Mechanical Engineering & Materials Science

The Department of Mechanical Engineering & Materials Science offers a **PhD** and **DSc** in either **Mechanical Engineering** or **Aerospace Engineering** along with a **DSc in Materials Science**. The department's research strengths include biomechanics, materials, energy, fluid mechanics, and rotary-wing aerodynamics. The doctoral student works in conjunction with their adviser in designing the program of study and research project. The dissertation is defended at the end of the research effort. A typical time to PhD after an undergraduate engineering degree is four to five years, but the length of program may vary, depending on the individual and the area of study.

The Department of Mechanical Engineering & Materials Science offers an **MS** degree in either **Mechanical Engineering, Aerospace Engineering,** or **Materials Science and Engineering**. The department also offers a **Master of Engineering in Mechanical Engineering** for those coming from fields closely related to mechanical engineering. The MS degrees can be done either as a course option or a thesis option. For the thesis option, the student will work closely with a faculty adviser on the thesis project. Typical time for an MS or MEng degree is one and one-half to two years, with the thesis option usually taking longer than the course option.

Faculty contact for the PhD program: Jessica Wagenseil (https://engineering.wustl.edu/Profiles/Pages/Jessica-Wagenseil.aspx)

Faculty contact for the MS and DSc programs: David Peters (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=92)

Faculty contact for the MS in Materials Science & Engineering: Katharine Flores (https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx)

Website:	https://mems.wustl.edu/graduate/programs

Faculty

Chair

Philip V. Bayly (https://engineering.wustl.edu/Profiles/Pages/Philip-Bayly.aspx)
Lilyan and E. Lisle Hughes Professor of Mechanical Engineering
PhD, Duke University
Nonlinear dynamics, vibrations, biomechanics

Associate Chairs

Katharine M. Flores (Materials Science) (https://engineering.wustl.edu/Profiles/Pages/Kathy-Flores.aspx)
PhD, Stanford University
Mechanical behavior of structural materials

David A. Peters (Mechanical Engineering) (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=92)
McDonnell Douglas Professor of Engineering
PhD, Stanford University
Aeroelasticity, vibrations, helicopter dynamics

Endowed Professors

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

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

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

Shankar M.L. Sastry (https://engineering.wustl.edu/Profiles/Pages/Shankar-Sastry.aspx)
Christopher I. Byrnes Professor of Engineering
PhD, University of Toronto
Materials science, physical metallurgy

Professors

Jianjun Guan (https://engineering.wustl.edu/Profiles/Pages/Jianjun-Guan.aspx)
PhD, Zhejiang University
Biomimetic biomaterials synthesis and scaffold fabrication

Srikanth Singamaneni (https://engineering.wustl.edu/Profiles/Pages/Srikanth-Singamaneni.aspx)
PhD, Georgia Institute of Technology
Microstructures of cross-linked polymers

Associate Professors

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

Jessica E. Wagenseil (https://engineering.wustl.edu/Profiles/Pages/Jessica-Wagenseil.aspx)
DSc, Washington University
Arterial biomechanics

Assistant Professors

Damena D. Agonafer (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=110)
PhD, University of Illinois at Urbana-Champaign
Computational fluid dynamics and computational physics

J. Mark Meacham (https://engineering.wustl.edu/Profiles/Pages/Mark-Meacham.aspx)
PhD, Georgia Institute of Technology
Micro-/Nanotechnologies for thermal systems and the life sciences

Rohan Mishra (https://engineering.wustl.edu/Profiles/Pages/Rohan-Mishra.aspx)
PhD, Ohio State University
Computational materials science

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

Patricia B. Weisensee (https://mems.wustl.edu/faculty/Pages/default.aspx?bio=112)
PhD, University of Illinois at Urbana-Champaign
Thermal fluids

Professors of the Practice

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

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

Teaching Professor

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

Joint Faculty

Richard L. Axelbaum (EECE) (https://engineering.wustl.edu/Profiles/Pages/Richard-Axelbaum.aspx)
Stifel & Quinette Jens Professor of Environmental Engineering Science
PhD, University of California, Davis
Combustion, nanomaterials

Elliot L. Elson (Biochemistry and Molecular Biophysics) (http://dbbs.wustl.edu/faculty/Pages/faculty_bio.aspx?SID=188)
Professor Emeritus of Biochemistry & Molecular Biophysics
PhD, Stanford University
Biochemistry and molecular biophysics

Michael D. Harris (Physical Therapy, Orthopaedic Surgery and MEMS) (https://pt.wustl.edu/faculty-staff/faculty/mike-harris-phd)
PhD, University of Utah
Whole body and joint-level orthopaedic biomechanics

Kenneth F. Kelton (Physics) (http://www.physics.wustl.edu/people/kelton_kenneth-f)
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) (http://www.neurosurgery.wustl.edu/patient-care/find-a-physician/clinical-faculty/eric-c-leuthardt-md-250)
MD, University of Pennsylvania School of Medicine
Neurological surgery

Lori Setton (BME) (https://bme.wustl.edu/faculty/Pages/faculty.aspx?bio=105)
Lucy and Stanley Lopata Distinguished Professor of Biomedical Engineering
PhD, Columbia University
Biomechanics for local drug delivery: tissue regenerations 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, BME) (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
DSc, Washington University
Materials, design, solid mechanics, fatigue and fracture

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

Lecturers

J. Jackson Potter
PhD, Georgia Institute of Technology
Senior design

H. Shaun Sellers
PhD, Johns Hopkins University
Mechanics and materials

Louis G. Woodhams
BS, University of Missouri-St. Louis
Computer-aided design

Senior Research Associate

Ruth J. Okamoto
DSc, Washington University
Biomechanics, solid mechanics

Research Assistant Professor

Anupriya Agrawal
PhD, Ohio State University
Materials science

Adjunct Instructors

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

Robert G. Becnel
MS, Washington University
FE Review

John D. Biggs
MEng, Washington University
Thermal science

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

Dan E. Driemeyer
PhD, University of Illinois
Thermoscience

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

John M. Griffith
BS, Washington University
Manufacturing

Jason Hawks
MS, Washington University
Structural analysis

Richard R. Janis
MS, Washington University
Building environmental systems

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

Hiroshi Tada
PhD, Lehigh University
Solid mechanics

Matthew J. Watkins
MS, Washington University
Finite elements

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

Laboratory and Design Specialist

Chiamaka Asinugo
MS, Washington University
Mechanical Engr. design

Professor Emeritus

Wallace B. Diboll Jr.
MSME, Rensselaer Polytechnic Institute
Dynamics, vibrations, engineering design

Degree Requirements

Please visit the following pages for information about

- Doctoral Degrees (http://bulletin.wustl.edu/grad/engineering/mechanical-engineering-materials-science/doctoral-degrees)
- Master of Science in Mechanical Engineering (MSME) (http://bulletin.wustl.edu/grad/engineering/mechanical-engineering-materials-science/ms-mechanical)
- Master of Science in Aerospace Engineering (MSAE) (http://bulletin.wustl.edu/grad/engineering/mechanical-engineering-materials-science/ms-aerospace)

- Master of Science (MS) in Materials Science and Engineering (http://bulletin.wustl.edu/grad/engineering/mechanical-engineering-materials-science/ms-materials)
- Master of Engineering (MEng) in Mechanical Engineering (http://bulletin.wustl.edu/grad/engineering/mechanical-engineering-materials-science/meng-mechanical)

Courses

Visit online course listings to view semester offerings for E37 MEMS (https://courses.wustl.edu/CourseInfo.aspx?sch=E&dept=E37&crslvl=5:8).

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 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. Prerequisites: calculus and computer programming.
Credit 3 units. EN: 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: 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: 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, 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: 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. Prerequisites: graduate standing or permission of instructor. (Prior to FL2015, this course was numbered: E33 5404.)
Same as E44 EECE 512
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 acceleration schemes. Prerequisite: senior or graduate standing or permission of the instructor.
Credit 3 units. EN: 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.

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: 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: TU

E37 MEMS 5422 Solar Energy Thermal Processes
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: 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 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: TU

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: 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 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: 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: 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 5515 Numerical Simulation in Solid Mechanics I

Solution of 2D and 3D elasticity problems using the finite element method. 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 Finite Elements or MEMS 5704 Aircraft Structures **and** MEMS 5500 Elasticity or MEMS 5501 Mechanics of Continua **and** graduate standing or permission of instructor.
Credit 3 units.

E37 MEMS 5516 Numerical Simulation in Solid Mechanics II

Solution of 2D and 3D elasticity problems using the finite element method. 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 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.
Credit 3 units. EN: 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: 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: 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? Prerequisites: undergraduate calculus and physics.
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 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: 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: 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: 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: 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 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: 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: 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: 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 Design Project
Credit variable, maximum 6 units.

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

E37 MEMS 600 Doctoral Research
Credit variable, maximum 9 units.

E37 MEMS 883 Master's Continuing Student Status

E37 MEMS 885 Masters Nonresident
