# SeaSoft Version 5 Release Notes

This release is the result of two years of basic research and development in several important fundamental areas; it is the most important release, with the most far-ranging consequences, in over 10 years. It represents a major advancement in the underlying physical and analytical models of wave-related low-frequency vessel excitations, in particular. We have included a comprehensive discussion outlining the nature of the new treatments and how they differ from the "legacy" models used in previous SeaSoft releases. The new version number for all simulations is 5.05.

These release notes have been expanded substantially since the "Pre-release Notes" were sent out in February 2003 (following the website release of the first public beta version of the software). You should therefore, at a minimum, scan this document for new material of possible significance to you.

The notes for the previous full release (version 4.32) should be reviewed for additional recent update information. A cumulative list of recent release note files available from SeaSoft follows:

| | |
|---|---|
| Release_Notes (January_02) | [v 4.32] |
| Release_Notes (April_01) | [v 4.20] |
| Release_Notes (June_00) | [v 4.14] |
| Release_Notes (Oct_99) | [v 4.07] |

If you have not checked out the web site (http://www.seasoft.org), you should make it a point to do so. Free access to all simulations is available to anyone who requests an on-line account. Free access is intended to help us work out the kinks in the Internet-based delivery model and will naturally be limited in duration.

## Release Highlights

- New "slow drift" wave force models for all vessel types (now referred to as "wave reflection" models; see discussion below).

- Improved wave-current interaction model.

- Improved higher-order "wave drag"-related low-frequency excitation mechanism (sometimes called the "wave absorption" or "wave dissipation" contribution).

- New treatment of non-Gaussian modal excitations for wave drift forces.

- Expansion of the number of elements in the wave period array to 100.

- Addition of a comprehensive new set of user-specified external quasi-static forcings.

- Addition of user-specified current and wind *spectral* input via text files.

- Addition of a comprehensive summary file (XCLDAT.stxt) to facilitate comparisons between simulation estimates and wave basin measurements.

- Automated calculation of current loads on mooring lines and risers.

- Addition of new built-in cylindrically symmetric wind and current forcing types.

- Addition of a data import feature for obtaining vessel or mooring system data from any like-versioned SeaSoft data file.

- Tension-elongation characteristics of arbitrary complexity for elastic mooring materials are now supported via user-supplied text input files.

# Significant Enhancements; Selected Details

## Wave drift force terminology note:

As a result of the introduction of nonlinear wave "drag" estimates for all vessel types (previously these estimates were only available for semisubmersible-type vessels), we have adopted a more suggestive and logically consistent terminology when discussing wave "drift" forces.

Historically, the designations "wave drift force" and "wave drift coefficient" have been applied to the wave energy-conserving second-order process of momentum transfer from waves to vessel via diffraction and reflection. In SeaSoft's simulations, these energy-conserving forces and coefficients derive either from built-in models, or from user-supplied text files, the latter usually being produced from the output of three-dimensional diffraction codes such as WAMIT.

Notwithstanding historical conventions, from a purely logical perspective wave "drift" forces actually comprise *two* components, the above-mentioned energy-conserving component, which we now call the "reflective" component, and a "dissipative" (or "absorptive") component. The dissipative component will on occasion be called the "drag" component, which use is also in keeping with our legacy terminology for the same effects as applied to semisubmersibles.

Because of the long (and misleading) historical association of "wave drift force" with the energy-conserving component (which we now call the "wave reflection force"), there will naturally be times when we lapse into historical usage and say or write "wave drift force" when we actually mean the *reflective* component only of the total drift force. In case of such lapses, the context of the remarks should serve to clarify whether we are in fact speaking of the reflective component or the *combined* reflective and dissipative components. A reference to the "wave drag force" always refers to the dissipative component.

## Updates and enhancements

Note: simulations group naturally into four classes: (1) "Comprehensive simulations" that encompass statics, low- and wave-frequency dynamics (**CALMsim**, **Moorsim**, **SALMsim**, **Sparsim**, **SPMsim**, **TLPsim**, and **Towsim**), (2) wave-frequency vessel motion simulations (**Shipsim**, **Discsim**, **Semisim**), (3) Individual simulations such as **Catsim**, **Moorsim**, or **Shipsim** and (4) all simulations taken as a group.

### >>> User-requested enhancements to comprehensive simulations

- The long-lamented difficulty in analyzing complex damaged line scenarios has been rectified. Users can now define the full complement of lines, risers, hoses, etc. at the beginning of a project and select individual lines or risers to be *excluded* from the analysis in any execution by simply identifying the excluded line identification number(s). That is, it is no longer necessary to physically eliminate the damaged line(s) (and modify the associated fairlead location or departure angle databases, etc.). Similarly, the damaged lines can be restored to functionality simply by removing them from the "excluded lines" list. All data for the excluded lines (in RANOUT, LOWOUT, SNAPOUT, etc.) is set to zero in the output stream so that the number of rows and columns of output tables is not affected by the excluded line list. This permits a more stable configuration for the employment of spreadsheet or text-editing macros that might be used for data post-processing.

- Current loads on mooring lines and risers may now be estimated automatically, eliminating the need to "simulate" current loads on the mooring/riser structures with an externally applied fixed force.

- Implemented new "cylindrically symmetric" wind and current quasi-static loading models. These are square-law drag models similar to the closely-related "Barge" model except that they can produce true azimuthally symmetric loadings as might be required for a caisson spar or CALM buoy. (The "Barge" model, by design, *always* exhibits azimuthal variation in the net force magnitude, even if the specified head-on and beam-on area parameters are equal.)

- Improved wave-frequency RMS line load estimation for highly nonlinear mooring systems in the new XCLDAT output summary. In RANOUT, RMS loads are estimated simply as the (nonlinear) load response to the RMS fairlead motions. This procedure underestimates RMS loads in "stiffening" nonlinear systems and overestimates RMS loads in "softening" nonlinear systems. The new XCLDAT procedure utilizes a rigorous statistical treatment that fully captures the nonlinear relationship between RMS fairlead motions and RMS line load fluctuations.

- Implemented user-specification of dry weight for mooring lines and risers. Previously, the dry weight (which is required to characterize inertial effects in the wave-frequency line dynamics algorithms) was estimated internally based on the submerged weight and the line/riser diameter. This legacy procedure fails for elements such as buoyancy-clad risers or TLP tendons; for these types of "moorings", specification of both wet and dry weight is required. Although a warning will be issued in version 5.x whenever a run is attempted without supplying a dry weight, the legacy dry weight estimation will still be invoked whenever a subline's specified dry weight is zero or negative.

- Expanded the handling of nonlinear elastic materials by instituting a tension-elongation input file capability. Previously, line elasticity was limited to functional forms which could be represented by a cubic tension-elongation (t-e) characteristic: $e(t) = A_1*t + A_2*t^2 + A_3*t^3$. This formulation proved to be occasionally problematic for highly nonlinear elastic materials at either the large or small tension end of the physical tension range due to the "rigidity" of the cubic model. The difficulty has been eliminated with the ability to input an arbitrary tension-elongation characteristic in tabular format.

>>> **Miscellaneous enhancements to comprehensive simulations**

- The built-in tanker wave "reflection" (previously "drift") model has been completely overhauled; the original "legacy" model remains available as a user-selectable option.

- The built-in semisubmersible/TLP wave "reflection" (previously "drift") model has been completely overhauled; the original "legacy" model remains available as a user-selectable option.

- The built-in spar wave "reflection" (previously "drift") model has been further improved.

- The individual line summary pages in SNAPOUT can now be eliminated, leaving only net vessel loads in the output stream to reduce SNAPOUT volume. This is particularly relevant for **SPMsim** where net vessel loads (used for turret bearing design) are the principal items of interest in SNAPOUT.

- Included estimated vessel wave force RAOs in addition to vessel motion RAOs to the output stream of all comprehensive simulations when "Output Vessel RAOs" flag is set.

- Complete overhaul of current affects on wave reflection forces. As in previous versions, the improved model can be combined with user-specified reflection coefficients, which only rarely are available with current corrections. The "legacy" current-interaction model remains available as a user option, although its use is deprecated.

- Reporting of "bounding box" extremes for low-frequency vessel motions. This is particularly useful for turret installations in which the lateral motion extremes of the turret centroid are important design considerations.

- Added support for correct evaluation, reporting and use of "Spectral Peak Periods" for "pink noise" (i.e., rectangular shaped) wave spectra.

- Complete overhaul of peak factor calculations for low-frequency motions to accommodate non-Gaussian excitation processes. This is discussed further in the addendum below.

>>> **User-requested enhancement to wave-frequency simulations**

- The "Air Gap" calculation in wave-frequency simulations has been renamed (to "Relative Motion") and enhanced to include the relative vessel-water particle displacement RAOs in all three (x,y,z) degrees of freedom. Previously this feature only provided a relative motion RAO for the *vertical* separation of a point on the vessel and the water surface. The calculation now includes all three vessel-relative displacements (i.e., relative [Vx,Vy,Vz]) so that when the flag is set, relative *horizontal* vessel-water particle RAOs are evaluated as well.

>>> **Miscellaneous enhancements to individual simulations**

- Added support for TLPs in **Catsim**.

- Added diagonal reflection to the member copy utility in **Semisim**.

- Added support for TLP RAOs in **Semisim**.

- Eliminated the need to terminate surface-piercing members just above the waterline in **Semisim**. This considerably simplifies draft changes for semis; previous versions required adjusting the tops of surface-piercing members as well when vessel draft changed. Note that **TLPsim** and **Sparsim** both use **Semisim** as their vessel-motion module, so that this change facilitates vessel pull-down calculations.

- Improved wave attack-angle dependence on quadratic roll damping in **Shipsim**. Regular wave roll RAOs now display the estimated roll damping corresponding to the wave direction; previously, the same roll damping was used for all RAOs, regardless of wave direction. This will in general produce larger roll estimates (both RAO and RMS) than the legacy procedure at all but beam-on wave headings.

- Increased the flexibility of **Slowsim** output by permitting user specification of the starting environmental angle for environmental coefficient evaluations.

- Changed the scaling of "Wave Group Spectrum" in **Slowsim** to conform with the most widely-used convention; this convention produces "Group Spectral" numerical values exactly 8.0 times those of earlier versions of **Slowsim**.

- Added the new wave absorption (a.k.a. dissipation or drag) coefficients to **Slowsim**'s output stream.

- Added a moonpool relative water level calculation for **Sparsim**.

- Added a current and wind "suck-down/suck-up" option for **Sparsim**. (These Bernoulli-based effects were detectable in the DeepStar model tests.)

- Improvements to the low-frequency sway-yaw modal analysis for **SPMsim**; these changes lead, in most circumstances, to somewhat lower values of low sway-yaw mode amplitudes in crossed conditions (but negligible changes in RANOUT system loads).

- Modifications to the pull-down calculation for **TLPsim**.

>>> **User-requested enhancements to all simulations**

- The number of elements in the wave period array has been extended. The new limit is 100 periods (the previous maximum was 40).

- Implemented a new "last page" option which permits importing from existing data files (1) vessel and environment data; (2) mooring system data; (3) Tug or CALM buoy data (**Towsim** and **CALMsim** only). The only limitation on this capability is that the source ("from") data file should be from the same generation (i.e., same version number) as the importing simulation; a runtime warning flags inappropriate importations.

- Increased the flexibility of coordinate array input items, mostly for streamlining input of fairlead locations for various popular mooring arrangements (such as grouped lines in FPSO moorings).

- Many on-line documentation changes, error warning traps and messages.

- Nomenclature change: "characteristic period" ==> "zero upcross period" in all output streams.

**Model test support enhancements (comprehensive simulations)**

- We have implemented user-specified current and wind *spectral* input via text files (WINDSPEC.txt, CRNTSPEC.txt) analogous to and rounding out existing user-input options for vessel RAOs (USERAOS.txt), wind, wave and current slow-drift coefficients (WINDCOFS.txt, DRFTCOFS.txt, CRNTCOFS.txt) and wave spectrum data (WAVSPEC.txt). Furthermore, all of these user options are supported by **Slowsim** for easy cross-checking against source data. This feature has been added due to the steadily increasing availability of non-analytic current and wind spectral data, particular from wave basin measurements.

  Previous to version 5.x, user-specified wind and current spectral input was limited to what we now call "point spectra"; that is, a single spectral value to be applied at the dominant ("surge") normal mode period. In this "legacy" scheme, the single point spectral value specified was also applied to the other low-frequency (sway and yaw) modes. The point spectrum option remains available for backwards compatibility.

- We have added vastly more comprehensive external forcing capabilities, including (a) forces acting on moorings and (b) forces acting on the vessel (the first has no effect on net *vessel* loads, while the latter does; this is most useful for turret-based FPSOs where turret loads and moments are required for bearing design.) The new capabilities include, for each external force request, several options related to that force: (1) force variability (via a "point spectrum" forcing specification), (2) a damping contribution associated with the force, (3) a vertical mean moment, (4) a vertical moment spectral contribution, (5) a damping contribution associated with the moment, and (6) a peak factor to be associated with the force-moment variability. This allows the user to "roll their own" variable low-frequency excitation mechanisms with tailored specifications. This feature was motivated by the need to simulate ill-behaved and chaotic vortex-shedding excitations (which can produce forces or moments or both) frequently observed during model tests.

- A flag was created to permit the determination of an "alternate equilibrium", for situations whose inherent symmetry permits two (or more) stable equilibrium points (such as a turret-moored tanker in the presence of a uniform current which in general possesses, by symmetry, two equilibrium yaw angles, one on either side of the oncoming current). This feature was motivated by the need to simplify comparisons between simulation and model test data; the simulation can now be coaxed to report results about the same stable equilibrium achieved during testing.

- We have implemented a new output file, "XCLDAT.stxt", which contains a tab-delimited motion and load summary suitable for copy/pasting directly into a spreadsheet. The data in XCLDAT.stxt is presented in a format that facilitates comparison with common wave-basin report formats, providing mean, low-and wave-frequency RMS, total RMS, and extreme values for all channels. For example, the "global composite" (x,y) range of mooring centroid positions and yaw angle extremes is synthesized from all three low-frequency degrees of freedom plus all relevant wave-frequency degrees of freedom. Similarly for all load variables, including net vessel loads. When metric units are in play, XCLDAT.stxt load units can be toggled between "basin-type" SI units (kiloNewtons) and legacy SeaSoft units (metric tons).

  XCLDAT.stxt should be considered a "beta" feature for this version, although since it acts in a "post-processing" capacity, bugs that might remain in this routine do not affect values in the legacy output files (LOWOUT, RANOUT, etc.)

- Increased the number of user-specified current profile points by eliminating the surface point, which was redundant. The maximum number of points in the current profile with depth, including the surface point, is now six. This change was made to accommodate the complexity of measured current profiles achieved during model testing.

## Minor Updates and Enhancements (partial list)

- Expanded all *DAT binary data files (SPMDAT, SHIPDAT, etc.) to accommodate new features; the resulting data files are now larger than their version 4.32 counterparts. As usual, data files are forward-compatible but *not backwards compatible* . The update and importation rules are:

  - Any earlier version of a simulation data file (e.g., SPMDAT) can be read by version 5.x of its corresponding simulation (i.e., **SPMsim**).

  - Simulations will accept *only* previous version data files produced by the *same* simulation. That is, you cannot import a version 4.32 SPMDAT file into **Catsim** version 5.x. Simulations will automatically enforce this requirement and issue an error message if you attempt an inappropriate importation.

  - To import a data file from a previous version of *a different* simulation (e.g., to import a version 3.x SPMDAT file into version 5.x **Catsim**), you must first update the data file to version 5.x using its native simulation (in this case bring the SPMDAT file up to date with **SPMsim** version 5.x) and *then* import the version 5.x SPMDAT file into **Catsim** version 5.x.

  The update process will make the data file unusable to its originating simulation, so you should work only on *copies* of existing data files with the new 5.x simulations.

- Change certain chevron alerts '>>>' to '==>' in runtime output streams to easily identify messages produced by wave-frequency support modules in service of comprehensive simulations.

- Additional improvements have been made to facilitate data file creation, modification and inter-simulation data portability. These capabilities, along with the new "last page" options for bulk importation of vessel and/or mooring data (discussed elsewhere above), considerably ease the process of building data files using information in pre-existing SeaSoft *DAT files. These improvements include the following:

  - When importing vessel motion data files (e.g., SEMIDAT or SHIPDAT) into comprehensive simulations (e.g., **Moorsim**, **SPMsim** or **Sparsim**) the importing application now initializes mooring data items to permit a less confusing and seamless workflow when producing new simulations from "scratch" by (1) creating and debugging the vessel data (in, e.g., **Shipsim** or **Semisim**) and (2) subsequently importing the vessel and/or environment data into **Moorsim**, **Towsim**, or whatever.

  - When importing comprehensive data files (e.g., SPMDAT or MOORDAT) into **Slowsim** and **Catsim,** certain essential data items required by the importing application are now automatically set.

  - As always, the importation considerations are: Importing *to* utility programs such as **Catsim** or **Slowsim** is routinely supported; importing *from* these simulations to any other is discouraged. Similarly, importations from comprehensive simulations (e.g., **Moorsim**) into vessel motion simulations (e.g., **Semisim**) for purposes of wave-frequency motion studies is generally supported, but the reverse process (e.g., importing *back* to **Moorsim** from **Semisim** after the wave-frequency studies) should be limited to the first-time process of creating a new comprehensive (MOORDAT) data file from a SEMIDAT starting point.

# Bug Fixes (partial list)

## All Simulations

- Fixed a bug that prevented proper saving of backup files (SHIPBAK, etc.) when importing data from earlier simulation versions.

- Fixed a bug that caused an empty DYNOUT file to be produced in certain circumstances.

- Fixed a bug that caused incorrect fairlead motion amplitudes to be used in SNAPOUT individual line load tables when the "Use spectral estimates for standard deviations (sigma)" flag was set.

- Eliminated an infinite loop that could occur when computing the shallow-water wavelength of very long-period waves.

## Individual Simulations

- Fixed a long-standing **CALMsim/Towsim** bug which caused the system "surge" period to be substantially overestimated. This in turn resulted in errors in the estimated amplitudes of low-frequency motions and loads in all elements, including anchor legs and hawser (or towline).

- Fixed an incorrect **Slowsim** output format error in the "Mean Reflection Force Frequency Distribution" label.

- Fixed a minor **Sparsim** bug which prevented the correct vessel heading from being used in certain line load evaluations.

- Fixed a **Sparsim/TLPsim/Moorsim (Semi)** bug affecting wave absorption loads and excitation. (See additional comments on this topic elsewhere in these notes.)

- Fixed a minor **Semisim** bug which produced incorrect wave slope calculations when the regular wave RAO excitation flag was set to "wave slope" rather than "wave height".

- Fixed a minor **SPMsim/CALMsim** bug which caused erroneous n-sigma loads to be output in some circumstances.

## Comprehensive Simulations

- Fixed a long-standing bug leading to the underestimation of equivalent low-frequency square-law damping contribution due to moorings and risers (Note: this is different from the more important low-frequency damping due to wave-frequency line motions). In most simulations this contribution is quite negligible but in a few special circumstances (in particular, simulations with variable wind and/or current but lacking waves) the contribution can be important.

- Fixed a minor bug in the average current load calculation that occurred when the last specified current depth value was less than the vessel draft.

- Fixed a minor bug in the current-associated wave reflection damping for the "legacy" model. Unfortunately, this means that the "legacy" results from version 4.32 cannot be perfectly reproduced in version 5.x.

## Numerical Differences Between v4.32 and v5.x with "Legacy" Flags Set

A commonly asked question goes like: "The output value of (some load, some motion, some position, ...) changed from version 4.32 to version 5.x; what caused that?"

Because of the many new features and vessel/mooring static and low-frequency environmental forcing modifications, this question is problematic because version 4.32 has no comparable capabilities. The various new models will in many circumstances give quite different results for the same environment, especially in highly crossed conditions.

However, we have provided "legacy" flags, which will permit version 5.x to approximately reproduce, *in most cases* , the results of 4.32. It is still meaningful, therefore to ask about output differences between version 4.32 and version 5.x with all "legacy" flags set. We will limit our discussion here to that situation.

Version 5.x with "legacy" flags appropriately set should reproduce the output from version 4.32 except for differences arising from numerical round-off, code optimizations, bug fixes and output formatting differences. With only a few exceptions, these differences should amount to a few percent at most.

**NOTE**: The most effective output file to use in studying numerical differences between versions is RANOUT. This is because it does not depend on the snapshot points chosen in LOWOUT/SNAPOUT and has not changed its format, making comparisons less difficult. It comprises mean, low-frequency and wave-frequency components and therefore represents all portions of the code base rather comprehensively.

- **LOWOUT**: A completely different format was adopted for circumscribing vessel low-frequency extremes. This comprises a "bounding box" that gives the approximate extreme (x,y) coordinates of the corners of a box that bounds the low-frequency motions of the mooring centroid, in conjunction with vessel yaw. The differences in the "Snapshot" locations used between versions makes comparisons of these snapshot points essentially impossible. These differences apply also to the snapshot points used in SNAPOUT. A bug correction in the legacy wave-reflection damping calculation will produce slightly different system damping, as noted elsewhere. A bug fix in the legacy wave-absorption model for Semis, Spars and TLPs will cause noticeable differences in mean loads, damping and excitation when the "Legacy" option is in effect for simulation of those vessels. Although these differences are generally small, they will leak through to all subsequent output streams, including RANOUT, DYNOUT, SNAPOUT.

- **RANOUT**: Differences when the "number of lines for dynamic evaluation" does not equal the total line number.

- **SNAPOUT**: See LOWOUT comments above. Also, differences in SNAPOUT "n-sigma minus" characteristic line load tables resulting from a bug fix and differences when the "number of lines for dynamic evaluation" does not equal the total line number.

- **SHIPRAO**, **TANKRAO**, etc.: There will be noticeable differences in roll RAOs due to modifications in the handling of roll damping noted elsewhere. Also, look for differences due to the modification of the "Air Gap" versus "Relative Motion" treatment.

- **SHIPRAN**, **TANKRAN**, etc.: There will be noticeable differences in RMS roll response due to modifications in the handling of roll damping noted elsewhere. Also, look for differences due to the modification of the "Air Gap" versus "Relative Motion" treatment.

- **SLOWOUT**: Differences due to a change in scale of the wave "Group Spectrum" noted elsewhere.

## "When is it safe to use the new features?"

There is always a certain level of risk in adopting new and relatively untested software, particularly simulation software, when predicted loads and motions change substantially between the old ("tried and true") and new treatments. We are very, very sensitive to this problem. Since the SeaSoft simulations are still evolving rather rapidly, and steadily incorporating completely new (and, we feel, vitally important) physical phenomena, this problem is not going away soon. We therefore want to make some comments regarding our level of confidence in this release.

We have spent more time (many hundreds of hours, over many months) analyzing model test data on a wide variety of vessels and conditions than ever before in the history of SeaSoft. These analyses have in fact dictated to a certain extent the feature set of this release by highlighting physical processes (e.g., "wave drag", current drag on lines & risers, wind and current vortex shedding from hull and moorings) that were clearly *very* important in some (but not all) circumstances. One of the gratifying aspects of this effort has been the realization that the simulations have reached a point where they can be used to discern unidentified (and sometimes surprising) physical phenomena in the model tests, which tests are almost always compromised in some way by errors in documentation or omission of information, or by fundamental errors in modeling.

One example of many we encountered in our QA process: In one set of tests we reviewed (comprising an extremely crossed condition reminiscent of the DeepStar Loop Current tests), the simulation predicted a mean FPSO heading 10 degrees from observed, an unacceptably large deviation. Careful inspection of the simulation results and model test measurements led to an unambiguous and incontrovertible conclusion: The industry-standard OCIMF wind coefficients used in the simulation were utterly inappropriate for the tested vessel. By a serendipitous circumstance clearly identified by **SPMsim**, the validity of this conclusion depended *only* on the validity of the OCIMF current coefficients (which are by now very satisfactorily established) and *not* on any assumptions regarding the validity of the problematic wave-current interaction modeling. Without the complete set of tools provided by **SPMsim** and **Slowsim**, the discrepancy in mean vessel heading would have remained an unresolved mystery. Using these tools, it would have been clear *in real time* that comprehensive wind force measurements *must* be added to the test matrix before terminating the tests in order to achieve a meaningful understanding of the system.

As an aside, we have concluded from our analyses of many model tests that wind coefficient measurements and current variability measurements are by far the most seriously damaging of all the commonly occurring basin measurement omissions, at least in crossed conditions; these omissions have led to the disheartening compromise in the quality and validity of many, if not most, existing model test series of tanker-based FPSOs. (The DeepStar FPSO series is a glowing exception to this circumstance; their usefulness is unrivalled precisely because neither of these important elements was neglected, although the inclusion of wind coefficient measurements was apparently due to serendipity, and not design.) Fortunately, the understanding of the importance of these elements is beginning to diffuse into the model test community, hopefully to the benefit of future test programs.

When we began building the SeaSoft simulation library some 20 years ago, we doubted that our simulations would ever reach the point where they would compete with model tests in providing understanding of the relative importance of the many contributing elements of the complex dynamics of offshore systems. We were wrong. Against all odds, that day has arrived.

How long it takes for you to begin to trust this new software at the same level as the previous release is a matter of personal risk tolerance. We hope we have withheld release long enough, and tested it thoroughly enough, that those of you who choose to transition immediately will be amply rewarded. Even if you choose to delay adoption of this release, we hope you will *always* include the new software as a component of your analysis, so that it can alert you to any problematic issues.

The most potentially problematic of the new features are (1) the non-Gaussian peak factor algorithm and (2) the wave dissipation/absorption feature of the wave drift force. If you suspect either of these features are giving problems, you should document the conditions and advise SeaSoft. Both features can be easily disabled via user-controllable "legacy" toggles if necessary.

# The Problem of Exponential Complexity, Part 2

In the release notes for version 4.32 (January, 2002), we made a point of explaining in some detail the quality-assurance (QA) problems that develop as the number of input "degrees of freedom" to a computer program become large. We showed that a crude estimate of the number of paths through a program like **SPMsim** version 4.32 is something like 10^105 (which assumes an "input complexity" equivalent to 350 independent binary "toggles"). With the many new options and vessel types incorporated into this release, we have increased the complexity by something like an additional 20 "toggles". This corresponds to a *multiplicative* increase in the number of independent paths by about one million. That is, there are a *million times* more independent paths through the code in version 5.x than the "modest" 10^105 present in 4.32.

We make this point once again to illustrate the utter futility of any achievable number of test runs finding all the problems or bugs in the software. How many of the 10^111 paths through the code in version 5.x got tested prior to release? At most, a few hundred. Fortunately, since most users invoke roughly the same miniscule subset of possible paths, this level of testing is not as miserably inadequate as it sounds.

But, the unfortunate reality remains: you are all now, and at the most fundamental level will always be, "alpha" testers, (that is, at some point in your explorations you will likely traverse a path through the code that has *never* before been tested) and there is absolutely nothing we can do to rectify that situation. And the more inventive you are in exploring "unusual" configurations or flag combinations, the more likely you are to come across an untested path (and, perhaps, an undiscovered bug).

So, especially after an upgrade such as this with lots of new material, you each need to be particularly alert for things that don't "look right" and to report them promptly so that we can review them carefully.

## Addendum: Expanded Discussion of Selected New Features

Some of the new developments included in this release are of considerable theoretical and practical importance; for the terminally curious, we include some additional detail here.

## Treatment of Non-Gaussian Wave Processes

One of the great simplifications in our line of work is that many of the underlying stochastic excitation processes (wind, current and first-order wave forces) are Gaussian in nature, or at least approximately so. Unfortunately, this simplification does not extend to the higher order wave "drift" forces (both reflective and dissipative), whose statistical character is decidedly non-Gaussian by virtue of the fact that they derive from nonlinear functions of wave amplitude.

Another useful simplification is that low-frequency oscillations in the moor can often be treated, at least to a first approximation, as lightly damped processes.

It is a fundamental feature of lightly-damped oscillatory systems that the output of such systems is approximately Gaussian regardless of the statistical nature (i.e., Gaussian or not) of the input. (This powerful result arises directly from the Central Limit Theorem.) Engineering inferences arising from this approximation naturally become progressively less satisfactory as damping levels rise from vanishingly small to criticality.

Previous to SeaSoft Version 5.x, this "lightly damped" approximation was used as a starting point to characterize all low-frequency system oscillations. An unavoidable consequence of this simplification (at least for mooring systems with approximately *linear* force-versus-offset characteristics such as might be encountered in moderate to deep water) is that oscillation measures, including "characteristic" and "extreme", are *symmetric* about the equilibrium point; that is, the dynamical extreme maximum and minimum offsets lie equidistant from the mean offset.

We have been uncomfortable with this treatment for some time now because the level of damping commonly encountered with our simulations is not always "light"; system damping levels of 25% to 50% or even greater are not uncommon. For these systems, the "lightly-damped" simplification is, at least theoretically, inadequate.

We have now remedied this deficiency with a robust non-Gaussian response model that gives moderate-to-heavily damped systems a realistic (and asymmetric) response characteristic. The signature of this model is that low-frequency extremes of the "principal" normal mode (i.e., "surge") in the "down-wave" direction will, for moderate damping levels of approximately linear systems, be noticeably larger than the extremes in the "up-wave" direction.

It should be noted that previous to Version 5.x, the SeaSoft simulations *did* generally display a plus- and minus-side asymmetry in the low-frequency "surge" oscillations, but this asymmetry was due to *mooring nonlinearity* and was particularly noticeable in shallow water, where mooring systems tend to be highly nonlinear in their force-versus offset character. This pre-V5.x asymmetry is unrelated to the asymmetry due to non-Gaussian excitations discussed above.

[It is interesting to note, however, that the two asymmetries work in opposite directions: the mooring asymmetry biases towards larger oscillation amplitudes in the direction of the quiescent equilibrium point, while the non-Gaussian asymmetry biases towards larger oscillations in the direction *away* from quiescent equilibrium. Therefore, depending on the interplay between mooring nonlinearity and non-Gaussian response, the *net* asymmetry may favor either direction, or the oscillations may be nearly symmetric due to cancellation of these two asymmetric contributions.]

# Wave Reflection, Wave Absorption and Wave-Current Interaction Models

When SeaSoft began to create comprehensive simulations of moored vessels in an ocean environment, our physical understanding of some of the important underlying processes was somewhat incomplete. These processes included the low-frequency excitation forces then known as "wave drift forces" (now called, by us at least, "wave reflection forces").

Rather than demand that customers adopt for their wave-drift coefficients the output of a 3-D diffraction model, along with all its associated computational baggage, we wanted to provide an easy-to-use, fast-to-compute built-in model for these forces. We therefore developed a fairly simple theory of the second-order wave forcings, based partly on our own analysis and partly on available model-test data. This model proved to be remarkably successful in reproducing a wide range of model test data, and life was good.

There were, however, a couple of flies in the ointment:

1. The model often produced *mean* "wave drift" loads that were somewhat *higher*, and *variable* wave-driven motions that were somewhat *lower* than we observed in model test programs.

These two effects generally worked together so that the very important *maximum* offsets and loads (mean + variation) were generally quite good, especially in aligned conditions.

2. When wave reflection (aka "drift") coefficients from "gold standard" diffraction analyses such as WAMIT were used instead of SeaSoft's built-in coefficients, simulation results were often surprisingly unsatisfactory, producing a significant underestimation of variable motions. These underestimates could obviously be "fixed" by an ad hoc adjustment of system damping (which is how time-domain analyses deal with such issues), but since SeaSoft computes all system damping from first principles (at present comprising up to 7 independent contributions), this was not a satisfactory option for us.

We originally believed that because SeaSoft's "drift" coefficients included an empirical component arising from model test data, that they might be picking up some aspect of the wave drift force that was missing from diffraction models. The first guess was that neglected dissipative processes ("wave absorption") might be playing a role. To address this possibility, in 1987 we implemented a "wave drag" calculation for semisubmersibles, because that vessel type offered a relatively clean implementation path and seemed intuitively to be most vulnerable to a dissipative component of the wave "drift" force. The development was soon abandoned because the wave absorption model never produced enough forcing (either mean or variable) to amount to much above the levels of experimental noise.

Another possibility we explored was the effect of current which is usually included in model tests of our target systems but is not accommodated in the standard 3-D diffraction models. We managed to develop a very clean theory of wave-current interaction that was implemented at about the same time as the semisubmersible drag model, but it too failed to explain completely the "missing excitation" characterizing the 3-D diffraction models. Since the built-in SeaSoft "drift" coefficients continued to do a rather good job of reproducing a large and varied collection of model test data, that sleeping dog was left in peace until 2001, although the problem continued to nag.

In 2001, partly motivated by the development of **Sparsim**, we began a more systematic investigation aimed at understanding why the SeaSoft "drift" coefficients for tankers often worked well when the presumably more rigorous and sophisticated diffraction analyses fell short. To this end we did some purely theoretical diffraction analysis (including an analytical treatment for vertical cylinders which is now available in the SeaSoft simulations for both spars and semisubmersibles). This effort put all the built-in SeaSoft coefficients (including the tanker coefficients) on an improved theoretical basis but did not result in a resolution of the "missing excitation" mystery. In fact, for some combinations of vessel size and wave periods the "revised" SeaSoft coefficients now suffered from the same "missing excitation" deficiency as the 3-D diffraction models! At that point it appeared we had made a leap backwards despite a (supposedly) improved understanding of the underlying physics of the problem.

But the story has a happy ending...

In exasperation, we revisited everything, including both the semisubmersible wave absorption problem and the current-wave interaction problem. We discovered to our surprise that in many circumstances of importance, wave-absorption effects could be more important for shipshapes than for semisubmersibles. And, we discovered deficiencies in the original implementation of our current-wave interaction which, when corrected, produced a markedly improved outcome in strongly crossed environmental conditions. With these two improvements, and with the addition of the non-Gaussian response model, the "missing excitation" mystery has largely been solved.

At this point we must counsel that the use of drift coefficients from common 3-D diffraction codes will in many cases lead to extremely unsatisfactory simulation results unless the coefficients are supplemented with SeaSoft current and wave absorption corrections. Be particularly wary of their uncorrected use in (1) highly crossed conditions and (2) for vessels in large waves with length/principal wavelength ratios near unity (or, as a rough guideline, between .5 and 1.5).

An added bonus to these developments: The simulations (**SPMsim** in particular) now perform much more respectably in highly crossed conditions than before. In fact, the performance in crossed conditions now appears sufficiently robust that we have shelved, for the time being at least, the objective of eliminating all "small-angle" approximations from the normal-mode analysis (which remains nonetheless a longer-term goal).

Note that the reworked SeaSoft surge and sway wave reflection coefficients should, for most shipshapes, semis and spars, compare favorably with coefficients produced by such "gold standard" diffraction analyses as WAMIT or HOBEM. The SeaSoft reflection-based *moment* coefficients for shipshapes, on the other hand, behave quite differently, particularly at long wave periods, than those developed from diffraction codes. For turret-moored vessels at least, vessel low-frequency wave moments are invariably dominated by the lateral force coefficients, so discrepancies in the moment coefficients are barely noticeable in simulation results. Still, the differences between the SeaSoft moment model and that of popular diffraction codes is of academic interest and we will be pursuing an understanding of this discrepancy as time permits.

## Experimental Status of the Recent Modifications

The many fundamental modifications incorporated in SeaSoft Version 5.x have been tested against a wide range of model tests in highly crossed conditions, including the recent exceptionally comprehensive DeepStar series which comprised tests of a turret-moored FPSO, a caisson spar, and a TLP. Each of these systems was exhaustively model tested in several Gulf of Mexico environments, including multiple hurricane and loop-current conditions. Various Deepstar contributors from industry and academia contributed simulation analyses (almost all submitted "state-of-the-art" time-domain analyses). One of SeaSoft's clients also contributed an analysis of the FPSO using **SPMsim**. We have also done a preliminary analysis the remaining tests using **Sparsim** and **TLPsim**. These preliminary model test-simulation comparisons are without exception extremely gratifying. **SPMsim**, **Sparsim** and **TLPsim** were able to explain the nuances of these tests to a degree that we (and most other reviewers as well) find astonishing.

The Deepstar tests are important in part because they focussed exclusively on highly crossed conditions. Typically, aligned environments produce the largest peak mooring loads. Crossed conditions, although often tested, are seldom carefully scrutinized, both because of their relative complexity and their relatively modest mooring loads. As a result, with the exception of SeaSoft's simulations, the analysis capabilities of moored vessels in crossed conditions by our industry is pretty dismal, as the attempts to analyze the results of the DeepStar tests with "state of the art" time-domain simulations attest.

We will be making a comprehensive set of SeaSoft simulation-DeepStar measurement comparisons available on our web site in coming weeks. The comparisons will be in the form of spreadsheet databases comprising all available DeepStar tests for the TLP, Spar and FPSO. Anyone with a more immediate need or desire to see these results should contact us directly.

# Current Drag on Mooring Lines and Risers

During beta testing, it was brought to our attention that the SeaSoft "current drag on lines & risers" feature, when applied to turret-moored FPSOs, produced substantially larger mean line load estimates than "industry standard" time domain tools such as Orcaflex and Dynfloat. (These larger load estimates basically translate into larger mean turret offsets in a current.) As a result, we looked into this discrepancy rather thoroughly. What we discovered turned out to be quite surprising and interesting, so we will share some of the details here.

We were advised by our beta tester that, in order to compute the lift and drag forces on cylindrical structures such as mooring lines, risers, etc., in the presence of a uniform flow field, Orcaflex (and, presumably, Dynfloat, Flexcom and other widely used time-domain tools) relies on a "principle", rather widely used in sub-sonic aerodynamics, called the "cross-flow principle" (hereafter, the "CFP"; see, e.g., index items in Hoerner, *Fluid Dynamic Drag*). In our treatment of this drag problem, working as usual from first principles, we did not rely on the CFP and therefore our estimates are, not surprisingly, in marked conflict with it, as noted by our beta tester.

After a rather careful review we have concluded that for offshore engineering purposes the CFP is inapplicable to either prototype scale or model scale structures, although for quite different reasons. That this issue was not settled experimentally and theoretically in this industry 50 years ago is a mystery, considering the ubiquitous occurrence of cylindrical structures at all scales in ocean engineering and their importance in all aspects of the art, including analysis, testing, installation, operation, and survival. In view of its importance, this issue will doubtless be addressed soon in the literature. We have not ourselves conducted a literature search, but the uncritical application of the CFP by some of the most visible analysts and wave basin centers in our industry suggests that at the very least its inadequacy has either not been widely understood or not sufficiently publicized.

Therefore, you should consider these facts as you design your systems:

- The CFP has been repeatedly shown (beginning nearly 100 years ago!) to be valid for "sub-critical" flows around smooth cylinders in the pristine (non-turbulent) flow environment of the worlds best wind tunnels. In this context, "sub-critical" refers to flows whose Reynold's number (Re) is less than the so-called "critical Reynold's number" associated with the partial re-attachment of a detached boundary layer following the onset of turbulence within the boundary layer. This re-attachment, which permits partial pressure recovery behind the cylinder, generally leads to a (sometimes dramatic) drop in the drag coefficient of smooth cylinders at Reynold's numbers in the super-critical range beyond 3x10^5 or so.

- The CFP has *also* been known for over 50 years to be *inapplicable* to super-critical flow (which occurs, again, at Reynold's numbers in excess of about 3x10^5 for smooth circular cylinders in non-turbulent flow, and at substantially lower values for rough cylinders and/or in a turbulent incident flow field).

- We were unable to find data on the validity of the CFP in turbulent flow as a function of turbulence parameter, or for rough cylinders as a function of roughness parameter, at any Reynold's number.

What is the physical basis for our assertion of the non-applicability of the CFP for ocean engineering applications? Some brief motivational comments will help to frame the basic argument:

- For smooth cylinders in non-turbulent flow, the success of the CFP for sub-critical flow and the failure of the CFP for super-critical flow suggests that the loss of the principal qualitative flow characteristic associated with sub-criticality, to wit a well-developed and coherent vortex street behind the cylinder, plays a central role in the failure of the CFP for super-critical flows.

- As one increases either turbulence in the incident flow, or roughness of the cylinder, the critical Reynold's number is reduced until a point is reached (somewhere around Re = 10^4 or even less) where there is in fact *no* identifiable transition between "super" and "sub" critical flow; this circumstance is also identifiable by a drag coefficient that departs little from 1.0 over a range of Re of five or more orders of magnitude. Again, the existence of an *identifiable* transition appears to be closely tied to the trans-critical *disappearance* of a highly structured downstream vortex street. In conditions which, because of a harsh flow environment or a severely roughened cylinder, there is no organized downstream vortex street even at *low* Reynold's number, there is likewise no identifiable transition from sub- to super-critical flow, either from the point of view of changes in the drag coefficient, or in the disappearance of an organized vortex street. It appears likely therefore that under such adverse conditions, which nonetheless apply to most ocean engineering circumstances (at both prototype and model scales; see additional discussion below), the CFP is inapplicable at *any* Reynold's number.

- Reynold's numbers of these structures at model scale are of the order of 10^2 or 10^3 and would therefore easily be sub-critical in very steady flow conditions; therefore one might at first glance feel justified in applying the CFP to model scale analyses. However, the level of turbulence in basin current flows is *immense* compared to that of the pristine environments for which the validity of the CFP was established. It is very doubtful that in the basin environment any coherent vortex structures whatever can be maintained, and it therefore seems extremely doubtful to us that the CFP maintains *any* validity in this environment, despite the suggestively small Re values. To our knowledge, its validity has certainly never been established in these harsh conditions, although it would be nearly trivial for any commercial model test facility to carry out the measurements necessary to confirm or refute these conjectures. The vessel offsets in the DeepStar model tests were very nearly sufficient to accomplish just that; they are at least suggestive that our analysis is correct as none of the analyses provided by sponsored time-domain advocates were able to reproduce the observed vessel offsets without the application of unrealistically large riser drag coefficients.

- The special case of mooring chains, with their convoluted and complex profiles, certainly cannot be treated as "smooth cylinders" capable of producing coherent downstream vortex structures; therefore the CFP must be considered experimentally unjustified for this type of line, even highly polished chains in smooth, non-turbulent flows.

- Reynold's numbers of mooring structures and risers at prototype scale are generally in the range of 10^5 to 10^6 at the high current speeds of greatest importance; that is, they are almost certainly always super-critical (even assuming non-turbulent flow) given the expected level of roughness due to line construction (wire rope, braided polyester, chain, etc.) or marine growth.

- It has been our experience in the analysis of model tests that the SeaSoft line drag model, which usually produces substantially greater current loads than CFP-based codes (often a factor of 2 or so), reproduces quite well the observed experimental vessel offsets.

To summarize our thoughts on the validity of the CFP: At prototype scale, the large Reynold's numbers and roughness parameters of mooring or riser structures prevents the formation of the coherent downstream vortex street required for applicability of the CFP. At model scale, despite very small Reynold's numbers, the free stream turbulence is generally so severe that, once again, the establishment of a coherent downstream vortex street is prevented. In virtually all cases of relevance to offshore engineering, therefore, we feel the CFP is inappropriate. How it has survived a half century of scrutiny to remain today a central element of any serious software tool is utterly beyond us.

Our strong recommendation therefore is to eschew any use of the CFP for the calculation of current loads on mooring or riser structures at either model scale or prototype scale. If we are at some point shown to be wrong about this, we will be happy to revise our analytical model to incorporate estimates of the CFP type.