

# Department of Ocean Engineering

## Current Goals and Objectives, Focus, and Priorities

Ocean engineering plays a pivotal role in man's understanding of his world, global climate, commerce, national security, and more, and MIT is—and must be—at the forefront of these areas. We see the leadership of the Department of Ocean Engineering (OE) in complex marine systems as enabling society to better shepherd the world's oceans. This is a truly challenging interdisciplinary engineering task, since it involves exploring and using the ocean and harnessing its resources in such a way that international stability, security, and prosperity are attained without jeopardizing the future health of our planet.

Ocean exploration is critical to understand our world (*U.S. News & World Report*, August 16–23, 2004). Mankind has limited knowledge of ocean physics, chemistry, and biology in the shallow ocean (the upper 1,000 meters). However, little is known about the remainder of the ocean. Some general knowledge of deep ocean biology is known from a few studies of deep marine life, but details of the deep ocean food web, resources, and properties are unknown.

The role of the ocean in global climate is enormous. The oceans form the largest reservoir on earth for holding dissolved greenhouse gasses. We are just beginning to understand how to measure the ocean to predict effects on global climate.

Improved ocean technology leads to increased capabilities and efficiencies for commerce and national security. There are vast resources in and under the ocean, with subsea oil and gas among the best known. The largest tonnage of products and materials that is transported on earth is moved over the ocean. There is a real need for faster, more fuel-efficient ships and more economical and rapid shipping systems.

The oceans play a major role in defense. Naval ships must operate in both the littoral and blue waters of the oceans. Security issues are important in littoral waters of the United States, where there is a need to monitor, identify, and respond to threats and emergencies. Designing and improving naval vessels and systems will help assure international freedom and security.

The mission of the Department of Ocean Engineering can be expressed as follows:

- To *educate* ocean engineers, preparing them for success and leadership in industry, government, and education;
- To *develop* and disseminate knowledge and technology on the interaction of the ocean and complex marine systems enabling safe, wise, and effective use, development, and preservation of the ocean, its natural resources, and the environment; and
- To *lead* the Institute in ocean technology activities, collaborating with other departments at the Institute to address the ocean's complex problems.

Consistent with this mission and responding to the ocean challenges and opportunities as outlined in the 2003 *Ocean Engineering Strategic Plan*, the department will focus its efforts on the following five specific thrust areas:

1. *Education.* The MIT Ocean Engineering Department aims to educate tomorrow's leaders in the vital fields of naval architecture and ocean engineering at the graduate and undergraduate level. New educational processes and perspectives are required to continue and improve undergraduate education in our field, recognizing its great importance despite limited resources available. OE intends to take a leadership role in evolving into an effective model for similar departments in small but important fields. Specifically, we plan to integrate the undergraduate programs into a track in Mechanical Engineering as a fully accredited ocean and mechanical engineering degree.
2. *Naval architecture and offshore engineering.* This involves the development and design of more efficient and environmentally sound ships, vessels, and platforms, including the development of technology for achieving higher ship speeds with minimal fuel cost and floating platforms with maximum capability in relation to their initial and continual cost.
3. *Autonomous marine systems.* Autonomous marine systems will play a vital role in the national interest for a diverse set of missions ranging from antisubmarine and mine warfare and homeland security to subsea energy exploration and production. Key challenges include navigation, communication, energy, propulsion, and autonomous control, some of which are core departmental strengths but some of which will be addressed more efficiently by developing new strategic partnerships with the offshore industry, the US Navy, and national laboratories.
4. *Energy generation from the ocean.* The production and distribution of energy are critical concerns to the modern world, and the oceans are both a significant source of energy and a medium for the transportation and management of energy commodities. Ocean engineering has and will continue to have a large impact on the issues of energy technology, economics, and ecological effects.
5. *Ocean exploration.* The oceans are the last unexplored frontier of our planet and still hide countless undiscovered mountain ranges, valleys, and volcanoes inhabited by unknown life forms. Also, the single most critical factor controlling the global climate is ocean dynamics. The Department of Ocean Engineering will continue to develop the technology to unlock these resources for worldwide utilization.

## **Accomplishments**

### **Discover Ocean Engineering**

For the sixth year, we have offered Discover Ocean Engineering: A Special Introduction to MIT (this year to the Class of 2007). This innovative program for incoming freshmen was set up in 1998 as a four-day program to provide a first glimpse of what engineering is all about. It also allows students to become familiar with some of the opportunities that the field of ocean engineering has to offer. In addition they get a jump-start on

becoming involved in campus life and building a close relationship between themselves, our faculty, and staff. As in the past, the agenda consisted of hands-on experience building small, remotely operated vehicles (ROVs), testing them in the MIT pool, and using them to explore Boston Harbor. This preorientation program remains extremely popular among students. It has inspired “Discover” ongoing programs in other departments spearheaded by Discover Ocean Engineering alumni.

### **T. Francis Ogilvie Young Investigator Lectureship in Ocean Engineering**

In November 2003, Dr. Paul Newman presented the 9th annual T. Francis Ogilvie Young Investigator Lecture. The lecture on “Navigating Autonomous Vehicles in Unknown Marine Environments: Algorithms and Architectures” addressed the long-term goal “To enable one or more autonomous vehicles to operate indefinitely in an a priori unknown environment with bounded error growth in navigation precision.” Dr. Newman is a departmental lecturer in information engineering at the Department of Engineering Science, Oxford University.

### **Robert Bruce Wallace Prize**

The winner of the 2004 Wallace Prize, which is awarded to an outstanding undergraduate in the Department of Ocean Engineering, was Jesse Austin-Breneman. Jesse was selected from a list of extremely qualified candidates and will be provided a full academic year of tuition and stipend for FY2005.

### **Martin A. Abkowitz International Fellowship Program**

The following individuals were awarded the Martin A. Abkowitz International Fellowship: Dr. Constantinos Evangelinos presented a paper at ICCS’s 2004 International Conference on Computational Science in Krakow, Poland, held in early June 2004; travel for student Jason Dahl to attend the conference Flow Induced Vibration to be held at Palaiseau, France, in July 2004; and travel for student Anna Michel to attend the conference on Laser Induced Plasma Spectroscopy and Applications to be held in Malaga, Spain, in late September 2004.

### **Ship Design and Shipbuilding Technology Symposium**

On May 5–6, 2004, the Department of Ocean Engineering hosted the annual Ship Design and Shipbuilding Technology Symposium, part of a series of symposia and workshops established in 1986, at the MIT Faculty Club. This symposium is held to establish and maintain positive communication with industry, US Navy laboratories and programs on research and education issues relevant to the Naval Construction and Engineering curriculum. Following an introduction by the faculty supervisor, the Naval Construction and Engineering Program (13-A) graduate students presented their theses and design projects, which as always were very well received. Rear Admiral Stephen E. Johnson, director of undersea technology, was the featured dinner speaker on May 5. Over 100 people from academia, industry, and the government attended this annual event.

## **Alumni Reunion**

The 24th annual Ocean Engineering reunion was held at the Westin St. Francis Hotel in San Francisco in October 2003. The reunion is traditionally held in conjunction with the Society of Naval Architects and Marine Engineers annual meeting. The 2003 reception was hosted by Professor Henry Marcus and was well attended by alumni, faculty, and guests.

## **Administrative Initiatives**

Professor Henrik Schmidt extended his position of acting department head for the Department of Ocean Engineering for this year. James O’Hearn assumed the position of acting administrative officer effective September 2003, replacing Carolyn Brooke.

## **Department Merger**

The Ocean Engineering Review Committee, established in September 2002, was given the task by the dean of identifying the strengths and weaknesses of the department and investigating the feasibility of Ocean Engineering becoming a subunit of another department. The committee completed a draft report in October 2003 and the final report in April 2004. A preliminary report was presented to the administration in June 2003. No specific merger was recommended; instead, the committee concluded that any merger the administration feels should be pursued ought to involve further investigation by a separate committee charged with identifying the intellectual synergies and the associated risks of such a merger. However, the committee was unanimous in establishing the importance of MIT’s Ocean Engineering to the Institute and the nation and the need to maintain a strong ocean engineering identity and degree program at the Institute.

In August 2003, the dean established a new committee—consisting of professors Baggeroer (chair), Sclavounos, and Yue from Ocean Engineering, Gutowski from Mechanical Engineering (ME), and Greitzer from Aeronautical and Astronautical Engineering (AAE)—that was given the task of identifying which merger would be feasible: one between OE and ME or one between OE and AAE. In October 2003, AAE faculty rejected a merger, and the committee’s deliberation continued focusing on a merger with ME. A report from this committee was orally presented to the dean in January 2004, and in final written form in April 2004. The committee concluded that while the two departments had expressed conditional support for a merger, the two sets of expectations were very different—but, it was concluded, the differences could be overcome. However, this committee reiterated the finding that an ocean engineering identity is crucial to the continued leadership of MIT in ocean science and technology. Also this committee identified the special nature of the department’s relationship with the US Navy through the 13-A program and with the Woods Hole Oceanographic Institution (WHOI) through the 13-W degree programs, requiring particular consideration.

With this background, the dean in January 2004 appointed an OE–ME Merger Committee, which was given the task to develop a plan for merging the two departments, consistent with the findings and recommendations of the previous two committees. This committee was cochaired by professors Ghoniem (ME) and Vandiver (OE), with the other members being Baggeroer and Triantafyllou from OE and Boyce and Gutowski from ME. In April 2004 the Ocean Engineering faculty developed a proposal for a merger that was submitted to the merger committee for consideration as a foundation for a successful merger. Rooted in the 2003 *Ocean Engineering Strategic Plan*, a core piece of the plan was the replacement of the current OE SB major with an Ocean Engineering track in the ME undergraduate program. Further, the proposal retained most of the current graduate degrees as *named* degrees, including the 13-A Naval Construction and Engineering degrees, the joint MIT/WHOI 13-W Oceanographic Engineering, in addition to the Ocean Engineering and Naval Architecture and Marine Engineering degrees in Course 13. It was proposed that the 13-B program be eliminated and integrated into another transportation program at the Institute. To retain a strong ocean engineering identity, the proposal suggested that ocean engineering must be included in a new strategic vision for the merged department and proposed the establishment of an ocean engineering laboratory (OEL) across the current ME divisions, but with certain unique responsibilities in regard to faculty promotions, faculty allocation, and teaching assignments to meet the unique needs of the 13-A and 13-W programs in particular. In addition to a laboratory director, the proposal addressed the governance issue by suggesting permanent representation of OEL faculty on all ME academic committees and the ME Council. The proposal requested that temporarily, during a transition period, OEL would be represented in the department and School leadership by an associate department head with a seat on the Engineering Council. Following the unspecified transition, the Engineering Council seat would be retained by the merged department. A final component of the proposal addressed the aging faculty demographics by requesting a total of four positions (TBA) assigned to Ocean Engineering during the transition period, mortgaged against future retirements. The TBA areas were consistent with the OE thrusts identified in the 2003 OE Strategic Plan: *Ocean Energy, Autonomous Marine Systems, Ocean Observation Systems, and Ocean Cyber-infrastructure*.

The OE merger proposal was presented to the ME Visiting Committee on April 27, 2004, and strongly endorsed, following which the dean encouraged the Merger Committee to work toward a merger along the lines outlined in the OE proposal. These deliberations were still ongoing in June 2004, but agreement has been achieved on a detailed plan for a named OE undergraduate track in ME and some consensus on the committee in regard to the other issues.

### **Strategic Planning**

A new *Ocean Engineering Strategic Plan* was completed and presented to the administration in early August 2003. Following the development of new department vision and mission statements, the Strategic Planning Committee identified the major challenges and opportunities facing Ocean Engineering and defined five main thrust areas the department plans to pursue over the next decade, as stated above, led by the

development of a new educational infrastructure for educating the ocean engineers of the future and followed by four research thrust areas, representing contributions the MIT Ocean Engineering Department is uniquely placed to lead, including advanced naval architecture and autonomous marine systems.

The strategic plan incorporates a detailed “Plan of Actions and Milestones,” but the implementation is still on hold, pending the outcome of the ME–OE merger deliberations.

### **Future Plans**

Professor John Leonard requested and was granted a sabbatical for the 2005 spring term. His plan is to spend his sabbatical leave for the academic year at the University of Ireland.

Professor Jerome Milgram requested and was granted sabbatical for AY2004. He decided to postpone his one-year sabbatical by one semester, starting in the spring 2004 semester, to allow him to develop and teach a new subject in boat design, as a result of strong student demand. Professor Milgram used his sabbatical leave to focus on his research on the project Dynamics of AUVs in Shallow Water and Waves.

Dr. Thomas Consi, who has been in the department since July 1997 and was senior lecturer in March 2000, has accepted a research faculty position at the University of Wisconsin as of June 2004. Dr. Consi has been instrumental in developing the Discover Ocean Engineering (DOE) orientation program. Professor Alexandra Techet will take over the responsibility of DOE this year with assistance from Dr. Richard Kimball, who will also be leaving the department as of September 2004. Dr. Kimball held a part-time lecturer position for this past year.

### **Personnel Information**

Captain David Herbein, USN, served as vice chairman of the American Society of Naval Engineers Northern New England Section’s two-day symposium on “Designing Warships for Zero Maintenance” held in Portsmouth, NH, in August.

Commander Timothy McCoy, USN, joined as a core faculty member the Energy Systems Analysis Consortium (ESAC). ESAC is a multiuniversity interdisciplinary group of faculty working in concert to conduct research and educate in the areas of power systems with marine and aerospace applications.

Ford professor Arthur Baggeroer was part of the Submarine Superiority Technical Advisory Group, a high-level panel sponsored by the Submarine Warfare Office to provide advice on sonar systems for current and future submarines. He continues to serve on the Ocean Studies Board and the Naval Studies Board. Professor Baggeroer also continues to be in high demand for providing his expertise to high-level navy advisory panels, such as the CNO Team A Task Force on ASW.

Dr. David Burke acted as department communications and D-Space coordinator.

Professor Chryssostomidis continues as director of the MIT Sea Grant College Program. He is also chief scientist for the National Naval Engineering Research and Education Consortium.

Professor John Leonard developed a curriculum development proposal for a new interdepartmental robotics subject, in collaboration with colleagues in AAE and EECS. The proposal was selected for funding by the School of Engineering in June 2004.

Professor Nicholas C. Makris is a member of the Science Definition Team and lead of the Surface Chemistry/Geophysics Subgroup, Lander for Jupiter Icy Moons Orbiter Mission, Project Prometheus, 1st Nuclear Powered Space Craft, NASA-DOE.

Professor Hank Marcus was cochairman of the Technical Committee for the World Maritime Technology Conference 2003 (sponsored by SNAME, the Society of Naval Architects and Marine Engineers); published "The International Liner Industry: Overview and Challenges," presented at the MIT/Marsoft Conference on Investment and Risk Management, August 2003; and published "The Term Structure of Second-Hand Prices: A Structural Partial Equilibrium Model" with George Dikos, MIT, September 2003. Professor Marcus was on sabbatical for AY2004.

Professors David Herbein and Timothy McCoy organized and successfully conducted seven short courses over a nine-week period for the Professional Summer Program in order to meet unique navy educational needs that cannot be met on campus during the regular academic year.

Professor Jerome Milgram continues a major experimental program concerning the forces on autonomous underwater vehicles (UAVs) in shallow waters with WHOI. This is in response to the navy's increased interest in operations in the littoral zone.

Professor Nicholas Patrikalakis continues as the Kawasaki professor of engineering.

Professor Henrik Schmidt continues as acting department head until a final decision is made regarding the future of the Ocean Engineering Department. Professor Schmidt is a member of the Dynamics of Earth and Ocean Systems Committee, advising the National Science Foundation (NSF) on the implementation of a new major research equipment initiative, which beginning in FY2006 will deploy a \$230M ocean observation infrastructure for use by the oceanographic and geophysical science communities. Together with colleagues at Princeton, Harvard, the Scripps Institute of Oceanography, WHOI, and others, Professor Schmidt won a new multidisciplinary university research initiative on adaptive ocean sampling with marine robotic networks. Professor Leonard is involved as well as a co-PI.

In October 2003, Professor Schmidt was invited by the MIT Parents Association to present a talk to MIT parents at the Institute's Family Weekend. The well-attended

lecture, “Exploring the Ocean with Artificial Dolphins,” highlighted the underwater robotic technology that MIT’s Department of Ocean Engineering is developing.

Professor Paul Sclavounos served on the OE–AAE–ME merger committee chaired by Baggeroer.

Professor Alexandra Techet won an ONR Young Investigator Program Award for the proposal “Synergistic Experimental Study of Chaotic Near-Surface Hydrodynamics of High-Speed Surface Piercing Vessels.” In May 2004, Professor Techet was again invited to teach the CMI course “Fish Swimming Hydrodynamics,” which she had taught in May 2003.

Professor Michael Triantafyllou served on the Ocean Engineering Review Committee and on the OE–ME Merger Committee.

Professor Kim Vandiver continues with his fifth year as the dean for undergraduate research. This includes being director of the Undergraduate Research Opportunities Program and director of the Edgerton Center, as well as the codirector of the Office of Academic Services. He is currently cochair of the OE–ME Merger Committee.

Professor Wierzbicki continues working on National Fracture of Ship Structures—A System Approach, which is funded by the Office of Naval Research (ONR, within the National Naval Responsibility Initiative). He also is doing work with the Cambridge–MIT Institute on development of novel stainless steel sandwich sheets and with the Department of Transportation through the MIT VOLPE Center regarding fracture prediction for extruded multicell profiles. Professor Wierzbicki was appointed to the editorial board of the *International Journal of Impact Engineering*.

Professor Dick Yue continues his service to the Institute as associate dean of engineering, with special responsibility for educational programs in the School of Engineering and the Institute. He also served on the OE–AAE–ME merger committee chaired by Baggeroer.

### **Student Awards**

Meghan Hendry-Brogan, Matthew Greytak, Anna Michel, Mark Rapo, Matthew Walter, and Sacha Wichers have been awarded or continued to receive the National Defense Science and Engineering Graduate (NDSEG) Fellowship that provides three years of funding toward tuition, stipend, and fees.

A Presidential Fellowship (WHOI) was provided to Celeste Fowler posthumously, spring 2004. She was also awarded an NDSEG Fellowship posthumously.

Cosimo Malesci received a \$2,000 undergraduate scholarship from the Society of Naval Architecture and Marine Engineers (SNAME) undergraduate fellowship.

The American Bureau of Shipping Fellowship was awarded to Matthew Fox.



Olivia Leiterman received \$5,000 for the Alfred Keil Fellowship for the wiser uses of science and technology.

At the OCEANS 2003 conference in September 2003, the MIT student section of the Marine Technology Society, under 13SEAS, was awarded “student section of the year.”

The iQuarium, a fascinating and playful interactive exhibit developed by a student iCampus team that included OE student Katie Wasserman and others, was launched at a reception at the MIT Museum’s Hart Nautical Gallery in February 2004 and became a permanent display as part of the Ocean Engineering exhibit in the Hart Nautical Gallery. The iQuarium visualizes the hydrodynamic mysteries of swimming fish.

MIT participated in the MATES ROV Competition, held in Santa Barbara, CA, on June 24–28. MIT competed in the “Explorer Class” against 12 other teams. MIT won the mission portion of the event and came in second overall. The MIT team also picked up awards for outstanding discussion of national marine sanctuaries and for safety procedures during the mission. Several Ocean Engineering students participated. Dr. Franz Hover of Ocean Engineering was the team mentor.

The MIT Project ORCA team won the 2004 Autonomous Underwater Vehicle Technology Competition, a highly publicized event that took place at the Naval Warfare Systems Center in San Diego from July 28 to August 1, 2004. This year’s contest involved finding and discriminating between various underwater targets, placing a marker on one of the targets, and surfacing in a recovery zone after the marker has been placed. MIT Ocean Engineering is one of the core Project ORCA sponsors.

## **Teaching and Curriculum**

As a result of the findings of the Ocean Engineering Review Committee and as a spin-off of the Strategic Planning exercise, the department’s Undergraduate Committee, chaired by Professor Patrikalakis, investigated the feasibility of replacing the current ocean engineering major with a jointly taught undergraduate track in another department, specifically Mechanical Engineering, similar to the 2-A track in Biomechanical Engineering. The committee presented its findings to the faculty, who subsequently incorporated it into the 2003 *Strategic Plan* as described elsewhere. It was found that not only was such a joint undergraduate degree in “ocean and mechanical engineering” feasible but that it would lead to a significant increase in the number of students studying ocean issues as part of their MIT undergraduate experience, as well as increase class sizes and OE faculty participation in undergraduate teaching at the Institute. It would give the students a “mainstream” ME degree in addition to their OE degree, thus overcoming the common misperception of ocean engineering being a “narrow” discipline. The plan for the OE track in Mechanical Engineering developed by Professor Patrikalakis and his colleagues on the OE Undergraduate Committee forms the core of the current proposal for such a new degree negotiated by the OE–ME Merger Committee in June 2004.

Professor Milgram developed and taught a new subject on boat design, following strong demand by students in OE and other departments. Professor Milgram is recognized as one of the principal world experts in boat design and, not surprisingly, he had 20 students taking the subject in the 2004 fall semester. As mentioned earlier, Professor Milgram delayed his well-deserved sabbatical to teach this class, 13.024 Numerical Marine Hydrodynamics, and revised the curriculum.

Dr. Franz Hover taught 13.017/018 Design of Ocean Systems I and II with Tom Consi this year. Teaching of 13.017/018 was based, as in previous years, on a single focusing challenge. Course 13.017 students made a final presentation entitled “Unser Weg Zum Rotor (Our Path to the Rotor)” to faculty, students, and invited guests in May 2004.

Together with faculty in EECS and AAE, Professor Leonard initiated a curriculum development proposal for a new interdisciplinary robotics course. The proposal was strongly endorsed by the three departments and was selected for funding by the dean in June 2004. Professor Leonard also taught 6.836 Embodied Intelligence as one of the results of his increased interaction and affiliation with the Computer Science and Artificial Intelligence Laboratory.

## **Current Research Projects**

### **Hydrodynamics**

*Free Surface Hydrodynamics of High-Speed Vessels (Sclavounos).* This research proposed the development of analytical and computational methods for the study of the hydrodynamic performance of high-speed vessels in calm water and in waves.

*The Numerical Simulation of Breaking Waves and Spray and the Resulting Entrainment of Air Around a Ship (Yue).* This is a three-year joint program between MIT and Science Applications International Corporation (SAIC) to (a) obtain scientific understanding, and (b) develop complementary numerical capabilities to simulate the breaking of waves, the formation of spraysheets and droplets, and the resulting entrainment.

*Mechanistic Investigation of Small-Scale Air-Sea Coupled Dynamics Using LES (Yue).* This project is designed to develop direct-numerical and large-eddy simulation (LES) capabilities for mechanistic modeling of small-scale coupled air-sea dynamics and to understand the detailed mechanisms of air-sea coupling by performing LES of both the air and ocean turbulent flows with coupled free-surface boundary conditions.

*Nonlinear Wave Effects in the Large Amplitude Motion Program (Yue, Liu).* The objective of the combined two-year effort is to develop an effective and practical model for reconstruction of nonlinear incident irregular wave-fields based on wave-probe data or wave-energy spectra and to incorporate the model into the SAIC Large Amplitude Motions Program (LAMP) for nonlinear ship motion predictions.

*Deterministic Modeling of Water Entry and Drop of Mine-Shaped Bodies: An Essential Development for Stochastic Modeling (Yue, Kim, Liu).* This is a project for the prediction of water-entry impact and motion dynamics of underwater mines.

*Direct Phase-Resolved Simulation of Large-Scale Nonlinear Ocean Wave-Field (Yue, Liu).* This research is proposed to develop a new powerful capability, called SNOW (simulations of nonlinear ocean wave-field), for predicting the evolution of large-scale nonlinear ocean wave-fields using direct physics-based phase-resolved simulations.

*Mechanics of Flow-Structure Interactions for Marine Cables (Triantafyllou).* A three-year theoretical and experimental effort is proposed to study the basic mechanisms governing the problem of flow-structure interaction of marine cables in shear flow. The experimental effort includes development of a forced-cylinder apparatus with closed loop control, which will allow simultaneous computer simulation and experimental data gathering.

*Multimode Response of Cables in the Ocean: Experiment-Based Prediction (Triantafyllou, Hover).* This research is designed to develop an experiment-based predictive methodology, which will also be implemented in WHOI-Cable, to predict the multimode vortex-induced vibration (VIV) response of long ocean cables and tethers; and to map VIV properties beyond the onset of the drag crisis, up to Reynolds number 400,000.

*Flow Visualization Apparatus for Flow-Induced Vibration at High Reynolds Number (Triantafyllou, Techet, Hover).* DURIP funds were received for a high-Reynolds number force-measuring and flow visualization apparatus to be used for flow-induced vibrations of bluff and streamlined bodies and unsteady motion of foils at high Reynolds number—at least 500,000 based on diameter or chord. The system will be specially designed and mounted on the MIT Propeller Tunnel.

## **Structures and Dynamics**

*Harvard University MURI Project (Wierzbicki).* The main objective of the proposed research program is to get an in-depth understanding of the mechanics of deformation and tearing of metal structures subjected to a contact or stand-off explosion. Based on this knowledge, an optimization process will be promoted and several innovative design concepts of hull protective structures will be put forward for immediate verification and implementation by the US Navy.

*Instron 8803 VHS Dynamic Test System for Studying Fracture Due to Explosive and Impact Loads (Wierzbicki).* Research is to expand the Integrated Circuits Lab's experimental base and to purchase unique equipment for testing materials and structures at high strain rate. This VHL system covers a wide range of strain rates up to 10 to the 3rd 1/sec and, in some loading configurations, an order of magnitude higher. The equipment can also be used for testing both materials and structures. A unique feature of the new system is that it will work parallel with our new custom design-and-build equipment for biaxial testing of materials.

*Advanced Ship Structural Design (Wierzbicki).* This research involves Professor Dale Karr of the University of Michigan to work together on the development of a fracture criterion from the physically based micromechanics and empirically based material testing and research involving Professor Al Brown of the University of Virginia to work together with the application of optimized sandwich panels for blast protection to the overall naval ship configuration.

## **Marine Robotics**

*Hydrodynamic Model for the REMUS Vehicle (Milgram).* This ONR proposal is to develop a computational model for REMUS motions under differing control commands through a range of vehicle depths and wave forces. MIT's proposal to WHOI is to extend the mathematical modeling of underwater vehicles and the REMUS Class vehicle in particular. This research will include the results of tank testing, comparison of the tank tests results with the open water test results, and development of an integrated mathematical model.

*Advanced Technologies for Autonomous Unmanned Surface Vessel Operation in Rough Seas (Yue, Liu).* This proposal describes the detailed tasks of the second phase of the seeding project on advanced technologies for autonomous unmanned surface vessel operation in rough seas. The research will be funded by ONR with the funding provided by DARPA.

*Development and Demonstration of a 3-D Flapping Foil Motion Control System for Advanced Marine Vehicles: CEROS 2003 Phase I Project (Yue, Liu).* The Phase I base program will cover Task 1: Flapping Foil Performance, in which MIT will lead the effort of analyzing the overall performance of 3-D flapping foil using numerical simulation program FLEX3D; Task 2: Vehicle Dynamic Simulation, in which MIT will assist the effort of integrating the 3-D flapping foil permanence model derived from Task 1 into LAMP for dynamic simulation of vehicle motion; and Task 3: Concept Design of a Flapping Foil Motion Control System, in which MIT will assist concept-level design of a flapping foil motion control system.

*Real-Time Feature-Relative Navigation and Obstacle Avoidance Using Wide-Beam Sonar (Leonard).* This research addresses the following two questions: (1) How can highly maneuverable AUVs use sonar for obstacle avoidance and feature relative navigation? and, (2) How can high maneuverability be exploited to develop new methods for mapping underwater scenes and for detecting and localizing objects?

*Initial Design of a Low-Cost Sonar System for Mapping Obstacle Avoidance, Detection, and Classification (Leonard).* MIT will perform experiments and numerical modeling for several different potential design configurations of a low-cost, wide-beam low-frequency (less than 100kHz) sonar system for mapping, obstacle avoidance, and object classification.

*Maneuvering Performance of Autonomous Underwater Vehicles (Hover).* This four-year effort will create high-fidelity models of Bluefin Robotics Corporation's BPAUV/Odyssey III

underwater vehicles, integrating experimental data and theoretical predictions into a comprehensive simulation tool. We will develop high-performance flight controllers for the vehicles in their various configurations; the focus will be on a linear control techniques, but we will also consider several highly nonlinear maneuvering scenarios. The proposed work includes substantial participation in field experiments with the vehicles, as well as assistance in formulating test procedures and developing improved vehicle designs.

## **Acoustics**

*Multistatic Active Acoustics of Ocean Waveguides (Schmidt)*. Professor Henrik Schmidt's research on the multistatic active acoustics project is to develop fundamental understanding of the acoustic environment of the seabed and to develop new numerical models of the 3-D scattering by seabed objects, such as mines and hazardous waste containers, on and below the seabed in shallow water. Closely tied to the multistatic acoustics effort is the Generic Ocean Array Technology Sonars (GOATS), a new system concept for acoustic observations in the ocean environment, replacing the traditional hard-wired hydrophone arrays. This is done by a virtual array of small underwater vehicles, each equipped with a small aperture array and linked together by high-bandwidth acoustic or optical links. GOATS is envisioned as the enabling technology that, with the new 3-D modeling capabilities, can be synergized into an entirely new sonar concept for mine countermeasures and undersea warfare in shallow water. This ONR project is conducted in close collaboration with the SACLANT Undersea Research Centre in La Spezia, Italy.

*Shallow Water MCM AND ASW Using Off-Board, Autonomous Sensor Networks and Multistatic, Time-Reversal Acoustics (Schmidt)*. This is a new project carried out jointly with Scripps and SACLANTCEN under a new ONR initiative, for which Professor Schmidt is chief scientist. This initiative is closely related to GOATS, aimed at developing multiplatform sonar concepts for seabed mapping and target detection.

*Adaptive Rapid Environmental Assessment (Schmidt)*. The objective of the MIT component in this research is to develop robust and reliable high-resolution navigation concepts, high-resolution acoustic tomography approaches, and optimal, adaptive-sampling strategies for collection of oceanographic and geological data by AUVs operating in a large-aperture sampling network.

*NPAL Acoustic Noise Field Coherence and Broadband Full Field Processing (Baggeroer)*. This research continues the NPAL low-range propagation experiments in the North Pacific. The primary focus for this effort is to study slope processes for propagation up and down slopes, over ridges, and around seamounts. Currently, the navy has extensive experience in deep water, or "blue water," and is now accumulating experience in the littoral, or "brown water." Important operating areas with changing bathymetry such as slopes, ridges, and seamounts include the western Pacific and the Arabian Sea near the Persian Gulf.

*Adaptive Array Processing in Stochastic and Snapshot-Limited Environment (Baggeroer).* Most adaptive array processing algorithms use the spectral density covariance matrix, which must be measured in any application. The paradox is that the more sensors that are in the array, the more “snapshots” that are required to estimate this matrix, so one can reach the point where additional sensors actually degrade performance. In addition, most algorithms treat the desired signal with a single degree of freedom representation, whereas the ocean imparts a stochastic aspect to it. This research focuses upon mitigating the snapshot limit problem and designing novel methods that treat the stochastic aspect of the signal.

*Matched Field Processing for Active and Passive Sonars (Baggeroer, Schmidt).* This project is part of the ONR series of funded monographs documenting the state of the art in several fields of ocean acoustics. Professors Baggeroer and Schmidt (MIT), Kuperman (Scripps Institute of Oceanography), and Dr. Mikhalevsky (SAIC) are the coauthors of a monograph on “Matched Field Processing.”

Professors Baggeroer and Schmidt pioneered the development of matched field processing (MFP) in the late 1980s. MFP is a physics-based signal-processing approach that incorporates the substantial information contained in the multipath structure of the acoustic field in the ocean waveguide into the processing, rather than considering it noise as was common in conventional sonar processing. Thus it was demonstrated that this approach could be used, for example, to estimate the range source using an acoustic array and not only the classical bearing estimate provided by towed sonar arrays. The concept was rapidly developed in the 1990s and is now being transitioned into the operational navy. Baggeroer and Schmidt have been tasked by ONR, together with colleagues at Scripps and SAIC, to put together a monograph on MFP, to be completed and published in 2004.

*Identifying the Causes of Geological Clutter in Continental Shallow Waters, Phase I: The Geological Clutter Acoustic Reconnaissance Experiment (Makris).* The ONR Geoclutter Program, for which Professor Makris is the chief scientist, is an interdisciplinary, multi-institutional, experimental/theoretical program that will extend for five years or more and cost upward of \$20 million. The purpose of this program is to determine the causes of environmental clutter in the navy’s long-range active sonar systems. Clutter is the primary problem in active sonar operations in continental shelf environments. Two major offshore field experiments were conducted in 2001 and 2003. The dominant cause of the clutter, as recently found in the 2003 experiment, is from highly concentrated fish schools. The program has essentially developed a new technology for rapidly imaging and making movies of large underwater fish schools over tens of kilometers in near real time. This technology may become important in monitoring fish abundance, behavior, and response to environmental conditions in the US continental shelf environments that are rapidly being depleted of fish stock.

*ONR Graduate Traineeship Award in Ocean Acoustics for Ms. Deanne Symonds (Makris).* Each year, ONR funds only one or two Graduate Traineeships in Ocean Acoustics nationally. Only the most promising young students are selected. Ms. Symonds was an MIT OE undergraduate. Her research involves correlation of long-range acoustic

imaging data with local measurements of fish school concentration acquired during a major offshore field experiment in which she took part.

*ONR Postdoctoral Fellowship Award in Ocean Acoustics for Dr. Purnima Ratilal (Makris).* Each year, ONR funds only one or two Postdoctoral Fellowships in Ocean Acoustics nationally. Only the most promising young graduates receive this award. The purpose of this funding is to allow Dr. Ratilal to develop her skills in the area of ocean acoustics. Under this funding, Dr. Ratilal codesigned and directed the final major offshore field experiment of the ONR Geoclutter Program and has developed a number of fundamental new theoretical results for propagation and scattering in a random medium and imaging in a waveguide. She is currently writing a paper for *Nature* on the newly developed technology for rapidly imaging fish schools over a wide area in near-real time.

*ONR Graduate Traineeship Award in Ocean Acoustics for Mr. Joshua Wilson (Makris).* Each year, ONR funds only one or two Graduate Traineeships in Ocean Acoustics nationally. Only the most promising young students are selected. Mr. Wilson was chosen this year, and his proposed research is to accurately measure wind speeds and so accurately classify the destructive power of a hurricane using underwater acoustic techniques.

### **Other Research**

Professor John Leonard continues with a research program for the US Office of Naval Research as part of its new Autonomous Operations Future Naval Capabilities initiative. The goal of this four-year effort, which commenced in the summer of 2002 and involves a team led by the MIT spin-off company Bluefin Robotics, is to demonstrate rapid undersea search and survey over large areas using heterogeneous networks of AUVs. MIT's role in this project is to create a sensor data fusion architecture for multiple AUV navigation based on a novel formulation of cooperative simultaneous localization and mapping by multiple autonomous vehicles. Professor Leonard is also working on Sea Grant Project Data Fusion for Large-Scale Cooperative Autonomous Ocean Mapping, which started in March 2004 and will continue for two years, and on a one-year Oxygen Research Project with S. Teller and D. Rus.

Ocean Engineering faculty continue to have strong ties to the Sea Grant College Program, and several faculty conduct research with the cost center being Sea Grant but involving students and staff in the department.

Professor Nicholas Patrikalakis continued research on a major NSF and ONR project regarding Solid Freeform Fabrication (SFF), which has as its objective the development of a generalized solid modeling method for SFF, providing support for design, representation, visualization, and manufacture of solids with local composition control, which is not possible in today's CAD/CAM systems. Professor Patrikalakis also worked on another NSF-funded project in the CAD area relating to the intrinsic watermarking of solid bounded by sculptured surfaces. In addition, Professor Patrikalakis continued research on a new major NSF/ITR project named Poseidon and based on an earlier National Oceanic and Atmospheric Administration-funded project of the same name,

for rapid real-time interdisciplinary ocean forecasting in a distributed computing environment focusing on adaptive sampling and adaptive modeling aspects of the problem.

In addition to other ongoing projects, Professor Michael Triantafyllou also continues with research funded by Sea Grant and NAVSEA on the development of a biomimetic underwater vehicle capable of swimming in strong currents and large waves, thanks to fishlike flapping fins. This research will have many uses for oceanographic, reconnaissance, and archeological work underwater.

In March 2004, Professor Alexandra Tchetet began a project with Sea Grant called Basic Scaling Laws in Fast-Starting and Rapidly Maneuvering Fish.

Professor Chrys Chryssostomidis carries out all his research at MIT Sea Grant. He continues his role as principal investigator for the National Naval Engineering Research and Education Consortium, funded as one of the three National Naval Responsibilities Initiatives. Other department faculty and staff involved in this program are David Burke, Tomasz Wierzbicki, Michael Triantafyllou, and Dick Yue.

**Henrik Schmidt**  
**Acting Department Head**  
**Professor of Ocean Engineering**

*More information about the Department of Ocean Engineering can be found on the web at <http://oe.mit.edu/>.*