Shock Mitigation for High Speed Planing Boats

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LONG-TERM GOALS

Navy SEALs and other occupants of Naval Special Warfare planing boats are exposed to repeated and severe shock loads during high-speed impact with waves in moderate to heavy sea conditions. The shock loads produce discomfort, loss in occupant performance, and both chronic and acute injuries. The long-term goal of the task Shock Mitigation for High Speed Planing Boats is to reduce debilitating shock loads without adversely affecting boat performance, through the development of water-impact, planing boat, and human injury dynamics theory, analysis tools, shock reduction concepts, and proofs-of-concept. The research is dual-use technology development with application to other Navy and Department of Defense (DoD) small boat operations, the U.S. Coast Guard, and private-sector commercial and pleasure boat markets.

OBJECTIVES

The long-term technological objectives of the Coastal Systems Station (CSS) shock mitigation research are 1) to advance the understanding of complex water-impact and planing boat dynamics phenomena through parallel experiments and theoretical developments, 2) to incorporate the resulting validated theory into design and analysis tools, and 3) to apply these tools to the development of shock reduction techniques. During FY95, CSS began to collaborate with the University of Michigan (UM) and the Office of Naval Research (ONR)-directed Gulf Coast Region Maritime Technology Center (GCRMTC) at the University of New Orleans (UNO). During FY96, the theoretical component of the CSS shock mitigation research transitioned to GCRMTC in the form of an ongoing research effort entitled Shock Reduction of Planing Boats. Obtaining accurate water-impact dynamic measurements in the laboratory and especially at sea are fraught with many pitfalls. CSS has a long history with impact measurements, and possesses the instrumentation, facilities, hardware, craft-of-opportunity, sea-test environment, and experience to provide high quality and cost-effective experimental data.

The two primary technological objectives of the FY98 CSS shock mitigation task were to: 1) provide asymmetric water-impact dynamic laboratory measurements to validate and guide the development of the evolving asymmetric capability of the UNO/UM water-impact code IMPACTUS, and 2) provide initial water-impact dynamic laboratory measurements to evaluate the UNO shock mitigation concept Local Flex, to validate and guide the development of the multi-DOF version of the IMPACTUS code. The first effort is important because the current state-of-the-art in planing boat dynamics theory and prediction codes is limited to three degrees of freedom (surge, heave, pitch). A boat operating in a

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seaway of course experiences important roll, sway, and yaw dynamics. The second effort is an important endeavor to identify an effective and feasible means to reduce injuries and discomfort experienced by occupants of high speed boats in heavy seas.

APPROACH

The dynamic measurements were obtained with the use of the CSS drop test model and two high-bandwidth triaxial piezo-resistive accelerometer sets. All drops were performed in the CSS Drop Test Pool using an overhead crane and quick-release mechanism.

For the asymmetric drop experiments, both triaxial accelerometer sets were mounted in the drop test model, separated transversely to port and starboard. Accurate high frequency roll and heave displacement, velocity, and acceleration time histories were obtained through an innovative syncing and data processing procedure developed specifically for this effort.

The second component of the investigation was the initial tests of the Local Flex concept, shown in Figure 1. Local Flex is a “lower-hull” shock mitigation concept, developed by UNO, that is similar to the CSS concept HSTEP investigated during FY97. With Local Flex, however, the keel of the second lower hull is hinged at the keel of the primary hull (in this case, the drop test model), and allowed to rotate in the transverse plane. Between the lower and primary hulls are tuned springs. In addition, the second hull is compliant, allowing deformation in the transverse plane during the water impact. IMPACTUS theory shows that the hull compliance contributes to the shock reduction.

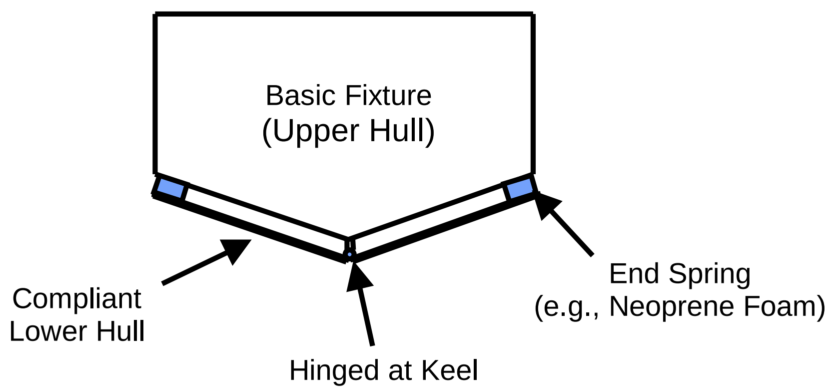

Figure 1. Local Flex Shock Reduction Concept

The drop test model was instrumented with a single triaxial accelerometer set and dropped through a systematic sequence including the baseline rigid configuration and two Local Flex configurations, two weight conditions, and three drop heights (a total of 18 primary configurations/conditions).

WORK COMPLETED

The asymmetric drop test measurements were completed in mid FY98, and the results were compared to those predicted by the IMPACTUS code. CSS has no current plans to continue with the asymmetric drop experiments.

The FY 98 Local Flex experiments were the initial measurements of the shock mitigation concept, to allow refinement of the multi-degree-of-freedom theory within the IMPACTUS code. One of the objectives of the upcoming FY 99 effort is to complete the validation of the theory and code, and then apply the code to the optimization and full performance evaluation of the Local Flex concept.

RESULTS

An example of the asymmetric impact experimental results is given in Figure 2, showing the starboard and port acceleration, and the associated roll angle and roll rate obtained from post-processing the acceleration data. This case is a 2-foot drop of the 641 pound model weight, dropped with an initial roll angle of 5.7 degrees. Results of the experimental/theoretical comparisons, given in (Lu, et al.), are excellent.

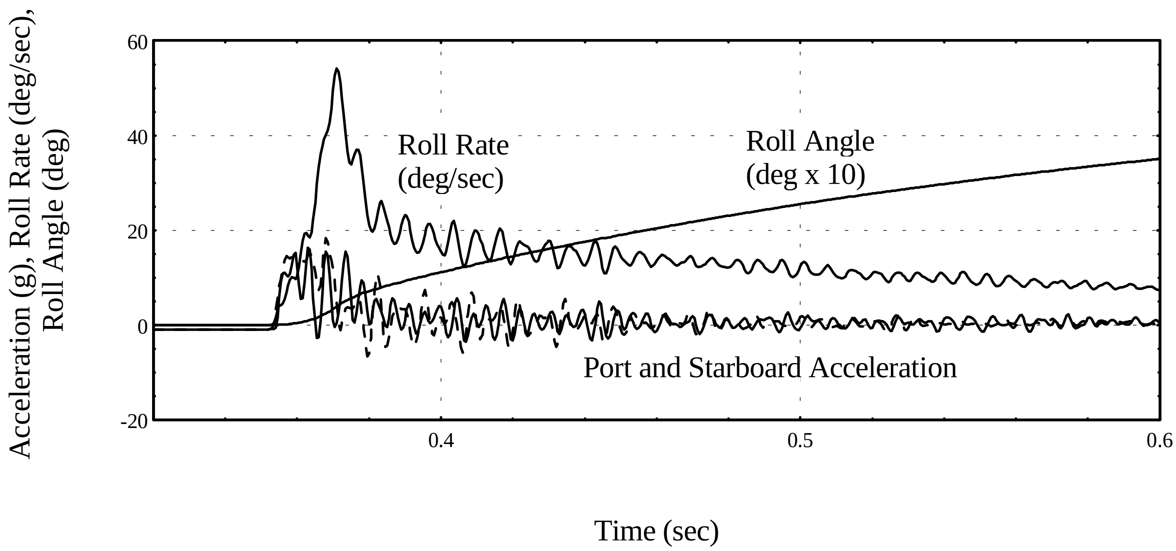

Figure 2. Sample Asymmetric Drop Test Time Histories

One of the important but somewhat ancillary results of the FY98 effort was obtained subsequent to the asymmetric impacts, and prior to the Local Flex experiments. This was the discovery of the cause of, and the means for mitigating, a high frequency component within the drop test data. While this component is not serious, it had detracted from the ability to discern the highest frequency components of interest within portions of the impact data. In general, this high frequency component was above that of interest within the various preceding investigations.

Complete rigidity is desired within the drop test model. A solid block of aluminum comes closest to achieving this goal. A light model is important, however, to allow investigation of a wide range of weight conditions. Thus, the light model was designed with extreme attention to stiffening, and yet possesses a small degree of inherent elastic characteristics that become apparent during the heavier weight and higher drop height conditions. Flat plate structural modes had been suspected that could be eliminated only with the addition of numerous gussets and other heavy structural elements within the model.

Dr. Vorus suggested that the model might instead be experiencing a first-order, longitudinal beam-bending phenomenon. Were this the case, the maximum resonance amplitudes would be seen at the center, and at the fore and aft ends, with the minimum occurring at the 1/4-length longitudinal positions. Measurements of heave amplitude were taken with the accelerometer positioned at the 1/2-length and 1/4-length positions. Comparison showed that the 1/4-length data indeed showed much less of the high frequency component, confirming the hypothesis. All of the Local Flex measurements were thus obtained with the accelerometer in the 1/4-length position, leading to remarkably clean data, and entirely eliminating the need for filtering.

The Local Flex drop test results are preliminary. The quality of the data is extremely high. While the initial experimental results do not show a dramatic reduction in the acceleration magnitude, the Local Flex configuration is not yet optimized. In FY99, the theory improvements and validation will be complete, allowing the full optimization and final concept evaluation.

IMPACT/APPLICATION

The FY98 asymmetric drop experiments are extremely important because they represent the first known systematic set of asymmetric impact test data. Dr. Troesch of UM and Dr. Vorus of UNO plan to apply the improved and validated asymmetric impact theory to extending planing boat dynamics theory into the roll, yaw, and sway degrees of freedom. Ultimately this would enable the prediction of six-DOF high-speed planing boat performance in severe and realistic seaway conditions. The successful effort to reduce the effect of high frequency contamination within the drop test model will allow CSS to use the system to investigate much higher frequency impact phenomena.

Following the multi-DOF IMPACTUS theory improvements and subsequent optimization of the Local Flex concept, CSS will perform final concept evaluation through additional drop test experiments in the CSS drop test facility. Dramatic reduction in the shock magnitude, if observed, will lead to an effort to integrate the concept into a craft-of-opportunity for at-sea proof-of-concept tests. A successful at-sea demonstration will then lead to a 6.3 transition to begin introducing the concept into the NSW high-speed boat fleet.

TRANSITIONS

The principal transition of the asymmetric drop experiments was the delivery of the drop test data to UM and UNO, allowing the investigators there to apply the validated theory (asymmetric version of IMPACTUS) to the development of six-DOF planing boat dynamics codes such as PowerSea.

The principal transition of the Local Flex experiments was the delivery of the drop test data to UM, allowing the investigators there to complete the development of the multi-DOF version of the IMPACTUS code and subsequent concept optimization.

RELATED PROJECTS

Dr. Vorus of UNO is the principal investigator of the GCRMTC project "Shock Reduction for High Speed Planing Boats." Dr. Troesch of UM participates in this research effort, along with UM Ph.D. student Rick Royce. Since FY96, one of the primary functions of the ONR-sponsored CSS task "Shock Mitigation for High Speed Planing Boats", has been to support the GCRMTC research.

Another related effort is the Michigan Sea Grant Software Transition, sponsored by a National Coastal Resources R&D Institute Grant, under which the planing boat dynamics code PowerSea was transitioned to the Navy and the commercial boating industry. PowerSea includes the variable deadrise capability developed in FY96 jointly by UM and CSS. PowerSea may also be the code of choice for including additional degrees of freedom, as facilitated by the asymmetric impact measurements.

A third related project is the Naval Health Research Center (San Diego) effort to compile injuries sustained by Mk V and NSW RIB operators at the various NSW Small Boat Units. The principal investigator at NHRC is Dr. Wayne Ensign. The sponsor is Dr. Thomas of ONR.

PUBLICATIONS

Peterson, R., 1997: "Drop Tests to Support Water-Impact and Planing Boat Dynamics Theory", CSS Technical Report 97/25, Coastal Systems Station, Panama City, FL.

Lu, L., Troesch, A., and Peterson, R., 1998: "Asymmetric Hydrodynamic Impact and Dynamic Response of Vessels", presented at 17th International Conference on Offshore Mechanics and Arctic Engineering, Lisbon, Portugal, 5-9 July.