Mechanical Engineering & Materials Science

About Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science (MEMS) offers the Bachelor of Science in Mechanical Engineering (BSME) and the Bachelor of Science in Applied Science (Mechanical Engineering). In addition, minors in aerospace engineering, energy engineering, environmental engineering science, materials science & engineering, nanoscale science & engineering, robotics, mechatronics, and mechanical engineering as well as in related scientific and engineering fields are available to students.

The MEMS curriculum emphasizes the core principles of mechanics (i.e., 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. During their first, sophomore and early junior years, students are focused on learning fundamental concepts in statics, dynamics, fluid mechanics and thermodynamics. During 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 MEMS students with a strong base in fundamental mathematics, science and engineering. It exposes the students to diverse applications of mechanics and materials, and it provides them with the flexibility to explore creative ideas through undergraduate research and project-based courses.

Mechanical engineering is critical to 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 MEMS 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.

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) as well as research-based master's (MS) and doctoral (PhD) degrees. The undergraduate curriculum provides an excellent foundation for graduate study, and a careful selection of electives during 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, whereas the PhD degrees are typically pursued by full-time students.

Website:	https://mems.wustl.edu/academics/undergraduate/index.html

Faculty

Chair

Philip V. Bayly (https://engineering.wustl.edu/faculty/Philip-Bayly.html)
The Lee Hunter Distinguished Professor of Mechanical Engineering
PhD, Duke University
Nonlinear dynamics, vibrations, biomechanics

Associate Chairs

David A. Peters (Mechanical Engineering) (https://engineering.wustl.edu/faculty/David-Peters.html)
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics, aerodynamics

Katharine M. Flores (Materials Science) (https://engineering.wustl.edu/faculty/Katharine-Flores.html)
Christopher I. Byrnes Professor of Engineering
PhD, Stanford University
Mechanical behavior of structural materials

Endowed Professors

Ramesh K. Agarwal (https://engineering.wustl.edu/faculty/Ramesh-Agarwal.html)
William Palm Professor of Engineering
PhD, Stanford University
Computational fluid dynamics, computational physics

Guy M. Genin (https://engineering.wustl.edu/faculty/Guy-Genin.html)
Harold & Kathleen Faught Professor of Mechanical Engineering
PhD, Harvard University
Solid mechanics, fracture mechanics

Mark J. Jakiela (https://engineering.wustl.edu/faculty/Mark-Jakiela.html)
Lee Hunter Professor of Mechanical Design
PhD, University of Michigan
Mechanical design, design for manufacturing, optimization, evolutionary computation

Srikanth Singamaneni (https://engineering.wustl.edu/faculty/Srikanth-Singamaneni.html)
Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Professors

Jianjun Guan (https://engineering.wustl.edu/faculty/Jianjun-Guan.html)
PhD, Zhejiang University
Biomimetic biomaterials synthesis, scaffold fabrication

Jessica E. Wagenseil (https://engineering.wustl.edu/faculty/Jessica-Wagenseil.html)
DSc, Washington University
Arterial biomechanics

Associate Professors

Spencer P. Lake (https://engineering.wustl.edu/faculty/Spencer-Lake.html)
PhD, University of Pennsylvania
Soft-tissue biomechanics

Xianglin Li (https://xianglinli.wixsite.com/mysite/)
PhD, University of Connecticut
Multiphase heat and mass transfer in energy systems; computational fluid dynamics

J. Mark Meacham (https://engineering.wustl.edu/faculty/Mark-Meacham.html)
PhD, Georgia Institute of Technology
Micro-/nanotechnologies for thermal systems and the life sciences

Rohan Mishra (https://engineering.wustl.edu/faculty/Rohan-Mishra.html)
PhD, The Ohio State University
Computational materials science

Amit Pathak (https://engineering.wustl.edu/faculty/Amit-Pathak.html)
PhD, University of California, Santa Barbara
Cellular biomechanics

Assistant Professors

Matthew R. Bersi (https://engineering.wustl.edu/faculty/Matthew-Bersi.html)
PhD, Yale University
Biomedical engineering

Sang-Hoon Bae (https://engineering.wustl.edu/faculty/Sang-Hoon-Bae.html)
PhD, University of California, Los Angeles
Materials growth, optoelectronics, renewable energy

Patricia B. Weisensee (https://engineering.wustl.edu/faculty/Patricia-Weisensee.html)
PhD, University of Illinois at Urbana-Champaign
Thermal fluids

Professors of the Practice

Kashif Masud Awan (https://engineering.wustl.edu/faculty/Kashif-Masud-Awan.html)
PhD, University of Ottawa
Biosensors, quantum computers, optical communication

Swami Karunamoorthy (https://engineering.wustl.edu/faculty/Swami-Karunamoorthy.html)
DSc, Washington University
Helicopter dynamics, engineering education

Teaching Professors

Emily J. Boyd (https://engineering.wustl.edu/faculty/Emily-Boyd.html)
PhD, University of Texas at Austin
Thermofluids

Ruth J. Okamoto (https://engineering.wustl.edu/faculty/Ruth-Okamoto.html)
DSc, Washington University
Biomechanics, solid mechanics

Research Assistant Professor

Hong Niu (https://engineering.wustl.edu/faculty/Hong-Niu.html)
PhD, Ohio State University
Biomaterials, regenerative medicine

Joint Faculty

Richard L. Axelbaum (Energy, Environmental & Chemical Engineering) (https://engineering.wustl.edu/faculty/Richard-Axelbaum.html)
Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Combustion, nanomaterials

Elliot L. Elson (Biochemistry & Molecular Biophysics) (https://profiles.wustl.edu/en/persons/elliot-elson/)
Professor Emeritus of Biochemistry & Molecular Biophysics
PhD, Stanford University
Biochemistry, molecular biophysics

Michael D. Harris (Physical Therapy, Orthopaedic Surgery, and Mechanical Engineering & Materials Science) (https://pt.wustl.edu/people/michael-d-harris-phd/)
PhD, University of Utah
Whole body and joint-level orthopaedic biomechanics

Kenneth F. Kelton (Physics) (https://physics.wustl.edu/people/kenneth-f-kelton/)
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 Biomedical Engineering) (https://neurosurgery.wustl.edu/people/eric-c-leuthardt-md/)
MD, University of Pennsylvania School of Medicine
Neurological surgery

Lori Setton (Biomedical Engineering) (https://engineering.wustl.edu/faculty/Lori-Setton.html)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomechanics for local drug delivery, tissue regeneration specific to the knee joints and spine

Matthew J. Silva (Orthopaedic Surgery) (http://www.orthoresearch.wustl.edu/content/Laboratories/2963/Matthew-Silva/Silva-Lab/Overview.aspx)
Julia and Walter R. Peterson Orthopaedic Research Professor
PhD, Massachusetts Institute of Technology
Biomechanics of age-related fractures and osteoporosis

Simon Tang (Orthopaedic Surgery and Biomedical Engineering) (http://www.orthoresearch.wustl.edu/content/Laboratories/3043/Simon-Tang/Tang-Lab/Overview.aspx)
PhD, Rensselaer Polytechnic Institute
Biological mechanisms

Senior Professors

Phillip L. Gould
PhD, Northwestern University
Structural analysis and design, shell analysis and design, biomechanical engineering

Kenneth L. Jerina (https://engineering.wustl.edu/faculty/Ken-Jerina.html)
DSc, Washington University
Materials, design, solid mechanics, fatigue, fracture

Shankar M.L. Sastry
PhD, University of Toronto
Materials science, physical metallurgy

Salvatore P. Sutera
PhD, California Institute of Technology
Viscous flow, biorheology

Barna A. Szabo
PhD, State University of New York at Buffalo
Numerical simulation of mechanical systems, finite-element methods

Senior Lecturer

Louis G. Woodhams (https://engineering.wustl.edu/faculty/Louis-Woodhams.html)
BS, University of Missouri–St. Louis
Computer-aided design

Lecturers

Chiamaka Asinugo (https://engineering.wustl.edu/faculty/Chiamaka-Asinugo.html)
MS, Washington University
Mechanical engineering design

Sharniece Holland (https://engineering.wustl.edu/faculty/Sharniece-Holland.html)
PhD, University of Alabama
Additive manufacturing, mathematics

Jeffery Krampf (https://engineering.wustl.edu/faculty/Jeff-Krampf.html)
MS, Washington University
Fluid mechanics, modeling, design

J. Jackson Potter (https://engineering.wustl.edu/faculty/Jackson-Potter.html)
PhD, Georgia Institute of Technology
Senior design

H. Shaun Sellers (https://engineering.wustl.edu/faculty/Shaun-Sellers.html)
PhD, Johns Hopkins University
Mechanics, materials

Adjunct Instructors

Ricardo L. Actis
DSc, Washington University
Finite element analysis, numerical simulation, aircraft structures

Robert G. Becnel
MS, Washington University
FE review

Andrew W. Cary
PhD, University of Michigan
Computational fluid dynamics

Richard S. Dyer
PhD, Washington University
Propulsion, thermodynamics, fluids

Timothy W. Jackson
PhD, University of Washington
Structural analysis, dynamics

Richard R. Janis
MS, Washington University
Building environmental systems

Gary D. Renieri
PhD, Virginia Polytechnic Institute and State University
Structural applications, composite materials

Krishnan K. Sankaran
PhD, Massachusetts Institute of Technology
Metallic materials

Michael C. Wendl
DSc, Washington University
Mathematical theory, computational methods in biology and engineering

Majors

Please visit the following pages for more information about our undergraduate programs:

- Bachelor of Science in Mechanical Engineering (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/bs-mechanical/)
- Bachelor of Science in Applied Science (Mechanical Engineering) (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/bs-applied-mechanical/)

Minors

Please visit the following pages for information about our minors:

- Minor in Aerospace Engineering (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/minor-aerospace/)
- Minor in Energy Engineering (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-energy/)
- Minor in Environmental Engineering Science (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-environmental/)
- Minor in Materials Science & Engineering (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/minor-materials/)
- Minor in Mechanical Engineering (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/minor-mechanical/)
- Minor in Mechatronics (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/minor-mechatronics/)
- Minor in Nanoscale Science & Engineering (http://bulletin.wustl.edu/undergrad/engineering/energy-environmental-chemical/minor-nanoscale/)
- Minor in Robotics (http://bulletin.wustl.edu/undergrad/engineering/mechanical-engineering-materials-science/minor-robotics/)

Courses

Visit online course listings to view semester offerings for E37 MEMS (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E37&crslvl=1:5).

E37 MEMS 1001 Machine Shop Practicum
Operation of basic machine tools including: lathe, drill press, grinder and mill. Machine tool use and safety are covered. Student shop privilege requires completion of this practicum.
Credit 1 unit. EN: TU

E37 MEMS 1004 Advanced Machine Shop Practicum
Students will learn to use the vertical machining centers (LPM and 2op), bed mill, and CNC Lathe. Conversation programming and CAD/CAM programming will be taught. Learning to load and unload tooling, set tooling offset, reconcile tools within a program, satisfy machine operational requirements, and complete safety checks will be part of the learning experience. You will learn to read G-Code and M-Code generated by the CAM program and recognize machining events in real time. Pre-requisites: MEMS 1001 Machine Shop Practicum.
Credit 1 unit. EN: TU

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.
Credit 2 units. EN: TU

E37 MEMS 103 Computer-Aided Design — AutoCAD
AutoCAD is the most used two-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 201 Numerical Methods and Matrix Algebra
This course provides students with computational tools for solving mechanical, structural, and aerospace engineering problems. An introduction to MATLAB will be presented, including data input/output, program flow control, functions and graphics. Topics covered include matrices, determinants, rank, vector spaces, solutions of linear systems, interpolation and curve fitting, numeric differentiation and integration, eigenvalue and initial-value problems, nonlinear equations, and optimization. Each topic will be treated in the context of a typical engineering application. Prerequisite: Math 217.
Credit 3 units. 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 2 units. EN: TU

E37 MEMS 203 Advanced Computer-Aided Design
Topics covered will include computer-aided design, analysis, and optimization of parts and assemblies; solid modeling of complex surfaces, creation of detail drawings, and dimensioning and tolerancing; assembly modeling, assembly constraints, and interference checking; motion constraints, force and acceleration analysis, and thermal analysis; and part optimization for weight, strength, and thermal characteristics using SOLIDWORKS software. Prerequisite: MEMS 202 or equivalent.
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 Statics and Mechanics of Materials
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 failure in beams, columns, and torsion members. Prerequisite: Physics 197. Corequisite: Math 217.
Credit 3 units. EN: TU

E37 MEMS 255 Dynamics
Review of vector algebra and calculus. Kinematics of a particle. Newton's laws and the kinetics of a particle. Work and energy. Impulse and momentum. Kinematics of rigid bodies. General theorems for systems of particles. Kinetics of rigid bodies. The inertia tensor. Computer problems form a significant part of the class. Corequisite: Math 217.
Credit 3 units. EN: TU

E37 MEMS 301 Thermodynamics
This course of classical thermodynamics is oriented toward mechanical engineering applications. It includes properties and states of a substance, processes, cycles, work, heat, and energy. Steady-state and transient analyses utilize the First and Second Laws of Thermodynamics for closed systems and control volumes, as well as the concept of exergy. Prerequisites: Chem 105 or 111A, Math 132, Physics 197.
Credit 3 units. EN: BME T, 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 3110 Machine Elements
This course includes weekly lectures and a bi-weekly lab. Lectures introduce the engineering design process, review stresses and failure theories, and present a variety of machine elements (such as bearings, shafts, gears, belts, springs, etc.) and their governing equations. In lab, students use a commercial CAD package (SolidWorks) to create and constrain models of machine assemblies, analyze stresses in machine components, and create animations to demonstrate machine motion. Course material is presented in the context of a semester-long engineering design problem that culminates in a final group project. Student teams generate their own design concept to embody in CAD and characterize it with engineering and analytical models. Prerequisite: MEMS 253. Corequisite: MEMS 3610.
Credit 3 units. EN: BME T, TU

E37 MEMS 312 Multidisciplinary Design & Prototyping
This hands-on course introduces students to the engineering design process and a variety of prototyping tools and techniques. Skills are developed through weekly studios, individual exercises, and a design project performed in small groups. Lectures focus on design principles and real-world issues for engineered products. The theme for this semester is "environmental data collectors," seeking to create accurate, robust, low-cost, and easy-to-use devices that measure and record physical conditions (such as temperature, chemical content, noise, light, wind velocity, etc.) for ecological and environmental research.
Credit 3 units. EN: TU

E37 MEMS 3410 Fluid Mechanics
Fundamental concepts of fluids as continua. Topics include: viscosity, flow fields, velocity, vorticity, streamlines, fluid statics, hydrostatic forces, manometers, conservation of mass and momentum, incompressible inviscid flow, dimensional analysis and similitude, flow in pipes and ducts, flow measurement, boundary-layer concepts, flow in open channels. Corequisite: MEMS 255. Prerequisites: Math 233 and Math 217.
Credit 3 units. EN: BME T, TU

E37 MEMS 3420 Heat Transfer
This course provides an 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 and MEMS 301, ESE 319, and MEMS 201 or ESE 318.
Credit 3 units. EN: BME T, TU

E37 MEMS 350 Solid Mechanics
A continuation of MEMS 253 containing selected topics in the mechanics of deformable solids, presented at a level intermediate between introductory strength of materials and advanced continuum mechanics. Lectures will discuss elastic and elasto-plastic response, failure criteria, composites, beams, and structural stability as well as provide an introduction of the tensorial formulation of stress and strain and the governing equations of 3D linear elasticity. Mathematical methods from calculus, linear algebra and linear differential equations will be used. Computer problems form a significant part of the class. MEMS 255 not required. Prerequisite: MEMS 253. Corequisite: MEMS 201 or ESE 318.
Credit 3 units. EN: BME T, TU

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: BME T, 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 105 or 111A and 151.
Credit 3 units. EN: BME T, 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 3 units.

E37 MEMS 4001 Fundamentals of Engineering Review
A review and preparation of the most recent NCEES Fundamentals of Engineering (FE) Exam specifications is offered in a classroom setting. Exam strategies will be illustrated using examples. The main topics for the review include engineering mathematics, statics, dynamics, thermodynamics, heat transfer, mechanical design and analysis, material science and engineering economics. A discussion of the importance and responsibilities of professional engineering licensure along with ethics will be included.
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 4050 Vibrations Lab
Laboratory experiments, data analysis, and simulation, focusing on vibration of mechanical systems; kinematic and 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. MATLAB will be used for data analysis and simulation. Pre-requisites: MEMS 3110 Co-requisite: MEMS 4310.
Credit 1 unit. 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: BME T, TU

E37 MEMS 411 Mechanical Engineering Design Project
Student groups work on an open-ended mechanical design problem and finish the semester by presenting a physical prototype and a formal report to an external review board. Groups are guided through the engineering design process by completing a set of project deliverables. The quality of these deliverables provides a basis for evaluation of individual and team performance. This course emphasizes the importance of user-centric design, communication and presentation skill, consideration of real-world constraints, sketching and creativity, prototyping, and data-driven decision making using engineering models and analyses. Prerequisites: MEMS 3110 & MEMS 3420.
Credit 3 units. EN: BME T, 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: BME T, 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 and MEMS 350.
Credit 3 units. EN: BME T, TU

E37 MEMS 4301 Modeling, Simulation and Control
Introduction to simulation and control concepts. Topics include: block diagram representation of single- and multiloop 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: BME T, TU

E37 MEMS 4310 Vibrations
Introduction to the analysis of vibrations in single-degree 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 319, and MEMS 201 or ESE 318.
Credit 3 units. EN: BME T, 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 nanotehnology and its potential application in various industries. The topics covered will 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, and so on. 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 3 units.

E37 MEMS 5001 Optimization Methods in Engineering
Analytical methods in design. Topics include: mathematical methods, linear and nonlinear programming, optimality criteria, fully stressed techniques for the design of structures and machine components, topological optimization, search techniques and genetic algorithms. Knowledge of calculus and computer programming is expected.
Credit 3 units. EN: BME T, TU

E37 MEMS 501 Graduate Seminar
This is a required pass/fail course for master's 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 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: BME T, TU

E37 MEMS 5104 CAE-Driven Mechanical Design
An introduction to the use of computer-aided engineering (CAE) tools in the mechanical design process. Topics include: integrating engineering analysis throughout the process; multidisciplinary optimization; and computer-aided design directed toward new manufacturing processes. Students will work with commercial and research software systems to complete several projects. Students should have experience and familiarity with a CAD tool, optimization and the finite element method. Prerequisite: MEMS 202 Computer-Aided Design or equivalent.
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, 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, multidimensional 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: BME T, TU

E37 MEMS 5404 Combustion Phenomena
This course provides an introduction to fundamental aspects of combustion phenomena, including relevant thermochemistry, fluid mechanics, and transport processes as well as the interactions among them. Emphasis is on elucidation of the physico-chemical processes, problem formulation and analytic techniques. Topics covered include non-premixed and premixed flames, deflagrations and detonations, particle combustion, flame extinction, flame synthesis, pollutant formation and methods of remediation. Contemporary topics associated with combustion are discussed throughout. Prerequisite: Senior or graduate standing or permission of instructor.
Same as E44 EECE 512
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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 acceleration schemes. Prerequisite: senior or graduate standing or permission of the instructor.
Credit 3 units. EN: BME T, TU

E37 MEMS 5413 Advanced Computational Fluid Dynamics
Scope and impact of computational fluid dynamics. Governing equations of fluid mechanics and heat transfer. Three-dimensional grid-generation methods based on differential systems. Numerical methods for Euler and compressible Navier-Stokes equation. Numerical methods for incompressible Navier-Stokes equations. Computation of transonic inviscid and viscous flow past airfoils and wings. Analogy between the equations of computational fluid dynamics, computational electromagnetics, computational aeroacoustics and other equations of computational physics. Non-aerospace applications — bio-fluid mechanics, fluid mechanics of buildings, wind and water turbines, and other energy and environment applications. Prerequisite: MEMS 5412 or permission of the instructor.
Credit 3 units. EN: TU

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. EN: TU

E37 MEMS 5417 Physical Acoustics
The primary focus of this course is on plane waves as an introduction to acoustical concepts of propagation, reflection and transmission, refraction, normal modes, horn theory, and absorption and dispersion. The course also includes more complicated problems (e.g., those involving spherical and cylindrical waves) and selected topics in applied acoustics including materials/damping, imaging, nondestructive evaluation, and acoustic microfluidics.
Credit 3 units.

E37 MEMS 5420 HVAC Analysis and Design I
Fundamentals of heating, ventilating, and air conditioning — moist air properties, the psychrometric chart, classic moist air processes, design procedures for heating and cooling systems. Design of HVAC systems for indoor environmental comfort, health, and energy efficiency. Heat transfer processes in buildings. Development and application of techniques for analysis of heating and cooling loads in buildings, including the use of commercial software. Course special topics can include LEED rating and certification, cleanrooms, aviation, aerospace, and naval applications, ventilation loads, animal control facilities, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.
Credit 3 units. EN: BME T, TU

E37 MEMS 5421 HVAC Analysis and Design II
Fundamentals of heating, ventilating, and air conditioning — energy analysis and building simulation, design procedures for building water piping systems, centrifugal pump performance, design of building air duct systems, fan performance, optimum space air diffuser design for comfort, analysis of humidification and dehumidification systems, and advanced analysis of refrigeration systems. HVAC analytical techniques will include the use of commercial software. Course special topics can include LEED rating and certification, management for energy efficiency, energy auditing calculations, aviation, aerospace, and naval applications, ventilation loads, building automation control, and on-site campus tours of state-of-the-art building energy and environmental systems.
Credit 3 units. EN: BME T, TU

E37 MEMS 5422 Solar Thermal Energy Systems
Fundamentals of radiation heat transfers and solar radiation, including basic terminology, atmospheric scattering and absorption, radiation interactions with surfaces, and selective surfaces. Components, cycles, and materials of concentrating solar power plants, including parabolic trough and solar towers. Overview over thermal storage, other solar thermal technologies and photovoltaics. This course includes a final project. Prerequisite: MEMS 3420 or equivalent.
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, TU

E37 MEMS 5425 Thermal Management of Electronics
As the demand for higher performance electronics continues its exponential growth, transistor density doubles every 18 to 24 months. Electronic devices with high transistor density generate heat and thus require thermal management to improve reliability and prevent premature failure. Demanding performance specifications result in increased package density, higher heat loads and novel thermal management technology. This course gives an overview of thermal management for micro/power electronics systems and helps engineers to develop a fundamental understanding of emerging thermal technologies. This course will include the following topics: background of electronics packaging; thermal design of heat sinks; single phase and multiphase flow in thermal systems; two-phase heat exchange devices for portable and high powered electronic systems; computational fluid dynamics for design of thermal systems. Prerequisites: senior or graduate standing.
Credit 3 units. EN: BME T, TU

E37 MEMS 5427 Fundamentals of Fuel Cells
This course is intended for the graduate and senior undergraduate Mechanical Engineering/ Materials Science/Chemical Engineering students interested in obtaining a fundamental background in fuel cell systems. Several types of fuel cells will be discussed, and the fundamental thermodynamics, kinetics of electrochemistry processes, and charge and mass transfer of fuel cells will be introduced. The primary focus will be placed on low temperature fuel cells based on polymer based electrolytes. The design, operation, performance, and reliability/durability of fuel cell systems will be discussed in detail. Specific interests to mechanical engineers, including water management and thermal management, will be a main focus of this course. Furthermore, the state of art research and development of fuel cell technologies may be presented through reading assignments from current literature.
Credit 3 units.

E37 MEMS 5500 Elasticity
Elastic constitutive relations for isotropic and anisotropic materials. Formulation of boundary-value problems. Application to torsion, flexure, plane stress, plane strain and generalized plane stress problems. Solution of three-dimensional problems in terms of displacement potentials and stress functions. Solution of two-dimensional problems using complex variables and conformal mapping techniques. Variational and minimum theorems.
Credit 3 units. EN: BME T, 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, and two-dimensional continua. Prerequisite: ESE 501/502 or instructor's permission.
Credit 3 units. EN: BME T, 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 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 318 and ESE 319 or equivalent.
Credit 3 units. EN: BME T, TU

E37 MEMS 5506 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: BME T, 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: BME T, TU

E37 MEMS 5510 Finite Element Analysis
This course covers the 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 5515 Numerical Simulation in Solid Mechanics I
The solution of 2D and 3D elasticity problems using the finite element method will be covered in this course. Topics include linear elasticity; laminated material; stress concentration; stress intensity factor; solution verification; J integral; energy release rate; residual stress; multi-body contact; nonlinear elasticity; plasticity; and buckling. Prerequisites: MEMS 424 or MEMS 5704; MEMS 5500 or MEMS 5501; and graduate standing or permission of instructor.
Credit 3 units.

E37 MEMS 5516 Numerical Simulation in Solid Mechanics II
The solution of 2D and 3D elasticity problems using the finite element method will be covered in this course. Topics include laminates and composite materials; nonlinear elasticity; plasticity; incremental theory of plasticity; residual stress; geometric nonlinearity; membrane and bending load coupling; multi-body contact; stress intensity factor; interference fit; and buckling analysis. Prerequisite: Graduate standing or permission of instructor.
Credit 3 units.

E37 MEMS 5520 Advanced Analytical Mechanics
Lagrange's equations and their applications to holonomic and non-holonomic systems will be covered in this course. 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 the 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 covered in this course include 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.
Credit 3 units. EN: BME T, TU

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 5562 Cardiovascular Mechanics
This course focuses on solid and fluid mechanics in the cardiac and cardiovascular system. Cardiac and cardiovascular physiology and anatomy. Solid mechanics of the heart, heart valves, arteries, veins and microcirculation. Flow through the heart chambers and blood vessels. Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: BME T, 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 590Z (463/563) Orthopaedic Biomechanics—Bones and Joints is *not* a prerequisite.
Credit 3 units. EN: TU

E37 MEMS 5565 Mechanobiology of Cells and Matrices
At the interface of the cell and the extracellular matrix, mechanical forces regulate key cellular and molecular events that profoundly affect aspects of human health and disease. This course offers a detailed review of biomechanical inputs that drive cell behavior in physically diverse matrices. In particular, cytoskeletal force-generation machineries, mechanical roles of cell-cell and cell-matrix adhesions, and regulation of matrix deformations are discussed. Also covered are key methods for mechanical measurements and mathematical modeling of cellular response. Implications of matrix-dependent cell motility in cancer metastasis and embryonic development are discussed. Prerequisite: graduate standing or permission of the instructor.
Credit 3 units. EN: BME T, TU

E37 MEMS 5566 Engineering Mechanobiology
Engineering Mechanobiology is a new paradigm for understanding and manipulating the biological function of plants, animals, and their cells. Mechanical force has emerged as a critical component of all biological systems, providing mechanisms to sculpt plants and animals during morphogenesis, to enable cell migration, polarization, proliferation, and differentiation in response to physical changes in the environment, and to modulate the function of single molecules. This course provides a foundation for understanding these factors across plant and animal cells. The course begins with an introduction to plant and animal cell biology and principles of signaling, then progresses to an overview of the cell wall and ECM and an introduction to the mechanics and statistical mechanics of solid, viscoelastic, and fibrous continua. The course then focuses on the questions of how do cells feel, how do cells converse with the ECM and wall, and how do cells remember? Knowledge of undergraduate calculus and physics is expected.
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: BME T, 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: BME T, 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: BME T, 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: BME T, 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: BME T, TU

E37 MEMS 5606 Soft Nanomaterials
Soft nanomaterials, which range from self-assembled monolayers (SAMs) to complex 3D 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: BME T, 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, bioinspired nanocomposites, and current research challenges. Prerequisite: MEMS 3610 or equivalent or permission of instructor.
Credit 3 units. EN: BME T, TU

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: BME T, TU

E37 MEMS 5610 Quantitative Materials Science & Engineering
This course will cover the mathematical foundation of primary concepts in materials science and engineering. Topics covered include mathematical techniques in materials science and engineering; Fourier series; ordinary and partial differential equations; special functions; matrix algebra; and vector calculus. Each topic will be 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: BME T, TU

E37 MEMS 5611 Principles and Methods of Micro and Nanofabrication
A hands-on introduction to the fundamentals of micro- and nano-fabrication processes with emphasis on cleanroom practices. The physical principles of oxidation, optical lithography, thin film deposition, etching and metrology methods will be discussed, demonstrated and practiced. Students will be trained in cleanroom concepts and safety protocols. Sequential micro-fabrication processes involved in the manufacture of microelectronic and photonic devices will be shown. Training in imaging and characterization of micro- and nano-structures will be provided. Prerequisite: graduate or senior standing or permission of the instructor
Credit 3 units. EN: BME T, TU

E37 MEMS 5612 Atomistic Modeling of Materials
This course will provide a hands-on experience using atomic scale computational methods to model, understand and predict the properties of real materials. It will cover modeling using classical force-fields, quantum-mechanical electronic structure methods such as density functional theory, molecular dynamics simulations, and Monte Carlo methods. The basic background of these methods along with examples of their use for calculating properties of real materials will be covered in the lectures. Atomistic materials modeling codes will be used to calculate various material properties. Prerequisites: MEMS 3610 or equivalent or permission of instructor.
Credit 3 units. EN: BME T, TU

E37 MEMS 5613 Biomaterials Processing
Biomaterials with 3D structures are important for tissue regeneration. The goal of this class is to introduce various types of biomaterials and fabrication approaches to create 3D structures. The relationship between material properties, processing methods, and design will be the primary focus. The topics include degradable biomaterials for scaffold fabrication, processing of tissue engineering scaffolds, processing of tissue engineering hydrogels, processing of drug delivery systems, and scaffold surface modification.
Credit 3 units. EN: BME T, TU

E37 MEMS 5614 Polymeric Materials Synthesis and Modification
Polymer is a class of widely used material. Polymer performance is highly dependent on its chemical properties. The goal of this class is to introduce methods for the synthesis and modification of polymers with different chemical properties. The topics include free radical polymerization, reversible addition-fragmentation chain transfer polymerization, atom transfer radical polymerization, step growth polymerization, cationic polymerization, anionic polymerization, ring-opening polymerization, and bulk and surface modification of polymers.
Credit 3 units. EN: BME T, TU

E37 MEMS 5615 Metallurgy and Design of Alloys
The design of materials used in critical structures (e.g., airplanes) entails optimizing and balancing multiple properties (e.g., strength, durability, corrosion resistance) to satisfy often conflicting requirements (e.g., better fuel efficiency, lower cost, operation in extreme conditions). Properties of metallic materials are determined by their "microstructure," which in turn is determined by their compositions and processing paths. An understanding of the multivariate relationships among compositions, processing parameters, microstructures, and properties is therefore essential to designing alloys and predicting their behavior in service. This course will discuss these relationships, with emphasis on the hierarchy of microstructural features, how they are achieved by processing, and how they interact to provide desirable property combinations -- essentially the physical metallurgy of alloys. This course will focus on high-performance alloys presently used in airframes as well as alloy design for state-of-the-art processes such as additive manufacturing. Prerequisite: MEMS 3610.
Credit 3 units. EN: BME T, TU

E37 MEMS 5616 Defects in Materials
Defects in materials play a critical role in controlling the properties of solids, which makes them interesting and necessary to study. The objective of this course is to provide a broad overview of defects in crystalline solids, their effect on properties, and methods of characterizing them. Course topics include crystal structures, defect classification, defect interactions, the role of defects in controlling properties of materials, and characterization techniques.
Credit 3 units. EN: BME T, TU

E37 MEMS 5617 Advanced Study of Solid-State Electronics
This course is designed for students who want to pursue advanced study in solid-state materials and electronic applications. It will provide fundamentals of 1) basic solid-state physics 2) phase equilibria and fabrication of emerging solid-state materials: 3D thin films (III-V, III-N, complex oxide) and low dimensional materials (0D, 1D, 2D) 3) electrical and photonic properties and 4) property manipulation: doping and strain engineering. Students will learn various emerging solid-state electronic devices such as HEMT, nano-materials based TFT, QD LEDs, nanogenerators, advanced solar cells and more. The goal of this course is to help students understand fundamentals to design new solid-state device architectures. The course is particularly beneficial for students who have an interest in the emerging semiconductor field.
Credit 3 units. EN: BME T, TU

E37 MEMS 5618 Electronic Behavior of Materials
This course is designed for students who want to understand electronic behavior of materials which is related to electronic/semiconductor research and industry. It will provide fundamentals of 1) crystal structures and bonding of electronic materials, 2) electronic movement in various materials, 3) electronic behavior in junctions, 4) electronic, optic, and magnetic properties correlation, 5) various electronic applications such as solar cells, light-emitting diodes, and transistors. The goal of the course is to help students understand basic knowledge and fundamental about electronic behavior in materials. The course is particularly beneficial for students who have an interest in the semiconductor research and industry.
Credit 3 units.

E37 MEMS 5619 Thermodynamics of Materials
Thermodynamics of mixtures and phase equilibria in materials systems. The course will review the laws of thermodynamics and introduce the principles of statistical mechanics along with thermodynamic variables and the relationships between them. It will cover thermodynamic equilibria in unary and multicomponent systems along with the construction of phase diagrams. The use of thermodynamics for understanding surfaces and interfaces, defects, chemical reactions, and other technical applications will be emphasized.
Credit 3 units.

E37 MEMS 5700 Aerodynamics
This course introduces fundamental concepts of aerodynamics, equations of compressible flows, irrotational flows and potential flow theory, singularity solutions, circulation and vorticity, the Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and the Prandtl-Glauert rule, supersonic thin airfoil theory, an introduction to performance, and basic concepts of airfoil design. Prerequisite: MEMS 3410 or permission of instructor.
Credit 3 units. EN: BME T, 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: BME T, 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: BME T, 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 2D 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: BME T, TU

E37 MEMS 5706 Aircraft Performance
This course introduces the principles and applications of aerodynamics to determine the performance of typical jet engine and propeller airplanes. The performance calculations include flight conditions of takeoff, climb, level flight, and landing. The topics covered also include range and endurance computation, turning flight, flight envelope, constraint analysis and design process. The knowledge and skill gained in this course can be readily applied in the preliminary design of an airplane. Prerequisite: senior or graduate standing in engineering, or permission of the instructor.
Credit 3 units. EN: BME T, TU

E37 MEMS 5707 Flight Dynamics
The course objective is to introduce methods for analyzing and simulating flight vehicle dynamics and to assess performance characteristics. Topics will include: aerodynamics, structural dynamics, vehicle forces and moments, vehicle equations of motion, rigid body and flexible body considerations, model linearization, longitudinal and lateral stability, stability and control augmentation, and aircraft handling qualities. The course focus is on the application of flight dynamics principles and MATLAB will be used extensively for modeling and simulation assignments and demonstrations.
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., physical/chemical deposition, lithography, wet/dry etching, and packaging), as well as application of MEMS theory to design/fabrication of devices in a cleanroom. Lectures cover specific processes and how those processes enable the structures needed for accelerometers, gyros, FR filters, digital mirrors, microfluidics, micro total-analysis systems, biomedical implants, etc. The laboratory component allows students to investigate those processes first-hand by fabricating simple MEMS devices.
Credit 3 units. EN: BME T, 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 597 MEMS Research Rotation
Independent research project that will be determined jointly by the doctoral student and the instructor. Assignments may include background reading, presentations, experiments, theoretical, and/or modeling work. The goal of the course is for the doctoral student to learn the background, principles and techniques associated with research topics of interest and to determine a mutual fit for the student's eventual doctoral thesis laboratory.
Credit 3 units.

E37 MEMS 598 Energy Analysis and Design Project
The Energy Analysis and Design Project is designed to provide mechanical engineering skills in energy applications, renewable energy, and technologies related to energy which can involve heat transfer, thermodynamics, and fluid mechanics. The project topic can be chosen by the student or can be developed by both the student and faculty sponsor. The subsequent research and analysis, conducted under the guidance and direction of the faculty sponsor, results in a final project report that is approved by the faculty sponsor. The course is normally completed over one or two semesters. Recent projects have included: Energy Modeling and Efficiency Improvements: A Comparison of TRACE 700 and eQuest, Analysis of Hydroelectric Power, Optimization of Residential Solar Thermal Heating in the United States, Analysis of Ocean Thermal Energy Conversion Systems, Laboratory Plug Load Analysis and Case Study, Modeling and Optimizing Hydronic Radiant Heating and Cooling Systems using Comsol Multiphysics, CFD Analysis in HVAC Applications, Energy Analysis of Waste Disposal Methods, CFD Analysis of Containment Solutions for Data Center Cooling, Energy Recovery Ventilation, Comparative Study of Green Building Rating Systems, Grid Energy Storage, Protection of Permafrost Under the Quinghai-Tibet Railway by Heat Pipe Technology, Investing in Residential Solar Photovoltaic Systems, How Piping Layout Effects Energy Usage, and Comparison of Building Energy Savings Between China and the United States.
Credit variable, maximum 3 units.

E37 MEMS 599 Master's Research
Credit variable, maximum 6 units.