Structural Load Prediction for High-Speed Planing Craft

1.0 OBJECTIVE.

The objective of this project are to develop and verify a practical method to use time domain simulation to drive structural design of high speed planing craft. Existing and developmental time-domain simulators will be enhanced and modified so as to calculate panel pressures, vessel kinematics, and loads for use in Finite Element Method (FEM) programs for structural analysis. Specifically, low aspect ratio strip theory will be extended to predict transient slamming loads created when a high-speed craft travels through irregular seas. The new analysis method must meet the following requirements:

- Predict transient hydrodynamic panel pressures for use in Finite Element Method (FEM) programs.
- Predict velocities, rates and accelerations for use in FEM programs.
- Calculate instantaneous shear forces and longitudinal bending moments for comparison and verification of FEM results.

2.0 BACKGROUND.

Currently there is a great deal of interest in high-speed planing boats. The USCG is in the middle of a long-term acquisition plan for the RB-S and RB-M patrol craft. USSOCOM has issued an RFQ for the CCM Mark I, a replacement craft for the workhorse 11m RIB. In the civilian sector, high-speed craft are important for new, competitive ferry services and possibly for high-speed freight services, both regulated by US Coast Guard.

Structural assessment of these craft has an important impact on their operational safety. A major problem in the design of high-speed planing boats such as fast ferries and patrol craft is predicting the panel loads for structural analysis. It is possible to predict the the stress in panels as a function of known loads, but it is very difficult to predict the loads for irregular sea states. Three-dimensional algorithms such as CFD are computationally intensive and cannot be used in time-domain simulation.

To illustrate the difficulty of designing high-speed planing craft, the Mark V is an 82-foot aluminum boat built to carry Special Operations Forces (SOF), primarily SEAL combat swimmers. The vessel has an estimated top speed of 47-50+ knots in SS2, and can cruise at 25-35 knots in SS3. This vessel was designed taking into account ABS rules, but the vessel's severe missions have resulted in structural failures and injuries to crew and passengers [1]. A better method of predicting structural loads is necessary for the design of future high-speed patrol boats and high-speed ferries.

Empirical algorithms have a limited range of applicability and are not well suited to time domain simulation. Spencer proposed a methodology for structural design of aluminum crewboats [2], using Savitsky's method [3] to predict the trim angle of the vessel, data from Fridsma [4] to predict peak accelerations, and a technique from Heller and Jasper [5] to predict hull pressure distributions. Given a pressure distribution, engineers can calculate maximum frame spacings and minimum panel thicknesses. This method is an historical basis for the dynamic pressure used in the USCG's NVIC 11-80 [6]. Unfortunately the method makes assumptions about sea states, missions, and hull geometry. Any significant deviations from these assumptions introduce uncertainty into the design process.

In 2005 SSC funded a project to study and compare "…the application, requirements and methods for the structural design of high speed craft..." used by various classification societies [7]. Classification society rules use empirical formulas to predict vertical accelerations, which are used in structural design calculations. A more direct method would be to use time-domain simulation to predict panel pressures for structural design.

Planing hull simulation programs based on low aspect ratio strip theory have been in existence for several decades [9]. These programs can predict the vertical accelerations of a planing monohull operating in a seaway with good engineering accuracy [10][11]. Maine Marine Composites, LLC recently was awarded a contract to extend low aspect strip theory to support a wide range of hullforms and to predict transverse forces (Office of Naval Research contract N00014-10-C-0196).

2.2 Justification for Project

The American Bureau of Shipping recognizes that time domain simulation is an effective way of predicting hull pressures for structural analysis of high speed craft [8]:
"Slamming loads cause whipping response of the entire hull particularly for high-speed craft operating in severe seas. The resulting dynamic stresses in the hull girder can be of the same order of magnitude as those induced by quasi-static wave bending moments. But their frequencies are much higher than those generated by wave and motion-induced loads, closer to the lowest natural frequency of the hull girder. Therefore, slam-induced whipping response of the hull could also have significant influence on the strength requirements…
"For detailed analysis, direct time-domain simulation involving short-term predictions are recommended as a minimum requirement for strength assessment for monohulls. In most cases involving high speeds, the absolute motions or relative motions will be of such large amplitude that nonlinear calculations will need to be employed..."

3.0 REQUIREMENTS.

3.1 Scope.

3.1.1 The Contractor shall develop a method for evaluating and collecting panel pressures from a time-domain planing hull simulation algorithm based on low aspect ratio strip theory. These panel pressures can be used in structural analysis of planing craft, especially for use with the Finite Element Method (FEM).

3.1.2 The Contractor shall validate the panel pressures generated by the new algorithm against measured data, and shall compare FEM results obtained from the panel pressures with results obtained by classification society rules.

3.1.3 The Contractor shall address the feasibility of extending the method to monohull vessels with tunnels or steps, to multihull vessels, and to simulation in all six degrees of freedom.

3.2 Tasks.

3.2.1 The Contractor shall modify an existing low aspect ratio time domain simulator for planing hulls, so that instantaneous panel pressures can be calculated. The simulator program will be extended to include the appropriate commands to cause the program to export pressure data in a file format compatible with an existing FEM program. (3 months)

3.2.2 The Contractor shall specify a target planing monohull for evaluation of the algorithms. If possible a patrol craft in the USCG or SOCOM fleet will be used, as detailed technical data may be available for such vessels. The vessel shall be equipped with an inertial measurement unit to capture instantaneous motion in six degrees of freedom. The vessel shall also be equipped with pressure sensors such as the FlexiForce® sensor system from Tekscan [12]. The vessel will be operated under known load conditions in a sea state greater than 4 feet. Instantaneous pressure and submergence data will be collected for comparison with simulated results. (2 months)

3.2.3 The Contractor will create a time-domain simulation model for the target vessel, and will simulate the design in a predetermined specified sea state. The results of the simulation will be:

- Vessel motions in the vertical plane (transient surge, heave and pitch, including position/angle, velocity/rate and accelerations).
- Estimated forces in the vertical plane (transient sway, roll and yaw).
- Panel pressures exported for a commercial FEM program.

(2 months)

3.2.4 The Contractor shall construct a finite element model of the target vessel. The Contractor will analyze the model using the panel pressures generated above in order to investigate the stresses in the primary structure and in the hull panels. The Contractor shall compare the primary shear force and bending moment from the FEM analysis with results obtained by direct integration of the panel pressures from the time-domain simulator.

(4 months)

The Contractor shall compare the results of the FEM analysis with:

- Panel pressures obtained by measuring the response of the target vessel.
- Results obtained by using ABS and DNV rules for the design of the target vessel.

(2 months)

3.2.6 The Contractor shall report results of the research program. (1 month)

1.0 GOVERNMENT FURNISHED INFORMATION.

1.1 Standards for the Preparation and Publication of SSC Technical Reports.

5.0 DELIVERY REQUIREMENTS.

The Contractor shall provide:

5.1 Quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 Technical paper documenting the time-domain simulation algorithm, extensions to the algorithm to estimate panel pressures, and key implementation details regarding the algorithms.

5.3 Transient wave elevation, vessel motion and panel pressure data collected with the instrumentation described above.

5.4 Simulation model of the target vessel geometry.

5.5 Finite element model, panel pressures and results.

5.6 Document comparing the results of the FEM analysis using simulation-based panel pressures with results obtained by using the methods described in ABS rules for high-speed craft.

5.7 White paper regarding the feasibility of applying simulation-based structural design to planing monohulls with steps or tunnels, and to planing multihulls.

5.8 All raw and condensed information developed during the project to SSC.

5.9 Print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 PERIOD OF PERFORMANCE.

6.1 Project Initiation Date: Date of award

6.2 Project Completion Date: 14 calendar months from the date of award.

7.0 GOVERNMENT ESTIMATE.

7.1 Project Duration: 14 months.

Total Estimate: $100,000

8.0 REFERENCES.

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4. Fridsma, Gerard (1971). *A Systematic study of the Rough Water Performance of Planing Boats (Irregular Waves -- Part II).* Report 11495, Davidson Laboratory, Stevens Institute of Technology, Hoboken, New Jersey.
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7. Stone, Kevin F., P.E. (2005). *Comparative Structural Requirements for High Speed Craft*, Report Number SSC-439, Ship Structure Committee, Washington, DC, February 2005.
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12. "FlexiForce." *Tactile Pressure Measurement, Pressure Mapping Systems, and Force Sensors and Measurement Systems*. Tekscan, Inc. 307 West First Street. South Boston, MA. 02127. Web. 23 Dec. 2009. <http://www.tekscan.com/flexiforce.html>.
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9.0 SUGGESTED CONTRACTING STRATEGY.

9.1 Maine Marine Composites LLC has an existing contract with the Department of the Navy, Office of Naval Research, ONR, CODE ONR-02, "…to develop technologies to address the problems of high speed planing craft shock mitigation…" This award, Number N0001410-C-0196, will result in new algorithms and simulation tools that can aid the planing craft designer. It may be possible to add funding and resources to this project so as to add the tasks and deliverables described in this proposal to the existing project.