CCDoTT
Center for the Commercial Deployment
of Transportation Technologies

LITERATURE REVIEW SUMMARY REPORT

Submitted to:

Office of Naval Research
875 North Randolph Street, Room 273
Arlington, VA 22203-1995

Dr. Paul Rispin, Program Manager
ONR Code 331
703.696.0339
rispinp@onr.navy.mil

In fulfillment of the requirements for:
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Agile Port and High Speed Ship Technologies

FY 05 Project 05-8, Program Element 2.35
Development of a Route/Mission Dependent Prediction Program for Rational Structural Dynamic Loads for High-speed Sealift Applications

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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

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PREFACE TO LITERATURE REVIEW SUMMARY REPORT

This document was never intended to be a stand-alone comprehensive study of project related literature and theory. It provided a starting point of theory to be expanded on as the project progressed with the expanded and relevant theory to be adequately treated in the Final Report.

This summary report relates to Task 8.1. Literature Search and Theory Review. The task was listed in the project to provide a brief summary of the current knowledge-base of slamming load prediction for the purpose of ensuring that the state-of-the-art in area of ship-structure slam load prediction is reviewed and ready for incorporation and extension.

The original FY 05 Full Proposal: Agile Port and High Speed Ship Technologies submitted to ONR listed Task 8.1 as a preparatory task. The intent of the task was to provide the necessary background and foundation information to begin work on the project. The deliverable was a summary document intended to provide a starting point for the technology to be used that would be built upon throughout the project and presented in the Final Report. This deliverable was to be delivered to CCDoTT as a summary of progress and was not listed to be in the deliverables to be submitted to ONR. In the multiple iterations of the proposal and contracting process, the deliverable became inadvertently listed in the extended cooperative agreement version of the Schedule of Deliverable Milestones. When the document was received, CCDoTT reviewed it, but, did not forward it to ONR as we had it listed as a program management deliverable for in house management of the program.

In reviewing the ONR deliverables list, we have become aware that it was scheduled to be submitted and is past due. For that reason, CCDoTT is now submitting Deliverable 8.1.

Respectfully submitted,

Steven M. Hinds
CCDOTT Program Administrator
6300 State University Drive, Suite 220
Long Beach, California 90807
Phone # 562.985.2259
e-mail shinds@csulb.edu

Working Paper 814.001-1

ROUTE OR MISSION DEPENDENT RATIONAL STRUCTURAL DYNAMIC LOADS PREDICTION FOR HIGH-SPEED MULTIHULLS

LITERATURE REVIEW SUMMARY

By:

CDI Marine Systems Development Division
900 Ritchie Highway, Suite 102
Severna Park, MD 21146

For:

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

In Performance Of:

Contract No. N00014-04-2-0003
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Task 8.1 Literature Search and Theory Review

CCDoTT Project Director:
Stanley Wheatley
CCDoTT
6300 State University Drive, Suite 220
Long Beach, CA 90815

CDIM-SDD Project Manager:
Manish Gupta
CDIM-SDD
900 Ritchie Highway, Suite 102
Severna Park, MD 21146

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FOREWORD

The work described in this report was prepared by CDI Marine Systems Development Division (CDIM-SDD) under subcontract to California State University, Long Beach Foundation (CSULB) for the Center for Commercial Deployment of Transportation Technologies (CCDoTT). The point of contact at CSULB was Mr. Stanley Wheatley. The Project Manager and Technical Lead for CDIM-SDD was Mr. Manish Gupta.

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1.0 INTRODUCTION

The current project is Phase II of an on-going three-phase program to develop a prediction tool to predict rational structural dynamic loads for high-speed multihull vessels. Phase I was successfully completed in the 2001-2002 fiscal year with the development and demonstration of the first part of the prediction tool. The first part was to predict the global hull loads that are wave height and frequency dependent and therefore could be predicted using a frequency-domain tool. The detail report describing the Phase I effort was provided in CDIM-SDD Working Paper 727-1, August 2002, submitted to CCDoTT.

The current Phase II effort is spread over two fiscal years. Under the present fiscal year, 2005, the first part of the current phase, Phase II-A, is being performed. The follow-on effort to complete Phase II, which is Phase II-B, will be performed during the following fiscal year. The final phase, Phase III, which is extensive validation of the tool along with incorporation into rule-making procedure, is scheduled for the out-years. The objective of the Phase II effort is to determine the probabilities of slamming, and the loads associated with slamming, which can be predicted using a time-domain program to be developed in the current phase. Under this current effort, Phase II-A, slamming load prediction algorithms are to be developed along with some limited verification on a few multihull type vessels.

One of the first tasks was to conduct a literature search and theory review to examine all contributing developments that have occurred in the ship slamming area. A lot of work has been done on the impact/slamming problem for ships in the last 30 years, including many by CDIM-SDD as referenced in Appendix A. All of these theories and publications were carefully reviewed to obtain an up-to-date understanding of the ship slamming, and specifically the slam load prediction methods. This report serves to provide a brief summary of this effort.

2.0 LITERATURE REVIEW

An extensive literature survey was conducted, encompassing all areas of ship slamming, to ensure all relevant material pertaining to the subject was identified. This included searching public domain technical databases, such as Engineering Village Compendex and NERAC, and university catalogues. CDIM-SDD's in-house document library was also reviewed for all pertinent publications. The focus was not only to obtain relevant papers and reports on slam load theories and prediction, but also on experimental and full-scale testing efforts relative to ship slamming.

After reviewing abstracts and contents of several hundred papers and reports, around fifty of them were concluded to be applicable in some form to the efforts at hand. Some of these CDIM-SDD had already identified during the Phase I effort. A bibliography of the selected papers and reports reviewed under this project are provided in Appendix-A.

3.0 SLAMMING THEORY

The term “slamming” in marine applications can refer to several distinct processes. Without additional clarification, “slamming” usually refers to hull bottom slamming. Conceptually, bottom slamming is an impact that is characterized by a rapid spike in pressure on the hull. It can be anywhere in the vicinity of the keel, but is usually near the forward end of the vessel. Other types of slamming include bow flare slamming (a rapid increase in pressure on the bow where it begins to flare), cross-structure slamming (impact on the cross-structure of a multihull), wave slapping (impact from waves on the side of the hull), and collision with other structures.

Multihulls are not always displacement-type vessels, but can be Surface Effect Ships (SES) or Air-Cushion Vehicles (ACV). Slamming of an SES or ACV is equivalent to the cross-structure impact on a displacement-type Multihull vessel with the added phenomenon of impacts being mitigated by the pressurized cushion on which they ride. CDIM-SDD's extensive experience in structural load prediction for SES and ACV is drawn upon to extend that knowledge base to the area of displacement-type Multihulls. Cross-structures for Multihulls can take complex shapes; however, a majority of these cross-structures are generally flat bottom, and theories covering flat-bottom slamming can be very well applied to these situations. Coincidently, a lot of research and testing has been done with flat plate slamming, which is a shape that has been the subject of both empirical and theoretical studies. Similar work has also been done with slamming of wedge and cylindrical shape bodies, which can be applied to the hull slamming of Multihulls.

The naval architecture community's understanding of slamming events is improving at a relatively slow pace. The first dedicated program to quantify slamming loads was conducted by the National Advisory Committee for Aeronautics (NACA, the predecessor to NASA) in the 1930's. NACA's interest in this discipline was in support of seaplanes and seaplane floats. Work has continued sporadically to the present day. Initial work simultaneously derived the theory for impact pressure and developed empirical tank test data. Between 1950 and 1980, semi-empirical methods emerged that fit curves with known theoretical relationships through test data. The hallmark works of Ochi, Chuang, and Jones and Allen were produced during that period. Since the 1980's, the objectives of research have changed to incorporate hydro-elastic effects and evaluation of slamming physics with computational models. Since the scope of the structural load prediction tool to be developed under this effort is geared more towards the early design stage as opposed to the detail design and design optimization stage, hydro-elastic phenomenon and computational methods focusing on the second order effects are not incorporated.

To date, the detailed physics of the slamming process remain ambiguous. In concept, it is known that there are several first order processes involved: the rapid change in added mass, momentum lost in free surface effects (spray and waves), air entrainment, hydro-elasticity and structural impedance. The challenge of analytically predicting slamming loads lies in quantifying the contribution of these processes. With this in mind, however, it is accepted in the community at large that the slamming process only yields local loads; not global loads. This argument divorces the severe accelerations due to ship motions from the set up of peak pressures on the hull, which really define an impact. The problems are somewhat related, but the peak pressure associated with a slam event is applied over a much smaller time scale. Further, the peak pressure is applied on a relatively small area, leading to a total force that is negligible on the global scale. With this argument adopted, the present work aims to quantify lifetime slamming loads on local areas of impact, and its contribution to the global loads will be investigated in follow-on efforts.

In the absence of more descriptive physics, the approach of employing semi-empirical methods seems to provide the most logical method to predicting slamming loads. Examining the order of magnitude and dimensional analysis provide a theoretical basis for relating the variables proportionally. Experimental work with different shapes, entry velocities and materials provides the coefficients that describe those relationships.

3.1 Methodology For Calculating Lifetime Loads

After the literature review, it appears that the best approach to predicting lifetime slamming loads is to use a combination of theoretical, semi-empirical and stochastic techniques. The assumption is that when the time-domain tool is fully developed, it will have a descriptive nature from which discrete impacts can be obtained, which can further provide the basis for calculating discrete loads. In traditional monohulls, a threshold entry velocity is often used to define an actual impact, which can be similarly applied to the hulls of the Multihulls. In the case of the cross-structures, however, such a threshold value is unnecessary since discrete impacts are obvious. As a result, slamming of the cross-structure is defined as any wetted contact of the hard structure.

3.2 Slam Pressure Theory

Of all the empirical and analytical work proposed by various authors, work by Chuang, et. al. (1976) appeared to be the most appropriate for the problem and scope at hand. The other proposed theories are not discarded, but will be referenced and incorporated depending upon their application to specific hullforms of interest and environmental and operational scenarios to which those hullforms are subjected.

Chung's theory will be initially adopted to calculate discrete loads during slam event definition. Three equations in particular, which are outlined in Chuang 1976, will be used. The first equation is a theoretical prediction based on a two-dimensional flat plate:

$$P_M = 4.5 \bullet V_O \quad (1)$$

where P_M is the maximum impact pressure of a slam event in psi, and V_o is the entry velocity in ft/sec. The coefficient accounts for the change in units so that resulting P_M is given in psi. The second equation is semi-empirical, and is based on drop tests of flat plates:

$$P_M = 0.68 \bullet V_O{}^2 \quad (2)$$

The third equation, which Chuang developed in conjunction with Milne, is based on drop tests of rigid wedges:

$$P_M = 0.433 \bullet \rho \bullet V_O{}^2 \quad (3)$$

where ρ is the water density. All of the formulations were derived in calm water.

It is critical also to note that these equations provide the peak impact pressure, not the design load. In order to obtain the design pressure, ideally one has to have the knowledge of the entire pressure distribution, which includes the peak pressure, over the area of interest. Since semi-empirical methods do not provide a deterministic approach to calculate the pressure distribution, a stochastic approach is necessary and will be discussed later in the project.

The entry velocity, V_o, is defined as the relative velocity between the craft and the water surface in the direction normal to the water surface. It is illustrated in Figure 1 with a small segment of both the vessel bottom and the water surface. To calculate entry velocity, both the instantaneous craft or vessel and wave speed must be transformed into local water surface normal and tangential (N-S) coordinates. Local craft speed includes contributions from all 3 degrees of freedom, heave, pitch and roll, in addition to the craft forward speed. The local wave speed is based on the wave celerity. The normal components of the local craft speed and the local water surface are added to get V_o.

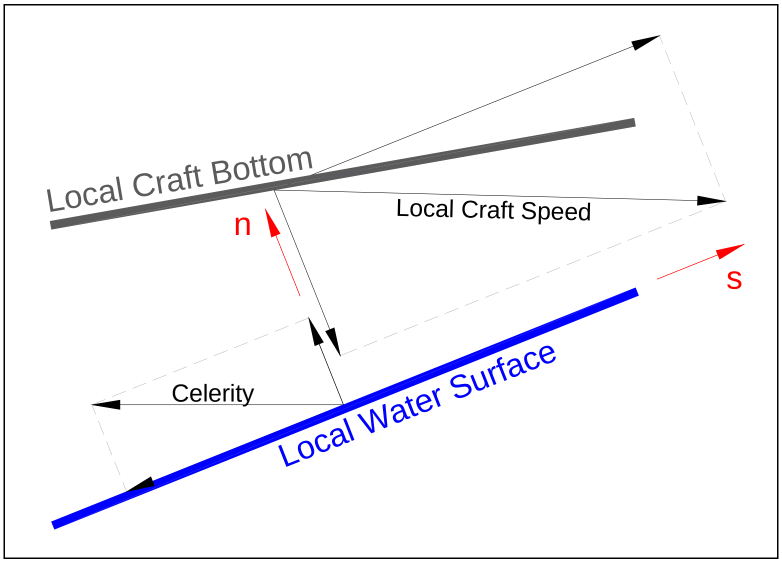

Figure 1. Hull Entry During Slam in N-S Coordinates

These equations will be incorporated into the time-domain slam prediction simulation tool. During simulation, as the relative velocity increases beyond a pre-determined threshold limit and/or when the cross-structure makes contact with the water surface, the three P_M equations will be calculated and written as an output to a file. As a result, discrete impacts can be tabulated for each simulation, which would then be used as the basis for extrapolation to lifetime loads.

3.3 Equivalent Uniform Design Pressure

Since the time-domain tool will calculate discrete peak impact pressures, a follow-on load calculation step will be required to obtain lifetime (design) loads. There are two steps involved in this process: 1) calculating a meaningful load from the peak impact pressures, and 2) extrapolation of those loads to lifetime maximum values. The hallmark work of Jones and Allen (1978) can be used for the former step. Jones and Allen introduced the notion of equivalent uniform design pressure, P_D, to get a meaningful load, which is illustrated in Figure 2. It is argued that any random slamming pressure distribution principally excites the first mode of vibration on a panel – deflection in the center of the panel, tapering to no deflection at the structural supports. Equivalent uniform design pressure is a uniform distribution of pressure over the panel that provides the same deflection at the center of the panel as the actual pressure distribution. The details of the Jones and Allen approach will be provided and discussed in the follow-on reports.

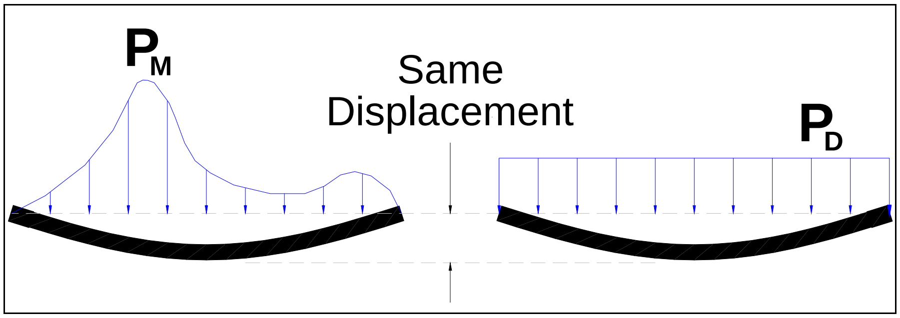

Figure 2. Equivalent Uniform Design Pressure

4.0 SUMMARY

This report provides a brief summary of the literature review and ship slamming theories investigated under the current scope of work. Of all the semi-empirical and analytical slam theories investigated, the work of Chuang et.al. appeared to be most applicable to the scope at hand. Other slam load prediction theories will be incorporated depending upon their applicability to specific vessel characteristics and operational profiles.

APPENDIX A

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