Hydromechanics Laboratory

Professor Gregory J. White
Director

The Naval Academy Hydromechanics Laboratory (NAHL) is a unique facility among universities in the United States. Operated by the Naval Architecture and Ocean Engineering Department, it has served the needs of the midshipmen, faculty, and the Navy for more than 26 years. The facility supports midshipmen courses and research, faculty research, and special projects for the U.S. Navy and U. S. Coast Guard in the areas of naval architecture and ocean engineering. What makes the NAHL unique is the combination of testing facilities available for student and faculty use. A large towing tank (380-ft x 26-ft x 16-ft) and a small towing tank (120-ft x 8-ft x 5-ft), both fitted with wave-makers, provide a wide range of capabilities including opportunities to evaluate scaling effects. The other major facilities in the NAHL include a coastal engineering wave basin (52-ft x 44-ft x 2-ft), a small wave tank with a sand beach (39-ft x 4-ft x 2-ft), a circulating water channel (16-in x 16-in test section), and a stability and ballasting tank.

The laboratory facilities are used on a weekly-basis by midshipmen in the Naval Architecture and Ocean Engineering majors, and are used each semester by midshipmen in Mechanical Engineering, Electrical Engineering, and Oceanography majors. In addition, more than 600 midshipmen use the facility for a number of laboratory classes each year as part of EN200, a core-engineering course taken by all midshipmen in non-engineering majors. As a result, nearly all midshipmen use the NAHL facilities at some point during their education at the Naval Academy.

In addition to classroom support, the NAHL facilities are used by midshipmen, faculty, and NAHL staff for both fundamental and applied research. During the past year, research programs conducted in the laboratory have included:

- Comparison of Three Methods for the Determination of the Hydrodynamic Roughness Function
- Study of the Hydrodynamic Drag on Bushnell's "*Turtle*"
- Scale Model Testing of Bushnell's "*Turtle*"
- Full-Scale Testing of a Recreation of Bushnell's "*Turtle*"
- A Hydrodynamic Study of Artificial Reefs: Fish Havens
- Resistance, Seakeeping, and Wake Survey Testing of the 2200 LT MCM (XH)
- Planar Motion Mechanism (PMM) testing in support of Permanent Military Professor (PMP)-designate Navy Commander Jeffrey W. Stettler's Massachusetts Institute of Technology (MIT) doctoral dissertation
- The Effect of Surface Roughness on Turbulent Boundary Layer Structure
- Hydrodynamic Performance of Ship Hull Coatings
- Experimental Study of Turbulence Stimulation on Full-Body Hull Forms
- Model tests of the new Naval Academy Sail Training Sloop
- Model tests of the Naval Academy's Ludders 44 Yawl
- Deep Water Ocean Non-Linear Wave Statistics
- Design and construction of towing carriage designed for small model testing

- Preparation for model testing the *HMS Inconstant*
- Cooperative research by the Webb Institute and the U.S. Naval Academy: Comparison of Ship Resistance Predictions Using Small Models
- Effects of displacement and longitudinal center of gravity variations on the performance of the Naval Academy's Solar Splash boat competition project
- Shallow Water Ship Trim and Squat
- Timber Wave Barrier

The Hydromechanics Laboratory is operated and maintained by a multi-talented staff, which includes three engineers/naval architects, two engineering technicians, and an office manager/secretary. Supporting laboratory efforts are the shop and model-making facilities in the Technical Support Department. The laboratory is further supported by a Memorandum of Understanding (MOU) with the Naval Station-Annapolis, providing support of diving operations in the laboratory.

The results of laboratory research efforts are reflected in journal articles written by faculty and laboratory staff members and in presentations at technical symposia. The Laboratory is actively represented in the International Towing Tank Conference (ITTC) and staff members are active participants in the Society of Naval Architects and Marine Engineers (SNAME), the American Society of Naval Engineers (ASNE), the Chesapeake Sailing Yacht Symposium (CSYS), the American Towing Tank Conference (ATTC), and the Coasts, Oceans, Ports and Rivers Institute (COPRI) of the American Society of Civil Engineers (ASCE). The diverse interests of these organizations reflect the broad nature of the Hydromechanics Laboratory's activities.

Sponsored Research

Ship Generated Waves

Researcher: Professor David L. Kriebel and Dr. Carolyn Q. Judge (Post-Doctoral Fellow)
Sponsor: Naval Facilities Engineering Service Center (NFESC)

The Naval Facilities Engineering Service Center (NFESC) has initiated an investigation of ship-generated waves, with the goal of developing engineering design guidance for predicting the characteristics of these waves as a function of ship hull geometry, ship speed, water depth, and distance from the passing ship sailing line. While ship-generated waves in deep water are understood fairly well, ship-generated waves in shallow water are not well understood. As a result, model tests were carried out in the Naval Academy Hydromechanics Laboratory in shallow water conditions where the ship draft is 50 to 90 percent of the water depth. Based on these data, coupled with data obtained from the literature, a new empirical method of predicting ship squat, trim, and ship-generated waves was developed. The key element of this approach is a modified definition of the Froude number that incorporates the water depth and ship draft.

Mooring Forces Induced by Passing Ships

Researchers: Professor David L. Kriebel, P.E. and Ms. Louise A. Wallendorf, Ocean Engineer, P.E.
Sponsor: Naval Facilities Engineering Services 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 Service Center.

Development of Design Guidelines for Timber Wave Screens

Researcher: Professor David L. Kriebel, P.E.
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.

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. This research effort 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 exposure.

The Effect of Surface Roughness on Turbulent Boundary Layer Structure

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

Turbulent boundary layers over rough surfaces occur in a wide range of flows. These include boundary layers on ships, in turbomachinery, in pipes, and on air and spacecraft. Meteorologists also wish to understand and predict the effect that roughness, such as terrestrial topography and vegetation, has on the atmospheric boundary layer for weather prediction. Recently, it has been pointed out that very smooth surfaces may exhibit significant roughness effects at high unit Reynolds number. For these reasons, a great deal of effort has made to quantify the effect of surface roughness on boundary layer structure. However, rough wall flows are much more poorly understood than flows over smooth walls. Townsend's wall similarity hypothesis states that the turbulence outside of the roughness sublayer, a layer extending out approximately five roughness heights from the wall, is independent of the surface condition at sufficiently high Reynolds number. However, some recent research casts doubt on the wall similarity hypothesis stating that roughness effects can be observed well into the outer layer. The repercussion of these results is that interaction of the inner and outer regions of the boundary layer may be more important than previously thought. They also imply that classical mixing length approaches to modeling the Reynolds shear stress in the outer region of rough wall boundary layers may not be appropriate. The purpose of the present study is to document and compare the mean velocity, Reynolds stress, and higher order velocity moment profiles over rough and smooth surfaces. From these results, it is hoped that the applicability of Townsend's wall similarity hypothesis can be evaluated, and the existence of a suitable roughness scaling parameter related to the surface topography of generic rough surfaces can be found. Both goals are important to properly model and predict turbulent flows over rough surfaces.

Resistance, Seakeeping, and Wake Survey Testing of the 2200 LT MCM (XH) HYSWAS Hull Form

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

Maryland Applied Physics Corporation (MAPC) has developed a unique hull-form for a new mine counter-measures ship with a very high-speed capability. This hull form is a modified version of the one tested by the Naval Academy's Hydromechanics Laboratory (NAHL) in May 2001. The modifications allow the ship to operate in shallower waters while still retaining the high-speed capability. The modifications included a decrease of the hullborne draft, reshaping the underwater hull, and a redesign of the underside of the cross-deck structure.

Three model test series have been performed to provide MAPC with foilborne powering and wake information, and wave loading information when foilborne at high speeds. This information will facilitate the design of the propeller for the ship and provide some information to help evaluate the foilborne seakeeping performance of the ship. For the Effective Horsepower (EHP) Test and Wave Loading Test the model was configured without foils. The foil resistance was calculated separately and added to the measured resistance. During the Wake Survey the foils were attached to the model to insure that the flow field in the vicinity of the propeller location was correctly scaled. For all of the tests the model was held rigidly in place at the desired draft and trim, and measurements were recorded for vertical force, drag force, and encounter wave amplitude. The model draft corresponded to a full-load condition of 1,400 LT (foilborne). The model trim varied between 0° and 3° (bow up) as prescribed in the test plan.

Independent Research

Tank Testing of Ludders 44 Navy Yawl

Researcher: Assistant Professor Paul H. Miller

Tank testing of the Ludders 44 yawl model in upright and heeled conditions was accomplished to support a paper for the Chesapeake Sailing Yacht Symposium. The Ludders yawl was the primary Navy sail-training vessel up until the late 1970's time frame. The performance of this yawl provides a basis of comparison for the more modern design that is now in service as well as next generation craft, which is currently in its final design stage.

Full-Scale Testing of a Recreation of Bushnell's *Turtle*

Researchers: Professor Marshall L. Nuckols, P.E.

The Discovery Channel series on Engineering Marvels sponsored the recreation of David Bushnell's *Turtle*, the first manned submarine to attack a warship. A full-scale recreation of the Revolutionary War submersible was built by the Massachusetts School of Art and Design using methods and materials available during that period. The almost 7,000 pound vessel was tested in the Naval Academy's 380-ft towing tank. Resistance tests on the unmanned vessel were performed in its "transit condition" (partially submerged) to attempt to determine the maximum speed at which it could reasonably have been propelled. In addition, submerged tests were performed to verify that the systems worked. Finally, human propelled tests in both transit and attack modes were performed.

Solar Splash Hull Testing

Researcher: Mr. John J. Zseleczky, Naval Architect, P.E.

Over the past several years, Naval Academy faculty and midshipmen have developed an interest in competing in the "Solar Splash" boat competition, which is held annually around the country. This is an intercollegiate contest with the goal of designing and building boats to excel over well-defined courses intended to rate their sprint, endurance and maneuvering capabilities. This year's class of midshipman had the benefit of two significantly different hulls to work with before starting their design studies. In order to quantify the merits and drawbacks of each hull type, the boats were ballasted to

similar conditions, instrumented and towed in the Hydromechanics Laboratory's 380-foot long towing tank. Measurements of speed, resistance and trim were made over a range of realistic loading conditions. The tests were conducted in full scale so no scaling calculations were required and a large part of the design guesswork was eliminated. The data obtained from these tests provided the midshipman designers with hard numbers that could be used to select the optimum power plant/propeller/battery combination. Insight was also gained on the static and dynamic stability of the hulls.

Design and Construction of a Small Model Towing Carriage

Researcher: Mr. Stephen W. Enzinger, Naval Architecture Technician

A towing carriage, to test ship models under six feet in length was designed and fabricated. The approach taken was to use "off the shelf" hardware to the extent possible to minimize machining requirements and hence cost. The unit is set up to measure ship model resistance, heave, and pitch, and is adaptable to various ship model configurations.

Planar Motion Mechanism Tests of a Novel Hull-Form

Researcher: CDR Jeffrey W. Settler, USN

CDR Settler, a Permanent Military Professor (PMP)-designate, assigned to the Naval Architecture and Ocean Engineering Department (NAOE), conducted a series of tests to validate and extend the database on the hydrodynamics characteristics and performance of a Novel hull-form. The experiments, conducted in the Naval Academy's Hydromechanics Laboratory's 380-foot towing tank, are in support of his doctoral thesis at the Massachusetts Institute of Technology (MIT) which is due to be completed in the summer of 2004.

Cooperative Research by the Webb Institute and the U.S. Naval Academy: Comparison of Ship Resistance Predictions Using Small Models

Researchers: U.S. Naval Academy Hydromechanics Laboratory staff
and Robinson Laboratory staff at the Webb Institute

Through a model exchange program, staff of the U.S. Naval Academy's Hydromechanics Laboratory (NAHL) and of the Webb Institute's Robinson Laboratory were able to validate the effectiveness of small models in predicting full-scale ship resistance. This cooperative effort has included an investigation into various methods of ship model turbulence stimulation and their effect on measured model resistance.

Research Course Project

A Hydrodynamic Study of Fish Haven Breakwaters

Researcher: Midshipman 1/C Brendan R. Gotowka, USN
Advisers: Professor Robert H. Mayer and Associate Professor Jennifer K. Waters

Fish Havens are a modular artificial reef system designed, fabricated, and installed by Artificial Reefs Inc. (ARI) of Gulf Breeze, Florida. Individual units are formed of concrete in the shape of a truncated pyramid, ranging in size from 4' - 6' tall, and 8' - 10' wide at the base. Traditionally, Fish Havens have been used successfully as a synthetic replacement for damaged corals as well as for creating new reef habitats in desolate ocean environments. ARI also proposes using their Fish Havens in a shoreline protection role. This study seeks to assess how effective this modular system would be in such a deployment.

Using 6" x 10" Fish Haven models provided by ARI, two different configurations of a Fish Haven breakwater were arranged in the sediment flume of the U.S. Naval Academy's Hydromechanics Laboratory. Different Bretschneider-spectrum wave series were propagated and changes in sediment bathymetry were compared with a no-breakwater (NBW) condition. Both Fish Haven configurations induced formation of a prominent sand berm of shallower depth and closer to shore than the NBW condition. Shoreline retreat was also reduced 33%.

A second means to assess Fish Haven effectiveness was to measure the amount of wave energy dissipated by the breakwater system. Series of steady waves of different frequencies were generated and wave height measurements were taken both before and after passing over the breakwater. Wave heights were then correlated with wave energy and compared with similar calculations made for the NBW condition. Results were inconclusive in part due to effects of wave reflection off the shoreline. Also, wave energy dissipation – in shallow water - is not proportional to changes in wave height (as originally assumed.) Future studies of wave energy dissipation should consider comparison of changes in wave energy flux, which is a function of both wave height and depth.

Scale-Model Testing of a Bushnell's *Turtle*

Researcher: Midshipman 1/C James Vandevort, USN
Adviser: LCDR Richard A. Schoenwiesner, USN

As a part of a project with the Discovery Channel, a resistance test series on a 1/8-scale model of the proposed recreation of Bushnell's *Turtle* was performed. The purpose of the test series was to provide information to another student designing the propeller for the vessel and to estimate the maximum speed that could be achieved using human propulsion.

HMS Inconstant: Preparation for Model testing

Researcher: Midshipman 1/C James Wolff, USN
Adviser: Professor Gregory J. White
Sponsor: U.S. Naval Academy Class of 1951

This research project was a small part of a long term effort to perform hydrodynamic performance analysis on selected ships from the Naval Academy Museum's historic model collection. The specific purpose of this project was to develop a methodology for lifting the lines from a historic ship model and to prepare a three-dimensional computer model which will be used to manufacture a new model. The new model was built to a suitable scale and constructed to facilitate testing in the Naval Academy Hydromechanics Laboratory (NAHL) 380-foot towing tank. The historic ship models are delicate specimens of significant historic interest which must not be damaged in the process. The primary challenge in this project was to create a methodology for lifting the model lines with enough information to allow for the construction of the computer model. A second challenge was to establish a process for using the information from the historic model to insure that the computer model accurately represents the historic model. The specific goal of this project was to document the processes developed and to have everything ready to begin construction of a new fiberglass and foam model.

The model chosen for this effort was the *HMS Inconstant* (model # 52 in the museum collection). The original ship was a 38-gun, 18-pounder 5th Rate British frigate built in 1783. As a long term project, a secondary goal was set to provide for a basis of comparison with past and future projects of a similar nature. This goal was to investigate any pertinent historical information such innovations of the time period or any particular data on the *Inconstant*. This model is also special because the superstructure has collapsed and therefore is just a bare hull. In being so it is the perfect model to test in the new measuring apparatus in the model shop.

Publications

Journal (Refereed) Manuscripts

SCHULTZ, Michael P., Assistant Professor, and FLACK, K.A., Associate Professor (Mechanical Engineering Department), "Turbulent Boundary Layers Over Surfaces Smoothed by Sanding," *American Society of Mechanical Engineering Journal of Fluids Engineering*, Vol. 125, pp. 18-27.

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.

Conference Proceedings

MILLER, Paul H., Assistant Professor, "Student Research Projects for the New Navy 44 Sail Training Craft," *Proceedings of the 16th Chesapeake Sailing Yacht Symposium*, Annapolis, MD, 21-23 March 2003.

Offshore-capable sail training craft (STC) specifically designed and built for the United States Naval Academy (USNA) have been a cornerstone of its seamanship training program since 1939. Currently the fourth generation of these craft is under development and this paper summarizes research projects performed by eight midshipmen in the areas of parametric design criteria, structures, appendage development and analytical tool evaluation. While the results are oriented toward the new sail training craft, they are general enough to apply to any medium-sized offshore sailing vessel.

NUCKOLS, Marshall L., Professor, and SCHOENWIESNER, Richard A., Lieutenant Commander, (USN), **"**The Re-Invention of Bushnell's TURTLE**,"** *Proceedings of Underwater Intervention 2003*, New Orleans, LA 10-12 Feb 2003. (CD-ROM Paper J-3-3)

The Discovery Channel, in cooperation with the UK Channel 4, is planning a documentary on the Revolutionary War submersible, *Turtle*, as a part of its "Inventing the Past" series. The *Turtle* was designed and built by David Bushnell in 1776 for the purpose of attacking the British fleet to break the blockade of New York harbor. The U.S. Naval Academy has been invited to be the primary engineering designers and testers for this project. This endeavor is being used as a mechanism for students to apply their naval engineering skills to a real-world project. Currently, design teams are developing specifications for the hull and calculating support system and habitability requirements based on historic documentation. Teams of craftsmen from the Massachusetts College of Art will use the designs to reconstruct the *Turtle* by early 2003 using authentic period methods and techniques. Finally, in the spring of 2003, the recreated vessel will undergo testing at the Naval Academy before being used for a re-enactment of its historic mission. This paper will detail the engineering work done by the Naval Academy, the construction techniques used by the Massachusetts College of Art, and the history of David Bushnell and his submersible, *Turtle*.

SCHULTZ, Michael P., Assistant Professor, and FLACK, K.A., Associate Professor (Mechanical Engineering Department), "Mean and Turbulent Velocity Profiles for Sandgrain Rough Surfaces," *3rd International Symposium of Turbulence and Shear Flow Phenomena (TSFP-3)*, Sendai, Japan, Vol. 1, pp.129-134.

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.

SCHULTZ, Michael P., Assistant Professor, and FLACK, K.A., Associate Professor (Mechanical Engineering Department), "Turbulent Boundary Layers Over Surfaces Smoothed by Sanding," *Bulletin of the American Physical Society: Division of Fluid Dynamics 55th Annual Meeting*, Vol. 47, No. 10, p.55.

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.

Technical Reports

WHITE, Gregory J., Professor, "Resistance, Seakeeping, and Wake Survey Testing of the 2200 LT MCM (XH) HYSWAS Hull Form," U.S. Naval Academy Division of Engineering and Weapons Report EW-01-03, February 2003.

The Maryland Applied Physics Corporation (MAPC) has developed a unique hull-form for a new mine countermeasures ship with a very high-speed capability. This hull form is a modified version of the one tested by the Naval Academy's Hydromechanics Laboratory (NAHL) in May 2001. The modifications allow the ship to operate in shallower waters while still retaining the high-speed capability. The modifications included a decrease of the hullborne draft, reshaping the underwater hull, and a redesign of the underside of the cross-deck structure.

Three model test series have been performed to provide MAPC with foilborne powering and wake information, and wave loading information when foilborne at high speeds. This information will facilitate the design of the propeller for the ship and provide some information to help evaluate the foilborne seakeeping performance of the ship. For the Effective Horsepower (EHP) Test and Wave Loading Test the model was configured without foils. The foil resistance was calculated separately and added to the measured resistance. During the Wake Survey the foils were attached to the model to insure that the flow field in the vicinity of the propeller location was correctly scaled. For all of the tests the model was held rigidly in place at the desired draft and trim, and measurements were recorded for vertical force, drag force, and encounter wave amplitude. The model draft corresponded to a full-load condition of 1,400 LT (foilborne). The model trim varied between 0° and 3° (bow up) as prescribed in the test plan.

WHITE, Gregory J., Professor, "Effective Horsepower Model Testing of an 18th Century Sailing Warship: USS Constitution (IX-21)," U.S. Naval Academy Division of Engineering and Weapons Report EW-05-03, May 2003.

The U. S. Naval Academy's Class of '51 Gallery of Ships contains a collection of British Dockyard Models of 16th through 19th century naval vessels. These models, built by dockyard craftsmen contemporaneously with their full-scale counterparts, are considered by experts to be accurate reproductions of the ships they represent. This permits the models to be used for research on the evolution of warship design during this period when most of the technical developments in sailing warships occurred. Historic sailing warships, however, have hull forms unlike modern vessels. They tended to be shorter, beamier, with shallower drafts, and very full, rounded bows. Therefore, the guidelines that exist for turbulent stimulation on scale models (Ridgely-Nevitt, 1967) needed to be evaluated in its application to these very different hull forms traveling at relatively slow speeds. The experiment documented in this report is the first step in an attempt to establish guidelines for determining the appropriate scale-model size and the placement of turbulent stimulation on historic sailing warships.

Presentations at Professional Meetings and Conferences

MILLER, P.H., Assistant Professor, "Student Projects for the New Navy 44," Chesapeake Sailing Yacht Symposium, St. John's College, Annapolis, MD, 22 March 2003.

NUCKOLS, M.L., Professor, "The Re-Invention of David Bushnell's *Turtle,*" 2003 Raouf Memorial Lecture, U.S. Naval Academy, Annapolis, MD, 27 February 2003.

SCHULTZ, M.P., Assistant Professor, "Turbulent Boundary Layers Over Surfaces Smoothed by Sanding," Bulletin of the American Physical Society: Division of Fluid Dynamics 55th Annual Meeting, Dallas, TX, November 2003.

SCHULTZ, M.P., Assistant Professor, "Turbulent Boundary Layers on Surfaces Covered with Marine Algae," 11th International Congress on Marine Corrosion and Fouling, San Diego, CA, July 2002.