFFSET POINT WAS DRY. AN ESTIMATE OF ETA WILL BE
C5 USED TO SEE IF THIS POINT CAN BE WET.
C5
    IF (Y1.LT.ETAMAX) GO TO 170
    KEY=4
    GO TO 230

C4 COMPUTE THE Y-COORDINATE OF THE WATER SURFACE..
C4
C4 170 ETA1=ETAF(Z1)
    IF (KEY.GT.1) GO TO 180

C5 SAVE INITIAL CALCULATIONS FOR USE WITH FINAL OFFSET POINT.
C5 THE INITIAL AND FINAL OFFSETS REFER TO THE SAME POINT.
C5
    EFIRST=ETA1
    YFIRST=Y1
    YO=Y1
    ZFIRST=Z1
    ZO=Z1

C4 TEST THE POSITION OF THE CURRENT OFFSET POINT RELATIVE TO THE
C4 WATER SURFACE. THE IF TEST IS SATISFIED IF THE POINT IS
C4 BELOW THE WATER SURFACE.
C4
180 IF (Y1.LT.ETA1) GO TO (212,210,200,190),KEY
C5
C5 THE CURRENT OFFSET POINT IS DRY. IF KEY=2, THE PREVIOUS POINT
C5 WAS WET, AND THE Z-COORDINATE OF THE INTERSECTION OF THE HULL
C5 AND THE WATER SURFACE MUST BE FOUND BY INTERPOLATION.
C5
    IF (KEY.NE.2) GO TO 181
    ZNEXT(L,J)=(Z1-ZO)/(Y1-ETA1+EY)*EY+ZO
    LWET=L
    KEY=3
    GO TO 220

181
C5 IF KEY = 4, THE ETA VALUE FOR THE LAST OFFSET POINT WAS NOT
C5 COMPUTED. COMPUTE ETA..
C5
190 EY=ETAF(ZO)-YO
C5
C5 THE CURRENT OFFSET POINT IS WET, AND THE PREVIOUS POINT IS DRY.
C5 INTERPOLATE TO FIND THE INTERSECTION OF THE HULL AND THE WATER
C5 SURFACE..

```

```

200      ZO=ZO+(Z1-ZO)/(Y1-ETA1+EY)*EY
        GO TO 211
C4
C4      A WET OFFSET POINT HAS BEEN LOCATED.  STORE THE REQUIRED
C4      COORDINATE VALUES..
C4
210      ZNEXT(L,J)=Z1
211      IF (I.EQ.N) GO TO 240
212      L=L+1
        ETA(L,J)=ETA1
        YWET(L,J)=Y1
        ZWET(L,J)=Z1
        ZLAST(L,J)=ZO
        KEY=2
C5
C5      SAVE THE COMPUTED COORDINATE OF THE WATER SURFACE..
C5
220      EY=ETA1-Y1
C5
C5      SAVE THE COORDINATES OF THE OFFSET POINT..
C5
230      YO=Y1
        ZO=Z1
C4
C4      INCREMENT THE INDEX OF THE OFFSET POINT FOR THIS STATION.  IF
C4      THE INDEX DOES NOT REFER TO THE LAST POINT, REPEAT THE LOOP.
C4
        I=I+1
        IF (I.LT.N) GO TO 160
        IF (I.GT.N) GO TO 250
C5
C5      FOR THE LAST OFFSET POINT, THE VALUES OF ETA1, X1, AND Y1 ARE
C5      THE SAME AS FOR THE FIRST OFFSET POINT.  REPEAT THE LOOP USING
C5      THESE VALUES..
C5
        ETA1=EFIRST
        Y1=YFIRST
        Z1=ZFIRST
        GO TO 180
C4
C4      A COMPLETE SEARCH OVER ALL THE OFFSET POINTS FOR THE CURRENT
C4      STATION HAS OBTAINED L WET OFFSET POINTS.  RESET ZLAST(1)
C4      IF THE LAST (AND ALSO THE FIRST) OFFSET POINT IS WET..
C4
240      ZLAST(1,J)=ZO
250      INPTS(J)=L
        IF (L.EQ.0) GO TO 260
        IF (LWET.EQ.L) LWET=0
        IPOINT(J)=LWET+1
        LSTA=J
        IF (ISTA.EQ.0) ISTA=J
C3
260      CONTINUE
        IF (ISTA.EQ.0) GO TO 520
C3
C3      FIND ENDS OF WETTED HULL..
C3
C3      XXF      = X-COORDINATE FORWARD
C3      XXA      = X-COORDINATE AFT
C3
        XXF=XOFF(ISTA)

```

XXA=XOFF(LSTA)
IF (NPROF.EQ.0) GO TO 410

SEARCH FOR ENDS USING THE PROFILE DATA..

XLAST	--	X-COORDINATE OF PREVIOUS PROFILE POINT
XXSTA	--	X-COORDINATE OF PRESENT PROFILE POINT
ETABAR	--	WAVE ELEVATION IN ABSOLUTE COORDINATES
Y0	--	SUBMERGENCE OF PREVIOUS PROFILE POINT (LAST.EQ.1)
Y1	--	SUBMERGENCE OF PRESENT PROFILE POINT
IEND=0	--	FORWARD END OF SHIP
IEND=1	--	AFT END OF SHIP
KEY=-1	--	SUBMERGENCE OF PRESENT PROFILE POINT UNKNOWN
KEY=0	--	WAVE ELEVATION NOT COMPUTED
KEY=1	--	WAVE ELEVATION COMPUTED
LAST	--	KEY VALUE FOR PREVIOUS PROFILE POINT
LWET=0	--	PREVIOUS PROFILE POINT WAS DRY (LAST.GE.0)
LWET=1	--	PREVIOUS PROFILE POINT WAS SUBMERGED (LAST.GE.0)

XLAST=XPROF(1)

LAST=-1

DO 400 I=2,NPROF

KEY=-1

IEND=0

XXSTA=XPROF(I)

IF (XXSTA.GT.XXF) GO TO 270

IEND=1

IF (XXSTA.LT.XXA) GO TO 270

IF (XLAST.GE.XXA) GO TO 390

270

KEY=0

Y1=YPROF(I)*C(2,2)+XXSTA*C(1,2)-YY(2)

IF (Y1.LT.-WVSUM) GO TO 310

IF (Y1.GT.WVSUM) GO TO 280

Y1=ETABAR(I)-Y1

KEY=1

IF (Y1.GE.0.0) GO TO 310

POINT IS DRY.

280

IF (IEND.NE.0) GO TO 300

IF (LAST.LT.0) GO TO 290

IF (LWET.EQ.0) GO TO 300

IF (LAST.NE.0) GO TO 340

290

Y0=YPROF(I-1)*C(2,2)+XLAST*C(1,2)-YY(2)

IF (Y0.GT.WVSUM) GO TO 300

Y0=ETABAR(I-1)-Y0

IF (Y0.GE.0.0) GO TO 340

300

LWET=0

GO TO 380

POINT IS WET.

310

IF (IEND.NE.0) GO TO 320

XXF=XXSTA

LWET=1

GO TO 380

320

IF (LAST.LT.0) GO TO 330

IF (LWET.NE.0) GO TO 360

IF (LAST.NE.0) GO TO 340

330

Y0=YPROF(I-1)*C(2,2)+XLAST*C(1,2)-YY(2)

IF (Y0.LE.-WVSUM) GO TO 360

```

      YO=ETABAR(I-1)-YO
      IF (YO.GE.0.0) GO TO 360
C5
C5
C5      INTERPOLATE FOR WATERLINE.
340    IF (KEY.NE.0) GO TO 350
      Y1=ETABAR(I)-Y1
      KEY=1
350    XXSTA=(XPROF(I-1)-XXSTA)/(Y1-YO)+XXSTA
      IF (IEND.NE.0) GO TO 360
      IF (XXSTA.GT.XXF) XXF=XXSTA
      GO TO 370
360    IF (XXSTA.LT.XXA) XXA=XXSTA
370    LWET=IEND
380    YO=Y1
390    LAST=KEY
      XLAST=XXSTA
400    CONTINUE
410    IF (NFWD.NE.1) GO TO 420
      IF (XXF.LT.FWD) XXF=FWD
420    IF (NAFT.NE.1) GO TO 430
      IF (XXA.GT.AFT) XXA=AFT

```

```

C3
-----
SECTION 3.0  ANOTHER INITIALIZATION

Resolve velocity vector into yawed and pitched coord's.
NOTE: Forces are calculated in local (ship) coordinate
      system.
-----

```

```

430  VT(1)=VX
      VT(2)=VY*CTHETA-VZ*STHETA
      VT(3)=VZ*CTHETA+VY*STHETA
      VT(4)=YY(10)
      VT(5)=YY(11)*CTHETA-YY(12)*STHETA
      VT(6)=YY(12)*CTHETA+YY(11)*STHETA
-----

```

```

      Loop over wet stations ISTA to LSTA.
      Also check to see if ship is out of water (SMALL)
-----

```

```

      LSAVE=0

```

```

      SMALL=(XXF-XXA)*1.0E-06
      IF (SMALL.LE.0.0) GO TO 520
      XXSTA=XXF
      DO 510 J=ISTA,LSTA
-----

```

```

      Section 4.1 - Get geometric station data, e.g. DX.
-----

```

```

      XXFWD=XXSTA
      XXSTA=XOFF(J)
      IF (INPTS(J).EQ.0) GO TO 510
      YC=YY(2)+CT(1,2)*XXSTA
      IF (J.NE.LSTA) GO TO 331

```

```

331  XXAFT=XXA
332  GO TO 332
    XXAFT=XOFF(J+1)
    CONTINUE
    DXFWD=XXFWD-XXSTA
    DXAFT=XXSTA-XXAFT
    DX=(DXFWD+DXAFT)/2.0
    XA=XXSTA-DXAFT/3.0
    XB=XXSTA+DXFWD/3.0
    DX1=(DXFWD*XB+DXAFT*XA)/2.0
    DX2=(DXFWD*XB**2+DXAFT*XA**2)/2.0+(DXFWD**3+DXAFT**3)/36.0

```

```

C-----
C
C      Section 4.2 - Call KRYLOV by section (j) and get 2-D
C                  integrals for that station.
C-----

```

```

C      CALL KRYLOV (J)
C-----

```

```

C      Section 4.3 - Compute the sectional volumes and moments
C                  about center of mass.
C-----

```

```

C
C      DVOL=AREA*DX
C      ADX1=AREA*DX1
C      ADX2=AREA*DX2
C      YDX=YMOM*DX
C      ZDX=ZMOM*DX
C-----

```

```

C      Load COMMON/SXGEOM/
C      AREAS(J)=AREA
C      DXS(J)=DX
C      DX1S(J)=DX1
C      DX2S(J)=DX2
C      YMOMS(J)=YMOM
C      ZMOMS(J)=ZMOM
C-----

```

```

C      SECTION 5.0 - SHIP MOTION RELATED FORCES
C-----

```

```

C      FBUOY(I,J) - Buoy force
C      FDAMP(I,J) - Damping force
C      FADMA(I,J) - Added Mass Force for purposes of analysis
C                  only since the added mass actually goes
C                  on the left hand side of the Equations.
C-----

```

```

C      Section 5.1 - Buoyancy Force
C-----

```

```

C      FBUOY(1,J)=CT(1,2)*DVOL
C      FBUOY(2,J)=CT(2,2)*DVOL
C      FBUOY(3,J)=0.
C      FBUOY(4,J)=-CT(2,2)*ZDX
C      FBUOY(5,J)=CT(1,2)*ZDX

```

FBUOY(6, J) = CT(2, 2)*ADX1-CT(1, 2)*YDX

Section 5.2 - Damping force

Get damping coefficients ...

This section will be changed to reflect the dependency on frequency of ship motion.

HVH=COEFF(1, 2, J)/G
SVS=COEFF(2, 2, J)/G
RVR=COEFF(3, 2, J)/G
CCV=COEFF(4, 2, J)/G

HVH=THVH(J, 21)/G
SVS=TSVS(J, 21)/G
RVR=TRVR(J, 21)/G
CCV=TCCV(J, 21)/G

HAH=THAH(J, 21)
SAS=TSAS(J, 21)
RAR=TRAR(J, 21)
CCA=TCCA(J, 21)

VS=VT(5)*ADX1-VT(3)*DVOL
VR=VT(4)*DVOL
FDAMP(1, J)=0.
FDAMP(2, J)=(VT(4)*ZDX-VT(2)*DVOL-VT(6)*ADX1)*HVH
FDAMP(3, J)=VS*SVS-VR*CCV
FDAMP(4, J)=VS*CCV-VR*RVR
FDAMP(5, J)=(VT(3)*ADX1-VT(5)*ADX2)*SVS+VT(4)*ADX1*CCV
FDAMP(6, J)=(VT(4)*ZDMOM*DX1-VT(2)*ADX1-VT(6)*ADX2)*HVH

Section 5.3 - Speed terms

5.3.1 - Speed terms associated with damping

UDAMP(1, J)=0.

UDAMP(2, J)=(2. *SPEED*YY(6))*HVH*DVOL
UDAMP(3, J)=-(2. *SPEED*YY(5))*SVS*DVOL
UDAMP(4, J)=0.
UDAMP(5, J)=(2. *SPEED*YY(5))*SVS*ADX1
UDAMP(6, J)=(2. *SPEED*YY(6))*HVH*ADX1

*** Extra speed terms from extended strip (X SCORES)

U2TEMP=(YY(2)*DVOL+YY(6)*ADX1+SPEED*DVOL*
* (VT(6)/OMEGAX(1)**2))*(THVCX(J, 21)/G)*
* SPEED

UDAMP(2, J)=UDAMP(2, J)+U2TEMP
UDAMP(6, J)=UDAMP(6, J)+U2TEMP*(ADX1/DVOL)

5.3.2 Speed terms associated with added mass

UADMA(1, J)=0.
UA21=(2. *SPEED*VT(6))*(HAH/G)*DVOL

```

1      UA22=(VT(4)*ZDX-VT(2)*DVOL-VT(6)*ADX1+SPEED*YY(6)
        *DVOL)*SPEED*(THACX(J,21)/G)
      UADMA(2,J)=UA21-UA22
      UA31=(-2.*SPEED*VT(5))*(SAS/G)*DVOL
      UA32=(VS-SPEED*YY(5))*(TSACX(J,21)/G)*SPEED
      UADMA(3,J)=UA31+UA32
      UADMA(4,J)=-VR*SPEED*TRACX(J,21)/G
      UA51=(2.*SPEED*VT(5))*(SAS/G)*ADX1
      UA52=((SPEED*YY(5)*ADX1)+(VT(3)*ADX1-VT(5)*ADX2))
1      *SPEED*TSACX(J,21)/G
      UADMA(5,J)=UA51+UA52
      UA61=(2.*SPEED*VT(6))*(HAH/G)*ADX1
      UA62=((SPEED*YY(6)*ADX1)+(VT(4)*ZDMOM*DX1-VT(2)*
1      ADX1-VT(6)*ADX2))*SPEED*THACX(J,21)/G
      UADMA(6,J)=UA61-UA62

```

```

      YFYA=HAH*DVOL+YFYA
      ZFZA=SAS*DVOL+ZFZA
      XMZA=CCA*DVOL+XMZA
      XMXR=RAR*DVOL+XMXR
      XMYR=XMYR-CCA*ADX1
      YMZA=YMZA-SAS*ADX1
      YMYR=SAS*ADX2+YMYR
      ZMYA=HAH*ADX1+ZMYA
      ZMZR=HAH*ADX2+ZMZR

```

Section 5.4 - Force due to weight of ship

```

      XFW=-CT(1,2)*DISPL
      YFW=-CT(2,2)*DISPL

```

Section 7.2 - So called "flare" force

```

      IF(TT.EQ.TTOLD(J)) GO TO 721
      TNEW(J)=TSTA(J)
      TAVG=TSTA(J)
      CALL TXIT(TAVG,IT,TX)
      CNEW(J)=COX(IT,TX,11,1,1,J)*ARX(IT,TX,J)/G
      TTNEW(J)=TT
      DC=CNEW(J)-COLD(J)
      DT=TNEW(J)-TOLD(J)
      DTT=TTNEW(J)-TTOLD(J)
      TOLD(J)=TNEW(J)
      TTOLD(J)=TTNEW(J)
      COLD(J)=CNEW(J)

```

```

      IF (DT.GT.0. AND.DTT.NE.0.) THEN !Relative Velocity indicates immersi
      FFLAR(2,J)=(DT/DTT)**2*(DC/DT)*DX
      FFLAR(6,J)=(DT/DTT)**2*(DC/DT)*DX1
      ELSE ! Relative velocity indicates emergence
      FFLAR(2,J)=0.
      FFLAR(6,J)=0.

```

```

      END IF
C
C 721 CONTINUE                                !Skip to here when TT=TTOLD
C-----
C      If there are no waves, skip over the wave loop -
C      [Do 500] and go to 510 (the other side of the section
C      loop).
C      IF (NWAVER.EQ.0) GO TO 510
C-----
C      SECTION 6.0 - WAVE-INDUCED FORCES
C-----
C
C      IF (LSAVE.NE.0) GO TO 450
C      IF (DXFWD.LT.SMALL) GO TO 441
C      DDXFWD=1.0/DXFWD
C      GO TO 460
C 441 DDXFWD=0.0
C      GO TO 460
C 450 DDXFWD=DDXAFT
C 460 IF (DXAFT.LT.SMALL) GO TO 461
C      DDXAFT=1.0/DXAFT
C      GO TO 470
C 461 DDXAFT=0.0
C
C 470 LSAVE=LSTA-J
C      IF (LSAVE.NE.0) LSAVE=INPTS(J+1)
C
C-----
C      Loop over waves (frequency index K)
C-----
C
C      DO 500 K=1,NWAVER
C-----
C      Section 6.1 - Compute integration multipliers...
C      DXCOS, DXSIN, DX1COS, DX1SIN.
C-----
C
C      XWC=XW(K)
C      XWSTA=XXSTA-XWC
C      SQSTA=XWSTA**2
C      XWAFT=XXAFT-XWC
C      SGAFT=XWAFT**2
C      XWFWD=XXFWD-XWC
C      SGFWD=XWFWD**2
C      DXWAFT=XWAFT*DDXAFT
C      DXWFWD=XWFWD*DDXFWD
C      WCOSB=CXK(K)
C
C      IF (JSAVE(K).EQ.0) GO TO 472
C      COSSTA=COSJ(K)
C      SINSTA=SINJ(K)
C      GO TO 473
C 472 CONTINUE
C      ARGSTA=WCOSB*XWSTA
C      COSSTA=COS(ARGSTA)
C      SINSTA=SIN(ARGSTA)
C 473 CONTINUE

```

```

C      IF (ABS(WCOSB*DX).GT.0.01) GO TO 480
C
C      DXCOS=DX*COSSTA
C      DXSIN=DX*SINSTA
C      DX1COS=DX1*COSSTA
C      DX1SIN=DX1*SINSTA
C      JSAVE(K)=0
C      GO TO 490
C
C 480    WCOSB2=2.0/WCOSB
C      XCSTA=COSSTA*XWSTA
C      XSSTA=SINSTA*XWSTA
C
C      IF (JSAVE(K).EQ.0) GO TO 481
C      COSFWD=COSJJ(K)
C      SINFWWD=SINJJ(K)
C      DWCFWD=DWC(K)
C      DWSFWD=DWS(K)
C      XCIFWD=XCI(K)
C      XSIFWD=XSI(K)
C      GO TO 482
C
C 481    ARGFWD=WCOSB*XWFWWD
C      COSFWD=COS(ARGFWD)
C      SINFWWD=SIN(ARGFWD)
C      DWCFWD=(COSFWD-COSSTA)/WCOSB
C      DWSFWD=(SINFWWD-SINSTA)/WCOSB
C      XCIFWD=(SINFWWD*XWFWWD-XSSTA+DWCFWD)*DDXFWD
C      XSIFWD=(XCSTA-COSFWD*XWFWWD+DWSFWD)*DDXFWD
C
C 482    ARGFT=WCOSB*XWFT
C      COSFT=COS(ARGFT)
C      SINFT=SIN(ARGFT)
C      DWCAFT=(COSSTA-COSFT)/WCOSB
C      DWSAFT=(SINSTA-SINFT)/WCOSB
C      XCIAFT=(XSSTA-SINFT*XWFT+DWCAFT)*DDXAFT
C      XSIAFT=(COSFT*XWFT-XCSTA+DWSAFT)*DDXAFT
C
C      DXCOS=(XCIAFT-XCIFWD)/WCOSB-DXWFT*DWSAFT+DXWFWWD*DWSFWD
C      DXSIN=(XSIAFT-XSIFWD)/WCOSB+DXWFT*DWCAFT-DXWFWWD*DWCFWD
C      DX1COS=XWC*DXCOS+((SGSTA*SINSTA-SGAFT*SINFT)*DDXAFT+(SGSTA*
1      SINSTA-SGFWD*SINFWWD)*DDXFWD+(XSIFWD-XSIAFT)*WCOSB2+XWFWWD*XCI
2      FWD-XWFT*XCIAFT)/WCOSB
C      DX1SIN=XWC*DXSIN+((SGFWD*COSFWD-SGSTA*COSSTA)*DDXFWD+(SGAFT*
1      COSAFT-SGSTA*COSSTA)*DDXAFT+(XCIAFT-XCIFWD)*WCOSB2+XWFWWD*XSI
2      FWD-XWFT*XSIAFT)/WCOSB
C
C      JSAVE(K)=LSAVE
C      IF (LSAVE.EQ.0) GO TO 490
C      COSJ(K)=COSFT
C      SINJ(K)=SINFT
C      COSJJ(K)=COSSTA
C      SINJJ(K)=SINSTA
C      DWC(K)=DWCAFT
C      DWS(K)=DWSAFT
C      XCI(K)=XCIAFT
C      XSI(K)=XSIAFT
C
C 490    CONTINUE
C      EXPSTA=EXP(WN(K)*YC)*WVAMP(K)

```

```

DXCOS=DXCOS*EXPSTA
DXSIN=DXSIN*EXPSTA
DX1COS=DX1COS*EXPSTA
DX1SIN=DX1SIN*EXPSTA

```

Section 6.2 - Compute exciting forces (wave dynamic pressure plus diffraction force)

```

HVVH=COEFF(1,2,J)/WVFRE(K)
SVS=COEFF(2,2,J)/WVFRE(K)
RVR=COEFF(3,2,J)/WVFRE(K)
CCV=COEFF(4,2,J)/WVFRE(K)

```

```

HAH=THAH(J,K)
HAH=HAH+1.
SAS=TSAS(J,K)
SAS=SAS+1.
RAR=TRAR(J,K)
CCA=TCCA(J,K)

```

```

HVVH=THVH(J,K)/WVFRE(K)
SVS=TSVS(J,K)/WVFRE(K)
RVR=TRVR(J,K)/WVFRE(K)
CCV=TCCV(J,K)/WVFRE(K)

```

```

AH1=CYK(K)*ZSO(K)-CCK(K)*ZCO(K)
AH2=CCK(K)*ZSO(K)+CYK(K)*ZCO(K)
AS1=CZK(K)*ZSO(K)
AS2=CZK(K)*ZCO(K)
AR1=CZK(K)*ZSY(K)+CCK(K)*ZCZ(K)-CYK(K)*ZSZ(K)
AR2=CZK(K)*ZCY(K)-CCK(K)*ZSZ(K)-CYK(K)*ZCZ(K)
FWVEX(1,J)=(CXK(K)*ZSO(K)-CSK(K)*ZCO(K))*DXCOS
+ (CXK(K)*ZCO(K)+CSK(K)*ZSO(K))*DXSIN+FWVEX(1,J)
YF1=AH1*HAH+AH2*HVVH
YF2=AH2*HAH-AH1*HVVH
FWVEX(2,J)=YF1*DXCOS+YF2*DXSIN+FWVEX(2,J)
ZF1=AS1*SAS+AS2*SVS+(AS1*CCA+AS2*CCV)*WN(K)
ZF2=AS2*SAS-AS1*SVS+(AS2*CCA-AS1*CCV)*WN(K)
FWVEX(3,J)=ZF1*DXCOS+ZF2*DXSIN+FWVEX(3,J)
FWVEX(4,J)=(AR1+(AS1*RAR+AS2*RVR)*WN(K)+AS1*CCA+
AS2*CCV)*DXCOS+(AR2+(AS2*RAR-AS1*RVR)*WN(K)+AS2*CCA
-AS1*CCV)*DXSIN+FWVEX(4,J)
FWVEX(5,J)=(CXK(K)*ZSZ(K)-CSK(K)*ZCZ(K))*DXCOS+
(CXK(K)*ZCZ(K)+CSK(K)*ZSZ(K))*DXSIN-ZF1*DX1COS-ZF2
*DX1SIN+FWVEX(5,J)
FWVEX(6,J)=(CSK(K)*ZCY(K)-CXK(K)*ZSY(K))*DXCOS-
(CSK(K)*ZSY(K)+CXK(K)
*ZCY(K))*DXSIN+YF1*DX1COS+YF2*DX1SIN+FWVEX(6,J)

```

C3

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

6.3 Speed dependent wave-exciting terms

```

DADX=SPEED*THACX(J,K)/WVFRE(K) !Turns acc.'s into Vel's
UWVEX(2,J)=AH1*DADX*DXSIN-AH2*DADX*DXCOS+UWVEX(2,J)
Another speed term - spatial derivative of damping in x
DCDX=SPEED*(THVCX(J,K)/G)*DVOL*WVFRE(K)/OMEGAX(1)
UWVEX(2,J)=UWVEX(2,J)+DCDX*ETAY(J,K)
UZF1=AS1*TSACX(J,K)+AS2*TSVCX(J,K)
UZF2=AS2*TSACX(J,K)-AS1*TSVCX(J,K)
1 UWVEX(3,J)=(-UZF1*DXSIN+UZF2*DXCOS)*(SPEED/WVFRE(K))
      +UWVEX(3,J)

UWVEX(4,J)=0. ! Modify this
UWVEX(5,J)=(-UZF1*DX1SIN+UZF2*DX1COS)*(SPEED/WVFRE(K))
1      + UWVEX(5,J)
UWVEX(6,J)=AH1*DADX*DX1SIN-AH2*DADX*DX1COS
DCDX1=SPEED*(THVCX(J,K)/G)*ADX1*WVFRE(K)/OMEGAX(1)
UWVEX(6,J)=DCDX1*ETAY(J,K)+UWVEX(6,J)

```

```

500 CONTINUE
510 CONTINUE

```

SECTION 7.0 - OTHER FORCES

Force resulting from acceleration caused by the rotating coordinates.

```

YA=VT(6)*VT(1)-VT(4)*VT(3)
YA=YA/G
ZA=VT(4)*VT(2)-VT(5)*VT(1)
ZA=ZA/G
XFN=0.
YFN=YFYA*YA
ZFN=ZFZA*ZA
XMN=XMZA*ZA
YMN=YMZA*ZA
ZMN=ZMYA*YA

```

SECTION 8.0 - INTEGRATE FORCES ALONG LENGTH OF HULL

Section 8.1 - Integrate buoyancy force

```

DO 801 J=ISTA,LSTA
XFB=FBUDY(1,J)+XFB
YFB=FBUDY(2,J)+YFB
ZFB=FBUDY(3,J)+ZFB
XMB=FBUDY(4,J)+XMB

```

```

      YMB=FBUOY(5,J)+YMB
      ZMB=FBUOY(6,J)+ZMB
801  CONTINUE
C
C-----
C      Section 8.2 - Integrate damping force
C-----
C
      DO 802 J=ISTA,LSTA
      XFD=FDAMP(1,J)+XFD
      YFD=FDAMP(2,J)+YFD
      ZFD=FDAMP(3,J)+ZFD
      XMD=FDAMP(4,J)+XMD
      YMD=FDAMP(5,J)+YMD
      ZMD=FDAMP(6,J)+ZMD
802  CONTINUE
C
C-----
C      Section 8.3 - Integrate exciting force
C-----
C
      DO 803 J=ISTA,LSTA
      XFX=FWVEX(1,J)+XFX
      YFX=FWVEX(2,J)+YFX
      ZFX=FWVEX(3,J)+ZFX
      XMX=FWVEX(4,J)+XMX
      YMX=FWVEX(5,J)+YMX
      ZMX=FWVEX(6,J)+ZMX
803  CONTINUE
C
C-----
C      Section 8.4 - Integrate Speed Related forces
C-----
C
      IF(JOBFO(2).NE.1) GO TO 814
      DO 804 J=ISTA,LSTA
      XFU=UDAMP(1,J)+UADMA(1,J)+UWVEX(1,J)+XFU
      YFU=UDAMP(2,J)+UADMA(2,J)+UWVEX(2,J)+YFU
      ZFU=UDAMP(3,J)+UADMA(3,J)+UWVEX(3,J)+ZFU
      XMU=UDAMP(4,J)+UADMA(4,J)+UWVEX(4,J)+XMU
      YMU=UDAMP(5,J)+UADMA(5,J)+UWVEX(5,J)+YMU
      ZMU=UDAMP(6,J)+UADMA(6,J)+UWVEX(6,J)+ZMU
804  CONTINUE
814  CONTINUE          !Go directly here to skip over
C
C-----
C      Section 8.5 - Integrate flare force
C-----
C
      IF(JOBFO(3).NE.1) GO TO 815
      DO 805 J=ISTA,LSTA
      YFF=FFLAR(2,J)+YFF
      ZMF=FFLAR(6,J)+ZMF
805  CONTINUE
815  CONTINUE          !Directly to here to skip over
C
C-----
C4   SET UP MATRIX OF FORCE COEFFICIENTS FOR FORCES AND ACCELERATIONS

```

C4 IN SHIP COORDINATE DIRECTIONS..

C4 520 CONTINUE

C4

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

C

SECTION 9.0 - TOTAL FORCES

Add up forces. Then resolve forces and moments into the ship offset coordinate system.

```
XFT=XFB+XFD+XFX+XFN+XFW+XFU
YFT=YFB+YFD+YFX+YFN+YFW+YFU+YFF
ZFT=ZFB+ZFD+ZFX+ZFN+ZFU
XMT=XMB+XMD+XMX+XMN+XMU
YMT=YMB+YMD+YMX+YMN+YMU
ZMT=ZMB+ZMD+ZMX+ZMN+ZMU+ZMF
```

```
XF=XFT*GAMMA
YF=YFT*GAMMA
TEMP=YF
ZF=ZFT*GAMMA
YF=YF*CTHETA+ZF*STHETA
ZF=ZF*CTHETA-TEMP*STHETA
XM=XMT*GAMMA
TEMP=YMT
YM=(YMT*CTHETA+ZMT*STHETA)*GAMMA
ZM=(ZMT*CTHETA-TEMP*STHETA)*GAMMA
```

SECTION 10.0 - LOAD MASS/INERTIA MATRIX A(I,J)

```
A(2,4)=0.0
DO 530 I=1,9
  AM(I)=RHO*AM(I)
530 CONTINUE
CC=CTHETA**2
CS=CTHETA*STHETA
SS=STHETA**2
A(2,2)=YFYA*CC+ZFZA*SS+SMASS
A(2,3)=(ZFZA-YFYA)*CS
A(3,2)=A(2,3)
A(2,5)=ZMYA*CS
A(2,6)=ZMYA*CC
A(3,3)=ZFZA*CC+YFYA*SS+SMASS
A(3,4)=XMZA*CTHETA
A(4,3)=A(3,4)
A(4,2)=XMZA*STHETA
A(4,4)=XMXR+PMI(1,1)
A(4,5)=XMYR*CTHETA+PMI(1,2)
A(5,4)=A(4,5)
A(4,6)=PMI(1,3)-XMYR*STHETA
A(6,4)=A(4,6)
A(5,2)=(ZMYA+YMZA)*CS
```

A(3,6)=-A(5,2)
A(6,3)=A(3,6)
A(5,3)=YMZA*CC-ZMYA*SS
A(3,5)=A(5,3)
A(5,5)=YMYR*CC+ZMZR*SS+PMI(2,2)
A(5,6)=(ZMZR-YMYR)*CS+PMI(2,3)
A(6,5)=A(5,6)
A(6,2)=ZMYA*CC-YMZA*SS
A(6,6)=ZMZR*CC+YMYR*SS+PMI(3,3)
RETURN

C

END

SUBROUTINE HULL

This subroutine calculates hull girder loads

```

COMMON /C / C(3,3)
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON / / NWAVES, WVSUM,
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2 WN(20), WNX(20), WNZ(20),
3 CSK(20), CCK(20), CXK(20),
4 CYK(20), CZK(20), XW(20)
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1 XOFF(25), YOFF(25,25), ZOFF(25,25),
2 XPROF(51), YPROF(51)
COMMON/COEFFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),
* THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
* THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
* TRACX(25,21), TCACX(25,21), THVCY(25,21),
* ITP(25), TXP(25), IFP(21), FXP(21)
COMMON /FORCE / XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /LHS / Y(13)
COMMON /MASS / RHO, G, GAMMA
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS / PMI(3,3)
COMMON/RESIST/SPEED
COMMON /V / VX, VY, VZ
COMMON/SXPROP/ SEGMA(26), SEGMOX(26), STRMAS(26), STRMOM(26),
* STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
COMMON/SXFOR/ FBUOY(6,25), FDAMP(6,25), FADMA(6,25), FWVEX(6,25),
* UDAMP(6,25), UADMA(6,25), UWVEX(6,25), FFLAR(6,25)
COMMON/SXGEOM/ AREAS(25), DXS(25), DX1S(25), DX2S(25),
* YMOMS(25), ZMOMS(25), ISTA, LSTA
COMMON/ACCEL/ACC(6)
COMMON/LOADS/ SIN2(25), SIN3(25), SIN4(25), SIN5(25), SIN6(25),
1 V2(25), V3(25), V4(25), V5(25), V6(25),
2 RED(6,25)
COMMON/OPTION/JOBCO, JOBFO(10)

```

SECTION 1.0 GET SECTIONAL INERTIA/MOMENT OF INERTIAS

```

DO 90 J=1,MSTA
XBAR(J)=XOFF(J)
STRMAS(J)=SEGMA(J)
SIN2(J)=0.
SIN3(J)=0.
SIN4(J)=0.
SIN5(J)=0.
SIN6(J)=0.
DO 91 I=1,6
RED(I,J)=0.
CONTINUE
CONTINUE

```

```

DO 100 J=1,MSTA
DSTRPI=XOFF(J)
DO 101 JJ=1,J

```

```

C      TVACCL=ACC(2)+XBAR(JJ)*ACC(6)
C      THACCL=ACC(3)-XBAR(JJ)*ACC(5)+YBAR(JJ)*ACC(4)
C-----NOTE!!! We are adding in weight of the section
C      by including gravitational acceleration. This
C      is different from standard strip theory load
C      computations. (They compute wave induce dynamic
C      loads) We are computing total loads at each time
C      step... We have the TOTAL HYDROSTATIC RESTORING
C      force not just the change due to unit wave/motion
C      [see eq. 70 STF METHOD/TRANS SNAME '70]
C
C      GVACCL=-G*COS(Y(4))
C      GHACCL=G*SIN(Y(4))
C
C      HACCL=-THACCL+GHACCL
C      VACCL=-TVACCL+GVACCL
C
C      SIN2(J)=STRMAS(JJ)*VACCL+SIN2(J)
C      SIN3(J)=STRMAS(JJ)*HACCL+SIN3(J)
C      SIN4(J)=STRMOX(JJ)*ACC(4)-((STRMAS(JJ)*YBAR(JJ))*
1      (ACC(3)+XBAR(JJ)*ACC(5)))+SIN4(J)
C      DSTPRI=XOFF(J)-(.5*DXS(J))
C      ZETMX=XBAR(JJ)-DSTPRI
C      SIN5(J)=ZETMX*STRMAS(JJ)*HACCL+SIN5(J)
C      SIN6(J)=ZETMX*STRMAS(JJ)*VACCL+SIN6(J)
C
C 101  CONTINUE
C-----
C-----
C-----
C 100  CONTINUE
C-----
C-----
C      SECTION 2.0  GET ADDED MASS FORCES FADMA( , )
C-----
C
C      DO 200 J=1,MSTA
C      DO 200 I=1,6
C      FADMA(I,J)=0.
200  CONTINUE
C
C      DO 201 J=ISTA,LSTA
C
C      AREA=AREAS(J)
C      DX=DXS(J)
C      DX1=DX1S(J)
C      DX2=DX2S(J)
C      YMOM=YMOMS(J)
C      ZMOM=ZMOMS(J)
C
C      DVOL=AREA*DX
C      ADX1=AREA*DX1
C      ADX2=AREA*DX2
C      YDX=YMOM*DX
C      ZDX=ZMOM*DX

```

```

C      HAH=THAH(J,21)/G
      SAS=TSAS(J,21)/G
      RAR=TRAR(J,21)/G
      CCA=TCCA(J,21)/G

C
C      AS=ACC(5)*ADX1-ACC(3)*DVOL
      AR=ACC(4)*DVOL
      FADMA(1,J)=0.
      FADMA(2,J)=(ACC(4)*ZDX-ACC(2)*DVOL-ACC(6)*ADX1)*HAH
      FADMA(3,J)=AS*SAS-AR*CCA
      FADMA(4,J)=AS*CCA-AR*RAR
      FADMA(5,J)=(ACC(3)*ADX1-ACC(5)*ADX2)*SAS+ACC(4)
1      *ADX1*CCA
1      FADMA(6,J)=(ACC(4)*ZMOM*DX1-ACC(2)*ADX1-
      ACC(6)*ADX2)*HAH

C
C 201  CONTINUE
C
C      SECTION 3.0  GET HYDRO FORCES (CALL THEM RED) AND THEN
C                  GET LOADS
C-----
C
C      DO 900 J=1,MSTA
900  CONTINUE
C
C      DO 300 I=2,3
      DO 301 J=1,MSTA
      REDSUM=0.
      DO 302 JJ=1,J
      REDSUM=-FBUOY(I,JJ)-FDAMP(I,JJ)-FADMA(I,JJ)-FWVEX(I,JJ)
      *      +REDSUM
      UTERMS=-UDAMP(I,JJ)-UADMA(I,JJ)-UWVEX(I,JJ)
      FTERMS=-FFLAR(I,JJ)
      IF(JOBFO(2).EQ.1) REDSUM=REDSUM+UTERMS
      IF(JOBFO(3).EQ.1) REDSUM=REDSUM+FTERMS
302  CONTINUE
      RED(I,J)=REDSUM*GAMMA
301  CONTINUE
300  CONTINUE
C-----
C
C      Now do moments
C
C      DO 310 IX=5,6
      IF(IX.EQ.5) I=3
      IF(IX.EQ.6) I=2
      DO 311 J=1,MSTA
      DSTRPI=XOFF(J)
C      DSTRPI=XOFF(J)-(.5*DXS(J))
      REDSUM=0.
C
C      DO 312 JJ=1,J
C
C      ARMJJ=XBAR(JJ)
      ARMX=ARMJJ-DSTRPI
      FDARM=FDAMP(I,JJ)*ARMX
      FWARM=FWVEX(I,JJ)*ARMX

```

```

      FBARM=FBUDY(I,JJ)*ARMX
      FAARM=FADMA(I,JJ)*ARMX
      FUARM=(UADMA(I,JJ)+UDAMP(I,JJ)+UWVEX(I,JJ))*ARMX
      FFARM=FFLAR(I,JJ)*ARMX
C
      REDSUM=-FBARM-FDARM-FAARM-FWARM+REDSUM
      IF(JOBFO(2).EQ.1) REDSUM=REDSUM-FUARM
      IF(JOBFO(3).EQ.1) REDSUM=REDSUM-FFARM
312  CONTINUE
C
      RED(IX,J)=REDSUM*GAMMA
C
311  CONTINUE
310  CONTINUE
C
C-----
C
C
      DO 305 J=1,MSTA
      V2(J)=SIN2(J)-RED(2,J)
      V3(J)=SIN3(J)-RED(3,J)
      V4(J)=SIN4(J)-RED(4,J)
      V5(J)=SIN5(J)-RED(5,J)
      V6(J)=SIN6(J)-RED(6,J)
C
305  CONTINUE
C
C-----OUTPUT FORCES FOR EACH SECTION
      RETURN
69   FORMAT(1X,I2,1X,6F15.4)
      END

```

SUBROUTINE KRYLOV (J)

```

C
COMMON /      /  NWAVES, WVSUM,
1             /  WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2             /  WN(20), WNX(20), WNZ(20),
3             /  CSK(20), CCK(20), CXK(20),
4             /  CYK(20), CZK(20), XW(20)
COMMON /      /  MSTA, NPROF, NFWD, NAFT, LPTS(25),
1             /  XOFF(25), YOFF(25,25), ZOFF(25,25),
2             /  XPROF(51), YPROF(51)
COMMON /      /  INPTS(25), IPOINT(25), YWET(25,25), ETA(25,25),
1             /  ZLAST(25,25), ZWET(25,25), ZNEXT(25,25)
COMMON /      /  ZCO(20), ZSO(20), ZCY(20), ZSY(20),
1             /  ZCZ(20), ZSZ(20)
COMMON /      /  DZK(20)
COMMON /      /  JSAVE(20), COSJ(20), SINJ(20),
$             /  COSJJ(20), SINJJ(20),
1             /  DWC(20), DWS(20), XCI(20), XSI(20)
COMMON /      /  ISAVE(20), CSI(20), SNI(20),
$             /  CSII(20), SNII(20),
1             /  DKC(20), DKS(20), ZCI(20), ZSI(20)
COMMON /AREA /  AREA, YMOD, ZMOD
AREA=0.0
YMOD=0.0
ZMOD=0.0
KSAVE=0
DO 110 K=1, NWAVES
    ZCO(K)=0.0
    ZSO(K)=0.0
    ZCY(K)=0.0
    ZSY(K)=0.0
    ZCZ(K)=0.0
    ZSZ(K)=0.0
    ISAVE(K)=0
110 CONTINUE
    LI=INPTS(J)
    II=IPOINT(J)
    LAST=II-1
    IF (LAST.EQ.0) LAST=LI
111 DO 190 I=II, LI
    ETA1=ETA(I, J)
    Y1=YWET(I, J)
    Z0=ZLAST(I, J)
    Z1=ZWET(I, J)
    Z2=ZNEXT(I, J)

C3
    DZ0=Z1-Z0
    DZ2=Z2-Z1
    DZ=(Z2-Z0)/2.0
    ZA=Z1-DZ0/3.0
    ZB=Z1+DZ2/3.0
    DZ1=(DZ2*ZB+DZ0*ZA)/2.0
    AREA=AREA+(ETA1-Y1)*DZ
    ZMOD=ZMOD+(ETA1-Y1)*DZ1
    YMOD=(ETA1**2-Y1**2)/2.0*DZ+YMOD
    IF (NWAVES.EQ.0) GO TO 190

C
    IF (KSAVE.EQ.0) GO TO 112
    SQ0=SQ1
    SQ1=SQ2
    DDZ0=DDZ2

```

```

      DZ20=DZ2E
      GO TO 130
112  SQ0=Z0**2
      SQ1=Z1**2
      IF (DZ0.EQ.0.0) GO TO 120
      IF ((DZ2/DZ0).GT.1.0E+06) GO TO 120
      DDZ0=1.0/DZ0
      DZZ0=Z0*DDZ0
      GO TO 130
120  DDZ0=0.0
      DZZ0=0.0
130  IF (DZ2.EQ.0.0) GO TO 140
      IF ((DZ0/DZ2).GT.1.0E+06) GO TO 140
      DDZ2=1.0/DZ2
      DZZ2=Z2*DDZ2
      GO TO 150
140  DDZ2=0.0
      DZZ2=0.0
150  SQ2=Z2**2
      KSAVE=0
      IF (I.EQ.LAST) GO TO 151
      IN=I
      IF (IN.EQ.LI) IN=0
      IF (Z1.EQ.ZLAST(IN+1,J) .AND. Z2.EQ.ZWET(IN+1,J)) KSAVE=1
151  CONTINUE
      IF(ETA1.GT.0. .AND. Y1.GT.0. ) ETA1=Y1
      DO 180 K=1,NWAVES
          CK=CCK(K)
          YK=CYK(K)
          ZK=CZK(K)
          EE=EXP(CK*ETA1)
          EY=EXP(CK*Y1)
          ARG=YK*ETA1
          CE=COS(ARG)
          SE=SIN(ARG)
          ARG=YK*Y1
          CY=COS(ARG)
          SY=SIN(ARG)
          D=CK**2+YK**2
          CK=CK/D
          YK=YK/D
          COSE=(CK*CE+YK*SE)*EE
          SINE=(CK*SE-YK*CE)*EE
          COSY=(CK*CY+YK*SY)*EY
          SINY=(CK*SY-YK*CY)*EY
          YCO=COSE-COSY
          YSO=SINE-SINY
          YCY=ETA1*COSE-Y1*COSY-CK*YCO-YK*YSO
          YSY=ETA1*SINE-Y1*SINY-CK*YSO+YK*YCO
C
          IF (ISAVE(K).EQ.0) GO TO 152
          COS1=CSI(K)
          SIN1=SNI(K)
          GO TO 153
152  ARG1=ZK*Z1
          COS1=COS(ARG1)
          SIN1=SIN(ARG1)
153  CONTINUE
          IF (ABS(ZK*DZ).GT.0.01) GO TO 160
C
          DZCOS=DZ*COS1

```

```

DZSIN=DZ*SIN1
DZ1COS=DZ1*COS1
DZ1SIN=DZ1*SIN1
ISAVE(K)=0
GO TO 170

```

C 160

```

ZK2=DZK(K)
ZCOS1=COS1*Z1
ZSIN1=SIN1*Z1

```

C

```

IF (ISAVE(K).EQ.0) GO TO 161
COS0=CSII(K)
SIN0=SNII(K)
DKC0=DKC(K)
DKS0=DKS(K)
ZC10=ZC1(K)
ZS10=ZS1(K)
GO TO 162

```

C 161

```

ARG0=ZK*Z0
COS0=COS(ARG0)
SIN0=SIN(ARG0)
DKC0=(COS1-COS0)/ZK
DKS0=(SIN1-SIN0)/ZK
ZC10=(ZSIN1-SIN0*Z0+DKC0)*DDZ0
ZS10=(COS0*Z0-ZCOS1+DKS0)*DDZ0

```

C 162

```

ARG2=ZK*Z2
COS2=COS(ARG2)
SIN2=SIN(ARG2)
DKC2=(COS2-COS1)/ZK
DKS2=(SIN2-SIN1)/ZK
ZC12=(SIN2*Z2-ZSIN1+DKC2)*DDZ2
ZS12=(ZCOS1-COS2*Z2+DKS2)*DDZ2

```

C

```

DZCOS=(ZC10-ZC12)/ZK-DZZ0*DKS0+DZZ2*DKS2
DZSIN=(ZS10-ZS12)/ZK+DZZ0*DKC0-DZZ2*DKC2
DZ1COS=((SQ1*SIN1-SQ0*SIN0)*DDZ0+(SQ1*SIN1-SQ2*SIN2)*DDZ2+(Z
1 S12-ZS10)*ZK2+Z2*ZC12-Z0*ZC10)/ZK
1 DZ1SIN=((SQ2*COS2-SQ1*COS1)*DDZ2+(SQ0*COS0-SQ1*COS1)*DDZ0+(Z
C C10-ZC12)*ZK2+Z2*ZS12-Z0*ZS10)/ZK

```

C

```

ISAVE(K)=KSAVE
IF (KSAVE.EQ.0) GO TO 170
CSI(K)=COS2
SNI(K)=SIN2
CSII(K)=COS1
SNII(K)=SIN1
DKC(K)=DKC2
DKS(K)=DKS2
ZC1(K)=ZC12
ZS1(K)=ZS12

```

C 170

CONTINUE

C

```

ZCO(K)=ZCO(K)+DZCOS*YCO-DZSIN*YSO
ZSO(K)=ZSO(K)+DZCOS*YSO+DZSIN*YCO
ZCY(K)=ZCY(K)+DZCOS*YCY-DZSIN*YSY
ZSY(K)=ZSY(K)+DZCOS*YSY+DZSIN*YCY
ZCZ(K)=ZCZ(K)+DZ1COS*YCO-DZ1SIN*YSO
ZSZ(K)=ZSZ(K)+DZ1COS*YSO+DZ1SIN*YCO

```

```

180     CONTINUE
190 CONTINUE
    IF (LI.EQ.LAST) RETURN
    LI=LAST
    II=1
    GO TO 111
C
    END
    FUNCTION LNEGF(M,N,N1,A,B,DTRMNT,Z)
C.. SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C.. FORTRAN IV EQUIVALENT OF LNEGS.
    REAL A(M,M),B(M,M),Z(M),DTRMNT,RMAX,RNEXT,W,DOV
    NM1=N-1
    DO 200 J=1,NM1
        J1=J+1
C.. FIND ELEMENT OF COL J, ROWS J-N, WHICH HAS MAX ABSOLUTE VALUE.
        LMAX=J
        RMAX=ABS(A(J,J))
        DO 110 K=J1,N
            RNEXT=ABS(A(K,J))
            IF (RMAX.GE.RNEXT) GO TO 110
            RMAX=RNEXT
            LMAX=K
110     CONTINUE
        IF (LMAX.NE.J) GO TO 120
C.. MAX ELEMENT IN COLUMN IS ON DIAGONAL
        IF (A(J,J)) 150,290,150
C.. MAX ELEMENT IS NOT ON DIAGONAL. EXCHANGE ROWS J AND LMAX.
120     DO 130 L=J,N
            W=A(J,L)
            A(J,L)=A(LMAX,L)
130     A(LMAX,L)=W
            DO 140 L=1,N1
                W=B(J,L)
                B(J,L)=B(LMAX,L)
140     B(LMAX,L)=W
            DTRMNT=-DTRMNT
C.. ZERO COLUMN J BELOW THE DIAGONAL.
150     Z(J)=1./A(J,J)
            DO 170 K=J1,N
                IF (A(K,J)) 160,190,160
                W=-Z(J)*A(K,J)
                DO 170 L=J1,N
                    A(K,L)=W*A(J,L)+A(K,L)
                DO 180 L=1,N1
                    B(K,L)=W*B(J,L)+B(K,L)
180     CONTINUE
200 CONTINUE
        IF (A(N,N)) 210,290,210
210     Z(N)=1./A(N,N)
C.. OBTAIN SOLUTION BY BACK SUBSTITUTION.
        DO 220 L=1,N1
            B(N,L)=Z(N)*B(N,L)
220     DO 250 K=1,NM1
            J=N-K
            J1=J+1
            DO 240 L=1,N1
                W=0.
                DO 230 I=J1,N
                    W=A(J,I)*B(I,L)+W
230     W=A(J,I)*B(I,L)+W
240     B(J,L)=(B(J,L)-W)*Z(J)

```

```
250 CONTINUE
C. . EVALUATE DETERMINANT.
    IF (DTRMNT) 260, 280, 260
260 DO 270 J=1, N
270 DTRMNT=DTRMNT*A(J, J)
280 LNEGF=1
    RETURN
C. . SINGULAR MATRIX, SET ERROR FLAG.
290 LNEGF=2
    DTRMNT=0.
    RETURN
C
    END
```

PROGRAM HYDREX2

PROGRAM HYDREX2

```

C CHARACTER*25 OFFIL,BIFIL,COFIL
  CHARACTER*30 TITLE
  COMMON/HEAD/TITLE
  COMMON/IOFILE/ OFFIL,BIFIL,COFIL
  COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
  INTEGER OUTPUT,BIF,OFF,COF
  COMMON /COEFF4 / COEFF4(6,12,8,25),AREAN(25,6)
  COMMON/SHIP/ISTA,LSTA,ISWL,LSWL,TF,TA,XCG,YCG,DISPL
  COMMON /DRFT12/ DRAFT(6,2),IDRAFT
  COMMON /SIGMA / NK, SIGMA(24), SIGMA0, ERRO, OM(12)
  COMMON /U / RHO, G
  COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
* YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
* ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
* Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
* XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
* DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
* DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
  LOGICAL WL,ADJUST
  DATA RHO /0.00088861607142/
  DATA ERRO/1.0E-37/
C DATA DM/ 0.000, 0.200, 0.400, 0.600, 0.800, 1.000,
C 1 1.200, 1.600, 2.000, 2.400, 2.800, 9.999/
C DATA DM/0.0,0.0992,.1718,.243,.3137,.3842,.45469,
C * .525,.59534,.49611,.7358,9.999/
  DATA DM/0.0,0.099,0.2,0.3,0.4,0.5,0.6,0.7,0.9,
  * 1.3,1.6,2.2/
  DATA INPUT/5/,OUTPUT/6/,BIF/1/,OFF/2/,COF/3/
C -----
C *** 1.0 Get DATA file names and assign/open files
C TYPE 902
  ACCEPT 901,BIFIL
  TYPE 903
  ACCEPT 901,OFFIL
  TYPE 904
  ACCEPT 901,COFIL
C OPEN(UNIT=BIF,STATUS='OLD',FILE=BIFIL)
  OPEN(UNIT=OFF,STATUS='OLD',FILE=OFFIL)
  OPEN(UNIT=COF,STATUS='NEW',FORM='UNFORMATTED',FILE=COFIL)
C *** 2.0 Read in data from two files
C CALL INDATA
  CLOSE(BIF)
  CLOSE(OFF)
  DO 10 J=1,6
    DRAFT(J,2)=DRAFT(J,1) !Aft draft = fwd draft
  10 CONTINUE
C *** 3.0 Float ship at indexed draft then compute added mass
C and damping coefficients using Frank Close Fit.
  DO 20 IDRAFT=1,6
    CALL FLOAT
    CALL HYDRO
  20 CONTINUE
C *** 4.0 Write to unformatted coefficient file containing

```

```

C      added mass and damping coefficients for each station
C      at six drafts and twelve frequencies.
C
WRITE (COF) MSTA           !Number of Stations
WRITE (COF) (OM(I),I=1,12) !Frequency (rad/sec)
WRITE (COF) (DRAFT(I,1),I=1,6) !Drafts
DO 30 L=1,MSTA           !Station index
DO 30 K=1,6             !Draft index
DO 30 J=1,12            !Frequency index
WRITE(COF) (COEFF4(K,J,I,L),I=1,8)
30 CONTINUE
WRITE (COF) ((AREAN(L,K),K=1,6),L=1,MSTA) !Section areas
STOP

C
901  FORMAT(A)
902  FORMAT(' Name of Basic INPUT File [BIF] ? > '$)
903  FORMAT(' Name of Offset File [OFF] ? > '$)
904  FORMAT(' Name of Coefficient File [COF] ? > '$)
C
END
SUBROUTINE HYDRO

C
C      CALCULATION OF HYDRODYNAMIC FORCE COEFFICIENTS FOR THE SHIP.
C
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON /COEFF4/ COEFF4(6,12,8,25),AREAN(25,6)
COMMON/DRFT12/DRAFT(6,2),IDRAFT
COMMON/SHIP/ISTA,LSTA,ISWL,LSWL,TF,TA,XCG,YCG,DISPL
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON /U / RHO, G
COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
* YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
* ZOFF(25,25),XPERP,XAPERP,SHIPL,SHIPB,SHIPT,
* Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
* XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
* DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
* DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
LOGICAL ADJUST, WL
COMMON / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1 RH02, RSIG, WN, W1, W2, ERR, XRI, YRI, EJT
COMMON //HAO(24),SAO(24),RAO(24),CAO(24),
1 HVO(24),SVO(24),RVO(24),CVO(24)
REAL
EQUIVALENCE (FA(1,1), HAO(1))
COMMON / BLOGP(20,20), YLOGP(20,20),
1 BLOGM(20,20), YLOGM(20,20)
REAL COEFF0(8), COEFF1(8)
EQUIVALENCE (COEFF1(1),HA1)
DATA TPI /6.2831853072/
NODES=NWL
ERR=ERRO
RH02=RHO*2.0
XXSTA=XXF
XWO=XWLF
VOL0=0.0
VOL1=0.0
VOLV=0.0
WPO=0.0

```

WP1=0.0

WP2=0.0

WPT=0.0

CR IS THE CENTER OF ROLL. ROLL IS ASSUMED TO BE ABOUT THE HORIZONTAL AXIS THROUGH THE GIVEN CENTER OF GRAVITY.

CR=YCG-DRAFT(IDRAFT,1)-(XFPERP-XCG)*TAN
STRIP CALCULATION PROCEDURE FOR EACH WET STATION..

DO 240 J=ISTA,LSTA

XXFWD=XXSTA

XXSTA=XOFF(J)

IF (J.EQ.LSTA) GO TO 122

XXAFT=XOFF(J+1)

XW2=XXAFT

IF (J.EQ.LSWL) XW2=XWLA

GO TO 124

122 XXAFT=XXA

XW2=XWLA

124 X1=XOFF(J)-XCG

INTEGRATE OVER WATERPLANE OF THE SHIP..

IF (J.LT.ISWL) GO TO 130

DXFWD=XW0-XXSTA

XW0=XXSTA

IF (.NOT.WL(J)) GO TO 130

DXAFT=XW0-XW2

DX=DXFWD+DXAFT

A=X1-DXAFT/3.0

B=X1+DXFWD/3.0

XW2=DXFWD*B*B+DXAFT*A*A+(DXFWD**3+DXAFT**3)/18.0

XW1=DXFWD*B+DXAFT*A

ZW=ZWL(J)

DZW=ZW*DX

WPO=WPO+DZW

WP1=WP1+ZW*XW1

WP2=WP2+ZW*XW2

WPT=WPT+DZW*ZW**2

SET UP STATION GEOMETRY..

130 NON=INPTS(J)

IF (NON.EQ.0) GO TO 140

NWL=0

IF (WL(J)) NWL=NODES

CALL STATN (ZOFF(1,J),Y1(1,J),ZWL(J),INPTS(J))

IF (NON.LE.0) GO TO 140

INTEGRATE OVER SUBMERGED VOLUME OF THE SHIP..

DXFWD=XXFWD-XXSTA

DXAFT=XXSTA-XXAFT

DX=(DXFWD+DXAFT)/2.0

VOLO=VOLO+AREA*DX

A=X1-DXAFT/3.0

B=X1+DXFWD/3.0

DX2=(DXFWD*B*B+DXAFT*A*A)/2.0+(DXFWD**3+DXAFT**3)/36.0

DX1=(DXFWD*B+DXAFT*A)/2.0

VOL1=VOL1+AREA*DX1

VOLV=VOLV+VERT*DX

```

C 140    CONTINUE
C        DO 150 I=1,8
C          COEFF0(I)=0.0
C 150    CONTINUE
C        CALL GIRL
C
C        DO 210 K=1,12
C          ESIG=OM(K)
C          RSIG=ESIG*RHO2
C          WN=ESIG*ESIG/G
C *** Zero (K=1) or Infinite (K=12) Frequency Computations
C          IF (K.EQ.1.OR.K.EQ.12) THEN
C            CALL BEER(K)
C          ELSE
C *** Non zero and non-infinite frequency computations
C            W1=TPI/WN
C            W2=2.0/WN
C            CALL WINE (K)
C          ENDIF
C
C-----
C 180    CONTINUE
C        DO 190 I=1,8
C          COEFF4(IDRAFT,K,I,J)=COEFF1(I)/AREA
C 190    CONTINUE
C
C          AREAN(J,IDRAFT)=AREA
C          HAO(K)=HA1
C          SAO(K)=SA1
C          RAO(K)=RA1
C          CAO(K)=CA1
C          HVO(K)=HV1
C          SVO(K)=SV1
C          RVO(K)=RV1
C          CVO(K)=CV1
C 210    CONTINUE
C-----
C
C        PRINTOUT Offset and Hydrodynamic Coefficient Info.
C
C        WRITE (OUTPUT,300) TITLE
C        WRITE(OUTPUT,301) J, XOFF(J), AREA, DRAFT(IDRAFT,1), CR,
C          *      DRAFT(IDRAFT,2)
C        WRITE (OUTPUT,302)
C        WRITE (OUTPUT,310) (OM(K), HAO(K), HVO(K), SAO(K), SVO(K), RAO(K),
C          1      RVO(K), CAO(K), CVO(K), K=1,12)
C *** Offset Information
C        WRITE(OUTPUT,705)
C          WRITE(OUTPUT,706)
C          N=LPTS(J)
C          M=0
C          IF (J.LT.ISTA) GO TO 670
C          IF (J.GT.LSTA) GO TO 670
C          M=INPTS(J)
C          IF (M.NE.0) WRITE(OUTPUT,710) (YOFF(I,J), ZOFF(I,J), Y1(I,J), ZOFF
C            1      (I,J), I=1,M)

```

```

        IF (WL(J)) WRITE (OUTPUT,720) ZWL(J)
670      M=M+1
        IF (M.LE.N) WRITE (OUTPUT,730) (YOFF(I,J),ZOFF(I,J),I=M,N)
C
220      CONTINUE
240      CONTINUE
        GAMMA=RHO*G
        DISPL=VOLO*GAMMA
C
        WPT=WPT/3.0
        YFYTO=WPO*GAMMA
        YFZRO=WP1*GAMMA
        XWA=0.0
        IF (WPO.NE.0.0) XWA=WP1/WPO
        XCB=VOL1/VOLO
        YCB=VOLV/VOLO
        XBM=WPT/VOLO
        ZBM=(WP2-WP1*XWA)/VOLO
        XGM=XBM+YCB
        ZGM=ZBM+YCB
        XWA=XWA+XCG
        XCB=XCB+XCG
        YCB=YCB+YCG
        XMXRO=XGM*DISPL
        ZMZRO=ZGM*DISPL
        WRITE (OUTPUT,270) TITLE
        WRITE (OUTPUT,281) DRAFT(IDRAFT,1), DRAFT(IDRAFT,2)
        WRITE(OUTPUT,290) WPO, XWA, WP1, WP2, WPT
        WRITE(OUTPUT,291) DISPL, VOLO, XCB, YCB, VOL1, VOLV
        WRITE(OUTPUT,292) ZBM, XBM, ZGM, XGM
        WRITE(OUTPUT,293) XMXRO, ZMZRO, YFYTO, YFZRO
        WRITE(OUTPUT,294) XXF, XXA
        WRITE (OUTPUT,280) XCG, YCG
C *** OUTPUT OF NOTES
        WRITE(OUTPUT,420)
        IF (ADJUST) WRITE( OUTPUT,430) ZMAX,YMAX
        IF (.NOT.ADJUST) WRITE (OUTPUT,440)
        IF (NWL.GT.0) GO TO 110
        GO TO 120
110      WRITE (OUTPUT,460) NWL
        IF (WMAX.GT.0.0) WRITE (OUTPUT,470) WMAX
120      CONTINUE
C
        RETURN
270      FORMAT (1H1/,B1(1H=)/,1X,A30,'HYDROSTATIC COEFFICIENTS'
        *,T64,'PROGRAM HYDREX',/,B1(1H=)/)
280      FORMAT (//B1(1H-)/,' NOTE: All moments are about',
        *'center of gravity' /,7X,'XCG=',F11.3,' YCG=',F11.3,/)
281      FORMAT(T5,' DRAFT (fwd) =',F8.2,/,T5,' DRAFT (aft) =',F8.2/)
290      FORMAT(T10,'----- WATERPLANE -----',/)
        *   T10,'Area',,T40,F13.2,T60,' units',/,/
        *   T10,'LCF',,T40,F13.2,T60,' units',/,/
        *   T10,'1st Long. Moment',,T40,E13.7,T60,' units',/,/
        *   T10,'2nd Long. Moment',,T40,E13.7,T60,' units',/,/
        *   T10,'2nd Transv. Moment',,T40,E13.7,T60,' units',/,/
291      FORMAT(T10,'----- VOLUME -----',/)
        *   T10,'Displacement',,T40,F13.2,T60,' units',/,/
        *   T10,'Volume of Displacement',,T40,E13.7,T60,' units',/,/
        *   T10,'LCB',,T40,F13.2,T60,' units',/,/
        *   T10,'VCB',,T40,F13.2,T60,' units',/,/
        *   T10,'Long. Moment',,T40,E13.7,T60,' units',/,/

```

```

*      T10, 'Vert. Moment', T40, E13. 7, T60, ' units ', /)
292  FORMAT(T10, '----- METACENTRIC HEIGHTS -----', /)
*      T10, 'BM (longitudinal)', T40, F13. 2, T60, ' units ', /
*      T10, 'BM (transverse)', T40, F13. 2, T60, ' units ', /
*      T10, 'GM (longitudinal)', T40, F13. 2, T60, ' units ', /
*      T10, 'GM (transverse)', T40, F13. 2, T60, ' units ', /)
293  FORMAT(T10, '-----HYDROSTATIC FORCES -----', /)
*      T10, 'Roll Restoring Moment', T40, E13. 7, T60, ' units ', /
*      T10, 'Pitch Restoring Moment', T40, E13. 7, T60, ' units ', /
*      T10, 'Heave Restoring Force', T40, E13. 7, T60, ' units ', /
*      T10, 'Pitch Induced Heave Force', T40, E13. 7, T60, ' units ', /)
294  FORMAT(/, T5, ' LWL begins at ', F10. 2, /
*      T5, ' LWL ends at ', F10. 2, /)
300  FORMAT(1H1/, B1(1H=), /, 1X, A30, 'ADDED MASS/DAMPING COEFFICIENTS'
*, T66, 'PROGRAM HYDREX', /, B1(1H=))
301  FORMAT (T36, 'Station '12/, T36, '-----', /,
*      T5, ' Dist. from F.P. ', F8. 2, T50, 'Area ', F11. 3, /
*      T5, ' DRAFT (fwd) ', F8. 2, T50, 'Roll Ctr abv WL', F11. 3/
*      T5, ' DRAFT (aft) ', F8. 2, /)
302  FORMAT(10X, '-----HEAVE-----',
*      4X, '-----SWAY-----', 4X, '-----ROLL-----',
*      4X, '---SWAY-ROLL---', /, 14X, 'A22', 5X, 'B22',
*      7X, 'A33', 5X, 'B33', 8X, 'A44', 6X, 'B44', 6X, 'A34', 6X, 'B34', /
*, 2X, 'Freq. ', /)
309  FORMAT ((1X, OPF22. 4, 3(5X, 1P2E10. 2)))
310  FORMAT(1X, F5. 2, 3X, F8. 4, F8. 4, 2X, F8. 4, F8. 4,
*      2X, F9. 2, F9. 2, F9. 1, F9. 1)
C
420  FORMAT (1H1/, 33(1H*), ' N O T E S ', 33(1H*))
430  FORMAT(T5, 'Generate additional offset points. ', /,
*      T5, 'Maximum segment height=', F10. 3/,
*      T5, 'Maximum segment width =', F10. 3/)
440  FORMAT(/T5, 'Use segments as defined by table of offsets. ')
450  FORMAT(T5, 'No internal free-surface segments are used. ')
460  FORMAT(T5, 13, 2X, 'nodes for internal free-surface. ')
470  FORMAT(5X, 'Add internal nodes if surface segment lengths',
*      ' exceed', F10. 3)
706  FORMAT (6X, 'Height above', 5X, 'Half', 15X,
*      'Submerged Offsets', /, 10X, 'Baseline', 5X, 'BREADth',
*      14X, '-Y-', 9X, '-Z-'/)
705  FORMAT (/////, 33(1H-), 'STATION OFFSETS', 32(1H-), /)
710  FORMAT (6X, 2F12. 3, F18. 3, F12. 3)
720  FORMAT (39X, 9HWATERLINE, F12. 3)
730  FORMAT (6X, 2F12. 3)
END
SUBROUTINE INDATA
C
COMMON/ID/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON /SIGMA / NK, SIGMA(24), SIGMA0, ERRO, OM(12)
COMMON / DRFT12/ DRAFT(6, 2), IDRAFT
COMMON/IOFILE/ OFFIL, BIFIL, COFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON /U / RHO, G
COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL
COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
*      YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*      ZOFF(25, 25), XFERP, XAPERP, SHIPL, SHIPB, SHIPT,
*      Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*      XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,

```

```

*          DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*          DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
LOGICAL ADJUST,WL

```

```

C          CHARACTER*81 CARDID
C          DATA DEGREE/0.01745 32925 19943/
C          DATA G /32.17/
C          DATA NWL/1/
C          WRITE(OUTPUT,197)
C ***      TITLE
C          READ (BIF,199) TITLE
C          WRITE(OUTPUT,196) TITLE
C ***      DRAFT (fwd),DRAFT (aft), long. loc's of DRAFT marks
C          READ (BIF,200) TF,TA,XFPERP,XAPERP
C          WRITE(OUTPUT,200) TF,TA,XFPERP,XAPERP
C ***      Center of Gravity (XCG aft of FP, YCG above BL)
C          READ (BIF,200) XCG,YCG,ZCG
C          WRITE(OUTPUT,200) XCG,YCG,ZCG
C ***      Six DRAFTs at which hydro. coeffs are computed
C          READ(BIF,200) (DRAFT(I,1),I=1,6)
C          WRITE(OUTPUT,200) (DRAFT(I,1),I=1,6)
C ***      Minimum segment lengths for Frank Close Fit
C          READ (BIF,201) YMAX,ZMAX,WMAX,NWL
C          WRITE(OUTPUT,201) YMAX,ZMAX,WMAX,NWL
C          ADJUST=ZMAX.GT.0.0.AND.YMAX.GT.0.0
C ***      Number of foreare profile points
C          READ (BIF,190) NFWD
C          WRITE(OUTPUT,190) NFWD
C          IF (NFWD.GT.25) CALL ERROR(15,IDUM,RDUM)
C ***      Coordinates of forward profile points
C          IF (NFWD.GT.0) READ (BIF,430) (YFWD(I),XFWD(I),I=1,NFWD)
C          WRITE(OUTPUT,430) (YFWD(I),XFWD(I),I=1,NFWD)
C ***      Number of aft profile points
C          READ (BIF,190) NAFT
C          WRITE(OUTPUT,190) NAFT
C          IF (NAFT.GT.25) CALL ERROR(16,IDUM,RDUM)
C ***      Coordinates of aft profile points
C          IF (NAFT.GT.0) READ (BIF,430) (YAFT(I),XAFT(I),I=1,NAFT)
C          WRITE(OUTPUT,430) (YAFT(I),XAFT(I),I=1,NAFT)

```

```

C
C-----
C

```

```

Section 2.0 - READ OFFSET file
The offset file can be an actual SHCP DATA File

```

```

C          WRITE(OUTPUT,198)
C ***      CARD TYPE A
C          READ (OFF,410) CARDID
C          WRITE(OUTPUT,410) CARDID
C ***      CARD TYPE B
C          READ (OFF,410)
C ***      CARD TYPE C
C          READ (OFF,412) SPACE,ZSCAL,YSCAL,SHIPL,NAPN,KINDO
C          WRITE(OUTPUT,412)SPACE,ZSCAL,YSCAL,SHIPL,NAPN,KINDO
C          IF (SPACE.EQ.0.0) SPACE=1.0
C          ZSCAL=1.0
C          YSCAL=1.0
C          MSTA=0

```

```

      NFWD=0
      NAFT=0
C
C *** CARD TYPE D
30  N=1
      MSTA=MSTA+1
      IF (MSTA.GT.25) CALL ERROR(10, IDUM, RDUM)
      READ (OFF, 416) STATNO, Y11, Z1, JTEST
      WRITE(OUTPUT, 417) STATNO, Y11, Z1, JTEST
      XOFF(MSTA)=STATNO*SPACE
      GO TO 50
40  CONTINUE                                !loop within each station
      N=N+1
      IF (N.GT.25) CALL ERROR(11, MSTA, RDUM)
      READ (OFF, 416) S, Y11, Z1, JTEST
      WRITE(OUTPUT, 417) S, Y11, Z1, JTEST
      IF (S.NE.STATNO) CALL ERROR(12, MSTA, RDUM)
50  YOFF(N, MSTA)=Z1*ZSCAL
      ZOFF(N, MSTA)=Y11*YSCAL
      IF (JTEST.EQ.0 .OR. JTEST.EQ.77777) GO TO 40
      LPTS(MSTA)=N                                !No. of points- MSTA
      IF (N.LT.2) CALL ERROR(13, MSTA, RDUM)
      IF (JTEST.EQ.88888) GO TO 30                !Go onto next station
      IF (JTEST.NE.99999) CALL ERROR(14, JTEST, RDUM)
C
C
      DO 220 J=1, MSTA
          XOFF(J)=-XOFF(J)
220  CONTINUE
      IF (NFWD.EQ.0) GO TO 240
      X=XOFF(1)
      DO 230 I=1, NFWD
          XFWD(I)=XFWD(I)+X
230  CONTINUE
240  CONTINUE
      X=XOFF(MSTA)
      DO 250 I=1, NAFT
          XAFT(I)=X-XAFT(I)
250  CONTINUE
      RETURN
180  FORMAT (5X, I5)
190  FORMAT (I5)
197  FORMAT(1H1//, 81(1H*))//, ' INPUT DATA ECHO ', T64,
      *'PROGRAM HYDREX'//, 81(1H*)//, 33(1H-),
      *'[B]F] DATA FILE', 32(1H-)//)
198  FORMAT(1H1//, 81(1H*))//, ' INPUT DATA ECHO ', T64,
      *'PROGRAM HYDREX'//, 81(1H*)//, 33(1H-),
      *'[OFF] DATA FILE', 32(1H-)//)
196  FORMAT(1X, A)
199  FORMAT(A)
200  FORMAT (6F10.2)
201  FORMAT (3F10.2, I5)
210  FORMAT (F10.2, I5, 5X, F10.2)
C
410  FORMAT (A)
412  FORMAT (4F10.3, 13X, I2, 4X, I1)
414  FORMAT (5X, I5, 5X, 'INPUT OF SHCP (TYPE D OFFSET DATA')
416  FORMAT (F6.3, 2F7.0, I6)
417  FORMAT (F7.3, 2F10.2, I6)
420  FORMAT (2I5, F10.2)
430  FORMAT (2F10.2)

```

```

C      END
      SUBROUTINE INSERT(A1,A2,J1,L1,L2)
C      Purpose: Inserts array A2 into array A1 at location J1.
      REAL A1(1), A2(1)
      IF (L1.LT.J1) GO TO 120
      M=L1+L2
      I=L1
      K=L1-J1+1
      DO 110 J=1,K
          A1(M)=A1(I)
          M=M-1
          I=I-1
110  CONTINUE
120  I=J1-1
      DO 130 K=1,L2
          M=K+I
          A1(M)=A2(K)
130  CONTINUE
      RETURN
      END
      SUBROUTINE STATN (Z,Y,ZW,NPTS)
C      CALCULATION OF DATA CONCERNING STATION GEOMETRY.
C      REVISION OF OFFSETS FOR GOOD RESULTS MAY BE PERFORMED.
C
C      NON = NUMBER OF CALCULATED MIDPOINTS.
C      NWL = NUMBER OF WATERLINE MIDPOINTS.
C      Z    = HORIZONTAL COORDINATE OF SEGMENT ENDPOINT.
C      Y    = VERTICAL COORDINATE OF SEGMENT ENDPOINT.
C      ZZ   = HORIZONTAL COORDINATE OF SEGMENT MIDPOINT.
C      YY   = VERTICAL COORDINATE OF SEGMENT MIDPOINT.
C      SNE  = HORIZONTAL COMPONENT OF UNIT NORMAL TO SEGMENT.
C      CSE  = VERTICAL COMPONENT OF UNIT NORMAL.
C      DEL  = LENGTH OF SEGMENT.
C      ROL  = MOMENT OF UNIT NORMAL ABOUT CENTER OF ROLL (CG).
C
      REAL Y(1),Z(1)
      COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
      INTEGER OUTPUT, BIF, OFF, COF
      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25,25), NAFT, XAFT(25),
*      YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*      ZOFF(25,25), XPERP, XAPERP, SHIPL, SHIPB, SHIPT,
*      Y1(21,25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*      XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XAFT, DX, DX1,
*      DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*      DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
      COMMON /      / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1      RHO2, RSIG, WN, W1, W2, ERR, XRI, YRI, EJT
      COMMON /      / HAO(24), SAO(24), RAO(24), CAO(24),
1      HVO(24), SVO(24), RVO(24), CVO(24)
      COMMON // ZNEW(20), YNEW(20), ZZNEW(20), YYNEW(20), CNEW(20), SNEW(20),
1DNEW(20), RNEW(20), MORE(20), I, K, ZO, YO, M1, MTOT, ZINT, YINT, NUMBER, M, N1
2, I1, JOB, ZS, YS, D, C, S, P, G, NUT
      LOGICAL ADJUST
      DATA LIMIT/20/
      DATA MAXPTS/20/
      AREA=0.0
      VERT=0.0
      ZO=0.0
      YO=Y(1)

```

```

MTOT=0
K=1
I1=K
IF (Z(1).EQ.0.0) I1=2
IF (I1.GT.NPTS) GO TO 130
C
C
C    CALCULATION LOOP FOR SUBMERGED OFFSET POINTS..
DO 120 I=I1,NPTS
    ZINT=Z(I)-Z0
    YINT=Y(I)-Y0
    D=SQRT(ZINT*ZINT+YINT*YINT)
    IF (D.EQ.0.0) GO TO 120
    IF (.NOT.ADJUST) GO TO 110
C
C
C    CODE INSTRUCTIONS FOR THE ADDITION OF POINTS..
NUMBER=MAXO(IABS(IFIX(ZINT/ZMAX)), IABS(IFIX(YINT/YMAX)))
MORE(K)=NUMBER
MTOT=MTOT+NUMBER
C
C
C    CONTINUE STANDARD PROCEDURE..
110  ZS=Z0+Z(I)
    YS=Y0+Y(I)
    AREA=AREA+YINT*ZS
    VERT=VERT+YINT*(Z0*(Y0-CR+YINT/3.0)+Z(I)*(Y0-CR+YINT/1.5))
    C=ZINT/D
    S=YINT/D
    CSE(K)=C
    SNE(K)=S
    DEL(K)=D
    ZZ(K)=0.5*ZS
    YY(K)=0.5*YS
    RDL(K)=(CR-YY(K))*S-ZZ(K)*C
    Z2(K)=Z0
    Y2(K)=Y0
    Z0=Z(I)
    Y0=Y(I)
    K=K+1
120  CONTINUE
C
C
C    END OF CALCULATION LOOP FOR SUBMERGED POINTS.
130  Z2(K)=Z0
    Y2(K)=Y0
    NON=K-1
C
C
C    ADD UPPERMOST SEGMENT..
IF (NWL.NE.0) GO TO 150
SECTION IS SUBMERGED.
IF (Z0.EQ.0.0) GO TO 200
IF (.NOT.ADJUST) GO TO 140
C
C
C    CODE INSTRUCTIONS FOR THE ADDITION OF POINTS..
NUMBER=IABS(IFIX(Z0/ZMAX))
MORE(K)=NUMBER
MTOT=MTOT+NUMBER
C

```

```

C      CONTINUE STANDARD PROCEDURE..
C
140  DEL(K)=ABS(ZO)
    CSE(K)=-1.0
    SNE(K)=0.0
    ZZ(K)=0.5*ZO
    YY(K)=YO
    ROL(K)=ZZ(K)
    NON=K
    K=K+1
    Z2(K)=0.0
    Y2(K)=YO
    GO TO 200
C
C      ADD SEGMENT UP TO WATERLINE..
C
150  ZINT=ZW-ZO
    YINT=-YO
    IF (NWL.LT.0) NWL=0
    IF (ZW.LE.0.0) NWL=0
    D=SQRT(ZINT*ZINT+YINT*YINT)
    IF (D.EQ.0.0) GO TO 170
    IF (.NOT.ADJUST) GO TO 160
C
C      CODE INSTRUCTIONS FOR THE ADDITION OF POINTS..
C
    NUMBER=MAXO(IABS(IFIX(ZINT/ZMAX)),IABS(IFIX(YINT/YMAX)))
    MORE(K)=NUMBER
    MTOT=MTOT+NUMBER
C
C      CONTINUE STANDARD PROCEDURE..
C
160  ZS=ZO+ZW
    YS=YO
    AREA=AREA+YINT*ZS
    VERT=VERT-YINT*(ZO*(CR+YINT/1.5)+ZW*(CR+YINT/3.0))
    C=ZINT/D
    S=YINT/D
    CSE(K)=C
    SNE(K)=S
    DEL(K)=D
    ZZ(K)=0.5*ZS
    YY(K)=0.5*YS
    ROL(K)=(CR-YY(K))*S-ZZ(K)*C
    NON=K
    K=K+1
    Z2(K)=ZW
    Y2(K)=0.0
C
C      ADD DECK AT WATERLINE..
C
170  CONTINUE
    IF (NWL.EQ.0) GO TO 200
    ZINT=ZW/FLOAT(NWL)
    IF (WMAX.EQ.0.0) GO TO 180
    IF (ZINT.LT.WMAX) GO TO 180
    NWL=IFIX(ZW/WMAX)+1
    ZINT=ZW/FLOAT(NWL)
180  D=ZINT*0.5
    DO 190 I=1,NWL
        DEL(K)=ZINT

```

C

```

SUBROUTINE POTST
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
* ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
* STOLD(120), PX(120,6)
COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150), WRFR(150),
* KK(150,4)
COMMON/A/NPAN, NPT, GEE, RHO, NKX, NKY, EYE, DT, TIM, UFWD
COMPLEX A, B, EYE
DIMENSION XPSL(3,4), XPSLR(3,4), PBB(120,120)
COMMON/PTST/ARE4(200,4), X4(200,4), Y4(200,4), Z4(200,4)
* , SEL(200,4)
DO 1500 J=1, NPAN
ARE4(J,4)=-1.0
JT=4
IF(KK(J,4).EQ.0) JT=3
DO 1500 JJ=1, JT
J2=1
IF(JJ.LT.JT) J2=JJ+1
KF=KK(J, JJ)
KG=KK(J, J2)
X4(J, JJ)=(XPT(KF)+XPT(KG)+XPAN(J))/3.0
Y4(J, JJ)=(YPT(KF)+YPT(KG)+YPAN(J))/3.0
Z4(J, JJ)=(ZPT(KF)+ZPT(KG)+ZPAN(J))/3.0
AF=XPT(KF)-XPAN(J)
BF=YPT(KF)-YPAN(J)
CF=ZPT(KF)-ZPAN(J)
AG=XPT(KG)-XPAN(J)
BG=YPT(KG)-YPAN(J)
CG=ZPT(KG)-ZPAN(J)
CALL SELF(AF, BF, CF, AG, BG, CG, FEE)
SEL(J, JJ)=FEE
CR=AF*BG-BF*AG
AR=BF*CG-CF*BG
BR=CF*AG-AF*CG
ARE4(J, JJ)=0.5*SQRT(AR*AR+BR*BR+CR*CR)
1500 CONTINUE
DO 127 NJ=1, NPAN
DO 1277 MJ=1, NPAN
1277 PBB(NJ, MJ)=0.00
P(NJ,1)=0.00
P(NJ,2)=0.00
P(NJ,3)=0.00
P(NJ,4)=0.00
P(NJ,5)=0.00
P(NJ,6)=0.00
DO 128 NK=1, 4
ARN=ARE4(NJ, NK)
IF(ARN.LT.0.0) GO TO 128
P1=0.0
P2=0.0
P3=0.0
P4=0.0
P5=0.0
P6=0.0
X=X4(NJ, NK)
Y=Y4(NJ, NK)
Z=Z4(NJ, NK)
DO 138 MJ=1, NPAN
DO 138 MK=1, 4
XF=X4(MJ, MK)
YF=Y4(MJ, MK)
ZF=Z4(MJ, MK)
ARM=ARE4(MJ, MK)
IF(ARM.LT.0.00) GO TO 138
IF(NJ.NE.MJ) GO TO 140
IF(MK.NE.NK) GO TO 140
FRA=SEL(MJ, MK)/ARM
GO TO 1380

```

```

        CSE(K)=-1.0
        SNE(K)=0.0
        YY(K)=0.0
        ZZ(K)=Z2(K)-D
        ROL(K)=ZZ(K)
        NON=K
        K=K+1
        Y2(K)=0.0
        Z2(K)=Z2(K-1)-ZINT
190  CONTINUE
        Z2(K)=0.0
        NON=K-1
C
C      END OF FIRST PASS.  ADD ADDITIONAL SEGMENTS IF REQUIRED..
C
200  IF (NON.GT.LIMIT) GO TO 290
        IF (.NOT.ADJUST) GO TO 280
        IF (NON.GT.MAXPTS) GO TO 280
        IF (MTOT.EQ.0) GO TO 280
        MTOT=MTOT+NON
        M1=NON-NWL
        IF (MTOT.LE.MAXPTS) GO TO 230
C
C      DECREASE MORE UNTIL MTOT IS EQUAL MAXPTS ..
C
210  DO 220 K=1,M1
        IF (MORE(K).LE.0) GO TO 220
        MORE(K)=MORE(K)-1
        MTOT=MTOT-1
        IF (MTOT.LE.MAXPTS) GO TO 230
220  CONTINUE
        GO TO 210
C
C      INSERT ADDITIONAL SEGMENTS AS INDICATED BY MORE ..
C
230  I=1
        DO 270 M=1,M1
            I1=I+1
            NUMBER=MORE(M)
            IF (NUMBER.LE.0) GO TO 260
            N1=NUMBER+1
            Z0=Z2(I)
            Y0=Y2(I)
            ZINT=Z2(I1)-Z0
            YINT=Y2(I1)-Y0
            ZINT=ZINT/FLOAT(2*N1)
            YINT=YINT/FLOAT(2*N1)
            D=DEL(I)/FLOAT(N1)
            C=CSE(I)
            S=SNE(I)
            DO 240 K=1,N1
                P=(K-1)*2
                Q=P+1.0
                ZNEW(K)=Z0+P*ZINT
                YNEW(K)=Y0+P*YINT
                ZZNEW(K)=Z0+Q*ZINT
                YYNEW(K)=Y0+Q*YINT
                RNEW(K)=(CR-YYNEW(K))*S-ZZNEW(K)*C
240  CONTINUE
            DO 250 K=1,NUMBER
                DNEW(K)=D

```

```

      CNEW(K)=C
250   SNEW(K)=S
      ZZ(I)=ZZNEW(N1)
      YY(I)=YYNEW(N1)
      ROL(I)=RNEW(N1)
      DEL(I)=D
      NUT=NON+1
      CALL INSERT (Z2, ZNEW(2), I1, NUT, NUMBER)
      CALL INSERT (Y2, YNEW(2), I1, NUT, NUMBER)
      CALL INSERT (ZZ, ZZNEW, I, NON, NUMBER)
      CALL INSERT (YY, YYNEW, I, NON, NUMBER)
      CALL INSERT (DEL, DNEW, I, NON, NUMBER)
      CALL INSERT (ROL, RNEW, I, NON, NUMBER)
      CALL INSERT (CSE, CNEW, I, NON, NUMBER)
      CALL INSERT (SNE, SNEW, I, NON, NUMBER)
260   I=I1+NUMBER
      NON=NON+NUMBER

```

```

270 CONTINUE
280 NOE=NON+NON

```

```

      RETURN

```

```

      ERROR DIAGNOSTICS..

```

```

      TOO MANY WET SEGMENTS..

```

```

290 WRITE (OUTPUT,300) XXSTA
      STOP 7

```

```

300 FORMAT(' More than 20 wet segments for station at X=',F13.5)

```

```

      END
      SUBROUTINE FLOAT

```

```

      THIS SUBROUTINE APPLIES THE GIVEN DRAFT TO THE ORIGINAL TABLE
      OF OFFSETS.

```

```

      COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
      INTEGER OUTPUT, BIF, OFF, COF

```

```

      COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL
      COMMON/DRFT12/ DRAFT(6,2), IDRAFT
      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25,25), NAFT, XAFT(25),
      *   YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
      *   ZOFF(25,25), XFPERP, XAPERP, SHIPL, SHIPB, SHIPT,
      *   Y1(21,25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
      *   XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
      *   DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
      *   DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
      LOGICAL WL, ADJUST

```

```

      PLACE SHIP AT GIVEN DRAFT..

```

```

      TF=DRAFT(IDRAFT,1)
      TA=DRAFT(IDRAFT,2)

```

```

      IF (XFPERP.NE.XAPERP) GO TO 130

```

```

XPERP=XOFF(1)
XAPERP=XOFF(MSTA)
IF (XPERP.NE.XAPERP) GO TO 130
TAN=0.0
IF (TF.EQ.TA) GO TO 140
WRITE(OUTPUT,570) XPERP,TF,TA
STOP 5
130 TAN=(TA-TF)/(XPERP-XAPERP)
140 ISTA=0
ISWL=0
LSWL=0
XX=XOFF(1)
DO 190 J=1,MSTA
  IF (XX.GE.XOFF(J)) GO TO 142
  WRITE (OUTPUT,575) J,XOFF(J),XX
  STOP 6
C
C
C    TJ IS DRAFT OF STATION J.
142  XX=XOFF(J)
    TJ=(XPERP-XX)*TAN+TF
    YNEXT=YOFF(1,J)-TJ
    N=0
    IF (YNEXT.GT.0.0) GO TO 152
    LSTA=J
    IF (ISTA.EQ.0) ISTA=J
    Y1(1,J)=YNEXT
    N=LPTS(J)
    DO 150 I=2,N
      YNEXT=YOFF(I,J)-TJ
      IF (YNEXT.GT.0.0) GO TO 160
      Y1(I,J)=YNEXT
150  CONTINUE
    I=N+1
    IF (YNEXT.EQ.0.0) GO TO 170
C
C
C    SECTION IS NOT SURFACE PIERCING..
152  INPTS(J)=N
    WL(J)=.FALSE.
    GO TO 190
C
C
C    SECTION IS SURFACE PIERCING.  FIND WATERLINE COORDINATES..
160  YO=YOFF(I-1,J)-TJ
    IF (YO.EQ.0.0) GO TO 170
    INPTS(J)=I-1
    ZO=ZOFF(I-1,J)
    ZWL(J)=ZO-YO*(ZOFF(I,J)-ZO)/(YNEXT-YO)
    GO TO 180
C
170  INPTS(J)=I-2
    ZWL(J)=ZOFF(I-1,J)
C
180  WL(J)=.TRUE.
    LSWL=J
    IF (ISWL.EQ.0) ISWL=J
190  CONTINUE
    IF (ISTA.NE.0) GO TO 200
    WRITE (OUTPUT,580)
    STOP 77

```

```

C
C      FIND FORWARD AND AFTER ENDS OF WETTED HULL..
C
200  XWLA=1.0E32
     XWLF=-XWLA
     IF (ISWL.EQ.0) GO TO 210
     XWLF=XOFF(ISWL)
     XWLA=XOFF(LSWL)
210  XXF=XOFF(ISTA)
     IF (NFWD.EQ.0) GO TO 250
     IF (NFWD.GT.1) GO TO 220
C
C      XFWD(1) DEFINED AS FORWARD END OF WATERLINE..
C
     XWLF=AMAX1(XFWD(1),XWLF)
     XXF=AMAX1(XWLF,XXF)
     GO TO 250
C
C      FIND FORWARD END OF WATERLINE AND FORWARD END OF WETTED HULL..
C
220  YO=(XFWD(1)-XFPERP)*TAN+YFWD(1)-TF
     DO 230 J=2,NFWD
         XX=XFWD(J)
         YNEXT=(XX-XFPERP)*TAN+YFWD(J)-TF
         IF (YNEXT.LT.0.0) GO TO 228
         IF (YO.GT.0.0) GO TO 229
         IF (YNEXT.EQ.0.0) GO TO 227
C
C      INTERPOLATE FOR WATERLINE..
C
         XO=XFWD(J-1)
         XX=(XX-XO)/(YO-YNEXT)*YO+XO
227  IF (XX.LE.XWLF) GO TO 229
         XWLF=XX
C
228  XXF=AMAX1(XX,XXF)
229  YO=YNEXT
230  CONTINUE
C
C      FIND AFTER END OF WATERLINE AND AFTER END OF WETTED HULL..
C
250  XXA=XOFF(LSTA)
     IF (NAFT.EQ.0) GO TO 290
     IF (NAFT.GT.1) GO TO 260
C
C      XAFT(1) DEFINED AS AFTER END OF WATER LINE..
C
     XWLA=AMIN1(XAFT(1),XWLA)
     XXA=AMIN1(XWLA,XXA)
     GO TO 290
C
C      FIND AFTER END OF WATERLINE AND AFTER END OF WETTED HULL..
C
260  YO=(XAFT(1)-XFPERP)*TAN+YAFT(1)-TF
     DO 270 J=2,NAFT
         XX=XAFT(J)
         YNEXT=(XX-XFPERP)*TAN+YAFT(J)-TF
         IF (YNEXT.LT.0.0) GO TO 268
         IF (YO.GT.0.0) GO TO 268
         IF (YNEXT.EQ.0.0) GO TO 267
C

```

```

C      INTERPOLATE FOR WATERLINE..
C      XO=XAFT(J-1)
      XX=(XX-XO)/(YO-YNEXT)*YO+XO
267    IF (XX.GE.XWLA) GO TO 269
      XWLA=XX
C
268    XXA=AMIN1(XX,XXA)
269    YO=YNEXT
270 CONTINUE
290 IF (ISWL.EQ.0) ISWL=26
C
420 FORMAT (32HOS T A T I O N   G E O M E T R Y)
480 FORMAT (22H0      DRAFT FWD (AT X =,F10.3,3H) =,F10.3/5X,17HDRAFT AF
1T (AT X =,F10.3,3H) =,F10.3)
570 FORMAT (61H0*** TWO DRAFTS SPECIFIED, AND LENGTH BETWEEN PERPS. IS
1 ZERO./31H *** BOTH PERPENDICULARS AT X =,F12.4/16H *** DRAFT FWD
2=,F12.4/16H *** DRAFT AFT =,F12.4)
575 FORMAT (12H0*** STATION,I3,5H (X =,F12.4,18H) IS OUT OF ORDER./29H
1 *** PREVIOUS STATION HAS X =,F12.4)
580 FORMAT (25H0*** SHIP IS ABOVE WATER.)
C
      END
      SUBROUTINE ERROR(NO,IDUM,RDUM)
      COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
      INTEGER OUTPUT,BIF,OFF,COF
      WRITE(OUTPUT,10) NO
      WRITE(OUTPUT,11) IDUM,RDUM
10     FORMAT(' STOPPED DUE TO ERROR NO. ',I2,/)
11     FORMAT(1X,I3,5X,F10.3)
      STOP
      END
      SUBROUTINE BEER (K)
C
C1     TWO-DIMENSIONAL HYDRODYNAMIC CALCULATION FOR THE SPECIAL CASE
C1     OF ZERO OR INFINITE FREQUENCY.
C1
C5
      COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*      YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*      ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
*      Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*      XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*      DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*      DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
      COMMON // HAH,SAS,RAR,CCA,HVH,SVS,RVR,CCV,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
      COMMON /      /      HAO(24,8),BLOGP(20,20),YLOGP(20,20),BLOGM(20
1,20),YLOGM(20,20),CONH(40),CONR(40,2),CROLL(40,40),CHEAV(40,40),HE
2AVI(20,20),HEAVT(20,20),ROLLI(20,20),ROLLT(20,20),EJI,CZRI,CZLI,SZ
3RI,SZLI,RARI,RALI,RBRI,RBLI,CLI,CRI,SLI,SRI,I,IPESO,J,NJ
C5
C5     INPUT AND OUTPUT LOGICAL UNITS.
      COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
      INTEGER OUTPUT,BIF,OFF,COF
C5
C5     OUTPUT LISTING PAGE HEADING DATA..
C5
      HAH=0.0
      SAS=0.0
      RAR=0.0

```

```

CCA=0.0
HVV=0.0
SVS=0.0
RVR=0.0
CCV=0.0
NN=NON-NWL

```

C3
C
C

```

IF (WN.NE.0.) GO TO 130
ZERO FREQUENCY CASE..

```

C3
C3

```

DO 120 I=1,NN
  XM1=ZZ(I)-Z2(1)
  XP1=ZZ(I)+Z2(1)
  YP1=YY(I)+Y2(1)
  FCR1=.5*ALOG(XM1**2+YP1**2)
  FCL1=.5*ALOG(XP1**2+YP1**2)
  ACR1=ATAN2(YP1,XM1)
  ACL1=ATAN2(YP1,XP1)
  DO 110 J=1,NN
    XM2=ZZ(I)-Z2(J+1)
    XP2=ZZ(I)+Z2(J+1)
    YP2=YY(I)+Y2(J+1)
    FCR2=.5*ALOG(XM2**2+YP2**2)
    FCL2=.5*ALOG(XP2**2+YP2**2)
    ACR2=ATAN2(YP2,XM2)
    ACL2=ATAN2(YP2,XP2)
    SIMJ=SNE(I)*CSE(J)-SNE(J)*CSE(I)
    CIMJ=CSE(I)*CSE(J)+SNE(I)*SNE(J)
    SIPJ=SNE(I)*CSE(J)+SNE(J)*CSE(I)
    CIPJ=CSE(I)*CSE(J)-SNE(I)*SNE(J)
    DCNR=SIPJ*(FCR1-FCR2)+CIPJ*(ACR1-ACR2)
    PCR=CSE(I)*(XM1*FCR1-YP1*ACR1-XM1-XM2*FCR2+YP2*ACR2+XM2)+SNE
1    (J)*(YP2*FCR2+XM2*ACR2+YP1-YP1*FCR1-XM1*ACR1-YP2)
    DCNL=CIMJ*(FCL2-FCL1)+CIMJ*(ACL2-ACL1)
1    PCL=CSE(J)*(XP2*FCL2-YP2*ACL2-XP2-XP1*FCL1+YP1*ACL1+XP1)+SNE
    (J)*(YP2*FCL2+XP2*ACL2-YP2-YP1*FCL1-XP1*ACL1+YP1)
    CROLL(I,J)=BLOGM(J,I)+2.0*(DCNR-DCNL)
    CHEAV(I,J)=BLOGP(J,I)+2.0*(PCR-PCL)
    ROLLT(I,J)=-YLOGM(J,I)-2.0*(PCR-PCL)
    HEAVT(I,J)=-YLOGP(J,I)-2.0*(PCR+PCL)
    IF (J.EQ.NN) GO TO 110
    XM1=XM2
    XP1=XP2
    YP1=YP2
    FCR1=FCR2
    FCL1=FCL2
    ACR1=ACR2
    ACL1=ACL2

```

```

110 CONTINUE
120 CONTINUE
GO TO 160

```

C3
C3
C3

```

INFINITE FREQUENCY CASE..

```

```

130 CONTINUE

```

```

DO 150 I=1,NN
  DO 140 J=1,NN
    CROLL(I,J)=BLOGM(J,I)
    CHEAV(I,J)=BLOGP(J,I)

```

```

        ROLLT(I, J)=-YLOGM(J, I)
        HEAVT(I, J)=-YLOGP(J, I)
140    CONTINUE
150    CONTINUE
C3
C3    SOLUTION FOR EITHER THE ZERO OR INFINITE FREQUENCY CASE..
C3
160    CONTINUE
        DO 170 I=1, NN
            CONH(I)=CSE(I)
            CONR(I, 1)=-SNE(I)
            CONR(I, 2)=ROL(I)
170    CONTINUE
            IT=LNEGT(40, NN, 1, CHEAV, CONH, ERR, HEAVI)
            IF (IT.EQ.0) GO TO 180
            IF (WN.EQ.0.0) WRITE (OUTPUT, 230)
            IF (WN.NE.0.0) WRITE (OUTPUT, 240)
            WRITE (OUTPUT, 270) XXSTA
            IF (IT.NE.0) GO TO 190
180    CONTINUE
            IT=LNEGT(40, NN, 2, CROLL, CONR, ERR, ROLLI)
            IF (IT.EQ.0) GO TO 200
            IF (WN.EQ.0.0) WRITE (OUTPUT, 250)
            IF (WN.NE.0.0) WRITE (OUTPUT, 260)
            WRITE (OUTPUT, 270) XXSTA
            IF (IT.EQ.1) GO TO 200
190    WRITE (OUTPUT, 280)
        STOP 10
C3
C3    EVALUATE VELOCITY POTENTIALS AND FORCE COEFFICIENTS..
C3
200    DO 220 I=1, NN
        PAH=0.0
        PAS=0.0
        PAR=0.0
        DO 210 J=1, NN
            PAH=PAH+CONH(J)*HEAVT(J, I)
            PAS=PAS+CONR(J, 1)*ROLLT(J, I)
            PAR=PAR+CONR(J, 2)*ROLLT(J, I)
210    CONTINUE
C6
C6    THE PRESSURES IN PHASE WITH THE SINUSOIDAL DISPLACEMENT ARE..
C6
C6    HEAVE -- PAH = PAH*RHO*ESIG*ESIG
C6    SWAY  -- PAS = PAS*RHO*ESIG*ESIG
C6    ROLL  -- PAR = PAR*RHO*ESIG*ESIG
C6
C6    THE ACCELERATION COMPONENTS OF THE FORCE ARE EQUAL
C6    IN MAGNITUDE TO THE ABOVE, BUT HAVE THE OPPOSITE SIGN.
C6
        DDD=DEL(I)
        DCI=CSE(I)*DDD
        DSI=-SNE(I)*DDD
        DFR=ROL(I)*DDD
C6
C6    INTEGRATION TO OBTAIN FORCE ACCELERATION COEFFICIENTS..
C6
        HAH=HAH+PAH*DCI
        SAS=SAS+PAS*DSI
        RAR=RAR+PAR*DFR
        CCA=PAR*DSI+PAS*DFR+CCA

```

```

C6
220 CONTINUE
    HAH=HAH*RHO2
    SAS=SAS*RHO2
    RAR=RAR*RHO2
    CCA=CCA*RHO2/2.0
    IF(WN.EQ.0.) HAH=99.    ! INFINITE AT ZERO FREQ
    RETURN

C
230 FORMAT (43H *** HEAVE MATRIX, ZERO ENCOUNTER FREQUENCY)
240 FORMAT (37H *** HEAVE MATRIX, INFINITE FREQUENCY)
250 FORMAT (47H *** SWAY-ROLL MATRIX, ZERO ENCOUNTER FREQUENCY)
260 FORMAT (41H *** SWAY-ROLL MATRIX, INFINITE FREQUENCY)
270 FORMAT (31H *** COEFFS. FOR STATION AT X =,F13.5)
280 FORMAT (26H *** EXECUTION TERMINATED.)

C
END
SUBROUTINE GIRL

C
C1
C1
C1
C6
C6
C6
C5
COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*   YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*   ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
*   Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*   XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*   DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*   DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
COMMON /      HAO(24,8),BLOGP(20,20),YLOGP(20,20),BLOGM(20,
120),YLOGM(20,20),I,J,ACLI,ACLT,ACRI,ACRT,APLI,APLT,APRI,APRT,CIMJ,
2CIPJ,DCNL,DCNR,DPNL,DPNR,FCLI,FCLT,FCRI,FCRT,FPLI,FPLT,FPRI,FPRT,P
3CL,PCR,PPL,PPR,SIMJ,SIPJ,ZMI,ZMT,ZPI,ZPT,YMI,YMT,YPI,YPT
DATA PIN/-3.14159265358979/
DATA TPI/6.28318530717958/
DO 150 I=1,NON
    ZMI=ZZ(I)
    ZPI=ZMI
    YMI=YY(I)-Y2(1)
    YPI=YY(I)+Y2(1)
    FPRI=ALOG(ZMI*ZMI+YMI*YMI)/2.0
    FPLI=FPRI
    FCRI=ALOG(ZMI*ZMI+YPI*YPI)/2.0
    FCLI=FCRI
    APRI=ATAN2(YMI,ZMI)
    APLI=APRI
    ACRI=ATAN2(YPI,ZMI)
    ACLI=ACRI
DO 150 J=1,NON
    J1=J+1
    YMT=YY(I)-Y2(J1)
    YPT=YY(I)+Y2(J1)
    ZMT=ZZ(I)-Z2(J1)
    ZPT=ZZ(I)+Z2(J1)
C
    CALCULATE ANGLES (MEASURED OUTSIDE SECTION)..

```

```

      APRT=ATAN2(YMT,ZMT)
      IF (ZMT.GE.0.0) GO TO 130
      IF (J1.GT.1) GO TO 110
      IF (YMT.LT.0.0) APRT=APRT+TPI
      GO TO 120
110    IF (YMT.GE.0.0) APRT=APRT-TPI
120    IF (YPT.LT.0.0) GO TO 130
      ACRT=PIN
      GO TO 140
130    ACRT=ATAN2(YPT,ZMT)
140    ACLT=ATAN2(YPT,ZPT)
      APLT=ATAN2(YMT,ZPT)
      FPRT=ALOG(ZMT*ZMT+YMT*YMT)/2.0
      FPLT=ALOG(ZPT*ZPT+YMT*YMT)/2.0
      FCRT=ALOG(ZMT*ZMT+YPT*YPT)/2.0
      FCLT=ALOG(ZPT*ZPT+YPT*YPT)/2.0
      SIMJ=SNE(I)*CSE(J)-SNE(J)*CSE(I)
      CIMJ=CSE(I)*CSE(J)+SNE(I)*SNE(J)
      SIPJ=SNE(I)*CSE(J)+SNE(J)*CSE(I)
      CIPJ=CSE(I)*CSE(J)-SNE(I)*SNE(J)
      DPNR=SIMJ*(FPRI-FPRT)+CIMJ*(APRI-APRT)
      PPR=CSE(J)*(ZMI*FPRI-YMI*APRI-ZMI-ZMT*FPRT+YMT*APRT+ZMT)+SNE
1    (J)*(YMI*FPRI+ZMI*APRI-YMI-YMT*FPRT-ZMT*APRT+YMT)
      DPNL=SIPJ*(FPLT-FPLI)+CIPJ*(APLT-APLI)
1    PPL=CSE(J)*(ZPT*FPLT-YMT*APLT-ZPT-ZPI*FPLI+YMI*APLI+ZPI)+SNE
      (J)*(YMI*FPLI+ZPI*APLI+YMT-YMT*FPLT-ZPT*APLT-YMI)
      DCNR=SIPJ*(FCRI-FCRT)+CIPJ*(ACRI-ACRT)
1    PCR=CSE(J)*(ZMI*FCRI-YPI*ACRI-ZMI-ZMT*FCRT+YPT*ACRT+ZMT)+SNE
      (J)*(YPT*FCRT+ZMT*ACRT+YPI-YPI*FCRI-ZMI*ACRI-YPT)
      DCNL=SIMJ*(FCLT-FCLI)+CIMJ*(ACLT-ACLI)
1    PCL=CSE(J)*(ZPT*FCLT-YPT*ACLT-ZPT-ZPI*FCLI+YPI*ACLI+ZPI)+SNE
      (J)*(YPT*FCLT+ZPT*ACLT-YPT-YPI*FCLI-ZPI*ACLI+YPI)
      BLOGP(J,I)=DPNR+DPNL-DCNR-DCNL
      YLOGP(J,I)=PPR+PPL-PCR-PCL
      BLOGM(J,I)=DPNR-DPNL-DCNR+DCNL
      YLOGM(J,I)=PPR-PPL-PCR+PCL
      IF (J.EQ.NON) GO TO 150
      FPRI=FPRT
      FPLI=FPLT
      FCRI=FCRT
      FCLI=FCLT
      APRI=APRT
      APLI=APLT
      ACRI=ACRT
      ACLI=ACLT
      ZMI=ZMT
      YMI=YMT
      ZPI=ZPT
      YPI=YPT
150    CONTINUE
160    CONTINUE
      RETURN
C      END
      SUBROUTINE WINE (K)
C
C1    TWO-DIMENSIONAL HYDRODYNAMIC CALCULATION FOR NON-ZERO FREQUENCIES.
C1
C6    THIS SUBROUTINE IS CALLED FOR EACH STATION AND ALL NON-ZERO
C6    FREQUENCIES WHEN THE HYDRODYNAMIC COEFFICIENTS ARE BEING
C6    GENERATED.

```

```

C6
C5
C5      INPUT AND OUTPUT LOGICAL UNITS.
C5      COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
C5      INTEGER OUTPUT, BIF, OFF, COF
C5
C5      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
*      YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*      ZOFF(25, 25), XFPERP, XAPERP, SHIPL, SHIPB, SHIPT,
*      Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*      XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
*      DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*      DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
COMMON // HAH, SAS, RAR, CCA, HVH, SVS, RVR, CCV, RH02, RSIG, WN, W1, W2, ERR, Z
1RI, YRI, EJT
COMMON / / HAO(24, 8), BLOGP(20, 20), YLOGP(20, 20), BLOGM(20
1, 20), YLOGM(20, 20), CONH(40), CONR(40, 2), CROLL(40, 40), CHEAV(40, 40), HE
2AVI(20, 20), HEAVT(20, 20), ROLLI(20, 20), ROLLT(20, 20), EJI, CZRI, CZLI, SZ
3RI, SZLI, RARI, PALI, RBRI, RBLI, CLI, CRI, SLI, SRI, I, IPESO, NI
DO 110 I=1, NON
NI=NON+I
CONH(I)=0.0
CONR(I, 1)=0.0
CONR(I, 2)=0.0
CONH(NI)=CSE(I)
CONR(NI, 1)=-SNE(I)
CONR(NI, 2)=ROL(I)
ZRI=WN*ZZ(I)
YRI=-WN*(YY(I)+Y2(1))
EJT=EXP(-YRI)
EJI=EJT
CALL ROMEO (CZRI, SZRI, RARI, RBRI, CRI, SRI)
CZLI=CZRI
SZLI=SZRI
RALI=RARI
RBLI=RBRI
CLI=CRI
SLI=SRI
CALL WOMEN (I, BLOGP(1, I), YLOGP(1, I), BLOGM(1, I), YLOGM(1, I), CHEAV
1 (1, I), CROLL(1, I), HEAVI(1, I), HEAVT(1, I), ROLLI(1, I), ROLLT(1, I))
110 CONTINUE
IF (NWL.EQ.0) GO TO 130
I=NOE-NWL+1
DO 120 I=1, NOE
CONH(I)=0.0
CONR(I, 1)=0.0
CONR(I, 2)=0.0
120 CONTINUE
130 IT=JULIET(1, CHEAV, CONH)
IF (IT.EQ.0) GO TO 140
WRITE (OUTPUT, 180) K, WN, XXSTA
IF (IT.NE.1) GO TO 150
140 IT=JULIET(2, CROLL, CONR)
IF (IT.EQ.0) GO TO 160
WRITE (OUTPUT, 190) K, WN, XXSTA
IF (IT.EQ.1) GO TO 160
150 WRITE (OUTPUT, 200)
STOP 11
C
160 HAH=0.0

```

```

SAS=0.0
RAR=0.0
CCA=0.0
HVV=0.0
SVS=0.0
RVR=0.0
CCV=0.0

C9
C9 SLIGHT INCREASE IN SPEED IF THE FINAL INTEGRATION AVOIDS THE
C9 INTERIOR SURFACE SEGMENTS..
C9 NI = NON - NWL
C9 DO *** I=1,NI
C9
DO 170 I=1,NON
CALL SONG (HEAVI(1,I),HEAVT(1,I),ROLLI(1,I),ROLLT(1,I),I)
170 CONTINUE
C6
C6 FORCE COEFFICIENTS.
C6 FORCE IS THAT WHICH MUST BE APPLIED TO THE CYLINDER (PER UNIT
C6 LENGTH) TO CAUSE SINUSOIDAL OSCILLATIONS AT THE GIVEN FREQUENCY
C6 AND UNIT AMPLITUDE.
C6 COEFFICIENTS ARE THE PARTIAL DERIVATIVES OF THE FORCE BY THE
C6 ACCELERATION OR VELOCITY COMPONENT OF THE GIVEN MOTION.
C6
C6 ACCELERATION TERMS..
C6
HAH=HAH*RHO2
SAS=SAS*RHO2
RAR=RAR*RHO2
CCA=CCA*RHO2/2.0
C6
C6 VELOCITY TERMS..
C6
HVV=HVV*RSIG
SVS=SVS*RSIG
RVR=RVR*RSIG
CCV=CCV*RSIG/2.0
C6
RETURN
C3
180 FORMAT (36H *** HEAVE MATRIX, FREQUENCY INDEX =,I3,15H, WAVE NUMBE
1R =,1PE13.5/31H *** COEFFS. FOR STATION AT X =,OPF13.5)
190 FORMAT (40H *** SWAY-ROLL MATRIX, FREQUENCY INDEX =,I3,15H, WAVE N
1UMBER =,1PE13.5/31H *** COEFFS. FOR STATION AT X =,OPF13.5)
200 FORMAT (26H *** EXECUTION TERMINATED.)
C
END
SUBROUTINE WOMEN
1 (I,BLOGP,YLOGP,BLOGM,YLOGM,CHI,CRI,HII,HTI,RII,RTI)
C
REAL BLOGP(1),BLOGM(1),YLOGP(1),YLOGM(1),CHI(1),HII(1),RII(1),CRI(
11),HTI(1),RTI(1)
C5
COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
* YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
* ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
* Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
* XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
* DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
* DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RHO2,RSIG,WN,W1,UU,ERR,X

```

```

1RT, YRT, EJT
COMMON / / HAO(24, 8), BP(20, 20), YP(20, 20), BM(20, 20), YM(2
10, 20), CONH(40), CONR(40, 2), CROLL(40, 40), CHEAV(40, 40), HEAVI(20, 20), H
2EAVT(20, 20), ROLLI(20, 20), ROLLT(20, 20), EJI, CZRI, CZLI, SZRI, SZLI, RARI
3, RALI, RBRI, RBLI, CLI, CRQ, SLI, SRI
DATA TPI/6. 28318530717958/
YYI=YY(I)
ZZI=ZZ(I)
SI=SNE(I)
CI=CSE(I)
DO 110 J=1, NON
  XRT=WN*(ZZI-Z2(J+1))
  YRT=-WN*(YYI+Y2(J+1))
  EJT=EXP(-YRT)
  CALL ROMEO (CZRT, SZRT, RART, RBRT, CRT, SRT)
  XRT=WN*(ZZI+Z2(J+1))
  CALL ROMEO (CZLT, SZLT, RALT, RBLT, CLT, SLT)
  CJ=CSE(J)
  SJ=SNE(J)
  SSS=SI*CJ
  TTT=SJ*CI
  UUU=CI*CJ
  VVV=SI*SJ
  CIPJ=UUU-VVV
  SIPJ=SSS+TTT
  SIMJ=SSS-TTT
  CIMJ=UUU+VVV
  SSS=SIMJ*(CLI-CLT)-CIMJ*(SLI-SLT)
  TTT=SIPJ*(CRQ-CRT)-CIPJ*(SRI-SRT)
  UUU=SJ*(RALI-RALT)+CJ*(RBLT-RBLI)
  VVV=SJ*(RARI-RART)+CJ*(RBRI-RBRT)
  WWW=EJT*(SZRT*CIPJ-CZRT*SIPJ)-EJI*(SZRI*CIPJ-CZRI*SIPJ)
  RRR=EJT*(SZLT*CIMJ-CZLT*SIMJ)-EJI*(SZLI*CIMJ-CZLI*SIMJ)
  GGG=EJI*(SZRI*CJ-CZRI*SJ)-EJT*(SZRT*CJ-CZRT*SJ)
  PPP=EJI*(SZLI*CJ+CZLI*SJ)-EJT*(SZLT*CJ+CZLT*SJ)
  CHI(J)=BLOGP(J)+2. 0*(TTT-SSS)
  CRI(J)=BLOGM(J)+2. 0*(TTT+SSS)
  HII(J)=YLOGP(J)+UU*(VVV+UUU)
  RII(J)=YLOGM(J)+UU*(VVV-UUU)
  CHN(NJ) = CHI(J)
  CRN(NJ) = CRI(J)
  NJ=NON+J
  CHI(NJ)=TPI*(WWW-RRR)
  CRI(NJ)=TPI*(WWW+RRR)
  HTI(J)=W1*(GGG-PPP)
  RTI(J)=W1*(GGG+PPP)
  CHN(J) = -CHI(NJ)
  CRN(J) = -CRI(NJ)
  IF (J.EQ.NON) GO TO 110
  EJI=EJT
  CRQ=CRT
  SRI=SRT
  CLI=CLT
  SLI=SLT
  RARI=RART
  RBRI=RBRT
  RALI=RALT
  RBLI=RBLT
  CZRI=CZRT
  SZRI=SZRT
  CZLI=CZLT

```

```

      SZLI=SZLT
110 CONTINUE
      RETURN
C
      END
      SUBROUTINE SONG (HAI,HOT,RAI,ROT,I)
C
      DIMENSION HAI(1), HOT(1), RAI(1), ROT(1), PP(6)
C5
      COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*      YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*      ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
*      Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*      XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*      DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*      DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
      COMMON // HAH,SAS,RAR,CCA,HVH,SVS,RVR,CCV,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
      COMMON / / HAO(24,8),BLOGP(20,20),YLOGP(20,20),BLOGM(20
1,20),YLOGM(20,20),CONH(40),CONR(40,2)
      PAH=0.0
      PAS=0.0
      PAR=0.0
      PVH=0.0
      PVS=0.0
      PVR=0.0
      DO 110 J=1,NON
        NJ=NON+J
        PAH=PAH+CONH(J)*HOT(J)-CONH(NJ)*HAI(J)
        PAS=PAS+CONR(J,1)*ROT(J)-CONR(NJ,1)*RAI(J)
        PAR=PAR+CONR(J,2)*ROT(J)-CONR(NJ,2)*RAI(J)
        PVH=PVH+CONH(J)*HAI(J)+CONH(NJ)*HOT(J)
        PVS=PVS+CONR(J,1)*RAI(J)+CONR(NJ,1)*ROT(J)
        PVR=PVR+CONR(J,2)*RAI(J)+CONR(NJ,2)*ROT(J)
110 CONTINUE
      DDD=DEL(I)
      DCI=CSE(I)*DDD
      DSI=-SNE(I)*DDD
      DFR=ROL(I)*DDD
C6
C6 THE PRESSURES ON THIS SEGMENT OF THE CYLINDER MAY BE CALCULATED.
C6
C6 THE PRESSURES IN PHASE WITH THE SINUSOIDAL DISPLACEMENT ARE..
C6
C6 HEAVE -- PAH = PAH*RHO*ESIG*ESIG
C6 SWAY -- PAS = PAS*RHO*ESIG*ESIG
C6 ROLL -- PAR = PAR*RHO*ESIG*ESIG
C6
C6 OF COURSE THE ACCELERATION COMPONENTS OF THE FORCE ARE EQUAL
C6 IN MAGNITUDE TO THE ABOVE, BUT HAVE THE OPPOSITE SIGN.
C6
C6 THE PRESSURES IN PHASE WITH THE SINUSOIDAL VELOCITY ARE..
C6
C6 HEAVE -- PVH = PVH*RHO*ESIG*ESIG
C6 SWAY -- PVS = PVS*RHO*ESIG*ESIG
C6 ROLL -- PVR = PVR*RHO*ESIG*ESIG
C6
C6
C6 INTEGRATION TO OBTAIN FORCE ACCELERATION COEFFICIENTS..
C6
      HAH=HAH+PAH*DCI

```

```

SAS=SAS+PAS*DSI
RAR=RAR+PAR*DFR
C6
CCA=PAR*DSI+PAS*DFR+CCA
C6 INTEGRATION TO OBTAIN FORCE VELOCITY COEFFICIENTS..
C6
HVV=HVV+PVH*DCI
SVS=SVS+PVS*DSI
RVR=RVR+PVR*DFR
CCV=PVR*DSI+PVS*DFR+CCV
C6
C6 AT THIS POINT THE PRESSURES REQUIRE THE MODIFICATIONS NOTED
C6 ABOVE TO GIVE THE DIMENSIONAL VALUES.
C6 THE INTEGRATIONS OF THE PRESSURES ARE COMPLETED ELSEWHERE
C6 IN THE PROGRAM TO GIVE DIMENSIONAL FORCE COEFFICIENTS.
C6
RETURN
C
END
SUBROUTINE ROMEO (C,S,RA,RB,CIN,SON)
C
C1 EXPONENTIAL INTEGRAL WITH COMPLEX ARGUMENT.
C1
C2 THE ARGUMENT IS SUPPLIED THROUGH BLANK COMMON AS THE VARIABLES
C2 X AND Y .
C2
C3 PARAMETERS AND VARIABLES.
C3 X -- REAL PART OF ARGUMENT
C3 Y -- IMAGINARY PART OF ARGUMENT
C3 E -- EXP( -Y )
C3 C -- COS( X )
C3 S -- SIN( X )
C3 CIN -- REAL RESULT
C3 SON -- IMAGINARY RESULT
C3 RA -- ALOG( X**2 + Y**2 )/2.0 - CIN
C3 RB -- ATAN( X/Y ) - PI/2.0 + SON
C3
C5
COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
* YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
* ZOFF(25,25),XPERP,XAPERP,SHIPL,SHIPB,SHIPT,
* Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
* XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
* DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
* DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON / / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1 RH02, RSIG, WN, W1, W2, ERR, X, Y, E
C5
C5 INPUT AND OUTPUT LOGICAL UNITS.
COMMON/IQ/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
DATA GAMMA /0.5772 15664 90153 28606 06512/
DATA HALFPI/1.5707 96326 79489 66192 31322/
C
AT=ATAN2(X,Y)
ARG=AT-HALFPI
C=COS(X)
S=SIN(X)
R=X*X+Y*Y
AL=0.5*ALOG(R)
TEST=0.00001

```

```

      IF (R.LT.1.) GO TO 130
      TEST=.1*TEST
      IF (R.LT.2.) GO TO 130
      TEST=.1*TEST
      IF (R.LT.4.) GO TO 130
      TEST=.1*TEST
130  SUMC=GAMMA+AL+Y
      SUMS=AT+X
      TC=Y
      TS=X
      COX=1.
      DO 140 K=2,501
        TO=TC
        FACT=COX/FLOAT(K)**2
        COX=K
        TC=FACT*(Y*TC-X*TS)
        TS=FACT*(Y*TS+X*TO)
        SUMC=SUMC+TC
        SUMS=SUMS+TS
        IF ((ABS(TC)+ABS(TS)).LE.TEST) GO TO 150
140  CONTINUE
      WRITE (OUTPUT,190) XXSTA,X,Y,WN
      STOP 12
150  CIN=E*(C*SUMC+S*SUMS)
      SON=E*(S*SUMC-C*SUMS)
      RA=AL-CIN
      RB=ARG+SON
      RETURN
C
190  FORMAT (59H0*** NON-CONVERGENT EXPONENTIAL INTEGRAL FOR STATION AT
1    X =,F13.5/22H *** PARAMETERS -- X =,1PE13.5,5H, Y =,E13.3,15H, WA
2    V2E NUMBER =,E13.5)
C
      END
      FUNCTION JULIET (N1,A,B)
C
C..  SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C..  FOR THE SPECIALIZED MATRICES IN THE SUBROUTINE WINE.
C
      REAL A(40,1),B(40,1)
C2
C2  THE A MATRIX MUST BE DIMENSIONED WITH EXACTLY 40 ROWS AND
C2  AT LEAST 40 COLUMNS. THE B MATRIX MUST ALSO BE DIMENSIONED
C2  WITH EXACTLY 40 ROWS AND AT LEAST N1 COLUMNS.
C3
C5  INPUT AND OUTPUT LOGICAL UNITS.
C5  COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
C5  INTEGER OUTPUT,BIF,OFF,COF
C5
C5  COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*    YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*    ZOFF(25,25),XPERP,XAPERP,SHIPL,SHIPB,SHIPT,
*    Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*    XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*    DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*    DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
      COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RH02,RSIG,WN,W1,W2,ERR,Z
      1RI,YRI,EJT
C

```

```

C      COMMON /      /      HAO(24, 8), BLOGP(20, 20, 4), CONH(40, 3), CROLL(40
1, 40, 2), HEAVI(20, 20, 4), EJI, CZRI, CZLI, SZRI, SZLI, RARI, RALI, RBRI, RBLI,
C      2CLI, CRG, SLI, SRI, Z(40)
C      N2=NOE/2
C      D=1.0
C      C. . COMPLETE THE MATRIX A.
C      DO 120 J=1, N2
C          L=N2+J
C          DO 110 I=1, N2
C              K=N2+I
C              A(I, L)=-A(K, J)
C              A(K, L)=A(I, J)
C      110 CONTINUE
C      120 CONTINUE
C      NM1=NOE-1
C      C. . SOLVE AT*X=B FOR X , WHERE AT IS THE TRANSPOSE OF THE
C      MATRIX A . STORE THE X VECTOR(S) IN B .
C      DO 210 J=1, NM1
C          J1=J+1
C      C. . FIND ELEMENT OF ROW J, COLS J--N, WHICH HAS MAX ABSOLUTE VALUE.
C      LMAX=J
C      RMAX=ABS(A(J, J))
C      DO 130 K=J1, NOE
C          RNEXT=ABS(A(J, K))
C          IF (RMAX. GE. RNEXT) GO TO 130
C          RMAX=RNEXT
C          LMAX=K
C      130 CONTINUE
C      IF (LMAX.NE. J) GO TO 140
C      C. . MAX ELEMENT IS ON DIAGONAL.
C      IF (A(J, J)) 170, 260, 170
C      C. . MAX ELEMENT IS NOT ON DIAGONAL.
C      C. . EXCHANGE COLUMNS J AND LMAX.
C      140 DO 150 L=J, NOE
C          W=A(L, J)
C          A(L, J)=A(L, LMAX)
C          A(L, LMAX)=W
C      150 CONTINUE
C      C. . EXCHANGE ROWS J AND LMAX.
C      DO 160 L=1, N1
C          W=B(J, L)
C          B(J, L)=B(LMAX, L)
C          B(LMAX, L)=W
C      160 CONTINUE
C      D=-D

```

C. . ZERO ROW J TO RIGHT OF DIAGONAL.

```
C
170   D=A(J,J)*D
      V=1.0/A(J,J)
      Z(J)=V
      DO 200 K=J1,NOE
        IF (A(J,K).EQ.0.0) GO TO 200
        W=-V*A(J,K)
        DO 180 L=J1,NOE
          A(L,K)=W*A(L,J)+A(L,K)
180   CONTINUE
      DO 190 L=1,N1
        B(K,L)=W*B(J,L)+B(K,L)
190   CONTINUE
200   CONTINUE
210   D=A(NOE,NOE)*D
      IF (A(NOE,NOE).EQ.0.0) GO TO 260
      Z(NOE)=1.0/A(NOE,NOE)
```

C. . OBTAIN SOLUTION BY BACK SUBSTITUTION.

```
C
      DO 220 L=1,N1
        B(NOE,L)=Z(NOE)*B(NOE,L)
220   CONTINUE
      DO 250 K=1,NM1
        J=NOE-K
        J1=J+1
        DO 240 L=1,N1
          W=0.0
          DO 230 I=J1,NOE
            W=A(I,J)*B(I,L)+W
230   CONTINUE
        B(J,L)=(B(J,L)-W)*Z(J)
240   CONTINUE
250   CONTINUE
      IF (ABS(D).LT.ERR) GO TO 270
```

C JULIET=0

C. . NO PROBLEMS DURING THIS EXECUTION.

C RETURN

C. . SINGULAR MATRIX--MAXIMUM ELEMENT IN ROW IS ZERO.

```
C
260   JULIET=3
      WRITE (OUTPUT,280)
      RETURN
```

C. . ABSOLUTE DETERMINANT VALUE LESS THAN ERROR VALUE..

```
C
270   JULIET=1
      WRITE (OUTPUT,290) D,ERR
      RETURN
```

```
C
280   FORMAT (20H0*** SINGULAR MATRIX)
290   FORMAT (18H0*** DETERMINANT =,1PE13.5,24H, ERROR SPECIFICATION =,
1E13.5)
```

C END

```

      FUNCTION LNEGT(M,N,N1,A,B,ERROR ,Z)
C
C.. SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C.. SOLVES   A*X=B   FOR   X , AND STORES THE   X   VECTOR(S) IN   B
C
      REAL A(M,M),B(M,M) ,Z(M),ERROR ,RMAX,RNEXT,W
C
C5
C5   INPUT AND OUTPUT LOGICAL UNITS..
      COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
      INTEGER OUTPUT,BIF,OFF,COF
C5
C
      D=1.0
      NM1=N-1
      IF (NM1.EQ.0) GO TO 210
      DO 200 J=1,NM1
        J1=J+1
C
C.. FIND ELEMENT OF COL J, ROWS J-N, WHICH HAS MAX ABSOLUTE VALUE.
C
      LMAX=J
      RMAX=ABS(A(J,J))
      DO 110 K=J1,N
        RNEXT=ABS(A(K,J))
        IF (RMAX.GE.RNEXT) GO TO 110
        RMAX=RNEXT
        LMAX=K
      110   CONTINUE
      IF (LMAX.NE.J) GO TO 120
C
C.. MAX ELEMENT IN COLUMN IS ON DIAGONAL
C
      IF (A(J,J)) 150,270,150
C
C.. MAX ELEMENT IS NOT ON DIAGONAL. EXCHANGE ROWS J AND LMAX.
C
      120   DO 130 L=J,N
            W=A(J,L)
            A(J,L)=A(LMAX,L)
            A(LMAX,L)=W
      130   CONTINUE
      DO 140 L=1,N1
            W=B(J,L)
            B(J,L)=B(LMAX,L)
            B(LMAX,L)=W
      140   CONTINUE
      D=-D
C
C.. ZERO COLUMN J BELOW THE DIAGONAL.
C
      150   D=A(J,J)*D
            Z(J)=1.0/A(J,J)
            DO 190 K=J1,N
              IF (A(K,J)) 160,190,160
      160   W=-Z(J)*A(K,J)
            DO 170 L=J1,N
              A(K,L)=W*A(J,L)+A(K,L)
      170   CONTINUE
            DO 180 L=1,N1
              B(K,L)=W*B(J,L)+B(K,L)

```

```

180     CONTINUE
190     CONTINUE
200     CONTINUE
210     D=A(N,N)*D
      IF (A(N,N).EQ.0.0) GO TO 270
      Z(N)=1./A(N,N)
C
C. . OBTAIN SOLUTION BY BACK SUBSTITUTION.
C
      DO 220 L=1,N1
        B(N,L)=Z(N)*B(N,L)
220     CONTINUE
      IF (NM1.EQ.0) GO TO 260
      DO 250 K=1,NM1
        J=N-K
        J1=J+1
        DO 240 L=1,N1
          W=0.
          DO 230 I=J1,N
            W=A(J,I)*B(I,L)+W
230         CONTINUE
          B(J,L)=(B(J,L)-W)*Z(J)
240       CONTINUE
250     CONTINUE
260     LNEGT=0
      IF (ABS(D).GE.ERROR) RETURN
      LNEGT=1
      WRITE (OUTPUT,280) D,ERROR
      RETURN
C
C. . SINGULAR MATRIX--MAXIMUM ELEMENT IN COLUMN IS ZERO.
C
270     LNEGT=3
      WRITE (OUTPUT,290)
      RETURN
C
280     FORMAT (18H0*** DETERMINANT =,1PE13.5,24H, ERROR SPECIFICATION =,
1E13.5)
290     FORMAT (20H0*** SINGULAR MATRIX)
C
      END

```

PROGRAM HYDREX3

PROGRAM HYDREX3

C

```
CHARACTER*25 PANFIL,MATFIL
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),
* ST(120),ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),
* PRFS(120),STOLD(120),PX(120,6)
COMMON/FS/AKZ(100,100),SS(100,100),CC(100,100),
* DKX(100),DKY(100),AKX(100),AKY(100)
COMMON/BD2/XPT(150),YPT(150),ZPT(150),WRF(150),
* WRFR(150),KK(150,4)
COMMON/A/NPAN,NPT,GEE,RHO,NKX,NKY,EYE,DT,TIM,UFWD
DIMENSION PF(6),PB(6),PT(6)
COMMON/WAVEX/OMEGA
COMMON/BP/BPRES(120),TPRES(120)
COMPLEX EYE
EYE=(0.0,1.0)
```

C

```
-----
TYPE 1
ACCEPT 4,PANFIL
TYPE 2
ACCEPT 4,MATFIL
OPEN(UNIT=2,FILE=PANFIL,TYPE='OLD')
OPEN(UNIT=3,FILE=MATFIL,FORM='UNFORMATTED',TYPE='NEW')
OPEN(UNIT=99,FILE='X.DAT',FORM='UNFORMATTED',TYPE='NEW')
CALL EBD
CALL POTST
WRITE(6,6)
WRITE(6,7) J,AN(J,1),AN(J,2),AN(J,3),
* XPAN(J),YPAN(J),ZPAN(J),AREA(J)
150 * CONTINUE
STOP
1 FORMAT(' Input name of [PAN] file >','$')
2 FORMAT(' Input name of [MAT] file >','$')
4 FORMAT(A)
6 FORMAT(' J',9X,'NX',9X,'NY',9X,'NZ',9X,'XP',9X,
* 'YP',9X,'ZP',9X,'AREA')
7 FORMAT(1X,I5,7F11.4)
END
```

```

SUBROUTINE PREP(J)
COMMON/BD/XPAN(120), YPAN(120), ZFAN(120), AREA(120), ST(120),
* ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
* STOLD(120), PX(120,6)
COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150), WRFR(150),
* KK(150,4)
COMMON/ARE/RR(500), XZJ(200), YXJ(200), ZYJ(200)
ZYT=0.0
YXT=0.00
XZT=0.00
J4=J*4
JT=4
IF(KK(J,4).EQ.0) JT=3
DO 20 JJ=1, JT
J4=J4+1
J2=1
IF(JJ.LT.JT) J2=JJ+1
KF=KK(J, JJ)
KG=KK(J, J2)
AG=XPT(KG)
BG=YPT(KG)
CG=ZPT(KG)
AF=XPT(KF)
BF=YPT(KF)
CF=ZPT(KF)
R=SQRT((AF-AG)**2+(BF-BG)**2+(CF-CG)**2)
XT=AF-XPAN(J)
YT=BF-YPAN(J)
ZT=CF-ZPAN(J)
ANX=(AF-AG)/R
ANY=(BF-BG)/R
ANZ=(CF-CG)/R
DOT=ANX*XT+ANY*YT+ANZ*ZT
XT=XT-DOT*ANX
YT=YT-DOT*ANY
ZT=ZT-DOT*ANZ
ZYT=ZYT+ZT*ANY-ANZ*YT
YXT=YXT+YT*ANX-ANY*XT
XZT=XZT+XT*ANZ-ANX*ZT
RR(J4)=R
CONTINUE
XZJ(J)=SIGN(AN(J,2), XZT)
YXJ(J)=SIGN(AN(J,3), YXT)
ZYJ(J)=SIGN(AN(J,1), ZYT)
RETURN
END

```

20

```

SUBROUTINE SELF(AF, BF, CF, AG, BG, CG, FEE)
REAL LB21, LA21
ASQ=AF*AF+BF*BF+CF*CF
BSQ=AG*AG+BG*BG+CG*CG
ADB=AF*AG+BF*BG+CF*CG
ADB2=ADB+ADB
ASAS=(AF*BG-BF*AG)**2+(CF*BG-BF*CG)**2+(AF*CG-BF*AG)**2
FF=0.00
DO 15 MK=1, 10
DO 15 NK=1, MK
LA21=FLOAT(NK-MK)
A2SQ=ASQ*LA21*LA21
DO 15 ML=1, 11-MK
DO 15 NL=1, 11-ML
LB21=FLOAT(NL-ML)
IF(LA21.NE.0.) GO TO 5
IF(LB21.LT.0.) GO TO 5
GO TO 15
R=SQRT(A2SQ+ADB2*LA21*LB21+BSQ*LB21*LB21)
FF=FF+1.0/R
CONTINUE
FEE=FF*ASAS*0.002
RETURN
END

```

5

15

```

SUBROUTINE SOLID(XPN,G,NSIDE)
DIMENSION CS(4),SN(4),Z(4),XPN(3,4)
G=-6.283185308
ACR12=XPN(1,1)*XPN(1,2)+XPN(2,1)*XPN(2,2)+XPN(3,1)*XPN(3,2)
ACR13=XPN(1,1)*XPN(1,3)+XPN(2,1)*XPN(2,3)+XPN(3,1)*XPN(3,3)
ACR23=XPN(1,2)*XPN(1,3)+XPN(2,2)*XPN(2,3)+XPN(3,2)*XPN(3,3)
IF(NSIDE.EQ.4) GO TO 40
G=-3.141592659
CS(1)=ACR23-ACR13*ACR12
CS(2)=ACR13-ACR12*ACR23
CS(3)=ACR12-ACR23*ACR13
SN(1)=XPN(1,1)*(XPN(2,2)*XPN(3,3)-XPN(3,2)*XPN(2,3))+
+ XPN(2,1)*(XPN(3,2)*XPN(1,3)-XPN(1,2)*XPN(3,3))+
+ XPN(3,1)*(XPN(1,2)*XPN(2,3)-XPN(2,2)*XPN(1,3))
SN(2)=SN(1)
SN(3)=SN(1)
SN(4)=0.
GO TO 50
40 ACR14=XPN(1,1)*XPN(1,4)+XPN(2,1)*XPN(2,4)+XPN(3,1)*XPN(3,4)
ACR24=XPN(1,2)*XPN(1,4)+XPN(2,2)*XPN(2,4)+XPN(3,2)*XPN(3,4)
ACR34=XPN(1,3)*XPN(1,4)+XPN(2,3)*XPN(2,4)+XPN(3,3)*XPN(3,4)
CS(1)=ACR24-ACR14*ACR12
CS(2)=ACR13-ACR23*ACR12
CS(3)=ACR24-ACR34*ACR23
CS(4)=ACR13-ACR34*ACR14
B241=XPN(2,2)*XPN(3,4)-XPN(3,2)*XPN(2,4)
B242=XPN(3,2)*XPN(1,4)-XPN(1,2)*XPN(3,4)
B243=XPN(1,2)*XPN(2,4)-XPN(2,2)*XPN(1,4)
B131=XPN(2,1)*XPN(3,3)-XPN(3,1)*XPN(2,3)
B132=XPN(3,1)*XPN(1,3)-XPN(1,1)*XPN(3,3)
B133=XPN(1,1)*XPN(2,3)-XPN(2,1)*XPN(1,3)
SN(1)=XPN(1,1)*B241+XPN(2,1)*B242+XPN(3,1)*B243
SN(2)=-(XPN(1,2)*B131+XPN(2,2)*B132+XPN(3,2)*B133)
SN(3)=-(XPN(1,3)*B241+XPN(2,3)*B242+XPN(3,3)*B243)
SN(4)=XPN(1,4)*B131+XPN(2,4)*B132+XPN(3,4)*B133
50 CONTINUE
D TYPE 8844,SN(1),CS(1)
D TYPE 8844,SN(2),CS(2)
D TYPE 8844,SN(3),CS(3)
D TYPE 8844,SN(4),CS(4)
8844 FORMAT(' SN,CS=',2F15.8)
SUM=SN(1)+SN(2)+SN(3)+SN(4)
IF(ABS(SUM).GT.0.01) GO TO 25
IF(ABS(CS(1)).GT.ABS(SN(1))) GO TO 25
IF(ABS(CS(2)).GT.ABS(SN(2))) GO TO 25
IF(ABS(CS(3)).GT.ABS(SN(3))) GO TO 25
1090 G=SUM*.25
IF(NSIDE.EQ.3) G=SUM*.1666666667
RETURN
25 ST=SN(NSIDE)
DO 30 I=1,NSIDE
IF((ABS(CS(I)).LT.9E-8).AND.(ABS(SN(I)).LT.9E-05))
+ GO TO 1090
IF(ST*SN(I).LT.0.) GO TO 1090
ST=SN(I)
C2=CS(I)/SQRT(SN(I)**2+CS(I)**2)
G=G+ACOS(C2)
30 CONTINUE
RETURN
END

```

```

      SUBROUTINE EBD
C  INITIALIZE PANELS AND COMPUTE BODY MATRIX
C
      COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
      * ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
      * STOLD(120),PX(120,6)
      COMMON/BD2/XPT(150),YPT(150),ZPT(150),WRF(150),WRFR(150),
      * KK(150,4)
      COMMON/A/NPAN,NPT,GEE,RHO,NKX,NKY,EYE,DT,TIM,UFW
      DIMENSION EP(120),EPP(120)
      COMPLEX EYE
C  READ IN BODY PANEL PARAMETERS
101  FORMAT(4I5)
100  FORMAT(3F10.0)
103  FORMAT(3F10.2)
104  FORMAT(I3)
C  NUMBER OF POINTS AND PANELS
      READ(2,101) NPT,NPAN
      TYPE 101, NPT,NPAN
C  COORDINATES OF POINTS
      READ(2,100) (XPT(N),YPT(N),ZPT(N),N=1,NPT)
      DO 7777 N=1,NPT
      TYPE 103, XPT(N),YPT(N),ZPT(N)
7777  CONTINUE
C  DEFINE CORNER POINTS OF EACH PANEL
      READ(2,101) (KK(N,1),KK(N,2),KK(N,3),KK(N,4),N=1,NPAN)
C  COMPUTE PANEL AREAS
      DO 150 J=1,NPAN
      K1=KK(J,1)
      K2=KK(J,2)
      K3=KK(J,3)
      K4=KK(J,4)
      IF(K4.EQ.0) GO TO 8
      XPAN(J)=(XPT(K1)+XPT(K2)+XPT(K3)+XPT(K4))*0.25
      YPAN(J)=(YPT(K1)+YPT(K2)+YPT(K3)+YPT(K4))*0.25
      ZPAN(J)=(ZPT(K1)+ZPT(K2)+ZPT(K3)+ZPT(K4))*0.25
      GO TO 9
C  TRIANGULAR PANELS
8      XPAN(J)=(XPT(K1)+XPT(K2)+XPT(K3))/3.0
      YPAN(J)=(YPT(K1)+YPT(K2)+YPT(K3))/3.0
      ZPAN(J)=(ZPT(K1)+ZPT(K2)+ZPT(K3))/3.0
      K4=K3
9      XA=XPT(K3)-XPT(K1)
      XB=XPT(K4)-XPT(K2)
      YA=YPT(K3)-YPT(K1)
      YB=YPT(K4)-YPT(K2)
      ZA=ZPT(K3)-ZPT(K1)
      ZB=ZPT(K4)-ZPT(K2)
C  COMPUTE PANEL AREAS
      AZ=XA*YB-YA*XB
      AX=YA*ZB-ZA*YB
      AY=ZA*XB-XA*ZB
      ARE=SQRT(AX*AX+AY*AY+AZ*AZ)
      AREA(J)=ARE*0.50
      AN(J,1)=-AX/ARE
      AN(J,2)=-AY/ARE
      AN(J,3)=-AZ/ARE
150  CONTINUE
808  FORMAT(1X,I5,5F11.4)
      DO 1308 J=1,NPAN
      JJJ=J
      CALL PREP(JJJ)
      ST(J)=0.00
      DO 1308 K=1,6
      PX(J,K)=0.00
1308  CONTINUE
      DO 308 J=1,NPAN
      JJJ=J
      AX=-AN(J,1)
      AY=-AN(J,2)
      AZ=-AN(J,3)
      XF=XPAN(J)
      YF=YPAN(J)
      ZF=ZPAN(J)
      DO 157 L=1,NPT
      WRF(L)=SQRT((XPT(L)-XF)**2+(YPT(L)-YF)**2+(ZPT(L)-ZF)**2)
      WRFR(L)=SQRT((XPT(L)-XF)**2+(YPT(L)-YF)**2+(ZPT(L)+ZF)**2)
157  CONTINUE

```

```

DO 500 I=1,3
WRITE(3) (AN(J, I), J=1, NPAN)
500 CONTINUE
WRITE(3) (XPAN(J), J=1, NPAN)
WRITE(3) (YPAN(J), J=1, NPAN)
WRITE(3) (ZPAN(J), J=1, NPAN)
WRITE(3) (AREA(J), J=1, NPAN)
DO 309 JL=1, NPAN
JLJ=JL
CALL GE(XF, YF, ZF, JLJ, VX, VY, VZ, VXR, VYR, VZR, JJJ)
VX=VX+VXR
VY=VY+VYR
VZ=VZ+VZR
C COMPUTE NORMAL VELOCITY AT PANEL J DUE TO PANEL JL
E(JL)=AX*VX+AY*VY+AZ*VZ
C INCREMENT PX MATRIX
FR1=-AREA(J)*VX*AN(J, 1)
FR2=-AREA(J)*VX*AN(J, 2)
FR3=-AREA(J)*VX*AN(J, 3)
PX(JL, 1)=PX(JL, 1)+FR1
PX(JL, 2)=PX(JL, 2)+FR2
PX(JL, 3)=PX(JL, 3)+FR3
PX(JL, 4)=PX(JL, 4)+YF*FR3-ZF*FR2
PX(JL, 5)=PX(JL, 5)+ZF*FR1-XF*FR3
PX(JL, 6)=PX(JL, 6)+XF*FR2-YF*FR1
309 CONTINUE
WRITE(99) (E(JL), JL=1, NPAN)
308 CONTINUE
DO 2424 K=1, 6
2424 WRITE(3) (PX(JL, K), JL=1, NPAN)
CLOSE (UNIT=99)
C INVERT E MATRIX
CALL MATIN(NPAN)
RETURN
END

```

```

C SUBROUTINE MATIN(NPAN)
C INVERST MATRIX
DIMENSION E(120, 120), BB(120), EST(120)
OPEN(UNIT=99, FILE='SCR', FORM='UNFORMATTED', TYPE='OLD')
DO 120 J=1, NPAN
120 READ(99) (E(J, I), I=1, NPAN)
DO 130 J=1, NPAN
DO 11 MM=1, NPAN
11 EST(MM)=0.00
BB(MM)=0.00
BB(J)=1.0
EST(J)=1.0/E(J, J)
DO 17 NIT=1, 6
DO 17 K=1, NPAN
B=BB(K)
DO 15 I=1, NPAN
15 IF(I.NE.K) B=B-E(K, I)*EST(I)
EST(K)=B/E(K, K)
17 CONTINUE
WRITE(3) (EST(K), K=1, NPAN)
130 CONTINUE
RETURN
END

```

C

```

SUBROUTINE GE(XF,YF,ZF,J,V1,V2,V3,V1R,V2R,V3R,NBT)
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
* ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/BD2/XPT(150),YPT(150),ZPT(150),WRF(150),WRFR(150)
* ,KK(150,4)
COMMON/ARE/RR(500),XZJ(200),YXJ(200),ZYJ(200)
DIMENSION XSA(3,4),XFA(3),XSAR(3,4)
J4=J*4
V1=0.00
V2=0.00
V3=0.00
V1R=0.00
V2R=0.00
V3R=0.00
XNJ=AN(J,1)
YNJ=AN(J,2)
ZNJ=AN(J,3)
NSIDE=4
IF(KK(J,4).EQ.0) NSIDE=3
DO 20 JJ=1,NSIDE
J2=1
IF(JJ.LT.NSIDE) J2=JJ+1
J4=J4+1
KF=KK(J,JJ)
AF=XPT(KF)
BF=YPT(KF)
CF=ZPT(KF)
R=RR(J4)
KG=KK(J,J2)
ANX=(AF-XPT(KG))/R
ANY=(BF-YPT(KG))/R
ANZ=(CF-ZPT(KG))/R
A=AF-XF
B=BF-YF
C=CF-ZF
TX=XZJ(J)*ANZ-YXJ(J)*ANY
TY=YXJ(J)*ANX-ZYJ(J)*ANZ
TZ=ZYJ(J)*ANY-XZJ(J)*ANX
EX1=A*ANX+B*ANY+C*ANZ
CALL GO(EX1,R,FF,WRF(KF),WRF(KG))
V1=V1+FF*TX
V2=V2+FF*TY
V3=V3+FF*TZ
XSA(1,JJ)=-A/WRF(KF)
XSA(2,JJ)=-B/WRF(KF)
XSA(3,JJ)=-C/WRF(KF)
EX1R=EX1+2.0*ZF*ANZ
CR=-CF-ZF
CALL GO(EX1R,R,FR,WRFR(KF),WRFR(KG))
V1R=V1R-FR*TX
V2R=V2R-FR*TY
V3R=V3R-FR*TZ
XSAR(1,JJ)=-A/WRFR(KF)
XSAR(2,JJ)=-B/WRFR(KF)
XSAR(3,JJ)=CR/WRFR(KF)
20 CONTINUE
G=6.283185307
IF(J.EQ.NBT) GO TO 84
CALL SOLID(XSA,G,NSIDE)
AGG=A*XNJ+B*YNJ+C*ZNJ
G=-SIGN(G,AGG)
84 CONTINUE
CALL SOLID(XSAR,GR,NSIDE)
AGGR=A*XNJ+B*YNJ-CR*ZNJ
GR=SIGN(GR,AGGR)
85 CONTINUE
7371 FORMAT(' G,GR=',2F15.5)
V1=V1+XNJ*G
V2=V2+YNJ*G
V3=V3+ZNJ*G
V1R=V1R+XNJ*GR
V2R=V2R+YNJ*GR
V3R=V3R-ZNJ*GR
5590 FORMAT(' V1,V2,V3=',3F15.5)
5591 FORMAT(' V1R,V2R,V3R=',3F15.5)
RETURN
END

```

C

```

SUBROUTINE POTST
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
* ACN(120), ACNW(120), AN(120, 3), E(120), P(120, 6), PRFS(120),
* STOLD(120), PX(120, 6)
COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150), WRFR(150),
* KK(150, 4)
COMMON/A/NPAN, NPT, GEE, RHO, NKX, NKY, EYE, DT, TIM, UFWD
COMPLEX A, B, EYE
DIMENSION XPSL(3, 4), XPSLR(3, 4), PBB(120, 120)
COMMON/PTST/ARE4(200, 4), X4(200, 4), Y4(200, 4), Z4(200, 4)
* , SEL(200, 4)
DO 1500 J=1, NPAN
  ARE4(J, 4)=-1.0
  JT=4
  IF(KK(J, 4).EQ.0) JT=3
  DO 1500 JJ=1, JT
    J2=1
    IF(JJ.LT.JT) J2=JJ+1
    KF=KK(J, JJ)
    KG=KK(J, J2)
    X4(J, JJ)=(XPT(KF)+XPT(KG)+XPAN(J))/3.0
    Y4(J, JJ)=(YPT(KF)+YPT(KG)+YPAN(J))/3.0
    Z4(J, JJ)=(ZPT(KF)+ZPT(KG)+ZPAN(J))/3.0
    AF=XPT(KF)-XPAN(J)
    BF=YPT(KF)-YPAN(J)
    CF=ZPT(KF)-ZPAN(J)
    AG=XPT(KG)-XPAN(J)
    BG=YPT(KG)-YPAN(J)
    CG=ZPT(KG)-ZPAN(J)
    CALL SELF(AF, BF, CF, AG, BG, CG, FEE)
    SEL(J, JJ)=FEE
    CR=AF*BG-BF*AG
    AR=BF*CG-CF*BG
    BR=CF*AG-AF*CG
    ARE4(J, JJ)=0.5*SQRT(AR*AR+BR*BR+CR*CR)
1500 CONTINUE
DO 127 NJ=1, NPAN
1277 DO 1277 MJ=1, NPAN
  PBB(NJ, MJ)=0.00
  P(NJ, 1)=0.00
  P(NJ, 2)=0.00
  P(NJ, 3)=0.00
  P(NJ, 4)=0.00
  P(NJ, 5)=0.00
  P(NJ, 6)=0.00
  DO 128 NK=1, 4
    ARN=ARE4(NJ, NK)
    IF(ARN.LT.0.0) GO TO 128
    P1=0.0
    P2=0.0
    P3=0.0
    P4=0.0
    P5=0.0
    P6=0.0
    X=X4(NJ, NK)
    Y=Y4(NJ, NK)
    Z=Z4(NJ, NK)
    DO 138 MK=1, NPAN
    DO 138 MK=1, 4
      XF=X4(MJ, MK)
      YF=Y4(MJ, MK)
      ZF=Z4(MJ, MK)
      ARM=ARE4(MJ, MK)
      IF(ARM.LT.0.00) GO TO 138
      IF(NJ.NE.MJ) GO TO 140
      IF(MK.NE.NK) GO TO 140
      FRA=SEL(MJ, MK)/ARM
      GO TO 1380

```

(THIS PAGE INTENTIONALLY LEFT BLANK)

**END
FILMED**

DATE: 12-90

DTIC