Naval Architecture and Ocean Engineering Department

Professor Robert H. Mayer
Chair

During the 2003-2004 academic year, the faculty and midshipmen associated with the two engineering disciplines encompassed by the Naval Architecture and Ocean Engineering Department pursued a variety of scholarly research and professional development activities. Within the naval architecture discipline, significant research was accomplished in the areas of ship design trends and innovations, full-bodied sailing vessels, and propeller and submarine sail configurations. Investigated efforts in ocean engineering included the hydrodynamic behavior of wave groups, mooring forces induced by passing ships, wave energy conversion and shoreline management studies, design of wave protection and port security barriers, and the design of diver re-breather and heating systems. Cross-discipline research included investigation of anti-fouling coatings, residual capacities of composite panels after blast damage, and refinements in vision-based wave sensing, high-resolution ultra sonic testing of composites, and engineering project team management training. Our midshipmen accomplished a number of independent research projects including a Trident Project investigating dynamic lift coefficients for high aspect-ratio control surfaces. These efforts were accomplished despite limited access to most of the Naval Academy's Hydrodynamic Laboratory (NAHL) facilities due to damaging effects caused by Tropical Storm Isabel in late September 2003. In part, certain research efforts were accomplished in facilities at Naval Surface Warfare Center, Carderock Division, and at Stevens Institute of Technology; the cooperative use of these facilities is greatly appreciated.

Research funds for these and other projects were made available from many sources including department operating funds and contracts and grants from the National Center for Advanced Manufacturing, the National Science Foundation (NSF); the Office of Naval Intelligence (ONI), the Office of Naval Research (ONR); the Naval Facilities Engineering Services Center (NFESC); the Naval Surface Warfare Center, Carderock Division (NSWC-CD); the U.S. Army Corps of Engineers; the U.S. Coast Guard, and RADM Guy Schaffer, USN, representing the Naval Academy's Class of 1951. The faculty and midshipmen of this department appreciate the cooperation and support provided by these sponsoring agencies and organizations.

The department's faculty and midshipmen continue to contribute to professional societies through participation in committees, publications in professional journals, and presentations at meetings and conferences, both nationally and internationally. These included manuscripts published in professional journals, several articles in conference proceedings, and presentations at numerous national and international symposia. An energized and up-to-date academic environment for both core and major courses is among the beneficial outcomes of this department's extensive and significant involvement in research.

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 120 ft and 380 ft wave/towing tanks. Results have been compared with theoretical developments that account for nonlinear effects on crest amplitudes. Work has also been concerned with investigation of wave-group statistics derived from Markov theory for wave runs and with the effects of breaking waves on group statistics. Recent work has involved a study of the effects of high frequency waves on general wave statistics of random waves. The work is continuing under the sponsorship of the Office of Naval Research.

Navigation Economic Analysis Technologies Program (NETS)

Researchers: Adjunct Assistant Professor Carolyn Q. Judge
and Associate Professor Jennifer K. Waters
Sponsor: U.S. Army Corps of Engineering, 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.

Shoreline Management Task Force of U.S.-Canada International Joint Commission on the Great Lakes

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

Professor Kriebel was appointed by the U.S. Army Corps of Engineers as one of two U.S. representatives to oversee research activities pertaining to joint U.S.-Canadian management of the Lake Ontario shorelines. The U.S.-Canada International Joint Commission on the Great Lakes regulates water levels in the Great Lakes to aid commercial navigation and hydro-power production. Proposals to increase lake levels for navigation in Lake Ontario would have adverse impacts on shoreline erosion for the Ontario and New York shorelines. Several consulting firms are undertaking a three-year study of these erosion impacts. A Shoreline Management Task Force, consisting of two U.S. representatives and two Canadian representatives, is overseeing and reviewing the work of the consultants.

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 U.S. Navy has recently been experiencing damage 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 Naval Academy's Hydromechanics Laboratory. In these tests, one ship model is moored using load cells while another ship model is towed past at various speeds and separation distances. Data is 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.

Development of Design Guidelines for Timber Wave Screens

Researcher: Professor David L. Kriebel
Sponsor: U.S. Coast Guard Civil Engineering Unit, Providence

The U.S. Coast Guard maintains numerous boat launches, piers, and floating docks that are used by small search-and-rescue vessels. A common problem is the lack of protection from wave attack. In many cases, the facilities are small and large breakwaters are not economically feasible. As a result, wave protection is provided by small low-cost vertical timber wave screens, also called wave barriers or wave fences. Research efforts at the Naval Academy include: (1) selected physical model tests on typical wave screens configurations, (2) development of a predictive model to assess wave transmission past wave screens and wave forces on wave screens, and (3) development of general design guidelines to be used by the Coast Guard in future repair or new construction of timber wave screens.

Composite Port Security Barrier Design Support

Researcher: Assistant 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. Their design consists of a series of mild steel floating units, each of which has three pontoons joined by a backbone structure. Although coated with 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 designing a retrofit package consisting of composite pontoons. Deliverables included drawings, specifications and manufacturing support.

Composite Temporary Anti-Boat Barrier System

Researcher: Assistant 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 works with NFESC and the contractors to develop the lighter composite system. Naval Academy support included wind tunnel testing, wave testing, finite element analysis and manufacturing support.

Composite Structural Integrity Assessment via High-Resolution Acoustic Microscopy

Researcher: Associate Professor Sarah E. Mouring
Sponsor: National Center for Advanced Manufacturing (NCAM)

This work consists of refining the high-resolution ultrasonic test (UT) imagery to be even more predictive of physical properties of composites. Parameters from the frequency spectrum of the UT waveforms, recorded during the imaging scan, are used to create "frequency domain" images. It is well documented that frequency domain parameters can be used to both detect and discriminate between different defect categories in composites, such as micro-cracking, delaminations, and porosity. Consequently, images can be constructed such that colored regions within the image are indicative of a particular defect class, such as micro-cracking, at those locations. The acoustic microscope, in conjunction with subsequent destructive tests, will be incorporated into physical models that will identify failure mechanisms. If successful, the UT acoustic microscope can be configured as a portable PC-based field instrument. The non-destructive evaluation (NDE), combined with the models, can be implemented in a portable field-rugged system. Preliminary results have been written in a reviewed proceedings paper and several presentations have been made. Further destructive and non-destructive testing is planned.

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. The acceptance and future growth of composite construction partially depends on the ability of the designer to predict accurately the hull performance of a ship subjected to different loading conditions. 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. However, in order to establish a simple model using composite materials, we need to use a more complex model, such as explicit finite element analyses, which 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. This will provide the necessary confidence in developing a simpler model into the existing Navy program, ULTSTR. At this time, finite element analysis has been performed along with material testing. Large-scale panel tests will be performed as soon as the test facilities are ready at the Naval Academy. Three reviewed proceedings papers, one invited proceedings paper, and several presentations have resulted from this research so far.

Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS) Model of Team Development across the Curriculum

Researcher: Associate Professor Sarah E. Mouring
Sponsor: National Science Foundation (NSF)

The Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS) Partnership is involved in engineering project team training research and includes faculty from the University of Maryland, Morgan State University, Howard University, and the U.S. Naval Academy. This partnership is developing a four-year, team-training curriculum model that can be integrated into any existing engineering curriculum. Full development of the model will include preparation of a complete undergraduate curriculum on team development topics, supportive faculty training workshops, and materials for formative and summative evaluation and research. The curriculum and supportive materials will be disseminated nationally via conferences, workshops, the BESTEAMS website and a national publication. Much of the early research includes development of the team-training curriculum at the Partnership institutions – including the Naval Academy. Four workshops were given this year throughout the country, and a faculty handbook is in preparation.

Passively Controlled Semi-Closed/Closed Re-breather Development

Researcher: Professor Marshall L. Nuckols
Sponsor: Office of Naval Research (ONR)

This is the fifth year of a 5-year research effort to develop a versatile, passively-controlled semi-closed re-breather for deep diving applications that can be switched to closed-circuit mode during shallow-water missions (depths less than 25 feet). Such a design is desired to safely satisfy the full range of Naval Special Warfare missions without the complexity and cost of electronically-controlled closed circuit re-breathers. The objectives of this effort are to optimize the design of respiratory-coupled circuit designs (using variable volume exhaust injection systems) using analytical predictive models, and verify from unmanned testing that safe alternatives to traditional semi-closed circuit designs are feasible. In so doing, we demonstrate that respiratory-coupled re-breather designs will provide divers with stable and predictable circuit oxygen levels across their full range of activity levels.

Tech Solution #TS-000108 Closed Circuit Re-breather

Researcher: Professor Marshall L. Nuckols
Sponsor: Office of Naval Research (ONR)

The objective of this one-year effort was to apply lessons learned during previous ONR-sponsored research in re-breather technology to design, fabricate and test a re-breather circuit capable of being manually switched between closed circuit mode using pure oxygen and semi-closed circuit operations. For instance, a combat swimmer can use this re-breather in a closed circuit mode with pure oxygen when a shallow, covert operation is called for, and then switch to semi-closed mode during a transit phase in which he may be at depths in excess of exposures that pure oxygen could be tolerated (oxygen partial pressures above 1.6 atmospheres). To switch from semi-closed to closed modes during the mission, the diver only needs to ascend to a depth where breathing pure oxygen can be tolerated (less than 25 feet of seawater), purge the circuit with oxygen and then activate a change-over switch to de-couple a sonic injection of fresh makeup gas. The

diver can then swim covertly in the closed-circuit mode without dumping circuit exhaust into the seawater. When it is necessary to descend to a deeper depth, during submarine entry for instance, the diver can purge the circuit again with an oxygen-rich nitrox mixture and then re-activate sonic injection of the makeup gas. The most direct solution, first proposed in the original project proposal, involves a modification of a closed-circuit, pure oxygen re-breather, such as the MK25 (LAR V) or equivalent, to allow it to be switched to semi-closed during excursions beyond 20 FSW.

Diver Heating For Combat Swimmers and Surface Supplied Divers

Researcher: Professor Marshall L. Nuckols
Sponsor: Office of Naval Research (ONR)

This was the first year of a 3-year effort funded by the Office of Naval Research to develop active diver heating systems for Swimmer Delivery Vehicles (SDVs) and surface-supplied divers using hydrogen catalytic reactions. The project also includes research in alternate storage methods for hydrogen.

Naval Forces under the Sea: The Rest of the Story

Researchers: Professor Marshall L. Nuckols and Donald Chandler
Sponsor: Office of Naval Research (ONR)

This was the second year of a two-year effort under funding from the Office of Naval Research to document the history of diving in a book to be titled Naval Forces Under the Sea: The Rest of the Story. Icons in the diving discipline were interviewed during FY03 and FY04 in this joint effort with the Undersea and Hyperbaric Medical Society prior to the publication of the book in FY04.

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

Researcher: Assistant 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. The goal of this research is to compare 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 exposure.

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

Researchers: Associate Professor Jennifer K. Waters and Professor Robert H. Mayer
(Naval Architecture and Ocean Engineering), and
Associate Professor Bradley E. Bishop and Assistant Professor Jenelle A. Piepmeier
(Weapons and Systems Engineering Department)
Sponsor: Office of Naval Research (ONR)

The U.S. Naval Academy (specifically, its principal investigators), the Stevens Institute of Technology, the University College of London and the Webb Institute are partners in the Atlantic Center for the Innovative Design and Control of

Small Ships. The partners appreciate the ONR concern that there is a deteriorating critical mass surrounding classical design centers for Naval Architecture and Marine Engineering in the U.S. 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 is addressing 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, inter-disciplinary 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, 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 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.

Comparative Analysis of Submarine Sail Configurations – Phase I

Researcher: Professor Gregory J. White
Sponsor: Office of Naval Intelligence (ONI)

The Naval Academy Hydromechanics Laboratory (NAHL) undertook a submarine model testing program for the Office of Naval Intelligence (ONI). The testing program consisted of two phases. The first phase was a systematic series of tests on a generic submarine hull to establish a baseline for further testing. This phase included establishing the forces and flow characteristics on a bare hull and a bare hull with a baseline sail configuration. The second phase of the project involved having a midshipman perform a test series of the baseline hull with two different sail configurations. The plans for the sail configurations were provided by ONI and the model sails were made by the model makers of the Technical Support Department (TSD) of the USNA Division of Engineering and Weapons. The Naval Academy Hydromechanics Laboratory set up and calibrated the Laboratory's Sub-Off submarine model for a series of unclassified resistance tests in the Naval Academy's 380 foot towing tank. Drag and lift forces were recorded for each test run. Flow visualization tests, utilizing yarn tufts, around and on the sails, were performed and recorded utilizing an underwater video camera. Unfortunately, during the early testing of the second phase, the Naval Academy was struck by the flooding from Tropical Storm Isabel in September 2003. The flooding destroyed the 380-ft. tank carriage speed control system. Project testing will resume as soon as repairs can be effected. A complete report will be presented to ONI as soon as practicable.

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*, B Vol. 270, pp. 755-763, April 2003.) Work is continuing.

Trident Scholar Projects

Determination of Dynamic Lift Coefficients for High Aspect Ratio Control Surfaces (Trident Report #325)

Researcher: Midshipman 1/C Jared R. Patton, USN
Adviser: Assistant Professor Paul H. Miller

The goal of this Trident Project was the determination of the maximum dynamic lift coefficient of high aspect ratio control surfaces to reduce the uncertainty in design. The effective design of rudders, diving planes and other control surfaces with high aspect ratios, (i.e., a larger depth in proportion to chord length,) is hindered by uncertainty in the dynamic coefficient of lift of the control surface as it passes through a transient fluid flow affected by the fluid free surface.

Data collection took place in the David Taylor Model Basin at the Naval Surface Warfare Center. Two 1/5-scale rudders were tested on a donated 15-foot vessel model. Strain gages were attached to the rudder and shaft to determine the strain distribution and overall deformation. A finite element model of the rudder and shaft correlated the measured strains to hydrodynamic pressures, which led to a determination of the resulting dynamic lift coefficients for various load cases. These were compared to computational fluid dynamics predictions of pressure plots for the same loading. Load cases included constant speed in still water, turning and response in waves. As a result of this project, engineers will have a better understanding of the peak loads on control surfaces, leading to safer and more efficient designs.

The Effect of Surface Roughness on Hydrodynamic Drag and Turbulence (Trident Report # 327)

Researcher: Midshipman 1/C Thomas A. Shapiro, USN
Advisers: Assistant Professor Michael P. Schultz
and Associate Professor Karen A. Flack (Mechanical Engineering Department)

The ability to accurately predict the drag forces on a ship before it is built would lead to more efficient designs. To do this, the effect of surface roughness on frictional drag must be well understood. The goal of this project was to identify the appropriate roughness scaling parameters for simple three-dimensional roughness with similar length scales to those found on ship hulls. In order to study and ultimately predict the effects of surface roughness on fluid flow and drag, flat plates with smooth and rough surface conditions were tested. Mesh and sandpaper were chosen as the rough surfaces because they are three dimensional, which is characteristic of naturally occurring surfaces.

The first phase of testing involved towing the plates in a tow tank to determine the overall frictional drag. These tests were done in the 115 m long tow tank located in the Naval Academy's Hydromechanics Laboratory. Detailed velocity measurements were also obtained with the plates in a re-circulating water channel located in the Hydromechanics Laboratory to determine the effect of the roughness on the turbulence near the surface. The velocity measurements were obtained with a laser Doppler velocimeter (LDV). The drag results from both sets of tests showed excellent agreement. It was also

observed that beyond a few roughness heights from the wall, the normalized turbulence was independent of the roughness. Proper scaling for the sandpaper was found to be a function of the roughness height, while the mesh surfaces were discovered to be a function of both roughness height and wire spacing. The results from this project will aid in the development of a general model of overall frictional drag from physical measures of the surface alone.

Midshipman Research Course Projects

Composite Structural Integrity Assessment via High-Resolution UT Microscopy

Researchers: Midshipman 1/C Eric D. Brege, USN and Midshipman 1/C Joseph C. Sands, USN
Advisers: Associate Professor Sarah E. Mouring,
Adjunct Professor Anthony N. Mucciardi (Mechanical Engineering Department),
and Professor Gabriel N. Karpouzian (Aerospace Engineering Department)
Sponsor: National Center for Advanced Manufacturing (NCAM)

This research, supported by the National Center for Advanced Manufacturing (NCAM), outlines the effort to develop a Non-Destructive Evaluation (NDE) / theoretical model-driven approach to predicting design life based the extent of microcracking through a composite structure. Microcracking is a phenomenon that exists when microscopic breaks occur in the matrix of a composite material, and is the primary cause of extensive loss of material properties. It can lead to delamination, debonding, and longitudinal splitting, all of which can lead to property damages such as changes in material stiffness and thermal expansion coefficient. Microcracking is caused when the energy being dissipated throughout the material exceeds the critical strain energy release rate. As part of this research, specimens were tested under varying static tensile load levels to failure in order to quantify these energies. The static tensile tests were performed at Johns Hopkins University Applied Physics Laboratory in Laurel, MD. The microcrack density of each specimen was obtained using NDE, specifically ultrasonic acoustic microscopy. NDE testing was performed at Matek Micro-Electronics in Yardley, PA. These results are being correlated to a dimensionless parameter so that it can be incorporated into the theoretical model. This theoretical model uses the shear lag approach to predict microcrack density as a function of load level. Once this prediction model is complete, a portable PC-based system can be configured in order to predict the remaining life in specific composite applications.

Wave Energy Conversion into Electrical Energy: A Linear Motion Approach using Magnets and Coils

Researcher: Midshipman 2/C Jonathan S. Connelly, USN
Adviser: Assistant Professor Michael P. Schultz

From the power output of a small PVC pipe wrapped with ten or twenty windings to a system that can be tested in the field, it is easy to grasp the concept of converting wave energy into electricity. The ocean can be viewed as a series of points. With passing waves, these points move up and down. This project takes what happens at a single point and uses this motion to move a buoy. The buoy is connected to magnets and as waves pass, the magnets pass through coils. This linear generator involves a complex balance of variables that it is difficult to simulate analytically. However, the present experimental results show promise for a practical wave energy conversion system based on similar principles.

Vision-Based Sensing of Water Waves

Researcher: Midshipman 1/C Jennifer L. Grob, USN
Advisers: Associate Professor Jennifer K. Waters
and Assistant Professor Jenelle A. Piepmeier (Weapons and Systems Engineering Department)
Sponsor: Office of Naval Research (ONR)

Vision-based water wave sensing is a technique that can be used to create a pro-active ride control system for high-speed marine vessels. This project investigated creating a vision-based wave sensing approach that will be able to determine pertinent wave characteristics, such as slope, height, and frequency. The main motivation behind this project was to create a ride control system for a vessel which will proactively adjust for the waves the vessel encounters. By

enabling the vessel to adjust for waves it has not yet encountered, the vessel's motions and seakeeping characteristics may be significantly improved, allowing it to reach higher speeds. Seakeeping is a major concern for high-speed vessels; therefore factors such as pitch, heave and accelerations need to be accounted for. In past research, systems have been mainly reactive to these factors, and now a vision-based system may allow these factors to be accounted for before the vessel reaches the wave. There have been recent tests in wave sensing for reactive systems that show the effects of heave and pitch are greatly reduced, and the ride becomes considerably smoother when the waves are accounted for. A pro-active system may theoretically reduce those factors even more effectively. The goal of this project was to study and characterize regular waves with the vision-based system. More importantly, this project focused on being able to see and analyze the water surface in a lab environment. Initial results at this point reveal promising results for future data analysis.

Comparing Submarine Sail Designs: A Qualitative and Quantitative Analysis

Researcher: Midsipman 1/C Paul D. Haagenson, USN
Adviser: Professor Gregory J. White
Sponsor: Office of Naval Intelligence (ONI)

In January of 2003, the Office of Naval Intelligence approached the Naval Academy with regards to testing two sail designs, and drawing conclusions as to their relative performance. The plan, as given in the Naval Academy Hydromechanics Laboratory (NAHL) Statement of Work to the Office of Naval Intelligence, called for two phases of testing. The first phase would consist of a series of tests on a generic submarine sail, in order to provide a baseline for determine the accuracy of the testing method and to provide a reference for the testing of unfamiliar shapes. The second phase of the project would involve conducting tests on two different sail designs, which will be referred to as Sail Design A and Sail Design B. Before the conclusion of the model test runs for Sail Design B, Tropical Storm Isabel rolled in from the Atlantic and compromised testing facilities, e.g., many key pieces of equipment, including the motors and controls for the NAHL 380 foot towing tank, were damaged. As a result, model testing in the 380 foot towing tank was suspended indefinitely. Because Sail Design B had yet to be tested, the project went from being a comparison of actual physical data to a series of hypothetical calculations. There was still a need to determine the difference in model performance characteristics between the two submarine sail shapes provided by ONI, but there was data from just two of the three sail designs originally scheduled for testing. There was not enough time in the project for developing Computational Fluid Dynamic (CFD) models of all three sails, so two more basic analytical approaches were tried. These were a Froude Type analysis and one based on data from Abbott and Von Doenhoff. Both proved to have significant weaknesses and were eventually considered inadequate for the intended purpose. It is interesting to note however, that both methods predicted that Sail Design B would be superior to Sail Design A.

Optimal Plans and Costs for Beach Re-nourishment Projects

Researcher: Midshipman 1/C Brett L. Jones, USN
Adviser: Professor Robert H. Mayer

An adaptation of the classical inventory system model of operations research is suggested for planning and scheduling beach re-nourishment projects. The costs of periodic re-nourishment are set against the economic and safety implications of the eroded beach. In situations where erosion rates are reasonably constant and re-nourishment costs reasonable to predict, optimal costs and schedules may be determined by mathematical techniques such as differential calculus. Properly formulated, the resulting models yield least-cost solutions and also reveal optimal relations between competing costs and alternative criteria such as recreational benefits and safety to backshore properties.

Surface Effect Ship Model Tests

Researcher: Midshipman 1/C Erik M. Lord, USN
Adviser: Associate Professor Jennifer K. Waters
Sponsor: Office of Naval Research (ONR)

The Surface Effect Ship (SES) is a design that has been investigated within the vessel design world since 1960. Yet, despite its versatility, the SES has been utilized very little, especially in naval applications. In general, the surface effect ship incorporates characteristics of twin-hull displacement vessels and air cushion craft. There are currently several

mission areas within the Navy in which the SES would provide a superior platform to the existing hull form - providing superb speed, stability, cargo-carrying capability, and sustainability.

This project was conducted using a nominal 1/64-scale model of a general surface-effect vessel. A matrix of tank testing, including on-hull and on-cushion assessments was conducted, with emphasis on performance areas in which little data has been collected. The three main areas in which this project focused included: (1) An investigation of the characteristics of the SES, and a general assessment of its applicability in today's U.S. Navy, (2) The establishment of the model testing capabilities for surface effect craft and the development of a testing matrix for further testing, and (3) An assessment of potential technological enhancements for surface effect craft.

Low-Speed Performance Characteristics of a Full Bodied Sailing Vessel

Researcher: Midshipman 1/C Charles E. Waltman, USN
Adviser: Professor Gregory J. White
Sponsor: Naval Academy Class of 1951

The initial goal of this project was to compare resistance data of the *HMS Inconstant* and the *USS Constitution*. The *USS Constitution* was specifically designed to defeat the 36-gunned British *HMS Perseverance* class frigate, of which the *HMS Inconstant* was one. Through resistance testing it was hoped to determine if the *USS Constitution* really was a better warship. The model testing of the *HMS Inconstant* was never completed due to the damage done to the Hydromechanics Laboratory by Tropical Storm Isabel. This forced a shift in the objectives of this project. Previous testing on the *USS Constitution* to determine where turbulent stimulators should be placed on full-bodied, slow-speed models left several questions unanswered. Without the ability to do model testing, the project focused on an analytical means of determining where turbulent stimulators should be placed to get an accurate representation of flow around the model. Several analytical methods exist to predict the growth of boundary layers. For this project the Vortex Panel method and the Thwaites-Walz integral method were used. The Vortex Panel method models uniform flow around a series of vortex sheets that are shaped to fit the hull form. The inputs for this program are half-breadths normalized with the model length. Three different waterlines were analyzed, along with the main diagonal. The Thwaites-Walz integral method applies tangential velocity vectors to a flat plate in order to create a pressure distribution and calculate boundary layer thickness and momentum values. The inputs for this program are the x/c and V/Uinf for the "upper half" of the waterline. These inputs are the positive x/c values and their corresponding V/Uinf values from the Vortex Panel Method outputs. The analytical methods were used to show the boundary layer growth and to see if it is possible to determine where the model turbulence stimulators should be placed. By comparing the analytical boundary layer to the test results from the 2001 model test data from the *USS Constitution*, the model test results for the different turbulence stimulator locations may be explained.

The Effect of Strakes on the Wake of a Circular Cylinder

Researcher: Midshipman 1/C Karin B. Wareing, USN
Adviser: Assistant Professor Michael P. Schultz

Helical strakes attached to a cylinder have the ability to limit the amount of oscillation the cylinder is subject to in a moving fluid. This, in turn, may significantly reduce structural loads. The addition of the strake limits the oscillation in both the transverse and in-plane directions by disrupting the vortex shedding process. Since the shedding cycle becomes less periodic, it becomes more difficult to come close to the natural frequency of the object and therefore limits the motion and loads on the object. This concept has been introduced in offshore platforms, such as the Genesis spar platform. Few previous studies of the alteration of the wake structure resulting from strakes are available in the literature. One study by Chyu and Rockwell found that strakes break up the spanwise coherence in a single plane of flow. However, little has been done to see the effects of the flow on the strake with regard to the shedding cycle and the resulting loads. Through the present experiments, the effects of the strakes were documented by analyzing the structure of the wake behind the cylinders.

Analysis, Design, Fabrication, and Testing of Scale Model and Full Size Composite Bladed Propellers for the Yard Patrol Craft

Researcher: Midshipman 2/C Christopher D. Wozniak, USN
Adviser: Assistant Professor Paul H. Miller
Sponsor: Naval Surface Warfare Center, Carderock Division (NSWC-CD)

This research preparatory course provided background research for a proposed Trident Project to be conducted in academic year 2005. The Navy has considered the feasibility of a composite bladed propeller, but to-date has not developed or tested any. The primary objectives of the proposed eventual Trident project are: evaluate two hub designs, perform a structural design of a Yard Patrol (YP) composite bladed propeller based on the better of the two hub designs, build and test an eight-inch scale model of the composite design, build and test a full scale YP propeller using the composite bladed technology. Time in this one-unit research project was spent learning the necessary computer programs and further researching composite materials, in preparation for the Trident Scholar project was approved for AY2005.

Professional Publications

Journal (Refereed) Manuscripts

DAWSON, Thomas H., Professor, "Stokes Correction for Nonlinearity of Wave Crests in Heavy Seas," *Journal of Waterway, Port, Coastal, and Ocean Engineering*, American Society of Civil Engineers, January/February 2004, Vol. 130, pp. 39-44.

The application of Stokes fifth-order wave theory to random deepwater waves is considered in connection with nonlinearity in crest amplitudes. The theory is shown to apply, on average, to crest amplitudes and wave heights, although differences exist for individual waves as a result of variation in wave frequency. Corrections to the Rayleigh law and associated predictions of fractions of waves exceeding crest threshold levels are shown to be in close agreement with measurements for heavy seas when significant wave height and average wave period are specified accurately.

MIKLOSOVIC, David S., Assistant Professor (Aerospace Engineering Department), SCHULTZ, Michael P., Assistant Professor, and ESQUIVEL, Christian E., Midshipman 1/C, USN, "Effects of Surface Finish on the Aerodynamic Performance of a Representative Stabilizer," *American Institute of Aeronautics and Astronautics* (*AIAA) Journal of Aircraft*, in press.

A sailboat centerboard, representative of a vertical stabilizer, was wind tunnel tested at different surface finish conditions to ascertain the effects on performance. The stabilizer model had a NACA 0009 airfoil section, an aspect ratio of 1.8, and a leading edge sweep angle of 22°. Tests were run at Reynolds numbers of $5x10^5$ and $1x10^6$, based on the mean aerodynamic chord. Surface finishes of 0.04-0.46 mils (1.0-11.6μm) RMS roughness height were generated by sanding with different grit abrasives and quantified using laser scanning techniques. The effects of the rougher surface finishes were to increase the maximum lift coefficient (20%), decrease the drag coefficient at maximum lift (51%) and increase the pitching moment coefficient (25%). The combination of the roughest surface finishes at the higher Reynolds number delayed flow separation to higher angles of attack and qualitatively changed the stall characteristics, resulting in the greatest improvements over the "smooth" surface conditions. These results indicate that polishing does not necessarily improve the performance of stabilizers, but the range of effect is outside the typical operating envelope of such control surfaces.

SCHULTZ, Michael P., Assistant Professor and FLACK, Karen A., Associate Professor (Mechanical Engineering Department), "Outer Layer Similarity in Fully Rough Turbulent Boundary Layers," *Experiments in Fluids*, in press.

Turbulent boundary layer measurements were made on a flat plate covered with uniform spheres and the same surface with the addition of a finer scale grit roughness. The measurements were carried out in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3000 to 15000, using a two-component, laser Doppler velocimeter (LDV). The results show that the mean profiles for all the surfaces collapse well in velocity defect form. Using the maximum peak to trough height (R_t) as the roughness length scale (k), the

roughness functions (ΔU^+) for both surfaces collapse, indicating that roughness texture has no effect on ΔU^+. The Reynolds stresses for the two rough surfaces also show good agreement throughout the entire boundary layer and collapse with smooth wall results outside of the roughness sublayer. Quadrant analysis and the velocity triple products show changes in the rough wall boundary layers that are confined to $y < 8k_s$, where k_s is the equivalent sand roughness height. The present results provide support for Townsend's wall similarity hypothesis for uniform three-dimensional roughness. However, departures from wall similarity may be observed for rough surfaces where $5k_s$ is large compared to the thickness of the inner layer.

SCHULTZ, Michael P., Assistant Professor, "Frictional Resistance of Antifouling Coating Systems," *American Society of Mechanical Engineering (ASME) Journal of Fluids Engineering*, in press.

An experimental study has been made to compare the frictional resistance of several ship antifouling hull coatings in the unfouled, fouled, and cleaned conditions. Hydrodynamic tests were completed in a towing tank using a flat plate test fixture towed at a Reynolds number (Re_L) range of $2.8\times10^6 - 5.5\times10^6$ based on the plate length and towing velocity. The results indicate little difference in frictional resistance coefficient (C_F) among the coatings in the unfouled condition. Significant differences were observed after 287 days of marine exposure, with the silicone antifouling coatings showing the largest increases in C_F. While several of the surfaces returned to near their unfouled resistance after cleaning, coating damage led to significant increases in C_F for other coatings. The roughness function, ΔU^+, for the unfouled coatings showed reasonable collapse to a Colebrook-type roughness function when the centerline average height ($k = 0.17R_a$) was used as the roughness length scale. Excellent collapse of the roughness function for the barnacle fouled surfaces was obtained using a new roughness length scale based on the barnacle height and percent coverage.

SCHULTZ, Michael P., Assistant Professor and FLACK, Karen A., Associate Professor (Mechanical Engineering Department), "Turbulent Boundary Layers over Surfaces Smoothed by Sanding," *American Society of Mechanical Engineering (ASME) Journal of Fluids Engineering*, Vol. 125, pp. 863-870, September 2003.

Flat plate turbulent boundary layer measurements have been made on painted surfaces, smoothed by sanding. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3,000 to 16,000, using a two-component, laser Doppler velocimeter (LDV). The mean velocity and Reynolds stress profiles are compared with those for smooth and sandgrain, rough walls. The results indicate an increase in the boundary layer thickness (δ) and the integral length scales for the unsanded, painted surface compared to a smooth wall. More significant increases in these parameters, as well as the skin-friction coefficient (C_f) were observed for the sandgrain surfaces. The sanded surfaces behave similarly to the smooth wall for these boundary layer parameters. The roughness functions (ΔU^+) for the sanded surfaces measured in this study agree within their uncertainty with previous results obtained using towing tank tests and similarity law analysis. The present results indicate that the mean profiles for all of the surfaces collapse well in velocity defect form. The Reynolds stresses also show good collapse in the overlap and outer regions of the boundary layer when normalized with the wall shear stress.

SCHULTZ, Michael P., Assistant Professor and MYERS, Alexandra, Midshipman 1/C, USN, "Comparison of Three Roughness Function Determination Methods," *Experiments in Fluids*, Vol. 35, pp. 372-379, October 2003.

Three methods have been used to experimentally determine the roughness function (ΔU^+) for several rough surfaces. These include the rotating disk, the towed plate, and the velocity profile methods. The first two are indirect methods in as much as they rely on measurements of overall torque or resistance and boundary layer similarity laws to obtain ΔU^+, whereas the velocity profile method provides a direct measurement of ΔU^+. The present results indicate good agreement between the towed plate and the velocity profile methods for all of the surfaces tested. Tests for the rotating disk were carried out at much higher unit Reynolds numbers. Using this method, the results for sandpaper rough surfaces agree within their uncertainty with a Nikuradse-type roughness function in the fully-rough regime, while a spray painted surface agrees with a Colebrook-type roughness function.

SILVERBERG, Jon P., (Trident Scholar, Class of 2003) and MILLER, Paul H., Assistant Professor, "Advanced Sailboat Performance-Based Design Methods," *Marine Technology*, in press.

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.

Conference Proceedings

FLACK, Karen A., Associate Professor (Mechanical Engineering Department), SCHULTZ, Michael P., Assistant Professor, and SHAPIRO, Thomas A., (Trident Scholar, Class of 2004), "Turbulence Structure over Two Types of Uniform Roughness," *Proceedings of the 10th EuroMech Turbulence Conference*, Trondheim, Norway, pp. 281-284, June 2004.

The rough wall boundary layer is of great engineering interest, including the applications of flow over ship hulls and airplanes, as well as fluid transport. Current engineering models treat roughness as a small perturbation to the smooth wall boundary layer. Understanding the extent of this perturbation for a variety or roughness types would improve predictive capabilities. In this investigation, comparisons of turbulent boundary layers developing over two types of rough walls and a smooth wall have been made. An increase in the physical growth of the boundary layer as well as an increase in C_f was measured for the rough surfaces. The two rough surfaces produced similar roughness functions, even for roughness heights that differed by a factor of 2. Furthermore, the profiles of the normalized Reynolds stresses for both the smooth and rough surfaces show agreement within experimental uncertainty in the overlap and outer regions of the boundary layer.

FLACK, Karen A., Associate Professor (Mechanical Engineering Department) and SCHULTZ, Michael P., Assistant Professor, "Mean and Turbulent Velocity Profiles for Sandgrain Rough Surfaces," *Proceedings of the 3rd International Symposium of Turbulence and Shear Flow Phenomena (TSFP-3)*, Sendai, Japan, pp. 129-134, June 2003.

Flat plate turbulent boundary layer measurements have been made on surfaces covered with fine and coarse sandpaper. The measurements were conducted in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3,000 to 16,000, using a two-component, laser Doppler velocimeter (LDV). The results indicate an increase in the boundary layer thickness (δ), the integral length scales, and the skin-friction coefficient (C_f) for the rough surfaces compared to the smooth wall. The roughness functions (ΔU^+) for the sandgrain surfaces agree within their uncertainty with previous results obtained using towing tank tests and similarity law analysis. For sandpaper, it appears that a single roughness length scale ($k = 0.75\ R_t$) is sufficient to characterize the physical surface. The present results indicate that the mean profiles for both the smooth and rough surfaces collapse well in velocity defect form. The Reynolds stresses also show good collapse outside the roughness sublayer when normalized with the wall shear stress.

FLACK, Karen A., Associate Professor (Mechanical Engineering Department) and SCHULTZ, Michael P., Assistant Professor, "The Extent of the Roughness Sublayer for Rough Wall Boundary Layers," *Bulletin of the American Physical Society: Division of Fluid Dynamics 56th Annual Meeting*, Vol. 48, No. 10, p. 88, November 2003.

The wall similarity hypothesis of Townsend states that the turbulence outside the roughness sublayer, a region extending 5 time the roughness height from the wall, is independent of surface condition at sufficiently high Reynolds number. While a great deal of experimental evidence exists to support Townsend's hypothesis, the

extent of the roughness sublayer is still not clear. In this investigation results from several rough wall studies are examined. The applicability of using the equivalent sandgrain roughness height as a universal measure of the sublayer is examined. The assumption of the hypothesis that the roughness is a small perturbation to the smooth wall case is also investigated and used to explain the apparent inconsistencies in turbulence structure noted over different roughness types.

GROB, Jennifer L., Midshipman 1/C, USN, WATERS, Jennifer K., Associate Professor, and PIEPMEIER, Jenelle A., Assistant Professor (Weapons and Systems Engineering Department), "Vision-Based Wave Sensing For High Speed Vessels," *Proceedings of the 36th Institute of Electrical and Electronics Engineers (IEEE) Southeastern Symposium On System Theory (SSST)*, Atlanta, GA, 14-16 March 2004. (CD-ROM)

Vision-based water wave sensing is a technique that can be used to create a pro-active ride control system for high-speed marine vessels. This project researches creating a vision-based wave sensing approach that will be able to determine pertinent wave characteristics, such as slope, height, and frequency. The main initial goal of this project is to develop a system that can acquire an image of a wave surface and accurately measure its characteristics. System equipment includes a stereo vision system from Pt. Grey Research. The stereo vision system is capable of producing point cloud images. MATLAB will be used to analyze the recorded data and compute critical information, such as local maximums and minimums, for examining wave characteristics. The goal of this project is to eventually study and characterize regular and irregular waves with the vision-based system. The tests of regular and irregular waves will determine the ultimate precision and accuracy of the camera, which will allow and further the goal of a vision-based proactive system for a high-speed vessel.

Louca, L., Imperial College, and MOURING, Sarah E., Associate Professor, "Damage Modeling of Marine Composites," *Proceedings of the Marine Applications of Composite Materials (MACM) 2004 Conference*, Melbourne, FL, pp. M1-M15, 16-18 March 2004.

Prediction of damage in composite structures is vital for assessing their tolerance to overstressing under various loading conditions. This paper presents a study of progressive damage prediction of a woven roving E-glass/vinyl ester laminated beam subjected to transverse shear. The laminate has been manufactured using the Seeman Composite Resin Infusion Moulding Process (SCRIMP). The damage modeling has been carried out using a finite element model capable of predicting the progression of damage and the residual capacity. A user subroutine has been written for this purpose and has been incorporated into an existing finite element package. Various failure criteria and modelling techniques using both shell and solid elements have been investigated. The effects of discretising the woven roving layers to unidirectional layers to model matrix cracking are reported. Delamination also has been incorporated in the models using resin rich layers between the plies which improved the correlation with the test data.

MAYER, Robert H., Professor, and WATERS, Jennifer K., Associate Professor, "Development and Success of a Multidisciplinary Curriculum in Ocean Environmental Engineering," *Proceedings of the Marine Environmental Engineering Technology Conference*, Washington, DC, August 2003. (CD-ROM)

This paper describes a new area of concentration within the ocean engineering major at the U.S. Naval Academy. Ocean environmental engineering, as the new curriculum is known, is defined as the application of engineering and management principles to the conservation of the marine environment and the sustainability of its natural resources. The essence of this curriculum is found in two fundamental courses within the major that are complimented by multi-disciplinary opportunities in other majors. The first fundamental course, Ocean Environmental Engineering, focuses on marine pollution: its principal causes, effects, and its remediation. The second, Ocean Resources Engineering, emphasizes methods for ocean resource assessment, recovery and appropriate utilization. Both courses have been successful in attracting students from a variety of engineering majors, and student assessments reflect a growing awareness and interest in marine environmental issues. Primary factors contributing to the success of this new curriculum are discussed in depth in the paper. One key factor is the broad scope of marine environmental engineering and management topics that finds appeal among various student interests. Diversified case studies, usually drawn from current events, are introduced in the fundamental courses to keep curriculum

focus both meaningful and timely. Another key factor is the inclusion of small group research and design projects that allow students to investigate areas of particular interest in depth, while also strengthening collaborative skills. Such efforts have included the investigation of tanker accidents and oil spills, the beneficial disposal of dredge materials, and the restoration of wetland and coral reef habitats. Educational opportunities in ocean environmental engineering are also available in the capstone design courses required of all engineering majors, and elective courses in such disciplines as environmental economics, environmental oceanography, environmental security, and marine environmental engineering. Details of selected capstone design projects and topical coverage of marine environment-related elective courses are also presented in the paper.

MILLER, Paul H., Professor, "Design, Verification, and Forensic Correlation of Composite Yacht Structures," *Proceedings of the Advanced Marine Materials Conference*, Royal Institute of Naval Architects, London, UK, pp. 121-127, 9-10 October 2003.

High performance marine composite structures are common in many competitive arenas. This paper highlights the lessons learned through analysis, testing and post-failure review of some of the composite structures used by Team Dennis Conner during the 2003 America's Cup. Materials were almost exclusively carbon fibre/epoxy prepreg laminates cured at elevated temperature and pressure. Specific research topics included resin/fibre content, full-scale testing of portions of the deck and rig and forensic analysis of the rig and hull. A side note includes a discussion of another post-accident structural analysis. The primary structural analysis tool was finite element analysis, which was seen to be reliable. Computational fluid dynamics combined with historical on-board data were used to generate many structural loads.

MOURING, Sarah E., Associate Professor, "Investigation into Residual Strength of Shock Damaged Composite Panels," *Proceedings of the National Science Foundation (NSF) Civil and Mechanical Systems 2003 Workshop 2003*, Arlington, VA, 22-24 September 2003. (CD-ROM)

Composite materials are being used more often for naval applications due to their high strength-to-weight ratios and stealth characteristics. However a primary design concern to the U.S. Navy is the effect of a shock load. In order to establish the damage tolerance of the structure, the residual strength and stiffness characteristics need to be determined after the structure has been subjected to the shock load. However this is difficult to accomplish, since there is little data documenting the effects of a pressure load caused by an explosion on a composite structure. This paper outlines an ongoing research project to investigate the residual strength and stiffness characteristics of composite panels subjected to varying levels of both static and impulsive loading. Results from short beam shear (SBS) testing used to establish the repeatability of the manufacturing process are discussed. A numerical simulation of the test also has been attempted in order to determine the accuracy of a damage model in predicting residual strength.

MOURING, Sarah E., Associate Professor and Louca, L., Imperial College, "Damage Prediction in Composite Structures," *Proceedings of the Royal Institute of Naval Architects (RINA) 2003 Conference on Advanced Marine Materials: Technology and Applications*, London, UK, pp. 129-134, 9-10 October 2003.

Composite panels are being used in increasing quantities for naval applications due to their high strength to weight ratio and stealth characteristics. However a primary design consideration for naval vessels is the effects of an impulsive load due to a shock loading. Key to the design process is to establish the damage tolerance of the structure involved which entails determining the residual strength and stiffness characteristics after the structure has been subjected to the impulsive load. However, little data exists for the effects of a pressure load on composites caused by a shock loading. In particular, the residual strength and stiffness of such components, which will influence the structural integrity of a naval vessel once they have been damaged by the shock, have received little attention for marine composites. This paper outlines an ongoing research project to investigate the residual strength and stiffness characteristics of a typical composite panel under various levels of both static and impulsive loading.

MOURING, Sarah E., Associate Professor and Louca, L., Imperial College, "Damage Prediction in Composite Structures," *Proceedings of the Society for the Advancement of Material and Process Engineering (SAMPE) 2004 Technical Conference*, Long Beach, CA, 17-20 May 2004. (CD-ROM)

Damage prediction in marine structures is extremely important in the assessment of tolerance due to overstressing in the harsh marine environment. There have been many successful damage models developed for steel structures; however, the development of damage models for composite structures lags behind. This paper presents a study of the prediction of progressive damage in a fiber reinforced composite beam subjected to transverse shear loading. The beams were manufactured from a glass woven roving using a novel vacuum assisted resin transfer molding technique. Several finite element models have been developed to model the progression of damage and the residual capacity of the beam. Both shell and solid elements have been investigated along with numerous failure criteria and validated against the experimental data.

MOURING, Sarah E., Associate Professor, MUCCIARDI, Anthony N., Adjunct Professor (Mechanical Engineering Department), and KARPOUZIAN, Gabriel N., Professor (Aerospace Engineering Department), "Composite Structural Integrity Assessment via High-Resolution Acoustic Microscopy," *Proceedings of the Society for the Advancement of Material and Process Engineering (SAMPE) 2004 Technical Conference*, Long Beach, CA, 17-20 May 2004. (CD-ROM)

This NCAM-supported research outlines the ongoing effort to develop a Non-Destructive Evaluation (NDE)/theoretical model-driven approach to determine the extent of microcracking and the prediction of the remaining life of advanced composites used in the space environment. This involves refining high-resolution ultrasonic (UT) images to be even more predictive of physical properties of the composites. Parameters from the frequency spectrum of the UT waveforms, recorded during the imaging scan, are used to create frequency domain images. It is well documented that frequency domain parameters can be used to both detect and discriminate between different defect categories in composites, such as microcracking, delaminations, and porosity. Consequently, images are constructed such that colored regions within the image are indicative of a particular defect class, such as microcracking, at those locations. The large database of the NDE observations is 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 is adopted as the failure criterion for laminates. In the future if successful, the UT acoustic microscope can be configured as a portable PC-based field instrument. So, the NDE, combined with the models, can both be implemented in a portable field-rugged system.

MOURING, Sarah E., Associate Professor, Louca, L., Imperial College, Boh, J., Imperial College, and Choo, Y., National University of Singapore, "Prediction of Progressive Damage in Composite Laminates," *Proceedings of the 14th International Offshore and Polar Engineering Conference*, Toulon, France, 23-28 May 2004. (CD-ROM)

This paper presents a study on the progressive damage prediction of a woven roving E-glass/vinyl ester laminated beam subjected to transverse shear. The laminated beam has been manufactured using the Seeman Composite Resin Infusion Molding Process (SCRIMP). The damage modeling has been performed using a finite element model capable of predicting the progression of damage and the residual capacity. A user subroutine has been written for this purpose and has been incorporated into an existing finite element package. Various failure criteria and modeling techniques using layerwise shell elements have been investigated. Experimental results are used for the validation of the proposed model.

SCHULTZ, Michael P., Assistant Professor and FLACK, Karen A., Associate Professor (Mechanical Engineering Department), "The Effect of a Secondary Roughness Length Scale on Fully Rough Turbulent Boundary Layers," *Bulletin of the American Physical Society: Division of Fluid Dynamics 56th Annual Meeting*, Vol. 48, No. 10, p. 87, November 2003.

Turbulent boundary layer measurements were made on a flat plate covered with uniform spheres and the same surface with the addition of a finer scale grit roughness. The measurements were carried out in a closed return water tunnel, over a momentum thickness Reynolds number (Re_θ) range of 3000 to 15000, using a two-component, laser Doppler velocimeter (LDV). The results show that the mean profiles for all the surfaces collapse well in velocity defect form. Using the maximum peak to trough height (R_t) as the roughness length scale (k), the roughness functions (ΔU^+) for both surfaces collapse, indicating that roughness texture has no effect on ΔU^+. The Reynolds stresses for the two rough surfaces also show good agreement throughout the entire boundary layer and

collapse with smooth wall results outside of the roughness sublayer. Quadrant analysis and the velocity triple products show changes in the rough wall boundary layers that are confined to $y < 8k_s$, where k_s is the equivalent sand roughness height. The present results provide support for Townsend's wall similarity hypothesis for uniform three-dimensional roughness. However, departures from wall similarity may be observed for rough surfaces where $5k_s$ is large compared to the thickness of the inner layer.

Smith, W.G. and KRIEBEL, David L., Professor, "Design of Timber Wave Screens," *Proceedings of Ports '04 Conference*, American Society of Civil Engineers, May 2004. (CD-ROM)

A common structural element found in several of the 1st Coast Guard District's waterfront facilities is a timber bulkhead or wave screen designed to block incoming waves and provide a calm mooring basin. Existing literature on timber wave screens address full-depth permeable, and partial-depth impermeable barriers, but there is no guidance on designing partial-depth permeable wave screens. Furthermore, the existing methods for determining wave forces and transmission coefficients for these wave screens are either computationally cumbersome (requiring the use of computer programs) or have not been validated against a sufficient range of environmental conditions. The U.S. Coast Guard has partnered with the U.S. Naval Academy to develop a comprehensive, empirical methodology similar to that found in the U.S. Army Corps of Engineers new Coastal Engineering Manual to assist engineers in designing repairs/replacement of timber wave-screens. New laboratory wave-tank experiments on scale-model wave screens were conducted during June-July 2003 at the U.S. Naval Academy. The data augment a larger set of existing wave tank test data previously obtained, and an analysis of all the data have been used to develop a design methodology that covers permeable and impermeable wave screens that extend to full depth or partial depth.

Technical Reports

JUDGE, Carolyn Q., Adjunct Assistant Professor, and WATERS, Jennifer K., Associate Professor, "A Review of Maritime Container Box Physical, Economic and Life-Cycle Statistics," U.S. Naval Academy Engineering and Weapons Report EW-02-04; Institute for Water Resources, Navigation and Water Resources Application Division.

This report summarizes the information gathered from shipping companies and container leasing companies regarding physical, economic and life-cycle properties of maritime container boxes. A synopsis of the information received from each company contacted along with relevant contact information is provided. The container box property data obtained were collected and analyzed; the resulting averages pf the properties investigated are discussed. A summary of relevant sections of the *Containerisation International Market Analysis: World Container Census 2003* report is also provided in this report and compared to the data obtained and analyzed independently where applicable. The data collected were found to be in general agreement with the published data.

JUDGE, Carolyn Q., Adjunct Assistant Professor, and WATERS, Jennifer K., Associate Professor, "An Analysis of Vessel Loading and Stability Software," U. S. Naval Academy Engineering and Weapons Report EW-03-04; Institute for Water Resources, Navigation and Water Resources Application Division.

A research effort investigating the impacts of vessel loading on performance in navigation channels is currently underway at USNA in support of the Institute for Water Resources (IWR) Navigation and Water Resources Application Division (CEIWR-NA) Deep-Draft Navigation Applications – Navigation Economic Analysis Technologies (NETS) program. To this end, it was desired to utilize commercial off-the-shelf software to investigate different loading scenarios. A preliminary study and analysis of available off-the-shelf marine vessel loading software was conducted. This report summarizes the contacts made and information gathered from software companies about onboard stability analysis programs for containerships. Information about the features of each software package, opinions on the different demo programs, and price and contact information are provided.

NUCKOLS, Marshall L., Professor and Adams, T. W., "Tech Solution Project: Closed Circuit Re-breather," Final Report, TechSolutions Project TS#000108, Office of Naval Research, March 2004.

The desired combat swimmer lockout depth from submarines is generally deeper than can be supported with closed-circuit, pure oxygen re-breathers such as the Drager LAR V (MK 25). Although the U.S. Navy MK 16 mixed-gas closed-circuit re-breather could support the depths required for submarine operations, its size and complexity make its use unpopular (reference CAPT Frank Butler email dated 3 June 1999). However, a passively-controlled semi-closed re-breather, which can be switched to closed-circuit mode, could satisfy the full range of these missions without the complexity and cost of the MK 16. While all re-breathers offer a provision for longer bottom times when compared to open-circuit SCUBA, they each have their own inherent dangers. Semi-closed circuit re-breathers re-circulate a mixture of nitrogen and oxygen (nitrox), or helium and oxygen (heliox) for deeper applications, by way of a breathing loop consisting of a counter-lung (breathing bags or bellows), hoses, a carbon dioxide scrubber, and a mouthpiece equipped with a closure mechanism to exclude water when the diver does not have the mouthpiece in the mouth. A small volume of fresh, oxygen-rich supply gas is injected into the breathing loop to compensate for the oxygen that the diver consumes during each pass of this re-circulated gas through the diver's lungs, thereby maintaining an acceptable partial pressure of oxygen in the re-circulating gas stream. A corresponding volume of circuit gas is exhausted from the breathing loop to maintain a near-constant circuit volume. This mixed-gas system increases the depth capability beyond that obtainable for closed circuit, pure oxygen rigs but is still more conservative of gas supplies than open-circuit SCUBA. Over the past two years, an ONR 321OE-sponsored project has investigated a number of respiration-coupled semi-closed re-breather designs, switchable to pure oxygen at shallow depths, that give the diver a predictable oxygen level in his breathing circuit, and minimize any decompression obligations over a wide range of depths, surface to 190 feet of seawater. In unmanned testing with laboratory prototypes, this approach has been shown to give the diver control over his oxygen partial pressure within a very narrow range, without the necessity for expensive, and complex, oxygen monitoring and control systems necessary in mixed-gas, closed-circuit re-breathers. An additional important feature with this design approach is the diver has the option to switch this semi-closed re-breather to a closed circuit mode, in water, during different phases of the dive mission. For instance, a combat swimmer can use this re-breather in a closed circuit mode with pure oxygen when a shallow, covert operation is called for, and then switch to semi-closed mode during a transit phase in which he may be at depths in excess of exposures that pure oxygen could be tolerated (oxygen partial pressures above 1.6 atmospheres). To switch from semi-closed to closed modes during the mission, the diver only needs to ascend to a depth where breathing pure oxygen can be tolerated (less than 25 feet of seawater), purge the circuit with oxygen and then activate a change-over switch to de-couple the mechanical linkage between the counter-lung and exhaust valve. The diver can then swim covertly in the closed-circuit mode without dumping circuit exhaust into the seawater. When it is necessary to descend to a deeper depth, during submarine entry for instance, the diver can purge the circuit again with an oxygen-rich nitrox mixture and then re-activate the mechanical coupling between the counter-lung and the exhaust valve.

Torum, A., Goda, Y., Kortenhaus, A., KRIEBEL, David L., Professor, and Burcharth, H., "Wave and Current Forces," Report of Working Group, International Standards Organization, March 2004.

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 2002-2004 in Grenada, Spain, Brussels, Belgium, Prague, Czech Republic, and Aalborg, Denmark. A draft committee report was prepared in 2004 and is being reviewed by the ISO.

Presentations at Professional Meetings and Conferences

BARTON, Oscar, Jr., Associate Professor (Mechanical Engineering Department), and MILLER, Paul H., Assistant Professor, "Composite Structural Mechanics at the United States Naval Academy," American Society for Engineering Education Annual Meeting, Nashville, TN, 23-25 June 2003.

FLACK, Karen A., Associate Professor (Mechanical Engineering Department) and SCHULTZ, Michael P., Assistant Professor, "Mean and Turbulent Velocity Profiles for Sandgrain Rough Surfaces," 3rd International Symposium of Turbulence and Shear Flow Phenomena (TSFP-3), Sendai, Japan, June 2003.

FLACK, Karen A., Associate Professor (Mechanical Engineering Department) and SCHULTZ, Michael P., Assistant Professor, "The Extent of the Roughness Sublayer for Rough Wall Boundary Layers," American Physical Society: Division of Fluid Dynamics 56th Annual Meeting, East Rutherford, NJ, November 2003.

GROB, Jennifer L., Midshipman 1/C, USN, WATERS, Jennifer K., Associate Professor, and PIEPMEIER, Jenelle A., Assistant Professor (Weapons and Systems Engineering Department), "Vision-Based Wave Sensing For High Speed Vessels," 36th Institute of Electrical and Electronics Engineers (IEEE) Southeastern Symposium On System Theory (SSST), Atlanta, GA, 14-16 March 2004.

JUDGE, Carolyn Q., Adjunct Assistant Professor, and WATERS, Jennifer K., Associate Professor, "Estimation of Vessel Loading and Other Research Activities Presently Underway in Support of IWR NETS," U.S. Army Corps of Engineers (USACE) Economic and Environmental Analysis Conference, Baltimore, MD, 13-15 April 2004.

JUDGE, Carolyn Q., Adjunct Assistant Professor, and WATERS, Jennifer K., Associate Professor, "Research into Relationships Applicable to Estimation of Vessel Loading and Transit Draft Estimation for Navigation Studies," U.S. Army Corps of Engineers (USACE) Economic and Environmental Analysis Conference, Baltimore, MD, 13-15 April 2004.

KRIEBEL, David L., Professor, "Probabilistic Performance of Beach Nourishment Projects," Coastal Engineering Today Conference, Gainesville, FL, 9 October 2003.

KRIEBEL, David L., Professor, "A Unified Description of Ship-Generated Waves," Permanent International Association of Navigation Congresses (PIANC) Workshop on Vessel Effects, Portland, OR, 29 October 2003.

Louca, L., Imperial College, and MOURING, Sarah E., Associate Professor, "Damage Modeling of Marine Composites," Marine Applications of Composite Materials (MACM) 2004 Conference, Melbourne, FL, 16-18 March 2004.

MAYER, Robert H., Professor, "Office of Naval Research NNR Project – U.S. Naval Academy Team Update" 2nd ACCeSS Meeting, London, England, 16 June 2003.

MAYER, Robert H., Professor, "Project Management Opportunities in an Ocean and Marine Engineering Curriculum," American Society for Engineering Education 2003 Annual Conference, Nashville, TN, 23 June 2003.

MAYER, Robert H., Professor, and WATERS, Jennifer K., Associate Professor, "Development and Success of a Multidisciplinary Curriculum in Ocean Environmental Engineering," Marine Environmental Engineering Technology Conference, Washington, DC, 21 August 2003.

MILLER, Paul H., Assistant Professor, "Forensic Correlation of Composite Yacht Structures," Society for the Advancement of Material and Process Engineering (SAMPE) Conference, Long Beach, CA, 18 May 2004.

MILLER, Paul H., Assistant Professor, "Design, Verification, and Forensic Correlation of Composite Yacht Structures," Advanced Marine Materials Conference, Royal Institute of Naval Architects, London, UK, 9-10 October 2003.

MILLER, Paul H., Assistant Professor, "Project-Based Coursework in a Naval Architecture Curriculum," American Society for Engineering Education Annual Meeting, Nashville, TN, 23-25 June 2003.

MOURING, Sarah E., Associate Professor, "Investigation into Residual Strength of Shock Damaged Composite Panels," National Science Foundation (NSF) Civil and Mechanical Systems Workshop 2003, Arlington, VA, 22-24 September 2003.

MOURING, Sarah E., Associate Professor, and Louca, L., Imperial College, "Damage Prediction in Composite Structures," Royal Institute of Naval Architects (RINA) 2003 Conference on Advanced Marine Materials: Technology and Applications, London, UK, 9-10 October 2003.

MOURING, Sarah E., Associate Professor, "Evaluation and Analysis of Advanced Composites using Non-Destructive Methods," National Center for Advanced Manufacturing (NCAM) Review, Huntsville, AL, 30 October 2003.

MOURING, Sarah E., Associate Professor, and Louca, L., Imperial College, "Damage Prediction in Composite Structures," Society for the Advancement of Material and Process Engineering (SAMPE) 2004 Technical Conference, Long Beach, CA, 17-20 May 2004.

MOURING, Sarah E., Associate Professor, MUCCIARDI, Anthony N., Adjunct Professor (Mechanical Engineering Department), and KARPOUZIAN, Gabriel N., Professor (Aerospace Engineering Department), "Composite Structural Integrity Assessment via High-Resolution Acoustic Microscopy," Society for the Advancement of Material and Process Engineering (SAMPE) 2004 Technical Conference, Long Beach, CA, 17-20 May 2004.

MOURING, Sarah E., Associate Professor, Louca, L., Imperial College, BOH, J., Imperial College, and Choo, Y., National University of Singapore, "Prediction of Progressive Damage in Composite Laminates," 14th International Offshore and Polar Engineering Conference, Toulon, France, 23-28 May 2004.

NUCKOLS, Marshall L., Professor, "Diver Heating For Combat Swimmers and Surface Supplied Divers," PMS/NSW and NAVSPECWARCOM NSW Technical Review, Panama City, FL, June 2004.

NUCKOLS, Marshall L., Professor, "Passively Controlled Semi-Closed/Closed Re-breather Development," PMS/NSW and NAVSPECWARCOM NSW Technical Review, Panama City, FL, June 2004.

NUCKOLS, Marshall L., Professor, "Development of Composite Cold Water Diving Garment Using a Combination of Liquids and Super-Insulation Aerogel Materials," PMS/NSW and NAVSPECWARCOM NSW Technical Review, Panama City, FL, June 2004.

Schmidt, L., Schmidt, J., Bigio, D., Lent, R., University of Maryland, MOURING, Sarah E., Associate Professor, Wilkens, G., Morgan State University, and Gloster, C., Howard University, "Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS) Intermediate Module Training," 2003 American Society for Engineering Education (ASEE) Annual Conference, Nashville, TN, 22-25 June 2003.

Schmidt, L., Schmidt, J., Bigio, D., Lent, R., University of Maryland, MOURING, Sarah E., Associate Professor, Wilkens, G., Morgan State University, and Gloster, C., Howard University, "Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS) Module Training for ENES 100," College Park, MD, August 2003.

Schmidt, L., Schmidt, J., Bigio, D., Lent, R., University of Maryland, MOURING, Sarah E., Associate Professor, Wilkens, G., Morgan State University, and Gloster, C., Howard University, "Building Engineering Student Team Effectiveness and Management Systems (BESTEAMS) Training Workshop: Training Undergraduates in Team Skills,"2003 American Society for Engineering Education (ASEE) Mid-Atlantic Regional Conference, Baltimore, MD, 24-25 October 2003.

Schmidt, L., Schmidt, J., Bigio, D., Lent, R., University of Maryland, MOURING, Sarah E., Associate Professor, Wilkens, G., Morgan State University, and Gloster, C., Howard University, "Training Undergraduates in Team Skills," National Collegiate Inventors and Innovators Alliance (NCIIA) Conference, San Jose, CA, 18-20 March 2004.

SCHULTZ, Michael P., Assistant Professor, "Comparison of the Hydrodynamic Performance of Fouling-Release Surfaces with Copper-Based Antifouling Coatings," Office of Naval Research (ONR) Biofouling Control Workshop, Baltimore, MD, July 2003.

SCHULTZ, Michael P., Assistant Professor and FLACK, Karen A., Associate Professor (Mechanical Engineering Department), "The Effect of a Secondary Roughness Length Scale on Fully Rough Turbulent Boundary Layers," American Physical Society: Division of Fluid Dynamics 56th Annual Meeting, East Rutherford, NJ, November 2003.

SCHULTZ, Michael P., Assistant Professor, "The Effect of Roughness on Turbulent Boundary Layers," Office of Naval Research (ONR) Turbulence Program Officer Brief, Annapolis, MD, May 2004.

WATERS, Jennifer K., Associate Professor, "Update of Student Projects at the Naval Academy," 2nd Meeting of the Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS), University College of London, London, UK, 15-19 June 2003.

WATERS, Jennifer K., Associate Professor, "Mooring Analysis Methods with Application to Actual Breakaways Caused by Passing Vessels," U.S. Section Permanent International Association of Navigation Congresses (PIANC) Annual Meeting, Portland, OR, 28-30 October, 2003.

WATERS, Jennifer K., Associate Professor, "Overview of the Naval Academy's ACCeSS Activities and Research," 3rd Meeting of the Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS), United States Naval Academy, Annapolis, MD, 5-7 November 2003.

WATERS, Jennifer K., Associate Professor, "United States Naval Academy's Naval Architecture & Warship Design Program," Office of Naval Research (ONR) International Workshop *Teaching Future Warship Designers*, University College London, UK, 17-19 May 2004.

WATERS, Jennifer K., Associate Professor, "Overview of the Naval Academy's ACCeSS Activities and Research," 4th Meeting of the Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS), University College London, UK, 24-26 May 2004.

WATERS, Jennifer K., Associate Professor, "Atlantic Center for the Innovative Design and Control of Small Ships (ACCeSS)," National Naval Responsibility in Naval Engineering (NNR-NE) Technical Review and Collaboration Meeting, St. Louis, MO, 2-4 June 2004.

WATERS, Jennifer K., Associate Professor, "ACCeSS Automation and Control Research," National Naval Responsibility in Naval Engineering (NNR-NE) Technical Review and Collaboration Meeting, St. Louis, MO, 2-4 June 2004.