Department of Mechanical Engineering

The breadth, depth, and versatility of mechanical engineering has never been more relevant to the world's challenges than it is today. Within this field, MIT's Department of Mechanical Engineering (MechE) remains a leader, defining and pushing the frontiers in both education and research and offering the top undergraduate and graduate mechanical engineering programs in the nation and the world, with the top minds in the field at the helm. We continue with pride on our mission to educate and mentor the next generation of leaders in industry, academia, and government at all levels. Our undergraduate program is at its highest enrollment in history with 490 students; our graduate program continues to thrive with more than 500 students; and our research programs also incorporate a growing postdoctoral population of nearly 70 fellows and associates.

Our 72 faculty members have an externally funded research portfolio of more than $50 million and a focus on bringing innovative technical solutions to major issues of the 21st century such as energy, water, health, transportation, and the environment. They are sharply focused as well on defining the next generation of engineering science and engineered processes needed to ensure a productive and prosperous future.

As a department, we are also focused on providing world-class educational and research spaces within which our faculty and students can pursue their work, and we strive to attract and enable top talent at all ranks. As a result, we have funded many space renovations throughout the department in recent years.

Our historical reflections over the past year, motivated by the MIT 150 Inventional Wisdom sesquicentennial celebration, have reminded us of the rich and remarkable past accomplishments that laid the foundation of mechanical engineering at MIT. During the past year, we have captured these as a written history of the department. Our long-standing mission to address individual and societal needs through the creative application of science follows a trajectory that had begun as early as 1870.

In this year's report, we provide snapshots of various areas of departmental excellence over the past year. Historical and celebratory activities revolving around the MIT 150 celebration are highlighted in a brief historical retrospective section. Subsequent sections of the report include a short synopsis of faculty news, including hiring and promotions; selected research highlights across the department; space renovation highlights undertaken or completed to enable our world-class programs; education highlights with brief overviews of our undergraduate and graduate programs; and awards and recognition. These sections provide a small sampling of the diversity, breadth, and depth of activities across the Department of Mechanical Engineering.

Historical Retrospective

The MIT 150 sesquicentennial event created an atmosphere across the campus that celebrated the inventive spirit of MIT, the *mens et manus* education and research environment that embodies MIT, and the unique and rich history of the innumerable contributions to society at large that have originated from MIT. It also provided a

time for us to reflect on the history of mechanical engineering at MIT in particular and celebrate what the Department of Mechanical Engineering is today.

The MIT 150 open house on Saturday, April 30, was indeed a grand celebration of our inventional wisdom, the result of extraordinary efforts by MechE faculty, student groups, and alumni. Our many department activities for this major event were orchestrated by professors David Parks and David Trumper. Throughout the day, faculty and students presented lectures and demonstrations on cutting-edge research topics, as well as exciting active demonstrations of biomedical product designs. Some of our many student teams, including the Electric Vehicle Team, MITERS, MIT Motorsport, and the Solar Electric Vehicle Team, showcased their recent projects in Rockwell Cage. Recent alums Bryan Schmidt and Nate Ball exhibited their automated rope climbing technology, which they invented as Course 2 undergraduates, in an exciting demonstration in Killian Court, with their Atlas Device taking them up a rope to the top of Building 3 and back again. The refurbished Hart Gallery engaged visitors with new exhibits drawing on the department's seven areas of research and presented models of bioinstrumentation and solar energy experimentation. The numerous exhibits and demonstrations of the day truly embodied the MIT motto *mens et manus*.

The MIT 150 celebration also provided an opportunity for us to reflect on the rich history of our department. We spent many hours combing through our archives and sampling faculty to compile major departmental events of the past 150 years as a way to remember and honor our impressive history and to use it as a solid base on which to build our unfolding future. An abbreviated MechE timeline is included below, and a more comprehensive PDF is available for download.

Mechanical Engineering's Rich History: An Abbreviated Timeline

1865: Mechanical engineering is one of six courses of study offered to the first class of MIT students.

1874: The department's first lab is established with the donation of a steam engine, inaugurating a focus on energy and power systems that remains at the core of MechE research today.

1893: MechE curricular options serve as the basis for Course 13, Naval Architecture, which later becomes Ocean Engineering in 1970 and then rejoins MechE in 2005.

1901: A program in naval construction is established as a collaboration between MIT and the US Navy. Its graduates include many of the Navy's fleet admirals.

1908: The first graduate program in MechE includes coursework in advanced steam and gas engineering, directed readings, and independent research.

1916: Lionel S. Marks publishes *Standard Handbook for Mechanical Engineers*, a codification of engineering knowledge that is still widely used today.

1929: The Sloan Automotive Laboratory is established.

1934: The Heat Measurements Laboratory, later renamed the Heat Transfer Laboratory, joins MechE.

1936: Joseph Keenan and Frederick Keyes publish *Steam Tables: Thermodynamic Properties of Water*, which remains a standard reference in the analysis and design of power systems.

1943: International expert on vibrations Jacob P. Den Hartog is recruited to MIT and serves as the MechE department head, bringing Westinghouse design school methods to the department's teaching of dynamics.

1946: Samuel C. Collins and colleagues perfect a helium liquefier that provides a reliable and affordable supply of liquid helium for research in superconductivity and semiconductors.

1957: H. Guyford Stever chairs the National Advisory Committee for Aeronautics Special Committee on Space Technology, which develops the plan for the National Civil Space Program.

1957: *An Introduction to the Mechanics of Solids*, by Stephen Crandall, Norman Dahl, and Thomas Lardner, provides the framework of equilibrium, kinematics, and constitutive response for the teaching of mechanics.

1961: Ascher Shapiro begins producing a series of films that introduce generations of students and practicing engineers to the complexities of fluid flow.

1971: Introduction to Design holds a design contest that becomes an annual robot-building competition. Course 2.70's (later renamed 2.007) experiential, hands-on apprenticeship becomes the department's flagship sophomore subject.

1975: Ocean Engineering faculty members launch a program on Arctic acoustics leading to such fundamental discoveries as the first proof of Arctic Ocean warming.

1977: The Laboratory for Manufacturing and Productivity (LMP) is established. LMP research has created advances such as microcellular foams, 3D printing, photovoltaic ribbon technology, and radio frequency identification (RFID) technology.

1978: Thomas Sheridan and William Verplank establish an eight-level taxonomy of human/machine interactions that becomes the basis for understanding how people interact with products and complex systems.

1981: Ioannis Yannas completes the synthesis and first clinical trials of "artificial skin" that emulates the regenerative properties of living skin.

1988: The MIT Sea Grant Autonomous Underwater Vehicle (AUV) Laboratory is established.

1992: The inaugural FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition is held, modeled after the sophomore Introduction to Design course. By 2010, the contest attracts 45,000 high schoolers from around the world.

1995: The first marine biomimetic robot is developed by professor Michael Triantafyllou and David Barrett.

2002: MechE's pioneering flexible engineering degree, Course 2-A, receives accreditation. 2-A students customize their own course of study.

2002: Amy Smith creates D-Lab and challenges students to design simple, affordable devices to address problems in the developing world.

2009: A team led by professor Gang Chen announces the first experimental confirmation of the breakdown in Planck's blackbody radiation law when heat is transferred between objects that are nanodistances apart, determining that heat transfer can be 1,000 times greater than the law predicts.

Faculty

New Faculty Appointments and Promotions

We are very pleased to welcome four new faculty members to the Mechanical Engineering Department.

Associate professor Nicholas X. Fang received his BS and MS in physics from Nanjing University and his PhD in mechanical engineering from the University of California, Los Angeles. He arrived at MIT earlier this year. Prior to joining MIT, he worked as an assistant professor at the University of Illinois at Urbana-Champaign. Professor Fang's areas of research are in nanophotonics and 3D nanomanufacturing. He was presented with the National Science Foundation (NSF) Career Award and the Society of Manufacturing Engineering's Outstanding Young Investigator Award in 2009, *Technology Review's* 35 Young Innovators Award in 2008, and the American Society of Mechanical Engineers (ASME) Pi Tau Sigma Gold Medal Award in 2006.

Assistant professor Kenneth Kamrin earned his BS at the University of California at Berkeley and a PhD in applied mathematics at MIT in 2008. From there, he went on to work as an NSF postdoctoral fellow at Harvard University. He joined MIT in January 2011. His research is in the mechanics of materials, with a focus on complex constitutive models, primarily for granular materials, as well as numerical simulation methods. He won the 2010 Metropolis Award from the American Physical Society for the best dissertation in computational physics.

Assistant professor Konstantin (Kostya) Turitsyn earned his PhD at the Landau Institute in Moscow, with a focus on nonlinear dynamics and statistical mechanics. His PhD thesis, completed in 2007, focused on the dynamics of polymers in random flows. Later, as a Rice-Kadanoff postdoctoral fellow at the University of Chicago, he worked on a wide variety of problems, including the nonlinear dynamics of vesicles in external flows, the dynamic collapse of gas cavities, the dynamics of plugs in microfluidic channels, and nonlinear waves in optical fibers. Before joining MIT, he was an Oppenheimer fellow at the Los Alamos National Laboratory.

Captain Mark Thomas, professor of the practice in naval architecture and engineering, earned his BS in electrical engineering from Oklahoma State University, his SM in electrical engineering from MIT, his NE in naval engineering from MIT, and his PhD in hydrodynamics from MIT. He is the US Navy's senior uniformed naval architect. His technical contributions encompass a wide range of naval engineering challenges, from keeping today's ships at sea and designing ships for the future to evaluating technology advancements for both today and tomorrow's Navy. Most recently he played a key technical role in the US Navy investigation of the sinking of the *Cheonan*, a Korean naval ship.

We are also pleased to announce the promotions of Domitilla Del Vecchio and Evelyn Wang, each from the rank of assistant professor to the rank of associate professor without tenure, as well as the promotion of Sang-Gook Kim from associate professor with tenure to full professor. Each brings a unique signature to the department and to the Institute in terms of individual achievements and contributions to research, education, mentorship, and service.

Domitilla Del Vecchio received her PhD from the California Institute of Technology in 2005 and, before joining MIT, worked as an assistant professor at the University of Michigan, Ann Arbor. Domitilla's research focuses on control of nonlinear systems and has two main thrusts: one in control of multivehicle systems and one in modular control versus retroactivity of the biomolecular networks of genes and proteins in living cells. She has demonstrated expertise in multidisciplinary dynamical system modeling and the ability to realize her research results in physical form, synthesize new methodologies, and work productively across broad multidisciplinary areas. Domitilla was presented with an NSF Career Award in 2007 and received the prestigious Donald P. Eckman Award from the American Automatic Control Council in 2010.

Evelyn Wang received her SB from MIT and her MS and PhD from Stanford University. She is an emerging leader in the areas of micro- and nanoscale heat and mass transfer processes, with a focus on the development of novel engineered structures that enable innovative solutions in thermal management, energy, and desalination systems. Her work is distinguished by a unique combination of state-of-the-art micro/nanofabrication, physical modeling, and quantitative analysis that enables insight into the underlying physics as well as an understanding of the engineering performance of complex interfacial engineering applications. She has been recognized with a Defense Advanced Research Projects Agency (DARPA) Young Faculty Award, a best paper award at ITherm 2010, and an Air Force Office of Scientific Research Young Investigator Award in 2011.

Sang-Gook Kim joined the MIT faculty in 2000. He earned a BS from Seoul National University in Korea, an MS from KAIST (Korea Advanced Institute of Science and Technology), and a PhD from MIT. He is considered an innovator and leader in multiscale systems design and manufacturing. His contributions to the fields of energy harvesting and lead zirconate titanate (PZT) processing for small-scale devices include breakthrough "firsts" as well as designs and processes that enable wide-scale and practical implementation of these technologies. Professor Kim's piezoelectric-coated cantilevered beam energy harvester is considered a milestone as the first functional microelectromechanical systems (MEMS) harvester that uses the resonant vibrational mode of the beam to harvest energy from the environment. He has recently trumped this development with a broadband energy harvester that capitalizes on the nonlinear stiffness of doubly anchored beams. He is also recognized for his innovations in PZT processing, specifically aimed at integrating thin film PZT with MEMS fabrication.

Professor Kim has been both a leader and an innovator in our undergraduate curriculum. He oversaw the department's highly successful accredited flexible engineering degree (Course 2-A, now the sixth largest major at MIT) during a critical stage of its growth. He also led the development and implementation of a

new undergraduate laboratory-based micro-/nanoengineering course that has been enthusiastically received by the students and the faculty, rapidly expanding in enrollment from six students to more than 50 in just three years.

Retirements

This year brings the retirement of two of the world's leading authorities in thermal year sciences and engineering.

For the past 44 years, professor Ernest G. Cravalho has been a leading authority in the fields of thermodynamics, heat transfer, cryopreservation of biomaterials, and energy conversion. He served as associate dean of the School of Engineering and associate director of the Harvard-MIT Division of Health Sciences and Technology. Professor Cravalho is a member of the American Society of Mechanical Engineers, the Institute of Medicine, and the National Academy of Sciences and is a founding fellow in the American Institute of Biological and Medical Sciences. He was named a Margaret MacVicar Faculty Fellow in 2000. He recently retired from his position as professor of mechanical engineering.

For the past 45 years, professor Borijove B. Mikić has been a leading authority in heat transfer, establishing groundbreaking theories for nucleate boiling, contact resistance in heat conduction, biological heat transfer, heat transfer enhancement, and the onset of turbulence. For 30 of those years, Bora and his wife Liba were housemasters at MIT, and he served as associate head of the Department of Mechanical Engineering for seven years. He has received numerous awards for his research, including the ASME Heat Transfer Memorial Award, and he is broadly recognized as an outstanding teacher at MIT. Bora retired from his position as professor of mechanical engineering this summer.

Deaths

We are sad to report the deaths of five of our former colleagues and leaders in mechanical engineering.

James Keck, the Ford professor of engineering, developed teaching and research programs in thermodynamics, kinetics, and mechanics. His work is widely used in the automotive industry in the design of efficient and clean engines. He was a member of the National Academy of Engineering, the American Academy of Arts and Sciences, and the American Physical Society.

Frank Ambrose McClintock, professor emeritus, was a pioneer in the melding of applied mechanics and materials science. In 1966, he coauthored a book on the subject with Ali Argon, *Mechanical Behavior of Materials*, that remains in print to this day. He was a fellow of the American Academy of Arts and Sciences and a member of the National Academy of Engineering.

Warren M. Rohsenow, professor emeritus, was the director of MIT's Heat Transfer Lab for 28 years, leading cutting-edge research on boiling heat transfer, gas turbines, heat exchangers, heat transfer in nuclear reactors, condensation, and cooling towers. He was a fellow of the American Academy of Arts and Sciences and the National Academy of

Engineering, an honorary member of the American Society of Mechanical Engineering, and a recipient of the ASME/American Institute of Chemical Engineers Max Jakob Memorial Award, the highest honor in the field of heat transfer.

Ain Sonin, an expert in advanced fluid mechanics, was the department's graduate officer for 25 years and earned several teaching awards. He was a member of the American Society of Mechanical Engineers, the American Physical Society, the American Nuclear Society, and the American Association for the Advancement of Science.

Guyford Stever was head of the Department of Mechanical Engineering at MIT from 1961 to 1965 and went on to be chief science advisor to Presidents Richard M. Nixon and Gerald R. Ford, as well as chief scientist of the US Air Force, president of Carnegie Mellon University, and director of the National Science Foundation. He was a member of the National Academy of Sciences, the National Academy of Engineering, and the Carnegie Commission on Science, Technology, and Government.

Research Highlights

MechE faculty members pursue vibrant research directions together with their students and postdocs and increasingly in interdisciplinary teams of faculty across the department, the School of Engineering, and the Institute. Within the department, we have organized around seven core disciplinary areas: mechanics; control, instrumentation, and robotics; design, manufacturing, and product development; energy sciences and engineering; ocean sciences and engineering; bioengineering; and micro- and nanoengineering. Research programs vary from fundamental disciplinary-based research to inventions of new technologies. A very small sampling of research highlights across these areas is provided here.

Pedro Reis: How Ribbons Roll—A Twist on Galileo

Esther and Harold E. Edgerton assistant professor Pedro Reis, along with other MIT researchers, conducted a variation of Galileo's seminal experiment on rolling objects with some surprising and interesting results. No one, including Galileo, had ever previously conducted the experiments using flexible objects until now. Reis and his team used a variety of flexible, hollow cylinders—essentially wide rubber bands the team members developed from scratch to achieve the precise characteristics they were looking for—to derive a set of equations to describe their behavior. Instead of finding that the objects became rounder as they rolled due to centrifugal force, they found that they actually lost their circular shape and became more peanut shaped. Reis and the other researchers say the unusual behavior is the result of a "delicate coupling between rolling, bending, and stretching." They hypothesize that their discovery might ultimately be applied to successful predictions of the shapes of carbon nanotubes in composite materials, the behavior of drill casings in deep wells, and the way blood cells move through veins and arteries.

Nicolas Hadjiconstantinou: Quieting Molecular Simulations

Molecular simulation continues to play an increasingly large role in the field of nanoscale science and engineering. Unfortunately, even more widespread application

of this methodology is limited by the computational cost associated with reducing the statistical uncertainty, or "noise," associated with these calculations. A group led by Nicolas Hadjiconstantinou, associate professor of mechanical engineering and codirector of the Computation for Design and Optimization program, has developed variance reduction methods for removing the statistical uncertainty associated with these calculations. These methods simulate only the deviation from equilibrium or, in other words, only the fraction of molecules that contribute toward a nontrivial signal. The resulting computational cost reduction is typically several orders of magnitude, thus enabling the simulation of previously intractable problems.

Harry Asada: Tiny Robots Monitor Nuclear Reactors for Radioactive Leaks

With the nuclear power plant leak crisis in Japan still fresh in people's minds, many are wondering what we can do going forward to prevent future leaks. Currently, the industry has very few methods for monitoring underground leaks, and those that do exist are either indirect and prone to error or extremely costly and time intensive. Harry Asada, Ford professor of engineering and director of MechE's d'Arbeloff Laboratory for Information Systems and Technology, recently led a team from the d'Arbeloff Laboratory to a solution in the form of small, egg-sized robots that dive into nuclear reactors and swim through underground pipes, directly checking for signs of corrosion. The underwater patrollers, equipped with cameras, are able to withstand a reactor's extreme, radioactive environment and as a result can transmit images in real time from within.

Kripa Varanasi: Frost-Free Planes Aren't As Simple as They Sound

Led by Kripa Varanasi, d'Arbeloff assistant professor of mechanical engineering, a research team at MIT has discovered that solving the issue of how to best deice a plane isn't as straightforward as was previously thought. Through their research, they discovered that one of the proposed solutions—the use of a superhydrophobic coating—doesn't work due to the formation of frost, which can completely undo any water-repelling properties and, in fact, could even promote the formation of ice. Using an environmental scanning electron microscope to study the process, Varanasi and his team learned that when superhydrophobic surfaces are exposed to supersaturated air such as is commonly found in clouds, frost forms and aggravates the problem instead of helping it. The team offers a possible solution instead that involves complex nanoscale texturing of a surface to improve its hydrophobic qualities by preventing the forming droplets from finding a suitable flat surface to stick to.

Timothy Gutowski: When Recycling Doesn't Pay—An Economic Analysis

A research team led by Timothy Gutowski, professor of mechanical engineering, conducted a life-cycle analysis on 25 products in eight categories that led to the discovery that recycling uses more energy as often as it uses less, and often it simply breaks even. The surprising realization was made after the team looked at the total energy used over the lifetime of each product rather than just the energy used in the manufacturing process itself. It was this long-term view that made the true energy cost clear. While recycling itself almost always costs less money and uses less energy than creating something new, the recycled item is almost always less energy efficient than a newer version, which over the lifetime of a product cancels out the cost savings

from recycling. Similarly, when used items are remanufactured and then sold to a new market, the market expands and often so does the energy used to power those items.

Tonio Buonassisi: Artificial Leaf Uses a Solar Cell to Split Water Molecules and Create Energy

In a joint effort with professor Daniel Nocera of MIT's Chemistry Department, Tonio Buonassisi, Singapore-MIT Alliance (SMA) assistant professor of mechanical engineering and manufacturing, led a team of researchers that developed a solar cell device to interface with a catalyst and create an artificial leaf, a device that will be able to harness solar energy by splitting water molecules. The artificial leaf, once complete, will be used as a low-cost device where electricity is unavailable or unreliable. Buonassisi's contribution was no small matter, requiring an innovative solution to the problem of silicon degrading rapidly by a very aggressive chemical environment created by the catalyst. His team had to protect the silicon surface while simultaneously allowing it to receive the incoming sunlight and interact with the catalyst. They solved the problem by coating the silicon with a protective layer in a way that remained low cost and high performance.

Gang Chen: Turning the Sun's Heat into Electricity

Led by Gang Chen, Carl Richard Soderberg professor of power engineering and director of the Pappalardo Micro and Nano Engineering Laboratories, a team of MIT researchers has developed an unusual, high-performance, and possibly less expensive way of turning the sun's heat into electricity. While solar thermal electricity systems in and of themselves aren't a new idea, this method produces power with an efficiency roughly eight times higher than ever previously reported for a solar thermoelectric device by generating and harnessing a temperature difference of about 200°C between the interior of the device and the ambient air, a concept considered quite radical in its immense power and low cost.

Roger Kamm: Competing Mechanisms Influence Tumor Cell Migration

Singapore research professor of biological and mechanical engineering Roger Kamm and mechanical engineering graduate student William Polacheck, in collaboration with Joseph Charest from the Charles Stark Draper Laboratory, have discovered that the direction in which fluid flows through bodily tissue determines how likely cancer cells are to spread (or metastasize) and that, armed with this information, it may be possible to limit the spread of cancer. Almost as important as their discovery is the 3D microfluidic system they invented that led to it. Whereas previous insights were based solely on the visualization of individual cells in a generated flow, Polacheck and Kamm's system allows them to look at the way cells interact with tissue that mimics natural breast tissue. Understanding how cancer cells break loose from their original tumor, make their way into the body's vascular system, and travel to another location is a critical step in the fight against cancer.

Pierre Lermusiaux: Predictive System for Ocean and Sound Waves

Research led by Pierre Lermusiaux, the Doherty associate professor in ocean utilization, created a data-driven method to aid the understanding and forecasting of how sound waves used for sonar imaging and underwater communications can be affected by the

interplay of large-scale currents, eddies, internal tides, and the irregular topography of the seafloor, among other things. Lermusiaux's hope is that the method will improve the accuracy of communications and the computer reconstruction of sonar images used to detect submarines and other objects or to study the seafloor, as well as ocean dynamics in general.

Alexandra Techet: 3D Imaging Unlocks Secrets of Unsteady Flows in the Marine Environment

Measuring the flow in the marine environment presents unique challenges, as evidenced by the Deepwater Horizon oil spill in 2010. There are few methods available for fully resolving 3D flow fields in highly unsteady 3D environments, such as those including multiphase flows with dense gas bubble fractions, engineering spray flows, or flows with partial occlusions such as marine organisms or particulate. Alexandra Techet, associate professor of mechanical and ocean engineering, recently developed a novel three-dimensional synthetic aperture imaging system for observation and analysis that has the potential to unlock many secrets of fluid flow in the complex marine environment for a wide range of naval, environmental, biological, and engineering applications. This time-resolved volumetric observational technique uses an array of cameras to acquire highly accurate flow maps in these challenging environments. These insights can yield more robust hydrodynamic models and engineering design tools, enabling the creation of a new generation of oceanographic vehicles for national defense and ocean exploration.

Yang Shao-Horn: Carbon Nanotubes Could Increase the Power of Batteries Tenfold

A research team led by Yang Shao-Horn, Gail E. Kendall associate professor of engineering, recently discovered that using carbon nanotubes for one of a battery's electrodes produced up to a tenfold increase in the amount of power it could deliver from a given weight of material relative to a conventional battery. In more good news, the carbon nanotube electrodes also demonstrated very good stability over time. Such a discovery could be applied to small portable devices and the improvement of battery life. To produce the powerful new electrode material, the team used a layer-by-layer fabrication method in which a base material is alternately dipped in solutions containing carbon nanotubes that have been treated with simple organic compounds that give them either a positive or negative net charge; when these layers are alternated on a surface, they bond tightly together because of the complementary charges, making a stable and durable film.

George Barbastathis: A Full-Scale Invisibility Cloak

In conjunction with his team at the Singapore-MIT Alliance for Research and Technology (SMART), George Barbastathis, Singapore research professor of optics and professor of mechanical engineering at MIT, was recently acknowledged for his work on an invisibility cloak that was named one of the top 10 breakthroughs in 2010 by *Physics World*. The cloak works by placing a wedge of calcite crystal—a crystalline form of calcium carbonate, the main ingredient in seashells and stalactites/stalagmites in caves—over an object. When the object is then illuminated by visible light and viewed from the

direction perpendicular to the wedge, it "disappears" from sight because the observer perceives the wedge as flat and thus nonexistent. And it's not just a simple illusion. The cloak is designed so that any scientific instrument would also be "fooled" into thinking the crystal surface is flat. Aside from its obvious potential applications in defense or law enforcement, the ability to render something invisible could have uses in research too, Barbastathis suggests, for example by providing a way to monitor animal behavior without any visible distraction.

These snapshots highlight many truly fundamental advances being made in our research programs. A careful reading of each also reveals the strong focus of these research groups on bringing engineering solutions to major challenges such as energy, the environment, and human health.

Education Highlights

The dedication of our faculty to educating the next generation of engineering leaders continues to be a passionately rendered signature of the Department of Mechanical Engineering. Our innovation in education is prevalent, as seen in our Women in Technology Program for high school juniors, which has established an exceptional record for attracting women to engineering; in our prefreshman and freshman courses and activities, such as Discover Mechanical Engineering and 2.00B Toy Product Design; in our Course 2, 2-A, and 2-OE undergraduate programs; and in our core and advanced graduate curriculum.

Undergraduate Program

The Department of Mechanical Engineering's curriculum development increasingly benefits from support from external sources. A gift from the Lufkin Foundation enabled us to expand our Micro and Nano Systems Laboratory offerings to meet the demand of high enrollment and bring state-of-the-art methods into our undergraduate core. Also, this year the department has teamed with National Instruments (NI) to expand the use of NI software and hardware for design to 10 mechatronics, robotics, manufacturing, control, and design courses in the next five years. NI is also supporting the development of an entirely new introduction to electronics, focusing on motor controllers and related applications, for incoming mechanical engineering sophomores.

The Mechanical Engineering Department remains the second-largest undergraduate program at MIT, and the recent trend of growing enrollment is continuing. In particular, we see continued growth in our groundbreaking customizable Course 2-A engineering major. Taken by itself, it is the sixth most popular undergraduate major at MIT and the fourth largest in the School of Engineering.

Undergraduate Enrollment, AY2007–AY2011

	AY2007	AY2008	AY2009	AY2010	AY2011
Sophomores					
2	98	93	114	76	94
2-A	29	41	51	67	64
2-OE	4	5	6	5	4
13	0	0	0	0	0
Subtotal	131	139	171	148	162
Juniors					
2	104	99	95	112	88
2-A	22	20	44	50	58
2-OE	4	3	4	6	5
13	0	0	0	0	0
Subtotal	130	122	143	168	151
Seniors					
2	87	99	90	80	104
2-A	31	27	26	49	57
2-OE	1	5	4	6	7
13	3	0	0	0	0
Subtotal	122	131	120	135	168
5th-year students					
2	13	12	7	4	5
2-A	1	2	5	5	4
2-OE	0	0	0	0	1
13	0	0	0	0	0
Subtotal	14	14	12	9	10
Total	**397**	**406**	**446**	**460**	**491**

Two of the most crucial undergraduate courses in our curriculum—and most anticipated by our students—are our popular design classes, 2.007 Introduction to Design and Manufacturing and 2.009 Product Engineering Processes. 2.007, taught by professor Daniel Frey, hosts the seminal robot competition as the course's final presentation and has been the inspiration for many copycat competitions around the world, including the yearly FIRST robot competition for high school students and the Robocon international robot design competition. This year, Robocon was held at MIT, emceed by Professor Frey and inspired by this year's 2.007 theme, Hackfest. The lively competition involved teams' robots going head to head to complete four famous MIT hacks throughout history for the highest number of points. The final for 2.009, offered to the largest MechE senior class ever this past year, requires student teams to provide professional-level presentations of the entire product development process and final prototypes of their products. This year, a food-themed product design was chosen as the class focus. The final presentations were given to a packed audience in Kresge Auditorium, and the event was emceed by the course's lead instructor, professor David Wallace.

Graduate Program

Our graduate program continues to be strong as well, with a total of 525 students including 93 women, 36 underrepresented minority students, and 220 international students. Our students are supported primarily by research assistantships. Fellowships are a primary means to continue to attract truly exceptional talent, including NSF fellowships, Department of Defense fellowships, internal endowed fellowships through the generosity of alumni and friends (including the Rohsenow, Shapiro, Harrington, Bailey, Lee, O'Brien, Sonin, Martin, Cook, Pappalardo, ABS, DuPont-MIT Alliance, and MIT Energy Initiative fellowships), Institute Presidential Fellowships, and fellowships from other sources. Our graduate program continues to attract a very talented applicant pool despite the increasingly aggressive recruitment of our competitors. We continue to seek to increase the number of fellowships to attract and secure the admission of top talent to our graduate program.

Graduate Enrollment, AY2007–AY2011

	AY2007	AY2008	AY2009	AY2010	AY2011*
Master's	209	208	204	201	212
Doctoral	260	236	244	262	268
Total	469	444	448	463	480

*Total does not include students pursuing the master of engineering degree (13), mechanical engineer degree (2), or naval engineer degree (30).

Space Renovation Highlights

The Mechanical Engineering Department has the privilege of being housed primarily within the original main buildings of the MIT Cambridge campus. We continue to transform these original spaces to modern world-class research and education spaces. Space renovations remain a priority and are a major need for the department to remain at the leading edge of mechanical engineering. The renovations vary in size from small to large to meet the needs of new incoming faculty, senior faculty entering new areas of research, and major shared laboratory and research office areas.

This past year began with the dedication ceremonies for two spaces newly renovated in the prior year: the Mechanical Engineering Student Commons, funded by alum BJ Park, and the Rohsenow Kendall Heat Transfer Laboratory, funded in part by alum Gail Kendall and by the department's Center for Clean Water and Clean Energy at MIT and the King Fahd University of Petroleum and Minerals. Since then, we have undertaken several additional research space renovations. Upgrades to the Experimental Marine Hydrodynamics Laboratory for naval engineering education and research (located on the second floor of Building 3), home to a propeller laboratory as well as state-of-the-art three-dimensional imaging of complex fluid dynamics phenomena, have been completed. Significant enhancements to the d'Arbeloff Laboratory on the ground floor of Building 1 have been undertaken to install chemical and biological hoods for

the study of feedback and control of cellular networks and systems of biological cells. A lab for associate professor Nicholas Fang in Building 35 for research in the area of metamaterials and novel materials processing was recently established, and upgrades to the department's Building 31 space for additional energy-related research in oxy-combustion and clean fuel technologies continue. Infrastructure upgrades to the air-handling systems that provide conditioned air for students and staff in the basements of Buildings 1 and 5 have also been initiated.

Lastly, a major renovation of the third floor of Building 3 is currently under way to develop an energy, controls, and mechanics nexus. This gut-level renovation covers more than 10,000 square feet of space and will open up one entire side of the third-floor corridor to create a contiguous space for graduate students, postdoctoral staff, and support staff. The space will also include a microscope facility room for undergraduate and graduate students, an optics research lab, an experimental fluids research lab, a classroom, and a new signature departmental meeting room.

In addition, MechE has consolidated and established an emeritus office space in the Center for Ocean Engineering and is upgrading several faculty offices and shared student office spaces throughout the department. The Center for Ocean Engineering is currently undergoing a major refurbishment as well, and preparations for the creation and installation of an ocean engineering timeline are well under way and will be complete this summer.

MechE also continues to focus on our common spaces, proudly housing the Hart Nautical Gallery, located on the first floor of Building 5. In collaboration with the MIT Museum, the Hart Gallery recently underwent a major refurbishment. Collections curator Kurt Hasselbalch, along with department head Mary Boyce and professor John Leonard, worked closely with a wide range of faculty and students to create an ongoing and evolving showcase of the tremendous range of important research conducted in the department. The gallery also features two rotating showcases of Mechanical Engineering research and products. The current exhibit presents recent prototypes in bioinstrumentation created by students and postdocs in the BioInstrumentation Laboratory of professor Ian Hunter as well as a display on solar energy created by students and postdocs in the group of professor Tonio Buonassisi. Also on display is an exhibit on the history of ship design. Forty of the museum's finest full-hull ship models depict 1,000 years of ship building, ranging from a 15th-century iron-clad warship to the swiftest clipper ships. Also featured is an extraordinary model of N.G. Herreshoff's *Reliance*, winner of the 1903 America's Cup. The Hart Gallery is free and open to the general public from 9 am to 5:30 pm seven days a week.

Keeping our spaces current and establishing the footprint for cutting-edge research is an ongoing priority for the department, as it is key to our ability to compete and lead in our field.

Awards and Recognition

Faculty

Triantaphyllos Akylas, professor of mechanical engineering, was recently elected a fellow of the American Physical Society. The society recognized him for his "elegant and insightful theoretical investigations of nonlinear surface and internal gravity wave phenomena."
Harry Asada, Ford professor of engineering, director of the d'Arbeloff Laboratory for Information Systems, and technology head of control, instrumentation, and robotics, was awarded the 2011 Ruth and Joel Spira Award for Distinguished Teaching. He was also recognized with the prestigious 2011 ASME Rufus Oldenburger Medal for lifetime achievement in automatic control.

George Barbastathis, SMART research professor of optics and professor of mechanical engineering, was recently named a fellow of the Optical Society of America.

Mary C. Boyce, Mechanical Engineering department head, was appointed as a Ford professor of engineering.

Gang Chen, the Carl Richard Soderberg professor of power engineering, was selected as a recipient of this year's Capers and Marion McDonald Award for Excellence in Mentoring and Advising in recognition of his outstanding mentoring contributions.

Nicholas Fang, associate professor of mechanical engineering, was named the d'Arbeloff career development chair.

Douglas P. Hart, professor of mechanical engineering, won the 2011 North American Enabling Technologies Award for an invention that dramatically increases the functionality of hearing aids.

Anette (Peko) Hosoi, associate professor of mechanical engineering, won the 2011 Bose Award for Excellence in Teaching.

Franz Hover, professor of mechanical engineering, was named the Finmeccanica career development chair of engineering.

Roger Kamm, the Cecil and Ida Green distinguished professor of biological and mechanical engineering, was elected a member of the Institute of Medicine.

Kenneth Kamrin, assistant professor of mechanical engineering, was named the Class of '56 career development chair.

Yang Shao-Horn, associate professor of mechanical engineering and materials science and engineering, was appointed as the Gail E. Kendall chair.

Peter So, professor of mechanical Engineering, was named the Singapore research professor of bioinstrumentation and bioimaging.

Konstantin Turitsyn, assistant professor of mechanical engineering, was appointed as the Edgerton career development chair.

J. Kim Vandiver, professor of mechanical engineering and ocean engineering and dean for undergraduate research, was recognized with the Arthur C. Smith Award for Meaningful Contributions and Devotion to Student Life and Learning.
Kripa Varanasi, d'Arbeloff assistant professor of mechanical engineering, was named the Doherty career development chair in ocean utilization.

Evelyn Wang, Esther and Harold E. Edgerton assistant professor, was presented with the Air Force Office of Scientific Research Young Investigator Award.

Staff

Barbara Hughey was honored with an MIT Excellence Award for her outstanding contribution to educating and mentoring undergraduate students in instrumentation.

Ed Jacobson, administrative assistant II, was the 2011 recipient of the Joseph (Tiny) Caloggero Service Award.

Angela Mickunas, assistant director for administration and research, Center for Clean Water and Clean Energy, was presented with one of this year's Infinite Mile Awards.

Undergraduate Students

Alfred A.H. Keil Ocean Engineering Development Fund Award for Excellence in Broad-Based Research in Ocean Engineering: Javier E. Ramos

AMP Inc. Award for Outstanding Performance in Course 2.002: Nigel C. Kojimoto and Marcel A. Thomas

Department Service Award for Outstanding Service to the Mechanical Engineering Department: Heather E. McDonald and Linda Liu

Ernest Cravalho Award for Outstanding Performance in Thermal Fluids Engineering: Vibin A. Kundukulam

International Competition Winners for 2.007: Wyatt Ubellacker, Cecilia Cantu, Jackson Crane, and Bee Vang

John C. and Elizabeth J. Chato Award for Excellence in Bioengineering: Sean M. Cockey, Bonnie L. Blackburn, and Jillian M. Oliveira

Lauren Tsai Memorial Award for Academic Excellence by a Graduating Senior: Lauren R. Hernley

Lockheed Martin Prize for Outstanding Sophomore in Mechanical and Systems Engineering: Ari S. Umans

Louis N. Tuomala Award for Outstanding Performance in Thermal Fluids Engineering: Reuben M. Aronson

Luis de Florez Award for Undergraduate Design: Ian McKay

Park Award for Outstanding Performance in Manufacturing: Luke M. Mooney and Emily W. Tow

Peter Griffith Prize for Outstanding Experimental Project: Yoshio S. Perez

Rabinowicz Tribology Award for Outstanding Undergraduate Research in Tribology: Michael P. Roberts

Robert Bruce Wallace Academic Prize for Academic Excellence in Ocean Engineering: Roberto J. Melendez

Society of Naval Architecture and Marine Engineering Award for an Outstanding Undergraduate in the Marine Field: Marie McGraw, Milo Feinberg, and Christian Welch

Thomas Sheridan Prize for Academic Excellence by a Graduating Senior: Brendan J. Englot

Whitelaw Prize for Originality in 2.007 Design and Contest: Phitchaya "Mangpo" Phothilimthana

Wunsch Foundation Silent Hoist and Crane Award for Academic Excellence: Omar O. Abudayyeh, John G. Boghossian, Riley E. Brandt, Carmen M. Graves, Daniel M. Kubaczyk, Vibin A. Kundukulam, Peter Lu, Amy Qian, Michael P. Roberts, Emily C. Shao, and Kathryn Olesnavage

2011 Phi Beta Kappa Inductees: John Boghossian, Carmen Graves, Caroline Hane-Weijman, Vibin A. Kunukulam, Linda Liu, Michael Roberts, Katrina Schoen, William Vega-Brown, and Teerawut Wannaphahoon

2011 Pi Tau Sigma Mechanical Engineering Honor Society Inductees: Omar Abudayyeh, Yazan Alnahhas, Nikolai Begg, John Boghossian, Stephanie Brown, Noah Caplan, Alysa Cardell, Mindy Eng, Jasmine Florentine, Evan Goldhaber, Vu Gong, Lauren Hemley, Sun Kim, Raymond Lewis, Linda Liu, Jean Martin, Heather McDonald, Ian McKay, Emily Obert, Javier Ramos, Zachary Rose, Ian Rust, Kevin Rustagi, Amarita Saigal, Katrina Schoen, Nathaniel Shoemaker-Trejo, Jesse Thornburg, Juan Valdez, William Vega-Brown, Kent Willis, and Nick Wiltsie

2011 Tau Beta Pi Inductees: John Boghossian, Vazrik Chiloyan, Vibin Kundukulam, Raymond Lewis, Linda Liu, Roberto Melendez, Katrina Schoen, Trevor Shannon, Emily Shao, Will Vega-Brown, and Lim Wannaphahoon

Graduate Students

American Bureau of Shipping Scholarship for Demonstrated Excellence in an Incoming Graduate Student in Ocean Engineering: Matthew L. Gildner and Leah R. Mendelson

Carl G. Sontheimer Prize for Creativity and Innovation in Design: Daniel S. Codd, Heidi Q. Chen, Lisa A. Schlecht, and Caroline M. Hane-Weijman

Clement F. Burnap Award for Outstanding Master of Science in the Marine Field: Emmanouil Sarris and Gregory E. Fennell

Luis de Florez Award for Graduate Design: Jacob E. McKenzie

Luis de Florez Award for Graduate Science: Daniel J. Payen

Meredith Kamm Memorial Award for Excellence in a Female Graduate Student: YI "Ellen" Chen and Maria J. Telleria

Rabinowicz Tribology Award for Outstanding Graduate Research in Tribology: Michael P. Roberts and Sanha Kim

Wunsch Foundation Silent Hoist and Crane Award for Outstanding Teaching Assistant in Course 2.002: Claudio V. DiLeo and Kaspar A. Loeffel

Wunsch Foundation Silent Hoist and Crane Award for Outstanding Teaching Assistant in Course 2.003: Audren D.P. Cloitre and Jason S. Ku

Wunsch Foundation Silent Hoist and Crane Award for Outstanding Teaching Assistant in Course 2.086: James D. Penn and Masayuki Yano

Looking Toward the Future

The MIT 150 celebration has given us a reason to pause and look back with pride at the many amazing accomplishments of the Department of Mechanical Engineering over its history as well as over this past year. We look forward with excitement to the innovation and creativity of our next 150 years.

Mary C. Boyce
Department Head
Gail E. Kendall Professor

Gareth H. McKinley
Associate Department Head for Research
School of Engineering Professor of Teaching Innovation

John H. Lienhard V
Associate Department Head for Education
Samuel C. Collins Professor