MECHANICAL ENGINEERING

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Mechanical engineering is among the most diversified of the traditional engineering disciplines. The mechanical engineer builds machines to extend our physical and mental capabilities and to convert traditional and novel energy sources into useful forms.

The role of the mechanical engineer has changed dramatically over the past few decades with the extensive use of high-performance computers (in such areas as computational fluid dynamics, materials design, control, and manufacturing), the interfacing of microelectromechanical systems and actuators via microprocessors to build high-precision sensors and devices, and the advent of advanced materials (e.g., composites, shape-memory alloys, ceramics, and superconductors) for new applications (e.g., coatings, biomaterials, and computer storage). These areas offer mechanical engineering students special opportunities for creativity, demanding that they learn not only in depth but also in breadth. Demands for increased energy efficiency and reduced environmental impact—as might be realized, for example, in novel gas turbine or electric hybrid vehicles—require that students understand the fundamentals of mechanics, thermodynamics, fluid mechanics, combustion, and materials science. In all these tasks, the utmost consideration of the modern mechanical engineer is improving the quality of human life. The engineer must also be constantly aware both of the finiteness of Earth's resources and its environment and of the burden that engineering places on them.

The educational mission of the Department of Mechanical Engineering and Materials Science is to provide an excellent education that will prepare students to become members of the next generation of mechanical engineers. To implement this mission, the department adheres to the following set of educational objectives: to provide a balanced technical and nontechnical education to enable graduates to enter highly selective graduate schools and/or to pursue technical careers in industry or government laboratories; to enable graduates to improve and adapt their skills to accommodate rapid technological changes; to prepare graduates to communicate effectively and to understand the ethical responsibilities and impact on society of their profession. To achieve these objectives, the following fundamental educational goals have been established for the Department of Mechanical Engineering and Materials Science: to provide a comprehensive introduction to basic science and mathematics, which form the foundation of mechanical engineering; to provide thorough training in analytical and experimental methods and in data analysis, including problem formulation; to provide instruction in the fundamentals of the design process, including project innovation, synthesis, and management, both individually and in a team setting; to provide both a technical and a nontechnical program of study in which oral and written communication skills are developed; to instill in students an understanding of their professional and ethical responsibilities, which affect society and their profession.

COURSES FOR NONMAJORS

Mechanics and mechanical engineering content can be found in several courses intended for those not majoring in science. See under Engineering and Applied Science.

THE MECHANICAL ENGINEERING PROGRAM

At Yale, three mechanical engineering programs are offered: a B.S. degree program with a major in Mechanical Engineering, a B.S. degree program with a major in Engineering Sciences (Mechanical), and a B.A. degree program with a major in Engineering Sciences (Mechanical). Prospective majors in both B.S. programs are advised to complete introductory physics and mathematics through calculus (MATH 115) by the end of their first year.

A student’s undergraduate engineering program may include one or more special project courses (MENG 471, 472), in which the student pursues a particular research interest through design-oriented projects and experimental investigations. Projects may be initiated by the student, may be performed in a team, or may be derived from the ideas of faculty members who place undergraduates in their ongoing research projects. All interested students should contact the director of undergraduate studies for more information on special project courses.

B.S. degree program in Mechanical Engineering This is the most technically intensive mechanical engineering degree program and is accredited by the Engineering Accreditation Commission of ABET, Inc. This program is appropriate for students who plan careers as practicing engineers in industry, consulting firms, or government as well as for students who are considering a career in research and plan to pursue an advanced degree in engineering.

B.S. degree program in Engineering Sciences (Mechanical) This non-ABET degree program is suitable for students who wish to gain significant expertise within mechanical engineering while combining their engineering studies with related disciplines. For example, a number of students have taken courses in architecture while pursuing a program in mechanical engineering that emphasizes structural mechanics; similarly, a student with an interest in computer graphics might combine engineering courses in computer-aided design with programming courses from the Department of Computer Science.

B.A. degree program in Engineering Sciences (Mechanical) In a society with increasing levels of technical sophistication, a well-rounded individual must have some background in science and technology. The non-ABET B.A. program is designed for students who may be planning careers in business, law, medicine, journalism, or politics but need to understand the impact that science and technology can have on society at large. An understanding of engineering methods and practices, combined with a traditional liberal arts education,
provides a strong background for a variety of careers. The program is well suited for students who wish to fulfill the requirements of two majors.

**The major for the Class of 2018** With DUS approval, the following changes to the requirements of the major may be fulfilled by students who declared their major under previous requirements.

**The major for the Class of 2019 and subsequent classes** For all three degree programs, the major requires a group of prerequisites or equivalents; several courses beyond the prerequisites; and a senior requirement, as indicated below.

**PREREQUISITES**

**B.S. degree program in Mechanical Engineering** The prerequisites in mathematics are MATH 112, 115, and ENAS 151, or the equivalent. The basic science prerequisites are PHYS 180, 181, or 200, 201; one laboratory from PHYS 165L or 205L, and one from PHYS 166L or 206L, or equivalents.

**B.S. degree program in Engineering Sciences (Mechanical)** The prerequisites in mathematics are MATH 112, 115, and ENAS 151, or the equivalent. The basic science prerequisites are PHYS 180, 181, or 200, 201; one laboratory from PHYS 165L or 205L, and one from PHYS 166L, 206L, or MENG 286L.

**B.A. degree program in Engineering Sciences (Mechanical)** The prerequisites in mathematics are MATH 112 and 115. The basic science prerequisite is physics at least to the level of PHYS 170, 171.

**REQUIREMENTS OF THE MAJOR**

**B.S. degree program in Mechanical Engineering** Nineteen term courses beyond the prerequisites are required as follows:

1. Advanced mathematics: ENAS 194 and MATH 222 or 225
2. Mechanical engineering and related: MENG 211, 280, 285, 286L, 361, 363L, 383, 389, 390, 489 (the senior requirement), ENAS 130, EENG 200, and at least one lecture course in chemistry numbered CHEM 161 or higher
3. Technical electives: four approved technical electives chosen in consultation with the director of undergraduate studies; either MENG 471 or 472 (not both) may be counted as one of the four technical electives

The curriculum in this program is arranged in prescribed patterns, but some departures from it are possible with approval of the DUS.

**B.S. degree program in Engineering Sciences (Mechanical)** The major requires twelve approved term courses in engineering, beyond the prerequisites and including the senior project, which can cover a broad array of topics within the subject provided that they contribute to a coherent program. Students should consult with the DUS at the beginning of their sophomore year.

**B.A. degree program in Engineering Sciences (Mechanical)** The program requires eight approved term courses beyond the prerequisites, including the senior project. Students should consult with the DUS at the beginning of their sophomore year.

**Credit/D/Fail** No courses taken Credit/D/Fail may be counted toward the Mechanical Engineering major, including prerequisites.

**SENIOR REQUIREMENT**

**B.S. degree program in Mechanical Engineering** MENG 489 satisfies the senior project requirement.

**B.S. degree program in Engineering Sciences (Mechanical)** Students satisfy the senior project requirement by completing MENG 404, 471 or 472, 489, or another upper-level design course (taken during the senior year) chosen in consultation with the DUS.

**B.A. degree program in Engineering Sciences (Mechanical)** Students satisfy the senior project requirement by completing MENG 471 or 472, or another upper-level design course (taken during their senior year) chosen in consultation with the DUS.

**REQUIREMENTS OF THE MAJOR**

**MECHANICAL ENGINEERING, B.S.**

**Prerequisites** MATH 112, 115, and ENAS 151, or equivalent; PHYS 180, 181, or 200, 201, and 2 labs (1 from PHYS 165L or 205L, and 1 from PHYS 166L or 206L, or equivalents)

**Number of courses** 19 term courses beyond prerequisites (incl senior req)

**Specific courses required** ENAS 130 and 194; EENG 200; MATH 222 or 225; MENG 211, 280, 285, 286L, 361, 363L, 383, 389, 390

**Distribution of courses** 4 technical electives chosen in consultation with DUS (only one of MENG 471 or MENG 472); 1 term course in chem numbered CHEM 161 or higher

**Substitution permitted** With DUS approval

**Senior requirement** MENG 489

**ENGINEERING SCIENCES (MECHANICAL), B.S.**

**Prerequisites** MATH 112, 115, and ENAS 151, or equivalent; PHYS 180, 181, or 200, 201, and 2 labs (1 from PHYS 165L or 205L; 1 from PHYS 166L, 206L, or MENG 286L)

**Number of courses** 12 term courses beyond prerequisites (incl senior project)

**Substitution permitted** With DUS approval

**Senior requirement** MENG 404, 471, or 472, 489 or another upper-level design course chosen in consultation with the DUS
ENGINEERING SCIENCES (MECHANICAL), B.A.
Prerequisites  MATH 112, 115; PHYS 170, 171
Number of courses  8 term courses beyond prerequisites (incl senior req)
Substitution permitted  With DUS approval
Senior requirement  MENG 471 or 472, or another upper-level design course chosen in consultation with the DUS

FACULTY OF THE DEPARTMENT OF MECHANICAL ENGINEERING AND MATERIALS SCIENCE

Professors  Charles Ahn, Ira Bernstein (Emeritus), Juan Fernández de la Mora, Alessandro Gomez, †Sohrab Ismail-Beigi, †Shun-Ichiro Karato, Marshall Long, Brian Scassellati, Jan Schroers, Udo Schwarz (Chair), Mitchell Smooke

Associate Professors  Aaron Dollar, Corey O’Hern

Assistant Professors  Eric Brown, Judy Cha, Rebecca Kramer-Bottiglio, Madhusudhan Venkadesan

Lecturers  Beth Anne Bennett, Andrew Foley, Joseph Zinter

†A joint appointment with primary affiliation in another department or school.

Courses

MENG 101b / ENAS 101b / ENVE 101b / EVST 105b, Energy, Engines, and Environment  Staff
Energy sustainability and global warming; thermodynamic fundamentals; engines (combustion technologies, fossil-fuel pollution, carbon capture and sequestration). Wind, solar, biomass, and other renewable energy sources. Designed for freshmen and sophomores in science and engineering and for non-science majors. Prerequisite: A score of 4 or 5 on Advanced Placement examinations in mathematics and/or science.  SC

* MENG 185a, Mechanical Design  Andrew Foley
A course designed for potential majors in mechanical engineering, with units on design, materials science, structural mechanics, utilization of a machine shop, mechanical dissection, and computers in mechanical engineering. Includes a design project competition. Prerequisite: physics at the level of PHYS 180, or permission of instructor  SC RP

MENG 211b, Thermodynamics for Mechanical Engineers  Jeeyoung Cha
Study of energy and its transformation and utilization. First and Second Laws for closed and open systems, equations of state, multicomponent nonreacting systems, auxiliary functions (H, A, G), and the chemical potential and conditions of equilibrium. Engineering devices such as power and refrigeration systems and their efficiencies. Prerequisites: PHYS 180 or 200, and MATH 115. QR, SC RP

MENG 280a, Mechanical Engineering I: Strength and Deformation of Mechanical Elements  Eric Brown
Elements of statics; mechanical behavior of materials; equilibrium equations, strains and displacements, and stress-strain relations. Elementary applications to trusses, bending of beams, pressure vessels, and torsion of bars. Prerequisites: PHYS 180 or 200, and MATH 115. QR, SC RP

MENG 285a, Introduction to Materials Science  Jan Schroers
Study of the atomic and microscopic origin of the properties of engineering materials: metals, glasses, polymers, ceramics, and composites. Phase diagrams; diffusion; rates of reaction; mechanisms of deformation, fracture, and strengthening; thermal and electrical conduction. Prerequisites: elementary calculus and background in basic mechanics (deformation, Hooke’s law) and structure of atoms (orbitals, periodic table). QB, SC RP

MENG 286Lb, Solid Mechanics and Materials Science Laboratory  Jan Schroers
Experiments that involve either structural mechanics or materials science. Comparisons between structural theories and experimental results. Relationships among processing, microstructure, and properties in materials science. Introduction to techniques for the examination to techniques for the structure of materials. SC RP ½ Course cr

MENG 361a, Mechanical Engineering II: Fluid Mechanics  Mitchell Smooke
Mechanical properties of fluids, kinematics, Navier-Stokes equations, boundary conditions, hydrostatics, Euler’s equations, Bernoulli’s equation and applications, momentum theorems and control volume analysis, dimensional analysis and similitude, pipe flow, turbulence, concepts from boundary layer theory, elements of potential flow. Prerequisites: ENAS 194 or equivalent, and physics at least at the level of PHYS 180. QR, SC RP

* MENG 363La or b, Fluid Mechanics and Thermodynamics Laboratory  Alessandro Gomez
Hands-on experience in applying the principles of fluid mechanics and thermodynamics. Integration of experiment, theory, and simulation to reflect real-world phenomena. Students design and test prototype devices. Prerequisites: MENG 211 and 361. WR, SC RP
MENG 383a, Mechanical Engineering III: Dynamics  Corey O’Hern
Kinematics and dynamics of particles and systems of particles. Relative motion; systems with constraints. Rigid body mechanics; gyroscopes. Prerequisites: PHYS 180 or 200, and MATH 120 or ENAS 151. QR, SC RP

MENG 386a, Electronic, Optical, and Magnetic Properties of Materials  Jee-young Cha
Introduction to quantum mechanics and the band theory of solids. Classification of metals, semiconductors, and insulators according to the band theory. Electronic, optical, and magnetic properties of solids; applications of these materials in electronic and optical devices. Prerequisite: MENG 285.

MENG 389b, Mechanical Engineering IV: Fluid and Thermal Energy Science  Mitchell Smooke
Fundamentals of mechanical engineering applicable to the calculation of energy and power requirements, as well as transport of heat by conduction, convection, and radiation. Prerequisites: MENG 211, 361, and ENAS 194; or permission of instructor. QR, SC RP

MENG 390b, Mechatronics Laboratory  Madhusudhan Venkadesan
Hands-on synthesis of control systems, electrical engineering, and mechanical engineering. Review of Laplace transforms, transfer functions, software tools for solving ODEs. Review of electronic components and introduction to electronic instrumentation. Introduction to sensors; mechanical power transmission elements; programming microcontrollers; PID control. Prerequisites: ENAS 194 or equivalent, ENAS 130, and EENG 200; or permission of instructor. QR RP

MENG 400a, Computer-Aided Engineering  Marshall Long
Aspects of computer-aided design and manufacture (CAD/CAM). The computer’s role in the mechanical design and manufacturing process; commercial tools for two- and three-dimensional drafting and assembly modeling; finite-element analysis software for modeling mechanical, thermal, and fluid systems. Prerequisite: ENAS 130 or permission of instructor. QR

MENG 441a / ENAS 441a, Applied Numerical Methods for Differential Equations  Beth Anne Bennett
The derivation, analysis, and implementation of numerical methods for the solution of ordinary and partial differential equations, both linear and nonlinear. Additional topics such as computational cost, error estimation, and stability analysis are studied in several contexts throughout the course. Prerequisites: MATH 115, and 222 or 225, or equivalents; ENAS 130 or some knowledge of Matlab, C++, or Fortran programming; ENAS 194 or equivalent. ENAS 440 is not a prerequisite. QR RP

* MENG 450b / APHY 450b / ENAS 450b, Advanced Synchrotron Techniques and Electron Spectroscopy of Materials  Charles Ahn
Introduction to concepts of advanced x-ray and electron-based techniques used for understanding the electronic, structural, and chemical behavior of materials. Students learn from world-leading experts on fundamentals and practical applications of various diffraction, spectroscopy, and microscopy methods. Course highlights the use of synchrotrons in practical experiments. Prerequisites: physics and quantum mechanics/physical chemistry courses for physical science and engineering majors, or by permission of instructor. QR, SC

MENG 462b, Theoretical Fluid Dynamics  Juan Fernández de la Mora
Derivation of the equations of fluid motion from basic principles. Potential theory, viscous flow, flow with vorticity. Topics in hydrodynamics, gas dynamics, stability, and turbulence. Prerequisite: MENG 361 or equivalent. QR, SC RP

* MENG 469a, Aerodynamics  Juan Fernández de la Mora
Review of fluid dynamics. Inviscid flows over airfoils; finite wing theory; viscous effects and boundary layer theory. Compressible aerodynamics: normal and oblique shock waves and expansion waves. Linearized compressible flows. Flows. Prerequisite: MENG 361 or permission of instructor. QR, SC

* MENG 471a and MENG 472b, Special Projects I  Beth Anne Bennett
Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. Focus on development of professional skills such as writing abstracts, prospectuses, and technical reports as well as good practices for preparing posters and delivering presentations. Permission of adviser and director of undergraduate studies is required.

* MENG 473a and MENG 474b, Special Projects II  Beth Anne Bennett
Faculty-supervised one- or two-person projects with emphasis on research (experiment, simulation, or theory), engineering design, or tutorial study. Students are expected to consult the course instructor, director of undergraduate studies, and/or appropriate faculty members to discuss ideas and suggestions for topics. These courses may be taken at any time during the student’s career and may be taken more than once. Prerequisites: MENG 471 or 472; permission of adviser and director of undergraduate studies.

MENG 480b, Mechanical Design: Process and Implementation  Aaron Dollar and Beth Anne Bennett
Study of the design process, including concept generation, project management, teamwork, detail design, and communication skills. Student teams implement a real-world design project with hardware objectives that can be achieved in a term, and a problem definition that allows room for creative solutions. Prerequisite: MENG 280, 361, or permission of instructor. SC RP