DEPARTMENT OF MECHANICAL ENGINEERING

Mechanical engineering is concerned with the responsible development of products, processes, and power, at scales ranging from molecules to large and complex systems. Mechanical engineering principles and skills are involved at some stage during the conception, design, development, and manufacture of every human-made object with moving parts. Many innovations crucial to our future will have their roots in the world of mass, motion, forces, and energy—the world of mechanical engineers.

Mechanical engineering is one of the broadest and most versatile of the engineering professions. This is reflected in the portfolio of current activities in the Department of Mechanical Engineering (MechE), one that has widened rapidly in the past decade. Today, our faculty are involved in a wide range of projects, including designing tough hydrogels, using nanostructured surfaces for clean water and thermal management of microelectronics, developing efficient methods for robust design, the building of robotics for land and underwater exploration, creating optimization methods that autonomously generate decision-making strategies, developing driverless cars, inventing cost-effective photovoltaic cells, developing thermal and electrical energy storage systems, using acoustics to explore the ocean of one of Jupiter's moons, studying the biomimetics of swimming fish for underwater sensing applications, developing physiological models for metastatic cancers, inventing novel medical devices, exploring 3D printing of nanostructures and macrostructures, and developing coatings to create nonstick surfaces.

The department carries out its mission with a focus on the seven areas of excellence described below. Our education and research agendas are informed by these areas, and these are the areas in which we seek to impassion the best undergraduate and graduate students.

Area 1: Mechanics: Modeling, Experimentation, and Computation (MMEC). At the heart of mechanical engineering lies the ability to measure, describe, and model the physical world of materials and mechanisms. The MMEC area focuses on teaching the fundamental principles, essential skills, and scientific tools necessary for predicting thermo-mechanical phenomena and using such knowledge in rational engineering design. We provide students with the foundations in experimental, modeling, and computational skills needed to understand, exploit, and enhance the thermo-physical behavior of advanced engineering devices and systems, and to make lifelong creative contributions at the forefront of the mechanical sciences and beyond. Research in the MMEC area focuses on four key thrusts:

- Computational mechanics
- Fluid dynamics and transport
- Mechanics of solid materials
- Nonlinear dynamics

The fundamental engineering principles embodied in these topics can be applied over a vast range of force, time, and length scales, and applications of interest in the MMEC area span the spectrum from the nano/micro world to the geophysical domain. A Course 2-A track is offered in this area.

Area 2: Design, Manufacturing, and Product Development. Design, manufacturing, and product development is the complete set of activities needed to bring new devices and technologies to the marketplace. These activities span the entire product life-cycle, from the identification of a market opportunity or need, through design, testing, manufacture and distribution, and end of useful life. Our work includes everything from understanding the voice of the customer to finding new ways of processing materials to improving product performance and tracking product flow through a distribution network. A central component of this area is the design and construction of novel equipment, either for consumer products or for industrial uses. This spans scales from meters to microns, and involves mechanical, electronic and electromechanical devices. Many MechE students apply design, manufacturing, and product development skills and techniques to extracurricular design work for organizations and student activities such as Design that Matters, Formula SAE, Satellite Engineering Team, and the Solar Electric Vehicle Team. Some projects lead to flagship products for new companies. A Course 2-A track in product development is offered along with a unique Master of Engineering degree in manufacturing.

Area 3: Controls, Instrumentation, and Robotics. The mission in this area is to promote research and education for automating, monitoring, and manipulating systems. The focus is on system-level behavior that emerges primarily from interactions and cannot be explained from individual component behavior alone. We seek to identify fundamental principles and methodologies that enable systems to exhibit intelligent, goal-oriented behavior, and develop innovative instruments to monitor, manipulate, and control systems. The core competencies in which we seek to excel are:

- Methodologies for understanding system behavior through physical modeling, identification, and estimation.
- Technologies for sensors and sensor networks; actuators and energy transducers; and systems for monitoring, processing, and communicating information.
- Fundamental theories and methodologies for analyzing, synthesizing, and controlling systems; learning and adapting to unknown environments; and effectively achieving task goals.

We seek to apply our core competencies to diverse areas of social, national, and global needs. These include health care, security, education, medical and security related imaging, space and ocean exploration, and autonomous systems in air, land, and underwater environments. We also offer a Course 2-A track in this area.

Area 4: Energy Science and Engineering. Energy is one of the most significant challenges facing humanity and is a central focus of mechanical engineering's contribution to society. Our research focuses on efficient and environmentally friendly energy conversion and utilization from fossil and renewable resources. Programs in the department cover many of the fundamental and technological aspects of energy, with applications to high performance combustion engines, batteries and fuel cells, thermoelectricity and photovoltaics, wind turbines, and efficient buildings. Work in very-low-temperature thermodynamics includes novel sub-Kelvin refrigeration. Efforts in high-temperature thermodynamics and its coupling with transport and chemistry include internal combustion engine analysis, design, and technology; control of combustion dynamics and emissions; thermoelectric energy conversion; low- and high-temperature fuel cells; and novel materials for rechargeable batteries and thermal energy storage. Work in heat and mass transport covers thermal control of electronics from manufacturing to end use; microscale and nanoscale transport phenomena; desalination and water purification; high heat flux engineering; and energy-efficient building technology. Work in renewable energy encompasses the design of offshore and floating wind turbines and tidal wave machines; and analysis and manufacturing of photovoltaic and thermophotovoltaic devices. Energy storage, hybrid systems, fuel synthesis, and integration of energy systems are active research areas in the department. We also offer a Course 2-A track in energy.

Area 5: Ocean Science and Engineering. The oceans cover over 70 percent of the planet's surface and constitute a critical element in our quality of life, including the climate and the resources and food that we obtain from the sea. This area's objectives are to support the undergraduate and graduate programs in ocean engineering, including the naval construction program, the MIT/Woods Hole Oceanographic Institution Joint Program in Applied Oceanography and the Course 2-OE degree in mechanical and ocean engineering. It also serves as the focus point of ocean-related research and education at MIT. Major current research activities include marine robotics and navigation of underwater vehicles and smart sensors for ocean mapping and exploration; biomimetics to extract new understanding for the development of novel ocean systems studying marine animals; the study of the mechanics and fluid mechanics of systems for ultradeep ocean gas and oil extraction; ocean wave and offshore wind energy extraction; the free surface hydrodynamics of ocean-going vehicles; the development of advanced naval and commercial ships and submersibles, including the all-electric ship; the mechanics and crashworthiness of ocean ships and structures; ocean transportation systems; ocean acoustics for communication, detection, and mapping in the ocean; and adaptive sampling and multidisciplinary forecasting of the ocean behavior. The design of complex ocean systems permeates all these areas and provides the cohesive link for our research and teaching activities.

Area 6: Bioengineering. Engineering analysis, design, and synthesis are needed to understand biological processes and to harness them successfully for human use. Mechanical forces and structures play an essential role in governing the function of cells, tissues, and organs. Our research emphasizes integration of molecular-to-systems–level approaches to probe the behavior of natural biological systems, and to design and build new systems, ranging from analysis of gene regulatory networks to microfluidic assays for drug screening or new technologies for quantitative, high-throughput biomedical imaging. Emphasis is also placed on creating new physiological or disease models, including multicellular engineered living systems, using nano- and micro-fabrication as well as new biomaterials. Applications include understanding, diagnosing, and treating diseases such as atherosclerosis, osteoarthritis, spinal cord injury or liver failure; new tools for drug discovery and drug development; and tissue-engineered scaffolds and devices for in vivo regeneration of tissues and organs. Work also includes design and fabrication of new devices and tools for rehabilitation of stroke victims and for robotic surgery. We offer many elective subjects at the undergraduate and graduate levels, as well as a bioengineering track in Course 2-A.

Area 7: Nano/Micro Science and Technology. The miniaturization of devices and systems of ever-increasing complexity has been a fascinating and productive engineering endeavor during the past few decades. Near and long term, this trend will be amplified as physical understanding of the nano world expands, and widespread commercial demand drives the application of manufacturing to micro- and nanosystems. Micro- and nanotechnology can have tremendous impact on a wide range of mechanical systems. Examples include microelectromechanical system (MEMS) devices and products that are already deployed as automobile airbag sensors, smart phone parts, and for drug delivery; stronger and lighter nanostructured materials now used in airplanes and automobiles; and nanostructured energy conversion devices that significantly improve the efficiency of renewable energy systems. Research in this area cuts across mechanical engineering and other disciplines. Examples include sensors and actuators; micro-fluidics, heat transfer, and energy conversion at the micro- and nanoscales; optical and biological micro- and nano-electromechanical systems (MEMS and NEMS); engineered nanomaterials; atomic scale precision engineering; and the nano-phoptonics in measurement, sensing, and systems design. Students interested in micro/nano technology are encouraged to explore the Course 2-A nanoengineering track.

In order to prepare the mechanical engineers of the future, the department has developed undergraduate and graduate educational programs of the depth and breadth necessary to address the diverse and rapidly changing technological challenges that society faces. Our educational programs combine the rigor of academic study with the excitement and creativity inherent to innovation and research.