General HydroStatics SeaKeeping

An Integrated, General Purpose Approach to Seakeeping and Hydrodynamic Analysis

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The General HydroStatics SeaKeeping software module, referred to in short as "SK", is Creative Systems' entrant into the world of hydrodynamics. Introduced in January of 2018, the module aims to provide users with an integrated, general purpose approach to seakeeping and hydrodynamic analysis. This paper is a moderately technical introduction for the interested individual or prospective SK user. After some introduction, the overall focus will be on the four (4) main areas that make SK unique in its class: Automation, Customization, Technical Capability, and Development & User Support. While some theoretical content is presented here, those specifically interested in a deeper mathematical basis of the module are invited to contact Creative Systems Inc. for a copy of the SK User's Manual.

Introduction

SeaKeeping is an optional software module within the GHS environment that provides users the tools to evaluate the dynamic performance of most mono-hull vessels, barges, docks, and floating structures. SK extends beyond the hydrostatic capabilities already offered by GHS, allowing users to tackle dynamic analyses, including:

- Motion Studies
- Cargo, Rigging, & Sea-fastening Calculations
- Habitability Studies
- Crane Operation Evaluations
- Foundation Design
- Wave Forcing Studies

Simple tasks, such as generating response-amplitude-operators (RAOs), computing accelerations at a point, or evaluating responses over a range of wave headings and/or speeds, are easily accomplished with relative speed and minimal input. Accessing output data is also readily done using the available data file options.

The software module may be utilized in three different ways: via the available SeaKeeping Wizard, direct calls via the command line, or by using the SEAKEEPING command in a run file. The Wizard, a graphical user interface designed to simplify analysis set-up, is an excellent tool for first-time users or when the complexity of an analysis is minimal. However, when a project demands a more complex, automated, or custom approach, the option to use the SEAKEEPING command in a run file is often preferable, and the flexibility that this approach offers users is unmatched.

While SK provides many features that may be found in other software tools, it excels in four key areas: Automation, Customization, Technical Capability, and Development & User Support. The following subsections will address each of these four key areas, speaking both to features and to some examples illustrating how the GHS-SeaKeeping Module is an ideal choice for seakeeping and hydrodynamic analysis.

Automation

Automation is one of the founding principles of GHS. Automation saves time, enables modification, improves productivity, and facilitates repeatability and consistency. SeaKeeping is true to this principle by enabling the design of a time-consuming or tedious dynamic analysis with relatively little set-up, requiring only essential input in a single run file or Wizard configuration. Within GHS, once the set-up is complete, the user's commands are interpreted, and the analysis will run without further input. Extending this paradigm to SeaKeeping means dynamic analyses are efficient and repeatable, yet easily modified.

Automation is especially beneficial in hydrodynamic calculations, which often require a large number of unique cases and produce a large amount of data. With SeaKeeping, evaluating many headings, speeds, and/or environmental conditions has never been more direct. Flexible syntax allows the specification of any number of wave headings and/or forward speeds, where each heading and/or speed may be specified individually, or as a range with any constant interval. Upon interpreting these input parameters, SeaKeeping will automatically set up each unique case. With this compact syntax, *hundreds of cases may be evaluated from a single command.*

Managing large-scale output is a major challenge when running dynamic analyses. Organizing, parsing, reviewing, and formatting output data can be a very time-consuming process.

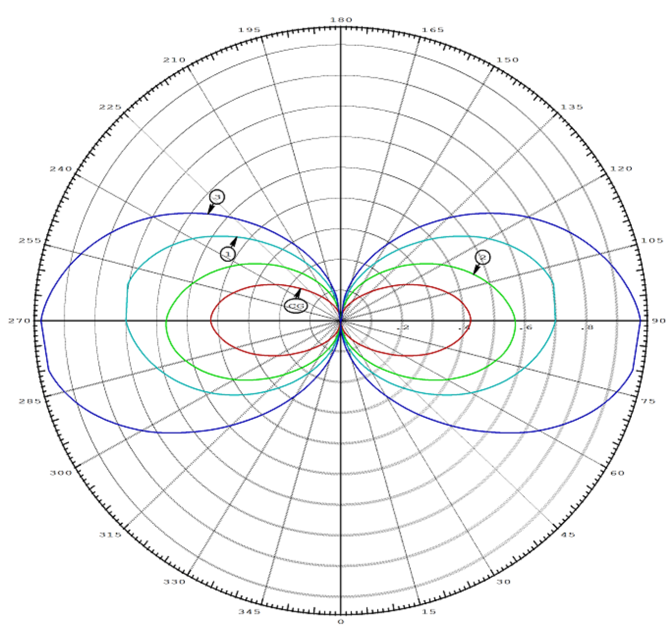

Figure 1. Automated Polar Plotting

To aid in this process, all SeaKeeping report output, including tables and plots, is created, formatted, and organized automatically during the run. Figure 1 shows an example polar plot generated automatically when evaluating sway accelerations at multiple point locations over 15 degree heading intervals at zero speed. If multiple speeds had been specified, multiple plots would have been returned. Other than the initial request for polar plot output, this plot was created without any additional user input.

A hierarchal case-by-case and point-by-point approach is used to automate the organization of long reports. This automated report structure makes it very easy to find worst-case headings, critical cases, or limiting cases, and then reference the specific condition within the report for more detailed inspection without spending extra time managing output. In this way, automated reporting saves time and aids in the review process.

Automated Dynamic Limits

A significant task when evaluating dynamic performance is quantifying the dynamic operability of a vessel. This usually requires running potentially hundreds of cases to investigate the vessel's entire operable range, and then comparing computed responses to design or regulatory limits. In many cases, assessing dynamic limits is a highly time-consuming process because the responses from each case need to be compared to a limit value. If multiple limits are required, the complexity of this task is further compounded. SeaKeeping offers users a unique and powerful method to set and evaluate dynamic limits automatically. Building upon the long-standing success of the hydrostatic LIMIT statement in GHS, SeaKeeping offers users the SEA LIMIT statement, which provides a generalized syntax that allows users to specify nearly any dynamic limit, and even create or combine multiple limits to create composite limits. The SEAKEEPING command will then automatically recognize any predefined dynamic limit(s) and create a plot for each limit without any further user input. Limit plots give visual indication as to which cases pass or fail the criteria, thereby giving immediate indication as to the dynamic operability of the vessel.

Customization

GHS is known for its flexible, generalized approach, which offers users a high level of customization within a well-defined set of theoretical methods. SeaKeeping meets this expectation by adopting several existing GHS paradigms: thoughtful input variable control, ready access to low- and high-level data, as well as integrated data post-processing capabilities. The combination of these paradigms with powerful hydrodynamic theory results in a dynamic analysis tool that encourages highly customizable solutions.

Input Variable Control

Control over input variables is critical to ensuring user customization. SEAKEEPING parameters are carefully designed to provide the user with an array of custom input and output options with minimal, yet clear, syntax. Basic parameters, such as units, point location(s), heading(s), and/or speed(s), are easy to define and easy to understand. More complex parameters, controlling such variables as derived responses, extreme amplitudes, or mesh settings, attempt to be both comprehensive and concise, with detailed technical documentation available to aid in understanding. Many parameters can work together to enable powerful customization through combination.

With SK, loading conditions may be specified to an exceptional level of detail.

Input variables aren't simply limited to the command parameters. Geometry, loading conditions, and wave environment variables are central in the design of a dynamic analysis. Because SeaKeeping is integrated within the GHS environment, these input variables are managed and modified by other intrinsic commands. Similarly, built-in geometry tools, such as Section Editor and/or Part Maker, may be used to view or modify geometry to suit the needs of the dynamic analysis. Combining these integrated capabilities with optional meshing parameters gives users a high level of control over geometry related factors, including:

- Fitting, joining, modification, and inspection of geometry
- Orientation and density of station sampling
- Fineness of the hydrodynamic mesh at each section
- Mesh and solution convergence
- Computation time

More circumscribed motions codes impose severe limitations on loading conditions, and often very little support is provided to develop complex and/or variable load conditions. With SeaKeeping, loading conditions may be specified to an exceptional level of detail. This is accomplished using a combination of distributed lightship weights, other fixed added weights, and tank loads, all of which may be specified as individual "weight components" effectively building-up a complex condition item-by-item. It is also possible to define a loading condition using a known water-plane orientation, such as defining a specific trim, heel, and depth, or even a single weight, center, and overall gyradii.

The wave environment is similarly customizable, offering options to specify single waves, wave ranges, or wave energy spectra. Multiple built-in spectra are available, including a single-parameter Pierson-Moskowitz spectrum, three different Bretschneider spectra, two JONSWAP spectra, the six-parameter Ochi-Hubble spectrum, the most-probable single-parameter Ochi-Hubble spectrum, and a custom data file option when real-world seaway observations are available. When it comes to the seaway discretization, both constant variance and constant bandwidth sampling methods are offered, which give the user additional control over the sampling process.

Data Access and Data Manipulation

Two key factors in a custom analysis are data access and the ability to easily manipulate the data. SeaKeeping gives the user optional access to low-level data, like hydrodynamic coefficients, forcing amplitudes and phase angles, as well as higher-level data like RAOs, response variance, response amplitudes, and/or derived responses. Integration with the GHS command language environment provides the necessary tools to manipulate this data quickly and easily using macro operations. This allows users to create highly complex and powerful run files that use SeaKeeping as the core solver but perform additional data post-processing. Examples of such custom run files include:

- Automated investigation of the required free-board via operating draft or foredeck modifications to minimize deck wetness
- Evaluation of certain complex criteria or operability requirements (such as cargo shifting)
- Investigation of the optimum loaded operating condition to minimize certain derived responses (specifically for passenger vessel operations)
- Investigation of the effects of quasi-static wind-induced heel on motions
- Short-crested seaway computations using custom asymmetric spreading functions
- Frequency-domain amplitude/phase output conversion into time domain signals

Technical Capability

SeaKeeping aims to be both advanced and practical. Balancing these two priorities is a key consideration when selecting any software tool. SK maintains excellent technical capability within a useable format by making strategic theoretical choices. This section will describe some of the unique technical capabilities that SeaKeeping offers, as well as some of the theoretical background that makes these features possible.

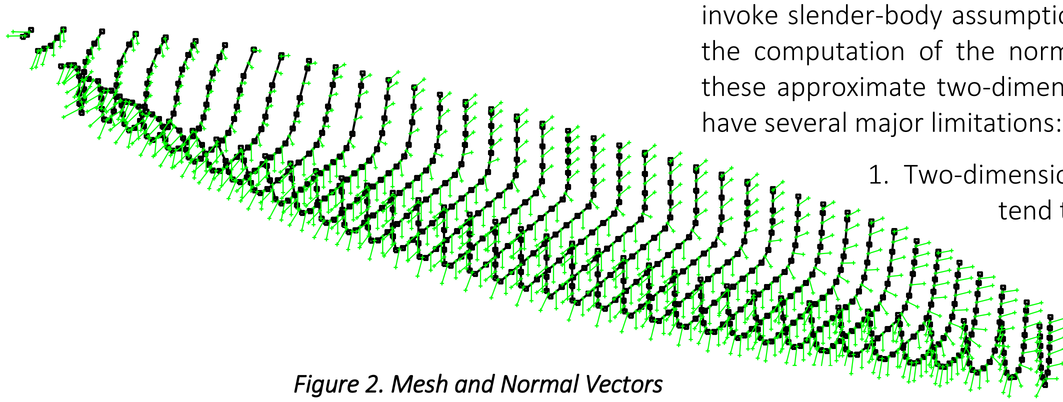

Figure 2. Mesh and Normal Vectors

SeaKeeping invokes a bespoke linear, six-degree-of-freedom, rigid-body, frequency-domain, higher-order, strip-theory method with forward speed capabilities. The formulation is unique because it removes many of the assumptions and simplifications inherent in classical strip theories while also extending the capabilities. Most notably, the SK method does not make any symmetry assumptions and eliminates many slender-body assumptions by using a unique 3D-to-2D modeling approach. This method also solves the two-dimensional radiation potential directly for each section using a higher-order Rankine panel method. By eliminating assumptions, using three-dimensional normal vectors, and keeping the panel methods two-dimensional, this method can accommodate anti-symmetric cases with full-coupling, and yet avoid a host of meshing issues and computational sensitivities that befall other theories. These improvements make the theory used by SeaKeeping highly robust, while offering improved technical capability for a wide range of applications.

3D-to-2D Meshing and Normal Vectors

An accurate mesh representation of the geometry is critical to ensuring a good hydrodynamic solution. Because SK invokes a strip-theory approach to the three-dimensional problem, effectively reducing the three-dimensional problem to the integration of multiple two-dimensional problems, the mesh representation in SeaKeeping is really a series of two-dimensional section meshes sampled and spaced at geometrically and parametrically controlled locations. Because of this reduction, most strip theories use approximate two-dimensional normal vector formulations, and many theories invoke slender-body assumptions to further simplify the computation of the normal vectors. However, these approximate two-dimensional normal vectors have several major limitations:

1. Two-dimensional normal vectors tend to over-predict near the ends of the hull, where slender-body

assumptions aren't valid. This is especially noticeable in the added mass and damping coefficients in pitch and yaw.

2. Approximate two-dimensional surge normal vectors tend to exhibit poor solution convergence in testing, especially when evaluating results with increasing section density.
3. Two-dimensional slender-body normal vectors omit the surge component in the pitch and yaw rotation vectors, which is invalid for deep bodies.

To remedy these issues, SeaKeeping instead computes the true three-dimensional normal vectors by first developing a triangular mesh of the submerged hull surface. Each triangular mesh element is associated with a single two-dimensional panel, thereby defining each panel normal vector as a true three-dimensional vector. This unique method has been heavily tested during development and includes unique logic to automatically retain panels around important features, such as corners and chines, while also identifying and removing unimportant features such as the "zero-thickness" section curves that are sometimes observed in section-based geometry files. Figure 2 shows an example mesh generated by SK using this method.

Higher-order Two-dimensional Panel Method

Most strip theories use conformal mapping or low-order two-dimensional panel methods to compute the forces at each section. While efficient, conformal mapping often does not accommodate complex ship sections and may be prone to mapping irregularities. Low-order panel methods can accommodate most ship sections, but they generally do not model the free-surface and are often subject to computational issues such as irregular frequencies and singularities. To avoid these issues, SeaKeeping uses a higher-order Rankine panel method with linearized boundary conditions to compute the radiation potential for each paneled section. In this method, boundary conditions are enforced over an entire panel by means of an integral, not just at a single colocation point. This results in a higher-order solution even when using a coarser mesh.

Use of Rankine sources also means the free surface is meshed at each section and the free-surface boundary conditions are enforced over each free-surface panel. In cases where the section is fully submerged, the free surface is modeled using an image source method to provide robust solutions.

> ***SK accommodates anti-symmetry by offering full-coupling and eliminating symmetry assumptions.***

Anti-symmetric and Full-Coupling Capabilities

SeaKeeping accommodates anti-symmetric cases by offering full-coupling options and eliminating symmetry assumptions. This capability is unavailable in other codes and is a key factor when evaluating realistic loading conditions, damaged conditions, non-zero heel and trim, and/or anti-symmetric geometry, among others.

To enable this advanced capability, the hull and free-surface are computationally modeled on both the port *and* starboard sides at all times. Also, all six modes of motion (Surge, Sway, Heave, Roll, Pitch, and Yaw) may be coupled such that each influences the others. To make this possible, SeaKeeping incorporates three major theoretical enhancements:

1. SeaKeeping computes the radiation potential for all six modes independently, much like a 3D panel method does, and then computes all 36 radiation coefficients where most codes compute only 18. This means all cross-coupling coefficients in the added mass and damping matrices will be computed and included in the equation of motion.
2. SeaKeeping uses a generalized physical mass matrix with all off-diagonal terms included. Some theories omit certain coupling terms from the inertia tensor by making assumptions about the distribution of the vessel's loaded mass. This is not the case in SK, where each

term of the generalized physical mass matrix is computed from the user-defined composite loading condition, so all added weights, lightship, tank loads, etc. and their inertial properties will be included in the matrix. The complete composite inertia tensor is then transformed according to the water-plane condition to ensure that the mass distribution is correctly considered even at large angles of heel or trim. This is an important consideration that is not available in other codes where loading conditions are restricted to zero heel and trim or assume small angles.

3. SeaKeeping uses a generalized hydrostatic stiffness matrix to more effectively capture the hydrostatic restoring forces on the vessel. This matrix is based on the generalized first-order hydrostatic restoring forces, and therefore includes all hydrostatic restoring terms that are typically omitted by other theories.

Development & User Support

Users are often surprised by the level of customer support they receive when they choose GHS. The SeaKeeping module is no different. All SK licenses include comprehensive technical documentation, which includes a very complete description of the theory and assumptions underlying the code, as well as core validation studies. All functional command and wizard documentation is embedded in the GHS help menu, so it is readily available to get new or seasoned users up and running quickly.

For questions or technical issues that require more direct support, maintenance and technical support subscriptions (M&S) give users unlimited technical support from Creative System's technical support team. If needed, users are even able to communicate directly with the developers, meaning technical or theoretical questions are promptly answered by the folks who create and maintain the code every day. When dealing with the inherent assumptions and complexities of hydrodynamics, this level of communication provides valuable piece of mind.

Many software tools available today suffer from a major lack of development support. This type of support isn't about answering technical or user questions, but about continual development, feature updates, bug fixes, and theoretical improvements. The development team at Creative Systems, Inc. takes pride in maintaining a continual active development cycle for all CSI products, including SeaKeeping. While all code is thoroughly tested prior to release, on occasion a specific issue will be identified in further testing. In these cases, suspected problems will always be promptly addressed by the development team. If an issue is found, most are resolved within a matter of days, with a new version uploaded and the user notified of the fix. Any changes are always noted publicly in the GHS Version Release Notes available on the Creative Systems website.

New feature updates represent a major portion of the development team's daily work. This means new features are always in the development pipeline and are released as soon as they pass internal testing and development steps. A major advantage to choosing any Creative Systems product is the input users may have in feature development. Many SeaKeeping features were added based on user comments and requests. Current SK users will often contact the SK development team with a specific recommendation or requirement. Collectively, this user feedback will shape a new feature, and the developers will provide a solution within a reasonable time-frame. Because SeaKeeping is a bespoke and modern code base, the product is always improving.

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