# Hydromechanics Laboratory

Professor David L. Kriebel, P.E.
Director

The Hydromechanics Laboratory supports midshipmen education, as well as midshipmen, faculty and staff research, in the areas of naval architecture and ocean engineering. The laboratory facilities include a large towing tank (380-ft long, 26-ft wide, and 16-ft deep), a small towing tank (120-ft long, 8-ft wide, and 5-ft deep), a coastal engineering wave basin (52-ft long, 48-ft wide, and 2-ft deep), a circulating water channel, 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 the Mechanical Engineering, Electrical Engineering, Systems Engineering, and Oceanography majors. In addition, more than 600 midshipmen use the laboratory each year in EN200, a core-engineering course taken by all midshipmen in science or humanities majors. As a result, nearly all midshipmen use the Hydromechanics Laboratory facilities at some point during their four years at the Naval Academy.

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

- Measurements of ship-generated waves in shallow water (Sponsor: Naval Facilities Engineering Service Center)
- Shallow water heave and trim in restricted channels. (Sponsor: Naval Facilities Engineering Services Center)
- Prototype model of ship barrier protection system for Kings Bay, GA (Sponsor: Naval Facilities Engineering Service Center)
- Performance of ship protection barriers in waves (Sponsor: Naval Facilities Engineering Service Center)
- Characteristics of deep water wave groups (Sponsor: Office of Naval Research)
- Development of “virtual” towing tank laboratory experiments. (Sponsor: Academic Dean Curriculum Development Project)
- Laser measurements of flow characteristics in the Hydromechanics Laboratory’s circulating water channel. (Sponsor: Hydromechanics Laboratory)
- Model tests of keel and rudder variations for the proposed new Naval Academy 44-foot sloops (Sponsor: Hydromechanics Laboratory)
- Velocity and turbulence measurements on smooth and rough plates using laser doppler anemometry (Sponsor: Hydromechanics Laboratory)
- Model tests and full scale trials correlations for the USCG 47-foot Motor Life Boat (Sponsor: Hydromechanics Laboratory)
- Selection and design of a trimaran hull form for the Solar Splash competition (Sponsor: Hydromechanics Laboratory)
- Planar Motion Mechanism tests in support of Permanent Military Professor (PMP)-designate Navy Commander Jeffrey W. Stettler’s doctoral dissertation (Sponsor: Hydromechanics Laboratory)
- Model tests, of an unmanned underwater vehicle (UUV) in waves (Sponsor: MIT/Woods Hole Sea Grant Program)
- Lift forces on a submarine operating near the surface in waves (Sponsor: Hydromechanics Laboratory)
- Model test techniques applicable to a Hydrofoil Small Waterplane Ship (HYSWAS) hull form (Sponsor: Hydromechanics Laboratory)

- Circulating water channel tests on an air cavity drag reduction concept (Sponsor: Hydronautics Research, Inc.)
- Model tests and propeller wake survey for a proposed 2200-ton Hydrofoil Small Waterplane Ship (HYSWAS) design (Sponsor: Maritime Applied Physics Corp)

The Laboratory is operated and maintained by a multi-talented staff, which includes four engineers/naval architects, three 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, reflects the broad nature of the Hydromechanics Laboratory's activities.

# Sponsored Research

## Ship Generated Waves

Researchers: Professor David L. Kriebel and Dr. Carolyn Judge (Naval Architecture and Ocean Engineering Department)
Sponsor: Naval Facilities Engineering Services Center (NFESC)

Waves generated by passing commercial ships often create problems in Navy ports. For example, these wave can excite large dynamic motions of moored Naval vessels and, as a result of the large forces transmitted in the mooring lines, either the moored ship or the pier can experience damage. Because of these damages, the Naval Facilities Engineering Command has initiated an investigation of the 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 the 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 are planned in the Naval Academy Hydromechanics Laboratory in shallow water conditions where the ship draft is 50 to 90 percent of the water depth.

## Air Cavity Drag Reduction

Researchers: Dr. Virgil Johnson and Dr. Rod Barr (Hydronautics Research, Inc.)
and Mr. Donald Bunker, Naval Architect Technician
Sponsor: Hydronautics Research, Inc.

Reduction of hydrodynamic drag through the use of controlled air cavities is not a new concept. The problem has been and remains, how to control the cavity, minimize airflow rate requirements, and how to reduce the flow instabilities resulting from this technique. A series of cavity-generating devices were tested in the circulating water channel. Photographs were taken of the cavities to determine cavity characteristics as a function of channel velocity.

## Prototype Models of Ship Barrier Protection System, Kings Bay, GA – Phase 1

Researcher: Ms. Louise A. Wallendorf, Ocean Engineer, P.E.
Sponsor: Naval Facilities Engineering Service Center (NFESC)

A 1/56$^{th}$ scale model of a prototype 1000-foot ship barrier protection system proposed for installation in Kings Bay, Georgia was constructed. The moored system consisted of 20 interconnected 50-foot modules with two operational gates, 100-foot and 500-foot in length, respectively. The system was installed in the coastal engineering tank and it's operation and performance in waves was videotaped. As a result of seeing the model, the designer modified the mooring system so that it was easier to install. The video provided a way to demonstrate the concept of a moored ship barrier system to the fleet.

## Prototype Models of Ship Barrier Protection System, Kings Bay, GA – Phase 2

Researcher: Ms. Louise A. Wallendorf, Ocean Engineer, P.E.
Sponsor: Naval Facilities Engineering Service Center (NFESC)

Five identical 1/10$^{th}$ scale models of the proposed ship barrier protection system were constructed, using the most current information from the structural engineer. The natural frequencies of a single module were measured for comparison with a numerical model. These models were connected and installed in the 380-foot wave tank, to model half of a proposed 500-foot gate section in the barrier. The models were subjected to hurricane wave conditions in Kings Bay, and their motions videotaped for a qualitative demonstration of the motions of the individual modules and the connections between the models for use by the fleet.

## Characteristics of Deep Water Wave Groups

Researchers: Professor Thomas H. Dawson
and Ms. Louise A. Wallendorf, Ocean Engineer, P.E.
Sponsor: Office of Naval Research (ONR)

As part of an ongoing research project on wave groups and their effects on statistics, long time histories of Joint North Sea Wave Project (JONSWAP) wave spectra were generated in the 120-foot wave tank. The statistics of the average number of waves between wave groups were studied and shown to diverge from predictions using Markov Theory for the highest waves in the data.

## Slow-Speed and Zero-Speed Seakeeping Model Tests of the 2200 LT MCM (XH) HYSWAS Hull Form

Researchers: Professor Gregory J. White and Mrs. Nancy A. Harris, Naval Architect
Sponsors: Maryland Applied Physics Corporation and Office of Naval Research (ONR)

A series of physical model tests were performed on a Hydrofoil Small Waterplane Ship (HYSWAS) for the specific purpose of measuring the low-speed seakeeping performance. The model was configured with foils to provide an accurate representation of the added-mass effects of these surfaces. The model was ballasted to reflect two different loading conditions, a light condition (2,000 LT) and a full load condition (2,200 LT). Measurements were recorded for pitch angle, pitch rate, roll angle, roll rate, heave acceleration, wave height, and forces at the top and bottom of the hull strut. Using this information, the roll and pitch accelerations and the bending moments on the strut was also determined. Tests were conducted for zero speed and slow speed (3 knots full scale) in sea state conditions 3, 4, 5, and 6. During the zero speed tests, runs were conducted with relative headings (to the waves) of 0, 30, 60, 90, 120, 150, and 180 degrees. All of the towed tests were conducted in head seas only, with the addition of a sea state 8 test run. The model performed much as was expected during both test series. The zero speed pitching motions were worsened as the vessel approached head or following seas. The zero speed rolling motions worsened as the heading approached beam seas. There were some small reductions in the rolling and pitching motion at the heavier displacement in the Zero Speed tests. The bending moments determine from the force measurements were quite large and dramatically increased as the relative heading approached 90°.

## Frictional Resistance of Ship Hull Coatings

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

The U.S. Navy presently uses ablative copper coatings on the hulls of its ships for biofouling control. Environmental concerns as well as the need to extend the present length between dry dockings have led to the development of alternative technologies. One of these is the non-toxic, fouling-release coating. However, it is largely unknown how the frictional drag of these coatings compares to ablative copper coatings. An experimental study is presently underway in the 380-foot towing tank at the U.S. Naval Academy Hydromechanics Lab to document the frictional resistance and surface roughness of several non-toxic, fouling release coatings and the traditional copper-based coatings. Flat plates coated with these antifouling systems will be tested in both the clean and fouled condition. Results from these tests should provide information to make better quantitative comparisons between fouling-release and copper-based antifouling coatings.

# Independent Research

## The Effect of Surface Finish on Turbulent Boundary Layer Structure

Researchers: Assistant Professor Michael P. Schultz
and Associate Professor Karen A. Flack (Mechanical Engineering Department)

Many engineering applications involve flows that develop for some length over surfaces that are rough. However, the bulk of basic turbulent boundary layer research has been carried out on smooth walls. The goal of this experimental investigation is to document the effect that surface finish has on frictional resistance and turbulent boundary layer structure. The study is presently ongoing in the recirculating water tunnel facility at the U.S. Naval Academy Hydromechanics Lab. Profiles of the axial and wall-normal velocity components in boundary layers developing on sprayed marine polyamide epoxy surfaces smoothed by sanding are being measured using Laser Doppler Velocimetry (LDV). The frictional resistance and boundary layer structure is being compared with those for smooth and sandgrain rough walls. The roughness of the test specimens is measured using a laser profilometer. It is hoped that this research will allow the identification of suitable roughness scaling parameters for frictional resistance and turbulence.

## The Relationship Between Frictional Resistance and Roughness for Surfaces Smoothed by Sanding

Researcher: Assistant Professor Michael P. Schultz

An experimental investigation has been carried out in the 380-foot towing tank at the U.S. Naval Academy Hydromechanics Lab to document and relate the frictional resistance and roughness texture of painted surfaces smoothed by sanding. Hydrodynamic tests were carried out in a towing tank using a flat plate test fixture towed at a Reynolds number ($Re_L$) range of 2.8´$10^6$ – 5.5´$10^6$ based on the plate length and freestream velocity. Results indicate an increase in frictional resistance coefficient ($C_F$) of up to 7.3% for an unsanded, as-sprayed paint surface compared to a sanded, polished surface. Significant increases in $C_F$ were also noted on surfaces sanded with sandpaper as fine as 600-grit as compared to the polished surface. The results show that, for the present surfaces, the centerline average height ($R_a$) is sufficient to explain a large majority of the variance in the roughness function ($\Delta U$) in this Reynolds number range. The results of this study have been published in the *Journal of Fluids Engineering*.

## Series 64 Model Tests

Researchers: Mrs. Nancy A. Harris, Naval Architect
and Mr. Stephen Enzinger, Naval Architect Technician

In June 2001, the Naval Academy's Hydromechanics Laboratory tested a 5.5 foot version of one of the Series 64 models in the 380-foot Towing Tank. This was precipitated by an interest in investigating the effects of Hama strips on resistance measurements in calm water. The Robinson Model Basin at Webb Institute had just performed a similar test and we were interested in comparing the results. In 1965, David Taylor Model Basin published results of a 10-foot model of the same shape, and comparisons were made to those results as well.

### Planer Motion Mechanism Tests of a Kayak Hull Form

Researchers: CDR Jeffrey W. Stettler, USN, and Hydromechanics Laboratory Staff

Utilizing the laboratory's Planer Motion Mechanism (PMM), a series of resistance and maneuvering tests were carried out in the 380-foot towing tank on a kayak hull form to quantify its performance in still water. The results of these tests will be used to help define the control system characteristics required for this hull form to function in the autonomous mode. The experimental results will then be compared to System Identification (SI) predictions techniques that have been developed at the Massachusetts Institute of Technology.

## Research Course Projects

### Performance of Ship Barrier Models in Waves

Researcher: Midshipman 1/C James Henry, USN
Advisers: Professor David L. Kriebel
and Ms. Louise A. Wallendorf, Ocean Engineer, P.E.
Sponsor: Naval Facilities Engineering Service Center (NFESC)

Two proposed designs for floating security barriers were tested in the wave tanks of the Hydromechanics Laboratory. The first barrier type, the Port Security Barrier (PSB), was tested to evaluate: (a) its resistance to towing and (b) its response in waves. In one set of tests, a single 1/10$^{th}$ scale PSB module was towed in the 120-foot wave tank at various angles of attack while forces on the hull were measured. In a second set of tests, five 1/10$^{th}$ modules were joined together to span the 380-foot wave tank and were subjected to various wave conditions. The structure motions were recorded along with the tension in the connectors between modules. The second barrier type, the Near Port Security barrier (N-PSB), was tested to evaluate its motions in waves when placed against a ship hull. This type of barrier has rollers to ride up-and-down the hull as it moves in waves. Tests were conducted to record its dynamic motions in heave and roll. Results of this project were used by Naval Facilities Engineering Services Center (NAVFAC) during the final design phase of the PSB and N-PSB, and full-scale units were installed at several Naval bases in the winter of 2001-2002 following testing.

### A Hydrodynamic Study of Artificial Reefs

Researcher: Midshipman 1/C Tara Inverso, USN
Advisers: Associate Professor Jennifer K. Waters,
Mr. Stephen Enzinger, Naval Architect Technician
and Ms. Louise A. Wallendorf, Ocean Engineer, P.E.

Artificial reef balls are semi-spherical, porous concrete forms placed in shallow water coastal locations for artificial reef construction. Some of the hydrodynamic properties of the reef balls were studied for a preliminary evaluation of their effectiveness in shore protection. The drag coefficient of a reef ball was measured by towing different balls underwater at various orientations and speeds in the 120-foot towing tank. The reef balls were tested in the coastal engineering wave flume where they were placed at three locations in two configurations for a given beach profile and subjected to regular waves. The beach profile was measured and the wave heights before and after the reef were measured.

### Performance of the USCG 47-foot Motor Life Boat Based on Methods of Prediction, Model Testing, and Full Scale Trials

Researcher: Midshipman 1/C Jon S. Erskine, USN
Advisers: Professor Bruce C. Nehrling and Professor Gregory J. White

The goal of this project was to compare the SHP and trim of the U.S. Coast Guard 47-foot Motor Life Boat (MLB) obtained from scale model testing with data from full-scale ship trials. An additional objective was to compare both data sets to computer predictions based on the methods developed by Daniel Savitsky and J.B. Hadler. The hull model configured to reflect the configuration of MLB 47206 at the time of the builder's trials and a series of bare hull EHP tests were performed to cover the range of speeds and conditions of the builder's trials. The EHP data were combined with typical theoretical predictions for the propulsive coefficient based on the specified propeller to predict the SHP and trim. The results of this comparison showed that the model testing SHP calculations provided a fairly accurate match to the performance characteristics of a hull reported in the builder's trials before its production and subsequent builder's test. The computer-based predictions slightly over estimated the SHP at the lower speeds and then underestimated by nearly 17% at the maximum speed. Although the computer predictions were close for SHP, the method tended to greatly overestimate the trim values at all but the maximum speed.

## Design of a Solar-Powered Trimaran – Solar Splash Competition 2002

Researcher: Midshipman 1/C Travis Chapman, USN
Advisers: Professor Gregory J. White
Mr. John Zseleczky, Naval Architect, P.E.
and Mr. Bill Beaver, Model Maker, P.E.

Solar Splash is the World Championship of Solar/Electric boating. It is an international competition that takes place each year to allow design teams to compete in five categories for the best design. The U.S. Naval Academy Mechanical Engineering Department decided to use the design competition as the central subject of their senior capstone design course for two groups of First Class Midshipmen. Midshipman Chapman, a naval architecture major, completed an independent research project by designing and building a boat for the Naval Academy team. The trimaran hull-form was chosen due to the limited time for the design and the flexibility in loading and outfitting that it provided. A 1/12$^{th}$ scale "concept" model was built and resistance tested in the 120-foot towing tank prior to beginning prototype construction. The hull was constructed using a "tortured plywood" method to allow for rapid construction and lightweight. The hull proved to be moderately fast and very stable. It will provide the platform for future teams to outfit with improved electrical/solar equipment and engines for future competitions.

## Model Tests of Rudder Variations for the Proposed New Naval Academy 44-Foot Sloops

Researcher: Midshipman 1/C W.T. Huebner, USN
Advisers: Assistant Professor Paul H. Miller and
Mr. John Zseleczky, Naval Architect, P.E.

The U.S. Naval Academy fleet of 44-foot sloops is nearing the end of its service life. Rather than replace the sloops with identical copies of the existing boats, it is possible to take advantage of experience gained over the past fifteen years and incorporate changes in the replacement boats. This research project was intended to evaluate new concepts for rudder design using model experiments. Two 1/10$^{th}$ scale models were built, one representing the existing Navy 44 and the other representing an updated version of the hull developed in a previous student project. The Hydromechanics Lab staff developed a single-post towing rig for the tests so that measurements of lift, drag and yaw moment could be obtained. Two rudder planforms were studied: the existing trapezoidal shape and a higher aspect ratio elliptical shape. Both rudder shapes were tested with and without a skeg. Given two hulls, two rudder planforms, and two skeg variations, a total of eight rudders were built and tested at various speeds and rudder deflections. Reasonable values of leeway and heel angles were estimated in advance for each speed using a Velocity Prediction Program. Even with this simplification, the test program encompassed over 200 test runs. As a check on scale effects, the turning diameter of the model was compared to the turning diameter of an existing full-scale boat. Each hull was brought up to speed, thrust was removed, and then the helm was put hard over. The turning tests also provided a qualitative measure of the effectiveness of the different rudder configurations.

### Lift Forces on a Submarine Operating Near The Surface in Waves

Researcher: Midshipman 1/C J. Campbell, USN
Advisers: Professor Rameswar Bhattacharyya
and Mr. John Zseleczky, Naval Architect, P.E.

One of the most difficult aspects of controlling the depth and attitude of a submarine occurs near the surface in a seaway. For this project, a five-foot long model of the parent hull of the Series 58 Submarine Series was used. These hulls are symmetrical about their longitudinal axis and polynomial equation defines the ordinates of the profile about that axis. The model was suspended from the towing carriage using two struts, and instrumented with force gages that measured vertical forces at each strut. Encountered wave elevation was also measured, using a sonic wave probe. A matrix of tests were run with variations in wave amplitude and frequency. Lift measurements at each strut attachment point were used to calculate total lift and pitch moment. The experimental results were compared with force predictions made using simple strip theory.

## Conference Proceedings

Ewing, Lesley and WALLENDORF, Louise A., Ocean Engineer, P.E., (ed.), *Proceedings of the Solutions to Coastal Disasters 2002 Conference*, American Society of Civil Engineers, San Diego, CA, 1011pp. (ISBN 0-7844-0605-7).

This Proceedings contains 83 papers written to accompany presentations at the conference. At the beginning of the 21st century, the world's population was 6 billion and expected to continue to grow to 9 million by the middle of the century. Much of this growth has occurred in coastal regions, where the population may be exposed to coastal hazards and disasters. There were four tracks at the conference: coastal storms, seismic events, impacts of climate change and shoreline change. Papers were selected that focused on the forces and processes that cause and contribute to coastal disasters, response mitigation strategies, design and engineering and coastal management focusing on preventing or decreasing the adverse effects of disasters.

HARRIS, Nancy A., Naval Architect and MITALAS, Peter C., Ensign, USN, "HYSWAS Calm Water Testing Techniques," *Proceedings of the 26th American Towing Tank Conference*, Webb Institute, Glen Cove, NY, 2001.

A scaled model of an 850-Ton HYSWAS (Hydrofoil Small Waterplane Area Ship), based on a design by MAPC (Maritime Applied Physics Corporation), was built in the Model Shop and tested in the Hydromechanics Laboratory at the U.S. Naval Academy. This effort supported a midshipman research project during the Spring Semester of 2001, and it will also be used for future midshipman projects as well as labs in the Advanced Marine Vehicle class offered in the Fall Semester of 2001. Various HYSWAS testing techniques were investigated. The goals of this initial testing included:

1) Determining the angles of attack of both foils that resulted in the correct amount of lift and a cancellation of the moments
2) Determining the drag of the model
3) Isolating the lift and drag characteristics of the foil shape.

The model was tested in calm water, fixed at the flying waterline in the following conditions:

1) Bare hull
2) With the main foils only
3) With both the main foils and the aft foils.

The foil angles were not actively controlled but were adjustable between runs. Flow visualization tests were performed to determine the angle of the flow going into the foils. Scale effects were investigated, and predictions based on theory and results of tests of foils at higher Reynolds numbers were made and compared to the results.

KRIEBEL, David L., Professor and WALLENDORF, Louise A., Ocean Engineer, P.E., "Air Gap Model Tests on a MOB Module," *Proceedings of the 10th International Conference On Offshore and Polar Engineering*, Stavanger, Norway, June 2001.

Physical model tests were conducted on a large semi-submersible model, representing a 1-to-70-scale model of a single module of the Mobile Offshore Base (MOB). Tests were conducted in head seas in two random sea states, with the model ballasted to a deep operating draft. This paper discusses the characteristics of the MOB model, the experimental setup and test conditions, the observed platform motions, and the degree of wave amplification under the hull leading to reductions in the effective air gap. These last measurements are based on nine wave gages located under the model, from which basic statistics, spectra, and probability distributions have been computed.

# Presentations

HARRIS, Nancy A., Naval Architect, "FastShip 5 Training Session for the Junior Class at Webb Institute of Naval Architecture," Webb Institute of Naval Architecture, Glen Cove, New York, March 15, 2002.