UNIVERSITY
OF
SOUTHAMPTON

DEPARTMENT OF SHIP SCIENCE

FACULTY OF ENGINEERING
AND APPLIED SCIENCE

USERS MANUAL OF PROGRAMME AEW2

by

P.A. Wilson

Ship Science Report No 2 1976

USERS MANUAL OF PROGRAMME AEW2

Introduction

Programme AEW2 is a digital computer programme to predict the motions and bending moments of a ship in regular and irregular waves.

The principle assumptions of the mathematical theory are that the motions can be considered as linear, and that the section shapes can be approximated by Lewis forms. These assumptions enable the strip theory to be used and as a consequence of the second assumption the two dimensional section added mass and damping coefficients can be calculated.

Section I describes the input parameters, Section II the mathematical background, Section III contains a generalized flow chart of the programme structure. In the appendices two examples are given, together with a list of diagnostic printouts that can be produced from the programme.

Section I

There are five channels for inputting and outputting information to and from the programme.

Channel 1 is used for the card reader. This is used for the basic ship data each time the programme is run.

Channel 2 is the line printer for the output of the motions and bending moments.

Channel 3 is a file that is pre-named DATA TAPE. This is only an output file and is used for dumping the values of the added mass and damping coefficients for the ship.

Channel 4 is a file that is pre-named DATA-TAPE. It is used only as an input file. Its use is only for reading information that has already been generated and dumped onto channel 3.

Channel 5 is a file pre-named TAPE PLOTONE. This channel is an output channel when the facility for plotting motions is requested. This will contain information about the frequencies, speeds, wave angles, and types of motion as well as the values of the motions.

a) Data Input

1) Date Card

This is a single card containing the date in 2A6 format.

2) Title Card

This card contains a title for the run in 13A6, A2 format, i.e. one complete card. This title appears at the top of every page. When Channel 3 is utilized, the first 30 characters of the title are written onto channel 3. When a subsequent run of the same ship is required, the first 30 characters of the new run are compared with the 30 characters that head channel 3.

3) Option Control

There are 14 option controls, some of which are inter-dependant. The format is 15I2.

Option Letter	Description	Options	
A	Integration	0	Simple Integration
		1	Trapezoidal
B	Moment	0	Calculate motions
		1	Calculate motions using mass distribution
		2	Calculate motions and moments using mass distribution
C	Mass Distribution	0	Mass
		1	Weight
D	Wave Spectra	0	Regular waves
		1	Neumann
		2	Pierson-Moskowitz
		3	I.T.T.C. two parameter
E	Degrees of Freedom	0	Vertical plane only
		1	Vertical and lateral plane
		2	Lateral plane only
F	Spreading function	0	No spreading
		N	Nth power of cosine used as spreading function
G	Two-dimensional properties	-1	Generate file on channel 3 no print out of two dimensional properties
		0	Generate file on channel 3
		1	Read file off channel 4 and printout numbers
		2	Read file off channel 4 and have no print out
H	Moment closure	0	Suppress closure calculation
		1	Calculate and print out closure results
I	Output	0	Dimensional
		1	Non-dimensional
J	Torsion axis	0	Centre of gravity
		1	Waterline
L	Plotting	0	No numbers written
		1	Write to channel 5 numbers to be plotted
M	Hull parameters	0	No call to MTHULL
		1	Uses parametric routine
N	Long term statistics	0	No call
		1	Call and print out regular data
		2	Call and no print of regular data
		3	No printing of regular data and no call to LTS
P	Slamming and wetness	0	No call
		1	Calls statistical motions at relevant ship stations
		2	Calls slamming package

One other number after P is required, this is the number of segments of the ship. If the option A is 0 then the information is required at the half stations starting at the bow, e.g. 1½. 2½ ..... 20½, if number of segments is 20. If option A is 1 then the information is required at the following stations 1, ... 21 if number of segments is 20.

If option M is 1 and selected skip the following details and go to the end of this section.

4 Ship Particulars

The card format is 10X, 3F10.5, F10.3. This card contains the ship length, water weight density, acceleration due to gravity and the ship displacement.

This card determines the units that the programme operates in.

5 Section Particulars

The card format is 4F10.4. There are option A + number of segments of these cards.

Each card contains the waterline breadth, area coefficient, draught and if required the centroid of each section.

The centroid of this section is measured from the waterplane downwards. If prior knowledge of these parameters is not known a two-dimensional Moorish Approximation is used.

6 Lateral Plane Card

The card format is 2F10.4. The information contained is the ships overall vertical centre of gravity measured from the waterline positively upwards, the second number is the radius of gyration in roll. This card is used only with E = 1 or 2.

7 Summary Mass Card

The card format is 2F10.4. The longitudinal radius of gyration of the ship followed by the longitudinal centre of gravity of the ship are on this card.

This card is required only when B is zero, otherwise these values are calculated from the mass distribution.

8 Section masses or weights

The card format is 3F10.4. These cards are only used if option B is non zero. For each of the sections, the weight or mass, the vertical centre of gravity and the roll gyradius is required.

The weight or mass is determined from option C.

The section V.C.G. is only necessary for lateral bending calculations and is measured vertically positively downwards from the ships overall vertical centre of gravity. If the section V.C.G.'s do not give agreement with the overall vertical centre of gravity then balancing is performed to satisfy this condition.

9 Moment Stations

The format is 3I10. The first number is the first station that the moments are calculated at, the second is the last station, and the third number is the increment between these stations.

When irregular seas have been specified one stations results are stored for spectral calculations. When a range of values are specified and printed, only midship values are stored for spectral conditions.

10 Run Control Card

The card format is 4F10.4. This card contains the wave amplitude, the initial frequency or wavelength, the final frequency or wavelength, and the increment between these values.

A maximum of 51 frequencies or wavelengths is allowed.

The wave amplitude is used for continuity within the programme. If the value is >0.0 the programme continues using the new values on the card. If the value is 0.0 the programme is stopped and new data is input from 2 onwards. If the value is negative the programme is stopped completely.

If for some reason, say a range greater than 51 wavelengths, then to run at some other wavelengths the values are put on this card and the cards that follow card 10 are duplicated.

The parameters 2, 3, 4 on this card are frequencies or wavelengths depending whether regular or irregular seas have been specified. If option D is non-zero they are frequencies, if option D is zero they are wavelengths.

11 Number of Speeds

This card contains the number of speeds the ship is run at, with a maximum of 10.

The format is I3.

12 Speeds

This card has format 10F8.2. This card contains a list of speeds in knots. The values are converted to the appropriate units and printed out in these units.

13 Roll Damping

This is only used if option E is non zero. The value is the specified fraction of critical damping at the natural resonance. The format of this card is F10.3.

14 Wave Angle

This card contains the initial, final and incremental wave angle in degrees that the ships heading values take. Head seas are designated by 180.0^o. The format is 3F10.4.

15 Wave Spectra

If Option D is non zero then this card is used. If the Newmann spectra is used the parameter is the wind speed in knots. If the Pierson-Moskowitz is used then the significant height of the waves is used. If the I.T.T.C.

two parameter is used, then two cards are required. The first contains the significant wave height, the second the mean period of the sea state.

In all cases the first card is of format I10, 10F5.1. The second card is 10X, 10F5.1.

The first cards first number is the number of spectra.

16 Irregular seas

If option P is 1 then the values of the absolute and relative acceleration, velocity and motion are output for specified stations.

This card has format I2. This is the number of stations that are specified.

17 Station Number

This card has a list of station numbers. Format 21 I2.
There are, card 16, of these stations.

18 Control

This card is now inserted according to choice in data card 10.

b Option Control M

This option is chosen for a parametric hull study by value of 1.

The data cards specified by data cards 4 and 5 are missed out and the following are inserted.

As a basic requirement of M being 1, the following values of certain options are also required

B = 0, C=0, H=0, N=0, G=0

Also no channel 3 is required.

Data Cards

M1 Format 8F10.3

Ship length
Circular M (length/displacement ratio)
Beam to draught ratio
Mid ship section coefficient Cm
Prismatic coefficient
Waterplane area coefficient Cw
Section coefficient at station 2
Half angle of entrance in degrees

Also, if there were two specified speeds, say 10 kts, and 20 kts

Probabilities might be as follows:

Group/Spec	10	20
1	0.50	0.50
2	0.60	0.40
3	0.70	0.30
4	0.95	0.05

Similarly this type of grouping is applied to direction and waveheight. In this case the waveheights can be in different groupings and the probabilities of being in a particular direction when the waveheight is in a group are required. There is one fact to remember when enumerating these probabilities, which is, remember the responses are to waves from $0^\circ \rightarrow 360^\circ$, but the programme will only need be run for angles of $0^\circ \rightarrow 180^\circ$. Thus for angles other than head and following seas, the probability of occurrence for angle is double that of what you might expect.

For example, if only angles of 0°, 45°, 90°, 135°, 180° are calculated, and the waveheights are grouped as above, then the probabilities might be

Group/angle	0	45	90	135	180	
1	0.125	0.25	0.25	0.25	0.125	(equal all direction)
2	0.08	0.16	0.16	0.40	0.20	
3	0.05	0.10	0.10	0.50	0.25	
4	0.00	0.00	0.00	0.40	0.60	

N.B. In group 1 each direction is equally probable, thus each direction has a probability of 0.125, so since the response at 90° is the same is 270°, its probability is therefore 2 x 0.125 = 0.25. In group 2, there is a probability split of 0.40 to 0.60 of following to head seas, within each band, equal probability, i.e. for head seas 0.60/3 = 0.20 for each heading is assigned.

The maximum values that can be attained are also input. The programme calculates for this value and increments of 10% of this value, the probability of the value be exceeded in a number of cycles assuming the conditions are the same. The number of cycles that are present are 500, 1500, 3000, 10000, 20000 cycles. A table of values are thus output.

Data Input

N1 Format 2I2

Number of waveheights NW (Max 10)
Number of waveheight ranges NR (Max 7)

N2 Format 10F8.3

Waveheights that are used in the calculations

N3 Format 8F10.3

Limits of waveheight ranges for direction. There will be NR-1 values. A maximum of 6 limits, meaning a maximum of seven ranges.

N4 Format 8F10.3

Limits of waveheight ranges for speeds. There are NR-1 values.

N5 Format 10F8.4

Probabilities of occurrence of waveheights of given period. The most rapidly varying data input will be waveheight, thus if there are KT periods, and NW waveheights, the first NW pieces of data are associated with mean period one, and the next NW with mean period two. The data is packed 10 to a data card no matter how many waveheights there have been input.

N6 Format 10F8.4

Probability of occurrence of given heading in given wave range. The most rapid varying data being direction. The data is again 10 to a data card no matter how many directions.

N7 Format 10F8.4

Probability of occurrence of given speed in given wave range. The most rapid varying data being speed. The data is again 10 to a data card no matter how many speeds.

N8 Format 2F10.3, or 3F10.3, or 5F10.3

This card has 2, 3 or 5 numbers depending which value of Option E has been chosen

If IE = 0, i.e. vertical motions only

VBMAX	Maximum vertical bending moment
VSMAX	Maximum vertical shearing force

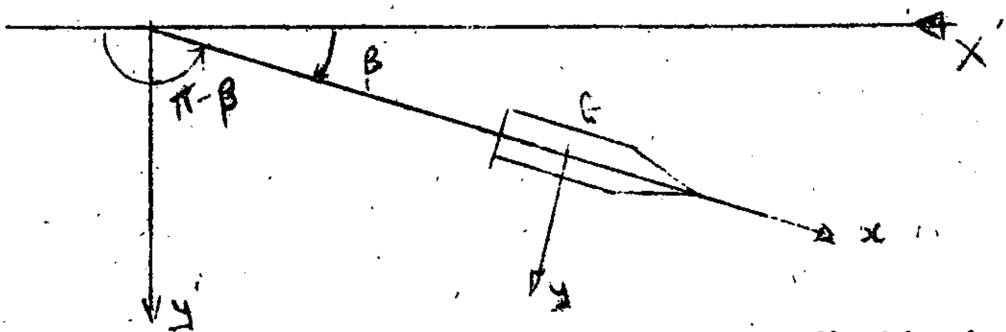
If IE = 2, i.e. lateral motions only

LBMAX	Maximum lateral bending moment
LSMAX	Maximum lateral shearing force
TMMAX	Maximum torsional moment

If IE = 1, i.e. both sets of motions

VBMAX, VSMAX, LBMAX, LSMAX, TMMAX

Taking co-ordinates as in figure 1, the o', x', y', z' system are fixed in space, the ox, y, z system is fixed in the centre of gravity of the ship



If the ship travels with speed V at some angle β defined by the diagram, (180° is head seas)

Let the linearised velocity potential for deep-water waves be given by

$$\Phi_\omega = - ace^{-kz'} \text{Cos } (kx' + \omega t)$$

where a is amplitude of wave

c is wave speed

k wave number

λ wave length

z' vertical co-ordinate positive downwards

x' horizontal axis at right angles to wave crests

t time

$$\text{Now } x' = -(x + Vt) \cos \beta - y \sin \beta$$

$$y' = +(x + Vt) \sin \beta - y \cos \beta$$

The surface elevation η (positive upwards) can be expressed as follows:-

$$\eta = \frac{1}{g} \left(\frac{\partial \Phi_\omega}{\partial z}\right)_{z'=o} = a \sin (kx' + \omega t)$$

now if this wave elevation is referenced with respect to the centre of gravity of this ship $x = o$, $y = o$

$$\eta = a \sin (-Vt \cos \beta \; k + \omega t)$$

$$\eta = a \sin (\omega_e t)$$

if we define $\omega_e = \omega - kV \text{ Cos } \beta$

Vertical Plane Equation

If z represents heave, and θ the pitch about the centre of gravity

z is measured positive downward

θ is measured positive bow-up

The equation of motion, neglecting the surge components

$$M\ddot{z} = \int_{x_s}^{x_b} \frac{dZ}{dx} dx + Z_w$$

$$\text{If } I_y\ddot{\theta} = -\int_{x_s}^{x_b} \frac{dz}{dx} x dx + M_w$$

where M = mass of ship

I_y = mass moment of inertia of ship about y axis

$\frac{dZ}{dx}$ = local sectional vertical hydrodynamic force on ships

x_s, x_b co-ordinates of stern and bow ends of ship, respectively

Z_w,M_w wave excitation force and moment on ship

If the force is taken to be of the form

$$\frac{dz}{dx} = -\frac{D}{Dt}(A_{33} (\dot{z} - x\dot{\theta} + V\theta)) - N_z (\dot{z} - x\dot{\theta} + V\theta) -\rho gB' (z - x\dot{\theta})$$

$\dot{z} - x\dot{\theta} + V\theta$ is the vertical velocity of the ship due motions

ρ is mass density of water

A_{33} local section vertical added mass

N_z local section damping force coefficient

B' local waterline beam

$$N_z = \frac{\rho g^2\bar{A}^2}{\omega_e^3}$$

$\bar{A}$ = ratio of generated wave to heave amplitude for vertical motions

Thus

$$\frac{dZ}{dx} = -A_{33} (\ddot{z}- x\ddot{\theta} + 2V\dot{\theta}) - (N_z - V \frac{dA_{33}}{dx}) (z - x\dot{\theta} + V\theta)$$

$$- \rho gB' (z - x\theta)$$

If this expression for $\frac{dZ}{dx}$ is substitutedinto the equation of motion then

$$a'\ddot{z} + b\dot{z} + c'z - d\ddot{\theta} - e\dot{\theta} - g'\theta = Z_w$$

$$A\ddot{\theta} + B\dot{\theta} + C\theta - D\ddot{z} - E\dot{z} - Gz = M_w$$

where

$$a' = M + \int A_{33} dx \,, \quad b = \int (N_z - V \frac{dA_{33}}{dx}) \, dx$$

$$c' = \rho g \int B' dx \,, \quad d = D = \int A_{33} \, x dx$$

$$e = \int (N_z x - 2V A_{33} - Vx \frac{dA_{33}}{dx}) \, dx$$

$$g' = \int (\rho g B' x - VN_z + V^2 \frac{dA_{33}}{dx}) \, dx$$

$$A = I_y + \int A_{33} \, x^2 \, dx$$

$$B = \int (N_z x^2 - 2 \, VA_{33} x - V x^2 \frac{dA_{33}}{dx}) \, dx$$

$$C = \int (\rho g B' x^2 - VN_z x + V^2 x \frac{dA_{33}}{dx}) dx$$

$$E = \int (N_z x - Vx \frac{dA_{33}}{dx}) \, dx \,, \qquad G = \int \rho g B' \, x dx$$

All the integrations are taken over the length of the ship

$$Z_w = \int_{x_s}^{x_b} \frac{dZ_w}{dx} \, dx, \qquad M_w = - \int_{x_s}^{x_b} \frac{dZ_w}{dx} \, x dx$$

where

$$\frac{dZ_w}{dx} = - \{ \rho g B' \eta + (N_z - \frac{VdA_{33}}{dx}) \dot{\eta} + A_{33} \ddot{\eta} \} \, e^{-k\bar{h}}$$

where $\bar{h}$ is the mean section draught

In this case $\bar{h} = TC_s$, T draught C_s section area coefficient

The solutions are found and expressed by:-

$$z = z_o \sin (\omega_e t + \partial)$$

$$\theta = \theta_o \sin (\omega_e t + \varepsilon)$$

where ∂, ε are the phase angles. The phases being relative to maximum wave slope at mid-ships.

The local vertical loading is given by:-

$$\frac{df_z}{dx} = -\delta m \, (\ddot{z} - x\ddot{\theta}) + \frac{dZ}{dx} + \frac{dZ_w}{dx}$$

where δm is section mass/unit length.

This is basically the sum of the inertial, hydrodynamic, hydrostatic and wave excitation forces.

Thus the vertical bending moment is given by, at some point x_o

$$BM_z\ (x_o) = \left[\int_{x_s}^{x_o} \text{ or } \int_{x_o}^{x_b} \right] (x - x_o)\ \frac{df_z}{dx}\ dx$$

This is obviously expressed by

$$BM_Z = BM_{Zo} \quad \sin \quad (\omega_e t + \sigma)$$

σ again is relative to maximum wave slope at midships.

Lateral Plane Equation

The coupled equations of motion of sway y (positive to starboard), yaw ψ (positive bow-starboard) at roll Φ (positive-starboard down) are

$$M y = \int_{x_s}^{x_b} \frac{dY}{dx}\, da + Y_w$$

$$I_z \ddot{\psi} - I_{xz} \ddot{\Phi} = \int_{x_s}^{x_b} \frac{dY}{dx}\ xdx + N_w$$

$$I_x \ddot{\Phi} - I_{xz} \ddot{\psi} = \int_{x_s}^{x_b} \frac{dK}{dx}\ dx - Mg\ \overline{GM}\ \Phi + K_w$$

where I_z = mass moment of inertia of ship about z axis

I_x = mass moment of inertia of ship about x axis

I_{xz} = mass product of inertia of ship about x-z plane

$\frac{dY}{dx}$ = local sectional lateral hydrodynamic force on ship

$\frac{dK}{dx}$ = local sectional hydrodynamic rolling moment on ship

Y_w, N_w, K_w, wave excitation force and moment on ship

$\overline{GM}$ = Initial metacentric height of ship taken hydrostatically

Now take the forces to be of the form

$$\frac{dY}{dx} = - \frac{D}{Dt} (M_s\ (\dot{y} + x\dot{\psi} - V\psi) - F_{rs}\dot{\Phi}) - N_s\ (\dot{y} + x\dot{\psi} - V\psi)$$

$$+ N_{rs}\dot{\Phi} + \overline{OG}\ \frac{D}{Dt} (M_s\dot{\Phi}) + \overline{OG}\ N_s\ \dot{\Phi}$$

where

OG is distance of ship CG from waterplane, positive up

M_s	sectional added mass
N_s	sectional lateral damping force coefficient
$M_{s\Phi}$	sectional added mass moment of inertia due to lateral motion
$N_{s\Phi}$	sectional damping moment coefficient due to lateral motion
I_r	sectional added mass moment of inertia
N_r	sectional damping moment coefficient
F_{rs}	sectional lateral added mass due to roll motion
N_{rs}	sectional lateral damping force coefficient due to roll motion

The added mass moment and damping moment coefficient are taken with respect to an axis at the waterplane.

Additional roll damping moment to account for viscous and bilge keel effects is taken as a particular fraction of roll damping:-

$$N_r^* = I_\Phi \; C_c/L - N_r \; (\omega_\Phi)$$

where N_r^* = sectional damping moment coefficient due to visoous and bilge effects.

I_Φ	fraction of critical roll damping (empirical data)
C_c	critical roll damping
L	length of ship
ω_Φ	nautical roll frequency
$N_r(\omega_\Phi)$	value of N_r at frequency ω_Φ

$$C_c = \frac{2Mg\,\overline{GM}}{\omega_\Phi}$$

If roll is taken alone

$$(I_x + \int I_r(\omega)\; dx)\ddot{\Phi} \quad + \quad (N_r + N_r^*)\dot{\Phi} \;+\; Mg\overline{GM}\;\Phi \;=\; F$$

For some frequency ω_e

$$\left[Mg\overline{GM} \;-\; \omega_e^2 \;\{I_x + \int I_r \;(\omega_e)\, dx\}\right] \Phi_o$$

$$+ \;(N_r + N_r^*)\; i\omega_e \Phi_o \;=\; F_o$$

$$Mg\overline{GM} \;=\; \omega_\Phi^2 \;(I_x + \int \; I_r(\omega_\Phi) \quad)$$

$$\Phi_o \left[\left\{ (\omega_\phi^2 - \omega_e^2)\, I_x + \int \left[\omega_\Phi^2\, I_r\, (\omega_\Phi) - \omega_e^2\, I_r\, (\omega_\Phi) \right] dx \right\} + i\underline{\omega_e}\; \zeta_\Phi\; C_c \right] = F_o$$

$$\left\{ (\omega_\Phi^2 - \omega_e^2)\, I_x + \int \left[\omega_\Phi^2\, I_r - \omega_e^2\, I_r\, (\omega_e) \right] dx + i\underline{\omega_e}\; \zeta_\Phi\, \frac{2\ \mathrm{Mg\ GM}}{\omega_\Phi} \right\} = \mathrm{Mg}\overline{\mathrm{GM}}\; F_o$$

So at $\omega_e = \omega_\Phi$

$$\Phi_o \; \{ \; i\zeta_\Phi\; 2\ \mathrm{MgGM} \; \} = \mathrm{Mg}\overline{\mathrm{GM}}\; F_o$$

$$\therefore \quad \Phi_o = \frac{-i}{2\zeta_o}\; F_o$$

so to find ζ_o from a known value of the roll response at resonance

$$R = \frac{1}{2\zeta_o}$$

The equation of motion can then be transformed into

$$\underset{\sim}{A}\; \underset{\sim}{M} = \underset{\sim}{F}$$

$$\underset{\sim}{A} = (a_{ij}) \qquad \begin{array}{l} i = 1 \text{ to } 3 \\ j = 1 \text{ to } 9 \end{array}$$

$$\underset{\sim}{F} = (Y_w,\, N_w,\, K_w)^T$$

$$\underset{\sim}{M} = (\ddot{y},\, \dot{y},\, y,\, \ddot{\psi},\, \dot{\psi},\, \psi,\, \ddot{\Phi},\, \dot{\Phi},\, \Phi)^T$$

$$a_{11} = M + \int M_s\, dx \qquad a_{12} = \int \left(N_s - \frac{VdM_s}{dx}\right) dx \qquad a_{13} = 0$$

$$a_{14} = \int M_s x dx \qquad a_{15} = \int \left(N_s x - 2VM_s - Vx\frac{dM_s}{dx}\right) dx$$

$$a_{16} = -V\, a_{12}, \qquad a_{17} = -\int \left(F_{rs} + \overline{OG}\, M_s\right) dx$$

$$a_{18} = -\int \left(N_{rs} - \overline{OG}\, \frac{VdM_s}{dx} + \overline{OG} N_s - \frac{VdF_{rs}}{dx}\right) dx$$

$$a_{19} = 0, \qquad a_{21} = \int M_s x dx, \quad a_{22} = \int (N_s x - Vx \frac{dM_s}{dx}) dx, \quad a_{23} = 0$$

$$a_{24} = I_z + \int M_s x^2 dx, \quad a_{25} = \int (N_s x^2 - \frac{d}{dx} (M_s x^2)) dx$$

$$a_{26} = -Va_{22}, \quad a_{27} = - I_{xz} - \int (F_{rs} + \overline{OG} M_s x) dx$$

$$a_{28} = - \int (N_{rs} x - \overline{OG} x \frac{dM_s}{dx} + \overline{OG} N_s x - Vx \frac{dF_{rs}}{dx}) dx$$

$$a_{29} = 0$$

$$a_{31} = - (M_{s\phi} + \overline{OG} M_s) dx$$

$$a_{32} = - \int (N_{s\Phi} + \overline{OG} N_s - V \frac{dM_{s\Phi}}{dx} - V\overline{OG} \frac{dM_s}{dx}) dx$$

$$a_{33} = 0$$

$$a_{34} = - I_{xz} - \int (M_{s\phi} x + CG x M_s) dx$$

$$a_{35} = - \int (N_{s\phi} x + \overline{OG} N_s x - Vx \frac{dN_{s\Phi}}{dx} - V\overline{OG} x \frac{dM_s}{dx}) dx - 2Va_{31}$$

$$a_{36} = - Va_{32}$$

$$a_{37} = I_x + \int (I_r dx + \overline{OG} M_{s\Phi} + \overline{CG} F_{rs} + \overline{CG}^2 M_s) dx$$

$$a_{38} = \int ((N_r + N_r^*) + \overline{OG} N_{s\Phi} + \overline{OG} N_{rs} + \overline{OG}^2 N_s$$
$$- V \frac{dI_r}{dx} + \overline{OG} \frac{dM_{s\phi}}{dx} + \overline{OG} \frac{dF_s}{dx} + \overline{OG}^2 \frac{dM_s}{dx}) dx$$

$$a_{39} = Mg \overline{GM}$$

The forces

$$Y_w = \int_{x_s}^{x_b} \frac{dY_w}{dx} dx, \; N_w = \int_{x_s}^{x_b} x \frac{dY_w}{dx} dx$$

$$K_w = \int_{x_s}^{x_b} \frac{dK_w}{dx} dx$$

$$\frac{dY_w}{dx} = \left[(\rho S \ + Mg) \ \frac{DV_w}{Dt} - VV_w \frac{dM_s}{dx} + N_s V_w + k \ (-M_{s\Phi} \frac{DV_w}{Dt} + V \frac{dM_{s\Phi}}{dx} Vw) \right] \frac{\sin \left(\frac{\pi B'}{\lambda} \sin \beta \right)}{\frac{\pi B'}{\lambda} \sin \beta}$$

$$\frac{dK_w}{dx} = \left[- \frac{D}{Dt} (M_{s\Phi} V_w) + \rho \left(\frac{B'^3}{12} - S \bar{z} \right) \frac{DV_w}{Dt} - N_{s\Phi} \ V_w \right] \frac{\sin \left(\frac{\pi B'}{\lambda} \sin \beta \right)}{\frac{\pi B'}{\lambda} \sin \beta}$$

$$- \ \overline{OG} \ \frac{dY_w}{dx}$$

V_w is lateral orbital wave velocity

S local section area

$\bar{z}$ local section at centre of buoyancy from waterline

$$v_w = - \frac{\partial \Phi_y}{\partial y}$$

Thus the equations of motion are solved to give

$$y = y_o \sin (\omega_e t + \kappa)$$

$$\psi = \psi_o \sin (\omega_e t + \alpha)$$

$$\Phi = \Phi_o \sin (\omega_e t + \nu)$$

The κ, α, ν are the phase angles relative to maximum wave slope at midships.

The local lateral and rotational loading are given by

$$\frac{df_y}{dx} = - \delta m \ (\ddot{y} + x\ddot{\psi} - \zeta\ddot{\Phi}) + \frac{dY}{dx} + \frac{dY_w}{dx}$$

$$\frac{dm_x}{dx} = - \delta m \gamma^2 \ddot{\Phi} + \delta m \zeta \ (\ddot{y} + x\ddot{\psi}) + g\rho \ (\frac{B'^3}{12} - S\bar{z} - S\overline{OG}$$

$$- g\delta m \zeta \Phi + \frac{dK}{dx} + \frac{dK_w}{dx}$$

where ζ is local centre of gravity positive down

γ is local gyradius of roll

The lateral bending and torsional moments at location x_o are then

$$BM_y\ (x_o) = \left[\int_{x_s}^{x_o} \text{or} \int_{x_o}^{x_b} \right] (x - x_o) \frac{df_y}{dx}\ dx$$

$$TM_x\ (x_o) = \left[\int_{x_s}^{x_o} \text{or} \int_{x_o}^{x_b} \right] (x - x_o) \frac{dM_x}{dx}\ dx$$

Then

$$BM_y = BM_{yo} \sin (\omega_e t + \tau)$$

$$TM_x = TM_{xo} \sin (\omega_e t + \mu)$$

The requirement on the local centre of mass is

$$\int_{x_s}^{x_b} \delta m \zeta dx = 0$$

and

$$\int_{x_s}^{x_o} \delta m \gamma^2 dx = I_x$$

$$I_{xz} = \int_{x_s}^{x_o} \delta m x\ \zeta dx$$

Wave Spectra Equations

The wave spectra for calculation in irregular seas is considered to be of the form of two separable functions

$$S\ (\omega,\mu) = S_1\ (\omega)\ S_2\ (\mu) \begin{cases} 0<\omega<\propto \\ -\pi/2 <\mu< \pi/2 \end{cases}$$

μ is angle relative to predominant direction of wave to ship

S_1 is frequency spectrum

S_2 is spreading function

The mean square spectrum is given by

$$\overline{a^2} = \int_0^\infty \int_{-\pi/2}^{\pi/2} S\ (\omega,\mu)\ d\omega d\mu$$

$$\text{Now} \int_{-\pi/2}^{\pi/2} S_2\ (\mu)\ \ d\mu\ \ = 1.0$$

Three types of spectra can be specified

Neuman

$$S_1\ (\omega) = 0.000827\ \frac{g^2\pi^3}{\omega^6}\ \exp\ (-2g^2/(\omega^2u^2)\ )$$

Pierson-Moskowitz

$$S_1\ (\omega) = \frac{0.0081}{\omega^5}\ g^2\ e^{-\ 3.11/h_{1/3}{}^2/\omega^4}$$

in metric units $h_{1/3}$ is significant wave height in metres

$$S_1(\omega) = \frac{0.0081g^2}{\omega^5}\quad e^{-33.50/h_{1/3}{}^2/\omega^4}$$

in imperial units, $h_{1/3}$ is significant wave height in feet

Two-Parameter

$$S_1\ (\omega) = \frac{AB}{\omega^5}\ e^{-B/\omega^4}$$

$$A = 0.25\ H_{i/3}{}^2 \qquad B = \left(0.817\ \frac{2\pi}{T}\right)^4$$

$$T = \frac{m_o}{m_1}$$), m_n is the n^{th} moment of the spectra

The spreading function is specified by, for short crested seas

$$S_2\ (\mu) = G(N)\ \cos^N \mu$$

where G(N) is a constant for each specified N

$S_2\ (\mu) = \delta\ (\mu)$ the Dirac Delta function, for long crested seas

SECTION III

STRUCTURE OF PROGRAMME

MASTER SEGMENT SCOR

This segment controls the calling of the main subroutines, depending upon the input parameters.

It has calls to DATE, PRELIMB, PRELIMC, ROLD, ALINT, COEFF, EXCITE, MOTION, BENDSH, TNIRPA, STATI, ACCEL, SPREAD, S1M102, and LTS.

Subroutine DATE

This reads the date as the first data card in 2A6 Format.

Subroutine PRELIMB

This subroutine reads in all the basic data up to the wave amplitude card. It processes and compares various input parameters with calculated values. It outputs on to the line printer the basic data.

The subroutine has calls to MTHULL, and function SINT. If something is drastically wrong with the input data, the subroutine will abort the programme with a message and an error number. The list of these error messages is found at the end of this Chapter.

Subroutine PRELIMC

This subroutine reads the running information control cards, i.e. wave amplitude, wave angle, frequencies and statistical information for spectra.

This has calls to the subroutines PAR, CKLEW, ZIPSMO, and TDLR.

There are two block data areas that are initialized by this subroutine. The first sets the array STS, with hollerith characters for outputting values in the subroutine STATI. The second sets the values of the array OMT, the frequency parameters of which there are 25 used in the calculation of the two dimensional properties.

Subroutine ROLD

This is called from SCOR, to provide the calculation of the resonant rolling frequency and also to use the input value of critical damping, to calculate a value of additional viscous damping.

Function SINT

This does integration by either a simple summation or trapezoidal rule. The choice being dictated by the first value of the function call.

Subroutine MTHULL

This subroutine calculates the beam, sectional area coefficients and draughts from basic input data $\underset{\smile}{M}$ for example, being one of the fourteen values required.

Once these values have been calculated it then proceeds as with a run that has the sectional area coefficients, draughts and beam as the input.

Subroutine CKLEW

This subroutine checks that the beam, draught and sectional areas of a section conform to the requirements of a Lewis form. If the section is below the minimum area allowed then the area is increased to this minimum. If the section area is larger than the maximum, the area is decreased to this maximum value. In both cases a message to this effect is printed.

The minimum section area coefficient is

$$\frac{3\pi}{32}\left[2 - \frac{D}{2B}\right]$$

The maximum section area coefficient is

$$\frac{\pi}{32}\left[\frac{B}{2D} + \frac{2D}{B} + 10\right]$$

where D is the section draught, B is the section beam.

Subroutine ZIPSMO

This calculates the so called 'added mass' and 'damping coefficient' per unit length of each station for all the frequency parameters set in the array OMT, for heaving and pitching motions. The method that is used is that attributable to O. Grim.

The only subroutine that is called is MATPAC.

Subroutine MATPAC

This subroutine is used for inverting the matrix that is generated by ZIPSMO. A method of Gaussian elimination is employed.

Subroutine TDLR

This subroutine calculates the so called 'added mass' and 'damping coefficients' for the lateral motions for all the frequencies. The method that is used is that of F. Ursell, but with a Lewis transformation applied to the circular cylinder. The method of least squares fit is used to determine the coefficients of the polynomials for added mass and damping. In this method 15 points are chosen around the section contour,

Subroutine ALINT

The subroutine is used to produce a linear interpolation of the two dimensional properties of the sections. This is required because all the two dimensional properties are calculated at preset frequencies, so when an actual value of frequency is used, the values will probably have not been calculated.

The interpolation method used is a six point forward and backward difference operator method.

Subroutine COEFF

This calculates the coefficients of the equations of motion of the ship.

Subroutine EXCITE

This calculates the wave exciting forces for whichever motions have been selected.

Subroutine MOTION

This subroutine solves the equations of motion with the coefficients and exciting forces that have been calculated in EXCITE and COEFF.

Subroutine BENDSH

This subroutine calculates the bending moments and shearing forces at any specified stations of the ship. These values are also output, in non-dimensional form if necessary.

The subroutine will store, even if no output is required, the values of bending moments and shearing forces at one station for outputting by TNIRPA.

Subroutine TNIRPA

This outputs the motions and bending moments calculations. One table of results contains the vertical motions and vertical bending moment, another table contains the lateral motions, lateral bending moment and torsional moment, and the third table contains the shearing forces, both lateral and vertical.

Subroutine PAR

This calculates the spectra that have been specified at the required frequencies.

Subroutine STAST

This routine is called when all the regular wave data has been calculated. With the information from subroutine PAR it forms the irregular sea response.

Subroutine ACCEL

This calculates the absolute and relative motions, velocity and acceleration at specified stations in the specified sea states. This calls function SINT. It outputs information for use in S1M102.

Subroutine S1M102

This calculates the probability of exceeding a specified probability of wetness, acceleration and slamming in a certain time span in the sea states that the ship has experienced.

It has the variances of the absolute acceleration, relative motion, and relative velocity as input via a common area from subroutine ACCEL.

Subroutine MATINS

This inverts a matrix returning the inverted matrix in the same array as when the subroutine was called. It has an identifier for singular matrices.

Subroutine LTS

This subroutine is called by SCOR. It has input from data cards of the waveheights, the probabilities of being at a specified waveheight with specified mean period, the probabilities of maintaining the specified speeds as the waveheight exceeds some value, and the probabilities of maintaining the specified directions as the waveheight exceeds some value. The maximum values of the bending moments and shearing forces are also input.

Calculations are done on these input values and then the actual computation of exceeding the value of the bending moment is done via subroutine PROBS.

List of errors output by PRELIMB and PRELIMC

Subroutine	Error No.	Reason
PRELIMB/C	0	No. of sections > 21 No. of wave angles > 25 No. of wave lengths > 51
PRELIMB	1	Weights > 1.02 Displacement or Weights < 0.98 Displacement
PRELIMB	2	Volume > 1.02 Displacement or Volume < 0.98 Displacement
PRELIMB	3	Centre of gravity - Centre of buoyancy is > 1.03 LBP, or < 0.97 LBP
PRELIMC	4	Error in increment of wave angle, wavelength, or station number
PRELIMC	5	The two dimensional properties calculations are incomplete due to a singular matrix in the calculations.
PRELIMC	6	File name of previous calculated two dimensional properties, does not tally with input values.

Other messages that can occur are due to the TDLR subroutine which when calculating the velocity potential of the laterial motions performs a check on the wave amplitude. Values that are output are the P, Q series of the potential and stream functions respectively. HO is Beam/(2 x Draught) of the section, SIG = Section area coefficient. XIB = HO x frequency parameter. The frequency parameter is one of the 25 preset values, and represents values of $\frac{\omega^2 D}{g}$, where D is the draught of the section.

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape./ Card. (DELETE AS REQUIRED)
Algol./ Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

```
15DEC75
EXAMPLE OF INPUT DATA INCLUDING MOST OPTIONS
 1 2 1 3 1 0 2 0 1 0 0 0 2 020
            57.0      1.025     9.80665    665.0
 0.83      0.617      2.09      0.885   }
 1.406     0.611      2.119     0.769   }
 2.772     0.584      2.149     0.747   } 21 section, beam, area coefficient, draught, centroid
 4.19      0.552      2.178     0.770   }
               etc

 1.51      4.3            [ Vertical Centre of Gravity, gy radius ]
 18.608            }
 17.017            } 21 section masses or weights
 16.051            }


        11        11         1          [ station numbers for bending moment calcs ]
  1.0         0.01       3.0        0.1 [ wave amplitude, wave frequencies ]
  2        [ Number of Speeds ]
  5.0      15.0      [ Speeds in knots ]
  0.18           [ Fraction of critical roll damping ]
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape/ Card. (DELETE AS REQUIRED)
Algol/ Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

```
 0.0        180.0      45.0       {wave angle card}
         10 1.0  1.0  1.0 }1.0  1.0  1.0  1.0  1.0  1.0  1.0 } Spectra parameters
            2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  9.5  9.9 }
103                  {number of waveheights, number of ranges}
  1.0       2.0     3.0       4.0    5.0      6.0        7.0       8.0    9.0    10.0

  4.0       7.5          {limits of waveheight ranges for direction}
  3.5       7.0          {limits of waveheight ranges for speed}
  0.01    0.01    0.01    0.01    0.01    0.0     0.0     0.0     0.0     0.0
  0.014   0.014   0.014   0.014   0.014   0.0     0.0     0.0     0.0     0.0
  0.01    0.01    0.01    0.01    0.01    0.01    0.01    0.0     0.0     0.0
  0.01    0.01    0.01    0.015   0.015   0.015   0.015   0.005   0.005   0.0
  0.005   0.01    0.01    0.015   0.015   0.015   0.015   0.005   0.005   0.005
  0.005   0.005   0.01    0.01    0.015   0.015   0.015   0.015   0.005   0.005
  0.0     0.005   0.01    0.01    0.015   0.015   0.015   0.015   0.01    0.005
  0.0     0.005   0.01    0.01    0.025   0.025   0.025   0.025   0.015   0.01
  0.0     0.0     0.01    0.01    0.025   0.03    0.025   0.02    0.015   0.015
  0.0     0.0     0.01    0.01    0.015   0.015   0.015   0.015   0.015   0.015

  0.125   0.25    0.25    0.25    0.125   0.067   0.133   0.20    0.20    0.40
  0.00    0.05    0.05    0.40    0.50          {Prob. of being in heading range of
                                                          waveheights}.
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape./ Card. (DELETE AS REQUIRED)
Algol./ Fortran Coding Form.

PROGRAMMER:

DEPARTMENT:

CONTRACT:

PROBLEM:

DATE:

PAGE: OF

Statement number

Identification

1 2 6 7 10 20 30 40 50 50 70 72 80

```
 0.50  0.50     0.70    0.30     0.90    0.10    [probabilities of being at speeds in given
                                                           wavelength range]

 6000.0    3000.0    2000.0    1500.0    2000.0  [max values of bending, torsion etc]
-1.0                [END OF DATA]
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape./ Card. (DELETE AS REQUIRED)
Algol./ Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

```
17DEC74
EXAMPLE SHOWING USE OF OPTION  M (BASIC PARAMETERS Ⓝ, etc)
01 0 0 0 0 0 0 0 0 0 0 0 0 020
1.1E2      8.15E0    3.17E0    7.73E-1   6.0E-1    7.3E-1    6.18E-1    7.38E0
5.7E-1     9.35E-1   5.64E-1   1.34E-1   4.9E-1      {BASIC PARAMETERS}
0.45E0     0.925E0   0.0
1.025       9.81              [ DENSITY      , GRAVITY CONSTANT]
27.5       -9.0
        11        11         1                 [STATION NUMBERS]
1.0          50.0      600.0     25.0          [WAVE AMPLITUDES, WAVE LENGTHS]
  4                                            [NUMBER OF SPEEDS]
 10.0     15.0       20.0        25.0          [SPEEDS IN KNOTS]
 180.0     180.0      0.0                     [ WAVE ANGLE]
-1.0                                          [END DATA]
```

UNIVERSITY of SOUTHAMPTON
Computation Laboratory

Tape / Card. (DELETE AS REQUIRED)
Algol / Fortran Coding Form

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

1 2 6 7 10 20 30 40 50 60 70 72 80

```
15DEC75
EXAMPLE OF INPUT DATA INCLUDING MOST OPTIONS
 1 2 1 3 1 0 2 0 1 0 0 0 2 020
            57.0      1.025     9.80665   665.0
 0.83      0.617      2.09      0.885
 1.406     0.611      2.119     0.769
 2.772     0.584      2.149     0.747      21 sections, beam, area coefficient, draught,
 4.19      0.552      2.178     0.770                                  centroid
               etc

 1.51      4.3             [ Vertical Centre of Gravity, gy radius ]
 18.608
 17.017
 16.051         21 section masses or weights


        11        11         1        [ station numbers for bending moment calcs ]
  1.0       0.01        3.0      0.1 [wave amplitude, wave frequencies]
  2        [Number of Speeds]
  5.0       15.0      [ Speeds in knots]
  0.18         [fraction of critical roll damping]
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape / Card. (DELETE AS REQUIRED)
Algol / Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

```
 0.0        180.0      45.0      [wave angle card]
        10 1.0  1.0  1.0  1.0   1.0 1.0  1.0  1.0  1.0  1.0  } Spectra parameters
           2.0  3.0  4.0  5.0  6.0  7.0  8.0  9.0  9.5  9.9
10 3                  [number of waveheights, number of ranges]
  1.0      2.0     3.0     4.0     5.0     6.0      7.0     8.0    9.0   10.0

  4.0      7.5         [limits of waveheight ranges for direction]
  3.5      7.0         [limits of waveheight ranges for speed]
  0.01    0.01   0.01     0.01    0.01   0.0      0.0     0.0     0.0     0.0
  0.014   0.014  0.014    0.014   0.014  0.0      0.0     0.0     0.0     0.0
  0.01    0.01   0.01     0.01    0.01   0.01     0.01    0.0     0.0     0.0
  0.01    0.01   0.01     0.015   0.015  0.015    0.015   0.005   0.005   0.0
  0.005   0.01   0.01     0.015   0.015  0.015    0.015   0.005   0.005   0.005
  0.005   0.005  0.01     0.01    0.015  0.015    0.015   0.015   0.005   0.005
  0.0     0.005  0.01     0.01    0.015  0.015    0.015   0.015   0.01    0.005
  0.0     0.005  0.01     0.01    0.025  0.025    0.025   0.025   0.015   0.01
  0.0     0.0    0.01     0.01    0.025  0.03     0.025   0.02    0.015   0.015
  0.0     0.0    0.01     0.01    0.015  0.015    0.015   0.015   0.015   0.015

  0.125   0.25   0.25     0.25    0.125  0.067    0.133   0.20    0.20    0.40
  0.00    0.05   0.05     0.40    0.50              [Prob. of being in heading range of
                                                                  waveheights]
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape./ Card. (DELETE AS REQUIRED)
Algol./ Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

```
 0·50     0·50      0·70      0·30       0·90      0·10      [probabilities of being at speeds in given
                                                                          wavelength range]

 6000·0      3000·0      2000·0      1500·0      2000·0      [max values of bending, torsion etc]
-1·0                 [END OF DATA]
```

UNIVERSITY of SOUTHAMPTON.
Computation Laboratory

Tape / Card. (DELETE AS REQUIRED)
Algol / Fortran Coding Form.

PROGRAMMER:
DEPARTMENT:
CONTRACT:
PROBLEM:
DATE:
PAGE: OF

Statement number | Identification

```
17DEC74
EXAMPLE SHOWING USE OF OPTION  M (BASIC PARAMETERS ⓜ,etc)
01 0 0 0 0 0 0 0 0 0 0 [illegible] 0 020
1.1E2      8.15E0    3.17E0    7.73E-1   6.0E-1    7.3E-1    6.18E-1    7.88E0
5.7E-1     9.35E-1   5.64E-1   1.34E-1   4.9E-1       {BASIC PARAMETERS}
0.45E0     0.925E0   0.0
1.025       9.81                 [ DENSITY          , GRAVITY  CONSTANT]
27.5       -9.0
        11        11         1                 [STATION  NUMBERS]
1.0          50.0      600.0     25.0          [WAVE AMPLITUDES, WAVE LENGTHS]
  4                                            [NUMBER OF SPEEDS]
 10.0     15.0       20.0        25.0          [SPEEDS IN KNOTS ]
 180.0     180.0      0.0                     [ WAVE  ANGLE]
-1.0                                          [END  DATA]
```