AQWA™-NAUT MANUAL

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CHAPTER 1 - INTRODUCTION

1.1 PROGRAM

AQWA-NAUT is a computer program which simulates the motions of floating structures in response to regular or irregular seas and steady wind and currents. A number of structures, arbitrarily connected by articulations or mooring lines, can be analysed in a single run of the program.

The program requires a full hydrostatic and hydrodynamic description of each structure. This can either be input via a card image data file or transferred directly from a backing file created as a result of an AQWA-LINE analysis.

1.2 MANUAL

The AQWA-NAUT User Manual describes the various uses of the program together with its method of operation. The theory and bounds of application are outlined for the analytical procedures employed within the various parts of AQWA-NAUT.

The method of data preparation and modelling is fully described and reference is made to the AQWA Reference Manual. The AQWA Reference Manual contains information common to one or more programs in the suite and a complete guide to the format used for input of data into the AQWA suite. It is necessary that both the AQWA-NAUT User Manual and AQWA Reference Manual are available when using the program AQWA-NAUT.

CHAPTER 2 - PROGRAM DESCRIPTION

AQWA-NAUT is a time domain program which uses linear hydrodynamic coefficients supplied by AQWA-LINE, or an equivalent source of linear hydrodynamic data, plus other hydrodynamic and hydrostatic information to simulate the motions of large floating structures in regular or irregular waves.

2.1 PROGRAM CAPABILITY

AQWA-LINE computes the linearised hydrodynamic fluid wave loading on a floating or fixed rigid body using 3-dimensional diffraction/radiation theory. The fluid forces are composed of reactive forces and active excitation forces. The reactive fluid loading is due to motions of the body and may be calculated by investigating the radiated wave field arising from body motions. The active or excitation loading, which induces motion, is composed of diffraction forces due to the scattering of the incident wave field and the Froude-Krylov force due to the pressure field in the undisturbed incident wave.

The incident wave acting on the body is assumed to be harmonic and of small amplitude compared to its wavelength. The fluid is assumed to be ideal so that potential flow theory is valid and therefore used to calculate the hydrodynamic coefficients. Effects which are attributable to the viscosity of the fluid are taken into account in the calculation of the current loads and other hull forces. The hydrostatic fluid forces may also be calculated using AQWA-NAUT and these, when combined with the hydrodynamic forces and body mass characteristics, may be used to calculate the small amplitude rigid body response about a mean position.

An AQWA-NAUT analysis involves meshing the total surface of a structure to create a hydrodynamic and hydrostatic model of it. The non-linear hydrostatic and Froude-Krylov wave forces can then be calculated from this model. At each timestep in a simulation this is performed, together with the calculation of the instantaneous value of all other forces. These are then applied to the structure, via the mathematical model (i.e. a set of non-linear equations of motion) and the resulting accelerations calculated. The position and velocity are determined at the subsequent timestep by integrating these accelerations in the time domain using a two stage predictor-corrector numerical integration scheme.

The process is then repeated at the following timestep and so the time history of the structure motion is produced.

2.2 THE COMPUTER PROGRAM

The program AQWA-NAUT may be used on its own or as an integral part of the AQWA suite of rigid body response programs when it then uses the data base created by AQWA-LINE. When AQWA-LINE is run, a data base is automatically created which contains full details of the fluid loading acting on the body. Another backing file, called the RESTART FILE, is also created and this contains all modelling information relating to the body or bodies being analysed. These two files may be used with subsequent AQWA-NAUT runs or with other AQWA programs. The use of backing files for storage of information has two great advantages which are:

- Ease of communication between AQWA programs so that different types of analyses can be performed with the same model of the body or bodies, e.g. AQWA-LINE regular wave hydrodynamic coefficients being input to AQWA-NAUT for regular or irregular (spectrum) wave simulation.

- Efficiency when using any of the AQWA programs. The Restart facility allows the user to progress gradually through the solution of the problem and an error made at one stage of the analysis does not necessarily mean that all the previous work has been wasted.

The programs within the AQWA SUITE are as follows:

AQWA-LIBRIUM Used to find the equilibrium characteristics of a moored or freely floating body or bodies. Steady state environmental loads may also be considered to act on the body (e.g. wind, wave drift and current).

AQWA-LINE Used to calculate the wave loading and response of bodies when exposed to a regular harmonic wave environment. The first order wave forces and second order mean wave drift forces are calculated in the frequency domain.

AQWA-FER Used to analyse the coupled or uncoupled responses of floating bodies operating in irregular waves. The analysis is performed in the frequency domain.

AQWA-NAUT Used to simulate the motion behaviour of a floating body or bodies operating in regular or irregular waves. Wind and current loads may also be considered and the body motions may be coupled or uncoupled. The analysis is performed in the time domain.

AQWA-DRIFT Used to simulate the motion behaviour of a floating body or bodies operating in irregular waves. The program has particular application to long period motions normally induced by wave drift forces. Wind and current loading may also be applied to the body. The analysis is performed in the time domain.

AQWA-WAVE Use to transfer pressure loads and accelerations from AQWA-LINE to a finite element program.

CHAPTER 3 - THEORETICAL FORMULATION

The theory of key analysis procedures within the AQWA suite of programs are indicated by the various topic headings listed within this section. Only those topics which are of direct relevance to the program being described by this manual (i.e. AQWA-NAUT) are given in detail. The theory which relates more directly to other programs within the AQWA suite is covered in more detail by the appropriate user manual which is duly referenced in this manual.

3.1 HYDROSTATIC LOADING

3.1.1 Hydrostatic Forces and Moments

AQWA-NAUT calculates the hydrostatic forces and moments directly from the integral of hydrostatic pressure on all the elements which make up the submerged part of the body. The hydrostatic force on each element is given by:

$$\bar{F} = -\bar{n} \int_A p(x,y,z)\ dA$$

where

$p(x,y,z)$	=	$-\rho.g.z$ for $z \leq 0$ i.e. the hydrostatic pressure
$\bar{n}$	=	the outward normal vector to the element
A	=	the area of the element
ρ	=	the density of water
g	=	the acceleration due to gravity

The cut waterplane area together with the locations of the centre of buoyancy and the centre of gravity of the body determine the hydrostatic stiffness matrix. At each timestep of the simulation the hydrostatic forces and moments are re-calculated based on the new submerged volume.

In AQWA-NAUT, the hydrostatic forces and stiffnesses acting on each body are specified with respect to a set of axes whose origin is located at and moves with the **centre of gravity** of the body, while the axes remain parallel to the **fixed reference axes** (FRA) (see Section 4.3) at all times.

If a suitable hydrostatic stiffness matrix for the structure is already known, this may be input directly to the program, thus removing the need to re-calculate the stiffness matrix at each timestep. Instead, the program treats the input as a LINEAR STIFFNESS matrix (see Section 4.5). If the buoyancy and stiffness matrices are input in this way then the hydrostatic forces acting on the structure in any position are given by the **matrix** equation:

$$F_{hys}(t) = B + K \, . \, (x_z - x_e)$$

where

B	=	the buoyancy force on the structure at equilibrium
K	=	the six degree of freedom stiffness matrix at the equilibrium position
x_z	=	the position and orientation of the centre of gravity w.r.t. the FRA
x_e	=	the position and orientation of the structure at time t w.r.t. the FRA
$F_{hys}(t)$	=	the hydrostatic force and moment at time t

3.1.2 Hydrostatic Equilibrium

The wave diffraction force, added mass, radiation damping and stiffness matrices of a particular structure must be calculated and expressed with respect to that structure's hydrostatic equilibrium position, i.e. the net hydrostatic and gravitational forces and moments must be zero. It is the motions about this position that AQWA-NAUT calculates. For more details of rules governing hydrostatic equilibrium, see the AQWA-LINE User Manual.

3.1.3 Hydrostatic Stiffness Matrix

For rigid body motion analysis about a mean equilibrium position, AQWA-NAUT requires a hydrostatic stiffness matrix for each body. If the matrix is expressed in terms of motions about the centre of gravity, it will take the following form:

$$K_{hys} = \rho * g * \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K33 & K34 & K35 & 0 \\ 0 & 0 & K43 & K44 & K45 & K46 \\ 0 & 0 & K53 & K54 & K55 & K56 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

where the various terms in the stiffness matrix are:

$$K33 = A$$

$$K34 = K43 = \int_A y\,dA + y_{wp}A$$

$$K35 = K53 = -\int_A x\,dA - x_{wp}A$$

$$K44 = \int_A y^2\,dA + 2y_{wp}\int_A y\,dA + y_{wp}^2 A + z_{gb}\,vol$$

$$K45 = K54 = -x_{wp}y_{wp}A - y_{wp}\int_A x\,dA - x_{wp}\int_A y\,dA - \int_A xy\,dA$$

$$K46 = -x_{gb}\,vol$$

$$K55 = \int_A x^2\,dA + 2x_{wp}\int_A x\,dA + x_{wp}^2 A + z_{gb}\,vol$$

$$K56 = -y_{gb}\,vol$$

The integrals are with respect to the body's cut waterplane area where the total area of the cut waterplane is A and the displaced volume of fluid is 'vol'. The following coordinates are also used:

x_{wp}, y_{wp} and z_{wp}	give the origin of the waterplane axes w.r.t. the centre of gravity
x_{gb}, y_{gb} and z_{gb}	give the centre of buoyancy w.r.t. the centre of gravity

Note: If the body is in a free-floating equilibrium state with no external forces acting on it, then the terms K46 and K56 will be equal to zero and the stiffness matrix will be symmetric.

3.2 MORISON FORCES AND WAVE LOADING

3.2.1 Morison Forces on Tubes

Morison forces, which are applicable to small tubular structures or parts of structures, can be included in an AQWA-DRIFT, AQWA-NAUT or AQWA-LIBRIUM analysis by the use of TUBE elements. The forces are calculated at each timestep (AQWA-DRIFT and AQWA-NAUT) or at each iteration (AQWA-LIBRIUM). The force (normal to the tube axis) on a TUBE element is given by:

F(Morison) = F(drag) + F(Froude-Krylov) + F(wave inertia)

(Note that only drag is calculated in AQWA-LIBRIUM)

$$F(drag) = 0.5 * \rho * C_d * V * Mod(V) * D * l$$

where

ρ	=	density of water
C_d	=	user-specified drag coefficient
V	=	relative fluid velocity (normal to tube axis), i.e.
V	=	V(current) + V(waves) - V(tube)
D	=	diameter of the tube
l	=	length of the tube

For AQWA-DRIFT and AQWA-NAUT only,

$$F(Froude\ Krylov) = \rho * vol * a_w$$

where

vol	=	displaced volume of the tube
a_w	=	local wave acceleration (normal to tube axis)

$$F(wave\ inertia) = \rho * vol * C_a(i) * a_w$$

where

$C_a(i)$	=	added mass coefficient in the 3 local directions X (axial), Y and Z (transverse) of the tube i.e.
$C_a(x)$	=	0
$C_a(y), C_a(z)$	=	user-specified coefficient (default value = 1)

3.2.2 Froude-Krylov Wave Forces

The Froude-Krylov wave forces (due to the wave pressures in an undisturbed fluid field) are calculated at each timestep by integrating the dynamic pressure acting on each submerged plate element of each structure. There are several wave theories available to calculate the Froude-Krylov wave forces and these are defined as follows:

1. Linear wave theory; deep water
2. Linear wave theory; finite depth
3. Second Order wave theory; deep water
4. Second Order wave theory; finite depth

The user can specify whether he wishes to use the first (linear) or second order theories and the program examines the wave and water depth parameters to decide whether a deep or finite depth theory should be used in the analysis.

AQWA-NAUT calculates the Froude-Krylov forces and moments directly from the integral of the wave pressure acting on all the elements which make up the submerged part of the body. The force on each element is given by:

$$\bar{F} = -\bar{n}\int_A p(x,y,z)\ dA$$

where p is now the dynamic wave pressure which depends on the wave theory as follows:

1. Linear, deep water

$$p(x,y,z) = \rho\ g\ a\ e^{kz}\cos(kx-\omega t)$$

2. Linear, finite depth

$$p(x,y,z) = \rho\ g\ a\ e^{kz}\left(\frac{1\ +\ e^{-2kz}\ e^{-2kd}}{1+e^{-2kd}}\right)\ \cos(kx-\omega t)$$

3. Second Order, deep water

$$p(x,y,z) = \rho\ g\ a\ [e^{kz}\ \cos(kx-\omega t)-0.5kae^{2kz}]$$

4. Second Order, finite depth

$$p(x,y,z) = \rho \; g \; a \; e^{kz} \left(\frac{1 + e^{-2kz} \; e^{-2kd}}{1 + e^{-2kd}} \right) \cos(kx - \omega t) \; +$$

$$\rho \; g \; \frac{k \; a^2 \; e^{-2kd}}{1 - e^{-4kd}} \left[\frac{6 e^{2kz} \; (1 + \; e^{-4kz} \; e^{-4kd}) \; - 1}{(1 - e^{-2kd})^2} \right] \cos 2(kx - \omega t) \; -$$

$$\rho \; g \; \frac{k \; a^2 \; e^{2kz}}{2} \left(\frac{1 + e^{-4kz} \; e^{-4kd}}{1 - e^{-4kd}} \right)$$

where

x	=	x cos θ + y sin θ
θ	=	wave direction
k	=	wave number (2π /wavelength)
ω	=	wave frequency
a	=	wave amplitude
d	=	water depth
ρ	=	density of water
g	=	acceleration due to gravity
t	=	time

At each timestep the Froude-Krylov wave forces and moments are re-calculated based on the new structure position.

3.3 DIFFRACTION/RADIATION WAVE FORCES

The total wave forces acting on a structure are the sum of the Froude-Krylov forces described above and the diffraction forces due to the disturbance of the incident waves by the structure. For large floating structures the diffraction and radiation components are of comparable magnitude and are calculated for regular waves by AQWA-LINE or similar programs. Details of the calculation can be found in the AQWA-LINE user manual.

In AQWA-NAUT the diffraction force and Froude-Krylov force (whether calculated from the structure mesh or input from AQWA-LINE directly) are added together to form the TOTAL WAVE FORCE coefficient which is used to calculate the wave forces at each timestep of the simulation.

The diffraction forces at each timestep depend upon the relative heading of the waves to the structure. AQWA-LINE calculates the diffraction forces for a number of user defined wave directions. The diffraction force at any relative wave heading can then be found by interpolating between these values. The relative wave heading is derived from the slow axis rotations (see Section 3.15.3) i.e. roll, pitch and yaw. If the linear hydrostatic stiffness option (LSTF) has been selected then only the slow axis yaw is used in the interpolation.

3.4 MEAN WAVE DRIFT FORCES

AQWA-NAUT does not calculate the response of a structure to mean wave drift forces.

3.5 SLOWLY VARYING WAVE DRIFT FORCES

AQWA-NAUT does not calculate the response of a structure to slowly varying wave drift forces.

3.6 INTERACTIVE FLUID LOADING BETWEEN BODIES

The importance of fluid interaction between structures will depend on both body separation distances and the relative sizes of the bodies. All the programs in AQWA can now handle full hydrodynamic interaction, including radiation coupling, for up to 10 structures. This is essential for accurate modelling of vessels which are in close proximity. The hydrodynamic interaction is applicable to all AQWA programs and includes not only the Radiation coupling but the Shielding Effects as well. There are some restrictions, the main ones being that hydrodynamic interaction cannot be used with forward speed and shear force, bending moment and splitting force cannot be calculated in the AGS if two or more hydrodynamically interacting structures are modelled.

3.7 STRUCTURAL ARTICULATIONS AND CONSTRAINTS

3.7.1. Articulations

Articulations are modelled in AQWA-NAUT by specifying a point on a structure about which 0, 1, 2 or 3 rotational freedoms are constrained (see Section 4.13).

Mathematically this corresponds to additional constraint equations in the formulation of the equations of motion. At each articulation between two structures (or a structure and ground) the constraint equation relates the acceleration of the articulation point on one structure to the acceleration of the articulation point on the other structure. These accelerations must be identical for compatibility, i.e.

$$a_{p1} = a_{g1} + w_1 * r_1 + w_1 * (w_1 * r_1)$$

$$a_{p2} = a_{g2} + w_2 * r_2 + w_2 * (w_2 * r_2)$$

where

a_{pi} = the translational acceleration of a point on structure i
a_{gi} = the translational acceleration of the centre of gravity of structure
w_i = the angular acceleration of structure i
r_i = the vector from the centre of gravity to the articulation on structure i
a_{p1} = a_{p2}

for each constrained freedom in the constraint equations.

3.7.2. Constraints

Constraints are modelled in AQWA-NAUT by modifying the equations of motion so that the accelerations in the constrained degrees of freedom are forced to be zero.

3.8 WIND AND CURRENT LOADING

3.8.1 Wind and Current

The wind and current drag are both calculated in a similar manner from a set of user-derived environmental load coefficients, covering a range of heading angles. The input coefficients are defined as

(drag force or moment)/(wind or current velocity) ^{2}

The force is calculated at each timestep by

$$F_j = C_j(\theta) * rv^2$$

where	F_j	=	the force vector for degree of freedom j
	C_j (θ)	=	the value of the wind or current coefficient for wind relative angle of incidence θ
	rv	=	the velocity relative to the slow position of the structure for the current or the velocity relative to the total position of the structure for the apparent wind.

The wind and current velocity in the above expression (rv) is calculated to be the relative velocity between the absolute wind and current velocity and the SLOW velocity of the structure. This is because the time scale of the wind and current flow is much longer than the typical wave periods, so the wind and current flows do not have time to develop in response to the wave frequency variations of position.

According to the above definition, the coefficients are dimensional and the user must conform to a consistent set of units. (For details see Appendix A of the Reference Manual.).

3.8.2 Yaw Rate Drag Force

It is clear that the wind and current loads, when calculated as described in Section 3.8.1, have no dependence on yaw rotational velocity. This contribution is calculated separately and the yaw rate drag moment (F_6) is given as follows:

$$F_6 = YRDC \cdot \sum_{i=L_{\min}}^{L_{\max}} x_i \cdot \left[(cy \cdot cur) - (cy + a_i) \cdot \sqrt{cx^2 + (cy + a_i)^2} \right]$$

where

$$cx = cur * \cos(\theta)$$
$$cy = cur * \sin(\theta)$$
$$a_i = x_i \cdot rz$$

In the above

cur	=	the magnitude of the relative wind or current
θ	=	the relative angle of incidence
rz	=	the yaw velocity
YRDC	=	the yaw rate drag coefficient
x_i	=	the position along the length of the structure

and the summation is over forty points equally spaced along the length of the structure between Lmin and Lmax.

If the centre of gravity is not at the geometric centre of the structure's projection on the water surface, the yaw rate drag will have a lateral component given by a very similar expression, i.e.

$$F_6 = YRDC * \sum_{i=L_{min}}^{L_{max}} [(cy * cur) - (cy + a_i) * \sqrt{cx^2 + (cy + a_i)^2}]$$

3.9 THRUSTER FORCES

Up to ten thruster forces may be applied to each body. The magnitude of the thrust vector is constant and the direction of the vector is fixed to and moves with the body. The program calculates the thruster moments from the cross product of the latest position vector of the point of application and the thrust vector.

3.10 MOORING LINES

The types of mooring lines available include both linear and non-linear cables. These can be summarized as follows:

A. Linear Cables

- Linear elastic cables (LINE)
- Winch cables (WINCH)
- Constant force cables (FORC)
- Pulleys (PULY)
- Drum winch cable (LNDW)

B. Non-Linear Cables

- Catenary cables (CATN)
- Steel wire cables (SWIR)
- Non-linear cables described by a POLYNOMINAL of up to fifth order (POLY)
- Composite catenary cables (COMP)
- Intermediate buoys and clump weights (BUOY)

Finally, fixed and floating fenders (FEND) can be defined. These are classified as a type of mooring line and have non-linear properties.

3.10.1 Force of Constant Magnitude and Direction

The constant "FORCE" line acts at the centre of gravity of the body in question. The force magnitude and direction are assumed fixed and DO NOT CHANGE with movement of the body. Thruster forces, which do change direction with the body, are described in Section 3.9.

3.10.2 Constant Tension Winch Line

The "WINCH" line maintains a constant tension provided the distance between the ends of the line is greater than a user specified 'unstretched length'. The direction of the tension depends on the movement of the end points.

3.10.3 Weightless Elastic Hawsers

The elastic hawser tensions are simply given by the extension over the unstretched length and their load/extension characteristics. The load/extension characteristics can either be linear (like a spring) or take the following polynomial form:

$$P(e) = a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_5 e^5 \qquad (3.10.1)$$

where

P = the line tension
e = the extension

3.10.4 Heavy Inelastic Catenary Chains

Catenaries in AQWA are considered to be uniform, inelastic, with significant mass and no fluid loading except for buoyancy. As the solution of the catenary equations is well documented (see Reference 1 in Appendix B) the summary of the solution used in AQWA is presented. The equations can be expressed in an axis system whose local X axis is the projection of the vector joining the attachment points on the sea bed and whose z axis is vertical. For catenaries which have zero slope at the contact/attachment point on the sea bed these equations can be written as:

$$L = \frac{T_0}{W} \sinh\left(\frac{Wx}{T_0}\right)$$

$$z = \frac{T_0}{W}\left(\cosh\left(\frac{Wx}{T_0}\right) - 1\right)$$

and $T_e = T_0 + Wz$

where

L = Length of the catenary from the attachment point on the structure to the contact point on the sea bed

Given the following notation,

T_e = Total tension at the attachment point on the structure
T_0 = Horizontal tension at the sea bed
W = Weight of the line less that of the displaced water per unit length
x = Horizontal distance between the attachment point on the structure and the **contact** point on the sea bed
x_r = Horizontal distance between the attachment point on the structure and the **anchor** point on the sea bed
z = Vertical distance between the attachment point on the structure and the anchor point on the sea bed

The stiffness matrix, (K), relating the force to the translational displacements at the attachment point of the structure, is written as:

$$K = K_{xz}\begin{bmatrix} \dfrac{WL}{T_e - T_0} & 1 & 0 \\ 1 & \dfrac{T_e}{x_r} & 0 \\ 0 & 0 & \dfrac{T_e}{zT_0}\left(x - \dfrac{LT_0}{T_e}\right) \end{bmatrix}$$

where

$$K_{xz} = T_0\left(z - \frac{WL^2}{T_e} + \left(x - \frac{LT_0}{T_e}\right) * \frac{WL}{(T_e - T_0)}\right)^{-1}$$

K is rotated about the Z axis until parallel to a reference axis system. The stiffness matrix, K, for each mooring line is defined at the attachment point on the structure, and must be translated to a common reference point and axis system. In the AQWA suite, the centre of gravity is chosen. This translation, as formulated in Section 3.10.3, is applied to any local stiffness matrix and force applied at a point on a structure.

3.10.5 Translation of the Mooring Line Force and Stiffness Matrix

The formulation of a vector translation may be applied directly to a force and displacement in order to translate the stiffness matrix, K, from the point of definition to the centre of gravity. It should be noted however that if the stiffness matrix is defined in a FIXED AXIS SYSTEM, which does **not** rotate with the structure, an additional stiffness term is required This relates the change of moment created by a constant force applied at a point when the structure is rotated.

The full 6∗6 stiffness matrix (K_g) for each mooring line, relating displacements of the centre of gravity to the change in forces and moments acting on that structure at the centre of gravity, is therefore given by

$$K_g = \begin{bmatrix} I \\ T_a^t \end{bmatrix} [K] \begin{bmatrix} I & T_a \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & P_m T_a^t \end{bmatrix}$$

$$K_g = \begin{bmatrix} K & K T_a \\ T_a^t K & T_a^t K T_a \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & P_m T_a^t \end{bmatrix}$$

where

$$T_a = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \qquad P_m = \begin{bmatrix} 0 & Pz & -Py \\ -Pz & 0 & Px \\ Py & -Px & 0 \end{bmatrix}$$

x,y,z = Coordinates of the attachment point on the structure relative to the centre of gravity.

Px,Py,Pz = The X, Y and Z components of the tension in the mooring line at the attachment point on the structure.

Note The term $P_m.T_a^t$ is NOT symmetric. In general, only a structure in static equilibrium will have a symmetric stiffness matrix. However this also means that if the mooring forces are in equilibrium with all other conservative forces then the TOTAL stiffness matrix will be symmetric.

The force at the centre of gravity (P_g) in terms of the forces at the attachment point (P_a) is given by:

$$P_g = \begin{bmatrix} I \\ T_a^t \end{bmatrix} \begin{bmatrix} P_a \end{bmatrix} = \begin{bmatrix} P_a \\ T_a^t \; P_a \end{bmatrix}$$

3.10.6 Stiffness Matrix for a Mooring Line Joining Two Structures

When two structures are attached by a mooring line, this results in a fully-coupled stiffness matrix, where the displacement of one structure results in a force on the other. This stiffness matrix may be obtained simply by considering that the displacement of the attachment point on one structure is equivalent to a NEGATIVE displacement of the attachment point on the other structure. Using the definitions in the previous section the $12 * 12$ stiffness matrix K_G is given by:

$$K_G = \begin{bmatrix} I \\ T_a^t \\ -I \\ -T_b^t \end{bmatrix} \begin{bmatrix} K \end{bmatrix} \begin{bmatrix} I & T_a & -I & -T_b \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & P_m T_a^t & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & P_n T_b^t \end{bmatrix}$$

where

$$T_b = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \qquad P_n = \begin{bmatrix} 0 & Pz & -Py \\ -Pz & 0 & Px \\ Py & -Px & 0 \end{bmatrix}$$

x,y,z	=	Coordinates of the attachment point on the second structure relative to its centre of gravity
Px,Py,Pz	=	The X, Y and Z components of the tension in the mooring line at the attachment point on the second structure

3.11 WAVE SPECTRA

The method of wave forecasting for irregular seas is achieved within the AQWA suite by the specification of wave spectra. For further details of spectral forms the reader is referred to Appendix E of the AQWA Reference Manual.

Because of the manner in which the drift force is calculated, it is required that the spectrum be defined such that the spectral area between adjacent spectral lines is equal. Thus spectral lines will be close together when the spectral density is large around the spectral peak, and spaced further apart when spectral density is low at either end of the spectrum.

The program does this by calculating the spectral density at a very large number of raster points on the frequency scale, which are equally spaced between the defined spectrum end frequencies. The program uses a default of 5000 raster lines. The raster is then divided into the required number of spectral 'packets' such that the spectral area of each packet is equal. Linear interpolation is used between the raster points to help define the limits of the packets. A spectral line is then placed at the frequency such that the first moment of area of the spectral energy in the packet is zero. This is equivalent to defining the spectral line which represents the packet at the centre of area of the packet.

3.12 STABILITY ANALYSIS

AQWA-NAUT performs no formal stability analysis, although it may be possible to determine an equilibrium configuration from a still water run. Some physical systems which can be modelled by AQWA-NAUT may be inherently statically or dynamically unstable. This may be detected by careful inspection of the resulting time histories. Note that dynamic instability is dependent on the initial conditions of the simulation. AQWA-LIBRIUM is designed to investigate the stability of systems and details are given in the AQWA-LIBRIUM User Manual.

3.13 FREQUENCY DOMAIN SOLUTION

AQWA-NAUT is a time-domain program for the analysis of non-linear systems in regular or irregular waves. Linear systems or linearised systems in irregular waves can be analysed in the frequency-domain by AQWA-FER. Details are given in the AQWA-FER User Manual.

3.14 TIME HISTORY SOLUTION IN IRREGULAR WAVES

AQWA-NAUT is a time-domain program for the analysis of non-linear systems in regular or irregular waves. For more details on the analysis of the systems in irregular waves please see AQWA-DRIFT User Manual.

When AQWA-NAUT is used with irregular waves:-

- convolution is mandatory
- 2nd order wave drift forces are not included

3.15 TIME HISTORY SOLUTION IN REGULAR WAVES

3.15.1 Time Integration of the Equation of Motion

At each timestep in the simulation, the position and velocity of the structure are known since they have been predicted at the previous timestep. From these, all the position and velocity dependent forces i.e. damping, mooring force, total wave force etc. are calculated. These are then summed to find the six total forces and moments for each structure (one for each degree of freedom). The total force is then equated to the product of the total mass (structural and added) and the rigid body accelerations.

The accelerations at the next timestep can thus be determined. It has been found necessary to use an extremely reliable two-stage predictor-corrector integration scheme to predict the position and velocity of the structures at the following time increment. The forces are then recomputed with the new position and velocity and the process is repeated to create, step by step, the time history of motion.

3.15.2 Initial Conditions and Transients

AQWA-NAUT solves the second order differential equations of motion for each structure, integrating them to form a time-history. For this, the program requires the initial conditions in order to begin the integration. Details of how the initial position is input can be found in Section 4.15 of the AQWA Reference Manual. As explained there, for simulations including wave frequency forces it is usual for the user to define an initial position which will prevent transients.

The wave frequency response of the structure is determined in the frequency domain by AQWA-LINE and is stored in the form of response amplitude operators (RAOs) at a series of frequencies. A time history of the wave frequency response can be found by combining the response amplitude operators with the corresponding wave frequency. This is done for each degree of freedom as follows:

$$x(t) = \mathrm{Re}\ a \,.\, X \,.\, \exp\left(-\omega.t + k.x_P\right) \qquad (3.14.5)$$

where

Re	=	the real part of the complex expression
X	=	the complex response amplitude operator at wave frequency ω
ω	=	the frequency of the regular wave component
k	=	the wave number corresponding to a wave of frequency ω
x_p	=	the distance from the origin of the wave system perpendicular to the wave direction
a	=	the amplitude of the regular wave component
x(t)	=	the instantaneous displacement at time t

A similar expression is used to calculate the initial velocity using the fact that

$$\dot{x} = i.\omega.x$$

where

x = the complex position at frequency ω
$\dot{x}$ = the complex velocity at frequency ω

This ensures that the TOTAL initial condition contains a position corresponding to the steady state solution in response to the wave frequency forces at that instant. By giving the structure that initial position close to its equilibrium position, transients can be minimised.

Where transients exist, an initial linear ramp damping function, which decays to zero magnitude after a specified time, can be applied to each structure's degree of freedom, i.e

$$D_i\,(t) = c_i\,t_f - c_i\,t$$

provided $t \leq t_f$,

where

i = structure degree of freedom
$D_i\,(t)$ = ramp damping
c_i = ramp damping coefficient
t_f = time at which ramp function decays to zero
t = time after start of simulation

This function suppresses initial transient effects but allows the true steady state response to develop after time t_f

If it is desired to examine transients then the user can specify a 'no-wave' condition and give the structure an initial displacement from the equilibrium condition.

3.15.3 Slow Axis Position

The total position of the structure can be thought of as being comprised of a slow position and a fast wave frequency position. These 'slow' and 'wave frequency' positions added together give the 'total' position.

In the case where both slow motions and wave frequency motions exist the current and wind forces (and wave drift forces in AQWA-DRIFT) are applied to the structure in an axis system which follows the SLOW position. This is done because the flows take a finite time to develop and cannot follow the rapid oscillations due to the wave frequency forces. For example, calculations of current drag, which involve the relative velocity, use the relative velocity between current and SLOW position. The force is then applied in the relative direction between current and yaw of the structure. The same applies to wind (and drift) forces. The slow position is obtained from the total position by filtering the position through a low pass 2 Pole Butterworth filter which separates out the slow and fast oscillations. This is achieved by solving the following equation at each timestep:

$$x_s(i) = b_o\, x_t(i) - a_1\, x_s(i-1) - a_2\, x_s(i-2) \qquad (3.14.6)$$

where

x_s = the filtered slow position

x_t = the total position

and the other variables are defined below.

The filter characteristics in the frequency domain are described by the transfer function (as shown in fig 3.1)

$$|H(f)|^2 = \frac{1}{1 + \left(\dfrac{\sin(\pi\ f\ DT)}{\sin(\pi\ CF\ DT)}\right)^4}$$

The cut-off frequency, CF, is chosen by the program to eliminate the wave frequency effects but to retain the slow drift effects.

```
          |
    1.0 -|.....                     |
          |    | .                   |
          |    |  .                  |
          |  0.01Hz.                 |<--- wave frequency domain---
          |  (100s)                  |
          |       .                  |
   |H(f)| |                          |
          |        .
          |
          |          .
          |
          |       CF   .
          |  cutoff | freq .
          |         |        .
          |         |             .  |
          |_________|________________|__________________________
                    |                |
                 0.02Hz           0.055Hz                  frequency
                  (60s)            (18s)                      (Hz)
```

Figure 3.1 - 2 Pole Butterworth Filter

The WAVE position is filtered out of the TOTAL position leaving the SLOW position.

The coefficients b_0 , a_1 and a_2 are derived from the following formulae:

DT	=	sampling rate (> 2.0 secs)
CF	=	cutoff frequency (0.02Hz)
A	=	$8+ 16.0 \sin(\pi.DT.CF)^4$
B	=	$(A - (A-64)^{0.5} / 2)^{0.5}$
C	=	$- (2/B) + ((4/B)^2 - 4))^{0.5} / 2$
a_1	=	B.C
a_2	=	C.C
b_0	=	1 + C. (B + C)

3.15.4 Motions at Wave Frequency

The structure will be subjected to the first order wave forces described above. The total wave frequency force is composed of the wave force, added mass force and damping force. It can be written:

$$F_{wf}(t) = \text{Re}\left[f - m_a\,\ddot{x}. - c_r.\dot{x} \right] . \exp(-\omega.t + k.x) \tag{3.14.2}$$

where

$\ddot{x}$	=	$-\omega^2 .x$
$\dot{x}$	=	$i\,\omega.x$
i	=	the imaginary quantity $(-1)^{0.5}$
w	=	the wave frequency
k	=	the wave number
f	=	the complex total wave force
x	=	the complex position, i.e. the complex response amplitude operator
$\dot{x}$	=	the complex velocity
$\ddot{x}$	=	the complex acceleration
c_r	=	the system linear damping matrix
m_a	=	the hydrodynamic added mass matrix

and

$$x = H\,F$$

$$H = (K - m_s\,\omega^2)^{-1}$$

where

m_s	=	the structural mass matrix
K	=	the total system stiffness matrix
F	=	the total wave frequency force

3.15.5 Harmonic Analysis at Wave Frequency

In order to aid the interpretation of results the simulations are post-processed on a cycle by cycle basis, a cycle being defined as the wave period. The following information is derived from the response:

1. mean amplitude
2. fundamental wave frequency response amplitude and phase
3. harmonic components amplitude and phase
4. residual error due to transients

This is achieved by transforming the response into the frequency domain by means of the discrete Fourier Transform. This allows the identification of the amplitude and phase of the fundamental wave frequency and harmonic components of the response up to that of the Nyquist frequency (half the sampling frequency) i.e.

$$X(f_k) = T \sum_{j=0}^{N-1} X_0(j)\ \exp^{-i 2\pi j \frac{k}{N}}$$

$$\mathrm{amp}(f_k) = |X(f_k)|$$

$$\Phi(f_k) = \tan^{-1}\left[\frac{\mathrm{Re}(x(f_k))}{\mathrm{Im}(x(f_k))}\right]$$

where

X_0	=	original response time history
f_k	=	k/NT
N	=	number of samples in cycle
k	=	harmonic component i.e.
		0 = d.c level
		1 = fundamental
		2 = first harmonic
		3 = second harmonic, etc

These components can then be combined by means of the inverse Fourier transform to create an equivalent time-history over the cycle

$$X_r(j) = \frac{1}{NT}\sum_{k=0}^{N-1} X(k)\ \exp^{i2\pi j\frac{k}{N}}$$

where

X_r = re-created response time history

From this the residual amplitude over the cycle can be derived as

$$amp_r = \sqrt{\frac{1}{N}\sum_{j=1}^{N} X_0(j)^2} - \sqrt{\frac{1}{N}\sum_{j=1}^{N} X_r(j)^2}$$

The residual amplitude gives a measure of how much transient effect has occurred during the cycle. A residual amplitude of greater than 10% indicates that there are significant transients in the response and that the cycle should be ignored.

3.16 LIMITATIONS OF THEORY

The main theoretical limitations of AQWA-NAUT should be clearly understood by the user. Since the program uses data calculated by AQWA-LINE, the limitations of the input data must also be understood. Refer to AQWA-LINE manual Section 3.15 for details of the assumptions made. The AQWA-LINE assumptions which affect the analysis, together with the major limitations due to assumptions inherent in AQWA-NAUT, are listed below:

AQWA-LINE assumptions

1. The theory at present relates to a body or bodies which have zero or small forward speed.

2. The wave frequency motions are to first order and hence must be of small amplitude.

3. The fluid domain is assumed ideal and irrotational in the calculations of the added mass, dampings and wave forces.

AQWA-NAUT assumptions

1. The diffraction and radiation parameters are calculated by AQWA-LINE (linear theory), therefore all terms such as diffraction force, added mass and radiation damping are linear quantities.

CHAPTER 4 - MODELLING TECHNIQUES

This chapter relates the theory in the previous section to the general form of the input data required for the AQWA suite. All modelling techniques related to the calculations within AQWA-NAUT are presented. This may produce duplication in the user manuals where the calculations are performed by other programs in the suite. Other modelling techniques which are indirectly related are included to preserve subject integrity; these are indicated accordingly.

Where modelling techniques are only associated with other programs in the AQWA suite, the information may be found in the appropriate sections of the respective user manuals. (The section numbers below correspond to those in the other user manuals as a convenient cross reference).

4.1 INTRODUCTION

Each type of analysis the user wishes to perform requires a model of the floating structure which may be different from the model used in other types of analysis. An approximate model may be acceptable in one analysis or even omitted altogether in another.

In general, there are only two differences in the models required for each program in AQWA.

The first is in the description of the structure geometry (the mass distribution model is common), which is achieved by describing one or more tube or pressure plate elements. In total the elements describe the whole structure and thus the hydrostatic and hydrodynamic model.

The second is in the description of the environment, i.e. mooring lines, wind, current, irregular and regular waves. These parameters are not common to all programs.

When using AQWA-NAUT, a hydrodynamic model is required from which the hydrostatic and Froude-Krylov wave forces are determined. The remaining structure hydrodynamic properties are determined from a linear radiation/diffraction program like AQWA-LINE. When AQWA-LINE has been run, all these parameters can be transferred automatically from backing files. If AQWA-LINE has not been run previously, the hydrodynamic and diffraction wave loading coefficients are required as input data.

The differences in the hydrostatic and hydrodynamic models, which are associated with the structure geometry for AQWA-LINE/LIBRIUM/NAUT, may be summarised in the form of simple restrictions, i.e.

Hydrostatic Model (AQWA-LINE/LIBRIUM/NAUT	-	Tubes and pressure plates. No restrictions
Hydrodynamic Model (AQWA-LINE)	-	Pressure plates. Restricted in geometry, size and proximity to each other and boundaries.
Hydrodynamic Model (AQWA-NAUT)	-	Tubes and pressure plates. Restricted only in size relative to the wave length

In practice this means that there is a hydrodynamic model for AQWA-LINE to which other elements are added for AQWA-NAUT. If the user wishes, and when restrictions allow, a more approximate model may be defined with less elements to minimise computing costs.

In some applications, it is sufficiently accurate to describe the hydrostatic and Froude=Krylov forces acting on the structure as coefficients and a structure surface model is not required. In this case all the hydrostatic and hydrodynamic loading coefficients and wave forces can either be transferred automatically from the AQWA-LINE backing file, or, if AQWA-LINE has not been run previously, they may be input manually.

4.2 MODELLING REQUIREMENTS FOR AQWA-NAUT

AQWA-NAUT requires models of the inertia, hydrostatic and hydrodynamic properties of the bodies, the moorings and the environmental loads. Some analyses using AQWA-NAUT might not require all of these parameters to be modelled. In general, AQWA programmes do not require modelling of ALL aspects of the system for two reasons:

1. The calculations associated with a particular model may have been done previously by one of the AQWA programs and the results can be transmitted either through backing files or manually as card image input.

2. The mechanics of the system are such that a model is not required.

4.2.1 When Used as an Independent Program

The models used by AQWA-NAUT follow closely the form used by the rest of the AQWA suite. In most cases, the same model should be applicable to all AQWA programs. However, the user may choose to adopt different models of the same system.

In AQWA-NAUT the total surface of the hull requires modelling as against only the wetted part of the hull in the AQWA-LINE model. Hence the user may choose either to use two different meshes for the two programs or to use a mesh which is acceptable to both. The size of the elements within the mesh is governed by the length of the wave to be used in the analysis.

The general modelling requirements for AQWA-NAUT are as follows:

1. Total body surface description

2. Body mass and inertia characteristics.

3. Wave hydrodynamic description.

4. Wind and current force coefficient description.

5. Description of mooring configuration.

6. Analysis environment description.

7. Time integration parameters.

These categories will be described in the following sections:

4.2.2 AQWA-NAUT Following an AQWA-LINE Run

After an AQWA-LINE run or a series of runs has been completed then it may be required to utilise the results in an AQWA-NAUT analysis. AQWA-LINE automatically produces a data-base file and RESTART FILE. These contain all the information required by AQWA-NAUT concerning the structure's mass and inertia properties, the hydrostatic properties and the wave hydrodynamic properties (in the form of a description of the added mass, damping and wave forces at a series of regular wave frequencies). This information corresponds to categories 1. 2. and 3. of Section 4.2.1. which, if requested, is automatically transferred to the AQWA-NAUT run.

4.3 DEFINITION OF STRUCTURE AND POSITION

Full details may be found in the AQWA Reference Manual.

4.3.1 Axis Systems

AQWA-NAUT uses several axis systems for different purposes.

1. FIXED REFERENCE AXES (FRA)

The OXY plane of the FRA lies on the free surface and OZ points vertically upwards.

2. LOCAL STRUCTURE AXES (LSA)

The LSA is always parallel to the FRA and the origin is located at and moves with the centre of gravity of each body (see Figure 4.1).

3. SLOW AXIS SYSTEM (SLA)

The slow axis system is similar to the (LSA) in that its origin is located at the centre of gravity, but differs in that it follows only the slow motion of the structure (order of 100 seconds).

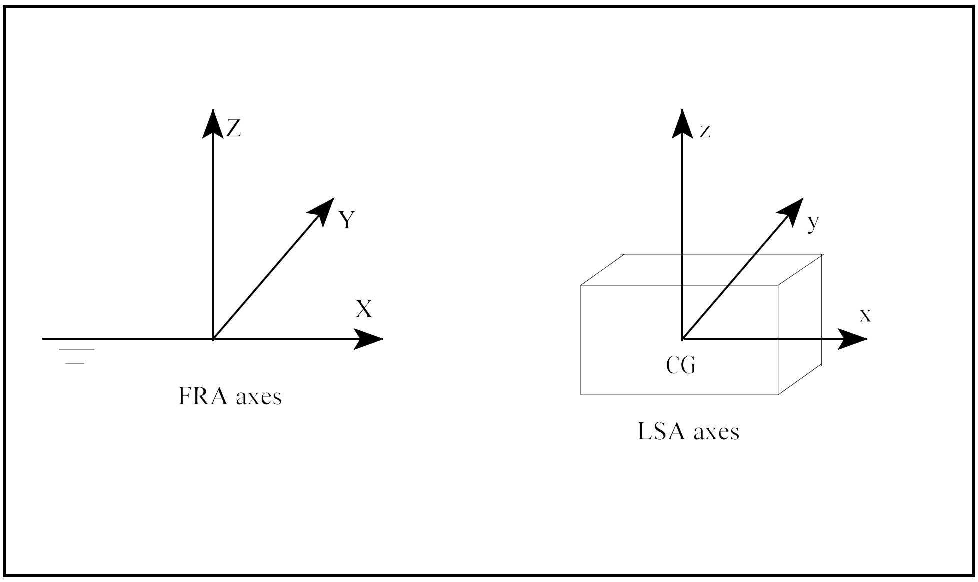


Figure 4.1 - Axis Systems

4.3.2 Conventions

The AQWA suite employs a common sign convention with the axes as defined in the previous section.

Translations of a body in the X, Y and Z direction are termed SURGE, SWAY and HEAVE and are positive in the positive direction of their respective axes. Rotations about the X, Y and Z axes are termed ROLL, PITCH and YAW. The positive sense of these is determined by the right hand screw rule.

4.3.3 The Structural Definition and Analysis Position

In the description of the body geometry and mass distribution, the user may define the structure in any position. There are, however, three **important considerations** when choosing the position in which to define the structure.

e.g. If the structure is a ship or barge, conventional terminology for motion along, and rotation about the longitudinal axis is SURGE and ROLL. However, if the longitudinal axis is defined parallel to the FRA Y-axis then rotational motion about this axis will be termed PITCH, and translational motion along this axis SWAY. Thus, conventional body surge and roll will be termed sway and pitch by the program.

For other structures, e.g. semi-submersibles, this may not be so relevant. The user must take due note of the terms associated with the motions about the axes and is recommended to define all ship/barge shaped structures with the longitudinal axis parallel to the FRA X-axis.

4.4 STRUCTURE GEOMETRY AND MASS DISTRIBUTION

When AQWA-NAUT is used following an AQWA-LINE run, the structure geometry and mass distribution are transferred automatically from the backing files produced by AQWA-LINE. This section therefore describes the modelling of the structure geometry and mass distribution when AQWA-NAUT is used independently. (See the AQWA-LINE user manual when this is not the case).

4.4.1 Coordinates

Any point on the structure in the modelling process is achieved by referring to the X, Y and Z coordinate of a point in the FRA which is termed a 'NODE'. The model of the structure geometry and mass distribution consists of a specification of one or more elements (see also Sections 4.1 and 4.4.2) whose position is defined by these nodes. Each node has a NODE NUMBER, which is chosen by the user to be associated with each coordinate point. Nodes themselves do not contribute to the model but may be thought of as a table of numbers and associated coordinate points to which other parts of the model refer.

Note that nodes are also used to define the position of other points not necessarily on the structure, e.g. the attachment points at each end of a mooring line. (Note: All nodes to be used during an analysis should be defined at the start of the analysis).

4.4.2 Elements and Element Properties

Each body is modelled by one or more finite elements. These elements could be a combination of tubes, point masses, point buoyancies and quadrilateral or triangular pressure plates. This facility enables simple modelling of bodies of arbitrary shape. With the exception of plate elements, each element is associated with a set of material and geometric properties which define the structural masses and inertias of the system. When pressure plates are used to simulate the fluid pressure, a point mass with equivalent mass and inertia is needed to model the mass distribution of the body.

The program allows the user to take full advantage of symmetry in specific problems. Up to four-fold symmetry is accommodated.

4.5 MORISON ELEMENTS

There are three Morison elements available within AQWA-DRIFT and AQWA-NAUT, namely:

- Tube element (TUBE)
- Slender Tube element (STUB)
- Disc element (DISC)

Tube elements are defined by specifying end nodes, diameter, wall thickness and endcut lengths (over which the forces are ignored). Each tube element may have a different drag and added mass coefficient associated with it. Drag coefficients can be defined as functions of Reynolds Number.

Full consideration is given to the variation of local fluid motion over the tube length and to partial submersion of members.

Morison drag and added mass are evaluated on all submerged or partially submerged tubes but, if the user wishes to suppress these calculations, the drag and added mass coefficients on any or all tubes of a given structure may be set to zero.

Slender tube (STUB) elements differ from TUBE elements in the following respects:

1. STUB elements permit tubes of non-circular cross section to be modelled, by allowing the tube properties (diameter, drag coefficient, added mass coefficient) to be specified in two directions at right angles.

2. Longer lengths of tube can be input, as the program automatically subdivides STUB elements into sections of shorter length for integration purposes.

3. An improved (second order) version of Morisons equation is used to calculate the drag and inertia forces on STUB elements. This is particularly useful in the study of dropped objects.

4. STUB elements should, however, only be employed if the (mean) diameter is small compared with the length.

A DISC element (DISC) has no thickness and no mass (users can define a PMAS and attach it to a disc if necessary), but has drag coefficient and added mass coefficient in its normal direction. Therefore, a DISC does not have Froude-Krylov and hydrostatic force. A DISC element has only a drag force and an added mass force.

4.5.1 Reynolds Number Dependent Drag Coefficients

Reynolds number effects on drag can be important at model scale. Drag coefficients are normally considered constant (as is often the case at full scale, i.e. large Reynolds numbers). However, experimental evidence shows that the Reynolds number is not just a simple function of the velocity and diameter for cylinders with arbitrary orientation to the direction of the fluid flow. Considerable improvement in agreement with model tests can be obtained by using a scale factor to obtain a local Reynolds Number and interpolating from classical experimental results,

where

Local Reynolds Number	=	(U*D/ν) / (scale factor)
U	=	local fluid velocity transverse to the axis of the tube
D	=	tube diameter
ν	=	kinematic viscosity of water

from which drag coefficients can be interpolated from the Wieselberg graph of drag coefficient versus Reynolds number for a smooth cylinder.

Alternatively, a general multiplying factor for drag can be used.

4.6 STATIC ENVIRONMENT

4.6.1 Global Environmental Parameters

The global or static environmental parameters are those which remain constant or static throughout an analysis and comprise the following:

Acceleration due to Gravity:	Used to calculate all forces and various dimensionless variables throughout the program suite.
Density of Water:	Used to calculate fluid forces and various dimensionless variables throughout the program suite
Water Depth:	Used in AQWA-NAUT, through the wave number, to determine whether the wave is in a deep water or finite depth regime and to calculate phase relationships for various parameters and the clearance from the sea bed.

4.7 LINEAR STIFFNESS

This section is ONLY applicable if the user specifies that the stiffness is to be considered linear, i.e. the stiffness remains linear even for large angle displacement. This is an optional specification (see Appendix A) and means that a linear stiffness matrix is used in the analysis instead of assembling the stiffness from the hydrostatic element description.

4.7.1 Hydrostatic Stiffness

There are some cases where a finite element mesh of a body is neither possible (through lack of detailed geometrical data) nor necessary (e.g. only horizontal planar motion is required, or the movement of the body is likely to be small). In these cases, the user can model the hydrostatic stiffness of that particular body via the LSTF option (Linear STIFfness). If the LSTF option is selected, then the only user input required is the buoyancy and hydrostatic stiffness matrix at equilibrium. The program will assume constant buoyancy and stiffness throughout.

4.7.2 Additional Linear Stiffness

The additional linear stiffness is so called to distinguish between the linear hydrostatic stiffness and linear stiffness terms from any other mechanism.

Although all terms in the additional linear stiffness can be included in the hydrostatic stiffness matrix, the user is advised to model the two separately. The most common situations where an additional stiffness model could be used are when

- modelling facilities for a particular mechanism are not available in the AQWA suite
- the hydrostatic stiffness matrix is incomplete
- the user wishes to investigate the sensitivity of the analysis to changes in the linear stiffness matrix.

In practice, it is only in unusual applications that the user will find it necessary to consider the modelling of additional linear stiffness.

4.8 WAVE FREQUENCIES AND DIRECTIONS

The wave frequencies and directions are those at which the wave loading, current and wind coefficients are defined. (Note that the wind and current coefficients vary with direction but not frequency). As they are transferred automatically from backing file when AQWA-NAUT is used as a post-processor the following notes refer to AQWA-NAUT when used as an independent program.

The above mentioned coefficients are dependent on frequency and/or direction. A range of frequencies and directions is therefore required as input data at which the coefficients are defined. There is only one criterion for the choice of values of frequency and direction, which is that sufficient values are required to adequately describe the variation of these coefficients within the range of regular waves or wave energy of spectra to be tested. Clearly, if this criterion is violated, approximate results will be obtained. Where possible the program will indicate this.

4.9 WAVE FREQUENCY COEFFICIENTS

The wave frequency coefficients are calculated by AQWA-LINE and then transferred automatically from backing file when AQWA-NAUT is used as a post-processor, thus the following notes refer to AQWA-NAUT when used as an independent program. The information relating to wave frequency coefficients falls into four categories as follows:

1. frequencies and directions at which the coefficients have been calculated

2. added mass and inertia matrices at each frequency

3. damping coefficient matrices at each frequency

4. diffraction wave forces at each frequency and direction

It is important that the wave frequency parameters are defined over the range of wave excitation frequencies and that the direction dependent parameters are defined over the expected RELATIVE angle of incidence.

For wave frequency motion, the added mass and damping matrices are required for the range of frequencies. The diffraction forces are required for the range of frequencies AND for the range of directions. AQWA-NAUT combines the diffraction forces (from AQWA-LINE) and the Froude-Krylov forces (calculated from the hydrodynamic mesh model) into a resultant total wave force. If the forces are being input manually, the user can input wave forces as either Froude-Krylov or diffraction, since the program does not differentiate between the two but merely sums them to get the total wave force.

4.10 WIND AND CURRENT LOADING COEFFICIENTS

The wind and current loading coefficients are required to model the forces and moments on the structure due to wind and current. These forces are proportional to the square of the relative velocity (based on the structure SLOW velocity).

For a simple box shape or similar bluff bodies these coefficients may be approximated by consideration of projected frontal areas and a suitable drag coefficient.

4.11 THRUSTER FORCES

Up to ten thruster forces may be specified. The point of application of the force vector is defined by a NODE. The magnitude of the vector remains constant and the direction of the vector is fixed in relation to the local structure axes (LSA).

4.12 CURRENT AND WIND VELOCITIES AND DIRECTIONS

The wind and current velocities and associated directions can be included as discussed in Section 4.14. Two types of current velocity can be specified; the first is a uniform velocity distributed over the submerged hull structure and the second is a profiled current velocity varying with both direction and depth between the sea bed and water surface. The latter is only utilised in the calculation of drag on Morison elements.

4.13 STRUCTURAL ARTICULATIONS AND CONSTRAINTS

4.13.1 Articulations

Structures in an AQWA-NAUT analysis can be freely floating, moored or connected to other structures by points of articulation. There are four different types of articulation available. These are as follows:

0	Ball and Socket	Free to rotate in all freedoms.
1	Universal	Free to rotate in two freedoms transmitting a moment in the third freedom at right angles to the first two.
2	Hinged	Transmitting a moment in two freedoms and free to rotate in the third freedom at right angles to the first two.
3	Locked	Transmitting a moment in all three freedoms and not free to rotate at all.

4.13.2 Constraints

A constraint can be applied to any degree of freedom. This has the effect of stopping the calculation of forces or moments and stopping motion in the specified constrained degrees of freedom.

Great care must be exercised if the degrees of freedom are constrained in a structure which is articulated either to another structure or to a fixed point. It is recommended that this should not be done.

4.14 REGULAR AND IRREGULAR WAVES IN AQWA-NAUT

4.14.1 REGULAR WAVE AND STARTING CONDITIONS

The user may specify only one regular wave frequency, amplitude and direction to be used in the simulation. The manner in which the frequency and amplitude data are specified can be used to examine particular problems as shown below:

1. A wave of zero frequency specifies that the only fluid forces the program is to compute are those on the Morison elements within the structure.

2. A wave frequency with zero amplitude corresponds to a still water condition which causes the radiation forces corresponding to that frequency to be computed. If examining a transient this frequency should correspond to that of the response.

3. A wave frequency and amplitude of finite value will drive the simulation with a wave of those parameters.

There is only one criterion for the choice of values of frequency and direction - that they should lie within the range of frequencies and directions for which the diffraction and radiation coefficients have been specified. If this criterion is violated, approximate results will be obtained. Where possible the program will indicate this.

The user can specify the order of wave theory he wishes to use in the analysis either as first order (linear) or second order (non-linear). Figure 4.2 shows the validity limits for both theories and from this the user should decide which theory gives the most acceptable error limit. In the figure, a is the wave amplitude and d is the water depth.

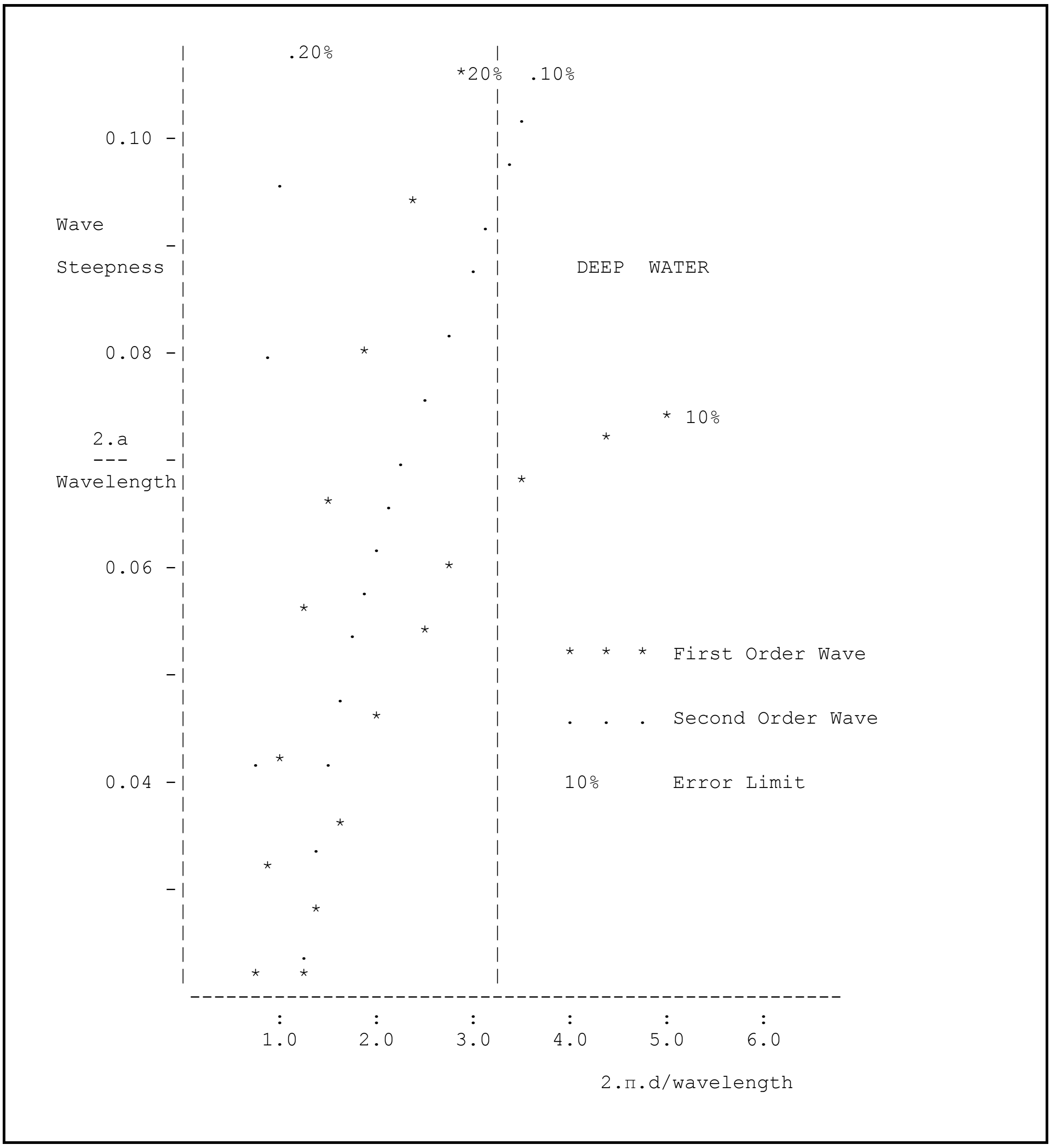


Figure 4.2 - Average Error Between Measured and First and Second Order Surface Elevations

The user can also specify a linear ramp damping coefficient for each degree of freedom of each structure. All damping functions will decay to zero after a time also specified by the user. These functions are intended to suppress initial transient effects when they are not desired. The initial magnitude of the damping coefficient is checked to ensure it does not exceed the critical damping corresponding to the highest frequency of the radiation parameters input, i.e.

$$c_i\, t_f \;\leq\; 2\,(m_s + m_a)\,\omega_m$$

where

i	=	structure degree of freedom
c_i	=	Ramp damping coefficient
t_f	=	time at which ramp function decays to zero
ω_m	=	highest frequency
m_s	=	structure mass or inertia
m_a	=	added mass or inertia at ω_m

4.14.2 WAVE SPECTRA, WIND AND CURRENT SPECIFICATION

The user may specify only one spectrum, wind and current speed and their associated directions. For the majority of applications, specification is quite straightforward and no knowledge of the way in which the spectra are used in any program is required. The two rules for specification of the spectrum are as follows:

1. The value of the spectral ordinate at the beginning and end of the frequency range should be small. If the values are not small, only part of the spectrum has effectively been specified.

2. The frequency defining the lower range of the spectrum **must be smaller than the lowest frequency specified in Deck 6**, as the frequency at the lower end of the range is used as both an upper limit to the drift frequencies and a lower limit to the wave frequencies.

4.15 MOORING LINES

4.15.1 Linear/Non-Linear Elastic Hawsers

Hawsers are defined by their unstretched lengths, end nodes on respective bodies and their load/extension characteristics. For linear hawsers, the line stiffness (load per unit extension) is required. For non-linear hawsers the program permits up to a fifth order polynomial approximation of the elastic property of the following form:

$$P(e) = a_1 e + a_2 e^2 + a_3 e^3 + a_4 e^4 + a_5 e^5 \qquad (4.15.1)$$

where P is the line tension and e is the extension. The use of a higher order polynomial than necessary could lead to erroneous negative stiffness while a lower order polynomial could be a perfectly adequate fit to the load extension curve. A typical load/extension curve is shown in Figure 4.3. It is always useful to check the polynomial fit prior to its use as input data. Note that the term a_1 is usually a good approximation to the linear stiffness for small extensions.

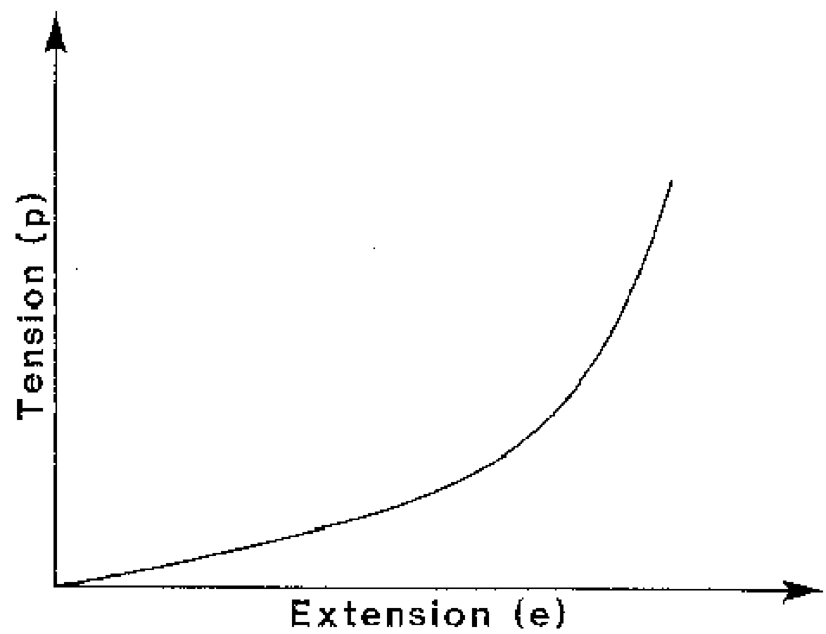


Figure 4.3 - Load/Extension Characteristics

4.15.2 Constant Tension Winch Line

A winch line is defined by its constant tension, attachment points and an 'unstretched length'. The attachment points are specified as nodes and determine the direction of the constant tension. The 'unstretched length' allows the line to go slack when the distance between the end points is less than it. If the user requires constant tension at all times, a zero unstretched length may be input.

4.15.3 'Constant Force' Line

The program allows the user to input a force of constant magnitude and direction. The force is always assumed to act at the centre of gravity of the body. The direction of the force is specified by a node on the body and a second node chosen such that the force vector is directed from node 1 to node 2. Once the direction is defined, the program maintains the magnitude and direction despite movement of the body. This facility can be used to input environmental forces where details of the forces (e.g. wind coefficients) are not available.

4.15.4 Catenary line

The catenary model allows uniform, inelastic, heavy catenary lines. Current drag on the line itself is ignored. The line is specified by the end nodes, length, weight in air per unit length and equivalent cross sectional area. The equivalent cross sectional area is numerically equal to the volume of water displaced by a unit length of the chain.

The user may specify maximum and minimum tensions in the line and maximum tension at the anchor. Default values are provided by the program. For length based calculations, the program will adjust the line length if the tension turns out to be outside the range specified (or the default values). If the user wishes to keep constant line length irrespective of the tension, a very large value of maximum allowable tension may be input. In all cases adequate warning messages will be signalled.
The program evaluates the line tension and stiffness according to a closed form solution of the catenary equations. The program allows the line to lift off the sea bed (i.e. the tangent to the line at the anchor has non-zero slope) up to the point where the line tension exceeds a user specified/default maximum.

The current version of AQWA only allows a horizontal sea bed and a catenary between a body and the sea bed. A catenary joining two bodies is NOT permitted.

Care must be exercised in the description of the catenary line such that the line is not lying horizontally and that the length is sufficient to allow the expected range of movement of its ends. Although the program caters for cases where the catenary line lifts off the sea bed, in practice most catenary chains are expected to function with a significant length of the line on the sea bed.

The following expression may help the user to check in advance if the catenary is likely to lift off from the sea bed. Just at lift off, T, the tension in the line is approximately related to s, the line length by the simple expression:

$$T/W = (s^2 + z^2)/2z \qquad (4.15.2)$$

where

W	=	the 'weight in water' per unit length of the chain
z	=	the vertical distance between the anchor point and the attachment point on the body.

By specifying T as given by equation (4.15.2) as the maximum tension, the user can ensure that the line does not 'lift off'.

4.15.5 STEEL WIRE CABLES

The Steel Wire (SWIR) facility allows modelling of the non-linear properties of a new steel wire rope. Although the SWIR cable is classified as a non-linear cable it is possible to model steel wire using linear (LINE) or non-linear (NLIN) lines.

4.15.6 INTERMEDIATE BUOYS AND CLUMP WEIGHTS

The Buoy card (BUOY) defines the properties of intermediate buoys and clump weights. Intermediate buoys cannot be used between structures but only between a structure and the sea bed.

4.15.7 THE PULLEY CORD (PULY)

The PULY facility allows the use of a pulley positioned on a line. A maximum of 2 pulleys is allowed for each pulley set. A PULY card must be proceeded by a LINE card.

4.15.8 THE DRUM WINCH (LNDW)

The LNDW card is used to model a winch or drum winch which winds in or pays out a linear elastic line starting at a user specified time.

4.15.9 FENDERS (FEND)

Fixed and floating fenders are available in AQWA. A fixed fender is graphically shown as a sphere in the AGS, or if the axis is defined, a cone whose axis is normal to structure plane to which it is fixed. A floating fender will be shown as a short cylinder. Emphasis has been put on the “realistic” graphical representation of the fender distortion. Fixed and floating fenders in AQWA can be modelled together with conventional mooring lines.

4.16 ITERATION PARAMETERS FOR SOLUTION OF EQUILIBRIUM

AQWA-NAUT performs no formal stability analysis, although it may be possible to determine an equilibrium configuration from a still water run. Some physical systems which can be modelled by AQWA-NAUT may be inherently statically or dynamically unstable. This may be detected by careful inspection of the resulting time histories. Note that dynamic instability is dependent on the initial conditions of the simulation. AQWA-LIBRIUM is designed to investigate the stability of systems and details are given in the AQWA-LIBRIUM user manual.

4.17 TIME HISTORY INTEGRATION IN IRREGULAR WAVES

AQWA-NAUT is a time-domain program for the analysis of non-linear systems in regular or irregular waves. Non-linear systems in irregular waves can also be analysed in the time-domain by AQWA-DRIFT.

4.17.1 TIMESTEP FOR SIMULATION

The timestep for a simulation should be chosen to be a small fraction of the period of variation of the most rapidly varying force or response.

4.17.2 SIMULATION LENGTH AND ACCURACY LIMITS

For the time history of motion in an irregular sea to be representative of the structure's motion characteristics in that sea, the time history has to be of sufficient length to allow averaging of maximum and minimum response. Motions simulated over a finite length of time contain some statistical error because the sample may, by chance, contain an unrepresentative number of large or small oscillations. Reference 5 explains that the variance of the mean square value of the slow drift position can be calculated assuming linear mooring stiffness and linear damping. This can provide a useful guide to the expected errors in statistical properties derived from a finite length simulation.

The variance of the mean square value can be calculated from the following:

$$\frac{(4\sigma^4)}{T}\int_0^T 1-\frac{t}{T}\rho^2(t)\;dt \tag{4.17.1}$$

where

σ^2	=	the true mean squared value
$\rho(t)$	=	the auto-correlation function of the process
T	=	the length of the simulation or process

Assuming light damping and linearity in the restoring stiffness and damping, the auto-correlation function is:

$$\rho(t) = \exp(-c\omega\, t^2) \cos(\omega\, t) \tag{4.17.2}$$

where

ω = natural frequency of oscillation

c = surge damping as a fraction of critical damping

Equation 4.17.1 can thus be evaluated. Since the statistical variation about the mean square value will be approximately Gaussian, the 98 per cent and 68 per cent confidence limits in simulated motion can be deduced and are plotted below.

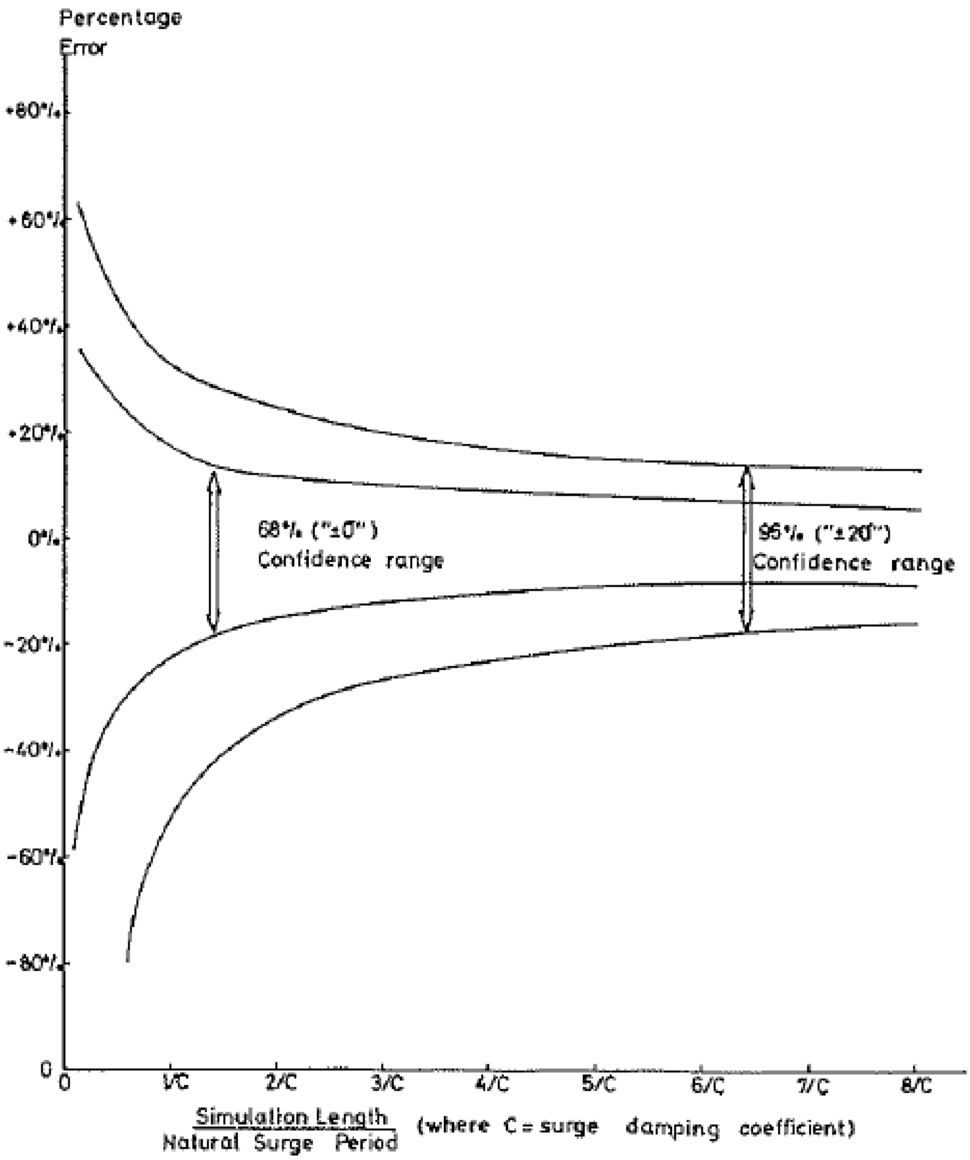


Figure 4.3 - Confidence Limits on Computation of Significant Motion

The graph shows that for a system with 10 percent damping, the length of simulation must be at least 40 times the structures natural period to achieve an estimate of the significant motion correct to +/- 20 per cent.

4.18 TIME HISTORY INTEGRATION IN REGULAR WAVES

4.18.1 Timestep for Simulation

The timestep for a simulation should be chosen to be a small fraction of the period of variation of the most rapidly varying force or response. A timestep of 0.5 seconds is typical.

4.18.2 Simulation Length and Accuracy Limits

The time history of motion in a regular sea has to be of sufficient length to allow a steady state condition to develop, i.e. all transients should have disappeared. There should also be sufficient record length to allow a number of cycles to be treated by harmonic analysis.

4.18.3 Initial Conditions and Start Time

It is important that the simulation should have as small an initial transient at the start as possible, especially if the user requires accurate harmonic analysis of the simulations. It is usual when performing a motion simulation to position the structure close to the equilibrium position of the structure under the influence of steady forces. In addition a linear ramp damping function can be applied to suppress transient effects for a short period after the start of the simulation. Motions during this period should not be considered in the harmonic analysis of the response.

4.19 SPECIFICATION OF OUTPUT REQUIREMENTS

See options list in Appendix A.

CHAPTER 5 - ANALYSIS PROCEDURE

This chapter assumes that the user is familiar with the analysis procedure and how to model the structure in its environment. It deals with the methodology of analysis associated with running the program and links the modelling information in the previous chapter with the stages of analysis necessary to solve a given type of problem. This involves classification of the types of problem, details of the program runs and stages within each program run, together with their associated options.

5.1 TYPES OF ANALYSIS

Classification of the types of problem (listed below) based on the function of the analysis, is the same whether the program is used independently, or as a post-processor to AQWA-LINE and is as follows:

- Calculation of steady state response of a floating system of one or more bodies to a regular wave. Determination of the fundamental and higher harmonic wave frequency responses over a number of cycles

- Simulation of wave frequency motions of one or more bodies in irregular waves.

- Examination of transient responses of structures in still water and wave conditions.

- Study of Morison type projectiles, whether above, through, or under the free surface, in still water or waves.

5.2 RESTART STAGES

All programs in the AQWA suite have the facility of running one or more stages of the analysis separately. These stages are referred to in the documentation as **restart stages** (See AQWA Reference Manual Chapter 2).

Use of the restart process thus implies that information is available on a backing file from a previous program run and not via the normal card image file. This process is also used to transfer information from one program to another program in the AQWA suite.

The stages are as follows:

Stage 1	-	Geometric Definition and Static Environment
Stage 2	-	Input of the Diffraction/Radiation Analysis Parameters
Stage 3	-	The Diffraction/Radiation Analysis
Stage 4	-	Input of the Analysis Environment
Stage 5	-	Motion Analysis
Stage 6	-	Graphical Display of Model and Results

Note that the graphics will permit visualisation of the geometric model and parameters at any point in the analysis, i.e. Stages 2 to 5 are not required to visualise the input data in Stage 1. **This only applies to the graphics**, as all other programs must progress from one stage to another with NO stages omitted. As Stage 3 has no direct calculations in programs other than AQWA-LINE, the programs will 'correct' a request to finish at Stage 2 to one to finish at Stage 3. This remains transparent and requires no action by the user.

5.3 STAGES OF ANALYSIS

A typical analysis using AQWA-NAUT requires the following stages:

1. Select a consistent set of units

2. Assemble geometric and material data for all the structures

3. Specify one or more point masses to represent the mass and mass inertia of each of the structures. (In the case of tubes, structural mass may be input through the geometric properties)

4. Calculate the coordinates of the node points for each of the mooring attachments and the elements used in the modelling of the body

5. Specify the water depth and the density of the water

6. Specify the wave diffraction/radiation coefficients and the frequencies and directions at which they are defined for each structure

The following preparation is required for AQWA-NAUT, whether used independently, or as a post processor to AQWA-LINE.

7. Prepare thruster forces and coefficients for wind and current drag for each structure

8. Specify the regular wave frequency, amplitude and direction and the wave theory to be used or specify parameters for each spectrum. The linear ramp damping coefficients and duration parameter should also be estimated if required

9. Determine mooring line combinations and properties

10. Specify initial positions for each structure and details of the simulation length and timestep

11. Perform a DATA run (i.e. with the DATA option switched on) which will provide preliminary checks on the card image data file

12. After a successful DATA run, rerun with the restart option.

CHAPTER 6 - DATA REQUIREMENT AND PREPARATION

This chapter describes the form in which data is expected by the program. It is not intended as a detailed list of the data requirements but describes the general data format for the analyses that may be performed when running AQWA-NAUT. The detailed format may be found in the AQWA Reference Manual. The input data file uses the concept of the card image deck which is a section of two or more records. The input file comprises a number of these decks. This manual assumes that the user is familiar with this concept, details of which may also be found in the AQWA Reference Manual.

A summary of the possible data that may be input is listed together with a summary for the analysis. In the latter case a typical input data summary is given where the more unusual facilities have been omitted.

Most data requirements listed are optional unless specified otherwise and if not input the program defaults are used. These defaults may be found, together with the detailed format description, in the AQWA Reference Manual.

6.0 ADMINISTRATION CONTROL - DECK 0 - PRELIMINARY DECK

This deck is always required when performing AQWA program runs. The information input relates directly to the administration of the analysis being performed and the control of the AQWA program being used.

Program control has the following functions:

- identification of the program to be used within the AQWA suite - the type of program analysis to be performed (if a choice exists) - the analysis stages to be performed (i.e. restart stages)

Administration of the analysis being performed is as follows:

- user title identification given to the analysis
- choice of output required from the program run (i.e. program options)

The above information is input to the program through the following cards contained in Deck 0.

JOB Card	-	This contains information stating the program to be used, the type of program analysis to be undertaken and the user identifier for the run in question.
TITLE Card	-	This lets the user prescribe a title for the run.
OPTIONS Card	-	Various program options are available within the AQWA suite which are common to all programs, while others are for use with specific programs. The options within AQWA-NAUT control the type of output required from the program and the restart stages of analysis to be performed (see Appendix A).
RESTART Card	-	If the restart option is used, then the start and finish stages of the analysis must be prescribed via the restart card.

For complete details of the above card formats see the AQWA Reference Manual. For a list of options for use within AQWA-NAUT, see Appendix A.

One option commonly used is the DATA option and it is worth noting its purpose. The DATA option performs Stages 1 to 4 of an AQWA-NAUT analysis. This means that all information relating to the analysis is read, allowing all data checking to be performed. After the user is satisfied with the acceptance of data, then the analysis can be undertaken by restarting the program at Stage 5 to perform the analysis itself.

6.1 STAGE 1 - DECKS 1 TO 5 - GEOMETRIC DEFINITION AND STATIC ENVIRONMENT

Input for Stage 1 of the analysis is only necessary if the restart stage at which the analysis begins is Stage 1 (see Chapter 5). If the restart stage is greater than 1, there should be **no data input** for Stage 1 of the analysis.

6.1.1 Description Summary of Physical Parameters Input

The data input in these decks relates to the description of each structure and the environment which normally remains unchanged throughout the analysis. This includes any point referenced on or surrounding the structure, the mass inertia, hydrostatic and hydrodynamic model and the (constant) water depth, i.e.

- the coordinates of any point on the structure or its surroundings referenced by any other deck

- element description of the structure mass and geometry using plate, point mass, point buoyancy and tube elements (see Appendix A of the AQWA Reference Manual)

- a table of material values associated with each element - a table of geometric values associated with each element - the depth and density of the water and acceleration due to gravity

The data requirement for each program in the AQWA suite is not the same and also depends on the type of analysis to be performed. These requirements are listed in detail in the later sections of this chapter.

6.1.2 Description of General Format

The input format of these decks is designed to provide checking of the data for the average user and outputs a suitable message to inform the user if the instructions for data preparation have been misinterpreted or are unusual. When running the program for the first time it is recommended that the PRCE option (see Appendix A) is used. This causes the data input in these decks to be output automatically in order that the user may check the program's interpretation of the data before proceeding to the next stage of the analysis.

6.1.3 Data Input Summary for Decks 1 to 5

Deck 1	-	The coordinates of points describing the elements
	-	The coordinates of the mooring line attachment points
	-	The coordinates of any points whose position or motions are requested by the user-specified options
Deck 2	-	Element description of the mass properties
	-	Element description of the hydrostatic model
	-	Element description of the hydrodynamic model
Deck 3	-	A table of material values associated with each element
Deck 4	-	A table of geometric values associated with each element
Deck 5	-	Static environmental parameters, i.e. the depth and density of the water and the acceleration due to gravity

The above information is required before an AQWA-NAUT simulation can be performed. The AQWA Reference Manual gives details of the format for these input data decks.

6.2 STAGE 2 - DECKS 6 TO 8 - THE DIFFRACTION/RADIATION ANALYSIS PARAMETERS

Input for Stage 2 of the analysis is only necessary if the restart stage at which the analysis begins is 1 or 2 (see Chapter 5) and the stage at which it finishes is 2 or greater. If the restart stage at which the analysis begins is greater than 2 there is **no input necessary** for Stage 2 of the analysis.

6.2.1 Description Summary of Physical Parameters Input

The data input in these decks relates to the equation of motion for a diffracting structure or structures in monochromatic waves. The data are defined for a range of frequencies and directions. (Note that the structural mass is input in Decks 1 to 5). For a specified frequency and direction the equation of motion can be written as:

$$M(s)\,\ddot{x} + M(a)\,\ddot{x} + C\,\dot{x} + K(t) = F(d) + F(t)$$

The parameters in the equation of motion are

M(s)	=	Structure Mass
K(t)	=	Instantaneous Hydrostatic Force
F(t)	=	Instantaneous Froude-Krylov Force

and for each frequency

M(a)	=	Added Mass Matrix
C	=	Radiation Damping Matrix

and for each frequency and each direction

X	=	Response Motion
F(d)	=	Diffraction Force

Note: If the LSTF option is used the time dependent hydrostatic and Froude-Krylov forces can be replaced by the hydrostatic stiffness matrix and the frequency and direction dependent Froude-Krylov force coefficients. This option should only be used for **small amplitude** motions.

6.2.2 Description of General Format

The input format and restrictions in these decks are designed to provide maximum cross checking on the data input when the more advanced facilities are used. This ensures that the program is able to output a suitable message to inform the user if the instructions for data preparation have been misinterpreted. In any event, the interpretation of the data input in these decks is output automatically in order that the user may check the results before proceeding to the next stage of the analysis.

It is important to recognise the different function of the specification of the frequencies and directions when using AQWA-LINE, which calculates the diffraction/radiation analysis parameters and when using other programs in the AQWA suite which is as follows:

- for AQWA-LINE the range of frequencies and directions specified are those at which the parameters are to be **calculated**.

- for AQWA-NAUT, the parameters are read from backing file automatically or input manually. In the latter case the range of frequencies and directions specified are those at which the parameters are to be input within these decks.

6.2.3 Data Input Summary for Decks 6 to 8

Deck 6	-	A range of frequencies	
	-	A range of directions	
	-	Details relating to alterations of the results of a previous run	
Deck 7	-	Linear hydrostatic stiffness matrix	( )
	-	Additional stiffness matrix	(required if the LSTF)
	-	The buoyancy force at equilibrium	(option is selected)
	-	The depth below the still water level of the centre of gravity at equilibrium	( ) ( )
	-	Added mass matrix	
	-	Additional mass matrix	(usually not required)
	-	Radiation damping matrix	
	-	Additional linear damping matrix	(usually not required)
	-	Diffraction forces	
	-	Froude-Krylov forces	(required if the LSTF) (option is selected)
	-	Response Motions (or RAOs)	
Deck 8	-	None	(no input required)

It is unusual for all the data above to be required for any one particular analysis, in which case the user simply omits the data which is not required. The following sections show the required data input for the available modes of analysis.

6.2.4 Input for AQWA-NAUT using the Results of a Previous AQWA-LINE Run

If there are no changes to the results from a previous AQWA-LINE run, all the data is read automatically from backing files and this stage is completely omitted. Thus these decks are not required at all and must be removed from the card image data deck as the analysis is restarted at the beginning of Stage 4.

Deck 6 to 8 - No Input Required

6.2.5 Input for AQWA-NAUT with Results from a Source other than AQWA-LINE

Although the parameters calculated by AQWA-LINE can be transferred automatically to other programs in the AQWA suite, this is NOT mandatory. This means that if the backing file produced by an AQWA-LINE run is NOT available (e.g. AQWA-LINE has not been run previously or the user wishes to input data from a source other than AQWA-LINE) then data may be input in these decks.

All data appropriate to the analysis (summarised in Section 6.2.3) may then be input in card image format. The exact input will depend on the type of analysis and the particular structure analysed.

Typically, input data required is as follows:

For a run with non linear Froude-Krylov and Hydrostatic forces

Deck 6 - A range of frequencies
- A range of directions

Deck 7 - Added mass matrix
- Radiation damping matrix
- Diffraction forces
- Response motions

Deck 8 - None

For a run with linear Froude-Krylov and Hydrostatic forces (LSTF option)

Deck 6	-	A range of frequencies
	-	A range of directions
Deck 7	-	Linear stiffness matrix
	-	Added mass matrix
	-	Radiation damping matrix
	-	Diffraction forces
	-	Froude-Krylov forces
	-	Response motions
Deck 8	-	None

6.2.6 Input for AQWA-NAUT with results from a previous AQWA-LINE Run and a Source other than AQWA-LINE

The new user is advised to ignore this facility

If the user wishes to APPEND to or CHANGE the parameters calculated by a previous AQWA-LINE run for the current analysis, this can be achieved by using the card image input as described in the previous section, in addition to reading the results from a previous AQWA-LINE run. As the program does not expect a backing file from AQWA-LINE to exist at Stage 2 of the analysis, the RDDB or the ALDB option must be used in the options list (see Section 6.0) to indicate that it exists and must be read. **Using this option means that Decks 6 to 8 are read twice, once from the backing file and once from the card image deck.**

To APPEND to the parameters calculated in a previous run, additional frequencies which differ from those existing may be input in Deck 6 together with values of the appropriate frequency dependent parameters in Decks 7 and 8 at these additional frequencies. Note that as all parameters are defined for a unique range of directions, these directions must not be redefined.

To CHANGE the parameters calculated in a previous run, these parameters are simply input in Decks 7 and 8 and depending on the type of input (see individual deck sections in the AQWA Reference Manual) the parameters will be either overwritten with the input values or become the sum of input values and original values.

6.3 STAGE 3 - NO DATA INPUT - DIFFRACTION/RADIATION ANALYSIS

6.3.1 Stage 3 in AQWA-NAUT

There is no input for Stage 3 in AQWA-NAUT as this stage corresponds to the diffraction/radiation analysis which has either been performed in AQWA-LINE or the values have been input by the user from a source other than AQWA-LINE (i.e. when the program is used independently).

6.4 STAGE 4 - DECKS 9 TO 18 - INPUT OF THE ANALYSIS ENVIRONMENT

Input for Stage 4 of the analysis is only necessary if the restart stage at which the analysis begins is 1 or 2 (see Chapter 5) and the restart stage at which the analysis finishes is 4 or greater. If the restart stage at which the analysis begins is greater than 4 there is NO INPUT for Stage 4 of the analysis.

6.4.1 Description summary of Physical Parameters Input

The data input in these decks relates to the description of the analysis environment and the structure coefficients associated with the environment as follows:

- Wind and current loading coefficients and thruster forces

These coefficients, which are defined at directions specified in Deck 6, are associated with the hull forces and are proportional to the square of the wind/current velocity. The thruster forces are maintained at both constant magnitude and direction to the specified structure.

- Articulations and constraints

Degrees of freedom can be constrained by specifying the structure and freedom. This sets the relevant degree of freedom to zero displacement. Structures can be connected to other structures by points of articulation. There are four different types of articulation available which are ball and socket, universal, hinged and locked joints.

- Wave condition and transient damping

The wave condition is defined by a wave frequency, amplitude, direction and the wave theory to be used in cases of regular waves. When irregular waves are used then the properties of the wave spectrum need to be input. Transient damping can be used to suppress transients for a limited duration after the start. This is achieved with a linear ramp damping function for each degree of freedom.

- Mooring lines

The physical characteristics and attachment points of mooring lines, hawsers and tethers may be input if required (see Section 4.15).

- Starting position

The initial position of each structure should be specified.

- Time integration parameters

The timestep to be used throughout the simulation and the number of timesteps required is specified. The user also specifies the start time of the simulation.

- Morison element parameter

This is either the Local Reynolds Number or a drag scale factor applied to the drag coefficients of Morison elements (already specified in Deck 4).

6.4.2 Data Input Summary for Decks 9 to 18

Deck 9	-	None
Deck 10	-	Wind loading coefficients for the superstructure
	-	Current loading coefficients for the hull
	-	Thruster force magnitude and direction
Deck 11	-	Wind and current speed and direction
	-	Profiled current data for Morison elements
Deck 12	-	Degrees of freedom of structures which are to be constrained
	-	Articulations
Deck 13	-	Wave frequency amplitude and direction or properties of wave spectrum (irregular waves).
	-	Wave Theory (with regular wave only)
	-	Transient damping (with regular wave only)
Deck 14	-	Description of each mooring line property
	-	Description of layout for each mooring configuration
Deck 15	-	Initial positions for each structure
Deck 16	-	Number of timesteps, timestep length and start time
Deck 17	-	Morison element parameters

6.5 STAGE 5 - NO DATA INPUT - MOTION ANALYSIS

Stage 5 is the motion analysis stage and requires no input.

CHAPTER 7 - DESCRIPTION OF OUTPUT

This chapter describes the comprehensive program output provided by AQWA-NAUT. The various program stages perform different types of analyses and the output for each stage of the analysis is described in detail in the following sections.

7.1 STRUCTURAL DESCRIPTION OF BODY CHARACTERISTICS

This information is only output when starting at Stage 1 or the PRDL option is used to print this information from backing file.

7.1.1 Properties of All Body Elements

The body surface geometry and mass characteristics are input to AQWA-NAUT through input Decks 1 to 4 (see Section 6.1). These data decks define the following parameters (see AQWA Reference Manual):

- Node numbers and positions
- Elements used to model the body
- Material properties of the elements
- Geometric properties of the elements

The information input to AQWA-NAUT to define the body characteristics is output by the program for checking and the body's resultant centre of mass and inertia matrix are output. The nodal coordinates are output in the Fixed Reference Axes system (FRA) and the format is shown in Figure 7.1.

```
* * * * C O O R D I N A T E   D A T A * * * *
        - - - - - - - - - -   - - - -

  INPUT   NODE

SEQUENCE   NO.      X         Y         Z
---------------------------------------------

   1       1     45.000   -45.000     0.000
   2       2     22.500   -45.000     0.000
   3       3      0.000   -45.000     0.000
   4      11     45.000   -45.000   -20.000
   5      12     22.500   -45.000   -20.000
   6      13      0.000   -45.000   -20.000
   7      21     45.000   -45.000   -40.000
   8      22     22.500   -45.000   -40.000
   9      23      0.000   -45.000   -40.000
  10      31     45.000   -22.500   -40.000
```

Figure 7.1 - Nodal Coordinate Output

Following the nodal coordinates, each body's element topology is output. The body topology describes the elements used in the model of the body (see Section 4.4.2). Details of each element are also output as shown in Figure 7.2. Each body in the analysis has a specific structure number associated with it which appears in the title of the output. The element topology output can be enhanced with more detailed information by using the PPEL program option (i.e. Print Properties of ELements).

```
 * * * E L E M E N T   T O P O L O G Y   F O R   S T R U C T U R E  1 * * *
       - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

 E L E M E N T    NODE      NODE      NODE      NODE    MATERIAL  GEOMETRY

 NUMBER    TYPE  NUMBER    NUMBER    NUMBER    NUMBER    NUMBER    NUMBER
 ---------------------------------------------------------------------------

    1     QPPL     1         2        12        11         0         0
    2     QPPL    11        12        22        21         0         0
    3     QPPL    21        22        32        31         0         0
    4     QPPL    31        32        42        41         0         0
    5     QPPL     2         3        13        12         0         0
    6     QPPL    12        13        23        22         0         0
    7     QPPL    22        23        33        32         0         0
    8     QPPL    32        33        43        42         0         0
    9     QPPL     1        11        14         4         0         0
   10     QPPL    11        21        24        14         0         0
```

Figure 7.2 - Element Topology Output

The body topology output references the material group number which has a mass or density value associated with it. The material group numbers are output as shown in Figure 7.3.

```
 * * * * M A T E R I A L   P R O P E R T I E S * * * *
         - - - - - - - -   - - - - - - - - - -

               MATERIAL
                GROUP
               NUMBER   DENSITY/VALUE
               -----------------------

                  1     332100000.000
```

Figure 7.3 - Material Property Output

The topology output also references the Geometry Group numbers used by the user. Each Geometry Group may have a range of properties associated with it. The number of relevant properties depends on the type of element under consideration. The Geometry Group numbers and the various parameters within each group are output as shown in Figure 7.4. Here the Point Mass element has six geometric parameters which are the prescribed inertia values. The localised element Drag and Added Mass coefficients are also printed.

```
      * * * * G E O M E T R I C    P R O P E R T I E S * * * *
              - - - - - - - - -    - - - - - - - - - -

            GEOMETRY

  INPUT     GROUP    ELEMENT   G E O M E T R I C   P A R A M E T E R

SEQUENCE     NO.      TYPE           1           2           3

--------------------------------------------------------------------

 1         1       PMAS          3.6253E+11  0.0000E+00  0.0000E+00

       ..........(output line continued below)...........


                                           DRAG       ADDED MASS
              N U M B E R              COEFFICIENT    COEFFICIENT

           4           5           6         C              C
                                              D              M
 ....  --------------------------------------------------------------

       3.4199E+11  0.0000E+00  3.5991E+11   0.00           0.00
```

Figure 7.4 - Geometric Property Output

The program, having accepted the user prescribed element distribution, now outputs the resultant Mass and Inertia characteristics of the bodies being modelled. An example of output is shown in Figure 7.5. The coordinates of the centre of gravity are with respect to the FRA used in defining the body and the inertia matrix is about the centre of gravity of the particular body. The types and total number of elements used to model the body are output. The number of elements output is based on the total coverage of the body's wetted surface and not the number input when utilising the program's symmetry facilities.

```
 * * * * * MASS   AND   INERTIA   PROPERTIES   OF   STRUCTURE   1 * * * * *
           ------------------------------------------------------


            NUMBER
              OF
         ELEMENT TYPE    ELEMENTS         MASS               WEIGHT
         ------------    --------         ----               ------

             PMAS            1       75593800.000       741575232.000

             TPPL           12              0.000               0.000

             QPPL          200              0.000               0.000

       ------------------------------------------------------------------

          T O T A L        213       75593800.000       741575232.000
       ------------------------------------------------------------------


                                 X           Y           Z
                         -----------------------------------

     CENTRE OF GRAVITY         1.100       1.175      35.000

     INERTIA MATRIX          3.024E+10   0.000E+00   0.000E+00

                             0.000E+00   1.150E+11   0.000E+00

                             0.000E+00   0.000E+00   1.150E+11
```

Figure 7.5 - Resultant Mass and Inertia

7.2 DESCRIPTION OF ENVIRONMENT

This information is output only if the program is starting at Stage 1 or the PRDL option is used to print this information from backing file.

The environmental parameters within AQWA-NAUT consist only of the fluid depth and density and the gravitational acceleration. The static environment is output as shown in Figure 7.6.

```
* * * * G L O B A L    P A R A M E T E R S * * * *
        - - - - - -    - - - - - - - - - -

WATER  DEPTH  . . . . . . . . . . . . . . . . =   250.000

DENSITY  OF  WATER  . . . . . . . . . . . . . =  1025.000

ACCELERATION  DUE  TO GRAVITY . . . . . . . . =     9.806
```

Figure 7.6 - Static Environment

Following the static environment data, the wave frequency and direction data or the properties of the wave spectrum are output. AQWA-NAUT may have up to ten wave frequencies/periods and ten associated wave directions for each body for a regular wave analysis. The output summary of wave frequencies and directions in case of a regular wave analysis is shown for Structure 1 in Figure 7.7. The output also shows details of other wave related parameters as follows:

- Wave number, i.e. $2.0 * \pi$ / (wavelength)
- Maximum element size (applicable to AQWA-LINE/NAUT)
- Depth ratio

The final information given in Figure 7.7 relates to the frequency dependent parameters. If these parameters have not already been input for certain frequencies, then these frequencies are listed as having undefined parameters.

```
      * * * * WAVE FREQUENCIES/PERIODS AND DIRECTIONS * * * *
              --------------------------------------

STRUCTURE  VARIABLE                 1         2         3         4
---------------------------------------------------------------------


    1   DIRECTION(DEGREES)        0.00     45.00     90.00      0.00

        FREQUENCY(RADS/SEC)    0.34907   0.36960   0.38080   0.39270

        FREQUENCY(HERTZ)       0.05556   0.05882   0.06061   0.06250

        PERIOD(SECONDS)          18.00     17.00     16.50     16.00

        WAVE NUMBER(K)         0.01247   0.01396   0.01481   0.01574

        WAVELENGTH(L)           503.68    450.19    424.38    399.23

        MAXIMUM ELEMENT SIZE     71.96     64.31     60.63     57.03

        DEPTH RATIO(D/L)          0.50      0.56      0.59      0.63

        DEPTH RATIO(K*D)          3.12      3.49      3.70      3.93

        PARAMETERS

---------------------------------------------------------------------
```

Figure 7.7 -Wave Frequencies and Directions for regular wave analysis

7.3 DESCRIPTION OF FLUID LOADING

This information is output only if the program is starting at Stage 1 or 2 or the PRDL option is used to print this information from backing file.

7.3.1 Hydrostatic Stiffness

This is only output when the LSTF option has been used i.e when the hydrostatic stiffness matrix is used to calculate the hydrostatic forces. In this case the hydrostatic stiffness matrix output by AQWA-NAUT, when printing from backing file, is in the analysis position used in AQWA-LINE for the diffraction/radiation analysis. An example output is shown in Figure 7.8.

```
                    HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1
                    - - - - - - - - - - - - - - - - - - - -

                    AT THE FREE-FLOATING EQUILIBRIUM POSITION
                    -----------------------------------------

               BUOYANCY FORCE . . . . . . . . . . . . =  3.2566E+09

               Z POSITION OF THE CENTRE OF GRAVITY  . = -1.0620E+01

                               STIFFNESS MATRIX
                               ----------------

           X           Y           Z          RX          RY          RZ
 --------------------------------------------------------------------------

  X  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

  Y  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00

  Z  0.0000E+00  0.0000E+00  8.1414E+07 -7.8525E+01 -7.8525E+01  0.0000E+00

 RX  0.0000E+00  0.0000E+00 -7.8525E+01  2.4408E+10  0.0000E+00  9.4230E+02

 RY  0.0000E+00  0.0000E+00 -7.8525E+01  0.0000E+00  2.4408E+10  2.6698E+03

 RZ  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

Figure 7.8 - Hydrostatic Stiffness Matrix Output

7.3.2 Added Mass and Wave Damping

The added mass and wave damping are functions of wave frequency and are therefore output for all specified values of frequency or period. The added mass and wave damping are expressed in matrix form and Figure 7.9 shows a typical added mass matrix for body one at a single frequency. (Damping being output in a similar fashion). Summary tables of variation of added mass and damping with wave frequency/period are also output.

```
          * * * * HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1 * * * *
                  ---------------------------------------

              WAVE PERIOD =  12.000 WAVE FREQUENCY =  0.5236

                                ADDED  MASS
                                -----------

         X           Y           Z           RX          RY          RZ
   -----------------------------------------------------------------------

    X  1.3084E+08  0.0000E+00  0.0000E+00  0.0000E+00 -8.7338E+08  0.0000E+00

    Y  0.0000E+00  1.3084E+08  0.0000E+00  8.7338E+08  0.0000E+00  0.0000E+00

    Z  0.0000E+00  0.0000E+00  2.2385E+08  0.0000E+00  0.0000E+00  0.0000E+00

   RX  0.0000E+00  8.7338E+08  0.0000E+00  8.9068E+10  0.0000E+00  0.0000E+00

   RY -8.7338E+08  0.0000E+00  0.0000E+00  0.0000E+00  8.9068E+10  0.0000E+00

   RZ  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.3823E+11
```

Figure 7.9 - Added Mass Matrix Output

7.3.3 Oscillatory Wave Excitation Forces

The wave loading output from AQWA-LINE is presented in tabular form for all the directions and frequencies specified by the user. The output gives the variation of wave force/moment with frequency for each direction (see Figure 7.10) and the variation of wave force/moment with direction for each frequency.

The wave forces/moments are output in terms of amplitude and phase. The phase being related to the incident wave form. (See Appendix C of the AQWA Reference Manual). The wave forces/moments are divided into their various components and output in terms of the following:

- Froude-Krylov forces/moments (when the LSTF option has been used)

- Diffraction forces/moments

- Total wave forces/moments (when the LSTF option has been used)

Figure 7.10 shows only the diffraction component, but the other forces are output in a similar format.

```
                          HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1
                          ---------------------------------------

                       DIFFRACTION FORCES-VARIATION WITH WAVE PERIOD/FREQUENCY
                       -------------------------------------------------------

  PERIOD FREQ  DIRECTION        X             Y             Z            RX             RY
             RZ
                  - - - - - - -       - - - - - -       - - - - - - - - - - -
------------------------------------------------------------------------------------------

  (SECS)(RAD/S)(DEGREES)   AMP    PHASE    AMP    PHASE    AMP    PHASE    AMP    PHASE    AMP
PHASE     AMP     PHASE

------------------------------------------------------------------------------------------
----------------------
  18.00 0.349    0.00 2.52E+07 -72.23 0.00E+00   0.00 1.96E+07 -154.64 0.00E+00   0.00 1.46E+08
90.88  0.00E+00    0.00
  17.00 0.370       2.66E+07 -67.54 0.00E+00   0.00 2.00E+07 -153.72 0.00E+00   0.00 1.63E+08
91.89  0.00E+00    0.00
  16.50 0.381       2.71E+07 -64.82 0.00E+00   0.00 2.01E+07 -153.26 0.00E+00   0.00 1.72E+08
92.51  0.00E+00    0.00
  16.00 0.393       2.73E+07 -61.85 0.00E+00   0.00 2.01E+07 -152.83 0.00E+00   0.00 1.81E+08
93.20  0.00E+00    0.00
  15.00 0.419       2.67E+07 -55.24 0.00E+00   0.00 1.99E+07 -152.00 0.00E+00   0.00 1.97E+08
94.70  0.00E+00    0.00
  14.00 0.449       2.42E+07 -47.99 0.00E+00   0.00 1.92E+07 -151.28 0.00E+00   0.00 2.09E+08
96.02  0.00E+00    0.00
  12.00 0.524       1.17E+07 -33.93 0.00E+00   0.00 1.58E+07 -150.55 0.00E+00   0.00 2.09E+08
95.35  0.00E+00    0.00

  18.00 0.349   45.00 1.86E+07 -72.52 1.86E+07 -72.52 1.96E+07 -154.63 1.06E+08 -89.12 1.06E+08
90.88  9.38E+00 -170.89
  17.00 0.370       1.99E+07 -68.01 1.99E+07 -68.01 2.00E+07 -153.70 1.20E+08 -88.11 1.20E+08
91.89  9.25E+00 -178.07
  16.50 0.381       2.05E+07 -65.42 2.05E+07 -65.42 2.01E+07 -153.24 1.27E+08 -87.48 1.27E+08
92.52  1.16E+01 -169.73
  16.00 0.393       2.09E+07 -62.61 2.09E+07 -62.61 2.02E+07 -152.81 1.34E+08 -86.78 1.34E+08
93.22  7.28E+00  -13.76
  15.00 0.419       2.11E+07 -56.51 2.11E+07 -56.51 1.99E+07 -151.96 1.48E+08 -85.21 1.48E+08
94.79  9.76E+00 -171.04
  14.00 0.449       2.02E+07 -50.20 2.02E+07 -50.20 1.93E+07 -151.20 1.60E+08 -83.71 1.60E+08
96.29  1.57E+01 -178.16
  12.00 0.524       1.43E+07 -41.53 1.43E+07 -41.53 1.60E+07 -150.30 1.72E+08 -82.55 1.72E+08
97.45  1.91E+01  -20.92
```

Figure 7.10 - Diffraction Forces/Moments

7.4 FREE FLOATING NATURAL FREQUENCIES AND RESPONSE AMPLITUDE OPERATORS

7.4.1 Natural Frequencies/Periods

AQWA-NAUT calculates the **uncoupled** natural frequencies/periods for each body at each user specified wave frequency (added mass being a function of wave frequency).

The damping values of the body motions are compared with and expressed as a percentage of the critical damping values (see Figure 7.11).

```
      * * * * NATURAL FREQUENCIES/PERIODS FOR STRUCTURE 1 * * * *
             -------------------------------------------

      N.B. THESE NATURAL FREQUENCIES DO *NOT* INCLUDE STIFFNESS
                       DUE TO MOORING LINES.

FREQUENCY FREQUENCY      UNDAMPED  NATURAL  FREQUENCIES(RADIANS/SECOND)

 NUMBER    (RAD/S)  SURGE(X)  SWAY(Y) HEAVE(Z) ROLL(RX) PITCH(RY) YAW(RZ)
-------------------------------------------------------------------------

  1        0.349     0.000     0.000    0.380    0.232    0.238    0.000
  2        0.370     0.000     0.000    0.382    0.232    0.238    0.000
  3        0.381     0.000     0.000    0.382    0.232    0.238    0.000
  4        0.393     0.000     0.000    0.383    0.232    0.238    0.000
  5        0.419     0.000     0.000    0.384    0.232    0.238    0.000
  6        0.449     0.000     0.000    0.384    0.232    0.238    0.000
  7        0.524     0.000     0.000    0.383    0.232    0.238    0.000

PERIOD    PERIOD              UNDAMPED  NATURAL  PERIOD(SECONDS)

NUMBER   (SECONDS)  SURGE(X)  SWAY(Y) HEAVE(Z) ROLL(RX) PITCH(RY) YAW(RZ)
-------------------------------------------------------------------------

  1        18.00     0.00      0.00     16.52    27.03    26.41    0.00
  2        17.00     0.00      0.00     16.46    27.03    26.41    0.00
  3        16.50     0.00      0.00     16.43    27.03    26.41    0.00
  4        16.00     0.00      0.00     16.41    27.04    26.41    0.00
  5        15.00     0.00      0.00     16.38    27.04    26.42    0.00
  6        14.00     0.00      0.00     16.37    27.04    26.42    0.00
  7        12.00     0.00      0.00     16.42    27.03    26.40    0.00

FREQUENCY FREQUENCY       APPROXIMATE  PERCENTAGE  CRITICAL DAMPING

 NUMBER    (RAD/S)  SURGE(X)  SWAY(Y)  HEAVE(Z) ROLL(RX) PITCH(RY) YAW(RZ)
--------------------------------------------------------------------------

  1        0.349     0.0       0.0       4.5      0.0      0.0     0.0
  2        0.370     0.0       0.0       4.3      0.0      0.0     0.0
  3        0.381     0.0       0.0       4.2      0.0      0.0     0.0
  4        0.393     0.0       0.0       4.0      0.0      0.0     0.0
  5        0.419     0.0       0.0       3.5      0.1      0.1     0.0
  6        0.449     0.0       0.0       3.0      0.1      0.2     0.0
  7        0.524     0.0       0.0       1.8      0.3      0.3     0.0
```

Figure 7.11 - Natural Frequencies/Periods

7.4.2 Response Amplitude Operators

The response amplitude operators, which are not required to calculate the wave frequency motion, will be output as zero if the user has not specified them in Deck 7. The output gives the variation of RAOs with frequency for each direction (see Figure 7.12) and their variation with direction for each frequency.

The RAOs are output in terms of amplitude and phase. The phase is related to the incident wave form (see Section 4.3.2 and the AQWA Reference Manual). All RAOs are given for unit wave amplitude.

```
                              HYDRODYNAMIC PARAMETERS FOR STRUCTURE 1
                              -------------------------------------

                                  R.A.O.S-VARIATION WITH WAVE PERIOD/FREQUENCY
                                  -------------------------------------------
  PERIOD FREQ  DIRECTION       X              Y             Z             RX             RY
            RZ
                   -  -  -  -  -  -  -       -  -  -  -  -  -       -  -  -  -  -  -  -  -  -  -
------------------------------------------------------------------------------------------

  (SECS)(RAD/S)(DEGREES)  AMP    PHASE    AMP    PHASE    AMP    PHASE   AMP     PHASE   AMP
PHASE    AMP      PHASE

------------------------------------------------------------------------------------------
----------------------
  18.00 0.349   0.00   0.7063  89.12   0.0000 151.89   2.1131  11.72   0.0000 -165.42   0.1733
92.72    0.0000    0.00
  17.00 0.370        0.6650  88.71   0.0000 157.11   3.2316  34.24   0.0000 -136.97   0.1326
93.78    0.0000  173.66
  16.50 0.381        0.6420  88.43   0.0000 123.38   3.8001  63.85   0.0000 -104.28   0.1152
94.46    0.0000  153.43
  16.00 0.393        0.6176  88.07   0.0000 154.34   3.0466  99.87   0.0000  -74.43   0.0981
95.37    0.0000  107.65
  15.00 0.419        0.5630  87.02   0.0000 160.91   1.2160 131.09   0.0000  -31.82   0.0692
97.39    0.0000   93.37
  14.00 0.449        0.4998  85.31   0.0000 157.97   0.5606 136.50   0.0000  -33.36   0.0453
100.37    0.0000  110.55

  18.00 0.349  45.00   0.5103  89.18   0.5100  89.18   2.1135  11.71   0.1027 -86.90   0.1119
93.10    0.0000   32.19
  17.00 0.370        0.4835  88.82   0.4833  88.81   3.2326  34.21   0.0761 -85.46   0.0824
94.54    0.0000    3.10
  16.50 0.381        0.4689  88.57   0.4687  88.56   3.8017  63.81   0.0646 -84.47   0.0696
95.53    0.0000  131.19
  16.00 0.393        0.4534  88.26   0.4533  88.25   3.0483  99.82   0.0530 -83.01   0.0570
96.99    0.0000 -173.77
  15.00 0.419        0.4192  87.39   0.4191  87.39   1.2174 131.01   0.0330 -78.78   0.0354
101.22    0.0000   50.15
  14.00 0.449        0.3803  86.06   0.3803  86.06   0.5620 136.37   0.0161 -67.91   0.0172
112.09    0.0000  138.80
```

Figure 7.12 - Response Amplitude Operators

7.5 DESCRIPTION OF STRUCTURE LOADING

This section outputs details of the loads on each structure, whether due to wind and current, thrusters, user applied constraints or mooring lines.

7.5.1 Thruster Forces and Wind and Current Coefficients

The thruster number and associated force vectors (relative to the relevant structure's centre of gravity axis system), along with the point of application (expressed in the FRA system), are output as shown in Figure 7.13.

```
        * * * * WIND/CURRENT LOADS FOR UNIT AMPLITUDE/VELOCITY * * * *
                ----------------------------------------------
             * * * * AND THRUSTER FORCES FOR STRUCTURE 1 * * * *
                    ------------------------------------

                               THRUSTER  FORCES
                               ----------------

 THRUSTER NODE  POSITION OF THRUSTER(FRA)    LOCAL THRUSTER FORCES IN
 NUMBER  NUMBER    X       Y       Z      SURGE(X)   SWAY(Y)    HEAVE(Z)
 -----------------------------------------------------------------------
    1      15    45.000  0.000  -20.000 -2.000E+06  0.000E+00  0.000E+00
```

Figure 7.13 - Thruster Force Output

In addition, the wind and current forces and moments, which are functions of direction, are output for each structure as shown in Figure 7.14.

The wind and current forces, which are both a function of the square of velocity, are given for unit velocity.

```
FORCES   FREQUENCY   DIRECTION(DEGREES)

------   ---------   -------------------------
DUE TO (RADIANS/SEC)   0.0       45.0      90.0
------ ------------- -------------------------

WIND
----
SURGE(X)
                   1.32E+03  1.07E+03  0.00E+00
SWAY(Y)
                   0.00E+00  1.07E+03  1.32E+03
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00 -1.94E+04 -2.39E+04
PITCH(RY
                   2.39E+04  1.94E+04  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00

CURRENT
-------
SURGE(X)
                   2.95E+06  2.40E+06  0.00E+00
SWAY(Y)
                   0.00E+00  2.40E+06  2.95E+00
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00  2.25E+07  2.77E+07
PITCH(RY
                  -2.77E+07 -2.25E+07  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00
```

Figure 7.14 - Wind and Current Force Coefficients

7.5.2 Structural Constraints

The active degrees of freedom of each structure in the analysis are signified by the character X in the constraint table as shown in Figure 7.15.

```
                 * * * *  CONSTRAINTS  * * * *
                          -----------


         STRUCTURE           ACTIVE FREEDOM TABLE

          NUMBER     X       Y       Z      RX      RY      RZ
        --------------------------------------------------------

           1         X       X       X       X       X       X
```

Figure 7.15 - Structure Constraints Table

7.5.3 Articulations

The articulation specified between each structure during the analysis is signified by the joint type number in the constraint table as shown in Figure 7.16, where the joint type can be identified from the following:

Joint Type Number	Type of Joint
1	Ball and Socket
2	Universal
3	Hinged
4	Locked

Type of Articulations Available

The output also specifies the structures and their nodes at which the articulation is located and also the nodes that define the joint plane.

```
                    * * * *  CONSTRAINTS  * * * *
                             -----------


 CONSTRAINT   JOINT  DEFINED ON       AT      IN DIRECTION AND DIRECTION
                      STRUCTURE      NODE       OF NODE      OF NODE
   NUMBER     TYPE     NUMBER       NUMBER       NUMBER       NUMBER
---------------------------------------------------------------------------

     1          1         1           11           13            0


          ..........(output line continued below)...........


           LINKED TO       AT      IN DIRECTION AND DIRECTION
           STRUCTURE      NODE       OF NODE      OF NODE
            NUMBER       NUMBER       NUMBER       NUMBER
          ---------------------------------------------------

              2            11           14           0
```

Figure 7.16 - Structure Articulations Table

7.5.4 Mooring Configurations

The mooring line configurations table (as shown in Figure 7.17), consisting of the type and properties of individual moorings, is output along with the mooring combination and group number. The location of the mooring line is identified by a pair of structure numbers and node numbers. In the case of linear moorings (i.e. linear lines, winch loads and constant forces), the properties are included in the general output either as stiffnesses or forces. However, in the case of non-linear moorings (i.e. non-linear hawsers or catenaries), the properties are output in an additional table as shown in Figure 7.18. The parameter list depends on the mooring type and is defined in the following table:

Parameter number	Polynomial (curve-fit of non linear stiffness)	Catenary
1	1st order polynomial coefficient	Weight/unit length
2	2nd order polynomial coefficient	Equivalent cross-sectional area
3	3rd order polynomial coefficient	Minimum tension at attachment points
4	4th order polynomial coefficient	Maximum tension at attachment point
5	5th order polynomial coefficient	Maximum tension at anchor point

Parameter List for Non-linear Moorings

Notes: (i) Non-linear moorings can have group properties, whereas the linear moorings have specific individual properties.

(ii) A structure number of zero means that the mooring is attached to a fixed point (e.g. a pier, sea bed, etc).

(iii) The equivalent cross-sectional area is equal to the volumetric displacement per unit length of the catenary. In general this area is not the same as the cross-sectional area (e.g. a chain will have a varying cross-sectional area along its length). It is used to calculate the buoyancy force on the catenary which is assumed to be constant along its length.

```
              * * * * CABLE/MOORING  LINE  CONFIGURATIONS * * * *
                      ----------------------------------

                  CABLE ATTACHMENTS( STRUCTURE - 0 - IS GROUND)
                  ---------------------------------------------

 COMBINATION    CABLE       ATTACHED TO AT NODE LINKED TO AT NODE UNSTRETCHED FORCE OR

  NUMBER   NUMBER/GROUP/TYPE STRUCTURE   NUMBER STRUCTURE NUMBER    LENGTH    STIFFNESS
 --------------------------------------------------------------------------------------

   1       1  2  NON-LINEAR      1          1       0        54     90.501

           2  2  NON-LINEAR      1         10       0        22     72.524

           3  3  NON-LINEAR      1         10       0        22     72.524

           5  0  LIN  ELASTIC    3         53       0        57     50.000   0.500E+07

           6  0  CONST F/DIRN    1         37       0        42      0.000   0.323E+07
```

Figure 7.17 - Mooring Configuration Table

```
              * * * * CABLE/MOORING  LINE  CONFIGURATIONS * * * *
                      ----------------------------------

 ------------------------------------------------------------------------
 GROUP   GROUP      PARAMETER  PARAMETER  PARAMETER  PARAMETER  PARAMETER
 NUMBER   TYPE          1          2          3          4          5
 ------------------------------------------------------------------------

   1    POLYNOMIAL  5.6481E+04 1.9731E+05 5.8376E+04 0.0000E+00 0.0000E+00

   2    POLYNOMIAL  6.0853E+04 1.4328E+05 2.8868E+04 0.0000E+00 0.0000E+00

   3     CATENARY   2.9790E+02 3.8070E-02 0.0000E+00 0.0000E+00 0.0000E+00
```

Figure 7.18 - Non-linear Mooring Properties

7.6 DESCRIPTION OF ENVIRONMENTAL CONDITIONS

This section outputs the details of the environmental conditions during the simulation (i.e. wind, wave and current).

7.6.1 Wind and Current Conditions (no waves)

The wind and current conditions are output as shown in Figure 7.19. This output consists of uniform wind and current fields with a superimposed profiled current condition, characterised by a variation of current speed and direction with water depth. However the latter variable can be set to a default value.

```
                * * * * ENVIRONMENTAL PARAMETERS * * * *
                        ------------------------

        UNIFORM CURRENT VELOCITY  . . . . . . . . . =     0.000

        UNIFORM CURRENT DIRECTION . . . . . . . . . =     0.000

        UNIFORM WIND VELOCITY . . . . . . . . . . . =     0.000

        UNIFORM WIND DIRECTION  . . . . . . . . . . =     0.000

        DEFAULT DIRECTION OF PROFILED CURRENT . . . =     0.000


                            CURRENT PROFILES
                            ----------------

           Z-ORDINATE            CURRENT              CURRENT
        W.R.T. SEA LEVEL         VELOCITY             DIRECTION

           -10.000                1.000                0.000
            -5.000                1.000                0.000
             0.000                2.000                0.000
```

Figure 7.19 - Wind and Current Conditions

7.6.2 Wave Conditions

The output as shown in Figure 7.20 lists the regular wave frequency, amplitude, direction and wave theory used to calculate the Froude-Krylov forces. Also output is the transient decay damping factor for each degree of freedom for each structure and the time after which the transient damping decay factors are no longer effective.

```
 * * * * REGULAR WAVE PARAMETERS AND INITIAL DAMPING FACTORS * * * *
         ---------------------------------------------------



         WAVE FREQUENCY(RADIANS/SEC) - - - - - - =    0.44880

         WAVE FREQUENCY(HERTZ) - - - - - - - - - =    0.07143

         WAVE NUMBER - - - - - - - - - - - - - - =    0.02054

         WAVE AMPLITUDE  - - - - - - - - - - - - =    0.50

         WAVE PERIOD - - - - - - - - - - - - - - =   14.00

         WAVE LENGTH - - - - - - - - - - - - - - =  305.87

         WAVE DIRECTION  - - - - - - - - - - - - =    0.00

         DAMPING DECAY FACTOR ZERO AT TIME - - - =    0.00

         TYPE OF WAVE THEORY - - - - - - - - - - = STOKES2(D/W)

                    INITIAL DAMPING MULTIPLIERS
                    ---------------------------

STRUCTURE   X          Y          Z          RX         RY         RZ
------------------------------------------------------------------------

  1    1.2543E+08 2.2451E+08 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

------------------------------------------------------------------------
```

Figure 7.20 - Regular Wave Parameters and Initial Damping Factors

7.7 TIME INTEGRATION PARAMETERS

7.7.1 Initial Positions

The initial position of the centre of gravity specified by the user for each structure will be output in the format shown in Figure 7.21.

```
* * * * INITIAL POSITION  AND VELOCITY OF THE CENTRE OF GRAVITY * * * *
        -------------------------------------------------------

STRUCTURE                      TRANSLATIONS(FRA)

 NUMBER   PARAMETER        X           Y           Z
-----------------------------------------------------------

   1      POSITION       0.000       0.000     -10.620



          VELOCITY       0.000       0.000       0.000
-----------------------------------------------------------



        ..........(output line continued below)...........



          ROTATIONS(FRA)                      DIRECTION COSINES
       RX           RY           RZ            X       Y       Z
---------------------------------------------------------------------
      0.000        0.000        0.000        1.0000  0.0000  0.0000
                                             0.0000  1.0000  0.0000
                                             0.0000  0.0000  1.0000
      0.000        0.000        0.000
---------------------------------------------------------------------
```

Figure 7.21 - Initial Positions

7.7.2 Integration parameters

The integration parameters used in the motion analysis are output as shown in Figure 7.22. These correspond to the number of records, the present time and timestep. Also output are the errors in amplitude and phase expected when the predictor-corrector integration scheme used in AQWA-NAUT is used for the given timestep for a range of frequencies.

```
* * * * T I M E   I N T E G R A T I O N   P A R A M E T E R S * * * *
        - - - - - - - - - - - - - - - - - - - - - - - - - - -


INTEGRATION SCHEME= TWO-STAGE PREDICTOR-CORRECTOR WITH THIRD ORDER ERRORS
-------------------------------------------------------------------------

                 STARTING RECORD NUMBER........     1

                 NUMBER OF TIME STEPS..........   141

                 PRESENT TIME STEP.............   1.000

                 PRESENT TIME..................   0.000

EXPECTED ERRORS FOR INTEGRATION OF SINUSOIDAL MOTION FOR TIMESTEP OF 1.0
------------------------------------------------------------------------

            FREQUENCY    PERIOD   AMPLITUDE ERROR  PHASE ERROR

            (RAD/SEC)  (SECONDS)    (PER CENT)      (DEGREES)
            --------------------------------------------------

            0.0200     314.16        0.0            0.0

            0.0300     209.44        0.0            0.0

            0.0500     125.66        0.0            0.0

            0.0700      89.76        0.0            0.1

            0.1000      62.83        0.0            0.2

            0.1500      41.89        0.0            0.3

            0.2000      31.42        0.1            0.6

            0.3000      20.94        0.2            1.3

            0.5000      12.57        0.9            3.4

            0.7000       8.98        2.4            5.9

            1.0000       6.28       10+            10+

            1.5000       4.19       10+            10+

            2.0000       3.14       10+            10+

            5.0000       1.26       10+            10+
```

Figure 7.22 - Integration Parameters

7.8 TIME HISTORY AND FORCE PRINTOUT

At each requested timestep the full description of the structure's position and the magnitude of all relevant forces is printed on the output listing. Figure 7.23 shows a typical example.

The example printout is of record number 21 of a simulation, i.e. it is a description of the state of affairs at the twenty first timestep of the run and occurs at a time of 20 seconds (since the timestep used during the analysis is 1 second).

The value of each variable is stated in the chosen set of consistent units and is with respect to the Fixed Reference Axis System.

```
   JOB TITLE-MODIFIED TEST 20 (FLOATING BOX, 40M DRAUGHT)

----------------------------------------------------------------------------------------------------------
-------------------
                                                             D E G R E E        O F   F R E E D O M
   RECORD NO.  STRUCTURE    POSITION,FORCES
                NUMBER      AND MOMENTS AT                X             Y            Z              RX
 RY            RZ
   TIME (SECS)             CENTRE OF GRAVITY           SURGE          SWAY        HEAVE            ROLL
PITCH          YAW


----------------------------------------------------------------------------------------------------------
-------------------

   RECORD NO.   21
       20.00      1            POSITION              0.2010       0.0000     -10.3016          0.0000
0.0136       0.0001
                                VELOCITY             -0.0925       0.0000      -0.0143           0.0000
-0.0036       0.0000
                             ACCELERATION            -0.0335       0.0000     -0.0612           0.0000
-0.0037       0.0000
                          RAO BASED POSITION          0.0906       0.0000      0.2673          0.0000
0.0134       0.0000
                          RAO BASED VELOCITY         -0.1045       0.0000      -0.0379           0.0000
-0.0082       0.0000
                           RAO BASED ACCEL           -0.0182       0.0000      -0.0538           0.0000
-0.0027       0.0000
                             DIFFRACTION            -1.1223E+07  -1.4693E+01   5.5449E+06    -7.2519E+01
5.5391E+07   0.0000E+00
                           LINEAR DAMPING            8.6186E+06   1.1908E+01   1.8205E+05      2.2768E+01
-1.6479E+07   1.2652E-04
                           FROUDE KRYLOV            -8.5587E+06  -1.1992E+01  -1.4022E+07      4.9352E+01
-3.1616E+07  -3.0992E+00
                            HYDROSTATIC              0.0000E+00   0.0000E+00   3.2307E+09      4.8407E+01
-5.7862E+06   0.0000E+00
                            TOTAL FORCE             -1.1163E+07  -1.4778E+01  -3.4218E+07      4.8008E+01
1.5096E+06  -3.0990E+00


----------------------------------------------------------------------------------------------------------
--------------------
```

Figure 7.23 - Timestep Printout

7.9 HARMONIC ANALYSIS OF TIME HISTORY

Once the simulation is completed it is post-processed to establish the amplitude and phase of the fundamental and harmonic responses of the structure to the wave frequency forces on a cycle by cycle basis which are output as shown in Figure 7.24. Also included in the output is the averaged cycle position (corresponding to a DC level) and the residual amplitudes unaccounted for by the harmonic analysis.

```
               HARMONIC ANALYSIS OF STRUCTURE  RESPONSE
               -----------------------------------------

                        STRUCTURE NUMBER =      1

                        WAVE AMPLITUDE   =  0.500

                        WAVE FREQUENCY   =  0.500

                        WAVE DIRECTION   =  0.000

-----------------------------------------------------------------------------------------------------------
----------------
                             AVERAGE    FUNDAMENTAL    1ST HARMONIC    2ND HARMONIC   3RD HARMONIC    4TH
HARMONIC   RESIDUAL

    CYCLE   START                     0.500 RAD/S     1.000 RAD/S     1.500 RAD/S    2.000 RAD/S     2.500
RAD/S   RESPONSE

   NUMBER   TIME                AMP      AMP   PHASE     AMP   PHASE     AMP   PHASE    AMP   PHASE     AMP
PHASE

-----------------------------------------------------------------------------------------------------------
----------------

       1    55.32  SURGE     0.001    0.002   43.2    0.000 -137.2    0.000   23.4    0.000  132.2    0.000
 37.2    10.34
                   SWAY      0.000    0.000   21.4    0.000  -46.2    0.000 -103.2    0.000  -67.4    0.000
143.2     2.17
                   HEAVE     0.000    0.673  167.2    0.125  125.1    0.053  -32.1    0.004  172.2    0.001
-105.1     1.73
                   ROLL      0.002    0.231  -84.2    0.003    3.2    0.000   91.3    0.000 -135.2    0.000
-63.2     3.45
                   PITCH    -0.031    1.265  -75.1    0.131  -33.9    0.021   -3.7    0.001  -77.1    0.001
 72.9     8.53
                   YAW      -0.456    0.001    7.8    0.000  175.2    0.000   53.1    0.000   23.8    0.000
 31.2     5.61

       2    67.32  SURGE     0.001    0.002   43.8    0.001 -121.2    0.000   23.4    0.000  132.8    0.000
 43.2     8.21
                   SWAY      0.000    0.000   22.4    0.000  -49.1    0.000 -103.2    0.000  -53.4    0.000
149.1     1.98
                   HEAVE     0.000    0.678  161.2    0.125  119.7    0.053  -32.1    0.005 -168.2    0.002
-119.1     1.67
                   ROLL      0.001    0.232  -73.2    0.003    1.2    0.000   91.3    0.000 -128.2    0.000
-58.2     2.76
                   PITCH    -0.025    1.253  -81.1    0.131  -37.1    0.021   -3.7    0.001  -82.1    0.000
 71.1     5.31
                   YAW      -0.471    0.001    8.1    0.000  179.5    0.000   53.1    0.000   31.1    0.000
 29.5     4.91
```

Figure 7.23 - Harmonic Analysis Printout

CHAPTER 8 - EXAMPLE OF PROGRAM USE

In this chapter an example problem using AQWA-NAUT is illustrated. The problem is one in which AQWA-LINE has been used to perform the analysis Stages 1 to 3. All steps in the subsequent analysis procedure are clearly shown, from the problem definition, through the data preparation, to the final analysis run itself. The method used in this chapter can be easily followed by the user and if so desired, the user can repeat the whole procedure, using the same data as used here, to obtain the same results. In this manner the new user can quickly obtain confidence in using the program.

8.1 BOX STRUCTURE

8.1.1 Problem Definition

The structure to be analysed in the example is a rectangular box for which the diffraction analysis has previously been performed using AQWA-LINE (i.e. Stages 1 to 3). This is the simplest and most common form of analysis, i.e. an AQWA-LINE run of Stages 1 to 3 followed by an AQWA-NAUT run. It is assumed that the user is familiar with the box structure example in AQWA-LINE. Although the example in the AQWA-LINE Manual includes post-processing Stages 4 and 5, this does not affect the AQWA-NAUT run of Stages 4 and 5 in any way.

The characteristics of the body are as follows:

Length	=	90.0 metres		
Breadth	=	90.0 metres		
Depth	=	55.0 metres		
Draught	=	40.0 metres		
Mass of the body	=	3.321E8 kg	=	3.321E5 tonnes

Mass inertia about the Fixed Reference Axes (FRA):

I_{xx} = 3.6253E11 kgm^2
I_{yy} = 3.4199E11 kgm^2
I_{zz} = 3.5991E11 kgm^2

The centre of gravity position vector is (0.0,0.0,-10.62) measured with respect to the FRA.

The environmental parameters are as follows:

Water depth	=	250.0 metres
Water density	=	1025.0 kg/metre^3

The frequencies and directions of the radiation/diffraction coefficients are as follows:

Wave periods	=	12 to 18 seconds
Wave directions	=	0.0, 45.0 and 90.0 degrees

The wave parameters are as follows:

Period	=	14 seconds
Amplitude	=	0.5 metres
Direction	=	0.0 degrees

The box structure is moored by horizontal soft moorings attached to the mid-sides of the box at the water line as shown in Figure 8.1.

Unstretched length of each mooring line	=	100.0 metres
Length of each mooring line at start of analysis	=	101.0 metres
Extension of each mooring line at start of analysis	=	1.0 metres
Stiffness of each mooring line	=	1.471E6 N/m
Pretension in each mooring line	=	1.471E6 newtons

In addition, a thruster force acts on the side of the box in the X direction as shown in Figure 8.1.

Thruster force	=	2.0E6 newtons

It is required to obtain the response of the box in regular waves. Note that the analysis is performed using SI units.

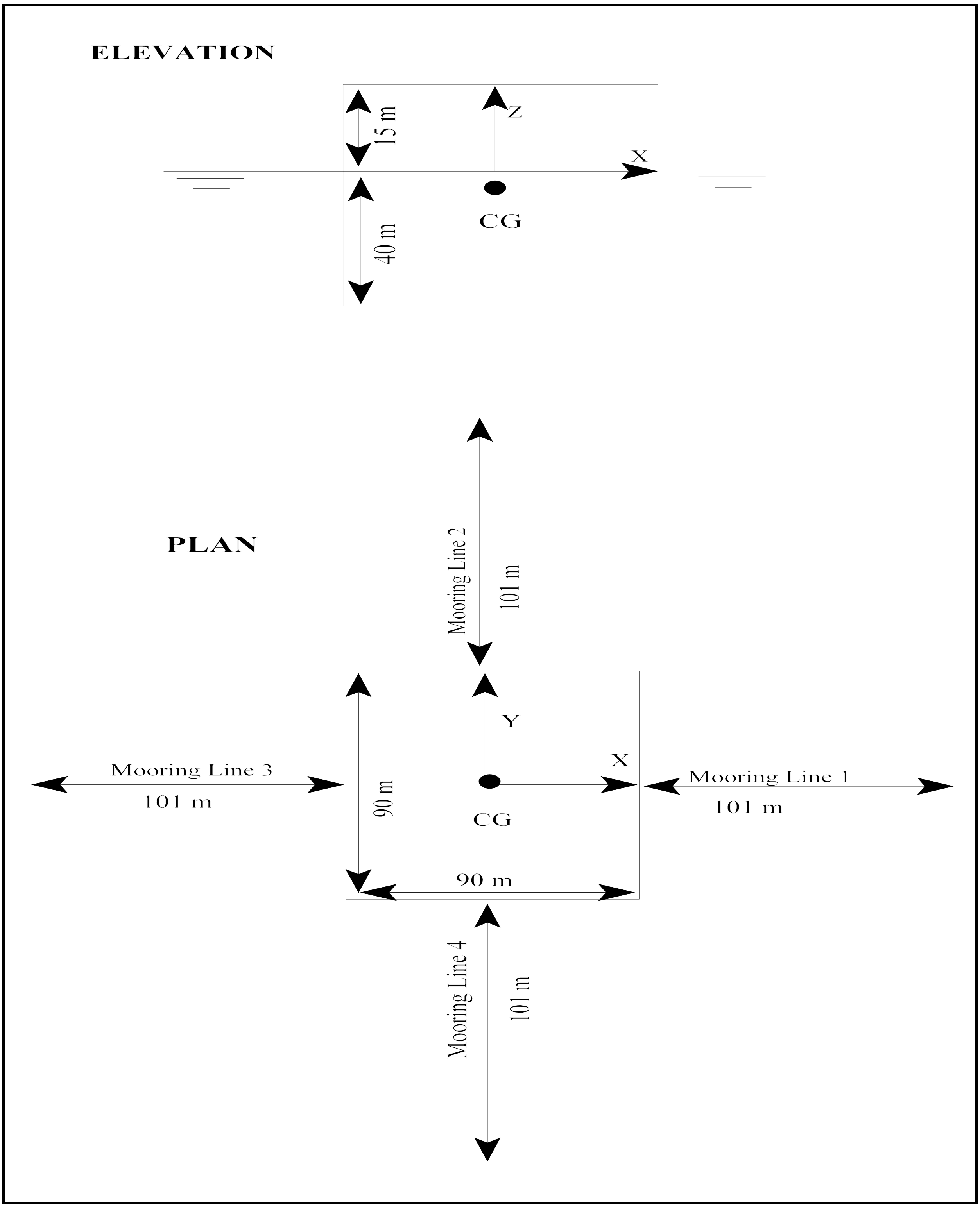


Figure 8.1 - General Layout of Box Structure

8.1.2 Idealisation of Box

The following is required for an AQWA-NAUT model:

- The mass and inertia properties of the body

- A representation of the surface of the body

Before starting the modelling exercise, it is necessary to decide the definition position of the body with respect to the FRA. The body is defined such that the bottom of the box is 40 metres below the X-Y plane of the FRA and parallel to it. In this example, the DEFINITION position and ANALYSIS position of the body are the same.

8.1.3 The Body Surface

The body has the property of 4-fold symmetry, which may be utilised when modelling the surface of the body since it is only necessary to describe one quarter of the box's surface and this is shown in Figure 8.2.

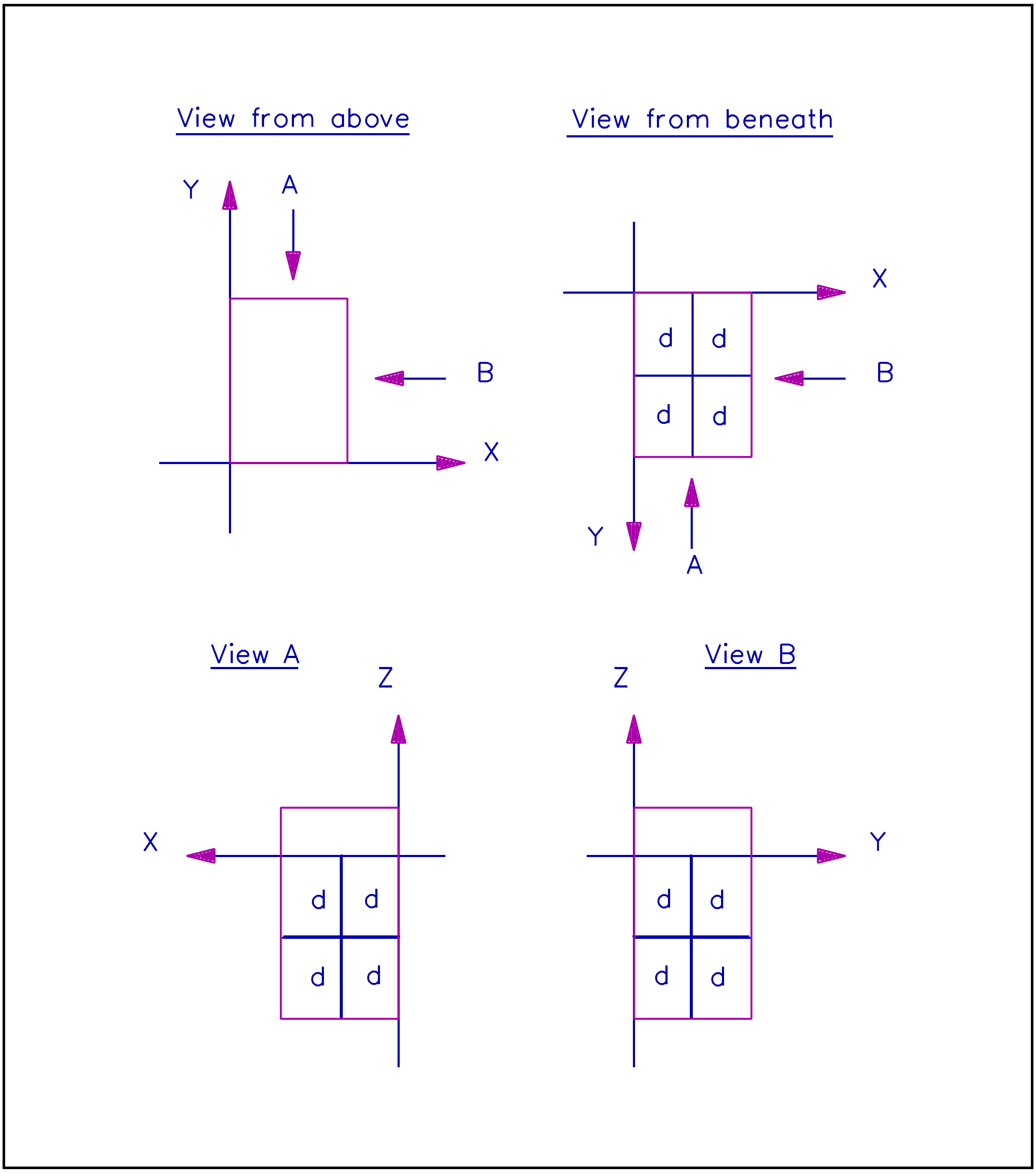
Type of Plate Element

Since each of the box surfaces is rectangular and planar, we may best utilise QPPL elements.

Sizing of QPPL Elements

The model beneath the free surface is the same as that used in AQWA-LINE and satisfies the AQWA-LINE modelling criteria (see AQWA-LINE User Manual Section 8.1.1). The superstructure is composed of non-diffracting quadrilateral plates whose only limitation is that their sides are less than 1/7 of the wavelength.

Additional nodes were placed on the structure and the sea bed to represent the mooring attachment points (see Figure 8.1).



d = diffracting element for AQWA-LINE

Figure 8.2 - Modelling of Body's Wetted Surface

8.1.4 The Body Mass and Inertia

The mass and inertia characteristics are modelled by using a single point mass element (PMAS) placed at the centre of gravity. This is positioned at X = 0.0, Y = 0.0, Z = -10.62 metres with respect to the FRA. This PMAS element will have the required mass and inertia properties described by the relevant material and geometric group properties as follows:

Mass input via material group 1 with associated value of 3.321E8 kg

Inertia input via geometry group 1 with associated values of:

I_{xx} = 3.6253E11 kgm
I_{yy} = 3.4199E11 kgm
I_{zz} = 3.5991E11 kgm

and $I_{xy} = I_{yz} = I_{zx} = 0.0$

8.1.5 AQWA-LINE Analysis

The model as described in the previous sections was run using AQWA-LINE for Stages 1 to 3 in order to generate the hydrodynamic data required by the AQWA-NAUT analysis. The diffraction forces for unit wave amplitude, the added mass, radiation damping and the response amplitude operators are calculated by AQWA-LINE for each wave frequency and direction.

8.1.6 Natural Frequencies

It is good practice when using AQWA-NAUT to perform some short and simple preliminary runs to ensure that the model has been formed correctly before embarking on long simulation runs.

The first check is to ensure that the model has the correct natural periods. This is achieved by performing a short run with the structure initially displaced from its still water equilibrium position and allowing it to oscillate at its natural frequency about the equilibrium position. The observed natural periods of the motion can be checked against simple calculations.

In the horizontal freedoms, AQWA-LINE gives no natural frequencies as the hydrostatic stiffness in these freedoms is zero. With the addition of the four mooring lines in this AQWA-NAUT analysis, all these freedoms will have stiffness and corresponding natural frequencies.

8.1.7 Hull and Superstructure Loading Coefficients

Data for the hull and superstructure loading coefficients for wind and current in this example are based on the projected area through the centroid in the three directions specified in Deck 6.

Wind and current forces per unit velocity acting on the body are given by:

$$\text{Force} = 0.5 * \text{Density} * \text{Area} * \text{Drag coefficient} * \cos(\text{heading})$$

Thus the forces in the X and Y directions, due to currents at 0, 45 and 90 degree headings, are respectively

F_X (0), F_Y (90) = $0.5 * 1025.0 * 40.0 * 90.0 * 1.6 * \cos(0)$ = 2.95E6 Ns^2/m^2
F_Y (0), F_X (90) = $0.5 * 1025.0 * 40.0 * 90.0 * 1.6 * \sin(0)$ = 0.00E0 Ns^2/m^2
F_X (45), F_Y (45) = $0.5 * 1025.0 * 40.0 * 127.0 * 1.3 * \cos(45)$ = 2.40E6 Ns^2/m^2

The corresponding moments at the centre of gravity (10.62 metres below the waterline, centre of area at Z = -20.0) are

At a heading of 0	M_X (0)	= 0.00E0	M_Y (0) =	-2.77E7
At a heading of 45	M_X (45)	= 2.25E7	M_Y (45) =	-2.25E7
At a heading of 90	M_X (90)	= 2.77E7	M_Y (90) =	0.00E0

The units for the moment coefficients are Ns^2/m.

Similarly, the forces on the superstructure due to the wind at 0, 45 and 90 degree headings in the X and Y directions respectively (for unit velocity) are:

F_X (0), F_Y (90) = $0.5 * 1.22 * 15.0 * 90.0 * 1.6 * \cos(0)$ = 1.32E3 Ns^2/m^2
F_Y (0), F_X (90) = $0.5 * 1.22 * 15.0 * 90.0 * 1.6 * \sin(0)$ = 0.00E0 Ns^2/m^2
F_X (45), F_Y (45) = $0.5 * 1.22 * 15.0 * 127.0 * 1.3 * \cos(45)$ = 1.07E3 Ns^2/m^2

The moments at the centre of gravity (10.62 metres below the waterline, centre of area at Z=+7.5) are:

At a heading of 0	M_X (0) =	0.00E0	M_Y (0) =	2.39E4
At a heading of 45	M_X (45) =	-1.94E4	M_Y (45) =	1.94E4
At a heading of 90	M_X (90) =	-2.39E4	M_Y (90) =	0.00E0

The units for the moment coefficients are Ns^2/m.

In addition, a thruster force of 2.0E6 N was applied to the box as shown in Figure 8.3, i.e. a thruster force vector of (-2.0E6,0,0) newtons.

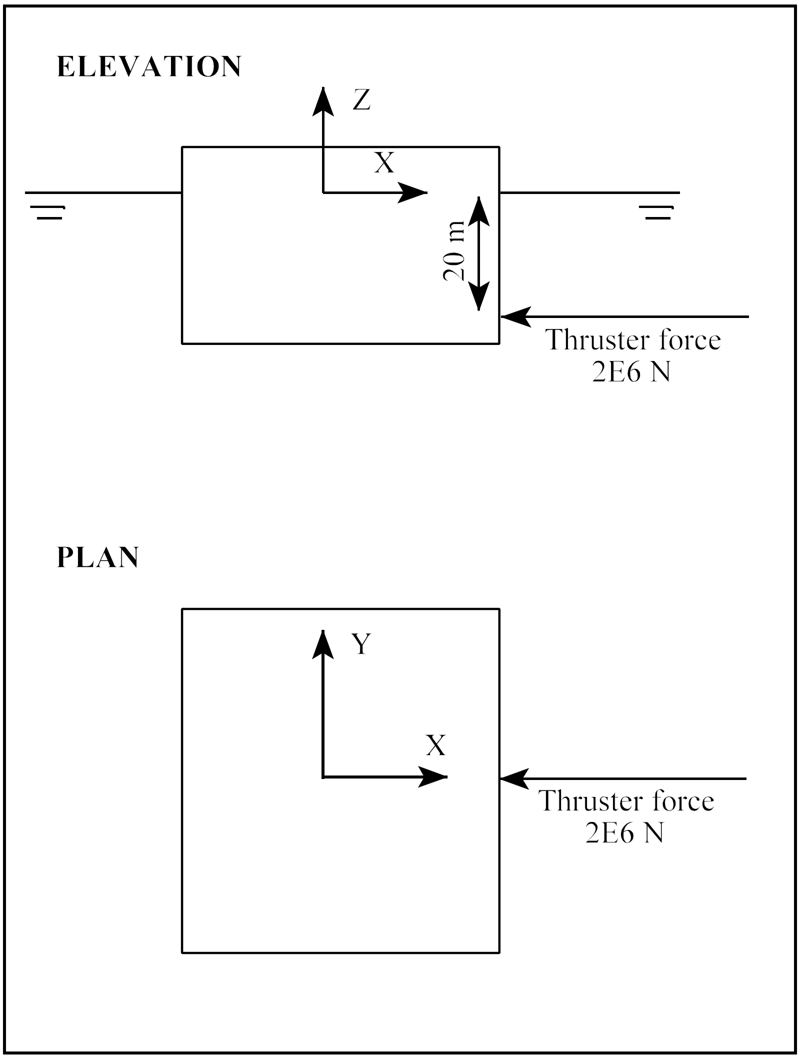


Figure 8.3 - Thruster Force

8.1.8 Wave, Current and Wind Conditions

The following wave condition was used in this example:

Wave Theory Type	Frequency (radians/sec)	Period (secs)	Wave Amplitude (metres)	Direction (Degrees)
Second Order Deep Water	0.448	14	0.5	0.0

The wind and current speeds and directions used were as follows:

Wind speed	=	15.0 m/s
Wind direction	=	0.0 degrees
Current speed	=	0.8 m/s
Current direction	=	0.0 degrees

No transient damping was applied to the system.

8.1.9 Specification of the Mooring Lines

The mooring lines are simple linear elastic hawsers and therefore require 1 line of input data for each mooring line. Each input line contains the stiffness, unstretched length and the structure numbers and node numbers of the two attachments points. For a line joining a structure to a fixed point, the structure number corresponding to the fixed point should be set to zero. The numbers and positions of the nodes to which the mooring lines are attached, must be input in the coordinate deck (i.e. Deck 1). Each mooring line is of 100 metres unstretched length and has a stiffness of 1.471E6 newtons per metre.

Each mooring line is pre-tensioned to 1.471E6 newtons (i.e. extended by 1 metre) to give the structure a significant yaw stiffness.

8.1.10 Initial Position for Analysis

The initial position used was the structure's equilibrium position which may be either the value used in the AQWA-LINE analysis or can be estimated manually. The positions were as shown:

```
SURGE(X)      SWAY(Y)   HEAVE(Z)   ROLL(RX)      PITCH(RY)     YAW(RZ)

   0.0           0.0    -10.62        0.0           0.0           0.0
```

8.1.11 Integration Parameters for Analysis

The integration parameters used the motion analysis were

Number of steps	= 100
Timestep	= 1.0 seconds
Starting time	= 0.0 seconds

8.1.12 Input Preparation for Data Run

Since the AQWA-NAUT model requires full surface modelling, an AQWA-NAUT data run is used to create the hydrodynamic model RESTART FILE. This consists of the following steps:

- input the node coordinate data
- input the model's element topology with associated material and geometry properties
- input the static environment
- obtain the detailed properties of elements used in each body
- obtain the final mass and inertia properties of each body
- input the wave period and direction

The input decks for Stages 1 and 2 are shown in Figure 8.4 and may be described as follows:

- JOB card provides identifier and program to be used
- TITLE card prescribes a title header for the run
- OPTIONS card contains the selected options which were:

  REST - informs the program to expect a restart card
  PPEL - requests detailed print out of element properties
  PRCE - requests an echo print out of the data decks input
  END - indicates the end of the options list

- RESTART card selects Stages 1 and 2 to be performed

- Deck 1

  Cartesian coordinates of the node points to be used in modelling the body together with the user selected node number. Note that Deck 1 utilises multiple node generation. Also note that the five hundred series nodes input are for mooring line definitions.

- Deck 2

  Element types used in describing the body together with definitions of planes of symmetry to be used. Note the FINI card is used to inform the program that no more structures are being input.

- Deck 3

  Defines the mass of the body together with the user defined material group number (i.e. 1). See reference to material group 1 by Deck 2 when defining the PMAS element. Note that pressure plate elements have no material properties (i.e. no mass or material density).

- Deck 4

  Defines the inertial properties of the body by placing them in geometry group 1 and nominating this group to the PMAS element in Deck 2. Again note that pressure plate elements have no geometry group properties.

- Deck 5

  This deck is used to input the water depth, the density of the water and the acceleration due to gravity.

- Deck 6

  The wave periods are input together with the wave directions. In this case a range of periods have been selected between 18.0 and 12.0 seconds. (Note that the input is in descending order as periods have been used.) The wave directions input are 0, 45 and 90 degrees (i.e. 0 degrees being along the positive X axis and 90 degrees being along the positive Y axis).The values of frequency and direction must correspond to those used in the AQWA-LINE analysis.

- Deck 7

  This deck has no input and so has a NONE deck header.

- Deck 8

  This deck has no input and so has a NONE deck header.

```
JOB BOX1  NAUT
TITLE               TEST RUN (FLOATING BOX 40M DRAUGHT AND 80 FACETS)
OPTIONS PRCE PPEL REST END
RESTART   1  2
    01    COOR
    01   1    3    1      45.0     -45.0     -40.0     -22.5       0.0       0.0
    01  11    3    1      45.0     -22.5     -40.0     -22.5       0.0       0.0
    01  21    3    1      45.0       0.0     -40.0     -22.5       0.0       0.0
    01 101    3    1      45.0     -45.0     -20.0     -22.5       0.0       0.0
    01 111    2   10      45.0     -22.5     -20.0       0.0     -22.5       0.0
    01 201    3    1      45.0     -45.0       0.0     -22.5       0.0       0.0
    01 211    2   10      45.0     -22.5       0.0       0.0     -22.5       0.0
    01 301    3    1      45.0     -45.0      15.0     -22.5       0.0       0.0
    01 311    3    1      45.0     -22.5      15.0     -22.5       0.0       0.0
    01 321    3    1      45.0       0.0      15.0     -22.5       0.0       0.0
    01 501    2   10      45.0       0.0       0.0     101.0       0.0       0.0
    01 502    2   10       0.0      45.0       0.0       0.0     101.0       0.0
    01 503    2   10     -45.0       0.0       0.0    -101.0       0.0       0.0
    01 504    2   10       0.0     -45.0       0.0       0.0    -101.0       0.0
 END01 999                 0.0       0.0    -10.62
    02    ELM1
    02SYMX
    02SYMY
    02QPPL DIFF     (2)(1,10)(2,10)(12,10)(11,10)
    02QPPL DIFF     (2)(2,10)(3,10)(13,10)(12,10)
    02QPPL DIFF     (2)(1,10)(11,10)(111,10)(101,10)
    02QPPL DIFF     (2)(101,10)(111,10)(211,10)(201,10)
    02QPPL          (2)(201,10)(211,10)(311,10)(301,10)
    02QPPL DIFF     (2)(1,1)(101,1)(102,1)(2,1)
    02QPPL DIFF     (2)(101,1)(201,1)(202,1)(102,1)
    02QPPL          (2)(201,1)(301,1)(302,1)(202,1)
    02QPPL          (2)(301,1)(311,1)(312,1)(302,1)
    02QPPL          (2)(311,1)(321,1)(322,1)(312,1)
 END02PMAS          (1)(999)(1)(1)
    02    FINI
    03    MATE
 END03             1 332.100E6
    04    GEOM
 END04PMAS         1 3.6253E11       0.0       0.0 3.4199E11       0.0 3.5991E11
    05    GLOB
    05DPTH     250.0
    05DENS    1025.0
 END05ACCG     9.806
    06    FDR1
    06PERD    1    6      18.0      17.0      16.5      16.0      15.0      14.0
    06PERD    7    7      12.0
 END06DIRN    1    3       0.0      45.0      90.0
    07    NONE
    08    NONE
```

Figure 8.4 - Data Decks Required for Stages 1 and 2

8.1.13 Input Preparation for Stage 4 Data Run

The AQWA-LINE run (see AQWA-LINE example in the AQWA-LINE User Manual) has previously been performed and the following information is contained on the HYDRODYNAMIC backing file, produced by AQWA-LINE, which is necessary for the AQWA-NAUT analysis:

- the wave periods and directions
- the analysis position of each body
- diffraction/radiation analysis giving wave loading coefficients

The decks for the AQWA-NAUT Stage 4 data run are shown in Figure 8.5 and the input may be described as follows:

-	JOB	card	provides identifier program, and type of analysis to be used
-	TITLE	card	prescribes a title header for the run
-	OPTIONS	card	contains the selected options:
	PRDL	-	print data list from restart file
	ALDB	-	indicates that the AQWA-LINE radiation/diffraction data basis to be used
	REST	-	indicates that a restart run is required
	END	-	indicates the end of the options list
-	RESTART	card	containing the start and finish stages

- Deck 9

  This deck has no input and so has a NONE deck header.

- Deck 10

  Wind and current loading coefficients and thruster forces for the structure.

- Deck 11

  Wind and current conditions during the analysis.

- Deck 12

  This deck has no input and so has a NONE deck header.

- Deck 13

  Description of the wave conditions.

- Deck 14

  Description of each mooring line property and combination.

- Deck 15

  Starting position for the motion analysis.

- Deck 16

  Time integration parameters.

- Deck 17

  This deck has no input and so has a NONE deck header.

- Deck 18

  Print Options - Print every 10th timestep, omitting Morison Drag

Note that the program RESTART, which starts at the beginning of Stage 4 and finishes at the end of Stage 4, is equivalent to the DATA option.

```
JOB BOX1  NAUT
TITLE               TEST RUN (FLOATING BOX 40M DRAUGHT 80 FACETS)
OPTIONS PRDL ALDB REST END
RESTART   4  4
    09    NONE
    10    HLD1
    10CUFX    1    3  2.9500E6  2.4000E6  0.0000E0
    10CUFY    1    3  0.0000E0  2.4000E6  2.9500E6
    10CURX    1    3  0.0000E0  2.2500E7  2.7700E7
    10CURY    1    3 -2.7700E7 -2.2500E7  0.0000E0
    10WIFX    1    3  1.3200E3  1.0700E3  0.0000E0
    10WIFY    1    3  0.0000E0  1.0700E3  1.3200E3
    10WIRX    1    3  0.0000E4 -1.9400E4 -2.3900E4
    10WIRY    1    3  2.3900E4  1.9400E4  0.0000E4
 END10THRS       111 -2.0000E6
    11    ENVR
    11CURR       0.8       0.0
 END11WIND      15.0       0.0
    12    NONE
    13    WAVE
    13PERD            14.00
    13WAMP           .5E 00
 END13WVDN             0.00
    14    MOOR
    14LINE    1  501    0  511  1.4715E6     100.0
    14LINE    1  502    0  512  1.4715E6     100.0
    14LINE    1  503    0  513  1.4715E6     100.0
 END14LINE    1  504    0  514  1.4715E6     100.0
    15    STRT
 END15POS1                 0.0       0.0    -10.62
    16    TINT
 END16TIME       100       1.0       0.0
    17    NONE
    18    PROP
    18PREV   10
 END18NOPR    1   18
```

Figure 8.5 - Input for Stage 4 Run on Box Structure

8.1.14 Information Supplied by Stage 4 Data Run

The DATA run produces the output shown in Figures 8.6 to 8.14.

Figure 8.6	-	AQWA-NAUT header page used for identification
Figure 8.7	-	Card echo (mandatory) for Decks 9 to 18 This is used to check data input
Figure 8.8	-	Wind/Current Loads and Thruster Forces Tabulation of the data input in Deck 10
Figure 8.9	-	Environmental parameters This table shows the wind and current conditions
Figure 8.10	-	Constraints This table shows all the freedoms that are active
Figure 8.11	-	Regular Wave Parameters and Initial Damping Factors The regular wave condition input in Deck 13 is tabulated along with the initial damping factors used to suppress transients
Figure 8.12	-	Cable/Mooring Line Configurations Tabulation of the mooring lines input in Deck 14
Figure 8.13	-	Initial Positions and Velocities of the Centre of Gravity Tabulation of the initial position input in Deck 15
Figure 8.14	-	Time integration parameters Tabulation of the timestep, number of samples and the starting time as input in Deck 16 along with the expected errors over the range of frequencies

```
 AAAAAA    QQQQQQ   WW       WW   AAAAAA        NN       NN   AAAAAA   UU      UU   TTTTTTTT
AAAAAAAA  QQQQQQQQ  WW       WW  AAAAAAAA       NNN      NN  AAAAAAAA  UU      UU  TTTTTTTTTT
AA    AA  QQ    QQ  WW       WW  AA    AA       NNNN     NN  AA    AA  UU      UU      TT
AA    AA  QQ    QQ  WW       WW  AA    AA       NNNNN    NN  AA    AA  UU      UU      TT
AAAAAAAA  QQ    QQ  WW       WW  AAAAAAAA  IIII NN NNN   NN  AAAAAAAA  UU      UU      TT
AAAAAAAA  QQ    QQ  WW  WW   WW  AAAAAAAA  IIII NN  NNN NN  AAAAAAAA  UU      UU      TT
AA    AA  QQ    QQ  WW  WW   WW  AA    AA       NN   NNNNN  AA    AA  UU      UU      TT
AA    AA  QQ QQ QQ  WW  WW   WW  AA    AA       NN    NNNN  AA    AA  UU      UU      TT
AA    AA  QQQQQQQQ  WWWWWWWWWWW  AA    AA       NN     NNN  AA    AA  UUUUUUUUUU     TTTT
AA    AA   QQQQQQ    WWWWWWWW    AA    AA       NN      NN  AA    AA   UUUUUUU       TTTT
              QQ


THE DEVELOPMENT OF THE AQWA SUITE WAS CARRIED OUT BY
          CENTURY DYNAMICS LIMITED
WHO ARE CONTINUALLY IMPROVING THE CAPABILITIES OF THE
HYDRODYNAMIC CALCULATIONS AS MORE ADVANCED TECHNIQUES
BECOME AVAILABLE.    SUGGESTIONS FROM USERS REGARDING
DEVELOPMENT WILL BE WELCOMED.


CENTURY DYNAMICS LIMITED
DYNAMICS HOUSE
86 HURST ROAD
HORSHAM
WEST SUSSEX
RH12 2DT


JOB TITLE : TEST RUN (FLOATING BOX 40M DRAUGHT 80 FACETS)
```

Figure 8.6 - AQWA-NAUT Header Page used for Identification

```
     DECK  9
     -------

     DECK 10
     -------

     10CUFX    1    3 2.950E+06 2.400E+06 0.000E+00 0.000E+00 0.000E+00 0.000E+00
     10CUFY    1    3 0.000E+00 2.400E+06 2.950E+06 0.000E+00 0.000E+00 0.000E+00
     10CURX    1    3 0.000E+00 2.250E+07 2.770E+07 0.000E+00 0.000E+00 0.000E+00
     10CURY    1    3-2.770E+07-2.250E+07 0.000E+00 0.000E+00 0.000E+00 0.000E+00
     10WIFX    1    3 1.320E+03 1.070E+03 0.000E+00 0.000E+00 0.000E+00 0.000E+00
     10WIFY    1    3 0.000E+00 1.070E+03 1.320E+03 0.000E+00 0.000E+00 0.000E+00
     10WIRX    1    3 0.000E+00-1.940E+04-2.390E+04 0.000E+00 0.000E+00 0.000E+00
     10WIRY    1    3 2.390E+04 1.940E+04 0.000E+00 0.000E+00 0.000E+00 0.000E+00
  END10THRS    0  111-2.000E+06 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

     DECK 11
     -------

        11CURR      0.80      0.00      0.00      0.00      0.00      0.00
      END11WIND    15.00      0.00      0.00      0.00      0.00      0.00

     DECK 12
     -------

     DECK 13N
     --------

        13PERD    0    0    14.000     0.000     0.000     0.000     0.000     0.000
        13WAMP    0    0     0.500     0.000     0.000     0.000     0.000     0.000
      END13WVDN   0    0     0.000     0.000     0.000     0.000     0.000     0.000

     DECK 14
     -------

        14LINE    1  501    0  511 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
        14LINE    1  502    0  512 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
        14LINE    1  503    0  513 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00
      END14LINE   1  504    0  514 1.472E+06 1.000E+02 0.000E+00 0.000E+00 0.000E+00


     DECK 15
     -------

      END15POS1              0.000     0.000   -10.620     0.000     0.000     0.000

     DECK 16
     -------

      END16TIME   0  100     1.000     0.000     0.000     0.000     0.000     0.000

     DECK 17
     -------

     DECK 18
     -------

        18PREV   10    0    0    0
      END18NOPR   1   18    0    0
```

Figure 8.7 - Card Echo of Decks 9 to 18

```
* * W I N D / C U R R E N T   L O A D S   F O R   U N I T   A M P L I T U D E / V E L O C I T Y * *
        - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
            * * * * A N D   T H R U S T E R   F O R C E S   F O R S T R U C T U R E   1 * * * *
                    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                                          THRUSTER  FORCES
                                          ----------------

            THRUSTER  NODE    POSITION OF THRUSTER (FRA)       LOCAL THRUSTER FORCES IN

             NUMBER  NUMBER      X          Y          Z      SURGE(X)     SWAY(Y)     HEAVE(Z)
            ---------------------------------------------------------------------------------------
                1     111      45.000    -22.500    -20.000  -2.000E+06   0.000E+00   0.000E+00

FORCES   FREQUENCY   DIRECTION(DEGREES)

------   ---------   --------------------------
DUE TO (RADIANS/SEC)   0.0      45.0      90.0
------ ------------- --------------------------

WIND
----
SURGE(X)
                   1.32E+03  1.07E+03  0.00E+00
SWAY(Y)
                   0.00E+00  1.07E+03  1.32E+03
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00 -1.94E+04 -2.39E+04
PITCH(RY
                   2.39E+04  1.94E+04  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00

CURRENT
-------
SURGE(X)
                   2.95E+06  2.40E+06  0.00E+00
SWAY(Y)
                   0.00E+00  2.40E+06  2.95E+06
HEAVE(Z)
                   0.00E+00  0.00E+00  0.00E+00
ROLL(RX)
                   0.00E+00  2.25E+07  2.77E+07
PITCH(RY
                  -2.77E+07 -2.25E+07  0.00E+00
YAW(RZ)
                   0.00E+00  0.00E+00  0.00E+00
```

Figure 8.8 - Wind/Current Loads and Thruster Forces

```
* * * * E N V I R O N M E N T A L   P A R A M E T E R S * * * *
        - - - - - - - - - - - - - - - - - - - - - - - -

  UNIFORM CURRENT VELOCITY  . . . . . . . . . =     0.800

  UNIFORM CURRENT DIRECTION . . . . . . . . . =     0.000

  UNIFORM WIND VELOCITY . . . . . . . . . . . =    15.000

  UNIFORM WIND DIRECTION  . . . . . . . . . . =     0.000
   NO PROFILED CURRENT
```

Figure 8.9 - Environmental Parameters

```
        * * * *  C O N S T R A I N T S  * * * *
                 - - - - - - - - - - - -


STRUCTURE                      ACTIVE FREEDOMS TABLE
 NUMBER      X        Y        Z       RX       RY        RZ
----------------------------------------------------------------

     1       X        X        X        X        X        X
```

Figure 8.10 - Constraints

```
 R E G U L A R   W A V E   P A R A M E T E R S   A N D   I N I T I A L   D A M P I N G   F A C T O R
S
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
-



                              WAVE FREQUENCY(RADIANS/SEC) - - - - - =    0.44880

                              WAVE FREQUENCY(HERTZ) - - - - - - - - =    0.07143

                              WAVE NUMBER - - - - - - - - - - - - - =    0.02054

                              WAVE AMPLITUDE  - - - - - - - - - - - =    0.50

                              WAVE PERIOD - - - - - - - - - - - - - =   14.00

                              WAVE LENGTH - - - - - - - - - - - - - =  305.87

                              WAVE DIRECTION  - - - - - - - - - - - =    0.00

                              DAMPING DECAY FACTOR ZERO AT TIME - - =    0.00

                              TYPE OF WAVE THEORY - - - - - - - - - = STOKES2(D/W)
```

Figure 8.11 - Regular Wave Parameters and Initial Damping Factors

```
                        C A B L E / M O O R I N G   L I N E   C O N F I G U R A T I O N S
                         - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                                                     +
                                   CABLE ATTACHMENTS( STRUCTURE - 0 - IS GROUND)
                                   ------------------------------------------

COMBINATION CABLE  CABLE       CABLE    ATTACHED TO  AT NODE  LINKED TO   AT NODE  UNSTRETCHED  FORCE OR
                                                                     +
  NUMBER    NUMBER GROUP       TYPE      STRUCTURE   NUMBER   STRUCTURE   NUMBER      LENGTH    STIFFNESS
 --------------------------------------------------------------------------------------------------------

    1          1     0     LIN  ELASTIC      1         501        0         511      100.000    0.147E+07

               2     0     LIN  ELASTIC      1         502        0         512      100.000    0.147E+07

               3     0     LIN  ELASTIC      1         503        0         513      100.000    0.147E+07

               4     0     LIN  ELASTIC      1         504        0         514      100.000    0.147E+07
```

Figure 8.12 - Cable/Mooring Line Configurations

```
                     I N I T I A L   P O S I T I O N   A N D   V E L O C I T Y   O F   T H E
                     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                        C E N T E R   O F   G R A V I T Y
                                       - - - - - - - - - - - - - - - - -

STRUCTURE                   TRANSLATIONS(FRA)          ROTATIONS(FRA)            DIRECTION COSINES

 NUMBER   PARAMETER      X          Y         Z          RX         RY         RZ         X       Y      Z

----------------------------------------------------------------------------------------------------------
  1      POSITION      0.000      0.000    -10.620      0.000      0.000      0.000     1.0000  0.0000 0.0000

                                                                                        0.0000  1.0000 0.0000

                                                                                        0.0000  0.0000 1.0000

         VELOCITY     0.000      0.000      0.000       0.000      0.000      0.000

----------------------------------------------------------------------------------------------------------
```

Figure 8.13 - Initial Positions and Velocities of the Centre of Gravity

```
* * * * T I M E   I N T E G R A T I O N   P A R A M E T E R S * * * *
        - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

  INTEGRATION SCHEME= TWO-STAGE PREDICTOR-CORRECTOR WITH THIRD ORDER ERRORS
  -------------------------------------------------------------------------

                  STARTING RECORD NUMBER........     1

                  NUMBER OF TIME STEPS..........   100

                  PRESENT TIME STEP.............   1.000

                  PRESENT TIME..................   0.000


EXPECTED ERRORS FOR INTEGRATION OF SINUSOIDAL MOTION FOR TIME-STEP OF  1.0000
-----------------------------------------------------------------------------

             FREQUENCY    PERIOD   AMPLITUDE ERROR  PHASE ERROR
             (RAD/SEC)  (SECONDS)    (PER CENT)      (DEGREES)
             --------------------------------------------------

               0.0200     314.16         0.0            0.0

               0.0300     209.44         0.0            0.0

               0.0500     125.66         0.0            0.0

               0.0700      89.76         0.0            0.1

               0.1000      62.83         0.0            0.2

               0.1500      41.89         0.0            0.3

               0.2000      31.42         0.1            0.6

               0.3000      20.94         0.2            1.3

               0.5000      12.57         0.9            3.4

               0.7000       8.98         2.4            5.9

               1.0000       6.28        10+            10+

               1.5000       4.19        10+            10+

               2.0000       3.14        10+            10+

               5.0000       1.26        10+            10+
```

Figure 8.14 - Time Integration Parameters

8.1.15 Wave Motion Analysis

Once the data input in Decks 8 to 18 are correct, the motion analysis stage is then performed.

As a program restart is being performed, the user must stream the RESTART file created by the previous program DATA run. The RESTART file are used to supply the program with the information contained within Decks 1 to 18 previously input.

The only data required to be input in card image format is in the preliminary deck. This contains only the information to indicate that a Stage 5 analysis is required as shown in Figure 8.14.

```
JOB BOX2  NAUT
TITLE                TEST RUN NUMBER 21 (FLOATING BOX 40M DRAUGHT 48 FACETS)
OPTIONS REST END
RESTART   5  5
```

Figure 8.15 - Data Input for Stage 5 in Box Example

8.1.16 Output from Motion Analysis Run

The output relating to the motion analysis stage (i.e. Stage 5) contains the information shown in Figures 8.16 to 8.17.

Figure 8.16 - Timestep printout

Figure 8.17 - Harmonic analysis of structure response

```
 JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
-------------------------------------------------------------------------------------------------------------------------------
                                                                          D E G R E E   O F   F R E E D O M
RECORD NO.  STRUCTURE    POSITION,FORCES
              NUMBER       AND MOMENTS AT                 X             Y             Z              RX            RY
RZ

 TIME (SECS)              CENTRE OF GRAVITY           SURGE          SWAY         HEAVE           ROLL         PITCH         YAW

-------------------------------------------------------------------------------------------------------------------------------
 RECORD NO.     1
      0.00      1      POSITION                     0.0000        0.0000      -10.6200         0.0000        0.0000        0.0000
                       VELOCITY                     0.0000        0.0000        0.0000         0.0000        0.0000        0.0000
                       ACCELERATION                 0.0000        0.0000        0.0000         0.0000        0.0000        0.0000
                       RAO BASED POSITION           0.0205        0.0000       -0.2033         0.0000       -0.0036        0.0000
                       RAO BASED VELOCITY           0.1118        0.0000        0.0866         0.0000        0.0100        0.0000
                      RAO BASED ACCEL              -0.0041        0.0000        0.0410         0.0000        0.0007        0.0000
                     MOORING                     0.0000E+00    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00    0.0000E+00
                     DIFFRACTION                 8.1034E+06    0.0000E+00   -8.4096E+06     0.0000E+00   -1.0965E+07    0.0000E+00
                     LINEAR DAMPING              0.0000E+00    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00    0.0000E+00
                     FROUDE KRYLOV              -6.6406E-02    2.2734E+00    1.5416E+07    -2.1063E+01   -1.3625E+01   -4.4631E+02
                     GRAVITY                     0.0000E+00    0.0000E+00   -3.2566E+09     0.0000E+00    0.0000E+00    0.0000E+00
                     CURRENT DRAG                1.8880E+06    0.0000E+00    0.0000E+00     0.0000E+00   -1.7728E+07    0.0000E+00
                     HYDROSTATIC                -2.4622E+01    1.1039E+02    3.2566E+09    -3.1602E+03    1.0753E+03    7.1869E+02
                     WIND                        2.9700E+05    0.0000E+00    0.0000E+00     0.0000E+00    5.3775E+06    0.0000E+00
                    ERROR PER TIMESTEP           0.0000E+00    0.0000E+00    0.0000E+00     0.0000E+00    0.0000E+00    0.0000E+00
                     TOTAL FORCE                 8.2884E+06    1.1266E+02    7.0075E+06    -3.1813E+03   -4.5547E+06   -4.5000E+07

 RECORD NO.    11
     10.00      1      POSITION                    -0.3992       -0.0001      -10.7702         0.0003       -0.0843       -0.2557
                       VELOCITY                    -0.0468        0.0002       -0.0044         0.0002        0.0239       -0.0504
                       ACCELERATION                 0.0250        0.0002        0.0279         0.0001        0.0174       -0.0048
                       RAO BASED POSITION          -0.2472       -0.0009       -0.1449         0.0000       -0.0210        0.0000
                       RAO BASED VELOCITY          -0.0150       -0.0001       -0.1077         0.0000       -0.0037        0.0000
                       RAO BASED ACCEL              0.0498        0.0002        0.0292         0.0000        0.0042        0.0000
                     MOORING                     1.2325E+06    2.2838E+02    7.9636E+03    -3.9180E+03    1.3290E+07    1.7105E+06
                     DIFFRACTION                 7.0412E+06    3.1130E+04    6.3079E+06     3.7444E+05   -9.9140E+07    1.3761E+02
                     LINEAR DAMPING              4.4393E+06   -2.3033E+04    5.7307E+04    -5.4723E+04   -9.7289E+06    2.6529E+06
                     FROUDE KRYLOV               3.5700E+06    6.9771E+04   -3.3605E+06     2.7960E+05    1.4230E+08   -2.0319E+05
                     GRAVITY                     0.0000E+00    0.0000E+00   -3.2566E+09     0.0000E+00    0.0000E+00    0.0000E+00
                     CURRENT DRAG                2.1131E+06    7.9421E+03    6.8477E+02     7.4439E+04   -1.9842E+07    2.7377E+01
                     HYDROSTATIC                -3.6116E+06    1.2453E+04    3.2688E+09     1.4144E+05    5.3609E+07   -3.5386E+04
                     WIND                        2.9854E+05    1.2001E+03    9.6742E+01    -2.1763E+04    5.4053E+06   -7.9391E+00
                     ERROR PER TIMESTEP          1.7817E-05   -7.6409E-07   -5.5534E-06     5.6007E-09    1.1823E-06    1.1551E-09
                           TOTAL FORCE                  1.3083E+07    1.0862E+05    1.5233E+07     9.3940E+05    1.0465E+08
-4.0875E+07
```

Figure 8.16 - Timestep Printout

JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)

RECORD NO. / TIME (SECS)	STRUCTURE NUMBER	POSITION,FORCES AND MOMENTS AT CENTRE OF GRAVITY	X SURGE	Y SWAY	Z HEAVE	RX ROLL	RY PITCH	RZ YAW
			D E G R E E	O F	F R E E D O M			
RECORD NO. 21								
20.00	1	POSITION	-0.0772	0.0002	-10.5045	-0.0014	0.1568	-0.9790
		VELOCITY	0.0125	-0.0018	-0.1047	-0.0011	-0.0544	-0.0934
		ACCELERATION	-0.0133	-0.0002	-0.0294	-0.0002	-0.0145	-0.0043
		RAO BASED POSITION	0.0890	0.0011	0.2668	-0.0001	0.0128	0.0000
		RAO BASED VELOCITY	-0.1042	-0.0012	-0.0386	0.0000	-0.0082	0.0000
		RAO BASED ACCEL	-0.0179	-0.0002	-0.0537	0.0000	-0.0026	0.0000
		MOORING	1.4275E+05	3.2375E+01	-6.6251E+03	4.5690E+03	9.9422E+05	6.6049E+06
		DIFFRACTION	-1.1151E+07	-1.4177E+05	5.5947E+06	-6.3748E+05	5.4614E+07	6.2887E+02
		LINEAR DAMPING	-1.3359E+06	1.7039E+05	1.3347E+06	3.8054E+05	5.3776E+06	4.9164E+06
		FROUDE KRYLOV	-1.6281E+06	-1.1474E+05	-1.4023E+07	-5.1743E+05	-6.3402E+07	-3.1696E+06
		GRAVITY	0.0000E+00	0.0000E+00	-3.2566E+09	0.0000E+00	0.0000E+00	0.0000E+00
		CURRENT DRAG	1.8214E+06	2.7214E+04	-8.0760E+02	2.5499E+05	-1.7102E+07	-2.2145E+02
		HYDROSTATIC	6.6590E+06	-1.1471E+05	3.2472E+09	-1.1026E+06	-9.9808E+07	-3.4016E+04
		WIND	2.9530E+05	3.7283E+03	-1.3094E+02	-6.7634E+04	5.3468E+06	6.3876E+01
		ERROR PER TIMESTEP	-1.6456E-04	-5.6917E-06	-3.7504E-04	-4.3087E-08	-2.6477E-06	2.2052E-09
		TOTAL FORCE	-7.1967E+06	-1.3568E+05	-1.6516E+07	-1.4877E+06	-9.5220E+07	-3.6682E+07

*** SYSTEM WARNING *** IMAGINARY RMS HARMONIC RESIDUAL FOR FREEDOM 3 STRUCTURE 1

RECORD NO. / TIME (SECS)	STRUCTURE NUMBER	POSITION,FORCES AND MOMENTS AT CENTRE OF GRAVITY	X SURGE	Y SWAY	Z HEAVE	RX ROLL	RY PITCH	RZ YAW
RECORD NO. 31								
30.00	1	POSITION	0.1371	0.0123	-10.4051	0.0039	-0.0673	-2.0958
		VELOCITY	0.0224	0.0028	0.1331	0.0013	0.0311	-0.1254
		ACCELERATION	-0.0187	-0.0011	-0.0343	-0.0002	-0.0017	

Figure 8.16 - Timestep Printout (Continued)

```
 JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
----------------------------------------------------------------------------------------------------------------------
------------
                                                                         D E G R E E   O F   F R E E D O M
 RECORD NO.  STRUCTURE    POSITION,FORCES
               NUMBER      AND MOMENTS AT                     X             Y             Z              RX           RY
      RZ

 TIME (SECS)               CENTRE OF GRAVITY                SURGE          SWAY         HEAVE           ROLL        PITCH
    YAW

----------------------------------------------------------------------------------------------------------------------
------------
 RECORD NO.   41
     40.00      1    POSITION                         -0.1392        0.0150      -11.0357         0.0017       0.0793
 -3.4860
                     VELOCITY                          0.0364        0.0046        0.0148         0.0010       0.0267
 -0.1501
                     ACCELERATION                      0.0276        0.0011        0.0754         0.0001       0.0030
 -0.0003
                     RAO BASED POSITION               -0.1785       -0.0045       -0.2778         0.0006      -0.0188
  0.0000
                     RAO BASED VELOCITY                0.0757        0.0018       -0.0170         0.0001       0.0047
  0.0000
                     RAO BASED ACCEL                   0.0359        0.0009        0.0560         0.0000       0.0038
  0.0000
                     MOORING                         3.7137E+05  -4.1148E+04   2.7349E+04     4.1737E+05  3.5805E+06
2.6071E+07
                      DIFFRACTION                     1.1954E+07   3.5781E+05  -1.6652E+06     2.1656E+06 -8.6575E+07
-2.3280E+03
                     LINEAR DAMPING                 -3.3148E+06  -4.3324E+05  -1.8865E+05    -8.8189E+05  4.9516E+06
7.8984E+06
                      FROUDE KRYLOV                  2.9011E+06   7.7841E+05   9.5609E+06     2.6660E+06  1.1296E+08
8.0514E+06
                     GRAVITY                         0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00  0.0000E+00
0.0000E+00
                      CURRENT DRAG                    1.7001E+06   3.7287E+04   2.0005E+02     3.4872E+05 -1.5962E+07
-4.3510E+02
                     HYDROSTATIC                     3.4150E+06  -2.1446E+05   3.2904E+09    -3.7266E+06 -5.0396E+07
5.1024E+04
                      WIND                           2.9172E+05   8.1088E+03   3.4376E+01    -1.4726E+05  5.2823E+06
1.4026E+02
                      ERROR PER TIMESTEP              1.7923E-04   1.6652E-05   3.8583E-04     9.1734E-08  1.6989E-06
-1.4487E-07
                      TOTAL FORCE                     1.5322E+07   6.1437E+05   4.1574E+07     1.9206E+06 -7.4252E+06
-2.9298E+06

 RECORD NO.   51
     50.00      1    POSITION                          0.2087        0.0053      -10.4648         0.0058      -0.1278
 -4.9844
                     VELOCITY                         -0.0431       -0.0039       -0.1617        -0.0025      -0.0550
 -0.1542
                     ACCELERATION                     -0.0050        0.0030       -0.0263         0.0011       0.0132
```

Figure 8.16 - Timestep Printout (Continued)

JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)

RECORD NO. / TIME (SECS)	STRUCTURE NUMBER	POSITION,FORCES AND MOMENTS AT CENTRE OF GRAVITY	X SURGE	Y SWAY	Z HEAVE	RX ROLL	RY PITCH	RZ YAW
			D E G R E E	O F	F R E E D O M			
RECORD NO. 61								
60.00	1	POSITION	0.1070	0.0735	-10.3768	0.0070	0.1300	-6.4462
		VELOCITY	-0.0144	-0.0015	0.1118	0.0021	0.0289	-0.1303
		ACCELERATION	-0.0142	-0.0045	-0.0505	-0.0017	-0.0189	0.0019
		RAO BASED POSITION	0.2316	0.0063	0.2333	-0.0011	0.0206	0.0000
		RAO BASED VELOCITY	-0.0325	-0.0007	0.0699	-0.0001	-0.0005	0.0000
		RAO BASED ACCEL	-0.0467	-0.0013	-0.0470	-0.0001	-0.0042	0.0000
		MOORING	-3.9098E+05	-2.0736E+05	-2.0296E+04	2.1844E+06	-4.8061E+06	6.0396E+07
		DIFFRACTION	-1.0407E+07	-3.9911E+05	-2.6505E+06	-2.7757E+06	1.0104E+08	4.0756E+03
		LINEAR DAMPING	1.4256E+06	1.2889E+05	-1.4238E+06	1.3728E+05	-4.2226E+06	6.8593E+06
		FROUDE KRYLOV	-3.7863E+06	-1.7244E+06	-3.4875E+06	-7.1553E+06	-1.4234E+08	-5.9546E+06
		GRAVITY	0.0000E+00	0.0000E+00	-3.2566E+09	0.0000E+00	0.0000E+00	0.0000E+00
		CURRENT DRAG	1.9162E+06	6.7969E+04	9.5442E+02	6.3509E+05	-1.7989E+07	-6.5570E+02
		HYDROSTATIC	5.4627E+06	-6.1831E+05	3.2368E+09	-1.2209E+07	-8.1884E+07	3.5510E+05
		WIND	2.9139E+05	9.6944E+03	1.4510E+02	-1.7631E+05	5.2768E+06	1.9730E+02
		ERROR PER TIMESTEP	-8.5160E-05	-3.1841E-05	1.1393E-05	-9.3129E-08	-1.4974E-06	2.5967E-07
		TOTAL FORCE	-7.4755E+06	-2.5181E+06	-2.7388E+07	-1.7354E+07	-1.2626E+08	1.6661E+07

*** SYSTEM WARNING *** IMAGINARY RMS HARMONIC RESIDUAL FOR FREEDOM 3 STRUCTURE 1

RECORD NO. / TIME (SECS)	STRUCTURE NUMBER	POSITION,FORCES AND MOMENTS AT CENTRE OF GRAVITY	X SURGE	Y SWAY	Z HEAVE	RX ROLL	RY PITCH	RZ YAW
RECORD NO. 71								
70.00	1	POSITION	0.1445	0.0585	-10.8929	0.0038	0.0144	-7.6599
		VELOCITY	0.0741	0.0081	0.0544	-0.0013	-0.0025	-0.0987

Figure 8.16 - Timestep Printout (Continued)

```
JOB TITLE-TEST RUN NUMBER 20 (FLOATING BOX 40M DRAUGHT AND 48 FACETS)
------------------------------------------------------------------------------------------------------------------------
                                                                     D E G R E E   O F   F R E E D O M
 RECORD NO.  STRUCTURE    POSITION,FORCES
              NUMBER      AND MOMENTS AT           X            Y            Z              RX            RY
      RZ
 TIME (SECS)              CENTRE OF GRAVITY      SURGE         SWAY        HEAVE           ROLL          PITCH
      YAW
------------------------------------------------------------------------------------------------------------------------
 RECORD NO.  81
     80.00     1     POSITION                    0.0144       0.0500     -10.6569         0.0224       -0.1422
 -8.3703
                     VELOCITY                   -0.0541       0.0071      -0.0988         0.0044        0.0203
 -0.0525
                     ACCELERATION                0.0202       0.0051       0.0137         0.0016        0.0201
  0.0051
                     RAO BASED POSITION         -0.2388      -0.0035      -0.1430         0.0012       -0.0184
  0.0000
                     RAO BASED VELOCITY         -0.0156      -0.0004      -0.1083        -0.0001       -0.0035
  0.0000
                     RAO BASED ACCEL             0.0481       0.0007       0.0288         0.0002        0.0037
  0.0000
                     MOORING                  3.6757E+04  -1.4893E+05   3.6141E+03     1.4535E+06    1.1884E+06
9.3595E+07
                     DIFFRACTION              6.8981E+06   2.3207E+05   6.3732E+06     1.4990E+06   -9.5687E+07
-1.1956E+04
                     LINEAR DAMPING           5.1094E+06  -6.7925E+05   1.2581E+06    -1.5250E+06   -1.0819E+07
2.7644E+06
                     FROUDE KRYLOV            3.8991E+06   2.2401E+06  -3.5066E+06     8.9132E+06    1.4089E+08
-7.8999E+06
                     GRAVITY                  0.0000E+00   0.0000E+00  -3.2566E+09     0.0000E+00    0.0000E+00
0.0000E+00
                     CURRENT DRAG             2.1040E+06   3.0346E+04   8.0482E+01     2.8103E+05   -1.9751E+07
-2.4690E+03
                     HYDROSTATIC             -6.0069E+06   8.8342E+05   3.2596E+09     3.7239E+06    9.0924E+07
3.4171E+05
                     WIND                     2.9205E+05   6.5749E+03   1.1468E+01    -1.2000E+05    5.2891E+06
6.5954E+02
                     ERROR PER TIMESTEP       1.8786E-05   2.9314E-05  -2.2333E-04     1.6144E-07    1.2923E-06
-4.3212E-07
                     TOTAL FORCE              1.0354E+07   2.8555E+06   7.1188E+06     1.7070E+07    1.3060E+08
4.3795E+07

 RECORD NO.  91
     90.00     1     POSITION                    0.1421       0.0947     -10.4484         0.0051        0.1619
 -8.5030
                     VELOCITY                   -0.0063      -0.0148      -0.0173        -0.0060       -0.0468
  0.0191
                     ACCELERATION               -0.0109      -0.0009      -0.0402        -0.0016       -0.0161
```

Figure 8.16 - Timestep Printout (Continued)

H A R M O N I C   A N A L Y S I S   O F   S T R U C T U R E   R E S P O N S E

STRUCTURE NUMBER = 1
WAVE AMPLITUDE = 0.500
WAVE FREQUENCY(RAD/SEC) = 0.449
WAVE PERIOD(SECONDS) = 14.000
WAVE DIRECTION = 0.000

CYCLE NUMBER	CYCLE START TIME		MEAN	FUNDAMENTAL AMP	FUNDAMENTAL PHASE	2ND HARMONIC AMP	2ND HARMONIC PHASE	3RD HARMONIC AMP	3RD HARMONIC PHASE	4TH HARMONIC AMP	4TH HARMONIC PHASE	RESIDUAL
1	0.00	SURGE	-0.202	0.236	92.0	0.060	82.0	0.040	84.5	0.030	86.0	0.040
2	14.00		-0.109	0.089	-116.3	0.074	-91.2	0.047	-90.5	0.035	-90.1	0.047
3	28.00		-0.002	0.162	87.2	0.018	69.1	0.010	75.3	0.007	79.0	0.009
4	42.00		0.159	0.112	150.2	0.022	-125.1	0.012	-115.0	0.009	-109.4	0.010
5	56.00		0.046	0.081	62.0	0.016	-42.4	0.008	-53.7	0.006	-61.3	0.007
6	70.00		0.156	0.199	111.6	0.030	105.5	0.018	100.3	0.013	97.6	0.017
7	84.00		0.111	0.022	-150.6	0.040	-88.0	0.026	-88.9	0.019	-89.4	0.025
1	0.00	SWAY	0.000	0.001	-19.5	0.000	-61.3	0.000	-73.5	0.000	-78.0	0.000
2	14.00		0.000	0.004	59.4	0.001	-31.9	0.000	-48.3	0.000	-57.1	0.000
3	28.00		0.013	0.002	33.9	0.003	-84.6	0.002	-87.4	0.002	-88.3	0.002
4	42.00		0.020	0.015	43.3	0.004	-62.2	0.002	-73.0	0.002	-78.0	0.002
5	56.00		0.055	0.017	91.8	0.002	-113.5	0.001	-106.0	0.001	-102.1	0.001
6	70.00		0.064	0.015	19.9	0.008	-81.4	0.005	-85.0	0.004	-86.7	0.005
7	84.00		0.086	0.038	80.5	0.005	97.1	0.003	94.3	0.002	92.7	0.003
1	0.00	HEAVE	-10.664	0.082	77.0	0.016	-47.4	0.007	-91.8	0.006	-126.8	0.026
2	14.00		-10.648	0.311	94.3	0.029	74.9	0.017	90.3	0.012	101.2	0.041
3	28.00		-10.616	0.401	112.8	0.033	71.4	0.022	60.2	0.017	51.5	0.060
4	42.00		-10.598	0.396	133.4	0.015	89.8	0.010	57.0	0.010	40.1	0.055
5	56.00		-10.601	0.332	153.2	0.015	-137.5	0.008	-131.7	0.006	-130.4	0.010
6	70.00		-10.618	0.230	159.5	0.019	-83.9	0.012	-75.3	0.009	-68.1	0.042
7	84.00		-10.632	0.181	143.9	0.012	-82.3	0.007	-97.1	0.005	-108.0	0.020

Figure 8.17 - Harmonic Analysis of Structure Response

H A R M O N I C   A N A L Y S I S   O F   S T R U C T U R E   R E S P O N S E

STRUCTURE NUMBER = 1
WAVE AMPLITUDE = 0.500
WAVE FREQUENCY(RAD/SEC) = 0.449
WAVE PERIOD(SECONDS) = 14.000
WAVE DIRECTION = 0.000

CYCLE NUMBER	CYCLE START TIME		MEAN	FUNDAMENTAL AMP	FUNDAMENTAL PHASE	2ND HARMONIC AMP	2ND HARMONIC PHASE	3RD HARMONIC AMP	3RD HARMONIC PHASE	4TH HARMONIC AMP	4TH HARMONIC PHASE	RESIDUAL
1	0.00	ROLL	0.000	0.000	-67.5	0.000	-106.6	0.000	-102.6	0.000	-102.9	0.000
2	14.00		0.000	0.002	-24.4	0.000	-71.9	0.000	-77.2	0.000	-79.9	0.000
3	28.00		0.003	0.001	120.7	0.001	123.1	0.000	111.4	0.000	106.0	0.000
4	42.00		0.005	0.007	-78.3	0.002	-92.2	0.001	-91.4	0.001	-91.2	0.001
5	56.00		0.007	0.002	44.1	0.002	91.4	0.001	90.0	0.001	89.7	0.001
6	70.00		0.013	0.011	-97.5	0.002	-103.8	0.001	-99.2	0.001	-97.1	0.001
7	84.00		0.009	0.003	-35.8	0.002	79.2	0.001	82.1	0.001	83.8	0.001
1	0.00	PITCH	-0.033	0.064	17.5	0.023	-59.1	0.013	-68.2	0.009	-73.2	0.012
2	14.00		0.057	0.192	103.8	0.042	100.2	0.026	97.0	0.019	95.6	0.026
3	28.00		0.010	0.054	-96.3	0.045	-90.0	0.028	-89.7	0.021	-89.6	0.027
4	42.00		-0.035	0.186	78.1	0.039	78.5	0.024	82.2	0.018	84.1	0.023
5	56.00		0.070	0.080	161.5	0.022	-125.3	0.012	-115.5	0.009	-109.9	0.011
6	70.00		-0.064	0.086	36.0	0.016	-33.3	0.008	-44.3	0.005	-52.7	0.005
7	84.00		0.055	0.176	109.8	0.034	106.6	0.021	100.9	0.015	98.0	0.020
1	0.00	YAW	-0.167	0.166	107.3	0.080	99.0	0.053	96.3	0.039	94.9	0.053
2	14.00		-1.108	0.436	95.5	0.217	93.0	0.144	92.4	0.108	92.2	0.143
3	28.00		-2.778	0.620	92.2	0.309	90.6	0.206	90.2	0.154	89.9	0.206
4	42.00		-4.838	0.679	90.1	0.338	89.1	0.225	88.7	0.169	88.3	0.222
5	56.00		-6.819	0.564	88.1	0.280	88.4	0.187	88.9	0.140	89.1	0.190
6	70.00		-8.166	0.280	80.7	0.139	82.8	0.092	84.0	0.069	84.3	0.091
7	84.00		-8.453	0.101	-68.0	0.048	-75.7	0.031	-82.4	0.023	-86.6	0.035

Figure 8.17 - Harmonic Analysis of Structure Response (Continued)

CHAPTER 9 - RUNNING THE PROGRAM

9.1 File Naming Convention for AQWA Files

Every file name consists of three parts:

- the file prefix — a two character lower case string used to identify a particular AQWA program. The file prefixes are as follows:

Program	Prefix
AQWA-**L**INE	a**l**
AQWA-LI**B**RIUM	a**b**
AQWA-**F**ER	a**f**
AQWA-**D**RIFT	a**d**
AQWA-**N**AUT	a**n**
AQWA-**W**AVE	a**w**

- the run identifer — a short name (up to six characters) to identify a particular run. It is suggested that lower case names be used. All the filenames associated with the run will contain the same run identifier in their names.

- the file extension — a three character lower case string to identify the type of the AQWA file (restart file, hydrodynamics file, etc.). The file extension is separated from the rest of the filename by a '.' character.

Example

The filename 'alvlcc.dat' consists of:

the prefix	al	(short for AQWA-LINE)
the run identifer	vlcc	(e.g. name of vessel)
the extension	**.**dat	(input data file)

9.2 AQWA File Organisation

Every run of an AQWA program involves the use of a number of specially named input, output and backing files. The following files are used by AQWA-NAUT:

(**.res**) file - **restart** file - backing file

The restart file is used to store all information relating to the structures being analysed. This information can easily be retrieved on the next run of the analysis sequence, so the input data for the next run can be considerably simplified. This file is an unformatted binary file.

(**.hyd**) file - **hydrodynamics database** file - backing file

This file is used by AQWA-NAUT and contains a subset of the restart file. It is read only if the ALDB option is used.

(**.pos**) file - **positions** file - backing file

This file contains the structure positions, for each timestep. It is used by AQWA-PLANE to plot trajectories.

(**.plt**) file - **graphics** file - backing file

This file is created and contains positions, velocities, accelerations and all force acting on the structure at every timestep of the simulation. It is used by AQWA-PLANE to produce time history plots.

(**.dat**) file - **input data** file

The input data file contains all the AQWA format data decks needed for the current stage of analysis (Information from previous stages of analysis may be supplied from the restart file.) The input data file is the only readable input file used in the AQWA suite. It is a normal ASCII text file.

(**.lis**) file - **output data** file - listing file

The output data file receives the main results from a program run. It is a normal ASCII text file. Note that this file contains Fortran carriage control characters - a '1' character in the first column to designate the top of a new page. This file can be printed on a LaserJet III with the APRINT command utility. See the PC User Guide for more information on printer control.

9.3 Program Size Requirements

The AQWA programs require an absolute minimum of 128Mb of RAM memory. However, 512Mb (or more) is recommended.

9.4 Run Commands

On a windows system there are two ways to run the AQWA programs.

9.4.1 **Drag and Drop**

When AQWA is installed there will be two run icons on the desktop, one for the AQWA Graphical Supervisor (AGS) and one for the analysis programs, including AQWA-NAUT. A single analysis can be run by dragging a data file with a .dat extension (e.g. from Windows Explorer) and dropping it on the desktop icon.

9.4.2 **Using a Command Prompt Window**

AQWA can be run as a batch program from a command prompt (or "DOS box"). A batch command file is provided for each version located in the directory \aqwa\utils. AQWA programs can be run from any directory provided \aqwa\utils is included in the PATH environment variable.

To run version 5.6c for example, type aqwa56c fname

where fname is the name of a data file <u>without</u> the extension.

AQWA normally displays a progress window while it is running and a message window when it has finished. These windows have to be closed by the user. To close these windows automatically use the /NOWIND option e.g.

Aqwa56c/nowind fname

9.4.3 **Running Multiple Analyses**

To allow many runs to be carried out consecutively without user intervention, AQWA will accept commands from a command file. To use this facility, the program must be run from a Dos window (or Command Prompt) as follows (example for version 5.5A):

aqwa55a std filename.ext

If no filename is input the default assumed is "stdtests.com". The command file must be a plain text ascii file (no formatting).

The commands available in the command file are:

! comment line
REM
ECHO
END
RUNDIR

RUN
COPY
RENAME
MOVE
DELETE

Abbreviations are not allowed. Meanings are similar to DOS commands

A short example of a command file is given below.

```
RUN LINE t0001
echo "T0001L - Faltinsen box aqwaline test complete"
copy alt0001.res abt0001.res
copy alt0001.res aft0001.res
copy alt0001.res adt0001.res
copy alt0001.res ant0001.res
RUN LIBRIUM t0001
echo "T0001B - Faltinsen box aqwalibrium test complete"
RUN FER t0001
echo "T0001F - Faltinsen box aqwafer test complete"
RUN DRIFT t0001
echo "T0001D - Faltinsen box aqwadrift test complete"
RUN NAUT t0001
echo "T0001N - Faltinsen box aqwanaut test complete"
RUNDIR C:\AQWA\56G\TESTS\MODEL2
echo "Change directory to path 'C:\AQWA\56G\TESTS\MODEL2' "
RUN LINE t0002
```

END ALL RUNS COMPLETE

APPENDIX A - AQWA-NAUT PROGRAM OPTIONS

The options listed below may be used when running the program AQWA-NAUT. They should appear on the options card, which follows the job identification card in Administration Deck 0 (see Section 6.0).

LIST OF OPTIONS FOR USE IN AQWA-NAUT

ALDB - READ AQWA-LINE DATABASE

Read the hydrodynamics database from the **hydrodynamics** (.HYD) file created by a previous AQWA-LINE run. This option is used:

I. If the user wishes to modify the hydrodynamic data calculated in a previous AQWA-LINE run, or add/modify nodes and non-diffracting elements, without having to re-run the AQWA-LINE radiation /diffraction analysis.

II. If the user is setting up an analysis with several structures, and wishes to pick up the hydrodynamic data for one or more structures, calculated in a previous AQWA-LINE run.

Note: Very often, there is data for only one structure in the hydrodynamics file, in which case the data is associated with Structure 1 in the new run. The RDDB option may also be used if the hydrodynamics file contains more than one structure, provided that all the structures appear, in the same order, in the new run.

CONV - CONVOLUTION

Instructs AQWA DRIFT or NAUT to use convolution method in radiation force calculation. This is a more rigorous approach to the radiation force calculation in time domain and will enhance the capability of handling non-linear response of structures.

Requests calculation of the full QTF matrix. From version 5.3j onward this option is needed to obtain this.

CRNM - CALCULATE RAOs WITH NO MOORINGS

This option may be used with AQWA-LINE but is more useful with the program AQWA-FER. This option investigates the calculation of RAOs using the values of added mass, wave damping, stiffness and wave forcing specified by the user. The RAOs are then written into the database.

DATA - DATA CHECK ONLY

This option is used to check the data input to the program and provides a means by which the user may check all input data whilst incurring minium cost of the program run. This option is equivalent to performing the analysis up to the end of the second stage in AQWA-LINE, and up to the end of Stage 4 in AQWA-DRIFT/FER/LIBRIUM/NAUT. If the data proved to be correct, then the program would be restarted at next stage of the analysis by using the RESTART option.

END - This is used to indicate the end of the option list.

FDLL - CALL ROUTINE "user-force"

This option instructs the program to call a routine called "user-force" at each stage of the calculation. This routine can be used to add externally calculated forces to the simulation.

LAAR - LOCAL ARTICULATION AXIS SYSTEM FOR ARTICULATION REACTION FORCE OUTPUT (LAA)

This option is used to output articulation reaction force in the local articulation axis system. This means that the moments in unconstrained freedoms, e.g. the hinge axis, will always be zero within roundoff.

LNST - THE LINEAR STARTING CONDITIONS

This option is used to start a simulation with the motions and velocities derived from the AQWA-LINE results. This can be used to limit the transient at the start of a simulation.

LSAR - LOCAL STRUCTURAL AXIS SYSTEM (LSA) FOR ARTICULATION REACTION FORCE OUTPUT

This option is used to output articulation reaction force in the local structural axis system. This means that the direction of the output reaction force will follow the structure.

LSTF - USE LINEAR STIFFNESS MATRIX TO CALCULATE HYDROSTATIC FORCES

This option should be used when the user wishes to use the linear stiffness matrix (calculated by AQWA-LINE or input in deck 7) as opposed to the program recalculating the hydrostatic stiffness from the hydrostatic element model. This normally will reduce the time to run the program substantially.

MCNV - CALCULATE C.I.F. USING ADDED MASS AND DAMPING

From version 5.3K onward the default method for calculation of the Convolution Integral Function uses the radiation damping only. This option forces the program to use the previous method based on both added mass **AND** damping.

NOCP - NO CURRENT PHASE SHIFT

This option switches off the wave phase shift due to a current speed. This is only applicable to versions 5.0C and onwards.

RDDB - READ DATABASE

Read the hydrodynamics database from the **restart** (.RES) file created by a previous AQWA-LINE run.

This option is used if the user wishes to modify the hydrodynamic data calculated in a previous AQWA-LINE run, without having to re-run the AQWA-LINE radiation/diffraction analysis.

Note: Normally, this would be done using the option ALDB (see above). The RDDB option is only needed if the hydrodynamics file from the previous AQWA-LINE run has been accidentally deleted.

Note that, as the model definition has to be read from the restart file **before** the hydrodynamics can be read, there is no possibility to change the model definition, when using this option (use ALDB instead).

RDEP - READ EQUILIBRIUM POSITION

This option can be used in FER, DRIFT and NAUT to read in the structure's equilibrium position from a previous LIBRIUM run as the start position. An AB*.EQP file should be copied to AF*.EQP before a FER run, to AD*.EQP before a DRIFT run or to AN*.EQP before a NAUT run.

REST - RESTART

This option is used when the program is being restarted at any stage greater than the first (see Section 5.2 of the AQWA program manual). A restart card must follow the options list when the restart option is used. This card indicates the stage at which the program is to continue and the stage at which the program is to stop (see Chapter 2).

TRAN - TRANSIENT ANALYSIS

This option switches off the slow axis system and stops printout of harmonic analysis at the end of a simulation run. This option should not in general be used. It is only provided as a workaround for DRIFT analysis for both drift and wave frequency motions if it diverges in the time integration.

PBIS - PRINT FORCE COMPONENTS AT EACH ITERATION STEP

Prints out positions and forces on each structure at each timestep. The scope of the printout can be controlled by selections in Deck 18.

PPEL - PRINT PROPERTIES OF EACH ELEMENT

This option allows the user to output complete details of each element used in the body modelling. All important details of the body elements are output together with the resultant properties of the bodies. It is only applicable when running Stage 1 of the analysis.

PRCE - PRINT CARD ECHO FOR DECKS 1 to 5

This option informs the program to output the input received by the program in reading Decks 1 to 5. This is the body modelling.