Hydromechanics Laboratory

Professor Gregory J. White
Director

The Naval Academy Hydromechanics Laboratory (NAHL) is a unique facility among universities in the United States that has served the needs of the midshipmen, faculty, and the Navy for more than 27 years. The facility supports midshipmen courses and research, faculty research, and special projects for the U.S. Navy and 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 Lab 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 x 4-ft 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 EN-200, 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.

At the start of the Fall semester, the Hydromechanics Laboratory was still recovering from the effects of Tropical Storm Isabel. All of the laboratory spaces had been thoroughly cleaned, painted, and made habitable. The ceiling tiles and air handler vents had been replaced. The new lab tables for the EN200 models had been assembled and installed. The coastal basin and the stability tank had been painted with a new epoxy-based sealer/paint. The laboratory staff had begun preservation and repair of the 120-foot tank wave board. The contractor working on the 120-foot tank towing carriage and the sediment flume tank wavemaker had delivered all the components and work was in progress to restore their operational capability. This left the Hydromechanics Laboratory in a position where it could support most of the labs for the EN200 and EN342 courses and some of the labs for EN342 courses. However, none of the labs three main wavemakers or two main towing carriages were operational. The contract to repair the wavemakers was still unfunded as was the contract to repair the 380-foot towing carriage.

Good news arrived before the end of the fiscal year. Funding to support the contracts for repairs to all of our remaining facilities had been found and the contracts were quickly awarded. Also by late October, the 120-foot towing carriage became fully operational and was able to be used to support the remaining laboratories in EN200 and a Bowman Scholar Project. By the end of the Fall semester, the Sediment Flume Tank was also operational and work had begun on the 120-foot tank wavemaker and the Coastal Basin wavemaker.

Over the fall-spring intercessional period, a combined effort by the NAHL Staff and MTS Corporation engineers and technicians resulted in the 120-foot tank and Coastal Basin wavemakers being ready for the start of the Spring semester. This effort allowed the Hydromechanics Laboratory to support the EN475 and SO430 courses for the first time in two years. The improved capability of the 120-foot towing carriage was put to the test supporting the EN246, EN353, and EN458 courses.

During the late Spring of 2005, work began on the 380-foot towing carriage and wavemaker. By the start of the Summer, the first operational testing of both systems was underway with a target completion date of early August. With the completion of the repairs to the 380-foot systems, all of the facilities damaged in Tropical Storm Isabel will be fully operational – almost two years after the storm.

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:

- *Safe Operational Envelope for Surfaced Submarine Operations* (Bowman Scholar Project)
- *Composite Propeller Design and Testing on USNA YP* (Trident Scholar Project)
- *Comparison of Theoretical and Experimental Predictions of Roll and Heave Motions for a Ship Model in Beam Seas* (Midshipmen Independent Research Project)
- *Experimental Determination of Hydrodynamic Coefficients for Heave Motions* (Midshipman Independent Research Project)
- *Experimental Wave Height Mapping Using Stereo-Photography* (Midshipman Independent Research Project)
- *Comparison of the Hydrodynamic Performance of Ship Bottom Paints* (Sponsor: Office of Naval Research)
- *Design and Construction of a Small Low-Velocity Flume Tank* (Sponsor: Hydromechanics Laboratory)
- *Lift Drag and Cavitation Measurements on a Whale Fin with Leading Edge Tubercles* (Sponsor: Hydromechanics Laboratory)
- *Velocity- Defect Scaling for Turbulent Boundary Layers with a Range of Relative Roughness* (Sponsor: Office of Naval Research)
- *Mooring Line Force Measurements on a Full-Bodied Ship Model When Subjected to The Wake of a Passing Ship* (Naval Facilities Command)

The 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

Mooring Line Force Measurements on a Full-Bodied Ship Model When Subjected to the Wake of a Passing Ship

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

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 force, and yaw moments experienced acting on the moored vessel. Results will also be used to validate computer codes used by the NAVFAC.

Comparison of the Hydrodynamic Performance of Ship Bottom Paints

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

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

Independent Research

Influence of Leading Edge Tubercles on Lifting Foil Performance

Researchers: Assistant Professor Mark M. Murray and Dr. Laurens Howle (Duke University)

This study is a basic investigation of the physics associated with the leading edge tubercles found on the flukes of humpback whales. Several tests were run in the recirculating water channel on modified foil models milled from aluminum with a general rudder-like planform. Comparisons of lift and drag at various angles of attack were made between the foil with a smooth leading edge and several foils with leading edge tubercles. Initial testing and comparison was performed below the inception cavitation. These experiments showed no significant difference in the lift and drag characteristics of the foils. Another series of experiments were run at velocities where cavitation was induced at higher attack angles. The analysis of the results of these experiments has not been completed.

Design and Construction of a Small Low-Velocity Flume Tank

Researcher: Associate Professor Michael P. Schultz

A recirculating water tunnel facility was designed and constructed for the investigation of turbulent boundary layers using precision optical techniques. The facility has a 10 centimeters by 20 centimeters test section that is 2 meters in length. The test section is fitted with a flexible top wall which is used to set the streamwise pressure gradient. The freestream velocity can be adjusted from 0 – 1.5 meters per second and is maintained using variable frequency alternating current (AC) drive units controlling two 5 horse power pumps. Flow quality is managed using a honeycomb flow straightener and a series of screens located in a settling chamber upstream of the test section. The contraction ratio of the nozzle is 10:1. Water quality is maintained using a filter and deaeration loop, and water temperature is controlled with a chiller unit. Optical access in the test section make measurement techniques such as laser Doppler velocimetry (LDV) and particle image velocimetry (PIV) feasible. Data are currently being collected in the facility in order to better understand the role that wall roughness plays in turbulent boundary layer structure.

Midshipman Research Course Projects

Comparison of Theoretical and Experimental Predictions of Roll and Heave Motions for a Ship Model in Beam Seas

Researcher: Midshipman 1/C David Hodapp, USN
Adviser: Professor Rameswar Bhattacharyya

The goal of this project was to create a simple theoretical model to predict motions of a ship in extreme beam seas and then compare the predictions with experimental model test data. One half of the project focused on the development and refinement of the prediction program and the other half focused on the setup, testing and analysis of the model data.

The model used for the study was 3.5 foot long and represented a ship hull similar to the Naval Academy Yard Patrol (YP). The hull was ballasted to realistic conditions of displacement, center of gravity and mass distribution, and then subjected to sinusoidal beam seas with varying wave height and frequency. The test rig restrained the model in sway, surge, and pitch and yaw motions and allowed freedom in roll and heave.

The simplified strip theory calculation method was developed and implemented using a standard spreadsheet program. This theoretical model was given the same restraints as the experimental model. A comparison of the theoretical and experimental data showed good agreement for small to moderate wave steepness and less agreement for the extreme wave steepness values.

Velocity- Defect Scaling for Turbulent Boundary Layers with a Range of Relative Roughness

Researcher: Midshipman 1/C Jonathan Connelly, USN
Advisers: Associate Professor Michael P. Schultz and Professor Karen A. Flack
Sponsor: Office of Naval Research (ONR)

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

Experimental Wave Height Mapping Using Stereo-Photography

Researcher: Midshipman 1/C Kathryn D'Epagnier, USN
Adviser: Associate Professor Jennifer K. Waters

Stereo photography shows promising application to producing wave images. Wave images investigated in this study were from hull wakes, specifically. A stereo camera took digital wave images, and from the images a MATLAB® program interpreted the matrix of X, Y, and Z data points to produce a surface image. The wave was sliced at a desired distance from the camera to result in a two-dimensional water level versus distance plot. This plot was the interpreted as a water level versus distance plot so as to compare with conventional wave gage data.

Preliminary data were taken at the wave tank at the Naval Surface Warfare Center - Carderock Division during the Fall of 2004. In the spring of 2005, the research focused on three-dimensional water level from Yard Patrol (YP) hull wakes. Data was collected for model YP hull wakes in a laboratory and for actual YP hull wakes in the Severn River.

The research focused on image improvement methods and feasibility or replacing conventional wave measurement methods with stereo photography. Laboratory images were improved by focusing on water texture enhancement and effective lighting. Various spray systems were tested and produced the conclusion that a fine, well-distributed spray is needed for optimal texturization. Techniques of direct lighting were employed by using spotlights at an angle as close to the water surface as possible, to enhance texture.

Challenges to the research were in processing the vast amount of data for a range unprecedented for stereo imagery. Once this obstacle is overcome, stereo photography has many applications. Such applications include: Navy ship development, to determine sonar placement on hulls, as well as wake signature and fuel efficiency. Stereo photography also could be used for Navy and civilian high-speed vessels. As digital photo resolution and computer processing improve, stereo photography will be pertinent to many interests within the Navy and the civilian world.

Experimental Determinations of Hydrodynamic Coefficients for Heave Motions

Researcher: Midshipman 1/C Emily Williams, USN
Adviser: Professor Gregory J. White

The purpose of this study was to go back to the basics, and try to repeat an experiment conducted almost 40 years ago by Vugts [1968]. A special rig needed to be designed, built, and tested in order to perform the experiments in the 120-foot towing tank at the Naval Academy Hydromechanics Laboratory (NAHL). The rig was designed to oscillate a cylinder (with a semi-circular cross-section) in heave and record the exciting force and generated wave data. From this information the hydrodynamic coefficients in heave were calculated and compared to Vugts' results. Therefore a complete set of hydrodynamic quantities was obtained to enable an analysis of the two-dimensional motion pattern of infinitely long cylinders in heave.

The results of the data show that our experiment was able to replicate those already performed. The differences between Vugts' data and ours could be caused by a number of reasons. It is possible, since his experiment was conducted in 1968, that with progression in technology our results are actually more accurate. It is also possible that Vugts left out some critical information in his report that would enable us to replicate his experiment exactly, causing a slight difference in final results. A thorough study could be undertaken to compare the two sets of results and investigate the cause of differences. Regardless of the variation in results, it can be concluded that the rig and model design were successful, and our data collection was accurate.

More research could be performed to perhaps test additional model shapes to further confirm results, and create a standard setup and data collection process. It would then perhaps be possible to revise the design of the rig to allow for multiple modes of motion with one rig.

The experiment as it is could be a great tool for students to gain a further understanding of added mass and damping. Further work could be done to write a lab to be performed during seakeeping class to demonstrate the effects of oscillating the model in water versus oscillating it in air, showing the resulting added mass and damping.

Bowman Scholar Project

Safe Operational Envelope for Surfaced Submarine Operations

Researcher: Midshipman 1/C Seth R Krueger, USN
Adviser: Lieutenant Tullio Celano, USN

Modern attack submarines are designed with submerged handling as the main focus, and are well-known for their poor surfaced seakeeping qualities. The purpose of this project is to define and improve the surfaced handling abilities in order to decrease the risk of significant damage or loss of the ship and its personnel.

In order to accurately model, observe, and measure submarine surface maneuvering characteristics, a scale model was constructed and towed in a variety of different head-on sea states. Many submarines have shown a tendency to "plunge" unexpectedly in a seaway, which results in significant immersion of open hatches, damage to topside rigging, and injury to or loss of personnel. In order to counter the tendency to plunge, submarines often run with a stern plane angle that will assist in keeping the bow from plunging. However, any increased stern plane angle while maneuvering on the surface will create an added value of resistance.

While trimming the submarine on the surface is common practice to avoid plunging, no study has been completed that would suggest both an efficient and effective stern plane angle. This project will vary the stern plane angle at a variety of velocity and sea state conditions. Measurements will include resistance, pitch, heave, wave frequency, velocity, and stern plane angle. Froude scaling enables a geometrically similar model to be built that will accurately simulate the full-scale responses of a surfaced submarine. Results from these tests can then be applied to fleet platforms in order to aid in safe surfaced maneuvering procedures.

Trident Scholar Project

Composite Propeller Design and Testing on U. S. Naval Academy Yard Patrol

Researcher: Midshipman 1/C Chris Wozniak, USN
Adviser: Associate Professor Paul H. Miller
Sponsors: Office of Naval Research (ONR) and Naval Surface Warfare Center - Carderock Division

The goal of this Trident Project was the design, fabrication and testing of the first composite propeller for the U.S. Navy. The U.S. Navy and much of the maritime industry use nickel-aluminum-bronze (NAB) as the primary material for propeller construction. This is done for many reasons, including its anti-biofouling characteristics, high stiffness, and low corrosion potential. It is essentially the industry standard. However, the drawbacks of using NAB are significant. As a cathodic metal, it experiences little corrosion itself, but leads to galvanic corrosion of the surrounding metal, including the hull. Additionally, it is heavy, reducing acceleration and fuel efficiency while adding weight both in propeller and its shaft. It is also an expensive metal, it is difficult to machine, and it creates significant noise and vibration. As an alternative, a composite bladed propeller may significantly reduce some of these problems. The Navy has considered the feasibility of a composite bladed propeller design, but several significant variables need investigation. The basic project goal was to design, build and test the Navy's first composite propeller. The detailed objectives of this Trident project were to: evaluate a potential hub design; perform a structural design of 108-foot Yard Patrol (YP) craft composite bladed propeller as well as the corresponding load analysis; and finally, build and test a full-scale YP propeller using the composite bladed technology.

The methodology was relatively simple although the analysis was complex. As the basic concept used composite bladed attached to a NAB hub, the first step was to develop a design for the hub-blade interaction. Once this was developed, the blade loads were predicted using computational fluid dynamics. They were then combined with the geometry in a finite element structural analysis program to determine fiber orientation and strength characteristics. A full-scale epoxy blade was then created using stereolithography and was used as a plug to create a fiberglass mold. This was used to manufacture the carbon/epoxy blades.

The YP was selected as the test platform as it: 1) was available; 2) has two propellers (in the event of failure); and 3) is used for many hours, often in harsh conditions. Testing included benchmarking the standard NAB propellers, installing and evaluation new polyurea-encapsulated propeller developed by the Naval Surface Warfare Center, and a short term evaluation of the composite-bladed propeller. The composite-bladed propeller was successfully run in "flank-ahead", "full-reverse" and intermediate speeds, and showed no sign of wear.

This project holds definite promise for the future of propulsor technology, specifically in the area of submarine vehicles. The potential for this technology to reduce cavitation, noise, weight and cost, cold significantly improve U.S. naval vessels.

Professional Publications

Journal (Refereed) Manuscripts

SCHULTZ, M.P., Associate Professor, "Frictional Resistance of Antifouling Coating Systems", *ASME Journal of Fluids Engineering*, Vol. 126, pp. 1039-1047.

> 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.