Mechanical Engineering

The Department of Mechanical Engineering offers undergraduate and graduate programs of instruction and research. Undergraduate programs are offered in Mechanical Engineering and in Engineering Mechanics. The B.S. in the Mechanical Engineering and Engineering Mechanics degree programs are accredited by the Engineering Accreditation Commission of ABET, [http://www.abet.org](http://www.abet.org). Graduate programs are offered leading to the M.S.E. and the Ph.D. degrees. A five-year accelerated B.S./M.S.E. program is also available.

Mechanical Engineering is of great importance in most contemporary technologies. Examples include aerospace, power generation and conversion, fluid machinery, design and construction of mechanical systems, transportation, manufacturing, production, biomechanics, and others. This wide range of applications is reflected in the four main stems of the undergraduate curriculum-thermal and fluid systems, mechanics and materials, robotics and control systems, and biomechanics. Engineering Mechanics is a more flexible program that enables students to pursue particular interests while centering on a smaller core of courses. Students may use this flexibility to follow specific interests in physics, mathematics, economics, biology, and other disciplines while receiving an engineering degree.

Design is a major component of both undergraduate programs. In the two-semester Engineering Design Project course taken by undergraduates during their senior year, students work in teams of three or four to design, construct, and test a mechanical device or system for an industrial sponsor.

A major effort of the department is directed toward the creation of a stimulating intellectual environment in which both undergraduate and graduate students can develop to their maximum potential. Faculty members encourage undergraduate students to participate in both fundamental and applied research along with the graduate students. In most junior and senior undergraduate classes, and in graduate classes, small enrollments permit close contact with faculty members. Students have excellent opportunities to participate actively in the classroom and laboratories and to follow special interests within a subject area.

Facilities

Most teaching and research facilities of the department, as well as the departmental office, are located in Latrobe, Krieger, Wyman, Maryland, and Hackerman Halls. The undergraduate laboratories are equipped with sophisticated data acquisition and analysis systems. A V-6 automobile engine with dynamometer and a computer-controlled milling machine are examples of facilities used for undergraduate instruction. The Mechatronics laboratory allows students to design and build their own robots for a class competition. The Senior Design laboratories are used by seniors to construct and test their prototypes in the yearlong design project course. Computer facilities are readily available throughout the department and the Whiting School.

Research facilities include laboratories in several disciplines. The Laboratory for Impact Dynamics and Rheology includes facilities for the study of failure, instabilities, impact and dynamic phenomena. The Hopkins Extreme Materials Institute addresses fundamental science issues associated with materials under extreme conditions, such as dynamic environments, human tissues, and impacts on planets and asteroids. The Laboratory for Active Materials and Biomimetics contains facilities for the characterization of tissues, active materials and biomaterials. These, coupled with electron microscopy facilities, enable innovative research on the mechanical properties of materials.

The Microspecimen Testing Laboratory has special tensile test machines for specimens as thin as 60 nanometers. The Computational Solid Mechanics Laboratory uses state-of-the-art finite-element techniques to study the physics of impact, wear, and more generally, the behavior of materials under high deformation and high-deformation rates. The calculations are conducted at length scales ranging from the nanoscale up to the macroscale.

A large hydrodynamics laboratory is the home of laser-based flow simulation and analysis research, and the Corssin wind tunnel is equipped with modern instrumentation for turbulence research. The heat transfer laboratory is equipped for research using holographic interferometry to study heat transfer in complex geometries with single- and two-phase flows.

The Laboratory for Computational Sensing and Robotics consists of numerous laboratories and collaborating research centers covering multiple domains. The robotics and mechatronics laboratory is fully equipped for the construction and testing of prototypes of novel robotic systems. The Dynamical Systems and Control laboratory is equipped for design, fabrication, and testing of advanced robotic arms and underwater robots. Experimental equipment includes a test-bed remotely operated underwater vehicle. The Locomotion in Mechanical and Biological Systems (LIMBS) laboratory is equipped with an industrial six-axis manipulator, and as well as the facilities for the development of mobile and medical robots.

Financial Aid

Scholarships and other forms of financial assistance for undergraduates are described under Admissions and Finances ([http://e-catalog.jhu.edu/archive/2013-14/undergrad-students/admissions-and-finances](http://e-catalog.jhu.edu/archive/2013-14/undergrad-students/admissions-and-finances)). In addition, selected undergraduates may be employed as laboratory assistants on research projects. Assistance in various forms is available for graduate students, including tuition fellowships, fellowships with stipend, research assistantships, and competitively-awarded hourly teaching assistant positions. Applications for graduate study must be received by January 15th for consideration.

Research assistantships support graduate students who work with professors on their research contracts and grants.

The Department of Mechanical Engineering offers two undergraduate programs: the Bachelor of Science in Mechanical Engineering and the Bachelor of Science in Engineering Mechanics. Both programs are accredited by ABET, the Accreditation Board for Engineering and Technology. The department offers concentrations in biomechanical engineering and aerospace engineering. For additional information regarding both the mechanical engineering and engineering mechanics academic programs, please consult the undergraduate advising manuals which are available on the departmental website at [http://www.me.jhu.edu/advise.html](http://www.me.jhu.edu/advise.html). For details and an explanation of ABET requirements, visit [www.abet.org](http://www.abet.org).

Requirements for the Bachelor’s Degree

See also General Requirements for Departmental Majors ([http://e-catalog.jhu.edu/archive/2013-14/undergrad-students/academic-policies](http://e-catalog.jhu.edu/archive/2013-14/undergrad-students/academic-policies)).
requirements-for-a-bachelors-degree) ; Writing Requirement, and the
department’s undergraduate advising manuals.

The Mechanical Engineering Program

The mission of the B.S. in mechanical engineering degree program is to
provide a rigorous educational experience that prepares a select group
of students for leadership positions in the profession and a lifetime
of learning. The faculty is committed to maintaining a modern and
flexible curriculum which, building on a foundation of basic sciences
and mathematics, develops a solid education in the mechanical
engineering sciences. The aim of the Mechanical Engineering program
is to build competence in the design and development of thermal,
fluid, and mechanical systems, to promote a broad knowledge of
the contemporary social and economic context, and to develop the
communication skills necessary to excel.

The program provides a basic background in thermal and mechanical
systems. Laboratory instruction, as well as the senior design project,
gives the student hands-on experience. Each student’s program
of study is planned in consultation with his or her faculty advisor.
Students are encouraged to develop depth in one or two areas of
concentration within mechanical engineering chosen from fluid
mechanics, mechanics of solids and design, heat transfer and energy,
robotics, and biomechanics. The choice of concentration is decided in
the junior year after consultation with the student’s faculty advisor.

The objectives for the B.S. in mechanical engineering degree program
are designed to provide a high-quality educational experience that is
tailored to the needs and interests of the student. The program will
educate an exceptional group of engineers who, after graduation, will
be:

1. successful and on track to become leaders among their peers in
   industry, government laboratories and other organizations, and
2. advanced students in the best graduate programs.

Students graduating from the B.S. in mechanical engineering will have
demonstrated the ability to:

• understand and apply the fundamentals of mathematics (through
  linear algebra and multivariate calculus), numerical methods,
  statistical analysis, and physical sciences (physics and chemistry)
  necessary to attain competence in the mechanical engineering
disciplines.
• design, conduct, evaluate, and report experiments including analysis
  and statistical interpretation of data.
• identify, formulate, and solve engineering problems in the areas of
  thermo-fluid and mechanical systems.
• use basic concepts from the mechanical engineering sciences,
  modern engineering tools (machine-tools, laboratory instrumentation,
  and computer hardware and software), and related subjects to
design mechanical engineering components and processes, taking
  into account constraints such as manufacturability, cost, safety,
environmental, and socio-political impacts.
• enter professional practice and/or graduate school with the
  recognition of the need for life-long learning and the ability to pursue
it.
• use effective communication, multidisciplinary teamwork, and
  possess awareness of professional and ethical responsibilities, and an
appreciation of the societal, economic, and environmental impacts of
engineering.

The Mechanical Engineering Curriculum is Structured as Follows

Mathematics (19 credits)

<table>
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<tr>
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<tr>
<td>or AS.110.211</td>
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<tr>
<td>EN.550.291</td>
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<td>or AS.110.211</td>
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<td>or AS.110.201</td>
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Statistics Elective at 300-level or above:

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<td>AS.173.112</td>
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<td>EN.510.101</td>
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Humanities (18 credits)

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**Mechanical Engineering program:**

Engineering elective and Technical Elective requirements in the general following courses (which can be counted toward the Mechanical Engineering Concentration are required to take at least five of these courses). Students pursuing the Aerospace Engineering Concentration are required to take at least five of the courses mentioned below.

**Aerospace Engineering Concentration**

A student may specialize in Aerospace Engineering once a solid background in the fundamentals of mechanical engineering has been developed through the core Mechanical Engineering or Engineering Mechanics courses. The essence of mechanics is the interplay between forces and motion. In biology, mechanics is important at the macroscopic, cellular, and subcellular levels.

At the macroscopic length scale biomechanics of both soft and hard tissues plays an important role in computer-integrated surgical systems and technologies, e.g., medical robotics. At the cellular level, issues such as cell motility and chemotaxis can be modeled as mechanical phenomena. At the subcellular level, conformational transitions in biological macromolecules can be modeled using molecular dynamics simulation, which is nothing more than computational Newtonian mechanics; statistical mechanics, or using coarse-grained techniques that rely on principles from the mechanics of materials.

In addition, much of structural biology can be viewed from the perspective of Kinematics, e.g., finding spatial relationships in data from the Protein Data Bank.

Each student who pursues the Biomechanics concentration will, in consultation with his or her academic advisor, choose the set of technical and mechanical engineering course electives that best matches the student’s interests. Upon completion of the concentration, notification of this achievement is placed on the student’s academic record and transcript.

A student may specialize in biomechanics once a solid background in the fundamentals of mechanical engineering has been developed through the basic courses. Students pursuing the biomechanics concentration within mechanical engineering are required to take at least four of the following courses. Two among the four should be chosen from the biomechanics-oriented courses, indicated by an asterisk (*).

*To obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher. While a course grade of C- or higher is preferred, up to 10 credits with a D or D+ grade will be accepted. For examples of areas of concentration and more details, see the undergraduate academic advising manual at [http://www.me.jhu.edu/advising.html](http://www.me.jhu.edu/advising.html).

** These courses are intended to complement the mechanical engineering electives. One of the three technical electives may be a computer language course taken at any level.

A program of not less than 126 credits must be completed to be eligible for the bachelor’s degree. All undergraduate students must follow a program approved by a faculty member in the department who is selected as the student’s advisor.

### Mechanical Engineering Electives (9 credits)

<table>
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<tr>
<th>Course Code</th>
<th>Course Title</th>
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<td>EN.530.403</td>
<td>Engineering Design Project</td>
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<tr>
<td>&amp; EN.530.404</td>
<td>and Engineering Design Project II</td>
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### Technical Electives (9 credits)

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<tbody>
<tr>
<td>EN.530.328</td>
<td>Fluid Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.418</td>
<td>Aerospace Structures &amp; Materials</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.424</td>
<td>Dynamics of Robots and Spacecraft</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.425</td>
<td>Mechanics of Flight</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.432</td>
<td>Jet &amp; Rocket Propulsion</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.444</td>
<td>Computer-Aided Fluid Mechanics and Heat Transfer</td>
<td>3</td>
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### Capstone Design (8 credits)

(grades below C- not accepted)

<table>
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<tbody>
<tr>
<td>EN.530.403</td>
<td>Engineering Design Project</td>
<td>8</td>
</tr>
</tbody>
</table>

### Total Credits: 126-127

**Biomechanics Concentration**

A student may specialize in Biomechanics once a solid background in the fundamentals of mechanical engineering has been developed through the core Mechanical Engineering or Engineering Mechanics courses. The essence of mechanics is the interplay between forces and motion. In biology, mechanics is important at the macroscopic, cellular, and subcellular levels.

At the macroscopic length scale biomechanics of both soft and hard tissues plays an important role in computer-integrated surgical systems and technologies, e.g., medical robotics. At the cellular level, issues such as cell motility and chemotaxis can be modeled as mechanical phenomena. At the subcellular level, conformational transitions in biological macromolecules can be modeled using molecular dynamics simulation, which is nothing more than computational Newtonian mechanics; statistical mechanics, or using coarse-grained techniques that rely on principles from the mechanics of materials.

In addition, much of structural biology can be viewed from the perspective of Kinematics, e.g., finding spatial relationships in data from the Protein Data Bank.

Each student who pursues the Biomechanics concentration will, in consultation with his or her academic advisor, choose the set of technical and mechanical engineering course electives that best matches the student’s interests. Upon completion of the concentration, notification of this achievement is placed on the student’s academic record and transcript.

A student may specialize in biomechanics once a solid background in the fundamentals of mechanical engineering has been developed through the basic courses. Students pursuing the biomechanics concentration within mechanical engineering are required to take at least four of the following courses. Two among the four should be chosen from the biomechanics-oriented courses, indicated by an asterisk (*).

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tr>
<td>EN.530.467</td>
<td>Thermal Design Issues for Aerospace Systems</td>
<td>3</td>
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<tr>
<td>EN.530.470</td>
<td>Space Vehicle Dynamics &amp; Control</td>
<td>3</td>
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<tr>
<td>AS.171.321</td>
<td>Introduction to Space, Science, and Technology</td>
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<tr>
<td>AS.270.318</td>
<td>Remote Sensing of the Environment</td>
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Other courses relevant to the concentration which don’t count toward the requirements include:

<table>
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<th>Course Title</th>
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<tbody>
<tr>
<td>AS.171.118</td>
<td>Stars and the Universe: Cosmic Evolution</td>
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<tr>
<td>EN.520.214</td>
<td>Signals &amp; Systems I</td>
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<tr>
<td>EN.520.401</td>
<td>Basic Communication</td>
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**Total Credits: 31**
<table>
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<td>Cell &amp; Tissue Engineering Laboratory</td>
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<tr>
<td>EN.530.495</td>
<td>Microfabrication Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.672</td>
<td>Biosensing &amp; BioMEMS *</td>
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</tr>
<tr>
<td>EN.540.405/605</td>
<td>The Design of Biomolecular Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.440</td>
<td>Micro/Nanotechnology: The Science and Engineering of Small Structures</td>
<td>3</td>
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<tr>
<td>EN.580.221</td>
<td>Molecules and Cells x</td>
<td>4</td>
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<tr>
<td>EN.580.421</td>
<td>Systems Bioengineering I xx</td>
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<tr>
<td>EN.580.422</td>
<td>Systems Bioengineering II xx</td>
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<td>Systems Bioengineering Lab I xx</td>
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<td>EN.580.424</td>
<td>Systems Bioengineering Lab xx</td>
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<tr>
<td>EN.580.440</td>
<td>Cell &amp; Tissue Engineer</td>
<td>3</td>
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<tr>
<td>EN.580.455</td>
<td>Introduction to Orthopaedic Biomechanics (Biomedical Engineering) *</td>
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<td>EN.530.101</td>
<td>Freshman Experiences in Mechanical Engineering</td>
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<td>EN.530.103</td>
<td>Introduction to Mechanics I</td>
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<td>Freshman Experiences in Mechanical Engineering</td>
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<td>EN.530.105</td>
<td>Mechanical Engineering Freshman Laboratory I</td>
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<td>Mechanical Engineering Freshman Laboratory II</td>
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<td>Statics and Mechanics of Materials</td>
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<td>Calculus III</td>
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<td>Mechanical Engineering Thermodynamics</td>
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<td>Electronics &amp; Instrumentation</td>
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<td>EN.530.291</td>
<td>Lin Alg &amp; Diff Equations</td>
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<td>Introduction to Fluid Mechanics</td>
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<td>Heat Transfer</td>
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<td>Design and Analysis of Dynamical Systems</td>
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<td>Materials Selection</td>
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<td>EN.530.364</td>
<td>Statistics Elective</td>
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<tr>
<td>EN.530.203</td>
<td>Mechanical Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.231</td>
<td>Mechanical Engineering Thermodynamics Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.232</td>
<td>Mechanical Engineering Thermodynamics Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.241</td>
<td>Electronics &amp; Instrumentation</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.291</td>
<td>Lin Alg &amp; Diff Equations</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.327</td>
<td>Introduction to Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.329</td>
<td>Introduction to Fluid Mechanics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.334</td>
<td>Heat Transfer</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.335</td>
<td>Heat Transfer Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>EN.530.343</td>
<td>Design and Analysis of Dynamical Systems</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.352</td>
<td>Materials Selection</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.354</td>
<td>Mechanical Engineering Elective</td>
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</tr>
<tr>
<td>EN.530.357</td>
<td>Mechanical Engineering Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.359</td>
<td>Technical Elective</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.362</td>
<td>Statistics Elective</td>
<td>3</td>
</tr>
</tbody>
</table>

**Note:** Some courses that from time to time may be counted toward the biomechanics concentration may require AS.030.205 Organic Chemistry I as a prerequisite. This course will count as a technical elective when taken to allow enrollment in the appropriate biomechanics concentration courses. Note that AS.030.205 has several prerequisites: AS.030.101 Introductory Chemistry I, AS.030.102 Introductory Chemistry II and AS.030.105 Introductory Chemistry Laboratory I. Students may not use the satisfactory/unsatisfactory option for required courses, including Humanities and Social Studies. Exceptions can be considered and approved by their faculty advisors. Further, the Department of Mechanical Engineering requires that grades of C- or better be obtained in all required engineering, mathematics, and science courses (i.e. grades of D, D+ or D-, or F will not be accepted). The department will accept D, D+ or D- grades only up to a maximum of 10 credits for Humanities and Social Sciences courses.

**Sample Program**

**First Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.108</td>
<td>4 AS.110.109</td>
</tr>
<tr>
<td>EN.510.101</td>
<td>3 EN.530.102</td>
</tr>
<tr>
<td>EN.530.101</td>
<td>2 EN.530.104</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Credits</th>
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<tbody>
<tr>
<td>15</td>
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**Second Year**

<table>
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<th>Fall</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.110.202</td>
<td>4 EN.530.291</td>
</tr>
<tr>
<td>EN.530.201</td>
<td>4 EN.530.202</td>
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<tr>
<td>EN.530.231</td>
<td>3 EN.530.215</td>
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<tr>
<td>EN.530.232</td>
<td>1 EN.530.216</td>
</tr>
<tr>
<td>AS.171.102</td>
<td>4 EN.530.241</td>
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<table>
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<tr>
<th>Credits</th>
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<tbody>
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**Third Year**

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
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<tbody>
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<td>EN.530.327</td>
<td>3 EN.530.334</td>
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<tr>
<td>EN.530.329</td>
<td>1 EN.530.335</td>
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<tr>
<td>EN.530.352</td>
<td>4 EN.530.343</td>
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<tr>
<td>EN.530.354</td>
<td>3 EN.530.357</td>
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<tr>
<td>EN.530.362</td>
<td>3 EN.530.364</td>
</tr>
<tr>
<td>EN.530.364</td>
<td>3 EN.530.367</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Credits</th>
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<tbody>
<tr>
<td>14</td>
</tr>
</tbody>
</table>
will have demonstrated the ability to

Students graduating from the B.S. in Engineering Mechanics programs
are designed to educate a select group of science-oriented engineers
to excel.

The educational objectives for the B.S. in engineering mechanics degree
are designed to educate a select group of science-oriented engineers
who, after graduation, will be successful and on track to become leaders
among their peers:

1. in the best graduate programs in engineering, science, medical
   schools, or law schools, and
2. in industry, government laboratories, and other organizations.

Students graduating from the B.S. in Engineering Mechanics programs
will have demonstrated the ability to

• understand and apply the fundamentals of mathematics (through
  linear algebra and multivariate calculus), numerical methods,
  statistical analysis, and physical sciences (physics and chemistry)
  necessary to attain competence in the mechanics or related
disciplines such as applied physics, bioengineering, or other
scientific/engineering disciplines.

• understand the interplay between engineering science and the
design, evaluation, and reporting of experiments including analysis
and statistical interpretation of data.

• identify, formulate, and solve engineering problems in the
mechanical sciences.

• use basic concepts from the mechanical sciences, mathematics, the
  basic sciences, and related subjects, as well as modern engineering
tools, to design mechanical engineering components and processes,
taking into account constraints such as manufacturability, cost,
safety, environmental, and socio-political impacts.

The curriculum is intended to enable graduates to explore fundamental
questions in many fields of engineering. Emphasis is placed on the
basic sciences (mathematics, physics, and chemistry) and on the
analysis, modeling, and design aspects of solid and fluid engineering
systems. Although specific core courses are required, the student
is encouraged and guided by his or her advisor to select an individual
program of study, within ABET guidelines, according to the student’s
particular goals. This program of study may range from a general study
of mechanics or engineering science to more specialized programs
in a variety of areas, such as robotics, fluid dynamics, environmental
engineering, mechanics of solids, experimental mechanics, dynamical
systems, mechanics of materials, or biomechanics.

This flexibility makes the program ideal for double-majors and for those
wishing to tailor a strong foundation for graduate work in a wide range
of disciplines. All mathematics elective and technical elective courses
must be at the 300-level or higher, unless approved by their faculty
advisor.

Mathematics (23 credits)
(grades below C- not accepted)

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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<tbody>
<tr>
<td>AS.110.108</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.109</td>
<td>4</td>
</tr>
<tr>
<td>AS.110.202</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.211</td>
<td></td>
</tr>
<tr>
<td>or AS.110.212</td>
<td></td>
</tr>
<tr>
<td>Mathematics elective</td>
<td>4</td>
</tr>
<tr>
<td>Statistics Elective at 300-level or above</td>
<td>3-4</td>
</tr>
<tr>
<td>EN.560.348</td>
<td></td>
</tr>
<tr>
<td>EN.550.310</td>
<td></td>
</tr>
<tr>
<td>Other qualified statistics courses can be taken upon advisor’s approval.</td>
<td></td>
</tr>
<tr>
<td>EN.550.291</td>
<td>4</td>
</tr>
<tr>
<td>or AS.110.212</td>
<td></td>
</tr>
<tr>
<td>or AS.110.201</td>
<td></td>
</tr>
<tr>
<td>&amp; AS.110.302</td>
<td></td>
</tr>
<tr>
<td>&amp; Diff Equations/Applic</td>
<td></td>
</tr>
</tbody>
</table>

Basic Science (16-17 credits)
(grades below C- not accepted)

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN.530.103</td>
<td>5</td>
</tr>
<tr>
<td>&amp; EN.530.104</td>
<td></td>
</tr>
<tr>
<td>or AS.171.101</td>
<td></td>
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<tr>
<td>&amp; AS.173.111</td>
<td></td>
</tr>
<tr>
<td>AS.171.102</td>
<td>5</td>
</tr>
<tr>
<td>&amp; AS.173.112</td>
<td></td>
</tr>
<tr>
<td>EN.510.101</td>
<td>3</td>
</tr>
<tr>
<td>or AS.030.101</td>
<td></td>
</tr>
<tr>
<td>Another basic science elective</td>
<td>4</td>
</tr>
<tr>
<td>Humanities (18 credits)</td>
<td>18</td>
</tr>
</tbody>
</table>

Six humanities and/or social science electives
### Introductory Engineering and Computing
EN.530.101 Freshman Experiences in Mechanical Engineering & EN.530.102 and Freshman Experiences in Mechanical Engineering 4
EN.530.105 Mechanical Engineering Freshman Laboratory I & EN.530.106 and Mechanical Engineering Freshman Laboratory II (provide the necessary engineering and computing instruction for freshmen and are strongly recommended.) 2

Alternate introductory courses are available. If EN.530.101-EN.530.102 and EN.530.105-EN.530.106 are not taken, students must take one course from each of the engineering and computing course lists below:

#### Introductory Engineering:
- EN.500.101 What Is Engineering?
- EN.510.101 Introduction to Materials Chemistry
- EN.520.137 Introduction To Electrical & Computer Engineering
- EN.570.108 Introduction Environmental Engineering
- EN.580.202 BME in the Real World

#### Computing:
- EN.500.200 Computing for Engineers and Scientists (recommended)
- EN.510.202 Computation and Programming for Materials Scientists and Engineers
- EN.580.200 Introduction to Scientific Computing in BME using Python, Matlab, and R
- EN.600.112 Introductory Programming for Scientists and Engineers
- EN.600.107 Introductory Programming in Java

Any other computing course approved by the faculty advisor. EN.600.107 should be taken as a last resort if none of the other computing options fits the student’s schedule.

### Other Required Engineering Courses
- EN.530.201 Statics and Mechanics of Materials 4
- EN.530.231 Mechanical Engineering Thermodynamics 3
- EN.530.327 Introduction to Fluid Mechanics 3
- EN.530.405 Mechanics of Solids and Structures 3
- or EN.530.215 Mechanics-Based Design
- EN.560.202 Dynamics 4

### Capston Design (8 credits)
(grades below C- not accepted)
- EN.530.403 Engineering Design Project & EN.530.404 and Engineering Design Project II 8

### Engineering Science Electives (12 credits)
(grades below C- not accepted) 12
- One course in the mechanics of solids (see below)
- One course in the mechanics of fluids (see below)
- One additional course in the mechanics of either solids or fluids (see below)
- One course in either materials or dynamics (see below)

### Engineering Mechanics Electives (6 credits)
(grades below C- not accepted) 6
- Two additional elective courses in the same area of engineering mechanics (solid mechanics, fluid mechanics, or dynamics, see below).

### Technical Electives (minimum of 18 credits)**
(grades below C- not accepted)

Engineering, Quantitative Studies, or Natural Science courses at or above the 300-level, chosen in consultation with the student’s advisor from any combination of courses in engineering, basic sciences, or mathematics.

**Total Credits 124-126**

* One must specifically teach writing (either AS.060.113 Expository Writing or AS.060.114 Expository Writing, AS.220.105 Fiction Poetry Writing I, or another course as approved by the student’s advisor). To obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher.

- Required Engineering Courses (minimum of 26 credits; grades below C- not accepted)

**++ Appropriate choices from the social sciences and philosophy may be also used to fulfill this requirement. Because of the importance of computer languages in modern technical society, students may take computer language courses at any level.**

Fluid mechanics courses may be chosen from courses such as:
- EN.530.328 Fluid Mechanics II 3
- EN.530.425 Mechanics of Flight 3
- EN.530.426 Biofluid Mechanics 3
- EN.530.444 Computer-Aided Fluid Mechanics and Heat Transfer 3
- EN.570.301 Environmental Engineering Fundamentals I 3

Dynamics courses may be chosen from courses such as:
- EN.530.343 Design and Analysis of Dynamical Systems 4
- EN.530.420 Robot Sensors/Actuators 4
- EN.530.424 Dynamics of Robots and Spacecraft 3
- EN.550.391 Dynamical Systems 4

Solid mechanics courses may be chosen from courses such as:
- EN.530.215 Mechanics-Based Design 3
- EN.530.405 Mechanics of Solids and Structures 3
- EN.530.414 Computer-Aided Design 3
- EN.530.416 Advanced Mechanical Design 3
- EN.530.448 Biosolid Mechanics 3
- EN.530.730 Finite Element Methods 3
- EN.560.320 Structural Design I 3
- EN.560.330 Foundation Design 3

Students may not use the satisfactory/unsatisfactory option for required courses, including Humanities and Social Sciences, unless approved by their faculty advisor. The department will accept D or D+ grades only up to a maximum of 10 credits except where indicated. All undergraduate students must follow a program approved by a faculty member in the department who is selected as the student’s advisor.

### Biomechanics Concentration

Engineering Mechanics (EM) is a highly flexible program offered by the Department of Mechanical Engineering, which is ideal for students who
want to specialize in any area of mechanics, including biomechanics. The essence of mechanics is the interplay between forces and motion.

In biology, mechanics is important at the macroscopic, cellular, and subcellular levels. At the macroscopic length scale biomechanics of both soft and hard tissues plays an important role in computer-integrated surgical systems and technologies (e.g., medical robotics). At the cellular level, issues such as cell motility and chemotaxis can be modeled as mechanical phenomena. At the subcellular level, conformational transitions in biological macromolecules can be modeled using molecular dynamics simulation (which is nothing more than computational Newtonian mechanics), statistical mechanics, or using coarse-grained techniques that rely on principles from the mechanics of materials. In addition, much of structural biology can be viewed from the perspective of Kinematics (e.g., finding spatial relationships in data from the Protein Data Bank).

Each student who pursues the biomechanics concentration within the EM major will, in consultation with his or her EM advisor, choose the set of technical and EM electives that best matches the student’s interests. Many electives from other departments are acceptable. The electives for the EM major are structured as follows:

**Engineering Science Electives (12 credits)**

- One course in solid mechanics
- One course in fluid mechanics
- One additional course in mechanics of either solids or fluids
- One course in either materials or dynamics

**Engineering Mechanics Electives (6 credits)**

Two additional courses in the same area of mechanics (i.e., fluids, solids, or dynamics)

**Technical Electives (18 credits)**

Chosen from 300-level courses in engineering and the sciences in consultation with the student’s faculty advisor.

Examples of bio-oriented courses which can be applied to the above three categories include (but are not limited to):

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS.020.346</td>
<td>Immunochemistry</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.363</td>
<td>Developmental Biology</td>
<td>3</td>
</tr>
<tr>
<td>AS.020.380</td>
<td>Eukaryotic Molecular Biology</td>
<td>3</td>
</tr>
<tr>
<td>AS.250.353</td>
<td>Computational Biology</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.426</td>
<td>Biofluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.440</td>
<td>Computational Mechanics Of Biological Macromolecules</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.445</td>
<td>Introduction to Biomechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.446</td>
<td>Experimental Methods in Biomechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.448</td>
<td>Biosolid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>EN.530.495</td>
<td>Microfabrication Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>EN.530.671</td>
<td>Statistical Mechanics in Biological Systems</td>
<td>3</td>
</tr>
<tr>
<td>EN.540.409</td>
<td>Modeling Dynamic/Control</td>
<td>4</td>
</tr>
</tbody>
</table>

This is not a complete list of possible courses that can be taken, and not all of these courses must be taken. Rather, students who wish to pursue the biomechanics concentration will take at least five courses such as those listed above. These five should be concentrated either at the cellular/subcellular length scale or in macroscopic biomechanics. Note that given the flexibility of the EM program, it would be possible for students to satisfy both of these kinds of concentrations simultaneously if they apply all 12 of their elective courses toward this end.

### Sample Program

#### First Year

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>AS.110.108</td>
<td>Calculus I</td>
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<tr>
<td></td>
<td>EN.510.101</td>
<td>Introduction to Materials Chemistry</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN.530.232</td>
<td>Mechanical Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>AS.171.102</td>
<td>General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
<td>1</td>
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#### Second Year

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>AS.110.202</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EN.530.201</td>
<td>Statics and Mechanics of Materials</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>EN.530.231</td>
<td>Mechanical Engineering Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN.530.232</td>
<td>Mechanical Engineering Thermodynamic: Laboratory</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>AS.171.102</td>
<td>General Physics: Physical Science Majors II</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>AS.173.112</td>
<td>General Physics Laboratory II</td>
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#### Third Year

<table>
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<tr>
<th>Semester</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>EN.530.327</td>
<td>Introduction to Fluid Mechanics</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>EN.530.329</td>
<td>Introduction to Fluid Mechanics Laboratory</td>
<td>1</td>
</tr>
</tbody>
</table>
Upon arrival, each graduate student is assigned to a faculty advisor to help map a tentative program for the first year and enter the intellectual life of the department. The student will remain in regular communication with the advisor. The advisor may use a variety of methods to assess the student’s progress, sometimes including special oral or written examinations. It is not necessary that a student have the same advisor in successive years. After serious research for a dissertation has begun, the research supervisor will automatically function as advisor. All Ph.D. students are required, and master’s students are strongly encouraged to attend the weekly Mechanical Engineering Graduate Seminars.

Requirements for the M.S.E. Degree

**Essay Option:** For the Master of Science in Engineering degree at least eight one-semester courses are required. At least half of them must be selected among those listed as graduate courses in this catalog. The remaining courses can be chosen from 300- and 400-level courses in this catalog, with the advisor’s approval. A completed piece of research conducted under the guidance of a full-time faculty member of the department and reported as a master’s essay is required. All students must follow a course of study approved by their individual advisor.

**Non-Essay Option:** The student must successfully complete a coordinated sequence of ten courses, which requires one year of full-time resident graduate study. At least six of the ten courses must be selected amongst the graduate courses of this catalog. The intent of this program is to provide the student with an intensive exposure to fundamental and advanced topics within mechanical engineering and engineering mechanics. Students must follow a course of study approved by their individual advisor.

Requirements for the Ph.D. Degree

As soon as the student is prepared to do so, he/she should fulfill the requirements for candidacy. In addition to general university requirements, the student must pass two exams. The first is an oral Departmental Qualifying Exam based on core courses. This exam is usually taken after the third semester. The second is a preliminary oral examination satisfying the Graduate Board requirements. This is a comprehensive examination in which students must demonstrate proficiency at the graduate level in their field of specialization.

Although there are no formal course requirements, students are presumed to be prepared by studies equal to six 600-level courses in their field of specialization and six courses in related fields. All candidates for the doctorate must complete two semesters as a teaching assistant as part of their training. All students are required to follow a course of study approved by their individual advisor.

The final and principal requirement for the doctorate is a piece of original research worthy of publication. Candidates must write a
dissertation describing their work in detail and successfully defend it in a final oral presentation and examination.

For current faculty and contact information go to http://www.me.jhu.edu/faculty.html

Faculty

Professor Hemker and his students seek to identify the underlying energy sources.

Kevin J. Hemker
Assistant Professor: multiscale materials modeling, damage and fracture mechanisms of materials in mechanical design, material degradation in extreme environments, nano-materials and structures, impact dynamics and wave propagation.

Dennis Gayme
Assistant Professor: Dynamics and control of nonlinear, networked and spatially distributed systems such as the electric power grid, and wind farms. Modeling of turbulence and transition to turbulence in wall bounded shear flows and wind farms. Grid integration of renewable energy sources.

Kevin J. Hemker
Professor, Alonzo G. Decker, Jr. Chair in Mechanical Engineering: Professor Hemker and his students seek to identify the underlying atomic-scale processes that govern the mechanical behavior of advanced material systems. They are making key observations and discoveries that define the way the mechanics and materials community thinks about and understands the properties of: nanocrystalline materials, MEMS and micro-lattice materials, thermal barrier coatings, armor ceramics, and high temperature structural materials.

Cila Herman
Professor: experimental heat transfer and fluid mechanics, optical measurement techniques, image processing. Thermacoustic refrigeration, influence of electric fields on boiling in terrestrial conditions and microgravity, heat exchangers, heat transfer in boiling, optical tomography, holographic interferometry, cooling of electronic equipment, digital image processing, heat transfer augmentation.

Joseph M. Katz
Professor, Whiting School Mechanical Engineering Chaired Professor, Gilman Scholar: cavitation phenomena, attached partial cavitation, cavitation in turbulent shear flows, jets and wakes. Multiphase flows: interaction between bubbles and flow structure, mixing mechanisms and droplet formation in water-fuel stratified shear flows, transport of microscopic particles and droplets in turbulent flows. Development of optical flow diagnostics techniques, including Particle Image Velocimetry (PIV) and Holographic Particle Image Velocimetry (HPIV). Applications of PIV and HPIV for measuring the characteristics of turbulence and addressing turbulence modeling issues. Complex flow structure and turbulence within turbo-machines: Wake-wake and blade-wake interactions in multistage axial turbomachines, flow and rotating stall in centrifugal pumps, development of optical diagnostics techniques for measurements in turbomachines. Oceanography: flow structure and turbulence in the bottom boundary layer of the coastal ocean; measurement of spatial distributions of plankton, particles and bubbles in the ocean; development of optical instrumen-tation, including submersible holography and PIV systems. Prevention of nozzle wear in abrasive water suspension jets (AWSJ) using porous lubricated nozzles. Flow-induced vibrations and noise, mechanisms of noise generation in turbulent separated flows and in turbomachines.

Marin Kobliarov
Assistant Professor: developing intelligent robotic vehicles that can perceive, navigate, and accomplish challenging tasks in uncertain, dynamic, and highly constrained environments. Performing research in analytical and computational methods for mechanics, control, motion planning, and reasoning under uncertainty, and in the design and integration of novel mechanisms and embedded systems. Application areas include mobile robots, aerial vehicles, and nanosatellites.

Charles Meneveau
Professor, Louis M. Sardella Chair in Mechanical Engineering, Director of the Center for Environmental and Applied Fluid Mechanics: theoretical, experimental, and numerical studies in turbulence, large-eddy-simulation, turbulence modeling, fractals and scaling in complex systems, small-scale structure of turbulence and velocity gradient dynamics, applications of LES to environmental flows, wind energy, development of data-intensive science tools to study turbulence.

Rajat Mittal
Professor: computational fluid dynamics, low Reynolds number aerodynamics, biomedical flows, active flow control, LES/DNS, immersed boundary methods, fluid dynamics of locomotion (swimming and flying), biomimetics and bioinspired engineering, turbomachinery flows.

Andrea Prosperetti
Professor, Charles A. Miller Jr. Chair in Mechanical Engineering: multiphase flow; theoretical and computational fluid mechanics and acoustics; gas and vapor bubbles.

K. T. Ramesh
Professor, Alonzo G. Decker, Jr. Professor of Science and Engineering, Director of the Center for Advanced Metallic and Ceramic Systems (CAMCS) and the Hopkins Extreme Materials Institute (HEMI): Nanomaterials, planetary impact, dynamic failure mechanisms, shock, impact, and wave propagation, high-strain-rate behavior of materials, injury biomechanics, constitutive and failure modeling.

Sean Sun
Vice Chair, Associate Professor: mechanobiology of the cell, molecular biomechanics and biophysics, molecular motors and muscle, statistical mechanics and nonlinear phenomena.

Jeff Tza-Huei Wang
Associate Professor: bioMEMS and microfluidics, single molecule manipulation and detection, nano/micro scale fabrication, conformational dynamics of biomolecules.

Tamer Zaki
Associate Professor: Transitional and turbulent shear flows: receptivity, linear and non-linear instability waves, secondary instability, breakdown to turbulence, direct numerical simulations, transition modelling. Two-fluid shear flows: linear and non-linear instability methods, interface tracking, the interaction of vortical disturbances with interfaces, direct numerical simulations, laminar-to-turbulence transition. Turbulence: boundary layer turbulence, separation, stratification, drag reduction, turbulence structures, direct numerical simulations, large-scale high-performance computing.

Secondary Faculty Appointments

Stephen Belkoff
Joint, Part-Time, and Research Appointments: Associate Professor (Orthopedic Surgery): biomechanics, orthopaedic implants, fracture fixation in osteoporotic bone, mechanism of injury, vertebroplasty.

Robert C. Cammarata
Joint, Part-Time, and Research Appointments: Professor (Materials Science and Engineering): structure, properties, and processing of thin films and nanostructured materials, thermodynamics and mechanics of surfaces, mechanical behavior of materials, nonindentation testing, stresses in thin films, novel electrochemical deposition methods, computer simulations.

Gregory L. Eyink

Lori Graham-Brady
Professor, Civil Engineering: stochastic finite element methods, probabilistic mechanics, stochastic simulation of material properties, micromechanics.

Daniel Naiman

Mark Robbins
Joint, Part-Time, and Research Appointments: Professor (Physics and Astronomy): Connecting and contrasting atomistic and macroscopic descriptions of non-equilibrium processes including friction, adhesion, large-strain mechanical deformation, fracture, heat flow, fluid flow, and boundary conditions at interfaces between different materials. Techniques include molecular simulations, continuum calculations and multiscale modeling approaches that bridge the two.

Dan Stoianovici
Joint, Part-Time, and Research Appointments: Professor (Brady Urological Institute): urology, medical robotics.

Russell H. Taylor
Joint, Part-Time, and Research Appointments: Professor (Computer Science): medical robotics, computer-assisted surgery.

Nitish V. Thakor
Joint, Part-Time, and Research Appointments: Professor (Biomedical Engineering): medical instrumentation and medical micro and nanotechnologies, neurological instrumentation, signal processing, computer applications.

Rene Vidal
Joint, Part-Time, and Research Appointments: Associate Professor (Biomedical Engineering): biomedical image analysis, computer vision, machine learning, dynamical systems, signal processing.

Timothy Weihs
Joint, Part-Time, and Research Appointments: Professor (Materials Science and Engineering), Director of the Center for Leadership Education: self-propagating exothermic reaction and joining with reactive multilayer foils, processing and characterization of thin films, layered materials, and thin film reactions, mechanical testing of metals and biological materials.

Senior Lecturer

David Kraemer
Senior Lecturer

Steven Marra
Senior Lecturer: Soft and hard tissue biomechanics, nonlinear mechanics of solids, mechanics of tissue damage.

Nathan Scott
Senior Lecturer: Principles and practice of engineering design education.

Professor emeritus

William N. Sharpe Jr.
Professor Emeritus: experimental solid mechanics; microelectromechanical systems (MEMS), microsample testing.

Associate Research Professor

Mehran Armand
Associate Research Professor (Applied Physics Laboratory).

Juan I. Arvelo Jr.
Assistant Research Professor (Applied Physics Laboratory).

Lester Su
Associate Research Professor: (Stanford University).

Liming Voo
Associate Research Professor (Applied Physics Laboratory).
Research Scientist
Alan Brandt

Research Professor
Ilene Busch-Vishniac
Research Professor (University of Saskatchewan).
Shiyi Chen
Research Professor (Peking University).
Allison Okamura
Research Professor (Stanford University).
Alexander Spector
Research Professor, Biomedical Engineering: biosolid mechanics, cell mechanics and biophysics, molecular motors, mathematical and computational modeling.

Pazhayannur Swaminathan
Research Professor (Applied Physics Laboratory).

David Van Wie
Research Professor (Applied Physics Laboratory).

Assistant Research Professor
Nitin Daphalapurkar
Assistant Research Professor.
Iulian Iordachita
Assistant Research Professor: robotics, medical robotics and instrumentation, mechanisms and mechanical transmissions for robots, advance electro-mechanical design, biologically-inspired mechanisms.

John Thomas
Assistant Research Professor (Applied Physics Laboratory).

Adjunct Associate Professor
Thomas Dragone
Adjunct Associate Professor: aerospace structures and materials, airframe structure design and development, materials science.

Adjunct Assistant Professors
Ryan Eustice
Adjunct Assistant Professor (Department of Naval Architecture and Marine Engineering, University of Michigan).
Jian Sheng
Adjunct Assistant Professor (University of Minnesota).

Adjunct Professor
Gabor Fichtinger
Adjunct Professor, Computer Science and Radiology: Director of Computer Integrated Surgical Systems and Technology (CISST).

Associate Research Scientist
Tihomir Hristov
Associate Research Scientist.
Xiaofeng Liu

Assistant Research Scientist.

Adjunct Associate Research Scientist
Edwin Malkiel
Adjunct Associate Research Scientist.

Adjunct Research Professor
Thomas Wright
Adjunct Research Professor: theoretical solid mechanics, wave propagation, dynamic failure, adiabatic shear localization, instabilities.

Lecturer
Yury Ronzhes
Joint, Part-Time, and Research Appointments: Lecturer.

For current course information and registration go to https://isis.jhu.edu/classes/

Courses
EN.530.101. Freshman Experiences in Mechanical Engineering. 2 Credits.
An overview of the field of mechanical engineering along with topics that will be important throughout the mechanical engineering program. This one-year course includes applications of mechanics, elementary numerical analysis, programming in Matlab, use of computer in data acquisition, analysis, design, and visualization, technical drawing, the design process and creativity, report preparation, teamwork, and engineering ethics. Corequisites: EN.530.103 and EN.530.105.
Instructor(s): S. Marra
Area: Engineering.

EN.530.102. Freshman Experiences in Mechanical Engineering. 2 Credits.
An overview of the field of mechanical engineering along with topics that will be important throughout the mechanical engineering program. This is the second half of a one-year course that includes applications of mechanics, elementary numerical analysis, programming in Matlab, use of computer data acquisition, analysis, design, and visualization; technical drawing, the design process and creativity, report preparation, teamwork, and engineering ethics.
Prerequisites: EN.530.101
Instructor(s): S. Belkoff
Area: Engineering.

EN.530.103. Introduction to Mechanics I. 2 Credits.
This is the first half of a one-year course offering in-depth study of elements of mechanics, including linear statics and dynamics, rotational statics and dynamics, thermodynamics, fluids, continuum mechanics, transport, oscillations, and waves. This is an alternate to AS.171.101, designed specifically for Mechanical Engineering and Engineering Mechanics students taking EN.530.101 concurrently. Restricted to Mechanical Engineering, Engineering Mechanics, Civil Engineering, Undecided Engineering Majors, or permission of instructor.
Instructor(s): J. Thomas
Area: Engineering, Natural Sciences.
EN.530.104. Introduction to Mechanics II. 2 Credits.
This is the second half of a one-year course offering in-depth study of elements of mechanics, including linear statics and dynamics, rotational statics and dynamics, thermodynamics, fluids, continuum mechanics, transport, oscillations, and waves. This is an alternate to AS.171.101, designed specifically for Mechanical Engineering and Engineering Mechanics students taking EN.530.102 concurrently.
Prerequisites: EN.530.103
Instructor(s): J. Thomas
Area: Engineering, Natural Sciences.

EN.530.105. Mechanical Engineering Freshman Laboratory I. 1 Credit.
Hands-on laboratory complementing EN.530.101 and EN.530.103, including experiments, mechanical dissections, and design experiences distributed throughout the year. Experiments are designed to give students background in experimental techniques as well as to reinforce physical principles. Mechanical dissections connect physical principles to practical engineering applications. Design projects allow students to synthesize working systems by combining mechanics knowledge and practical engineering skills. Corequisites: EN.530.101 and EN.530.103.
Instructor(s): S. Marra
Area: Engineering.

EN.530.106. Mechanical Engineering Freshman Laboratory II. 1 Credit.
Hands-on laboratory complementing EN.530.102 and EN.530.104, including experiments, mechanical dissections, and design experiences distributed throughout the year. Experiments are designed to give students background in experimental techniques as well as to reinforce physical principles. Mechanical dissections connect physical principles to practical engineering applications. Design projects allow students to synthesize working systems by combining mechanics knowledge and practical engineering skills.
Prerequisites: EN.530.105
Instructor(s): S. Belkoff
Area: Engineering.

EN.530.110. Chair’s Dialogue on Grand Engineering Challenges. 1 Credit.
The purpose of this course is to allow the ME Chair and students to engage in a meaningful dialog about grand engineering challenges facing the world today. Based on the premise that these challenges constitute the opportunity of a lifetime disguised as a series of unsolvable problems, the course will explore the technical, scientific, political, and societal facets of these challenges and the opportunities for engineers to engage in topics such as: energy, the environment, medical health and national security.

EN.530.201. Statics and Mechanics of Materials. 4 Credits.
Equilibrium of rigid bodies, free-body diagrams, design of trusses. One-dimensional strain and stress, Hooke’s law. Properties of areas. Stress, strain, and deflection of components subjected to uniaxial tension, simple torsion, and bending. Co-listed with EN.560.201. Recommended Course Background: AS.171.101 or EN.530.103 and EN.530.104 or Permission Only.
Instructor(s): T. Igusa
Area: Engineering.

EN.530.202. Dynamics. 4 Credits.
Basic principles of classical mechanics applied to the motion of particles, system of particles and rigid bodies. Kinematics, analytical description of motion; rectilinear and curvilinear motions of particles; rigid body motion. Kinetics: force, mass, and acceleration; energy and momentum principles. Introduction to vibration. Includes laboratory experience.
Prerequisites: (EN.530.201 or EN.560.201 ) AND (AS.171.101 OR (EN.530.103 AND EN.530.104 ) ) AND AS.110.109
Instructor(s): N. Nakata
Area: Engineering.

EN.530.215. Mechanics-Based Design. 3 Credits.
Prerequisites: EN.530.201 OR EN.560.201
Instructor(s): T. Nguyen
Area: Engineering.

EN.530.231. Mechanical Engineering Thermodynamics. 3 Credits.
Prerequisites: AS.110.109
Instructor(s): J. Katz
Area: Engineering.

EN.530.232. Mechanical Engineering Thermodynamics Laboratory. 1 Credit.
This course is the complementary laboratory course and a required corequisite for EN.530.231. Corequisite: EN.530.231
Instructor(s): S. Marra
Area: Engineering, Natural Sciences.

EN.530.241. Electronics & Instrumentation. 4 Credits.
Introduction to basic analog electronics and instrumentation with emphasis on basic electronic devices and techniques relevant to mechanical engineering. Topics include basic circuit analysis, laboratory instruments, discrete components, transistors, filters, op-amps, amplifiers, differential amplifiers, power amplification, power regulators, AC and DC power conversion, system design considerations (noise, precision, accuracy, power, efficiency), and applications to engineering instrumentation.
Prerequisites: AS.171.102
Instructor(s): D. Kraemer
Area: Engineering.
EN.530.319. Molecular Modeling and Simulation for Engineers. 3 Credits.
Nanosized engineering materials and devices behave in ways that are profoundly different from their traditional macroscopic counterparts. This course will provide students with an introduction to this exciting and rapidly evolving field. Through a combination of lectures, case-studies, and hands-on applications, students will (i) develop an understanding of the principles that govern the performance of nanoscale engineering systems, and (ii) learn how molecular modeling tools can assist in the design and analysis of such systems. Recommended Course Background: AS.110.107/AS.110.109, General Physics II
Area: Engineering.

EN.530.327. Introduction to Fluid Mechanics. 3 Credits.
Fluid statics. Control volumes and surfaces, kinematics of fluids, conservation of mass. Linear momentum in integral form. Bernoulli’s equation and applications. Dimensional analysis. The Navier-Stokes equations. Laminar and turbulent viscous flows. External flows, lift and drag. Prerequisites: Co-requisite: EN.530.329
Instructor(s): D. Gayme
Area: Engineering.

EN.530.328. Fluid Mechanics II. 3 Credits.
Instructor(s): C. Meneveau
Area: Engineering.

EN.530.329. Introduction to Fluid Mechanics Laboratory. 1 Credit.
This course is the complementary laboratory course and a required co-requisite for EN.530.327. Corequisite: EN.530.327
Instructor(s): S. Marra
Area: Engineering.

EN.530.334. Heat Transfer. 3 Credits.
Instructor(s): C. Herman
Area: Engineering.

EN.530.335. Heat Transfer Laboratory. 1 Credit.
This is the laboratory that supports EN.530.334 Heat Transfer. Corequisites: EN.530.334
Instructor(s): S. Marra
Area: Engineering.
EN.530.403. Engineering Design Project. 4 Credits.
This senior year “capstone design” course is intended to give some practice and experience in the art of engineering design. Students working in teams of two to four will select a small-scale, industry-suggested design problem in the area of small production equipment, light machinery products, or manufacturing systems and methods. A solution to the problem is devised and constructed by the student group within limited time and cost boundaries. Preliminary oral reports of the proposed solution are presented at the end of the first semester. A final device, product, system, or method is presented orally and in writing at the end of the second semester. Facilities of the Engineering Design Laboratory (including machine shop time) and a specified amount of money are allocated to each student design team for purchases of parts, supplies, and machine shop time where needed. Recommended Course Background: ME Majors: EN.530.215, EN.530.327; EM & BME Majors: EN.530.215 or EN.530.405, and EN.530.327.
Instructor(s): N. Scott
Area: Engineering.

EN.530.404. Engineering Design Project II. 4 Credits.
The Senior Design Project, a unique two-semester course, is the capstone of Johns Hopkins’s Mechanical Engineering Program. In the class, students working in small teams tackle specific design challenges presented by industry, government, and nonprofit organizations. The sponsors provide each team with a budget, access to world-class resources, and technical contacts. Ultimately, each team conceptualizes a novel solution to the sponsor’s problem and then designs, constructs, and tests a real-world prototype before presenting the finished product and specifications to the sponsor. The course requires students to draw upon the four years of knowledge and experience they’ve gained in their engineering studies and put it to practical use. Throughout the year, they produce progress reports as they design, build, and test the device they are developing. Combining engineering theory, budget and time management, and interactions with real clients, the senior design project is critical to students’ preparation for the transition from school to the workplace.
Prerequisites: EN.530.403
Instructor(s): N. Scott
Area: Engineering
Writing Intensive.

EN.530.405. Mechanics of Solids and Structures. 3 Credits.
This course provides an introduction to the mathematical and theoretical foundations of the mechanics of solids and structures. We will begin with the mathematical preliminaries used in continuum mechanics: vector and tensor calculus, then introduce kinematics and strain measures, descriptions of stress in a body, frame indifference, conservation laws: mass, momentum, energy balance, and entropy. These concepts will be applied to develop the constitutive equations for solids and fluids, methods for solving boundary value problems that occur in engineering structures, energy methods and foundations of the finite element method.
Instructor(s): J. El-Awady
Area: Engineering, Natural Sciences.

EN.530.410. Biomechanics of the Cell. 3 Credits.
Mechanical aspects of the cell are introduced using the concepts in continuum mechanics. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.
Instructor(s): A. Spector; S. Sun
Area: Engineering, Natural Sciences.

EN.530.414. Computer-Aided Design. 3 Credits.
The course outlines a modern design platform for 3D modeling, analysis, and manufacturing of mechanical systems using the “Pro/E” package by PTC. The package includes the following components: • Pro/ENGINEER: is the kernel of the design process, spanning the entire product development, from creative concept through detailed product definition to serviceability. • Pro/MECHANICA: is the main analysis and simulation component for kinematic, dynamic, structural, thermal and durability performance. • Pro/NC: is a numeric-control manufacturing package. This component provides NC programming capabilities and tool libraries. It creates programs for a large variety of CNC machine tools.
Instructor(s): D. Stoianovici
Area: Engineering.

EN.530.415. Energy Engineering: Fundamentals and Future. 3 Credits.
Area: Engineering, Natural Sciences.

EN.530.416. Advanced Mechanical Design. 3 Credits.
A continuation of EN.530.215 expanding on topics such as fatigue, fracture, and various mechanical components and including linkage systems and cams. Student teams will be assigned different experimental and/or computational projects. Recommended Course Background: EN.530.215
Prerequisites: EN.530.215
Instructor(s): M. Dehghani
Area: Engineering.

EN.530.418. Aerospace Structures & Materials. 3 Credits.
An introduction to the design of aircraft and spacecraft structures and components. This course will build on skills learned in EN.530.215 and EN.530.352. Recommended Course Background: EN.530.352 or instructor permission.
Instructor(s): T. Dragone
Area: Engineering.

EN.530.420. Robot Sensors/Actuators. 4 Credits.
Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, micro-actuators, position sensors, and proximity sensors. Mechanical Engineering and Engineering Mechanics majors only.
Prerequisites: (171.101 and 171.102 or 530.103 and 530.104), and 110.108 and 110.109, and (110.202 or 110.211), and (EN.550.291 or AS.110.302) and (EN.530.241 or EN.520.345)
Instructor(s): D. Kraemer
Area: Engineering.

EN.530.421. Mechatronics. 3 Credits.
Students from various engineering disciplines are divided into groups of two to three students. These groups each develop a microprocessor-controlled electromechanical device, such as a mobile robot. The devices compete against each other in a final design competition. Topics for competition vary from year to year. Class instruction includes fundamentals of mechanism kinematics, creativity in the design process, an overview of motors and sensors, and interfacing and programming microprocessors.
Prerequisites: EN.530.420 or permission of instructor
Instructor(s): G. Chirikjian
Area: Engineering.
EN.530.424. Dynamics of Robots and Spacecraft. 3 Credits.
An introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion, stability theory, and Hamilton’s principle.
Area: Engineering.

EN.530.425. Mechanics of Flight. 3 Credits.
Instructor(s): K. Phillips
Area: Engineering.

EN.530.426. Biofluid Mechanics. 3 Credits.
The course covers associated aircraft and spacecraft and power generation. The first part reviews the relevant thermodynamics and fluid mechanics, including isentropic compressible flow, Rayleigh and Fanno lines, shock and expansion waves. Subsequently, the performance of various forms of aviation gas turbines, including turbo-jet, turbo-fan, turbo-prop and ram-jet engines are discussed, followed by component analyses, including inlet nozzles, compressors, combustion chambers, turbines and afterburners. Axial and centrifugal turbomachines are discussed on detail, including applications in aviation, power generation and liquid transport. The section on foundations of combustion covers fuels, thermodynamics of combustion, and energy balance. The last part focuses on rockets, including classification, required power for space flight, chemical rocket components, and combustion involving liquid and solid fuels.
Instructor(s): R. Mittal
Area: Engineering.

EN.530.432. Jet & Rocket Propulsion. 3 Credits.
The course covers associated aircraft and spacecraft and power generation. The first part reviews the relevant thermodynamics and fluid mechanics, including isentropic compressible flow, Rayleigh and Fanno lines, shock and expansion waves. Subsequently, the performance of various forms of aviation gas turbines, including turbo-jet, turbo-fan, turbo-prop and ram-jet engines are discussed, followed by component analyses, including inlet nozzles, compressors, combustion chambers, turbines and afterburners. Axial and centrifugal turbomachines are discussed on detail, including applications in aviation, power generation and liquid transport. The section on foundations of combustion covers fuels, thermodynamics of combustion, and energy balance. The last part focuses on rockets, including classification, required power for space flight, chemical rocket components, and combustion involving liquid and solid fuels.
Instructor(s): J. Katz
Area: Engineering.

EN.530.437. Energy and the Environment. 3 Credits.
This course focuses on topics of current and developing energy sources and their impact on the environment. It is an upper-level multidisciplinary course that draws on science and engineering topics from the core curriculum related to dynamics, thermodynamics, fluid mechanics and heat transfer, electrical and environmental engineering, and requires integration of understanding achieved in core studies. After the general introduction, the course will begin with a review of energy, energy conversion and thermodynamics related topics to provide a framework for the understanding of current and modern future technologies. After the discussion of fossil fuels and related energy and environmental topics, special attention will be devoted to modern trends in nuclear energy generation (generation IV nuclear reactors), renewable energy with emphasis on solar energy and hydrogen as energy carrier. Topics of sustainability and the environmental impact of energy consumption will be addressed.
Instructor(s): C. Herman
Area: Engineering, Natural Sciences.

EN.530.440. Computational Mechanics Of Biological Macromolecules. 3 Credits.
Biological macromolecules such as proteins and nucleic acids consist of thousands of atoms. Whereas crystallographic data of these molecules provide baseline information on their threedimensional structure, their biological function can depend to a great extent on mechanical characteristics such as conformational flexibility. In this course, we will examine numerical methods for modeling shape fluctuations in large biomolecules using coarse-grained elastic network models. The course will consist of lectures, reading papers, and performing computer projects. No prior knowledge of biochemistry or molecular biology is required.
Instructor(s): G. Chirikjian
Area: Engineering.

EN.530.441. Introduction to Biophotonics. 3 Credits.
The primary aim for this course is to explore the unique and diverse properties of light that makes it suited for diagnosis, imaging, manipulation and control of biological structure and function from the nanoscale to the tissue level. The course will focus on different optical spectroscopic and microscopic modalities that provide biochemical and morphological information, while introducing new ideas on analysis and interpretation of the acquired data. We will also discuss manipulation methods, including optical tweezers and laser scissors, and low-level light therapy. In all of these areas, the idea is to develop a basic understanding of the subject and to use it for finding solutions to real-world problems in healthcare. Discussions and open exchanges of ideas will be strongly emphasized.
Instructor(s): I. Barman
Area: Engineering.

EN.530.444. Computer-Aided Fluid Mechanics and Heat Transfer. 3 Credits.
Computer simulation has become an essential part of science and engineering and this course introduces the student to the use of computer simulation in the disciplines of heat transfer and fluid mechanics. The commercial software COMSOL is used a wide variety of problems, ranging from simple models for which analytical solutions are available, to complex, unsteady, multiphysics real-life problems. Problems will be solved by identifying proper governing equations and boundary conditions first, and then implementing these in the COMSOL environment. Applications will include heat conduction, convection and radiation, internal and external flows, with applications ranging from mechanical to biomedical and aerospace engineering.
Instructor(s): C. Herman
Area: Engineering.

EN.530.445. Introduction to Biomechanics. 3 Credits.
An introduction to the mechanics of biological materials and systems. Both soft tissue such as muscle and hard tissue such as bone will be studied as will the way they interact in physiological functions. Special emphasis will be given to orthopedic biomechanics. Recommended Course Background: EN.530.215/EN.530.216 and Lab or equivalent. If you have not taken this course or an equivalent, please contact the instructor before registering to ensure you have the appropriate background knowledge to succeed in this course.
Instructor(s): S. Belkoff
Area: Engineering.
EN.530.446. Experimental Methods in Biomechanics. 3 Credits.
An introduction to experimental methods used in biomedical research. Standard experimental techniques will be applied to biological tissues, where applicable and novel techniques will be introduced. Topics include strain gauges, extensometers, load transducers, optical kinematic tracking, digital image correlation, proper experimental design, calibration and error analysis. Of particular emphasis will be maintaining native tissue temperature and hydration. Laboratory will include "hands-on" testing.
Area: Engineering, Natural Sciences.

EN.530.448. Biosolid Mechanics. 3 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include concepts of small and large deformation, stress, constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Recommended Course Background: AS.110.201 and AS.110.302, as well as a class in statics and mechanics
Area: Engineering.

EN.530.451. Cell & Tissue Engineering Laboratory. 2 Credits.
Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn basic cell culture procedures and specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Co-listed with EN.580.451. Senior and Graduate students only; others Permission Required. Lab Fee: $100
Instructor(s): E. Haase; J. Wang.

EN.530.452. Cell & Tissue Engineering Laboratory. 2 Credits.
This laboratory course will consist of three experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. $100 lab fee will be charged. Co-listed with EN.580.452.
Instructor(s): E. Haase; J. Wang.

EN.530.454. Manufacturing Engineering. 3 Credits.
An introduction to the various manufacturing processes used to produce metal and nonmetal components. Topics include casting, forming and shaping, and the various processes for material removal including computer-controlled machining. Simple joining processes and surface preparation are discussed. Economic and production aspects are considered throughout. Open only to seniors in Mechanical Engineering and Engineering Mechanics and other majors at all levels.
Instructor(s): Y. Ronzhes
Area: Engineering.

EN.530.457. Intro To Acoustics. 3 Credits.
This course is an introduction to the science of sound and its applications to music, speech communication, science, and engineering. Topics will include hearing, speech, wave propagation, microphones and loudspeakers, noise control, underwater sound, and room acoustics. Recommended Course Background: EN.530.327
Area: Engineering, Natural Sciences.

EN.530.464. Energy Systems Analysis. 3 Credits.
This course discusses the grid integration of renewable energy systems. The main emphasis is on grid level effects of renewable energy, particularly wind power systems. It begins with an introduction to basic power system concepts along with power flow analysis (and optimization). Then, important concepts for wind power systems are discussed. Following that, integration issues for wind power at the transmission level and solar cell integration at the distribution level are introduced. The last part of the course will focus on current research in these areas. Students will choose a system to research and present a project or literature review at the end of the term. Prior knowledge of optimization is helpful, but not required.
Instructor(s): D. Gayme
Area: Engineering.

EN.530.467. Thermal Design Issues for Aerospace Systems. 3 Credits.
This course deals with processes, systems, instruments, and equipment for aerospace systems. Issue of energy conversion and thermal design are emphasized. Topics include thermodynamic concepts and heat transfer processes for aerospace systems (with emphasis on radiation), the space environment, influence of gravity on heat transfer, power generation for space systems (energy sources, solar cell arrays, energy storage), thermal control (analysis techniques, design procedures, active versus passive design, heating and refrigeration), environmental effects.
Area: Engineering.

EN.530.470. Space Vehicle Dynamics & Control. 3 Credits.
In this course we study applied spacecraft orbital and attitude dynamics and their impact on other subsystems. In the orbital dynamics part of the course, we discuss some the issues associated with orbital insertion, control and station keeping. Focus is on the two-body problem regime where conic solutions are valid. Orbit perturbations are also considered. For attitude dynamics, different attitude representations such as direction cosines, quaternions, and angles are introduced. Then we look at the forces and moments acting on space vehicles. Attitude stability and control considerations are introduced.
Instructor(s): M. O’zimek; T. McGee
Area: Engineering.

EN.530.485. Physics and Feedback in Living Systems. 3 Credits.
The complex mechanisms of living systems cannot be reduced to a set of base pairs: genes are only one part of mystery of life. Rather, organisms must develop, move, interact, and function in their natural environment, and thus are constrained by the laws of physics. For example, during locomotion an animal must accelerate according to Newton’s laws by applying forces between itself and the environment. Beyond physical principles alone, biological systems extensively use feedback to enhance stability and facilitate adaptation in the presence of a changing world. This course examines the critical roles that physical principles and feedback mechanisms play in life, with special emphasis on animal locomotion and its control. Juniors and Seniors only.
Prerequisites: AS.110.109
Instructor(s): N. Cowan
Area: Engineering.

EN.530.491. Special Topics. 1 Credit.
Selected topics for third- and fourth-year students in mechanical engineering and other engineering departments. Offered by arrangement with faculty adviser and instructor in charge.
Instructor(s): Staff.
EN.530.495. Microfabrication Laboratory. 4 Credits.
This laboratory course is an introduction to the principles of microfabrication for microelectronics, sensors, MEMS, and other synthetic microsystems that have applications in medicine and biology. Course comprised of laboratory work and accompanying lectures that cover silicon oxidation, aluminum evaporation, photore sist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Seniors only or Permission Required.
Instructor(s): A. Andreou; J. Wang
Area: Engineering, Natural Sciences.

EN.530.525. Independent Research. 3 Credits.
Students pursue research problems individually or in pairs. Although the research is under the direct supervision of a faculty member, students are encouraged to pursue the research as independently as possible.
Instructor(s): Staff.

EN.530.526. Independent Study. 1 - 3 Credit.
Students pursue research problems individually or in pairs. Although the research is under the direct supervision of a faculty member, students are encouraged to pursue the research as independently as possible.
Instructor(s): Staff.

EN.530.527. Independent Study. 1 - 3 Credit.
Students pursue research problems individually or in pairs. Although the research is under the direct supervision of a faculty member, students are encouraged to pursue the research as independently as possible.
Instructor(s): Staff.

EN.530.597. Research-Summer. 1 - 3 Credit.
Instructor(s): Staff.

EN.530.599. Independent Study. 1 - 3 Credit.
Instructor(s): Staff.

EN.530.600. MSE Graduate Research.
Instructor(s): Staff.

The course focuses on the optimal control of dynamical systems subject to constraints and uncertainty by studying analytical and computational methods leading to practical algorithms. Topics include calculus of variations, nonlinear local optimization, global stochastic search, dynamic programming, linear quadratic (gaussian) control, numerical trajectory optimization, model-predictive control. Advanced topics include approximate dynamic programming and optimal control on manifolds. The methods and algorithms will be illustrated through implementation of various simulated examples. Recommended Course Background: AS.110.201 and AS.110.302; experience with control systems; programming in MATLAB.
Instructor(s): M. Kobilarov.

This course provides an introduction to the mathematical and theoretical foundations of the mechanics of solids and materials. We will begin with the mathematical preliminaries of continuum mechanics: vectors and tensors calculus, then introduce the kinematics of deformation and descriptions of stress in a continuum: Eulerian and Lagrangian descriptions, followed by conservation laws: mass, momentum, and energy balance, and entropy. These concepts will be applied to develop the concepts of constitutive relations: frame invariance, material symmetry, and dissipation. The second half of the course will be devoted to elasticity, both classical and finite elasticity, and solution methods for boundary value problems.
Instructor(s): T. Nguyen.

EN.530.606. Mechanics of Solids and Materials II.
An overview of the area of the mechanics of solids and materials, with the intent of providing the foundation for graduate students interested in research that involves these disciplines. The course is based on the principles of continuum mechanics, and covers the fundamental concepts of elasticity, plasticity, and fracture as applied to materials. One objective is to get graduate students to the point that they can understand significant fractions of research seminars and papers in this area. This mathematically rigorous course emphasizes the setup and solution of boundary value problems in mechanics, and attempts to integrate the primary behaviors with deformation and failure mechanisms in materials. Special topics covered may include (depending on the interests of the student body) wave propagation, viscoelasticity, geomechanics or biomechanics.
Instructor(s): J. El-Awady
Area: Engineering.

EN.530.610. Statistical Mechanics in Biological Systems.
Application of equilibrium and nonequilibrium concepts in statistical mechanics to biology is presented in some detail. Topics include many-body dynamics and equilibrium ensembles, thermodynamics and phase transitions, free energy functionals, computer simulations of biological systems, nonequilibrium model such as the Langevin equation and the Fokker-Planck equation, kinetic models of biochemical networks, Markov models of stochastic systems and pattern formation in nonequilibrium systems. Emphasis will be on quantitative understanding of biological problems.

This course teaches in-depth and hands-on understanding of numerical methods for solid mechanics problems. The course begins with a review of the fundamental concepts of the finite element method for linear boundary value problems (BVP) and initial boundary value problems (IBVP) in solid mechanics. Then more advance methods for nonlinear BVPs are presented and applied to problems of material inelasticity and finite elasticity. Topics covered include the strong and weak statements of the BVP, weighted residual methods, time integration, Newton-type methods for nonlinear problems, and error estimation and convergence.
Instructor(s): T. Nguyen.

EN.530.616. Introduction to Linear Systems.
This course examines linear, discrete- and continuous-time, and multiinput-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. ME EN.530.616 can be used to fulfill the requirement of BME EN.580.616 or ECE EN.520.601.
Instructor(s): N. Cowan.

EN.530.620. Robot Sensors and Actuators (Graduate).
Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, microactuators, position sensors, and proximity sensors.
Instructor(s): L. Whitcomb.

EN.530.621. Fluid Dynamics I.
Instructor(s): A. Prosperetti.
EN.530.622. Fluid Dynamics II.
Instructor(s): J. Katz.

EN.530.624. Dynamics of Robots and Spacecraft (Graduate).
An introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion, stability theory, and Hamilton's principle.
Instructor(s): G. Chirikjian.

EN.530.625. Turbulence.
Instructor(s): C. Meneveau.

Nonlinear dynamical systems theory are discussed in the context of mechanics, engineering and biological problems. Concepts such as stability, bifurcations, limit cycles and chaos are illustrated using simple analytic theories as well as practical examples. Emphasis are placed on developing intuition using analytic approaches and simple numerical calculations. The course is appropriate for graduate students with foundational knowledge of solid and fluid mechanics, and some notions of statistical mechanics and biological concepts.
Instructor(s): C. Meneveau.

In the first part of the course, the focus is on steady and transient two- and three-dimensional heat conduction. Energy balances and the energy equation are reviewed, and mathematical methods for solving partial differential equations are discussed. Heat transfer with a phase change, and contemporary conduction problems are discussed. In the second part of the course radiative properties and thermal radiation exchange are reviewed. The equation of transfer for participating media is developed, and simplification is discussed.
Instructor(s): S. Sun.

EN.530.632. Convection.
This course begins with a review of the phenomenological basis of the constitutive models for energy and mass flux. Then, using the transport theorem, general conservation and balance laws are developed for mass, species, energy, and entropy. Scaling analysis is used to determine when simplifications are justified, and simplified cases are solved analytically. Experimental results and correlations are given for more complex situations. Free, mixed, and forced internal and external convection are studied, and convection with a phase change is also explored.
Instructor(s): C. Meneveau.

EN.530.635. Mixing & Combustion.
Mixing of fluids, covering ideas from dynamical systems and mixing in turbulent flows. Combustion of gaseous and liquid fuels; chemistry, kinetics, deflagrations and detonations, premixed and non-premixed flames, effect of turbulence, spray and droplet combustion, combustion systems.
Instructor(s): G. Chirikjian.

This course focuses on advanced topics related to energy and thermodynamics. The objective of this course is to provide a thorough understanding of the environmental impacts related to energy conversion systems. The use of the second law of thermodynamics is introduced to quantify the performance of energy conversion systems. Topics such as global warming, alternative energy sources (solar, wind power, geothermal, tides, etc.) and new technology (fuel cells and hydrogen economy) and resources and sustainable development are addressed. A section of the course is devoted to current trends in nuclear energy generation and environmental issues associated with it.
Instructor(s): C. Herman.

EN.530.642. Plasticity.
Instructor(s): J. El-Awady.

EN.530.646. Robot Devices, Kinematics, Dynamics, and Control.
Graduate-level introduction to the mechanics of robotic systems with emphasis on the mathematical tools for kinematics and dynamics of robot arms and mobile robots. Topics include the geometry and mathematical representation of rigid body motion, forward and inverse kinematics of articulated mechanical arms, trajectory generation, manipulator dynam-ics, actuation, and design issues, manipulator control, and additional special topics. Recommended course background: multivariable integral and differential calculus, classical physics, linear algebra, ordinary differential equations.
Programming: Knowledge of the Matlab programming language including data input/output, 1-D and 2-D arrays, and user-defined function calls. Students with experience with these language elements are encouraged to use them in the Matlab language. Students with experience in other programming languages (C, C++, Python, Java, etc.) should be able to self-tutor themselves in the Matlab language as part of the programming exercises.
Instructor(s): L. Whitcomb.

Graduate-level introduction to adaptive identification and control. Emphasis on applications to mechanical systems possessing unknown parameters (e.g., mass, inertia, friction). Topics include stability of linear and nonlinear dynamical systems, Lyapunov stability, input-output stability, adaptive identification, and direct and indirect adaptive control. Recommended Course Background: AS.110.106, AS.110.107/AS.110.109, AS.110.202; Physics I, II; AS.110.201, AS.110.302, Equations, linear control theory, and Matlab.
Instructor(s): L. Whitcomb.

This course is a survey of group theory with an emphasis on applications in mechanical design research. In particular, the representation theory of finite groups, compact Lie groups, and certain noncompact unimodular groups is reviewed, and Fourier analysis on these groups is applied as a tool in design problems. The concentration is on applications in CAD, discrete and computational geometry, and robotics. Specific applications include modern interpolation, deformation of solid models, and pattern matching.
Instructor(s): G. Chirikjian.
EN.530.650. System Identification.
This course will cover several fundamental approaches system identification, including spectral, prediction error, subspace, and "online" (adaptive) identification methods. The emphasis will be on LTI systems, but some time will be devoted to state identification for classes of nonlinear dynamical systems, such as those that are linear in parameters.
Instructor(s): N. Cowan.

EN.530.653. Advanced Systems Modeling.
This course covers the following topics at an advanced level: Newton’s laws and kinetics of systems of particles and rigid bodies; Lagrange's equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion: structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Langrange, Kane’s formulation of dynamics, computing torques with O(n) recursive manipulator dynamics; Luh-Walker-Paul, Hollerbach, O(n) dynamic simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which relates the topics of this course to his or her research.
Instructor(s): G. Chirikjian.

EN.530.654. Advanced Systems Modeling II.
A continuation of EN.530.653, this course covers the following topics at an advanced level: Newton’s laws of kinematics of systems of particles and rigid bodies; Lagrange’s equations for single- and multi-degree-of-freedom systems composed of point masses; normal mode analysis and forced linear systems with damping, the matrix exponential and stability theory for linear systems; nonlinear equations of motion; structure, passivity, PD control, noise models and stochastic equations of motion; manipulator dynamics: Newton-Euler formulation, Langrange, Kane’s formulation of dynamics, computing torques with O(n) recursive manipulator dynamics: Luh-Walker-Paul, Hollerbach, O(n) dynamics simulation: Rodrigues-Jain-Kreutz, Saha, Fixman. There is also an individual course project that each student must do which relates the topics of this course to his or her research.
Instructor(s): G. Chirikjian.

An advanced course on the microscopic mechanisms that control the mechanical behavior of materials. Methods and techniques for measuring, understanding, and modeling: plasticity, creep, shear banding, and fracture will be addressed. Subjects to be covered include dislocation theory and strengthening mechanisms, high temperature diffusion and grain boundary sliding, shear localization, void formation, ductile rupture, and brittle fracture.

EN.530.657. Physical Acoustics.
This course provides a foundation for modern acoustics including derivation of wave equation and its solution in various media, sound radiation, sound propagation, instrumentation and sound/structure interaction. Specific applications of focus will be determined by the research interests of the students in the class.
Instructor(s): A. Prosperetti.

An advanced course on the theoretical treatment and modeling of the mechanisms of deformation in solids at intermediate and high temperatures. Topics include diffusion of point defects; vacancy migration; diffusion of solutes; cooperative and diffusion-less transformations; dislocation obstacle interactions; dislocation climb and cross-slip; friction forces in metals, alloys and covalent crystals.
Instructor(s): J. El-Awady.

EN.530.660. Computational Analysis of Stochastic Processes.
This class will cover stochastic processes (including both discrete and continuous time, and including both discrete and continuous state), leading to a rigorous treatment of stochastic differential equations and filtering, emphasizing computation. The class will draw from examples relevant to engineering, such as the Kalman filter. The course will comprehensively, but rapidly review all needed material in probability and statistics.
Prerequisites: 580.616 or 530.616 Linear Dynamical Systems.

EN.530.661. Applied Mathematics for Engineering.
This course presents a broad survey of the basic mathematical methods used in the solution of ordinary and partial differential equations: linear algebra, vector calculus, power series, Fourier series, separation of variables, integral transforms.
Instructor(s): M. Hilpert.

This course discusses the grid integration of renewable energy systems. The main emphasis is on grid level effects of renewable energy, particularly wind power systems. It begins with an introduction to basic power system concepts along with power flow analysis (and optimization). Then, important concepts for wind power systems are discussed. Following that, integration issues for wind power at the transmission level and solar cell integration at the distribution level are introduced. The last part of the course will focus on current research in these areas. Students will choose a system to research and present a project or literature review at the end of the term. Prior knowledge of optimization is helpful, but not required.
Instructor(s): D. Gayme.

EN.530.671. Statistical Mechanics in Biological Systems.
Principles of statistical physics are discussed in the context of biological problems. After an introduction, topics covered will include equilibrium theory of liquids and polymers, theory of chemical reactions in complex environments, stochastic models, dynamics of membranes and channels, theory of biological motors, computer simulations of liquids and proteins.
Instructor(s): S. Sun.

EN.530.672. Biosensing & BioMEMS.
The course discusses the principles of biosensing and introduces micro- and nano-scale devices for fluidic control and molecular/cellular manipulation, measurements of biological phenomena, and clinical applications.
Instructor(s): J. Wang.
EN.530.676. Locomotion in Mechanical and Biological Systems. Advanced graduate course on the mechanics of locomotion in animals and machines, and neural control of locomotion. Terrestrial, aquatic, and aerial locomotion modes are considered. Topics include dynamical systems theory, linear and nonlinear differential equations, Poincaré and Floquet theory, and system identification techniques. Recommended Course Background: graduate course in robotics, controls, or dynamical systems theory, and a basic understanding of probability theory; or permission of instructor. Instructor(s): N. Cowan.

EN.530.678. Nonlinear Control and Planning in Robotics. The course starts with a brief introduction to nonlinear systems and covers selected topics related to model-based trajectory planning and feedback control. Focus is on applications to autonomous robotic vehicles modeled as underactuated mechanical systems subject to constraints such as obstacles in the environment. Topics include: nonlinear stability, stabilization and tracking, systems with symmetries, differential flatness, backstepping, probabilistic roadmaps, stochastic optimization. Recommended Course Background: multi-variable/ differential calculus, AS.110.302, AS.110.201, undergraduate linear control, basic probability theory. Instructor(s): M. Kobilarov.

EN.530.701. Uncertainty Analysis and Downscaling. This course will describe several approaches used to infer small-scale information from large-scale observations (downscaling). Downscaling is especially useful for multi-scale phenomena characterized with power-law spectra or fractal geometry. Topics: Self-consistency conditions across length-scales to determine model parameters in coarse-grained simulations. Tools for characterizing scale-invariant (fractal) processes. Sample applications of downscaling as practiced today: (i) multi-scale transport phenomena in fluids, (ii) rainfall modeling in hydrology. The process of inferring small-scale information from large-scale observations is most often inherently uncertain. The second part of this course will explore uncertainty models in the analytical context of downscaling. Topics: assimilation of data and models (Kalman filtering and related methods for nonlinear models and very large data sets), statistical analysis of spatial-temporal data (independent components analysis, kernel methods). Applications to downscaling in atmospheric data.

EN.530.707. Robot System Programming. This course seeks to introduce students to open-source software tools that are available today for building complex experimental and fieldable robotic systems. The course is grouped into four sections, each of which building on the previous in increasing complexity and specificity: tools and frameworks supporting robotics research, robotics-specific software frameworks, integrating complete robotic systems, and culminates with an independent project of the student’s own design using small mobile robots or other robots in the lab. Students will need to provide a computer or a virtual-box (with at least a few GB of memory and a few tens of GB of disc space) running Ubuntu 12.04 (or one of its variants). Students should have an understanding of intermediate programming in C/C++ (including data structures and dynamic memory allocation) Familiarity with Linux programming. Familiarity with software revision control systems (e.g. subversion, mercurial, git), linear algebra. Recommended Course Background: EN.530.646 and EN.600.436. Instructor(s): L. Whitcomb.

EN.530.721. Advanced Concepts in Computational Fluid Dynamics. This course will introduce students to advanced concepts in computational fluid dynamics (CFD) including fast linear sparse solvers, and curvilinear, unstructured and Cartesian grid based methods for complex flows. Students will also learn how to develop fast flow solvers on large-scale shared and distributed memory computers. Area: Engineering.


EN.530.732. Fracture of Materials. An advanced examination of fracture mechanisms in ductile and brittle materials. Both the mechanics and the materials aspects are covered with importance placed on the synthesis of the two approaches. Topics include linear elastic fracture mechanics, ductile fracture, the J-integral, atomistic aspects of fracture in polycrystalline materials, fracture in ceramics and polymers, influence of the material microstructure on fracture toughness and ductility in FCC and BCC materials.


EN.530.757. Mechanics of Nanomaterials. The course provides a basic understanding of nanomaterials and nanomechanics. Develops the necessary background in mechanics, mechanical properties and modeling to understand the mechanics of nanomaterials and related problems in nanomechanics and nanotechnology. We will also examine the mechanics of nanoscale assemblies and microscale structures used for investigating nanoscale phenomena. Each student will be expected to complete a paper on a research topic chosen together with the instructor. A mechanics background is NOT required to take this course.

EN.530.759. Research Seminar in Plasticity and Failure. A weekly research seminar featuring ongoing research as well as reviews of new papers of interest in the general areas of plasticity and failure. The course will have an emphasis on dynamic phenomena, but will consider both engineering materials and biological systems. Students will be expected to make two presentations during the semester. Permission of instructor and advisor required. Instructor(s): K. Ramesh.


EN.530.767. Computational Fluid Dynamics.
Advanced introduction to finite-difference and finite-volume approaches to modeling incompressible flows. Computer project requiring programming.
Instructor(s): R. Mittal.

EN.530.772. Non-Linear Finite Elements.
This course will discuss state of the art theoretical developments and modeling techniques in nonlinear computational mechanics, for problems with geometric and material nonlinearities. Large deformation of elastic-plastic and visco-plastic materials, contact-friction and other heterogeneous materials like composites and porous materials will be considered. A wide variety of applications in different disciplines, e.g. metal forming, composite materials, polycrystalline materials will be considered. Co-listed with EN.560.772.
Instructor(s): S. Ghosh.

EN.530.773. Topics in Applied Mathematics Engineering.
Instructor(s): A. Prosperetti.


EN.530.790. Advanced Finite Element Methods and Multi-Scale Methods.

EN.530.800. Independent Study.
Instructor(s): Staff.

EN.530.801. Graduate Research.
Instructor(s): Staff.

EN.530.802. Graduate Research.
Instructor(s): Staff.

EN.530.803. Mechanical Engineering Seminar.
Instructor(s): Staff.

EN.530.804. Mechanical Engineering Seminar.
Instructor(s): Staff.

Instructor(s): J. Katz.

EN.530.808. Graduate Seminar in Fluid Mechanics.
Instructor(s): Staff.

Instructor(s): Staff.

EN.530.897. Research-Summer.
Instructor(s): Staff.

EN.530.899. Independent Study-Summer.
Instructor(s): Staff.

Cross Listed Courses

Physics Astronomy

AS.171.321. Introduction to Space, Science, and Technology. 3 Credits.
Topics include space astronomy, remote observing of the earth, space physics, planetary exploration, human space flight, space environment, orbits, propulsion, spacecraft design, attitude control and communication. Crosslisted by Departments of Earth and Planetary Sciences, Materials Science and Engineering and Mechanical Engineering. Recommended Course Background: AS.171.101-AS.171.102 or similar; AS.110.108-AS.110.109.
Instructor(s): H. Moos; S. Murray
Area: Engineering, Natural Sciences.

General Engineering

Instructor(s): Staff.

EN.500.745. Seminar in Computational Sensing and Robotics.
Seminar series in robotics. Topics include: Medical robotics, including computer-integrated surgical systems and image-guided intervention. Sensor based robotics, including computer vision and biomedical image analysis. Algorithmic robotics, robot control and machine learning. Autonomous robotics for monitoring, exploration and manipulation with applications in home, environmental (land, sea, space), and defense areas. Biorobotics and neuromechanics, including devices, algorithms and approaches to robotics inspired by principles in biomechanics and neuroscience. Human-machine systems, including haptic and visual feedback, human perception, cognition and decision making, and human-machine collaborative systems. Cross-listed Mechanical Engineering, Computer Science, Electrical and Computer Engineering, and Biomedical Engineering.
Instructor(s): Staff.

Cross-listed with Mechanical Engineering.
Instructor(s): J. Guest.

Electrical Computer Engineering

EN.520.353. Control Systems. 3 Credits.
Modeling, analysis, and an introduction to design for feedback control systems. Topics include state equation and transfer function representations, stability, performance measures, root locus methods, and frequency response methods (Nyquist, Bode).
Instructor(s): D. Tarraf
Area: Engineering, Quantitative and Mathematical Sciences.

Civil Engineering

EN.560.201. Statics & Mechanics of Materials. 4 Credits.
Basic principles of classical mechanics applied to the equilibrium of particles and rigid bodies at rest, under the influence of various force systems. In addition, the following topics are studied: free body concept, analysis of simple structures, friction, centroids and centers of gravity, and moments of inertia. Includes laboratory experience. Co-listed with EN.530.201. Recommended Course Background: AS.171.101, or EN.530.103/EN.530.104 or instructor permission.
Instructor(s): T. Igusa
Area: Engineering.
Geography Environmental Engineering

EN.570.661. Applied Math For Engineer.
This course presents a broad survey of the basic mathematical methods used in the solution of ordinary and partial differential equations: linear algebra, power series, Fourier series, separation of variables, integral transforms.
Instructor(s): M. Hilpert.

Biomedical Engineering

Cell and tissue engineering is a field that relies heavily on experimental techniques. This laboratory course will consist of three six experiments that will provide students with valuable hands-on experience in cell and tissue engineering. Students will learn basic cell culture procedures and specialized techniques related to faculty expertise in cell engineering, microfluidics, gene therapy, microfabrication and cell encapsulation.
Experiments include the basics of cell culture techniques, gene transfection and metabolic engineering, basics of cell-substrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction. Co-listed with EN.530.451. Senior and Graduate students only; others, instructor permission required. Fall semester only.
Lab Fee: $100
Instructor(s): E. Haase
Area: Engineering, Natural Sciences.

EN.580.616. Introduction to Linear Dynamical Systems.
This course examines linear, discrete- and continuous-time, and multi-input-output systems in control and related areas. Least squares and matrix perturbation problems are considered. Topics covered include state-space models, stability, controllability, observability, transfer function matrices, realization theory, feedback compensators, state feedback, optimal regulation, observers, observer-based compensators, measures of control performance, and robustness issues using singular values of transfer functions. BME EN.580.616 can be used to fulfill the requirement of ME EN.530.616 or ECE EN.520.601.
Instructor(s): S. Sarma.

Entrepreneurship and Management

EN.660.461. Engineering Business and Management. 3 Credits.
An introduction to the business and management aspects of the engineering profession, project management, prioritization of resource allocation, intellectual property protection, management of technical projects, and product/production management. Preference will be given to Mechanical Engineering students. No audits. Recommended Course Background: EN.660.105
Instructor(s): I. Izenberg; M. Agronin
Area: Engineering.