Chapter 7

ANALYSIS OF MULTIPLE BODIES (NBODY>1)

WAMIT includes the capability to analyze multiple bodies which interact hydrodynamically and mechanically. Each of the separate bodies may oscillate independently with up to six degrees of freedom. (Additional generalized modes can be defined for each body, as described in Chapter 8.) The bodies may be freely floating, fixed, or constrained by external forces. The basic theory for multibody interactions with waves is similar to that of a single body as described in Chapter 12. The principal extension is to increase the maximum number of degrees of freedom from 6 for a single body, to $6N$ for N bodies (N is hereafter used to denote the number of bodies and the index $K = 1, 2, ..., N$ is used to denote each of the N bodies.). For example, when two bodies are present the maximum possible number of degrees of freedom becomes 12, 6 for each body. In this example, modes $7, 8, 9$ represent translation of body 2 in the direction of the x,y and z-axes of the coordinate system fixed on that body. These modes correspond to surge, sway and heave for the second body, respectively. Modes $10, 11, 12$ represent rotation about the same axes. The extension of this convention to more bodies is evident. Thus, some output quantities are given in vector or matrix form with dimensions $6N$ or $(6N) \times (6N)$, respectively.

Separate GDF files must be input for each body. The specification of the GDF filenames and coordinates of each body is different in the two alternative POT file formats (Sections 3.1 and 3.2). Further details are included in the corresponding sections below. The individual GDF files for each body are unchanged from the case where $N = 1$, thus GDF files can be combined without modification to analyze multiple-body configurations. However the units of measurement, identified by the parameter GRAV, must be the same for all bodies. The program assigns GRAV based on the value in the GDF file for the first body (K=1). If the value of GRAV for another body differs from this by more than a small tolerance (GTOL=0.1) the run is terminated with an appropriate error message.

WAMIT assumes that there are no planes of hydrodynamic symmetry when $N > 1$. If geometric symmetry is specified for individual bodies, via their respective GDF input files, the program reflects about the corresponding planes and increases the number of panels accordingly. The total number of unknowns is the sum of the number required to

describe each body, including reflections. Thus the run times and memory requirements are substantially increased.

- When $N > 1$ walls can be defined using the procedure described in Section 10.10. The procedure described in Section 5.3 is not supported when $N > 1$.

The multiple-body extensions are essentially the same for analyses based on the low-order and higher-order methods. However it is impossible to use both methods simultaneously for different bodies. If NBODY>1 and ILOWHI=1 the option IALTPOT=2 must be used.

The GEOMXACT subroutines described in Section 6.8 can be used for multiple bodies, but special attention is required unless all of the bodies using the same subroutine have identical dimensions. Most of the existing GEOMXACT subroutines read in the appropriate dimensions from the GDF file in scalar form, to initialize parameters within the subroutine for subsequent calls. If the same subroutine is initialized again for another body, the dimensions are overwritten. As a result the dimensions in the last GDF file are applied to all of the bodies using the same subroutine. In cases where bodies with different dimensions are represented by the same subroutine, the dimensions used in subsequent calls should be saved within the subroutine as arrays with dimension NBODY. The subroutine FPSO12 in GEOMXACT illustrates this procedure for two FPSO hulls with different dimensions. To call attention to this problem, a warning message is issued if two or more bodies use the same value of IGDEF in GEOMXACT.

There are three alternative ways to input parameters to the FORCE subprogram. Alternative Form 1 can be used for freely floating bodies, and the more general Alternative 2 Form can be used for bodies subject to external forces. Alternative 3 includes a Global Force Control file (GFRC) and a separate FRC file for each body, each being in either Form 1 or 2. These three alternative are described respectively in Sections 7.3, 7.4, and 7.5.

7.1 INPUT TO POTEN (IALTPOT=±1)

If IALTPOT=1 is specified in the configuration file, or if this parameter is not specified and is set by default, a Global Geometric Data File (GGDF) must be input. The name of this GGDF file is specified in the FNAMES.WAM file, or interactively if no GDF filename is included in FNAMES.WAM. The filenames of each individual body are input in the GGDF file. This option can only be used for the low-order method (ILOWHI=0).

If IALTPOT=1 the data in the Global Geometric Data File (GGDF) are listed below:

```
header
-1.0 GRAV
NBODY
GDF(1)
XBODY(1,1) XBODY(2,1) XBODY(3,1) XBODY(4,1)
MODE(1,1) MODE(2,1) MODE(3,1) MODE(4,1) MODE(5,1) MODE(6,1)
.
.
.
GDF(N)
XBODY(1,N) XBODY(2,N) XBODY(3,N) XBODY(4,N)
MODE(1,N) MODE(2,N) MODE(3,N) MODE(4,N) MODE(5,N) MODE(6,N)
```

If IALTPOT=-1, corresponding to earlier versions of WAMIT, the data in the Global Geometric Data File (GGDF) are listed below:

```
header
-1.0 GRAV
NBODY
GDF(1)
XBODY(1,1) XBODY(2,1) XBODY(3,1) XBODY(4,1)
IRAD(1) IDIFF(1)
MODE(1,1) MODE(2,1) MODE(3,1) MODE(4,1) MODE(5,1) MODE(6,1)
.
.
.
GDF(N)
XBODY(1,N) XBODY(2,N) XBODY(3,N) XBODY(4,N)
IRAD(N) IDIFF(N)
MODE(1,N) MODE(2,N) MODE(3,N) MODE(4,N) MODE(5,N) MODE(6,N)
```

The only difference between these two formats is the inclusion of separate values IRAD,IDIFF for each body when IALTPOT=-1. The latter is generally not necessary, and is considered redundant with the assignment of IRAD and IDIFF in the POT file. However users of earlier versions who wish to do so may continue to use old GGDF files by assigning

IALTPOT=-1. This option is deprecated and may not be supported in later versions of WAMIT.

'header' denotes a one-line ASCII header dimensioned CHARACTER∗72.

-1.0 is the flag which indicates that the file is a Global GDF file. (Any real number less than or equal to zero is acceptable.) (Note that in an ordinary GDF file this parameter is ULEN, which must be positive.)

GRAV is the acceleration of gravity, using the same units of length as in ULEN(K) of the GDF files. If lengths are input in meters or feet, input 9.80665 or 32.174, respectively for GRAV. (The same units of length must be used in each GDF file if $N > 1$.)

NBODY is the total number of bodies.

GDF(K) is the name of the K-th Geometric Data File.

XBODY(1,K),XBODY(2,K),XBODY(3,K) are the (X, Y, Z) coordinates of the origin of the body-fixed coordinate system of the K-th body, relative to the *global coordinate system*, input in the dimensional units of the length ULEN(K). The global coordinate system is used in place of the body coordinate system to define field-point data (fluid pressures, velocities, and free-surface elevation). The origin of the global coordinate system must be located on the free surface.

XBODY(4,K) is the angle in degrees between the $x-$axis of the body coordinate system of the K-th body and the $X-$axis of the global system (see Figure 5.2). The direction of the global Z-axis, and of the z-coordinate in each body coordinate system, must be positive upward and perpendicular to the undisturbed free surface.

IRAD(K), IDIFF(K) are indices used to specify the components of the radiation and diffraction problems to be solved for the K-th body. The following options are available, depending on the values of IRAD(K) and IDIFF(K):

IRAD(K)= 1: Solve for the radiation velocity potentials due to all six rigid-body modes of motion of the K-th body.

IRAD(K)= 0: Solve the radiation problem only for those modes of motion specified by setting the elements of the array MODE(I,K)=1 (see below).

IRAD(K)= -1: Do not solve any component of the radiation problem.

IDIFF(K)= 1: Solve for all diffraction components, i.e. the complete diffraction problem.

IDIFF(K)= 0: Output only the exciting forces in the modes specified by MODE(I,K)=1.

IDIFF(K)= -1: Do not solve the diffraction problem.

MODE(I,K) is a six-element array of indices for the K-th body, where I=1,2,3 correspond to the surge, sway and heave translational modes along the body-fixed (x, y, z) axes, and I=4,5,6 to the roll, pitch and yaw rotational modes about the same axes, respectively. Each of these six indices should be set equal to 0 or 1, depending on whether the corresponding radiation mode(s) and diffraction component(s) are required. (See the options IRAD(K)=0 and IDIFF(K)=0 above.)

The data in the GDF file for each individual body is as described in Section 3.1. Panel coordinates and symmetry indices are defined in terms of the local body coordinates of

the respective body, as for a single-body application. For each body there is a respective dimensional length ULEN(K), and a corresponding value of gravity GRAV(K). ULEN(K) must be input in the same dimensional units for every body. ULEN(K) must be a positive number greater than 10^{-5}. An error return and warning statements are generated if the last restriction is not satisfied. ULEN(1), the characteristic length of the first body, is used to nondimensionalize the outputs as described in Chapter 4.

The values GRAV(K) in all GDF files are read, and used to check for consistency of units among the different bodies. An error return occurs if any GRAV(K) differs from GRAV(1) by more than 0.1 units in absolute value (0.1 m/s^2 or 0.1 ft/s^2 if these units are used.) (The value of GRAV(1) is used for all calculations and outputs.) The Potential Control File (POT) is described in Section 3.1, and is unchanged when $N > 1$. However the values of the array XBODY in the POT file (or in the optional configuration file), and array MODE which are specified in the POT file are all ignored, since these are superseded by the individual values for each body in the GGDF file. (If IALTPOT=-1, the same statement applies to IRAD, IDIFF.)

7.2 INPUT TO POTEN (IALTPOT=2)

If IALTPOT=2 is assigned in the configuration file, the POT file is as described in Section 3.2. This Alternative Form of the POT file includes all of the relevant data for each body as is described above for the GGDF file when IALTPOT=1. (This is considered to be a more efficient scheme to adopt for multiple-body analyses.)

To summarize, when NBODY>1 and IALTPOT=2, the POT file should include the applicable value of NBODY, followed by appropriate data for each body, as shown in Section 3.2. A separate GDF file must be input for each body. No other changes are required in the input files.

7.3 INPUT TO FORCE (IALTFRC=1)

If IALTFRC=1 the format of the FRC file is as shown below:

```
header
IOPTN(1) IOPTN(2) IOPTN(3) IOPTN(4) IOPTN(5) IOPTN(6) IOPTN(7) IOPTN(8) IOPTN(9)
VCG(1)
XPRDCT(1,1,1) XPRDCT(1,2,1) XPRDCT(1,3,1)
XPRDCT(2,1,1) XPRDCT(2,2,1) XPRDCT(2,3,1)
XPRDCT(3,1,1) XPRDCT(3,2,1) XPRDCT(3,3,1)
VCG(2)
XPRDCT(1,1,2) XPRDCT(1,2,2) XPRDCT(1,3,2)
XPRDCT(2,1,2) XPRDCT(2,2,2) XPRDCT(2,3,2)
XPRDCT(3,1,2) XPRDCT(3,2,2) XPRDCT(3,3,2)
.
.
VCG(N)
XPRDCT(1,1,N) XPRDCT(1,2,N) XPRDCT(1,3,N)
XPRDCT(2,1,N) XPRDCT(2,2,N) XPRDCT(2,3,N)
XPRDCT(3,1,N) XPRDCT(3,2,N) XPRDCT(3,3,N)
NBETAH
BETAH(1) BETAH(2) ...  BETAH(NBETAH)
NFIELD
XFIELD(1,1) XFIELD(2,1) XFIELD(3,1)
XFIELD(1,2) XFIELD(2,2) XFIELD(3,2)
XFIELD(1,3) XFIELD(2,3) XFIELD(3,3)
.
.
XFIELD(1,NFIELD) XFIELD(2,NFIELD) XFIELD(3,NFIELD)
```

The only difference relative to the case of a single body (Section 3.3), is that the VCG and 3×3 matrix of each body's radii of gyration are entered in succession.

7.4 INPUT TO FORCE (IALTFRC=2)

If IALTFRC=2 the format of the FRC file is the same as described in Section 3.4 for a single body, except that the array specifying (XCG,YCG,ZCG) is extended to include all bodies, and the external force matrices have dimensions NDFR × NDFR. NDFR= $\sum_{n=1}^{N}(6+\text{NEWMDS}(n))$ is the total number of degrees of freedom including all rigid body modes and generalized modes. The normal format is as follows:

```
header
IOPTN(1) IOPTN(2) IOPTN(3) IOPTN(4) IOPTN(5) IOPTN(6) IOPTN(7) IOPTN(8) IOPTN(9)
RHO
XCG(1) YCG(1) ZCG(1) XCG(2) YCG(2) ZCG(2) ...
...  XCG(N) YCG(N) ZCG(N)
IMASS
EXMASS(1,1) EXMASS(1,2) ...  EXMASS(1,NDFR)
EXMASS(2,1) EXMASS(2,2) ...  EXMASS(2,NDFR)
.
.
EXMASS(NDFR,1) EXMASS(NDFR,2) ...  EXMASS(NDFR,NDFR)
IDAMP
EXDAMP(1,1) EXDAMP(1,2) ...  EXDAMP(1,NDFR)
EXDAMP(2,1) EXDAMP(2,2) ...  EXDAMP(2,NDFR)
.
.
EXDAMP(NDFR,1) EXDAMP(NDFR,2) ...  EXDAMP(NDFR,NDFR)
ISTIF
EXSTIF(1,1) EXSTIF(1,2) ...  EXSTIF(1,NDFR)
EXSTIF(2,1) EXSTIF(2,2) ...  EXSTIF(2,NDFR)
.
.
EXSTIF(NDFR,1) EXSTIF(NDFR,2) ...  EXSTIF(NDFR,NDFR)
NBETAH
BETAH(1) BETAH(2) ...  BETAH(NBETAH)
NFIELD
XFIELD(1,1) XFIELD(2,1) XFIELD(3,1)
XFIELD(1,2) XFIELD(2,2) XFIELD(3,2)
XFIELD(1,3) XFIELD(2,3) XFIELD(3,3)
.
.
XFIELD(1,NFIELD) XFIELD(2,NFIELD) XFIELD(3,NFIELD)
```

As in Section 3.4, the integers (IMASS,IDAMP,ISTIF) are set equal to one if the matrix follows, and equal to zero if no corresponding external matrix is included in the file. Omitting the matrix is equivalent to including the matrix with zero values for all elements.

The same format can be used with the external force matrices in separate files and with the corresponding filenames replacing the matrices in the FRC file. This option is specified by the values (IMASS,IDAMP,ISTIF)=2:

```
header
IOPTN(1) IOPTN(2) IOPTN(3) IOPTN(4) IOPTN(5) IOPTN(6) IOPTN(7) IOPTN(8) IOPTN(9)
RHO
XCG(1) YCG(1) ZCG(1) XCG(2) YCG(2) ZCG(2) ...
...  XCG(N) YCG(N) ZCG(N)
2
MASS (filename containing inertia matrix)
2
DAMP (filename containing damping matrix)
2
STIF (filename containing stiffness matrix)
NBETAH
BETAH(1) BETAH(2) ...  BETAH(NBETAH)
NFIELD
XFIELD(1,1) XFIELD(2,1) XFIELD(3,1)
XFIELD(1,2) XFIELD(2,2) XFIELD(3,2)
XFIELD(1,3) XFIELD(2,3) XFIELD(3,3)
.
.
XFIELD(1,NFIELD) XFIELD(2,NFIELD) XFIELD(3,NFIELD)
```

The separate external force data files MASS, DAMP, STIF contain a one-line header plus the three corresponding matrices shown in the first format.

As in Section 3.4, it is also possible in Version 6 to specify the Alternative Form 2 by inserting the integer 2 in the second line, but that option is deprecated.

The first line of this file, and all lines beginning with the variable NBETAH, are identical to the data in Alternative 1 FRC file. The data which differ in Alternative 2 are described in Section 3.4.

7.5 INPUT TO FORCE (IALTFRC=3)

Alternative Form 3 includes one Global FRC file (GFRC) and N FRC files. The FRC file for each body can take either the form of Alternative 1 or Alternative 2. With this option existing FRC files for single bodies can be used without modification. Note however that this precludes the consideration of external mass, damping and stiffness forces which produce coupling interactions between the bodies.

If IALTFRC=3 the input parameters in the GFRC file are listed below:

```
header
IOPTN(1) IOPTN(2) IOPTN(3) IOPTN(4) IOPTN(5) IOPTN(6) IOPTN(7) IOPTN(8) IOPTN(9)
RHO
FRC(1)
FRC(2)
.
.
FRC(N)
NBETAH
BETAH(1) BETAH(2) ...  BETAH(NBETAH)
NFIELD
XFIELD(1,1) XFIELD(2,1) XFIELD(3,1)
XFIELD(1,2) XFIELD(2,2) XFIELD(3,2)
XFIELD(1,3) XFIELD(2,3) XFIELD(3,3)
.
.
XFIELD(1,NFIELD) XFIELD(2,NFIELD) XFIELD(3,NFIELD)
```

The first three lines of this file, and all lines beginning with the variable NBETAH, are identical to the data in the Alternative Form 2 FRC file.

FRC(K) is the name of the FRC file for body K. The Form of each separate file must be 1 or 2, and this is specified by the optional array IALTFRCN in the configuration file, as described in the following section.

Some of the data given in N FRC files are read but neglected, if the same data is given in the GFRC file. For example, the data IOPTN and RHO in the FRC files for each body are neglected and the corresponding parameters provided by the GFRC file are used.

As with IALTFRC=2, it is possible to specify IALTFRC=3 by inserting the integer 3 on line 2 of this file, but this practice is deprecated in Version 6 and may not be supported in later versions.

7.6 PARAMETERS IN THE CONFIGURATION FILE

The configuration file (CFG) described in Section 3.7 includes several inputs that are relevant to the analysis of multiple bodies. These include IALTFRCN, IGENMDS, IRR, ITRIM, NBODY, NEWMDS, NPTANK, XBODY and XTRIM. If IALTFRC=3 the array IALTFRCN must be specified in the CFG, unless the default values 1 are applicable for all bodies. The parameters IRR, NBODY, XBODY, and NEWMDS can be specified either in the CFG or in other input files, as indicated in Section 3.9. A typical configuration file used for all of these parameters is as follows, with explanatory comments on each line:

```
IALTPOT=2    (use POT format in Section 3.2)
IALTFRC=3    (use FRC format in Section 7.5)
IALTFRCN=2 1 2  (Form of FRC file for each body)
IGENMDS(1)=-1  (Body 1: IGENMDS=-1)
IGENMDS(2)=1  (Body 2: IGENMDS=1)
IGENMDS(3)=2  (Body 3: IGENMDS=2)
IRR(1)=2  (Body 1: IRR=2)
IRR(2)=1  (Body 2: IRR=1)
IRR(3)=1  (Body 3: IRR=1)
ITRIMWL=1  Trim waterlines for at least one body
NPTANK(1)=(8-11) (12-15)  (Body 1: tank patches or panels)
XBODY(1) = -5.0 0.0 0.0 0.0  (Body 1 coordinates)
XBODY(2) = 0.0 0.0 0.0 0.0  (Body 2 coordinates)
XBODY(3) = 5.0 0.0 0.0 90.0  (Body 3 coordinates)
XTRIM(1) = 1.0 15. 0.  (Body 1 trim coordinates)
XTRIM(2) = 0.0 0.0 0.0  (Body 2 trim coordinates)
XTRIM(3) = 5.0 0.0 10.0  (Body 3 trim coordinates)
```

Some of these inputs are illustrated in the test runs TEST05, TEST13 and TEST13a described in Appendix A.

As explained in Section 9.1, different values of the irregular-frequency parameter IRR can be assigned for each body, as indicated in the example above, by including the body index in parenthesis. This is a new feature implemented in Version 6.4. Alternatively, the same value of IRR can be input for all bodies using either of the formats of Version 6.3. Thus input files used with earlier versions are compatible with use in Version 6.4, without modifications. More specific information for inputting IRR when NBODY>1 is given in Section 9.5.

As explained in Section 10.7, the parameter NPTANK which identifies internal tanks must be associated with the corresponding body. Thus the input NPTANK(1) defines the tanks to be in body 1. The associated inputs RHOTANK and ZTANK are identified by the number of each tank, and not by the body number. The number of each tank is defined by the order of the inputs NPTANK in the CFG file.

7.7 OUTPUT

The nondimensionalizations given in Chapter 4 hold for all output quantities. L=ULEN(1), the dimensional length for Body 1, is the characteristic length and is used for the nondimensionalization of the output quantities.

The added mass (A_{ij}), damping coefficients (B_{ij}) and hydrostatic coefficients($C(i,j)$) are matrices of dimension up to $6N \times 6N$. These quantities are defined in the direction of the axes of the corresponding body coordinate systems. For example $A_{1,9}$ is the added mass in the direction of the x-axis of the coordinate system of Body 1 (surge added mass) due to the motion of the Body 2 in the direction of the z-axis of Body 2 (heave motion).

The forces (X_i) and the motion amplitudes (ξ_i) are vectors of dimension up to $6N$. These quantities are also defined in the direction of the axes of the coordinates system of the corresponding body. For example, X_{17} is the pitch exciting moment about the y-axis of Body 3. The **phases** of the forces and motion amplitudes and of the field quantities such as the field pressure and field velocity, are defined relative to the phase of the incident wave at the origin of the global coordinate system.

The pressure drift force and moment (Option 9) returns values for each body in its respective body coordinate system.

When Option 8 is specified (momentum drift force and moment) the quantities calculated are the global horizontal drift forces and mean yaw moment acting on the entire ensemble of bodies. It is possible to compare these outputs with the total drift force and moment from pressure integration, by summing the latter outputs for the forces and moments on each body. This provides a useful check on consistency. Special attention is required if the body coordinates are not parallel to the global coordinates system.