2 Introduction and Background

2.1 Introduction

VisualSMP™ is a suite of tools used in the prediction and analysis of a ship's seakeeping characteristics. Included in VisualSMP is the SMP95 monohull strip theory based seakeeping program (the base module of the system), the SEP96 seakeeping analysis program, the STH97 time history program, and the SWMP96 SWATH strip theory based seakeeping program, all developed by the US Navy. SEP96, STH97, and SWMP96 are available as separate modules in the VisualSMP system. The US Navy has selected Proteus Engineering to distribute these tools commercially, and Proteus has used it experience in seakeeping analysis and software development to integrate and extend them, resulting in VisualSMP. VisualSMP adds an integrated frame work which allows seamless access to the graphical pre- and post-processor, execution of the seakeeping modules, and tools to simulate and visualize the motion of the ship in a seaway.

SMP95 is a strip theory based frequency domain seakeeping program that provides predictions of monohull ship motion (i.e. displacements, velocities, and accelerations) for a ship advancing at constant speed, on arbitrary headings in both regular waves and irregular seas. The irregular seas are modeled using either the two parameter Bretschneider, the three parameter Jonswap, or the six-parameter Ochi-Hubble wave spectral models. Both long-crested and short-crested results are provided, short-crested waves are generated using a cosine squared spreading function. In addition to the 6DOF responses, SMP95 will predict the absolute motion, velocity, and acceleration, as well as the relative motion and velocity for various locations on the ship. SMP95 will calculate the probabilities and frequencies of submergence, emergence, and/or slamming occurrence for various locations on the ship. Recent innovations for calculating added resistance have been integrated into SMP95.

SMP95 input models consist of hull offsets, appendage dimensions, and controller coefficients. The hull offsets are described by points on sections and the stem and stern profile. The current version of SMP95 allows 70 stations and 70 points per station. The current list of appendage types available to the analyst is:

Sonar Dome	Bilge Keels	Passive fins
Active Fins	Shaft Brackets	Propeller Shafting
Skegs	Propeller's	Rudders
Roll Tanks		

Proteus Engineering has developed pre and post processor programs for VisualSMP using the Microsoft Windows Graphical User Interface (GUI). These tools speed the data input process and provide graphical tools to view the computed results. The preprocessor is integrated into the Regular and Irregular Wave Modules and is used to input required geometry data, the seaway description, loading conditions, and operating conditions through a series of dialogs, which the user interacts with using the keyboard and mouse. All geometric information is graphically displayed for visual verification that the input data is correct. The postprocessor provides graphical tools for browsing the VisualSMP irregular sea output data. The plots take the form of speed polar diagrams, which show the ships response to a motion as a function of speed and heading, or Response Amplitude Operator (RAO) plots.

VisualSMP requires at least a Pentium 90 processor running Windows 95,98 or NT platform with 32 Mb of RAM and 30 MB of disk space. VisualSMP will generate an additional 10-30 MB of data per ship condition that is analyzed.

2.2 Background

In February 1999 a Cooperative Agreement was established between the Naval Sea Systems Command and Proteus Engineering for the commercialization of the US Navy Seakeeping tools. Proteus Engineering developed the architectural framework for the system that includes a graphical user interface, seamless integration of the legacy seakeeping tools, neutral file exchange format capabilities, and time histories/visualization to create VisualSMP.

VisualSMP also has the ability to import data from International Marine Software Associates (IMSA) Data File format (idf) files created by FastShip and other hull form definition software supporting the standard.

2.2.1 SMP95

SMP95 is the successor to the long standing SMP(81,87,91). The differences between the previous versions of SMP and SMP95 are the merging of research code, additional appendages types, and the Lin-Reed added resistance algorithm. SMP95 was also split into a regular wave module and an irregular wave module similar to the way the SWATH motions program was.

The U.S. Navy Standard Ship Motion Program (SMP) provides predictions of the motions, i.e., displacements, velocities, and accelerations for a ship advancing at constant speed, with arbitrary heading. The program is divided into a regular wave module and irregular seas module. The irregular seas are modeled using a two-parameter Bretschneider wave spectral model. Both long-crested and short-crested results are provided. In addition to the six-degree-of-freedom responses, the absolute motion, velocity, acceleration, as well as the relative motion and velocity for various locations on the ship can also be obtained. The probabilities and frequencies of submergence, emergence, and/or slamming occurrence for various locations on the ship are also available.

SMP95 was written in modular form to simplify future updating. The hull and appendage input, speed, heading, and sea condition calculation conditions, and statistical response output tables have all been standardized. A new theory, associated with hull and appendage lift damping, has been implemented for roll. Nonlinear predictions for roll in irregular seas are obtained using an iterative procedure. Finally, interfacing with other programs required in the design process (performance assessment program, speed polar graphical program, and time history generation program) is provided by standard output files that can be saved by the user. Thus SMP need only be run once for a particular ship and the results are saved on computer files for later use in other programs.

By 1977 it was recognized that there was a need for a user-oriented, state-of-the-art ship motion prediction tool, that would be easy to use and maintain. This tool (SMP) would facilitate the incorporation of seakeeping considerations into the hull design at the earliest possible stage. In order to assure that this new tool would be of use to the design community, a planning committee composed of members from NAVSEA and NSWC, CD was formed to participate in the development of SMP.

This planning committee developed the input/output requirements, calculation procedures, and program structure for SMP. Most of the committee members were also involved in developing theory providing source breakdown for the construction of SMP. Each task was headed by a committee member who drew on laboratory and external contract sources in the development of the task.

SMP95 currently provides the capability to obtain:

1. Rigid body motions- the rigid body responses include the displacements, velocities, and accelerations of the six-degree-of-freedom responses, surge, sway, heave, roll, pitch, and yaw.

2. Motions at a point- These responses include longitudinal, lateral, and vertical displacements, velocities, and accelerations for up to ten arbitrary points.
3. Relative motions and velocities for up to 10 arbitrary points- These points can be different than the points used in the motion at a point calculation.
4. Probability and frequency of occurrence of slamming, emergence, and/or submergence at the points where relative motion is calculated.
5. Added resistance in waves.
6. Slam pressures and forces.

2.2.2 SWATH Motions

The mathematatical model for the motions of a Small Waterplane Twin Hull (SWATH) ship in waves has been developed over a period of years by the US. Navy. As described in "Assessing the Seaworthiness of SWATH Ships" by McCreight, the mathematical modules used for the SWATH responses to waves follows the strip theory of Salvesen, Tuck, and Faltisen. This theory was applied to twin hull configurations and utilized an expression presented by Thwaites in "Incompressible Areodynamics" to develop a model for the cross flow drag and body lift contributions to the forces. Hong introduced surge into the model in the paper "improvements in the prediction of Heave and Pitch Motions for SWATH Ship" in 1980. Subsequently, McCreight and Stahl developed semi-empirical expressions for the cross flow drag and lift contributions for the vertical plane responces and added the effect of downwash on the lift of the aft stabilizers. Accurate modeling of the vertical plane motions was the focus of this effort; no changes to Lees's mathematical model for the transverse plane motions were made at that time. The mathematical model for transverse plane motions and appendages was modified in 1994 to include damping terms that couple heave, pitch, and roll.

The remainder of this section will describe background evolution of the six degree of freedom mathematical model for the motions of SWATH ships in waves as implemented in the VisualSMP module SwmpComponent. The solver in this component is SWMP96. With this model, only geometric and mass properties are required in order to predict the six degrees-of-fredom motions of SWATH ships.

Whereas the Lee and Hong mathematical model used the Frank Close Fit Technique to evaluate the velocity potentials, the SWMP software includes approximations. The velocity potentials are not evaluated. Instead, the added mass and damping coefficients are approximated using expressions developed and reported by Dalzell while at Stevens Institute of Technology. The wave exciting forces and moments are approximated as a function of added mass and damping.

The approximate approach for the added mass and damping coefficients of SWATH configurations was developed by Dalzell in the late 1970's. This approach was advantageous because it significantly reduced computer time compared to the Frank Close Fit Technique calculations. Consequently, it facilitated evaluations of numerous hull forms in design studies. The approximations assumed that the cross sections had wall sided struts centered over hulls with elliptical cross sections; this corresponded to ship configurations at that time. Subsequent advances in computers diminished the motivation for approximations and a wider variety of cross sections was considered as the SWATH concept matures. Consequently, the Frank Close Fit Technique was incorporated into the SWMP program, and was optionally utilized to calculate the added mass and damping coefficients. However, since utilization of the velocity potentials for the exciting forces and moments required a reorganization of the program, the wave exciting forces and moments continue to be calculated as functions of the added mass and damping coefficients.

Predictions from SWMP for the vertical plane agreed well with model scale experimental results for all headings through moderate speeds, but predictions for the transverse plane responses were not reliable. Fortunately, for many SWATH configurations, the roll natural period is in a range where little wave energy occurs, resulting in little roll response.

The latest modifications to SWMP, implements the mathematical model described in detail in McCreight's report "Predicting the Motions of SWATH Ships in Waves – A Validated Mathematical Model" dated 1995. In SWMP96, exciting forces and moments are a function of the velocity potentials which are calculated using the Frank Close Fit Technique. The mathematical model for the effects of appendages differs somewhat to the earlier model in SWMP. Expressions to define the lift and drag coefficients for the transverse plane were developed. These coefficients vary with the geometry of the ship and are determined within the program. Corrections to Lee's derivation for the cross flow drag and lift components for the transverse plan were made. Consequently this resulted in the vertical velocities from the cross flow drag to contribute to the forces, as well as new damping terms. This resulted in the coupling of the transverse and vertical planes of motions.

SWMP96 currently provides the capability to obtain:

1. Rigid body motions- the rigid body responses include the displacements, velocities, and accelerations of the six-degree-of-freedom responses, surge, sway, heave, roll, pitch, and yaw.
2. Motions at a point- These responses include longitudinal, lateral, and vertical displacements, velocities, and accelerations for up to ten arbitrary points.

2.2.3 Seakeeping Evaluations

The Seakeeping Evaluation Program (SEP) can be used to estimate the seaworthiness of SWATH or monohull ships early in the design process. Estimation of the seaworthiness of ships can be useful in several ways. In early design studies, prediction of the effect of hull form modifications on ship motions can have an impact on the design, permitting the selection of a seaworthy hull form, from among those which meet other design requirements. The ability to readily analyze the relationship between hull form modifications and seaworthiness can allow consideration of many hull forms in a short period of time. When a ship has been built, estimation of seaworthiness utilizing frequency domain prediction methods can facilitate prediction of the potential ability of the ship to carry out a new mission. This can result in consideration of the effect of hull form modifications on performance.

There are three major components used in the seakeeping evaluation: the rigid body motion transfer functions for the particular hull form, the data which gives the probability of occurrence of various sea conditions, and the seakeeping criteria which describe when performance is degraded due to ship motions. The transfer functions must be generated using Visual Ship Motion Program (SMP) for monohull ships or SWATH Motions Program (SWMP) for SWATH ships.

Required input data for the SEP includes motion transfer functions which have been generated by either the SWMP or the Visual SMP, as well as data files which contain results from analysis of Spectral Ocean Wave Model (SOWM) data. This data defines the joint probability of occurrence of significant wave height, spectral modal (peak) period, and wind speed for various geographical locations.

Although there are limitations to the analysis used in SEP, it provides the means of easily, quickly, and consistently estimating the seaworthiness of hull forms for a range of missions, giving consideration to a wide range of spectra and their probabilities of occurrence at a large number of geographical points. The method of predicting seaworthiness used here is useful in comparing the performance of hull forms.

This chapter describes the use of SEP and the options available to the program user. The output includes printed tables of operability. Various indices of seaworthiness and the tables used to present them are discussed in the next section. A description of data files is given in Section 9.7.

2.2.3.1 Seakeeping Indices

The indices of seaworthiness developed in this seakeeping evaluation are based on a frequency domain analysis utilizing long term wave statistics. The indices represent the average performance of the hull form over a long period of time. The indices neither estimate the seaworthiness of the hull form at a particular moment in time, nor give consideration to factors such as duration of sea conditions.

The joint probability of occurrence of significant wave height, spectral modal (peak) period, and wind speed is based on analysis of more than fifteen years of the U.S. Navy's Spectral Ocean Wave Model (SOWM)[1] data, which was generated using historical data for barometric pressure fields and resulting wind velocity fields. In applying this data, it is assumed that all spectra can be represented using the Bretschneider wave spectrum. The cosine spreading function is used to represent short crested seas. It is also assumed that the wind and waves have the same dominant direction, and that all directions are equally likely.

The criteria represent the level of ship responses to waves at which performance will be degraded. If any criterion is exceeded, it is assumed that performance would be degraded. The degradation may be in the ability of the crew to perform its functions, in the integrity or performance of the equipment, or in the integrity of the hull form.

2.2.3.2 Wind Effects

For air operations, the effects of wind can be included through the use of relative wind envelopes which represent when the relative wind speed is acceptable for performing a particular mission; other wind effects are not considered. When wind effects are used, SEP provides two wind probability data alternatives. The SOWM database, which has joint probabilities of occurrence of significant wave height, spectral modal period, and wind speed can be accessed. Alternatively, wind speed can be represented as a function of significant wave height and spectral modal period can be accessed. In the latter case, absolute wind speed must be defined as a function of significant wave height, using a polynomial which is defined in the input data.

2.2.3.3 Limitations

The indices of seaworthiness developed in SEP are estimates and are not presented as being an absolutely accurate prediction. As noted above, a number of assumptions are made concerning the character of the seaway. The Bretschneider wave spectrum does not represent all possible spectral distributions. The cosine-squared spreading function does not represent all short crested seas. There are currently unused probability distributions of wave direction and wind direction for each set of significant wave height, spectral modal period, and wind speed. Further, all analysis is done in the frequency domain which incorporates various assumptions about the statistics of the seaway and the linearity of the responses of the ship.

These limitations could be removed. The accessed wave probability database could be expanded and responses to a wider range of seaways could be calculated. However, the size of the database would consequently become large and computation time would increase. Time domain analysis, which allows for consideration of a wider range of seaways and has the potential for more accurate modeling of ship responses could be used. However, due to the

[1] Pierson, W.J., "The Spectral Ocean Wave Model (SWOM), A Northern Hemisphere Model for Specifying and Forecasting Ocean Wave Spectra," DTNSRDC Report 82/001 (July 1982).

computation time required and the amount of data produced, only a limited number of wave and operating conditions could be considered using time domain analysis.

A higher level of analysis which incorporates some of these modifications should be carried out in some cases. In any case, a balance in the level of sophistication should be maintained among the various components in the analysis: the accuracy of the prediction of the ship motions, the sophistication of the criteria and the representation of the wave and wind environment.

2.2.3.4 Seakeeping Evaluation Data

A number of seakeeping indices are generated by SEP. For each geographical location specified, a series of tables may be printed. In addition, two summary tables are always printed. A brief description of each table follows:

2.2.3.5 Limiting Significant Wave Heights (LSWH) Table

The LSWH table is an estimate of the largest significant wave height, at which none of the specified seakeeping motion criteria is exceeded by the particular hull form. This table is given only when the wave data does not include consideration of wind effects (i.e., WIND = NO WIND). In this table, a value is given for each ship speed and relative wave heading. Responses to those spectra which would occur at the indicated geographical location are used to calculate the LSWH.

In calculation the LSWH, the 95 percent and/or 50 percent model period confidence bands (input as JBAND) can be utilized. That is, for each significant wave height band of 0.5 meters, the modal period which is most likely to occur, and a band surrounding it, which constitutes 95 or 50 percent of those spectra expected from the significant wave height band, are considered. Consequently, for a specific ship speed and relative wave heading, the LSWH for JBAND = 50 will be equal to or greater than the LSWH for JBAND = 95, which is equal to or greater than the minimum LSWH for all the spectra. Furthermore, the spectra considered will in general vary with geographical location and season.

The LSWH is a conservative value since it is a minimum value, determined using a representation of all spectra which might occur for the specified confidence band. It is possible that the LSWH will be determined by the least probable spectrum. However, when the 95 percent confidence band is used, the LSWH indicates that the performance will not be limited for essentially all spectra which might be encountered which are less than or equal to the LSWH. Consequently, when the LSWH is high, relative to the SEA State specified in the Operational Requirements a hull form with a high LSWH would be a good choice, given that the criteria are well chosen.

The LSWHs are especially useful when an operational requirement states that a hull form must be able to perform a specific mission through a sea state at particular speeds and headings. In this case, the LSWH must be at least as large as the significant wave height corresponding to the specified sea state. The LSWH values should be interpreted carefully, in conjunction with the Percent Time of Operation Table values (see 9.2.3.3).

For each ship speed, the LSWH values for all relative wave headings are averaged. Similarly, for each relative wave heading, the LSWH values for all ship speeds are averaged. These average values are not necessarily good indicators of seaworthiness. When LSWH values are very low for some conditions and very high for others, the average values may be misleading since they could be interpreted as indicating that the operability would be acceptable.

2.2.3.6 Limiting Seakeeping Factors Table

For each speed-heading combination a number identifying the criterion which limits operability and is associated with the LSWH is given in this table. The identifying numbers are defined in the Seakeeping Motion Criteria Table.

2.2.3.7 Percent Time of Operation (PTO) Tables

The PTO, or Percent Time of Operation, is an estimate of the percent of time a hull form could operate in a given environment, given a set of motion criteria, and the specified geographical location. The PTO values indicate the percentage of time, averaged over a long period of time, that a hull form could operate in the particular region. Consequently, the PTOs do not represent the percent of time a hull form would be operable in every possible time span.

The PTO values are given as a function of speed and heading. All spectra which might occur are included in this calculation. The PTO is effectively calculated by determining whether a hull form would exceed any of the limiting criteria in each of the wave spectra, which the wave statistics indicate might be encountered for a specific geographical location and season. The probabilities of occurrence of those spectra, for which none of the criteria is exceeded, are then summed, in order to calculate the total percentage of time a hull form could operate in the specified environment, within the specified operating constraints.

Three PTO tables may be printed. The first, which represents the PTO based on the motion criteria only, is always printed. Following this table, the minimum and average of the values in the table are given. In addition, a weighted average of the PTOs is given. The average utilizes the speed-heading profile which is input as IHVWT(I,J.).

The second and third PTO tables will be printed whenever consideration is being given to wind effects. These tables present the PTO, based on both motion criteria and absolute wind envelopes. For each absolute wind speed, the wind envelopes identify the ship speeds and relative wave headings for which a particular air operation could be performed without degradation in performance. A weighted average PTO is also printed. The first of these two tables presents the PTO, with consideration given to both the ship motion criteria and the wind envelopes. The last table also indicates ship motions and the wind envelopes; however, these results are normalized with respect to those conditions where wind does not limit operability.

2.2.3.8 Percent Time of Occurrence of Significant Wave Height and Percent Time of Operation Table

Information is given for a particular geographical location in this table. Values are given as a function of significant wave height band, where each band is 0.5 meters wide. Discrete and cumulative percent time of occurrence of spectra and discrete and cumulative Percent Time of Operation are printed as a function of significant wave height band. The "discrete" values are relative to all of the spectra in each individual band, and the "cumulative" values are relative to all of the spectra with significant wave heights up to the upper limit of the band. The PTO values are the weighted (according to the speed-heading weights, IHVWT(I,J) average, presented as a function of significant wave height. This information is very useful in evaluating the degree to which a hull form meets the Operational Requirements. If the program user chooses values for IHVWT(I,J) properly, an estimate of the percent time of operation through the specified sea state can be obtained for the hull form.

When wind is not considered, as significant wave height increases, the cumulative PTO will approach the weighted average PTO, given below the first table of PTOs as a function of ship speed and heading. When wind is considered, there is an option regarding whether or not the PTO will be normalized, relative to those conditions where wind does limit performance. If the PTO is not normalized, then the PTO may be less than 100 at all significant wave heights. This occurs when the wind conditions are unacceptable for all wind speeds for one or more ship speed-wave heading combinations. In such a case, the cumulative PTO will approach the average weighted PTO, which includes motion criteria and the wind envelope. If the PTO is normalized, however, the PTO will not necessarily tend toward one of the average weighted values. This has been shown to be correct analytically.

2.2.3.9 Percent Time Each Criterion Limits Operability

This table is printed only when the wind is considered. It is an estimate of the percent of the time operability is limited due to each criterion. The percent considered is determined relative to the likelihood of occurrence of those wind conditions during which operability is acceptable. For each modal period-wind speed-ship speed-wave heading combination, the limiting criterion is determined. The difference between the likelihood of the highest significant wave height and the limiting significant wave height is determined. Average and weighted average PTOs are then determined. This is an approximate measure, since no consideration is given as to whether another criterion also would have limited operability at significant wave heights greater than the limiting significant wave height. At any given condition, the limitation to operability is assumed to be due to only the criterion which first limits operability.

2.2.3.10 Seakeeping Evaluation Table

The summary of the Seakeeping Evaluation Table for the composite of the Ocean basin selected, and for each specified geographical location: grid point, sub-projection, latitude, and longitude are given. Also, when wind is not considered (i.e., WIND=NO WIND), the minimum and average LSWH and corresponding confidence band (50% or 95%). The minimum, maximum, minimum normalized, maximum normalized, average, weighted average, weighted average with wind, and the weighted average normalized PTOs are listed.

2.2.3.11 Limiting Significant Wave Height Due to Ship Motions and Corresponding Failing Criteria Table

This table is independent of geographical location and is the basis of the LSWH and PTO calculations. The LSWH for each ship speed, relative wave heading, and spectral modal period is given. A table of the corresponding limiting criteria is also given. This table can be useful in analyzing performance characteristics of hull forms. For example, it can be readily seen if there are large variations in performance as a function of speed, heading, and spectral modal period. In addition, the speeds and headings at which a ship could operate without degradation in performance can be determined for a Bretschneider wave spectrum of any significant wave height which has any one of the modal periods listed. For each spectral modal period, speed, and heading, the LSWH indicates the lowest significant wave height when performance is degraded. Consequently, if a particular LSWH is larger than the significant wave height of the spectrum of interest, performance would not be degraded for the spectrum of interest.

2.2.3.12 Range of Validation

The seakeeping Evaluation Program (SEP) can be used to estimate the seaworthiness of SWATH or monohull ships.

Although data to validate this methodology is limited, it is encouraging that results for a destroyer from SEP[2] agree reasonably well with an operator's assessments[3] of operability.

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[2] McCreight, Kathryn K. and Ralph G. Stahl, "Recent Advances in the Seakeeping Assessment of Ships," Naval Engineers Journal (May 1985).

[3] Kehoe, James W. Kenneth S. Brower, and Edward N. Comstock, "Seekeeping and Combat System Performance -- the Operator's Assessment," Naval Engineers Journal (May 1983).

2.2.4 Time History

2.2.5 Visualization