

Department of Mechanical Engineering

This has been a good year for the Department of Mechanical Engineering. We maintained our ranking as the number one department in the field according to *U.S. News and World Report*. Our students and faculty have continued to be recognized for their originality and impact on research, education, and leadership in the field of mechanical engineering. The various honors bestowed include awards from national and international organizations. The full list can be found at the end of this article, but we mention here that Charles Vest (professor of mechanical engineering) was elected to be the new president of the National Academy of Engineering. In addition, Robert Langer (professor of chemical and mechanical engineering) and Charles Vest were both awarded the Presidential Medal for Technology.

We are very pleased to welcome the six new faculty members who joined us this year: Tonio Buonassisi (PhD, University of California, Berkeley, energy), Franz Hover (PhD, MIT, robotics), Rohit Karnik (PhD, University of California, Berkeley, microfluidics), Pierre Lermusiaux (PhD, Harvard, ocean sciences), Evelyn Wang (PhD, Stanford University, energy), and Maria Yang (PhD, Stanford University, design). These appointments are consistent with our strategic plan of making hires that simultaneously strengthen our mechanical engineering core and extend our research activities into exciting new application areas. The retirement of Woodie Flowers, after many years of extraordinary service to engineering education at both Institute and high school levels, is a tremendous loss.

Since we expect to have almost 10 new hires in the next two to three years as a result of the merger of ocean engineering and mechanical engineering, we thought it was more important than usual to think carefully and strategically about how we will deploy these hires. In addition to decisions to be made in the areas of hiring, we also have to consider the option, for example, of using three junior faculty slots to hire two senior faculty members. The department's Research Council spent the entire year studying this critical issue in detail and made specific recommendations to the mechanical engineering faculty at the end of the spring term. Based on this we have identified our hiring priorities for the next three years and expect to make three new appointments in the coming year. Accordingly, we have initiated searches in the areas of computational mechanics, energy, and design and manufacturing.

We have begun a discussion with a foreign university for an exciting collaborative program between their mechanical engineering department and ours. If this comes to fruition, the Department of Mechanical Engineering at MIT will receive \$50 million over five years of which \$10 million will be for endowed graduate fellowships in the department and \$40 million will be for joint research programs in four thrust areas: energy, desalination, and design and manufacturing for energy and environmental applications, and micro/nanotechnology for biomedical applications. Our partnering university will have research students cosupervised by MIT faculty, and their faculty will have the opportunity to visit MIT and sit in on our classes and pick up techniques they can then implement in their home university. The details of the agreement are being

worked out and we are optimistic that it will be signed and that the program will soon begin. Further details will be given in next year's report.

We are about to launch an initiative on *how* we teach (rather than *what* we teach). We invited many guest speakers during the past year to address us on modern developments in this area, and it is clear that, while many of our faculty members have developed and adopted new teaching methods, there are many methods well beyond the standard chalk-and-talk lecture that we have not yet adopted widely. These methods include the use of concept questions, mud cards (on which students pinpoint concepts muddiest to them) and personal response systems, reflective memoranda, assessments based on learning objectives, and discovery-based learning. We will kick off this initiative in September with a departmental retreat where we will have discussions led by academic leaders in engineering education (from Harvard, Stanford, and Carnegie Mellon Universities) and representatives from some of the most creative technology companies (including Apple and IDEO). Through generous support of Alex and Brit d'Arbeloff, we will have funding for this effort to assist, recognize, and reward faculty participants.

The summer Women's Technology Program for high school juniors that we started last year is continuing. This year it is being funded by Alex and Brit d'Arbeloff. The program is conceived, developed, and taught by a small group of women mechanical engineering graduate students. Twenty female high school students came to MIT for four weeks to take classes, work on design, and build Rube Goldberg machines. The program was intended for young women who are good at math and science but intimidated by technology. It was a great success and we plan to continue offering it in future years.

The Center for Ocean Engineering has had an outstanding year: negotiations are nearing completion for a multiyear, million plus dollars/year project funded by Chevron concerning deep water hydrocarbon production. Faculty in the center are also centrally involved in the pending underwater surveillance and monitoring SMART program with Singapore, which will bring \$43 million over five years. The Naval Construction and Engineering Program continues to be strong. The program held a successful US Navy-MIT-Industry Ship Design Symposium in May where student teams presented both conversion and new concept ship designs to civilian and naval ship-building authorities.

Professor Tau-Yi Toong passed away this year. He joined the faculty in 1952 and worked in the fields of combustion, heat transfer, and fluid mechanics. He wrote a book on combustion dynamics considered to be the definitive book on the subject at that time.

Some 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 below:

Professor Nicolas Hadjiconstantinou is a member of Areas 1 (mechanics) and 7 (micro/nanotechnology). His research focuses on developing molecular-based descriptions of small-scale thermal and mechanical phenomena for which traditional macroscopic

formulations fail. Equal emphasis is given to theoretical descriptions and the development of efficient molecular methods for the simulation of complex systems of engineering interest.

Professor Daniel Frey's group in Area 2 (design and manufacturing) studies the design process by means of probabilistic models and empirical investigations. They recently demonstrated that teams of engineers selecting design concepts by iterated comparison with a baseline attain better results than teams that use voting procedures such as the Borda count. This work has been recognized with a Best Paper Award from the American Society of Mechanical Engineering.

Professor David Trumper's (Area 3, controls, robotics, instrumentation) research efforts center on designing novel precision electromechanical systems. He is engaged in an active collaboration with Professor Robert Hocken of the University of North Carolina, Charlotte, and Mark Schattenburg of the Kavli Institute at MIT in projects for precision motion systems in support of accurate measurement devices for use in semiconductor fabrication and nanotechnology. These projects are also investigating fabrication of extreme accuracy gratings for use as reference artifacts in nanometrology systems. In collaboration with the Control Systems Group at the MIT Lincoln Laboratory, Professor Trumper and his students have designed advanced fast steering mirrors for optical communications, such as might be used in high-speed data links from spacecraft to earth or between aircraft. These fast steering mirrors are used to maintain tracking of the tightly focused optical beams used for such communications. Their experimentally-demonstrated prototype has the highest performance of any reported beam steering mirror system and is the subject of a current patent filing. Most recently, Professor Trumper's group is studying novel approaches for high-speed, high-accuracy scanned probe microscopes for nanometrology, such as might be used in semiconductor fabrication.

Professor Cheng's group in Area 4 (energy) and the Sloan Automotive Laboratory have made major advances in a new combustion system for an internal combustion engine. The homogeneous-charge-compression-ignition (HCCI) engine can significantly increase fuel economy and lower harmful exhaust emissions. This group successfully developed the control strategy for transitioning a gasoline engine between the conventional spark-ignition mode and the HCCI mode. Current work involves extending the control strategy to turbo-charged engines.

Professor Alexandra Techet of Area 5 (ocean science and engineering) and her experimental hydrodynamics group have identified key hydrodynamic criteria for the inception of splash for water-entry problems, which applies for bodies with and without high-speed rotation. The inception criterion is related to dynamic wetting angle and is affected by the surface coating up to a certain impact speed, above which splash will always occur. Key hydrodynamic forces are modeled using empirical data. This project, funded by the Office of Naval Research, also has direct applications to ship slamming and naval ballistics research as well as impact of liquid droplets on solid surfaces.

Professor Matthew Lang's group in Area 6 (bioengineering) has been studying biological motors and cellular machinery with advanced techniques in single molecule biophysics. They have designed a next-generation instrument capable of combined optical trapping and single molecule fluorescence, fluorescence resonance energy transfer (FRET) detection. This instrument permits measurements of biomechanical force at the piconewton level and position at the nanometer level, while observing a system using single molecule fluorescence. To demonstrate the capability of the instrument, a model DNA hairpin was reversibly opened with force and the state of the hairpin, open and closed, was observed with fluorescence, FRET, changes. The lab is applying these next-generation instruments to the study of kinesin and ClpXP biological motors and the cell machinery of actin filament-actin binding protein interactions. In collaboration with the Belcher group, the lab has developed a new tether strategy for single molecule measurements based on the M13 phage virus.

Professor Todd Thorsen's group in Area 7 (micro/nanotechnology) is developing microfluidics-based tools for cell biology. The need for faster and cheaper technologies to extract biological information, at the molecular and cellular levels, has driven the trend to miniaturize laboratory techniques in the last two decades. Working toward this goal, we are fabricating devices from biocompatible elastomers the size of a postage stamp with embedded microchannel networks controlled by thousands of integrated elastomeric valves. Innovative projects under active investigation in the laboratory include microfluidic devices for high-density cell toxicity screening, human fertility monitoring, and bacterial biofilm formation in human dental plaque.

Some 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 mentioned below.

Professors Sang-Gook Kim, Todd Thorsen, and Carol Livermore are developing a new subject, 2.674 Micro/Nano Engineering Laboratory. It is designed for undergraduates who are planning future study in micro/nanotechnology. Students are first exposed to the essential tools of micro/nanoscience and engineering and then are taught to think and learn about the underlying scientific and engineering principles through the hands-on experience of observing, building, and manipulating nano/bio/microstructures.

Professor Yang Shao-Horn created a new subject, 2.625, entitled Electrochemical Systems: Fundamentals, Materials, and Applications, in fall 2006. This cross-disciplinary subject covers thermodynamics and kinetics of chemical and electrochemical reactions, principles of catalysis and electrocatalysis, and synthesis and properties of bulk materials and nanomaterials of relevance; the course also discusses state-of-the-art electrochemical energy technologies such as lithium rechargeable batteries, electrochemical capacitors, fuel cells, photoelectrochemical cells, and electrolytic cells. The subject includes laboratory demonstration of electrochemical measurements such as electrochemical impedance spectroscopy, cyclic voltammetry, and current and voltage step methods. Students from mechanical, chemical, and electrical engineering; materials science; physics; and chemistry and students from Harvard take this class.

Professor Nicolas Hadjiconstantinou has introduced subject 2.370(U)/2.37(G), Molecular Mechanics, in response to the growing interest in microelectromechanical systems and nanotechnology within the department and the Institute in general. The subject aims to introduce students to the fundamentals of molecular modeling in engineering in a way that complements the macroscopic approaches taught in core mechanical engineering subjects. For example, particular emphasis is given to presentation of the molecular origin of macroscopic approaches as a means of highlighting the connection between the two but also as a means of understanding the limitations of the latter. The subject also provides an introduction to molecular simulation, which is rapidly pervading the field.

Undergraduate Program

Table 1. Undergraduate Enrollment in Mechanical Engineering and Ocean Engineering (Figures in Parentheses), Academic Years 2003 to 2007

	AY2003	AY2004	AY2005	AY2006	AY2007
Sophomores	76 (6)	113 (8)	126 (4)	130 (4)	131
Juniors	81 (5)	72 (6)	105 (6)	126 (5)	130
Seniors	107 (6)	91 (5)	105 (8)	122 (5)	122
5th-year students			13 (0)	0 (0)	14
Total	281	295	367	392	397

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

- Department Service Award for Outstanding Service to the Department of Mechanical Engineering: Brentan Alexander, Julie Arsenault, Krishnan Sriram, Helen Tsai
- Park Award for outstanding performance in manufacturing: Gina Angelosanto, Stuart Rossen
- Society of Naval Architecture and Marine Engineering Award for Outstanding Undergraduate in the Marine Field: Ashley Cantieny, Edward Huo, Evan Karlik, James Sannino
- Robert Bruce Wallace Academic Prize for Academic Excellence and Outstanding Potential for Professional Leadership in Ocean Engineering: Julie Arsenault
- Alfred A. H. Keil Ocean Engineering Development Fund Award for Excellence in Broad-Based Research in Ocean Engineering: Ashley Cantieny, Edward Huo
- American Bureau of Shipping Award for advanced research in marine engineering and naval architecture: Bridget Downey
- Carl G. Sontheimer Prize for Creativity and Innovation in Design: Alex Slocum, Jr.
- John C. and Elizabeth J. Chato Award for Excellence in Bioengineering: Bryan Owens, Stephanie Reed
- Padmakar P. Lele Student Award for Outstanding Research and Thesis: Brentan Alexander, Won Yong Lee, Emily Pfeiffer, Amit Surana

- Outstanding Undergraduate Assistant in Course 2.007 Design and Manufacturing I: Daniel Schultz
- Luis de Florez Award for Outstanding Ingenuity and Creativity: Mark Cote, Ilan Moyer, Gregory Schroll
- Peter Griffith Prize for Outstanding Undergraduate Thesis: Emmanuel Sin
- AMP Inc. Award for Outstanding Performance in Course 2.002 Mechanics and Materials II: Tania Ullah, Orian Welling
- Wunsch Foundation Silent Hoist and Crane Award for Outstanding Teaching Assistants in Course 2.007 Design and Manufacturing I: Moneer Helu, Lucas Hernandez-Mena, Morgan Laidlaw, Stuart Rossen
- Excellence in Bioengineering: Iliana Jaatma
- Outstanding Research and Thesis: Arvind Narayanaswamy
- Whitelaw Prize (originality in design, 2.007 contest): Adam Paxson, Jeremy Richardson
- International Design Contest (2.007 contest): Stephanie Sidelko, David Sanchez, Nathaniel Sharpe, Lawrence Maligaya

Graduate Program

Our graduate program continues to be strong, with a total of 469 students. Of the students in the master's program, 22 percent are international, 16 percent are women, and five percent are persons of color. Our students were supported by research assistantships, 13 National Science Foundation fellowships, eight Department of Defense fellowships, and 66 fellowships from other sources (including the National Aeronautics and Space Administration, Woods Hole Oceanographic Institution, Dupont, Gates, and Lemelson).

Table 2. Graduate Enrollment in Mechanical Engineering and Ocean Engineering (Figures in Parentheses), Academic Years 2003 to 2007

	AY2003	AY2004	AY2005	AY2006	AY2007
Master's	170 (73)	180 (81)	194 (87)	174 (70)	209
Doctoral	181 (28)	178 (29)	190 (37)	200 (35)	260
Total	351 (101)	358 (110)	384 (124)	374 (105)	469
Total ME & OE	452	468	508	479	469

This past year, 832 students applied for admission to our graduate programs; 25 percent of them were offered admission, of whom 59 percent matriculated.

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

- Meredith Kamm Memorial Award for the Outstanding Mechanical Engineering Woman Graduate Student: Paula Echeverri, Melissa Read

- Daphne and George Hatsopoulos \$50,000 Innovation and Thesis Award:
Tim Fofonoff
- Link Foundation Doctoral Research Fellowship to foster ocean engineering and ocean instrumentation research: Brenden Epps
- Clement F. Burnap Award for outstanding masters of science in the marine field:
Evan Lee
- Lemelson-MIT Student Prize: Nathan Ball
- Marine Technology Society's Outstanding Student Section Award: 13SEAs
- MIT's \$100K Entrepreneurship Competition, Business Venture Grand Prize:
Nevan Hanumara and Conor Walsh
- MIT's \$100K Entrepreneurship Competition, Development Grand Prize:
Amy Banzaert
- Best Student Paper Award at the 153rd Meeting of the Acoustical Society of America: Kevin Cockrell

Faculty Notes

The following awards and prizes were presented to our faculty:

- Rohan Abeyaratne: president of the American Academy of Mechanics
- Lallit Anand: Khan International Medal for outstanding lifelong contributions to the field of plasticity
- Arthur Baggeroer: Outstanding Electrical and Computer Engineer Award, Purdue University, Distinguished Alumnus of Purdue University
- John Brisson: Promotion to full professor
- Steven Dubowsky: Best Paper Award at the 12th World Congress in Mechanism and Machine Science
- Dan Frey: ASME Best Paper Award in Design Theory and Methodology
- Ahmed Ghoniem: Ronald C. Crane Professorship in the School of Engineering
- Linda Griffith: MacArthur "Genius" Fellowship
- David Hardt: Ralph E. Cross and Eloise F. Cross Professorship in Mechanical Engineering
- Robert Langer: National Medal of Technology
- John Leonard: Promotion to full professor, best paper in 2006 to appear in IEEE Transactions on Robotics and Automation
- Carol Livermore: NSF CAREER Award, Deshpande Award for Innovation, Spira Award for Distinguished Teaching
- Christopher Magee: 2006 Elsevier prize for the best paper in Technological Forecasting and Social Change

- Gareth McKinley: Editorial board of the Journal of Fluid Mechanics, elected to the USNC/TAM (US National Committee on Theoretical and Applied Mechanics of the National Academy of Engineering)
- Chiang Mei: Theodore Von Karman Medal of the American Society of Civil Engineers
- Thomas Peacock: NSF CAREER Award, promotion to associate professor without tenure
- Yang Shao-Horn: 2006 Dupont Young Faculty Award, promotion to associate professor without tenure
- Alexander Slocum: Pappalardo Professorship, Deshpande Award for Innovation
- Nam Suh: president of Korea Advanced Institute of Science and Technology (KAIST), honorary doctorate from the Technion, SPE's Lifetime Achievement Award
- Subra Suresh: honorary doctorate from Sweden's Royal Institute of Technology (Kungliga Tekniska Högskolan), honorary member of the Spanish Royal Academy of Sciences
- Charles Vest: President of the National Academy of Engineering, National Medal of Technology
- David Wallace: MacVicar Fellow, Bose Award for Excellence in Teaching, Everett Moore Baker Memorial Award for Excellence in Undergraduate Teaching
- Dick Yue: Philip J. Solondz Professorship

Rohan Abeyaratne
Department Head
Quentin Berg Professor of Mechanics

Additional information about the Department of Mechanical Engineering can be found at <http://meche.mit.edu/>.