COMPUTER SOFTWARE PRODUCT END ITEMS

UPDATE TO GLOBAL FE MODEL

Submitted to:

SPAWAR Systems Center San Diego
53560 Hull Street, Code 2206
San Diego, California 92152-5001

Attention:
Mr. Mark Tukeman, Code 2712
(619) 553-1510

In fulfillment of the requirements for:

Contract No. N66001-02-D-0039
Development of Port Related Transportation Technologies
to Advance Military Responsiveness to National Needs

Task Order No. 0017
Liberty Class Initial Ship Design

CDRL Data Item No. A001BA

Security Classification: Unclassified

Prepared and Submitted by:

Center for the Commercial Deployment of Transportation Technologies
California State University, Long Beach Foundation
6300 State University Drive, Suite 220 • Long Beach, CA 90815 • 562.985.7394

December 15, 2005

Kvaerner Masa Marine

VERY HIGH SPEED TRIMARAN ROPAX (VHSTR) DESIGN DEVELOPMENT

Task 2 Technical Report: Completion of Global Finite-Element Model

Prepared For:

Science Applications International Corporation
1710 SAIC Drive, MS 2-8-1
McLean, VA 22102

By:

Kvaerner Masa Marine
201 Defense Highway
Suite 202
Annapolis, MD 21401

KMM Project 561-2
SAIC Subcontract 4400069958

TABLE OF CONTENTS

SECTION I

1. SUMMARY

As part of the structural design process for the "Liberty Class" Very High Speed Trimaran Ropax (VHSTR), Kvaerner Masa Marine (KMM) has built a global finite-element (FE) model of the vessel. Task 2.0 of the CCDoTT Fiscal Year 2002 Program focuses on the refinement of the global FE model, to bring it in accordance with both Classification Society recommendations and the current vessel arrangement. The purpose of this report is to document the completed FE model's geometry and construction.

The global FE model has been constructed in accordance with KMM's "Methodology for Global Finite Element Analysis of Very High-Speed Trimaran Ropax," Rev. 2 (Appendix A). This methodology is a revised version of that described in KMM's Preliminary Structural Design Report, submitted to CCDoTT for Task 4.2 (Milestone 5) of the Very High Speed Trimaran (VHST) Technology Elements Development study, Program Element Number 2.16, for the CCDoTT Fiscal Year 2001 Program (Reference 1). The revised methodology has been approved by the American Bureau of Shipping (ABS).

The model reflects the VHSTR arrangement, as defined by the General Arrangement, Dwg. No. 1101.1, Rev. -, dated May 21, 2003 (Reference 2). The model includes representation of all primary structure, and of secondary structure members effective in resisting global loads. Structural scantlings have been taken from preliminary structural calculations.

KMM has maintained an interface with ABS and implemented their recommendations for the development of the global FE model to show structural adequacy of the preliminary design, towards receiving Approval In Principle. The global model has been submitted to ABS for review towards the issue by ABS of a letter of approval; however, at the time of writing ABS has not completed its review. A letter from ABS acknowledging receipt of the model is included in the present report as Appendix E. A letter of approval for the model will be provided to SAIC prior to the 25 June 2003 deadline for Task 3.0.

In the FY2002 scope of work, construction of the global model has been completed. Development of loads, application of loads, and assessment of results were not included in the FY2002 scope of work and have not been performed.

SECTION II

1. INTRODUCTION

As part of the structural design process for the “Liberty Class” Very High Speed Trimaran Ropax (VHSTR), Kvaerner Masa Marine (KMM) has built a global finite-element (FE) model of the vessel. The purpose of this report is to document the completed FE model’s geometry and construction.

The global FE model has been developed for the purpose of assessing the strength of the VHSTR under longitudinal and transverse loads. These loads may include shear forces and bending moments induced by the vessel’s still-water buoyancy or by waves; accelerations due to ship motions in waves; seakeeping loads such as slamming; and racking.

The global FE model has been constructed in accordance with the methodology described in KMM’s “Methodology for Global Finite Element Analysis of Very High-Speed Trimaran Ropax,” Revision 1 (Appendix A). The model reflects the current general arrangement of the VHSTR, as defined in the General Arrangement drawing (Reference 2). The model includes discrete representation of all primary structure. Secondary structure effective in resisting global loads is implicitly represented through the use of orthotropic shell elements. Structural scantlings have been taken from preliminary structural calculations prepared under Task 3 of KMM’s FY2002 scope of work.

In the FY2002 scope of work, construction of the global model has been completed. Development of loads, application of loads, and assessment of results were not included in the FY2002 scope of work and have not been performed.

2. DESCRIPTION OF THE VESSEL

The VHSTR is a large trimaran of novel design. The hullform features a narrow main hull extending for the vessel’s full length and shorter, symmetric side hulls. The hulls are joined by a multi-deck crossdeck structure. The vessel is powered by waterjets driven by gas turbine engines. Propulsion machinery is fitted in all three hulls.

As a large, multi-deck vessel, the VHSTR’s global structural response involves the interaction of its decks, hull, side structure, and bulkheads. For instance, under longitudinal bending the decks are in tension or compression, while longitudinal bulkheads, house sides and casings transfer shear loads between the decks. Due to the vessel’s multi-hull configuration, torsion and shear loads may be generated in the cross-deck structure as the main hull and side hulls encounter differing loads.

The Liberty Class VHSTR is designed to be a dual-use vessel with both commercial and military applications. It may operate as a cruise ship carrying passengers or as a transport ship for wheeled vehicle cargoes. The vessel features a cargo hold in the main hull with strengthened cargo decks. In the transport role, wheeled or containerized/palletized cargoes may be carried. In the cruise role, additional crew cabins or temporary passenger facilities (e.g., conference rooms) may be installed in the cargo area. The hull side above the bulkhead deck and the superstructure side have several hundred large openings for windows and balconies on passenger cabins.

The vessel's particulars are given in Appendix B.

3. STRUCTURAL DESIGN

The VHSTR is has been designed in accordance with the Lloyd's Register of Shipping, Rules and Regulations for the Classification of Ships, July 1999, for unlimited ocean service. The ship's structure has been designed in accordance with Part 3 (Ship Structures, General); Part 4, Chapter 1 (General Cargo Ships); and Part 4, Chapter 2 (Ferries, Roll-on Roll-off Ships, and Passenger Ships) as applicable.

All ship structure is steel, with Grade AH36 high tensile steel used to the maximum possible extent to minimize the weight of the vessel. For design purposes, the bulkhead deck has been taken as Deck 5. The weather deck has been taken as Deck 7.

The vessel's hulls are longitudinally framed, except that the bottom structure aft of forward of Frame 106 and the entire hull forward of Frame 121 is transversely framed. The cross-deck structure below Deck 5 is longitudinally framed. Initial scantlings for the main hull and side hull structure were calculated using standard design formulas from Lloyd's Rules.

Decks 5 to 7 continuously span the full breadth of the vessel. Below Deck 5 there are independent decks in each hull. Decks 8 and above span the full width of the superstructure; Dec. The double bottom and the hull decks are longitudinally framed, except that transverse floors are fitted on every frame under the propulsion and auxiliary machinery (Frames 0 to 23 below Deck 3 in the main hull, Frames 5 to 17 below Deck 3 in the side hulls). All decks in the superstructure are longitudinally framed throughout. Design loads for all decks were taken from Lloyd's Rules for enclosed decks, weather decks, or superstructure decks as appropriate. The cargo decks (Decks 3 and 4) were designed to support wheeled vehicle cargoes equivalent to a U.S. Marine Corps MTVR truck.

The vessel's house sides are longitudinally framed below Deck 9 and transversely framed above Deck 9. The house side plating aligns with the inner shell plating of the side hulls over the length of the side hulls. Longitudinal bulkheads are fitted between Decks 5 and 7 in line with the side hulls and house sides, port and starboard, for structural continuity. A longitudinal bulkhead is fitted between Decks 9 and 13 in the superstructure, port and starboard, from Frames 24 to 101.

Transverse watertight bulkheads are fitted in the main hull and side hulls as required to comply with subdivision and stability regulations, extending to Deck 5. Transverse fire zone bulkheads are fitted in the hulls and superstructure above Deck 5, as required to comply with structural fire protection regulations. Fuel, water, and other liquids are carried in integral, double-hulled tanks below Deck 3. All transverse bulkheads are vertically framed. Longitudinal tank bulkheads are longitudinally framed.

Noteworthy structural features of the VHSTR design include the following:

- Several hundred openings for passenger cabin balconies in the superstructure side plating above Deck 9.
- Large open areas in the superstructure side plating aft of Frame 19, between Decks 7 and 10 (in way of the gas turbine supply air intakes).
- No superstructure side plating aft of Frame 19 between Decks 10 and 13.
- No deck plating aft of Frame 19, on Decks 11 and 12.
- A large casing aft of Frame 19, containing gas turbine exhaust uptakes.
- Large openings in Deck 14 in way of the pools, including a length of “strip deck” between Frames 50 and 69.
- A promenade extending from Frames 44 to 88, including openings over centerline in Decks 9 and 10.
- Large openings for an atrium in Deck 8 and for a decorative dome in Deck 9, between frames 32 and 38 on centerline.
- A large opening in Deck 7 in way of the show lounge, between Frames 94 and 106.
- Discontinuous deck plating between Frames 94 and 106 on Deck 6, in way of the show lounge.
- No deck plating between Frames 90 and 106 on Deck 5.
- Large cargo door opening in the starboard side of the main hull above Deck 4, between Frames 63 and 68 and between Frames 101 and 106.

Reference 3 shows the midship structural scantlings of the Liberty Class VHSTR. Additional structural arrangement drawings shall be included in the Preliminary Design Booklet prepared for Task 3.

4. GLOBAL FINITE ELEMENT MODEL

4.1. General

The global FE model has been constructed using visualNastran for Windows 2002 software from MSC Software. It is a half-hull model, representing the starboard side of the vessel over its complete length. The model may be mirrored in the future for the analysis of asymmetric load conditions.

Construction of the global model was begun under the FY2001 scope of work. In FY2002, the model was completed. Work performed on the model in FY2002 included the following:

- Finalization and approval by ABS of the global model analysis methodology. The proposed analysis methodology was described in the FY2001 Preliminary Structural Design report (Reference 1). The model construction methodology as approved by ABS and applied to the model is described in the present report.
- Addition of discrete window and balcony openings to the global model, in accordance with the analysis methodology as approved by ABS.
- Modification of the model geometry to match the current General Arrangement drawing (Reference 2).
- Definition of element properties for the fore and aft ends of the model, to match the structural calculations and structural drawings.

4.2. Model Geometry

The geometry and structural arrangement of the model is based on the General Arrangement drawing (Reference 2) and the Lines Plan (Reference 4).

The global model includes representation of all structure that contributes to the global strength of the VHSTR. It includes the following steel plate panel components:

- Hull and demihull bottom, side and transom plating
- All house sides
- All decks from the tank top (Deck 1) to Deck 15
- All plate floors and plate girders in the double bottom
- Major longitudinal structural bulkheads present on both the port and starboard sides
- All transverse watertight bulkheads, main fire zone bulkheads, and house-end bulkheads
- All major structural tanks below Deck 3
- All fixed cargo ramps
- All major casings, stair enclosures, and elevator enclosures

The global model includes the following primary framing components:

- Deck girders, floors and transverse frames
- Side shell and bulkhead stringers
- Main vertical frames on the hull side, house side, bulkheads, and deep tanks
- Coamings around major deck openings
- Pillars

Where the VHSTR’s port and starboard arrangements are asymmetric, the side expected to have the least structural strength or rigidity has been reproduced in the model. For instance, the large cargo door openings in the starboard hull are represented.

All significant window openings, deck openings and shell openings in longitudinal structure are discretely represented in the model. Examples include atrium openings in the decks, and window/balcony openings in the hull and house side.

In some locations, minor deviations have been made from the geometry in the reference drawings. This has been done only in locations where the differences will not affect the global response of the model. Similarly, the geometry of the model has been simplified in areas where doing so will not affect the global response. For instance, the propulsion machinery spaces aft have been modeled with a transverse frame spacing of 2.5m, neglecting the presence of intermediate floors at 1.25m spacing. In the forepeak, stringer flats between the primary decks have not been modeled.

As one example, the machinery spaces aft are shown on the structural drawings to have transverse frames at 1.25m spacing. In the model, only every second frame is represented, to avoid an increase in mesh density.

Due to the preliminary state of the VHSTR design, some features of the vessel were not been defined in sufficient detail to be represented in the global model. Examples include air conditioning intake plenums in the superstructure and gas turbine supply air intake openings in the house side aft.

Appendix C contains images of the global model, including overall views, plan views of the decks, sections in way of the MFZ bulkheads, and profiles.

4.3. Model Construction

The global model has a nominal mesh size as follows:

- Longitudinally: one element between transverse frames. The longitudinal dimension of elements is typically 2.5m.
- Vertically: one element between decks or stringers (except one element for all pillars). Element vertical dimensions typically range between 3.0 to 5.0 m, except in way of shell openings.
- Transversely: as limited by girder/longitudinal bulkhead spacing, with a maximum aspect ratio of about 3.0. Element transverse dimensions typically range from 0.62m to 5.3m.

The mesh has been refined in way of structural details such as window and balcony openings in the hull and house sides, to permit these features to be discretely modeled. **Error! Reference source not found.** in Appendix C is a detail view of the typical mesh structure in way of these openings. Larger openings have been represented by deleting elements from the global mesh.

The global model includes discrete representation of all plate panel structures listed in Section 4.2, as shell elements with in-plane normal, in-plane shear, and bending stiffness (Nastran CQUAD4 and CTRIA3 formulations). Both four-node and three-node orthotropic shell elements have been used in the model. Rectangular quadrilateral elements have been used to the maximum possible extent. Triangular elements have been used only where necessary to avoid element warping, facilitate mesh transitions, or represent complex geometry.

Limits on aspect ratio, internal angles, etc. have not been enforced on elements in way of shell openings. The shapes of these elements should lead to an artificial increase in local stress levels when the global model is run, which is conservative.

The global model includes discrete representation of all primary framing members listed in Section 4.2, as two-node beam elements with axial and bending stiffness (Nastran CBAR formulation). The bending stiffness of the beams allow them to support the normal loads that will be applied to the shell panels of the model. Because the plate elements used in the model have out-of-plane (bending) stiffness properties, there is no issue of incompatibility at connections between beam elements and plate elements.

The completed model has 31,161 elements and 15,479 nodes. The construction of the model is shown in the images in Appendix C.

4.4. Element Properties

Element properties have been chosen to represent the structural scantlings shown on the Midship Section drawing, Reference 3, and on other preliminary scantling drawings developed by KMM. Different element property sets have been defined for each deck, each fire zone, and each level of side shell and bulkheads between decks.

The properties of the orthotropic shell elements account for the axial, shear, and bending stiffness of the attached stiffeners. Each orthotropic element has been assigned the thickness of the plating it represents. In the direction parallel to the stiffeners, the elastic modulus of each element has been assigned as follows:

$$E_P = E_{\text{Material}} \times \left(\frac{\text{Cross-sectional area of plate plus attached stiffeners}}{\text{Cross-sectional area of plate alone}} \right)$$

The mass density of the element has been chosen to represent the plate plus attached stiffeners. Stiffener directions have been defined for each orthotropic element using Nastran's "material angle" property.

Beam elements representing primary structure have been assigned the cross-sectional area, material stiffness, and mass density properties of the members they represent, with no attached plate. The inertia property of each element is that for a cross-section consisting of the member plus an effective width of attached plate. The neutral axis of each element has been offset to place the neutral axis of the "hybrid" cross section at the mid-plane of the plate elements.

Beam elements representing pillars have been assigned the area, inertia, material stiffness, and mass density properties of the members they represent.

Members in the vertical centerline plane of the global model have been assigned half-thickness, half-area, and half-inertia properties. These properties will be changed to their full values if the global model is mirrored to create a full-hull model.

Lists of element properties are given in Appendix D. The total self-weight of the elements in the half-model is 11,260 mt.

4.5. Acceptance of Model by Class

The global model has been submitted to ABS for review towards the issue by ABS of a letter of approval. However, at the time of writing ABS has not completed its review. A letter from ABS acknowledging receipt of the model is included as Appendix E. A letter of approval for the model will be provided to SAIC prior to the 25 June 2003 deadline for Task 3.0.

4.6. Loads and Boundary Conditions

The calculation of loads and application of boundary conditions to the global model were not part of the FY2002 scope of work and have not been performed at this time. Loading methodology is discussed in Appendix A.

4.7. Assessment of Results

Assessment of the global model was not part of the FY2002 scope of work and has not been performed at this time. Assessment methodology is discussed Appendix A.

5. REFERENCES

1. “Very High Speed Trimaran (VHST) Technology Elements Development, Task 4.2: Preliminary Structural Design, Milestone 5.” Kvaerner Masa Marine, February 21, 2003.

2. “General Arrangement,” KMYT drawing 1110.1, Revision -, dated May 21, 2003.

3. “Midship Section,” KMM drawing 561-101-01. In-progress revision, June 6, 2003.

APPENDIX A – GLOBAL MODEL FEA METHODOLOGY

Methodology for Global Finite Element Analysis of Very High-Speed Trimaran Ropax

Submitted to:

American Bureau of Shipping
16855 Northchase Drive
Houston, TX 77060

Submitted by:

Kvaerner Masa Marine
Suite 207
1525 W. 8th Ave
Vancouver, BC. V6J 1T5

Project 534-2
Revision 2
28 May 2003

1.0 Introduction

A global finite-element (FE) model will be used to verify the structural feasibility of the Liberty Class VHSTR, by showing that the vessel has adequate global hull strength for the sea loads it is expected to encounter in service. The global model may also be used to identify local areas of high stress, which may be analyzed using local models in future work.

The VHSTR is a large, multi-deck vessel. Its strength is governed by the interaction of its decks, hull, side structure, and bulkheads. (For instance, under longitudinal bending the decks are in tension or compression, while longitudinal bulkheads, house sides and casings transfer shear loads between the decks.) Intended primarily for operation as a cruise ship, the VHSTR also has numerous openings in longitudinal structure for windows, doors, atriums, etc., all of which affect the response of the hull girder. In addition to longitudinal loads, as a trimaran the VHSTR may also encounter torsion and shear of the cross decks as the main hull and sidehull encounter differing sea loads, and transverse bending. The complex behavior of the ship's structure lends itself to finite-element analysis.

The global model will be developed and analyzed by a procedure similar to that outlined in Section 2/3.7, "Direct Calculation," of the ABS "Guide for Building and Classing Passenger Vessels" (Reference 1). The model will be built and analyzed using MSC.visualNastran for Windows 2002 software. This is a general-purpose analysis tool that combines the MSC.Nastran FE solver with a FEMAP graphic pre-/post-processor. The model will be solved using linear static methods.

The global model will be loaded with sea loads calculated by the Large Amplitude Motions Program (LAMP 2). The calculation process will be validated against existing model test data for large trimarans. The global model will be loaded with pressures and rigid body accelerations corresponding to maximum wave loads, and a quasi-static analysis will be performed to obtain stresses and deformations.

In FY2001 work, the global model will be developed to an advanced stage. The geometry of the model has been fully defined and meshed, and structural properties have been assigned to the majority of elements. Before analysis can begin, it will be necessary to add non-structural mass to the model, and apply constraints. Loads will also need to be computed and applied.

Analysis of the global model will consist of checking in-plane normal and shear stresses under applied loads. Stresses will be compared to allowable values defined by ABS. Arrangement and structural features that are detrimental to global strength will be identified for redesign.

2.0 Global Model Construction

2.1 Model Geometry

The global model will represent all structure that contributes to the global strength of the VHSTR. It will include the following plate panel components:

- Hull and demihull bottom, side and transom plating
- All house sides
- All decks from the tank top (Deck 1) to Deck 14
- All plate floors and plate girders in the double bottom
- All longitudinal structural bulkheads
- All transverse watertight bulkheads, fire zone bulkheads, and house-end bulkheads
- All major structural tanks below Deck 3
- All fixed cargo ramps
- All major casings

The global model will also include discrete representation of all primary framing (girders, transverses, stringers, and vertical frames) and pillars. Shell, deck, and longitudinal bulkhead openings will be discretely modeled.

The geometry of the global model will be based on the following references:

- General Arrangement drawing (deck outlines at and above Deck 5, locations of structural bulkheads and pillars, deck openings, tanks, ramps)
- Lines Plan drawing (hull sections, deck outlines below Deck 5)
- Midship Section drawing (girder lines, pillar lines, frame spacing, deck heights)

Small deviations from the geometry in these drawings will be permitted to avoid unacceptable element shapes when the model is meshed, so long as the deviations do not affect the global response of the model.

Due to the preliminary state of the VHSTR design, some features of the vessel have not been defined in sufficient detail to be represented in the global model. These features can be added to the model in the future. One example of such a feature is air conditioning intake plenums.

Initially, only one side of the vessel will be modeled. The model can be mirrored about the centerline vertical plane to generate a full-hull model if required in later stages of the project, (such as for racking, transverse bending, or torsion analyses).

2.2 Meshing and Element Properties

The nominal mesh size of the global model will be as follows:

- Longitudinally: one element between transverse frames

- Vertically: one element between decks or stringers (except one element for all pillars)
- Transversely: as limited by girder/longitudinal bulkhead spacing and by aspect ratio. (See below.)

A smaller mesh size may be used in areas where high stresses or large deformations are expected, such as at the fore and aft ends of the bridge structure and in way of corners on the wet deck. There will be a smooth transition of mesh size between these areas and the remainder of the global model.

Plate panel structures (plating plus attached stiffeners, as listed above under Geometry) will be modeled as orthotropic plate elements with in-plane normal, in-plane shear, and bending stiffness (Nastran CQUAD4 and CTRIA3). Each element will be assigned the thickness of the plating it represents. In the direction parallel to the stiffeners, the elastic modulus of each element will be as follows:

$$E_P = E_{\text{Material}} \times \left(\frac{\text{Cross-sectional area of plate plus attached stiffeners}}{\text{Cross-sectional area of plate alone}} \right)$$

The elastic modulus at right angles to the stiffeners and the shear moduli will be those of the base material, with no allowance for the presence of stiffeners. The mass density of the element will be chosen to represent the plate plus attached stiffeners.

If areas occur in the model where stiffeners are not parallel and/or not equally spaced, and these areas contribute to the primary strength of the vessel, stiffened plating shall be represented by a combination of isotropic plate elements and rod elements. All properties of the plate elements shall be those of the unstiffened plating. The rod elements shall be located at the edges of the plate elements, parallel to the nominal stiffener direction. The cross-sectional area of each rod element shall be equal to the sum of the areas of the stiffeners on the adjacent panel.

Rectangular quadrilateral elements will be used to the maximum possible extent. Other plate elements (except those in way of small openings) will have will have all internal angles between 45° and 135° if possible. In general, the maximum aspect ratio (longest edge/shortest edge) for plate elements shall be 3:1, and additional element boundaries shall be added to the model as necessary to achieve this. Higher aspect ratios shall be accepted for elements framing shell or house side openings, and for elements representing structure that does not contribute to the longitudinal strength of the vessel (e.g., double bottom floors).

Shell, deck, and main bulkhead openings – such as atriums, service openings, doorways, and window or balcony openings – will be discretely modeled. Openings smaller than the nominal mesh size will be "framed" with triangular and tetrahedral elements. The aspect ratio and corner angles of these elements shall be as required to achieve an accurate representation of the opening size and shape.

Girders, transverse frames, stringers, and vertical frames will be modeled as two-node beam elements with axial and bending stiffness (Nastran CBAR). The beam elements will be assigned the area, material stiffness, and mass density properties of the members they represent, with no attached plate. The inertia property of each element will be that for a cross-section consisting of the member plus an effective width of attached plate. The neutral axis of each element will be offset to place the neutral axis of the “hybrid” cross section at the mid-plane of the plate elements.

Pillars will be modeled as two-node beam elements with axial and bending stiffness; these elements will be assigned the area, inertia, material stiffness, and mass density properties of the members they represent.

All element properties will be based on initial scantlings calculated for the VHSTR. Different plate element property sets will be defined for each deck, each fire zone, and each level of side shell and bulkheads between decks. This will allow the element properties to be updated quickly if changes are necessary.

Members in the vertical centerline plane of the global model shall be assigned half-thickness, half-area, and half-inertia properties. These properties will be changed to their full values when the global model is mirrored to create a full-hull model.

2.3 Development of Wave Loads

Determining the wave loads to be applied to the finite element model will be an important part of the structural analysis of the Liberty Class VHSTR. This novel ship is of a size and configuration that has never been built and, therefore, there is quite limited design experience that can be used as a basis for this design. The structural design must, therefore, be based on a first principles approach where the wave loads are calculated directly using advanced computational methods. KMM proposes to use the Large Amplitude Motions Program (LAMP 2) to calculate the wave loads. The analysis will follow the approach presented by Shin, Chung, Lin, Zhange and Engle in SNAME Transactions 1997 (Reference 2).

LAMP 2 is a 3-dimensional, nonlinear, time domain sea keeping software code that uses large amplitude incident waves, and employs nonlinear hydrostatic and Froude-Krylov wave exciting forces with linear hydrodynamic forces (added mass and damping and diffraction) (Reference 3). The program is suitable because it has proven to be effective in calculating wave loads on high-speed ships and can account for nonlinearities caused by the vessels complex hull geometry such as the effects of the wave piercing bow or possible wave interactions with the cross deck structure.

LAMP 2 will be first validated against model test data for a large high-speed trimaran that was tested at VTT in Finland by Kvaerner Masa-Yards Technology (Reference 4). These tests included tests in both irregular and regular waves for a segmented model. The center hull was divided into eight sections and between each section was fitted a force/moment transducer. A force/moment transducer was also fitted in the cross deck between the main center hull and the port side hull. Measurements were made in head seas and oblique seas. This data will be very valuable for ensuring that the wave forces predicted for the high-speed trimaran cruise ship are reliable and will be provided to ABS for review.

The hull form developed for the VHSTR is similar to the hull form developed for the VHST DASH project. Seakeeping model test results are also available for this ship and will be used to validate LAMP. In this case loads were not measured and only motions data is available, however, comparing the motions results from LAMP to the model test values still will provide a useful calibration. The relevant data will be provided to ABS for review.

Wave loads are more complex on a trimaran than on a conventional monohull because there are more potential load cases to consider. The highest loading can be expected on the long center hull in the form of vertical and horizontal bending moments. The center hull is relatively slender and will carry a majority of the bending moments. In oblique seas the loading on the cross deck structure becomes critical as relatively large torsion moments and vertical shear forces can be generated. Also slamming on the cross deck should be checked to ensure that there is sufficient clearance between the cross deck and the free surface. The following Dominant Load Parameters (DLPs) have been identified based on the ABS HSC Guide:

- Vertical Bending Moment
- Transverse Bending Moment
- Vertical acceleration
- Torsion Moment
- Cross structure shear force
- Roll

The vessel will be designed for unrestricted service in the North Atlantic. KMM and SAIC will develop a matrix of headings and sea conditions expected to create the largest wave loads on the hull for each of the DLPs. Normally the highest wave conditions create the highest loads, however, wave conditions that could cause motion resonances will also be investigated. The matrix will be submitted for review by ABS before being used in the time domain seakeeping analysis.

Random irregular waves will be generated in LAMP and the wave induced global loads including bending moments, shear and lateral forces at any section along the ship will be calculated. At the point in time where the highest global loads are predicted in LAMP for each of the Dominant Load Parameters the hull pressure distribution and rigid body accelerations will be output to the finite element model for a quasi-static analysis. The panel pressures will output using the LMPRES post processor, which is capable of interpolating the pressures for the smaller element size of the FEA model. The accelerations will be used to calculate the inertia loads on the hull.

The underside of the cross deck may be subjected to slamming in large waves. LAMP will be used to calculate relative velocity between the hull and the free surface during slamming and a semi-empirical method will be used to determine the slamming pressure. The slamming pressure will be used to check the design pressures used for the development of scantlings for the local structure and to confirm that slamming does not create significant global loads. It is not planned to analyze the transient response of the hull at this stage. If considerable slamming is predicted further analysis of slamming will be carried-out in a later stage of the design development.

3.0 Plan of Further Work

3.1 Model Completion

At the completion of FY2001, the following additional work will be required to prepare the global model for analysis:

1. Non-structural mass must be added to all deck plate elements to achieve the correct lightship weight distribution and VCG for the VHSTR.
2. Constraints must be applied to the model. The constraints will be a minimum set to resist free-body translation and rotation of the model. (Under applied loads, all constraint reactions should be negligible.) For the half-model, symmetry constraints will also be applied on the centerline vertical plane.
3. Appropriate loads must be applied to the model. These include live loads from passengers and crew, provisions loads, tank contents, and cargo as well as sea loads (discussed above).

3.2 Assessment of the Global Model

The half-hull model will be analyzed for stresses and deflections due to the applied loads. A full-hull model will be analyzed for stresses and deflections under transverse loads. Assessment criteria will be taken from Section 2, Table 2, “Limiting Failure Criteria,” of Reference 1. Buckling strength will be assessed in accordance with Section 2/3.11.2, “Buckling Criteria,” of Reference 1.

The global model results may indicate that some areas of the VHSTR design require rework to improve the strength of the vessel. For instance, stress concentrations might be evident at the connections between the hulls and the wet deck under torsion or racking loads. Openings for windows and balcony doors could reduce the shear capacity of side sweeps and longitudinal bulkheads. Any changes made to the VHSTR design to rectify such problems would have to be incorporated in the global model, and the model would have to be re-analyzed.

3.3 Local Models

Reference 1 requires that a global model be supplemented by fine-mesh models, to assess areas of local high stresses. These models would represent features such as openings in longitudinally-effective structure, engine casings, and girders and transverse frames with service openings. Local models would be loaded by applying displacements from the global model to nodes at the perimeter of the local models. Second-order interpolation would be used to obtain displacements for local-model nodes that did not correspond directly to global-model nodes. The local models will also be reloaded with the appropriate local loads.

Detailed assessment of the VHSTR design using local models would only be appropriate as long as the global model matches the planned configuration of the vessel. As the VHSTR is still being developed, it is conceivable that the global model and the design could diverge before the global model analysis is complete. The usefulness of local models based on the current VHSTR concept, and what models would be necessary, will be determined after the global model analysis is complete.

4.0 References

1. "ABS Guide for Building and Classing Passenger Vessels, March 2001." Houston, American Bureau of Shipping, 2001.

2. Shin, Y., Chung, J., Lin, W., Zhang, S., Engle, A., "Dynamic Loadings for Structural Analysis of Fine Form Container Ship Based on a Non-linear Large Amplitude Motions and Loads Method", SNAME Transactions, Vol. 105. New York, Society of Naval Architects and Marine Engineers, 1997.

3. Beck, R., and Read, A., "Modern Computational Methods for Ships in a Seaway", SNAME Transactions, Vol. 109. New York, Society of Naval Architects and Marine Engineers, 2001.

4. Hakala, M., and Rantanen, A., "Force Measurements of the Segmented Trimaran Model", Research Report VAL3244E/94/LAI, VTT Manufacturing Technology, 1995.

APPENDIX B – VHSTR DESIGN DATA

APPENDIX C – GLOBAL MODEL GEOMETRY

APPENDIX D – GLOBAL MODEL ELEMENT PROPERTIES

APPENDIX E – ABS LETTER OF RECEIPT FOR GLOBAL MODEL

KVAERNER MASA MARINE, INC. PROPRIETARY INFORMATION