

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. Both programs are accredited by ABET, the Accreditation Board for Engineering and Technology. 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 three main stems of the undergraduate curriculum—thermal and fluid systems, mechanics and materials, and robotics and control systems. Engineering Mechanics is a more flexible program that enables students to pursue particular interests while centering around a smaller core of courses. Students may use this flexibility to follow specific interests in physics, mathematics, economics, etc., 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 potentials. 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.

The Faculty

Ilene Busch-Vishniac, Professor: electromechanical sensors and actuators, noise control, and micro-automation.

Shiyi Chen, Professor: computational fluid dynamics, statistical theory and computation of

fluid turbulence, mesoscopic physics and lattice Boltzman computational methods, multiphase flows and boiling.

Gregory S. Chirikjian, Professor (Chair): design, kinematics, motion planning dynamics and control of mechanisms, and robots, computational aspects of nanotechnology and conformational analysis of biological macromolecules.

Noah J. Cowan, Assistant Professor: Sensor-based control of locomotion and manipulation, machine learning, and biologically inspired robotics.

Andrew S. Douglas, Professor (Associate Dean for Academic Affairs, Whiting School of Engineering): dynamic fracture of ductile materials, mechanics of active materials, mechanics of soft tissue.

Kevin J. Hemker, Professor: Understanding and predicting mechanical performance by correlating microsample tensile testing with transmission electron microscopy in order to identify the fundamental processes controlling deformation in advanced structural materials, thermal barrier coatings, MEMS, and nanocrystalline materials. Employing high resolution and analytical electron microscopy to characterize and study nanostructured materials and dislocation core geometries. HREM observations of dislocation cores in single crystalline gold and iridium.

Cila Herman, Professor: Experimental heat transfer and fluid mechanics, optical measurement techniques (holographic interferometry) applied to heat transfer measurements, heat transfer enhancement, boiling in microgravity and under the influence of electric fields, cooling of electronic equipment, thermoacoustic refrigeration, MEMS, heat transfer in oscillating flows, heat exchangers. Experimental visualization of temperature fields and study of heat transfer enhancement in oscillatory flow in a grooved channel.

Joseph Katz, Professor, Whiting School Mechanical Engineering Chaired Professor: Experimental fluid mechanics, quantitative visualization of complex flows, turbomachines, breaking waves, bubbly and cavitating flows, stratified shear flows and oceanographic flows, development of advanced diagnostic techniques, PIV, holography for laboratory and field application. Statistical geometry of subgrid-scale stresses determined

from holographic particle image velocimetry measurements.

- Omar M. Knio**, Professor: computational fluid mechanics, reacting shear flows, physical acoustics, atmospheric and oceanic flows, energetic materials, microfluids, uncertainty quantification.
- Charles Meneveau**, Professor: Experimental, numerical, and theoretical studies in turbulence; subgrid scale modeling and large-eddy simulation; fractals; application of novel data-analysis techniques to shed new light on the long-standing turbulence problem; development of improved models for engineering applications.
- Jean-François Molinari**, Assistant Professor: Computational solid mechanics, adaptive meshing, optimization, constitutive modeling, tribology, impact, dynamic damage and failure mechanisms, nanotribology, nanocrystalline materials.
- Allison M. Okamura**, Assistant Professor: Virtual and teleoperated environments: haptic interfaces, tactile and force feedback, virtual fixtures, medical robotics, surgical simulation, educational applications. Robotic fingers and hands: dexterous manipulation, tactile sensing, haptic exploration, object modeling.
- Andrea Prosperetti**, Professor, Charles A. Miller Jr. Chair in Mechanical Engineering: Theoretical and computational fluid mechanics and acoustics; multiphase flow; gas and vapor bubble acoustics; microfluidic systems.
- K. T. Ramesh**, Professor: Nanostructured materials, high strain rate behavior and dynamic failure of materials, biomimetics, mechanics of gene expression.
- William N. Sharpe Jr.**, Professor, Alonzo Decker Chair in Mechanical Engineering: Experimental solid mechanics; testing of small specimens; mechanical properties of MEMS materials. Effect of specimen size on Young's Modulus and fracture strength of polysilicon.
- Lester K. Su**, Assistant Professor: experimental fluid mechanics, turbulent mixing and combustion, combustion systems, laser diagnostics, interaction of experiments and simulations, spray and droplet dynamics.
- Sean Sun**, Assistant Professor: theoretical biophysics, mechanics of molecular motors, statistical mechanics of liquids, quantum dynamics in complex systems.
- Jeff Tza-Huei Wang**, Assistant Professor: BioMEMS; microfluidics; micro total analysis system (μ -TAS); nanofabrication and microfabrication; experimental molecular dynamics; single molecule manipulation and detection;

ultrasensitive molecular sensing basing on confocal microscopy, fluorescence resonance energy transfer (FRET), and fluorescence correlation spectroscopy (FCS).

- Louis L. Whitcomb**, Professor: Nonlinear dynamical systems, design, and model-based control of mechanical systems. Focus areas of robot control: underwater robotics vehicles, robot arms, and medical robotics; adaptive force control of position/velocity controlled robots: theory and experiment. Adaptive identification of dynamically positioned underwater robotic vehicles.

Joint, Part-Time, and Research Appointments

- Juan I. Arvelo, Jr.**, Assistant Research Professor (Applied Physics Laboratory).
- Stephen Belkoff**, Associate Professor (Orthopedic Surgery): biomechanics.
- Robert C. Cammarata**, Professor (Materials Science and Engineering): mechanical properties of thin films and multilayers.
- Edmund Yee-Su Chao**, Professor (Orthopedic Surgery): musculoskeletal biomechanics.
- Andrew F. Conn**, Senior Lecturer (Conn Consulting, Inc.): mechanical engineering design.
- Thomas Dragone**, Adjunct Associate Professor: aerospace structures and materials, airframe structure design and development, materials science.
- Gregory L. Eyink**, Professor (Department of Applied Mathematics and Statistics).
- Edwin Fitzgerald**, Doctor of the University.
- Gregory D. Hager**, Professor (Computer Science): robotics, visual tracking, and vision-based interaction.
- Thomas T. Huang**, Research Professor (Newport News Ship Building): computational fluid dynamics.
- Robert Ivester**, Adjunct Associate Professor.
- Robert H. Kraichnan**, Homewood Professor (Los Alamos National Laboratories).
- Reza Malek-Madani**, Fellow by Courtesy.
- Hasan N. Oguz**, Associate Research Professor: fluid mechanics.
- Thomas Osborn**, Professor (Earth and Planetary Sciences): physical oceanography.
- Marc B. Parlange**, Professor (Geography and Environmental Engineering): hydrology, environmental fluid mechanics.
- Aleksander S. Popel**, Professor (Biomedical Engineering): fluid mechanics, physiological flows and transport.
- Yue-Hong Qian**, Adjunct Associate Professor, Mechanical Engineering (Princeton University).

Mark Robbins, Professor (Physics and Astronomy): nanomechanics, molecular origins of macroscopic mechanical behavior, especially friction, adhesion, and yield.

Jack C. Roberts, Research Professor (Applied Physics Laboratory): advanced composite materials.

Scott Schoenfeld, Fellow by Courtesy

Kathleen Stebe, Professor (Chemical and Biomolecular Engineering): surfactants and interfacial flows, Marangoni effects, dynamic surface tension, dynamics of self-assembly of amphiphiles.

Daniel J. Stilwell, Adjunct Assistant Professor (Virginia Polytechnic Institute and State University): autonomous robotic systems, nonlinear control theory.

Daniel Stoianovici, Associate Professor (Brady Urological Institute): medical robotics.

Russell H. Taylor, Professor (Computer Science): medical robotics.

Natish V. Thakor, Professor (Biomedical Engineering): medical instrumentation, microcomputers, VLSI, robotics.

Rene Vidal, Assistant Professor (Biomedical Engineering).

Liming Voo, Associate Research Professor (Applied Physics Laboratory).

Timothy Weihs, Associate Professor (Materials Science and Engineering): deposition and mechanical properties of thin films.

Dennis Wickenden, Research Professor (Applied Physics Laboratory).

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

Shujia Zhou, Associate Adjunct Professor.

Facilities

Most teaching and research facilities of the department, as well as the departmental office, are located in Latrobe Hall. 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. A separate laboratory is used by the seniors to construct and test their prototypes in the yearlong design project course. Computer facilities are readily available to undergraduates 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 dynamic phenomena. The Laboratory for Active Materials and Biomimetics contains facilities for the characterization of active materials and biomaterials. These, coupled with electron microscopy facilities, enable innovative research on the mechanical properties of materials. 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 microscale up to the macroscale. A large hydrodynamics laboratory is the home of several laser-based flow visualization setups, and the Corrsin 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 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 haptic exploration laboratory is equipped for research in the development and control of robotic manipulators for haptic exploration, and also houses several haptic interfaces for simulating immersive virtual environments. Graduate students use this local system, as well as the university's computers and national supercomputers, in the course of their research.

Financial Aid

Scholarships and other forms of financial assistance for undergraduates are described under Admissions and Finances (see page 17). 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 supplementary teaching assistantships. Applications for graduate study received by December 15 are given preference in financial aid decisions.

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

Undergraduate Programs

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 programs, including updated scheduling and course offerings, please consult the undergraduate advising manuals which are available from the department office in Latrobe Hall and on the departmental Web site at www.me.jhu.edu. For details and an explanation of ABET requirements, see their Web site at www.abet.org.

Requirements for the Bachelor's Degree

See also General Requirements for Departmental Majors, page 46; Writing Requirement, page 42; 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 adviser. 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, and robotics. The choice of concentration is decided in the junior year after consultation with the student's faculty adviser.

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 a select group of engineers who, after graduation, will be successful and on track to become leaders among their peers as (1) engineers in industry, government laboratories and other organizations, or (2) advanced students in the best graduate programs. In these endeavors, they will:

- Apply and cultivate their understanding and mastery of the fundamental scientific, engineering, and professional principles at the foundation of Mechanical Engineering.
- Apply advanced mathematical, computational and experimental techniques to respond to demands of advanced technology, economy, and efficiency that put an ever-increasing premium on the quantitative aspects of engineering.
- Contribute to society as broadly educated, articulate, and ethical citizens, who are at ease in multidisciplinary teams.
- Strive to continually update and renew their knowledge throughout their careers, to excel in a rapidly changing world.

The Mechanical Engineering curriculum is structured as follows:

Mathematics (19 credits: grades of D or D+ not accepted)

- 110.108 Calculus I
- 110.109 Calculus II
- 110.202 Calculus III (or 110.211 Honors Multivariable Calculus and Linear Algebra or 110.201 Linear Algebra [Fall Semester])
- 550.291 Linear Algebra/Differential Equations (or 110.212 Honors Multivariable Calculus and Linear Algebra or 110.302 Differential Equations [Spring Semester])
- Statistics Elective at the 300-level or above (e.g. 560.435 Probability and Statistics in Civil Engineering or 550.310 Probability and Statistics)

Science (13 credits: grades of D or D+ not accepted)

- 171.101 Physics I
- 173.111 Physics Lab I
- 171.102 Physics II
- 173.112 Physics Lab II
- 510.101 Introduction to Materials Chemistry or 030.101 Chemistry I

Humanities (21 credits)

Seven humanities and/or social science electives (designated H or S in this catalog); of which one must specifically teach writing (such as 500.211 Technical Communications, 060.113 Expository Writing or 220.105 Introduction to Fiction and Poetry Writing) and one must be in economics. To obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher and the five free electives (not including the writing or economics electives) must be chosen from one or two coherent areas of concentration. For examples of areas of concentration and more details, see the departmental advising guide and the Web site (www.me.jhu.edu).

Required Engineering Courses (48 credits: grades of D or D+ not accepted)

530.101 Freshman Experiences in Mechanical Engineering
530.106 Computing in Mechanical Engineering
530.201 Statics and Mechanics of Materials
530.202 Dynamics
530.215 Mechanics-Based Design
530.231 Mechanical Engineering Thermodynamics
530.327 Introduction to Fluid Mechanics
530.334 Heat Transfer
530.341 Electronics and Instrumentation
[or 520.213 Circuits followed by 520.345 Electrical and Computer Engineering Laboratory (which can be used as a Technical Elective) or 525.134 Electrical Engineering Laboratory II.]
530.343 Design and Analysis of Dynamical Systems
530.352 Materials Selection
530.454 Manufacturing Engineering
530.461 Engineering Business and Management
[or 551.105 Introduction to Business and 551.341 Business Process and Quality Management.]

Capstone Design (8 credits)

530.403/404 Engineering Design I/II

Mechanical Engineering Electives (9 credits)

Three courses (300-level or higher) in mechanical engineering

Technical Electives (9 credits)

Three (E), (Q), or (N) courses at or above the 300-level, chosen from any combination of courses in

engineering, basic sciences, or mathematics selected in consultation with the student's adviser. 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 127 credits must be completed to be eligible for the bachelor's degree.

Students may not use the satisfactory/unsatisfactory option for required courses, including (H) and (S), unless approved by their faculty adviser. The department will accept D grades only up to a maximum of 10 credit hours 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 adviser.

Sample Program:**• Year 1***Fall*

110.108 Calculus I	4
510.101 Intro Materials Chemistry	3
530.101 Freshman Experiences in Mechanical Engineering	4
H/S Elective	<u>3</u>
Subtotal	14

Spring

110.109 Calculus II	4
171.101 General Physics I	4
173.111 General Physics I Lab	1
530.106 Computing in Mech. Eng.	3
H/S Elective	<u>3</u>
Subtotal	15

• Year 2*Fall*

110.202 Calculus III	4
530.201 Statics and Mechanics	3+1
530.231 Mechanical Engineering Thermodynamics	3+1
171.102 General Physics II	4
173.112 General Physics II Lab	1
Subtotal	17

Spring

550.291 Linear Algebra/Differential Equations	4
530.202 Dynamics	3+1
530.215 Mechanics-Based Design	3+1
Writing Elective	<u>3</u>
Subtotal	15

• **Year 3**

Fall

530.327 Intro Fluid Mechanics	3+1
530.352 Materials Selection	3+1
Electronics Elective	3
Statistics Elective	3
H/S Elective	<u>3</u>
Subtotal	17

Spring

530.334 Heat Transfer	3+1
530.343 Design and Analysis of Dynamic Systems	3+1
Mechanical Engineering Elective	3
Technical Elective	3
H/S Elective	<u>3</u>
Subtotal	17

• **Year 4**

Fall

530.403 Engineering Design Project I	4
530.454 Manufacturing Engineering	3
530.461 Engineering Business and Management	3
Technical Elective	3
H/S Elective	<u>3</u>
Subtotal	16

Spring

530.404 Engineering Design II	4
Mechanical Engineering Elective	3
Mechanical Engineering Elective	3
Technical Elective	3
H/S Elective	<u>3</u>
Subtotal	<u>16</u>
Total	127

The Engineering Mechanics Program

The mission of the B.S. in Engineering Mechanics 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 Engineering Mechanics program is to build competence in the analysis, design, and development of physical systems consisting of fluid and solid components, to promote a broad knowledge of the contemporary social and economic context, and to develop the communication skills necessary to excel.

The Engineering Mechanics Program concentrates on the scientific fundamentals of the behavior of solids and fluids. The program is designed to be highly flexible while providing the student with a broad scientific and technical background in the mechanical sciences.

This flexibility 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/her adviser 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, aerospace engineering, 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 adviser.

The educational objectives for the B.S. in Engineering Mechanics degree are designed to provide a high-quality educational experience that is tailored to the needs and interests of the student. Each student's program of study is planned in consultation with his or her faculty adviser. The program will educate a select group of science-oriented engineers who, after graduation, will be successful and on track to become leaders among their peers as (1) advanced students in the best graduate programs in engineering, science, medical schools, or law schools, or (2) as engineers in industry, government laboratories and other organizations. In these endeavors, they will:

- Apply and cultivate their understanding and mastery of the fundamental scientific, engineering, and professional principles at the foundation of Mechanics.
- Apply advanced mathematical, computational and experimental techniques to respond to demands of advanced technology, economy, and efficiency that put an ever-increasing premium on the quantitative aspects of engineering.
- Contribute to society as broadly educated, articulate, and ethical citizens, who are at ease in cross-disciplinary and multidisciplinary teams.

- Strive to continually update and renew their knowledge throughout their careers, to excel in a rapidly changing world.

The specific requirements for the engineering mechanics program are either “Mathematics with a focus on applications” or “Mathematics with a focus on fundamentals.”

Mathematics with a focus on applications: (23 credits; grades of D or D+ not accepted)...

- 110.108 Calculus I
- 110.109 Calculus II
- 110.202 Calculus III, (or 110.211 Honors Multivariable Calculus and Linear Algebra, or 110.201 Linear Algebra [semester one])
- 550.291 Linear Algebra/Differential Equations, (or 110.212 Honors Multivariable Calculus and Linear Algebra, or 110.302 Differential Equations [semester two])
- Another Mathematics Elective
- Statistics Elective at the 300 level or above (e.g. 560.435 Probability and Statistics in Civil Engineering or 550.310 Probability and Statistics)

Mathematics with a focus on fundamentals: (23 credits; grades of D or D+ not accepted)

- 110.108 Calculus I
- 110.109 Calculus II
- 110.211-212 Honors Multivariable Calculus and Linear Algebra
- 110.302 Differential Equations with Applications
- Statistics Elective at the 300 level or above (e.g. 560.435 Probability and Statistics in Civil Engineering or 550.310 Probability and Statistics)

Basic Science (16 credits; grades of D or D+ not accepted)

- 171.101 Physics I
- 173.111 Physics Lab I
- 171.102 Physics II
- 173.112 Physics Lab II
- 510.101 Introduction to Materials Chemistry (or 030.101 Chemistry I)
- Another basic science elective

Humanities (18 credits)

Six humanities and/or social science electives (designated H or S in this catalog) of which one must specifically teach writing (such as 060.113 Expository Writing or 220.105 Introduction to Fiction and Poetry Writing) and one must be in economics. To

obtain coherence and depth in these humanities and social science electives, at least six credits must be at the 300-level or higher and the four free electives (not including the writing or economics electives) must be chosen from one or two coherent areas of concentration. For examples of areas of concentration and more details, see the departmental advising guide and the Web site (www.me.jhu.edu).

Required Engineering Courses (minimum of 26 credits; grades of D or D+ not accepted)

Introductory course in computing (530.106 Mechanical Engineering Computing recommended).

Introductory course for freshmen: students must choose one of the following (*=strongly recommended, **=recommended):

- 530.101 Freshman Experiences in Mechanical Engineering**
- 510.102 Materials and their Influence on Technology*
- 520.137 Introduction to Electrical and Computer Engineering
- 500.101 Introduction to Engineering**
- 570.108 Introduction to Environmental Engineering
- 530.201 Statics and Mechanics of Materials
- 560.202 Dynamics
- 530.231 Mechanical Engineering Thermodynamics
- 530.405 Mechanics of Solids and Structures (or 530.215 Mechanics Based Design)
- 530.327 Introduction to Fluid Mechanics

Capstone Design (8 credits)

530.403/404 Engineering Design I/II

Engineering Science Electives (12 credits; grades of D or D+ not accepted)

- One course in the mechanics of solids
- One course in the mechanics of fluids
- One course in the mechanics of either solids or fluids
- One course in either materials or dynamics

Engineering Mechanics Electives (6 credits)

Two additional elective courses in the same area of engineering mechanics (solid mechanics, fluid mechanics or dynamics).

Technical Electives (minimum of 18 credits)

A minimum of four (E), (Q), or (N) courses at or above the 300-level, chosen in consultation with the student's adviser from any combination of courses in engineering, basic sciences, or mathematics.

Appropriate choices from the social sciences and philosophy may be also used to fulfill this requirement (for example, 180.315 Game Theory, 150.420 Formal Concepts of Philosophy), if approved by the student's adviser. Because of the importance of computer languages in modern technical society, students may take computer language courses at any level. Acceptable courses include 600.107 Introduction to Programming in Java and 600.109 Introduction to Programming in C.

Fluid mechanics courses may be chosen from courses such as:

- 530.328 Fluid Mechanics II
- 530.425 Mechanics of Flight
- 570.301 Environmental Engineering I: Fundamentals
- 580.460 Physiological Fluid Mechanics
- 580.461 Biological Transport

Dynamics courses may be chosen from courses such as:

- 530.343 Design and Analysis of Dynamic Systems
- 530.424 Dynamics of Robots and Spacecraft
- 530.420 Robot Sensors and Actuators
- 171.204 Classical Mechanics
- 550.391 Dynamical Systems

Solid mechanics courses may be chosen from courses such as:

- 530.215 Mechanics Based Design*
- 530.405 Mechanics of Solids and Structures, if not used to satisfy the required engineering courses
- 530.414 Computer-Aided Design
- 530.416 Advanced Design
- 530.730 Finite Element Methods
- 560.301 Theory of Structures
- 560.302 Structural Analysis and Design
- 560.455 Structural Mechanics
- 580.450 Mechanics of Living Tissue

A program of not less than 127 credits must be completed to be eligible for the bachelor's degree.

Students may not use the satisfactory/unsatisfactory option for required courses, including (H) and (S), unless approved by their faculty adviser. The department will accept D grades only up to a maximum of 10 credit hours 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 adviser.

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 adviser, 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 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 adviser.

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

- 020.386 Macromolecular Machines
- 250.353 Biomolecular Dynamics and Ensembles
- 510.420 Topics in Biomaterials Science
- 530.440 Computational Mechanics of Biological Macromolecules
- 530.445 Introductory Biomechanics
- 530.571 Statistical Mechanics in Biological Systems

530.495 Microfabrication Laboratory
 540.409 Modeling Dynamics and Control for
 Chemical and Biological Systems
 540.426 Introduction to Macromolecules
 550.435 Bioinformatics and Statistical Genetics
 580.430 Cardiovascular Systems Mechanics
 580.431 Biomechanics and Motor Control
 580.455 Introduction to Orthopaedic
 Biomechanics
 580.460 Physiological Fluid Mechanics
 600.439 Principles of Computational Biology

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 six courses such as those listed above. These six 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 towards this end.

Aerospace Engineering Concentration

The Department of Mechanical Engineering offers an Aerospace Engineering Concentration. A student may specialize in Aerospace Engineering once a solid background in the fundamentals of Mechanical Engineering (ME) has been developed through the basic ME courses. The Aerospace Engineering Concentration requires knowledge/background in several fields including advanced dynamics, flight mechanics, propulsion, aerospace materials and structures, signal processing, control systems, astrophysics and space systems. Students pursuing the Aerospace Engineering Concentration are required to take at least six of the following courses (essentially constituting the three ME electives and the three Technical Electives in the general ME program):

535.442 Control Systems for ME Application
 530.424 Dynamics of Robots and Spacecraft
 530.425 Mechanics of Flight
 530.432 Jet and Rocket Propulsion
 530.418 Aerospace Structures and Materials
 615.444 Space Systems I
 615.445 Space Systems II

Six of the seven courses listed above are required. The seventh course is not required but is highly recommended. Other courses relevant to this concentration include:

171.118 Stars and the Universe
 520.214 Signals and Systems
 530.328 Fluid Mechanics II

520.401 Basic Communication
 525.445 Modern Navigation Systems

Accelerated Programs

The Department of Mechanical Engineering offers to qualified undergraduates accelerated programs that permit admission to graduate study as early as the end of junior year. Students may be concurrently enrolled as undergraduate and graduate students during their senior year and thus reduce the time needed to get an M.S.E. or Ph.D.

Students interested in the accelerated program should submit to the department chair (preferably by January 15, before the spring semester of the junior year) a letter of intent, a transcript, and an outline of the proposed academic program (developed in consultation with a faculty adviser) for formal approval by the faculty.

Graduate Programs

Admission and Advising

To be admitted to graduate study in the Department of Mechanical Engineering, applicants must submit credentials sufficient to convince the faculty that they have a good chance of obtaining the advanced degree in a reasonable time. No academic degree is required, but the applicant should have at least two years of good undergraduate training, or the equivalent, and should have achieved very high marks or have given other evidence of outstanding ability. Graduate Record Examination scores must be submitted.

Upon arrival, each graduate student is assigned to a faculty adviser to help him/her to map out a tentative program for the first year and enter the intellectual life of the department. The student is expected to remain in regular communication with the adviser. The adviser 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 adviser in successive years. After serious research for a dissertation has begun, the research supervisor will automatically function as adviser.

Requirements for the M.S.E. Degree

For the master of science in engineering degree at least eight one-semester courses are required. At least half of them should be selected among those listed as *graduate courses* in this catalog. 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 adviser.

A non-thesis master of science in engineering degree is also offered. The student must successfully complete a coordinated sequence of ten courses, which typically requires one year of full-time resident graduate study. 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. All students must follow a course of study approved by their individual adviser.

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 a departmental oral exam based on core courses. This exam is usually taken after the third semester of enrollment. The second is an 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; it is taken after the departmental exam.

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 adviser.

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 pass a final oral examination which is essentially a defense of the dissertation.

Undergraduate Courses

530.101 (E) Freshman Experiences in Mechanical Engineering

An overview of the field of mechanical engineering along with topics that will be useful throughout the mechanical engineering program. Examples of the latter are dissection of an IC engine, MatLab, the design process, report preparation, and teamwork.

Busch-Vishniac 4 credits fall

530.106 (E,Q) Computing in Mechanical Engineering

Basic elements of computer operation, programming in FORTRAN; elementary numerical analysis including differentiation and integration; introduction to use of software in data transfer, analysis, and visualization. Prerequisite: 110.109.

Su 3 credits spring

530.201 (E,N) Statics and Mechanics of Materials

Equilibrium of rigid bodies, free-body diagrams, design of trusses. One-dimensional stress and strain, Hooke's law. Properties of areas. Stress, strain, and deflection of components subjected to uniaxial tension, simple torsion, and bending. Prerequisite: 171.101 or permission of instructor.

Staff 4 credits (3 hours lecture, 1 hour lab) fall

530.215 (E) Mechanics-Based Design

Stresses and strains in three dimensions, transformations. Combined loading of components, failure theories. Buckling of columns. Stress concentrations. Introduction to the finite element method. Design of fasteners, springs, gears, bearings, and other components. Prerequisite: 530.201.

Ramesh 4 credits (3 hours lecture, 1 hour lab) spring

530.231 (E,N) Mechanical Engineering Thermodynamics

Properties of pure substances, phase equilibrium, equations of state. First law, control volumes, conservation of energy. Second law, entropy, efficiency, reversibility. Carnot and Rankine cycles. Internal combustion engines, gas turbines. Ideal gas mixtures, air-vapor mixtures. Introduction to combustion. Prerequisites: 110.109, 171.102. Corequisite: 110.202.

Katz 4 credits (3 hours lecture, 1 hour lab) fall

530.327 (E,N) Introduction to Fluid Mechanics

Physical properties of fluids. 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: 110.302 or 550.291, 560.202.

Su 4 credits (3 hours lecture, 1 hour lab) fall

530.328 (E,N) Fluid Mechanics II

Linear and angular momentum in integral form, applications to turbomachines. The Navier-Stokes equations. Inviscid flow. Laminar viscous flow. Boundary layers. Turbulence. Compressible flows. Projects using computational tools, design of pipe network.

Meneveau 3 credits spring

530.334 (E,N) Heat Transfer

Conduction in one, two, and three dimensions. External and internal forced convection, convection with change in phase. Performance and design of heat exchangers. Black-body radiation, Stefan-Boltzmann law. Computational modeling and experimental study of selected topics

in conduction, convection, and radiation. Prerequisites: 530.231, 530.327.

Herman 4 credits (3 hours lecture, 1 hour lab)
spring

530.341 (E) Electronics and Instrumentation Lab

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: Physics I and II, Linear Algebra, Differential Equations.

Cowan, Whitcomb 3 credits fall

530.343 (E,W) Design and Analysis of Dynamic Systems

Modeling and analysis of damped and undamped, forced and free vibrations in single and multiple degree-of-freedom linear dynamical systems. Introduction to stability and control of linear dynamical systems. Prerequisites: 110.108, 110.109, 110.202, and 550.291.

Okamura 4 credits (3 hours lecture, 1 hour lab)
spring

530.352 (E) Materials Selection

An introduction to the properties and applications of a wide variety of materials: metals, polymers, ceramics, and composites. Considerations include availability and cost, formability, rigidity, strength, and toughness. This course is designed to facilitate sensible materials choices so as to avoid catastrophic failures leading to the loss of life and property. Prerequisite: 530.215 or permission of instructor.

Hemker 4 credits (3 hours lecture, 1 hour lab) fall

530.403-404 (E,Q,N,W) Engineering Design Project

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 or sooner. 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. Prerequisites: For mechanical engineering majors: 530.215, 530.327. For engineering mechanics majors and biomedical engineering majors: 530.215 or 530.405, and 530.327. To receive credit for this course, both semesters must be completed.

Conn, Sharpe 8 credits academic year

530.405 (E,N) Mechanics of Solids and Structures

Continuum Mechanics provides a rigorous basis to the study of deformable solids and fluids. Review of vector calculus and tensor analysis. Kinematics of a body. Stress. Conservation laws. Constitutive equations for solids and fluids. Linear elasticity. Energy methods and foundations of the finite element method. Prerequisites: 110.201, 550.291 or 110.212, 530.215 or 560.206 or permission of the instructor.

Molinari 3 credits spring

530.410 (E, N) Biomechanics of The Cell and Organisms

Prerequisite: Introductory physics, a year of calculus. Preferably linear algebra also 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.

Sun 3 credits

530.414 (E) Computer-Aided Design

This course attempts to integrate the concepts developed in 530.215 with the use of the computer as a design tool. The topics covered include the design of mechanical systems. Extensive use is made of computer-aided design software, including object modeling, system assembly, and mechanism solution procedures. Computer-aided drafting and dimensioning. Prerequisite: 530.215.

Stoianovici 3 credits

530.416 (E,N) Advanced Mechanical Design

A continuation of 530.215 covering linkage synthesis, cams, fatigue, fracture, and various mechanical components such as gears, springs, brakes, weldments. Prerequisite: 530.215.

Sharpe 3 credits

530.418 (E,N) Aerospace Structures and Materials

An introduction to the design of aircraft and spacecraft structures and components. This course will build on skills learned in 530.215, Mechanics-Based Design and 530.352, Materials Selection. Prerequisites: 530.215, 530.352 or consent of instructor.

Hemker 3 credits

530.420 (E) Robot Actuators and Sensors

Introduction to modeling and use of actuators and sensors in mechatronic design. Topics include electric motors, solenoids, micro-actuators, position sensors, and proximity sensors. Laboratory. Prerequisites: 171.101, 171.102, 110.108, 110.109, 110.202, 550.291, and 520.345.

Okamura, Whitcomb 3 credits fall

530.421 (E) Mechatronics

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.

Chirikjian 3 credits spring

530.424 (E) Dynamics of Robots and Spacecraft

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. Prerequisite: 560.202.

Chirikjian 3 credits spring/even years

530.425 (E,N) Mechanics of Flight

Elements of flight dynamics: aerodynamics forces, gliding, cruising, turning, ascending, descending, stability, etc. Review of the pertinent fluid mechanic principles. Application to two-dimensional airfoils and theory of lift. Three-dimensional airfoils. Boundary layers. Effects of compressibility. Subsonic and supersonic flight. Prerequisites: 530.231, 530.327, 530.328 (may be taken concurrently), or permission of the instructor.

Prosperetti 3 credits spring odd years

530.432 (E) Jet and Rocket Propulsion

The course covers several topics associated with power generation and conversion. Gas turbines, such as turbojet, turbo-fan, and turbo-prop engines, as well as their components, are discussed. Included are the characteristics of compressors, turbines, combustion chambers, diffusers, and nozzles. A brief introduction to rocket propulsion with liquid and solid fuels is also given. The second part of the course deals with internal combustion engines, including two- and four-stroke engines as well as diesel engines. Prerequisites: 530.231, 530.327.

Katz 3 credits fall/odd years

530.435 (E,N) Refrigeration and Heating, Ventilating, and Air Conditioning

This course deals with processes and equipment used for refrigeration and heating, ventilating, and air conditioning. Topics include thermodynamic refrigeration cycles, refrigerants, air conditioning systems, indoor air quality, heat load, cooling load. Prerequisite: 530.334.

Herman 3 credits fall/even years

530.440 (E,N) Computational Mechanics of Biological Macromolecules

Biological macromolecules such as proteins and nucleic acids consist of thousands of atoms. Whereas crystallographic data of these molecules provides baseline information on their three-dimensional 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. Prerequisite: Knowledge of linear algebra and differential equations.

Chirikjian 3 credits

530.445 Introduction to Biomechanics

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. Prerequisite 530.215.

Belkoff 3 credits fall

530.446 (E, N) Experimental Biomechanics

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.

Belkoff 3 credits

530.454 (E) Manufacturing Engineering

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. Prerequisites: 530.215 and 530.352 or permission of instructor.

Sharpe 3 credits fall

530.457 (E, N) Introduction to Acoustics

This course is an introduction to the science of sound and its applications to music, speech communication, science, and engineering. Topics include hearing, speech, wave propagation, microphones and loudspeakers, noise control, underwater sound, and room acoustics. Assignments will include laboratory and field measurements of acoustic phenomena.

Busch-Vishniac 3 credits

530.461 (E) Engineering Business and Management

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. Prerequisites: 530.215 and 530.352 or permission of instructor.

Conn 3 credits fall

530.467 (E) Thermal Design Issues for Aerospace Systems

This course deals with processes, systems, instruments and equipment for aerospace systems. Issues 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 tech-

niques, design procedures, active versus passive design, heating and refrigeration), environmental effects.

Herman 3 credits

530.487 (E,N) Introduction to Microelectromechanical Systems (MEMS)

For engineering and science majors. An introduction to materials and basic devices with examples of applications for sensing and actuation. Lectures will be complemented with a set of laboratory experiments. Prerequisite: senior or graduate standing or permission of instructor.

Sharpe 3 credits

530.491-492 Special Topics

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.

Staff 1-3 credits

530.495 Microfabrication Laboratory

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, photoresist deposition, photolithography, plating, etching, packaging, design and analysis CAD tools, and foundry services. Co-listed as 520/580.495.

Andreou, Wang 4 credits fall

530.525-526 Independent Research

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.

Staff 1-3 credits

530.527 Independent Study

Staff 1-3 credits

Graduate Courses

530.601 Continuum Mechanics

An introduction to the foundations of continuum mechanics. Vectors and tensors; properties and basic operations. Kinematics of deformation; Eulerian and Lagrangian descriptions of motion. Stress in a continuum. Conservation laws; mass and momentum balance. Thermodynamics; energy balance and entropy. Constitutive equations; invariance under a change of observer and material symmetry. Fluids and solids; viscous and elastic response. The Navier-Stokes equations. Finite elasticity. Linear elasticity.

Molinari 3 hours fall

530.602 Mechanics of Solids

An introduction to elasticity, plasticity, viscoelasticity, and fracture, using the mathematical tools developed in 530.601 Continuum Mechanics. Stress and equilibrium.

Kinematics. Principle of virtual work. Constitutive relations: linear elasticity, plasticity, and viscoelasticity. Illustrative boundary value problems. Linear elastic fracture mechanics. Micromechanics of inelastic deformations. Prerequisite: 530.601 or permission of instructor.

Ramesh 3 hours spring

530.612 Computational Solid Mechanics

More than an introduction to the use of numerical methods in solid mechanics problems, this is a hands-on course where students will develop their own portfolio of finite element techniques. Topics covered include meshing techniques, error estimation and convergence, adaptive strategies, contact and friction, time integration, elastic and inelastic solids. Graduate students only.

Molinari 3 hours spring

530.621-622 Fluid Dynamics I, II

Kinematics. Stress. Conservation of mass, momentum, and energy. Newtonian fluids. The Navier-Stokes equations. Inviscid flows. Laminar viscous flows. Vorticity. Instability. Turbulence. Boundary layers. External flows. Compressible flows. Introduction to non-Newtonian fluids.

Meneveau, Knio, Katz 3 hours fall/spring

530.625 Turbulence

Fundamental equations of fluid mechanics, Reynolds averaging, and the closure problem. Scaling and self-preservation in boundary-free and wall-bounded shear flows. Isotropic turbulence and spectral theories. Vorticity dynamics, intermittency, and cascade models. Turbulence modeling: one- and two-equation models, Reynolds stress modeling, and large-eddy simulations. Overview of modern developments in turbulence theory: renormalization-group theory, chaos, fractals, etc.

Meneveau 3 hours fall/even years

530.631 Conduction and Radiation

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.

Herman 3 hours fall/odd years

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.

Prosperetti 3 hours

530.635 Mixing and 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.

Su 3 hours

530.639 Scientific Computing

An introduction to the foundations of scientific computing. Monte Carlo simulation, molecular dynamics simulation, fast Fourier transform and applications, optimization, sparse matrices, numerical methods for time dependent PDEs, parallel programming with message passing systems, data parallel programming, parallel libraries for numerical linear algebra, parallel programs for PDE problems, techniques for high performance scientific computation.

Chen 3 hours

530.640 Statistical Mechanics and Molecular Dynamics

This course introduces basic concepts of non-equilibrium statistical mechanics and molecular dynamics for engineers. Topics include Master Equation, Brownian motion, the Boltzmann equation, the hydrodynamic theory from statistical mechanics, the fluctuation and dissipation theorem, path integral, effective action, Monte Carlo method, and molecular dynamics simulation.

Chen 3 hours

530.642 Plasticity

The theory of the inelastic behavior of metallic materials. Experimental background and fundamental postulates for the plastic stress-strain relations. Mechanisms of plastic flow; single-crystal and polycrystalline plasticity. Boundary value problems. Variational principles, uniqueness and the upper and lower bound theorems of limit analysis. Slip line theory. Dynamic plasticity and wave phenomena. Finite strain plasticity and instability.

Ramesh 3 hours

530.645 Kinematics

A theoretical treatment of the geometry of motion of rigid bodies, mechanisms, and robotic manipulators. Topics include, but are not limited to, (1) parametrization of spherical motion, (2) forward and inverse kinematics of robotic manipulators.

Chirikjian 3 hours fall/even years

530.646 Introduction to Robotics

Graduate-level introduction to robotics with emphasis on the mathematical tools for kinematics and dynamics. Topics include forward and inverse kinematics, trajectory generation, position sensing and actuation, and manipulator control.

Okamura, Cowan 3 hours fall

530.647 Adaptive Systems

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.

Whitcomb 3 hours spring/even years

530.650 Dynamics and Control of Marine Vehicles

Seminar on the dynamics, navigation, and control of marine vehicles. Topics include finite-dimensional approximate dynamical models, navigational techniques, and control methods for surface and underwater vehicles, and historical overview. Emphasis on underwater robotic vehicles.

Whitcomb 3 hours

530.651 Haptics for Virtual Reality

Graduate-level introduction to the field of haptics, focusing on virtual environments that are displayed through the sense of touch. Topics covered include human haptic sensing and control, types of haptic interfaces (tactile and force), haptic rendering and modeling of virtual environments, and medical applications such as tele-surgery and surgical simulation. Course work includes homework, reading and discussion of research papers, presentations, and a final project. Appropriate for students in any engineering discipline with interest in virtual reality or computer integrated surgical systems.

Okamura 3 credits alternate falls

530.652 Bridging Length Scales in Materials Behavior

Addresses the tools needed to bridge the macroscopic, continuum, mesoscopic, microscopic, and atomic length scales that currently bound the physical theories and models that have been developed to describe materials behavior.

Hemker 3 hours

530.653 Advanced Systems Modeling

This course covers the following topics at an advanced level: Newton's laws and 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, Lagrange, 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 related the topics of this course to his or her research.

Chirikjian 3 hours

530.656 Mechanisms of Deformation and Fracture

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.

Hemker 3 hours

530.659 Computational Methods of Engineering Mathematics

This graduate course covers the following topics in the context of mechanical engineering problems: linear algebra, systems of linear ordinary differential equations, Fourier analysis, Sturm Liouville Theory and Special Functions, curvilinear coordinate systems, stochastic models of classical mechanical systems, variational calculus.

Chirikjian, Eyink 4 hours fall

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, power series, Fourier series, separation of variables, integral transforms. Intended for students with the equivalent of four semesters of undergraduate mathematics typical of engineering programs.

Staff 3 hours spring

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 membrane and channels, theory of biological motors, computer simulation of liquids and proteins.

Sun 3 hours fall

530.672 Biosensing and 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.

Wang 3 hours spring

530.675 Observer Theory and Application

This course addresses in state estimation for finite dimensional linear and nonlinear dynamical systems. Topics include classical observer theory for linear dynamical systems and Kalman filters as well as more recent developments in state estimation techniques for nonlinear dynamical systems. Applications to state estimation of physical systems. Prerequisites: state-space linear control theory, probability and stochastic processes, linear algebra, and differential equations.

Whitcomb 3 hours

530.676 Sensor-Based Locomotion and Manipulation

Prereq: grad course in robotics, controls, or dynamical systems theory; or Perm. Req'd. Introduction to the mechanics of locomotion and manipulation. In this context students will learn topics such as Lagrangian and Hamiltonian mechanics, impacts, Poincare analysis, non-holonomic mechanics, and friction.

Cowan 3 hours

530.687 Foundations of Computational Biology and Bioinformatics

This course presents the fundamental concepts in equilibrium and non-equilibrium statistical mechanics and apply

them to topics in modern molecular computational biology. Monte Carlo and statistical ensembles are presented. Field theories are introduced to describe the mechanics of membranes, cytoskeleton and biofluids. Kinetic theory, master equations and Fokker-Planck equations are discussed in the context of ion channels and molecular motors.

Sun, Bader 3 hours fall

530.688 Foundations of Computational Biology and Bioinformatics II

This course uses statistical mechanics and information theory to develop probabilistic models for biological data, with a primary focus on sequence data and graphical models. Topics will include probability theory, score matrices, hidden Markov models, suffix trees, phylogenetic inference, random graph theory, and network inference. Prerequisites: Mathematics through linear algebra and differential equations; Molecular biology and genetics at the level of 580.221 or equivalent; 600.226 or equivalent. Homework assignments will require programming in a language of choice, and students will have access to a linux cluster as a computational resource.

Sun, Bader 3 hours spring

530.710 Applied Optics

Optic-based techniques are being utilized as measurement and data transmission tools in a growing number of applications. The objective of this course is to introduce graduate students with limited background in optics (but with background in graduate-level mathematics) to the fundamentals of optics and their implementation. Topics covered include reflection, refraction, fluorescence, phosphorescence and diffraction of light; review of geometric optics, lenses, lens systems (microscope, telescope), mirrors, prisms; aberrations, astigmatism, coma, and methods to correct them; light as an electromagnetic wave; Fourier optics; spectral analysis of optical systems; coherent and incoherent imaging, holography, interferometry, diffraction grating; lasers, polarization, light detectors; elements of non-linear optics, birefringence; optical fibers, data transmission, and networking.

Katz 3 hours

530.726 Hydrodynamic Stability

An investigation of the stability of fluid motions. Viscous and inviscid theory of linear stability: superposed fluids, shear flows, boundary layers, parallel flows. Initial-value problem. Absolute and convective instability. Nonlinear stability theory: energy methods, multiple scales, and numerical investigations.

Prosperetti 3 hours

530.727 Experimental Methods in Fluids

Measurement techniques in fluid mechanics and their applications, limitations and uncertainty are examined. Velocity measurement techniques include 2-D and stereo Particle Image Velocimetry (PIV), holographic PIV with appropriate background in optics, laser, acoustic, and global Doppler Velocimetry, hot wire anemometry, and methods based on molecular tagging. Techniques for measurements of pressure, sound, and shear-stress

include piezo-electric, piezo-resistive, and MEMS-based sensors.

Katz 3 hours fall

530.730 Finite Element Methods

The basic concepts of the FEM are presented for one-, two-, and three-dimensional boundary value problems (BVPs). Problems from heat conduction and solid mechanics are addressed. The key topics include relationships between strong, weak, and variational statements of BVPs, weighted residual methods with an emphasis on the Galerkin method, specialization of Galerkin approximations of weak statements and Ritz approximations of variational statements to obtain finite element formulations, specific element formulations, convergence properties, solutions of linear systems of equations, and time-dependent problems.

Anandarajah 3 hours fall

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.

Hemker, Douglas 3 hours

530.733 Microelectromechanical Systems

This seminar course will survey the various manufacturing processes and microdevices that fall under the general category of Microelectromechanical Systems (MEMS). Teams will design devices to be fabricated off-campus. On-campus lab exercises will be included. Prerequisites: graduate standing and permission of instructor. Limit: 20.

Sharpe 3 hours

530.748 Stress Waves Impact, and Shocks

Elastic waves in unbounded media. Elastic waveguides. Waves in elastic-plastic and nonlinear elastic materials. Analysis of impact on materials and structures. Impact on various scales, from planetary to microscopic. Shock waves. Impact signatures in materials (time permitting).

Ramesh 3 hours

530.751 Finite Elasticity

Large elastic deformations. The balance laws of mass and momentum. Elasticity and hyperelasticity. The boundary value problems of elasticity. Variational principles. Exact solutions in elastostatics by the inverse and semi-inverse methods. Incremental elastic deformations. Bifurcations and elastic stability.

Staff 3 hours

530.753 Fatigue

High-cycle and low-cycle fatigue. Constant amplitude and spectrum loading. Phenomenological relations. Special emphasis on notches and on short cracks.

Sharpe 3 hours

530.754 Viscoelasticity

The linear theory of viscoelasticity is considered. The basic mathematical tools (e.g., Laplace transforms) are first introduced, and then integrated into a continuum mechanics-oriented description of the response of viscoelastic materials. Stress relaxation and creep phenomena are described; the complex moduli are developed, with specific reference to the physical mechanism associated with the frequency dependence of the properties. Techniques for measurement of linear viscoelastic properties are discussed. Wave propagation in viscoelastic solids is examined. A number of initial-boundary value problems are solved to illustrate the theory.

Ramesh 3 hours

530.755 Readings at the Mechanics and Materials

Interface

Selected articles on the general topic of plasticity and failure will be reviewed and discussed in an open class format. Papers from each discipline will be covered, and a serious attempt will be made to link the mechanics and materials approaches. The interplay between continuum-level mechanics and microstructural-level materials behavior will be explored and emphasized throughout the course. Examples of topics of interest include dislocation mechanisms and the form of plastic constitutive functions, void growth, and shear localization.

Hemker, Ramesh 2 hours

530.756 Advanced Analytical Electron Microscopy

This course will focus on the techniques used to perform analytical electron microscopy. Special emphasis will be placed on the novel experiments and techniques associated with the use of a Gatan Imaging Filter. The lectures will cover both the theory and practical aspects of energy loss spectroscopy and require a strong understanding of the fundamental principles of transmission electron microscopy. Prerequisites: 270.621, 270.622, or equivalent.

Hemker, Veblen 3 hours

530.757 Nanomechanics

A research-level course examining the mechanics of nanoscale assemblies and microscale structures used for investigating nanoscale phenomena. Applications in scanning probe systems, materials, and biology will be of interest. Each student will be expected to complete a paper on a research topic chosen together with the instructor.

Ramesh 3 hours fall

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.

530.761 Mathematical Methods of Engineering

This is the first part of a two-semester course (with 530.762) which presents mathematical methods of engineering

with a focus on complex analysis and partial differential equations. Specific topics include analytic functions, the theory of residues, contour integrals, series solution of second order ODEs, special functions and their applications, integral transformations.

Staff 3 hours

530.762 Advanced Mathematical Methods of Engineering

A unified view of the classical methods of applied mathematics based on the theory of finite-dimensional and Hilbert spaces. Matrix theory, systems of ordinary differential equations, Fourier series, eigenfunction expansions. Green's functions. Designed to follow either 530.661 or 530.761.

Prosperetti 3 hours spring

530.763 Topics in Complex Systems: Chaos, Fractals and Self-Organization

Chaos in low-dimensional dynamical systems: maps and ordinary differential equations. Lagrangian chaos and mixing in two-dimensional laminar flows. Fractal geometry, Julia sets, collage theorem, multifractals. Applications to growth processes, turbulence, and Brownian motion. Self-organized criticality.

Meneveau 3 hours fall/odd years

530.764 Perturbation Methods

A study of various asymptotic methods for the approximate solution of ordinary and partial differential equations. Representative topics include the regular perturbation method, the method of strained coordinates, the multi-scale method, singular perturbation theory, WKBJ theory, turning-point problems, etc. Prerequisites: ordinary and partial differential equations.

Prosperetti 3 hours

530.766 Numerical Methods

Elementary introduction to numerical methods for the solution of fundamental problems in engineering. Computer assignments requiring programming.

Knio 3 hours fall

530.767 Computational Fluid Dynamics

Advanced introduction to major approaches in the simulation of the incompressible flow: finite-difference, finite-element, finite-volume, boundary-element, spectral, and Lagrangian discretizations. Computer project requiring programming.

Chen, Knio 3 hours spring

530.768 Topics in Low-Mach-Number Flows

Contents vary from year to year. Topics include stratified free-shear flows, buoyancy-induced flows, Rayleigh-Taylor instability, internal gravity waves, zero and low-Mach number combustion, sound generation by vortical flow, flow acoustics interactions. Prerequisite: 530.621.

Knio 3 hours

530.771 Orientational Phenomena

This advanced graduate course covers a diverse set of topics including rotational Brownian motion and diffusion; statistical mechanics of macromolecules; and applications of group-theoretic ideas in mechanics.

Chirikjian 3 hours

530.773 Topics in Applied Mathematics for Engineering

The material covered in this course depends on the class's and instructor's interests. Topics include: multiple-scale methods applied to non-linear oscillations and wave propagation, homogenization, singular perturbations, non-linear waves, complex variables and conformal mapping, calculus of variations, and others.

Prosperetti 3 hours

530.777 Multi-Phase Flow

An introduction to basic contemporary ideas concerning gas, liquid, and solid-fluid two-phase flows.

Prosperetti 3 hours

530.778 Special Topics

Staff 1-3 hours

530.800 Independent Study

Staff 1-3 hours

530.801-802 Graduate Research

Staff 1-3 hours

530.803-804 Mechanical Engineering Research Seminar

Staff 1 hour

Cross-listed

270.621 Transmission Electron Microscopy: Practice and Applications

270.622 Transmission Electron Microscopy: Theory and Understanding

500.601-602 Seminars in Environmental and Applied Fluid Mechanics

520/580.672 Biosensing and BioMEMS

560.201 Statics and Mechanics of Materials

560.202 Dynamics

560.730 Finite Element Methods

580.448 Biomechanics of the Cell and Organisms

580.687-688 Foundations of Computational Biology and Bioinformatics

Robotics		
Mechanical Engineering	530.343	Design and Analysis of Dynamic Systems
	530.420	Robot Actuators and Sensors
	530.421	Mechatronics
	530.424	Dynamics of Robots and Spacecraft
	530.645	Kinematics
	530.646	Introduction to Robotics
	530.649	Robot Motion Planning
	530.651	Haptics for Virtual Reality
	530.676	Sensor-Based Locomotion and Manipulation
Computer Science	600.410	Sensory Engineering
	600.435	Artificial Intelligence
	600.445-6	Computer-Integrated Surgery I and II
	600.452	Computer-Integrated Surgery Seminar
	600.461	Computer Vision
	600.646	Advanced Computer-Integrated Surgery II
	600.652	Advanced Computer-Integrated Surgery Seminar
Electrical/Computer Engineering	520.214	Signals and Systems
	520.353	Control Systems
	520.454	Control Systems Design
	520.614	Linear System Theory
	520.615	Linear Control Theory
	520.621	Introduction to Nonlinear Systems
Biomedical Engineering	580.631	Biomechanics and Motor Control