Naval Architecture and Ocean Engineering Department

Professor Robert H. Mayer
Chair

During the 2005-2006 academic year, the faculty and midshipmen associated with the two engineering disciplines encompassed by the Naval Architecture and Ocean Engineering Department (NAOE) pursued a variety of scholarly research and professional development endeavors. Among faculty research activities were the investigation of the reliability of coastal structures, port security barriers, and antifouling coatings for ship structures, the design of low-cost autonomous surface vessels, and development of a fish cage for open-ocean aquaculture. Various Independent Midshipman Research Projects were mentored with projects ranging from the design of a control system for an underwater vehicle to the assessment of submarine motions near the free-surface interface.

Research funds for these and other projects were made available from many sources including contracts and grants from the National Oceanic and Atmospheric Administration (NOAA); the Naval Air Systems Command, Orlando Division (NASC-OD); the Naval Facilities Engineering Services Center (NFESC); the Naval Sea Systems Command; the Naval Surface Warfare Center, Carderock Division (NSWC-CD); the Office of Naval Research (ONR), various activities of the U.S. Army Corps of Engineers, and the U.S. Coast Guard Engineering Logistics Center. The faculty and midshipmen of this department are greatly appreciative of the cooperation and support provided by these sponsoring agencies and organizations.

In view of his continued and highly significant research accomplishments, Associate Professor Michael P. Schultz was afforded special recognition by his peers as this year's recipient of the Class of 1951 Civilian Faculty Research Excellence Award. Also of note, Professor David L. Kriebel is a co-founder of the new Center for Chesapeake Bay Observation and Modeling (CCBOM). The CCBOM brings together faculty in four academic departments (NAOE, Oceanography, Mathematics, Chemistry) to undertake both field observations and computer modeling of oceanographic and environmental phenomena in the Chesapeake Bay. Associate Professor Jennifer K. Waters, Assistant Professor David W. Fredriksson and CDR Patrick J. Hudson, USN, are all actively involved in Center activities.

The faculty continues to contribute to professional societies through participation in committees, publications in professional journals, and presentations at meetings and conferences, both nationally and internationally. These activities included representation on small craft design review boards, safety councils, and consulting work for many U.S. Government programs. Also, more than 50 manuscripts were published in professional journals, conference proceedings, or as technical reports. Among the beneficial outcomes of this department's extensive and significant involvement in research is an energized and up-to-date academic environment for the curriculum.

Sponsored Research

Wave Groups and Wave Breaking in Random Seas

Researcher: Professor Thomas H. Dawson
Sponsor: Office of Naval Research (ONR)

Wave groups in random deep-water waves are being studied experimentally using the Naval Academy's 380-foot wave/towing tank. Results have been compared with theoretical work that accounts for nonlinear effects on crest amplitudes. Statistical descriptions of wave groups and wave breaking have been considered. Recent efforts have involved preparation of a monograph based on some 20 years of work in this project. Work continues.

Engineering Support for Development of a Submersible Fish Cage for Open Ocean Aquaculture

Researcher: Assistant Professor David W. Fredriksson
Sponsor: National Oceanic and Atmospheric Administration (NOAA)

This project involves collaborative work with the University of New Hampshire (UNH) during the summers of 2006 and 2007 in support of a National Oceanic and Atmospheric Administration (NOAA) Small Business Innovation Research (SBIR) grant to JPS Industries. This year's research effort included the design of a feed-hose buoy described in the Year I work plan of the proposal. Follow-on work will include writing a technical report, design review and data processing.

Flow Characteristics through a Cylindrical Fish Cage

Researcher: Assistant Professor David W. Fredriksson
Sponsor: University of New Hampshire

The purpose of this project is to perform a series of tests in the Naval Academy's Hydromechanics Laboratory 380-foot wave/towing tank to investigate flow characteristics around a gravity fish cage. The fish cage is constructed around a steel flotation pipe with hanging nets. Two objectives were to measure drag on the small-size cage and determine flow characteristics about certain positions inside and outside the cage. The resulting data set was supplied to researchers at the University of New Hampshire (UNH) for Computational Fluid Dynamic (CFD) modeling.

Hydrodynamic Particle Trajectories: Computation and Validation

Researchers: Assistant Professor David W. Fredriksson and
Professor Reza Malek-Madani, Professor George C. Nakos, Associate Professor Gary O. Fowler,
and Associate Professor John F. Pierce (Mathematics Department)
Sponsor: National Oceanic and Atmospheric Administration (NOAA), Chesapeake Bay Office

The objective of this project is to complete a two-part effort to study the robustness of particle trajectory computation from data obtained from implementation of QUODDY in the Chesapeake Bay. In the first part, numerical algorithms designed and based on standard Runge-Kutta schemes for computing solutions of ordinary differential equations are applied to the system of ODEs obtained from the velocity field constructed from QUODDY data.

In the second part of the research, a Nortek AWAC current meter was deployed in support of the QUODDY modeling effort. The instrument was deployed for 30 days between the entrance of the Severn River and the main channel of the Chesapeake Bay in approximately 10 meters of water. In an effort to obtain the major tidal current velocity constituents, the instrument recorded three-dimensional velocity components at 0.5 meter depth bins *i.e.,* 20 locations in the water column. The instrument was later recovered for data verification.

Navigation Analysis Technologies Program (NETS)

Researchers: Adjunct Assistant Professor Carolyn Q. Judge and Associate Professor Jennifer K. Waters
Sponsor: U.S. Army Corps of Engineers, Institute for Water Resources

A previous study at the U.S. Naval Academy involved looking at gross-scale predictions for how general vessel parameters and shipping trends are changing. This research found that the numbers of vessel calls on U.S. ports and vessel dimensions are increasing. Vessel size is not increasing proportionately, however. Beam and length are increasing much faster than draft. To incorporate these findings into future channel design and economic analysis, more details are needed. These parametric changes affect the vessel's loading and stability characteristics as well as vessel operations. The current research at the U.S. Naval Academy focuses on a more detailed study of vessel characteristics and looking in-depth at loading issues. Investigation into off-design vessel operations with respect to vessel powering is also being conducted.

Mooring Forces Induced by Passing Ships

Researchers: Professor David L. Kriebel and Louise A. Wallendorf, P.E. (Hydromechanics Laboratory)
Sponsor: Naval Facilities Engineering Service Center (NFESC)

The Navy has recently been experiencing damages to moored ships and piers as a result of excessive motions of the moored vessel caused by passing ship traffic. Many Navy piers are located alongside commercial navigation channels where commercial vessels enter/exit port at a high rate of speed. The waves generated by these vessels may then induce large surge, sway, or yaw motions of any vessels moored at the pier. In order to better understand this problem, a series of physical model tests are being conducted in the Hydromechanics Laboratory. In these tests, one ship model will be moored using load cells while another ship model will be towed past at various speeds and separation distances. Data will be analyzed to develop empirical guidelines on the surge force, sway forces, and yaw moments experienced acting on the moored vessel. Results will also be used to validate computer codes used by the Naval Facilities Engineering Command (NAVFAC.)

Wave Forces on Submerged Training Wall

Researcher: Professor David L. Kriebel
Sponsor: U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers is responsible for dredging operations at the mouth of the Mississippi River that ensures that the river is navigable for ocean-going ships. As part of an effort to reduce dredging costs, a submerged training wall is being designed to partially confine the river flow to maintain high flow velocities sufficient to mobilize sediment. The training wall is a vertical sheet-pile structure that penetrates the river bottom and extends upward to near but slightly below the normal water surface. The project involves applying a mathematical theory for wave-structure interaction to predict wave force on the submerged wall. Results of this analysis will be compared to laboratory measurements made by the Corps of Engineers.

Reliability of Coastal Structures

Researcher: Professor David L. Kriebel
Sponsor: U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers is responsible for designing, building, and maintaining more than 1,500 breakwaters and jetties at ports and harbors throughout the United States. As part of an effort to improve the design and function of this project, stochastic reliability methods were applied to the design of stone or rubble-mound structures. In this work, the probability of structural damage is predicted based on probabilistic inputs of the forcing mechanisms (waves and water levels) and the structural strength (stone dimension, design slope, structure elevation, etc). Results will be used to refine the design procedures through incorporation of rational factors of safety derived using reliability theory.

Harbor Flushing for Akutan Harbor, Alaska

Researcher: Professor David L. Kriebel
Sponsor: U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers Alaska District is designing a new fishing harbor for Akutan Island in the Aleutian Island chain. As part of the harbor design, it is important to maintain adequate flushing and tidal water circulation to prevent buildup of harmful pollutants in the harbor that may originate from the fishing vessels or from fish processing. The project involves the construction of small-scale physical model to simulate the tidal flushing within the harbor. This is being conducted in the Coastal Engineering Basin of the Hydromechanics Laboratory. A model of the harbor is being constructed and a series of computer controlled pumps and values are being constructed to simulate the changing water levels due to tides. Subsequent testing will involve use of photographic methods to record dye concentrations as a surrogate for pollutants.

Composite Port Security Barrier Design Support

Researcher: Associate Professor Paul H. Miller
Sponsor: Naval Facilities Engineering Service Center (NFESC)

To provide protection from small craft attack, the Navy has deployed static port security barriers (PSB) at major naval bases. The design consists of a series of mild steel floating units, each of which has three pontoons joined by a backbone structure. Although coated with a corrosion-resistant barrier paint, initial units have shown premature corrosion leading to higher-than-desired maintenance requirements. Potential solutions to this problem include improved surface preparation, material substitution or the use of a different paint system. Alternate materials include marine grade aluminum, stainless steel and composite materials. This research project involved evaluating and performing feasibility studies on PVC, CPVC, HDPE and ABS plastics.

Composite Temporary Anti-Boat Barrier System Support

Researcher: Associate Professor Paul H. Miller
Sponsor: Naval Facilities Engineering Service Center (NFESC)

To provide protection from small craft attack, the Navy has deployed static port security barriers (PSB) at major naval bases. The standard unit is designed to withstand attacks from large boats. This makes the barrier large and difficult to deploy. A more rapidly deployable, temporary system with reduced capacity was desired. This research project involved collaborative work with NFESC and the contractors to develop a lighter composite system. U.S. Naval Academy support included still-water and wave testing in the Hydromechanics Laboratory, full-scale structural testing at Naval Station Annapolis, finite element analysis and manufacturing support.

USCG 123-ft WPB Side Shell Panel Buckling Test

Researchers: Associate Professor Paul H. Miller and Commander Jeffrey W. Stettler, USN
Sponsor: U.S. Coast Guard Engineering Logistics Center (USCG)

The USCG's 123-ft WPB, a coastal patrol boat, is an extended version of its 110-ft WPB. The extended boats have suffered a variety of structural damage, and various analyses of the damage have been performed. One key element of these studies, and the suspected mechanism of structural failure in at least one case, involves a buckling failure of a stiffened hull panel. The buckling strength in the area of the failure has been increased by application of a doubler plate, and subsequent theoretical modeling of this area predicts that the increase in strength is adequate to resist failure. However, the geometry of the modified area is fairly complicated, especially as regards the effect of the doubler plate. The purpose of this project was to experimentally investigate the compression buckling of a test panel designed to simulate the modified side shell plating on the USCG 123-ft WPB. The test panel was designed and constructed by the U.S. Coast Guard Engineering Logistics Center. Compression buckling testing was carried out on the Ship Structures Panel Test Machine in the Structures Laboratory at the Naval Academy. Test results demonstrated a larger ultimate compressive strength than predicted by the basic Finite Element Analysis. However, due to a design oversight of the test panel, the ultimate collapse of the test panel

occurred in one of the end bays of the test panel due to a local stress concentration there, vice in the center frame bay of the test panel as desired. Therefore, the ultimate compressive strength of the desired center frame bay, although larger than anticipated, was not explicitly determined.

Residual Strength and Stiffness of Blast Damaged Composite Panels

Researcher: Associate Professor Sarah E. Mouring
Sponsor: Office of Naval Research (ONR)

Conventional fiberglass composite construction has dominated the recreational boating industry for the past four decades. The U.S. Navy, however, has not been as quick to embrace composite materials as alternatives to traditional materials such as steel and aluminum. Recently, there have been major improvements in composite fabrication (resin infusion and pre-impregnated reinforcements mainly) plus an increased demand for reduced electronic signatures for naval applications. Due to these improvements and the need for fast, light-weight naval ships, composite materials are being chosen more frequently for naval applications. This trend is evident in the incorporation of composite materials in new secondary ship structures and replacement of metallic components with composite ones. However, there is a lack of confidence when designing primary structures using composite materials compared to traditional materials.

Understanding the performance of composite materials and their failure (damage/ruptures), when subjected to explosion, is essential for their use in hull construction. However, there has been very little work on the determination of ultimate or residual strength of composite structures after an explosion. At this time, ultimate strength can be predicted for steel structures with different damage conditions using the DoN ULTSTR software program. This program has not been used to predict ultimate strength of composite structures. Part of this proposed study includes the incorporation of composite material properties and damage models into the ULTSTR ultimate strength program which currently only deals with steel ships. In order to establish an appropriate model for composite materials, a more complex model such as explicit finite element analyses has to be validated against large-scale tests. This is required in order to ensure that the various failure patterns can be correctly modeled and the parameters which influence the behavior are fully understood.

At this time, finite element analysis has been performed along with experimental work. Baseline large-scale panel tests have been performed this year with further testing to follow. Large and small panels have been tested under impact. Numerous reviewed and invited proceedings papers, two journal papers, and many presentations have resulted from this research over the past three years.

Dynamic Ballasting of Ship Models

Researchers: Associate Professor Sarah E. Mouring and Associate Professor Jennifer K. Waters
Sponsor: U.S. Army Corps of Engineers

The research project is one part of a larger project sponsored by the U.S. Army Corps of Engineers. In this particular project, the dynamic ballasting of ship models was investigated in order to design an appropriate test rig. The determination of the pitch and yaw gyradii of a given hull model was the main focus.

There are several methods used to measure the pitch and yaw gyradii of a hull model, including the Lamboley test, the incline-swing test, and the bifilar suspension test. The bifilar suspension test, known commonly as the swing test, has been shown to be a very simple and accurate method to measure the gyradii. In this test, a hull is suspended symmetrically by two vertical wires. Knowing the length of the wires and spacing between the wires and measuring the period of simple harmonic motion, the gyradius can be determined. This can be performed for both yaw and pitch gyradius measurements.

To implement the bifilar suspension test, it was determined that a hull with a maximum weight of 5-6 tons could be suspended from two 10-ton steel gantry cranes. The gantry cranes chosen were tri-adjustable (height, width, and span), collapsible, and portable (swivel-lock casters). For this testing, it was suggested that the casters be

removed and the cranes be bolted directly to the floor. Also I-beam stabilizer kits were recommended for added stiffness. This design is currently under review by the Corps of Engineers.

Development of a Design Optimization System for Early-Stage Ship Arrangements

Research: Professor Bruce C. Nehrling
Sponsor: Office of Naval Research (ONR)

This multi-year research effort involves developing an early-stage functional general arrangement design optimization process. This project originated through ONR's National Naval Research Initiative program. The lead organization is the University of Michigan. Methodologies being investigated include multi-criterion optimization, fuzzy set theory, and real-coded integer genetic algorithms. The initial effort is being directed at modeling the general arrangement of a corvette size warship. The goal is to derive, within fuzzy constraints, a near optimal arrangement topology followed by a physical sizing of the spaces. An adaptive modeling language is being used to develop and manipulate the graphic displays. This research effort is expected to continue for one or two more years.

Effective Horsepower, Seakeeping, and Maneuvering Tests on a Mobile Landing Platform (MLP)

Researchers: Professor Bruce C. Nehrling and John J. Zseleczky, P.E. (Hydromechanics Laboratory)
Sponsor: Naval Surface Warfare Center, Carderock Division

During May of 2006, the U.S. Naval Academy Hydromechanics Laboratory (NAHL) conducted hydrodynamic model tests on a concept hull form of a Mobile Landing Platform (MLP). The MLP is a key component of the Maritime Pre-positioning Force (Future) squadron. It is envisioned to be a mobile "pier in the ocean", capable of conducting vehicle, supply, and troop transfers with a wide range of other surface ships and vehicles while underway in the open ocean. The MLP's primary operational modes will be a relatively high speed transit condition at a draft of approximately 8 meters and a low-speed cargo transfer condition at a draft of approximately 13 meters. Based on its mission requirements the MLP will be a large ship with some hull parameters falling outside current norms. The objective of the experimental tests conducted by the NAHL on this unique hull form is to provide the Naval Sea Systems Command (NAVSEA) MLP design team with technical information on this hull's powering, seakeeping, and maneuvering characteristics. A comprehensive report was written during the summer of 2006.

Comparison of the Hydrodynamic Performance of Fouling-Release Surfaces with Copper-Based Antifouling Coatings

Researcher: Associate Professor Michael P. Schultz
Sponsor: Office of Naval Research (ONR)

The primary purpose of a ship antifouling system is to limit the increase in drag that will be incurred with fouling settlement on the hull. Ineffectiveness in this endeavor will lead to an increase in energy consumption and a platform that is unable to meet its mission. The introduction of non-toxic, fouling-release coating systems as alternatives to traditional biocide-based antifoulings has necessitated a change in philosophy with respect to these coatings. Since fouling-release coatings do not prevent settlement, various methods to quantify the tenacity of adhesion of organisms on these systems have been offered. Among these are the hard fouling adhesion test, the water jet cleaning method, the towed foil technique, and the turbulent channel flow apparatus. Data from these tests are of particular interest because fouling-release surfaces that cannot "self clean" due to hydrodynamic forces or be mechanically cleaned without significant damage will likely suffer large drag penalties. For these systems to serve as viable alternatives to traditional biocide-based systems, their hydrodynamic performance must compare favorably with traditional systems over the entire coating life cycle. At present, the data from which to make these fundamental comparisons are not available. This research compares the hydrodynamic performance of the fouling-release coating systems and traditional copper-based systems in the unfouled, fouled, and cleaned conditions over several cleaning cycles and several years of exposure.

Surface Roughness Effects on Drag and Turbulent Boundary Layer Structure

Researchers: Associate Professor Michael P. Schultz and
Professor Karen A. Flack (Mechanical Engineering Department)
Sponsor: Office of Naval Research (ONR)

In turbulence research, a great deal of attention has been given to the "canonical" smooth wall, zero pressure gradient boundary layer. Smooth wall boundary layer studies far outnumber rough wall studies. While the smooth wall studies have provided a basis of understanding turbulent wall flows, in most engineering applications, surface roughness is present (*i.e.,* ship hulls, atmospheric boundary layers, turbomachinery). It is, therefore, of interest to gain a better physical understanding of these flows. The goal of the present research is to do this by documenting fully-developed turbulent boundary layers on a range of rough surfaces. From this, the similarity of both the mean velocity and turbulence structure on rough and smooth walls can be critically evaluated.

Surface Roughness Effects on Wall-Bounded Shear Flows

Researcher: Associate Professor Michael P. Schultz
Sponsor: Office of Naval Research (ONR)

The goal of this research is to gain a better physical understanding of the effect of roughness on wall-bounded turbulence by documenting and analyzing fully-developed turbulent pipe and boundary layer flow with roughness. The research will be conducted in two phases which will draw upon both unique experimental facilities and state-of-the-art measurement techniques. The first phase which is currently ongoing utilizes the Princeton Superpipe facility. Commercial steel pipe is being tested in order to document the mean flow, pressure gradient, and turbulence structure over a very large Reynolds number range. These results will allow an improved Moody diagram to be developed and will provide insight into the behavior of rough wall turbulence for a large range of Reynolds number. The second phase will be carried out in the high Reynolds number water tunnel facility at the United States Naval Academy and at the matched index of refraction facility at Johns Hopkins University. High resolution, laser Doppler velocimetry (LDV) and particle image velocimetry (PIV) will be used to measure the turbulence over a systematically varied series of rough surfaces. From this, a model for skin-friction drag based on the principal roughness parameters will be generated. This funding supports sabbatical research at Princeton University and at The Johns Hopkins University.

Forces and Moments on a Submarine Operating in the Vicinity of the Bottom

Researcher: Commander Jeffrey W. Stettler, USN
Sponsor: Naval Air Systems Command, Training Systems Division

Current and future submarine missions require submerged submarine operations in littoral areas, some of which are relatively shallow, requiring the submarine to operate in close proximity to the bottom. Understanding the hydrodynamic interaction between a submarine and the bottom is crucial to understanding the maneuverability and controllability of submarines operating in this littoral environment. The purpose of this sponsored research project was to experimentally investigate the forces and moments on a submarine operating in the vicinity of the bottom, including effects of varying submarine speed and altitude above the bottom. Instrumented testing of a standard submarine shape (a Series 58 hull) was conducted in the 120 ft towing tank of the Naval Academy Hydromechanics Laboratory. Test results demonstrated a strong "suction" force on a submarine operating in the vicinity of the bottom. This "suction" force draws the submarine toward the bottom, and increases monotonically with both velocity and altitude. When the "suction" force is non-dimensionalized (by the velocity squared), it becomes nearly constant at each altitude, increasing monotonically (roughly quadratically) as the altitude decreases (i.e. as the submarine approaches the bottom). The investigation suggests a simple mathematical means for quantifying the bottom "suction" effect for submarine simulators.

Marine Casualty Response and Salvage Engineering Enhancement

Researcher: Commander Jeffrey W. Stettler, USN
Sponsor: Supervisor of Salvage and Diving (NAVSEA 00C), Naval Sea Systems Command

As technology has improved, fewer numbers of marine casualties occur (including ship groundings, sinkings, and collisions). The downside to this good news is that there are now far fewer opportunities for real-world "on-the-job" training for current and future marine casualty responders and salvage forces of the U.S. Navy and U.S. Coast Guard. One strategic element of the overall U.S. Navy Salvage Force Readiness Plan is the formal education of junior and mid-grade officers in the variety of applied engineering principles necessary for responding to the range of ship casualties. Under this project, the U.S. Naval Academy provides experienced technical expertise and summer workshop instruction. The workshops provide education in applied engineering principles and practices for marine casualty response and salvage for junior and mid-grade engineering officers in the U.S. Navy and U.S. Coast Guard (active and reserve), as well as Navy civilian and contractor engineers. In conjunction with the workshops, the project supports investigation and implementation of novel techniques for educating current and future marine casualty responders through hands-on practical salvage engineering projects.

The Atlantic Center for the Innovative Design and Control of Small Ships

Researcher: Associate Professor Jennifer K. Waters and Professor Robert H. Mayer
Sponsor: Office of Naval Research (ONR)

The U.S. Naval Academy, the Stevens Institute of Technology, Webb Institute and the University College of London are partners in the Atlantic Center for the Innovative Design and Control of Small Ships. The partners appreciate the concern of the Office of Naval Research that there is a deteriorating critical mass surrounding classical design centers for Naval Architecture and Marine Engineering in the United States. Unless this critical mass is regenerated, it is inevitable that U.S. Naval ships will eventually lag in both innovation and technical development. A major challenge in U.S. Navy ship design in the 21st Century is ensuring performance and affordability with a reduced crew size while also maintaining high reliability and damage control. This challenge is particularly evident in the design of vessels to meet the Navy's new and emerging needs in the littoral zone. These needs require fast, relatively small vessels capable of operating in the range of weather and ocean conditions encountered in the littoral environment while also meeting the Navy's payload requirements. The Atlantic Center proposes to address this issue by focusing on two key areas. First is in establishing an environment where engineering disciplines associated with hull design and ship automation can be brought together within the context of the total ship system architecture. Second is the utilization of this unique education and research environment in the recruiting, training and long-term career development of the best and brightest young engineers in the U.S. By capitalizing on its partnership, the Atlantic Center will provide the creative, interdisciplinary environment in which to educate the next generation of Naval Engineers, and will open the door to exciting long-term career opportunities for graduates of the program. In this fashion, the Atlantic Center will foster and instill innovation and creativity into the future leadership of the U.S. Navy, and will ensure the nation's ability to maintain superior naval forces.

Research into Relationships Applicable to Estimation of Vessel Loading and Transit Draft Estimation for Navigation Studies

Researcher: Associate Professor Jennifer K. Waters
Sponsor: Institute for Water Resources, U.S. Army Corps of Engineers

The Navigation Economics Technologies (NETS) research effort is part of the Army Corps of Engineers Planning Models Improvement program. The NETS effort is charged with improving tools and techniques for Corps of Engineer navigation economic analysis. To this end, a number of different focused research efforts are being conducted to support the NETS program, including detailed cargo, ballast and maritime container box specifications and estimations of life-cycle costs. A critical review of commercial off-the-shelf software for loading analysis has been conducted to assist in the effort.

Further investigations include estimation and refinement of [variable] immersion and other stability characteristics for deep-draft vessels. This study includes research concerning the design specifications for disposition of bunkerage and ballast for containerized cargo carriers, bulk carriers and other vessel types.

An additional study and evaluation of horsepower and specific fuel consumption issues for deep-draft vessels is also part of this effort. Present vessel operating costs generally encompass to two modes of propulsion or power consumption: "at-sea" and "in-port." The former assumes application of the prime mover (operating at service speed) and auxiliary units while the latter generally assumes use of only auxiliary power units for in-port power generation. What is needed is a refinement of power and fuel consumption with varying speeds (not just consumption versus power) to accurately reflect variability in operations of motorships.

Independent Research

Bioengineering Study of the Cardiovascular System of Mammals

Researcher: Professor Thomas H. Dawson

The cardiovascular system of mammals is studied using engineering principles and their application to the design and process of the system. A consequence of this work has been the discovery of the scaling laws governing the cardiovascular system of mammals, including humans. Publications include the earlier book: *Engineering Design of the Cardiovascular System of Mammals* (Prentice Hall Bioengineering Series) and the more recent papers: "Similitude in the Cardiovascular System of Mammals"(*Journal of Experimental Biology*, Vol. 204, pp. 395-407, February 2001); and "Scaling Laws for the Capillary Vessels of Mammals at Rest and in Exercise" (*Proceedings of the Royal Society London*, Vol. 270, pp. 755-763, April 2003), and "Modeling of Vascular Networks" (*Journal of Experimental Biology*, Vol. 208, pp. 1687-1694, May 2005). Work is continuing as time and circumstances permit.

Comparative Analysis of Submarine Sails

Researchers: Professor Gregory J. White, Mr. William E. Beaver, P.E. (Hydromechanics Laboratory), and Ensign Paul D. Haagenson, USN

Sponsor: Naval Academy Hydromechanics Laboratory (NAHL)

The objective of the project was to perform a comparative experimental hydrodynamic analysis of two submarine sail configurations and then rank the sail configurations on the basis of the drag and flow characteristics. The experiments were to be performed in the NAHL's 380' towing tank using the 13-ft SUBOFF model for the baseline hull. The model testing began in August of 2003 with system calibration and testing of the baseline hull and a baseline generic sail. Those tests were completed in August. Testing on the two sail variants was underway when Tropical Storm Isabel arrived. The flooding from the storm surge associated with Isabel severally damaged all of the NAHL facilities and made further testing impossible. In November of 2005, the 380' towing tank at the NAHL once again became fully operational. The models of the two sail configurations were repaired and updated (they had been damaged in the flood). The SUBOFF model and towing sting were also refurbished. The plan was completed during December 2005. The test matrix consisted of runs made at speeds ranging from 2 fps to 13 fps for the bare hull, and with the two sail configurations. A total of 89 model runs were made to cover the test matrix and include repeat runs for determining testing precision and repeatability from day to day. Based on the results it is clear that the additional volume in the second sail came at the cost of additional wetted surface. Even a somewhat improved foil shape could not offset the increased frictional drag. However, it should be noted that the increase in drag was consistently on the order of 2–3%.

Trident Scholar Projects

Design and Implementation of an Autonomous Surface Vessel (Trident Report # 346)

Researcher: Midshipman 1/C Caleb M. Reed, USN
Advisers: Associate Professor Jennifer K. Waters and
Associate Professor Bradley E. Bishop (Weapons and Systems Engineering Department)
Sponsor: Office of Naval Research (ONR)

Autonomous vehicles are only beginning to make the impact that they soon will have in a variety of applications. Research is ongoing to provide unmanned vehicles with higher cognitive abilities in order to simplify or eliminate the role of an operator. Advancing the understanding and development of Autonomous Surface Vessels (ASVs), the objective of this research project, will be beneficial to not only the military, but also in many commercial and research applications.

Multiple criteria were considered in selecting the type of vessel and maneuvering hardware most appropriate for the desired applications. A semi-planing monohull with an electric motor and single rudder was selected as the test bed for this research. In addition, sensors were chosen to provide the necessary data for an autonomous controller. These sensors were integrated onto a single circuit board which included a dedicated microprocessor for their operation and control. Different communication techniques were investigated to allow the primary microprocessor to pass information to a secondary microprocessor which produced the output for the control motors.

Techniques for mathematically modeling the vessel were investigated, and physical experiments were conducted to determine the maneuvering parameters of the vessel, required for the model's development. From this model, a control system was developed to guide the vessel to a desired position following waypoints based on the input of the sensors. These waypoints were automatically determined from information stored on an off-board computer. Data was collected in order to improve the functionality of the sensors and navigational techniques.

During this research, numerous challenges specific to small, low-cost ASVs were encountered and investigated. In the end, a fully functional low-speed miniature ASV was developed and tested in the waters surrounding the U.S. Naval Academy. This platform represents an important step forward in autonomous marine surface vessels.

Combined Effects of Pulsed Film Cooling and Upstream Wakes on Gas Turbine Heat Transfer (Trident Report # 348)

Researcher: Midshipman 1/C Kristofer M. Womack, USN
Advisers: Associate Professor Michael P. Schultz and
Associate Professor Ralph J. Volino (Mechanical Engineering Department)

The combined effects of pulsed film cooling and upstream wakes were studied. In film cooling, compressed air is routed around the combustion chamber of a gas turbine engine and bled through holes on the surface of the turbine blades. This compressed air creates a protective film of relatively cool air that reduces the heat transfer between the combustion gases and the blades. Diverting air from the combustor reduces the power and efficiency of the turbine, however, pulsing the air may provide equivalent or acceptable protection for the turbine blades with less cooling air. Previous pulsed film cooling studies have been completed with a simplified, continuous freestream flow. In an actual turbine, the combustion gases pass through a cascade of rotor blades and stator vanes, which interrupt the flow, sending wakes downstream to subsequent rows of turbine blades.

In this study, periodic wakes were added to the mainstream flow. A large test plate was constructed with a row of holes through which film cooling air could be pulsed. A wind tunnel provided a wall jet at a controlled velocity across the test plate. A wake generator was located upstream of the test plate to simulate the effect of

upstream turbine blades, so that the resulting flow field, film cooling effectiveness, and heat transfer could be studied. Continuous film cooling resulted in better blade protection than pulsed film cooling at equivalent wake frequencies. For the cases with a continuous freestream and the cases with lower wake frequencies, continuous film cooling jets blowing at half the free-stream velocity provided the best protection. For the highest wake frequency tested, continuous film cooling jets blowing at a velocity equal to the freestream velocity provided the best protection. Finally, when comparing pulse timing relative to the wake passing, there was some improvement in blade protection when the cooling jet was on as the wake passed over the cooling holes, however in most cases, differences were small. This study suggests that, for the geometry tested, continuous film cooling provides better protection for gas turbine blades for the same amount of cooling air.

Midshipman Research Course Projects

Structural Behavior of Composite Panels Subjected to Impact and In-Plane Compression

Researcher: Midshipman 1/C James R. Armstrong, USN and Midshipman 1/C Mary K. Dann, USN
Adviser: Associate Professor Sarah E. Mouring
Sponsor: Office of Naval Research (ONR)

Even with all of the advantages of composite materials, there is much less known about the behavior of composites compared to traditional materials under certain types of loading such as shock or impact loading. In particular, composites subjected to impact loading exhibit different modes of failures and severity of damage depending on whether the impact is classified as high- or low-velocity. In this research project, which is part of an ongoing ONR-sponsored project at the United States Naval Academy, there were three phases of testing with respect to both small panels and large panels. The first phase concerned testing large baseline panels under in-plane compressive loading. The second phase included subjecting small composite panels to varying impacts. In the third phase, larger panels were subjected to various impact energies. The results of these three phases will be used in the larger ONR-sponsored project to determine the residual strength of impact-damaged composite panels.

Low Speed Impact of Fiberglass Yacht Panels

Researcher: Midshipman 1/C Timothy F. Fleury, USN
Adviser: Associate Professor Paul H. Miller
Sponsor: Westport Shipyards, Westport, WA

Composite materials offer significant advantages when used in vessels of all sizes. In particular, their ability to be easily shaped and the low maintenance requirements particularly appeal to buyers of recreational craft. The Navy is also very interested in composites, but questions remain about their damage tolerance. This project was sponsored by Westport Shipyards and supported by the Naval Station Annapolis, the Naval Sea Systems Command (NAVSEA) and the Office of Naval Research (ONR) as it looked at the damage tolerance of larger composite vessels.

The particular laminates were designed for semi-displacement craft in the 130’-165’ overall length. Applicable to the Academy, this includes the proposed Yard Patrol (YP) vessels. Currently many of the core materials used in large craft are seeing reformulation due to air quality issues. Of particular interest to Westport was the effect of finding a substitute core material for one that is no longer in production. This project used analytical and experimental techniques to compare four different proposed core materials. The polyester/E-glass skin laminates were kept constant throughout. The desired load condition for analysis was a 2-knot impact against a piling. Analysis included simple fracture mechanics models which were limited in accuracy by unavailable material properties. Additionally, linear and geometrically nonlinear finite element analysis compared predicted stress levels. The final step was full-scale impacts. Panels measuring 5 x 10 feet were bolted to a YP and impacted against a simulated piling in the Naval Station basin.

The finite element analysis and the tests correlated well, with both predicting similar ranking of the materials. In terms of practical usage, all of the tested cores behave similarly.

Behavior of Thick Composite Panels Subjected to Impact

Researcher: Midshipman 1/C David R. Haines, USN
Adviser: Associate Professor Sarah E. Mouring
Sponsor: Office of Naval Research (ONR)

This project involved fabricating a test rig to be used in the low-velocity impact test rig at Naval Service Warfare Center (NSWC), Carderock Division. Four 3' x 4' GRP panel specimens were strain gauged and wired for the impact testing. After impact testing, these specimens will be tested in the Ships Structures Laboratory under in-plane compression to failure. These test results can be compared to baseline panel tests to determine the residual strength of the panels. One baseline panel was tested under in-plane compression as part of the project.

Performance Improvement for Chesapeake Bay Log Canoes

Researcher: Midshipman 1/C Bryan J. Lingle, USN
Adviser: Associate Professor Paul H. Miller
Sponsor: Judge John North

Log canoes have been sailing on the Chesapeake Bay for over a century. Built in the late 19th-century, they were designed without the aid of modern performance prediction methods. The goal of this project was to improve the sailing performance of the Chesapeake Bay log canoe "Island Bird" using both a velocity prediction program and hydrodynamic tank testing. This vessel's original shape, as well as the highly modified 2005 hull shape, were compared and used as a basis for a new hull shape. The original hull form was taken from a set of 1936 plans. The modified shape was found by taking offsets off the hull in St. Michael's, MD.

The velocity prediction program (VPP) used was PCSAIL2.5, a Microsoft Excel-based program into which the hull and sail parameters for Bird were entered in order to predict the canoe's speed and resistance at various true wind speeds and angles. Maxsurf was used to generate digital hull forms to obtain hull parameters for Island Bird and to generate templates for the construction of two 52" tank models. The tank testing involved upright zero yaw, resistance testing in the USNA Hydromechanics Laboratory's 120-foot tow tank.

The performance of both the original and current hull forms was analyzed using both the VPP and tank testing. Results from both methods indicate the 2005 modifications yielded increased resistance across the speed range and lower performance under sail. An important characteristic not studied was hull stability, a significant factor in Log Canoe success. Following that initial analysis, the VPP and Maxsurf were used to conduct a sensitivity study to determine the optimal hull shape for the log canoe. The final proposed hull shape should provide improved stability and performance over the original and modified hull forms.

Development of a Design for an Ocean-Observing Platform in the Vicinity of the Confluence of the Severn River and the Chesapeake Bay at Annapolis, MD

Researcher: Midshipman 1/C Richard A. Mayer, USN
Advisers: Assistant Professor David W. Fredriksson and Associate Professor Jennifer K. Waters

Ocean-observing systems provide invaluable services to many facets of modern society, from the scientific community to the general public. The need to integrate discrete and independent systems into a large-scale, interconnected network is ever-present. Constituent systems include the Chesapeake Bay Observing System (CBOS). The United States Naval Academy has established the Center for Chesapeake Bay Observing and Modeling (CCBOM) in part to add an additional ocean-observing platform to the CBOS.

The objective of this research project was to produce a feasible design for an ocean-observing platform in the Chesapeake Bay, considering such factors as: site selection, sediment characterization, radial fetch analysis, wind hindcasting, wave forecasting, tidal current velocity determination, platform design and economic analysis. Through analysis, design and iteration a feasible design was devised.

Parametric Design of an Offshore Cruising Sailboat

Researcher: Cadet 1/C Sarah Morin, USCG
Advisers: Associate Professor Paul H. Miller,
and Todd Tailor, U.S. Coast Guard Academy

A sailboat design study was conducted to optimize parameters for a specified circumnavigation course. The course was an easterly course that passed through the Suez Canal and the Straights of Magellan. Research was done into how different parameters affect the usability of a boat and then a Velocity Prediction Program was used to determine how each parameter affected speed. A 40-foot sloop with a 6-foot draft, length-to-beam ratio of 3.5, fin keel, and fractional rig was determined to be the optimal design.

Continuation of the Human-Powered Hydrofoil Project

Researcher: Midshipman 1/C Brandon G. Poythress, USN
Adviser: Professor Gregory J. White
Sponsor: Naval Academy Hydromechanics Laboratory (NAHL)

The human-powered hydrofoil project is an ongoing effort within the Naval Architecture program at the United States Naval Academy. The overall goal of this project is to continue the design efforts on a human powered hydrofoil platform capable of traveling 20 knots while supporting 200-240 pounds. Because a human being will be powering this vehicle with, at most, about ¾ horsepower, the total drag budget is only 9.4 pounds. In the late 1990's a team from MIT came extremely close to reaching this goal, achieving somewhere in the vicinity of 18 knots under human power.

During the fall of 2005 and the spring of 2006, research efforts concentrated on the initial lifting of the hydrofoil hull out of the water and developing a means of controlling the transverse stability of the vehicle. A number of alternative plans for generating the needed lift while staying within the drag budget were investigated. Many proved to be unworkable, or too heavy, or not strong enough. The documentation of these efforts will hopefully prevent the next student from venturing down those paths, and may lead them to a more optimal solution.

The final outcome of this effort is a system for transitioning from a large, slow speed foil for initial takeoff to a much smaller high performance foil for high speeds. A five-foot span, low-speed foil was designed and constructed during the later part of this effort. Unfortunately, the foil was not completed in time to perform tank testing to confirm its theoretic performance.

Design and Construction of an Underwater Remotely-Operated Vehicle Control System

Researcher: Midshipman 1/C Dominic J. Simone, USN
Adviser: Commander CDR Patrick Hudson, USN

The goal of this project was to design, build, and integrate a new control system into a workable Remotely Operated Vehicle (ROV). The new system was to be completely intuitive and allow for one-handed movement control of the ROV. A 3D motion controller was used to provide this intuitive control. Such a control can be pushed, pulled or twisted in any direction along all axes. Whatever action is desired of the ROV can easily be commanded by mimicking the action on the ball of the controller using only one hand. The system required two microprocessors to interpret the signals from the control and to drive the appropriate ROV thrusters. Completion of this project resulted in design of the circuits, fabrication of the circuit boards, programming of the microprocessors, integrating the control system into the ROV, and final in-water testing.

Submarine Motions near the Free Surface: Experimental Determination of Vertical Forces in a Regular Seaway

Researcher: Midshipman 1/C Michael P. Shaughnessy, USN
Adviser: Professor Rameswar Bhattacharyya

The topics of vertical forces and motions of a submarine operating under waves have been addressed in numerous theoretical studies. Existing empirical studies and data are limited, and in many cases, classified. This experiment had two primary objectives. The first objective was to conduct an experiment to measure vertical forces acting on a submarine model moving under regular waves at various depths and speeds. The second objective was to calculate theoretical vertical forces based on existing equations and conduct a comparison with experimental data. The trends in experimental vertical force amplitudes matched predictions to a high degree, however experimental force amplitudes were consistently lower than values predicted according to Cummins' equations. Several possible explanations are provided in the report.

Leak Path Investigation, Cofferdam Design and Construction for Submarine Main Ballast Tank Waterborne Maintenance

Researcher: Midshipman 1/C Taylor J. South, USN
Adviser: Commander Jeffrey W. Stettler, USN
Sponsor: Supervisor of Salvage and Diving (NAVSEA 00C), Naval Sea Systems Command

In response to the results of the initial testing of a set of submarine main-ballast-tank blanking patches developed by the Naval Sea Systems Command (00C5), additional leak paths to the main ballast tanks were investigated. Using docking drawings, the potential leak paths were located on third and fourth flight Los Angeles class submarines (SSN 751–773). This allowed the systems that posed a concern of leakage to be isolated in order to obtain the individual drawing and dimensions of the systems. With this information, focus was first placed on the WLR-9 AE Detection hydrophone. An aluminum box-type cofferdam was designed to eliminate the WLR-9 hydrophone as a leak path. After structural calculations were performed to validate the design, an engineering drawing was created. For a potential test on the USS Boise (SSN 764), the WLR- 9 cofferdam was fabricated in accordance with the engineering drawing. Finally, a finite element structural analysis of the WLR-9 cofferdam was performed to provide a more accurate stress prediction.

Professional Publications

Journal (Refereed) Manuscripts

CONNELLY, Jonathan S., Ensign, USN, and SCHULTZ, Michael P., Associate Professor (co-authors), "Velocity-Defect Scaling for Turbulent Boundary Layers with a Range of Relative Roughness," *Experiments in Fluids*, 2006, Vol. 40, pp. 188-195.

> Velocity profile measurements in zero pressure gradient, turbulent boundary layer flow were made on a smooth wall and on two types of rough walls with a wide range of roughness heights. The ratio of the boundary layer thickness (δ) to the roughness height (k) was $16 \leq \delta/k \leq 110$ in the present study, while the ratio of δ to the equivalent sand roughness height (k_s) ranged from $6 \leq \delta/k_s \leq 91$. The results show that the mean velocity profiles for all the test surfaces agree within experimental uncertainty in velocity-defect form in the overlap and outer layer when normalized by the friction velocity obtained using two different methods. The velocity-defect profiles also agree when normalized with the velocity scale proposed by Zagarola & Smits (1998). The results provide evidence that roughness effects on the mean flow are confined to the inner layer, and outer layer similarity of the mean velocity profile applies even for relatively large roughness.

FREDRIKSSON, David W., Assistant Professor (co-author), "Drag Force Acting on Biofouled Net Panels," *Aquacultural Engineering,* in press.

Measurements were made to assess the increase in drag on aquaculture cage netting due to biofouling. Drag force was obtained by towing net panels, perpendicular in a tow tank and in the field. The net panels were fabricated from netting stretched within a one-meter-square pipe frame. They were towed at various speeds, and drag force was measured using a bridle arrangement terminating in a load cell. The frame without netting was also drag tested so that net-only results were obtained by subtracting out the frame contribution. Measurements of drag force and velocity were processed to yield drag coefficients.

Clean nets were drag tested in the University of New Hampshire (UNH) 36.5 m long tow tank. Nets were then exposed to biofouling during the summer of 2004 at the UNH open ocean aquaculture demonstration site 1.6 km south of the Isles of Shoals, NH, U.S.A. Nine panels were recovered on October 6, 2004 and drag tested at sea. The majority of the growth was skeleton shrimp with some colonial hydroids, blue mussels and rock borer clams. The net panels had been subject to different antifouling treatments, so growth varied amongst the panels. Drag force measurements were made using a bridle-pulley-load cell configuration similar to that employed in the tow tank. Fixtures and instruments were mounted on an unpowered catamaran that was towed alongside a workboat. Increases in net-only drag coefficient varied from 6% to 240% of the clean net values. Biofouled drag coefficients generally increased with solidity and volume of growth.

FREDRIKSSON, David W., Assistant Professor (co-author), "Hydrodynamic Forcing of Long-Line Mussel Farms: Observations," *American Society of Civil Engineers Journal of Waterways, Port, Coastal and Ocean Engineering,* in press.

The first detailed observations of the motion and loading of a mussel (shellfish) long-line are described in order to identify the dominant modes of flow-structure interaction and provide a baseline for prediction of future structures. A long-line is typically a 120 m long sequence of surface floats beneath which is looped rope bearing the mussel crop. Accelerometer and load cell data from sensors mounted on the structure along with remote radar data are examined in the context of wave and current measurements. The mussels comprise the largest mass and drag element of the structure. The tidally affected pre-tensioning of the mooring lines dominates the background load. However, waves and currents increase the maximum load by potentially 100% over this value. The floats at each end of the long-line follow the wave orbital motion reasonably well, more so than the floats in the middle of the backbone. The mussel-laden loops of rope (droppers) clearly respond differently to the floats, implying flexibility in the vertical dimension. This suggests flow around the droppers, which influences mussel feeding ability and hence production, is complex and highly three-dimensional.

KRIEBEL, David L., Professor (co-author), "The Engineering Impact of the Tsunami in Thailand," *The Bridge, Journal of the National Academy of Engineering,* Summer 2005, Vol. 35, No. 2, pp 4-13.

This paper describes the impacts of the 26 December 2004 Indian Ocean tsunami on beaches and coastal infrastructure in Thailand. The authors visited affected areas on Thailand in early February 2005 as part of a team on engineering investigators sponsored by the American Society of Civil Engineers. Investigations included observations of wave height and water level, beach erosion, damage to port and harbors, and damage to buildings located along the coast. The paper documents some of the observations of the assessment team, and includes "lessons learned" that can minimize effects on infrastructure and loss of life in future tsunami events.

MOURING, Sarah E., Associate Professor (co-author), "Current Research into Modeling of Shock Damage to Large Scale Composite Panels," *Journal of Materials Science,* in press.

This study aims at modeling the damage incurred to large woven roving E-glass/vinyl-ester composite panels subjected to shock loads, with particular emphasis on developing an effective, simple to use delamination model. An energy criterion for failure is applied at resin-rich layers which are modeled in between every ply. The finite element program Abaqus/Explicit together with a user material subroutine (VUMAT) is used to simulate both large and small scale impact tests. The resin-rich layers are modeled as non-linear elastic. Matrix and fiber damage is modeled at the woven plies using Hashin's 2D stress-based failure criteria with a once-only degradation of the material properties.

SCHULTZ, Michael P., Associate Professor, and SHAPIRO, Thomas A., Ensign, USN (co-authors), "Experimental Support for Townsend's Reynolds Number Similarity Hypothesis on Rough Walls," *Physics of Fluids*, 2005, Vol. 17, Article # 035102.

The Reynolds number similarity hypothesis of Townsend states that the turbulence beyond a few roughness heights from the wall is independent of the surface condition. The underlying assumption is that the boundary layer thickness (δ) is large compared to the roughness height (k). This hypothesis was tested experimentally on two types of three-dimensional, rough surfaces. Boundary layer measurements were made on flat plates covered with sandgrain and woven mesh roughness in a closed return water tunnel at a momentum thickness Reynolds number (Re_θ) of ~14000. The boundary layers on the rough walls were in the fully rough flow regime ($k_s^+ \geq 100$) with the ratio of the boundary layer thickness to the equivalent sand roughness height, δ/k_s, greater than 40. The results show that the mean velocity profiles for rough and smooth walls collapse well in velocity defect form in the overlap and outer regions of the boundary layer. The Reynolds stresses for the two rough surfaces agree well throughout most of the boundary layer and collapse with smooth wall results outside of $3k_s$. Higher moment turbulence statistics and quadrant analysis also indicate the differences in the rough wall boundary layers are confined to $y < 5k_s$. The present results provide support for Townsend's Reynolds number similarity hypothesis for uniform three-dimensional roughness in flows where $\delta/k_s \geq 40$.

STETTLER, Jeffrey W., Commander, USN, (co-author), "Investigating the Steady and Unsteady Maneuvering Dynamics of an Azimuthing Podded Propulsor," *Transactions of the Society of Naval Architects and Marine Engineers*, 2005, Vol. 113.

This paper provides highlights of results of a recent investigation completed at the Massachusetts Institute of Technology and U.S. Naval Academy pertaining to the characterization of the steady and unsteady maneuvering force dynamics associated with an azimuthing podded propulsor. Highlighted results include quasi-steady and unsteady forces, as well as several methods of flow visualization.

WATERS, Jennifer K., Associate Professor, and MAYER, Robert H., Professor, "Ocean Engineering Capstone Design Projects for Harnessing Energy from the Ocean Environment," *Sea Technology*, Arlington, VA, in press.

Development of ocean-related renewable energy technologies continues to gain more interest, especially as renewable energy types and contributions increase. While there are many advantages to harnessing energy from ocean sources, there are also many challenges – including environmental, structural, regulatory and socio-political issues. Recently, Midshipmen (students) at the U.S. Naval Academy (USNA) have tackled these challenges as part of their capstone design course in ocean engineering and have conducted feasibility-level designs for harnessing energy from the ocean environment. The types of ocean energy systems investigated and designed by the students have varied widely and have included: (1) ocean thermal energy conversion (OTEC), (2) tidal-induced current energy, and (3) offshore wind energy projects. Highlights of the design approach, issues and findings from the projects are summarized here.

Conference Proceedings

FREDRIKSSON, David W., Assistant Professor (co-author), "Mooring Load Analysis of a Korean Designed Submersible Open Ocean Aquaculture Cage System Using the Finite Element Method," *Proceedings of the World Aquaculture Society, Aqua 2006,* Florence, Italy, May 2006, p. 231.

> The expansion of near shore aquaculture in Korea is may only be feasible is aquaculture facilities are moved into the open ocean. A numerical model study was conducted to investigate the dynamics of a Korean designed marine aquaculture system, consisting of a modified gravity cage. The cage system can be submerged through an arrangement of pulley systems operated by underwater motor in case of an emergency. The system is analyzed using two mooring configurations. The first consists of a single point, high tension mooring that passes through the cage and the second mooring configuration consists of the same single-point component with three additional anchor legs connected to the upper rim. The characteristics of the mooring load response in the lines under waves and in currents and the response amplitude operators were calculated for the single and three point mooring configuration for both surface and submerged arrangements. The static mooring loads without current and wave loading were similar for both configurations. It was calculated that the three-point mooring was more adequate than the single point mooring for the submersible aquaculture cage system. The wave induced response amplitude operators for the single point system with the influence of the currents were identical to those without currents.

KRIEBEL, David L., Professor (co-author), "An Empirical Model for Ship-Generated Waves," *Proceeding of the 5th International Symposium on Ocean Wave Measurement and Analysis,* Madrid, Spain, July 2005. (CD-ROM)

> A new model for the prediction of ship-generated wave heights has been developed based on an empirical analysis of more then 1,200 data points from small-scale model tests reported in the literature. The new model was then validated at full-scale in field trials conducted using a training vessel owned by the U.S. Naval Academy. Predictions using the new model appear to be superior to those made using the more established model of Sorensen and Weggel.

KRIEBEL, David L., Professor (co-author), "Coastal Engineering Impacts of the 2004 Tsunami in Thailand," *Proceedings of the 5th International Symposium on Ocean Wave Measurement and Analysis*, Madrid, Spain, July 2005. (CD-ROM)

> Lessons learned from an American Society of Civil Engineers visit to the southwest coast of Thailand after the Sumatra tsunami are discussed. Observations of the wave along the coast and the condition of the beaches and ports on Phuket Island and the Phang Nga province shoreline are reported.

MOURING, Sarah E., Associate Professor (co-author), "Impact Tests on VARTM Fabricated Woven Roving Vinyl Ester Laminates," *Proceedings of the 16th International Offshore and Polar Engineering (ISOPE) Conference and Exhibition,* Long Beach, CA, 28 May – 2 June 2006. (CD-ROM)

> Damage caused to composite marine vessels due to impact with floating debris is an important design consideration for modern vessels. Experimental results of small scale panels subjected to low velocity impact on Vacuum Assisted Resin Transfer Moulding (VARTM) produced specimens are presented. The effect of impactor size and kinetic energy are investigated. Damage was observed for all impact energies, in particular delamination on the back face. Comparison of the contact force and panel deflections are investigated using a simple analytical model based on a spring mass idealisation and a non-linear finite element analysis (FEA). The simple analytical model was found to give good correlation at low energy values despite the fact that only elastic behavior was considered. The FEA model allowed for delamination, which was the dominant damage mechanism observed in the tests, using novel cohesive elements placed at natural resin rich layers throughout the thickness of the panels. Reasonable correlation with the damage

patterns observed was obtained. Modifications to the model also are currently under investigation to improve the through thickness behavior.

MOURING, Sarah E., Associate Professor (co-author), "The Use of High-Resolution Acoustic Microscopy for Assessing the Integrity of Composite Structures," *Proceedings of the Thirteenth International Conference on Composites/Nano Engineering (ICCE-13)*, Tenerife, Spain, 31 July – 6 August 2005. (CD-ROM)

This paper outlines a proposed method to determine the extent of microcracking and the associated predicted remaining life of advanced composite structures using a novel Non-Destructive Evaluation (NDE)/theoretical model-driven technique. This effort involved refining high-resolution ultrasonic (UT) images to be even more predictive of physical properties of the composites. The large database of the NDE observations was used to correlate with the results of a shear-lag analysis for the stress and strain calculations in conjunction with an energy-based failure criterion. The strain energy release rate for crack initiation and propagation was adopted as the failure criterion for the laminates.

MOURING, Sarah E., Associate Professor (co-author), "Current Research into Modeling of Shock Damage to Large Scale Composite Panels," *Proceedings of the Conference, Advances in Multi-Scale Modeling of Composite Materials and Components*, Monterey, CA, 25-30 September 2005. (CD-ROM)

This study aims at modeling the damage incurred to large woven roving E-glass/vinyl-ester composite panels subjected to shock loads, with particular emphasis on developing an effective, simple to use delamination model. An energy criterion for failure is applied at resin-rich layers which are modeled in between every ply. The finite element program Abaqus/Explicit together with a user material subroutine (VUMAT) is used to simulate both large and small scale impact tests. The resin-rich layers are modeled as non-linear elastic. Matrix and fiber damage is modeled at the woven plies using Hashin's 2D stress-based failure criteria with a once-only degradation of the material properties.

MOURING, Sarah E, Associate Professor, and LEVIS, William R., Midshipman 1/C, USN (co-authors), "Structural Response of Impact-Damaged Composite Panels," *Proceedings of the OCEANS 2005 Marine Technology Society/Institute of Electrical and Electronics Engineers (MTS/IEEE) Conference,* Washington, DC, 18–23 September 2005. (CD-ROM)

Internal damage due to impulse events, such as impact or shock, may not be detected by visual inspection in composite structures. This internal damage can cause significant reductions in strength and may lead to catastrophic failure. Therefore there is a need first to understand completely the effects of an impact event on a composite material. As part of this research project, a simple energy model has been used to better quantify the behavior of glass reinforced polymers (GRP) panels subjected to impact. Sixteen 0.229 m x 0.178 m x 0.006 m woven roving GRP panels were impacted with varying energy levels and tup sizes to compare the experimental results to that of the energy model.

MOURING, Sarah E., Associate Professor, "Structural Behavior of Impacted Composite Panels," *Proceedings of the National Science Foundation, Civil and Mechanical Systems Workshop*, Arlington, VA, 5-8 March 2006. (CD-ROM)

Impact damage due to unforeseen events is an important design issue for composite marine vessels. This paper reviews experimental results of small-scale composite panels subjected to low-velocity impact. The effect of impactor size and kinetic energy are investigated. Comparison of the contact force and panel deflections is made using non-linear finite element analysis (FEA). The FE model allowed for delamination using novel cohesive elements placed at naturally resin rich layers throughout the thickness of the panels. Reasonable correlation with the damage patterns observed was obtained. Modifications to the model are currently under investigation to improve the through thickness behavior.

NEHRLING, Bruce C., Professor (co-author), "Fuzzy Optimal Allocation of Spaces to Zone-Decks in General Arrangements," *Proceedings of the 2006 International Marine Design Conference (IMDC 2006)*, Ann Arbor, MI, May 2006, pp. 651-671.

A general approach for the knowledge-based, computer-aided preliminary design of the general arrangements of naval vessels using fuzzy optimization is described. This arrangement process involves a series of two, essentially two-dimensional problems: the allocation of spaces to Zone-decks (one deck within one vertical zone), and then the topological and detailed geometric arrangement of the spaces assigned to each Zone-deck. The solutions are constrained by global location preferences within the ship, relative adjacency and separation preferences among the spaces, and Zone-deck space utilization goals. The development and testing of an efficient genetic algorithm that performs the optimal allocation process is described. The algorithm is used to optimize the allocation for a 70 space-17 Zone-deck test design that is representative of a full-scale, small combatant.

SCHULTZ, Michael P., Associate Professor, and CONNELLY, Jonathan S., Ensign, USN (co-authors), "Investigation of Outer Layer Similarity for Rough Wall Boundary Layers," *Proceedings of the 4th International Symposium on Turbulence and Shear Flow Phenomena (TSFP-4)*, Williamsburg, VA, June 2005, pp. 503-507.

Based upon literature reviews, the papers of Jiménez (2004) and Flack *et al.* (2005) have concluded that changes to the turbulence structure across the boundary layer can be expected in rough wall flows where the boundary layer thickness (δ) is not much larger than the roughness height (k) or equivalent sand roughness height (k_s). The two studies state that outer layer similarity in the turbulence may cease to exist in cases where $\delta/k \leq 50$ or $\delta/k_s \leq 40$, respectively. In order to explore a limiting roughness height for boundary layer similarity, an experimental investigation was carried out on six rough surfaces representing two types of three dimensional roughness (sandpaper and woven mesh) in which $16 \leq \delta/k \leq 110$ and $6 \leq \delta/k_s \leq 91$. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 6,100 to 13,000, using a two-component, laser Doppler velocimeter (LDV). The present results indicate that the mean velocity defect profiles for both the smooth and rough surfaces collapse well in both classic scaling and using the velocity scale of Zagarola & Smits (1998). The Reynolds stresses for all the surfaces collapse with smooth wall results outside of 2-4k_s. These results indicate that turbulence similarity in the outer layer may be more robust than previously thought.

SCHULTZ, Michael P., Associate Professor (co-author), "Effects of Roughness on Turbulence Spectra and Correlation Measurements," *Bulletin of the American Physical Society: Division of Fluid Dynamics 58th Annual Meeting*, Chicago, IL, November 2005, Vol. 50, No. 9, p. 151.

Zero pressure gradient, fully-developed, turbulent boundary layers have been documented on a smooth flat plate and a fully rough surface in a water tunnel facility. The roughness is produced using a wire mesh affixed to the surface. Profiles of the streamwise and wall-normal velocity components were acquired using laser Doppler velocimetry (LDV). Additional LDV data were acquired with high sampling rates at two locations in the profiles, corresponding to $y/\delta_{99} = 0.1$ and $y/\delta_{99} = 0.4$. From these data, turbulence spectra of the Reynolds normal stresses and shear stress are computed. Flow field measurements were also made using particle image velocimetry (PIV) in the streamwise planes both normal to the surfaces and parallel to the surfaces. From the PIV data, two point correlations of the turbulence quantities are computed. The presentation will focus on the similarities and differences between the spectra and the correlations on the rough and smooth walls, adding to comparisons of the mean flow and turbulence statistics between rough and smooth surfaces presented previously.

SCHULTZ, Michael P., Associate Professor, and CONNELLY, Jonathan S., Ensign, USN (co-authors), "Outer Layer Turbulence Similarity for Rough Wall Boundary Layers," *Bulletin of the American Physical Society: Division of Fluid Dynamics 58th Annual Meeting*, Chicago, IL, November 2005, Vol. 50, No. 9, p. 151.

> The outer layer similarity hypothesis of Townsend states that turbulence beyond a few roughness heights from the wall is independent of the surface condition. In order to explore a limiting roughness height for boundary layer similarity, an experimental investigation was carried out on six rough surfaces representing two roughness types of three dimensional roughness (sandpaper and woven mesh) in which the boundary layer thickness to roughness height varied from 16 to 110. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number range of 6,100 to 13,000, using a two-component, laser Doppler velocimeter (LDV). The Reynolds stresses and higher-order moments, as well as quadrant analysis of the rough surfaces show collapse with smooth wall results outside of a roughness sublayer. These results indicate that turbulence similarity in the outer layer may be more robust than previously thought and changes to the turbulent structure appear to be confined to a roughness sublayer, even for very large roughness.

SCHULTZ, Michael P., Associate Professor, and CONNELLY, Jonathan S., Ensign, USN (co-authors), "Velocity-Defect Scaling for Turbulent Boundary Layers with a Range of Relative Roughness," *Bulletin of the American Physical Society: Division of Fluid Dynamics 58th Annual Meeting*, Chicago, IL, November 2005, Vol. 50, No. 9, pp. 151-152.

> Velocity profile measurements in zero pressure gradient, turbulent boundary layer flow were made on a smooth wall and on two types of rough walls with a wide range of roughness heights. The ratio of the boundary layer thickness (δ) to the roughness height (k) was $16 \leq \delta/k \leq 110$ in the present study, while the ratio of δ to the equivalent sand roughness height (k_s) ranged from $6 \leq \delta/k_s \leq 91$. The results show that the mean velocity profiles for all the test surfaces agree within experimental uncertainty in velocity-defect form in the overlap and outer layer when normalized by the friction velocity obtained using two different methods. The velocity-defect profiles also agree when normalized with the velocity scale proposed by Zagarola & Smits (1998). The results provide evidence that roughness effects on the mean flow are confined to the inner layer, and outer layer similarity of the mean velocity profile applies even for relatively large roughness.

WATERS, Jennifer K., Associate Professor (co-author), "A Stereo Vision-Based Wave Surface Measurement Project," *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition,* Chicago, IL, Paper 2006-2364, June 2006.

> Measuring the three-dimensional characteristics of the ocean surface has a variety of applications. For example, surface measurements of vessel wakes could be used for improving hull designs. In the study of ocean surfaces, accurate surface measurements could be used for verifying ocean wave models or in lieu of such models in the study of various surface properties (i.e. microwave backscatter, etc.). We present vision-based wave sensing technique can be used to determine measure water surface heights and compute pertinent wave characteristics, such as slope, height, or frequency. Using a commercially available stereo imaging system, students can acquire an image of a wave surface and accurately measure its characteristics. System configuration and data analysis methods are discussed. Data generated using this method can be verified using traditional wave gauges, and used for a variety of student project or laboratory experiments. Sample results from student projects in wave tank and natural water environments are presented.

WATERS, Jennifer K., Associate Professor (co-author), "Hardware Selection and Modeling for a Small Autonomous Surface Vessel," *Proceedings for the 38th Southeastern Symposium on System Theory*, Cookeville, TN, Paper MB3.5, 5-7 March 2006.

> This paper focuses on the process of selecting hardware for use in the design of a small autonomous surface vessel design. Hull form, powering and instrumentation are discussed, with hardware specifications and performance data. Existing mathematical models appropriate for the vessel are outlined and a discussion of model identification using traditional and in situ methods is presented.

WATERS, Jennifer K., Associate Professor (co-author), "Design of an Autonomous Surface Vessel," *Proceedings of the World Maritime Technology Conference (WMTC 2006), Stream 3: Naval Engineering*, London, UK, 6-10 March 2006. (CD-ROM)

> In this work, the first phase of an undergraduate research project is discussed. Topics include the motivation for and development of the hardware and necessary sensors for a small (81cm) autonomous surface vessel (ASV). Details of the final platform are discussed, including vessel specifications, actuation design, instrumentation and on-board control. The vessel will be used for studies on small ASVs in littoral zones, including advanced navigation and control scenarios.

WATERS, Jennifer K., Associate Professor, and MAYER, Robert H., Professor, "Ocean Energy Design Projects at the U.S. Naval Academy," *Proceedings of the OCEANS 2005 Marine Technology Society/Institute of Electrical and Electronics Engineers (MTS/IEEE) Conference*, Washington, DC, September 2005. (CD-ROM)

> This paper presents a synopsis of three different ocean energy capstone design projects performed as part of the undergraduate ocean engineering curriculum at the U.S. Naval Academy dealing with: (1) Offshore Wind Energy, (2) Tidal-Induced Current Energy, and (3) Ocean Thermal Energy Conversion (OTEC). As more types and more quantities of renewable sources of energy are contributing to our nation's energy supply, the feasibility of ocean-related renewable energy sources is being more carefully considered and comprehensively investigated. While there are many advantages to harnessing energy from ocean sources, there are also many challenges – including environmental, structural, regulatory and socio-political challenges. The design approach, design process highlights and final findings from the three ocean-based renewable energy projects are presented here.

Technical Reports

FREDRIKSSON, David W., Assistant Professor, and HUDSON, Patrick J, Commander, USN, (Naval Architecture and Ocean Engineering Department), MALEK-MADANI, Reza, Professor (Mathematics Department) and WALLENDORF, Louise A., P.E. (Hydromechanics Laboratory), Measured Current Velocity Characteristics off Tolley Point in the Chesapeake Bay: 18 October 2005 to 15 November 2005. USNA Engineering and Weapons Report EW-02-06.

> Velocity profile, pressure and temperature data sets were obtained from a Nortek acoustic wave and current meter off Tolley Point in the Chesapeake Bay. The instrument was deployed in approximately 12 meters of water at the position 38° 56.08676 N Latitude by 76° 25.25433 W Longitude. The data sets were processed to obtain the primary tidal constituents for the region determined by the NOAA National Ocean Service. The entire data set is provided for documentation purposes in Appendix A of this report.

KRIEBEL, David L., Professor, "Mooring Loads due to Parallel Passing Ships," Technical Report TR-6056-OCN, Naval Facilities Engineering Service Center, Port Hueneme, CA, 30 September 2005.

> If a moving ship passes close to a moored ship, hydrodynamic loads are imparted on the moored ship. These loads must be resisted by the mooring system and include time varying surge and sway forces, as well as time-varying yaw moments. In this study, laboratory scale model tests were conducted to measure the loads on a moored ship resulting from a passing ship moving parallel to the moored vessel. Variations in the model tests included changes in the passing vessel speed, vessel displacement, water depth, and separation distance between the two ships. Empirical equations were developed that describe the variation in the peak mooring loads with changes in the above parameters. These equations notably describe the increase in loads with the increasing speed of the passing vessel, the increase in loads with increasing draft-to-depth ratio, and the decrease in loads with increasing separation between the vessels.

MILLER, Paul, Associate Professor, "Notes on Ship Structures," USNA Engineering and Weapons Report 05-06, May 2006.

> Ships are one of the most complex engineering systems and are the largest moving objects created by man. The structural challenges inherent in their design are immense. Recent failures, such as those in the DDG-51 and CG-47 classes illustrate the difficulty in balancing structural and performance criteria. While traditional structural design methods are well documented in texts, no ship structural design text has been written in the last twenty years. This 148-page report was intended as a supplementary text for EN358: Ship Structures. The material presents all the basic information necessary for the structural design of a metal ship, and also presents modern methods such as finite element analysis and reliability methods.

SILVERBERG, Jonathan P., Ensign, USN, and MILLER, Paul H., Associate Professor, "Advanced Sailboat Performance-Based Design Methods," USNA Engineering and Weapons Report EW-06-06, May 2006.

> Sailing performance remains a primary factor in sailboat design. However, only yachts limited to America's Cup or Volvo Ocean Race normally have the resources to use all the available sailing prediction methods. Today there are three methods of making performance predictions of vessels: parametric predictions, tank testing, and computational fluid dynamics (CFD). This study examines these performance prediction methods and provides recommendations for their use. Parametric analysis was conducted using the spreadsheet Velocity Prediction Program (VPP) PCSail. Tank testing was conducted in the 120-foot towing tank in the United States Naval Academy's Hydromechanics Laboratory. CFD computations were performed using FKS, a PC-based code from the Naval Surface Warfare Center, Carderock, and by SPLASH, a code from Southbay Simulations, Inc. Acquiring and comparing the data from the three performance prediction methods was a project reported in an earlier article. Analyzing and reducing the errors in these methods is the focus of this paper. Furthermore, this paper shows how to construct a simple VPP in a spreadsheet which even calculates optimum mast rake angle.

STETTLER, Jeffrey W., Commander, USN, "Experimental Investigation of Forces and Moments on a Submarine Shape Operating in the Vicinity of the Bottom," USNA Engineering and Weapons Report EW-01-06, June 2006.

> This report provides results of a test program which has investigated the forces and moments on a generic submarine shape (Series 58 hull form) operating in the vicinity of a smooth bottom. The results demonstrate a strong "suction" force on a submarine operating in the vicinity of the bottom. This "suction" force draws the submarine toward the bottom, and increases monotonically with both velocity and altitude. When this "suction" force is non-dimensionalized (by the velocity squared), it becomes nearly constant at each altitude, increasing monotonically (roughly quadratically) as the altitude decreases (i.e. as the submarine approaches the bottom). This suggests a simple mathematical means for quantifying this "suction" effect for submarine simulators. The test results also demonstrate only small changes in pitch moment and axial force (resistance) as altitude decreases. The slight increase in resistance near the bottom at higher speeds is consistent with an expected increase in the frictional component of resistance due to the

increased relative velocity along the bottom of the hull as the submarine moves near the bottom. A brief investigation is also made as to the effect of static pitch angle (submarine trim) on the "suction" force. The results demonstrate a general symmetry in "lift" force and pitch moment between the mid-tank results (far from the bottom) and the near-bottom results. There is little impact of the altitude on the magnitudes of the forces for the same static pitch angle. It is also noted that even one full degree up upward pitch angle is insufficient to overcome the bottom "suction" effect. It could be extrapolated that it would probably require two full degrees of upward pitch angle to overcome the bottom "suction" effect.

Torum, A., Goda, Y., Kortenhaus, A., KRIEBEL, David L., Professor, and Burcharth, H., "Wave and Current Forces," Report of Working Group, International Standards Organization, Final Report, February 2006.

The International Standards Organization (ISO) published design guidelines that can be adopted by local building codes around the world. As part of this broad effort, a working group of noted coastal engineering experts was formed to develop guideline for computing wave and current forces on marine structures. Professor Kriebel is the United States representative to this working group, having been appointed by the Structural Engineering Institute of the American Society of Civil Engineers. The working group conducted meetings in Grenada, Spain, Brussels, Belgium, Prague, Czech Republic, and Aalborg, Denmark. The final report was accepted in 2006 by the ISO

WATERS, Jennifer K., Associate Professor, "Deep-Draft Vessel Geometries," *Institute for Water Resources, U.S. Army Corps of Engineers*, Alexandria, VA, September 2005 with updates through May 2006.

In order to support testing, validation and use of the U.S. Army Corps' program CADET (Channel Analysis and Design Evaluation Tool), a variety of detailed vessel hull geometries have been collected for use with the program and associated research of channel design. A total of one hundred sixty four (164) real, presently or recently operational vessels are provided within 16 categories, ranging from barges to tankers. The vessel geometries have been provided in electronic format. Details on the file format and tips on viewing and manipulating the files, as well as tabular summaries of the vessels and previews of their geometries are included in the summary document.

Presentations at Professional Meetings and Conferences

FLACK, Karen A., Professor (Mechanical Engineering Department), and SCHULTZ, Michael P., Associate Professor, CONNELLY, Jonathan S., Ensign, USN, "Investigation of Outer Layer Similarity for Rough Wall Boundary Layers," 4th International Symposium on Turbulence and Shear Flow Phenomena (TSFP-4), Williamsburg, VA, June, 2005.

FLACK, Karen A., Professor (Mechanical Engineering Department), and SCHULTZ, Michael P., Associate Professor, SHAPIRO, Thomas A., Ensign, USN, and CONNELLY, Jonathan S., Ensign, USN, "Turbulence Results for Rough Wall Boundary Layers," John Hopkins University Mechanical Engineering Department Seminar, Baltimore, MD, February 2005.

FLACK, Karen A., Professor (Mechanical Engineering Department), SCHULTZ, Michael P., Associate Professor, and CONNELLY, Jonathan S., Ensign, USN, "Outer Layer Turbulence Similarity for Rough Wall Boundary Layers," The American Physical Society: Division of Fluid Dynamics 58th Annual Meeting, Chicago, IL, November 2005.

FREDRIKSSON, David W., Assistant Professor, "Objectives of the Open Ocean Aquaculture Engineering Workshop," Open Ocean Aquaculture Engineering Workshop, Torshavn, Faroe Islands, August 2005.

FREDRIKSSON, David W., Assistant Professor, DeCew, J.C., University of New Hampshire, Tsukrov, I., University of New Hampshire, "Development of Structural Models for Evaluating HDPE Plastic Net Pens used in Marine Aquaculture," Open Ocean Aquaculture Engineering Workshop, Torshavn, Faroe Islands, August 2005.

FREDRIKSSON, David W., Assistant Professor, KRIEBEL, David L., Professor, and WALLENDOR, Louise A., P.E., "The USNA Center for Chesapeake Bay Observation and Modeling," Presentation at the University of Maryland, Horn Point Laboratory in support of the Chesapeake Bay Observing System, Cooperative Expansion and Integration Demonstration, University of Maryland, March 2006.

FREDRIKSSON, David W., Assistant Professor, "The USNA Center for Chesapeake Bay Observation and Modeling," Presentation at the National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, May 2006.

Johnson, H., and Louca, Luke, Imperial College, and MOURING, Sarah E., Associate Professor, "Current Research into Modeling of Shock Damage to Large Scale Composite Panels," Advances in Multi-Scale Modeling of Composite Materials and Components Conference, Monterey, CA, 25-30 September 2005.

Kim, Tae-Ho, Chonnam National University, and FREDRIKSSON, David W., Assistant Professor, "Mooring Load Analysis of a Korean Designed Submersible Open Ocean Aquaculture Cage System Using the Finite Element Method," Aqua 2006, World Aquaculture Society, Florence, Italy, May 2006.

Louca, Luke, Imperial College, and MOURING, Sarah E., Associate Professor, "Impact Tests on VARTM Fabricated Woven Roving Vinyl Ester Laminates," 16th International Offshore and Polar Engineering Conference and Exhibition, Long Beach, CA, 28 May – 2 June 2006.

MILLER, Paul H., Associate Professor, "Marine Composites Engineering: The Basics," International Boatbuilders Exhibition and Conference, Miami, FL, October 2005.

MILLER, Paul H., Associate Professor, "Marine Composites Engineering: Advanced Methods," International Boatbuilders Exhibition and Conference, Miami, FL, October 2005.

MOURING, Sarah E., Associate Professor, MUCCIARDI, Anthony N., Adjunct Professor (Mechanical Engineering), and KARPOUZIAN, Gabriel N., Professor (Aerospace Engineering), "The Use of High-Resolution Acoustic Microscopy for Assessing the Integrity of Composite Structures," Thirteenth International Conference on Composites/Nano Engineering, ICCE-13, Tenerife, Spain, 31 July – 6 August 2005.

MOURING, Sarah E., Associate Professor, Louca, Luke, Imperial College, LEVIS, William R., Midshipman 1/C, USN, "Structural Response of Impact-Damaged Composite Panels," OCEANS 2005 Marine Technology Society/Institute of Electrical and Electronics Engineers (MTS/IEEE) Conference, Washington, DC, 18 – 23 September 2005.

MOURING, Sarah E., Associate Professor, "Structural Behavior of Impacted Composite Panels," National Science Foundation, Civil and Mechanical Systems Workshop, Arlington, VA, 5-8 March 2006.

MOURING, Sarah E., Associate Professor, "Introduction to Composite Materials," Lafayette College, Departments of Civil and Environmental Engineering and Mechanical Engineering, Easton, PA, 14 April 2006.

NEHRLING, Bruce C., Professor, Nick, Eleanor, and Parsons, Michael G., "Fuzzy Optimal Allocation of Spaces to Zone-Decks in General Arrangements," 2006 International Marine Design Conference (IMDC 2006), Ann Arbor, MI, 16-19 May 2006.

REED, Caleb M., Midshipman 1/C, USN, BISHOP, Bradley E., Associate Professor (Weapons and Systems and Engineering Department), and WATERS, Jennifer K., Associate Professor, "Hardware Selection and Modeling for a Small Autonomous Surface Vessel," 38th Southeastern Symposium on System Theory, Cookeville, TN, 5-7 March 2006.

REED, Caleb M., Midshipman 1/C, USN, BISHOP, Bradley E., Associate Professor (Weapons and Systems Engineering Department), and WATERS, Jennifer K., Associate Professor, "Design of an Autonomous Surface Vessel," World Maritime Technology Conference (WMTC 2006), Stream 3: Naval Engineering, London, UK, 6-10 March 2006.

SCHULTZ, Michael P., Associate Professor, "Comparison of the Hydrodynamic Performance of Fouling-Release Surfaces with Copper-Based Antifouling Coatings," Office of Naval Research Biofouling Control Workshop, Baltimore, MD, June 2005.

SCHULTZ, Michael P., Associate Professor, and FLACK, Karen A., Professor (Mechanical Engineering Department), "Comparison of Turbulence over Rough and Smooth Walls," 3rd International Workshop on Wall-Bounded Turbulent Flows, Chicago, IL, November 2005.

SCHULTZ, Michael P., Associate Professor, and FLACK, Karen A., Professor (Mechanical Engineering Department), "Rough-Wall Turbulent Boundary Layers," Office of Naval Research Turbulence Workshop, Princeton, NJ, September 2005.

SCHULTZ, Michael P., Associate Professor, FLACK Karen A., Professor (Mechanical Engineering Department), CONNELLY, Jonathan S., Ensign, USN, "Velocity-Defect Scaling for Turbulent Boundary Layers with a Range of Relative Roughness," American Physical Society: Division of Fluid Dynamics 58th Annual Meeting, Chicago, IL, November 2005.

STETTLER, Jeffrey W., Commander, USN, Hover, F.S., Massachusetts Institute of Technology, and Triantafyllou, M.S., Massachusetts Institute of Technology, "Investigating the Steady and Unsteady Maneuvering Dynamics of an Azimuthing Podded Propulsor," Annual Meeting of the Society of Naval Architects and Marine Engineers (SNAME), Houston, TX, October 2005.

VOLINO, Ralph J., Associate Professor, FLACK, Karen A., Professor (Mechanical Engineering), and SCHULTZ, Michael P., Associate Professor, "Effects of Roughness on Turbulence Spectra and Correlation Measurements," American Physical Society: Division of Fluid Dynamics 58th Annual Meeting, Chicago, IL, November 2005.

WATERS, Jennifer K., Associate Professor, "Summary of U.S. Naval Academy's Atlantic Center for the Innovative Design and Control of Small Ships Activities," NNRNE Annual Program Review, Washington, DC, 19-21 July 2005.

WATERS, Jennifer K., Associate Professor, and MAYER, Robert H., Professor, "Ocean Energy Design Projects at the U.S. Naval Academy," OCEANS 2005 Marine Technology Society/Institute of Electrical and Electronics Engineers (MTS/IEEE) Conference, Washington, DC, September 2005.