# Implementation Plan (Revised): Changes in HydroDyn to Support Multiple WAMIT Bodies

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## Changes to the HydroDyn input file:

* Add **NBody** - Number of WAMIT bodies to be used (-) [>=1; only used when PotMod=1. If NBodyMod=1, the WAMIT data contains a vector of size 6\*NBody x 1 and matrices of size 6\*NBody x 6\*NBody; if NBodyMod>1, there are NBody sets of WAMIT data each with a vector of size 6 x 1 and matrices of size 6 x 6]
* Add **NBodyMod** - Body coupling model {1: include coupling terms between each body and NBody in HydroDyn equals NBODY in WAMIT, 2: neglect coupling terms between each body and NBODY=1 with XBODY=0 in WAMIT, 3: Neglect coupling terms between each body and NBODY=1 with XBODY=/0 in WAMIT} (switch) [only used when PotMod=1]
	+ 1: include coupling terms between each body (PtfmRefxt/yt/zt/ztRot should match XBODY(1)/(2)/(3)/(4) in WAMIT and NBody should match NBODY in WAMIT)
	+ 2: neglect couplings between each body and NBODY=1 with XBODY=0 in WAMIT (PtfmRefxt/yt/zt/ztRot may differ from XBODY(1)/(2)/(3)/(4) in WAMIT)
	+ 3: neglect couplings between each body and NBODY=1 with XBODY=/0 in WAMIT (PtfmRefxt/yt/zt/ztRot should match XBODY(1)/(2)/(3)/(4) in WAMIT)
* Change **PotFile** from single string to arrays of size NBody (unless NBodyMod=1)
* Change **WAMITULEN** from scalars to arrays of size NBody (unless NBodyMod=1)[[1]](#footnote-1)
* Add **PtfmRefxt, PtfmRefyt, PtfmRefzt** - The xt/yt/zt offset of the body reference points from (0,0,0) (meters) [1 to NBody] [only used when PotMod=1. IF NBodyMod=2, PtfmRefzt must be 0.0]
* Add **PtfmRefztRot** – The rotation about zt of the body reference frame(s) from xt/yt (degrees) [1 to NBody] [only used when PotMod=1]
* Change **PtfmVol0**, **PtfmCOBxt**, **PtfmCOByt** from scalars to arrays of size NBody
* Expand **PLATFORM ADDITIONAL STIFFNESS AND DAMPING** entries to match NBody and NBodyMod.
	+ When NBodyMod=1, **AddF0** is one vector of size 6\*NBody x 1 and **AddCLin**, **AddBLin**, and **AddBQuad** are each one matrix of size 6\*NBody x 6\*NBody.
	+ When NBodyMod=2 or 3, there are NBody **AddF0** vectors each of size 6 x 1 and there are NBody **AddCLin**, **AddBLin**, and **AddBQuad** matrices each of size 6 x 6.

Note:

If NBody > 1, then MnDrift and NewmanApp cannot equal 8

## Module-level input and output changes:

Change u%MESH from having 1 node to NBody nodes.

Change y%MESH from having 1 node to NBody nodes.

Eliminate y%AllHdroOrigin.[[2]](#footnote-2)

Similarly change the input and output meshes in the WAMIT and WAMIT2 modules from having 1 node to NBody nodes.

## Influence of NBodyMod

The NBodyMod flag indicates how WAMIT data for the bodies is handled.

When it is set to 1, a single set of WAMIT data is used for the entire set of bodies, meaning coupling terms are included. The WAMIT data has 6\*NBody load components and degrees of freedom.

When NBodyMod is set to 2 or 3, coupling terms between the bodies are neglected. In that case, each body will have a corresponding set of WAMIT data for its own 6 loads and 6 degrees of freedom. NBodyMod=2 expects the WAMIT analyses to use bodies centered at the origin rather than at their displaced and rotated locations in the overall support structure. NBodyMod=3 expects the WAMIT analyses to use bodies offset to their proper positions within the support structure.

In all cases, HydroDyn needs to know the positions and heading of each platform body (PtfmRefxt/yt/zt/ztRot) because all output from WAMITis in the local body coordinate system (the origin/orientation of the body’s GDF file)[[3]](#footnote-3). This addresses the wave radiation forces for each body, based on that body’s motions.

For wave excitation, the WAMIT coefficients need to be adjusted when NBodyMod=2 because WAMIT’s wave phases are derived relative to the incident wave elevation at the origin of the global coordinate system and the positioning of the bodies is only done in HydroDyn, not in WAMIT. In this case, wave excitation phases need to be adjusted based on PtfmRefxt and PtfmRefyt, PtfmRefzt must be zero, and the headings of the excitation need to be shifted based on PtfmRefztRot. No adjustments are needed when NBodyMod is 1 or 3.

The implications/requirements of each NBodyMod option are listed below.

**NBodyMod options and input requirements**

|  |  |  |  |
| --- | --- | --- | --- |
| **NBodyMod** | **1** | **2** | **3** |
| WAMIT hydrodynamics coupled? | Yes (6Nx6N matrices and 6Nx1 vectors) | No (N 6x6 matrices and 6x1 vectors) | No (N 6x6 matrices and 6x1 vectors) |
| Body analysis in WAMIT | All put in their correct position/orientation in a single analysis(XBODY in WAMIT must match PtfmRefxt/yt/zt/ztRot) | Each type of body analyzed separately at origin and unrotated heading(XBODY must be 0 in WAMIT) | Each body analyzed separately at its correct offset position/orientation(XBODY in WAMIT must match PtfmRefxt/yt/zt/ztRot) |
| PotFile input | Only first entry will be used | One entry for each body(duplicates are okay) | One entry for each body(throw error if duplicates since that will indicate overlapping bodies) |
| WAMITULEN input | Only first entry will be used | One value for each body | One value for each body |
| Body location needed by HydroDyn to localize loads (because WAMIT outputs loads relative to body center / orientation) (PtfmRefxt/yt/zt/ztRot) | Yes | Yes | Yes |
| Wave kinematics correction needed | No | Yes | No |
| Recommended handling of wave excitation vector | A single vector (6\*NBody) | NBody separate 6-DOF vectors | NBody separate 6-DOF vectors |
| Notes |  | This can be used to work with a platform offset (relative to the turbine tower centerline) in HydroDyn, e.g. the WindFloat. |  |

## Body Meshes

The mesh for each body should be positioned and oriented according to PtfmRefxt/yt/zt/ztRot, and this mesh should be used consistently. This allows the WAMIT coefficients to be applied directly to the mesh, as long as the WAMIT coefficients are first corrected for the body heading PtfmRefztRot if it is nonzero.

## Structure and preprocessing of hydrodynamic data arrays

Data related to the linear hydrodynamic coefficients from WAMIT that need to be considered are wave excitation (), added mass (, damping (), hydrostatic restoring (), and wave radiation retardation kernel (). When NBodyMod=1, there will be one of each of these arrays, coming from a single WAMIT root file for the coupled body analysis. When NBodyMod is 2 or 3, there will be sets of arrays for each body, coming from a WAMIT root file specific to each body (though the root file can be the same when NBodyMod=2).

Because WAMIT creates outputs in the local body reference frames while meshes in FAST use displacements that are oriented relative to the global rather than local frame, a rotational transformation is needed in the WAMIT data for any body that has a PtfmRefztRot offset.

PtfmRefztRot will be referred to in equations as going forward for brevity. The rotation matrix to go between the global reference frame and a heading rotation of PtfmRefztRot is

That is, *R* is the DCM from global to local.

### Wave Excitation

Because wave excitation coefficients do not involve any interaction between load components, no adjustments are required in how these coefficients are structured. For N bodies, there will be a total of 6N wave excitation coefficients, 6 for each body.

where each body’s coefficients are

For multiple coupled bodies, it makes sense to use a global vector (), whereas for uncoupled bodies it would likely be easiest to keep each vector distinct (). Wave excitation coefficients would be about the body’s reference point; if that reference point is shifted, the wave elevation can be adjusted rather than adjusting the coefficients themselves (see details below).

WAMIT’s output is oriented with the body, so the wave excitation vector should be transformed to give output in the global orientation frame, which is what the HydroDyn body mesh uses.

where is the body’s PtfmRefztRot value and **R** is the corresponding rotation matrix. Similarly, when loading any second-order wave excitation data from WAMIT, the coefficients in surge and sway should be adjusted for the body’s heading, as should the coefficients in roll and pitch.

**When NBodyMod=2**, additional adjustments are needed to account for the offsets (PtfmRefxt, PtfmRefyt) and heading (PtfmRefztRot) of each body because the WAMIT wave excitation data in this case was based on each body being centered and unrotated at the origin.

A phase shift in the wave excitation frequency components is needed to move the incident wave point from the global origin to a different location (X,Y). For first-order excitation, this phase shift is

where is the wave frequency, is its wave number (dependent on frequency), and is its heading (dependent on frequency).

For second-order wave excitation, the phase shift needs to consider two wave frequencies, and simultaneously. For sum frequencies, it becomes

For difference frequencies, it becomes

Lastly, the headings used in the wave excitation data need to be shifted to adjust for the body’s rotated heading (since the WAMIT analysis used an unrotated body when NBodyMod=2):

The overall adjustment needed for any 6-DOF set of first-order wave excitation coefficients is

and for second-order wave excitation coefficients is

Note that when , , or is called in the above equations, the value(s) for in its computation is the original heading of each wave frequency component, not the adjusted heading .

Note: phase shifting is already incorporated in the wave kinematics calculations in Waves2.f90. It might be beneficial to check between the WAMIT2.f90 additions and the existing implementation in Waves2.f90.

### Radiation

**When NBodyMod=1** (multiple bodies with hydrodynamic coupling), a single non-sparse global matrix is needed for added mass (A), and another one for damping (B). The added mass (A) matrix is described below; the same formulation applies to the damping (B) matrix. The matrices would have size 6Nx6N to represent the interactions of every degree of freedom of every body. It can be thought of as a composition of six-by-six matrices:

Each shown diagonal sub-matrix is the 6-by-6 matrix of each body (the effect of the body’s degrees of freedom on itself). The off-diagonal sub-matrix represent coupling between bodies (within these off-diagonal sub-matrices, diagonal terms represent coupling between the same DOF of different bodies, while off-diagonal entries represent coupling between different DOFs of different bodies).

**When NBodyMod is 2 or 3,** (multiple bodies treated as hydrodynamically independent), there are no off-diagonal matrices in the global added mass or damping matrices and these matrices are instead just composed of individual matrices for each body, i.e.

This reflects that radiation forces and moments on each body are independent of the other bodies. In this situation, it is simpler to deal with the hydrodynamics of each body independently through its own 6-by-6 matrices rather than using a global matrix, i.e.

Because the wave radiation retardation kernel matrix is calculated from the damping matrix, its structure will follow that of the damping matrix. For coupled bodies, it will be a single global 6Nx6N matrix. For uncoupled bodies it will be N 6x6 matrices.

**In all NBodyMod cases**, when a body’s heading (PtfmRefztRot) is nonzero, a correction must be made to transform the matrices from local to global coordinates. This can be done by changing each 6 by 6 added mass and damping sub-matrix individually. In the following transformation, and are the rotation matrices for the PtfmRefztRot values of body i and body j, respectively. When NBodyMod=2 or 3, only the diagonal sub-matrices are used so i=j.

The resulting 6x6 sub-matrices expressed in global coordinates, and the full 6Nx6N matrices expressed in global coordinates in the case of NBodyMod=1, are not assumed to be symmetrical. This is a change from the current implementation, in which radiation coefficient matrix symmetry is assumed during preprocessing.

The R matrices have no effect on the heave or yaw degrees of freedom, so the transformations could be made more efficient if preprocessing time is an issue.

### Hydrostatics

Hydrostatics data and calculations follow the form of the wave radiation matrices as determined by NBody and NBodyMod. When NBodyMod=1, the hydrostatic input file is expanded to have 6\*NBody rows and columns. When NBodyMod is 2 or 3, individual hydrostatic data files are read in for each body. Each row or column of the hydrostatic coefficient matrix/matrices corresponds to a load component or degree of freedom in the respective body’s local coordinate system. Accordingly, the hydrostatic sub-matrices should be transformed similarly to the added mass (A) and damping (B) matrices to adjust for any nonzero PtfmRefztRot values:

Note that the hydrostatic stiffness matrix in global coordinates is not necessarily symmetrical.

## Wave Excitation Calculations

For multiple bodies, the wave excitation vector needs to be expanded to size 6N or replicated into N size-6 matrices specific to each body, consistent with the change in added mass and damping matrices. Aside from handling of additional load components, no further change in the wave excitation approach is needed.

If represents the discrete Fourier transform of the wave elevation at the global origin (), the wave elevation at the global origin is

The wave excitation force on a single body in DOF can be written as

Where is the excitation coefficient, which includes any necessary phase and heading adjustments, and .

### Second-Order Excitation

The application of multiple bodies for second-order wave excitation follows an analogous approach to that for first-order excitation.

Second-wave excitation for a single body currently has the following forms. For difference-frequency excitation, with QTF ,

where

For sum-frequency excitation,

where is the floor function defined as . (Details in Duarte/Sarmento/Jonkman, AIAA, 2014.)

Note that the wave excitation coefficients used in the above equation have already been corrected for the body’s position and heading if needed when NBodyMod=2.

## Wave Radiation Calculations

Wave radiation calculations for multiple bodies requires applying the standard linear hydrodynamics (Cummins) equation to the appropriate form of the coefficients—e.g. () or (). The generic equation for wave radiation forces is

or

where is the infinite-frequency added mass matrix. Each element of the wave radiation retardation kernel, , is calculated as

If hydrodynamic couplings are included (NBodyMod=1), () should be applied to global vectors and matrices to give the full list of radiation forces/moments:

For bodies with independent hydrodynamics, () is applied to each body separately; each body undergoes a process that is essentially the same as the existing single-body radiation force calculation.

## Hydrostatic Calculations

The hydrostatic force and moments at the platform’s undisplaced position were previously (where is WtrDens, is Gravity, and is PtfmVol0).

This needs to be changed to account for each body’s offset position. For each body, the hydrostatic force about the body’s reference point when the platform is undisplaced is now

The hydrostatic reaction forces to body displacements can follow the same matrix equation approach (in terms of dimensions) as the wave-radiation calculations, as determined by NBody and NBodyMod. No change is needed in how a given hydrostatic reaction force is calculated. The hydrostatic matrix (if NBodyMod=1) or matrices (if NBodyMod=2,3) can be multiplied by the displacement/rotation vector/vectors in global coordinates after the hydrostatic matrix has been expressed in global coordinates.

1. Note (as background): When NBODY>1 in WAMIT, ULEN(1) is used to nondimensionalize the output. [↑](#footnote-ref-1)
2. Note: The OpenFAST glue code uses y%AllHdroOrigin to transfer all PF+ST loads from HD to ED without considering the displacement in the moment transfer for the ST loads. We’ll need to do the equivalent now without AllHdroOrigin [↑](#footnote-ref-2)
3. *Jason notes: All output from WAMIT is in the local body coordinate system (the origin of the GDF file). The wave phases are derived relative to the incident wave elevation at the origin of the global coordinate system. The local coordinate system is offset from the global coordinate system by XBODY in WAMIT. HydroDyn assumes PtfmRefxt = XBODY(1), PtfmRefyt = XBODY(2), PtfmRefzt = XBODY(3), and XBODY(4) = 0, except for when NBodyMod=2.* [↑](#footnote-ref-3)