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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

COST, SCHEDULE, AND PERFORMANCE ELEMENTS FOR COMPARISON OF HYDRODYNAMIC MODELS OF NEAR-SURFACE UNMANNED UNDERWATER VEHICLE OPERATIONS

by

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December 2017

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As emerging technology spurs new requirements for the development and acquisition of increasingly advanced military platforms, the defense acquisition community needs a comprehensive decision-support framework to make informed investment decisions for software selection. Through a determination of key characteristics that form the basis of a decision process, this report outlines a framework for software selection that includes cost, schedule, and performance considerations. Furthermore, the resultant software selection criteria are subject to a practical demonstration to compare the following software packages that predict hydrodynamic loads: Standard Ship Motion Program (SMP), SUBMOT, Aegir, and Large Amplitude Motion Program (LAMP). The creation of a uniform set of simulation input data, for use with these four candidate software packages, details this selection process. We present a comparison of the software-generated data with experiment data gathered from tow tank trials as an analysis of tradeoffs between cost, schedule, performance, and simulation fidelity. The practical demonstration showed that Aegir and LAMP were more labor-intensive than the other software packages and that Aegir and LAMP simulation results were typically closer to the scale model experiment results. Resulting recommendations include decision-support framework application and fidelity analysis prior to software selection for most effective program support.

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN SYSTEMS ENGINEERING

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and

MASTER OF SCIENCE IN ENGINEERING SYSTEMS

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LIST OF ACRONYMS AND ABBREVIATIONS

AMRDEC	Army Aviation and Missile Research Development and Engineering Center
CAD	computer-aided design
CFD	computational fluid dynamics
COTS	commercial off the shelf
CSV	comma separated values
DOD	Department of Defense
DOE	design of experiments
DOS	disk operating system
GUI	graphic user interface
HSC	high-speed computing environment
IT	information technology
LAMP	Large Amplitude Motion Program
LES	large eddy simulation
NFA	Numeric Fluid Analysis
NMCI	Navy/Marine Corp Intranet
NPS	Naval Postgraduate School
NSWCCD	Naval Surface Warfare Center, Carderock Division
NURBS	non-uniform rational basis
POC	point of contact
OS	operating system
RANS	Reynolds-averaged Navier-Stokes
SAFE	safe access file exchange
SE	systems engineering
SME	subject matter expert
SMP	Standard Ship Motion Program
T&E	testing and evaluation
UUV	unmanned undersea vehicle
VM	virtual machine

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EXECUTIVE SUMMARY

As technological concepts associated with military platforms further develop, project managers and resource sponsors need to make challenging investment decisions for programmatic software utilization. Faced with cost, schedule, and performance factors that determine the success of an acquisition program, it is vital to make the appropriate investment decisions. For this reason, the defense acquisition community needs a means to ensure decision makers consider all attributes affecting cost, schedule, and performance. This would inform and improve investment decisions regarding the procurement and implementation of software.

Investment decisions regarding the procurement and implementation of software span a seemingly infinite spectrum of choices, ranging from the development of a new software application, purchasing commercial off-the-shelf (COTS) software, or even repurposing software that was developed for a specific purpose but is discovered to be useful for unintended applications. Furthermore, factors become very complex, considering the underlying characteristics of software that dictate how it performs calculations. Navigating the endless pool of software attributes requires an informed process that comprehensively assesses the key factors and considerations to drive the formulation of decisions.

In order to make appropriate decisions for the program, it is imperative that the impacts to cost, schedule, and performance are synthesized and compared among the potential software candidates. An informed decision should be based on factors decomposed from the following high-level categories:

- **Cost –** The initial procurement cost and long-term maintenance costs associated with a software candidate.
- **Schedule –** The delay between selecting a software candidate and full programmatic implementation, as well as time required for all aspects of usage such as creating inputs, running simulations, and extracting meaningful information from the software.

- **Human Capital –** The implications associated with overall complexity and requisite skills required to properly utilize a software candidate.
- **Fidelity –** The level of accuracy for each software candidate and ensuing usefulness of data for programmatic needs.
- **Life-cycle Support –** Additional considerations pertaining to long-term use of a software candidate.

Through the careful analysis and decomposition of these categories, this report outlines critical elements that must be captured by any chosen decision method for selecting software. In order to determine the effectiveness of the resultant framework, this research documents a practical demonstration for a scenario to select the most appropriate hydrodynamic load–simulation software for a developing UUV program. This demonstration is relevant because many software applications are currently available for hydrodynamic modeling, which presents a real-world software selection problem.

To emulate the actual challenges encountered by project managers, engineers, and resource sponsors, and to ensure the relevance to the defense acquisition community, the selection pool includes software candidates that implement different mathematical methodologies, including strip theory and panel methods. This research scrutinizes four software candidates for the effectiveness of the various modeling equations employed by each and for factors organic to their use within scope of the decision support framework.

The scope of this report includes documenting a process for the selection of the most appropriate software candidate, and this study provides the results of utilizing the software selection decision-support framework in a real-world scenario. The objective is to determine the programmatic requirement for software fidelity and the desired cost with respect to procurement expenses, implementation time, human capital, and life-cycle support up front. The next objectives are to determine potential options available and determine the best methodology to assess the performance of each option in comparison to the initial requirement. This will form the basis for selection of the most appropriate software candidate.

This report describes a software decision-support framework and provides a demonstration through exploration and quantification of taxonomy elements for each software code as well as comparisons of tow-tank experiments with numerical simulations performed by four different hydrodynamic load–simulation software packages. A static set of input data, which matches the conditions tested in the tow tank, is used as input to the software applications to produce comparable output data from each. This is not a comprehensive study of all hydrodynamic load–simulation software currently available, but it represents two major methodologies among the four software applications. Additionally, the scope was limited to constant amplitude, single frequency waves approaching the UUV at a single direction. Time and resource constraints limit this report from describing fidelity in terms of the complex and numerous real-world conditions a maritime vessel would experience. This report expresses the fidelity of each software candidate by using experimental and simulated data from single direction waves produced by a wave generator in the tow tank, which are sufficient for the determinations described by this study.

The resultant decision support framework of this study is designed to allow for a program office with a known fidelity requirement to choose the software candidate that meets the requirement at an acceptable cost. It is important to consider the tangible and non-tangible costs of implementing a software application into the system engineering activities of an acquisition program. As a catalyst to ensure all costs are considered and accounted for, it is recommended to implement this framework to ensure that the time and cost constraints and fidelity requirements are appropriately considered.

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I. INTRODUCTION

A. BACKGROUND

In the increasingly expanding scientific and technical fields, it is highly desirable to have the ability to predict accurately system performance to evaluate its effectiveness and capabilities. These predictions may inform decision makers as to whether a system should advance to the following phase, whether issues in the current phase need to be addressed, or whether to invest in a project at all. The means in which one obtains information varies widely. An experiment with the actual system in question in real-world environmental conditions would provide the most accurate information, but coordinating and executing such an experiment would be time-consuming, costly, and potentially not practical if the experiment resulted in the loss of the system (e.g., testing system vulnerability). Scale-models operating in appropriately scaled conditions may provide accurate results at a lower cost, but confidence in these results cannot be assured without validation, as some physical effects are scale dependent. Still less costly is calculating predicted results through either regression or theoretical analyses. While these make for a cost-effective answer to a discrete question, each has drawbacks. Accumulating data for regression can be slow and cumbersome, for a result that is often not very accurate. Theoretical analysis is often complex, difficult to defend for those unfamiliar with the equations, and is only as accurate as the assumptions required to solve the equations. Finally, simulations can play a valuable role in obtaining information, as they provide rigorous analyses in a relatively short amount of time. Developing software specific to a problem can induce additional costs, but those costs may fall short of product testing or scale model experiments. Using existing software to fit a new problem, if possible, could provide the most accurate information needed in a shorter amount of time and for less cost than the alternatives.

One can apply this concept to predict the behavior of maritime vessels and the influence of their surrounding environmental conditions. In the context of unmanned undersea vehicles (UUVs), it is of particular interest to study the behavior of vessels operating near the surface where substantial amounts of wave-induced loads exist.

Factors such as sea state or wave height, surface currents, temperature gradients based on depth and solar radiation throughout the day, and even salinity all affect the performance characteristics of a vessel operating near the surface.

Given unlimited time and financial resources, the most accurate simulation with the largest parameter space will always be preferable. However, with the financial and scheduling constraints of most defense acquisition programs, trade-offs must be made between model fidelity, cost of simulation, and time requirements. This study aims to present the many attributes that contribute to these traits, provide a generic decision-support process to obtain the best solution to any particular problem, and apply this methodology in the real-world scenario of predicting the wave-induced loads on UUVs operating near the surface in a seaway.

B. PROBLEM STATEMENT

Project managers and systems engineers need to make investment decisions for predicting performance with limited resources. While the full range of options for these predictions include testing the actual system, scale models, reuse of existing simulations, and development of new software, it can be a more cost-effective option to research existing software packages designed for specific types of projections. In order to make investment decisions for any program, the information for cost, schedule, and performance needs to be synthesized and compared. The intent of this project is to provide a general framework of considerations for determining the applicability and "true cost" of software packages—that is, the total amount of man-hours, dollars, and schedule time involved in every aspect of implementation including user access, training, and maintenance. Currently, decision makers do not have comprehensive resources available to ensure all relevant attributes are considered, some of which are not intuitively linked to actual implementation cost.

In the specific case of predicting hydrodynamic loads, many software packages are currently available. In addition to the general framework of software attributes, a follow-on practical demonstration explores several different software packages with various user requirements and analytical techniques.

This study aims to inform programmatic investment decisions by:

- researching usage requirements and considerations for software packages
- developing a comparison of parameter fidelity, cost, schedule impacts, and additional programmatic considerations
- developing a comprehensive methodology by which decision-makers can use valuable information to make informed decisions with confidence
- implementing the methodology with four software packages to measure total human capital elements of usage
- estimating output accuracy by comparing to tow tank experiments

C. GOALS AND OBJECTIVES

After performing a careful analysis of the problem, the ultimate focus of this study was to determine the impact of navigating the trade space of cost, schedule, and fidelity among software options. The goals and objectives for this project include the following:

- Create a general framework to determine which attributes of software packages need to be considered for implementation. As a starting point, the following were investigated: initial acquisition, usage requirements, ease of use, time to learn and execute simulation, maintainability, ownership, and fidelity/degree of accuracy. Additional findings from previous research contributed to the final framework to create a more complete list of considerations for software implementation.
- Quantify and compare cost, schedule, and other aspects of the software packages that will affect overall programmatic cost and ease of implementation.

The following objectives pertain to the practical demonstration:

- Determine quantitative or qualitative metrics for the aforementioned elements to facilitate comparison among software packages.
- Compare software predictions to experimental data to estimate degree of accuracy of hydrodynamic load predictions.

D. SYSTEMS ENGINEERING PROCESS

System life-cycle models demonstrate the basic flow of activities pertaining to the development of a system and can be implemented to draw attention to key aspects of the project. Typical life-cycle models and their associated stages and decision gates fall into two categories: linear, (sequential) and iterative. Sequential models, such as “waterfall” and “Vee,” progress in linear phases through each of the life-cycle stages.

The team used a tailored waterfall SE process in exploring the general problem and integrated the practical demonstration after we identified software package attributes and created a primitive framework for the informed decision methodology. We incorporated some elements of the spiral method due to the iterative nature of constant reassessment. Since this project did not involve creation of a physical product to be manufactured, operated, or retired, the team identified problem-specific activities from system engineering (SE) development processes as opposed to identifying product-oriented tasks. This process resulted in a series of analyses that inform subsequent steps.

The process as a whole included six steps: initial usage analysis, review of the hydrodynamic models, usage analysis of hydrodynamic models, testing and evaluation (T&E)/data analysis, develop solution criteria, and conclusions. Initial usage analysis considered model availability and other key software attributes. Other tasks involved stakeholder and needs analysis and the product from this step was an initial framework of cost and schedule elements.

Review of hydrodynamic models determined required inputs and outputs as well as underlying model development. Usage analysis explored the time needed to gain proficiency with each model, expertise support required, cost to acquire, and other cost and schedule metrics required from the taxonomy developed during the initial usage analysis. Gathering the data acted as validation of the initial cost and schedule framework. The following task was T&E/data analysis, during which data generated from each of the software package simulations was compared to experimental data involving a model produced by rapid prototyping. The tow tank runs served as “true” loads for comparison since testing an actual UUV would have been well beyond the scope of available resources. This process informed the development of solution criteria, during which the team determined a methodology for evaluating software that decision-makers could potentially apply to a broad range of software comparisons. The project concluded with major takeaways found in the development of this report. Figure 1 illustrates this process, identifying the six steps and the interim products involved.

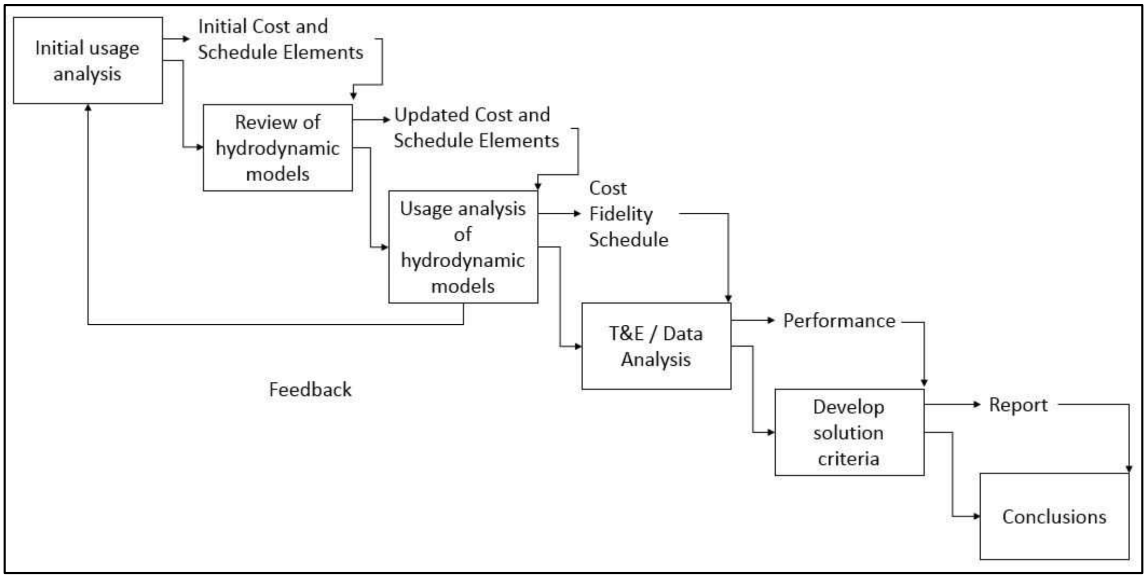

Figure 1. Tailored SE Process Model

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II. SOFTWARE ATTRIBUTE FRAMEWORK

A. COST AND SCHEDULE TAXONOMY

Software procurement price is not representative of actual life-cycle cost because it does not account for the man-hours and dollars expended towards learning, support infrastructure, additional analyses required, and other aspects of utilization. It is easy to overlook less intuitive, but crucial factors such as time required to learn the software, create simulation input, and extract meaningful data from the output. The purpose of the decision framework is to reveal more readily cost and schedule effects of software-selection decisions, enabling decision makers to be more aware of implementation requirements and to make decisions that are more informed. Both research and experience contributed to the hierarchy of cost and schedule attributes shown in Figure 2, with the intent of capturing a thorough range of considerations when selecting software. Sources consulted include the *Defense Acquisition Guidebook* (Defense Acquisition University 2017), and R. Pressman's software engineering text (Pressman and Maxim 2014).

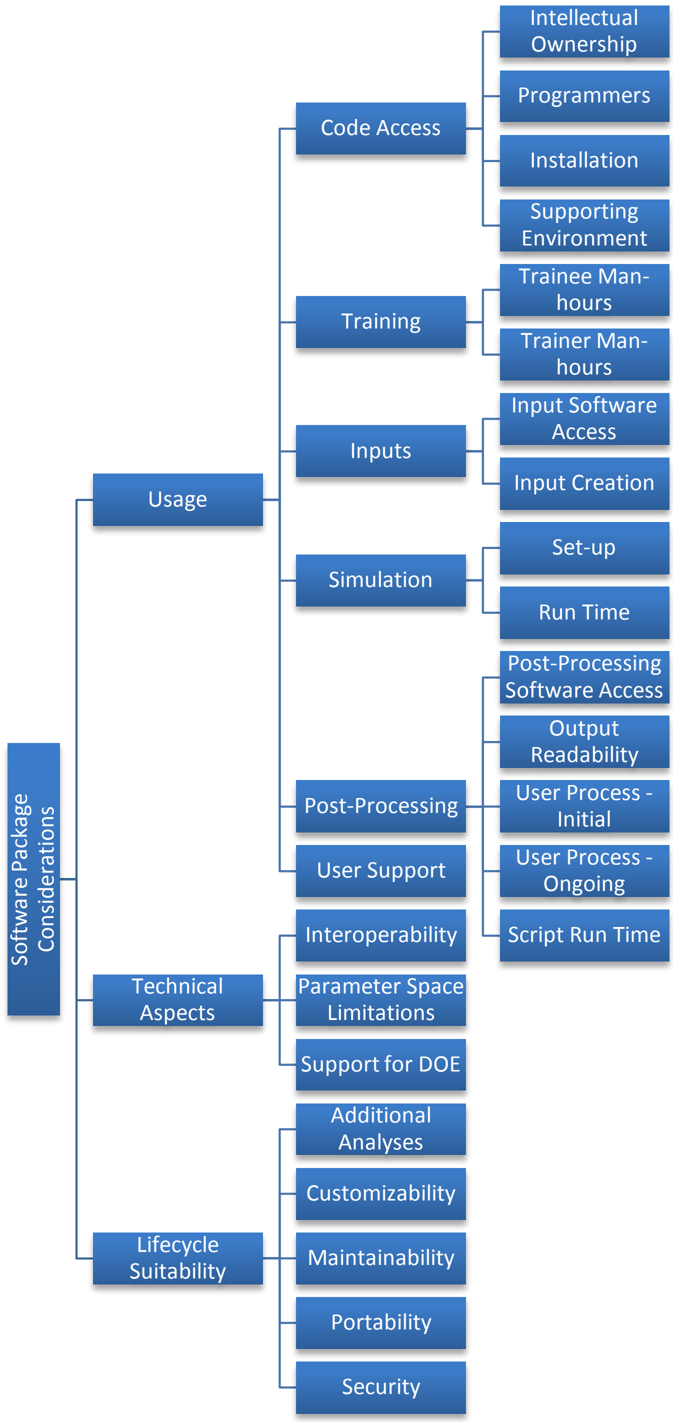

Figure 2. Software Cost and Schedule Taxonomy

In order to articulate the definitions and metrics for taxonomy elements, the team consulted the Glossary of Defense Acquisition Acronyms and Terms (2017) and Business Dictionary (2017) in addition to the aforementioned sources. Ultimately, descriptions were tailored to address software users' scope of concerns, and each element is defined more specifically as follows:

Usage: All elements affecting the actual use of software, including code access, training, inputs, simulation, outputs, and user support

Code Access: All elements affecting the process of making software available to users, including ownership, installation, and supporting environment

Owner: Person(s) or organization with the right to sell or otherwise provide software to users

Programmer: Person(s) who completed actual programming for the software; this will influence user support and method for access. This may or may not be the software owner

Installation: Process of transferring software to user assets

Supporting Environment: Accumulation of any additional software or hardware required to use the software package in question; this could include data libraries, operating systems, high speed computing environments, etc.

Training: Hours spent learning/teaching, and troubleshooting simulation problems, including both new users and trainers

Input: The process of creating values to enter into software for simulations, including all aspects of procuring additional software, calculating values, and transforming values into acceptable format for the software package

Simulation: Both the user set-up to prompt simulation start and actual software analysis, measured in run time

Post-Processing: The process of manipulating data for further analysis, including procuring any additional software needed, initial one-time processes (developing scripts or other methodologies), and ongoing user processes (all repeatable steps for actually processing data)

Output Readability: Comprehensibility of software output prior to post-processing

User Support: Level of support available to users upon acquiring the software package, including documentation, tutorials, or ad-hoc troubleshooting support

Technical Aspects: Mechanical and methodological considerations that impact software implementation, including interoperability, parameter space limitations, and support for design of experiments (DOE)

Interoperability: Ability of software to run with existing user hardware and software platforms, and to interact with input and output software packages. In this case, interoperability measures are dependent on current user assets, while portability measures projected potential to run software with additional hardware or software

Parameter Space Limitations: Degree to which simulation outputs include the entire viable solution space; considerations include variable scope, computational limits, and any underlying assumptions that would limit output

Support for DOE: Degree to which software would support DOE analysis; highly dependent on user DOE methods, but could include considerations such as relationship among variables, user ability to manipulate variables, output format

Life-cycle Suitability: Relative longevity of software within the program, determined by capability to answer other program questions, customizability, maintainability, portability, and vulnerability

Additional Analyses: Degree to which software can answer other program questions in the near future (e.g., hydrodynamics of multiple vehicles in addition to single vehicles)

Customizability: Degree to which software can be customized for specific user needs, likely dependent on ability of owners and programmers to make additions or edits

Maintainability: While this typically refers to programmer ease with the maintenance process, in this case maintainability refers to the level of maintenance available to users after purchase. Considerations include whether owners will issue regular updates, availability of maintenance upon request, and amount of user time and effort associated with maintenance to enhance longevity of software life cycle

Portability: Software package's ability to run with other hardware or software platforms in addition to those included with initial installation

Security: Ease of adaptation for information security purposes; rather than security measures of the software itself, this describes how labor-intensive it would be to maintain organization security standards with adaptation of a given software package

While most usage elements can be measured in terms of man-hours, influence on schedule, or procurement cost, the technical and operational suitability considerations require qualitative assessment. One way to assess these elements is with ratings of high, medium, and low to facilitate comparison. General rating criteria is provided in Table 1. For all criteria described, a high rating is more favorable than a low rating. The criteria is written in such a way that ratings are not absolute, but also relative to other software candidates to highlight further any differences among options.

Table 1. Qualitative Rating Criteria

Taxonomy Element	Low	Medium	High
Output Readability	Output cannot be understood without post processing	Some outputs can be understood without post processing, or output can be understood by experienced software user	Output is readable and understood by inexperienced users
User Support	No support available unless an experienced software user is willing to help	Some user support available, but may have errors or does not cover all features available in the software	Extensive user support is available that expands to all features, uses.

Taxonomy Element	Low	Medium	High
Interoperability	Not operable with existing assets, including input/output software if applicable; may require new assets to be purchased and manual transfer of input/output information	Operable with user assets but may require adjustments (such as different OS), or there may be limitations to data transfer among input/output programs	Operable with existing user assets without modification and interactions with input/output software require little effort from user
Parameter Space Limitations	Extensive limits to viable solution space	Some limits to viable solution space	No known limitations to viable solution space provided by output
Support for DOE	Minimally supportive of DOE analysis; would require extensive user time	Somewhat supportive of DOE analysis; some features lend themselves to easy data transfer or analysis but requires some additional user effort	Very supportive of DOE analysis - either provides output in format needed for DOE software or contains all capabilities within software package for DOE analysis
Additional Analyses	Limited scope of analysis; might answer only the question at hand, but program office would have no other uses for software	Performs some related analysis but does not cover the realm of possible future analyses	Capable of performing all related analyses in the foreseeable future
Customizability	Software cannot be customized, or can only be customized with funding levels that would not fall within the program budget	Software can be customized with limits, or with some budget/schedule strain	Highly customizable, software customization would likely fall within future time and budget constraints
Maintainability	Software cannot be maintained beyond initial acquisition	Limited maintenance beyond initial acquisition, or maintenance will only be available if funded by user	Owners/programmers will actively maintain software beyond initial acquisition for bug fixes and continued compatibility with supporting environment

Taxonomy Element	Low	Medium	High
Portability	Once acquired, software and related data cannot be transferred to additional assets, users, software packages, or different version of the same software package (e.g., Excel 2010)	Some can be transferred among assets, users, and software packages, but there are some limitations, or with funding for some modification to enhance functionality	Software is entirely and easily transferrable among assets, users, and supporting software
Security	Ensuring security will require extensive user resources beyond current procedures (e.g., software contains classified algorithms that will require new computer labs or higher personnel clearance)	Data security will require some additional user steps, such as a safe for external storage	Data will be secure with software use and will not require any user resources (time or money) beyond current procedures; classification level is determined by inputs

Rating criteria are purposely broad for application across many software types and environments. Decision makers need to determine implications of these attributes as they pertain to specific environments as well as the relative importance of each.

B. FIDELITY

Decision makers must also determine the level of fidelity required from software to support the project adequately. In this case, fidelity is synonymous with validity and is defined as the degree to which a simulation or software package represents analogous real-world scenarios (Department of Defense Systems Management College 2001; Gross et al. 1999; Roza et al. 1999). This is important to the decision makers because programmatic decisions (e.g., system design features, operational limitations) will be based upon the simulation results. Depending on the size of the program, this could result in increased funding and schedule of the program based on the simulation results. The software package must have the confidence of the decision makers so that there is low risk in these programmatic decisions.

It is important to note that fidelity is not a global property; the fidelity determined for a particular application of the software only applies to that situation. Software must be validated for each specific case for which it will be used. If simulation outputs have been confirmed accurate within a limited scope of the possible simulation space, then the software has only been validated under those specific conditions. To accurately apply a fidelity metric to an entire software package as opposed to a simulation or group of simulations, the entire solution space would need to be examined.

Methodologies for determining fidelity vary based on program goals and resources. Often software fidelity is approximated through personal or vicarious experience with little consideration of less familiar software programs. These qualitative fidelity assessments might include shorthand low/medium/high approximation, or perhaps more detail behind software limits and specialties if the assessor is knowledgeable enough to provide information that is more extensive. While these word-of-mouth investigations could yield some valuable generalizations about relative accuracy with various scenario types, they are limited by users' existing knowledge base and prone to bias. These approximations of fidelity can be particularly misleading when program managers overestimate the similarities between past and future analyses, assuming software that was useful for a previous problem will suffice for the current situation.

Ensuring compliance to the theoretical basis of results can also help with fidelity assessments, especially when the relationship between the variables and output has been well established. This is an example of verification, not to be mixed with validation, which would require comparison to real scenarios. Verifying the software would ensure that the relationships among variables is modeled as required.

Another method would involve comparing simulated data to actual performance results, which ideally include data from the system of interest in its operating environment. Resource limitations can render a full-scale operational test impractical to support software choices for preliminary analysis, in which case a controlled testing environment could suffice. A recognized shortcoming of this more affordable option is that fidelity measures would only apply to the conditions of the testing environment.

If new experimental data is not an option, comparisons with historic data might be more practical. While this approach could save time and money, results could be misleading if conditions of historic data will not match the project modeling needs. This is especially true with simulations with varying fidelity metrics among given conditions. Additionally, historic data sets often do not provide all information required to confirm consistent environments. For example, if a seaway spectrum were measured but not the directionality, the data set would provide wave heights and lengths but not directions.

Determining a methodology to assess software packages' fidelity would need to balance program needs with available resources. While expert opinion does not validate software, obtaining it is a small investment to gain useful rule-of-thumb assessments, such as ranges of sea states that work well with the simulations. Verification of the underlying formulas of the software packages can also provide some assurance of the mathematical rigor, but may be tedious and time consuming.

Methods that actually validate software involve comparison to real-world results potentially includes the actual system, full-scale prototype, or scale-model testing. Using the actual system is most accurate, but is not an option for analyses prior to manufacture, and could put the system at risk depending on the nature of the test (e.g., shock test). Full scale prototype testing would provide the second-most accurate results. Unfortunately, it is costly, limits environmental control, and may even limit ability to measure all environmental influences. Scale models allow for more affordable and controlled experimental designs, but results could vary due to scale-effects. Experimental accuracy and cost increase with the size of the scale model, so results from a half size model are likely more representative of system behavior than result from a 1/5 scale model. If program managers decide that scale modeling is the most practical, they may want to design experiments with the largest scale the program can afford.

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III. SOFTWARE PACKAGE COMPARISON

A. METHODOLOGY

To demonstrate cost, schedule, and performance comparison methodologies among software packages, a practical demonstration was developed comparing software that models hydrodynamic loads. Simulations in this demonstration model a UUV and simulate the impacts of operating in a near-surface environment. Out of the many codes available to the government for hydrodynamic load modeling, the following specific software packages were chosen for this study:

1. SMP
2. SUBMOT
3. Aegir
4. LAMP

These four software packages represent different modeling methodologies and mathematical equations. More specifically, the Standard Ship Motion Program (SMP) and SUBMOT are strip theory software, while Aegir and Large Amplitude Motion Program (LAMP) utilize panel methods. Strip theory is based on the concept that a rigid vessel is comprised of many two-dimensional sections that can be used mathematically to calculate its hydrodynamic properties; the analytical process involves decomposing the vessel into individual strips and integrating the effects of the environment on each of the sections to predict the overall hydrodynamic properties of the vessel (Salvesen, Tuck, and Faltinsen 1970).

Panel method software, on the other hand, considers the entire fluid volume, creating panels on the hull and free surface along which the correct boundary conditions are imposed (Hess and Smith 1967). Aegir is similar to traditional panel-method codes but not identical or typical. Aegir is a high order boundary element method based on a non-uniform rational B-spline (NURBS) representation of the solid body and an integral B-spline representation of the fluid flow. Multiple types of the same code were included in this demonstration to illustrate the different ways that the same type of code could be created, for example for graphical user interface (GUI) or disk operating system (DOS) command lines. Even with similarities in underlying theories, software packages within similar theoretical bases can still have very different applications, learning curves, and input/output formats.

The original intent of this study was also to include Numeric Fluid Analysis (NFA) and NavyFOAM for comparison, which are both examples of fluid volume solvers that require the entire fluid domain to be meshed. This is an increased level of complexity above the panel methods. The anticipated results for meshed fluid volume software included higher fidelity metrics with greater cost and schedule impacts, since a high-speed computing environment (HSC) would be required. Due to the delays with the local HSC at NPS and the requirement of becoming proficient with grid generation and volumetric meshing, NFA and NavyFOAM were removed from the scope of this demonstration due to time constraints. Further study of this software would benefit similar cost, schedule, and performance analyses.

1. Determination of Cost and Schedule Metrics

To compare cost and schedule data, the team recorded hours spent pertaining to all aspects of adopting a particular package for program use, including access, training, and simulation. In addition, qualitative ratings were determined based on software capabilities and characteristics. Data for overall implementation feasibility was gathered and compared across most factors depicted in Figure 2. However, trainer hours and procurement costs were not applicable to this comparison. To learn the software and determining qualitative ratings, the team referred to user guides for SMP (Conrad 2005), SUBMOT (Hong 2014), Aegir (Navatek 2016), and LAMP (Leidos Corp 2017).

2. Determination of Fidelity

In order to validate the software packages, no actual systems were available so the most viable option involved utilizing a scale model with the tow tank at the Naval Postgraduate School (NPS). The tow tank size, length of 36 feet, determined scaling size. The vessel and waves needed ample space to model an ocean environment. The objective was to create a controlled experiment directly comparable to the simulated hydrodynamic load predictions that can support an objective analysis of the fidelity of each software package. The experiment was conducted outside of our physical control and was dependent upon those performing the experiment on our behalf.

In order to be effective for programmatic use, validation must cover all conditions that could be of interest. In this particular case, conditions would include forward speed, length to diameter ratio, pitch angle, various relative wave headings, irregular sea ways, nearby vessels, bottom effects, among many others. To illustrate the validation process for this demonstration, the three parameters of interest are depth, wavelength, and wave height.

The software packages are capable of running simulations with conditions outside the three selected parameters of depth, wave height, and wavelength, but those simulations would require a larger set of experimental data. Planning for software validation involves ensuring compatibility between parameter space, scale size, and facilities. For example, testing different headings at forward speeds would require a maneuvering basin rather than a tow tank. Another important planning aspect involves ensuring the parameter space to be validated is manageable, as the testing process for various conditions can very quickly exceed allocated resources.

Ideal experiment practices would also have included more rigorous uncertainty analysis of the experiment results, as the usage of experimental data is dependent upon its inherent uncertainty. This uncertainty can be random or systematic in nature. Thus, a thorough analysis of the uncertainty should be conducted to include the instruments being used for measurement and data collection, environmental induced errors, and experimental noise. One approach involves running approximately 30 trials at a select number of conditions. The uncertainty distribution at those points is then assumed to be consistent across the entire parameter space. This would be sufficient to ascertain inherent uncertainty of the experimental design, providing a range for how much the experiment might deviate from reality. For this demonstration, each experimental measurement point was run two or three times to get an idea of the uncertainty associated with each point. The uncertainty for the force in the z-axis and moment about the y-axis were estimated at +/- 0.15 lbs. and +/- 2.5 in-lbs., respectively.

All aspects of the experiment in the tow tank mimicked the input parameters of the software simulations. In order to produce valid data for comparison, the input data remained static throughout the course of this study, although formatting differences were essential due to differences in each software package. The tow tank and wavemaker for this experiment are pictured in Figure 3.

Figure 3. Tow Tank and Wavemaker at NPS Lab

The tank is capable of regular and irregular wave generation at various wave frequencies and amplitudes. To best suit tank dimensions, the three-dimensional printed model, shown in Figure 4, measured 4x40 inches. The vessel was hollow, made of several interlocking pieces. The parallel mid-body was 36 inches, and the remaining length was comprised of two half hemispheres on either end of the cylinder. No appendages were included.

Figure 4. Printed Vessel in the Tow Tank

Since typical underwater vehicles have length/diameter ratios anywhere from 8:1 to 12:1, a 10:1 ratio was selected for this experiment. Thus, the dimensions are fairly proportionate to the designs for which the software packages are intended.

The experiment design included the following limitations:

- Wave reflection: To prevent wave reflection from altering experiment output, a 12-degree incline with perforations served as a wave-absorbing beach. Previous experience with this method has shown that this wave-absorbing beach is effective for high frequency waves, but less so for low-frequency waves. Wave absorption was sufficient to allow long collection times throughout the trials.

- Finite depth: The depth of the tow tank was 36 inches. Some software packages did not model effects of finite depth, so assumptions derived from inputs were slightly inconsistent.

- Finite width: With a finite width of three feet, the tow tank would cause some wave reflection from the side walls. No mitigating actions were taken for this limitation.

- Experimental noise: The wave maker is attached directly to the tow tank and introduces high frequency vibrations into the tank. These vibrations were picked up by the load cell and contained in the time history data as high frequency noise. The energy content of this noise was minimized by increasing the rigidity of the tow carriage with stiffeners. Since the frequency content was considerably higher than the frequency of interest, this noise was easily identified and removed during the experimental data analysis process.

Despite these recognized inconsistencies with experimental conditions and software inputs, the experimental results were the best option for fidelity assessments within resource constraints.

Tow tank run conditions served as inputs to each of the software packages. Afterwards, experimental data from the tow tank served as the comparison points with all simulation results to determine relative fidelity. Validation experiments typically occur during software simulation studies to ensure one tests identical conditions, allowing for adjustments to the experiment if necessary. However, we ran these tests separately, which caused some discrepancies between the simulation data ranges and the available experimental data. Thus, the ranges of frequencies are not identical among data sets displayed in Section G. The experimental scenarios included testing two depths using constant amplitude, single frequency waves of two different amplitudes and various frequencies. Conditions are summarized in Table 2.

Table 2. Summary of Experiment Conditions

Parameter	Value	Unit
model diameter	4	inches
model length	40	inches
model centerline depths	4 and 8	inches
model pitch angle	0	degrees
model speed	0	inches/sec
relative wave heading	180 (head seas)	degrees
water depth	36	inches
wave amplitudes	0.5 and 1.0	inches
wave frequencies	1.75, 1.43, 1.24, 1.11, 1.01, 0.94, 0.87, 0.82	Hz
sampling rate	50	Hz
sampling duration	60	seconds

We made no attempt at a single fidelity metric, since codes can be better/worse in various portions of the parameter space. Rather, this research team calculated percent error for each experimental condition at each wavelength. Since results varied between the two experiments run for each set of environmental conditions, "actual" results for percent error calculations were assumed equal to data point on the trend line resulting from experimental data.

B. STANDARD SHIP MOTION PROGRAM

1. Usage: Code Access

SMP is an example of strip theory software and was developed at Naval Surface Warfare Center, Carderock Division (NSWCCD). Although another software package used in this study is also based on strip theory, an important aspect to point out for SMP is that it is an example of repurposing an existing software package. It was originally developed for simulating surface ship motions, but it was believed that it could also be used to predict underwater vehicle loads. SMP is managed by the developers at NSWCCD.

To gain access to the software, this team contacted the custodian at NSWCCD , and obtained a file transfer via Army Aviation and Missile Research Development and Engineering Center (AMRDEC) safe access file exchange (SAFE) three business days later. The relatively quick turnaround during this study is not necessarily constant as it is dependent upon the workload of a particular custodian. Since intellectual ownership is within the Department of Defense (DOD), there were no procurement costs or limitations for use within the organization. Man-hours involved for the file request were negligible.

Installation time was negligible in this case, as it was limited to saving the binary file on the recipient's computer. Additionally, there were no libraries or auxiliary files required since it is a stand-alone executable program. This also allows the user to forego the typical Windows installation process associated with installing software. A recognized caveat to installation is that the user would either need write privileges on the hard drive, or require prior enterprise-level approval. This would cause schedule delays within some systems such as Navy/Marine Corp Intranet (NMCI).

Additional software was not required to run SMP. The Operating System (OS) used for this particular software package was Windows 7, and the file was compiled in a Windows environment. There is also potential for compatibility with other systems if compiled for a specific OS. As a result, no additional time or costs were incurred for the supporting environment.

1. Usage: Inputs

In order to perform calculations of hydrodynamic loads on a vessel, SMP requires a specifically formatted input file. The input file extension is .”inp” and contains the data necessary for calculations. The necessary data includes detailed physical dimensions of the vessel, physical units, load particulars, and hull lines that form the various sections of the vessel. For this study, we developed the input file for SMP, shown in Appendix A, in accordance with *SMP95: Standard Ship Motion Program User Manual*. In addition to the input file, the test team was required to modify an existing batch file supplied with the software. This .bat file handled the auxiliary file creation during SMP execution. This file points to the directory of the SMP executable and directs the .inp file to be designated as an argument.

In order to develop the correct geometry that matched the vessel used in the experiment, the team utilized two methods to calculate the hull lines section of the input file. A routine was developed with MATLAB and as a means of verification of the dimensions, an Excel spreadsheet was configured to perform calculation of the hull dimensions. This process was complex for multiple reasons. First, the terms in the documentation and variable designations require some translation; for example, “VKDES” as design speed in knots is not an intuitive association. The user was required to interpret these terms in order to develop the geometry correctly. Next, the coordinate system was unique. The software requires user inputs for the vessel in terms of stations, or hull sections, which are laid out in a very specific order. Last, the input files required very specific formatting and the documentation is provided in terms of the FORTRAN programming language.

Another aspect of interest is the fact that SMP does not offer much flexibility for different wave frequencies. The frequencies simulated are static as they are hard-coded into the software. Wave headings are static as well, offered in increments of 15 degrees spanning a range from zero to 180 degrees.

An alternate method of calculating the hull lines for the input file is possible with Rhinoceros (Rhino), which is a software program with capabilities to create vessel geometry, and the Photon plugin, which can export the data in the required format. This makes SMP more complex than other strip theory programs that simply require the radius of the body of revolution, but also adds flexibility.

After completing the preparatory work of generating the necessary hull geometry, the actual .inp file was created. The .inp file was viewed and edited in Notepad because it is a text file. Of the 19 total record sets in the .inp file, the team was primarily concerned with record sets one through six. Record sets seven and beyond were left as zero values because they are related to hull features not present on a cylindrical UUV with dome-shaped end caps. Record set one was populated with the title which was used to name the output file and show specifics related to the simulated UUV. Specifics in record set one include the name of the vessel, length, and diameter. Record set two was left to the default in the example .inp file provided by the developer. Record set three was used to set the physical units to feet, the mass density of water, gravity, and kinematic viscosity. In record set four, we set the input values for beam, draft, UUV length, and displacement. At record set five, the team set the values for free-surface correction, distance from the keel to the center of gravity, pitch, roll, and yaw. Record set six was used to configure the three-dimensional geometry of the vessel. This was set by designating stations in the x direction and by station offsets in both the y and z directions. For SMP coordinates, x is along the longitudinal axis of the vessel, y is perpendicular horizontally, and z is perpendicular vertically.

The end user of SMP is able to have many different input files with which to perform hydrodynamic load simulations because the desired .”inp” file is designated in the form of an argument at runtime.

2. Usage: Training

A significant amount of time is required for a new user to become proficient with SMP. There are three unique phases when running simulations with SMP, and each requires training. The phases are: developing the geometry, programming the input file and batch file, and analyzing the output data.

Developing the geometry can be done in several ways. As mentioned in the previous section, for this study the team used MATLAB and Excel to calculate the y and z-offsets for 20 different stations spanning the length of the vessel. To do this, each of the nose cones were divided into five stations, and the body of the vessel was divided into 10 stations. The stations were then normalized to fit the actual length of the vessel in feet. For each station 10 y and z-coordinates were calculated. At 20-degree intervals, ranging from zero to 180 degrees, the y-coordinates were calculated using the expression $r\left(\sin(radians(\theta))\right)$, where r is the radius of the body in feet and θ is the angle between the y-axis the segment between the coordinate location and the intersection of the x-axis along the y-z plane. The z-coordinates were calculated with the expression $-r\left(\cos(radians(\theta))\right)+(L_{nc})$, where L_{nc} is equal to the radius (r) in feet.

Programming the input file required research of the available documentation and familiarization with FORTRAN formatting. FORTRAN formatting in the .inp file required the team to place the correct amount of spaces between data points to properly program the file. The Windows batchfile was a different format that required the user to learn a specific syntax for programming. The batch file was short, and resources for the syntax are abundant. Programming the batch file required little time to learn.

The final phase was to take the data from the output file and conduct the analysis. For this, the team first had to determine which data points were useful. As shown in Appendix E, SMP creates a large amount of output data. For this study, the team was interested in the data in a single table that showed the results of the simulation for a vessel with a velocity of zero and a heading of 180 degrees. The data was in text format and contained many undesirable spaces between each of the columns. In order to manipulate this data into a format useful for analysis, and to make the process efficient, the team decided to automate the extraction. A Python script was written to open the .out file, copy the data from the desired table into an array, remove spaces between data in excess of one space, replace the remaining spaces with a comma, and then save the contents of the array to a comma separated values (CSV) file. This task did not take a significant amount of time because the user was an experienced programmer. This could be an area that requires a noteworthy amount of training for a less experienced user. Note that Python is not the only way to perform this task; there are many different options. Automated data extraction is recommended.

The time spent during this study to become an informed SMP end user was approximately 16 hours. After learning how to operate the software through each of the phases, a process was developed and the learning curve for training additional users was significantly reduced.

3. Usage: Simulation

For the simple vessel geometry used for this study, SMP required less than 10 seconds to perform the entire sequence of calculations and predict the hydrodynamic forces on the vessel. The end user only needed a Windows environment, the compiled binaries file, a batch file, and a valid input file to run the software.

4. Usage: Post-processing

SMP generates simulated hydrodynamic load data in a fixed-format file that provides the amplitude and phase of the load signal. The data is presented in tables based on velocity and wave heading. By default, the velocity ranges from zero to three knots in increments of one and the heading ranges from zero to 180 degrees in increments of 15 degrees. Minimal manipulation of the data is required since the values are already in a usable format. The data manipulation consists of copying the values and formatting them as desired for graphing or other presentation methods.

There was an important discovery while performing post-simulation data analysis. The team discovered an internal limit with the computational algorithm that drives SMP. This internal limit does not allow the geometry to be set below the calm water surface, thus preventing simulations for submerged vessels. This internal check was unknown to the SMEs who had believed the code should be able to be used for a submerged body. The results herein, therefore, are computed with a static value for draft, which is used to calculate depth of the vessel. We informed the custodians of SMP at NSWCCD of this finding and they are now working to determine the root cause. For this reason, we did not include SMP with the other software codes in the fidelity comparison within this report.

An example SMP output file is in Appendix E.

5. Qualitative Ratings

Table 3 shows the qualitative ratings for SMP attributes.

Table 3. SMP Qualitative Ratings

Characteristics		Rating	Rationale
Usage	Output Readability	Medium	Requires additional calculations to produce dimensional force
	User Support	Medium	Limited SME support available
Technical Aspects	Interoperability	Medium	Compatible with software typical of a Windows environment
	Parameter Space Limitations	Medium	Ability to configure a wide range of values vessel parameters but the wave frequencies are static
	Support for DOE	Medium	Wide parameter space allows input of DOE values for simulation and comparison
Life-cycle Suitability	Advanced Features	Low	Ability to try different wave environments and hull designs but wave frequencies are static
	Customizability	Low	Users have no access to source
	Maintainability	Low	Software is under the control of a custodian at NSWCCD
	Portability	Low	Only compatible with Windows
	Security	High	Nothing inherently classified in software, security protocol affected by content, not software use

C. SUBMOT

1. Usage: Code Access

SUBMOT was also created at NSWCCD. Similar to SMP, initial request through the custodian led to an AMRDEC SAFE file exchange. A custodian at NSWCCD, who is also the only SME, manages the software. Time between request and file transfer was 35 business days, as the code was saved on a stand-alone computer and proper permissions were required for transfer. Man-hours for the initial request were negligible, and no procurement cost was involved.

Installation time was negligible, as it involved saving a binary file on the computer with write permissions on the hard drive. A Linux OS was required for SUBMOT since the developer compiled the software using Linux. For this study, a Virtual Machine (VM) was configured with Ubuntu version 16.04, the current release. To facilitate the creation of a VM, we used a VMware Workstation. The team already owned a valid license for this software, but if virtualization is the chosen method for running SUBMOT, there may or may not be a license fee associated. VMware is not freeware, but there are other options, such as Virtual Box by Oracle, that are. Since the file was not compiled as stand-alone executable software, Intel FORTRAN libraries needed to be downloaded as well. The Intel FORTRAN libraries are not free, but for this study, the team was able to obtain them at no cost under an educational license. Time for installation was negligible.

The SUBMOT user for this study was very experienced in virtualization and various aspects of creating and configuring VMs. A less experienced user may require a substantial amount of time to install the OS, required libraries, and OS variables required to operate the software.

For SUBMOT, there is potential for Windows compatibility, but compiling using Windows with Intel FORTRAN compiler has previously resulted in numerous errors. Modifications necessary for compilation in a Windows environment would potentially cause schedule delays.

2. Usage: Inputs

To create an input file for SUBMOT, the user has to calculate manually the geometry of the vessel and enter the incremental values for the three-dimensional coordinate system into the input file. This can be accomplished with various software applications. For this study, Microsoft Excel was used. This process was relatively simple considering SUBMOT only requires the user to enter the radius of the body of revolution at various x-coordinates (the x-axis runs parallel to the vessel's major axis). Since the

UUV used in the experiment and simulations for this study was a smooth cylinder, it made sense to use the body of revolution geometry. In contrast to SMP, this made it much simpler to determine the geometry but also less flexible. Since SUBMOT has the ability to accept a non-body of revolution geometry, the input is very similar to SMP.

Once the geometry was calculated, the rest of the input file was populated. A SUBMOT input file, extension .tst, accepts entries for 37 different records. For this study, the team was only concerned with records one through 10. Record one was used to describe the simulated vessel as user information. Record two contained data for the number of stations along the x-axis of the vessel, number of stations for which added mass are computed, the number of wave frequencies to be used during the simulation and values for gravity and the mass density of water. Record set three was where the values of each desired wave frequency were defined. These frequencies were calculated specifically to traverse a range of non-dimensional wavelength values (designated as λ/L, where λ equals wavelength and L equals vessel length) ranging from 0.5 to 5.0. First, the period in seconds was calculated with the expression $\sqrt{\frac{2\pi\lambda}{g}}$, where λ equals wavelength and g equals the gravitational constant. Next the radians/second were calculated with the expression $\frac{2\pi}{T}$, where T equals time in seconds. We used this process to populate all 46 frequencies into record set three. Record set four set the number of wave headings and wave speeds to one, set the option for body of revolution, and the time step to one. Record set five had the wave heading to 180 degrees. Record set six was populated with input values for the pitch angle and the location of the axis of symmetry for the submerged body. We used record set seven to set the sectional forces computed for the stations along the x-axis. Record set eight was populated with the length of the vessel, beam, draft, length for non-dimensionalization, and the radii of gyration for yaw, pitch, and roll. Record set nine was used to configure the location of each station with respect to the origin from stern to bow and record set ten was set to the vessel displacement in long tons.

Appendix B shows a sample input file.

3. Usage: Training

To become proficient with SUBMOT, a considerable amount of time is required. Each of the various tasks required to run SUBMOT involves some form of training. Prior to developing an input file and running the software, the configuration of a Linux environment, installation of necessary libraries, and configuration of the OS environmental variables all required specialized skills. Once the environment was configured, the user determined the geometry for the simulated vessel with an Excel spreadsheet.

Developing the input file required the user to reference the available documentation quite often to interpret the terminology. For instance, the designation of "XBE" as wave heading is not necessarily intuitive. Translation was necessary to ensure we placed all of the variables in the correct location. Additionally, the SUBMOT input file is formatted in FORTRAN and as is the documentation. One interesting observation the team made when working with SUBMOT was that over time to support changing requirements, there are now multiple similar input parameters, all of which need to be changed instead of just one. This required extra detail when setting the simulation depth in three locations in contrast to SMP, which only required data entries in a single location.

Another area that required training for the user was the Linux command line interface syntax. Installing the Intel FORTRAN libraries, setting an environmental variable that tells the OS to use the libraries, and traversing the file structure were common tasks associated with using SUBMOT. For this study, the user was very experienced in the Linux OS, but it would have been a significant area for training if a less experienced user were designated. To highlight the need for use of the Linux command line interface, the commands required to designate the use of the Intel FORTRAN library when running SUBMOT, navigate to the appropriate directory, and execute SUBMOT are shown in Figure 5.

```
:~$ export LD_LIBRARY_PATH=/home/NPS/compilers/linux/compiler/lib/intel64_lin
:~$ cd /home/submot
:~$ ./SUBMOT.exe
```

Figure 5. SUBMOT Commands for Intel FORTRAN library

The time spent for this study to become an informed SUBMOT end user was approximately 17.3 hours. After learning how to operate the software and develop input files, the learning curve for training additional users is significantly reduced.

4. Usage: Simulation

For the simple vessel simulated for this study, SUBMOT required less than eight seconds to perform the entire sequence of calculations required to predict hydrodynamic forces on a vessel. It is reasonable to suspect that the run time may slightly increase with a more complex hull geometry. With some Linux savvy and a valid input file, the software is simple to run.

5. Usage: Post-processing

The data in the SUBMOT output file required some formatting and additional calculations to determine the actual load on the vessel in the simulation. What was provided to the user in the output file was non-dimensional force and moment magnitude per wave amplitude along with the phase of the loads. To extract the desired data from the output file efficiently and to reduce the risk of human induced data transfer error, the end user automated the process with a Python script.

The automated script extracted the data by opening the .PR1 output file, storing the data in the “E. F & M” table in an array, removing the unnecessary spaces, replacing the remaining spaces with a comma, and dumping the contents of the array into a CSV file. The values were put into a spreadsheet and calculations were performed to obtain the dimensional force.

Appendix F shows an example SUBMOT output file.

6. Qualitative Ratings

Table 4 shows the qualitative ratings for SUBMOT.

Table 4. SUBMOT Qualitative Ratings

Characteristics		Rating	Rationale
Usage	Output Readability	Low	Requires additional calculations to produce dimensional force
	User Support	Low	There is currently one SME
Technical Aspects	Interoperability	Low	Unique input and output file format and the data requires additional calculations to obtain dimensional force
	Parameter Space Limitations	Medium	Ability to specify a wide range of wave frequencies but the amplitude is not a parameter because it is based on strip theory
	Support for DOE	Medium	Ability to specify a wide range of wave frequencies
Life-cycle Suitability	Advanced Features	Medium	Regular and irregular wave environments available for simulation
	Customizability	Low	Users have no access to source code
	Maintainability	Low	Only one person maintains the code, users have no access to source
	Portability	Low	Only compatible with Linux environments and has dependencies on specific libraries
	Security	High	Nothing inherently classified in software, security protocol affected by content, not software use

D. AEGIR

1. Usage: Code Access

Navatek Ltd. is a company that specializes in complex computational fluid dynamics simulation and design as well as marine systems engineering and integration. Navatek created the software package Aegir and graphical user interface (GUI) Navasim.

Aegir is similar to traditional panel-method codes but not identical or typical. Aegir is a high order boundary element method based on a non-uniform rational B-spline (NURBS) representation of the solid body and an integral B-spline representation of the fluid flow. The usage of Aegir in this report was through the Navasim GUI and therefore this assessment is on both products. We gained access to Aegir through a NSWCCD point of contact. Government use is free, and the transfer of files occurred via DropBox the same day of request. Dropbox is a free, web-based file transfer and storage service. Man-hours to request access were negligible.

The operating system for Aegir use is Windows and Linux, which was compatible with the computers available. The installation time for Aegir is zero. Separate input file creation for Aegir is possible without the Navasim GUI and executed through the command line. The Navasim GUI is compatible with a Windows OS and installs with an installer wizard, with a user time of about 10 minutes from start to finish. Administrative rights to install software is required, so some organizations may experience schedule delays waiting for information technology (IT) employees to perform the installation.

2. Usage: Inputs

Aegir is the hydrodynamic analysis software code. Navasim provides the user with a GUI. The user provides information into the Navasim GUI and saves the file. This creates a namelist input file, which then executed by Aegir. Appendix C provides an example namelist file. The first tab encountered by the user is the Master Input Tab. The user selects either a steady or a time-domain solution. A time-domain solution is required for a wave environment.

The only required supporting software is Rhino three-dimensional modeling software. Rhino creates a non-uniform rational B-spline (NURBS) surface geometry open source three-dimensional modeling (3dm) file. The surface geometry file did not incur any additional procurement costs since Rhino was already accessible due to anticipated input requirements. Access to Rhino was not immediate in that it required installation onto the NPS computers used as part of the project. This took several days in queue for IT personnel to complete the installation.

A 3dm geometry created in the Rhino modeling software uploads into the interface. Aegir requires specific requirements of the geometry, explained in the training section. The Master Input Tab, shown in Figure 6, is the tab for the user to provide information regarding the physical constraints and velocity of the model.

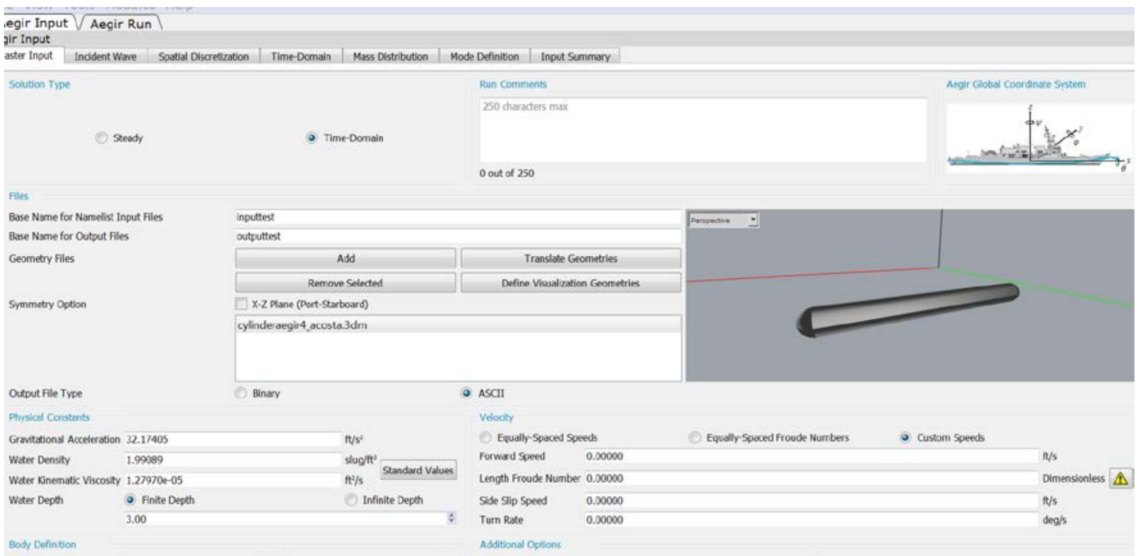

Figure 6. Aegir Master Input Tab

The next tab to be completed is the Incident Wave Tab, shown in Figure 7, which allows the user to define the wave environment run in the simulation.

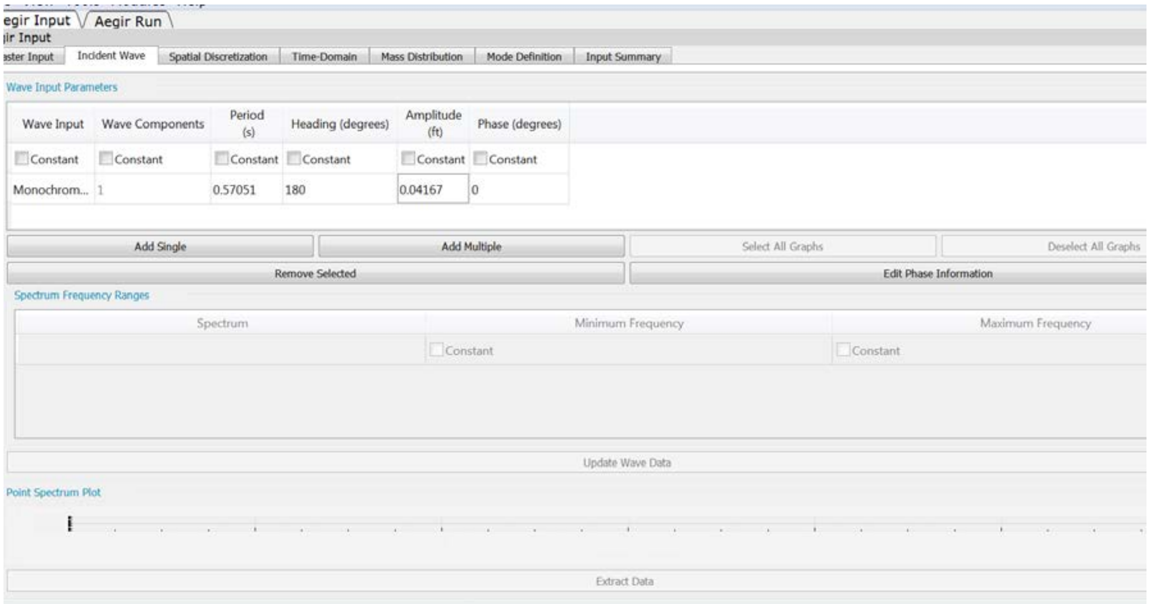

Figure 7. Aegir Incident Wave Tab

Next is the Spatial Discretization Tab, shown in Figure 8, which allows the user to define the panel size of the free surface as well as the geometry of the vessel. The geometry used in our analysis simulated an unmanned underwater vehicle. Using a small panel size creates a finer mesh on the free surface and geometry and more accurate solution. However, the software will run longer.

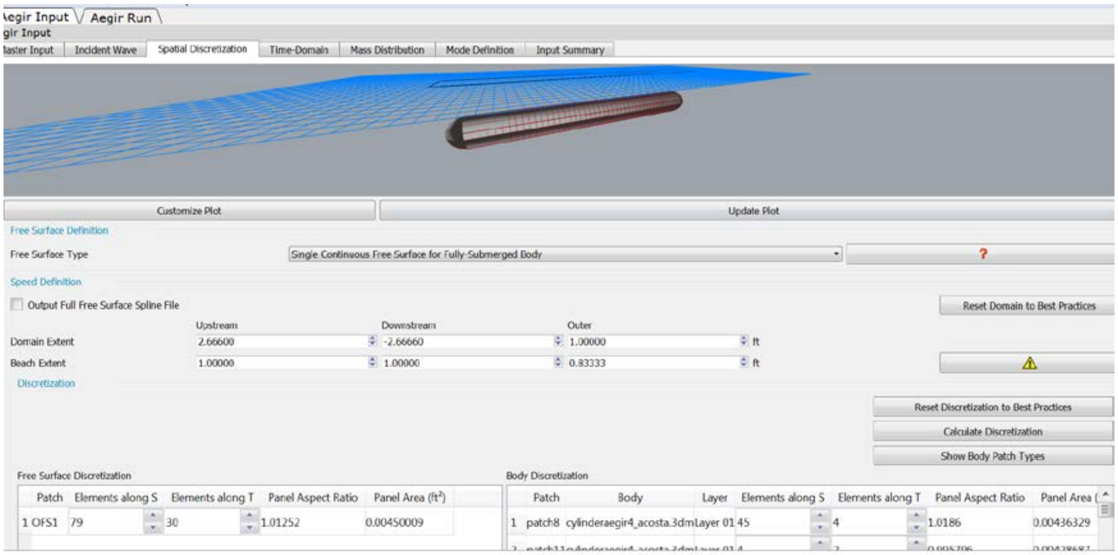

Figure 8. Aegir Spatial Discretization Tab

The Mass Distribution Tab, shown in Figure 9, is next, which allows the user to determine the mass properties of the geometry.

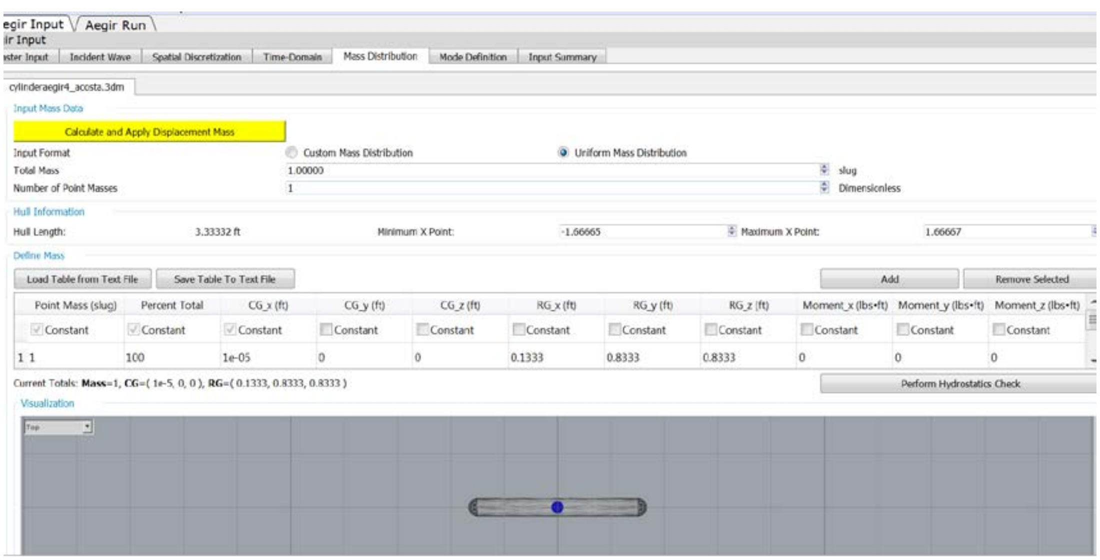

Figure 9. Aegir Mass Distribution Tab

The last tab completed by the user is the Mode Definition Tab, shown in Figure 10, which allows the user to select the movement of the geometry body during the simulation.

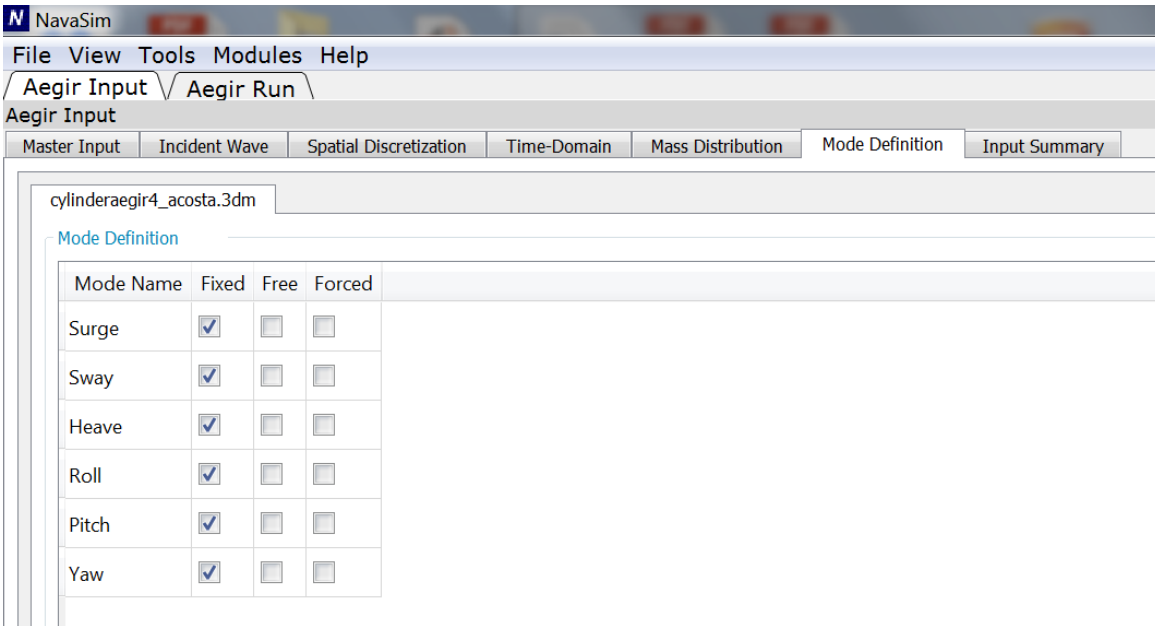

Figure 10. Aegir Mode Definition Tab

3. Usage: Training

Aegir has multiple user training documents to help troubleshoot the software. The document to start with for any new user is the *Aegir User Guide* (Navatek 2016). This document was instrumental in ensuring Aegir would accept the geometry created in Rhino. During the upload of the geometry into the Navasim GUI, the software analyzes it for certain requirements that Aegir has for proper geometry construction. Display of error codes then occurs and the *Aegir User Guide* provides descriptions of the codes.

The geometry compliance of Aegir was the single largest portion of the learning curve to overcome before running the software. Aegir requires the geometry created as a wire-frame structure and a mesh patch created along the surface of the geometry. The EdgeSrf command in Rhino created the correct mesh. There are various methods to creating patches in Rhino but the EdgeSrf command usage occurred due to its usage in the *Aegir User Guide*. Each patch must have a unique name. The patches must have four sides. The vector of the patch must also be oriented in the geometry file correctly. The u-vector should point in the direction of the fluid flow. The normal vector should point into the geometry. The v-vector should follow the right-hand rule (describing the orientation of vectors in three-dimensions) according to the directions of the other vectors.

The *Aegir Input Module User Guide* is the training document that describes the Aegir Input User GUI. This training document details each of the input tabs required to run the simulation. It includes all of the possible input selections and describes those selections in a clear and descriptive manner so that the user can understand the selection.

Navatek also supplies the user with multiple examples including steady and time-domain solutions. It provides a tutorial detailing the use of both the steady option as well as the time-domain option through a systematic procedure. Various documentation provided details best practices, validation and verification, the theory that Aegir is based upon, and papers and theses related to Aegir. We did not use this documentation, but it could be helpful in a more extensive case study.

4. Usage: Simulation

Proper configuration of the input GUI makes Aegir seamless to execute. The Input Summary Tab in the input GUI allows the user to save the input file to a folder. Saving of the input file allows the file import into the Run Module of Aegir. The duration of the run time of Aegir depends upon the patch size of the free surface and geometry and the time step and simulation duration. Aegir typically ran from 10 to 30 minutes per run for the simple geometry chosen in the experiment. However, geometries that are more complex may take more computing time.

Navatek suggests completion of temporal convergence, domain convergence and spatial convergence tests (in that order) before executing the software package. The completion of a spatial convergence test occurred in our study. The use of best practices values eliminated the usage of the other convergence tests. The spatial convergence test determined the resolution required for accurate results while minimizing the run time of the software to the most extent. Three panel resolution runs were completed, and the team selected a panel size from the results. Recording a script of input values for each run eased the data transfer process.

5. Usage: Post-processing

Aegir provides an output file detailing the force and moment results. Appendix G provides a portion of an output file. One can load the file into the user GUI by using the steady or time-domain output modules, depending on which solution chosen originally. The output user GUI allows the user to select which data to display and graphs the corresponding data. Figure 11 provides an example of the GUI.

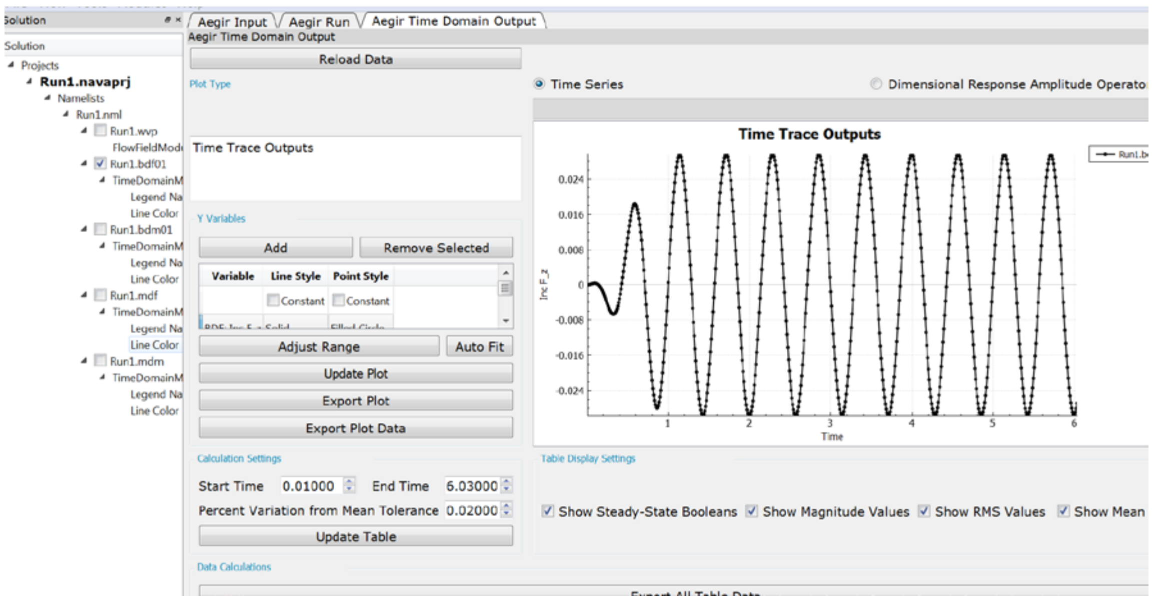

Figure 11. Aegir Time Domain Output GUI

It also allows data exportation for more analysis. Post processing of the data had MATLAB code parse the output file for the hydrodynamic forces and moments at each recorded time and plot them. Analyzing the graph of the force and moment time histories completed by a MATLAB routine determined the amplitude of each during steady state conditions. Subtracting the maximum and minimum steady-state values of the time histories and dividing by two, due to its sinusoidal property, accomplished this analysis. This same routine was required of the LAMP results as well located in section E5.

6. Qualitative Ratings

Table 5 shows the qualitative ratings for Aegir attributes.

Table 5. Aegir Qualitative Ratings

Characteristics		Rating	Rationale
Usage	Output Readability	High	The data can be loaded directly into the user GUI and exported for a more detailed analysis. The export file arranges each row of data to a time step.
	User Support	High	Navatek provides numerous training documents and has SMEs available for support
Technical Aspects	Interoperability	Low	Aegir requires a Rhino 3dm file for its geometry.
	Parameter Space Limitations	High	Aegir has no known limitations to the parameter space
	Support for DOE	Medium	Aegir allows for multiple values to be iterated on multiple runs if desired by the user
Life-cycle Suitability	Additional Analyses	High	Aegir allows for multiple advanced problem types including elastic modes and slamming, global loads, linear radiation, linear diffraction, and wave energy converter
	Customizability	High	Aegir is freely licensed for government, academic, and commercial uses. Availability of source code is given on request. The Navasim GUI has customization through script and macro commands and visual programming.
	Maintainability	Medium	Aegir is maintained by Navatek and updates it quarterly but can support changes on request.
	Portability	Low/ Medium	Navasim GUI requires operating on Windows computers. This rating for Aegir would be medium due to it running on Windows and Linux OS.
	Security	High	Nothing inherently classified in software, security protocol affected by content, not software use

E. LAMP

1. Usage: Code Access

Although software is owned by Leidos, the Navy is granted "Government Purpose Rights" to the code, which includes distribution to federal employees and contractors for government work at no charge. Request time was negligible. However, time between initial request and AMRDEC SAFE file exchange was 56 business days (13 business days after in-person follow-up request). Because the code is maintained by an individual with a varying workload, the 56 days is representative of only one instance, and may differ on any subsequent request.

Installation required saving the binaries onto a computer with user write permissions, resulting in negligible man-hours and schedule impact. Operating system was Windows 7, which was compatible with the computers available.

2. Usage: Inputs

Running the LAMP executable file required a written input file with a .in file extension which enables the user to specify 33 line items for use in the code. The 33 line items are termed data sets, and they range from file title and computer directory locations to detailed input variables such as time step size, vessel headings and velocities, and environmental conditions including wavelength and wave amplitudes. An example of a LAMP input file is available in Appendix D.

Data set four calls for a vessel geometry source file in the form of ."lmp." The .lmp file is a viewable ASCII file. Two numbers, separated by a space, are the first relevant data and are on the top line identifying the number of stations and waterlines that define the vessel. There are 55 stations defined in the geometry file used in the baseline simulation, meaning that there are 55 points along the x-axis from bow to stern of the vessel. Additionally, 10 waterlines are present at each station listed from keel to sheer, or from bottom to top. Figure 12 illustrates the physical geometry generated from the file. Only half of the geometry is created because LAMP assumes symmetry and accounts for this in its simulations.

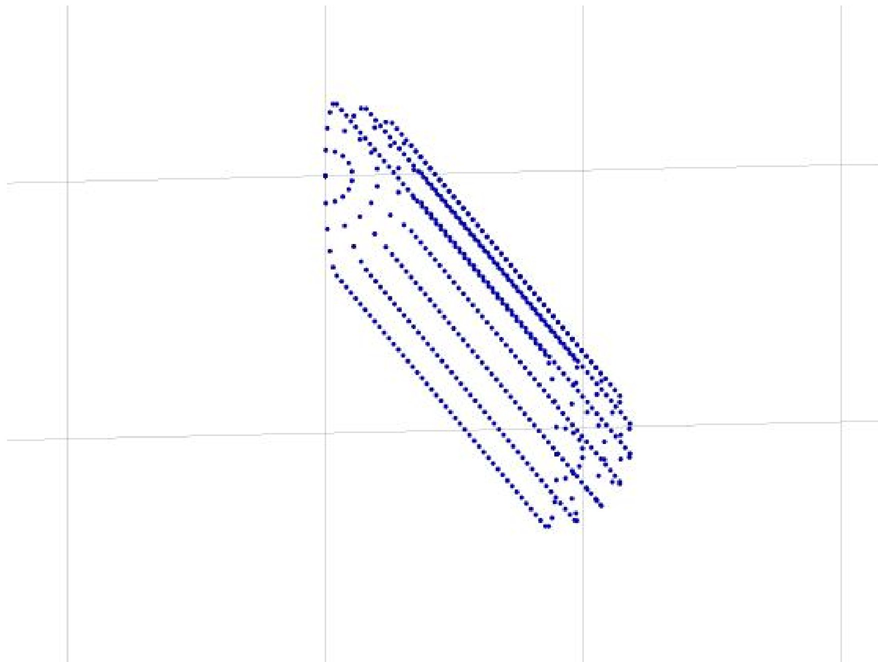

Figure 12. Physical Vessel Geometry Generated with MATLAB

Under the top line of the geometry file with the total stations and waterlines are the individual data points making up the geometry. Each row in the file represents a point in the global coordinate system with x, y, and z coordinates, and in summation, the entirety of the vessel displays as a mesh. Rhino can be used to create the geometry and export its mesh into the proper .lmp format required by LAMP using the Photon plug-in. Though this process did take considerable time, it was only because the user was new to the software; it would have taken much longer to generate an acceptable and accurate geometry file without support to aid in file generation. This support came in the form of a MATLAB routine written specifically to generate a .lmp geometry file with dimensions, number of stations, and number of waterlines as input.

Once a user creates and saves the geometry file to an appropriate directory, the PRELAMP executable file can be opened in DOS (command prompt) and through the appropriate commands, generate the input file. Even though the geometry file is its own entity saved to the computer, the input file references it in data set 4, so therefore it is embedded and does not require direct manipulation in the LAMP process.

Data set 13 specifies the motion type of the vessel, forced sinusoidal in this case. It is valid to specify the amplitude of the forced sinusoidal motion as zero, which we did in our case to mimic a fixed captive model test. This allows the software code to keep the vessel fixed in its simulation, measuring the effects of the environmental conditions surrounding it.

Data set 14 specifies the number and size of time steps in the simulation. This allows the user to control how long the simulation runs and to be able to measure results in the desired increments of time. For a simulation of 1,000 time steps and 0.009 second increments, a total simulation time of nine seconds was captured. Since our wave periods of interest were approximately one second, this total simulation time allowed for a wave amplitude ramp-up during the first five seconds while still providing us the ability to capture about five steady-state cycles.

Data sets 16 and 17 allow the user to identify the ships initial position and velocity in the user-defined dimensions. In our case, the vessel starts at origin (0, 0, 0) and is stationary (velocity equal to 0).

Data set 21 describes the incident wave characteristics and represents the defining environmental conditions for the simulation. Wavelength, amplitude, and relative wave heading are considered. The non-dimensional wavelengths of interest correspond to physical wavelengths ranging from 1.667 to 11.667 feet, and with deep-water linear wave theory, frequency can be determined and input in the form of radians per second. Head seas are assumed for our simulations, resulting in a wave direction of 180 degrees in the LAMP input file.

3. Usage: Training

A considerable amount of time is necessary for any individual not already familiar with LAMP to become proficient in its use. There is more than sufficient literature available to the user to become modestly capable, but there is one thing in particular that underscores running the LAMP family of executable files: familiarity with command prompt methods. PRELAMP, LAMP, and LAMPOST (the post-processing executable designed to assist the user in gaining valuable information from the output files) all require a DOS operating environment to function. Figure 13 illustrates this working environment.

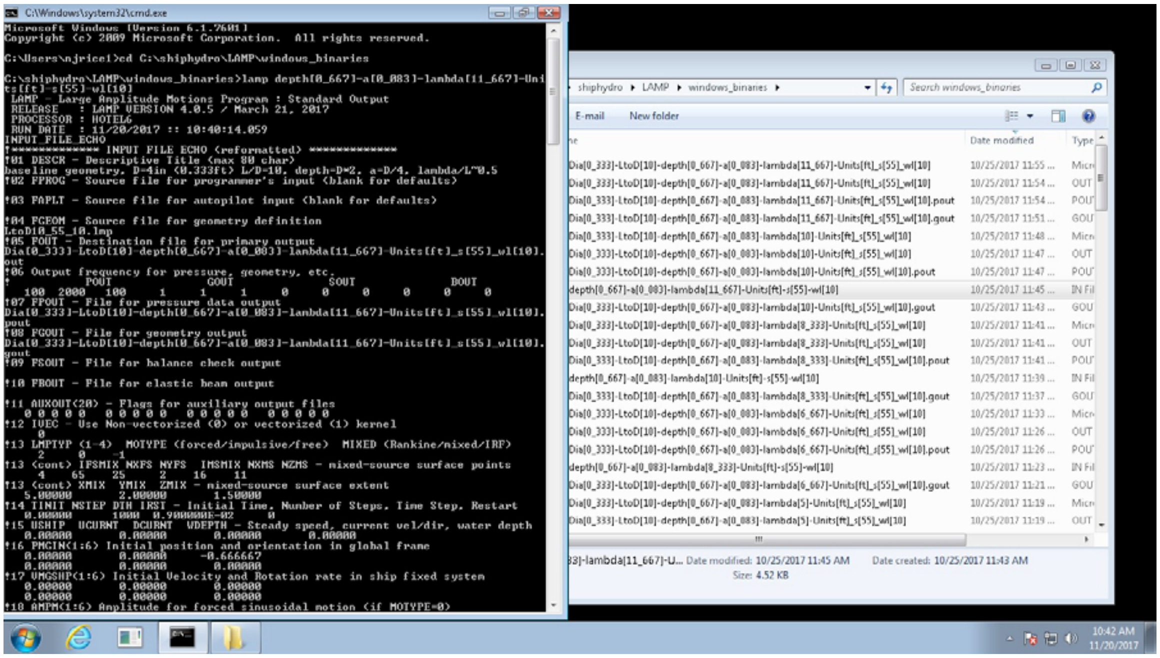

Figure 13. Command Line Interface for Running LAMP

The user must possess some basic knowledge of how to navigate the directories to be successful with LAMP. There are only a handful of commands actually necessary, but a core understanding of command line prompts is essential. Change directory,”CD,” allows the user to navigate to a particular directory- in this case the location of the LAMP executables. “Call” simply activates, or opens, the file in question, similar to double clicking in windows. “LAMP” runs the program executable when all preliminary requirements are met. From first exposure of command line prompt, it took approximately two hours of hands-on learning to become comfortable with the process.

The LAMP program itself is fairly intuitive, with command prompts asking what the user wishes to accomplish by having the different options listed and requesting user feedback by entering the list number followed by the enter, or return key. PRELAMP and LAMPOST are identical in this regard. However, knowing which list item to enter and what that item will accomplish requires having a working knowledge of the code. There is a fine balance between reading the literature and experimenting in the code, as neither is an efficient means by itself to become proficient. Reading the literature for the LAMP family of code is both rewarding and cumbersome, as it enlightens the reader with knowledge of the inner workings yet fails to address basic ordering and nomenclature. To obtain a minimal proficiency in working with the software code, five to 10 hours of reading through the various literature documents is recommended. After five hours, it can be reasonably assumed that the user would know where to find the information needed, and after 10 hours a more in-depth (if only slight more so) understanding of the code can be gained. Although 10 hours may grant an individual greater insight, each data set in the input file requires readdressing the topic through reading. In order to get to the point that any data was generated, over 20 hours of combined reading and hands-on experimenting was required.

Rhino (version 5) was the geometry support tool discussed above. This tool did not have as thorough of supporting literature as LAMP itself, and therefore a majority of the training was via hands-on experimenting. Attempting to create a geometric shape proved difficult, as joining the multiple shapes- including a 36-inch long cylinder and two 2-inch end caps on either end for a total length of 40 inches- together to create one surface was unrealistic to judge with the human eye. In addition to the Rhino program difficulty, saving a file compatible with LAMP was an obstacle. There was no organic ability within Rhino to save the geometry file as .”lmp” and therefore further research was required on the Photon plugin, which made it possible to export the geometry to the appropriate format.

Although the geometry file was continually progressing and more time would have resulted in a final product, help was required via a MATLAB routine previously created to obtain the proper file. The time spent learning the program and plug-in to this point in the process exceeded 17 hours.

4. Usage: Simulation

Once the geometry and input files were completed, setting up LAMP to run the simulation took a negligible amount of time. The command prompt environment only required calling the input file, and this file references the geometry file internally so time required to initiate the simulation is negligible.

As previously mentioned, LAMP uses panel method simulations to provide relevant hydrodynamic data. The two types of panels used are geometry panels of the vessel body and panels of the free surface of water in the direct vicinity (above) of the vessel. The size of each of these types of panels should be comparable to one another in order to ensure smooth, or fluid, interaction between the two. However, selecting a panel size too small will provide accurate results but at the price of extended simulation run times. Panels too large run the risk of missing valuable data potentially captured had additional panels been used. Therefore, using panels that are too large reduces accuracy. Comparing the various simulation time and panel size parameters to determine the most accurate results at the lowest resolution (to minimize the simulation run time) could be accomplished simply by altering variables within the input file and MATLAB routine, and therefore the time required was negligible between runs. It required an additional four man-hours to determine the most effective combination of total simulation time and panel size. This was accomplished via a convergence study of fine, medium, and course granularity for vessel geometry panel sizes and free surface panel sizes.

Because LAMP simulates hydrodynamic forces at each time step, it requires a greater amount of time to compute the entirety of the results than do strip theory codes. For the initial simulation time of nine seconds with time steps of 0.009 seconds, 1,000 time steps required between three minutes, 37 seconds and four minutes, 22 seconds depending on frequency input. Despite the longer run times, computer simulation takes place independent of user interaction, and therefore one should not compare it directly to time requirements in the simulation set up areas of training and inputs, which are inherently user intensive activities.

5. Usage: Post-processing

Upon completion of the simulation run, LAMP writes an output file to a user-defined directory specified in the input file. An example of a LAMP output file is available in Appendix H. LAMP writes a time history of force to the output file as discrete points. The number of points and their spacing is specified in the input file. However, a more succinct and clear statement is necessary to make any claim on the accuracy of the simulations. Therefore, MATLAB was again called upon to evaluate the data output. MATLAB coding parsed the output file, noting the hydrodynamic forces and moments at each time step and plotting them for a graphical view of the problem. An example of this is illustrated in Figure 14, which depicts a time history of the simulated vertical forces. The data points represent each time step for which the calculations were performed. The horizontal axis displays time, in seconds, while the vertical axis represents force in pounds (lbs.).

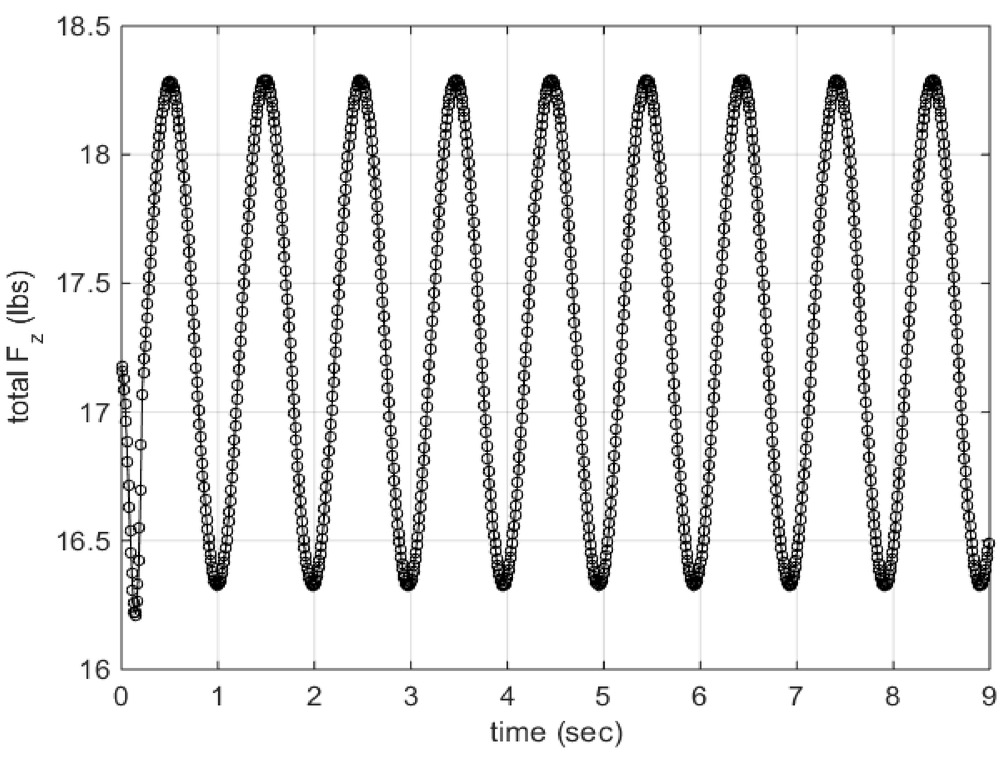

Figure 14. Time History of Forces in the Z Direction

The time history depicts periodic loading since the loads are wave-induced, and the frequency of the signal is the same as that of the wave. Transient effects that eventually decay away are apparent during the first half cycle of the simulation. These are to be expected with any simulation, and best practices would mandate omission of this portion of the signal during any following analyses.

MATLAB further analyzed the sinusoidal force and moment time histories to determine the amplitude of each by subtracting the maximum and minimum steady-state values of the time histories and dividing by two. Once we wrote the initial routine, input file parameters could be changed and run through LAMP with different output results.

6. Qualitative Ratings

Table 6 shows the qualitative ratings for LAMP attributes.

Table 6. LAMP Qualitative Ratings

Characteristics		Rating	Rationale
Usage	Output Readability	Low	Output file displays time history of multiple variables, but does not contain header information explaining the content. The user manual must be consulted to determine the format.
	User Support	Medium	Extensive documentation provides thorough, but not exhaustive, explanation. Additional support available from program SME.
Technical Aspects	Interoperability	Medium	Though difficult to take full advantage of, the program supports various input files and can be analyzed with multiple OTS products due to the simplistic .txt formatting.
	Parameter Space Limitations	High	Very robust program code with high number of potential variables and associated values. Generally not limited.
	Support for DOE	Medium	No direct tool to compute the ideal factors, but individual runs and relative ease of use with external tools allows for quick analyses.

Characteristics		Rating	Rationale
Life-cycle Suitability	Additional Analyses	High	The entire LAMP family of packages allows for numerous, certainly not all, desired user capabilities.
	Customizability	High	Vast number of data sets and data points with customizable variables allows for most applications.
	Maintainability	Medium	The single point of failure/program owner counters the simple, binary code format and the fact that it is currently in use.
	Portability	Low	Once obtained, the software code operates only in the windows environment. Significant manipulation or formatting would be required to allow operation on any other platform.
	Security	High	Nothing inherently classified in software, security protocol affected by content, not software use

F. SOFTWARE PACKAGE SUMMARY

Table 7 shows a summary of measurements and ratings for each software packages.

Table 7. Software Comparison Summary

Attribute	Metric	SMP	SUBMOT	Aegir	LAMP
Usage					
Code Access Time	Business Days	3	35	1	56
Installation	Man-hours	0	0	0/ .2 (GUI)	0
Supporting Environment Access	Man-hours	0	1	1	3
Training - Trainee	Man-hours	16	17.3	25	51
Input Software Access	Man-hours	0	0	1	2
Input Creation	Man-hours	2	2	30	35
Simulation Set-up	Man-hours	<1	<1	2	8
Simulation Run Time	Minutes	<1	<1	7-10	3-5
Post-Processing Software Access	Man-hours	0	0	0	0
User Process - Initial	Man-hours	3	4	6	6

Attribute	Metric	SMP	SUBMOT	Aegir	LAMP
User Process - Ongoing	Hours	<1	<1	1	1
Output Readability	H/M/L Rating	Medium	Low	High	Low
User Support	H/M/L Rating	Medium	Low	High	Medium
Technical Considerations					
Interoperability	H/M/L Rating	Medium	Low	Low	Low
Parameter Space Limitations	H/M/L Rating	Medium	Medium	High	High
Support for DOE	H/M/L Rating	Medium	Medium	Medium	Medium
Operational Suitability					
Additional Analyses	H/M/L Rating	Low	Medium	High	High
Customizability	H/M/L Rating	Low	Low	Medium	High
Maintainability	H/M/L Rating	Low	Low	Medium	Medium
Portability	H/M/L Rating	Low	Low	Low/ Medium	High
Security	H/M/L Rating	High	High	High	High

While trainee man-hours and procurement costs are important attributes, they were not applicable to this study, as the learning was accomplished without trainers and all software was available at no charge.

G. FIDELITY COMPARISON

This section compares the software simulation predictions to the experimentally measured results from the tow tank. This is not an exhaustive fidelity comparison but rather only a small portion of such an undertaking but is useful in that it discusses key considerations, highlights difficult aspects, and shows some typical steps required. The simulation results presented below are the researcher's best efforts to obtain the highest quality results from the simulations working within the time constraints of the project. Due to these constraints, only a limited spatial resolution study was performed and best practices guidelines were used for the choice of temporal resolution as well as other parameter settings. Therefore, it may be possible to get improved results provided more time to ensure that the simulations were run with parameter settings optimized for this specific problem. For all graphs, experimental data points are shown rather than a line, since the inherent experimental uncertainty prevents us from knowing where exactly the "true" value would lie on the graphs. The variation in the multiple experimental data points for each wave amplitude does give some indication of the possible range of the true value. Simulation output, on the other hand, can correctly be displayed as a line on the graph since the output does not vary given identical inputs.

For all cases, the vertical force and pitching moment were the quantities of interest. Comparison among and between all simulations and experiments is of Force in the Z direction and Moment in the y-axis. For a given model depth and wavelength, the results are presented over a range of non-dimensional wavelengths. There are no substantial forces on the y-axis or moments about the x-axis or z-axis due to symmetry and the relative wave heading tested. There are forces in the x-axis direction, but we know that viscous effects (resistance to gradual deformation) are important. These are inviscid (negligible viscosity) codes so they cannot accurately capture that force. To allow for comparisons, it was ensured that common wavelengths were explored in the simulation and the experiments. The significance of using wavelengths (λ) with respect to length of the vessel (L) is that in doing so, the independent variable is non-dimensionalized. Therefore, the results displayed should capture the actual behavior of a submerged vessel of any given size in appropriate environmental conditions relative to those in our study. In other words, the results are scalable and one can reasonably expect this to provide reliable information for similar problems of larger size.

Figures 5 through 10 are graphs showing the force and moment results as a function of non-dimensional wavelength. Figures 5 through 7 show the vertical force F_z while Figures 8 through 10 show the pitching moment M_y. The force and moment are reported about the center of buoyancy of the model, which due to model symmetry is on the centerline of the model at its longitudinal midpoint. M_y is the moment about the y-axis which means it results form a vertical force acting along the longitudinal direction of the model.

For all three scenarios tested and simulated, the force results show a localized maximum around the non-dimensional wavelength of 0.75. As the non-dimensional wavelength increases, there is a notable reduction in force until it reaches number one, after which the force values again increase to the overall maximum around the non-dimensional wavelength of two. Further increases in non-dimensional wavelength result in a slow decrease in force values. Similarly, all three scenarios tested and simulated produced moment results showing what appears to be a localized maximum just under the non-dimensional wavelength of 0.5, although this study did not explore small enough wavelengths to show this. The maximum moment occurs around the non-dimensional wavelength of one, and as non-dimensional wavelength is further increased, the moment values slowly decrease. Both experimental and simulation data follow these trends.

The F_z for the 4-inch depth, 0.5-inch wave amplitude scenario is shown in Figure 15. SUBMOT shows the lowest forces and Aegir shows the highest across the entire band of non-dimensional wavelengths 0.5 to 3.5. Aegir illustrated the highest force data value of 0.8 lbs at a non-dimensional wavelength of two. All four data sets had a downward trend between 0.75 to one non-dimensional wavelengths. While the experimental data tracks closer to LAMP for these values, it is generally bounded by the SUBMOT and Aegir simulation data.

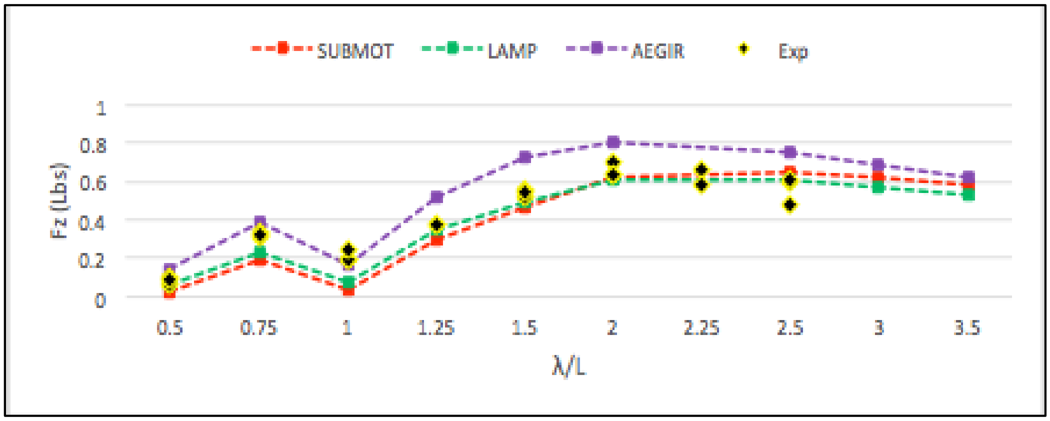

Figure 15. Z Force for 4-inch Depth and 0.5-inch Amplitude

Table 8 shows the corresponding percent error at each wavelength (λ).

Table 8. Z Force Percent Error: 4-Inch Depth and 0.5-Inch Amplitude

λ/L	SUBMOT	LAMP	AEGIR
0.5	(69.2%)	(31.5%)	(69.5%)
0.75	39.5%	28.5%	20.3%
1	(82.5%)	(62.1%)	(23.4%)
1.25	21.7%	8.2%	38.9%
1.5	14.1%	8.9%	33.2%
2	5.9%	8.4%	21.4%

The F_z for the 4-inch depth, 1-inch wave amplitude scenario is shown in Figure 16. SUBMOT shows the lowest forces and Aegir shows the highest across the entire band 0.5 to 3.5 non-dimensional wavelengths. Aegir illustrated the highest force data value 1.6 lbs. at two non-dimensional wavelengths. All four data sets had a downward trend between 0.75 to one non-dimensional wavelengths and then began an upward trend towards two non-dimensional wavelengths. The experimental data is generally bounded by the LAMP and Aegir simulation data up to 2.25 non-dimensional wavelengths where it reaches 1.6 lbs F_z and is greater than the three software codes.

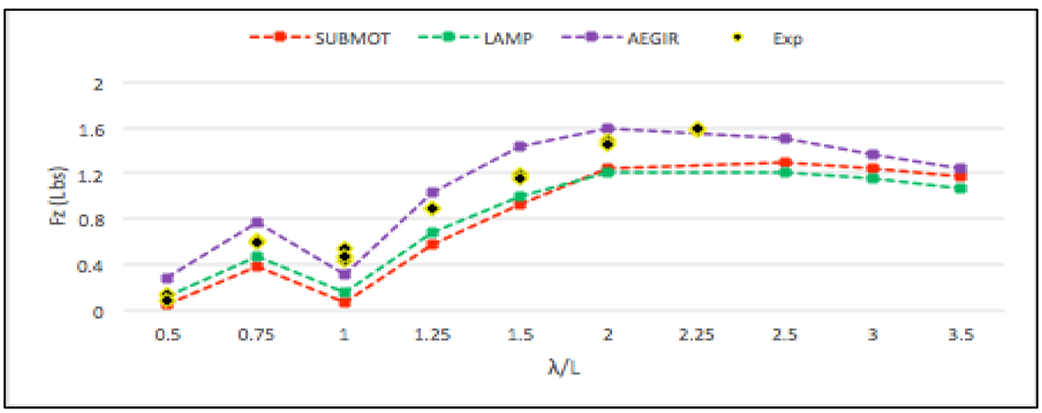

Figure 16. Z Force for 4-inch Depth and 1-inch Amplitude

Z Force percent error calculations for the conditions in Figure 6 at each wavelength are displayed in Table 9.

Table 9. Z Force Percent Error: 4-inch Depth and 1-inch Amplitude (λ is the wavelength)

λ/L	SUBMOT	LAMP	AEGIR
0.5	(52.2%)	(11.3%)	(162.8%)
0.75	35.3%	21.5%	28.7%
1	(84.9%)	(67.1%)	(34.1%)
1.25	34.8%	22.6%	15.8%
1.5	20.8%	15.4%	22.7%
2	15.8%	17.8%	8.6%

The vertical force F_z upon the body is shown in Figure 17 at a depth of eight inches and a wave amplitude of one inch. The graph shows the simulation codes (SUBMOT, LAMP, and Aegir) and the experimental data from the tow tank. As seen in the graph, the simulation codes all provide very similar results across the non-dimensional wavelength spectrum. The trend of the simulation results is identical and shows great consistency among the simulations. The experimental data also follows the same trend over the non-dimensional wavelengths spectrum and is slightly lower in force as the non-dimensional wavelengths increase.

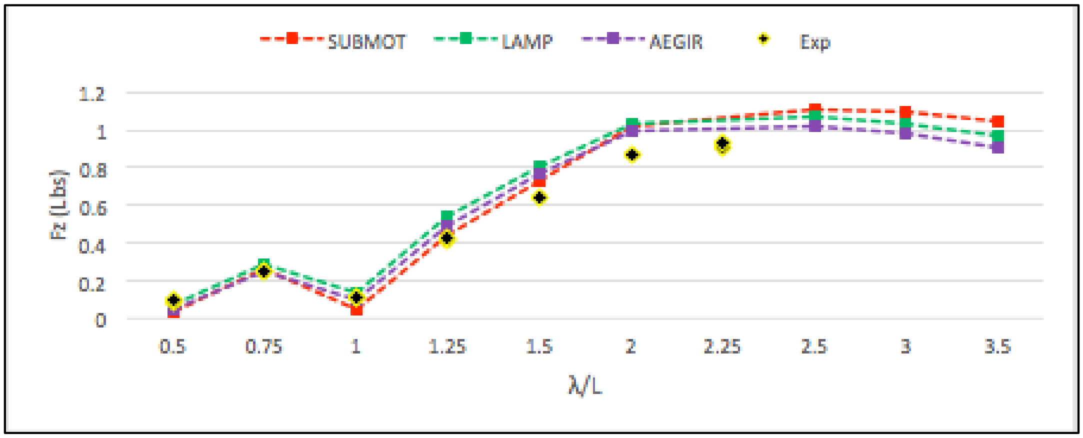

Figure 17. Z Force for 8-inch Depth and 1-inch Amplitude

Corresponding percent error values are shown in Table 10.

Table 10. Z Force Percent Error: 8-inch Depth and 1-inch Amplitude (λ is the wavelength)

λ/L	SUBMOT	LAMP	AEGIR
0.5	(67.1%)	(22.8%)	(50.7%)
0.75	4.9%	15.2%	0.6%
1	(51.5%)	(23.1%)	(11.8%)
1.25	4.1%	28.0%	15.5%
1.5	12.9%	25.2%	18.1%
2	17.4%	18.3%	14.0%

M_y for the 4-inch depth, 0.5-inch wave amplitude scenario is shown in Figure 18. SUBMOT and LAMP simulation predictions are very similar, while Aegir depicts a noticeably larger moment over the non-dimensional wavelength range of one to two. While the experimental data tracks closer to Aegir for these values, it is generally bounded by the simulation data and follows the same trend of initial decline.

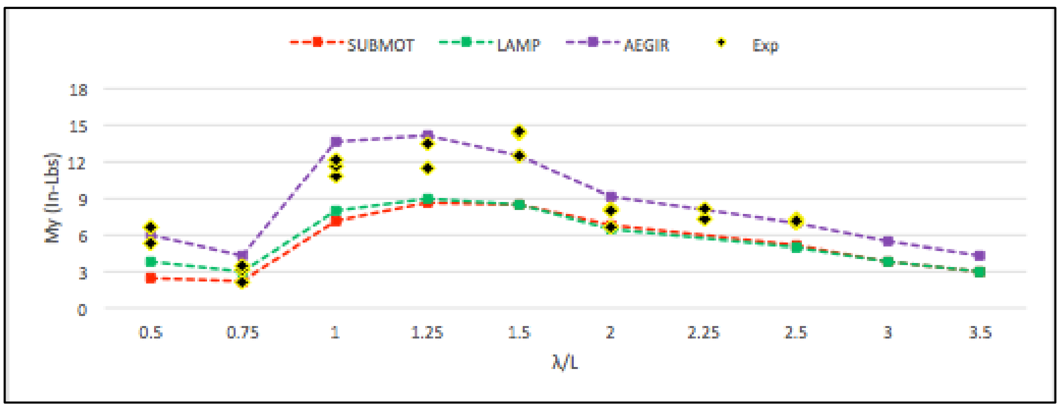

Figure 18. Y Moment for 4-inch Depth and 0.5-inch Amplitude

Y Moment percent error values for the conditions in Figure 8 at each wavelength are displayed in Table 11.

Table 11. Y Moment Percent Error: 4-inch Depth and 0.5 -inch Amplitude (λ is wavelength)

λ/L	SUBMOT	LAMP	AEGIR
0.5	60.1%	39.2%	2.3%
0.75	(24.4%)	(1.8%)	(46.6%)
1	38.9%	30.6%	17.5%
1.25	33.7%	30.5%	8.8%
1.5	31.6%	31.6%	0.8%
2	29.4%	31.5%	3.5%
2.25	n/a		
2.5	28.6%	30.6%	2.6%

M_y for the 4-inch depth, 1-inch wave amplitude scenario is illustrated in Figure 19. SUBMOT and LAMP software codes follow a similar trend line, while Aegir depicts a more exaggerated spike of 27 in-lb between 0.75 and 1.25 non-dimensional wavelengths. While the experimental data tracks closer to Aegir for these values, it is generally bounded by the simulation data and follows the same trend of initial decline.

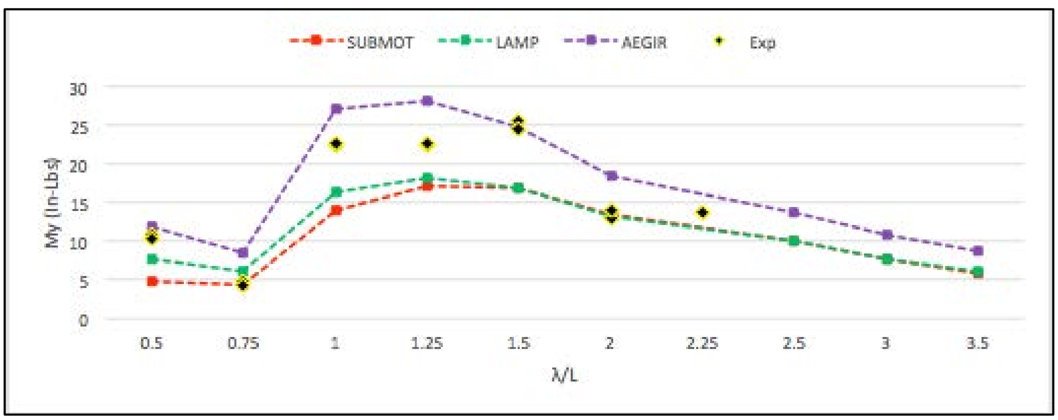

Figure 19. Y Moment for 4-inch Depth and 1-inch Amplitude

Corresponding percent error calculations are shown in Table 12.

Table 12. Y Moment Percent Error: 4 -inch Depth and 1-inch Amplitude (λ is wavelength)

λ/L	SUBMOT	LAMP	AEGIR
0.5	54.1%	27.1%	12.3%
0.75	(2.2%)	(34.4%)	(89.8%)
1	37.5%	27.9%	20.2%
1.25	27.7%	23.6%	18.7%
1.5	24.5%	24.3%	11.3%
2	21.0%	22.6%	8.0%

M_y for the eight inch depth, one-inch wave amplitude scenario is illustrated in Figure 20. SUBMOT, LAMP, and Aegir software codes as well as the Experimental Data all follow a similar trend line with the exception of one experimental point. The three codes show a peak of 14 in-lb between 1.25 and 1.5 non-dimensional wavelengths. The experimental data does show a single value of 17 in-lb at 1.5 non-dimensional wavelengths. All data was relatively flat between 0.5 and 0.75 non-dimensional wavelengths.

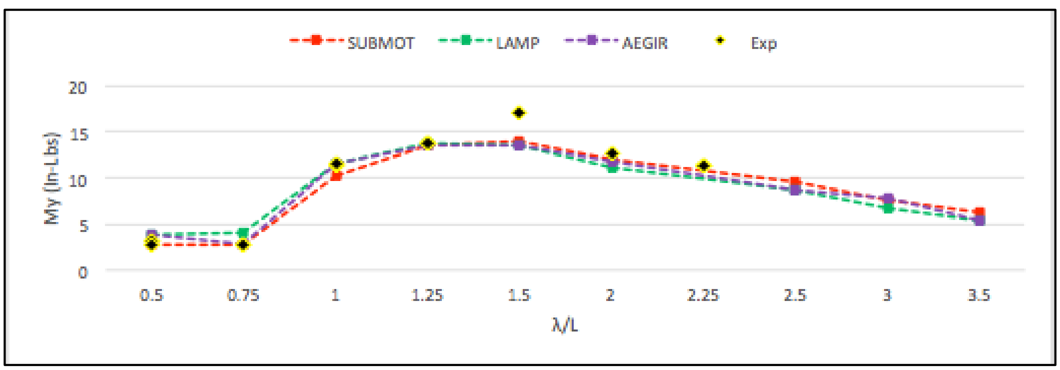

Figure 20. Y Moment for 8-inch Depth and 1-inch Amplitude

Corresponding percent error calculations are shown in Table 13.

Table 13. Y Moment Percent Error: 8-inch Depth and 1-inch Amplitude (λ is wavelength)

λ/L	SUBMOT	LAMP	AEGIR
0.5	(5.7%)	(25.3%)	(25.3%)
0.75	(0.1%)	(51.1%)	(4.8%)
1	10.7%	0.9%	0.9%
1.25	2.7%	0.0%	1.6%
1.5	8.5%	11.6%	11.6%
2	5.4%	13.1%	6.8%

To summarize data comparison of the three software package predictions to the tow tank experimental results, it was realized that maximum moments occurred near the non-dimensional wavelength of one and maximum forces occurred near two non-dimensional wavelengths. A key take-a-away is software and experimental data are dependent on the specific environmental conditions and change with these conditions. The tow tank and software produced similar results at eight inch depths with one inch amplitudes for both force and moment trends, but there was more discrepancy among results at shallower depths. For this study, Aegir and LAMP results were typically closer to experiment results than SUBMOT, both with and without inclusion of data points for which the force was essentially zero. However, a more in-depth study of fidelity involving more rigorous uncertainty analyses and a wider solution space would be required to make more deterministic claims about the relative fidelity of these software packages.

IV. DECISION SUPPORT PROCESS

Software suitability ultimately depends on the project requirements. Once the fidelity requirement has been determined for imminent analytical needs, program managers can compare options and perform trade-offs among cost, schedule, long-term program impacts, and other factors unique to the mission.

A. FIDELITY REQUIREMENTS

Foremost, the software needs to meet fidelity requirements for a project. A thorough set of fidelity requirements would detail which output variables are critical, how accurate the prediction needs to be, and under what conditions those fidelity requirements are applicable. For example, an analysis of alternatives (AoA) for UUV concepts might require outputs for a variety of configurations and operating conditions with 25–50% accuracy, while a detailed design project to optimize size of control surfaces of a UUV would require 5–10% accuracy for more specific concept configurations and operating conditions.

It is apparent from the test results that software fidelity can vary given different environmental conditions. Figures 7 and 10 show similar accuracy among SUBMOT, LAMP, and Aegir for both M_y and F_z at an eight-inch depth. As depth increases, the influence of the wave environment decreases. It seems that all three codes will give similarly accurate results for all depths at or below eight inches, although this would need to be validated with further testing. The physics of the problem are more complex when the vehicle is very close, a diameter or less, to the surface (shown in Figures 5, 6, 8, and 9), and therefore the specific solution methods of the codes become more important. LAMP matched experimental data most closely across all conditions, with an average of 23.4% error.

B. COST AND SCHEDULE REQUIREMENTS

If multiple software packages meet the fidelity requirements, then cost and schedule considerations should be considered to determine which option is best for the project at hand, and perhaps which option is best for long-term program support. No single variable from our taxonomy is universally more important than the others, as each mission has different needs. Thus, decision makers need to prioritize among performance, cost, and schedule, and consider which variables will have the most impact to those goals based on program infrastructure, staffing, and IT environment.

Usage is the variable with the most observable impact to cost and schedule. When considered thoroughly, these variables highlight not only time and effort to run software, but the effort involved in gaining access, creating readable input, and making the raw output useful for further analysis. Additionally, the time to learn and run supporting programs needs to be considered. Though not typically the forefront of software decisions, it is possible for supporting programs to require more user time and effort than the main software package. These metrics can form the basis of a baseline cost and schedule estimate, and can help determine whether the software packages are within resource constraints. This category is a logical starting point for suitability assessments, since the quantifiable attributes support direct budget and schedule inputs.

Technical aspects within the decision support framework highlight indirect cost and schedule impacts due to interoperability issues, and considerations of applicability for project analyses. Determining interoperability with environment, parameter space limitations, and DOE support could inform estimates for cost and schedule impact and provide some assessment for goodness of fit with the study at hand and any future projects.

Life-cycle suitability attributes are especially important if the software acquisition is intended to provide ongoing support for years into the program future. Then the applicability to future analyses, maintenance, and other attributes become more prominent to avoid the additional cost and training time of a new procurement.

C. SOFTWARE SELECTION EXAMPLE

The following hypothetical software selection scenario illustrates application of the decision support framework. The scenario involves a manager selecting software for an innovative design division that specializes in feasibility studies for UUVs. Typical assignments involve quick turn-around analyses for a wide variety of concepts and conditions. To further illustrate, the workforce is mostly made up of systems engineers with understanding of a broad range of disciplines, but no expertise in hydrodynamic simulation codes. Employees typically remain in this department for three to five years. The IT environment supports multiple operating systems, including Windows and Linux, and there are no specific interoperability requirements for transferring data. Since projects and staff tenure are fairly short-term, there is little pressure for the acquisition to be long-term, especially if procurement and integration costs are low.

The fidelity requirement for this division would be low fidelity output across a broad range of UUV configurations (variants have different sizes, speeds, and appendages) and operating conditions. Assuming the calculations in SMP are adjusted to allow for changes in depth, all four software packages could potentially meet the fidelity criteria.

Since multiple options would meet the fidelity criteria, the usage attributes must be considered. With quick turn-around projects and a high workforce attrition rate, code access and training times would be of particular importance for new users. It is important to note that overall project time includes not only software simulations, but the entire input and post-processing procedures. If the entirety of the process is not included in comparisons, unforeseen budget and schedule increases could ensue. If choices are restricted to the four software packages compared in the practical demonstration, it is apparent that inputs for Aegir and LAMP require considerably more time than SUBMOT and SMP. This same trend follows for simulation set-up.

The most important technical consideration for this scenario is the parameter space limitations, due to the broad range of analyses required. If there are variable or solution space limits, schedules need to reflect time for any manual work-arounds or extrapolation of results. SUBMOT and SMP have medium ratings for this attribute, while LAMP and Aegir have high ratings.

The decision makers in this scenario would need to prioritize between parameter space limitations and schedule impacts. In this case, we will assume that schedule is the deciding factor, including training time with the high turnover rate. SMP would be the most logical choice with the shortest times for code access, training, and post-processing. SUBMOT would be the next logical choice with slightly more post-processing and training time required.

For continued support of UUV design throughout its life cycle, a program office might want to invest in all these types of codes, including meshed fluid volume software such as NFA or NavyFOAM, to provide the broadest range of analyses for program decisions. This would require quite an investment of time and money as the infrastructure is put into place and users learn the codes. It is quite important to realize and prepare for this effort well in advance of programs' need for decision support, as there will not be time for software selection when milestones are imminent.

In most cases, the software selection process will not be straightforward, as there will be multiple, competing program needs that favor different software attributes. However, the basic process of application remains the same. Once fidelity metrics are determined, the importance of other attributes must be assessed. At that point, software packages can be evaluated for suitability with each attribute, and a selection is made based on suitability of attributes in order of importance.

V. SUMMARY AND CONCLUSIONS

A. REVIEW OF FINDINGS

This project examined software selection criteria for project analyses. While the practical demonstration focused on hydrodynamic modeling software packages, the considerations and processes are applicable to multiple types of software procurements. More specifically, objectives included the following:

(1) Create a general framework to determine which attributes of software packages need to be considered for implementation

The resulting taxonomy in Figure 2 illustrates attributes that determine cost and schedule impacts in terms of usage, technical considerations, and life-cycle suitability. These attributes help determine the total amount of man-hours, dollars, and schedule time invested into acquiring and using software for the duration of one project or multiple analyses. Additionally, OS and supporting software restrictions can greatly limit software choices, so developing a flexible IT environment can be helpful for the best selection and easiest implementation.

Appropriate fidelity parameters will vary by project and can be calculated by comparing simulation output to representative real-world data, such as scaled model experiments. These comparisons need to include different experimental conditions, as fidelity levels vary by situation within software packages.

(2) Quantify and compare cost, schedule, and other aspects of the software packages that will affect overall programmatic cost and ease of implementation

Attribute comparison within the decision framework included both quantitative and qualitative comparisons in terms of man-hours, schedule time, dollars, and user ratings. The practical demonstration involved applying the framework to four software packages. Table 7 summarizes these findings.

(3) Compare software outputs to experimental data to estimate degree of accuracy of hydrodynamic load predictions

Simulation output for the four software packages was compared to experimental data as a basis for fidelity comparisons. Overall findings indicated that fidelity at greater depths was comparable among SUBMOT, LAMP, and Aegir, while shallower depths brought more discrepancy among results. LAMP and Aegir were closer to experiment results at the shallower depths and wave amplitudes.

Beyond the experiment results, it became apparent how much effort could potentially be expended validating software. It is a process that requires extensive resources and coordination, and needs to be planned for as early as possible in the software selection process. Model creation, facility arrangements, and any potential problems with experiment design can all cause substantial delays if not resolved in advance.

(4) Demonstrate how the software decision framework can support software acquisitions

Chapter IV illustrated an application process with hypothetical project requirements and considerations. After fidelity requirements are determined, both importance and assessments of other software attributes must be combined to determine the most suitable choice.

B. AREAS FOR FUTURE RESEARCH

For the decision support framework, future research could focus on determining the most influential software attributes specific to certain realms of analysis including scientific analysis, business, human behavior.

More specific to the practical demonstration, future studies could also include the high fidelity software packages that require an HSC environment, such as NFA and NavyFOAM. Additional experiment conditions, such as alternative sea states and vehicle types would also provide more insight into fidelity comparisons across a broader solution space.

C. CONCLUSIONS AND RECOMMENDATIONS

True cost and schedule impact of software acquisition involves multiple aspects that are not necessarily reflected in the procurement price including the supporting environment, user training, input/output processes, technical aspects, and life-cycle suitability. It is recommended that project managers utilize the decision support framework when deciding among software packages to gain a broader understanding of the total cost and schedule impact of each choice. Total cost is driven not only by user effort to set up and run the simulations, but also by the effort needed to use and run auxiliary software to create the inputs and analyze the outputs of the programs. This is typically not readily apparent when considering implantation of one of these simulations.

Moreover, we recommend that project managers ensure software packages meet fidelity requirements. A SME’s anecdotal experience is never enough substantiation for the fidelity of results. The basis of comparison for fidelity will vary based on the nature of the project and the available resources for fidelity determination. A sound methodology for fidelity assessment, such as comparison to experimental data, could help to ensure that analytical software packages enhance the decision-making process to the highest possible extent within resource constraints.

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APPENDIX A. SMP INPUT FILE

```
Unmanned and Unafraid Pain Train  DRAFT 1.66 FT  TRIM 0.00 FT
# RECORD SET 2 - Program options
    2    0    0    1    0    0    0    0
# RECORD SET 3 - Physical units
FEET          1.9905   32.1725 0.0000128
# RECORD SET 4 - Hull particulars
    3.3333    0.3333    1.6667      1.00    3.0000    1.0000    0.0000
# RECORD SET 5 - Load particulars
#    GMNOM     DELGM        KG    KPITCH     KROLL      KYAW
    0.0167       0.0      0.15      0.25      0.35      0.25
# RECORD SET 6 - Hull lines
   20    0    0    0
    0.0000   10    0
    0.0000  0.000  0.003  0.005  0.007  0.008  0.008  0.007  0.005  0.003  0.000
    0.0000  0.158  0.159  0.160  0.163  0.165  0.168  0.171  0.173  0.175  0.175
    0.2500   10    0
    0.2500  0.000  0.011  0.021  0.029  0.033  0.033  0.029  0.021  0.011  0.000
    0.2500  0.133  0.135  0.141  0.150  0.161  0.172  0.183  0.192  0.198  0.200
    0.5000   10    0
    0.5000  0.000  0.023  0.043  0.058  0.066  0.066  0.058  0.043  0.023  0.000
    0.5000  0.100  0.104  0.116  0.133  0.155  0.178  0.200  0.218  0.229  0.233
    0.7500   10    0
    0.7500  0.000  0.034  0.064  0.087  0.098  0.098  0.087  0.064  0.034  0.000
    0.7500  0.067  0.073  0.090  0.117  0.149  0.184  0.217  0.243  0.261  0.267
    1.0000   10    0
    1.0000  0.000  0.046  0.086  0.115  0.131  0.131  0.115  0.086  0.046  0.000
    1.0000  0.033  0.041  0.065  0.100  0.144  0.190  0.233  0.269  0.292  0.300
    1.8000   10    0
    1.8000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
    1.8000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
    3.6000   10    0
    3.6000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
    3.6000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
    5.4000   10    0
```

```
5.4000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
5.4000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
7.2000   10    0
7.2000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
7.2000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
9.0000   10    0
9.0000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
9.0000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
10.000   10    0
10.000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
10.000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
12.600   10    0
12.600  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
12.600  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
14.400   10    0
14.400  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
14.400  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
16.200   10    0
16.200  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
16.200  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
18.000   10    0
18.000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
18.000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
19.000   10    0
19.000  0.000  0.046  0.086  0.115  0.131  0.131  0.115  0.086  0.046  0.000
19.000  0.033  0.041  0.065  0.100  0.144  0.190  0.233  0.269  0.292  0.300
19.250   10    0
19.250  0.000  0.034  0.064  0.087  0.098  0.098  0.087  0.064  0.034  0.000
19.250  0.067  0.073  0.090  0.117  0.149  0.184  0.217  0.243  0.261  0.267
19.500   10    0
19.500  0.000  0.023  0.043  0.058  0.066  0.066  0.058  0.043  0.023  0.000
19.500  0.100  0.104  0.116  0.133  0.155  0.178  0.200  0.218  0.229  0.233
19.750   10    0
19.750  0.000  0.011  0.021  0.029  0.033  0.033  0.029  0.021  0.011  0.000
19.750  0.133  0.135  0.141  0.150  0.161  0.172  0.183  0.192  0.198  0.200
20.000   10    0
20.000  0.000  0.003  0.005  0.007  0.008  0.008  0.007  0.005  0.003  0.000
20.000  0.158  0.159  0.160  0.163  0.165  0.168  0.171  0.173  0.175  0.175
```

```
# RECORD SET 7 - Sonar dome particulars
    0
# RECORD SET 8 - Bilge keel particulars
    0
# RECORD SET 9 - Fin particulars
    0
# RECORD SET 10 - Skeg particulars
    0
# RECORD SET 11 - Propeller shaft particulars
    0
# RECORD SET 12 - Propeller shaft bracket particulars
    0
# RECORD SET 13 - Propeller particulars
    0
# RECORD SET 14 - Rudder particulars
    0
# RECORD SET 15 - Passive stabilizers
    0
# RECORD SET 16 - Sinkage and trim
    0
# RECORD SET 17 - Wave profile
    0
# RECORD SET 19 - Stop
STOP
```

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APPENDIX B. SUBMOT INPUT FILE

```
** CIRC. CYL. WITH HEMI SPHERES AT BOTH ENDS: (L=40 IN) L/D=10 & ZKGG=-2D**
   17    3   46    0  32.174  1.98918   0.0       0.0       -0.66667  1.0
11.01332  10.05374  9.30795   8.70679   8.20884   7.78759   7.42518   7.10906
6.83017   6.58171   6.35854   6.15663   5.97281   5.80453   5.64971   5.50666
5.37395   5.25039   5.13498   5.02687   4.92530   4.82966   4.73938   4.65398
4.57303   4.49617   4.42305   4.35340   4.28693   4.22341   4.16264   4.10442
4.04858   3.99495   3.94340   3.89380   3.84602   3.79995   3.75551   3.71259
3.67111   3.63098   3.59215   3.55453   3.51807   3.48272
    1    1    5    0  15.0    -1.0      1.0       10.0      45.0
180.0
0.0       10.0      0.0       -0.66664  1.0       1.0
    0    1    2    3    3    3    3    3    3    3
    3    3    3    3    2    1    0
3.33332   0.33332   0.83330   3.33332   0.2175    0.78083   0.78083
-1.66666  -1.63433  -1.58333  -1.55560  -1.22228  -0.99996  -0.66664  -0.33332
0.0       0.33332   0.66664   0.99996   1.22228   1.55560   1.58333   1.63433
1.66666
0.0079335           0.0       0.0       0.01667   0.01667   0.0
0.16666   0.0       0.0       0.0       0.0       0.0       0.0       120.0
0.0       0.08333   0.14433   0.16666   0.16666   0.16666   0.16666   0.16666
0.16666   0.16666   0.16666   0.16666   0.16666   0.16666   0.14433   0.08333
0.0
    0
    0
    0
    0
    0
    0
    0
    0
    0
    0
    0
```

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APPENDIX C. AEGIR INPUT FILE

```
! Aegir namelist input file generated on Fri Oct 27 16:20:43 2017
!
&NamelistVersion
xVersionNumber = 1.09000
xBinaryOutput = 0
&end

&INPHeader
&end

&PhysicalConstants
xGravity = 32.17405
xDensity = 1.99089
xKinVisc = 1.2797e-5
xWaterDepth = 3.00000
&end

&Formulation
xFormDom = 0
xFormRad = 1
xFormFSE = 1
xFormINC = 1
xFormBody = 1
xFormFK = 1
xFormLIN = 1
xFormSS = 0
xFormADR = 0
xFormMotion = 1
&end

&RunSettings
xRunBVP = 0
xRunLocal = 0
xSym_xz = .false.
xSym_yz = .false.
&end

&ShipSpeed
xdomainspeed1 = 0.00000
xdomainspeed2 = 0.00000
xdomainspeed3 = 0.00000
&end

&RunTimes
xtRamp = 1.00000
xtFinish = 6.03000
xtRestart = 0.00000
&end

&Snapshot
xnSnap = 2
xSnapArr = 0.00000, 6.03000
xMovieStep = 0.00000
xMovieStart = 0.00000
xMovieEnd = 0.00000
&end

&OutputFiles
xFilenmSVB = '0'
xFilenmSV1 = 'Run1.sv1'
xFilenmSV2o = '0'
xOutname = 'Run1'
xFilenmSV2i = '0'
xFilenmSVM = ''
&end
```

```
&DISHeader
&end

&TemporalDiscretization
xTimeStep = 0.01000
xkWavFilterWeight = 1.00000
&end

&FreeSurfaceDomain
xfsid = 1
xiarg2 = 0
xfsupext = 2.66660
xfsdownext = -2.66660
xfsoutext = 1.00000
xbchupw = 1.00000
xbchupwst = 2.00000
xbchdw = 1.00000
xbchdwst = 2.00000
xbchow = 0.83333
xbchowst = 2.00000
&end

&Dims
xnBody = 1
xnHull = 1
xnLayer = 1
xnPatch = 12
&end

&SpatialDiscretization
xMeshDensity = 1.00000
xnFsPatch = 1
xFsPatchID = 1
xFsPatchName = 'OFS1'
xFsOrder = 3
xFsSpan = 79
xFsTpan = 30
xFsSSpc = 1
xFsTspc = 1
xPatch_BodID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
xPatch_HullID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
xPatch_GroupClass = 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
xPatch_ID = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
xPatch_Name = 'patch8', 'patch11', 'patch7', 'patch9', 'patch2', 'patch4',
'patch12', 'patch10', 'patch5', 'patch1', 'patch3', 'patch6'
xPatch_RhinoLaynm = 'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01',
'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01', 'Layer 01'
xPatch_Layer = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
xPatchCompID = -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1, -1
xSchemaName = '-1', '-1', '-1', '-1', '-1', '-1', '-1', '-1', '-1', '-1', '-1', '-1'
xPatch_Order = 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3
xPatch_Span = 45, 4, 45, 4, 4, 4, 4, 4, 45, 4, 4, 45
xPatch_Tpan = 4, 2, 4, 2, 2, 2, 2, 2, 4, 2, 2, 4
xPatch_Sspc = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
xPatch_Tspc = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1
&end

&NumericalSchemes
xmScheme = 1
xmSchemeOrder = 4
xFsScheme = 1
xTdOrder = 2
xQSelf = 8
xQFar = 2
xQGalerkin = 2
```

```
xQInterp = 5
xFSolveSubp = 2
xFSolveSubpOrder = 3
xFSolveGridDepth = 4
xbie = 0
xunstTransom = 4
xnVarTol = 0.00400
xStdTransom = .true.
xQForceSub = 0
&end

&MDDHeader
&end

&MeanBodyPositions
xbody_cad_hull_tx = 0
xbody_cad_hull_ty = 0
xbody_cad_hull_tz = -0.16667
xbody_cad_hull_rot_x = 0
xbody_cad_hull_rot_y = 0
xbody_cad_hull_rot_z = 0
xbody_hull_mean_tx = 0
xbody_hull_mean_ty = 0
xbody_hull_mean_tz = 0
xbody_hull_mean_rotx = 0
xbody_hull_mean_roty = 0
xbody_hull_mean_rotz = 0
&end

&GeneralizedModeDefinition
xnModes = 0
&end

&FreeModes
xnFree = 0
&end

&ForcedModes
xnForced = 0
&end

&PowerTakeOff
xPTOon = 0
&end

&InitialConditions
xnInitConditions = 0
&end

&LinearViscousDamping
xLinearViscDamp = 0
&end

&LinearTethers
xTethers = 0
&end

&HydroelasticHeader
&end

&HydroelasticDims
xHydroelasticOn = 0
&end

&Slamming
```

```
xSlammingOn = .false.
&end

&BODHeader
&end

&Hoerner
xCD = 0.00000
&end

&GeometryFile
xrhinofile = 'cylinderaegir4_acosta2.3dm'
xrhinovisualfile = ''
&end

&MassDistribution
xnLumps = 1
xMass = 1
xCG_x = 0.00001
xCG_y = 0.00000
xCG_z = 0.00000
xRG_x = 0.13300
xRG_y = 0.83300
xRG_z = 0.83300
xMom_xy = 0.00000
xMom_xz = 0.00000
xMom_yz = 0.00000
&end

&SETHeader
&end

&SolverOptions
xStd_fBow = 0.00875
xStd_Fss = 0.00875
xStd_Fsp = 0.00875
xRefit_HULL = .false.
xRefit_BULB = .false.
xRefit_ALL = .true.
&end

&TimeDomainSolver
xDump2Bod = .false.
xTwoBodSkip = 0.00000
xPressCap = .false.
&end

&ExtrnFlowHeader
&end

&ExtrnFlowVars
&end

&IRF
xFname_inc_irf = ''
&end

&INCHeader
&end

&WaveComponents
xnComps = 1
xPeriod = 0.57051
xHeading = 180.00000
xAmplitude = 0.04166
```

```
xPhase = 0.00000
&end

&APPHeader
&end

&SchemaDefinition
xBCtype = -1
&end

&LDDHeader
&end

&LoadPoints
xnLoad = 0
xRotLoad = 1
&end

&VisualizationHeader
&end

&OutputVisualization
xvisual = 0
&end

&OutputMotionPts
xnLoc = 0
&end

&GUIOnlyHeader
&end

&GUIOnly
xForwardSpeed = 0.00000
xSideSlipSpeed = 0.00000
xUnitLabel = 1
xBaseInputName = 'Run1'
xBaseOutputName = 'Run1'
xSVMFile = 'testSVM'
xHullLengths = ('cylinderaegir4_acosta2.3dm', 1, 3.33332)
xpanelLength = [[[0.06740]]]
xfracDraft = 0.00000
xdeltaZRatio = [[[0]]]
xoperationTime = [[2.00000]]
xcurrSeed = 0
xseeds = [[[]]]
xseedPhaseGenerator = [[[]]]
xtRamp = [[1.00000]]
xtFinish = [[6.03000]]
xsnapArray = [[[0, 6.03000]]]
xSpectraTimeSteps = [[0.01000]]
xtimeStepFactors = 1
xcurrTimeStepFactor = 1.00000
xFroudeNum = 0.00000
xDomainExtents = [[(2.66660, -2.66660, 1.00000)]]
xBeachExtents = [[(1.00000, 1.00000, 0.83333)]]
xBeachStrength = [[(2.00000, 2.00000, 2.00000)]]
xFSGap = [[[0.00400]]]
xFSOrder = [[[3]]]
xFSSpan = [[[79]]]
xFSTpan = [[[30]]]
xPatch_Order = [[[3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3]]]
xPatch_Span = [[[45, 4, 45, 4, 4, 4, 4, 4, 45, 4, 4, 45]]]
xPatch_Tpan = [[[4, 2, 4, 2, 2, 2, 2, 2, 4, 2, 2, 4]]]
xExtentXF = [[[-2.66660, 2.66660]]]
```

```
xExtentYF = [[[-1, 1]]]
xExtentSpanF = [[[10]]]
xExtentTpanF = [[[2]]]
xExtentOrderF = [[[3]]]
xCurrentMeshDensity = 1.00000
xMeshDensityFactors = 1
xDomainExtMul = [(1.00000, 1.00000, 1.00000)]
xcurrDomainExtMul = '1.00000-1.00000-1.00000'
xbody_hull_mean_tx = 0
xbody_hull_mean_ty = 0
xbody_hull_mean_tz = 0
xbody_hull_mean_rotx = 0
xbody_hull_mean_roty = 0
xbody_hull_mean_rotz = 0
xnComps = 1
xPeriod = 0.57051
xHeading = 180
xAmplitude = 0.04166
xPhase = 0.00000
xMinFreq =
xMaxFreq =
xSpectraNames = 'Mono-T0.57051-H180-1'
xCurrentSpectraName = 'Mono-T0.57051-H180-1'
xHs = -1
xTm = -1
xincTable = 0.57051, 180.00000, 0.04166, 0.00000
xProblemType = 2
xcurrRadProb = ''
xRadProbs = ''
xirfCoupled =
xirfForced =
xirfRuns = []
xirfHeadings =
xirfPeriods = []
xirfFreq = []
xirfDiffChecked = []
xRunComments = ''
&end
```

APPENDIX D. LAMP INPUT FILE

```
            depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]-s[55]-wl[10]
!01 DESCR - Descriptive Title (max 80 char)
baseline geometry, D=4in (0.333ft) L/D=10, depth=D*2, a=D/4, lambda/L~0.5
!02 FPROG - Source file for Programmers Input (blank for defaults)

!03 FAPLT - Source file for Autopilot Input (blank for defaults)

!04 FGEOM - Source file for geometry definition
LtoD10_55_10.lmp
!05 FOUT - Destination file for primary output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].out
!06 Output frequency for pressure, geometry, etc.
!      POUT        GOUT      SOUT      BOUT
  100 2000 100    1 1 1      0 0 0      0 0 0
!07 FPOUT = File for pressure data output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].pout
!08 FGOUT = File for panel geometry output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].gout
!09 FSOUT = File for load balance output

!10 FBOUT = File for elastic beam output

!11 AUXOUT(20) - Flags for auxiliary output files
   0 0 0 0 0   0 0 0 0 0   0 0 0 0 0   0 0 0 0 0
!12 IVEC - Use Non-vectorized (0) or ivectorized (1) kernel
    0
!13 LMPTYP (1-4)  MOTYPE (forced/impulsive/free)  MIXED (Rankine/mixed/IRF)
    2                   0                                   -1
!13 (cont) IFSMIX NXFS NYFS  IMSMIX NXMS NZMS - mixed-source surface points
             4        65     25     2        16      11
!13 (cont) XMIX  YMIX  ZMIX - mixed-source surface extent
    5.00000      2.000000      1.500000
!14 TINIT NSTEP DTH IRST - Initial Time, Number of Steps, Time Step, Restart
    0.0    1000  0.009  0
!14 (cont) FRST - Name for restart file
!14 (cont) FBDMEM - Name for body panel free surface memory file
!14 (cont) FWLMEM - Name for waterline free surface memory file
!15 USHIP  UCURNT  DCURNT  WDEPTH - Steady speed, current vel/dir, water depth
    0.0     0.0      0.0      0.0
!16 PMGIN(1:6) Initial location and orientation in global system
     0.000000     0.000000     -0.666667      0.000000      0.000000      0.000000
!17 VMGSHP(1:6) Initial Velocity and Rotation rate in ship fixed system
     0.000000     0.000000      0.000000      0.000000      0.000000      0.000000
!18 AMPM(1:6) Amplitude for forced sinusoidal motion (if MOTYPE=0)
     0.000000      0.000000     0.000000      0.000000      0.000000      0.000000
!19 OMEGM(1:6) Frequency for forced sinusoidal motion (if MOTYPE=0)
     0.000000      0.000000      0.000000      0.000000      0.000000      0.000000
!20 SWTCH(1:6) Sets which modes of motion will be considered
    0    0    0    0    0    0
!21 ISEA  NWAVES  NWSC
    1        1         2
!21 (cont) FREQW  PHASEW  AMPW  HEADW = component wave data
   4.16264     0.000000      0.08333  180
!21 (cont) WSCSTP  WSCFAC = wave scaling data
     0     0.0
    25    1.0
!22 GRAVIN  RHOIN  LENIN  ANGIN - Scale Factors for Input
    32.200000    1.940000     3.3333     57.29578
!23 GRAVOUT  RHOOUT  LENOUT  ANGOUT - Scale Factors for Output
    32.200000    1.940000     3.3333     57.29578
!24 GSHIFT(3), GORIG(3), GROT(3) - Input geometry transformation
    0.0 0.0 -0.5
    0.0 0.0 0.0
    0.0 0.0 0.0
                                  Page 1
```

```
            depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]-s[55]-wl[10]
!25 SMA = Ship mass, SMI(1,1),(2,1),(3,1),(1,2)...(3,3) Mom. of Inertia
      0.26335
      0.0075765    0.000000     0.000000
      0.000000      0.505103     0.000000
      0.000000      0.000000     0.505103
!26 RGRAV = center of gravity in input system
     0.000000 0.00000 0.000000
!27 SYMGEO= 1 for Symmetry in calc., SYMINP =1 for symmetry in input
     0    1
!28 NCOMP0 ...
     0
!28 (cont) KCTYPE0 NEWWL0 KSPWL0 SPWL0 NEWST0 KSPST0 SPST0,1->NCOMP0
!     0    20    1     0.000000    50    1      0.000000
!29 IVM, IHM, ITM, NBCA, NBMX ...
     0    0    0    0    0
!29 (cont) XMC(123,1->NBCA)
!       .000000      .000000     0.000000
!29 (cont) XMS(123,I), AMS(I), AIS(123,I), AMI(123,I), DWS(I), AWS(I), EWS(I),
(I=1->NBMX)
!      0.000 0.000 0.000  0.000000  0.0 0.0 0.0  0.0 0.0 0.0  0.0 0.0 0.0
!29 (cont) STRDMP(2,4) structural damping, fraction of critical in 1st 2 modes
!          for vertical, horizontal, torsional, and tension vibration
    0.1 0.2
    0.1 0.2
    0.1 0.2
    0.1 0.2
!30 KINVIS (kinematic viscosity)  IHROLL (roll damping option)
    0.000010804                         0
!31 IHLIFT (hull lift option)
     0
!32 NFIN - Number of wing-like appendages (e.g. rudder, fins)
     0
!32 (cont) Values for one wing-like appendage - rudder
!    0.0      0.0     0.0
!    0.0      0.0     0.0
!    0.0      0.0     0.0
!    0.0  0.0  0.0
!33 NBK - Number of plate-like appendages (e.g. bilge keels)
     0
```

Page 2

APPENDIX E. SMP OUTPUT FILE

```
                    SMP95 - REGULAR WAVE MODULE

                          NSWC/CD - DTMB

                 SEAKEEPING DEPARTMENT - CODE 5500

                         DATE = 21-SEP-17

                         TIME = 08:13:49

SMPREGW audit trail = 21-SEP-17 08:13:49
                                        I N P U T   C A R D S
        COLUMN  1         2         3         4         5         6         7         8
 LINE  12345678901234567890123456789012345678901234567890123456789012345678901234567890
   1   Unmanned and Unafraid Pain Train  DRAFT 1.66 FT  TRIM 0.00 FT
   2   # RECORD SET 2 - Program options
   3       2    0    0    1    0    0    0    0
   4   # RECORD SET 3 - Physical units
   5   FEET          1.9905   32.1725 0.0000128
   6   # RECORD SET 4 - Hull particulars
   7       3.3333    0.3333    1.6667      1.00    3.0000    1.0000    0.0000
   8   # RECORD SET 5 - Load particulars
   9   #    GMNOM     DELGM        KG    KPITCH     KROLL      KYAW
  10       0.0167       0.0      0.15      0.25      0.35      0.25
  11   # RECORD SET 6 - Hull lines
  12      20    0    0    0
  13       0.0000   10    0
  14       0.0000  0.000  0.003  0.005  0.007  0.008  0.008  0.007  0.005  0.003  0.000
  15       0.0000  0.158  0.159  0.160  0.163  0.165  0.168  0.171  0.173  0.175  0.175
  16       0.2500   10    0
  17       0.2500  0.000  0.011  0.021  0.029  0.033  0.033  0.029  0.021  0.011  0.000
  18       0.2500  0.133  0.135  0.141  0.150  0.161  0.172  0.183  0.192  0.198  0.200
  19       0.5000   10    0
  20       0.5000  0.000  0.023  0.043  0.058  0.066  0.066  0.058  0.043  0.023  0.000
  21       0.5000  0.100  0.104  0.116  0.133  0.155  0.178  0.200  0.218  0.229  0.233
  22       0.7500   10    0
  23       0.7500  0.000  0.034  0.064  0.087  0.098  0.098  0.087  0.064  0.034  0.000
  24       0.7500  0.067  0.073  0.090  0.117  0.149  0.184  0.217  0.243  0.261  0.267
  25       1.0000   10    0
  26       1.0000  0.000  0.046  0.086  0.115  0.131  0.131  0.115  0.086  0.046  0.000
  27       1.0000  0.033  0.041  0.065  0.100  0.144  0.190  0.233  0.269  0.292  0.300
  28       1.8000   10    0
  29       1.8000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
  30       1.8000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
  31       3.6000   10    0
```

```
      3.6000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      3.6000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      5.4000   10    0
      5.4000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      5.4000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      7.2000   10    0
      7.2000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      7.2000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      9.0000   10    0
      9.0000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      9.0000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      10.000   10    0
      10.000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      10.000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      12.600   10    0
      12.600  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      12.600  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      14.400   10    0
      14.400  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
                                   I N P U T   C A R D S
   COLUMN  1         2         3         4         5         6         7         8
LINE  12345678901234567890123456789012345678901234567890123456789012345678901234567890
      14.400  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      16.200   10    0
      16.200  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      16.200  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      18.000   10    0
      18.000  0.000  0.057  0.107  0.144  0.164  0.164  0.144  0.107  0.057  0.000
      18.000  0.000  0.010  0.039  0.083  0.138  0.196  0.250  0.294  0.323  0.333
      19.000   10    0
      19.000  0.000  0.046  0.086  0.115  0.131  0.131  0.115  0.086  0.046  0.000
      19.000  0.033  0.041  0.065  0.100  0.144  0.190  0.233  0.269  0.292  0.300
      19.250   10    0
      19.250  0.000  0.034  0.064  0.087  0.098  0.098  0.087  0.064  0.034  0.000
      19.250  0.067  0.073  0.090  0.117  0.149  0.184  0.217  0.243  0.261  0.267
      19.500   10    0
      19.500  0.000  0.023  0.043  0.058  0.066  0.066  0.058  0.043  0.023  0.000
      19.500  0.100  0.104  0.116  0.133  0.155  0.178  0.200  0.218  0.229  0.233
      19.750   10    0
      19.750  0.000  0.011  0.021  0.029  0.033  0.033  0.029  0.021  0.011  0.000
      19.750  0.133  0.135  0.141  0.150  0.161  0.172  0.183  0.192  0.198  0.200
      20.000   10    0
      20.000  0.000  0.003  0.005  0.007  0.008  0.008  0.007  0.005  0.003  0.000
      20.000  0.158  0.159  0.160  0.163  0.165  0.168  0.171  0.173  0.175  0.175
  # RECORD SET 7 - Sonar dome particulars
      0
  # RECORD SET 8 - Bilge keel particulars
      0
  # RECORD SET 9 - Fin particulars
      0
  # RECORD SET 10 - Skeg particulars
      0
  # RECORD SET 11 - Propeller shaft particulars
      0
```

```
# RECORD SET 12 - Propeller shaft bracket particulars
    0
# RECORD SET 13 - Propeller particulars
    0
# RECORD SET 14 - Rudder particulars
    0
# RECORD SET 15 - Passive stabilizers
    0
# RECORD SET 16 - Sinkage and trim
    0
# RECORD SET 17 - Wave profile
    0
# RECORD SET 19 - Stop
STOP
```

LIMITS ON ARRAY INPUTS - REGULAR WAVE MODULE

Input	Variable Name	Limit Name	Limit	Record Set
Speeds	NVK	MXNVK	8	4

(Note: For some options NVK is calculated from data in the indicated record)

Input	Variable Name	Limit Name	Limit	Record Set
Input stations	NSTATN	MXNSTATN	70	6

(Note: if VGOPTN = 1 the maximum number of input stations allowed is reduced by 2)

Input	Variable Name	Limit Name	Limit	Record Set
Load stations	NLOADS	MXNLOADS	10	6
Offsets per station	NOFSET	MXNOFSET	70	6

(Note: if VGOPTN = 1 the maximum number of offsets per station allowed is reduced by 1)

Input	Variable Name	Limit Name	Limit	Record Set
Sonar domes	NSDSET	MXNSDSET	1	7
Bilge keel sets	NBKSET	MXNBKSET	2	8
Bilge keel stations	NBKSTN	MXNBKSTN	35	8
Fin sets	NFNSET	MXNFNSET	2	9
Skeg sets	NSKSET	MXNSKSET	2	10
Propeller shaft sets	NPSSET	MXNPSSET	6	11
Shaft bracket sets	NSBSET	MXNSBSET	2	12
Propeller sets	NPRSET	MXNPRSET	2	13
Maximum number of coeffs to define resistance	NRESC	MXNRESC	30	13
Rudder sets	NRDSET	MXNRDSET	2	14
Passive stabilizers	NPSTAB	MXNPSTAB	3	15
Sinkage and trim input values	NSTRI	MXNSTRI	10	16
Wave profile - froude number values read in	NWPRIFN	MXNWPRIFN	12	17
Wave profile - input station values read in	NWPRIST	MXNWPRIST	15	17
Wave profile - station values	NWPST	MXNWPST	15	17

(Note: An array limit can be changed by changing the corresponding parameter <limit name> in the file PARAM.DEF and recompiling.)

INPUT DESCRIPTION

```
RECORD SET 1 - TITLE
   Unmanned and Unafraid Pain Train  DRAFT 1.66 FT  TRIM 0.00 FT


RECORD SET 2 - PROGRAM OPTIONS

  OPTION    VLACPR     RAOPR    RLDMPR    LRAOPR     ADRPR   ORGOPTN    VGOPTN
       2         0         0         1         0         0         0         0


RECORD SET 3 - PHYSICAL UNITS

   UNITS       RHO       GRAV      GNU
FEET         1.9905    32.1725 0.00001280


RECORD SET 4 - HULL PARTICULARS

    LPP       BEAM     DRAFT    DSPLMT     VKDES     VKINC     AMODL
  3.3333    0.3333    1.6667      1.00    3.0000    1.0000    0.0000


RECORD SET 5 - LOAD PARTICULARS

   GMNOM     DELGM      KG      KPITCH     KROLL      KYAW
    0.02      0.00      0.15      0.25      0.35      0.25


RECORD SET 6 - HULL LINES - OFFSETS

NO. OF STATIONS = 20    NLOADS =  0    NBB =  0    LKNPF =  0    LSTLW =  0


  STATION   NOFFSET KNP      OFFSETS- Y=HALF BREADTH, Z=WATERLINE (FROM KEEL)
k, statn, nsofst, knpf =     1    0.0000   10    0
   0.0000        10              Y=   0.00   0.00   0.00   0.01   0.01   0.01   0.01   0.00   0.00   0.00
   0.0000        10              Z=   0.16   0.16   0.16   0.16   0.17   0.17   0.17   0.17   0.17   0.17
k, statn, nsofst, knpf =     2    0.2500   10    0
   0.2500        10              Y=   0.00   0.01   0.02   0.03   0.03   0.03   0.03   0.02   0.01   0.00
   0.2500        10              Z=   0.13   0.14   0.14   0.15   0.16   0.17   0.18   0.19   0.20   0.20
k, statn, nsofst, knpf =     3    0.5000   10    0
   0.5000        10              Y=   0.00   0.02   0.04   0.06   0.07   0.07   0.06   0.04   0.02   0.00
   0.5000        10              Z=   0.10   0.10   0.12   0.13   0.16   0.18   0.20   0.22   0.23   0.23
k, statn, nsofst, knpf =     4    0.7500   10    0
   0.7500        10              Y=   0.00   0.03   0.06   0.09   0.10   0.10   0.09   0.06   0.03   0.00
   0.7500        10              Z=   0.07   0.07   0.09   0.12   0.15   0.18   0.22   0.24   0.26   0.27
k, statn, nsofst, knpf =     5    1.0000   10    0
   1.0000        10              Y=   0.00   0.05   0.09   0.12   0.13   0.13   0.12   0.09   0.05   0.00
```

```
   1.0000        10             Z=   0.03   0.04   0.06   0.10   0.14   0.19   0.23   0.27   0.29   0.30
k, statn, nsofst, knpf =     6    1.8000   10    0
   1.8000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
   1.8000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =     7    3.6000   10    0
   3.6000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
   3.6000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =     8    5.4000   10    0
   5.4000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
   5.4000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =     9    7.2000   10    0
   7.2000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
   7.2000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    10    9.0000   10    0
   9.0000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
   9.0000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    11   10.0000   10    0
  10.0000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
  10.0000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    12   12.6000   10    0
  12.6000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
  12.6000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    13   14.4000   10    0
  14.4000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
  14.4000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    14   16.2000   10    0
  16.2000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
  16.2000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    15   18.0000   10    0
  18.0000        10             Y=   0.00   0.06   0.11   0.14   0.16   0.16   0.14   0.11   0.06   0.00
  18.0000        10             Z=   0.00   0.01   0.04   0.08   0.14   0.20   0.25   0.29   0.32   0.33
k, statn, nsofst, knpf =    16   19.0000   10    0
  19.0000        10             Y=   0.00   0.05   0.09   0.12   0.13   0.13   0.12   0.09   0.05   0.00
  19.0000        10             Z=   0.03   0.04   0.06   0.10   0.14   0.19   0.23   0.27   0.29   0.30
k, statn, nsofst, knpf =    17   19.2500   10    0
  19.2500        10             Y=   0.00   0.03   0.06   0.09   0.10   0.10   0.09   0.06   0.03   0.00
  19.2500        10             Z=   0.07   0.07   0.09   0.12   0.15   0.18   0.22   0.24   0.26   0.27
k, statn, nsofst, knpf =    18   19.5000   10    0
  19.5000        10             Y=   0.00   0.02   0.04   0.06   0.07   0.07   0.06   0.04   0.02   0.00
  19.5000        10             Z=   0.10   0.10   0.12   0.13   0.16   0.18   0.20   0.22   0.23   0.23
k, statn, nsofst, knpf =    19   19.7500   10    0
  19.7500        10             Y=   0.00   0.01   0.02   0.03   0.03   0.03   0.03   0.02   0.01   0.00
  19.7500        10             Z=   0.13   0.14   0.14   0.15   0.16   0.17   0.18   0.19   0.20   0.20
k, statn, nsofst, knpf =    20   20.0000   10    0
  20.0000        10             Y=   0.00   0.00   0.00   0.01   0.01   0.01   0.01   0.00   0.00   0.00
  20.0000        10             Z=   0.16   0.16   0.16   0.16   0.17   0.17   0.17   0.17   0.17   0.17


 RECORD SET 7 - SONAR DOME PARTICULARS

   NSDSET
        0
```

RECORD SET 8 - BILGE KEEL PARTICULARS

NBKSET
0

RECORD SET 9 - FIN PARTICULARS

NFNSET	IACTFN	IFCLCS	IAGC	FALIM	FVLIM
0	0	0	0	0.000	0.000

RECORD SET 10 - SKEG PARTICULARS

NSKSET
0

RECORD SET 11 - PROPELLER SHAFT PARTICULARS

NPSSET
0

RECORD SET 12 - PROPELLER SHAFT BRACKETS

NSBSET
0

RECORD SET 13 - PROPELLER PARTICULARS

NPRSET
0

RECORD SET 14 - RUDDER PARTICULARS

NRDSET
0

RECORD SET 15 - NO PASSIVE STABILIZERS

```
 RECORD SET 16 - SINKAGE AND TRIM

   STOPTN
        0


 RECORD SET 17 - WAVE PROFILE

   WPOPTN
        0


 RECORD SET 20 - STOP

   STOP
   STOP


 END INPUT DATA

 NATURAL ROLL PERIOD TPHI Seconds

IROLLG   =          0.0

TPHI air w/o appendages  =    1.01

A44G     =          0.0

TPHI wet w/o appendages  =    1.04

A44G     =          0.0

TPHI wet w/o appendages  =    1.04

For NATPER call  1 to RDEVAL

A44G     =          0.0
A44AP    =          0.0

TPHI wet with appendages =    1.04

D44G     =          0.0
ET       =      -0.8989

TPHI w/appendages,damping =   2.37

 Unmanned and Unafraid Pain Train  DRAFT 1.66 FT  TRIM 0.00 FT

                           TABLE OF SHIP PARTICULARS
```

SHIP CHARACTERISTICS -

SHIP LENGTH (LPP)	3.33 FEET	LENGTH/BEAM	10.001
BEAM AT MIDSHIPS	0.33 FEET	BEAM/DRAFT	0.200
DRAFT AT MIDSHIPS	1.67 FEET	DRAFT/BEAM	5.001
DISPLACEMENT (S.W.)	0.0 L. TONS	DISPL/(.01LPP)**3	204.494
DESIGN SHIP SPEED	3.00 KNOTS	FROUDE NUMBER	0.489

VERTICAL LOCATIONS -

C. OF GRAVITY (VCG)*	-0.18 FEET	VCG/BEAM	-0.549
C. OF GRAVITY (KG)**	0.15 FEET	KG/BEAM	0.450
METACENTRIC HT. (GM)	0.02 FEET	GM/BEAM	0.050
METACENTER (KM)**	0.17 FEET	KM/BEAM	0.500
C. OF BUOYANCY (KB)**	0.17 FEET	KB/BEAM	0.500

LONGITUDINAL LOCATIONS*** -

C. OF GRAVITY (LCG)	1.66 FEET	LCG/LENGTH	0.499
C. OF BUOYANCY (LCB)	1.66 FEET	LCB/LENGTH	0.499
C. OF FLOTATION (LCF)	0.00 FEET	LCF/LENGTH	0.000

MOTION CHARACTERISTICS -

ROLL GYRADIUS	0.12 FEET	RG/BEAM	0.350
PITCH GYRADIUS	0.83 FEET	PG/LPP	0.250
YAW GYRADIUS	0.83 FEET	YG/LPP	0.250
ESTIMATED ROLL PERIOD	1.04 SECONDS	ROLL FREQ (RADIANS)	6.055

COMPUTED AREAS -

WATERPLANE	0.0 SQ. FEET	AWP/(LPP*BEAM)	0.000
WETTED SURFACE, HULL	3.3 SQ. FEET	WS/(2LD+2BD+LB)	0.245

HULL COEFFICIENTS -

BLOCK (CB)	0.143
SECTION (CX)	0.157
PRISMATIC (CP)	0.914

* WATERLINE REFERENCE
** KEEL REFERENCE
***F.P. REFERENCE

Unmanned and Unafraid Pain Train DRAFT 1.66 FT TRIM 0.00 FT

TABLE OF SHIP APPENDAGE PARTICULARS

NOTE: IF A "SET" REPRESENTS A PAIR OF APPENDAGES (E.G., BILGE KEELS), THEN THE WETTED SURFACE IS COMPUTED FOR THE TOTAL AREA OF BOTH APPENDAGES.

Vertical Wave Exciting Forces 1
Velocity = 0.000
Heading = 180.00

			SURGE			HEAVE			PITCH		
Omega	OmegaE	Lambda/L	Amp	Real	Imag	Amp	Real	Imag	Amp	Real	Imag
0.20000	0.20000	1516.08606	0.3009E+00	0.3009E+00	0.1191E-06	0.7468E-01	-0.7468E-01	-0.1847E-04	0.6346E-03	0.6346E-03	0.1901E-06
0.51366	0.51366	229.84450	0.3005E+00	0.3005E+00	-0.5413E-06	0.4673E+00	-0.4673E+00	0.4302E-04	0.1807E-02	0.1807E-02	-0.7866E-06
0.82503	0.82503	89.09550	0.3954E+00	0.2996E+00	-0.2581E+00	0.1203E+01	-0.1203E+01	0.1810E-04	0.1967E-01	0.4044E-02	0.1925E-01
1.13411	1.13411	47.15015	0.5706E+00	0.2980E+00	-0.4865E+00	0.2283E+01	-0.2283E+01	-0.8952E-04	0.6944E-01	0.7437E-02	0.6904E-01
1.44092	1.44092	29.20854	0.8366E+00	0.2955E+00	-0.7826E+00	0.3711E+01	-0.3711E+01	0.5547E-02	0.1816E+00	0.1239E-01	0.1811E+00
1.74549	1.74549	19.90474	0.1179E+01	0.2914E+00	-0.1143E+01	0.5496E+01	-0.5496E+01	0.2141E-01	0.3941E+00	0.1983E-01	0.3936E+00
2.04782	2.04782	14.46124	0.1588E+01	0.2847E+00	-0.1563E+01	0.7653E+01	-0.7653E+01	0.3759E-01	0.7554E+00	0.3007E-01	0.7548E+00
2.34794	2.34794	11.00058	0.2055E+01	0.2741E+00	-0.2037E+01	0.1020E+02	-0.1020E+02	0.6472E-01	0.1324E+01	0.4512E-01	0.1323E+01
2.64586	2.64586	8.66276	0.2570E+01	0.2579E+00	-0.2557E+01	0.1313E+02	-0.1313E+02	0.1890E+00	0.2168E+01	0.8025E-01	0.2167E+01
2.94160	2.94160	7.00848	0.3122E+01	0.2345E+00	-0.3113E+01	0.1647E+02	-0.1647E+02	0.5265E+00	0.3367E+01	0.1698E+00	0.3363E+01
3.23516	3.23516	5.79425	0.3700E+01	0.2000E+00	-0.3695E+01	0.2024E+02	-0.2021E+02	0.1067E+01	0.5020E+01	0.3409E+00	0.5008E+01
3.52658	3.52658	4.87621	0.4284E+01	0.1183E+00	-0.4283E+01	0.2448E+02	-0.2442E+02	0.1655E+01	0.7247E+01	0.5929E+00	0.7223E+01
3.81586	3.81586	4.16490	0.4863E+01	0.7938E-01	-0.4862E+01	0.2918E+02	-0.2910E+02	0.2107E+01	0.1019E+02	0.8563E+00	0.1015E+02
4.10302	4.10302	3.60232	0.5422E+01	-0.1723E-01	-0.5422E+01	0.3433E+02	-0.3423E+02	0.2650E+01	0.1398E+02	0.1231E+01	0.1393E+02
4.38808	4.38808	3.14950	0.5929E+01	-0.1301E+00	-0.5928E+01	0.3979E+02	-0.3957E+02	0.4213E+01	0.1875E+02	0.2163E+01	0.1862E+02
4.67105	4.67105	2.77947	0.6353E+01	-0.2611E+00	-0.6347E+01	0.4554E+02	-0.4486E+02	0.7812E+01	0.2464E+02	0.4383E+01	0.2425E+02
4.95194	4.95194	2.47309	0.6683E+01	-0.3907E+00	-0.6672E+01	0.5180E+02	-0.4976E+02	0.1437E+02	0.3202E+02	0.8939E+01	0.3075E+02
5.23078	5.23078	2.21645	0.6881E+01	-0.5471E+00	-0.6859E+01	0.5869E+02	-0.5365E+02	0.2380E+02	0.4130E+02	0.1664E+02	0.3781E+02
5.50757	5.50757	1.99927	0.6915E+01	-0.7012E+00	-0.6879E+01	0.6526E+02	-0.5551E+02	0.3432E+02	0.5225E+02	0.2716E+02	0.4464E+02
5.78233	5.78233	1.81378	0.6812E+01	-0.8482E+00	-0.6759E+01	0.7000E+02	-0.5448E+02	0.4394E+02	0.6389E+02	0.3957E+02	0.5016E+02
6.05508	6.05508	1.65406	0.6538E+01	-0.9688E+00	-0.6465E+01	0.7132E+02	-0.5002E+02	0.5085E+02	0.7457E+02	0.5239E+02	0.5307E+02
6.34885	6.34885	1.50453	0.6036E+01	-0.1056E+01	-0.5943E+01	0.6757E+02	-0.4118E+02	0.5358E+02	0.8259E+02	0.6445E+02	0.5165E+02
6.66512	6.66512	1.36513	0.5247E+01	-0.1078E+01	-0.5135E+01	0.5774E+02	-0.2813E+02	0.5042E+02	0.8494E+02	0.7289E+02	0.4361E+02
7.00561	7.00561	1.23566	0.4116E+01	-0.1006E+01	-0.3991E+01	0.4381E+02	-0.1352E+02	0.4167E+02	0.8113E+02	0.7587E+02	0.2873E+02
7.37219	7.37219	1.11583	0.2636E+01	-0.8089E+00	-0.2508E+01	0.2890E+02	-0.1116E+01	0.2888E+02	0.7281E+02	0.7226E+02	0.8944E+01
7.76684	7.76684	1.00531	0.8906E+00	-0.4564E+00	-0.7648E+00	0.1550E+02	0.5285E+01	0.1457E+02	0.6305E+02	0.6205E+02	-0.1118E+02
8.19172	8.19172	0.90373	0.1043E+01	0.7570E-01	0.1040E+01	0.4297E+01	0.3917E+01	0.1767E+01	0.5310E+02	0.4708E+02	-0.2457E+02
8.64914	8.64914	0.81067	0.2714E+01	0.7618E+00	0.2605E+01	0.7644E+01	-0.2585E+01	-0.7194E+01	0.4018E+02	0.3006E+02	-0.2666E+02
9.14159	9.14159	0.72568	0.3878E+01	0.1439E+01	0.3601E+01	0.1421E+02	-0.8995E+01	-0.1100E+02	0.2386E+02	0.1370E+02	-0.1953E+02
9.67177	9.67177	0.64830	0.4175E+01	0.1811E+01	0.3762E+01	0.1484E+02	-0.1126E+02	-0.9669E+01	0.8982E+01	0.1170E+01	-0.8905E+01
10.24255	10.24255	0.57806	0.3372E+01	0.1546E+01	0.2997E+01	0.1055E+02	-0.9272E+01	-0.5025E+01	0.5109E+01	-0.5034E+01	-0.8730E+00
10.85704	10.85704	0.51448	0.1589E+01	0.5781E+00	0.1481E+01	0.6112E+01	-0.6109E+01	-0.1865E+00	0.5755E+01	-0.4788E+01	0.3192E+01
11.51861	11.51861	0.45708	0.6773E+00	-0.6147E+00	-0.2843E+00	0.3832E+01	-0.3106E+01	0.2245E+01	0.5061E+01	-0.6766E+00	0.5016E+01
12.23084	12.23084	0.40539	0.1975E+01	-0.1226E+01	-0.1549E+01	0.1486E+01	-0.2400E+00	0.1467E+01	0.6201E+01	0.3309E+01	0.5245E+01
12.99763	12.99763	0.35897	0.1850E+01	-0.8448E+00	-0.1646E+01	0.2277E+01	0.1960E+01	-0.1159E+01	0.5001E+01	0.3904E+01	0.3126E+01
13.82315	13.82315	0.31738	0.5582E+00	-0.1378E-01	-0.5580E+00	0.3584E+01	0.2099E+01	-0.2905E+01	0.3376E+00	0.3375E+00	-0.7912E-02
14.71189	14.71189	0.28019	0.8017E+00	0.3248E+00	0.7329E+00	0.1642E+01	0.9446E+00	-0.1343E+01	0.4130E+01	-0.3876E+01	-0.1426E+01
15.66871	15.66871	0.24702	0.7924E+00	0.6351E-01	0.7899E+00	0.2008E+01	0.2219E+00	0.1996E+01	0.3255E+01	-0.2933E+01	-0.1413E+01
16.69881	16.69881	0.21748	0.4573E+00	0.8562E-01	-0.4492E+00	0.2065E+01	-0.4241E+00	0.2021E+01	0.2424E+01	0.2245E+01	-0.9122E+00
17.80781	17.80781	0.19124	0.6045E+00	0.3244E+00	-0.5101E+00	0.1312E+01	-0.5233E+00	-0.1203E+01	0.2486E+01	0.2465E+01	0.3228E+00
19.00175	19.00175	0.16796	0.9280E+00	-0.2856E+00	0.8829E+00	0.9340E+00	0.4575E-01	-0.9329E+00	0.1554E+01	-0.1553E+01	0.7133E-01
20.28714	20.28714	0.14735	0.3980E+00	-0.1879E+00	-0.3509E+00	0.7546E+00	-0.1602E+00	0.7374E+00	0.4001E+00	-0.2383E+00	0.3214E+00
21.67098	21.67098	0.12913	0.3436E+00	0.2958E+00	-0.1749E+00	0.4601E+00	0.3974E+00	-0.2320E+00	0.3804E+00	0.3703E+00	-0.8721E-01
23.16081	23.16081	0.11305	0.3131E+00	-0.2077E+00	0.2343E+00	0.4182E+00	-0.4090E+00	0.8736E-01	0.1701E+00	-0.1353E+00	-0.1031E+00
24.76475	24.76475	0.09888	0.1119E+00	0.1116E+00	-0.8652E-02	0.3762E+00	0.3740E+00	-0.4081E-01	0.3273E-01	-0.1619E-01	-0.2844E-01
26.49154	26.49154	0.08641	0.2727E+00	-0.2175E-01	-0.2718E+00	0.2238E+00	-0.2230E+00	-0.1837E-01	0.3488E+00	0.4215E-01	0.3462E+00
28.35058	28.35058	0.07545	0.1585E+00	-0.3790E-01	0.1539E+00	0.1450E+00	-0.1436E+00	0.1966E-01	0.2962E+00	0.3589E-01	-0.2940E+00
30.35202	30.35202	0.06583	0.1587E+00	-0.2455E-02	0.1587E+00	0.7439E-01	0.7031E-01	0.2429E-01	0.2731E+00	-0.4660E-03	-0.2731E+00

32.50675	32.50675	0.05739	0.9374E-01	0.6087E-02	0.9355E-01	0.6938E-01	0.6721E-01	0.1720E-01	0.1857E+00	-0.1074E-01	-0.1853E+00
34.82652	34.82652	0.05000	0.3723E-01	-0.2703E-02	0.3713E-01	0.4520E-01	-0.4356E-01	0.1208E-01	0.1254E+00	0.1090E-02	-0.1254E+00

APPENDIX F. SUBMOT OUTPUT FILE

```
** CIRC. CYL. WITH HEMI SPHERES AT BOTH ENDS: (L=40 IN) L/D=10 & ZKGG=-2D**
               ABSOLUTE AMPLITUDES OF MOTION AT SPEED =          0.00000  KNOTS
                                            FROUDE NO. =          0.00000
                                            WAVE ANGLE =        180.00000  DEGREES
                                            WATER DEPTH =         0.00000
     MOTION AMPLITUDE IN FT OR (0.5*DL*RAD)/(WAVE AMP)
```

WAVEF	ENCOF	WLRAT	H1B	H1PH	H2B	H2PH	H3B	H3PH	H4B	H4PH	H5B	H5PH	H6B	H6PH
11.013	3.483	0.500	0.003	90.00	0.000	0.00	0.003	-179.01	0.000	0.00	0.048	-89.60	0.000	0.00
10.054	3.483	0.600	0.024	90.00	0.000	0.00	0.022	-179.08	0.000	0.00	0.046	-89.48	0.000	0.00
8.992	3.483	0.750	0.037	90.00	0.000	0.00	0.035	-178.84	0.000	0.00	0.068	91.03	0.000	0.00
8.707	3.483	0.800	0.034	90.00	0.000	0.00	0.032	-178.81	0.000	0.00	0.121	91.02	0.000	0.00
8.209	3.483	0.900	0.017	90.00	0.000	0.00	0.017	-179.01	0.000	0.00	0.233	91.07	0.000	0.00
7.788	3.483	1.000	0.010	-90.00	0.000	0.00	0.009	2.71	0.000	0.00	0.340	91.10	0.000	0.00
7.425	3.483	1.100	0.044	-90.00	0.000	0.00	0.042	1.90	0.000	0.00	0.435	91.11	0.000	0.00
6.965	3.483	1.250	0.099	-90.00	0.000	0.00	0.096	1.76	0.000	0.00	0.550	91.10	0.000	0.00
6.830	3.483	1.300	0.119	-90.00	0.000	0.00	0.115	1.73	0.000	0.00	0.581	91.09	0.000	0.00
6.582	3.483	1.400	0.156	-90.00	0.000	0.00	0.153	1.67	0.000	0.00	0.633	91.06	0.000	0.00
6.359	3.483	1.500	0.193	-90.00	0.000	0.00	0.190	1.61	0.000	0.00	0.675	91.03	0.000	0.00
6.157	3.483	1.600	0.229	-90.00	0.000	0.00	0.225	1.55	0.000	0.00	0.707	90.99	0.000	0.00
5.973	3.483	1.700	0.262	-90.00	0.000	0.00	0.259	1.50	0.000	0.00	0.731	90.95	0.000	0.00
5.805	3.483	1.800	0.294	-90.00	0.000	0.00	0.291	1.44	0.000	0.00	0.748	90.92	0.000	0.00
5.650	3.483	1.900	0.324	-90.00	0.000	0.00	0.321	1.38	0.000	0.00	0.760	90.88	0.000	0.00
5.507	3.483	2.000	0.352	-90.00	0.000	0.00	0.349	1.32	0.000	0.00	0.768	90.84	0.000	0.00
5.374	3.483	2.100	0.378	-90.00	0.000	0.00	0.376	1.27	0.000	0.00	0.772	90.81	0.000	0.00
5.250	3.483	2.200	0.403	-90.00	0.000	0.00	0.401	1.22	0.000	0.00	0.773	90.77	0.000	0.00
5.135	3.483	2.300	0.426	-90.00	0.000	0.00	0.424	1.16	0.000	0.00	0.772	90.74	0.000	0.00
5.027	3.483	2.400	0.448	-90.00	0.000	0.00	0.446	1.12	0.000	0.00	0.769	90.71	0.000	0.00
4.925	3.483	2.500	0.468	-90.00	0.000	0.00	0.466	1.07	0.000	0.00	0.765	90.68	0.000	0.00
4.830	3.483	2.600	0.487	-90.00	0.000	0.00	0.486	1.03	0.000	0.00	0.760	90.65	0.000	0.00
4.739	3.483	2.700	0.505	-90.00	0.000	0.00	0.504	0.98	0.000	0.00	0.753	90.62	0.000	0.00
4.654	3.483	2.800	0.521	-90.00	0.000	0.00	0.521	0.94	0.000	0.00	0.746	90.59	0.000	0.00
4.573	3.483	2.900	0.537	-90.00	0.000	0.00	0.537	0.91	0.000	0.00	0.738	90.57	0.000	0.00
4.496	3.483	3.000	0.552	-90.00	0.000	0.00	0.552	0.87	0.000	0.00	0.730	90.54	0.000	0.00
4.423	3.483	3.100	0.566	-90.00	0.000	0.00	0.566	0.84	0.000	0.00	0.721	90.52	0.000	0.00
4.353	3.483	3.200	0.579	-90.00	0.000	0.00	0.579	0.80	0.000	0.00	0.712	90.50	0.000	0.00
4.287	3.483	3.300	0.592	-90.00	0.000	0.00	0.592	0.77	0.000	0.00	0.704	90.48	0.000	0.00
4.223	3.483	3.400	0.603	-90.00	0.000	0.00	0.604	0.74	0.000	0.00	0.695	90.46	0.000	0.00
4.163	3.483	3.500	0.615	-90.00	0.000	0.00	0.615	0.72	0.000	0.00	0.686	90.44	0.000	0.00
4.104	3.483	3.600	0.625	-90.00	0.000	0.00	0.626	0.69	0.000	0.00	0.677	90.43	0.000	0.00
4.049	3.483	3.700	0.635	-90.00	0.000	0.00	0.637	0.67	0.000	0.00	0.667	90.41	0.000	0.00
3.995	3.483	3.800	0.645	-90.00	0.000	0.00	0.646	0.64	0.000	0.00	0.659	90.39	0.000	0.00
3.943	3.483	3.900	0.654	-90.00	0.000	0.00	0.655	0.62	0.000	0.00	0.650	90.38	0.000	0.00

3.894	3.483	4.000	0.663	-90.00	0.000	0.00	0.664	0.60	0.000	0.00	0.641	90.36	0.000	0.00
3.846	3.483	4.100	0.671	-90.00	0.000	0.00	0.673	0.58	0.000	0.00	0.632	90.35	0.000	0.00
3.800	3.483	4.200	0.679	-90.00	0.000	0.00	0.681	0.56	0.000	0.00	0.624	90.34	0.000	0.00
3.756	3.483	4.300	0.687	-90.00	0.000	0.00	0.688	0.54	0.000	0.00	0.615	90.33	0.000	0.00
3.713	3.483	4.400	0.694	-90.00	0.000	0.00	0.696	0.52	0.000	0.00	0.607	90.32	0.000	0.00
3.671	3.483	4.500	0.701	-90.00	0.000	0.00	0.703	0.51	0.000	0.00	0.599	90.31	0.000	0.00
3.631	3.483	4.600	0.707	-90.00	0.000	0.00	0.709	0.49	0.000	0.00	0.591	90.29	0.000	0.00
3.592	3.483	4.700	0.714	-90.00	0.000	0.00	0.716	0.48	0.000	0.00	0.583	90.29	0.000	0.00
3.555	3.483	4.800	0.720	-90.00	0.000	0.00	0.722	0.46	0.000	0.00	0.576	90.28	0.000	0.00
3.518	3.483	4.900	0.726	-90.00	0.000	0.00	0.728	0.45	0.000	0.00	0.568	90.27	0.000	0.00
3.483	3.483	5.000	0.731	-90.00	0.000	0.00	0.733	0.43	0.000	0.00	0.561	90.26	0.000	0.00

ABSOLUTE AMPLITUDES OF MOTION AT SPEED = 0.00000 KNOTS
FROUDE NO. = 0.00000
WAVE ANGLE = 180.00000 DEGREES
WATER DEPTH = 0.00000

MOTION AMPLITUDE IN FT OR DEGREE/(WAVE AMP)

WAVEF	ENCOF	WLRAT	H1B	H1PH	H2B	H2PH	H3B	H3PH	H4B	H4PH	H5B	H5PH	H6B	H6PH
11.013	11.013	0.500	0.003	90.00	0.000	0.00	0.003	-179.01	0.000	0.00	1.642	-89.60	0.000	0.00
10.054	10.054	0.600	0.024	90.00	0.000	0.00	0.022	-179.08	0.000	0.00	1.570	-89.48	0.000	0.00
8.992	8.992	0.750	0.037	90.00	0.000	0.00	0.035	-178.84	0.000	0.00	2.321	91.03	0.000	0.00
8.707	8.707	0.800	0.034	90.00	0.000	0.00	0.032	-178.81	0.000	0.00	4.161	91.02	0.000	0.00
8.209	8.209	0.900	0.017	90.00	0.000	0.00	0.017	-179.01	0.000	0.00	8.015	91.07	0.000	0.00
7.788	7.788	1.000	0.010	-90.00	0.000	0.00	0.009	2.71	0.000	0.00	11.695	91.10	0.000	0.00
7.425	7.425	1.100	0.044	-90.00	0.000	0.00	0.042	1.90	0.000	0.00	14.952	91.11	0.000	0.00
6.965	6.965	1.250	0.099	-90.00	0.000	0.00	0.096	1.76	0.000	0.00	18.895	91.10	0.000	0.00
6.830	6.830	1.300	0.119	-90.00	0.000	0.00	0.115	1.73	0.000	0.00	19.965	91.09	0.000	0.00
6.582	6.582	1.400	0.156	-90.00	0.000	0.00	0.153	1.67	0.000	0.00	21.777	91.06	0.000	0.00
6.359	6.359	1.500	0.193	-90.00	0.000	0.00	0.190	1.61	0.000	0.00	23.200	91.03	0.000	0.00
6.157	6.157	1.600	0.229	-90.00	0.000	0.00	0.225	1.55	0.000	0.00	24.296	90.99	0.000	0.00
5.973	5.973	1.700	0.262	-90.00	0.000	0.00	0.259	1.50	0.000	0.00	25.120	90.95	0.000	0.00
5.805	5.805	1.800	0.294	-90.00	0.000	0.00	0.291	1.44	0.000	0.00	25.719	90.92	0.000	0.00
5.650	5.650	1.900	0.324	-90.00	0.000	0.00	0.321	1.38	0.000	0.00	26.134	90.88	0.000	0.00
5.507	5.507	2.000	0.352	-90.00	0.000	0.00	0.349	1.32	0.000	0.00	26.398	90.84	0.000	0.00
5.374	5.374	2.100	0.378	-90.00	0.000	0.00	0.376	1.27	0.000	0.00	26.542	90.81	0.000	0.00
5.250	5.250	2.200	0.403	-90.00	0.000	0.00	0.401	1.22	0.000	0.00	26.587	90.77	0.000	0.00
5.135	5.135	2.300	0.426	-90.00	0.000	0.00	0.424	1.16	0.000	0.00	26.552	90.74	0.000	0.00
5.027	5.027	2.400	0.448	-90.00	0.000	0.00	0.446	1.12	0.000	0.00	26.452	90.71	0.000	0.00
4.925	4.925	2.500	0.468	-90.00	0.000	0.00	0.466	1.07	0.000	0.00	26.302	90.68	0.000	0.00
4.830	4.830	2.600	0.487	-90.00	0.000	0.00	0.486	1.03	0.000	0.00	26.111	90.65	0.000	0.00
4.739	4.739	2.700	0.505	-90.00	0.000	0.00	0.504	0.98	0.000	0.00	25.888	90.62	0.000	0.00
4.654	4.654	2.800	0.521	-90.00	0.000	0.00	0.521	0.94	0.000	0.00	25.640	90.59	0.000	0.00
4.573	4.573	2.900	0.537	-90.00	0.000	0.00	0.537	0.91	0.000	0.00	25.373	90.57	0.000	0.00
4.496	4.496	3.000	0.552	-90.00	0.000	0.00	0.552	0.87	0.000	0.00	25.090	90.54	0.000	0.00
4.423	4.423	3.100	0.566	-90.00	0.000	0.00	0.566	0.84	0.000	0.00	24.799	90.52	0.000	0.00
4.353	4.353	3.200	0.579	-90.00	0.000	0.00	0.579	0.80	0.000	0.00	24.494	90.50	0.000	0.00
4.287	4.287	3.300	0.592	-90.00	0.000	0.00	0.592	0.77	0.000	0.00	24.186	90.48	0.000	0.00
4.223	4.223	3.400	0.603	-90.00	0.000	0.00	0.604	0.74	0.000	0.00	23.882	90.46	0.000	0.00

4.163	4.163	3.500	0.615	-90.00	0.000	0.00	0.615	0.72	0.000	0.00	23.566	90.44	0.000	0.00
4.104	4.104	3.600	0.625	-90.00	0.000	0.00	0.626	0.69	0.000	0.00	23.257	90.43	0.000	0.00
4.049	4.049	3.700	0.635	-90.00	0.000	0.00	0.637	0.67	0.000	0.00	22.945	90.41	0.000	0.00
3.995	3.995	3.800	0.645	-90.00	0.000	0.00	0.646	0.64	0.000	0.00	22.638	90.39	0.000	0.00
3.943	3.943	3.900	0.654	-90.00	0.000	0.00	0.655	0.62	0.000	0.00	22.335	90.38	0.000	0.00
3.894	3.894	4.000	0.663	-90.00	0.000	0.00	0.664	0.60	0.000	0.00	22.044	90.36	0.000	0.00
3.846	3.846	4.100	0.671	-90.00	0.000	0.00	0.673	0.58	0.000	0.00	21.732	90.35	0.000	0.00
3.800	3.800	4.200	0.679	-90.00	0.000	0.00	0.681	0.56	0.000	0.00	21.451	90.34	0.000	0.00
3.756	3.756	4.300	0.687	-90.00	0.000	0.00	0.688	0.54	0.000	0.00	21.155	90.33	0.000	0.00
3.713	3.713	4.400	0.694	-90.00	0.000	0.00	0.696	0.52	0.000	0.00	20.871	90.32	0.000	0.00
3.671	3.671	4.500	0.701	-90.00	0.000	0.00	0.703	0.51	0.000	0.00	20.597	90.31	0.000	0.00
3.631	3.631	4.600	0.707	-90.00	0.000	0.00	0.709	0.49	0.000	0.00	20.328	90.29	0.000	0.00
3.592	3.592	4.700	0.714	-90.00	0.000	0.00	0.716	0.48	0.000	0.00	20.048	90.29	0.000	0.00
3.555	3.555	4.800	0.720	-90.00	0.000	0.00	0.722	0.46	0.000	0.00	19.799	90.28	0.000	0.00
3.518	3.518	4.900	0.726	-90.00	0.000	0.00	0.728	0.45	0.000	0.00	19.543	90.27	0.000	0.00
3.483	3.483	5.000	0.731	-90.00	0.000	0.00	0.733	0.43	0.000	0.00	19.289	90.26	0.000	0.00

ABSOLUTE AMPLITUDES OF MOTION AT SPEED = 0.00000 KNOTS
FROUDE NO. = 0.00000
WAVE ANGLE = 180.00000 DEGREES
WATER DEPTH = 0.00000

MOTION AMPLITUDE IN FT/A OR RAD/(K*A), A=WAVE AMP.

WAVEF	ENCOF	WLRAT	H1B	H1PH	H2B	H2PH	H3B	H3PH	H4B	H4PH	H5B	H5PH	H6B	H6PH
11.013	0.000	0.500	0.003	90.00	0.000	0.00	0.003	-179.01	0.000	0.00	0.008	-89.60	0.000	0.00
10.054	0.000	0.600	0.024	90.00	0.000	0.00	0.022	-179.08	0.000	0.00	0.009	-89.48	0.000	0.00
8.992	0.000	0.750	0.037	90.00	0.000	0.00	0.035	-178.84	0.000	0.00	0.016	91.03	0.000	0.00
8.707	0.000	0.800	0.034	90.00	0.000	0.00	0.032	-178.81	0.000	0.00	0.031	91.02	0.000	0.00
8.209	0.000	0.900	0.017	90.00	0.000	0.00	0.017	-179.01	0.000	0.00	0.067	91.07	0.000	0.00
7.788	0.000	1.000	0.010	-90.00	0.000	0.00	0.009	2.71	0.000	0.00	0.108	91.10	0.000	0.00
7.425	0.000	1.100	0.044	-90.00	0.000	0.00	0.042	1.90	0.000	0.00	0.152	91.11	0.000	0.00
6.965	0.000	1.250	0.099	-90.00	0.000	0.00	0.096	1.76	0.000	0.00	0.219	91.10	0.000	0.00
6.830	0.000	1.300	0.119	-90.00	0.000	0.00	0.115	1.73	0.000	0.00	0.240	91.09	0.000	0.00
6.582	0.000	1.400	0.156	-90.00	0.000	0.00	0.153	1.67	0.000	0.00	0.282	91.06	0.000	0.00
6.359	0.000	1.500	0.193	-90.00	0.000	0.00	0.190	1.61	0.000	0.00	0.322	91.03	0.000	0.00
6.157	0.000	1.600	0.229	-90.00	0.000	0.00	0.225	1.55	0.000	0.00	0.360	90.99	0.000	0.00
5.973	0.000	1.700	0.262	-90.00	0.000	0.00	0.259	1.50	0.000	0.00	0.395	90.95	0.000	0.00
5.805	0.000	1.800	0.294	-90.00	0.000	0.00	0.291	1.44	0.000	0.00	0.429	90.92	0.000	0.00
5.650	0.000	1.900	0.324	-90.00	0.000	0.00	0.321	1.38	0.000	0.00	0.460	90.88	0.000	0.00
5.507	0.000	2.000	0.352	-90.00	0.000	0.00	0.349	1.32	0.000	0.00	0.489	90.84	0.000	0.00
5.374	0.000	2.100	0.378	-90.00	0.000	0.00	0.376	1.27	0.000	0.00	0.516	90.81	0.000	0.00
5.250	0.000	2.200	0.403	-90.00	0.000	0.00	0.401	1.22	0.000	0.00	0.542	90.77	0.000	0.00
5.135	0.000	2.300	0.426	-90.00	0.000	0.00	0.424	1.16	0.000	0.00	0.565	90.74	0.000	0.00
5.027	0.000	2.400	0.448	-90.00	0.000	0.00	0.446	1.12	0.000	0.00	0.588	90.71	0.000	0.00
4.925	0.000	2.500	0.468	-90.00	0.000	0.00	0.466	1.07	0.000	0.00	0.609	90.68	0.000	0.00
4.830	0.000	2.600	0.487	-90.00	0.000	0.00	0.486	1.03	0.000	0.00	0.629	90.65	0.000	0.00
4.739	0.000	2.700	0.505	-90.00	0.000	0.00	0.504	0.98	0.000	0.00	0.647	90.62	0.000	0.00
4.654	0.000	2.800	0.521	-90.00	0.000	0.00	0.521	0.94	0.000	0.00	0.665	90.59	0.000	0.00
4.573	0.000	2.900	0.537	-90.00	0.000	0.00	0.537	0.91	0.000	0.00	0.681	90.57	0.000	0.00

4.496	0.000	3.000	0.552	-90.00	0.000	0.00	0.552	0.87	0.000	0.00	0.697	90.54	0.000	0.00
4.423	0.000	3.100	0.566	-90.00	0.000	0.00	0.566	0.84	0.000	0.00	0.712	90.52	0.000	0.00
4.353	0.000	3.200	0.579	-90.00	0.000	0.00	0.579	0.80	0.000	0.00	0.726	90.50	0.000	0.00
4.287	0.000	3.300	0.592	-90.00	0.000	0.00	0.592	0.77	0.000	0.00	0.739	90.48	0.000	0.00
4.223	0.000	3.400	0.603	-90.00	0.000	0.00	0.604	0.74	0.000	0.00	0.752	90.46	0.000	0.00
4.163	0.000	3.500	0.615	-90.00	0.000	0.00	0.615	0.72	0.000	0.00	0.764	90.44	0.000	0.00
4.104	0.000	3.600	0.625	-90.00	0.000	0.00	0.626	0.69	0.000	0.00	0.775	90.43	0.000	0.00
4.049	0.000	3.700	0.635	-90.00	0.000	0.00	0.637	0.67	0.000	0.00	0.786	90.41	0.000	0.00
3.995	0.000	3.800	0.645	-90.00	0.000	0.00	0.646	0.64	0.000	0.00	0.797	90.39	0.000	0.00
3.943	0.000	3.900	0.654	-90.00	0.000	0.00	0.655	0.62	0.000	0.00	0.807	90.38	0.000	0.00
3.894	0.000	4.000	0.663	-90.00	0.000	0.00	0.664	0.60	0.000	0.00	0.816	90.36	0.000	0.00
3.846	0.000	4.100	0.671	-90.00	0.000	0.00	0.673	0.58	0.000	0.00	0.825	90.35	0.000	0.00
3.800	0.000	4.200	0.679	-90.00	0.000	0.00	0.681	0.56	0.000	0.00	0.834	90.34	0.000	0.00
3.756	0.000	4.300	0.687	-90.00	0.000	0.00	0.688	0.54	0.000	0.00	0.842	90.33	0.000	0.00
3.713	0.000	4.400	0.694	-90.00	0.000	0.00	0.696	0.52	0.000	0.00	0.850	90.32	0.000	0.00
3.671	0.000	4.500	0.701	-90.00	0.000	0.00	0.703	0.51	0.000	0.00	0.858	90.31	0.000	0.00
3.631	0.000	4.600	0.707	-90.00	0.000	0.00	0.709	0.49	0.000	0.00	0.866	90.29	0.000	0.00
3.592	0.000	4.700	0.714	-90.00	0.000	0.00	0.716	0.48	0.000	0.00	0.872	90.29	0.000	0.00
3.555	0.000	4.800	0.720	-90.00	0.000	0.00	0.722	0.46	0.000	0.00	0.880	90.28	0.000	0.00
3.518	0.000	4.900	0.726	-90.00	0.000	0.00	0.728	0.45	0.000	0.00	0.887	90.27	0.000	0.00
3.483	0.000	5.000	0.731	-90.00	0.000	0.00	0.733	0.43	0.000	0.00	0.893	90.26	0.000	0.00

SUBMOT RESULTS: E. F & M

WLB	F1B	F1PAB	F2B	F2PAB	F3B	F3PAB	F4B	F4PAB	F5B	F5PAB	F6B	F6PAB
0.5000	0.284E-03	-90.00	0.398E-10	0.00	0.513E-03	1.91	0.238E-12	0.00	0.119E-02	91.47	0.111E-09	0.00
0.6000	0.185E-02	-90.00	0.326E-09	0.00	0.345E-02	2.40	0.106E-11	0.00	0.947E-03	92.24	0.864E-10	0.00
0.7500	0.232E-02	-90.00	0.355E-09	0.00	0.442E-02	3.37	0.101E-11	0.00	0.113E-02	-86.40	0.102E-09	0.00
0.8000	0.199E-02	-90.00	0.384E-09	0.00	0.381E-02	3.60	0.799E-12	0.00	0.190E-02	-86.17	0.169E-09	0.00
0.9000	0.883E-03	-90.00	0.186E-09	0.00	0.174E-02	3.70	0.287E-12	0.00	0.327E-02	-85.78	0.293E-09	0.00
1.0000	0.483E-03	90.00	0.170E-09	0.00	0.891E-03	-174.37	0.206E-12	0.00	0.432E-02	-85.50	0.379E-09	0.00
1.1000	0.187E-02	90.00	0.444E-09	0.00	0.363E-02	-175.04	0.614E-12	0.00	0.505E-02	-85.34	0.437E-09	-178.50
1.2500	0.375E-02	90.00	0.710E-09	0.00	0.744E-02	-175.11	0.105E-11	0.00	0.567E-02	-85.25	0.504E-09	-175.22
1.3000	0.430E-02	90.00	0.717E-09	0.00	0.857E-02	-175.13	0.115E-11	0.00	0.577E-02	-85.26	0.522E-09	-173.59
1.4000	0.527E-02	90.00	0.862E-09	0.00	0.106E-01	-175.21	0.130E-11	0.00	0.587E-02	-85.31	0.514E-09	178.74
1.5000	0.607E-02	90.00	0.112E-08	0.00	0.123E-01	-175.31	0.139E-11	0.00	0.587E-02	-85.39	0.506E-09	-177.98
1.6000	0.674E-02	90.00	0.118E-08	0.00	0.138E-01	-175.43	0.144E-11	0.00	0.578E-02	-85.50	0.491E-09	-178.00
1.7000	0.727E-02	90.00	0.113E-08	0.00	0.149E-01	-175.56	0.146E-11	0.00	0.564E-02	-85.62	0.499E-09	-179.35
1.8000	0.770E-02	90.00	0.134E-08	0.00	0.159E-01	-175.71	0.145E-11	0.00	0.547E-02	-85.76	0.473E-09	-179.76
1.9000	0.804E-02	90.00	0.156E-08	-86.43	0.167E-01	-175.85	0.144E-11	0.00	0.528E-02	-85.90	0.488E-09	-178.35
2.0000	0.829E-02	90.00	0.142E-08	-80.86	0.173E-01	-176.00	0.141E-11	0.00	0.508E-02	-86.05	0.452E-09	179.57
2.1000	0.849E-02	90.00	0.167E-08	-83.63	0.177E-01	-176.15	0.137E-11	0.00	0.487E-02	-86.19	0.429E-09	-178.08
2.2000	0.863E-02	90.00	0.154E-08	-89.03	0.181E-01	-176.30	0.133E-11	0.00	0.466E-02	-86.34	0.400E-09	0.00
2.3000	0.873E-02	90.00	0.173E-08	-85.76	0.183E-01	-176.44	0.129E-11	0.00	0.446E-02	-86.48	0.407E-09	0.00
2.4000	0.879E-02	90.00	0.155E-08	-85.99	0.185E-01	-176.58	0.125E-11	0.00	0.426E-02	-86.61	0.385E-09	0.00
2.5000	0.881E-02	90.00	0.160E-08	-84.40	0.186E-01	-176.71	0.120E-11	0.00	0.407E-02	-86.74	0.396E-09	0.00
2.6000	0.882E-02	90.00	0.152E-08	-89.34	0.186E-01	-176.84	0.117E-11	0.00	0.389E-02	-86.87	0.327E-09	0.00
2.7000	0.880E-02	90.00	0.160E-08	-89.10	0.186E-01	-176.97	0.112E-11	0.00	0.371E-02	-86.99	0.325E-09	0.00
2.8000	0.877E-02	90.00	0.162E-08	-91.26	0.186E-01	-177.08	0.107E-11	0.00	0.355E-02	-87.11	0.287E-09	0.00

2.9000	0.872E-02	90.00	0.158E-08	-88.28	0.185E-01	-177.20	0.102E-11	0.00	0.339E-02	-87.22	0.277E-09	0.00
3.0000	0.867E-02	90.00	0.158E-08	-87.76	0.184E-01	-177.30	0.982E-12	0.00	0.324E-02	-87.33	0.276E-09	0.00
3.1000	0.860E-02	90.00	0.164E-08	-88.63	0.183E-01	-177.41	0.914E-12	0.00	0.310E-02	-87.43	0.281E-09	0.00
3.2000	0.853E-02	90.00	0.166E-08	-88.46	0.181E-01	-177.50	0.909E-12	0.00	0.296E-02	-87.52	0.247E-09	0.00
3.3000	0.845E-02	90.00	0.156E-08	-87.53	0.180E-01	-177.60	0.885E-12	0.00	0.284E-02	-87.62	0.254E-09	0.00
3.4000	0.836E-02	90.00	0.160E-08	-86.71	0.178E-01	-177.69	0.803E-12	0.00	0.272E-02	-87.70	0.226E-09	0.00
3.5000	0.827E-02	90.00	0.157E-08	-89.01	0.176E-01	-177.77	0.810E-12	0.00	0.260E-02	-87.79	0.224E-09	0.00
3.6000	0.818E-02	90.00	0.148E-08	-87.76	0.174E-01	-177.85	0.766E-12	0.00	0.250E-02	-87.87	0.216E-09	0.00
3.7000	0.809E-02	90.00	0.151E-08	-86.11	0.172E-01	-177.93	0.753E-12	0.00	0.240E-02	-87.94	0.200E-09	0.00
3.8000	0.800E-02	90.00	0.143E-08	-88.28	0.170E-01	-178.00	0.721E-12	0.00	0.230E-02	-88.01	0.194E-09	0.00
3.9000	0.790E-02	90.00	0.141E-08	-91.56	0.168E-01	-178.07	0.685E-12	0.00	0.221E-02	-88.08	0.185E-09	0.00
4.0000	0.781E-02	90.00	0.154E-08	-90.58	0.166E-01	-178.13	0.583E-12	0.00	0.213E-02	-88.15	0.192E-09	0.00
4.1000	0.771E-02	90.00	0.143E-08	-88.47	0.164E-01	-178.20	0.674E-12	0.00	0.204E-02	-88.21	0.178E-09	0.00
4.2000	0.762E-02	90.00	0.134E-08	0.00	0.162E-01	-178.26	0.564E-12	0.00	0.197E-02	-88.27	0.165E-09	0.00
4.3000	0.752E-02	90.00	0.140E-08	0.00	0.160E-01	-178.31	0.611E-12	0.00	0.190E-02	-88.33	0.163E-09	0.00
4.4000	0.743E-02	90.00	0.140E-08	0.00	0.158E-01	-178.37	0.599E-12	0.00	0.183E-02	-88.38	0.150E-09	0.00
4.5000	0.734E-02	90.00	0.133E-08	0.00	0.156E-01	-178.42	0.551E-12	0.00	0.176E-02	-88.43	0.146E-09	0.00
4.6000	0.724E-02	90.00	0.136E-08	0.00	0.154E-01	-178.47	0.510E-12	0.00	0.170E-02	-88.48	0.140E-09	0.00
4.7000	0.715E-02	90.00	0.135E-08	0.00	0.152E-01	-178.52	0.578E-12	0.00	0.164E-02	-88.53	0.125E-09	0.00
4.8000	0.706E-02	90.00	0.136E-08	0.00	0.151E-01	-178.56	0.480E-12	0.00	0.158E-02	-88.57	0.135E-09	0.00
4.9000	0.698E-02	90.00	0.123E-08	0.00	0.149E-01	-178.61	0.459E-12	0.00	0.153E-02	-88.62	0.128E-09	0.00
5.0000	0.689E-02	90.00	0.132E-08	0.00	0.147E-01	-178.65	0.466E-12	0.00	0.148E-02	-88.66	0.118E-09	0.00

SUBMOT RESULTS: E. F & M FOR PLOT

WO	WE	WLR	F1B	F2B	F3B	F4B	F5B	F6B
11.013	11.013	0.500	0.2844E-03	0.3980E-10	0.5128E-03	0.2378E-12	0.1190E-02	0.1105E-09
10.054	10.054	0.600	0.1854E-02	0.3262E-09	0.3455E-02	0.1056E-11	0.9471E-03	0.8644E-10
8.992	8.992	0.750	0.2324E-02	0.3553E-09	0.4424E-02	0.1015E-11	0.1126E-02	0.1023E-09
8.707	8.707	0.800	0.1985E-02	0.3837E-09	0.3811E-02	0.7994E-12	0.1897E-02	0.1694E-09
8.209	8.209	0.900	0.8826E-03	0.1858E-09	0.1742E-02	0.2874E-12	0.3267E-02	0.2933E-09
7.788	7.788	1.000	0.4827E-03	0.1704E-09	0.8912E-03	0.2057E-12	0.4318E-02	0.3789E-09
7.425	7.425	1.100	0.1872E-02	0.4439E-09	0.3634E-02	0.6138E-12	0.5050E-02	0.4368E-09
6.965	6.965	1.250	0.3750E-02	0.7095E-09	0.7437E-02	0.1046E-11	0.5665E-02	0.5041E-09
6.830	6.830	1.300	0.4297E-02	0.7175E-09	0.8567E-02	0.1146E-11	0.5771E-02	0.5218E-09
6.582	6.582	1.400	0.5266E-02	0.8616E-09	0.1060E-01	0.1297E-11	0.5874E-02	0.5143E-09
6.359	6.359	1.500	0.6074E-02	0.1119E-08	0.1232E-01	0.1390E-11	0.5866E-02	0.5065E-09
6.157	6.157	1.600	0.6737E-02	0.1180E-08	0.1376E-01	0.1443E-11	0.5780E-02	0.4909E-09
5.973	5.973	1.700	0.7272E-02	0.1133E-08	0.1494E-01	0.1463E-11	0.5643E-02	0.4987E-09
5.805	5.805	1.800	0.7700E-02	0.1339E-08	0.1589E-01	0.1454E-11	0.5472E-02	0.4727E-09
5.650	5.650	1.900	0.8035E-02	0.1556E-08	0.1666E-01	0.1436E-11	0.5280E-02	0.4884E-09
5.507	5.507	2.000	0.8294E-02	0.1416E-08	0.1726E-01	0.1410E-11	0.5076E-02	0.4524E-09
5.374	5.374	2.100	0.8488E-02	0.1669E-08	0.1773E-01	0.1370E-11	0.4869E-02	0.4289E-09
5.250	5.250	2.200	0.8629E-02	0.1537E-08	0.1807E-01	0.1325E-11	0.4662E-02	0.3997E-09
5.135	5.135	2.300	0.8725E-02	0.1726E-08	0.1832E-01	0.1289E-11	0.4458E-02	0.4074E-09
5.027	5.027	2.400	0.8785E-02	0.1553E-08	0.1849E-01	0.1255E-11	0.4260E-02	0.3848E-09
4.925	4.925	2.500	0.8815E-02	0.1602E-08	0.1858E-01	0.1204E-11	0.4069E-02	0.3960E-09
4.830	4.830	2.600	0.8819E-02	0.1521E-08	0.1862E-01	0.1168E-11	0.3886E-02	0.3268E-09
4.739	4.739	2.700	0.8803E-02	0.1601E-08	0.1862E-01	0.1118E-11	0.3712E-02	0.3246E-09

4.654	4.654	2.800	0.8771E-02	0.1617E-08	0.1857E-01	0.1066E-11	0.3546E-02	0.2869E-09
4.573	4.573	2.900	0.8724E-02	0.1576E-08	0.1849E-01	0.1018E-11	0.3388E-02	0.2767E-09
4.496	4.496	3.000	0.8666E-02	0.1581E-08	0.1839E-01	0.9817E-12	0.3239E-02	0.2756E-09
4.423	4.423	3.100	0.8600E-02	0.1640E-08	0.1826E-01	0.9139E-12	0.3098E-02	0.2807E-09
4.353	4.353	3.200	0.8525E-02	0.1661E-08	0.1811E-01	0.9092E-12	0.2963E-02	0.2474E-09
4.287	4.287	3.300	0.8445E-02	0.1565E-08	0.1796E-01	0.8848E-12	0.2837E-02	0.2536E-09
4.223	4.223	3.400	0.8361E-02	0.1602E-08	0.1779E-01	0.8028E-12	0.2718E-02	0.2256E-09
4.163	4.163	3.500	0.8273E-02	0.1566E-08	0.1761E-01	0.8097E-12	0.2605E-02	0.2239E-09
4.104	4.104	3.600	0.8182E-02	0.1481E-08	0.1742E-01	0.7660E-12	0.2498E-02	0.2159E-09
4.049	4.049	3.700	0.8089E-02	0.1507E-08	0.1723E-01	0.7526E-12	0.2397E-02	0.2001E-09
3.995	3.995	3.800	0.7995E-02	0.1427E-08	0.1703E-01	0.7207E-12	0.2302E-02	0.1938E-09
3.943	3.943	3.900	0.7901E-02	0.1410E-08	0.1683E-01	0.6853E-12	0.2211E-02	0.1845E-09
3.894	3.894	4.000	0.7806E-02	0.1539E-08	0.1663E-01	0.5834E-12	0.2127E-02	0.1922E-09
3.846	3.846	4.100	0.7710E-02	0.1431E-08	0.1643E-01	0.6737E-12	0.2045E-02	0.1778E-09
3.800	3.800	4.200	0.7616E-02	0.1343E-08	0.1623E-01	0.5640E-12	0.1969E-02	0.1651E-09
3.756	3.756	4.300	0.7521E-02	0.1404E-08	0.1603E-01	0.6106E-12	0.1896E-02	0.1635E-09
3.713	3.713	4.400	0.7428E-02	0.1403E-08	0.1583E-01	0.5994E-12	0.1826E-02	0.1496E-09
3.671	3.671	4.500	0.7335E-02	0.1329E-08	0.1564E-01	0.5507E-12	0.1761E-02	0.1463E-09
3.631	3.631	4.600	0.7244E-02	0.1363E-08	0.1544E-01	0.5099E-12	0.1699E-02	0.1402E-09
3.592	3.592	4.700	0.7153E-02	0.1352E-08	0.1525E-01	0.5781E-12	0.1639E-02	0.1252E-09
3.555	3.555	4.800	0.7064E-02	0.1359E-08	0.1506E-01	0.4803E-12	0.1584E-02	0.1351E-09
3.518	3.518	4.900	0.6976E-02	0.1231E-08	0.1487E-01	0.4589E-12	0.1531E-02	0.1280E-09
3.483	3.483	5.000	0.6889E-02	0.1316E-08	0.1468E-01	0.4657E-12	0.1480E-02	0.1180E-09

H1-H3 WITH FT/A AND H4-H6 WITH DEG/A

SUBMOT RESULTS: MOTION RESULTS FOR PLOT

WO	WE	WLR	H1B	H2B	H3B	H4B	H5B	H6B
11.013	11.013	0.500	0.3018E-02	0.2134E-09	0.2749E-02	0.1124E-07	0.1642E+01	0.1520E-06
10.054	10.054	0.600	0.2362E-01	0.2099E-08	0.2224E-01	0.6117E-07	0.1570E+01	0.1428E-06
8.992	8.992	0.750	0.3701E-01	0.2845E-08	0.3542E-01	0.7587E-07	0.2321E+01	0.2101E-06
8.707	8.707	0.800	0.3372E-01	0.3269E-08	0.3247E-01	0.6445E-07	0.4161E+01	0.3699E-06
8.209	8.209	0.900	0.1687E-01	0.1771E-08	0.1661E-01	0.2665E-07	0.8015E+01	0.7157E-06
7.788	7.788	1.000	0.1024E-01	0.1794E-08	0.9381E-02	0.2168E-07	0.1170E+02	0.1020E-05
7.425	7.425	1.100	0.4371E-01	0.5110E-08	0.4183E-01	0.7283E-07	0.1495E+02	0.1285E-05
6.965	6.965	1.250	0.9950E-01	0.9205E-08	0.9648E-01	0.1462E-06	0.1890E+02	0.1669E-05
6.830	6.830	1.300	0.1186E+00	0.9656E-08	0.1153E+00	0.1687E-06	0.1997E+02	0.1792E-05
6.582	6.582	1.400	0.1565E+00	0.1243E-07	0.1529E+00	0.2108E-06	0.2178E+02	0.1891E-05
6.359	6.359	1.500	0.1934E+00	0.1723E-07	0.1896E+00	0.2482E-06	0.2320E+02	0.1986E-05
6.157	6.157	1.600	0.2288E+00	0.1930E-07	0.2250E+00	0.2823E-06	0.2430E+02	0.2045E-05
5.973	5.973	1.700	0.2624E+00	0.1962E-07	0.2587E+00	0.3123E-06	0.2512E+02	0.2199E-05
5.805	5.805	1.800	0.2942E+00	0.2450E-07	0.2907E+00	0.3380E-06	0.2572E+02	0.2200E-05
5.650	5.650	1.900	0.3241E+00	0.2996E-07	0.3208E+00	0.3625E-06	0.2613E+02	0.2392E-05
5.507	5.507	2.000	0.3521E+00	0.2863E-07	0.3491E+00	0.3858E-06	0.2640E+02	0.2326E-05
5.374	5.374	2.100	0.3784E+00	0.3537E-07	0.3757E+00	0.4058E-06	0.2654E+02	0.2310E-05
5.250	5.250	2.200	0.4030E+00	0.3407E-07	0.4006E+00	0.4243E-06	0.2659E+02	0.2251E-05
5.135	5.135	2.300	0.4260E+00	0.3995E-07	0.4240E+00	0.4454E-06	0.2655E+02	0.2395E-05
5.027	5.027	2.400	0.4476E+00	0.3745E-07	0.4459E+00	0.4678E-06	0.2645E+02	0.2357E-05
4.925	4.925	2.500	0.4678E+00	0.4020E-07	0.4664E+00	0.4842E-06	0.2630E+02	0.2524E-05

4.830	4.830	2.600	0.4868E+00	0.3967E-07	0.4856E+00	0.5060E-06	0.2611E+02	0.2164E-05
4.739	4.739	2.700	0.5046E+00	0.4332E-07	0.5037E+00	0.5218E-06	0.2589E+02	0.2230E-05
4.654	4.654	2.800	0.5213E+00	0.4534E-07	0.5207E+00	0.5362E-06	0.2564E+02	0.2043E-05
4.573	4.573	2.900	0.5371E+00	0.4574E-07	0.5367E+00	0.5521E-06	0.2537E+02	0.2039E-05
4.496	4.496	3.000	0.5519E+00	0.4744E-07	0.5518E+00	0.5742E-06	0.2509E+02	0.2100E-05
4.423	4.423	3.100	0.5659E+00	0.5082E-07	0.5660E+00	0.5769E-06	0.2480E+02	0.2209E-05
4.353	4.353	3.200	0.5791E+00	0.5312E-07	0.5794E+00	0.6200E-06	0.2449E+02	0.2009E-05
4.287	4.287	3.300	0.5916E+00	0.5161E-07	0.5921E+00	0.6527E-06	0.2419E+02	0.2123E-05
4.223	4.223	3.400	0.6035E+00	0.5440E-07	0.6041E+00	0.6413E-06	0.2388E+02	0.1945E-05
4.163	4.163	3.500	0.6146E+00	0.5476E-07	0.6155E+00	0.7019E-06	0.2357E+02	0.1986E-05
4.104	4.104	3.600	0.6253E+00	0.5326E-07	0.6263E+00	0.7220E-06	0.2326E+02	0.1970E-05
4.049	4.049	3.700	0.6354E+00	0.5569E-07	0.6365E+00	0.7732E-06	0.2295E+02	0.1877E-05
3.995	3.995	3.800	0.6450E+00	0.5414E-07	0.6462E+00	0.8096E-06	0.2264E+02	0.1866E-05
3.943	3.943	3.900	0.6541E+00	0.5490E-07	0.6555E+00	0.8445E-06	0.2233E+02	0.1824E-05
3.894	3.894	4.000	0.6629E+00	0.6146E-07	0.6643E+00	0.7918E-06	0.2204E+02	0.1948E-05
3.846	3.846	4.100	0.6711E+00	0.5858E-07	0.6727E+00	0.1013E-05	0.2173E+02	0.1847E-05
3.800	3.800	4.200	0.6790E+00	0.5632E-07	0.6807E+00	0.9438E-06	0.2145E+02	0.1757E-05
3.756	3.756	4.300	0.6866E+00	0.6026E-07	0.6883E+00	0.1146E-05	0.2115E+02	0.1781E-05
3.713	3.713	4.400	0.6938E+00	0.6162E-07	0.6956E+00	0.1272E-05	0.2087E+02	0.1667E-05
3.671	3.671	4.500	0.7007E+00	0.5972E-07	0.7026E+00	0.1336E-05	0.2060E+02	0.1668E-05
3.631	3.631	4.600	0.7073E+00	0.6262E-07	0.7093E+00	0.1433E-05	0.2033E+02	0.1634E-05
3.592	3.592	4.700	0.7136E+00	0.6346E-07	0.7157E+00	0.1916E-05	0.2005E+02	0.1491E-05
3.555	3.555	4.800	0.7198E+00	0.6515E-07	0.7218E+00	0.1922E-05	0.1980E+02	0.1644E-05
3.518	3.518	4.900	0.7256E+00	0.6025E-07	0.7277E+00	0.2292E-05	0.1954E+02	0.1590E-05
3.483	3.483	5.000	0.7312E+00	0.6572E-07	0.7334E+00	0.3053E-05	0.1929E+02	0.1496E-05

UU, BETA, ZKGG, ZKG, THETA, HDPTH, GMT = 0.0000 180.0000 -0.6666 -0.6667 0.0000 0.0000 0.0167

SUBMOT RESULTS: S. F & M FOR PLOT AT FDRIFT & FSUB = 1.000 1.000

WO	WE	WLR	FF1B	FF2B	FF3B	FF4B	FF5B	FF6B
11.013	11.013	0.500	-0.1280E-06	-0.8671E-10	0.1089E-01	-0.7887E-13	0.2802E-03	0.7975E-12
10.054	10.054	0.600	-0.5634E-06	-0.2218E-09	0.1789E-01	-0.6461E-13	0.5630E-03	-0.5265E-10
8.992	8.992	0.750	0.3579E-06	-0.2083E-09	0.3047E-01	-0.3054E-12	0.1181E-02	-0.4859E-10
8.707	8.707	0.800	0.6809E-06	-0.3060E-09	0.3255E-01	-0.5766E-12	0.1242E-02	-0.1153E-09
8.209	8.209	0.900	-0.2795E-06	0.4131E-10	0.3438E-01	-0.2705E-11	0.1308E-02	-0.2083E-09
7.788	7.788	1.000	-0.4234E-05	-0.1850E-09	0.2811E-01	-0.3811E-11	0.7504E-03	-0.1864E-09
7.425	7.425	1.100	-0.1082E-04	-0.3549E-09	0.2620E-01	-0.7120E-11	0.7386E-03	-0.2796E-09
6.965	6.965	1.250	-0.2303E-04	-0.2836E-09	0.2180E-01	-0.1107E-10	0.6565E-03	-0.2526E-09
6.830	6.830	1.300	-0.2712E-04	0.3600E-09	0.2017E-01	-0.1561E-10	0.6179E-03	-0.9888E-10
6.582	6.582	1.400	-0.3467E-04	0.3127E-10	0.1690E-01	-0.9906E-11	0.5337E-03	-0.8444E-10
6.359	6.359	1.500	-0.4101E-04	0.2948E-09	0.1380E-01	-0.1013E-10	0.4481E-03	-0.2586E-09
6.157	6.157	1.600	-0.4592E-04	0.7519E-09	0.1099E-01	-0.1324E-10	0.3673E-03	-0.3047E-09
5.973	5.973	1.700	-0.4942E-04	0.7243E-09	0.8494E-02	-0.1329E-10	0.2949E-03	-0.2439E-09
5.805	5.805	1.800	-0.5164E-04	-0.1193E-09	0.6322E-02	-0.6772E-11	0.2316E-03	-0.2053E-09
5.650	5.650	1.900	-0.5274E-04	-0.2271E-09	0.4463E-02	-0.7395E-11	0.1782E-03	-0.8691E-10
5.507	5.507	2.000	-0.5295E-04	0.6849E-09	0.2888E-02	-0.8919E-11	0.1340E-03	0.1913E-10
5.374	5.374	2.100	-0.5245E-04	0.8040E-10	0.1562E-02	-0.9463E-11	0.9796E-04	-0.8039E-10
5.250	5.250	2.200	-0.5141E-04	0.1209E-08	0.4490E-03	-0.1153E-10	0.6854E-04	0.1078E-09
5.135	5.135	2.300	-0.4995E-04	0.5913E-09	0.4740E-03	-0.1153E-10	0.4521E-04	0.1544E-09

5.027	5.027	2.400	-0.4822E-04	0.1200E-08	0.1235E-02	-0.9235E-11	0.2686E-04	0.1618E-09
4.925	4.925	2.500	-0.4631E-04	0.7911E-09	0.1868E-02	-0.1011E-10	0.1244E-04	0.4966E-10
4.830	4.830	2.600	-0.4429E-04	-0.4018E-09	0.2383E-02	-0.8076E-11	0.1503E-05	-0.9712E-10
4.739	4.739	2.700	-0.4222E-04	0.7573E-09	0.2805E-02	-0.8350E-11	-0.6784E-05	0.1431E-09
4.654	4.654	2.800	-0.4015E-04	0.7870E-09	0.3148E-02	-0.6709E-11	-0.1286E-04	-0.1414E-09
4.573	4.573	2.900	-0.3811E-04	0.5312E-09	0.3421E-02	-0.6946E-11	-0.1712E-04	0.1108E-09
4.496	4.496	3.000	-0.3609E-04	0.1045E-08	0.3633E-02	-0.5900E-11	-0.1998E-04	0.1533E-09
4.423	4.423	3.100	-0.3419E-04	0.4598E-09	0.3796E-02	-0.5395E-11	-0.2180E-04	0.2147E-09
4.353	4.353	3.200	-0.3228E-04	-0.2257E-09	0.3914E-02	-0.5020E-11	-0.2280E-04	-0.6229E-10
4.287	4.287	3.300	-0.3049E-04	-0.6351E-09	0.3999E-02	-0.4586E-11	-0.2322E-04	0.9410E-11
4.223	4.223	3.400	-0.2884E-04	0.6919E-09	0.4058E-02	-0.2321E-11	-0.2320E-04	0.2864E-09
4.163	4.163	3.500	-0.2719E-04	-0.2239E-09	0.4088E-02	-0.2253E-11	-0.2286E-04	0.2100E-09
4.104	4.104	3.600	-0.2568E-04	0.7727E-09	0.4102E-02	-0.2278E-11	-0.2229E-04	-0.1371E-09
4.049	4.049	3.700	-0.2423E-04	0.9455E-09	0.4098E-02	-0.3607E-11	-0.2156E-04	0.1641E-09
3.995	3.995	3.800	-0.2288E-04	0.6583E-09	0.4081E-02	-0.3832E-11	-0.2073E-04	-0.9592E-10
3.943	3.943	3.900	-0.2161E-04	-0.6264E-09	0.4053E-02	-0.3533E-11	-0.1983E-04	0.1316E-09
3.894	3.894	4.000	-0.2049E-04	0.2753E-10	0.4020E-02	-0.3931E-11	-0.1891E-04	-0.1218E-09
3.846	3.846	4.100	-0.1926E-04	0.4564E-09	0.3971E-02	-0.3743E-11	-0.1796E-04	-0.1312E-09
3.800	3.800	4.200	-0.1828E-04	0.4638E-09	0.3925E-02	-0.3245E-11	-0.1704E-04	-0.1641E-10
3.756	3.756	4.300	-0.1723E-04	-0.3298E-11	0.3868E-02	-0.2964E-11	-0.1611E-04	-0.9439E-10
3.713	3.713	4.400	-0.1629E-04	0.8263E-09	0.3809E-02	-0.2314E-11	-0.1522E-04	-0.1043E-09
3.671	3.671	4.500	-0.1545E-04	0.9846E-09	0.3750E-02	-0.2432E-11	-0.1437E-04	-0.9631E-10
3.631	3.631	4.600	-0.1465E-04	0.2524E-09	0.3688E-02	-0.2196E-11	-0.1354E-04	0.6552E-10
3.592	3.592	4.700	-0.1381E-04	0.1908E-09	0.3620E-02	-0.1735E-11	-0.1276E-04	0.5089E-10
3.555	3.555	4.800	-0.1316E-04	0.6092E-09	0.3559E-02	-0.1225E-11	-0.1202E-04	0.3118E-10
3.518	3.518	4.900	-0.1248E-04	0.1046E-08	0.3493E-02	-0.1387E-11	-0.1131E-04	-0.8763E-10
3.483	3.483	5.000	-0.1183E-04	0.1381E-08	0.3427E-02	-0.1453E-11	-0.1065E-04	0.2598E-10

SF IN LBS AND SM IN FT-LBS: WLA = 120.000

WO	WE	WLR	FF1B	FF2B	FF3B	FF4B	FF5B	FF6B
11.013	11.013	0.500	-0.5269E-08	-0.3568E-11	0.4480E-03	-0.1082E-13	0.3843E-04	0.1094E-12
10.054	10.054	0.600	-0.3339E-07	-0.1315E-10	0.1060E-02	-0.1276E-13	0.1112E-03	-0.1040E-10
8.992	8.992	0.750	0.3314E-07	-0.1929E-10	0.2822E-02	-0.9426E-13	0.3645E-03	-0.1500E-10
8.707	8.707	0.800	0.7173E-07	-0.3224E-10	0.3429E-02	-0.2025E-12	0.4360E-03	-0.4048E-10
8.209	8.209	0.900	-0.3726E-07	0.5508E-11	0.4584E-02	-0.1202E-11	0.5812E-03	-0.9256E-10
7.788	7.788	1.000	-0.6969E-06	-0.3045E-10	0.4628E-02	-0.2091E-11	0.4117E-03	-0.1023E-09
7.425	7.425	1.100	-0.2156E-05	-0.7069E-10	0.5219E-02	-0.4727E-11	0.4903E-03	-0.1856E-09
6.965	6.965	1.250	-0.5923E-05	-0.7295E-10	0.5607E-02	-0.9494E-11	0.5628E-03	-0.2166E-09
6.830	6.830	1.300	-0.7544E-05	0.1002E-09	0.5610E-02	-0.1447E-10	0.5730E-03	-0.9169E-10
6.582	6.582	1.400	-0.1119E-04	0.1009E-10	0.5453E-02	-0.1065E-10	0.5740E-03	-0.9081E-10
6.359	6.359	1.500	-0.1519E-04	0.1092E-09	0.5113E-02	-0.1250E-10	0.5531E-03	-0.3193E-09
6.157	6.157	1.600	-0.1935E-04	0.3169E-09	0.4630E-02	-0.1860E-10	0.5159E-03	-0.4280E-09
5.973	5.973	1.700	-0.2351E-04	0.3446E-09	0.4041E-02	-0.2107E-10	0.4676E-03	-0.3867E-09
5.805	5.805	1.800	-0.2754E-04	-0.6361E-10	0.3372E-02	-0.1204E-10	0.4117E-03	-0.3650E-09
5.650	5.650	1.900	-0.3134E-04	-0.1349E-09	0.2652E-02	-0.1465E-10	0.3530E-03	-0.1721E-09
5.507	5.507	2.000	-0.3486E-04	0.4510E-09	0.1901E-02	-0.1957E-10	0.2942E-03	0.4200E-10
5.374	5.374	2.100	-0.3807E-04	0.5836E-10	0.1134E-02	-0.2290E-10	0.2370E-03	-0.1945E-09
5.250	5.250	2.200	-0.4096E-04	0.9631E-09	0.3577E-03	-0.3062E-10	0.1820E-03	0.2863E-09

5.135	5.135	2.300	-0.4350E-04	0.5149E-09	0.4127E-03	-0.3346E-10	0.1312E-03	0.4482E-09
5.027	5.027	2.400	-0.4572E-04	0.1137E-08	0.1171E-02	-0.2919E-10	0.8488E-04	0.5115E-09
4.925	4.925	2.500	-0.4765E-04	0.8139E-09	0.1921E-02	-0.3469E-10	0.4267E-04	0.1703E-09
4.830	4.830	2.600	-0.4928E-04	-0.4471E-09	0.2651E-02	-0.2995E-10	0.5576E-05	-0.3602E-09
4.739	4.739	2.700	-0.5066E-04	0.9088E-09	0.3366E-02	-0.3340E-10	-0.2714E-04	0.5725E-09
4.654	4.654	2.800	-0.5182E-04	0.1016E-08	0.4063E-02	-0.2886E-10	-0.5531E-04	-0.6084E-09
4.573	4.573	2.900	-0.5275E-04	0.7353E-09	0.4736E-02	-0.3205E-10	-0.7899E-04	0.5111E-09
4.496	4.496	3.000	-0.5347E-04	0.1548E-08	0.5382E-02	-0.2914E-10	-0.9867E-04	0.7573E-09
4.423	4.423	3.100	-0.5408E-04	0.7273E-09	0.6005E-02	-0.2845E-10	-0.1149E-03	0.1132E-08
4.353	4.353	3.200	-0.5441E-04	-0.3805E-09	0.6598E-02	-0.2821E-10	-0.1281E-03	-0.3500E-09
4.287	4.287	3.300	-0.5465E-04	-0.1138E-08	0.7168E-02	-0.2740E-10	-0.1387E-03	0.5623E-10
4.223	4.223	3.400	-0.5488E-04	0.1317E-08	0.7721E-02	-0.1472E-10	-0.1472E-03	0.1817E-08
4.163	4.163	3.500	-0.5482E-04	-0.4514E-09	0.8244E-02	-0.1514E-10	-0.1537E-03	0.1411E-08
4.104	4.104	3.600	-0.5479E-04	0.1648E-08	0.8750E-02	-0.1620E-10	-0.1585E-03	-0.9746E-09
4.049	4.049	3.700	-0.5460E-04	0.2131E-08	0.9234E-02	-0.2709E-10	-0.1620E-03	0.1233E-08
3.995	3.995	3.800	-0.5438E-04	0.1565E-08	0.9700E-02	-0.3036E-10	-0.1642E-03	-0.7600E-09
3.943	3.943	3.900	-0.5412E-04	-0.1568E-08	0.1015E-01	-0.2948E-10	-0.1655E-03	0.1098E-08
3.894	3.894	4.000	-0.5397E-04	0.7251E-10	0.1059E-01	-0.3451E-10	-0.1660E-03	-0.1069E-08
3.846	3.846	4.100	-0.5329E-04	0.1263E-08	0.1099E-01	-0.3453E-10	-0.1657E-03	-0.1210E-08
3.800	3.800	4.200	-0.5309E-04	0.1347E-08	0.1140E-01	-0.3140E-10	-0.1649E-03	-0.1589E-09
3.756	3.756	4.300	-0.5244E-04	-0.1004E-10	0.1177E-01	-0.3007E-10	-0.1635E-03	-0.9576E-09
3.713	3.713	4.400	-0.5192E-04	0.2633E-08	0.1214E-01	-0.2458E-10	-0.1617E-03	-0.1108E-08
3.671	3.671	4.500	-0.5149E-04	0.3282E-08	0.1250E-01	-0.2702E-10	-0.1596E-03	-0.1070E-08
3.631	3.631	4.600	-0.5103E-04	0.8793E-09	0.1285E-01	-0.2550E-10	-0.1573E-03	0.7608E-09
3.592	3.592	4.700	-0.5021E-04	0.6937E-09	0.1316E-01	-0.2103E-10	-0.1546E-03	0.6168E-09
3.555	3.555	4.800	-0.4990E-04	0.2310E-08	0.1350E-01	-0.1549E-10	-0.1519E-03	0.3942E-09
3.518	3.518	4.900	-0.4934E-04	0.4134E-08	0.1381E-01	-0.1827E-10	-0.1490E-03	-0.1154E-08
3.483	3.483	5.000	-0.4869E-04	0.5681E-08	0.1410E-01	-0.1993E-10	-0.1460E-03	0.3564E-09

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APPENDIX G. AEGIR OUTPUT FILE (PORTION)

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TITLE = "Body #    1 Force History"
VARIABLES = time        Inc F_x Inc F_y Inc F_z Inc M_x Inc M_y Inc M_z Loc F_x Loc F_y Loc F_z Loc M_x Loc M_y Loc M_z Mem F_x Mem F_y Mem F_z Mem M_x Mem M_y Mem M_z
  0.100000000000E-01     -0.980232177365E-06     -0.708190536459E-11      0.877909154171E-05     -0.465479155693E-10      0.750461519381E-05     -0.219175146191E-11
  0.200000000000E-01     -0.770104598283E-05     -0.275642050317E-10      0.342430471804E-04     -0.180358834175E-09      0.591137910670E-04     -0.290677118451E-10
  0.300000000000E-01     -0.255083447246E-04     -0.595727939952E-10      0.741740092358E-04     -0.387938934766E-09      0.195979000790E-03     -0.109672776076E-09
  0.400000000000E-01     -0.591456991112E-04     -0.100332057676E-09      0.125227582775E-03     -0.649969113361E-09      0.454621246497E-03     -0.270248902179E-09
  0.500000000000E-01     -0.112559747488E-03     -0.146275052247E-09      0.183065480958E-03     -0.942073220469E-09      0.865432845712E-03     -0.533160116812E-09
  0.600000000000E-01     -0.188731116558E-03     -0.193177452824E-09      0.242518040295E-03     -0.123573779378E-08      0.145137548786E-02     -0.915942375420E-09
  0.700000000000E-01     -0.289535053914E-03     -0.236311571356E-09      0.297772132977E-03     -0.149935811413E-08      0.222690683677E-02     -0.143050198229E-08
  0.800000000000E-01     -0.415635232588E-03     -0.270616345335E-09      0.342579453904E-03     -0.169938271277E-08      0.319716233121E-02     -0.208248257601E-08
  0.900000000000E-01     -0.566413389469E-03     -0.290878836194E-09      0.370479723948E-03     -0.180152637054E-08      0.435741269296E-02     -0.287081666471E-08
  0.100000000000E+00     -0.739936610578E-03     -0.291922560379E-09      0.375033035986E-03     -0.177202023396E-08      0.569281112081E-02     -0.378747325204E-08
  0.110000000000E+00     -0.932963194562E-03     -0.268797781187E-09      0.350055381829E-03     -0.157886694998E-08      0.717843736488E-02     -0.481740847761E-08
  0.120000000000E+00     -0.114098712952E-02     -0.216968935301E-09      0.289851338922E-03     -0.119306866276E-08      0.877963897822E-02     -0.593872160912E-08
  0.130000000000E+00     -0.135832032563E-02     -0.132494379236E-09      0.189437966114E-03     -0.589796395734E-09      0.104526631728E-01     -0.712301380073E-08
  0.140000000000E+00     -0.157821087515E-02     -0.121938237196E-10      0.447541555128E-04      0.250529360563E-09      0.121455660036E-01     -0.833594240588E-08
  0.150000000000E+00     -0.179299477961E-02      0.146200884572E-09     -0.147149992157E-03      0.134127504707E-08      0.137993792027E-01     -0.953795928172E-08
  0.160000000000E+00     -0.199427780842E-02      0.343915636439E-09     -0.387948765244E-03      0.268877304945E-08      0.153495090126E-01     -0.106852170135E-07
  0.170000000000E+00     -0.217314344842E-02      0.581028087551E-09     -0.677905866008E-03      0.429166585226E-08      0.167273359450E-01     -0.117306232451E-07
  0.180000000000E+00     -0.232038228523E-02      0.856388940456E-09     -0.101577267908E-02      0.614043424354E-08      0.178619796246E-01     -0.126250196925E-07
  0.190000000000E+00     -0.242673763581E-02      0.116757278121E-08     -0.139872288032E-02      0.821712451650E-08      0.186821888632E-01     -0.133184597280E-07
  0.200000000000E+00     -0.248316183866E-02      0.151086039265E-08     -0.182232569550E-02      0.104952852084E-07      0.191183139260E-01     -0.137615553681E-07
  0.210000000000E+00     -0.248107731127E-02      0.188125349501E-08     -0.228055927933E-02      0.129401194767E-07      0.191043156653E-01     -0.139068632264E-07
  0.220000000000E+00     -0.241263631029E-02      0.227252246484E-08     -0.276586481151E-02      0.155088543110E-07      0.185797648527E-01     -0.137102775008E-07
  0.230000000000E+00     -0.227097328161E-02      0.267728656591E-08     -0.326924101501E-02      0.181513232282E-07      0.174917846629E-01     -0.131323976727E-07
  0.240000000000E+00     -0.205044376647E-02      0.308712566291E-08     -0.378037791113E-02      0.208107541582E-07      0.157968898706E-01     -0.121398381731E-07
  0.250000000000E+00     -0.174684403500E-02      0.349272179295E-08     -0.428782775281E-02      0.234247497846E-07      0.134626778919E-01     -0.107064489361E-07
  0.260000000000E+00     -0.135760594595E-02      0.388402802497E-08     -0.477921024056E-02      0.259264431373E-07      0.104693293226E-01     -0.881441666846E-08
  0.270000000000E+00     -0.881961975076E-03      0.425046151419E-08     -0.524144834012E-02      0.282458073002E-07      0.681087903311E-02     -0.645521837717E-08
  0.280000000000E+00     -0.321075906896E-03      0.458111737589E-08     -0.566103030431E-02      0.303110942348E-07      0.249622312940E-02     -0.363040241538E-08
  0.290000000000E+00      0.321864666004E-03      0.486499905846E-08     -0.602429286691E-02      0.320503748461E-07     -0.245016791794E-02     -0.352174562986E-09
  0.300000000000E+00      0.104159715634E-02      0.509126050012E-08     -0.631772003770E-02      0.333931494103E-07     -0.798785401315E-02      0.335622915809E-08
  0.310000000000E+00      0.183077642144E-02      0.524945568538E-08     -0.652825149558E-02      0.342719957752E-07     -0.140603658731E-01      0.746039727202E-08
  0.320000000000E+00      0.268001227811E-02      0.532978994816E-08     -0.664359426062E-02      0.346242210162E-07     -0.205954923484E-01      0.119148350891E-07
  0.330000000000E+00      0.357795263930E-02      0.532336816184E-08     -0.665253113247E-02      0.343934817299E-07     -0.275059188591E-01      0.166632992434E-07
  0.340000000000E+00      0.451141189236E-02      0.522243399654E-08     -0.654521931723E-02      0.335313379149E-07     -0.346902140501E-01      0.216393753067E-07
  0.350000000000E+00      0.546554320738E-02      0.502059563819E-08     -0.631347272921E-02      0.319987061542E-07     -0.420341546011E-01      0.267672931758E-07
  0.360000000000E+00      0.642405254591E-02      0.471303246838E-08     -0.595102164860E-02      0.297671789154E-07     -0.494123710594E-01      0.319629708525E-07
  0.370000000000E+00      0.736945125248E-02      0.429667782515E-08     -0.545374373793E-02      0.268201791894E-07     -0.566902907312E-01      0.371352723978E-07
  0.380000000000E+00      0.828334327222E-02      0.377037388290E-08     -0.481986086460E-02      0.231539217517E-07     -0.637263472029E-01      0.421874604482E-07
```

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APPENDIX H. LAMP OUTPUT FILE

```
  Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10]
 LAMP - Large Amplitude Motions Program : Primary Output File
 RELEASE    : LAMP VERSION 4.0.5 / March 21, 2017
 PROCESSOR : HOTEL6
 RUN DATE  : 10/25/2017 :: 11:51:02.012
!************* FILE PARSING DATA *************
FILE_PARSING_DATA
!Number of ships
     1
!Number of geometry files
     1
!Number of components read from each geometry file
     1
!Input Symmetry flags for each geometry file
     1
!Initial geometry transformations each geometry file
   0.00000        0.00000      -0.500000
   0.00000        0.00000       0.00000
   0.00000        0.00000       0.00000
END_OF_FILE
!************* INPUT FILE ECHO *************
INPUT_FILE_ECHO
!************* INPUT CONTROL FILE *************
!01 DESCR - Descriptive Title (max 80 char)
baseline geometry, D=4in (0.333ft) L/D=10, depth=D*2, a=D/4, lambda/L~0.5
!02 FPROG - Source file for Programmers Input (blank for defaults)

!03 FAPLT - Source file for Autopilot Input (blank for defaults)

!04 FGEOM - Source file for geometry definition
LtoD10_55_10.lmp
!05 FOUT - Destination file for primary output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].out
!06 Output frequency for pressure, geometry, etc.
!       POUT         GOUT        SOUT       BOUT
  100 2000 100    1 1 1       0 0 0       0 0 0
!07 FPOUT = File for pressure data output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].pout
!08 FGOUT = File for panel geometry output
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10].gout
!09 FSOUT = File for load balance output

!10 FBOUT = File for elastic beam output

!11 AUXOUT(20) - Flags for auxiliary output files
   0 0 0 0 0   0 0 0 0 0   0 0 0 0 0   0 0 0 0 0
!12 IVEC - Use Non-vectorized (0) or ivectorized (1) kernel
     0
!13 LMPTYP (1-4)  MOTYPE (forced/impulsive/free)  MIXED (Rankine/mixed/IRF)
     2                    0                                            -1
!13 (cont) IFSMIX NXFS NYFS  IMSMIX NXMS NZMS - mixed-source surface points
             4        65     25      2        16      11
!13 (cont) XMIX  YMIX  ZMIX - mixed-source surface extent
    5.00000       2.000000       1.500000
!14 TINIT NSTEP DTH IRST - Initial Time, Number of Steps, Time Step, Restart
    0.0     1000  0.009  0
!14 (cont) FRST - Name for restart file
!14 (cont) FBDMEM - Name for body panel free surface memory file
!14 (cont) FWLMEM - Name for waterline free surface memory file
!15 USHIP  UCURNT  DCURNT  WDEPTH - Steady speed, current vel/dir, water depth
    0.0    0.0     0.0     0.0
!16 PMGIN(1:6) Initial location and orientation in global system
      0.000000     0.000000     -0.666667     0.000000     0.000000     0.000000
!17 VMGSHP(1:6) Initial Velocity and Rotation rate in ship fixed system
                                       Page 1
```

```
Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10]
    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000
!18 AMPM(1:6) Amplitude for forced sinusoidal motion (if MOTYPE=0)
    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000
!19 OMEGM(1:6) Frequency for forced sinusoidal motion (if MOTYPE=0)
    0.000000    0.000000    0.000000    0.000000    0.000000    0.000000
!20 SWTCH(1:6) Sets which modes of motion will be considered
   0    0    0    0    0    0
!21 ISEA  NWAVES  NWSC
   1       1           2
!21 (cont) FREQW  PHASEW  AMPW  HEADW = component wave data
   4.16264    0.000000    0.08333  180
!21 (cont) WSCSTP  WSCFAC = wave scaling data
   0    0.0
   25   1.0
!22 GRAVIN  RHOIN  LENIN  ANGIN - Scale Factors for Input
    32.200000    1.940000    3.3333    57.29578
!23 GRAVOUT  RHOOUT  LENOUT  ANGOUT - Scale Factors for Output
    32.200000    1.940000    3.3333    57.29578
!24 GSHIFT(3), GORIG(3), GROT(3) - Input geometry transformation
   0.0 0.0 -0.5
   0.0 0.0 0.0
   0.0 0.0 0.0
!25 SMA = Ship mass, SMI(1,1),(2,1),(3,1),(1,2)...(3,3) Mom. of Inertia
    0.26335
    0.0075765   0.000000    0.000000
    0.000000    0.505103    0.000000
    0.000000    0.000000    0.505103
!26 RGRAV = center of gravity in input system
   0.000000 0.00000 0.000000
!27 SYMGEO= 1 for Symmetry in calc., SYMINP =1 for symmetry in input
   0    1
!28 NCOMP0 ...
   0
!28 (cont) KCTYPE0 NEWWL0 KSPWL0 SPWL0 NEWST0 KSPST0 SPST0,1->NCOMP0
!    0    20    1    0.000000    50    1    0.000000
!29 IVM, IHM, ITM, NBCA, NBMX ...
   0    0    0    0    0
!29 (cont) XMC(123,1->NBCA)
!     .000000     .000000    0.000000
!29 (cont) XMS(123,I), AMS(I), AIS(123,I), AMI(123,I), DWS(I), AWS(I), EWS(I),
(I=1->NBMX)
!    0.000 0.000 0.000  0.000000  0.0 0.0 0.0  0.0 0.0 0.0  0.0 0.0 0.0
!29 (cont) STRDMP(2,4) structural damping, fraction of critical in 1st 2 modes
!           for vertical, horizontal, torsional, and tension vibration
  0.1 0.2
  0.1 0.2
  0.1 0.2
  0.1 0.2
!30 KINVIS (kinematic viscosity)  IHROLL (roll damping option)
  0.000010804                      0
!31 IHLIFT (hull lift option)
   0
!32 NFIN - Number of wing-like appendages (e.g. rudder, fins)
   0
!32 (cont) Values for one wing-like appendage - rudder
!  0.0     0.0    0.0
!  0.0     0.0    0.0
!  0.0     0.0    0.0
!  0.0  0.0  0.0
!33 NBK - Number of plate-like appendages (e.g. bilge keels)
   0
END_OF_FILE
!********* PROGRAMMERS FILE ECHO *********
                              Page 2
```

```
   Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10]
!01  nlfs     Nonlinear free surface option
    0
!02  icutwl   method for cutting panelization at the waterline/wave surface
    0
!03  iasym    switch for axisymmetric calculation (obsolete)
   -1
!04  nlfrc    switch for non-linear pressure/force calculation
    1
!05  ifsdif   switch for free surface gradient calculation scheme
    5
!06  igf      order of integration for TGFs
    1
!07  layer    number of panel layers for multi-pole integration
    1
!08  mbeg     number of time steps for TGF convolution
  600
!09  ipdif    switch for differencing methods
    1
!10  icdms    TGF influence function storage option
    2
!11  iculpn   switch for culling bad panels from TGF or pressure calcs.
    0
!12  idyna    dynamics solver to use (not used for most cases)
    0
!13  beachrad, beachamp - width and strength of damping beach
  -1.0000      -1.0000
END_OF_FILE
!********** AUTOPILOT FILE **********
!01 ITHRUST - switch for thrust control
     0
!02 ICOURSE - switch for course keeping autopilot
     0
!03 NRUD, KRUD(i) -  number of rudders, fin index of each
     2     1     2
!04 RUDLIM, RUDDRT, RUDPBD, RDVINC  - Rudder inputs : maximum deflection
!    limit (deg), maximum deflection rate (deg/unit time), proportional
!    band (deg), velocity increment (velocity units)
   35.0000       61.2375       5.00000       0.00000
!05 IROLLS - switch for roll stabilization
     0
!06 IEXTFOR - external force option flag
     0
END_OF_FILE
!************** GEOMETRY FILE  1 **************
   3
Circular cylinder parallel midbody with hemispheric end caps
single surface, with y-axis symmetry, Dia = 4 inch, L/D = 10
origin on centerline at amidship, +X to bow, +Y to port, +Z up
hull - port side
   55   10
  1.66666667    0.00000000    -0.00000000
  1.66666667    0.00000000    -0.00000000
  1.66666667    0.00000000    -0.00000000
  1.66666667    0.00000000    -0.00000000
  1.66666667    0.00000000    -0.00000000
  1.66666667    0.00000000    0.00000000
  1.66666667    0.00000000    0.00000000
  1.66666667    0.00000000    0.00000000
  1.66666667    0.00000000    0.00000000
  1.66666667    0.00000000    0.00000000
  1.65850942    0.00000000    -0.05150283
  1.65850942    0.01761501    -0.04839683
  1.65850942    0.03310538    -0.03945346
                                        Page 3
```

```
  Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10]
  -1.59796421    0.08667102    0.10329050
  -1.59796421    0.04611668    0.12670455
  -1.59796421    0.00000000    0.13483617
  -1.63483617    0.00000000   -0.09796421
  -1.63483617    0.03350573   -0.09205624
  -1.63483617    0.06297018   -0.07504494
  -1.63483617    0.08483949   -0.04898210
  -1.63483617    0.09647591   -0.01701131
  -1.63483617    0.09647591    0.01701131
  -1.63483617    0.08483949    0.04898210
  -1.63483617    0.06297018    0.07504494
  -1.63483617    0.03350573    0.09205624
  -1.63483617    0.00000000    0.09796421
  -1.65850942    0.00000000   -0.05150283
  -1.65850942    0.01761501   -0.04839683
  -1.65850942    0.03310538   -0.03945346
  -1.65850942    0.04460276   -0.02575142
  -1.65850942    0.05072039   -0.00894337
  -1.65850942    0.05072039    0.00894337
  -1.65850942    0.04460276    0.02575142
  -1.65850942    0.03310538    0.03945346
  -1.65850942    0.01761501    0.04839683
  -1.65850942    0.00000000    0.05150283
  -1.66666667    0.00000000   -0.00000000
  -1.66666667    0.00000000   -0.00000000
  -1.66666667    0.00000000   -0.00000000
  -1.66666667    0.00000000   -0.00000000
  -1.66666667    0.00000000   -0.00000000
  -1.66666667    0.00000000    0.00000000
  -1.66666667    0.00000000    0.00000000
  -1.66666667    0.00000000    0.00000000
  -1.66666667    0.00000000    0.00000000
  -1.66666667    0.00000000    0.00000000
END_OF_FILE
!************* DERIVED DATA ECHO *************
DERIVED_DATA_ECHO
!Ship mass, mass moment of inertia
  0.742660509E-02
  0.192298885E-04   0.00000000        0.00000000
   0.00000000      0.128200022E-02   0.00000000
   0.00000000       0.00000000      0.128200022E-02
!Center of gravity
  0.406662131E-17  0.345860241E-18 -0.150001496
!Sectional load calculation options and points
     0     0     0     0     0     0     0     0
     0
     0
!Mass distribution for sectional loads
     0     0
  0.500004947      -0.500004947
  0.492408834E-01 -0.492408834E-01
!Initial position and velocity vectors
  0.406662131E-17  0.345860241E-18 -0.150001496
   0.00000000       0.00000000        0.00000000
  0.406662131E-17  0.345860241E-18 -0.200002089
   0.00000000       0.00000000        0.00000000
  0.406662131E-17  0.345860241E-18 -0.200002089
   0.00000000       0.00000000        0.00000000
   0.00000000       0.00000000        0.00000000
   0.00000000       0.00000000        0.00000000
   0.00000000       0.00000000        0.00000000
   0.00000000       0.00000000        0.00000000
!Incident Wave
                                   Page 12
```

```
   Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl[10]
     1
     1
   1.33930087       0.00000000       0.249992479E-01
   3.14159274      -0.874227766E-07  -1.00000000
   1.79372680
     2
    0    0.00000000
   25    1.00000000
!Appendage data
     0
     0
END_OF_FILE
!************** END OF INPUT FILE ECHO **************
  0.000000E+00
  0.135552693E-16  0.115285599E-17 -0.666666985E+00  0.000000000E+00
0.000000000E+00  0.000000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
 -0.544718E-03 -0.252282E-10  0.171748E+02 -0.109066E-11  0.264567E-03 -0.642282E-06
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00
  0.900000E-02
  0.135552693E-16  0.115285599E-17 -0.666666985E+00  0.000000000E+00
0.000000000E+00  0.000000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
 -0.553260E-02 -0.135787E-07 -0.855820E-02 -0.878850E-11  0.726009E-01  0.129940E-07
  0.135175E-06  0.152776E-10  0.766691E-05  0.419550E-16  0.163532E-06  0.108926E-10
 -0.373496E-02 -0.170264E-09  0.171683E+02 -0.747825E-11  0.181391E-02 -0.642665E-06
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00
  0.180000E-01
  0.135552693E-16  0.115285599E-17 -0.666666985E+00  0.000000000E+00
0.000000000E+00  0.000000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
 -0.881356E-02 -0.278334E-07 -0.288479E-01 -0.139935E-10  0.115592E+00 -0.296172E-07
  0.128923E-05  0.917780E-10  0.367187E-04  0.401633E-15  0.155817E-05  0.393168E-10
 -0.112875E-01 -0.797251E-09  0.171573E+02 -0.225999E-10  0.548122E-02 -0.643411E-06
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00
  0.270000E-01
  0.135552693E-16  0.115285599E-17 -0.666666985E+00  0.000000000E+00
0.000000000E+00  0.000000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
 -0.117341E-01 -0.361684E-07 -0.593620E-01 -0.186119E-10  0.153789E+00 -0.261295E-07
  0.573739E-05  0.203190E-09  0.109712E-03  0.178989E-14  0.692385E-05  0.174907E-09
 -0.241368E-01 -0.255024E-08  0.171417E+02 -0.483268E-10  0.117192E-01 -0.643492E-06
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00
  0.360000E-01
  0.135552693E-16  0.115285599E-17 -0.666666985E+00  0.000000000E+00
0.000000000E+00  0.000000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
 -0.142684E-01 -0.242112E-07 -0.985459E-01 -0.226249E-10  0.186892E+00  0.780407E-07
```

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APPENDIX I. MATLAB ROUTINES

Special coding routines were required to supplement geometry input file generation as well as reading LAMP files and subsequently analyzing them.

MATLAB routines used for each of these tasks are provided in the subsections below.

WRITE LAMP GEOMETRY


```
%
% *** UPDATED on 09 October 2017 ***
%
% MAXCMP: max number of surface components [25]
% MAXSTA: max number of stations [75]
% MAXWL: max number of waterlines [75]
% MAXBP: max number of body surface panels for hydrodynamics [2500]
% MAXBP0: max number of body surface panels for hydrostatics [9000]
%
clear variables;
%
Header = {'Circular cylinder parallel midbody with hemispheric end caps';...
    'single surface, with y-axis symmetry, Dia = 4 inch, L/D = 10';...
    'origin on centerline at amidship, +X to bow, +Y to port, +Z up'};
SurfaceTitle = {'hull - port side'};
Diameter = 4/12; %ft
LtoD = 10;
NumberOfBowStations = 6; %also number of stern stations
NumberOfMidbodyStations = 43;
NumberOfWaterlines = 10;

Directory = 'C:\shiphydro\LAMP\windows_binaries';
%Directory = 'H:\MyDocs\Research\SimulationSoftware\MatLabRoutines';
Filename = 'LtoD10_55_10.lmp';

%--------------------------------------------------------------------------

rho = Diameter / 2;
Length = LtoD*Diameter;

NumberOfSternStations = NumberOfBowStations;
TotalNumberOfStations = NumberOfBowStations + NumberOfMidbodyStations +↙
NumberOfSternStations;
BowStationsVector = [1:1:NumberOfBowStations];
MidbodyStationsVector = [BowStationsVector(end)+1:1:BowStationsVector(end) ↙
+NumberOfMidbodyStations];
SternStationsVector = [MidbodyStationsVector(end)+1:1:MidbodyStationsVector(end) ↙
+NumberOfSternStations];
MidbodyStationSpacing = (Length-Diameter)/(NumberOfMidbodyStations+1);
MidbodyStationsX = [(Length-Diameter)/2:-MidbodyStationSpacing:-(Length-Diameter)/2];
MidbodyStationsX = MidbodyStationsX(2:end-1);
BowAzimuthalAngleVector = linspace(-90,90,NumberOfWaterlines);
BowZenithAngleVector = linspace(0,90,NumberOfBowStations);
MidbodyZenithAngleVector = linspace(180,0,NumberOfWaterlines);
SternAzimuthalAngleVector = linspace(-90,90,NumberOfWaterlines);
SternZenithAngleVector = linspace(90,180,NumberOfSternStations);

Count = 0;
for i = BowStationsVector
    Count = Count + 1;
    Station(i).Data = zeros(NumberOfWaterlines,3);
```

```
    for j = 1:NumberOfWaterlines
        X = rho*cosd(BowAzimuthalAngleVector(j))*sind(BowZenithAngleVector(Count));
        Y = rho*sind(BowAzimuthalAngleVector(j))*sind(BowZenithAngleVector(Count));
        Z = rho*cosd(BowZenithAngleVector(Count));
        Station(i).Data(j,:) = [(Length-Diameter)/2 + Z X Y];
    end
end

Count = 0;
for i = MidbodyStationsVector
    Count = Count + 1;
    Station(i).Data = zeros(NumberOfWaterlines,3);
    for j = 1:NumberOfWaterlines
        X = MidbodyStationsX(Count);
        Y = rho*sind(MidbodyZenithAngleVector(j));
        Z = rho*cosd(MidbodyZenithAngleVector(j));
        Station(i).Data(j,:) = [X Y Z];
    end
end

Count = 0;
for i = SternStationsVector
    Count = Count + 1;
    Station(i).Data = zeros(NumberOfWaterlines,3);
    for j = 1:NumberOfWaterlines
        X = rho*cosd(SternAzimuthalAngleVector(j))*sind(SternZenithAngleVector(Count));
        Y = rho*sind(SternAzimuthalAngleVector(j))*sind(SternZenithAngleVector(Count));
        Z = rho*cosd(SternZenithAngleVector(Count));
        Station(i).Data(j,:) = [-(Length-Diameter)/2 + Z X Y];
    end
end

NumberOfHeaderLines = length(Header);
FileID = fopen([Directory filesep Filename],'w');
fprintf(FileID,'    %i\n',NumberOfHeaderLines);
for i = 1:NumberOfHeaderLines
    fprintf(FileID,'%s\n',Header{i});
end
fprintf(FileID,'%s\n',SurfaceTitle{1});
fprintf(FileID,'    %i    %i\n',TotalNumberOfStations,NumberOfWaterlines);
for i = 1:TotalNumberOfStations
    for j = 1:NumberOfWaterlines
        fprintf(FileID,'  %.8f    %.8f    %.8f\n',Station(i).Data(j,:));
    end
end
fclose(FileID);

figure(1)
hold on;
for i = 1:TotalNumberOfStations
    plot3(Station(i).Data(:,1),Station(i).Data(:,2),Station(i).Data(:,3),'.','Color',[0 0↙
```

```
0.7])
    hold on;
    %plot3(Station(i).Data(:,1),-Station(i).Data(:,2),Station(i).Data(:,3),'.','Color',[0 ↙
0 0.7])
end
xlabel('X (ft)')
ylabel('Y (ft)')
zlabel('Z (ft)')
axis equal
grid on; box on;
set(gca,'CameraPosition',[1 1 1],'CameraTarget',[0 0 0]);
print([Filename(1:end-4) '-Graphic'],'-dpdf','-r300');
```

READ LAMP OUTPUT FILE


```
clear all;
close all;

Directory = 'C:\shiphydro\LAMP\windows_binaries';
Filename = 'Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl
[10].out';

FileID = fopen([Directory filesep Filename],'r');

Keyword = '!14 TINIT NSTEP DTH IRST - Initial Time, Number of Steps, Time Step, Restart';
TempStr = 'AnythingOtherThanTheKeyword';
while(~strcmp(TempStr,Keyword))
    TempStr = fgetl(FileID);
end
TempStr = fgetl(FileID);
TempData = str2num(TempStr);
NumberOfIterations = TempData(2);

Keyword = '!************* END OF INPUT FILE ECHO *************';
TempStr = 'AnythingOtherThanTheKeyword';
while(~strcmp(TempStr,Keyword))
    TempStr = fgetl(FileID);
end

Time = zeros(NumberOfIterations,1);
FirstOrderPressure = zeros(NumberOfIterations,6);
SecondOrderPressure = zeros(NumberOfIterations,6);
HydrostaticAndFroudeKrylovPressure = zeros(NumberOfIterations,6);
for i = 1:NumberOfIterations
    for j = 1:10
        tempdata = fgetl(FileID);
        if(j == 1)
            Time(i) = str2double(tempdata);
        elseif(j == 5)
            FirstOrderPressure(i,:) = str2num(tempdata);
        elseif(j == 6)
            SecondOrderPressure(i,:) = str2num(tempdata);
        elseif(j == 7)
            HydrostaticAndFroudeKrylovPressure(i,:) = str2num(tempdata);
        end
    end
end

save([Directory filesep Filename(1:end-4) '.
mat'],'Time','FirstOrderPressure','SecondOrderPressure','HydrostaticAndFroudeKrylovPressu
re');
```

ANALYZE LAMP OUTPUT FILE


```
clear all;
close all;

Directory = 'C:\shiphydro\LAMP\windows_binaries';
Filename = 'Dia[0_333]-LtoD[10]-depth[0_667]-a[0_083]-lambda[11_667]-Units[ft]_s[55]_wl↙
[10]';

load([Directory filesep Filename '.mat'])

TotalHydro = FirstOrderPressure + SecondOrderPressure +↙
HydrostaticAndFroudeKrylovPressure;

MaxForce = max(TotalHydro)
MinForce = min(TotalHydro)

TotalForce = MaxForce - MinForce

figure(1)
subplot(4,1,1)
plot(Time,FirstOrderPressure(:,3),'x','Color',[0 0 0],'MarkerSize',4)
ylabel('1st order F_z (lbs)')
grid on; box on;
subplot(4,1,2)
plot(Time,SecondOrderPressure(:,3),'x','Color',[0 0 0],'MarkerSize',4)
ylabel('2nd order F_z (lbs)')
grid on; box on;
subplot(4,1,3)
plot(Time,HydrostaticAndFroudeKrylovPressure(:,3),'x','Color',[0 0 0],'MarkerSize',4)
ylabel('Static & F-K F_z (lbs)')
grid on; box on;
subplot(4,1,4)
plot(Time,TotalHydro(:,3),'x','Color',[0 0 0],'MarkerSize',4)
xlabel('time (sec)')
ylabel('total F_z (lbs)')
grid on; box on;
```

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