Department of Mechanical Engineering

This has been a transformative year for the Department of Mechanical Engineering (ME). We recognized that the department has evolved dramatically over the past decade and that its longtime organization into three divisions was outdated. Instead, seven key thrust areas were identified that span our mechanical engineering core competencies and address critical mechanical engineering or societal needs and opportunities. These areas are as follows:

1. Mechanics
2. Product realization
3. Controls, instrumentation, and robotics
4. Energy science and engineering
5. Ocean science and engineering
6. Bioengineering
7. Nano/micro science and technology

The three areas of mechanics, product realization, and controls, instrumentation, and robotics are based on the need to predict mechanical and thermal phenomena, to synthesize new artifacts and systems, and to automate, monitor, and manipulate systems, respectively. The three areas of energy science and engineering, ocean science and engineering, and bioengineering are motivated by both fundamental and applied needs in efficient energy conversion and utilization technologies for sustainable energy supplies; in ocean exploration, responsible exploitation, transportation, and security; and in the life sciences and medicine, respectively. Finally, the area of nano/micro science and technology focuses on the need to develop the foundations and applications of the rapidly developing new field of the very small.

The department will carry out its mission with a focus on these areas, and all of our activities—undergraduate and graduate education, research agenda, and academic organization—will be informed by these areas. These are the areas in which we shall seek to achieve excellence, impact, and critical mass, and in which we shall attract and impassion the best undergraduate and graduate students and faculty.

Most departments in the MIT School of Engineering contribute to these same areas; furthermore, the methodologies brought to bear in these areas are common to virtually all of engineering. The former is a result of the multidisciplinary complexity of our increasingly advanced engineering systems; the latter is the result (perhaps) of convergent evolution. Mechanical engineering faculty must and do participate in many different communities that transcend traditional engineering disciplinary boundaries.

But we also recognize the essential mechanical engineering distinction: the importance of mechanical and thermal phenomena in all of our activities. These phenomena provide the focus for our models and methodologies, the inspiration for our processes and products, the "medium" for our engineering and technological innovation, the bases for our larger multidisciplinary inquiries, and the examples with which we develop engineering and problem-solving skills in our students.

The department is committed to contributing significantly to the vibrancy of engineering in the 21st century. In particular, the seven areas shall permit us to provide our students with meaningful connections between engineering and the humanities and arts, social sciences, and management; to motivate our students with inspiring and new engineering opportunities for real impact and creative expression; to share with our students our sense of passion for mechanical *mens et manus;* and to promote in our student body both diversity in background and a richness of professional styles, interests, and career aspirations.

A second major organizational change that occurred this year is that the Institute decided to fold the activities and programs of the Department of Ocean Engineering (OE) into ME. The newly constituted department will continue as the Department of Mechanical Engineering and retains the Course 2 label. We firmly believe that the oceans are critical to the future of humankind. We intend to keep the study of the oceans vibrant and visible and to maintain MIT's premier position as a center of excellence for ocean science and engineering.

In order to help sustain the visibility of ocean studies at MIT, we have created a Center for Ocean Engineering. Its director is Professor Michael Triantafyllou. The department will continue to sustain and grow MIT's relationship with the Woods Hole Oceanographic Institution and the US Navy. In addition, we have retained most of the graduate degrees in ocean engineering and created a new SB degree in mechanical and ocean engineering.

As a consequence of the merger, many of the department's core disciplinary areas have been strengthened. In particular, we have added the following numbers of faculty members to our various areas: eight in mechanics (three focus on fluids, two on structures, and three on acoustics), two in robotics, two in product realization (more specifically, design), one in energy, and one in systems. In addition we have two new professors of the practice who specialize in naval ship design.

In order to introduce the faculty to each other and develop closer interactions between them, Neil and Jane Pappalardo provided funding for five graduate fellowships. These have been used to initiate five new joint projects between ME and former OE faculty. This funding is enabling the following collaborations: Professors Tom Peacock and Alex Techet (experimental fluid mechanics); Professors Paul Sclavounos and Alex Slocum (wind energy); Professors David Parks and Tomasz Wierzbicki (fracture); Professors Doug Hart and John Leonard (robotic systems); and Professors Jean-Jacques Slotine and Michael Triantafyllou (biomimetic multiagent robotics).

Research Highlights

As can be inferred from the awards received by the faculty, the department has many thriving and vibrant research programs. A few research projects, selected randomly, are described here.

Professor Kimberly Hamad-Schifferli's group has developed nanoscale antennas for controlling biology. An external field can be used to "talk to" the antennas, turning on and off the activity of proteins in cells that are linked to the nanoantennas. This technology will enable new routes for diagnosing diseases and manipulating a wide range of biological functions noninvasively.

Professor Nick Makris' group has answered the question of whether there is an ocean beneath the frozen surface of Jupiter's moon Europa. They have shown that the strange cycloidal arcs that extend for thousands of kilometers across Europa's surface are tidally driven fractures and that these cycloids can form only if an ocean of liquid water is present below Europa's ice shell. They are currently working with NASA to put a landed package on Europa's surface to make seismic measurements.

Professor George Haller of our Nonlinear Dynamical Systems Lab has solved the long-standing problem of determining a flow separation criterion for unsteady flow. Flow separation is the prime reason for aerodynamic performance loss for helicopter rotors, turbines, diffusers, and airplanes. Prandtl's classic 1904 theory describes separation in steady flows, but an unsteady separation criterion has only now been theoretically proven and experimentally validated. Current work involves the implementation and use of the theory in smart flow control.

Professor Nicolas Hadjiconstantinou, working in the broad area of atomistic modeling, has been establishing modern theoretical approaches for describing small-scale mechanics beyond the limits of classical continuum theories. In particular, he has formulated a hybrid atomistic-continuum method in which, by limiting the molecular treatment to the regions only where it is needed, the formulation allows the simulation of large-scale problems requiring modeling at the molecular scale without the prohibitive cost of a fully molecular solution.

Professor Daniela Pucci de Farias' research group has addressed fundamental issues arising from the high dimensionality of most decision-making and optimization problems in systems of practical interest. They are attempting to delineate limits on achievable performance, propose optimality paradigms, and design optimization algorithms that reflect those limits, with the ultimate goal of achieving a methodology that is scalable, robust, and widely used. Applications currently being considered include ocean exploration, homeland security, and electricity grids.

Education Highlights

Our educational programs remain strong. Our subjects continue to be popular, and their contents are continually updated and revitalized. A number of new subjects have been developed in the past couple of years, a few of which are described below.

Professors Kim Hamad-Schifferli and Linda Griffith have created the subject 2.772 Thermodynamics of Biomolecular Systems, which introduces fundamental concepts in molecular thermodynamics including derivation of the laws of classical thermodynamics using statistical mechanics. Applications of the subject to conformation of macromolecules, cooperative interactions between macromolecules, and molecular self-assembly into mesoscale structures are explored. The subject is intended to provide a sophomore-level foundation for further study in molecular mechanics, biomechanics, nanotechnology, polymer science, and structural biology. It will also serve as a core required subject for the new undergraduate major in biological engineering.

Professor Daniela Pucci de Farias has created the subject 2.193 Decision-Making in Large-Scale Systems. About a third of the subject is devoted to a background on exact dynamic programming; the remainder is dedicated to theory, algorithms, and applications in approximate dynamic programming. Students are encouraged to propose research problems from their own areas as class projects and to explore applications of the subject's ideas. The subject has been designed to be cross-disciplinary and has attracted students from Mechanical Engineering, Electrical Engineering and Computer Science, Aeronautics and Astronautics, Operations Research, Engineering Systems, and Ocean Engineering, among others.

The subject 2.672 Projects Lab has been a long-standing cornerstone of our undergraduate program. The students are presented with a technical problem that they are to observe, model, simulate, and solve, much like a technical consulting problem. They must draw upon any number of disciplines, and little guidance is given. Professor Matt Lang has introduced a new 2.672 lab experiment using optical tweezers to measure the torque and rotational velocity of the biological motor of bacterial flagella. The experiment permits students to explore life at a low Reynolds number. Students work with an optical microscope to measure distances on the scale of nanometers and forces at the level of piconewtons. One student finished his report with a statement that compared the flagellum motor, based on mass and volume, to a high-end V-8 Mustang engine.

A new subject, 2.76 Multiscale System Design and Manufacturing, has been developed by professors Culpepper and Kim that is one of the first courses anywhere on multiscale system engineering. The subject enables our students to learn how to design, model, and fabricate mechanical systems that are comprised of nano-, micro-, meso-, and macroscale components. The subject covers the phenomena and physics that govern the behavior of mechanical components on the nano/micro/meso/macroscale, how to model systems with different scale components, and how to engineer systems in which parts from different scales work together. Students master the materials via a term project in which they design, model, fabricate, and test a multiscale system: a scanning tunneling microscope.

The Undergraduate Committee, after numerous conversations with the leadership of our undergraduate honor society, conducted a very useful survey of the majors on our undergraduate curriculum. The results have been illuminating and will drive some curricular changes in the upcoming year.

Undergraduate Program

Table 1. Undergraduate Enrollment in Mechanical Engineering and Ocean Engineering (Figures in Parentheses), Academic Years 2000 to 2005

	AY2000	AY2001	AY2002	AY2003	AY2004	AY2005
Sophomores	121 (9)	106 (8)	83 (3)	76 (6)	113 (8)	126 (4)
Juniors	113 (4)	116 (5)	91 (5)	81 (5)	72 (6)	105 (6)
Seniors	149 (6)	127 (4)	118 (7)	107 (6)	91 (5)	105 (8)
5th-year students						13 (0
Totals	383 (19)	349 (17)	292 (15)	264 (17)	276 (19)	349 (18)
Total ME and OE	**402**	**366**	**307**	**281**	**295**	**367**

The following honors and prizes were awarded to our undergraduate students:

- Department Service Award for Outstanding Service to the ME Department: Ethan Crumlin, Christopher DiBiasio, Christopher MacMinn, Arlis Reynolds, Timothy Suen, and Amy Wong
- Society of Naval Architecture and Marine Engineering Award for Outstanding Undergraduate in the Marine Field: Lauren Cooney
- Robert Bruce Wallace Academic Prize for Academic Excellence and Outstanding Potential for Professional Leadership in Ocean Engineering: Jesse Austin-Breneman, 2005, and Michael J. Stanway, 2006
- Alfred A. H. Keil Ocean Engineering Development Fund Award for Excellence in Broad-Based Research in Ocean Engineering: Heather Brundage, spring 2005, and Michael J. Stanway, fall 2006
- American Bureau of Shipping Award for an Outstanding Incoming Graduate Student: Matthew Fox
- Carl G. Sontheimer Prize for Creativity and Innovation in Design: Xiaodong Lu
- Thomas Sheridan Prize for Creativity in Man-Machine Integration: Thaddeus Stefanov-Wagner
- John C. and Elizabeth J. Chato Award for Excellence in Bioengineering: Jeffrey Hsu
- Padmakar P. Lele Student Award for Outstanding Research and Thesis: Kevin Chen and Meredith Silberstein
- Outstanding UAs, Course 2.670: Richard Diaz and Adam Kaczmarek
- Luis de Florez Award for Outstanding Ingenuity and Creativity: Alexander Mark Mekelburg, 1st Place, and Nathan Barker Ball, 2nd Place
- Peter Griffith Prize: Ian Collier
- AMP Inc. Award for Outstanding Performance in Course 2.002: Ali Ahmed and Miguel Saez
- Whitelaw Prize for Originality in 2.007 Design and Contest: Cynthia Walker, Robert Panas, and Emmanuel Sin
- International Design Competition for Course 2.007: Mark Cote, Robert Panas, Phillip Dawson, Sang Nguyen, and Derrick Tann
- Wunsch Foundation Silent Hoist and Crane Award for Outstanding TAs in Course 2.007: Jaime Werkmeister and Patrick Willoughby
- Outstanding Performance in Course 2.008: Thor Eusner and Wey-Jiun Lin
- Academic Excellence in Course 2.002: Justin Moore and Christopher MacMinn

Graduate Program

Our graduate program continues to be strong (Table 2). Of the students in the master's program, 29% are international, 23% are women, and 4% are persons of color. Our students were supported by research assistantships, 24 National Science Foundation fellowships, 41 Department of Defense fellowships, and 35 fellowships from other sources (National Institutes of Health: 19, National Aeronautics and Space Administration; 5, Department of Energy: 5, other federal: 6).

Table 2. Graduate Enrollment in Mechanical Engineering and Ocean Engineering (Figures in Parentheses), Academic Years 2000 to 2005.

	AY2000	AY2001	AY2002	AY2003	AY2004	AY2005
Master's	213 (66)	220 (70)	189 (81)	170 (73)	180 (81)	194 (87)
Doctoral	171 (36)	161 (36)	179 (26)	181 (28)	178 (29)	190 (37)
Total	384 (102)	383 (106)	368 (107)	351 (101)	358 (110)	384 (124)
Total	**406**	**489**	**475**	**452**	**468**	**508**

This past year, 718 students applied for admission to our graduate programs; 27% of them were offered admission, of whom 54% matriculated.

The Meredith Kamm Memorial Award for the Outstanding ME Woman Graduate Student was shared by Katherine Lilienkamp and Nur-Aida Abdul Rahim.

Faculty Notes

Mechanical Engineering faculty members received the following honors and awards during AY2005.

Ali Argon—Outstanding Mechanical Engineer award and honorary doctorate in engineering from Purdue University

Klaus-Jurgen Bathe—honorary doctorate from the Technical University of Madrid (Universidad Politecnica de Madrid)

Mary Boyce—ASME fellow

Martin Culpepper—Presidential Early Career Award for Scientists and Engineers; and named one of Technology Review's 100 Young Innovators

Forbes Dewey—fellow of the American Physical Society

Daniela Pucci de Farias—NSF Career Award

Dan Frey—NSF Career Award; Noyce assistant professorship

Leon Glicksman—ASME fellow

Elias P. Gyftopoulos—AAAS fellow

George Haller— Young Investigator Award, Applied Mechanics Division, ASME

Kimberly Hamad-Schifferli—Edgerton assistant professorship

Neville Hogan—honorary doctorate from the Dublin Institute of Technology

Roger Kamm—Germeshausen professorship

Gareth McKinley—MIT Class of 1960 fellow

Bora Mikic—AAAS fellow

Thomas Peacock—ARCO assistant professorship

Ely Sachs—SME fellow

Henrik Schmidt—Pioneer's Silver Medal for Underwater Acoustics from the Acoustical Society of America

Alex Slocum—Leonardo da Vinci Award for Innovation, ASME

Amy Smith—MacArthur Foundation fellow

Joseph Smith—Georgia Tech's Engineering Hall of Fame (the highest honor bestowed by the College of Engineering at Georgia Tech)

Kim Vandiver—2005 Distinguished Achievement Award from the Offshore Technology Conference

In addition, Deshpande Center for Technological Innovation honors were awarded to John Brisson, for his novel ice-cream production method; Martin Culpepper, for HexFlex: enabling nanofabrication with a six-axis nanomanipulator; and Yang Shao-Horn, for engineered electrode assemblies for PEM fuel cells

Rohan Abeyaratne
Department Head
Quentin Berg Professor of Mechanics and MacVicar Faculty Fellow

More information about the Department of Mechanical Engineering can be found online at http://me.mit.edu/.