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.

Contact for the PhD program: Prof. Jessica Wagenseil, jessica.wagenseil@wustl.edu

Contact for the MS and DSc programs: Prof. David Peters, dap@wustl.edu

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

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

Professor

Guy M. Genin (https://engineering.wustl.edu/Profiles/Pages/Guy-Genin.aspx)
PhD, Harvard University
Solid mechanics, fracture mechanics

Associate Professors

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

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

Parag Banerjee (https://engineering.wustl.edu/Profiles/Pages/Parag-Banerjee.aspx)
PhD, University of Maryland
Materials sciences and engineering, nanostructured materials, materials synthesis, and novel devices for storing and harvesting energy
Spencer P. Lake (https://engineering.wustl.edu/Profiles/Pages/Spencer-Lake.aspx)  
PhD, University of Pennsylvania  
Soft tissue biomechanics

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 (https://mems.wustl.edu/faculty/Pages/Harold-Brandon.aspx)  
DSc, Washington University  
Energetics, thermal systems

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

Joint Faculty

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

Elliot L. Elson (Biochemistry and Molecular Biophysics) (http://bmbweb.wustl.edu/faculty/faculty/elliot-elson)  
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

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, biomechanics

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

Lecturers

Emily J. Boyd  
PhD, University of Texas at Austin  
Thermofluids
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

Hanford Gross  
BS, Washington University  
Engineering project management

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

Mary K. Malast  
DSc, Washington University  
Materials science

Professor Emeritus

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

Degree Requirements

Please refer to the following sections for information about:

- Doctoral Degrees (p. 3)
- MS in Mechanical Engineering (p. 4)
- MS in Aerospace Engineering (p. 5)
- MS in Materials Science and Engineering (p. 5)
- MEng in Mechanical Engineering (p. 6)

PhD in Mechanical Engineering or Aerospace Engineering

Policies & Regulations

A key objective of the doctoral program is to promote cutting-edge multidisciplinary research and education in the areas of mechanical engineering and materials science. Students are selected for admission to the program by a competitive
process, and they typically start in the fall semester. On arriving at Washington University in St. Louis, the student will be advised by the temporary adviser on all procedural issues. The student will choose a permanent adviser by the end of the first year of residency in the program.

The following is a brief summary of the requirements for doctoral students:

1. Pass the qualifying exams. Qualifying exams should be taken by the end of the third semester.
2. Prepare and defend a research proposal. The research proposal should be defended by the end of the fifth semester.
3. Write and successfully defend the doctoral dissertation.
4. Complete a minimum of 36 hours of course credit, and a minimum of 24 credits of doctoral research; total of 72 credits to earn the PhD degree.
5. Satisfy the applicable teaching requirements of the Graduate School.

Degrees Offered

The Department of Mechanical Engineering & Materials Science (MEMS) offers the following doctoral degrees:

- PhD in Mechanical Engineering
- PhD in Aerospace Engineering
- DSc in Mechanical Engineering, Aerospace Engineering, or Materials Science

The Doctor of Science (DSc) has similar requirements to the PhD but without the teaching requirement. For a list of differences, please refer to the DSc and PhD Comparison (PDF) (https://mems.wustl.edu/graduate/programs/Documents/DoctoralComparisonSection.pdf).

- One may also pursue a PhD in Materials Science — through the Institute of Materials Science & Engineering (IMSE) — but work with professors from the Department of Mechanical Engineering & Materials Science. For details on this program, visit the IMSE Graduate Program (http://imse.wustl.edu/program) webpage.

For more information on MEMS PhD degrees, visit the MEMS Graduate Degree Programs (https://mems.wustl.edu/graduate/programs/Pages/default.aspx) webpage.

MS in Mechanical Engineering (MSME)

Master of Science in Mechanical Engineering Thesis Option

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course work, and a minimum of 6 units must be Master's Research (MEMS 599).

The overall grade-point average must be 2.70 or better.

Courses may be chosen from 400- and 500-level offerings. All must be engineering, math or science courses with the following restrictions:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed, and these must be from courses not required for the BSME degree (if counted for the MSAE) or not required for the BSAE degree (if counted for the MSME degree) with the exception of MEMS 4301 Modeling, Simulation and Control, which can count toward the MS.
- Each course must be approved by the candidate’s thesis adviser.
- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- A minimum of 15 units of the total 30 units must be in MEMS courses.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Master of Science in Mechanical Engineering Course Option

The quantitative requirement for the degree is 30 credit hours (normally 10 courses) completed with a grade-point average of 2.70 or better.

Course programs may be composed from one area of specialization below (MSME) or in aerospace engineering (MSAE). They must conform to the following distribution:

<table>
<thead>
<tr>
<th>Category</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Mathematics</td>
<td>6</td>
</tr>
<tr>
<td>Area of Specialization</td>
<td>15</td>
</tr>
<tr>
<td>Electives</td>
<td>9</td>
</tr>
</tbody>
</table>

Elective courses may be chosen in any area of engineering or mathematics at the 400 level or higher. Of the 30 units, a minimum of 24 must be in 500-level courses. No more than 6 units may be in 400-level courses; but core requirements for the ME undergraduate degree are not allowed with the exception of MEMS 4301 which is allowed. A maximum of 3 credits of Independent Study, MEMS 400 or MEMS 500, may be used as an elective. A minimum of 15 units must be in MEMS. Non-engineering courses (such as T-courses or finance and entrepreneurship) cannot be counted. Full-time MS students
in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Degree candidates will plan their course programs with the help of a departmental adviser. Use the links below to find courses in the areas of specialization.

**Engineering Areas of Specialization for the MS in Mechanical Engineering**

- Applied Mechanics (https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx)
- Dynamics/Mechanical Design (https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx)
- Solid Mechanics/Materials Science (https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx)
- Fluid/Thermal Sciences (https://mems.wustl.edu/graduate/programs/Pages/MS-in-Mechanical-Engineering.aspx)
- Energy Conversion and Efficiency (https://mems.wustl.edu/graduate/programs/Pages/specialized-tracks.aspx)
- Numerical Simulation in Solid Mechanics (https://mems.wustl.edu/graduate/programs/Pages/specialized-tracks.aspx)

**MS in Aerospace Engineering (MSAE)**

**Master of Science in Aerospace Engineering Thesis Option**

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course work, and a minimum of 6 units must be Master's Research (MEMS 599).

The overall grade-point average must be 2.70 or better.

Courses may be chosen from 400- and 500-level offerings. All must be engineering, math or science courses with the following restrictions:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
- A maximum of 6 units of 400-level courses are allowed, and these must be from courses not required for the BSME degree (if counted for the MSAE) or not required for the BSAE degree (if counted for the MSME degree) with the exception of MEMS 4301 which is allowed.
- Each course must be approved by the candidate's thesis adviser.
- A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
- A minimum of 15 units of the total 30 units must be in MEMS courses.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

**Master of Science in Aerospace Engineering Course Option**

The quantitative requirement for the degree is 30 credit hours (normally 10 courses) completed with a grade-point average of 2.70 or better.

Course programs must be focused in the area of aerospace engineering. They must conform to the following distribution:

<table>
<thead>
<tr>
<th>Component</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Mathematics</td>
<td>6</td>
</tr>
<tr>
<td>Aerospace</td>
<td>15</td>
</tr>
<tr>
<td>Electives</td>
<td>9</td>
</tr>
</tbody>
</table>

Elective courses may be used to accumulate additional credits in other areas of engineering or in mathematics. A maximum of 3 credits of Independent Study (MEMS 500) may be included as an elective course. A maximum of 6 units of 400-level courses (not required for a MEMS undergraduate degree) with the exception of MEMS 4301 may also be included. Non-engineering courses (such as T-courses or finance and entrepreneurship) cannot be counted as engineering electives. A minimum of 15 units must be in MEMS.

Full-time MS students are required to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Degree candidates will plan their course programs with the help of a departmental adviser.

**MS in Materials Science and Engineering**

**Master of Science in Materials Science and Engineering Thesis Option**

The quantitative requirement for the degree is 30 credit hours. A minimum of 24 of these units must be course work, and a minimum of 6 units must be Master's Research (MEMS 599).

The overall grade-point average must be 2.70 or better.

Courses are to be Engineering courses at the 500 level or above, or Chemistry or Physics courses at the 400 level or above, and course work must include 3 units (one course) of mathematics at the graduate level. The following restrictions apply:

- A maximum of 3 units of Independent Study (MEMS 500) are allowed.
• A maximum of 6 units of 400-level courses are allowed.
• Each course must be approved by the candidate's thesis adviser.
• A maximum of 6 units of transfer credit is allowed for courses taken at other graduate institutions, and these must have been taken with grade B or better.
• A minimum of 15 units of the total 30 units must be in MEMS courses.

The student must also write a satisfactory thesis and successfully defend it in an oral examination before a faculty committee consisting of at least three members, at least two of which are from the Department of Mechanical Engineering & Materials Science.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

Master of Science in Materials Science and Engineering Course Option

The quantitative requirement for the degree is 30 credit hours (normally 10 courses) completed with a grade point average of 2.70 or better. Full-time MS students are required to take MEMS 501 Graduate Seminar every semester, which is a zero-unit, pass-fail course.

Course work must include 18 units of materials science courses (six courses) with at least one course from each of the following four areas as well as 3 units (one course) of mathematics at the graduate level. An approved list of courses in the following four areas can be found on the MEMS website (https://mems.wustl.edu/graduate/programs/Pages/MS-in-Materials-Science-Engineering.aspx) under graduate MS programs in materials science and engineering.

(A) Structure
(B) Characterization
(C) Properties
(D) Synthesis and Processing

The remaining 9 units (three courses) are electives and may be chosen according to the general criteria above, as long as they contribute to a coherent program of study in materials science.

MEng in Mechanical Engineering

Master of Engineering in Mechanical Engineering

The Master of Engineering in Mechanical Engineering (MEng in ME) is a one- to two-year program offered by the Department of Mechanical Engineering & Materials Science of Washington University in St. Louis. The program is especially tailored for: 1) individuals who plan to change careers and enter the ME profession; 2) international students seeking to establish U.S. credentials in the ME profession; and 3) current professionals working in mechanical engineering who wish to advance their skills and education. A distinctive feature of the program is the ability to customize the course content to meet specific individual needs.

Degree requirements are as follows:

Candidates for admission should have an undergraduate degree in engineering, the physical sciences or mathematics with a GPA of 2.75 or better.

It should be emphasized that, in many states, the MEng in ME will not be sufficient to qualify the degree recipient to sit for a Professional Engineering Exam.

• 30 units of credit in engineering or mathematics courses are required, and these must be at the 400 level or higher. Courses from the other engineering departments (CSE, EECE, ESE and BME) are encouraged. Washington University Continuing Education Courses (i.e., the T-courses or the U-courses) are not permitted.
• All courses must be taken for a grade, with an overall GPA of 2.70 or higher.
• At least 9 of the 30 units must be in MEMS courses at the 500 level. Allowed courses include Engineering Project Management (MEMS 5804).
• All 400-level courses must be either: 1) approved for the Master of Science Degree in ME or AE; or 2) approved by the MEMS faculty for application to the MEng degree.
• No more than 9 units of Independent Study are allowed.
• No more than 6 units may be transferred from another university, and these units must be in engineering or math courses at the 400 level or above, with a grade of B or better, and be courses not required for the candidate's BS degree.

Full-time MS students in any area are required every semester to take MEMS 501 Graduate Seminar, which is a zero-unit, pass-fail course.

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 5012 Analysis and Design of Fluid-Power Systems
Design of hydraulic and pneumatic control and power systems using advanced concepts and analytical tools. Topics include: analysis of fluid flow through orifices and between parallel and inclined planes; theory of spool and flapper valves, feasibility, synthesis, analysis and applications of fluid systems, configuration of pumps, motors, fluid lines and valves, accumulators and storage devices, integration of components into systems, power systems, servo-systems, hydrostatic transmissions, performance diagrams using MATLAB and Simulink, design and analysis of fluid power systems.
Credit 3 units. EN: TU

E37 MEMS 502 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 504 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 aerelastic 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

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 5416 Turbulence

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
Extraterrestrial solar radiation, solar radiation on Earth's surface, and weather bureau data. Review of selected topics in heat transfer. Methods of solar energy collection and solar energy storage. Transient and long-term solar system performance. Prerequisite: MEMS 342 or equivalent. Credit 3 units. EN: TU

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

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

E37 MEMS 5500 Elasticity
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 5504 Fracture Mechanics
Classical fracture and fatigue analysis and their limitations. Topics include: Griffith-Irwin, linear-elastic fracture-mechanics analysis, historical aspects, formulation of stability criteria, subcritical crack growth, anisotropic and inhomogeneous effects, fracture-control analysis, with applications to fracture-safety analysis relating to nuclear reactors, aircraft, rotating machinery, elastic-plastic fracture-mechanics analysis and future prospects and applications. Prerequisites: graduate standing or permission of instructor.
Credit 3 units. EN: TU

E37 MEMS 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 2-D and 3-D 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. Prerequisite: graduate standing or permission of instructor.
Credit 3 units.

E37 MEMS 5516 Numerical Simulation in Solid Mechanics II
Solution of 2-D and 3-D 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.

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
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
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 5602 (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 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
deforation of polymers as influenced by molecular structure
and morphology of amorphous, crystalline and fibrous polymers;
deforation 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
ceramics, with particular emphasis on the use of these materials
for space, missile, rocket, high-speed aircraft, nuclear and solid-
state applications.
Credit 3 units. EN: TU

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

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

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

E37 MEMS 5606 Soft Nanomaterials
Soft nanomaterials, which range from self-assembled
monolayers (SAMs) to complex 3-D polymer structures,
gaining increased attention owing to their broad-range
applications. The course introduces the fundamental aspects of
nanotechnology pertainied 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/GNT 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 5609 Electronic Materials Processing
This course covers “unit processes” for manufacturing semiconductor chips. Topics include: crystal growth and doping of wafers, oxidation and diffusion, ion implantation, deposition, etching, cleaning and lithography. Processes are described with key concepts derived from science and engineering and process integration is covered for devices such as transistors and light emitting diodes. Nanoprocessing concepts are highlighted in the end to provide students with practical and advanced knowledge of semiconductor manufacturing. Prerequisites: undergraduate engineering mathematics, materials science and basic electronics or instructor’s permission. Credit 3 units. EN: TU

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

E37 MEMS 5611 Principles and Methods of Micro and Nanofabrication
A hands-on introduction to the fundamentals of micro- and nanofabrication 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 microfabrication processes involved in the manufacture of microelectronic and photonic devices will be shown. Training in imaging and characterization of micro- and nanostructures will be provided. Prerequisite: graduate or senior standing or permission of the instructor. 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, singularly solutions, circulation and vorticity, Kutta-Joukowski theorem, thin airfoil theory, finite wing theory, slender body theory, subsonic compressible flow and Prandtl-Glauert rule, supersonic thin airfoil theory, introduction to performance, basic concepts of airfoil design. Prerequisite: graduate standing or permission of instructor. Credit 3 units. EN: TU

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

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

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

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

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.

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

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.

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