Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science (MEMS) offers the Bachelor of Science degree in Mechanical Engineering (BSME). In addition, minors in aerospace, robotics, mechatronics, nanoscale science, and energy engineering, and in related scientific and engineering fields, are available to students. The MEMS curriculum emphasizes the core principles of mechanics (the study of forces, materials and motion) that underlie mechanical engineering. The common curriculum during the student's early academic development encourages breadth of understanding, interdisciplinary thinking and creativity. Freshman, sophomore and early junior years are focused on learning fundamental concepts in statics, dynamics, fluid mechanics and thermodynamics. In the junior and senior years, students choose electives that emphasize their specific interests and prepare them for a particular professional or academic career. The undergraduate curriculum for the BSME degree provides Mechanical Engineering & Materials Science students with a strong base in fundamental mathematics, science and engineering; exposes the students to diverse applications of mechanics and materials; and provides the flexibility to explore creative ideas through undergraduate research and project-based courses.

Mechanical engineering is critical in a variety of important emerging technologies. Mechanical engineers design and develop artificial organs, prosthetic limbs, robotic devices, adaptive materials, efficient propulsion mechanisms, high-performance aerospace structures, and advanced renewable energy systems. The core concepts of mechanics, thermal systems and materials science are at the heart of these technologies.

Mission Statement

The Mechanical Engineering & Materials Science faculty is committed to providing the best possible undergraduate mechanical engineering education possible. We strive to nurture the intellectual, professional and personal development of the students, to continually improve the curriculum, to be professionally current, and to maintain state-of-the-art facilities for teaching and learning.

We seek to prepare students for professional practice with a scientifically grounded foundation in the major topics of mechanical engineering: solid mechanics, mechanical design, dynamics and vibrations, systems control, fluid mechanics, thermal science and materials science.

Bachelor of Science Degree in Mechanical Engineering

The mission of the undergraduate program in mechanical engineering is to prepare students within the broad and evolving field of mechanical engineering. The program instills in students a capacity for creative design through critical and analytical thought. The BSME is the first step toward a career in industry, academia or government; it encourages a commitment to independent, lifelong learning and professional development. In addition to their technical studies, students learn to communicate their ideas clearly and to conduct themselves in an ethical and socially responsible manner.

The curriculum is a four-year program leading to the first professional degree, Bachelor of Science in Mechanical Engineering, which is accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org). The curriculum prepares the student for professional practice or postgraduate education in a broad spectrum of mechanical and other engineering or professional fields. The curriculum provides critical knowledge in solid mechanics, fluid mechanics, thermodynamics and heat transfer, materials science, dynamics and control, and design. The curriculum has 34 units of mathematics and basic sciences, 58 units of engineering topics, and 28 units of general education for a total degree requirement of 120 units. The general education includes 18 units of social science and humanities.

Core courses must be taken for credit (grade). The social science and humanities courses may be taken Pass/Fail. The undergraduate program provides the necessary foundations in these areas and the opportunity to specialize in topics of particular interest. Specialization is accomplished by judicious choice of engineering electives taken in 300-, 400- or 500-level courses approved by the student's adviser. At the end of the four-year program, the student is ready to go on to graduate education, research or professional practice.

Program Educational Objectives

Program educational objectives are broad statements that describe what graduates are expected to attain within a few years of graduation. These objectives are based on the needs of the program's constituencies.

Within several years from graduation, graduates of the Bachelor of Science in Mechanical Engineering program are expected to:

- Engage in professional practice and/or advanced study.
- Further their knowledge and skills through education and/or professional development.
- Serve society by using and communicating their knowledge and values.
Student Outcomes

Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge and behaviors that students acquire as they progress through the program.

The Student Outcomes are:

(a) An ability to apply knowledge of mathematics, science and engineering.
(b) An ability to design and conduct experiments, as well as to analyze and interpret data.
(c) An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability.
(d) An ability to function on multidisciplinary teams.
(e) An ability to identify, formulate and solve engineering problems.
(f) An understanding of professional and ethical responsibility.
(g) An ability to communicate effectively.
(h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context.
(i) A recognition of the need for, and an ability to engage in, life-long learning.
(j) A knowledge of contemporary issues.
(k) An ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Bachelor of Science in Applied Science (Mechanical Engineering)

The Bachelor of Science in Applied Science (Mechanical Engineering) degree program will offer a degree path for students to gain technical knowledge in mechanical engineering with more course selection flexibility. Students who do not desire to become licensed engineers but seek to acquire analytical engineering thinking skills may choose to pursue this program. The added degree flexibility will allow these students to pursue additional second majors and/or minors and increase their ability to participate in programs such as study abroad.

Pre-medical Option

Research and practice in the biological and medical sciences increasingly involves advanced technology, including mechanical engineering. For those interested in a career in medicine, the pre-medical option in Mechanical Engineering & Materials Science makes it possible to obtain an accredited Bachelor of Science and simultaneously meet the admission requirements of most medical and dental schools. The program also provides a foundation for graduate study and research in biomedical engineering. The essential requirements of the pre-medical option are two semesters of general biology (Biol 2960, Biol 2970), two semesters of general chemistry with a laboratory, and two semesters of organic chemistry with a laboratory (Chem 261, Chem 262). One semester of biochemistry (Biol 451) is highly recommended. One semester of organic chemistry may be counted as an upper-level MEMS elective; the student must take 6 units of other upper-level mechanical engineering electives to complete the 9-unit requirement. The pre-medical option is easier for those who have a high school background in biology or, by reason of advanced placement, have reduced requirements in the Common Studies portion of the curriculum. For additional information on the pre-medical option, please refer to the pre-medical education section located in the introduction to the School of Engineering & Applied Science's Undergraduate Programs.

Graduate Programs

The department offers programs for graduate study at both the master's and doctoral levels. All programs are designed to direct advanced study into an area of specialization and original research that includes recent scientific and technological advances.

A graduate degree can provide significant advantages and rewards to a mechanical engineer, including increased income and a wider range of career options. Graduate programs include professional, course-option master's degrees (MS and MEng) and research-based master's (MS) or doctoral (PhD) degrees. The undergraduate curriculum provides an excellent foundation for graduate study, and a careful selection of electives in the third and fourth years can facilitate the transition to graduate work. The master's degrees can be pursued on a part-time or full-time basis, while PhD degrees are typically pursued by full-time students.

Departmental website: http://mems.wustl.edu

Chair

Philip V. Bayly
Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Duke University
Nonlinear dynamics, vibrations, biomechanics

Associate Chairs

Katherine M. Flores (Materials Science)
PhD, Stanford University
Mechanical behavior of structural materials

Kenneth L. Jerina (Mechanical Engineering)
Earl E. and Myrtle E. Walker Professor of Engineering
DSc, Washington University
Materials, design, solid mechanics, fatigue and fracture
Endowed Professors

Ramesh K. Agarwal
William Palm Professor of Engineering
PhD, Stanford University
Computational fluid dynamics and computational physics

Thomas G. Harmon
Clifford W. Murphy Professor
PhD, Massachusetts Institute of Technology
Reinforced and prestressed concrete, structural design, fiber reinforced polymers

Mark J. Jakiela
Lee Hunter Professor of Mechanical Design
PhD, University of Michigan
Mechanical design, design for manufacturing, optimization, evolutionary computation

David A. Peters
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics

Shankar M.L. Sastry
Catherine M. and Christopher I. Byrnes Professor of Engineering
PhD, University of Toronto
Materials science, physical metallurgy

Professor

Guy M. Genin
PhD, Harvard University
Solid mechanics, fracture mechanics

Associate Professors

Srikant Singamaneni
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Jessica E. Wagenseil
DSc, Washington University
Biomechanics

Assistant Professors

Parag Banerjee
PhD, University of Maryland
Materials sciences and engineering, nanostructured materials, materials synthesis, and novel devices for storing and harvesting energy

Spencer P. Lake
PhD, University of Pennsylvania
Soft tissue biomechanics

J. Mark Meacham
PhD, Georgia Institute of Technology
Micro-/Nanotechnologies for thermal systems and the life sciences

Rohan Mishra
PhD, Ohio State University
Computational materials science

Amit Pathak
PhD, University of California, Santa Barbara
Biomechanics

Professors of the Practice

Harold J. Brandon
DSc, Washington University
Energetics, thermal systems

Swami Karunamoorthy
DSc, Washington University
Helicopter dynamics, engineering education

Joint Faculty

Richard L. Axelbaum (EECE)
PhD, University of California, Davis
Combustion, nanomaterials

Elliot L. Elson (Biochemistry and Molecular Biophysics)
The Alumni Endowed Professor in Biochemistry and Molecular Biophysics
PhD, Stanford University
Biochemistry and molecular biophysics

Kenneth F. Kelton (Physics)
Arthur Holly Compton Professor of Arts & Sciences
PhD, Harvard University
Study and production of titanium-based quasicrystals and related phases

Eric C. Leuthardt (Neurological Surgery and BME)
MD, University of Pennsylvania School of Medicine
Neurological surgery

Matthew J. Silva (Orthopedic Surgery)
PhD, Massachusetts Institute of Technology
Biomechanics of age-related fractures and osteoporosis

Larry A. Taber (BME)
Dennis and Barbara Kessler Professor of Biomedical Engineering
PhD, Stanford University
Biomechanics, mechanics of development

Simon Tang (Orthopedic Surgery, BME)
PhD, Rensselaer Polytechnic Institute
Biological mechanisms

Stavros Thomopoulos (Orthopedic Surgery)
PhD, University of Michigan
Development, healing and tissue engineering of the tendon-to-bone insertion
Senior Research Associate
Ruth J. Okamoto
DSc, Washington University
Biomechanics, solid mechanics

Senior Professors
Phillip L. Gould
PhD, Northwestern University
Structural analysis and design, shell analysis and design, biomechanical engineering
Salvatore P. Sutera
PhD, California Institute of Technology
Viscous flow, biorheology
Barna A. Szabo
PhD, State University of New York–Buffalo
Numerical simulation of mechanical systems, finite-element methods

Senior Lecturer
Jerry W. Craig
MS, Pittsburg State University
Computer aided design

Lecturers
Emily J. Boyd
PhD, University of Texas at Austin
Thermo fluids
H. Shaun Sellers
PhD, Johns Hopkins University
Mechanics and materials

Adjunct Instructors
Ricardo L. Actis
DSc, Washington University
Finite element analysis, numerical simulation, aircraft structures
Carl A. Baggett
BS, University of Missouri–Columbia
Design
Thomas L. Bever
BS, Washington University
Design, mechanical systems
John D. Biggs
MEng, Washington University
Thermal science
Andrew W. Cary
PhD, University of Michigan
Computational fluid dynamics
Richard S. Dyer
PhD, Washington University
Propulsion, thermodynamics, fluids
John M. Griffith
BS, Washington University
Manufacturing
Hanford Gross
BS, Washington University
Engineering project management
Raimo J. Hakkinen
PhD, California Institute of Technology
Aerodynamics, experimental methods in fluid dynamics
Richard R. Janis
MS, Washington University
Building Environmental Systems
Adetunji Onikoyi
PhD, University of California, Santa Barbara
Thermo Sciences
Rigoberto Perez
PhD, Purdue University
Fatigue and Fracture
Dale M. Pitt
DSc, Washington University
Aeroelasticity
Gary D. Renieri
PhD, Virginia Polytechnic Institute and State University
Structural applications, composite materials
Frederick W. Roos
PhD, University of Michigan
Aerodynamics, fluid dynamics
Hiroshi Tada
PhD, Lehigh University
Solid mechanics
Michael C. Wendl
DSc, Washington University
Mathematical theory and computational methods in biology, and engineering

Laboratory and Design Specialist
Mary K. Malast
DSc, Washington University
Materials science

Professors Emeriti
Wallace B. Diboll Jr.
MSME, Rensselaer Institute of Technology
Dynamics, vibrations, engineering design
Paul C. Paris  
PhD, Lehigh University  
Classical mechanics, solid mechanics, dynamics, fracture mechanics, stochastic processes

**Majors**

Please see the sections below for information about the Bachelor of Science in Mechanical Engineering (p. 5) and the Bachelor of Science in Applied Science (Mechanical Engineering) (p. 6).

**Bachelor of Science in Mechanical Engineering**

The Department of Mechanical Engineering & Materials Science offers a four-year curriculum leading to a professional baccalaureate degree, a Bachelor of Science in Mechanical Engineering (BSME). This degree is designed to prepare students for graduate school, a professional graduate program or industry; the program is accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org). The BSME curriculum is structured around a basic core of 58 units and a complementary mechanical engineering program of at least 62 units to complete the degree requirement of a total of 120 units.

**Basic Core Courses**

**Humanities, Social Science and Writing**

Humanities and social science electives  15  
Engr 4501 Engineering Ethics and Sustainability  1  
Engr 4502 Engineering Leadership and Team Building  1  
Engr 4503 Conflict Management and Negotiation  1  
Engr 310 Technical Writing  3  
Unit Subtotal  21

**Mathematics and Computation**

Math 132  Calculus II  3  
Math 233  Calculus III  3  
Math 217  Differential Equations  3  
ESE 318  Engineering Mathematics A  3  
ESE 319  Engineering Mathematics B  3  
ESE 326  Probability and Statistics for Engineering  3  
CSE 200  Engineering and Scientific Computing  3  
Unit Subtotal  21

**Physical Sciences**

Chem 111A  General Chemistry I  3  
Chem 151  General Chemistry Laboratory I  2  
Physics 117A  General Physics I  4  
or Physics 197  Physics I  4  
Physics 118A  General Physics II  4  
or Physics 198  Physics II  4  
Physical or Life Science (Biol, EPSc, EnSt, Physics, Chem)  3  
Unit Subtotal  16

**Mechanical Engineering Courses**

MEMS 202  Computer-Aided Design  3  
MEMS 205  Mechanics and Materials Science Laboratory  2  
MEMS 253  Engineering Mechanics I  3  
MEMS 255  Engineering Mechanics II  3  
MEMS 301  Thermodynamics  3  
MEMS 305  Fluid Mechanics and Heat Transfer Laboratory  2  
MEMS 3110  Machine Elements  3  
MEMS 350  Engineering Mechanics III  3  
MEMS 3410  Fluid Mechanics  3  
MEMS 3420  Heat Transfer  3  
MEMS 3610  Materials Science  3  
MEMS 405  Vibrations and Machine Elements Laboratory  2  
MEMS 411  Mechanical Engineering Design Project  3  
MEMS 412  Design of Thermal Systems  3  
MEMS 4301  Modeling, Simulation and Control  3  
MEMS 4310  Dynamics and Vibrations  3  
ESE 230  Introduction to Electrical and Electronic Circuits  4  
MEMS electives  9  
Free electives  4  
Unit Subtotal  62

**Selected MEMS Electives**

MEMS 3601  Materials Engineering  3  
MEMS 4101  Manufacturing Processes  3  
MEMS 424  Introduction to Finite Element Methods in Structural Analysis  3  
MEMS 5001  Optimization Methods in Engineering  3  
MEMS 5101  Analysis and Design of Fluid-Power Systems  3  
MEMS 5102  Materials Selection in Design  3  
MEMS 5301  Nonlinear Vibrations  3  
MEMS 5302  Theory of Vibrations  3  
MEMS 5401  General Thermodynamics  3  
MEMS 5402  Radiation Heat Transfer  3  
MEMS 5403  Conduction and Convection Heat Transfer  3  
MEMS 5410  Fluid Dynamics I  3  
MEMS 5411  Fluid Dynamics II  3  
MEMS 5412  Computational Fluid Dynamics  3  
MEMS 5413  Advanced Computational Fluid Dynamics  3  
MEMS 5414  Aeroelasticity and Flow-Induced Vibrations  3
MEMS 5416  Turbulence  3
MEMS 5420  HVAC Analysis and Design I  3
MEMS 5421  HVAC Analysis and Design II  3
MEMS 5422  Solar Energy Thermal Processes  3
MEMS 5423  Sustainable Environmental Building Systems  3
MEMS 5424  Thermo-Fluid Modeling of Renewable Energy Systems  3
MEMS 5500  Elasticity  3
MEMS 5501  Mechanics of Continua  3
MEMS 5504  Fracture Mechanics  3
MEMS 5506  Experimental Methods in Solid Mechanics  3
MEMS 5507  Fatigue and Fracture Analysis  3
MEMS 5510  Finite Element Analysis  3
MEMS 5520  Advanced Analytical Mechanics  3
MEMS 5560  Interfaces and Attachments in Natural and Engineered Structures  3
MEMS 5561  Mechanics of Cell Motility  3
MEMS 5563  Orthopaedic Biomechanics-Bones and Joints  3
MEMS 5564  Orthopaedic Biomechanics-Cartilage/Tendon  3
MEMS 5601  Mechanical Behavior of Materials  3
MEMS 5602  Non-metallics  3
MEMS 5603  Materials Characterization Techniques I  3
MEMS 5604  Materials Characterization Techniques II  3
MEMS 5605  Mechanical Behavior of Composites  3
MEMS 5606  Soft Nanomaterials  3
MEMS 5607  Introduction to Polymer Blends and Composites  3
MEMS 5608  Introduction to Polymer Science and Engineering  3
MEMS 5609  Electronic Materials Processing  3
MEMS 5610  Quantitative Materials Science and Engineering  3
MEMS 5611  Principles and Methods of Micro and Nanofabrication  3
MEMS 5700  Aerodynamics  3
MEMS 5701  Aerospace Propulsion  3
MEMS 5703  Analysis of Rotary-Wing Systems  3
MEMS 5704  Aircraft Structures  3
MEMS 5705  Wind Energy Systems  3
MEMS 5801  Micro-Electro-Mechanical Systems I  3
MEMS 5802  Micro-Electro-Mechanical Systems II  3

MEMS 1001  Machine Shop Practicum  1
MEMS 1003  Mechanical Engineering Design and Build  1
MEMS 101  Introduction to Mechanical Engineering and Mechanical Design  2

**Bachelor of Science in Applied Science (Mechanical Engineering)**

The Bachelor of Science in Applied Science (Mechanical Engineering) program provides substantive and consistent training in mechanical engineering with maximum flexibility. This program is advantageous if a student wishes to pursue a more flexible program than the accredited BSME degree program. It is especially suitable for a double major in combination with mathematics, physics, chemistry, biology, economics or another engineering discipline. The program can be planned to provide a background for graduate work in biological, medical or management fields. The BS in Applied Science is a nonprofessional degree and is not accredited by the Engineering Accreditation Commission of ABET (http://www.abet.org).

The degree requirements include the residency and general requirements of the university and the school. The Bachelor of Science in Applied Science (Mechanical Engineering) degree requirements are:

- Complete at least a total of 120 applicable units
- Complete a minimum of 60 units at Washington University
- Complete at least 42 units at the 300 level or higher
- Complete at least 48 units in mathematics, natural science and engineering
- Complete at least 30 units of mechanical engineering (MEMS) courses
- Satisfy the SEAS English composition requirement
- Satisfy the SEAS humanities and social science requirement
- Satisfy the residency requirement of 30 units of 300-level or higher engineering courses
- Earn at least a 2.0 cumulative GPA in all applicable courses taken at Washington University
- Earn at least a 2.0 cumulative GPA in mechanical engineering (MEMS) courses

**Minors**

Please see the sections below for information about the minors in aerospace engineering (p. 6), energy engineering (p. 7), environmental engineering science (p. 7), nanoscale science and engineering (p. 7), robotics (p. 7), mechatronics (p. 8), and mechanical engineering (p. 8).

**The Minor in Aerospace Engineering**

Whether students are intent on a career in aviation, or simply enthusiastic about space and flight, a minor in aerospace engineering can satisfy their scientific curiosity, prepare them
The minor in aerospace engineering is available to all undergraduates but is most attractive to those pursuing a degree in mechanical engineering. The minor in aerospace engineering requires a minimum of 15 units of courses selected from the list below; it is possible to earn the minor without increasing the number of units (120) required for the BSME.

Aerospace engineering deals with the analysis, design and performance of flight vehicles such as transport and military aircraft, helicopters, missiles and launch vehicles, and spacecraft. Students learn about aerospace engineering by taking courses in aerodynamics, aircraft flight dynamics and control, aerospace propulsion, aerospace structures and aerospace vehicle design. Students also may have the opportunity to gain experience in aerospace engineering design through collaborative programs with local companies such as Boeing. Aerospace engineers from industry teach courses as adjunct instructors at Washington University, and many Washington University regular faculty members have extensive aerospace industry experience.

Units required: 15

Required courses:

- MEMS 4301 Modeling, Simulation and Control 3
- or ESE 441 Control Systems
- MEMS 5700 Aerodynamics 3

Total units 6

Core courses: (3-6 units)

- MEMS 5701 Aerospace Propulsion 3
- MEMS 5704 Aircraft Structures 3

Electives: (3-6 units)

Any course from the aerospace MS concentration list can be used as an aerospace minor elective.

To find out more about this minor, contact the department chair or the adviser for the minor in aerospace engineering or visit the minor web page.

The Minor in Energy Engineering

This minor will provide students with course work that will enhance their background, knowledge and skills in the topical area of energy engineering. The minor covers classes in several fields of science and engineering, encompassing the Department of Energy, Environmental & Chemical Engineering; the Department of Electrical & Systems Engineering; and the Department of Mechanical Engineering & Materials Science. A minor in energy engineering requires the completion of 18 units. It is open to undergraduate students pursuing an engineering major, students from the sciences (biology, chemistry, physics) in Arts & Sciences, and students pursuing the environmental studies major. The detailed requirements for the minor can be found on the minor in energy engineering web page. Questions regarding the minor should be directed to a member of the committee for the energy engineering minor: Professor Pratim Biswas (EECE), Professor Hiro Mukai (ESE) or Professor David Peters (MEMS).

The Minor in Environmental Engineering Science

The minor in environmental engineering science may be earned by students receiving any of the Bachelor of Science degrees offered by the School of Engineering & Applied Science or the Environmental Studies degree or the Earth and Planetary Sciences degree offered by the College of Arts & Sciences. The 21–22 unit program prepares a graduate to seek an entry-level position as an environmental engineer, scientist or analyst. The minor also provides a solid foundation for undertaking graduate study in environmental engineering. The detailed requirements for the minor can be found on the minor in environmental engineering science web page. Questions regarding the minor should be directed to a member of the committee for the environmental engineering minor: Professor Pratim Biswas (EECE) or Professor Jay Turner (EECE).

The Minor in Nanoscale Science and Engineering

Nanotechnology deals with materials, structures or devices one of whose dimensions are in the 1 to 100 nm length scale. These entities have properties (physical, chemical or biological) that are very different from their bulk counterparts and can be tuned to obtain novel and desired functionalities. The goal of this minor is to enhance the background, knowledge and skills in the topical area of nanotechnology. The minor covers classes in several fields of science and engineering; encompassing all the departments in the School of Engineering & Applied Science and several in the School of Arts & Sciences. It is open to any undergraduate student pursuing an Engineering or Arts & Sciences (chemistry, physics, biology, environmental studies) major. The Departments of Computer Science & Engineering; Energy, Environmental & Chemical Engineering; and Mechanical Engineering & Materials Science sponsor the minor.

For more information and requirements, contact a member of the Committee to Oversee the Nanoscale Science Minor: Parag Banerjee (MEMS, Coordinator), Pratim Biswas (EECE), or Victor Gruev (CSE) or visit the minor in nanoscale science web page.

The Minor in Robotics

Robotic systems have wide application in modern technology and manufacturing. Robots can vary in complexity and use, from microrobots for surgical procedures to moderate-size robots common in manufacturing and undersea exploration to macrorobots used for disposal of nuclear wastes or deployed as arms on space-station modules. The program designed for
a minor in robotics provides a fundamental understanding of robotic operation and preliminary training in design and use of robots.

**Units required:** 18

**Prerequisites:**

- Math 217: Differential Equations 3
- Physics 117A: General Physics I 4
  or Physics 197: Physics I
- Physics 118A: General Physics II 4
  or Physics 198: Physics II
- CSE 131: Computer Science I 3
  or CSE 200: Engineering and Scientific Computing

**Required courses:**

- MEMS 255: Engineering Mechanics II 3
- ESE 351: Signals and Systems 3
  or MEMS 4310: Dynamics and Vibrations
- ESE 446: Robotics: Dynamics and Control 3
- ESE 447: Robotics Laboratory 3

**Total units:** 12

Two courses chosen with the approval of the director of the program for a minor in robotics. Suggested courses are:

- CSE 452A: Computer Graphics 3
- CSE 546T: Computational Geometry 3
- MEMS 3110: Machine Elements 3
- MEMS 4301: Modeling, Simulation and Control 3
  or MEMS 4302: Aircraft Flight Dynamics and Control
  or ESE 441: Control Systems
- ESE 407: Analysis and Simulation of Discrete Event Systems 3
- ESE 435: Electrical Energy Laboratory 3

To find out more about this minor, contact the department chair or the adviser of the minor in robotics or visit the minor web page.

### The Minor in Mechatronics

Advancements in power electronics, electronic sensors, and computer hardware and software have led to an expanding role for “smart” systems, which combine electronic and mechanical components. Automotive examples illustrate this point. The replacement of carburetors by fuel injection systems is almost universal, and hybrid/electric cars are replacing traditional automobiles. Not only are auxiliary devices such as fuel pumps, air bags, and air-conditioner compressors driven by electric motors controlled by microprocessors, but fundamental components such as intake and outtake valves soon will be driven in this way. The internal combustion engine itself may be replaced by fuel cells and motors. Medical devices, micro-

electromechanical systems, robots, fly-by-wire aircraft and wind turbines also all rely on electronic sensing of mechanical parameters and actuation of motion. These examples suggest strongly that engineers who are adept in the design, analysis and simulation of electromechanical systems will be in demand. The minor in mechatronics is created to encourage our students to study this important subject and provide recognition to those who do so.

The proposed minor program consists of four required courses, two electives and one prerequisite:

**Four required courses:**

- MEMS 255: Engineering Mechanics II 3
- MEMS 411: Mechanical Engineering Design Project 3
- ESE 444: Sensors and Actuators 3
- ESE 446: Robotics: Dynamics and Control 3

**Total units:** 12

**Two electives from the following:**

- MEMS 4301: Modeling, Simulation and Control 3
  or MEMS 4302: Aircraft Flight Dynamics and Control
  or ESE 441: Control Systems
- MEMS 4310: Dynamics and Vibrations 3
- MEMS 5101: Analysis and Design of Fluid-Power Systems 3
- ESE 336: Principles of Electronic Devices 3
- ESE 442: Digital Control Systems 3
- ESE 482: Digital Signal Processing 3
- CSE 467S: Embedded Computing Systems 3
- CSE 550S: Mobile Robotics 3

**Prerequisite:**

Basic programming course: CSE 131 Computer Science I or CSE 200 Engineering and Scientific Computing.

To find out more about this minor, contact the department chair or the adviser for the minor in mechatronics or visit the minor web page.

### The Minor in Mechanical Engineering

The minor in mechanical engineering complements studies in a field related to mechanical engineering, such as biomedical engineering, electrical engineering, physics, chemistry or architecture. The minor is intended to provide students with a credential that could enhance their opportunities for employment or graduate study. Completion of the minor demonstrates that the student has pursued a structured program approved by the faculty of the Department of Mechanical Engineering & Materials Science.

Students pursuing the minor in mechanical engineering must complete a total of 18 units of course work as described below.
Courses selected for the minor program may count toward program requirements of the student’s major. The subjects selected for a minor in mechanical engineering are expected to constitute a coherent program within the field of mechanical engineering. Courses taken under the pass/fail grading option cannot be used for a minor program.

**Required courses:**

- MEMS 253 Engineering Mechanics I 3
- or BME 240 Biomechanics
- MEMS 255 Engineering Mechanics II 3
- or Physics 411 Mechanics
- MEMS 350 Engineering Mechanics III 3

**Total units**

9

**Three electives from the following:**

- MEMS 301 Thermodynamics 3
- or EECE 203 Thermodynamics I in EECE
- or BME 320B Bioengineering Thermodynamics
- MEMS 3110 Machine Elements 3
- MEMS 3410 Fluid Mechanics 3
- MEMS 3610 Materials Science 3
- MEMS 4310 Dynamics and Vibrations 3
- EECE 203 Thermodynamics I in EECE 3

**Total units**

9

To find out more about this minor, contact the department chair or the adviser for the minor in mechanical engineering or visit the minor web page.

**Courses**

Visit https://courses.wustl.edu to view semester offerings for E37 MEMS.

---

**E37 MEMS 101 Introduction to Mechanical Engineering and Mechanical Design**

Mechanical engineers face new challenges in the areas of energy, materials and systems. This course introduces students to these areas through team-based, hands-on projects that emphasize engineering design, analysis and measurement skills. The course is strongly recommended for mechanical engineering majors. Students from other disciplines are welcome and encouraged to enroll.

Credit 2 units. EN: TU

---

**E37 MEMS 102 Computer-Aided Design — SketchUp**

SketchUp 3D modeling software is widely used in diverse fields such as architecture, engineering, product design, theatre production and accident and crime reconstruction. SketchUp allows fast 3-dimensional modeling of design concepts, ground contours and animations, with lighting, shades and shadows, colors and textures. The course includes introduction, modeling shapes, modeling complex shapes, adding colors and textures, using library parts, animation, 2-dimensional drawings and rendering 3-D models. A SketchUp project allows students to work on designs in their field of interest.

Credit 1 unit. EN: TU

---

**E37 MEMS 103 Computer-Aided Design — AutoCAD**

AutoCAD is the most used 2-dimensional drawing software for architectural and engineering production drawings. Introduction to AutoCAD, title blocks, drawing setup, absolute and relative coordinates, drawing entities, layouts, drafting geometry, dimensioning, plotting drawings to scale, sectional and other special views, isometric pictorial views. Class work involves typical drawings from industry.

Credit 1 unit. EN: TU

---

**E37 MEMS 202 Computer-Aided Design**

An introduction to computer-aided engineering design in the context of mechanical and structural engineering. Students learn the fundamentals of spatial reasoning and graphical representation. Freehand sketching skills, including pictorial and orthographic views, are applied to the design process. Computer modeling techniques provide accuracy, analysis and visualization tools necessary for the design of structures, devices and machines. Topics include: detailing design for production; fasteners; dimensioning; tolerancing; creation of part and assembly drawings; computer-aided design, analysis and optimization of parts and assemblies; solid modeling of complex surfaces; assembly modeling; assembly constraints; and interference checking.

Credit 3 units. EN: TU

---

**E37 MEMS 203 Advanced CAD**

Computer-aided design, analysis and optimization of parts and assemblies; solid modeling of complex surfaces, creation of detail drawings, dimensioning and tolerancing; assembly modeling, assembly constraints, interference checking; motion constraints, force and acceleration analysis, thermal analysis; part optimization for weight, strength and thermal characteristics using Unigraphics software. MEMS 203 is an extension of the basic course, MEMS 202.

Credit 3 units. EN: TU
E37 MEMS 205 Mechanics and Materials Science Laboratory
Laboratory experiments and exercises focusing on mechanical properties of engineering materials; metallography; heat treatment; beam deflection; stress and strain measurement; properties and structure of engineering materials; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports; and presentation of data. Prerequisite: MEMS 253. Corequisite: MEMS 3610.
Credit 2 units. EN: TU

E37 MEMS 253 Engineering Mechanics I
Principles of statics, solid mechanics, force systems and equilibrium. Equivalent systems of forces and distributed forces. Applications to trusses, frames, machines, beams and cables. Mechanics of deformable solids and indeterminate problems. Stress, strain, deflection, yield and fracture in beams, columns and torsion members. Prerequisite: Physics 197 or 117A. Corequisite: Math 217.
Credit 3 units. EN: TU

E37 MEMS 255 Engineering Mechanics II
Credit 3 units. EN: TU

E37 MEMS 301 Thermodynamics
Topics include: classical thermodynamics, thermodynamic properties, work and heat, first and second laws, entropy, irreversibility, availability, thermodynamic cycle analysis, mixtures of ideal gases, combustion processes and chemical equilibrium. Applications to engineering systems are discussed. Prerequisites: Chem 111A, Math 132, Physics 197 or 117A.
Credit 3 units. EN: TU

E37 MEMS 305 Fluid Mechanics and Heat Transfer Laboratory
Laboratory experiments and exercises focusing on fluid properties, flow phenomena, thermal science and heat transfer phenomena; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports; and presentation of data. Prerequisite: MEMS 3410. Corequisite: MEMS 3420.
Credit 2 units. EN: TU

E37 MEMS 311 Machine Elements
Overview of the steps in the engineering design process and an introduction to several classes of machine elements such as bearings, gears, belts, brakes and springs. Underlying analytical models of the machine elements are presented along with guidelines about designing and choosing such elements for practical applications. A case study of the steps of the design process as well as the rationale for choosing particular machine elements is discussed. Prerequisites: MEMS 251 or MEMS 253, MEMS 361.
Credit 4 units. EN: TU

E37 MEMS 3110 Machine Elements
Overview of the steps in the engineering design process and an introduction to several classes of machine elements such as bearings, gears, belts, brakes and springs. Underlying analytical models of the machine elements are presented along with guidelines about designing and choosing such elements for practical applications. A case study of the steps of the design process as well as the rationale for choosing particular machine elements is discussed. Prerequisites: MEMS 253 and MEMS 3610.
Credit 3 units. EN: TU

E37 MEMS 3401 Fluid Mechanics Laboratory
Physical laboratory exercises focusing on fluid properties and flow phenomena covered in MEMS 3410. Calibration and use of a variety of equipment; acquisition, processing and analysis of data by manual as well as automated methods; training in formal report writing. Prerequisite: MEMS 3410.
Credit 1 unit. EN: TU

E37 MEMS 3410 Heat Transfer
Introductory treatment of the principles of heat transfer by conduction, convection or radiation. Mathematical analysis of steady and unsteady conduction along with numerical methods. Analytical and semi empirical methods of forced and natural convection systems. Boiling and condensation heat transfer. Radiation between black-body and real surfaces. Radiation network analysis. Physical laboratory exercises focusing on heat-transfer phenomena. Calibration and use of a variety of laboratory instrumentation; acquisition, processing and analysis of data. Prerequisites: MEMS 3410, ESE 317 or ESE 318 and ESE 319.
Credit 4 units. EN: TU

E37 MEMS 3420 Heat Transfer
Introductory treatment of the principles of heat transfer by conduction, convection or radiation; analysis of steady and unsteady conduction with numerical solution methods; analytical and semi-empirical methods of forced and natural convection; boiling and condensation heat transfer; and radiation heat transfer. Prerequisites: MEMS 3410, ESE 318 and ESE 319.
Credit 3 units. EN: TU

E37 MEMS 350 Engineering Mechanics III
A continuation of MEMS 253 containing selected topics in the mechanics of deformable solids, presented at an intermediate level between introductory strength of materials and advanced continuum mechanics. Lectures discuss elastic and elasto-plastic response, failure criteria, composites, beams and structural stability, as well as an introduction of the tensorial formulation of stress and strain and the governing equations of 3-D linear elasticity. Mathematical methods from calculus, linear algebra and linear differential equations are used. Computer
E37 MEMS 3601 Materials Engineering
The application of fundamental materials science principles in engineering disciplines. Topics include: design of new materials having unique property combinations, selection of materials for use in specific service environment, prediction of materials performance under service conditions, development of processes to produce materials with improved properties, structural and functional use of metals, polymers, ceramics and composites.
Credit 3 units. EN: TU

E37 MEMS 361 Materials Science
Introduction to the chemistry and physics of engineering materials. Topics include: atomic and molecular interpretation of physical and chemical properties, the relationships between physical and chemical properties, and performance of an engineering material. Laboratory exercises focus on the properties and structure of engineering materials. Prerequisite: Chem 111A.
Credit 4 units. EN: TU

E37 MEMS 3610 Materials Science
Introduction to properties, chemistry and physics of engineering materials; conduction, semiconductors, crystalline structures, imperfections, phase diagrams, kinetics, mechanical properties, ceramics, polymers, corrosion, magnetic materials, and thin films; relationship of atomic and molecular structure to physical and chemical properties; selection of materials for engineering applications; relationships between physical properties, chemical properties and performance of engineering materials. Prerequisite: Chem 111A.
Credit 3 units. EN: TU

E37 MEMS 400 Independent Study
Independent investigation on topic of special interest. Prerequisites: junior or senior standing and permission of department chair. Students must complete the Independent Study Approval form available in the department office.
Credit variable, maximum 6 units.

E37 MEMS 4001 Fundamentals of Engineering Review
The topics found in most fundamentals of engineering exams are reviewed and illustrated using examples. A discussion of the importance of licensing exams and the strategies for taking these exams are discussed. The main topics for review include: engineering mathematics, basic chemistry, engineering mechanics, engineering economics, thermodynamics, electrical circuits and materials science.
Credit 1 unit.

E37 MEMS 405 Vibrations and Machine Elements Laboratory
Laboratory experiments and exercises focusing on vibration of mechanical systems; kinematic response, dynamic response and design of mechanisms and machine components; displacements, velocities and accelerations in mechanical systems and components; response to static and dynamic forces; transient and steady state response; design of mechanical components for power transmission; calibration and use of instrumentation; acquisition, processing and analysis of data; principles of experimentation and measurement; statistical analysis of data; preparation of laboratory reports and presentation of data. Prerequisite: MEMS 3110. Corequisite: MEMS 4310.
Credit 2 units. EN: TU

E37 MEMS 4101 Manufacturing Processes
Manufacturing processes and machinery are explained and described. Topics include: analytical tools of machine science, heat transfer, vibrations and control theory are applied to the solution of manufacturing problems, analytical development and application of engineering theory to manufacturing problems, machine tools and automated production equipment.
Credit 3 units. EN: TU

E37 MEMS 411 Mechanical Engineering Design Project
Small student teams complete design projects in an environment simulating a research and development setting. First, working individually, students complete a conceptual design study for three design briefs. These are presented to the instructors and students for review and selection of favored concepts. Following the group concept selection, small teams (3–4 students) are formed for each favored project. These teams produce a preliminary working prototype, an engineering analysis proposal and associated engineering analyses, a final working prototype that is “documented” in an appropriate manner (e.g., a CAD model), and a publication that informs other interested parties of its existence. Prerequisite: MEMS 311.
Credit 3 units. EN: TU

E37 MEMS 412 Design of Thermal Systems
Analysis and design of advanced thermo-fluid systems. Student teams participate in the design process, which could involve research, design synthesis, codes, standards, engineering economics, a design project report and formal presentations. Topics include thermo-fluid systems and components such as: power, heating and refrigeration systems; pumps, fans, compressors, combustors, turbines, nozzles, coils, heat exchangers and piping. Prerequisite: MEMS 301 Thermodynamics.
Credit 3 units. EN: TU

E37 MEMS 422 Analysis and Design of Modern Structures II
Analysis and design of concrete elements and structures for strength and deformation. Design and use of concrete beams, beam-columns, long columns, one-way and two-way slab systems, and footings as used in indeterminate frames. Exercises focus on phenomena of structural behavior analysis and design. Prerequisite: MEMS 421.
Credit 3 units. EN: TU

E37 MEMS 423 Behavior and Design of Structural Systems
Analysis and design of realistic building and bridge structures with computer-aided design tools. Capstone use of analysis and design concepts in the design of “real-world” structures. Prerequisites: MEMS 422.
Credit 4 units. EN: TU

E37 MEMS 424 Introduction to Finite Element Methods in Structural Analysis
Application of finite element methods to beams, frames, trusses and other structural components. Modeling techniques for
different types of structural engineering problems. Topics in stress analysis, applied loads, boundary conditions, deflections and internal loads, matrix methods, energy concepts, structural mechanics and the development of finite element modeling methods. Prerequisites: MEMS 253, MEMS 350 and ESE 318. Credit 3 units. EN: TU

E37 MEMS 4301 Modeling, Simulation and Control
Introduction to simulation and control concepts. Topics include: block diagram representation of single- and multi-loop systems; control system components; transient and steady-state performance; stability analysis; Nyquist, Bode and root locus diagrams; compensation using lead, lag and lead-lag networks; design synthesis by Bode plots and root-locus diagrams; state-variable techniques; state-transition matrix; state-variable feedback. Prerequisites: MEMS 255, ESE 318 and ESE 319. Credit 3 units. EN: TU

E37 MEMS 4302 Aircraft Flight Dynamics and Control
An integrated treatment of aircraft stability, flight control, aircraft dynamics, flying qualities and the application of control theory to the synthesis of automatic flight control systems. Topics include: flight stability and control, military and civilian aircraft, automatic control systems to provide stabilization, autopilots to aid in navigation and landing. Prerequisites: MEMS 3410, ESE 317 or ESE 318 and ESE 319. Credit 3 units. EN: TU

E37 MEMS 431 Structural Dynamics and Vibrations
Free and forced vibration of multidegree of freedom and distributed parameter mechanical systems and structures. Methods of Laplace transform, complex harmonic balance, matrix formulation and Fourier series. Transient response of continuous systems by partial differential equations and nonlinear structural response. Laboratory experiments. Prerequisites: MEMS 255, ESE 318 and ESE 319. Credit 4 units. EN: TU

E37 MEMS 4310 Dynamics and Vibrations
Introduction to the analysis of vibrations in single- and multidegree of freedom systems; free and forced vibration of multidegree of freedom and distributed parameter mechanical systems and structures; methods of Laplace transform; complex harmonic balance; matrix formulation; Fourier series; and transient response of continuous systems by partial differential equations. Prerequisites: MEMS 255, ESE 318 and ESE 319. Credit 3 units. EN: TU

E37 MEMS 4401 Combustion and Environment
Introduction to combustion and its application in devices. Topics include: chemical thermodynamics and kinetics; ignition and explosion; deflagration and detonation waves; transport phenomena and the governing equations for heat and mass transfer in chemically reacting flows; laminar and turbulent flame propagation; non-premixed flames; the emission of combustion-generated pollutants and subsequent interaction with the environment; toxic-waste incineration; and practical combustion devices. Prerequisites: MEMS 301, MEMS 342 or equivalent. Credit 3 units. EN: TU

E37 MEMS 463 Nanotechnology Concepts and Applications
The aim of this course is to introduce to students the general meaning, terminology and ideas behind nanotechnology and its potential application in various industries. The topics covered include nanoparticles — properties, synthesis and applications, carbon nanotubes — properties, synthesis and applications, ordered and disordered nanostructured materials and their applications, quantum wells, wires and dots, catalysis and self-assembly, polymers and biological materials, nanoelectronics and nanophotonics, nanomanufacturing and functional nanodevices, health effects and nanotoxicity, etc. Prerequisite: none. Students with a background in general physics, chemistry and biology should be able to comprehend the material. Credit 3 units.

E37 MEMS 500 Independent Study
Independent investigation on topic of special interest. Prerequisites: graduate standing and permission of the department chair. Students must complete the Independent Study Approval Form available in the department office. Credit variable, maximum 6 units.

E37 MEMS 501 Graduate Seminar
This is a required pass/fail course for masters and doctoral degrees. A passing grade is required for each semester of full-time enrollment. A passing grade is received by attendance at the weekly seminars.

E37 MEMS 50101 Analysis and Design of Fluid-Power Systems
Design of hydraulic and pneumatic control and power systems using advanced concepts and analytical tools. Topics include: analysis of fluid flow through orifices and between parallel and inclined planes, theory of spool and flapper valves, feasibility, synthesis, analysis and applications of fluid systems, configuration of pumps, motors, fluid lines and valves, accumulators and storage devices, integration of components into systems, power systems, servo-systems, hydrostatic transmissions, performance diagrams using MATLAB and Simulink, design and analysis of fluid power systems. Credit 3 units. EN: TU

E37 MEMS 5102 Materials Selection in Design
Analysis of the scientific bases of material behavior in the light of research contributions of the past 20 years. Development of a rational approach to the selection of materials to meet a wide range of design requirements for conventional and advanced applications. Although emphasis is placed on mechanical properties, acoustical, optical, thermal and other properties of interest in design are discussed. Credit 3 units. EN: TU

E37 MEMS 5103 Advanced Machine Design
Advanced machine design topics including: stress, strain and strain energy in one dimension; applications to oil-well sucker rods, turbine, compressor and propeller and helicopter blades. Advanced beam theory applied to tie rods; beams on elastic...

Credit 3 units. EN: TU

**E37 MEMS 5201 Advanced Topics in Concrete Systems**

Analysis and design of prestressed concrete members. Topics include: direct design of composite and noncomposite members for flexure, design of continuous beams, flexural strength, shear strength, and design of anchorage zone.

Credit 3 units. EN: TU

**E37 MEMS 5202 Advanced Topics for Structural Systems**

Advanced topics and current research on plastic design and analysis of space frames; plate and box girders; and torsion in structures. Prerequisite: permission of instructor.

Credit 3 units. EN: TU

**E37 MEMS 5301 Nonlinear Vibrations**

In this course, students are introduced to concepts in nonlinear dynamics and vibration and application of these concepts to nonlinear engineering problems. Specific topics include: modeling of lumped and continuous nonlinear systems (strings, beams and plates); vibrations of buckled structures; perturbation and other approximate analytical methods; the use and limitations of local linearization; properties of nonlinear behavior, such as dimension and Lyapunov exponents; stability of limit cycles; bifurcations; chaos and chaotic vibrations; experimental methods and data analysis for nonlinear systems. Concepts are reinforced with a number of examples from recently published research. Applications include aeroelastic flutter, impact dynamics, machine-tool vibrations, cardiac arrhythmias and control of chaotic behavior.

Credit 3 units. EN: TU

**E37 MEMS 5302 Theory of Vibrations**

Analytical methods in vibrations. Topics include: Duhamel's integral, Laplace and Fourier transforms and Fourier series with applications to transient response, forced response and vibration isolation; Lagrange's equations for linear systems, discrete systems, degrees of freedom, reducible coordinates, holonomic constraints and virtual work; matrix methods and state variable approach with applications to frequencies and modes, stability and dynamic response in terms of real and complex modal expansions, dynamic response of continuous systems by theory of partial differential equations, Rayleigh-Ritz and Galerkin energy methods, finite difference and finite element algorithms.

Credit 3 units. EN: TU

**E37 MEMS 5401 General Thermodynamics**

General foundations of thermodynamics valid for small and large systems, and for equilibrium and nonequilibrium states. Topics include: definitions of state, work, energy, entropy, temperature, heat interaction and energy interaction. Applications to simple systems; phase rule; perfect and semi-perfect gas; bulk-flow systems; combustion, energy and entropy balances; availability analysis for thermo-mechanical power generation; and innovative energy-conversion schemes. Prerequisite: graduate standing or permission of instructor.

Credit 3 units. EN: TU

**E37 MEMS 5402 Radiation Heat Transfer**

Formulation of the governing equations of radiation heat transfer. Topics include: electromagnetic theory of radiation; properties of ideal and real surfaces; techniques for solutions of heat transfer between gray surfaces; radiation in absorbing, emitting and scattering media.

Credit 3 units. EN: TU

**E37 MEMS 5403 Conduction and Convection Heat Transfer**

This course examines heat conduction and convection through various fundamental problems that are constructed from the traditional conservation laws for mass, momentum and energy. Problems include the variable-area fin, the unsteady Dirichlet, Robbins and Rayleigh problems, multi-dimensional steady conduction, the Couette flow problem, duct convection and boundary layer convection. Though some numerics are discussed, emphasis is on mathematical technique and includes the extended power series method, similarity reduction, separation of variables, integral transforms, and approximate integral methods.

Credit 3 units. EN: TU

**E37 MEMS 5404 Combustion Phenomena**

Introduction to fundamental aspects of combustion phenomena including relevant thermochemistry, fluid mechanics and transport processes. Emphasis is on elucidation of the physico-chemical processes, problem formulation and analytical techniques. Topics covered include: ignition, extinction, diffusion flames, particle combustion, deflagrations and detonations. Prerequisite: graduate standing or permission of instructor.

Credit 3 units. EN: TU

**E37 MEMS 5410 Fluid Dynamics I**

Formulation of the basic concepts and equations governing a Newtonian, viscous, conducting, compressible fluid. Topics include: transport coefficients and the elements of kinetic theory of gases, vorticity, incompressible potential flow; singular solutions; flow over bodies and lifting surfaces; similarity method; viscous flow, boundary layer, low Reynolds number flows, laminar and turbulent flows.

Credit 3 units. EN: TU

**E37 MEMS 5411 Fluid Dynamics II**

Governing equations and thermodynamics relations for compressible flow. Topics include: kinetic theory of gases; steady, one-dimensional flows with friction and heat transfer; shock waves; Rankine-Hugoniot relations; oblique shocks; reflections from walls and flow interfaces, expansion waves, Prandtl-Meyer flow, flow in nozzles, diffusers and inlets, two- and three dimensional flows; perturbation methods; similarity rules; compressible laminar and turbulent boundary layers; acoustic phenomena. Emphasis is relevant to air vehicles.

Credit 3 units. EN: TU

**E37 MEMS 5412 Computational Fluid Dynamics**

Computational fluid dynamics relevant to engineering analysis and design. Topics include: fundamentals of finite-difference, finite-volume and finite-element methods; numerical algorithms for parabolic, elliptic and hyperbolic equations; convergence, stability and consistency of numerical algorithms; application of numerical algorithms to selected model equations relevant to fluid flow, grid-generation techniques and convergence.
E37 MEMS 5413 Advanced Computational Fluid Dynamics

E37 MEMS 5414 Aeroelasticity and Flow-Induced Vibrations
This course deals with the interactions between aerodynamics, dynamics and structures in aerospace systems. Topics covered include unsteady aerodynamics, finite-state aerodynamic models, classical fixed-wing flutter, rotary-wing aeroelasticity and experimental methods in aeroelasticity. Emphasis is given to the prediction of flutter and limit cycles in aeroelastic systems. Credit 3 units.

E37 MEMS 5415 Viscous Fluid Dynamics

E37 MEMS 5416 Turbulence

E37 MEMS 5420 HVAC Analysis and Design I

E37 MEMS 5421 HVAC Analysis and Design II
Energy calculations to estimate the quantity of energy needed to heat and cool building structures. Fundamentals of incompressible flow, basics of centrifugal pump performance, and design procedures for water piping systems. Space air diffuser design to assure that temperatures, humidities and air velocities within occupied spaces are acceptable. Air duct design and fan analysis for optimally distributing air through building air duct systems. Performance analysis of refrigeration systems, including the effects of pressure losses and heat transfer. Direct contact heat and mass transfer. Credit 3 units. EN: TU

E37 MEMS 5422 Solar Energy Thermal Processes
Extraterrestrial solar radiation, solar radiation on earth’s surface, and weather bureau data. Review of selected topics in heat transfer. Methods of solar energy collection and solar energy storage. Transient and long-term solar system performance. Prerequisite: MEMS 5421 or equivalent. Credit 3 units. EN: TU

E37 MEMS 5423 Sustainable Environmental Building Systems
Sustainable design of building lighting and HVAC systems considering performance, life cycle cost and downstream environmental impact. Criteria, codes and standards for comfort, air quality, noise/vibration and illumination. Life cycle and other investment methods to integrate energy consumption/conservation, utility rates, initial cost, system/component longevity, maintenance cost and building productivity. Direct and secondary contributions to acid rain, global warming and ozone depletion. Credit 3 units. EN: TU

E37 MEMS 5424 Thermo-Fluid Modeling of Renewable Energy Systems
Overview of sustainable energy systems. Fundamentals of energy conversion. Renewable energy sources and energy conversion from wind, biomass, solar-thermal, geothermal and ocean/waves. Applications to energy storage, fuel cells, green air and ground transportation, energy-efficient buildings. Energy-economics modeling, emissions modeling, global warming and climate change. Credit 3 units. EN: TU

E37 MEMS 5500 Elasticity
stress intensity factors, damage tolerance analysis, fracture. Topics include: stress vs. fatigue life analysis, progression: fatigue crack initiation, crack propagation and fracture. The course covers the three major phases of metal fatigue for computing fatigue life of metallic structural components. The course objective is to demonstrate practical methods of computing fatigue life of metallic structural components. The course covers the three major phases of metal fatigue progression: fatigue crack initiation, crack propagation and fracture. Topics include: stress vs. fatigue life analysis, cumulative fatigue damage, linear elastic fracture mechanics, stress intensity factors, damage tolerance analysis, fracture toughness, critical crack size computation and load history development. The course focus is on application of this technology to design against metal fatigue and to prevent structural failure.

Credit 3 units. EN: TU

E37 MEMS 5501 Mechanics of Continua
A broad survey of the general principles governing the mechanics of continuous media. Topics include: general vector and tensor analysis, rigid body motions, deformation, stress and strain rate, large deformation theory, conservation laws of physics, constitutive relations, principles of continuum mechanics and thermodynamics, two-dimensional continua. Prerequisites: ESE 501–502 or instructor's permission.

Credit 3 units. EN: TU

E37 MEMS 5502 Plates and Shells
Introduction to the linear theory of thin elastic plates and shells. The emphasis is on application and the development of physical intuition. The first part of the course in the body of the course focuses on the analysis of plates under various loading and support conditions. The remainder of the course deals mainly with axisymmetric deformation of shells of revolution. Asymptotic methods are used to solve the governing equations. Applications to pressure vessels, tanks and domes. Prerequisites: BME 240 or MEMS 253, ESE 317 or equivalent.

Credit 3 units. EN: TU

E37 MEMS 5503 Structural Stability
Theorems of Equilibrium and Stability. Topics include: classification of instability phenomena, postbuckling behavior and imperfection-sensitivity, systems with multiple degrees of freedom, buckling of columns, beam-columns, and frames using classical and variational methods and stability and nonlinear behavior of plates and shells.

Credit 3 units. EN: TU

E37 MEMS 5504 Fracture Mechanics
Classical fracture and fatigue analysis and their limitations. Topics include: Griffith-Irwin, linear-elastic fracture-mechanics analysis, historical aspects, formulation of stability criteria, subcritical crack growth, anisotropic and inhomogeneous effects, fracture-control analysis, with applications to fracture-safety analysis relating to nuclear reactors, aircraft, rotating machinery, elastic-plastic fracture-mechanics analysis and future prospects and applications. Prerequisites: graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5505 Experimental Methods in Solid Mechanics
Current experimental methods to measure mechanical properties of materials are covered. Lectures include theoretical principles, measurement considerations, data acquisition and analysis techniques. Lectures are complemented by laboratory sections using research equipment such as biaxial testing machines, pressure myographs, indentation devices for different scales, and viscometers.

Credit 3 units. EN: TU

E37 MEMS 5507 Fatigue and Fracture Analysis
The course objective is to demonstrate practical methods for computing fatigue life of metallic structural components. The course covers the three major phases of metal fatigue progression: fatigue crack initiation, crack propagation and fracture. Topics include: stress vs. fatigue life analysis, cumulative fatigue damage, linear elastic fracture mechanics, stress intensity factors, damage tolerance analysis, fracture toughness, critical crack size computation and load history development. The course focus is on application of this technology to design against metal fatigue and to prevent structural failure.

Credit 3 units. EN: TU

E37 MEMS 5510 Finite Element Analysis
Theory and application of the finite element method. Topics include: basic concepts, generalized formulations, construction of finite element spaces, extensions, shape functions, parametric mappings, numerical integration, mass matrices, stiffness matrices and load vectors, boundary conditions, modeling techniques, computation of stresses, stress resultants and natural frequencies, and control of the errors of approximation. Prerequisite: graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5511 Advanced Analytical Mechanics
Lagrange's equations and their applications to holonomic and nonholonomic systems. Topics include: reduction of degrees of freedom by first integrals, variational principles, Hamilton-Jacobi theory, general transformation theory of dynamics, applications such as theory of vibrations and stability of motion, and use of mathematical principles to resolve nonlinear problems. Prerequisite: senior or graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5512 Composite Structures
An introduction to the analysis and design of structures using finite elements. Topics include: elementary theory of elasticity, plate theories and buckling of plate structures, finite element formulation of 2-D elasticity and plate problems. Hands-on use of finite element software is emphasized. A major design project is included.

Credit 3 units. EN: TU

E37 MEMS 5513 Computational Structural Mechanics
Introduction to composite materials. Topics include: anisotropic elasticity and laminate theory; beams and columns of composite materials; plates and panels; transverse shear deformation effects; twisting and stretching shear coupling; honeycomb core sandwich panels; composite shells; energy methods for statics, stability and dynamics; hygrothermal effects; strength and failure theories.

Credit 3 units. EN: TU

E37 MEMS 5520 Advanced Analytical Mechanics
Lagrange's equations and their applications to holonomic and nonholonomic systems. Topics include: reduction of degrees of freedom by first integrals, variational principles, Hamilton-Jacobi theory, general transformation theory of dynamics, applications such as theory of vibrations and stability of motion, and use of mathematical principles to resolve nonlinear problems. Prerequisite: senior or graduate standing or permission of instructor.

Credit 3 units. EN: TU

E37 MEMS 5560 Interfaces and Attachments in Natural and Engineered Structures
Attachment of dissimilar materials in engineering and surgical practice is a challenge. Bimaterial attachment sites are common locations for injury and mechanical failure. Nature presents several highly effective solutions to the challenge of bimaterial attachment that differ from those found in engineering practice. This course bridges the physiologic, surgical and engineering approaches to connecting dissimilar materials. Topics in this course are: natural bimaterial attachments; engineering principles underlying attachments; analysis of the biology of attachments in the body; mechanisms by which robust attachments are formed; concepts of attaching dissimilar materials in surgical practice and engineering; and bioengineering approaches to more effectively combine dissimilar materials.
E37 MEMS 5561 Mechanics of Cell Motility
A detailed review of biomechanical inputs that drive cell motility in diverse extracellular matrices (ECMs). This class discusses cytoskeletal machineries that generate and support forces, mechanical roles of cell-ECM adhesions, and regulation of ECM deformations. Also covered are key methods for cell level mechanical measurements, mathematical modeling of cell motility, and physiological and pathological implications of mechanics-driven cell motility in disease and development. Credit 3 units.

E37 MEMS 5563 Orthopaedic Biomechanics-Bones and Joints
Basic and advanced solid mechanics applied to the musculoskeletal system, with a primary focus on bone and joint mechanics. Topics include: forces in joints; gait analysis; axial, torsional and bending loading of bones; mechanical properties (elastic, fracture, creep, fatigue) and composition of bone; bone adaptation and basic concepts of bone biology; joint kinematics; total hip and knee replacement; mechanical consequences of injury (fracture) and disease (osteoporosis). This class is geared to graduate students and upper level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent.
Same as BME 563
Credit 3 units. EN: TU

E37 MEMS 5564 Orthopaedic Biomechanics-Cartilage/Tendon
Basic and advanced viscoelasticity and finite strain analysis applied to the musculoskeletal system, with a primary focus on soft orthopaedic tissues (cartilage, tendon and ligament). Topics include: mechanical properties of cartilage, tendon and ligament; applied viscoelasticity theory for cartilage, tendon and ligament; cartilage, tendon and ligament biology; tendon and ligament wound healing; osteoarthritis. This class is geared to graduate students and upper-level undergraduates familiar with statics and mechanics of deformable bodies. Prerequisites: BME 240 or equivalent. Note: BME 5902 (463/563) Orthopaedic Biomechanics—Bones and Joints is NOT a prerequisite.
Same as BME 564
Credit 3 units. EN: TU

E37 MEMS 5601 Mechanical Behavior of Materials
A materials science-based study of mechanical behavior of materials with emphasis on mechanical behavior as affected by processes taking place at the microscopic and/or atomic level. The response of solids to external or internal forces as influenced by interatomic bonding, crystal/molecular structure, crystalline/noncrystalline defects and material microstructure are studied. The similarities and differences in the response of different kinds of materials viz., metals and alloys, ceramics, polymers and composites are discussed. Topics covered include physical basis of elastic, visco elastic and plastic deformation of solids; strengthening of crystalline materials; visco elastic deformation of polymers as influenced by molecular structure and morphology of amorphous, crystalline and fibrous polymers; deformation and fracture of composite materials; mechanisms of creep, fracture and fatigue; high strain-rate deformation of crystalline materials; and deformation of noncrystalline materials. Credit 3 units. EN: TU

E37 MEMS 5602 Non-metallics
Structure, mechanical and physical properties of ceramics and cermets, with particular emphasis on the use of these materials for space, missile, rocket, high-speed aircraft, nuclear and solid-state applications.
Credit 3 units. EN: TU

E37 MEMS 5603 Materials Characterization Techniques I
An introduction to the basic theory and instrumentation used in transmission electron, scanning electron and optical microscopy. Practical laboratory experience in equipment operations, experimental procedures and material characterization.
Credit 3 units. EN: TU

E37 MEMS 5604 Materials Characterization Techniques II
Introduction to crystallography and elements of X-ray physics. Diffraction theory and application to materials science including following topics: reciprocal lattice concept, crystal-structure analysis, Laue methods, rotating crystal methods, powder method, and laboratory methods of crystal analysis.
Credit 3 units. EN: TU

E37 MEMS 5605 Mechanical Behavior of Composites
Analysis and mechanics of composite materials. Topics include micromechanics, laminated plate theory, hydrothermal behavior, creep, strength, failure modes, fracture toughness, fatigue, structural response, mechanics of processing, nondestructive evaluation, and test methods. Prerequisite: graduate standing or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5606 Soft Nanomaterials
Soft nanomaterials, which range from self-assembled monolayers (SAMs) to complex 3-D polymer structures, are gaining increased attention owing to their broad-range applications. The course introduces the fundamental aspects of nanotechnology pertained to soft matter. Various aspects related to the design, fabrication, characterization and application of soft nanomaterials are discussed. Topics covered include but are not limited to SAMs, polymer brushes, Layer-by-layer assembly, responsive polymers structures (films, capsules), polymer nanocomposites, biomolecules as nanomaterials and soft lithography.
Credit 3 units. EN: TU

E37 MEMS 5607 Introduction to Polymer Blends and Composites
The course covers topics in multicomponent polymer systems (polymer blends and polymer composites) such as: phase separation and miscibility of polymer blends; surfaces and interfaces in composites; microstructure and mechanical behavior; rubber-toughened plastics; thermoplastic elastomers; block copolymers; fiber-reinforced and laminated composites; techniques of polymer processing with an emphasis on composites processing; melt processing methods such as injection molding and extrusion; solution processing of thin films; selection of suitable processing methods; and materials selection criteria for specific applications. Advanced topics include: nanocomposites such as polymer/CNT composites, biomimetic approaches and current research challenges. Prerequisite: MEMS 361 or equivalent or permission of instructor.
E37 MEMS 5608 Introduction to Polymer Science and Engineering
Topics covered in this course are: the concept of long-chain or macromolecules, polymer chain structure and configuration, microstructure and mechanical (rheological) behavior, polymer phase transitions (glass transition, melting, crystallization), physical chemistry of polymer solutions (Flory-Huggins theory, solubility parameter, thermodynamics of mixing and phase separation), polymer surfaces and interfaces, overview of polymer processing (extrusion, injection molding, film formation, fiber spinning) and modern applications of synthetic and bio-polymers.
Credit 3 units. EN: TU

E37 MEMS 5609 Electronic Materials Processing
This course covers "unit processes" for manufacturing semiconductor chips. Topics include: crystal growth and doping of wafers, oxidation and diffusion, ion implantation, deposition, etching, cleaning and lithography. Processes are described with key concepts derived from science and engineering and process integration is covered for devices such as transistors and light emitting diodes. Nanoprocessing concepts are highlighted in the end to provide students with practical and advanced knowledge of semiconductor manufacturing. Prerequisites: undergraduate engineering mathematics, materials science and basic electronics or instructor's permission.
Credit 3 units. EN: TU

E37 MEMS 5610 Quantitative Materials Science and Engineering
Quantitative Materials Science and Engineering covers the mathematical foundation of primary concepts in materials science and engineering. Topics covered are: mathematical techniques in materials science and engineering; Fourier series; ordinary and partial differential equations; special functions; matrix algebra; and vector calculus. Each is followed by its application to concepts in: thermodynamics; kinetics and phase transformations; structure and properties of hard and soft matter; and characterization techniques. This course is intended especially for students pursuing graduate study in materials science.
Credit 3 units. EN: TU

E37 MEMS 5611 Principles and Methods of Micro and Nanofabrication
An introduction to the fundamentals of micro and nanofabrication processes. Topics covered are: principles of optical lithography; electron-beam lithography; alternative nanolithography techniques; thin film deposition and metrology methods; the physical and chemical processes of wet and dry etching; cleanroom concepts and safety protocols; sequential microfabrication processes; the manufacture of microelectronic and photonic devices; imaging and characterization of micro and nanostructures; and examples of existing and emerging micro and nanodevices.
Credit 3 units. EN: TU

E37 MEMS 5700 Aerodynamics
Fundamental concepts of aerodynamics, equations of compressible flows, irrotational flows and potential flow theory, singularity solutions, circulation and vorticity, Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and Prandtl-Glauert rule, supersonic thin airfoil theory, introduction to performance, basic concepts of airfoil design. Prerequisite: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 5701 Aerospace Propulsion
Propeller, jet, ramjet and rocket propulsion. Topics include: fundamentals of propulsion systems, gas turbine engines, thermodynamics and compressible flow, one-dimensional gas dynamics, analysis of engine performance, air breathing propulsion system, the analysis and design of engine components, and the fundamentals of ramjet and rocket propulsion.
Credit 3 units. EN: TU

E37 MEMS 5703 Analysis of Rotary-Wing Systems
This course introduces the basic physical principles that govern the dynamics and aerodynamics of helicopters, fans and wind turbines. Simplified equations are developed to illustrate these principles, and the student is introduced to the fundamental analysis tools required for their solution. Topics include: harmonic balance, Floquet theory and perturbation methods.
Credit 3 units. EN: TU

E37 MEMS 5704 Aircraft Structures
Basic elements of the theory of elasticity; application to torsion of prismatic bars with open and closed thin-wall sections; the membrane analogy; the principle of virtual work applied to 2-D elasticity problems. Bending, shear and torsion of open and closed thin-wall section beams; principles of stressed skin construction, structural idealization for the stress analysis of wings, ribs and fuselage structures. Margin of safety of fastened connections and fittings. Stability of plates, thin-wall section columns and stiffened panels. Application of the finite element method for the analysis of fastened connections, structural fittings and problems of local stability of aircraft structural components.
Credit 3 units.

E37 MEMS 5705 Wind Energy Systems
A comprehensive introduction to wind energy systems, a practical means of extracting green and sustainable energy. Topics include: a historical perspective of wind turbines; horizontal axis and vertical axis wind turbines; the basic parameters such as power rating and efficiency; the structural components ranging from blade and hub to nacelle and tower; wind turbine aerodynamics, aeroelasticity and control systems; blade fatigue; statistical wind modeling; unsteady airfoil aerodynamics and downstream wake; and environmental considerations such as noise and aesthetics. Prerequisite: senior or graduate standing in engineering or permission of the instructor.
Credit 3 units. EN: TU

E37 MEMS 5801 Micro-Electro-Mechanical Systems I
Introduction to MEMS: Microelectromechanical systems (MEMS) are ubiquitous in chemical, biomedical and industrial (e.g., automotive, aerospace, printing) applications. This course covers important topics in MEMS design, micro-/nanofabrication, and their implementation in real-world devices. The course includes discussion of fabrication and measurement technologies (e.g.,
A second course in MEMS. Topics include: physical microsystems; pressure sensors; accelerometers; microfluidics and micro-scale thermal phenomena; electro-osmotic flows; microvalves; micropumps; optical MEMS; active flow control; system and constraints on microsystem design; compliant mechanisms; microfabricated electrochemical sensors; bio-MEMS; and case studies. Prerequisite: MEMS 5801 or permission of instructor. Credit 3 units. EN: TU

E37 MEMS 5804 Engineering Project Management
Basic fundamentals and advanced concepts of engineering project management applicable to projects and programs, both large and small. Project management skills, techniques, systems, software and application of management science principles are covered and related to research, engineering, architectural and construction projects from initial evaluations through approval, design, procurement, construction and startup. Credit 3 units. EN: TU

E37 MEMS 5912 Biomechanics Journal Club
This journal club is intended for graduate students and advanced undergraduates with an interest in biomechanics. We review landmark and recent publications in areas such as brain, cardiovascular and orthopedic biomechanics, discussing both experimental and modeling approaches. This course meets once weekly at a time to be arranged. Credit 1 unit. EN: TU

E37 MEMS 598 Energy Design Project
Credit variable, maximum 6 units.

E37 MEMS 599 Masters Research
Credit variable, maximum 6 units.