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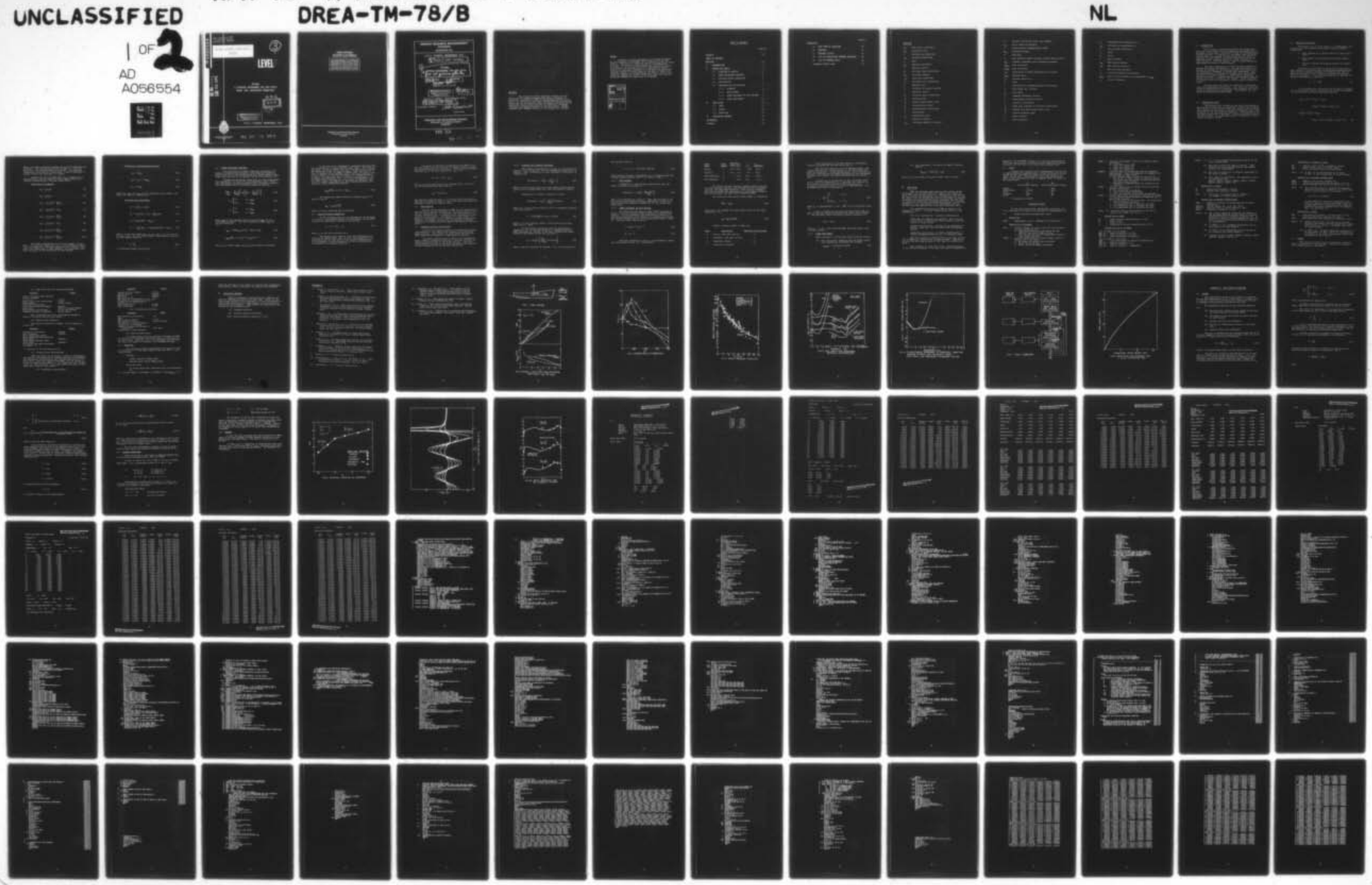

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PHHS
A FORTRAN PROGRAMME FOR SHIP PITCH, HEAVE AND SEAKEEPING PREDICTION

D.R.E.A. TECHNICAL MEMORANDUM 78/B

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D.R.E.A. TECHNICAL MEMORANDUM 78/B

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PHHS.

A FORTRAN PROGRAMME FOR SHIP PITCH, HEAVE AND SEAKEEPING PREDICTION.

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ABSTRACT

The theoretical basis and user's manual are described for the computer program PHHS (Pitch and Heave in Head Seas), developed at DREA for seakeeping prediction purposes. In addition to the usual vertical motion calculations, algorithms are included for added resistance, relative motion corrections (wave profile and dynamic swell-up), slamming pressures, and human tolerance to vertical motion. Worked examples and a FORTRAN listing of the program are included.

RESUME

On décrit la base théorique et le contenu du manuel de l'utilisateur du programme PHHS (Tangage et levée, mer debout), élaboré par le CRDA aux fins de prévision de la tenue à la mer. En plus des calculs habituels d'accélération verticale, on trouve les algorithmes pour les cas de résistance accrue, les corrections pour le déplacement relatif (profil et gonflement dynamique de la houle), les pressions exercées lorsque le navire pique du nez dans la vague et la tolérance humaine aux accélérations verticales. On y trouve aussi des exemples du travail effectué et une liste des expressions FORTRAN utilisées dans le programme.

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NOTATION

A_{ij}	added mass coefficient
A_{WP}	waterplane area
a	incident wave amplitude
a_{33}	sectional added mass
B	beam
B_{ij}	damping coefficient
b	empirical factor
b_s	sectional beam coefficient
b_{33}	sectional damping
C_{ij}	restoring coefficient
c_s	sectional area coefficient
$\overline{c}$	damping ratio
D	freeboard for given location
d	empirical factor
d_s	sectional draft coefficient
F_i	exciting force
F_n	Froude number based on LBP
f_i	Froude-Kriloff force
g	gravitational acceleration
h	half-siding
h_i	diffraction force
I	moment of inertia
I_{wp}	waterplane moment of inertia

k	section form-factor (also, wave number)
k_{yy}	pitch radius of gyration
L	length between perpendiculars (LBP)
M_{wp}	waterplane moment
m	ship mass
P_t	most probable impact pressure during time interval t
R_{AW}	frequency dependent wave resistance response
R_{WAVE}	wave resistance
R_{WIND}	wind resistance
r_{AW}	coefficient of added resistance due to waves
r_{MAX}	maximum value
s_x	relative motion at x
T	draft
t	time period in slamming pressure calculation
V	ship speed; V_K, in knots
V_W	wind speed
$\hat{V}$	slamming threshold velocity
x	longitudinal distance from CG
$\ddot{z}$	vertical acceleration
$\ddot{z}_n$	human body response to vertical acceleration
$\ddot{z}_M$	maximum root mean square value of $\ddot{z}_n$
β	section deadrise angle
δ	model variable
ζ	wave elevation

ζ_x	undeformed wave amplitude at x
ζ_{xd}	deformed wave amplitude at x
ζ^*	wave profile correction
η_3	heave
η_5	pitch
ρ	water density
σ_{RM}	RMS relative motion
σ_{RV}	RMS relative velocity
ω	wave circular frequency
ω_e	circular frequency of encounter
ω_{MAX}	wave circular frequency corresponding to r_{MAX}
ω_n	natural frequency

1. INTRODUCTION

This technical memorandum presents the theoretical basis and user's manual for the computer program PHHS (Pitch and Heave in Head Seas), developed at DREA for seakeeping prediction purposes. In addition to the normal vertical motion calculations, the program includes algorithms for added resistance, relative motion corrections (wave profile and dynamic swell-up), slamming pressures, human tolerance to vertical motion, and deck wetness. Most of these additional algorithms are unique to this program.

The basic computation of pitch and heave response is adapted from Frank and Salvesen[1]. The added resistance algorithm is obtained by incorporating model test results into the theoretical framework of Jinkine and Ferdinande[2]. Relative motions are corrected for dynamic swell-up following van Sluijs[3], and wave profile is accounted for using the method of Shearer[4]. Slamming and deck wetness algorithms are adapted from Ochi and Motter[5] and Chuang[6]. Human tolerance to vertical motion is assessed via the procedure proposed by Payne[7].

Program input and output are tailored to facilitate full scale seakeeping predictions. Both input and output are fairly straightforward yet flexible, and generally use ordinary naval architectural terminology. Two examples are provided to demonstrate program usage.

2. THEORETICAL BASIS

The methods used in PHHS for the basic calculation of ship motions in head seas are generally accepted as standard. The equations of motion are solved for regular waves by linear strip theory and the results extended to irregular seas by application of the superposition principle. The procedures are described adequately in Reference 1 and will therefore only be outlined herein. The algorithms unique to PHHS will be described in greater detail.

2.1 EQUATIONS OF MOTION

The application of strip theory to a displacement hull for pitch and heave prediction involves certain standard assumptions:

a. Ship response is a linear function of wave excitation.

b. Ship length is much greater than either beam or draft.

c. Viscous, planing and surging effects are negligible.

Attention is restricted to the head sea direction, as this results in the most severe pitching and heaving motions. Thus, for the frequency response calculations, the ship is heading with speed V into a train of long-crested regular waves of frequency ω. The exciting frequency is then the frequency of encounter ω_e, given by

$$\omega_e = \omega + \omega^2 \frac{V}{g} \tag{1}$$

It is assumed that the motions of the ship in response to the encountered regular waves are both linear and harmonic. The coupled heave and pitch equations then are:

$$(A_{33} + m)\ddot{\eta}_3 + B_{33}\dot{\eta}_3 + C_{33}\eta_3 + A_{35}\ddot{\eta}_5 + B_{35}\dot{\eta}_5 + C_{35}\eta_5 = F_3 \tag{2}$$

$$A_{53}\ddot{\eta}_3 + B_{53}\dot{\eta}_3 + C_{53}\eta_3 + (A_{55} + I_5)\ddot{\eta}_5 + B_{55}\dot{\eta}_5 + C_{55}\eta_5 = F_5 \tag{3}$$

where η_3 is heave (positive upward) and η_5 pitch (positive bow downward). The axis system is given in Fig. 1. m is ship mass and I_5 the pitching moment of inertia. The subscript convention is the same as in Reference 1, that is subscript 3 refers to heave and subscript 5 to pitch.

Expressions for the added mass (A_{ij}), damping (B_{ij}), restoring (C_{ij}) and exciting force (F_i) coefficients are obtained from Reference 1 and are listed below.

<u>Added Mass and Damping</u>

$$A_{33} = \int_L a_{33} d\xi \tag{4}$$

$$B_{33} = \int_L b_{33} d\xi \tag{5}$$

$$A_{35} = -\int_L a_{33} \xi d\xi - \frac{V}{\omega_e^2} B_{33} \tag{6}$$

$$B_{35} = -\int_L b_{33} \xi d\xi + V A_{33} \tag{7}$$

$$A_{53} = -\int_L a_{33} \xi d\xi + \frac{V}{\omega_e^2} B_{33} \tag{8}$$

$$B_{53} = -\int_L b_{33} \xi d\xi - V A_{33} \tag{9}$$

$$A_{55} = \int_L a_{33} \xi^2 d\xi + \frac{V^2}{\omega_e^2} A_{33} \tag{10}$$

$$B_{55} = \int_L b_{33} \xi^2 d\xi + \frac{V^2}{\omega_e^2} B_{33} \tag{11}$$

The above integrations are over the length L of the ship. The sectional added mass, a_{33}, and wave-making damping, b_{33}, are computed by conformal mapping at each station. Generally the Lewis-form[1] is used; however, for excessively bulbous sections, the MIT bulb-form[8] is used instead.

Hydrostatic Restoring Coefficients

$$C_{33} = \rho g A_{wp} \qquad (12)$$

$$C_{35} = C_{53} = -\rho g M_{wp} \qquad (13)$$

$$C_{55} = \rho g I_{wp} \qquad (14)$$

where A_{wp}, M_{wp}, and I_{wp} are the waterplane area, moment, and moment of inertia, respectively.

Exciting Force and Moment

$$F_3 = \rho\zeta \int_L (f_3 + h_3) d\xi \qquad (15)$$

$$F_5 = -\rho\zeta \int_L [\xi(f_3 + h_3) + \frac{V}{i\omega_e} h_3] d\xi \qquad (16)$$

$$f_3 = g b_s \exp(ikx - k d_s c_s) \qquad (17)$$

$$h_3 = -\frac{\omega}{\rho\omega_e}(\omega_e^2 a_{33} - i\omega_e b_{33}) \exp(ikx - k d_s c_s) \qquad (18)$$

where ζ is the wave amplitude, b_s, d_s, and c_s are the sectional beam, draft, and area coefficients, respectively, and k is the wave number, given by

$$k = \frac{\omega^2}{g} \qquad (19)$$

x is measured forward from the CG.

2.2 ADDED RESISTANCE RESPONSE

The calculation of added resistance is based on the method of Jinkine and Ferdinande[2], with empirical modifications suitable to fast surface ship hull forms derived from model tests carried out by Murdey[9] and by Strom-Tejsen et al[10].

Jinkine and Ferdinande found that for fast cargo ships, the experimental curves of the non-dimensional added resistance coefficient r_{AW} plotted against wave frequency ω could be well approximated by the following empirical equation:

$$\frac{r_{AW}}{r_{MAX}} = \left[\frac{\omega}{\omega_{MAX}}\right]^b \exp\left[\frac{b}{d}\left(1 - \left[\frac{\omega}{\omega_{MAX}}\right]^d\right)\right] \qquad (20)$$

$$b = \begin{cases} 11 & \omega \leq \omega_{MAX} \\ -8.5 & \omega > \omega_{MAX} \end{cases} \qquad (21)$$

$$d = \begin{cases} 14 & \omega \leq \omega_{MAX} \\ -14 & \omega > \omega_{MAX} \end{cases} \qquad (22)$$

where r_{MAX} is the maximum value of r_{AW} with ω_{MAX} the corresponding frequency. For fast cargo hull forms, r_{MAX} and ω_{MAX} are given by[2]

$$r_{MAX} = 3600(k_{yy}/L)^2 F_n^{1.5} \exp(-3.5F_n) \qquad (23)$$

$$\omega_{MAX}\sqrt{L/g} = 1.17F_n^{-1/7}(k_{yy}/L)^{-1/3} \qquad (24)$$

where F_n is Froude number and k_{yy} pitch radius of gyration.

As pointed out by Lewthwaite[11], equations (23) and (24) are inaccurate for frigate-destroyer hull forms. For hulls of this type, therefore, model test data have been used to derive new empirical curves for r_{MAX} and ω_{MAX}. These are shown in Fig. 2, together with equations (23) and (24), for $k_{yy}/L = .25$, a value typical of fast surface ships. For different values of k_{yy}/L, the r_{MAX} curve must be scaled by $.0625(k_{yy}/L)^2$, in accordance with equation (23). As to the new empirical curve for ω_{MAX}, (k_{yy}/L)-scaling is not required; furthermore, this curve is closely approximated by the following equation, obtained by linear regression analysis.

$$\omega_{MAX}\sqrt{L/g} = 2.79 - 1.18F_n \tag{25}$$

The dimensional added resistance response R_{AW} is related ro r_{AW} by

$$R_{AW} = r_{AW}(\rho g a^2 \frac{B}{L}) \tag{26}$$

where a is wave amplitude and B ship beam.

2.3 RELATIVE MOTION CORRECTION

If the incoming waves are not deformed by the presence of the hull, the relative motion s_x (with respect to the water surface) at longitudinal location x is given by

$$s_x = \eta_3 - x\eta_5 - \zeta_x \tag{27}$$

where ζ_x is the wave elevation at x.

Experiments show, however, that wave deformation by the hull is significant[4], and, in fact, the assumption of an undeformed wave is valid only at the forward perpendicular. This phenomenon of wave deformation by the oscillating hull is referred to as dynamic swell-up.

An option is therefore incorporated into PHHS to correct the relative motion response for dynamic swell-up using the experimental data of van Sluijs[3]. This procedure involves replacing ζ_x in the above equation by ζ_{xd}, i.e.,

$$s_x = \eta_3 - x\eta_5 - \zeta_{xd} \tag{28}$$

where ζ_{xd} is the amplitude of the deformed wave, related to ζ_x, the undeformed wave amplitude, by

$$\zeta_{xd} = F(F_n, x)\zeta_x \tag{29}$$

The empirical function $F(F_n, x)$ is derived from van Sluijs's data and is plotted in Fig. 3. Note that this correction will probably be invalid for bulbous bows.

2.4 WAVE PROFILE

Another option available in PHHS is the calculation of the profile of the wave generated by the hull purely as a result of forward motion. If selected, this wave profile correction, denoted by ζ^*, is applied to the calculation of probability of deck wetness. The method for calculating ζ^* is adapted from Shearer[4], and is described in more detail in Appendix A. An example is also given in Appendix A showing reasonable correlation between computed and measured wave profiles.

2.5 IRREGULAR SEAWAY CALCULATIONS

Motions in irregular seaways are calculated by linear superposition of the regular wave response with the seaway power spectrum. This yields root mean square motions from which quantitative measures of seakeeping are derived.

The seaway spectrum used in PHHS is the Gospodnetic-Miles quadratic regression spectrum[12], derived from data obtained at Station India in the North Atlantic. This is a two-parameter spectrum, of which the parameters are significant wave height and energy-averaged wave period.

2.5.1 SLAMMING AND SLAMMING PRESSURES

The slamming calculations are based on the statistical theory of Ochi and Motter[5] and the experimental impact data of Chuang[6]. First, probability of keel emergence at station x is computed from

$$\mathrm{Prob(Keel)} = \exp\left[- \frac{T^2}{2\sigma_{RM}^2} \right] \tag{30}$$

where T is draft and σ_{RM} is root mean square relative motion (corrected for dynamic swell-up), both evaluated at station x.

Probability of a slam at station x is then

$$\mathrm{Prob(Slam)} = \exp\left[- \frac{\hat{v}^2}{2\sigma_{RV}^2} \right] \mathrm{Prob(Keel)} \tag{31}$$

where σ_{RV} is rms relative velocity and $\hat{v}$ is slamming threshold velocity, given by

$$\hat{v} = .0195\sqrt{Lg} \Big/ (.03 \cot\beta + h/B)/2 \tag{32}$$

where β is local deadrise angle, h half-siding and B beam. PHHS uses h = .011B.

Of much greater importance than the probability of slamming is the statistical estimate of slamming pressure. PHHS calculates p_t, defined as the most probable peak impact pressure experienced during time duration t:

$$p_t = \rho k \sigma_{RV}^2 \ln \left[\frac{t\sigma_{RV}}{2\pi\sigma_{RM}} \mathrm{Prob(Keel)} \right] \tag{33}$$

where t must be expressed in seconds. k is a form factor for the section, given by

$$k = 1 + (1 - \exp(-5\beta))\ (\frac{\pi}{2}\cot\beta)^2 \tag{34}$$

This equation provides a reasonable fit to Chuang's data[6] for *deadrise angles greater than 5°, as shown in Fig. 4.*

2.5.2 DECK WETNESS

Probability of deck wetness (green water over the deck) at station x is given by

$$\text{Prob(D.W.)} = \exp\left[-\frac{(D - \zeta^*)^2}{2\sigma_{RM}^2}\right] \tag{35}$$

where D is freeboard at station x. Note that because of the wave profile and dynamic swell-up, probability of deck wetness is generally greatest somewhat aft of the forward perpendicular.

2.5.3 HUMAN TOLERANCE TO SHIP MOTIONS

The vibration ride quality index (VRQI) proposed by Payne[7] is used to quantify human tolerance to vertical ship motions. In this procedure, the physiological effect of a vehicle's acceleration time history $\ddot{z}$ is assessed by driving four dynamic models with it, and observing the models' output $\ddot{z}_n$. The basic model equations are

$$\ddot{\delta} + 2\overline{c}\omega_n\dot{\delta} + \omega_n^2\delta = \ddot{z} \tag{36}$$

$$\ddot{z}_n = \ddot{z} - \ddot{\delta} \tag{37}$$

The model parameters $\overline{c}$ and ω_n, as determined by Payne from physiological data, are *listed below.*

Model Name	Model Number	Frequency Range (H_z)	$\overline{c}$	ω_n (rad/sec)
Spinal	1	4.6 - 11.7	.224	52.9
Visceral	2	0.4 - 4.6	.40	25.1
Body Vibration	3	> 11.7	1.0	52.9
Low Frequency	4	< 0.4	1.0	1.57

The spinal and body vibration models control relatively high frequency motions, and therefore need be considered only for very high speed vehicles. Only the low frequency and visceral models are appropriate to conventional displacement ship motions, and hence are included in PHHS.

The vibration ride quality index (VRQI) is defined as

$$\text{VRQI} = \ddot{z}_M/g \tag{38}$$

where $\ddot{z}_M$ is the maximum root mean square value of the model outputs $\ddot{z}_n$, i.e.,

$$\ddot{z}_M = \max_n \ddot{z}_n \text{ (RMS)} \tag{39}$$

Payne's proposed limits on VRQI are:

Limit	Description	VRQI Must Be Less Than
A	Severe, less than one hour	.5
B	Tolerable, less than one hour	.2
C	Long-term, severe	.2
D	Long-term, tolerable	.1

Limits generated by the VRQI method for sinusoidal vertical accelerations are plotted in Fig. 5.

With specific regard to the low frequency model, Fig. 5 shows that at very low frequencies (.1 Hz and below) this model is pessimistic. Below approximately .2 Hz, tolerance to vertical accelerations increases significantly with decreasing frequency, but Payne's low frequency model does not reflect this.

A simple way of accounting for this increased tolerance at very low frequencies is to multiply the value of $\ddot{z}_4$, as obtained by solving the basic model equations, by a "tolerance weighting factor", F(f), below approximately .2 Hz. Mathematically this is expressed as

$$\ddot{z}_4^* = \begin{cases} \ddot{z}_4 & f \geq f_o \\ F(f)\ddot{z}_4 & f < f_o \end{cases} \qquad (40)$$

where f_o is approximately .2 Hz. VRQI is now calculated using $\ddot{z}_4^*$.

F(f) is chosen so that the long term severe limit of VRQI follows the 50% motion sickness incidence curve of Fig. 5. The following simple expression gives an adequate fit:

$$F(f) = f/f_o \qquad (41)$$

with f_o = .17 Hz. The resulting VRQI long term severe limit is shown in Fig. 6.

2.5.4 ADDED RESISTANCE

Added resistance in head seas arises from two sources:

(1) wave resistance, computed from the added resistance response by evaluating the integral

$$R_{WAVE} = 2\int_o^\infty (R_{AW}/a^2)S(\omega)d\omega \qquad (42)$$

(2) wind resistance, calculated in PHHS by Taylor's method[13]

$$R_{WIND} = .002B^2 (V_W + V_K)^2 \quad (43)$$

where V_W is wind speed and V_K ship speed, both in knots.

3. USER GUIDE

PHHS has undergone many modifications since initial development and has inevitably lost some of the simplicity built into its original structure. Consequently, some effort has been devoted to minimizing complications both for the user who simply runs the program and for the programmer who wishes to modify the program for particular purposes. For the user, the inputs have been kept straightforward without sacrificing flexibility. For the benefit of the programmer, all individual program segments have been kept reasonably small.

The fundamental structure of PHHS is shown in the flowchart of Fig. 7. The main computational blocks in the program are:

hull form calculations - basically hydrostatics;

added mass and damping calculations - done for each station over a sufficiently wide frequency range and stored in large arrays;

response calculations - solution of the equations of motion, using data from the added mass and damping arrays;

seakeeping calculations - motions, probabilities of events, slamming pressures, etc. in irregular seas.

Note that output is released both to the line printer and to TAPE 90, a scratch file in mass storage. TAPE 90 may be saved for plotting purposes or for input to another program.

Four examples of input and output, illustrating most of the options available to the user, are given in Appendix B.

Appendix C is a FORTRAN listing of the program; Appendices D and E are, respectively, listings of some significant program variables and functions of the individual program units.

3.1 INPUT

Program input consists of an alphanumeric title and up to eight records of numerical data. These records are in free format and may individually occupy one or more cards at the option of the user. Two systems of units are available in PHHS, either international (SI) or English (FPS), as shown in the table below.

	SI International System	FPS Foot-pound-second System
Length	m	feet
Displacement	tonnes	tons
Force	N	lb
Pressure	kPa*	psi
Speed	kt	kt

* Equivalent to kN/m^2

Systems of Units

In the input description, dimensioned quantities are first indicated in SI units with FPS units in parentheses, eg.

XL length between perpendiculars, m(ft)

Record (0)

NAME Alphanumeric title. Maximum of 40 characters.

Record (1), 6 integers

IOPT - control integer for form of section data arrays to be input as Record (3).
- 0 - Dimensional input for BAM (beam) and DRT (draft); area coefficient for AIR.
- 1 - BAM, DRT and AIR are non-dimensional values of beam, draft and area.

IRESP - controls specification of which regular wave responses are to be output.
- 0 - No output of regular wave responses.
- 1 - Heave and pitch only.
- 2 - Heave, pitch and added resistance.

INOUT - controls the system of units to be used in input and output.
0 - Input FPS, Output FPS.
1 - Input SI, Output FPS.
2 - Input FPS, Output SI.
3 - Input SI, Output SI.

IRANGE - controls range of frequencies used for response calculations. This is necessary, for example, for computations at model scale.
0 - The default range is used: $0.2 \leq \omega \leq 2.0$. The choice of these values is based on the observation that the energy of real sea spectra lie within these limits.
1 - Minimum and maximum values are defined in Record (4).

ICORR - controls application of dynamic swell-up and wave profile corrections.
0 - No corrections are applied.
1 - Both corrections are applied.
2 - Only wave profile corrections are applied.

IFAST - permits more rapid execution by reducing the number of frequencies and/or stations in computing the regular wave responses.
0 - No reduction in execution time. 49 frequencies and 21 stations are used.
1 - 25 frequencies and 21 stations are used.
2 - 49 frequencies and 11 stations are used.
3 - 25 frequencies and 11 stations are used.

Note: (1) Execution time is approximately in the ratio 4:2:2:1 for IFAST = 0, 1, 2, 3.

Record (2), 4 reals

XL - length between perpendiculars, m (ft)
B - beam, m (ft)
T - draft, m (ft)
D - freeboard at forward perpendicular, m (ft)

Record (3), 63 or 64 reals

(i) If IOPT = 0, 63 reals:
BAM (I) - beam at station I, m (ft)
DRT (I) - draft at station I, m (ft)
AIR (I) - area coefficient at station I

(ii) If IOPT = 1, 64 reals:
AMAX - area coefficient at station of maximum area
BAM (I) - beam at station I ÷ B
DAR (I) - draft at station I ÷ T
AIR (I) - area at station I ÷ (AMAX*B*T)

Notes: (1) I = 1 at the forward perpendicular and 21 at the after perpendicular.

(2) Data must be given for <u>all</u> 21 stations. Thus, inputs of 0.0 for beam and area at the perpendiculars are permissible.

(3) Data must be given for 21 stations regardless of the value of IFAST.

(4) After AMAX (if applicable), the sequence of data for this record is: BAM(1), DRT(1), AIR(1), BAM(2), DRT(2), AIR(2), BAM(3), DRT(3), AIR(3), etc.

<u>Record (4), 2 reals</u>

W1 - lowest wave frequency, rad/sec
W2 - highest wave frequency, rad/sec

Note: (1) Record (4) is required only if IRANGE = 1. For IRANGE = 0, ignore Record (4).

<u>Record (5), 1 integer, 3*NPOS reals</u>

NPOS - number of stations for seakeeping calculations, maximum 10.
XPOS(I)- station number (FP = 0.0, AP = 20.0)
BETA(I)- deadrise angle at station XPOS(I), deg.
FB(I) - freeboard at XPOS(I), m (ft).

Notes: (1) The station numbering convention for XPOS(I) is the standard American system, which is slightly different from the convention of Record (3). In Record (3), however, station numbers are not explicitly input; station parameters are simply input sequentially.

(2) If BETA(I) = 0.0, slamming calculations are not performed for station XPOS(I).

(3) If FB(I) = 0.0, probability of deck wetness is not computed for station XPOS(I).

(4) Sequence of data is NPOS, XPOS(1), BETA(1), FB(1), XPOS(2), BETA(2), FB(2), etc.

Record (6), 1 integer, 2 reals

NSP - absolute value of NSP is number of speeds
UK - lowest speed, knots or Froude number
DUK - speed increment, knots or Froude number

Note: (1) If NSP > 0, UK and DUK must be in knots; if NSP < 0, UK and DUK must be Froude numbers.

Record (7), 1 integer, 2*NSEA reals

NSEA - number of sea states, maximum 10.
HS(I) - significant wave height of sea state I, m (ft)
TS(I) - energy-averaged wave period of sea state I, sec.

Note: (1) The following equation, obtained by regression analysis of the data of Miles[14], is offered as a guide to the variation of TS with HS:

$$TS = 6.17 + 5(HS/g)^{1/2} \tag{44}$$

Caution should be exercised in applying this equation, however, since considerable variation of wave period with significant wave height is exhibited by natural seaways (see, for example, Fig. 1 in Reference 11).

Record (8), 2 reals

THR - time period for which p_t is calculated for the stations specified in Record (7), hours.
VWKT - wind speed for wind resistance calculation, knots.

Notes: (1) Recall from Section 2.5.1 that p_t is the most probable peak impact pressure experienced during time duration t, where t = 3600*THR, since THR is input in hours.

(2) If VWKT < 0.0, the wind resistance calculation is not performed; if VWKT > 99.0, the wind-wave relationship of the 12th International Towing Tank Conference is used, Fig. 8.

3.2 OUTPUT

This section contains lists of lineprinter output in order of appearance on the printout. They may be compared with examples given in Appendix B.

(a) Input data and Hull Form Calculations.

Quantity	Units
Title, including time and date	
Control integers	
L, B, T, D	m (ft)
Beam, draft, area coefficient	m (ft)
Displacement	tonnes (tons)
Hull form coefficients	
Stations and deadrise angles	degrees
Speed data	knots or Froude numbers
Wave heights and periods	m (ft) and seconds
Slamming duration, windspeed	hours, knots

This is printed once; the following two groups of output are printed once for each speed.

(b) Regular Wave Responses.

This output is omitted if IRESP = 0; it consists of a table of:

Quantity	Units
Frequency of encounter	rad/sec
Wave frequency	rad/sec
Wave length/ship length	
Heave amplitude/wave amplitude	
Heave phase	degrees *
Pitch amplitude/wave slope	
Pitch phase	degrees *
Coefficient of added resistance (if IRESP = 2)	

* relative to the wave crest at CG.

(c) Irregular Wave Calculations.

These are output in two parts; a table of preliminary calculations including certain standard measures of seakeeping and seakeeping calculations at the stations specified in the input data. Both parts require that NSEA > 0; the second requires in addition that NPOS > 0. All quantities are averaged across the NSEA seastates; these mean values are given in the right-most column of this output.

(i) Preliminary Calculations.

Quantity	Units
Significant wave height	m (ft)
Average period	seconds
RMS pitch	degrees
RMS heave at CG	m (ft)
RMS absolute acceleration at CG	g's
Probability of deckwetness at FP	
Probability of slam at st. 4	
Added resistance	N (lb)
Wind resistance	N (lb)

(ii) Station Calculations.

Quantity	Units
RMS absolute acceleration	g's
VRQI	
RMS relative motion	m (ft)
RMS relative velocity	m/sec (ft/sec)
Probability of keel emergence	
Probability of slamming	
Slamming pressure as defined in Section 2.4	kPa (psi)
Probability of deck wetness	

(d) Mass-storage Output.

The scheme given above is generally followed for TAPE 90 output with the notable difference that all units are in the FPS system. There are also a few omissions and additions for which the reader is referred to the FORTRAN listing.

3.3 EXECUTION

The following storage requirements and execution time are applicable to a CDC 6400 computer under the NOS 1.1 operating system.

Storage:

Loader requires 71000_8 words.

Running field length 56000_8 words.

Execution time:

To within about 20%, execution time is approximated by:

$$T = (((.0007\ NPOS + .0003)NSEA + .003)NSP + .035)N_{ST}N_{FR} + 10$$

where N_{ST} and N_{FR} are the number of stations and frequencies, respectively, used to calculate the regular wave responses.

4. CONCLUDING REMARKS

PHHS is basically a state-of-the-art computer program for seakeeping prediction in head seas. Hence, as the ship motion research field progresses, it will be necessary to update PHHS periodically to keep abreast of theoretical and experimental developments. Improvements are particularly desirable in the following areas:

(i) slamming pressures

(ii) relative motion corrections

(iii) motion prediction above $F_n = 0.35$

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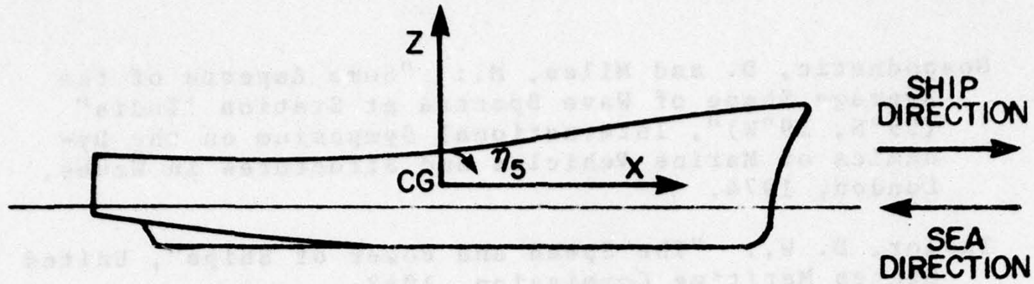

FIG. 1 AXIS SYSTEM

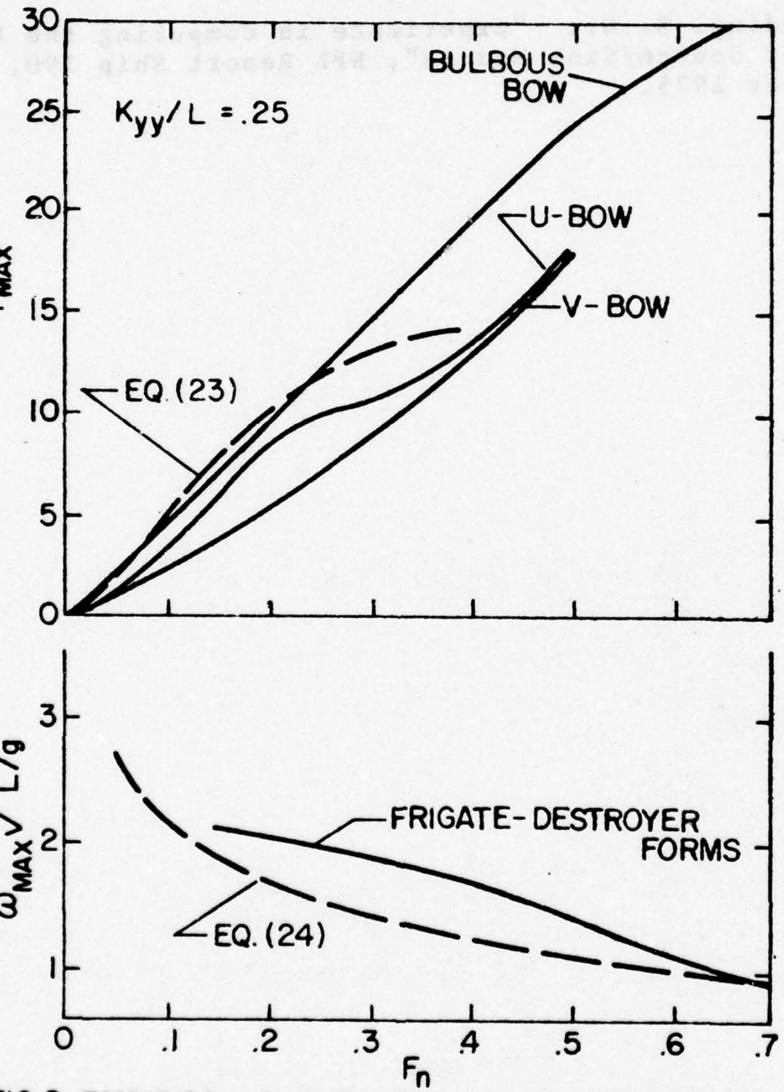

FIG. 2 EMPIRICAL CURVES FOR ADDED RESISTANCE COEFFICIENTS r_{MAX} AND ω_{MAX}

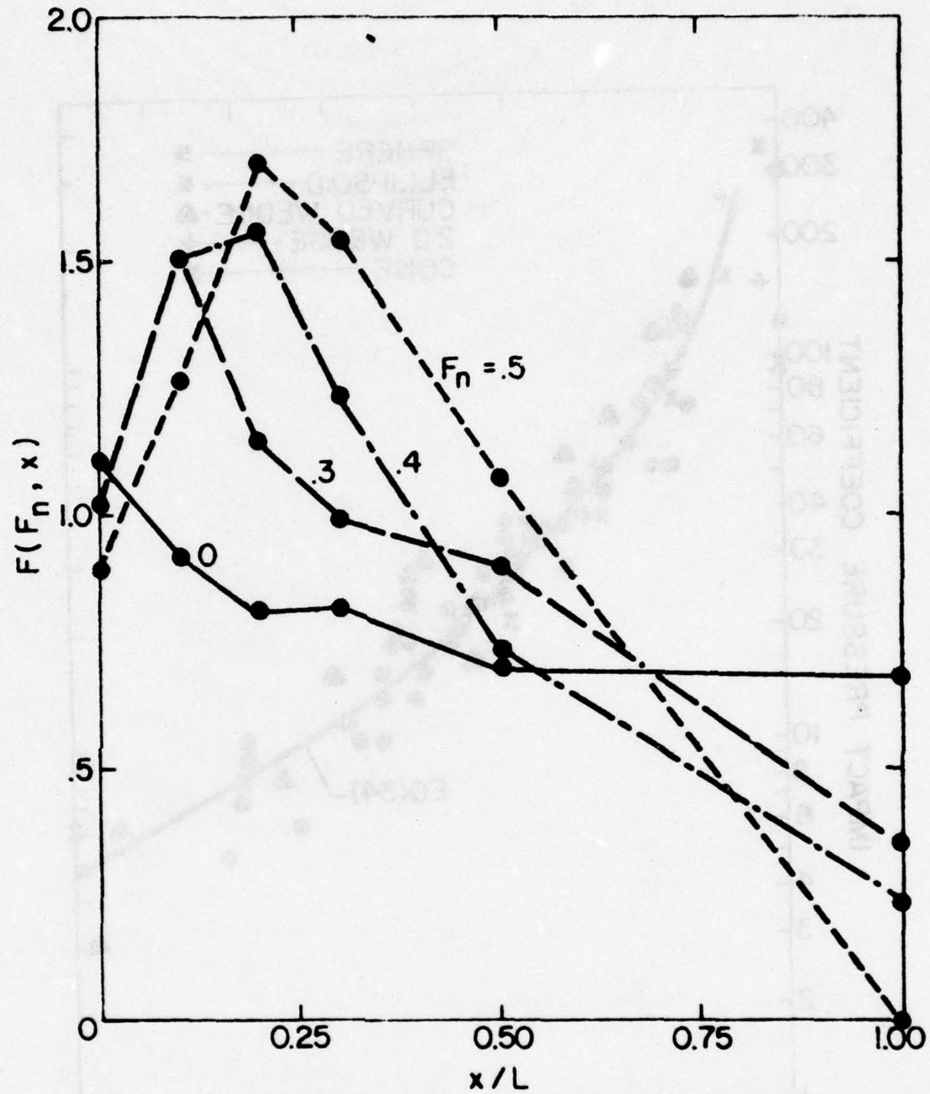

FIG 3 DYNAMIC SWELL-UP CORRECTION

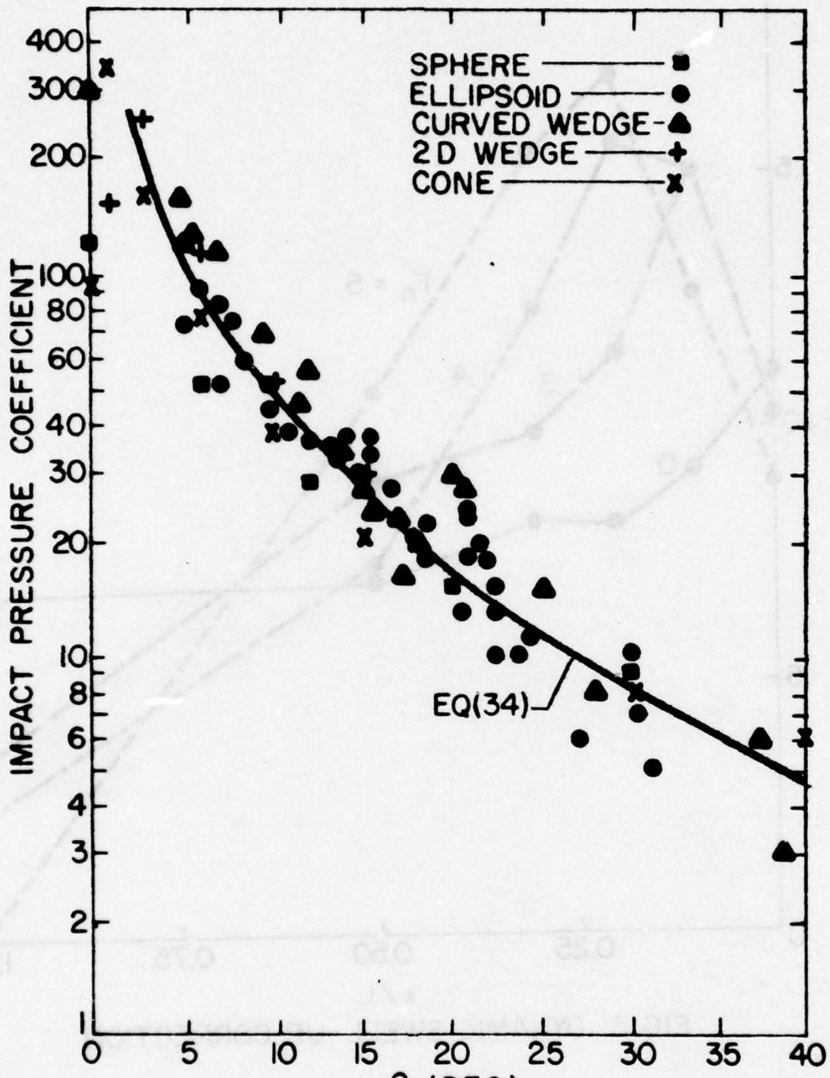

FIG 4 IMPACT PRESSURE COEFFICIENT

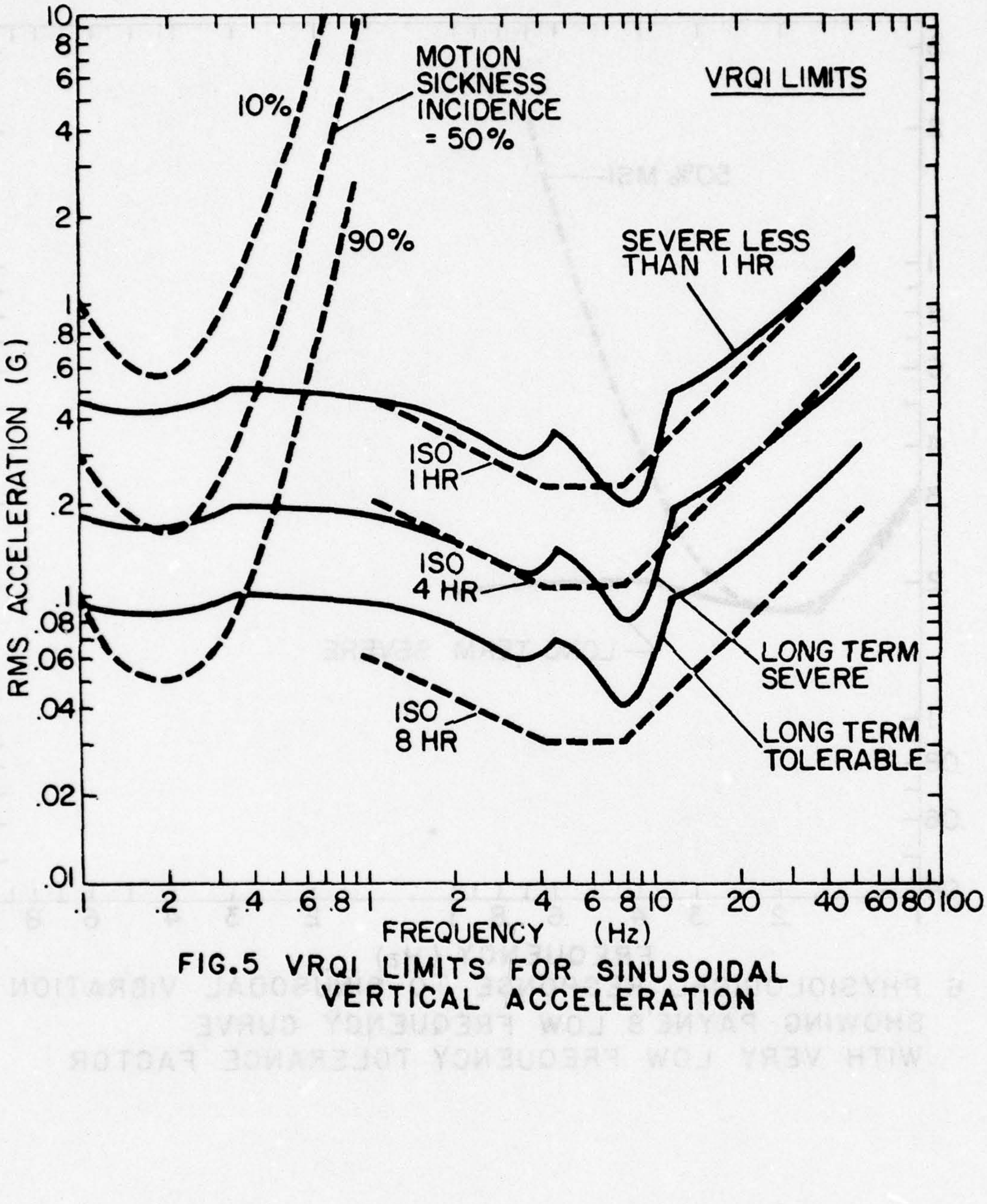

FIG.5 VRQI LIMITS FOR SINUSOIDAL VERTICAL ACCELERATION

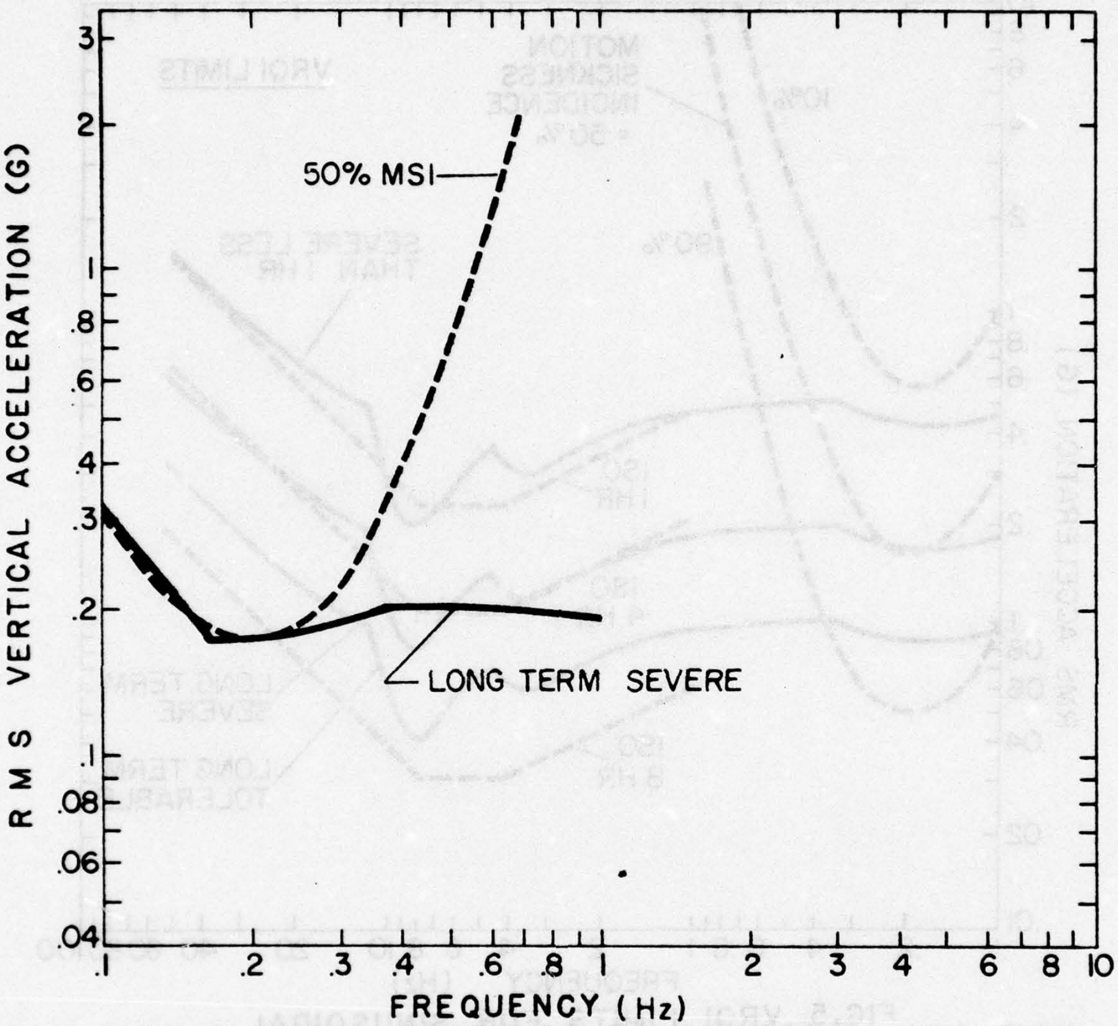

FIG. 6 PHYSIOLOGICAL RESPONSE TO SINUSODAL VIBRATION SHOWING PAYNE'S LOW FREQUENCY CURVE WITH VERY LOW FREQUENCY TOLERANCE FACTOR

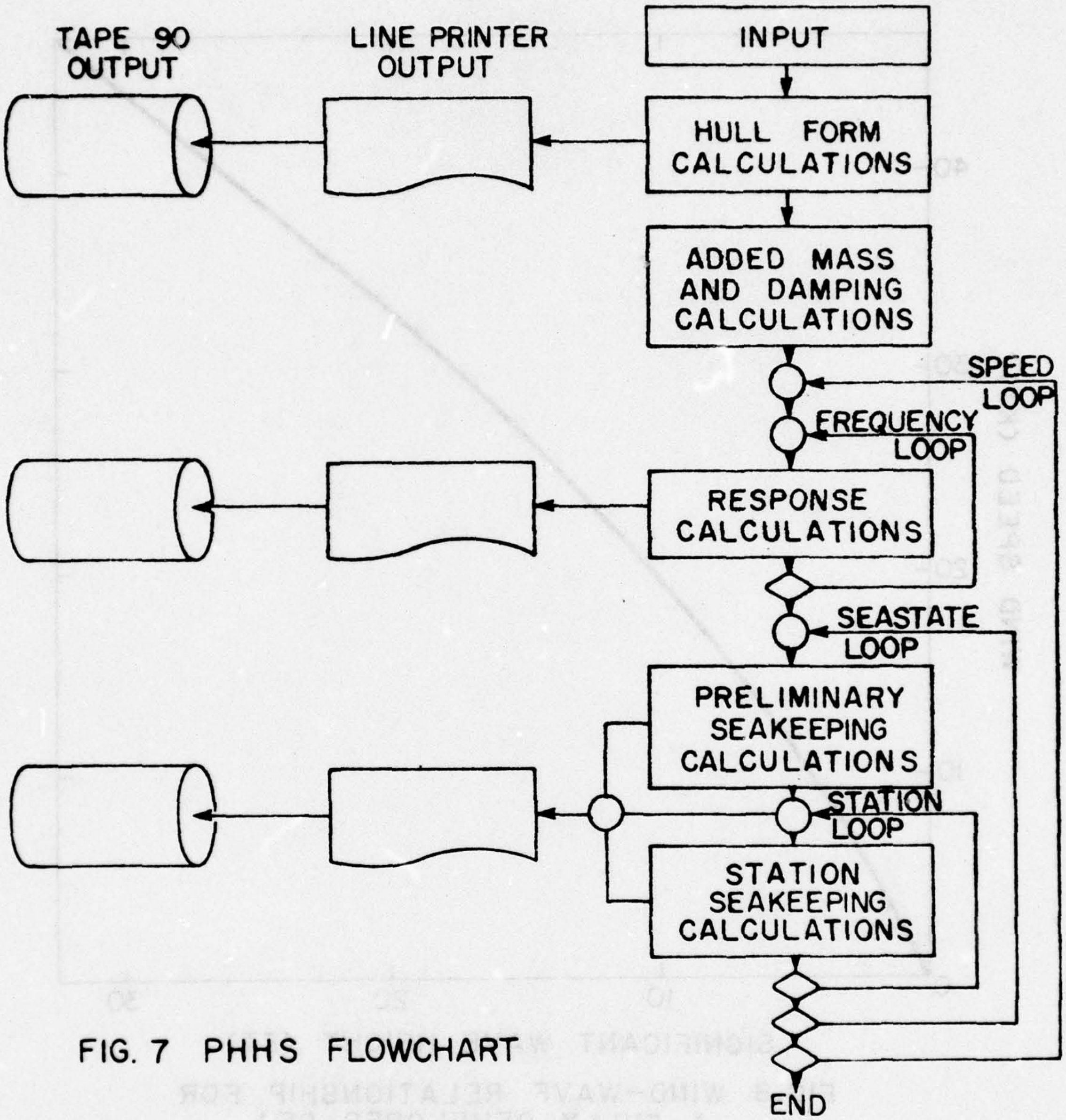

FIG. 7 PHHS FLOWCHART

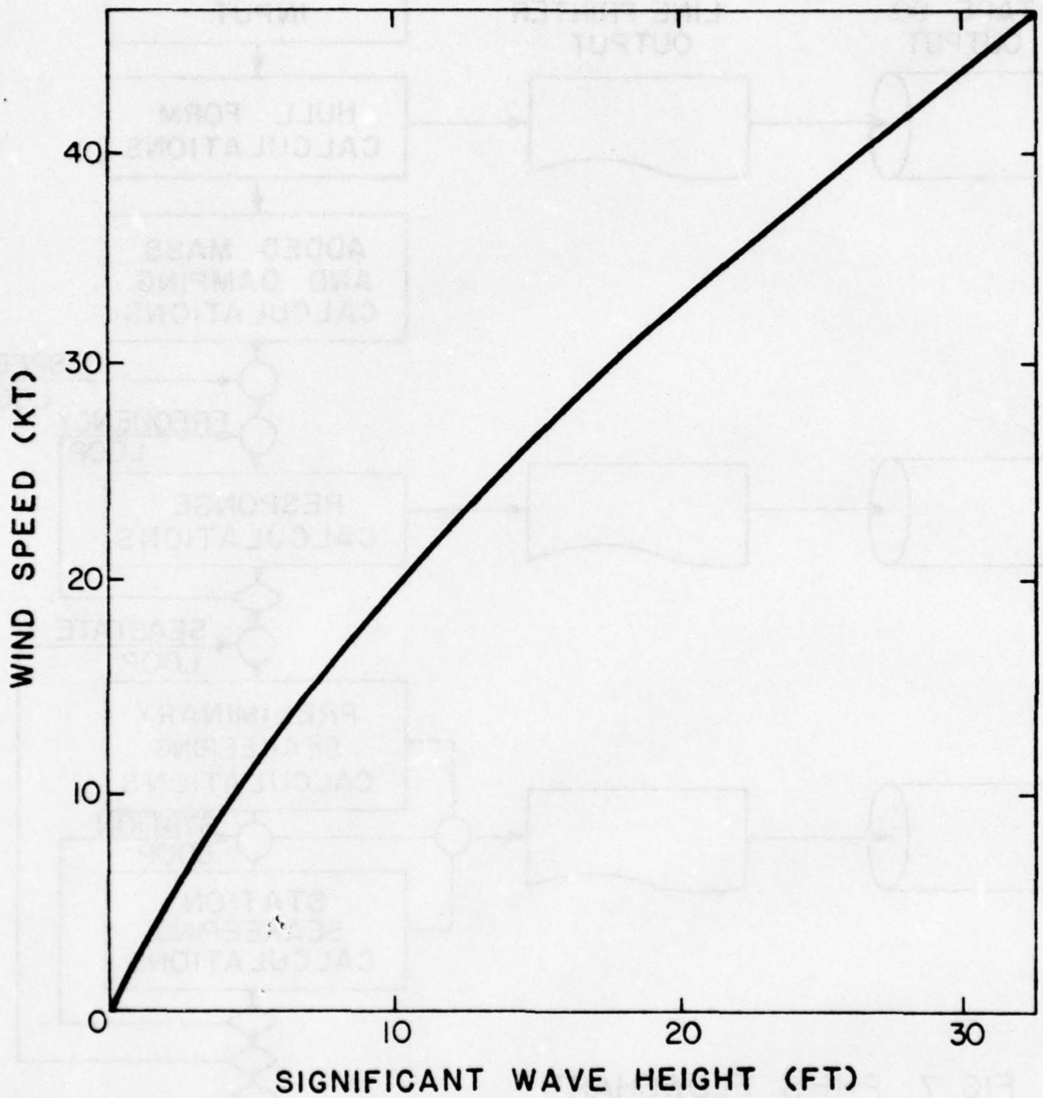

FIG.8 WIND-WAVE RELATIONSHIP FOR A FULLY DEVELOPED SEA

APPENDIX A: WAVE PROFILE ALGORITHM

A.1 METHOD

This algorithm is based on the analysis by Shearer[4] for the wave disturbance due to a "thin-ship". A single line of sources located on the centre-line of the vessel is used to represent the below-water portion of the hull.

The assumptions inherent in the following analysis are:

(a) Fluid velocity changes in the region of the hull are small relative to forward speed.

(b) The height of generated waves is small relative to their length.

(c) Sinkage and trim are negligible.

(d) The hull is effectively vertical at the waterline.

(e) Viscous effects are negligible.

The hull is divided into 21 stations between FP and AP and each segment of the hull between stations i and i+1 is replaced by a single source with strength M_i,

$$M_i = \frac{V}{4\pi}(S_{i+1} - S_i) \qquad \text{(A-1)}$$

where V is forward speed and S_i is the area of station i.

The source is located at the mid-section of the segment at a depth equal to the centroid of $(S_{i+1} - S_i)$. Examination of several shiplike sections and bulbous forward sections from the Davidson-A destroyer gives a simple relationship between section centroid and area coefficient C_x:

$$\frac{z_c}{T} = \begin{cases} \frac{1}{6} + \frac{1}{3} C_x & C_x \leq 1 \\ \frac{2}{5} + \frac{1}{10} C_x & C_x \geq 1 \end{cases} \qquad \text{(A-2)}$$

This is illustrated in Figure A-1.

In order to account for a bulbous bow or a transom stern, additional sources may be placed at the FP and AP.

The total wave disturbance ζ^* is obtained by summation of the disturbances ζ_i due to the N individual sources.

$$\zeta^* = \sum_{i=1}^{N} \zeta_i \qquad \text{(A-3)}$$

In the following development of the disturbance due to a single source, the subscript i is implied throughout, relating quantities to the hull segment between stations i and i+1. The subscript is omitted for notational simplicity.

Consider a source of strength M, moving with speed V at depth z. An associated wavenumber k is defined by

$$k = \frac{g}{V^2} \qquad \text{(A-4)}$$

The wave profile ordinate ζ at distance x from the source (positive forward) along the longitudinal axis is

$$\zeta = \frac{M}{V}(8kI_1 + \frac{4}{\pi}I_2)$$

where

$$I_1 = \begin{cases} 0 & x > 0 \\ \int_0^{\frac{\pi}{2}} \sec^3\theta \exp(-kz \sec^2\theta)\cos(kx \sec\theta)d\theta & x \le 0 \end{cases} \quad \text{(A-5)}$$

and

$$I_2 = \pm \int_0^{\frac{\pi}{2}} \sec\theta d\theta \int_0^{\infty} \frac{(k \sec^2\theta \sin mz - m \cos mz)\exp(-mx \cos\theta)m\, dm}{(k^2\sec^4\theta + m^2)} \quad \text{(A-6)}$$

where I_2 has the same sign as x.

Since numerical procedures available for solving the above integrals are too slow to be applied directly in a computer program, the method of interpolation over a table of previously computed values is used. To optimize the interpolation algorithm we seek to reduce the number of variables in I_1 and I_2. To this end we introduce a Froude-scaled system denoted by primed quantities. Using the factor R, the scaling equations are:

$$x' = Rx \quad \text{(A-7)}$$

$$z' = Rz \quad \text{(A-8)}$$

$$S' = R^2 S \quad \text{(A-9)}$$

$$V' = R^{1/2} V \quad \text{(A-10)}$$

On substitution we find as expected

$$\zeta' = R\zeta \quad \text{(A-11)}$$

Of present interest is the relationship

$$\zeta = R\frac{M}{V}(8k'I_1' + \frac{4}{\pi}I_2') \tag{A-12}$$

If we let the primed system be specifically that in which $k = 1$, then

$$\zeta = \frac{Mk}{V}(8I_1' + \frac{4}{\pi}I_2') \tag{A-13}$$

where the quantity in parentheses is a function of only x' and z'. The form of this function is shown in Figure A-2. Note that, with suitable scaling, this figure gives the theoretical disturbance due to a single source.

For the total disturbance, equation (A-13) is evaluated for each source and summed according to equation (A-3).

A.2 FORTRAN SUBPROGRAM

This calculation is performed by FUNCTION PROFILE and the associated subprograms ZETA, CSET and ZETAP.

A table of values for $(8I_1' + \frac{4}{\pi}I_2')$ is stored in BLOCK-DATA ZETAP. The corresponding values of x' and z' are:

x':	-40 to 2.5	in steps of .25
	3 to 10	in steps of 1
	15 to 40	in steps of 5
z':	.01, .02, .05, .1, .2, .5, 1., 2.	

Extrapolation outside these ranges of x' and z' is performed according to the rules given below; the limits of validity are, however, uncertain.

Extrapolation Rules:

(a) $x' < -40$ No amplitude decay.

(b) $x' > 40$ Zero is returned.

(c) $z' < .01$ $z' = .01$ is used.

(d) $z' > 2$ Amplitude decays as $1/z'$.

The integrals I'_1 and I'_2 were evaluated by single and double trapezoidal quadrature using a variable step size such that the difference in the argument of the trigonometric function in each integral did not exceed .1 radians. This is of the same order as the step sizes discussed by Standing[15] who suggests an error limit of 1 to 2% for the resulting calculations.

A.3 EXAMPLE

A test case was run based upon wave profiles for model tests of the Dutch Compact Frigate design carried out at the Netherlands Ship Model Basin. The data is reported by van Sluijs[3].

In Figure A-3, a comparison is shown between this data (scaled up to a full-scale LBP of 63 m.) and wave profile predictions made with the subprogram PROFILE. The agreement is reasonable.

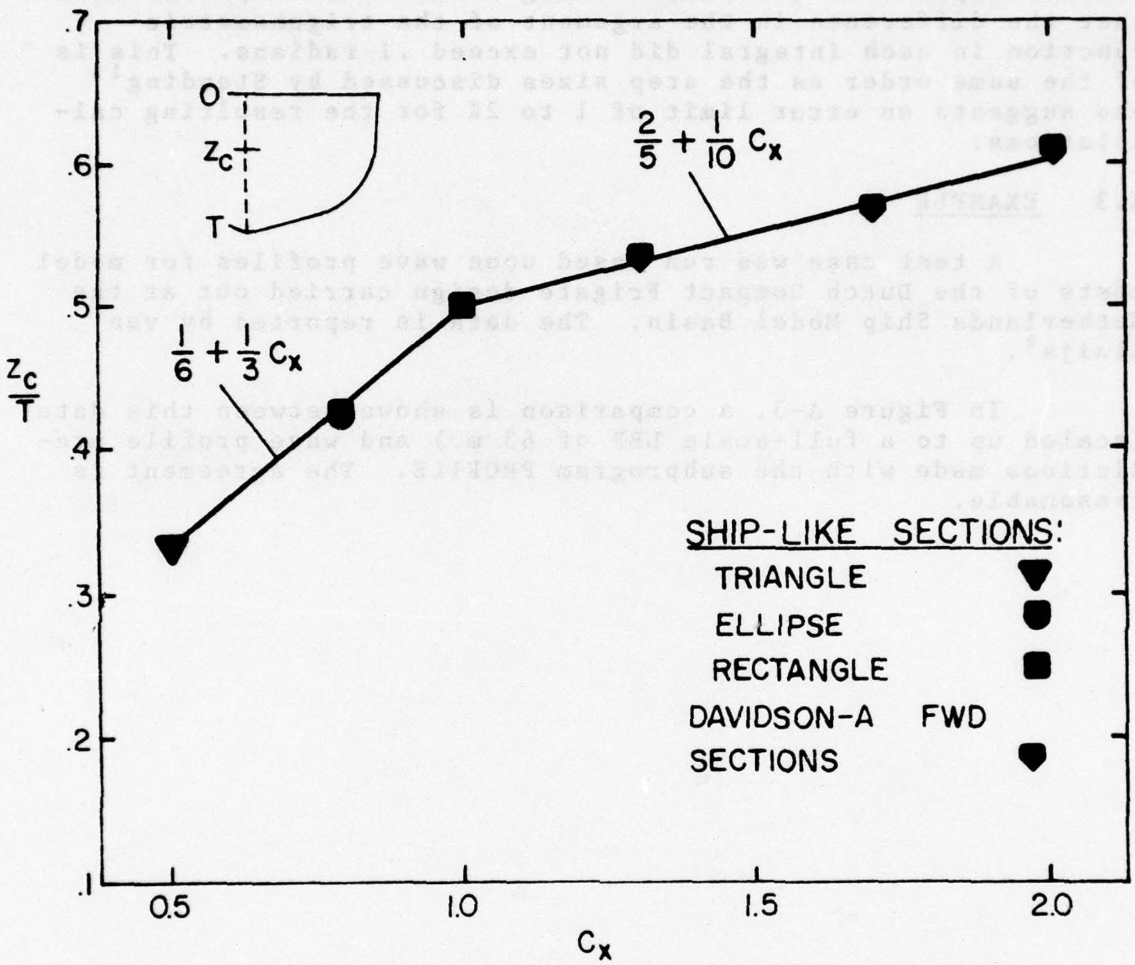

FIG.A1 VERTICAL LOCATION OF CENTROID

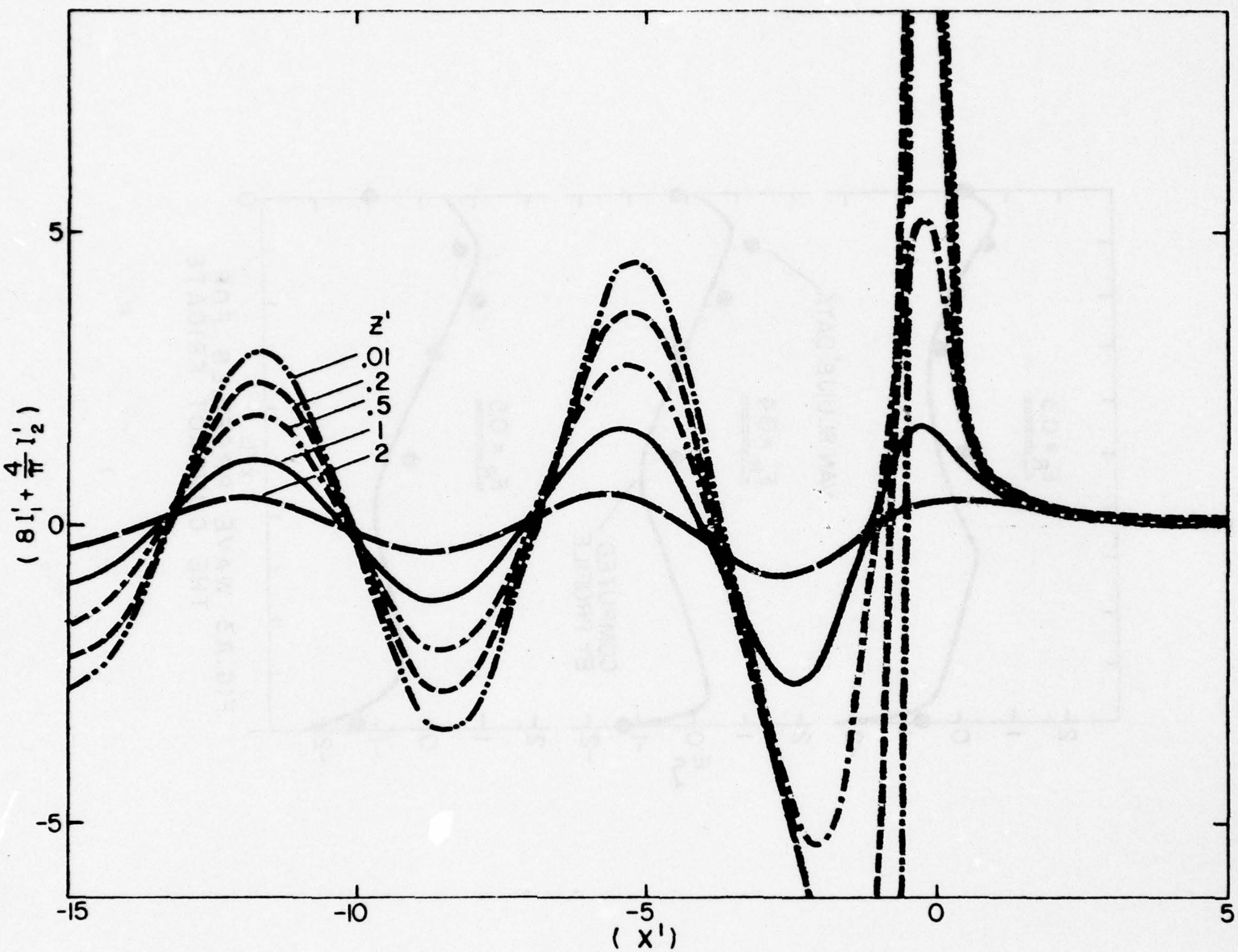

FIG. A2 FUNCTION ($8I_1' + \frac{4}{\pi} I_2'$) VS X'

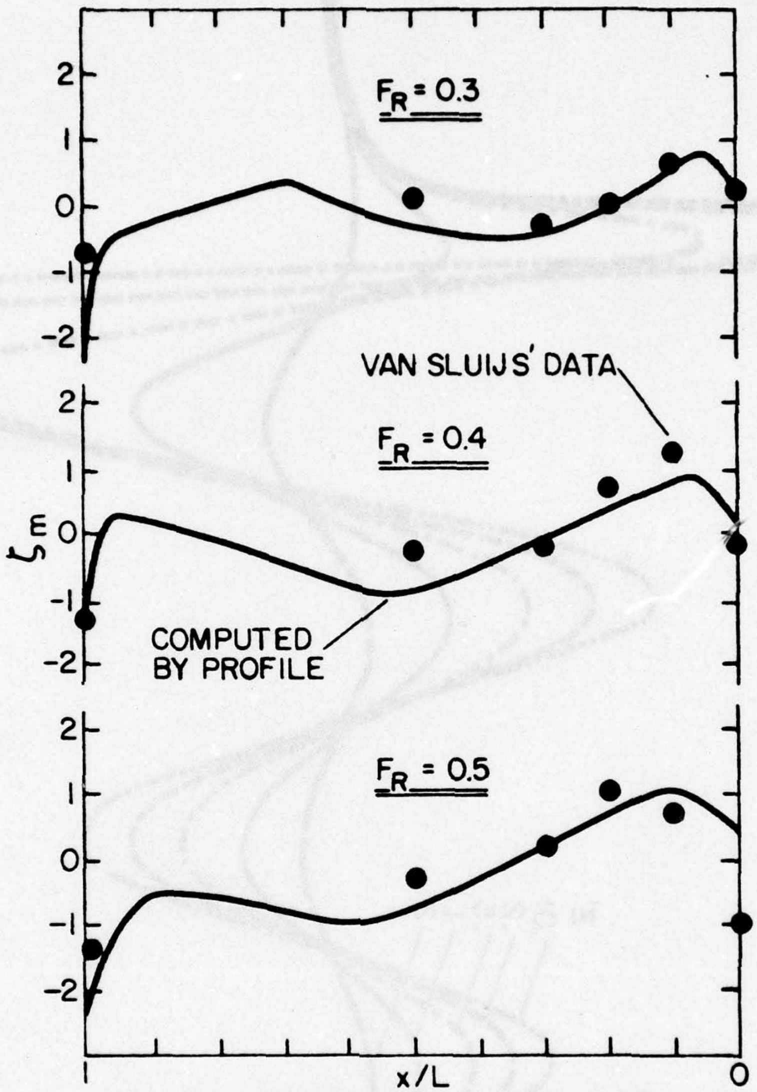

FIG.A3 WAVE PROFILES FOR THE COMPACT FRIGATE

APPENDIX B: EXAMPLES

B.1

Type:	Friesland destroyer, full-scale
Units:	Non-dimensional SI in / SI out
Options:	Full corrections / Fast execution
Speeds:	17.92 kt and 28.16 kt
Stations:	0, 2 and 4
Seas:	SS5, with ± 10% and ± 20% period variation

Execution Time: 17.8 seconds

Input data:

```
FRIESLAND
1     2     3     0     1     3
112.4      11.74      3.9      6.5989
0.822
0.0255      0.1667      0.0036
0.2283      1.0      0.1664
0.4259      1.0      0.3357
0.5869      1.0      0.4891
0.7138      1.0      0.6243
0.8149      1.0      0.7418
0.8927      1.0      0.834
0.9506      1.0      0.909
0.9813      1.0      0.9562
0.994      1.0      0.9868
1.0      1.0      1.0
1.0      1.0      0.9988
1.0      1.0      0.9818
0.9915      1.0      0.9481
0.9711      1.0      0.8884
0.9421      1.0      0.8068
0.9046      1.0      0.7032
0.8518      1.0      0.5616
0.7751      0.7026      0.3896
0.6746      0.4052      0.2115
0.5196      0.1025      0.0587
3
0.0      56.95      6.60
2.0      36.4      5.94
4.0      17.4      0.0
2      17.92      10.24
```

```
5
3.048     7.096
3.048     7.983
3.048     8.87
3.048     9.757
3.048     10.644
1.0     100.0
```

PITCH AND HEAVE IN HEAD SEAS

FRIESLAND 11.26.14. 78/03/28.

ICPT= 1 IRESP= 2 INOUT= 3

IRANGE= 0 ICORR= 1 IFAST= 3

DIMENSIONS : IN - M OUT - M

L = 112.400 B = 11.740 T = 3.900 D = 6.599

ST	BEAM	DRAFT	AREA
0	.299	.650	.696
1	2.680	3.900	.599
2	5.000	3.900	.648
3	6.890	3.900	.685
4	8.380	3.900	.719
5	9.567	3.900	.748
6	10.480	3.900	.768
7	11.160	3.900	.786
8	11.520	3.900	.801
9	11.670	3.900	.816
10	11.740	3.900	.822
11	11.740	3.900	.821
12	11.740	3.900	.807
13	11.640	3.900	.786
14	11.401	3.900	.752
15	11.060	3.900	.704
16	10.620	3.900	.639
17	10.000	3.900	.542
18	9.100	2.740	.588
19	7.920	1.580	.636
20	6.100	.400	.906

DISP = 2949.1 TONNES

CB= .559 CM= .822 CP= .679 CW= .800

LCB/L = .510 LCF/L = .542

XPOS	BETA	FB
0.00	56.95	6.60
2.00	36.40	5.94
4.00	17.40	0.00

NSP= 2 UK=17.92 DUK=10.24

HS	TS
3.05	7.10
3.05	7.98
3.05	8.87
3.05	9.76
3.05	10.64

THR= 1.00 VWKT= 100.00 DEFAULT USED

V(KT)= 17.9 FROUDE= .278

SELECTED RESPONSES

W-E R/S	W R/S	LAMBDA/ LENGTH	HEAVE	PHASE DEG	PITCH	PHASE DEG	COEF OF REST
.2376	.2000	13.7076	.9898	-.06	.9873	-89.13	.0000
.4677	.3515	4.4370	.9645	-.22	.9949	-94.36	.0060
.6978	.4806	2.3735	.8885	.12	.9751	-102.03	.1860
.9278	.5950	1.5485	.7742	1.69	.8887	-114.01	1.8629
1.1579	.6989	1.1226	.6677	.89	.7127	-132.82	7.3070
1.3880	.7946	.8684	.4424	-21.17	.4245	-165.29	5.8727
1.6181	.8839	.7019	.1176	32.86	.0877	152.49	2.7227
1.8482	.9678	.5854	.1480	38.29	.0342	-45.59	1.2953
2.0782	1.0473	.4999	.0644	28.43	.0374	-61.71	.6671
2.3083	1.1230	.4348	.0081	63.76	.0160	-67.33	.3695
2.5384	1.1954	.3837	.0120	-158.89	.0040	-36.27	.2175
2.7685	1.2648	.3427	.0272	-105.66	.0015	-70.17	.1346
2.9986	1.3317	.3092	.0044	-57.37	.0039	151.71	.0869
3.2286	1.3963	.2812	.0098	43.33	.0012	38.55	.0581
3.4587	1.4587	.2577	.0045	-69.90	.0022	13.91	.0400
3.6888	1.5193	.2375	.0050	-89.82	.0009	99.06	.0283
3.9189	1.5781	.2202	.0038	-41.18	.0013	127.74	.0205
4.1490	1.6354	.2050	.0054	4.38	.0009	169.01	.0152
4.3790	1.6911	.1917	.0057	36.18	.0010	-120.65	.0114
4.6091	1.7455	.1800	.0043	87.47	.0013	-77.72	.0087
4.8392	1.7986	.1695	.0046	157.38	.0011	-39.13	.0068
5.0693	1.8506	.1601	.0055	-158.95	.0007	17.38	.0053
5.2994	1.9014	.1517	.0045	-124.59	.0007	86.81	.0042
5.5294	1.9512	.1440	.0025	-65.34	.0008	127.25	.0034
5.7595	2.0000	.1371	.0030	10.41	.0004	163.62	.0027

V(KT)= 17.9 FROUDE= .278

UNITS :
DIMENSION - M
SPEED - M/S
FORCE - N
PRESSURE - KPA

						MEAN
SIG. WAVE HT.	3.05	3.05	3.05	3.05	3.05	3.05
WAVE PERIOD	7.10	7.98	8.87	9.76	10.64	8.87
PITCH(DEG)	.867	1.046	1.131	1.135	1.099	1.056
HEAVE	.306	.392	.462	.513	.555	.445
ACC.CG(G)	.044	.049	.050	.047	.044	.047
PROB(D.W.)FP	.0002	.0009	.0008	.0003	.0001	.0004
PROB(SLAM)ST.4	.0008	.0006	.0001	.0000	.0000	.0003
RA(SEA)	19581.5	22909.0	21332.2	17533.4	13704.9	19012.2
RA(WIND)	18733.6	18733.6	18733.6	18733.6	18733.6	18733.6

ST. 0.00						
ACC.(G)	.1677	.1833	.1786	.1638	.1463	.1680
VRQI	.1941	.2131	.2077	.1900	.1690	.1948
REL.MOT.	1.514	1.675	1.671	1.563	1.415	1.567
REL.VEL.	2.342	2.317	2.168	1.947	1.722	2.099
PROB(KEEL)	.9119	.9274	.9271	.9171	.8999	.9167
PROB(SLAM)	.0000	.0000	.0000	.0000	.0000	.0000
PRESSURE	76.77	74.07	64.19	51.39	39.91	61.27
PROB(DW)	.0002	.0009	.0008	.0003	.0001	.0004

ST. 2.00						
ACC.(G)	.1417	.1550	.1512	.1388	.1242	.1422
VRQI	.1640	.1803	.1758	.1610	.1434	.1649
REL.MOT.	1.593	1.627	1.536	1.386	1.229	1.474
REL.VEL.	2.864	2.624	2.343	2.056	1.804	2.338
PROB(KEEL)	.0499	.0566	.0399	.0191	.0065	.0344
PROB(SLAM)	.0046	.0033	.0011	.0002	.0000	.0018
PRESSURE	177.45	149.55	106.99	64.67	30.29	105.79
PROB(DW)	.0041	.0051	.0027	.0007	.0001	.0025

ST. 4.00						
ACC.(G)	.1159	.1271	.1242	.1143	.1025	.1168
VRQI	.1342	.1478	.1444	.1324	.1182	.1354
REL.MOT.	1.121	1.112	1.029	.918	.810	.998
REL.VEL.	2.115	1.898	1.672	1.458	1.278	1.684
PROB(KEEL)	.0024	.0021	.0008	.0001	.0000	.0011
PROB(SLAM)	.0008	.0006	.0001	.0000	.0000	.0003
PRESSURE	88.82	55.91	0.00	0.00	0.00	28.95

V(KT)= 28.2 FROUDE= .436

SELECTED RESPONSES

W-E R/S	W R/S	LAMBDA/ LENGTH	HEAVE	PHASE DEG	PITCH	PHASE DEG	COEF OF REST
.2591	.2000	13.7076	.9927	-.07	.9958	-89.09	.0000
.5778	.3727	3.9481	.9878	-.22	1.0199	-97.34	.0469
.8965	.5109	2.1004	.9937	-.93	1.0193	-110.84	1.4847
1.2152	.6296	1.3830	1.1156	-11.80	.9574	-134.03	10.9627
1.5339	.7353	1.0141	.8584	-73.53	.6680	174.27	10.0784
1.8526	.8315	.7931	.0346	-112.49	.1349	127.70	4.0836
2.1713	.9203	.6474	.0803	21.32	.0063	-55.44	1.7638
2.4900	1.0033	.5447	.0426	21.68	.0208	-79.07	.8513
2.8087	1.0814	.4689	.0219	35.51	.0146	-25.65	.4507
3.1274	1.1555	.4107	.0175	-88.69	.0036	-133.91	.2568
3.4461	1.2260	.3648	.0073	160.72	.0029	-145.99	.1552
3.7648	1.2935	.3277	.0052	134.80	.0008	-20.07	.0984
4.0835	1.3583	.2972	.0039	152.51	.0014	-24.50	.0649
4.4021	1.4208	.2716	.0051	-171.64	.0013	.86	.0443
4.7208	1.4811	.2500	.0057	-139.63	.0014	58.87	.0311
5.0395	1.5394	.2314	.0042	-91.52	.0016	99.84	.0224
5.3582	1.5960	.2153	.0043	-28.33	.0012	135.43	.0165
5.6769	1.6510	.2012	.0049	11.69	.0008	-169.72	.0124
5.9956	1.7045	.1887	.0040	46.42	.0008	-108.34	.0094
6.3143	1.7567	.1777	.0024	100.34	.0008	-66.23	.0073
6.6330	1.8075	.1678	.0024	174.72	.0006	-33.11	.0057
6.9517	1.8572	.1590	.0029	-148.93	.0002	19.44	.0045
7.2704	1.9058	.1510	.0020	-132.19	.0003	117.68	.0037
7.5891	1.9534	.1437	.0002	-103.10	.0004	135.60	.0030
7.9078	2.0000	.1371	.0012	49.63	.0001	116.56	.0024

V(KT)= 28.2 FROUCE= .436

UNITS :
DIMENSION - M
SPEED - M/S
FORCE - N
PRESSURE - KPA

						MEAN
SIG. WAVE HT.	3.05	3.05	3.05	3.05	3.05	3.05
WAVE PERIOD	7.10	7.98	8.87	9.76	10.64	8.87
PITCH(DEG)	.883	1.113	1.215	1.226	1.188	1.125
HEAVE	.405	.532	.614	.660	.681	.578
ACC.CG(G)	.077	.094	.097	.092	.085	.089
PROB(D.W.)FP	.0003	.0033	.0051	.0032	.0012	.0026
PROB(SLAM)ST.4	.0309	.0357	.0226	.0089	.0026	.0201
RA(SEA)	27162.4	37199.7	39678.2	35258.2	29204.3	33700.6
RA(WIND)	30301.0	30301.0	30301.0	30301.0	30301.0	30301.0
ST. 0.00						
ACC.(G)	.2292	.2710	.2733	.2542	.2299	.2515
VRQI	.2593	.3086	.3130	.2918	.2639	.2873
REL.MOT.	1.500	1.780	1.854	1.775	1.639	1.709
REL.VEL.	2.811	2.887	2.783	2.543	2.280	2.661
PROB(KEEL)	.9103	.9354	.9404	.9351	.9243	.9291
PROB(SLAM)	.0007	.0011	.0007	.0002	.0000	.0005
PRESSURE	113.68	117.88	108.39	89.81	71.73	100.30
PROB(DW)	.0003	.0033	.0051	.0032	.0012	.0026
ST. 2.00						
ACC.(G)	.1946	.2307	.2333	.2175	.1970	.2146
VRQI	.2202	.2629	.2675	.2498	.2262	.2453
REL.MOT.	1.614	1.774	1.750	1.614	1.453	1.641
REL.VEL.	3.528	3.340	3.054	2.711	2.398	3.006
PROB(KEEL)	.0539	.0893	.0835	.0539	.0273	.0616
PROB(SLAM)	.0112	.0154	.0102	.0037	.0009	.0083
PRESSURE	287.77	279.66	226.50	159.31	102.61	211.17
PROB(DW)	.0219	.0425	.0389	.0219	.0090	.0268
ST. 4.00						
ACC.(G)	.1609	.1916	.1946	.1819	.1651	.1788
VRQI	.1822	.2185	.2232	.2090	.1896	.2045
REL.MOT.	1.552	1.608	1.520	1.367	1.218	1.453
REL.VEL.	3.778	3.417	3.032	2.653	2.335	3.043
PROB(KEEL)	.0426	.0529	.0372	.0171	.0060	.0311
PROB(SLAM)	.0309	.0356	.0226	.0089	.0026	.0201
PRESSURE	1233.41	1028.29	729.49	438.51	216.54	729.25

B.2

Type:	Davidson-A, model-scale
Units:	FPS in / FPS out
Options:	Heave and pitch responses only
Speeds:	Froude numbers .24, .35 and .45
Frequency limits:	Corresponding to L/λ = .5 and L/λ = 2

Execution time: 72.3 seconds

Input data:

```
DAVIDSON A
0      1      0      1      0      0
17.41      1.854      0.635      0.7503
0.0      0.635      0.0
0.24      0.635      2.08
0.422      0.635      1.7
0.63      0.635      1.304
0.87      0.635      1.184
1.12      0.635      1.03
1.332      0.635      0.938
1.55      0.635      0.862
1.718      0.635      0.814
1.826      0.635      0.786
1.854      0.635      0.786
1.854      0.635      0.765
1.848      0.635      0.738
1.82      0.635      0.706
1.788      0.635      0.65
1.756      0.56      0.663
1.706      0.475      0.67
1.636      0.39      0.682
1.508      0.3      0.703
1.322      0.22      0.721
1.096      0.13      0.756
2.4097      4.8195
0
-3      0.25      0.1
0
```

PITCH AND HEAVE IN HEAD SEAS

DAVIDSON A   13.06.28. 77/12/13.

IOPT= 0   IRESP= 1   INOLT= 0

IRANGE= 1   ICORR= 0   IFAST= 0

DIMENSIONS :   IN - FT   OUT - FT

L = 17.410   B = 1.854   T = .635   D = .750

ST	BEAM	DRAFT	AREA
0	0.000	.635	0.000
1	.240	.635	2.080
2	.422	.635	1.700
3	.630	.635	1.304
4	.870	.635	1.184
5	1.120	.635	1.030
6	1.332	.635	.938
7	1.550	.635	.862
8	1.718	.635	.814
9	1.826	.635	.786
10	1.854	.635	.786
11	1.854	.635	.765
12	1.848	.635	.738
13	1.820	.635	.706
14	1.788	.635	.650
15	1.756	.560	.663
16	1.706	.475	.670
17	1.636	.390	.682
18	1.508	.300	.703
19	1.322	.220	.721
20	1.096	.130	.756

DISP = .3 TONS

CB= .536   CM= .786   CP= .682   CW= .739

LCB/L = .485   LCF/L = .576

SPECIFIED OMEGA-MIN.MAX = 2.4097 4.8195

NSP= -3   UK= .25   DUK= .10   FROUDE NO.

NO IRREGULAR SEA SPECIFIED

V(KT)= 3.5 FROUDE= .250

SELECTED RESPONSES

W-F R/S	W R/S	LAMBDA/ LENGTH	HEAVE	PHASE DEG	PITCH	PHASE DEG
3.4775	2.4097	2.0001	1.0957	3.26	1.0845	-123.63
3.5944	2.4713	1.9015	1.1456	2.97	1.0958	-127.55
3.7113	2.5322	1.8112	1.2004	2.47	1.1076	-131.44
3.8283	2.5924	1.7280	1.2544	1.98	1.1204	-134.95
3.9452	2.6520	1.6513	1.3246	.72	1.1315	-139.24
4.0622	2.7109	1.5804	1.4084	-1.32	1.1407	-144.16
4.1791	2.7691	1.5146	1.5064	-4.35	1.1469	-149.87
4.2961	2.8267	1.4534	1.6141	-8.51	1.1467	-156.39
4.4130	2.8838	1.3965	1.7243	-13.92	1.1358	-163.77
4.5299	2.9402	1.3434	1.8251	-20.79	1.1067	-172.13
4.6469	2.9962	1.2937	1.8960	-28.82	1.0547	178.96
4.7638	3.0515	1.2472	1.9192	-37.66	.9774	169.94
4.8808	3.1064	1.2035	1.8898	-48.62	.8635	159.39
4.9977	3.1607	1.1625	1.8013	-59.60	.7362	149.61
5.1147	3.2145	1.1239	1.6996	-68.40	.6363	142.56
5.2316	3.2679	1.0875	1.5712	-76.93	.5391	136.72
5.3485	3.3208	1.0532	1.4310	-85.03	.4521	132.24
5.4655	3.3732	1.0207	1.2920	-92.67	.3793	129.10
5.5824	3.4251	.9899	1.1620	-99.90	.3218	126.99
5.6994	3.4767	.9608	1.0417	-106.88	.2767	125.62
5.8163	3.5278	.9332	.9314	-113.72	.2420	124.63
5.9333	3.5785	.9069	.8312	-120.48	.2152	123.59
6.0502	3.6288	.8820	.7395	-127.28	.1941	122.30
6.1671	3.6787	.8582	.6562	-134.14	.1771	120.46
6.2841	3.7282	.8355	.5802	-141.09	.1629	117.97
6.4010	3.7773	.8140	.5108	-148.20	.1507	114.82
6.5180	3.8261	.7933	.4479	-155.43	.1397	110.99
6.6349	3.8745	.7736	.3907	-162.82	.1296	106.56
6.7519	3.9225	.7548	.3390	-170.36	.1202	101.60
6.8688	3.9702	.7368	.2925	-178.04	.1113	96.19
6.9857	4.0176	.7195	.2507	174.09	.1029	90.40
7.1027	4.0646	.7029	.2135	166.06	.0950	84.35
7.2196	4.1114	.6871	.1805	157.84	.0876	78.10
7.3366	4.1578	.6718	.1514	149.34	.0806	71.71
7.4535	4.2038	.6572	.1259	140.55	.0741	65.29
7.5704	4.2496	.6431	.1037	131.26	.0679	58.87
7.6874	4.2951	.6295	.0845	121.31	.0622	52.51
7.8043	4.3403	.6165	.0682	110.42	.0568	46.27
7.9213	4.3852	.6039	.0545	98.02	.0518	40.13
8.0382	4.4298	.5918	.0435	83.58	.0471	34.17
8.1552	4.4741	.5802	.0352	66.42	.0426	28.38
8.2721	4.5182	.5689	.0297	46.42	.0384	22.74
8.3890	4.5620	.5580	.0271	25.04	.0345	17.29
8.5060	4.6056	.5475	.0267	4.76	.0308	11.98
8.6229	4.6488	.5374	.0278	-12.46	.0273	6.79
8.7399	4.6919	.5276	.0296	-26.31	.0240	1.72
8.8568	4.7347	.5181	.0316	-37.42	.0209	-3.32
8.9738	4.7772	.5089	.0333	-46.42	.0180	-8.34
9.0907	4.8195	.5000	.0347	-53.86	.0153	-13.45

V(KT)= 4.9 FROUDE= .350

SELECTED RESPONSES

W-E R/S	W R/S	LAMBDA/ LENGTH	HEAVE	PHASE DEG	PITCH	PHASE DEG
3.9046	2.4097	2.0001	1.2777	1.62	1.1519	-130.64
4.0482	2.4733	1.8985	1.3779	-.11	1.1665	-136.35
4.1918	2.5361	1.8057	1.4800	-2.08	1.1825	-141.65
4.3355	2.5979	1.7207	1.5938	-4.77	1.1960	-147.26
4.4791	2.6590	1.6426	1.7257	-9.01	1.1983	-154.07
4.6227	2.7192	1.5707	1.8665	-14.81	1.1863	-161.98
4.7664	2.7787	1.5041	1.9983	-22.25	1.1518	-170.89
4.9100	2.8374	1.4425	2.0964	-31.17	1.0881	179.50
5.0537	2.8954	1.3853	2.1364	-41.11	.9939	169.79
5.1973	2.9528	1.3320	2.1035	-51.28	.8773	161.02
5.3409	3.0094	1.2823	1.9930	-62.96	.7265	152.01
5.4846	3.0654	1.2359	1.8565	-73.15	.6023	145.58
5.6282	3.1208	1.1924	1.7174	-82.00	.5085	141.39
5.7719	3.1756	1.1516	1.5609	-90.48	.4267	139.04
5.9155	3.2299	1.1133	1.4080	-98.52	.3638	138.05
6.0591	3.2835	1.0772	1.2644	-106.24	.3174	137.71
6.2028	3.3366	1.0432	1.1311	-113.77	.2834	137.37
6.3464	3.3892	1.0110	1.0080	-121.21	.2578	136.55
6.4900	3.4413	.9807	.8943	-128.65	.2375	134.99
6.6337	3.4929	.9519	.7897	-136.11	.2202	132.51
6.7773	3.5440	.9247	.6937	-143.61	.2044	129.16
6.9210	3.5946	.8988	.6061	-151.16	.1892	125.04
7.0646	3.6447	.8742	.5263	-158.77	.1745	120.27
7.2082	3.6945	.8509	.4545	-166.42	.1602	114.96
7.3519	3.7437	.8286	.3903	-174.08	.1462	109.23
7.4955	3.7926	.8074	.3334	178.25	.1327	103.15
7.6391	3.8410	.7872	.2834	170.56	.1200	96.80
7.7828	3.8891	.7679	.2397	162.83	.1082	90.25
7.9264	3.9367	.7494	.2018	155.09	.0973	83.55
8.0701	3.9840	.7317	.1693	147.30	.0874	76.76
8.2137	4.0309	.7148	.1414	139.42	.0784	69.91
8.3573	4.0774	.6986	.1175	131.40	.0704	63.05
8.5010	4.1236	.6830	.0972	123.19	.0632	56.24
8.6446	4.1694	.6681	.0800	114.70	.0568	49.51
8.7883	4.2149	.6537	.0655	105.78	.0511	42.92
8.9319	4.2600	.6400	.0533	96.22	.0460	36.47
9.0755	4.3048	.6267	.0431	85.77	.0413	30.21
9.2192	4.3493	.6139	.0348	74.07	.0372	24.18
9.3628	4.3935	.6017	.0283	60.71	.0334	18.37
9.5064	4.4374	.5898	.0233	45.28	.0299	12.79
9.6501	4.4810	.5784	.0199	27.97	.0266	7.45
9.7937	4.5242	.5674	.0180	9.76	.0236	2.33
9.9374	4.5672	.5567	.0173	-7.70	.0208	-2.56
10.0810	4.6100	.5465	.0174	-23.13	.0182	-7.25
10.2246	4.6524	.5366	.0179	-36.04	.0157	-11.75
10.3683	4.6946	.5270	.0185	-46.58	.0134	-16.07
10.5119	4.7365	.5177	.0190	-55.18	.0112	-20.22
10.6555	4.7781	.5087	.0193	-62.29	.0092	-24.20
10.7992	4.8195	.5000	.0194	-68.25	.0073	-27.94

V(KT)= 6.3 FROUDE= .450

SELECTED RESPONSES

W-E R/S	W R/S	LAMBDA/ LENGTH	HEAVE	PHASE DEG	PITCH	PHASE DEG
4.3317	2.4097	2.0001	1.5082	-2.19	1.1981	-138.62
4.5020	2.4748	1.8962	1.6653	-6.34	1.1993	-146.45
4.6723	2.5388	1.8018	1.8168	-10.53	1.2058	-153.28
4.8427	2.6019	1.7155	1.9785	-16.60	1.1906	-161.29
5.0130	2.6640	1.6365	2.1307	-24.60	1.1468	-170.38
5.1833	2.7252	1.5638	2.2438	-34.24	1.0702	179.94
5.3537	2.7855	1.4968	2.2892	-44.99	.9623	170.42
5.5240	2.8450	1.4349	2.2541	-56.03	.8366	162.17
5.6943	2.9037	1.3775	2.1429	-67.16	.7025	155.62
5.8647	2.9616	1.3241	1.9727	-78.48	.5696	150.96
6.0350	3.0187	1.2744	1.8240	-87.97	.4901	148.35
6.2053	3.0752	1.2281	1.6530	-97.13	.4248	147.43
6.3757	3.1310	1.1847	1.4845	-105.90	.3779	146.99
6.5460	3.1861	1.1441	1.3239	-114.41	.3442	146.15
6.7163	3.2405	1.1059	1.1727	-122.73	.3182	144.44
6.8867	3.2944	1.0701	1.0317	-130.93	.2959	141.71
7.0570	3.3476	1.0363	.9012	-139.03	.2747	138.05
7.2273	3.4003	1.0044	.7816	-147.02	.2537	133.63
7.3977	3.4524	.9744	.6732	-154.90	.2325	128.62
7.5680	3.5040	.9459	.5761	-162.65	.2113	123.17
7.7383	3.5551	.9189	.4901	-170.26	.1905	117.42
7.9087	3.6056	.8933	.4148	-177.75	.1706	111.45
8.0790	3.6557	.8690	.3495	174.88	.1518	105.31
8.2493	3.7052	.8459	.2934	167.60	.1345	99.03
8.4197	3.7543	.8240	.2455	160.39	.1187	92.65
8.5900	3.8030	.8030	.2050	153.22	.1045	86.17
8.7603	3.8512	.7830	.1708	146.06	.0919	79.60
8.9307	3.8990	.7640	.1420	138.88	.0807	72.95
9.1010	3.9463	.7457	.1178	131.63	.0710	66.24
9.2713	3.9933	.7283	.0975	124.27	.0625	59.49
9.4417	4.0398	.7116	.0806	116.74	.0552	52.72
9.6120	4.0860	.6956	.0664	108.99	.0488	45.98
9.7823	4.1318	.6803	.0545	100.91	.0433	39.30
9.9527	4.1772	.6656	.0445	92.39	.0384	32.73
10.1230	4.2223	.6514	.0362	83.25	.0341	26.32
10.2933	4.2670	.6379	.0293	73.26	.0303	20.10
10.4637	4.3113	.6248	.0237	62.12	.0268	14.11
10.6340	4.3554	.6122	.0192	49.48	.0237	8.37
10.8043	4.3991	.6001	.0157	35.03	.0209	2.91
10.9747	4.4424	.5885	.0132	18.79	.0182	-2.26
11.1450	4.4855	.5772	.0116	1.38	.0157	-7.11
11.3153	4.5283	.5664	.0107	-15.97	.0133	-11.59
11.4857	4.5707	.5559	.0102	-32.00	.0110	-15.61
11.6560	4.6129	.5458	.0099	-46.02	.0088	-18.89
11.8263	4.6548	.5360	.0096	-57.64	.0068	-20.81
11.9967	4.6964	.5266	.0091	-66.27	.0049	-19.79
12.1670	4.7377	.5174	.0082	-70.06	.0034	-11.87
12.3373	4.7787	.5086	.0070	-63.98	.0027	7.10
12.5077	4.8195	.5000	.0067	-41.02	.0031	23.90

```
      PROGRAM PHHS(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT,TAPE6=OUTPUT,
     ,TAPE90)
C  PHHS   PITCH AND HEAVE IN HEAD SEAS.
C  LEVEL 5  FEB 77
      COMPLEX AI,AIW,EFH,EMP,EFX,XC,CFH,CFP,CAB
      DIMENSION DX(21),DRT(21),BAM(21),AIR(21),OUT(13,10),CON(4)
     $,ADMS(21,49),DAMP(21,49),ARR(21),INDX(7),HS(10),     AX(10,10),RM(1
     $0,10),RV(10,10),XPOS(10),DR(10),PK(10,10),BETA(10),PT(10,10),NVW(2
     )),VW(10),AVE(9),      BETD(10),WORD(5),BAMM(21),DRTT(21),TS(10)
     ,,VRQI2(10,10),PSM(10),   VRQI4(10,10),VQM(10)   ,PS(10,10),TH(10)
      REAL AXM(10),RMM(10),RVM(10),PKM(10),PTM(10),FF( 8,2),NAME(8),LONG
      REAL ZWE(49),ZW(49),ZLL(49),ZH(49),ZHP(49),ZP(49),ZPP(49),ZCR(49)
     ,,KNOT,AVW(10),SS(12),FB(10),PDW(10,10),PDWM(10)
      LOGICAL NSTAT,NOSEA,NORESP,NOCR,NOIN,NOOUT,PROFIL,NOSLUI,POS4
      COMMON/CCM1/XC,G(4,5)
      DATA(FF(1,I),I=1,2)/8HPITCH(DE,2HG)/
      DATA(FF(2,I),I=1,2)/8HHEAVE    ,1H /
      DATA(FF(3,I),I=1,2)/8HACC.CG(G,1H)/
      DATA(FF(5,I),I=1,2)/8HPROB(D.W,4H.)FP/
      DATA(FF( 6,I),I=1,2)/8HPROB(SLA,6HM)ST.4/
      DATA(FF( 7,I),I=1,2)/8HRA(SEA)  ,5H     /
      DATA(FF( 8,I),I=1,2)/8HRA(WIND) ,5H     /
      RESP(W,WN,C)=(1.+(2.*C*W/WN)**2)/((1.-W/WN)**2+(2.*C*W/WN)**2)
      LONG=3.2808
      FORCE=4.4482
      PRESS=6.8948
      KNOT=1.6878
      RAD=57.2958
      RHO = 1.9905
      GRAV =32.18
C* RECORD 0.
C FORTY CHARACTER TITLE.
      READ(1,2005) NAME
      NAME(5)=TIME(XX)
      NAME(6)=DATE(XX)
      NAME(7)=NAME(8)=10H
      WRITE(2,2006)NAME
C* RECORD 1.
C  CONTROL INTEGER, IOPT=0; BAM,DRT=BEAM,DRAFT; AIR=CX.
C                   IOPT=1; BAM,DRT,AIR=NON-DIMENSIONAL BEAM,DRAFT,AREA.
C  CONTROL INTEGER, IRESP=0; NO REGULAR WAVE RESPONSES.
C                   IRESP=1; PITCH + HEAVE.
C                   IRESP=2; PITCH + HEAVE   + RAW.
C  CONTROL INTEGER,          INPUT OUTPUT
C                   INOUT=0; FPS   FPS
C                   INOUT=1;  SI   FPS
C                   INOUT=2; FPS    SI
C                   INOUT=3;  SI    SI
C  CONTROL INTEGER, IRANGE=0; DEFAULT RANGE OF OMEGA USED
C                   IRANGE=1; RANGE OF OMEGA SPECIFIED.
C  CONTROL INTEGER, ICORR=0; NO CORRECTIONS.
C                   ICORR=1; WAVE DEFORMATION AND WAVE-MAKING CORRECTIONS.
C                   ICORR=2; WAVE-MAKING CORRECTION ONLY.
C  CONTROL INTEGER, IFAST=0; 49 FREQUENCIES, 21 STATIONS
C                   IFAST=1; 25 FREQUENCIES, 21 STATIONS
```

```
C                       IFAST=2; 49 FREQUENCIES, 11 STATIONS
C                       IFAST=3; 25 FREQUENCIES, 11 STATIONS
      READ(1,*) IOPT,IRESP,INOUT,IRANGE,ICORR,IFAST
      WRITE(2,1103)IOPT,IRESP,INOUT,IRANGE,ICORR,IFAST
      NORESP=NOCR=.TRUE.
      IF(IRESP.GT.0)NORESP=.FALSE.
      IF(IRESP.GT.1)NOCR=.FALSE.
      NOIN=NOOUT=.TRUE.
      IOUT=INOUT/2
      IIN=INOUT-2*IOUT
      IF(IIN.EQ.1)NOIN=.FALSE.
      IF(IOUT.EQ.1)NOOUT=.FALSE.
      PROFIL=.FALSE.
      NOSLUI=.TRUE.
      IF(ICORR.LT.1) GO TO 241
      PROFIL=.TRUE.
      IF(ICORR.GT.1) GO TO 241
      NOSLUI=.FALSE.
C* RECORD 2.
C  LENGTH, BEAM,DRAFT,FREEBOARD AT FP.
  241 READ(1,*) XL,B,T,D
      WSP=10HM
      IF(NOIN)WSP=10HFT
      WORD(1)=10HFT
      WORD(2)=10HF/S
      WORD(3)=10HLB-F
      WORD(4)=10HPSI
      WORD(5)=10HTONS
      IF(NOOUT)GOTO782
      WORD(1)=10HM
      WORD(2)=10HM/S
      WORD(3)=10HN
      WORD(4)=10HKPA
      WORD(5)=10HTONNES
  782 IF(NOIN)GOTO730
      XL=XL*LONG
      B=B*LONG
      T=T*LONG
      D=D*LONG
  730 SLG=SQRT(XL*GRAV)
      IF(NOOUT)GOTO 731
      WRITE(2,2001)WSP,WORD(1),XL/LONG,B/LONG,T/LONG,D/LONG
      GOTO732
  731 WRITE(2,2001)WSP,WORD(1),XL,B,T,D
  732 IF(IOPT.EQ.0) GO TO 2
C  IF IOPT=1       ...
C* RECORD 3A.
C  AREA COEFFICIENT OF MAX SECTION.
      READ(1,*)AMAX
C* RECORDS 3B.
C  NON-DIMENSIONAL BEAM, DRAFT, AREA, 21 STATIONS.
      READ(1,*)(BAM(I),DRT(I),AIR(I),I=1,21)
      DO 1 I=1,21
      BAM(I)=BAM(I)*B
      DRT(I)=DRT(I)*T
```

```
    1  CONTINUE
       AMAX=AMAX*B*T
       DO 21 I=1,21
       IF(AIR(I).LE.0.0) GO TO 21
       AIR(I)=AIR(I)*AMAX/(BAM(I)*DRT(I))
   21  CONTINUE
       GO TO 3
    2  CONTINUE
C  IF IOPT=0        ...
C* RECORDS 3.
C  BEAM, DRAFT, AREA COEFFICIENT, 21 STATIONS.
       READ(1,*) (BAM(I),DRT(I),AIR(I),I=1,21)
       IF(NOIN)GOTO3
       DO 733 I=1,21
       BAM(I)=BAM(I)*LONG
  733  DRT(I)=DRT(I)*LONG
    3  CONTINUE
       WRITE(2,2002)
       IF(NOOUT)GO TO 520
       WRITE(2,2003)(I-1,BAM(I)/LONG,DRT(I)/LONG,AIR(I),I=1,21)
       GO TO 722
  520  WRITE(2,2003) (I-1,BAM(I),DRT(I),AIR(I),I=1,21)
  722  DD=0.05
       DD3 = DD/3.0
       DO 1700 I=1,21
1700   ARR(I) = BAM(I)*DRT(I)*AIR(I)/XL**2
       VOL = 4.0*ARR(2)+ARR(3)+ARR(1)
       DO 1701 I=3,19,2
1701   VOL = VOL+ARR(I)+4.0*ARR(I+1) + ARR(I+2)
       VOL = VOL*DD3
       XLCB =4.0*ARR(2)+2.0*ARR(3)
       DO 1702 I=3,19,2
1702   XLCB = XLCB+ARR(I)*(I-1)+4.0*ARR(I+1)*(I)+ARR(I+2)*(I+1)
       XLCB =XLCB*DD*DD3/VOL
       CW = 4.0*BAM(2)+BAM(3)+BAM(1)
       DO 1703 I =3,19,2
1703   CW =CW+BAM(I)+4.0*BAM(I+1)+BAM(I+2)
       CW=CW*DD3
       XLCF =4.0*BAM(2)+2.0*BAM(3)
       DO 1704 I =3,19,2
1704   XLCF = XLCF+BAM(I)*(I-1)+4.0*BAM(I+1)*I+BAM(I+2)*(I+1)
       XLCF = XLCF*DD*DD3/CW
       CW =CW/B
       C5 = 4.0*(BAM(2)+BAM(3))
       DO 1705 I =3,19,2
1705   C5=C5+BAM(I)*(I-1)**2+4.0*BAM(I+1)*I**2+BAM(I+2)*(I+1)**2
       C5=C5*DD**2*DD3/B
       DO 1706 I=1,21
       BAMM(I)=BAM(I)
       DRTT(I)=DRT(I)
       BAM(I) = BAM(I)/XL
1706   DRT(I) = DRT(I)/XL
       X = ARR(1)
       M= 1
       DO 1707 I =2,21
```

```
      IF(X.GT.ARR(I)) GO TO 1707
      X =ARR(I)
      M=I
1707  CONTINUE
      CM=X/(BAM(M)*DRT(M))
      CB= VOL*XL**2/(B*T)
      CP = CB/CM
      DISP = RHO*GRAV*CB*XL*B*T/2240.
      XCG = XLCB
      C33 = CW*B/XL
      C35 = XLCF*B/XL*CW-XCG*C33
      C55 = (C5+XCG*XCG*CW-2.*XLCF*CW*XCG)*B/XL
      IF(NOOUT) GO TO 734
      WRITE(2,2010)DISP/.98421,WORD(5)
      GOTO735
  734 WRITE(2,2010) DISP,WORD(5)
  735 WRITE(2,2008)CB,CM,CP,CW
      WRITE(2,2009)XLCB,XLCF
      IST=IWE=1
      IFAST=IFAST+1
      GO TO(473,474,475,474),IFAST
  474 IWE=2
      IF(IFAST.LT.4) GO TO 473
  475 IST=2
  473 W1=.2
      FWE=FLOAT(IWE)
      W3=2.
      IF(IRANGE.EQ.0)GO TO 900
C* RECORD 4.
C  READ OMEGA-MIN,  OMEGA-MAX
      READ(1,*)W1,W3
      WRITE(2,901)W1,W3
  900 CONTINUE
C* RECORD 5A.
C  NUMBER OF STATIONS.
      READ(1,*)NPOS
      NSTAT=.FALSE.
      IF(NPOS.LE.0)NSTAT=.TRUE.
      IF(NSTAT)GO TO 305
      WRITE(2,220)
      POS4=.FALSE.
      DO 13 I=1,NPOS
      TH(I)=0.0
C* RECORDS 5B.
C  STATION NUMBER, DEADRISE (DEG), FREEBOARD (UNITS).
      READ(1,*)XPOS(I),BETA(I),FB(I)
      IF(NOIN)GOTO37
      FB(I)=FB(I)*LONG
   37 IF(NOOUT)GOTO39
      WRITE(2,2012)XPOS(I),BETA(I),FB(I)/LONG
      GOTO40
   39 WRITE(2,2012)XPOS(I),BETA(I),FB(I)
   40 IF(BETA(I).LE.0.0)GOTO13
      IF(XPOS(I).NE.4.0) GO TO 1610
      B1=BETA(I)
```

```
      POS4=.TRUE.
 1610 BETD(I)=BETA(I)
      Q=BETA(I)/RAD
      TQ=TAN(Q)
      TH(I)=.0195*SLG/(.03/TQ+.011)/2
      BETA(I) = 1.+(1.-EXP(-5.*Q))*(1.5708/TQ    )**2
   13 CONTINUE
      IF(POS4)GOTO1615
      IF(AIR(5).GE.1.0) GO TO 1424
  305 CALL KBL(BAMM(5),DRTT(5),AIR(5),B1R,B1)
 1615 IF(B1.GT.5.0) GO TO 1412
 1424 B1=.708
      GO TO 306
 1412 B1=.06/TAN(B1/RAD)+.022
C* RECORD 6.
C  NUMBER OF SPEEDS, LOWEST,INCREMENT.
C  IF NSP IS NEGATIVE, FROUDE NUMBERS ARE INPUT
  306 READ(1,*)NSP,UK,DUK
      WSP=10H
      IF(NSP.LT.0)WSP=10HFROUDE NO.
      WRITE(2,2004)NSP,UK,DUK,WSP
      IF(NSP.GT.0) GO TO 120
      NSP=-NSP
      UK=UK*SLG/KNOT
      DUK=DUK*SLG/KNOT
C* RECORD 7.
C  NUMBER OF SEAS, SIG WAVE HEIGHT,PERIOD.
  120 READ(1,*)NSEA
      IF(NSEA.LT.0)NSEA=0
      NOSEA=.TRUE.
      IF(NSEA.EQ.0) GOTO 501
      DO 228 K=1,10
  228 AVW(K)=10H
      AVW(NSEA)=10H      MEAN
      NOSEA=.FALSE.
      READ(1,*) (HS(K),TS(K),K=1,NSEA)
      IF(NOIN)GO TO 740
      DO 741 K=1,NSEA
  741 HS(K)=HS(K)*LONG
  740 WRITE(2,221)
      IF(NOOUT)GO TO 742
      WRITE(2,2013)(HS(K)/LONG,TS(K),K=1,NSEA)
      GOTO743
  742 WRITE(2,2013)(HS(K),TS(K),K=1,NSEA)
C* RECORD 8.
C  HOURS SLAMMING,WIND SPEED(KT).
C  DEFAULT VALUES ARE THR=1 HR, WIND RESISTANCE TO BE IGNORED.
  743 THR=1.
      VWKT=-99.
      READ(1,*)THR,VWKT
C  VWKT, WIND SPEED, KT
C  IF .LT. ZERO   WIND RESISTANCE WILL BE IGNORED.
C  IF .GT. 99    12TH ITTC RELATIONSHIP WILL BE USED
      NVW(1)=NVW(2)=10H
      IVW=2
```

```
      IF(VWKT.GE.0.)GO TO 105
      IVW=1
      NVW(1)=10HWIND REST.
      NVW(2)=10H IGNORED
      GO TO 106
  105 IF(VWKT.LE.99.)GO TO 106
      IVW=3
      NVW(1)=10HDEFAULT US
      NVW(2)=10HED
  106 WRITE(2,222) THR,VWKT,NVW
      GO TO 500
  501 WRITE(2,224)
  500 IF(NOSEA.AND.NORESP) GO TO 600
C  TAPE90 IS A SCRATCH FILE FOR PLOTTING ETC.
C  TAPE90 OUTPUT IS IN PROGRAM INTERNAL (IE FPS) UNITS.
C  THIS WRITE : 135 WORDS.
      WRITE(90)NAME,XL,B,T,D,BAMM,DRTT                          ,AIR,D
     DISP,CB,CM,CP,CW,XLCB,XLCF,NPOS,XPOS,BETD,NSP,UK,DUK,NSEA,HS,TS,THR
     ,,VWKT,  IOPT,IRESP,INOUT,IRANGE,ICORR,IFAST-1
      ENDFILE 90
      IF(NSTAT)GO TO 307
      DO 11 I=1,NPOS
      J=INT(XPOS(I))
      IF(J.LT.20) GO TO 9
      DR(I)=DRT(21)
      GO TO 10
  9   DR(I)=DRT(J+1)+(XPOS(I)-J)*(DRT(J+2)-DRT(J+1))
   10 DR(I)=XL*DR(I)
  11  CONTINUE
  307 FACTOR = SQRT(XL/GRAV)
      AI = (0.,1.)
      C33=C33*GRAV/(VOL*XL)
      C53=C35*GRAV/(VOL*XL**2)
      C35=C35*GRAV/VOL
      C55=C55*GRAV/(VOL*XL)
      DO 1801 I=2,20
      DX(I)=.05
1801  CONTINUE
      DX(1)=DX(21)=.025
C  COMPUTE SECTIONAL ADDED MASS AND DAMPING
C  FOR NFR FREQUENCIES AT EACH STATION
      U=KNOT*(UK+(NSP-1)*DUK)
      WMAX=W3+W3*W3*U/GRAV
      U=KNOT*UK
      WMIN=W1+W1*W1*U/GRAV
      DFR=((WMAX-WMIN)/48.)
      DO 1802 IFR=1,49,IWE
      W=WMIN+DFR*(IFR-1)
      OMEN=W*FACTOR
      DO 1802 I=1,21,IST
      IF(AIR(I).LE.0.0) GO TO 1822
      CALL ADMAB(BAM(I),DRT(I),AIR(I),OMEN,
     1ADMS(I,IFR),DAMP(I,IFR))
C  PRECAUTION TO AVOID NONSENSE OUTPUT AT HIGHER FREQUENCIES
      IF(ADMS(I,IFR).GT.0.0)GO TO 1802
```

```
      ADMS(I,IFR)=ADMS(I,IFR-1)
      GO TO 1802
 1822 ADMS(I,IFR)=DAMP(I,IFR)=0.
1802  CONTINUE
C  SPEED LOOP
      DO 1803 ISP=1,NSP
      U=(UK+(ISP-1)*DUK)
      DFP=0.0
      IF(PROFIL)DFP=PROFILE(0.0,BAMM,DRTT,AIR,XL,U,0)
      U=KNOT*U
      FROUDE=U/SLG
      IF(NOSLUI) GO TO 1818
      DO 1819 IS=1,10
      R=XPOS(IS)/20.
 1819 SS(IS)=DEFWAV(R,FROUDE)
      SS(11)=DEFWAV(0.0,FROUDE)
      SS(12)=DEFWAV(0.2,FROUDE)
      GO TO 1820
 1818 DO 1821 IS=1,12
 1821 SS(IS)=1.0
C  COMPUTE MAX. FREQ., DIVIDE INTO NSPI INTERVALS
 1820 WMAX=W3+W3*W3*U/GRAV
      WMIN=W1+W1*W1*U/GRAV
      DW=((WMAX-WMIN)/48.)
      WD=DW*IWE
C  COMPUTE FREQUENCY RESPONSE
      DO 100 I=1,13
      DO 100 J=1,NSEA
100   OUT(I,J)=0.0
      DO 304 K=1,NSEA
      IF(NSTAT)GO TO 304
      DO 4 I=1,NPOS
      AX(I,K)=RM(I,K)=RV(I,K)=0.0
      VRQI2(I,K)=VRQI4(I,K)=0.
    4 CONTINUE
  304 CONTINUE
      IF(NORESP) GO TO 835
      WRITE(2,206)
      IF(NOCR)GO TO 834
      WRITE(2,1102)U/KNOT,FROUDE
      GO TO  835
  834 WRITE(2,1100)U/KNOT,FROUDE
  835 CONTINUE
C  FREQUENCY LOOP.
      DO 1804 IFR=1,49,IWE
      W=WMIN+DW*(IFR-1)
      WW=W
      IF(U.LE.0.0)GO TO 1805
      XI=0.5*GRAV/U
      WW=-XI+SQRT(XI*XI+2.*W*XI)
1805  W2=W*W
      QW=WW*WW/GRAV
      ELL=6.2832/QW/XL
```

```
      AIW=AI*W
      OMEN=W*FACTOR
      OMENW=WW*FACTOR
      A33=B33=0.0
      A35=B35=0.0
      A55=B55=0.0
      EFH=EMP=(0.,0.)
      R=(W-WMIN)/DFR
      P=R/FWE
      N=1+INT(P)
      M=IWE*INT(R/FWE)+1
      P=P-N+1
      DO 1806 I=1,21,IST
C  INTERPOLATE FOR ADMH  DAMH AT EACH STATION
      ADMH=ADMS(I,M)+P*(ADMS(I,M+IWE)-ADMS(I,M))
      DAMH=DAMP(I,M)+P*(DAMP(I,M+IWE)-DAMP(I,M))
C  COMPUTE SPEED INDEPENDENT COMPONENTS
      XO=DX(I)*IST
      X=(XCG-.05*(I-1))
      X1=X*XO
      X2=X*X1
      A33=A33+ADMH*XO
      B33=B33+DAMH*XO
      A35=A35-ADMH*X1
      B35=B35-DAMH*X1
      A55=A55+ADMH*X2
      B55=B55+DAMH*X2
      EFX=CMPLX(ADMH,-DAMH)
      CAB=CEXP(AI*QW*X*XL)
      XI=EXP(-QW*DRT(I)*XL*AIR(I))
      XC=OMENW/OMEN*EFX*XI
      CFH=BAM(I)*XI-XC
      CFP=-CFH*X-AI*FROUDE*XC/OMEN
      XC=CAB*XO
      EFH=EFH+CFH*XC
      EMP=EMP+CFP*XC
1806  CONTINUE
C  SCALE AND INTRODUCE SPEED EFFECTS
      X1=OMEN*VOL
      X2=OMEN*X1
      A33=A33/X2
      A35=A35/X2
      A55=A55/X2
      B33=B33/X1
      B35=B35/X1
      B55=B55/X1
      X2=FROUDE*A33
      X1=FROUDE/OMEN**2*B33
      A53=A35+X1
      A35=A35-X1
      B53=B35-X2
      B35=B35+X2
      A55=A55+FROUDE*X2/OMEN**2
      B55=B55+FROUDE*X1
C  FINAL SCALING
```

```
C   HEAVE FACTORED BY M
C   PITCH FACTORED BY M*L**2
       B33=B33/FACTOR
       A35=A35*XL
       B35=B35/FACTOR*XL
       A53=A53/XL
       B53=B53/(FACTOR*XL)
       B55=B55/FACTOR
       EFH=EFH*GRAV/(VOL*XL)
       EMP=EMP*GRAV/(VOL*XL**2)
C   HYDRODYNAMIC MATRIX
       XC=-W2*(A33+1.)+AIW*B33+C33
       CALL MATG(1,1)
       XC=-W2*A35+AIW*B35+C35
       CALL MATG(1,3)
       XC=-W2*A53+AIW*B53+C53
       CALL MATG(3,1)
       XC=-W2*(A55+.0625)+AIW*B55+C55
       CALL MATG(3,3)
       G(1,5)=REAL(EFH)
       G(2,5)=AIMAG(EFH)
       G(3,5)=REAL(EMP)
       G(4,5)=AIMAG(EMP)
C      SOLVE FOR MOTIONS
       CALL SOLV(G,CON,4,5,INDX,ICKG)
C   REGULAR WAVE RESPONSES
       IF(NORESP) GO TO 515
C   HEAVE
       X0=SQRT(CON(1)**2+CON(2)**2)
       PX0=ATAN2(CON(2),CON(1))*RAD
C   PITCH
       A6=SQRT(CON(3)**2+CON(4)**2)/QW
       PA6=ATAN2(CON(4),CON(3))*RAD
C   ADDED RESISTANCE
  515 CR=RAW(WW,XL,0.25,FROUDE,AIR(2),AIR(11))
C   RESPONSE SPECTRA
       IF(NOSEA) GO TO 510
       DO 1812 K=1,NSEA
       X1=SEAST(HS(K),TS(K),WW)/(1.+2.*U*WW/GRAV)
       OUT(1,K)=OUT(1,K)+X1*(CON(3)**2+CON(4)**2)
       P=X1*(CON(1)**2+CON(2)**2)
       OUT(2,K)=OUT(2,K)+P
       OUT(3,K)=OUT(3,K)+P*W2*W2
       IS=11
       X=XL*XCG
       DO 1813 J=5,7,2
       XX=CON(1)-X*CON(3)
       YY=CON(2)-X*CON(4)
       XC=CMPLX(XX,YY)-CEXP(WW*WW*X*AI/GRAV)*SS(IS)
       P=X1*(CABS(XC))**2
       OUT(J,K)=OUT(J,K)+P
       OUT(J+1,K)=OUT(J+1,K)+P*W*W
       X=XL*(XCG-0.20)
 1813 IS=12
       IF(NSTAT)GO TO 308
```

```
      DO 5 I=1,NPOS
      R=XPOS(I)/20.
      X=XL*(XCG-R)
      AXX=X1*((CON(1)-X*CON(3))**2+(CON(2)-X*CON(4))**2)*W2**2
      AX(I,K)=AX(I,K)+AXX
      VRQI2(I,K)=VRQI2(I,K)+AXX*RESP(W,25.1,.4)
      S=1.
      IF(W.LT.1.07)S=W/1.07
      VRQI4(I,K)=VRQI4(I,K)+AXX*RESP(W,1.571,1.)*S
      XX=CON(1)-X*CON(3)
      YY=CON(2)-X*CON(4)
      XC=CMPLX(XX,YY)-CEXP(WW*WW*X*AI/GRAV)*SS(I)
      P=X1*(CABS(XC))**2
      RM(I,K)=RM(I,K)+P
      RV(I,K)=RV(I,K)+P*W2
    5 CONTINUE
  308 OUT(12,K)=OUT(12,K)+X1*CR
 1812 CONTINUE
  510 IF(NORESP) GO TO 1804
      ZWE(IFR)=W
      ZW(IFR)=WW
      ZLL(IFR)=ELL
      ZH(IFR)=X0
      ZHP(IFR)=PX0
      ZP(IFR)=A6
      ZPP(IFR)=PA6
      ZCR(IFR)=CR
      IF(NOCR) GO TO 512
      WRITE(2,1101)W,WW,ELL,X0,PX0,A6,PA6,CR
      GO TO 1804
  512 WRITE(2,1101)W,WW,ELL,X0,PX0,A6,PA6
 1804 CONTINUE
      IF(NOSEA)GO TO 310
      DO 227 K=1,9
  227 AVE(K)=0.
      DO 1825 K=1,NSEA
      OUT(12,K)=OUT(12,K)*(RHO*GRAV*B*B/XL)*WD
      DO 1814 J=1,3
 1814 OUT(J,K)=SQRT(WD*OUT(J,K))
      DO 1825 J=5,8
 1825 OUT(J,K)=SQRT(WD*OUT(J,K))
      DO 1815 K=1,NSEA
      OUT(1,K)=RAD*OUT(1,K)
 1815 OUT(3,K)=OUT(3,K)/GRAV
      THRESH=.00038*XL*GRAV /B1/B1
      DO 1817 K=1,NSEA
      DF=T
      IF(DF.LT.0.0)DF=0.0
      XX=.5*((DF/OUT(7,K))**2+THRESH/OUT(8,K)**2)
      IF(XX.GT.670.)XX=670.
      OUT(10,K)=EXP(-XX)
      DPF=D-DFP
      IF(DPF.LT.0.0)DPF=0.0
      OUT(9,K)=.5*(DPF/OUT(5,K))**2
      IF(OUT(9,K).GT.670.)OUT(9,K)=670.
```

```
1817 OUT(9,K)=EXP(-OUT(9,K))
     IF(NSTAT)GO TO 309
     DO 6 I=1,NPOS
     DO 6 K=1,NSEA
     AX(I,K)=SQRT(WD*AX(I,K))/GRAV
     RM(I,K)=SQRT(WD*RM(I,K))
     RV(I,K)=SQRT(WD*RV(I,K))
     IF(VRQI4(I,K).GT.VRQI2(I,K))VRQI2(I,K)=VRQI4(I,K)
     VRQI2(I,K)=SQRT(WD*VRQI2(I,K))/GRAV
6    CONTINUE
309  UUK=UK+(ISP-1)*DUK
     IF(IVW-2)180,181,182
182  DO 183 K=1,NSEA
     VW(K)=SQRT(590.+135.*HS(K))-24.29
     IF(VW(K).LT.0.0)VW(K)=0.0
183  CONTINUE
     GO TO 184
181  DO 185 K=1,NSEA
185  VW(K)=VWKT
184  DO 186 K=1,NSEA
186  OUT(13,K)=.002*B*B*(UUK+VW(K))**2
     GO TO 187
180  DO 188 K=1,NSEA
188  OUT(13,K)=0.
187  DO 189 K=1,NSEA
     AVE(1)=AVE(1)+HS(K)/NSEA
     AVE(2)=AVE(2)+TS(K)/NSEA
     AVE(3)=AVE(3)+OUT( 1,K)/NSEA
     AVE(4)=AVE(4)+OUT( 2,K)/NSEA
     AVE(5)=AVE(5)+OUT( 3,K)/NSEA
     AVE(6)=AVE(6)+OUT( 9,K)/NSEA
     AVE(7)=AVE(7)+OUT(10,K)/NSEA
     AVE(8)=AVE(8)+OUT(12,K)/NSEA
189  AVE(9)=AVE(9)+OUT(13,K)/NSEA
     WRITE(2,206)
     WRITE(2,202)UUK,FROUDE,(WORD(K),K=1,4),AVW
     IF(NOOUT)GOTO 760
     WRITE(2,203)(HS(K)/LONG,K=1,NSEA),AVE(1)/LONG
     GO TO 773
760  WRITE(2,203)(HS(K),K=1,NSEA),AVE(1)
773  WRITE(2,207)(TS(K),K=1,NSEA),AVE(2)
     WRITE(2,204)(FF(1,L),L=1,2),(OUT(1,K),K=1,NSEA),AVE(3)
     IF(NOOUT) GO TO 770
     WRITE(2,204)(FF(2,L),L=1,2),(OUT(2,K)/LONG,K=1,NSEA),AVE(4)/LONG
     GO TO 771
770  WRITE(2,204)(FF(2,L),L=1,2),(OUT(2,K),K=1,NSEA),AVE(4)
771  WRITE(2,204)(FF(3,L),L=1,2),(OUT(3,K),K=1,NSEA),AVE(5)
     WRITE(2,205)(FF(5,L),L=1,2),(OUT(9,K),K=1,NSEA),AVE(6)
     WRITE(2,205)(FF( 6,L),L=1,2),(OUT(10,K),K=1,NSEA),AVE(7)
     IF(NOOUT) GO TO 772
     WRITE(2,223)(FF( 7,L),L=1,2),(OUT(12,K)*FORCE,K=1,NSEA),AVE(8)
    **FORCE
     WRITE(2,223)(FF( 8,L),L=1,2),(OUT(13,K)*FORCE,K=1,NSEA),AVE(9)
    **FORCE
     GOTO761
```

```
772 WRITE(2,223)(FF( 7,L),L=1,2),(OUT(12,K),K=1,NSEA),AVE(8)
    WRITE(2,223)(FF( 8,L),L=1,2),(OUT(13,K),K=1,NSEA),AVE(9)
761 WRITE(2,226)
    IF(NSTAT)GO TO 310
    DO 38 I=1,NPOS
    DDR=0.
    IF(PROFIL)DDR=PROFILE(XPOS(I),BAMM,DRTT,AIR,XL,UUK,0)
    DO 8 K=1,NSEA
    XY=FB(I)-DDR
    IF(XY.LT.0.0)XY=0.0
    XX=DR(I)
    IF(XX.LT.0.0)XX=0.0
    PK(I,K)=.5*(XX/RM(I,K))**2
    PS(I,K)=PK(I,K)+.5*(TH(I)/RV(I,K))**2
    PDW(I,K)=.5*(XY/RM(I,K))**2
    IF(PK(I,K).GT.670.)PK(I,K)=670.
    IF(PS(I,K).GT.670.)PS(I,K)=670.
    IF(PDW(I,K).GT.670.)PDW(I,K)=670.
    PS(I,K)=EXP(-PS(I,K))
    PDW(I,K)=EXP(-PDW(I,K))
  8 PK(I,K)=EXP(-PK(I,K))
    AXM(I)=RMM(I)=RVM(I)=PKM(I)=PTM(I)=0.
    PSM(I)=0.
    PDWM(I)=0.0
    VQM(I)=0.
    DO 12 K=1,NSEA
    AXM(I)=AXM(I)+AX(I,K)/NSEA
    VQM(I)=VQM(I)+VROI2(I,K)/NSEA
    RMM(I)=RMM(I)+RM(I,K)/NSEA
    RVM(I)=RVM(I)+RV(I,K)/NSEA
    PKM(I)=PKM(I)+PK(I,K)/NSEA
    PSM(I)=PSM(I)+PS(I,K)/NSEA
    PDWM(I)=PDWM(I)+PDW(I,K)/NSEA
    IF(BETA(I).LE.0.0) GO TO 12
    PT(I,K)=RHO*BETA(I)*(RV(I,K)**2*ALOG(572.9578*THR*RV(I,K)*PK(I,K)/
   $RM(I,K)))/144.
    IF(DR(I).LE.0.)PT(I,K)=0.
    IF (PT(I,K) .LT. 0.0) PT(I,K)=0.0
    PTM(I)=PTM(I)+PT(I,K)/NSEA
12  CONTINUE
    WRITE(2,208) XPOS(I)
    WRITE(2,209) (AX(I,K),K=1,NSEA),AXM(I)
    WRITE(2,1104)(VROI2(I,K),K=1,NSEA),VQM(I)
    IF(NOOUT)GO TO 780
    WRITE(2,210)(RM(I,K)/LONG,K=1,NSEA),RMM(I)/LONG
    GO TO 781
780 WRITE(2,210) (RM(I,K),K=1,NSEA),RMM(I)
781 IF(NOOUT)GOTO 762
    WRITE(2,211)(RV(I,K)/LONG,K=1,NSEA),RVM(I)/LONG
    GO TO 763
762 WRITE(2,211) (RV(I,K),K=1,NSEA),RVM(I)
763 WRITE(2,212) (PK(I,K),K=1,NSEA),PKM(I)
    IF(BETA(I).LE.0.0.OR.XPOS(I).GT.10) GO TO 7
    WRITE(2,214)(PS(I,K),K=1,NSEA),PSM(I)
    IF(NOOUT) GO TO 764
```

```
      WRITE(2,213)(PT(I,K)*PRESS,K=1,NSEA),PTM(I)*PRESS
      GO TO 7
  764 WRITE(2,213)(PT(I,K),K=1,NSEA),PTM(I)
    7 IF(FB(I).LE.0.0)GOTO38
      WRITE(2,219)(PDW(I,K),K=1,NSEA),PDWM(I)
   38 CONTINUE
  310 IF(NORESP)GO TO 311
C  TAPE90 OUTPUT IS IN PROGRAM INTERNAL (IE FPS) UNITS.
C  THIS WRITE : 394 WORDS.
      WRITE(90)U/KNOT,FROUDE,ZWE,ZW,ZLL,ZH,ZHP,ZP,ZPP,ZCR
      ENDFILE 90
  311 IF(NOSEA) GO TO 1803
C  TAPE90 OUTPUT IS IN PROGRAM INTERNAL (IE FPS) UNITS.
C   THIS WRITE : 932 WORDS.
      WRITE(90)U/KNOT,FROUDE,OUT,AX,VRQI2,RM,RV,PK,PS,PT,PDW
      ENDFILE 90
 1803 CONTINUE
      STOP
  600 WRITE(2,225)
      STOP
 2001 FORMAT( /5X,*DIMENSIONS :        IN - *,A10,10X,*OUT - *A10
     *       //5X,3HL =F8.3,5X,3HB =F7.3,5X,3HT =F7.3,5X,3HD =F7.3)
 2002  FORMAT(/4X,2HST,9X,4HBEAM6X,5HDRAFT6X,4HAREA)
 2003  FORMAT(4XI2,4X3F10.3)
 2004 FORMAT( /5X,4HNSP=I3,5X,3HUK=F5.2,5X,
     *4HDUK=F5.2,5X,A10)
 2005  FORMAT(8A10)
 2006 FORMAT(1H1/5X,*PITCH AND HEAVE IN HEAD SEAS*//5X,4A10,2(2X,2A10))
 2008  FORMAT(/5X,3HCB=F5.3,5X,3HCM=F5.3,5X,3HCP=F5.3,5X,3HCW=F5.3)
 2009  FORMAT(/5X,7HLCB/L =F5.3,5X,7HLCF/L =F5.3)
 2010  FORMAT(//5X,6HDISP =F7.1,2X,A10)
 2012 FORMAT(3F9.2)
 2013 FORMAT(2F9.2)
  202  FORMAT(//10X*V(KT)=*F5.1,10X,*FROUDE=*F8.3//5X*UNITS :*/5X,*DIMENS
     SION - *,A10/5X,*SPEED - *,A10/5X,*FORCE - *,A10/5X,*PRESSURE - *,A
     A10,5X,10A10)
  203  FORMAT(/5X13HSIG. WAVE HT.,3X,11(1XF9.2))
  204  FORMAT(/5X2A8,11F10.3)
  205  FORMAT(/5X2A8,11F10.4)
  206  FORMAT(1H1)
  207  FORMAT(/5X*WAVE PERIOD*5X11F10.2)
  208 FORMAT(/5X*ST.*F5.2)
  209 FORMAT(5X*ACC.(G)*9X,11F10.4)
  210 FORMAT(5X*REL.MOT.     *4X,11F10.3)
  211 FORMAT(5X*REL.VEL.      *3X,11F10.3)
  212 FORMAT(5X*PROB(KEEL)*6X,11F10.4)
  213 FORMAT(5X*PRESSURE*8X,11F10.2)
  214 FORMAT(5X*PROB(SLAM)*6X,11F10.4)
  219 FORMAT(5X*PROB(DW)*8X,11F10.4)
  220 FORMAT(/5X*XPOS*4X*BETA*6X*FB*)
  221 FORMAT(/5X*HS*7X*TS*)
  222 FORMAT(/5X*THR=*F6.2,10X,*VWKT= *,F7.2,5X,2A10)
  223 FORMAT(/5X,2A8,11F10.1)
  224 FORMAT(/5X,*NO IRREGULAR SEA SPECIFIED*)
  225 FORMAT(1H1////5X,*NEITHER REGULAR NOR IRREGULAR SEAWAY COMPUTATION
```

```
      NS REQUESTED*//5X,*EXECUTION TERMINATED*)
  226 FORMAT(/)
  901 FORMAT(/5X,*SPECIFIED OMEGA-MIN,MAX = *2F9.4)
 1100 FORMAT(5X,*V(KT)=*,F5.1,10X,*FROUDE=*,F8.3
     *                        //5X,*SELECTED RESPONSES*//9X,*W-E*,6X,
     $*W*,7X,*LAMBDA/*,2X,*HEAVE*,3X,*PHASE*,3X,*PITCH*,3X,*PHASE*/
     $9X,*R/S*,6X,*R/S*,5X,*LENGTH*,12X,*DEG*,13X,           *DEG*/)
 1101 FORMAT(5X,3F9.4,F8.4,F8.2,F8.4,F8.2,F9.4)
 1102 FORMAT(5X,*V(KT)=*,F5.1,10X,*FROUDE=*,F8.3
     *                        //5X,*SELECTED RESPONSES*//9X,*W-E*,6X,
     $*W*,7X,*LAMBDA/*,2X,*HEAVE*,3X,*PHASE*,3X,*PITCH*,3X,*PHASE*,3X,
     $*COEF OF*/9X,*R/S*,6X,*R/S*,5X,*LENGTH*,12X,*DEG*,13X,         *DEG
     G*,6X,*REST*/)
 1103 FORMAT(/5X,*IOPT=*I3, 5X,*IRESP=*,I3, 5X,*INOUT=*,I3//5X*IRANGE=*
     ,,I3,5X,*ICORR=*,I3,5X,*IFAST=*,I3)
 1104 FORMAT(5X,*VRQI*,12X,11F10.4)
      END
```

```
      SUBROUTINE ADMAB (BEAM,DRFT,AREA,OMEN,ADMH,DAMH)
      DIMENSION SY(10),SZ(10),SSB(10),SPB(10),SDB(10),SSA(10),SPA(10),SD
     1A(10),SLW(10),EPA(5,6),EQA(5,6),EPC(5),EPB(5),EPX(5),EQX(5),EPY(5)
     Z,EQY(5)
      ADMH=0.
      DAMH=0.
      IF(BEAM.LE.0.0.OR.DRFT.LE.0.0) GO TO 77
      IF(.NOT.(BEAM.LE.(1.2*DRFT).AND.AREA.GT.1.2)) GO TO 6002
      DEL=OMEN*OMEN*DRFT
      CALL BULB(AREA,BEAM,DRFT,DEL,ADMH,DAMH)
      ADMH=ADMH*1.570796*(OMEN*DRFT)**2
      DAMH=(DAMH/OMEN)**2
      RETURN
 6002 CONTINUE
      SBBB=AREA
      SBB=BEAM
      SBH=0.5*BEAM/DRFT
 7003 SAN=3.14159+(SBBB*4.0-3.14159)*SBH/(SBH+1.0)**2
      SWA=5.55165-1.57078*SAN
      SAZN=(2.35619+SQRT(SWA))/SAN
      SA=(SBH-1.0)*SAZN/(SBH+1.0)
      SB=SAZN-1.0
      SAA=SA*SA+3.0*SB
      SAAA=SA*SAA+3.0*SA*SB
      EPB(1)=1.0+SA+SB
      EPB(2)=0.63662*(0.33333*(1.0+SA)-1.80*SB)
      EPB(3)=0.31831*(0.06667+0.06667*SA+1.28571*SB)
      EPB(4)=0.63662*(0.00952+0.00952*SA+0.11111*SB)
      EPB(5)=0.31831*(0.00793+0.00793*SA+0.08182*SB)
      SF10=9.*SB*(0.2-0.14286*SA-0.03704*SAA-0.01818*SAAA)
      SF10=SF10-((1.0+SA)*(0.3333+0.06667*SA+0.02857*SAA+0.01587*SAAA))
      SF20=-(1.0+SA)*(0.06667+0.02857*SA+0.01587*SAA)
      SF20=SF20-9.0*SB*(0.14286+0.03704*SA+0.01818*SAA)
      SF3=-(1.0+SA)*(0.02857+0.01587*SA)-9.0*SB*(0.03704+0.01818*SA)
      SF4=-(1.0+SA)*0.01587-9.0*SB*0.01818
      SFRPA=.5*OMEN**2*BEAM
      SFRPB=SFRPA
      SW=SFRPA/(1.0+SA+SB)
 8003 SY0=SFRPA
      SSB0=3.14159*SIN(SY0)
      SSA0=SIN(SY0)*ALOG(1.781*SY0)-1.57078*COS(SY0)-SY0
      SSA0=SSA0+0.30556*SY0**3-0.01903*SY0**5
      SFP1=0.0
      SFQ1=0.0
      SQ=-0.05236
      SWF=0.0
      SLWM=0.0
      DO 8004 LS=1,10
      SLS=LS
      SLSP=SLS*0.15708
      SNSL=SIN(SLSP)
      SN3SL=SIN(3.0*SLSP)
      SY(LS)=SW*((1.0+SA)*COS(SLSP)+SB*COS(3.0*SLSP))
      SZ(LS)=SW*((1.0-SA)*SNSL-SB*SN3SL)
      SEZ=3.14159/EXP(SZ(LS))
```

```
      SSB(LS)=SEZ*SIN(SY(LS))
      SPB(LS)=SEZ*COS(SY(LS))
      SDB(LS)=SSB(LS)-SSB0*(1.0-SLS/10.0)
      SY2=SY(LS)*SY(LS)
      SY3=SY2*SY(LS)
      SZ2=SZ(LS)*SZ(LS)
      SZ3=SZ2*SZ(LS)
      SYZ=SY(LS)*SZ(LS)
      SLOG=0.31831*ALOG(1.781*SQRT(SY2+SZ2))
      STAN=0.50-0.31831*ATAN(SZ(LS)/SY(LS))
      SSA(LS)=SSB(LS)*SLOG-SPB(LS)*STAN-SY(LS)*(1.0+0.91667*SZ2)
      SSA(LS)=SSA(LS)+SY3*(0.30556+0.01903*(10.0*SZ2-SY2))
      SSA(LS)=SSA(LS)+SYZ*(1.5-0.09514*SZ3+0.34722*(SZ2-SY2))
      SPA(LS)=SPB(LS)*SLOG+SSB(LS)*STAN+SZ(LS)*(1.0-0.91667*SY2)
      SPA(LS)=SPA(LS)+SZ3*(0.30556-0.08681*SZ(LS)+0.01903*(SZ2-10.0*SY2)
     1)
      SPA(LS)=SPA(LS)+SYZ*(0.09514*SY3)-0.75*SZ2
      SPA(LS)=SPA(LS)+SY2*(0.75-0.08681*SY2+0.52083*SZ2)
      SDA(LS)=SSA(LS)-SSA0*(1.0-SLS/10.0)
      SQ=-SQ
      SFM=((1.0+SA)*SNSL+3.0*SB*SN3SL)*(0.15708+SQ)
      SFQ1=SFQ1+SPB(LS)*SFM
      SFP1=SFP1+SPA(LS)*SFM
      SWF=SWF+SFM/EXP(SZ(LS)*SFRPB/SFRPA)
      SLWN=SFM*SEZ/(6.28318+40.0*SQ)
      SLW(LS)=SLWM+SLWN
      SLWM=SLW(LS)+SLWN
 8004 CONTINUE
      DO 8010 LS=1,9
      SLS=LS
 8010 SLW(LS)=SLW(10)*SLS/10.0-SLW(LS)
      SFQ1=SFQ1-0.50*SPB(10)*SFM
      SFP1=SFP1-0.50*SPA(10)*SFM
      SWF=(SWF-0.50*SFM/EXP(SZ(10)*SFRPB/SFRPA))/(1.0+SA+SB)
      EPA(1,1)=SSA0
      EQA(1,1)=SSB0
      EPC(1)=SLW(10)
      SQ=-0.05236
      DO 8005 KS=2,5
      EPA(KS,1)=0.0
      EQA(KS,1)=0.0
      EPC(KS)=0.0
      SK=(KS-1)*2
      SQ=-0.05236
      DO 8005 MS=1,9
      SQ=-SQ
      SM=MS
      SMSIN=1.27324*(0.15708+SQ)*SIN(SK*SM*0.15708)
      EPA(KS,1)=EPA(KS,1)+SDA(MS)*SMSIN
      EQA(KS,1)=EQA(KS,1)+SDB(MS)*SMSIN
      EPC(KS)=EPC(KS)+SLW(MS)*SMSIN
 8005 CONTINUE
      EPA(1,2)=-SW
      EPA(2,2)=-1.0-0.21221*SW
      EPA(3,2)=-SA-0.02122*SW
```

```
      EPA(4,2)=-SAA-0.00606*SW
      EPA(5,2)=-SAAA-0.00253*SW
      EPA(1,3)=-0.33333*SW
      EPA(2,3)=0.38197*SW
      EPA(3,3)=-1.0-0.13642*SW
      EPA(4,3)=-SA-0.02358*SW
      EPA(5,3)=-SAA-0.00868*SW
      EPA(1,4)=-0.20*SW
      EPA(2,4)=0.15158*SW
      EPA(3,4)=0.17684*SW
      EPA(4,4)=-1.0-0.09646*SW
      EPA(5,4)=-SA-0.02040*SW
      EPA(1,5)=-0.1429*SW
      EPA(2,5)=0.09903*SW
      EPA(3,5)=0.06752*SW
      EPA(4,5)=0.11427*SW
      EPA(5,5)=-1.0-0.07428*SW
      DO 8006 KS=1,5
      DO 8006 LS=2,5
 8006 EQA(KS,LS)=0.0
      NEQ=5
 9903 IEPB=7070
      NEP=NEQ+1
      DO 9933 IEQ=1,NEQ
      DO 9948 LEQ=1,NEQ
      EPA(LEQ,NEP)=0.0
 9948 EQA(LEQ,NEP)=0.0
      EPA(IEQ,NEP)=1.0
      IEQY=1
      IF(EPA(IEQ,1))9934,9931,9934
 9931 IF(EQA(IEQ,1))9934,9910,9934
 9934 EQP=EPA(IEQ,1)*EPA(IEQ,1)+EQA(IEQ,1)*EQA(IEQ,1)
      EPT1=EPA(IEQ,1)
      EQT1=EQA(IEQ,1)
      DO 9935 JEQ=1,NEP
      EPT=(EPA(IEQ,JEQ)*EPT1+EQA(IEQ,JEQ)*EQT1)/EQP
      EQT=(EQA(IEQ,JEQ)*EPT1-EPA(IEQ,JEQ)*EQT1)/EQP
      EPA(IEQ,JEQ)=EPT
 9935 EQA(IEQ,JEQ)=EQT
      IEQX=0
      IEQY=2
      IF(IEQ-NEQ)9937,9938,9910
 9938 MEQX=IEQ-1
      MEQY=1
      GO  TO 9939
 9937 MEQY=IEQ+1
      MEQX=NEQ
 9939 DO 9940 LEQ=MEQY,MEQX
      IEQX=IEQX+1
      EQP=EPA(LEQ,1)
      EPQ=EQA(LEQ,1)
      DO 9940 JEQ=1,NEP
      EPT=EPA(IEQ,JEQ)*EQP-EQA(IEQ,JEQ)*EPQ
      EQT=EPA(IEQ,JEQ)*EPQ+EQA(IEQ,JEQ)*EQP
      EPA(LEQ,JEQ)=EPA(LEQ,JEQ)-EPT
```

```
9940 EQA(LEQ,JEQ)=EQA(LEQ,JEQ)-EQT
     IEQY=3
     IF(IEQ-1)9910,9944,9945
9945 IF((NEQ-1)-IEQX)9910,9944,9938
9944 DO 9946 LEQ=1,NEQ
     DO 9946 JEQ=1,NEQ
     NEQU=JEQ+1
     EPA(LEQ,JEQ)=EPA(LEQ,NEQU)
9946 EQA(LEQ,JEQ)=EQA(LEQ,NEQU)
9933 CONTINUE
9952 DO 9953 IEQ=1,NEQ
     EPX(IEQ)=0.0
     EQX(IEQ)=0.0
     EPY(IEQ)=0.0
     EQY(IEQ)=0.0
     DO 9953 JEQ=1,NEQ
     EPX(IEQ)=EPX(IEQ)+EPA(IEQ,JEQ)*EPB(JEQ)
     EQX(IEQ)=EQX(IEQ)+EQA(IEQ,JEQ)*EPB(JEQ)
     EPY(IEQ)=EPY(IEQ)+EPA(IEQ,JEQ)*EPC(JEQ)
     EQY(IEQ)=EQY(IEQ)+EQA(IEQ,JEQ)*EPC(JEQ)
9953 CONTINUE
     GO TO 8009
9906 FORMAT(81H THIS SUBROUTINE ADMAB IS NOT ABLE TO FIND THE ADDED MAS
    1S AND DAMPING COEFFICIENT)
9910 WRITE(6,9906)
     GO TO 7499
8009 SF1=SF10-SW*(1.0+SA)*0.78540
     SF2=SF20-SW*0.78540*SB
     SPF=EPX(1)*SFP1-EQX(1)*SFQ1+EPX(2)*SF1+EPX(3)*SF2+EPX(4)*SF3
     SPF=SPF+EPX(5)*SF4
     SC=SPF/(0.7854*(1.0+SA+SB)**2)
     SAR=3.14159*SW*SQRT(EPX(1)**2+EQX(1)**2)
     ADMH=3.14159*SC*(OMEN*BEAM)**2/8.0
     DAMH=(SAR/OMEN)**2
7499 CONTINUE
     RETURN
  77 ADMH=DAMH=0.0
     RETURN
     END
```

```
      SUBROUTINE BULB(SIGMA,BEAM,DRAFT,DELTA,ADMA,ABAR)
C         *** THE DRAUGHT IS TAKEN AS THE LENGTH OF REFERENCE ***
      IMPLICIT COMPLEX (F,Z)
      COMPLEX CLOG,CEXP,CONJG ,CMPLX
      DIMENSION X(14),FS(14),FC(14),F(14,9),PSI(14,10),PSICS(14,2),
     1 ALPHA(10,2),IPIV(10),AUX(20),SUMPHI(9),TRIG(2)
      EQUIVALENCE  (ZETA,TRIG),(PSI(1,10),X(1))
  161 FORMAT(*BULB: ERROR --- THE MATRIX IS INDETERMINATE
     1; THE RAND IS :*,I3)
  162 FORMAT(*BULB: ERROR --- NO PROFILE OF THE FAMILY CAN FIT SECTION
     1;    TRY ALTERING CALL TO BULB IN ADMAB*)
      BOVERT=BEAM/ (2.0*DRAFT)
      Q=.0374
      ZETA0=(.9937122,.1119643)
      EPSILN=1.E-25
C         COMPUTE THE PARAMETERS OF THE MAPPING
30    U=1.+BOVERT
      V=1.-BOVERT
      IF(U.EQ.0..OR.V.EQ.0.)GO TO 91
      A=2.*BOVERT*(1.-1.2732*SIGMA)/(U*V)
      IF (A+1..LT.EPSILN.OR.A.GT.0.)  GO TO 91
      A1=1.+A
      A2=1.-A
      B=A1*A2*V/(A*V-U)
      AB=B*A1
      AB2=B/A2
      SCALX=1./(1.-AB2)
      A0=SQRT(-A)
      DX0=(1.+AB/A2**2)*Q*SCALX
      A1=A1*A1
      A2=-8.*A*AB
      A3=-4*A
C         COMPUTE THE VARIOUS COMPONENTS OF PHI AT THE BOTTOM
      SUMFC=EXP(-DELTA)*DX0
      SUMFS=.57721+ALOG(DELTA)
      U=1.
      R=DX0
      V=ATAN(A0)*DX0/A0
      DO 35 J=1,9
      J1=2*J
      J2=J1-1
      R=-R
      V=-(R/J2+V)/A
      SUMPHI(J)=R*(1.-DELTA)+SCALX*DELTA*J1*(R/J2-B*V)
      U=U*DELTA/J2
      SUMFS=U/J2+SUMFS
      U=U*DELTA/J1
   35 SUMFS=SUMFS+U/J1
      SUMFS=SUMFC*SUMFS
C         FOR THE 14 OTHER POINTS, COMPUTE THE COMPONENTS OF PHI AND PSI
      ZETA=(1.,0.)
      ZSCALE=CMPLX(0.,SCALX*DELTA)
      DO 50 I=1,14
      Q=-Q
      ZZ=ZETA*((1.,0.)+B/(ZETA**2+A))
```

```
      U=1./(A3*TRIG(2)**2+A1)
      DX=1.+AB*U+A2*(U*TRIG(1))**2
   45 DX=DX*TRIG(2)*(.1122+Q)*SCALX
      X(I)=REAL(ZZ)*SCALX
      Y3=AIMAG(ZZ)*SCALX
      ZZ=ZSCALE*ZZ
   44 FS(I)=(.57721,0.)+CLOG(-ZZ)
      FC(I)=CEXP(ZZ)
      ZZ2N=(1.,0.)
      ZETA2N=(1.,0.)
      ZETINV=CONJG(ZETA)
      ZINT=CLOG((ZETA-A0)/(ZETA+A0))/(2.*A0)
      DO 49 J=1,9
      J1=2*J
      J2=J1-1
      ZETAN=ZETA2N*ZETINV
      ZETA2N=ZETAN*ZETINV
      ZZN=ZZ2N*ZZ/J2
      ZZ2N=ZZN*ZZ/J1
      ZINT=-(ZINT+ZETAN/J2)/A
      F(I,J)=ZETA2N+ZETA2N*ZZ+ZSCALE*J1*(B*ZINT-ZETAN/J2)
      FS(I)=FS(I)-ZZN/J2+ZZ2N/J1
      SUMPHI(J)=SUMPHI(J)+REAL(F(I,J))*DX
   49 PSI(I,J)=AIMAG(F(I,J))
      FS(I)=FC(I)*FS(I)
      SUMFC=SUMFC+REAL(FC(I))*DX
      SUMFS=SUMFS+REAL(FS(I))*DX
      PSICS(I,1)=3.14159*AIMAG(FC(I))
      PSICS(I,2)=AIMAG(FS(I))
      ZETA=ZETA*ZETA0
   50 CONTINUE
      SUMFC=3.14159*SUMFC
C        FIND ALPHA IF POSSIBLE, PRINT A MESSAGE IF NOT
      CALL LLSQ(PSI,PSICS,14,10,2,ALPHA,IPIV,EPSILN,IER,AUX)
      IF (IER) 95,56,95
C        COMPUTE ADMA,DAMP,ABAR
   56 CF=SUMFS
      SF=SUMFC
      DO 60 I=1,9
      SF=SF-ALPHA(I,1)*SUMPHI(I)
   60 CF=CF-ALPHA(I,2)*SUMPHI(I)
      DAMP=1./(ALPHA(10,2)**2+ALPHA(10,1)**2)
      ABAR=3.14159*SQRT(DAMP)*DELTA
      ADMA=1.273239*DAMP
      ADMA =ADMA*(CF*ALPHA(10,2)+SF*ALPHA(10,1))
      DAMP=6.28319*DAMP
      RETURN
   95 WRITE (6,161)   IER
      GO TO 3276
   91 WRITE (6,162)
 3276 ADMA=0.0
      ABAR=0.0
      STOP
      END
```

```
      FUNCTION DEFWAV(X,FN)
C   COMPUTES WAVE AMPLITUDE DEFORMATION BY INTERPOLATION.
C   DATA :  VAN SLUIJS,PROC. SYMP. DYNAMICS OF
C   MARINE VEHICLES AND STRUCTURES IN WAVES,LONDON,1974.
      REAL XL(6),FR(4),Z(4,6),C(4),B(4,5)
      INTEGER INDEX(4)
      COMMON/BC/B,C,XL,FR,Z
      DATA XL/0.0,.1,.2,.3,.5,1./
      DATA FR/0.0,.3,.4,.5/
      DATA Z/
     *1.11,1.02,1.03,.90,.92,1.52,1.51,1.27,.81,1.15,1.57,1.70,.82,1.00
     $,1.24,1.55,.70,.90,.74,1.08,.69,.36,.24,0.0/
      J=1
      DO 100 JJ=2,5
      IF(X.LE.XL(JJ)) GO TO 150
  100 J=JJ
  150 K=1
      DO 200 KK=2,3
      IF(FN.LE.FR(KK))GO TO 250
  200 K=KK
  250 CALL BSET(J,K,1)
      CALL BSET(J+1,K,2)
      CALL BSET(J,K+1,3)
      CALL BSET(J+1,K+1,4)
      CALL SOLV(B,C,4,5,INDEX,ID)
      DEFWAV=C(1)+C(2)*X+C(3)*FN+C(4)*X*FN
      RETURN
      END


      SUBROUTINE BSET(J,K,L)
      COMMON/BC/A(4,5),B(4),D(6),E(4),F(4,6)
      A(L,1)=1.
      A(L,2)=D(J)
      A(L,3)=E(K)
      A(L,4)=D(J)*E(K)
      A(L,5)=F(K,J)
      RETURN
      END


      SUBROUTINE KBL(BM,DT,CA,B,BD)
      PI=3.14159265
      IF(            DT.LE.0.0.OR.CA.LE.0.0)GO TO 100
      BM2=BM/2
      DB=DT/BM2
      B=3.0*(1.0+DB)
      C=1.0+DB*(10.0-10.185916*CA+DB)
      A=0.5*(B-SQRT(C))
      AY=2.0*(A-DB)-1.0
      BY=2.0*(1.0+DB-A)
      AZ=2.0*A-DB-2.0
      BZ=BY
      AG=PI/7.
      S1=SIN(AG)
      C1=COS(AG)
      S2=S1**2
      C2=C1**2
      Y=S1*(AY+BY*S2)*BM2
      Z=C1*(AZ+BZ*C2)*BM2
      B=ATAN2(DT-Z,Y)
      BD=B*57.2958
      RETURN
  100 BD=90.0
      B=PI/2.
      RETURN
      END
```

```
      SUBROUTINE LLSQ(A,B,M,N,L,X,IPIV,EPS,IER,AUX)
C   THE ABOVE CARD SHOULD BE PLACED IN PROPER SEQUENCE
C         BEFORE COMPILING THIS UNDER  IBM FORTRAN G.
C
C     ..................................................................
C
C        SUBROUTINE LLSQ
C
C        PURPOSE
C           TO SOLVE LINEAR LEAST SQUARES PROBLEMS, I.E. TO MINIMIZE
C           THE EUCLIDEAN NORM OF B-A*X, WHERE A IS A M BY N MATRIX
C           WITH M NOT LESS THAN N. IN THE SPECIAL CASE M=N SYSTEMS OF
C           LINEAR EQUATIONS MAY BE SOLVED.
C
C        USAGE
C           CALL LLSQ (A,B,M,N,L,X,IPIV,EPS,IER,AUX)
C
C        DESCRIPTION OF PARAMETERS
C           A      - M BY N COEFFICIENT MATRIX (DESTROYED).
C           B      - M BY L RIGHT HAND SIDE MATRIX (DESTROYED).
C           M      - ROW NUMBER OF MATRICES A AND B.
C           N      - COLUMN NUMBER OF MATRIX A, ROW NUMBER OF MATRIX X.
C           L      - COLUMN NUMBER OF MATRICES B AND X.
C           X      - N BY L SOLUTION MATRIX.
C           IPIV   - INTEGER OUTPUT VECTOR OF DIMENSION N WHICH
C                    CONTAINS INFORMATIONS ON COLUMN INTERCHANGES
C                    IN MATRIX A. (SEE REMARK NO.3).
C           EPS    - INPUT PARAMETER WHICH SPECIFIES A RELATIVE
C                    TOLERANCE FOR DETERMINATION OF RANK OF MATRIX A.
C           IER    - A RESULTING ERROR PARAMETER.
C           AUX    - AUXILIARY STORAGE ARRAY OF DIMENSION MAX(2*N,L).
C                    ON RETURN FIRST L LOCATIONS OF AUX CONTAIN THE
C                    RESULTING LEAST SQUARES.
C
C        REMARKS
C           (1) NO ACTION BESIDES ERROR MESSAGE IER=-2 IN CASE
C               M LESS THAN N.
C           (2) NO ACTION BESIDES ERROR MESSAGE IER=-1 IN CASE
C               OF A ZERO-MATRIX A.
C           (3) IF RANK K OF MATRIX A IS FOUND TO BE LESS THAN N BUT
C               GREATER THAN 0, THE PROCEDURE RETURNS WITH ERROR CODE
C               IER=K INTO CALLING PROGRAM. THE LAST N-K ELEMENTS OF
C               VECTOR IPIV DENOTE THE USELESS COLUMNS IN MATRIX A.
C               THE REMAINING USEFUL COLUMNS FORM A BASE OF MATRIX A.
C           (4) IF THE PROCEDURE WAS SUCCESSFUL, ERROR PARAMETER IER
C               IS SET TO 0.
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
C
C        METHOD
C           HOUSEHOLDER TRANSFORMATIONS ARE USED TO TRANSFORM MATRIX A
C           TO UPPER TRIANGULAR FORM. AFTER HAVING APPLIED THE SAME
C           TRANSFORMATION TO THE RIGHT HAND SIDE MATRIX B, AN
C           APPROXIMATE SOLUTION OF THE PROBLEM IS COMPUTED BY
```

```
C        BACK SUBSTITUTION. FOR REFERENCE, SEE
C        G. GOLUB, NUMERICAL METHODS FOR SOLVING LINEAR LEAST
C        SQUARES PROBLEMS, NUMERISCHE MATHEMATIK, VOL.7,
C        ISS.3 (1965), PP.206-216.
C
C     ..................................................................
C
C
      DIMENSION A(1),B(1),X(1),IPIV(1),AUX(1)
C
C     ERROR TEST
      IF(M-N)30,1,1
C
C     GENERATION OF INITIAL VECTOR S(K) (K=1,2,...,N) IN STORAGE
C     LOCATIONS AUX(K) (K=1,2,...,N)
    1 PIV=0.
      IEND=0
      DO 4 K=1,N
      IPIV(K)=K
      H=0.
      IST=IEND+1
      IEND=IEND+M
      DO 2 I=IST,IEND
    2 H=H+A(I)*A(I)
      AUX(K)=H
      IF(H-PIV)4,4,3
    3 PIV=H
      KPIV=K
    4 CONTINUE
C
C     ERROR TEST
      IF(PIV)31,31,5
C
C     DEFINE TOLERANCE FOR CHECKING RANK OF A
    5 SIG=SQRT(PIV)
      TOL=SIG*ABS(EPS)
C
C
C     DECOMPOSITION LOOP
      LM=L*M
      IST=-M
      DO 21 K=1,N
      IST=IST+M+1
      IEND=IST+M-K
      I=KPIV-K
      IF(I)8,8,6
C
C     INTERCHANGE K-TH COLUMN OF A WITH KPIV-TH IN CASE KPIV.GT.K
    6 H=AUX(K)
      AUX(K)=AUX(KPIV)
      AUX(KPIV)=H
      ID=I*M
      DO 7 I=IST,IEND
      J=I+ID
      H=A(I)
```

```
      A(I)=A(J)
    7 A(J)=H
C
C     COMPUTATION OF PARAMETER SIG
    8 IF(K-1)11,11,9
    9 SIG=0.
      DO 10 I=IST,IEND
   10 SIG=SIG+A(I)*A(I)
      SIG=SQRT(SIG)
C
C     TEST ON SINGULARITY
      IF(SIG-TOL)32,32,11
C
C     GENERATE CORRECT SIGN OF PARAMETER SIG
   11 H=A(IST)
      IF(H)12,13,13
   12 SIG=-SIG
C
C     SAVE INTERCHANGE INFORMATION
   13 IPIV(KPIV)=IPIV(K)
      IPIV(K)=KPIV
C
C     GENERATION OF VECTOR UK IN K-TH COLUMN OF MATRIX A AND OF
C     PARAMETER BETA
      BETA=H+SIG
      A(IST)=BETA
      BETA=1./(SIG*BETA)
      J=N+K
      AUX(J)=-SIG
      IF(K-N)14,19,19
C
C     TRANSFORMATION OF MATRIX A
   14 PIV=0.
      ID=0
      JST=K+1
      KPIV=JST
      DO 18 J=JST,N
      ID=ID+M
      H=0.
      DO 15 I=IST,IEND
      II=I+ID
   15 H=H+A(I)*A(II)
      H=BETA*H
      DO 16 I=IST,IEND
      II=I+ID
   16 A(II)=A(II)-A(I)*H
C
C     UPDATING OF ELEMENT S(J) STORED IN LOCATION AUX(J)
      II=IST+ID
      H=AUX(J)-A(II)*A(II)
      AUX(J)=H
      IF(H-PIV)18,18,17
   17 PIV=H
      KPIV=J
   18 CONTINUE
```

```
C                                                                       LLSQ1640
C        TRANSFORMATION OF RIGHT HAND SIDE MATRIX B                     LLSQ1650
   19 DO 21 J=K,LM,M                                                    LLSQ1660
      H=0.                                                              LLSQ1670
      IEND=J+M-K                                                        LLSQ1680
      II=IST                                                            LLSQ1690
      DO 20 I=J,IEND                                                    LLSQ1700
      H=H+A(II)*B(I)                                                    LLSQ1710
   20 II=II+1                                                           LLSQ1720
      H=BETA*H                                                          LLSQ1730
      II=IST                                                            LLSQ1740
      DO 21 I=J,IEND                                                    LLSQ1750
      B(I)=B(I)-A(II)*H                                                 LLSQ1760
   21 II=II+1                                                           LLSQ1770
C        END OF DECOMPOSITION LOOP                                      LLSQ1780
C                                                                       LLSQ1790
C                                                                       LLSQ1800
C        BACK SUBSTITUTION AND BACK INTERCHANGE                         LLSQ1810
      IER=0                                                             LLSQ1820
      I=N                                                               LLSQ1830
      LN=L*N                                                            LLSQ1840
      PIV=1./AUX(2*N)                                                   LLSQ1850
      DO 22 K=N,LN,N                                                    LLSQ1860
      X(K)=PIV*B(I)                                                     LLSQ1870
   22 I=I+M                                                             LLSQ1880
      IF(N-1)26,26,23                                                   LLSQ1890
   23 JST=(N-1)*M+N                                                     LLSQ1900
      DO 25 J=2,N                                                       LLSQ1910
      JST=JST-M-1                                                       LLSQ1920
      K=N+N+1-J                                                         LLSQ1930
      PIV=1./AUX(K)                                                     LLSQ1940
      KST=K-N                                                           LLSQ1950
      ID=IPIV(KST)-KST                                                  LLSQ1960
      IST=2-J                                                           LLSQ1970
      DO 25 K=1,L                                                       LLSQ1980
      H=B(KST)                                                          LLSQ1990
      IST=IST+N                                                         LLSQ2000
      IEND=IST+J-2                                                      LLSQ2010
      II=JST                                                            LLSQ2020
      DO 24 I=IST,IEND                                                  LLSQ2030
      II=II+M                                                           LLSQ2040
   24 H=H-A(II)*X(I)                                                    LLSQ2050
      I=IST-1                                                           LLSQ2060
      II=I+ID                                                           LLSQ2070
      X(I)=X(II)                                                        LLSQ2080
      X(II)=PIV*H                                                       LLSQ2090
   25 KST=KST+M                                                         LLSQ2100
C                                                                       LLSQ2110
C                                                                       LLSQ2120
C        COMPUTATION OF LEAST SQUARES                                   LLSQ2130
   26 IST=N+1                                                           LLSQ2140
      IEND=0                                                            LLSQ2150
      DO 29 J=1,L                                                       LLSQ2160
      IEND=IEND+M                                                       LLSQ2170
      H=0.                                                              LLSQ2180
```

```
      IF(M-N)29,29,27
   27 DO 28 I=IST,IEND
   28 H=H+B(I)*B(I)
      IST=IST+M
   29 AUX(J)=H
      RETURN
C
C     ERROR RETURN IN CASE M LESS THAN N
   30 IER=-2
      RETURN
C
C     ERROR RETURN IN CASE OF ZERO-MATRIX A
   31 IER=-1
      RETURN
C
C     ERROR RETURN IN CASE OF RANK OF MATRIX A LESS THAN N
   32 IER=K-1
      RETURN
      END
```

```
      SUBROUTINE MATG(I,J)
      COMPLEX XC
      COMMON/CCM1/XC,G(4,5)
      T1=G(I,J)=REAL(XC)
      T2=G(I,J+1)=-AIMAG(XC)
      G(I+1,J+1)=T1
      G(I+1,J)=-T2
      RETURN
      END
```

```
      FUNCTION PROFILE(XQ,BAM,DRT,AIR,XL,VKT,NEW)
C  RETURNS WAVE PROFILE ORDINATE AS A FUNCTION OF
C  STATION XQ
C  ALL UNITS ARE FPS UNLESS STATED.
C  BAM - BEAM  ST.0-20.
C  DRT - DRAFT  ST.0-20.
C  AIR - CX     ST.0-20.
C  XL  - LBP.
C  VKT - SPEED, KNOTS.
C  NEW * IF ZERO, EXECUTION IS NORMAL.
C         OTHERWISE, HULL LINE COMPUTATIONS ONLY ARE PERFORMED.
      REAL BAM(21),DRT(21),AIR(21),M,MFP,MAP,MPF,MPA
      LOGICAL NFRST,AFP,AAP
      COMMON/PROF/MFP,M(21),MAP,UFP,U(21),UAP,WORK(22),X(21)
      DATA NFRST/.FALSE./
      IF(NFRST.AND.NEW.EQ.0) GO TO 500
      THIRD=1./3.
      SIXTH=THIRD/2.
      PI=3.14159265
      XST=XL/20.
      DX=XST/2.
      DO 100 I=1,21
      X(I)=(I-1)*XST-DX
  100 M(I)=BAM(I)*DRT(I)*AIR(I)
      DO 150 I=1,21
      IF(AIR(I).GT.1.0) GO TO 160
      A0=SIXTH
      A1=THIRD
      GO TO 150
  160 A0=.4
      A1=.1
  150 U(I)=DRT(I)*(A0+A1*AIR(I))
      MFP=M(1)/4./PI
      UFP=U(1)
      AFP=.TRUE.
      IF(M(1).GT.0.0) AFP=.FALSE.
      MAP=-M(21)/4./PI
      UAP=U(21)
      AAP=.TRUE.
      IF(M(21).GT.0.0) AAP=.FALSE.
      DO 170 I=2,21
      AD=M(I)-M(I-1)
      IF(ABS(AD).LT.1.E-10) GO TO 175
      WORK(I)=(M(I)*U(I)-M(I-1)*U(I-1))/AD
      GO TO 170
  175 WORK(I)=(U(I)+U(I-1))*.5
  170 CONTINUE
      DO 180 I=2,21
      IJ=23-I
      U(IJ)=WORK(IJ)
  180 M(IJ)=(M(IJ)-M(IJ-1))/4./PI
      IF(NFRST) RETURN
      NFRST=.TRUE.
  500 W=VKT*1.6878
      PROFILE=0.
```

```
      XQST=XQ*XST
      DO 600 I=2,21
      SRCE=W*M(I)
      XAT=X(I)-XQST
      DP=ZETA(XAT,SRCE,U(I),W,NERR)
      PROFILE=PROFILE+DP
  600 WORK(I)=NERR
      WORK(1)=0.0
      IF(AFP) GO TO 700
      XAT=-XQST
      MPF=W*MFP
      DP=ZETA(XAT,MPF,UFP,W,NERR)
      PROFILE=PROFILE+DP
      WORK(1)=NERR
  700 WORK(22)=0.0
      IF(AAP) GO TO 800
      XAT=XL-XQST
      MPA=W*MAP
      DP=ZETA(XAT,MPA,UAP,W,NERR)
      PROFILE=PROFILE+DP
      WORK(22)=NERR
  800 RETURN
      END
```

```
      FUNCTION RAW(W,XL,PRG,FR,C1,CM)
C     COMPUTES ADDED RESISTANCE COEFFICIENT USING EMPIRICAL METHOD
C     BASED ON JINKINE  FERDINANDE  FRIGATE-DESTROYER MODEL TEST DATA.
      DIMENSION UB(11),VB(11)
      DATA UB/0.0,1.6,3.5,5.9,8.4,9.9,10.7,11.7,13.4,15.6,18.1/
      DATA VB/0.0,1.1,2.4,3.8,5.4,7.1,8.9,10.7,11.7,14.9,17.4/
      GRAV=32.17
      IF (FR .GT. 0.0) GO TO 1
      RAW=0.0
      RETURN
1     CONTINUE
      A=PRG**2
      B=SQRT(XL/GRAV)
      IF (CM .LT. 0.9) GO TO 2
      RM=3600.*A*FR**1.5*EXP(-3.5*FR)
      WM=1.17*FR**(-1./7.)*A**(-1./3.)/B
      GO TO 99
2     CONTINUE
      WM=(2.79-1.18*FR)/B
      IF (C1 .LE. 1.0) GO TO 3
C     BULBOUS BOW
      RM=48.0*FR
      IF (FR .GT. 0.5) RM=24.0+32.0*(FR-0.5)
      GO TO 99
3     CONTINUE
      I=FR/0.05+1
      DF=FR-(I-1)*0.05
      IF (C1 .LT. 0.7) GO TO 4
C     U-BOW
      RM=UB(I)+DF*(UB(I+1)-UB(I))/0.05
      GO TO 99
4     CONTINUE
C     V-BOW
      RM=VB(I)+DF*(VB(I+1)-VB(I))/0.05
99    CONTINUE
      WM=W/WM
      B=11.0
      D=14.0
      IF (WM .LT. 1.0) GO TO 100
      B=-8.5
      D=-14.0
100   RAW=RM*EXP(B*(1.0-WM**D)/D)*WM**B
      RETURN
      END
```

```
      FUNCTION SEAST(HH,TT,WW)
C     HH IS SIG. WAVE HT. IN FT, TT IS PERIOD IN SEC, WW IS FREQUENCY IN
C     RAD/SEC. OUTPUT SPECTRUM HAS UNITS FT**2/(RAD/SEC).
      COMMON/SSGM/A00(80),A10(80),A01(80),A20(80),A11(80),A02(80)
      DIMENSION F(2)
      H=HH*.3048-4.016
      T=TT-9.159
      W=WW*TT/6.283185
      IF (W.GT.0.05) GO TO 2
      SEAST=0.
      RETURN
2     IF (W.LE.4.0) GO TO 3
      SEAST=0.
      RETURN
3     CONTINUE
      N=INT(W/.05)
      DO 1 I=1,2
      M=N+I-1
1     F(I)=A00(M)+A10(M)*H+A01(M)*T+A20(M)*H*H+A11(M)*H*T+A02(M)*T*T
      S=F(1)+(F(2)-F(1))*(W-N*.05)*20.
      SEAST=S*HH**2*TT/101.1593
      RETURN
      END
      BLOCK DATA
      COMMON/SSGM/A00(80),A10(80),A01(80),A20(80),A11(80),A02(80)
      DATA A00/0.,0.,.00001,.00018,.00133,.00324,.00709,.01325,.02618,
     1.05336,.11641,.2503,.4943,.83054,1.23195,1.59871,1.79955,1.76253,
     21.56762,1.30231,1.07908,.91784,.77733,.66816,.57326,.49269,.43533,
     3.38482,.33183,.28287,.25230,.23205,.21658,.2037,.19481,.18371,
     4.17350,.16129,.14752,.14327,.13558,.12091,.10697,.09764,.09052,
     5.08372,.07646,.06884,.05932,.05156,.04350,.03660,.03037,.02363,
     6.01831,.01466,.01117,.00829,.00561,.00395,.00283,.00225,.00143,
     7.00057,.00006,-.00041,-.00032,-.00012,-.00005,-.00032,-.00059,
     8-.00077,-.00097,-.00080,-.00047,-.00032,-.00022,-.00014,-.00008,
     9-.00003/
      DATA A10/0.0,0.0,-.00001,-.00004,-.00043,-.00134, .00255, .00387,
     1-.00543,-.00475,-.00017,.00901,.02629,.04993,.06652,.06000,.03906,
     2.00467,-.03727,-.06926,-.07963,-.06424,-.05265,-.04332,-.03261,
     3-.01857,-.01263,-.00911,-.00801,-.00336,.00342,.00539,.00458,.004,
     4.00652,.00907,.00923,.01084,.01613,.01451,.01063,.00839,.00592,
     5.00532,.00714,.00877,.01007,.01077,.01001,.00923,.00750,.00467,
     6.00175,.00034,.00066,.00106,.00095,.00090,.00102,.00091,.00068,
     7.00036,.00050,.00077,.00093,.00073,.00027,.00018,.00015,.00003,
     8-.00009,-.00013,-.00013,-.00009,-.00006,-.00003,-.00001,-.00001,
     90.0,0.0/
      DATA A01/0.0,0.0,.00001,.00003,0.0,-.00067,-.0024,-.00558,-.00822,
     1-.01065,-.01169,-.01241,-.00664,.01278,.03974,.06999,.08177,.0558,
     2.01841,.0027,-.00276,-.01522,-.03524,-.03485,-.03189,-.03983,
     3-.03554,-.03005,-.02822,-.02864,-.02787,-.02231,-.01716,-.01219,
     4-.01098,-.01213,-.01061,-.01317,-.02021,-.00812,.00344,.00783,
     5.01083,.01190,.01113,.01021,.00988,.00930,.01115,.01152,.01164,
     6.01193,.01243,.01189,.01054,.00913,.00785,.00674,.00554,.00475,
     7.00422,.00403,.00345,.00256,.00184,.00129,.00124,.00120,.00109,
     8.00093,.00073,.00051,.00027,.00021,.00023,.00021,.00017,.00013,
     9.00007,.00004/
```

```
 DATA A20/0.,0.,0.,0.,0.,.00005,.00009,.00016,.00035,.00033,.00022,
1.00079,.00172,.00417,.00481,.00119,-.0066,-.00935,-.00604,-.00044,
2.00188,.00049,.00021,-.00021,-.0003,-.00107,-.00137,-.00081,
3.00131,.00251,.00183,.00020,-.00063,-.00076,-.00087,-.0006,-.0005,
4.00013,.00108,.0005,-.00001,.00023,.00042,.00046,.00045,.00052,
5.0003,.00017,-.00002,-.00015,-.00011,.00002,.00011,.00008,-.00012,
6-.00028,-.00012,.00011,.00036,.0004,.00035,.00013,.00027,.00054,
7.00058,.00040,-.00003,-.00014,-.0001,.00001,.00014,.0002,.00022,
8.00015,.00004,-.00001,-.00003,-.00003,-.00002,-.00001/
 DATA A11/0.,0.,0.,.00002,.0002,.00041,.00077,.00112,.00146,.00103,
1-.00103,-.00667,-.01387,-.02494,-.02849,-.01366,.01256,.02414,
2.02513,.01785,.01365,.01369,.01287,.0119,.00914,.00604,.00441,
3.00222,-.00303,-.00754,-.00807,-.00403,-.00067,.00046,.00026,
4-.00086,-.00096,-.0031,-.00798,-.00544,-.00238,-.00232,-.00222,
5-.00222,-.00281,-.00349,-.00324,-.00292,-.00199,-.00146,-.00011,
6-.00094,-.00047,-.00007, .00031,.00056,.00019,-.00028,-.00073,
7-.00075,-.00059,-.00010,-.00016,-.00055,-.00054,-.0003,.0003,
8.00048,.00036,.00016,-.00002,-.0001,-.00011,-.00005,.00006,.00013,
9.00015,.00014,.00009,.00005/
 DATA A02/0.,0.,0.,-.00004,-.00021,-.00016,.00027,.0014,.00193,
1.00188,.00082,.00042,-.00032,.00428,.00436,-.00858,-.02142,-.0177,
2-.01166,-.00411,.00016,.00259,.00845,.00818,.00924,.01304,.01044,
3.00776,.00819,.00995,.00943,.00585,.00222,-.00011,-.00139,-.00171,
4-.00314,-.00183,.00268,-.00207,-.00614,-.0063,-.00615,-.00599,
5-.00532,-.00432,-.0036,-.0029,-.003,-.00267,-.00211,-.00171,
6-.00145,-.00095,-.00043,-.00001,.00051,.00094,.00126,.00134,
7.00133,.00118,.00108,.00104,.0009,.00078,.00062,.0005,.00044,
8.00043,.00036,.00029,.00025,.00022,.00018,.00014,.00008,.00004,
9.00002,.00001/
 END
```

```
      SUBROUTINE SOLV(A,X,N,M,INDX,ICK)
      DIMENSION A(N,M),X(N),INDX(N)
      ICK=0
      DO10 I=1,N
      INDX(I)=0
   10 X(I)=0.0
      DO 20 J=1,N
      ZZ=1.0E-10
      IROW=0
      DO 30 I=1,N
      IF(INDX(I).NE.0) GO TO 30
      TEST=ABS(A(I,J))
      IF(TEST.LE.ZZ) GO TO 30
      ZZ=TEST
      IROW=I
   30 CONTINUE
      IF(IROW.EQ.0)GO TO 20
   40 INDX(IROW)=J
      ZN=A(IROW,J)
      II=N+1
      DO 50 K=1,II
   50 A(IROW,K)=A(IROW,K)/ZN
      DO 60 I=1,N
      IF(I.EQ.IROW)GO TO 60
      I1=J+1
      II=N+1
      DO 61 K=I1,II
      A(I,K)=A(I,K)-A(I,J)*A(IROW,K)
   61 CONTINUE
   60 CONTINUE
   20 CONTINUE
      DO 80 I=1,N
      IF(INDX(I).GT.0) GO TO 80
      TEST=ABS(A(I,N+1))
      IF(TEST.GT.1.0E-8)GO TO 99
   80 CONTINUE
      DO 70 I=1,N
      IF(INDX(I).EQ.0) GO TO 70
      X(INDX(I))=A(I,N+1)
   70 CONTINUE
      RETURN
   99 WRITE(2,100)
  100 FORMAT(20X11HNO SOLUTION)
      ICK=1
      RETURN
      END
```

```
      FUNCTION ZETA(XX,A,ZZ,V,NERR)
C   WAVE PROFILE ORDINATE AT X,DUE TO SOURCE STRENGTH
C   A, AT DEPTH Z, MOVING AT V. FPS UNITS.
C   NERR: ERROR FLAG.
C         =0    ,XX,ZZ WITHIN RANGE OF DATA.
C         =1    ,ZZ HIGH    , EXTRAPOLATED.
C         =10   ,ZZ LOW, LOWEST VALUE USED.
C         =100  ,XX HIGH, ZERO RETURNED.
C         =1000,XX LOW, EXTRAPOLATED.
C         =444  ,V.LE.0.0
C   ERROR CODES ARE ADDITIVE
      LOGICAL NFRST,NZERO
      INTEGER INDX(4)
      COMMON/QP/Q(4,5),P(4),ZD(8),XD(185),Y(8,185)
      DATA NFRST/.FALSE./,PI/3.14159265/
      DATA ZD/.01,.02,.05,.1,.2,.5,1.,2./
      PI2=2.*PI
      IF(NFRST) GO TO 200
      NFRST=.TRUE.
      DO 100 I=1,171
  100 XD(I)=.25*(I-1)-40.
      DO 110 I=172,179
  110 XD(I)=I-169
      DO 120 I=180,185
  120 XD(I)=(I-177)*5.
C   CHECK XX,ZZ,WITHIN RANGE
  200 IF(V.GT.0.0) GO TO205
      ZETA=0.0
      NERR=444
      RETURN
  205 C=32.18/V/V
      F=1.0
      NERR=0
      NZERO=.TRUE.
      X=XX*C
      Z=ZZ*C
      IF(X.GE.-40.) GO TO 210
      NERR=NERR+1000
      IQ=IFIX((-40.-X)/PI2)
      X=X+PI2*(IQ+1)
      GO TO 220
  210 IF(X.LE.40.) GO TO 220
      NZERO=.FALSE.
      NERR=NERR+100
  220 IF(Z.GE.0.01) GO TO 230
      NERR=NERR+10
      IF(Z.LE.0.0) NZERO=.FALSE.
      Z=.01
      GO TO 240
  230 IF(Z.LE.2.0) GO TO 240
      NERR=NERR+1
      F=2./Z
      Z=2.
  240 IF(NZERO) GO TO 300
      ZETA=0.
```

```
      RETURN
C  LOCATE I,J
  300 I=1
      DO 310 II=2,7
      IF(Z.LE.ZD(II)) GO TO320
  310 I=II
  320 IF(X.GE.3.) GO TO 330
      J=IFIX(4.*(X+40.))+1
      GO TO 350
  330 IF(X.GE.15.) GO TO 340
      J=IFIX(X)+169
      GO TO 350
  340 IF(X.GT.35.) GO TO 360
      J=IFIX(X/5.)+177
      GO TO 350
  360 J=184
C  INTERPOLATE
  350 CALL CSET(I,J,1)
      CALL CSET(I+1,J,2)
      CALL CSET(I,J+1,3)
      CALL CSET(I+1,J+1,4)
      CALL SOLV(Q,P,4,5,INDX,ID)
      ZETA=P(1)+X*P(2)+Z*P(3)+X*Z*P(4)
      ZETA=ZETA*F*A*C/V
      RETURN
      END
```

```
      SUBROUTINE CSET(I,J,K)
      COMMON/QP/Q(4,5),P(4),Z(8),X(185),Y(8,185)
      Q(K,1)=1.
      Q(K,2)=X(J)
      Q(K,3)=Z(I)
      Q(K,4)=Z(I)*X(J)
      Q(K,5)=Y(I,J)
      RETURN
      END
```

```
      BLOCK DATA ZETAP
      COMMON/QP/Q(4,5),P(4),ZD(8),XD(185),Z(8,185)
      DATA ((Z(I,J),I=1,8),J=  1, 12)/
     *-1.568722,-1.553123,-1.507271,-1.433859,-1.297586, -.961660,
     * -.583655, -.215086,-1.511668,-1.496540,-1.452077,-1.380911,
     *-1.248869, -.923773, -.558863, -.204643,-1.360081,-1.346368,
     *-1.306073,-1.241598,-1.122038, -.828098, -.499114, -.181427,
     *-1.122804,-1.111368,-1.077775,-1.024050, -.924498, -.680228,
     * -.407910, -.146806, -.814065, -.805632, -.780876, -.741315,
     * -.668102, -.489043, -.290736, -.102869, -.452631, -.447745,
     * -.433423, -.410582, -.368440, -.266177, -.154731, -.052300,
     * -.060664, -.059652, -.056724, -.052137, -.043894, -.025310,
     * -.008252,  .001787,  .337629,  .334679,  .325956,  .311883,
     *  .285484,  .218671,  .139637,  .056037,  .717493,  .710740,
     *  .690830,  .658847,  .599217,  .450584,  .279726,  .107065,
     * 1.055159, 1.044997, 1.015066,  .967041,  .877664,  .655902,
     *  .403228,  .151661, 1.329328, 1.316367, 1.278209, 1.217020,
     * 1.103253,  .821658,  .502334,  .186999, 1.522511, 1.507539,
     * 1.463471, 1.392834, 1.261585,  .937263,  .570700,  .210809/
      DATA ((Z(I,J),I=1,8),J= 13, 24)/
     * 1.622141, 1.606077, 1.558799, 1.483042, 1.342352,  .995176,
     *  .603856,  .221524, 1.621390, 1.605224, 1.557656, 1.481451,
     * 1.340001,  .991400,  .599496,  .218387, 1.519627, 1.504365,
     * 1.459459, 1.387541, 1.254116,  .925750,  .557634,  .201496,
     * 1.322498, 1.309096, 1.269663, 1.206529, 1.089476,  .801892,
     *  .480621,  .171810, 1.041624, 1.030927,  .999456,  .949087,
     *  .855791,  .627140,  .373014,  .131093,  .693911,  .686603,
     *  .665103,  .630717,  .567135,  .412026,  .241306,  .081809,
     *  .300540,  .297099,  .286975,  .270815,  .241098,  .169669,
     *  .093540,  .026973, -.114323, -.113655, -.111698, -.108503,
     * -.102280, -.085027, -.061187, -.030030, -.525005, -.520242,
     * -.506242, -.483762, -.441744, -.336284, -.213280, -.085658,
     * -.905915, -.897323, -.872069, -.831570, -.756128, -.568425,
     * -.353239, -.136429,-1.233131,-1.221218,-1.186201,-1.130081,
     *-1.025680, -.766854, -.472250, -.179137,-1.485900,-1.471383,
     *-1.428715,-1.360356,-1.233293, -.918966, -.562743, -.211058/
      DATA ((Z(I,J),I=1,8),J= 25, 36)/
     *-1.647952,-1.631715,-1.583996,-1.507567,-1.365593,-1.014949,
     * -.618869, -.230120,-1.708538,-1.691578,-1.641741,-1.561943,
     *-1.413791,-1.048413, -.636875, -.235039,-1.663141,-1.646508,
     *-1.597639,-1.519416,-1.374267,-1.016810, -.615357, -.225403,
     *-1.513802,-1.498532,-1.453681,-1.381914,-1.248830, -.921626,
     * -.555361, -.201706,-1.269039,-1.256092,-1.218079,-1.157286,
     *-1.044647, -.768313, -.460340, -.165323, -.943366, -.933564,
     * -.904808, -.858858, -.773836, -.565982, -.335953, -.118433,
     * -.556438, -.550415, -.532776, -.504646, -.452751, -.326864,
     * -.189733, -.063884, -.131865, -.130024, -.124688, -.116270,
     * -.100995, -.065572, -.030629, -.005028,  .304220,  .301732,
     *  .294336,  .282360,  .259767,  .201787,  .131535,  .054490,
     *  .724769,  .718074,  .698302,  .666512,  .607148,  .458606,
     *  .286670,  .110956, 1.103490, 1.092970, 1.061953, 1.012161,
     *  .919414,  .688801,  .425045,  .160814, 1.416485, 1.402764,
     * 1.362336, 1.297489, 1.176848,  .877820,  .537895,  .200894/
      DATA ((Z(I,J),I=1,8),J= 37, 48)/
     * 1.643753, 1.627658, 1.580255, 1.504256, 1.362985, 1.013556,
```

```
*  .617974,  .228611, 1.770464, 1.752977, 1.701485, 1.618962,
* 1.465663, 1.087123,  .660022,  .242129, 1.787919, 1.770114,
* 1.717698, 1.633719, 1.477811, 1.093430,  .661103,  .240486,
* 1.694139, 1.677122, 1.627026, 1.546793, 1.397931, 1.031528,
*  .620808,  .223655, 1.494044, 1.478878, 1.434233, 1.362755,
* 1.230236,  .904708,  .541304,  .192561, 1.199202, 1.186845,
* 1.150466, 1.092250,  .984432,  .720325,  .427218,  .149024,
*  .827166,  .818409,  .792622,  .751389,  .675166,  .489379,
*  .285370,  .095658,  .400433,  .395850,  .382343,  .360791,
*  .321150,  .225858,  .124367,  .035713, -.054911, -.054998,
* -.055287, -.055661, -.055961, -.054103, -.045916, -.027123,
* -.510778, -.506327, -.493271, -.472270, -.432892, -.333207,
* -.214943, -.088949, -.938809, -.930057, -.904356, -.863112,
* -.786177, -.594062, -.372162, -.145892,-1.312127,-1.299581,
*-1.262728,-1.203636,-1.093618, -.820259, -.507664, -.194350/
 DATA ((Z(I,J),I=1,8),J= 49, 60)/
*-1.607022,-1.591429,-1.545620,-1.472207,-1.335674, -.997401,
* -.612807, -.231220,-1.804448,-1.786749,-1.734758,-1.651469,
*-1.496692,-1.114016, -.680761, -.254094,-1.891246,-1.872522,
*-1.817531,-1.729465,-1.565922,-1.162293, -.706952, -.261415,
*-1.861014,-1.842420,-1.787824,-1.700422,-1.538221,-1.138604,
* -.689365, -.252586,-1.714562,-1.697256,-1.646457,-1.565168,
*-1.414427,-1.043764, -.628695, -.228010,-1.459932,-1.445001,
*-1.401196,-1.331140,-1.201356, -.883022, -.528327, -.189081,
*-1.111958,-1.100352,-1.066336,-1.011983, -.911440, -.665777,
* -.394151, -.138101, -.691414, -.683885, -.661869, -.626756,
* -.562002, -.405030, -.234219, -.078147, -.223774, -.220829,
* -.212301, -.198804, -.174228, -.116612, -.058263, -.012886,
*  .262320,  .260454,  .254828,  .245650,  .228112,  .181775,
*  .122891,  .053645,  .736807,  .730198,  .710625,  .679111,
*  .620116,  .471635,  .297988,  .117292, 1.170058, 1.159071,
* 1.126622, 1.074499,  .977283,  .734825,  .456041,  .174040/
 DATA ((Z(I,J),I=1,8),J= 61, 72)/
* 1.534718, 1.519991, 1.476549, 1.406838, 1.277037,  .954682,
*  .587013,  .220264, 1.807425, 1.789835, 1.737981, 1.654823,
* 1.500151, 1.117073,  .682457,  .252960, 1.970295, 1.950906,
* 1.893767, 1.802178, 1.631965, 1.211296,  .736049,  .269937,
* 2.012089, 1.992086, 1.933149, 1.838716, 1.663348, 1.230783,
*  .744012,  .269967, 1.928972, 1.909590, 1.852487, 1.761029,
* 1.591316, 1.173543,  .705367,  .252865, 1.724827, 1.707273,
* 1.655559, 1.572770, 1.419277, 1.042338,  .622033,  .219517,
* 1.411088, 1.396471, 1.353402, 1.284493, 1.156889,  .844558,
*  .498729,  .171834, 1.006112,  .995369,  .963699,  .913076,
*  .819522,  .591809,  .342715,  .112641,  .534112,  .527949,
*  .509753,  .480732,  .427362,  .299238,  .163366,  .045517,
*  .023714,  .022561,  .019100,  .013695,  .004216, -.015369,
* -.028386, -.025426, -.493768, -.489787, -.478150, -.459369,
* -.423932, -.332666, -.220719, -.095790, -.986242, -.977320,
* -.951155, -.909111, -.830506, -.632925, -.401641, -.161165/
 DATA ((Z(I,J),I=1,8),J= 73, 84)/
*-1.422822,-1.409459,-1.370242,-1.307309,-1.189977, -.897260,
* -.559739, -.217401,-1.775749,-1.758726,-1.708757,-1.628629,
*-1.479460,-1.108806, -.684888, -.260872,-2.022142,-2.002476,
*-1.944747,-1.852222,-1.680156,-1.253789, -.768901, -.288710,
*-2.145475,-2.124357,-2.062372,-1.963071,-1.778563,-1.322412,
```

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* -.806056, -.298989,-2.136661,-2.115385,-2.052953,-1.952979,
*-1.767376,-1.309509, -.793483, -.290859,-1.994702,-1.974587,
*-1.915587,-1.821155,-1.646001,-1.214919, -.731374, -.264612,
*-1.726842,-1.709150,-1.657293,-1.574348,-1.420674,-1.043554,
* -.623005, -.221676,-1.348210,-1.334069,-1.292669,-1.226513,
*-1.104153, -.805152, -.474576, -.164543, -.880980, -.871310,
* -.843073, -.798036, -.715002, -.513734, -.294856, -.096623,
* -.353077, -.348534, -.335386, -.314542, -.276515, -.186783,
* -.094671, -.022048,  .203477,  .202545,  .199587,  .194619,
*  .184671,  .155792,  .113740,  .054582,  .754491,  .748072,
*  .728972,  .698147,  .640182,  .492862,  .317469,  .128477/
 DATA ((Z(I,J),I=1,8),J= 85, 96)/
* 1.265696, 1.254114, 1.219832, 1.164699, 1.061640,  .803371,
*  .503731,  .194954, 1.704851, 1.688754, 1.641197, 1.564825,
* 1.422412, 1.067637,  .660660,  .249730, 2.043766, 2.024088,
* 1.966007, 1.872811, 1.699284, 1.268590,  .778055,  .289197,
* 2.260088, 2.237994, 2.172821, 2.068311, 1.873934, 1.392862,
*  .848036,  .310654, 2.338751, 2.315572, 2.247221, 2.137673,
* 1.934126, 1.431660,  .865565,  .312490, 2.273003, 2.250152,
* 2.182782, 2.074863, 1.874543, 1.381372,  .828798,  .294299,
* 2.064929, 2.043818, 1.981581, 1.881944, 1.697212, 1.243857,
*  .739238,  .256923, 1.725434, 1.707386, 1.654174, 1.569050,
* 1.411468, 1.026410,  .601696,  .202418, 1.273697, 1.259864,
* 1.219063, 1.153872, 1.033486,  .741383,  .424036,  .133944,
*  .736093,  .727384,  .701664,  .660670,  .585372,  .405490,
*  .216734,  .055584,  .144678,  .141698,  .132834,  .118873,
*  .093884,  .038845, -.007737, -.027897, -.464711, -.461702,
* -.452945, -.438664, -.411145, -.336238, -.235642, -.111338/
 DATA ((Z(I,J),I=1,8),J= 97,108)/
*-1.054604,-1.045709,-1.019642, -.977630, -.898608, -.696584,
* -.452825, -.189498,-1.588177,-1.573864,-1.531865,-1.464348,
*-1.338014,-1.019576, -.645569, -.257384,-2.031524,-2.012600,
*-1.957049,-1.867856,-1.701373,-1.284558, -.801460, -.310562,
*-2.355782,-2.333349,-2.267497,-2.161846,-1.964957,-1.474136,
* -.910171, -.345450,-2.538976,-2.514372,-2.442149,-2.326353,
*-2.110823,-1.575302, -.964135, -.359548,-2.567476,-2.542189,
*-2.467981,-2.349075,-2.128000,-1.580304, -.959059, -.351621,
*-2.436953,-2.412540,-2.340924,-2.226247,-2.013276,-1.487206,
* -.894245, -.321793,-2.152796,-2.130785,-2.066255,-1.963006,
*-1.771515,-1.300101, -.772692, -.271567,-1.729934,-1.711730,
*-1.658422,-1.573223,-1.415493,-1.028964, -.600976, -.203755,
*-1.192072,-1.178873,-1.140304,-1.078781, -.965238, -.689132,
* -.388907, -.122327, -.570388, -.563105, -.541953, -.508384,
* -.446929, -.300458, -.148981, -.032186,  .098253,  .099053,
*  .101127,  .104095,  .108607,  .113831,  .104342,  .061118/
 DATA ((Z(I,J),I=1,8),J=109,120)/
*  .773450,  .767586,  .750053,  .721595,  .667697,  .528498,
*  .355490,  .151725, 1.413680, 1.401371, 1.364889, 1.306076,
* 1.195836,  .917810,  .588722,  .233819, 1.978803, 1.960667,
* 1.907055, 1.820824, 1.659776, 1.257097,  .789089,  .301998,
* 2.432541, 2.409558, 2.341705, 2.232712, 2.029580, 1.524294,
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```

AD-A056 554 DEFENCE RESEARCH ESTABLISHMENT ATLANTIC DARTMOUTH (NO--ETC F/G 13/10
PHHS. A FORTRAN PROGRAMME FOR SHIP PITCH, HEAVE AND SEAKEEPING --ETC(U)
APR 78 M MACKAY, R T SCHMITKE

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*-1.843208, -.501889,-8.377563,-8.515954,-8.934885,-9.829771,
*-9.292397,-3.797799,-1.179133, -.337056,-9.377961,-9.700542,
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 END
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APPENDIX D: LIST OF SIGNIFICANT PROGRAM VARIABLES

PROGRAM NAME	NOTATION OR CONVENTIONAL SYMBOL	QUANTITY
AIR	A(x) or C_X	station area or area coefficient
AMAX	C_M	area coefficient of station of maximum area
AX		RMS acceleration
A6	η_5	pitch
B	B	beam
BAM(I)	B(x)	station beam
BETA(I)	β	deadrise angle
CB	C_B	block coefficient
CM	C_M	area coefficient of station of maximum area
CP	C_P	prismatic coefficient
CR	r_{AW}	coefficient of added resistance
CW	C_W	waterplane coefficient
D	D	draft
DISP	Δ	displacement
DRT	D(x)	station draft
DUK		speed increment
ELL	λ/L	wavelength / ship length
FACTOR	$(L/g)^{1/2}$	non-dimensionalising factor for frequency

PROGRAM NAME	NOTATION OR CONVENTIONAL SYMBOL	QUANTITY
FB(I)		freeboard
HS(I)	H_S	significant waveheight
ICORR		correction control integer
IFAST		execution time control integer
INOUT		unit control integer
IOPT		dimension control integer
IRANGE		frequency range control integer
IRESP		response control integer
NAME		title
NPOS		number of stations
NSEA		number of seastates
NSP		number of speeds
OMEN	$\omega_e(L/g)^{1/2}$	non-dimensional frequency of encounter
OMENW	$\omega(L/g)^{1/2}$	non-dimensional wave frequency
OUT(I, J)		array of seakeeping quantities:
OUT(1, J)		RMS pitch
OUT(2, J		RMS heave
OUT(3, J)		RMS acceleration at CG
OUT(4, J)		RMS acceleration at st. 2
OUT(5, J)	σ_{RMO}	RMS relative motion at FP
OUT(6, J)	σ_{RVO}	RMS relative velocity at FP
OUT(7, J)	σ_{RM4}	RMS relative motion at st. 4

PROGRAM NAME	NOTATION OR CONVENTIONAL SYMBOL	QUANTITY
OUT(8, J)	σ_{RV4}	RMS relative velocity at st. 4
OUT(9, J)		Prob (D.W.) at FP
OUT(10, J)		Prob (Slam) at st. 4
OUT(11, J)		not used
OUT(12, J)	R_{WAVE}	added resistance
OUT(13, J)	R_{WIND}	wind resistance
PA6	ε_5	pitch phase
PDW(I, K)		Prob (D.W.)
PK(I, K)		Prob (Keel)
PS(I, K)		Prob (Slam)
PXO	ε_3	heave phase
RM(I, K)	σ_{RM}	RMS relative motion
RV(I, K)	σ_{RV}	RMS relative velocity
T	T	draft
THR	t	time period for slamming pressure calculation
THRESH	$\hat{v}$	slamming threshold velocity
TS(I)	T_S	average wave period
UK		lower limit of speed
VOL	∇/L^3	volume / length ratio
VWKT	V_W	wind speed
W	ω_e	frequency of encounter
WW	ω	wave frequency

PROGRAM NAME	NOTATION OR CONVENTIONAL SYMBOL	QUANTITY
W1		lower limit of wave frequency
W3		upper limit of wave frequency
XCG	LCG	longitudinal centre of gravity
XL	LBP	length between perpendiculars
XLCB	LCB	longitudinal centre of buoyancy
XLCF	LCF	longitudinal centre of floatation
XO	η_3	heave
ZCR(I)	r_{AW}	coefficient of added resistance
ZH(I)	η_3	heave
ZHP(I)	ε_3	heave phase
ZLL(I)	λ/L	wavelength / ship length
ZP(I)	η_5	pitch
ZPP(I)	ε_5	pitch phase
ZW(I)	ω	wave frequency
ZWE(I)	ω_e	frequency of encounter

APPENDIX E: LIST OF PROGRAM UNITS

NAME	LISTED (L) OR, CDC LIBRARY (C)	FUNCTION
ADMAB	L	returns added mass and damping from Lewis-form conformal mapping
BULB	L	returns added mass and damping from MIT bulb-form conformal mapping
DATE	C	returns current date in A10 format
DEFWAV/BSET	L	computes wave deformation by interpolation of van Sluijs[13] data
KBL	L	estimates deadrise angle of station 4 if not in input data
LLSQ	L	least-squares-fit subroutine used by BULB
MATG	L	sets up equations of motion
PROFILE	L	wave profile calculation as described in Appendix A
RAW	L	returns coefficient of added resistance
SEAST/BLOCK-DATA	L	Gospodnetic-Miles regression spectrum
SOLV	L	simultaneous equation solver
TIME	C	returns current time in A10 format
ZETA/CSET	L	surface disturbance due to a single source
ZETAP	L	block-data used by ZETA

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13. ABSTRACT

The theoretical basis and user's manual are described for the computer program PHHS (Pitch and Heave in Head Seas), developed at DREA for seakeeping prediction purposes. In addition to the usual vertical motion calculations, algorithms are included for added resistance, relative motion corrections (wave profile and dynamic swell-up), slamming pressures, and human tolerance to vertical motion. Worked examples and a FORTRAN listing of the program are included

DSIS
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KEY WORDS

Pitch, heave, seakeeping, added resistance, wave profile, dynamic swell-up, slamming, human tolerance to ship motion.

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