Johns Hopkins

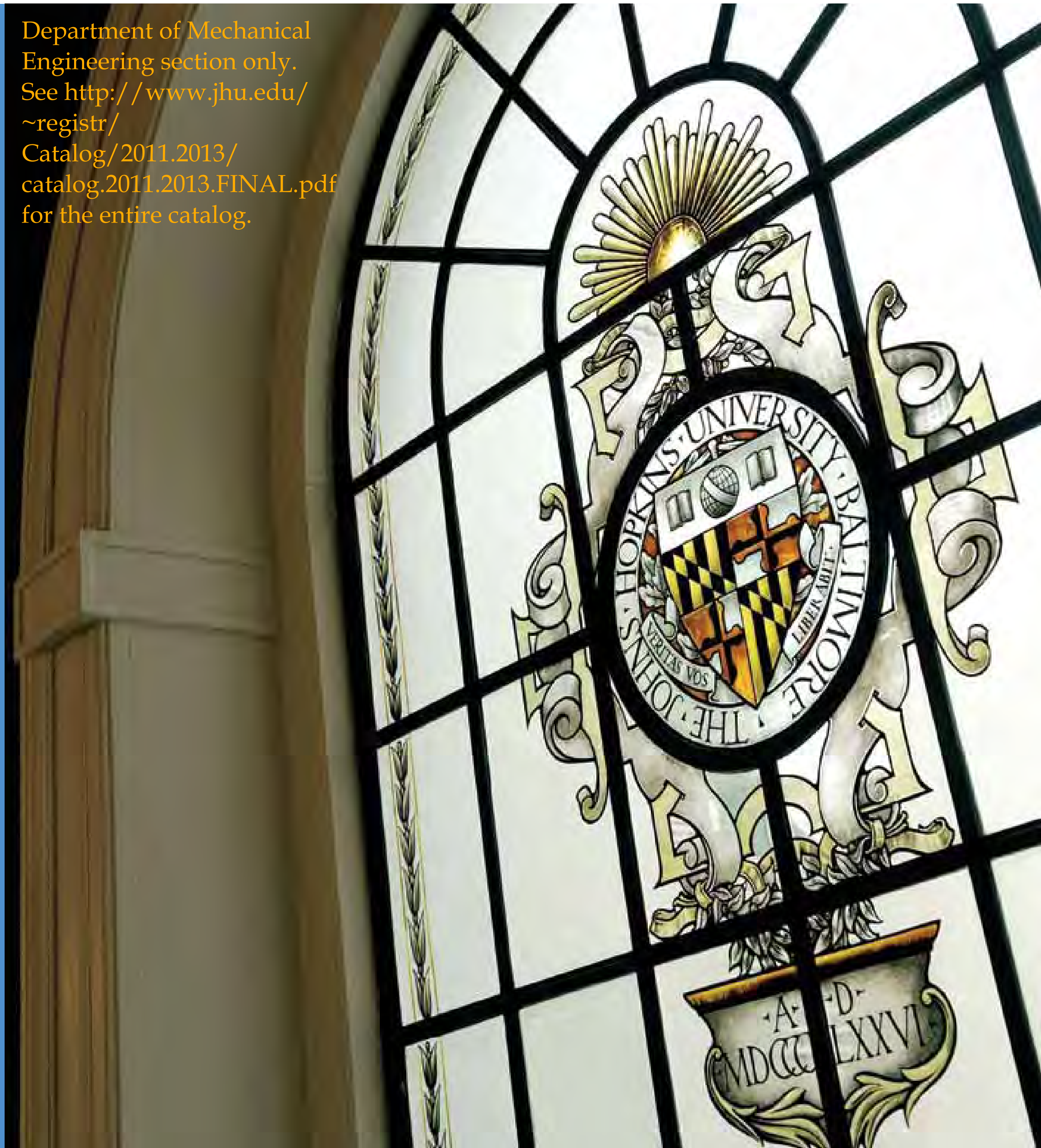
Arts and Sciences / Engineering *2011–2013*

JOHNS HOPKINS
UNIVERSITY

Zanvyl Krieger School of Arts and Sciences
Whiting School of Engineering

Undergraduate and Graduate Programs 2011–2013

Department of Mechanical Engineering section only. See http://www.jhu.edu/~registr/Catalog/2011.2013/catalog.2011.2013.FINAL.pdf for the entire catalog.



The Unique Appeal of Johns Hopkins

The fusion of learning and research is the hallmark of graduate and undergraduate study at the Zanvyl Krieger School of Arts and Sciences and the Whiting School of Engineering of The Johns Hopkins University. The pages that follow present the university's unique intellectual life and educational philosophy. The academic programs described here, and the faculty who teach them, constitute the strengths that have long distinguished Hopkins as a private, selective institution.

The unique educational philosophy of Johns Hopkins was first articulated more than a century ago by Daniel Coit Gilman, the university's first president. Gilman believed that the highest quality education can only be carried out in a research environment, and that the best training, whether undergraduate or graduate, takes place under the supervision of an active researcher. This belief in the inseparability of education and research has become the distinguishing feature of the university's academic programs. In both the School of Arts and Sciences and the School of Engineering, undergraduate education, graduate education, and the conduct of primary research are interrelated in an organic way. There has never been a separate undergraduate college at Hopkins.

This educational philosophy has also led to the remarkably low student-faculty ratio on the Homewood campus, for it requires the kind of close interaction between faculty and students that occurs in small seminars, in the supervision required for independent projects, or in the research laboratory. Academic requirements for undergraduates are highly flexible and designed to enhance rather than restrain creativity. Like graduate students, undergraduates are largely free of university-wide curricular requirements, so that every scholar can proceed at his or her own speed. As a result, many Hopkins undergraduates quickly find themselves enrolled in advanced seminars, engaged in independent study projects, or incorporated into research teams with faculty, graduate students, and postdoctoral fellows. Courses that focus on some well-defined objective in depth are more characteristic of the Hopkins curriculum than broad introductory surveys. Upper-level courses are heavily attended by both undergraduates and graduates in a continuation of the Hopkins tradition of relaxing the distinction between the two groups.

Beyond the classroom, the learning experience continues in research laboratories, on playing fields, in theater and art workshops, and through a wide range of contacts with professors, administrators, and other students. What you read here should give you a sense of the unique spirit and appeal of Hopkins and a sense of how your educational goals might be fulfilled here. If you are interested in further information on any particular course offerings or on the nature of student life, please contact the academic departments or the Office of Undergraduate Admissions.

The main number for the Johns Hopkins University Homewood campus is 410-516-8000.
The Johns Hopkins University website is **www.jhu.edu**.

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. 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 around a smaller core of courses. Students may use this flexibility to follow specific interests in physics, mathematics, economics, 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.

The Faculty

Gregory S. Chirikjian, Professor: computational structural biology (in particular, computational mechanics of large proteins), conformational statistics of biological macromolecules, developed theory for 'hyper- redundant' (snakelike) robot motion planning, designs and builds hyper-redundant robotic manipulator arms, applied mathematics (applications of group theory in engineering), self-replicating robotic systems.

Noah J. Cowan, Associate Professor: robotics, computer vision and control, mobile robotics and legged locomotion, biomechanics and bio-inspired robotics.

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

Jaafar El-Awady, Assistant Professor: damage and fracture mechanisms of materials under high-temperature for aerospace and nuclear applications, materials degradation, microstructure evolution, impact dynamics and wave propagation, nano- and micro-mechanics, nanomaterials, continuum theory of dislocations, multiscale materials modeling.

Kevin J. Hemker, Professor (Chair), Alonzo G. Decker, Jr. Chair in Mechanical Engineering: research aimed at identifying the microstructural details that govern the macroscopic mechanical response of metals, alloys and advanced structural materials. Traditional interests include: high temperature mechanical behavior, transmission electron microscopy, deformation behavior of intermetallic alloys, experimental characterization of dislocation core structure, and microsample testing. Relatively new research topics include the characterization and modeling of bond coat layers for thermal barrier coatings, deformation behavior of nanocrystalline materials, and characterization of materials for MEMS applications.

Cila Herman, Professor: experimental heat transfer and fluid mechanics, optical measurement techniques, image processing. Thermoacoustic 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 turbomachines: 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 instrumentation, 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.

Omar M. Knio, Professor: computational fluid mechanics, turbulent flow, chemically-reacting flow, energetic materials, oceanic and atmospheric flows, dynamical systems, physical acoustics, multiscale methods, asymptotic and stochastic techniques.

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.

Thao (Vicky) Nguyen, Assistant Professor: biomechanics: mechanical behavior, growth and remodeling of fibrous soft tissues. Constitutive Modeling: thermomechanics, viscoelasticity, viscoplasticity of shape memory polymers and polymer composites. Fracture Mechanics: fracture and failure of rate dependent materials.

Allison M. Okamura, Professor: virtual and teleoperated environments: haptic feedback in virtual environments, prosthetics, rehabilitation robotics, human-machine collaborative systems, reality-based modeling, robotic fingers and hands; tactile sensing, medical robotics and surgical assistance, education and learning using haptics.

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. Chair in Mechanical Engineering, Director of the Center for Advanced Metallic and Ceramic Systems (CAMCS): Nanomaterials, planetary impact, dynamic failure mechanisms, shock, impact, and wave propagation, high-strain-rate behavior of materials, injury biomechanics, constitutive and failure modeling.

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

Sean Sun, Associate Professor: biomechanics and biophysics, molecular motors, proteins and membranes, cell motility, statistical mechanics.

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

Louis L. Whitcomb, Professor, Director of the Laboratory for Computational Sensing and Robotics: dynamics and control of nonlinear systems, nonlinear control, adaptive identification and control, force control, robotics, medical robotics, underwater robot vehicles, industrial robotics, advanced electro-mechanical design, sensor and actuator design.

Joint, Part-Time, and Research Appointments

Mehran Armand, Associate Research Professor (Applied Physics Laboratory).

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

Stephen Belkoff, Associate Professor (Orthopedic Surgery): biomechanics, orthopaedic implants, fracture fixation in osteoporotic bone, mechanism of injury, vertebroplasty.

Alan Brandt, Research Scientist, (Applied Physics Laboratory): ocean physics including internal waves, turbulence, mixing, and bio-physical interactions. Coastal, estuarine, and environmental fluid dynamics.

Ilene Busch-Vishniac, Research Professor.

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

Shiyi Chen, Research Professor: statistical theory and computation of fluid turbulence, mesoscopic physics and Lattice Boltzmann computational methods, molecular dynamics and granular flows, computational fluid dynamics and numerical analysis, micro- and nano-fluidics, flow through porous media and environmental sciences, nonlinear dynamics and applied mathematics, large scale computing and parallel algorithm, multiscale phenomena and computational methods.

Andrew F. Conn, Industrial Liaison (Conn Consulting, Inc.): mechanical engineering design.

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

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

Gregory L. Eyink, Professor (Department of Applied Mathematics and Statistics): mathematical physics, fluid mechanics, turbulence, dynamical systems, partial differential equations, nonequilibrium statistical physics, geophysics and climate.

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

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

Tihomir Hristov, Associate Research Scientist.

Iulian Iordachita, Associate Research Scientist: robotics, medical robotics and instrumentation, mechanisms and mechanical transmissions for robots, advance electro-mechanical design, biologically-inspired mechanisms.

Hyung-Suk Kang, Associate Research Scientist.

James Lee, Adjunct Professor.

Edwin Malkiel, Adjunct Associate Research Scientist.

Steven Marra, Senior Lecturer.

Daniel Naiman, Professor, Applied Mathematics and Statistics: statistics, computational probability, bioinformatics.

Mark Robbins, 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.

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

Jian Sheng, Adjunct Assistant Professor (University of Minnesota).

Alexander Spector, Research Professor, Biomedical Engineering: biosolid mechanics, cell mechanics and biophysics, molecular motors, mathematical and computational modeling.

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

Lester Su, Associate Research Professor: experimental fluid mechanics, turbulent mixing and combustion, combustion systems, laser diagnostics, interaction of experiments and simulations, spray and droplet dynamics.

Pazhayannur Swaminathan, Research Professor (Applied Physics Laboratory).

Russell H. Taylor, Professor (Computer Science): medical robotics, computer-assisted surgery.

Nitish V. Thakor, Professor (Biomedical Engineering): medical instrumentation and medical micro and nanotechnologies, neurological instrumentation, signal processing, computer applications.

Eric Tytell, Assistant Research Scientist.

David Van Wie, Research Professor (Applied Physics Laboratory).

Rene Vidal, Associate Professor (Biomedical Engineering): biomedical image analysis, computer vision, machine learning, dynamical systems, signal processing.

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

Timothy Weihs, Associate 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.

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

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. 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 failure, instabilities, impact and dynamic phenomena. 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 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 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 (see page 23). 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 5 for consideration.

Research assistantships 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 academic programs, please consult the undergraduate advising manuals which are available on the departmental website at **http://www.me.jhu.edu/advise.html**. For details and an explanation of ABET requirements, visit **www.abet.org**.

Requirements for the Bachelor's Degree

See also General Requirements for Departmental Majors, page 48; Writing Requirement, page 44; 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 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.

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 lifelong 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; grades of D, D+, D- or F not accepted)

110.108 Calculus I

110.109 Calculus II

110.202 Calculus III (or 110.211 Honors Multivariable Calculus

550.291 Linear Algebra/Differential Equations (or 110.212 Honors Multivariable Calculus or 110.201 Linear Algebra, plus 110.302 Differential Equations)

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 (12 credits; grades of D, D+, D- or F not accepted)

530.103-104 Introduction to Mechanics I/II

171.102 Physics II

173.112 Physics Lab II

510.101 Introduction to Materials Chemistry or 030.101 Chemistry I

Humanities (18 credits)

Six humanities and/or social science electives (designated H or S in this catalog); of which one must specifically teach writing (either 060.113 or 060.114 Expository Writing, 220.105 Introduction to Fiction and Poetry Writing, 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. 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 academic advising manual at **http://www.me.jhu.edu/advising.html**.

Required Engineering Courses (51 credits; grades of D, D+, D- or F not accepted)

530.101/102 Freshman Experiences in Mechanical Engineering I/II

530.105/106 Mechanical Engineering Freshman Laboratory I/II

530.201 Statics and Mechanics of Materials

530.202 Dynamics

530.215 Mechanics-Based Design
530.231 Mechanical Engineering Thermodynamics
530.241 Electronics and Instrumentation [or 520.213 Circuits followed by 520.345 Electrical and Computer Engineering Laboratory or 525.134 Electrical Engineering Laboratory II.]
530.327 Introduction to Fluid Mechanics
530.334 Heat Transfer
530.343 Design and Analysis of Dynamical Systems
530.352 Materials Selection
530.414 Computer Aided Design
530.454 Manufacturing Engineering
660.461 Engineering Business and Management [or 660.105 Introduction to Business and 660.341 Business Process and Quality Management.]

Capstone Design (8 credits; grades of D, D+, D- or F not accepted)

530.403/404 Engineering Design Project I/II

Mechanical Engineering Electives (9 credits; grades of D, D+, D- or F not accepted)

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

Technical Electives (9 credits; grades of D, D+, D- or F not accepted)

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 advisor. 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.

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 basic Mechanical Engineering courses. This concentration requires knowledge and 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 five of the following courses (which can be counted toward the Mechanical Engineering elective and Technical Elective requirements in the general Mechanical Engineering program):

530.328 Fluid Mechanics II
530.418 Aerospace Structures and Materials
530.424 Dynamics of Robots and Spacecraft
530.425 Mechanics of Flight
530.432 Jet and Rocket Propulsion
530.467 Thermal Design Issues for Aerospace Systems
530.470 Space Vehicle Dynamics and Control
535.442 Control Systems for ME Applications
615.444 Space Systems I
615.445 Space Systems II

Any five of the courses listed above are required. A sixth course amongst this list, though not required is highly recommended.

Other courses relevant to the concentration which don't count toward the requirements include:

171.118 Stars and the Universe
520.214 Signals and Systems
520.401 Basic Communications
525.445 Modern Navigation Systems

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 (*).

- 530.410 Biomechanics of the Cell*
- 530.426 Biofluid Mechanics*
- 530.440 Computational Biomechanics of Biological Macromolecules*
- 540.440 MicroNanotechnology (Chemical and Biomolecular Engineering)*
- 530.445 Introduction to Biomechanics*
- 580.455 Introduction to Orthopaedic Biomechanics (Biomedical Engineering)*
- 530.448 Biosolid Mechanics*
- 530.672 Biosensing and BioMEMS*
- 580.221 Molecules and Cells (Prerequisite: 030.101 Introductory Chemistry)
- 580.421 through 580.423 Systems Bioengineering I with lab: Cells and Membranes, Cardiovascular Systems (Prerequisite: 580.221 Molecules and Cells)
- 510.431 Biocompatibility of Materials
- 510.435 Mechanical Properties of Biomaterials
- 580.440 Cellular and Tissue Engineering
- 530/580.452 Cellular and Tissue Engineering Laboratory
- 530.495 Microfabrication Lab

Note: Some courses on this list may require 030.205 Organic Chemistry as a prerequisite. This course will count as a technical elective when taken to allow enrollment in the appropriate biomechanics concentration courses. Note that 030.205 has several prerequisites: 030.101-102 Intro to Chemistry and 030.105-106 Chemistry labs.

Students may not use the satisfactory/unsatisfactory option for required courses, including (H) and (S). 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- will not be accepted). The department will accept D, D+ or D- grades only up to a maximum of 10 credit hours for Humanities (H) and Social Sciences (S) courses.

Sample Program:

• Year 1

Fall

110.108 Calculus I	4
510.101 Intro to Materials Chemistry	3
530.101 Freshman Experiences in Mechanical Engineering I	2
530.103 Intro to Mechanics I	2
530.105 Mechanical Engineering Freshman Lab I	1
H/S Elective	3
Subtotal	15

Spring

110.109 Calculus II	4
530.102 Freshman Experiences in Mechanical Engineering II	2
530.104 Intro to Mechanics II	2
530.106 Mechanical Engineering Freshman Lab II	1
H/S Elective: Writing	3
H/S Elective	3
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
530.241 Electronics and Instrumentation	3+1
Subtotal	16

• Year 3

Fall

530.327 Intro to Fluid Mechanics	3+1
530.352 Materials Selection	3+1
530.414 Computer Aided Design	3
H/S Elective	3
Statistics Elective	3
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
Subtotal	14

• Year 4

Fall

530.403 Engineering Design Project I	4
530.454 Manufacturing Engineering	3
660.461 Engineering Business and Management	3
Technical Elective	3
H/S Elective	3
Subtotal	16

Spring

530.404 Engineering Design Project II	4
Mechanical Engineering Elective	3
Mechanical Engineering Elective	3
Technical Elective	3
H/S Elective	3
Subtotal	16
Total	**126**

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 modeling of fluid and solid systems, to promote a broad knowledge of the contemporary social and economic context, and to develop the communication skills necessary 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 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.

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.
- enter graduate school and/or professional practice with the tools needed for life-long learning and the recognition of its importance.
- 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 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.

Either Mathematics with a focus on applications (23 credits; grades of D, D+, D- or F not accepted)

110.108 Calculus I
110.109 Calculus II
Either 110.202 Calculus III, or 110.211 Honors Multivariable Calculus, or 110.201 Linear Algebra [semester one]
Either 550.291 Linear Algebra/Differential Equations, or 110.212 Honors Multivariable Calculus, 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)

…or Mathematics with a focus on fundamentals (23 credits; grades of D, D+, D- or F not accepted)

110.108 Calculus I
110.109 Calculus II
110.211 Honors Multivariable Calculus I
110.212 Honors Multivariable Calculus II
110.302 Differential Equations
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 (16-17 credits; grades of D, D+, D- or F not accepted)

530.103-104 Introduction to Mechanics I/II *or* 171.101 Physics I and 171.111 Physics Lab I
171.102 Physics II and 171.112 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 (either 060.113 or 060.114 Expository Writing, 220.105 Introduction to Fiction and Poetry Writing, 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 of D, D+, D- or F not accepted)

Introductory Engineering and Computing
530.101-102 Freshman Experiences in Mechanical Engineering I and II and 530.105-106 Mechanical Engineering Freshman Laboratory I and II provide the necessary engineering and computing instruction for freshmen and are strongly recommended.

Alternate introductory courses are available. If 530.101-102 and 530.105-106 are not taken, students must take one course from each of the engineering and computing course lists below:

Introductory Engineering:
500.101 What is Engineering? (recommended)
520.137 Introduction to Electrical and Computer Engineering
570.108 Introduction to Environmental Engineering

Computing:
500.200 Computing for Engineers
560.220 Civil Engineering Analysis
600.107 Introduction to Java
Any other computing course approved by the faculty advisor

Other Required Engineering Courses:
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; grades of D, D+, D- or F not accepted):

530.403-404 Engineering Design Project I/II

Engineering Science Electives (12 credits; grades of D, D+, D- or F not accepted):

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

Engineering Mechanics Electives (6 credits; grades of D, D+, D- or F not accepted)

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

Technical Electives (minimum of 18 credits; grades of D, D+, D- or F not accepted)
A minimum of four (E), (Q), or (N) 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.

Appropriate choices from the social sciences and philosophy may be also used to fulfill this requirement (for example, 180.305 Game Theory, 150.420 Logic), if approved by the student's advisor. 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:

530.328 Fluid Mechanics II
530.425 Mechanics of Flight
530.426 Biofluid Mechanics
530.444 Computer Aided Fluid Mechanics and Heat Transfer
570.301 Environmental Engineering I: Fundamentals

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
530.448 Biosolid Mechanics
530.730 Finite Element Methods
560.206 Solid Mechanics and Theory of Structures
560.445 Advanced Structural Analysis

A program of 127-128 credits, based on the requirements above 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 advisor. The department will accept D or 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 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):

250.353 Computational Biology
530.426 Biofluid Mechanics
530.440 Computational Mechanics of Biological Macromolecules
530.445 Introductory Biomechanics
530.446 Experimental Biomechanics
530.448 Biosolid Mechanics

530.495 Microfabrication Laboratory
540.409 Modeling Dynamics and Control for Chemical and Biological Systems
580.455 Introduction to Orthopaedic Biomechanics
550.471 Combinational Analysis

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:

• Year 1

Fall

110.108 Calculus I	4
510.101 Intro to Materials Chemistry	3
Intro to Engineering Elective and Lab I	3
H/S Elective (1)	3
Basic Science Elective	3
Subtotal	16

Spring

110.109 Calculus II	4
Intro to Computing Elective *or* Intro to Engineering Elective and Lab II	3
H/S Elective (2)	3
H/S Elective (3) (writing)	3
Subtotal	13

• 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
Technical Elective (1)	4
Subtotal	16

• Year 3

Fall

530.327 Intro Fluid Mechanics	3+1
Engineering Mechanics elective (solids)	3+1
Technical Elective (2)	4
Statistics Elective	3
Subtotal	15

Spring

Engineering Mechanics elective (fluids)	3+1
Engineering Mechanics elective (solids/fluids)	3+1
Technical Elective	3
Mathematics Elective	3
H/S Elective (4)	3
Subtotal	17

• Year 4

Fall

530.403 Engineering Design Project I	4
Engineering Mechanics elective	3
Engineering Mechanics elective	3
Engineering Mechanics elective (materials/dynamics)	3
H/S Elective (5)	3
Subtotal	16

Spring

530.404 Engineering Design Project II	4
Technical Elective (4)	4
Technical Elective (5)	4
H/S Elective (6)	3
Subtotal	15
Total	**127**

The Concurrent Five-Year Bachelor's / Master's Program

The Mechanical Engineering Department offers a concurrent five-year bachelor's/master's program for mechanical engineering and engineering mechanics majors. Applications to the BS/MSE program should be submitted by January 5 for consideration of Spring admission and June 15 for possible Fall admission, during applicant's junior (3rd) year.

To apply for admission, the student must submit an application. In addition, the student will need to present a statement of purpose, college transcripts, and three letters of recommendation; two of which should be from Mechanical Engineering faculty.

Upon acceptance into the program, students will be asked to develop an outline of their proposed academic program with their advisor.

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 thrive in a program of advanced course work and/or research. No academic degree is required, but the applicant should have at least two years of relevant 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 advisor to help map 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 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 graduate students 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: A non-essay 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. 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. All 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 of enrollment. 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; it is taken after the Departmental Qualifying 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 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.

Undergraduate Courses

530.101-102 (E) Freshman Experiences in Mechanical Engineering I and II
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 are 530.103-104 and 530.105-106, and 110.109 (for spring).
Staff 2 credits each semester/offered yearly

530.103-104 (E) Introduction to Mechanics I and II
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 alternative to 171.101, designed specifically for Mechanical Engineers and Engineering Mechanics students taking 530.101-102 concurrently. Corequisites are 530.101-102 and 530.105-106 (laboratory).
Staff 2 credits each semester/offered yearly

530.105-106 (E) Mechanical Engineering Freshman Laboratory I and II
Hands-on laboratory complementing 530.101-102 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 are 530.101-102.
Staff 1 credit each semester/offered yearly

530.110 Chair's Dialogue on Grand Engineering Challenges
The purpose of this course is to allow the Mechanical Engineering Department Chair and students to engage in a meaningful dialogue 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.
Hemker 1 credit fall

530.201 (E) 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 530.103 and 530.104; or permission of instructor.
Graham-Brady 4 credits
(3 hours lecture, 1 hour lab) fall

530.202 (E) Dynamics
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. Prerequisite: 530.201 or 560.201.
Nakata 4 credits
(3 hours lecture, 1 hour lab) spring

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 or 560.201.
Ramesh, Wang 4 credits
(3 hours lecture, 1 hour lab) spring

530.231 (E) 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. Corequisite: 171.102; Prerequisite: 110.109.
Meneveau, Katz 4 credits (3 hours lecture, 1 hour lab) fall

530.241 (E) Electronics and Instrumentation Laboratory
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 or Intro to Mechanics I and II, plus Physics II. Corequisites: one of three Linear Algebra and Differential Equations course options: 1) 550.291, 2) both 110.201 and 110.302, or 3) both 110.201 and 110.306.
Cowan, Whitcomb 3 credits fall

530.327 (E) 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, plus 530.202.
Mittal 4 credits (3 hours lecture, 1 hour lab) fall

530.328 (E) 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) Heat Transfer
Steady and unsteady conduction in one, two, and three dimensions. Elementary computational modeling of conduction heat transfer. External and internal forced convection. Performance and design of heat exchangers. Boiling and condensation. Black-body and gray-body radiation, Stefan-Boltzmann law view factors and some applications. Prerequisites: 530.231, 530.327.
Herman, Prosperetti 4 credits (3 hours lecture, 1 hour lab) spring

530.343 (E) 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, plus for Mechanical Engineering majors 530.241.
Sun, Cowan 4 credits (3 hours lecture, 1 hour lab) spring

530.344 (E) Dynamic Systems Laboratory
This is an alternate laboratory course for the lab component in 530.343 (Design and Analysis of Dynamic Systems). This lab course is required for students who have taken the course abroad or outside JHU.
Okamura 1 credit 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) 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.
Hemker 8 credits academic year

530.405 (E) Mechanics of Solids and Structures
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 values problems that occur in engineering structures, energy methods, and foundations of the finite element method. Prerequisites: 110.201, Linear Algebra and Differential Equations, and 530.215 or permission of the instructor.
Ramesh 3 credits spring

530.410 (E, N) Biomechanics of the Cell and Organisms
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. Prerequisite: Introductory physics, a year of calculus, and preferably, linear algebra.
Sun 3 credits spring

530.414 (E) Computer-Aided Design
The course outlines a modern design platform for 3D modeling, analysis, simulation, 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.

Stoianovici 3 credits each semester

530.415 (E, N) Energy Engineering: Fundamentals and Future
This course examines the science and engineering of contemporary and cutting-edge energy technologies. Materials Science and Mechanical Engineering fundamentals in this area will be complemented by case studies that include fuel cells, solar cells, lighting, thermoelectrics, wind turbines, engines, nuclear power, biofuels, and catalysis. Students will consider various alternative energy systems, and also to research and engineering of traditional energy technologies aimed at increased efficiency, conservation, and sustainability. Prerequisite: undergraduate course in thermodynamics. Co-listed with 500.405.
Erlebacher, Katz, Hemker 3 credits

530.418 (E) 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 or 530.103 and 530.104, plus 171.102, 110.108, 110.109, 110.202, 550.291, and either 530.241 or 520.345.
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. Prerequisite: 530.420 or permission of instructor.
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 or 530.202.
Chirikjian 3 credits spring/even years

530.425 (E) 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, Herman 3 credits spring/odd years

530.426 (E) Biofluid Mechanics
Course will cover selected topics from physiological fluid dynamics, including respiratory flow patterns, blood flow and pulse propagation, aerodynamics of phonation and speech, rheology of blood flow in the microcirculation, aquatic animal propulsion, and animal flight.
Mittal 3 credits fall

530.432 (E) Jet and Rocket Propulsion
The course covers several topics associated with power generation and conversion. Gas turbines, such as turbo-jet, 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 spring/alternating years

530.435 (E) 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) 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

530.444 (E) Computer-Aided Fluid Mechanics and Heat Transfer
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 on 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.
Herman 3 credits spring/odd years

530.445 (E, N) 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

530.448 (E) Biosolid Mechanics
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, constitu-

tive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity, and experimental methods. Prerequisites: Linear Algebra and Differential Equations. A prior class in statics and mechanics (e.g. 530.201) will be helpful.
Nguyen 3 credits

530.449 (E) Compressible Flow
One-dimensional flow: acoustic, expansion and shock waves. Rankine-Hugoniot relations. Quasi-one-dimensional flow: variable area duct, de Laval nozzle, choking. Unsteady waves. Shock tube. Two-dimensional flow; expansion fans, oblique shocks, characteristics. Linearized flow. Transonic and supersonic flight.
Prosperetti 3 credits

530.451 (E) Cell and Tissue Engineering Laboratory
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-subtrate interactions I, cell-substrate interactions II, and cell encapsulation and gel contraction.
Wang 2 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.
Staff 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. Recommended prerequisite: 530.327.
Prosperetti 3 credits

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 techniques, design procedures, active versus passive design, heating and refrigeration), environmental effects.
Herman 3 credits

530.470 (E) Space Vehicle Dynamics and Control
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 of 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.
Staff 3 credits spring

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 advisor and instructor in charge.
Staff 1-3 credits

530.495 (E, N) 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

530.496 (E) Micro/Nanoscience and Biotechnology
An introduction to the physical and chemical principles important to MEMS, BioMEMS, and bionanotechnology. Topics include scaling laws, colloids and surfaces, micro and nanofluidics, thermal forces and diffusion, chemical forces, electrokinetics, electric aspects of surface chemistry, capillary forces and surface tension, and top-down and bottom-up nanofabrication.
Wang 3 credits fall/even years

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

530.600 Master's Graduate Research
Staff

530.605 Mechanics of Solids and Materials I
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 class will be devoted to elasticity, both classical and finite elasticity, and solution methods for boundary value problems.
Ramesh, Nguyen 3 hours fall

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.
Ramesh, El-Awady 3 hours spring

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.
Sun 3 hours fall

530.612 Computational Solid Mechanics
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.
Nguyen 3 hours spring/even years

530.620 Robot Sensors and Actuators (graduate level)
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.
Whitcomb 3 hours fall

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

530.624 Dynamics of Robots and Spacecraft (graduate level)
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.
Chirikjian 3 hours spring/even years

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.
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

530.637 Energy and the Environment
The 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 technologies (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.
Prerequisite: Thermodynamics
Herman 3 hours fall

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

530.646 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.
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

530.653 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, 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 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

530.657 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 of the class.
Prosperetti 3 hours

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, and computer simulations 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. Co-listed as 580.672.
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 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. Prerequisite: graduate course in robotics, controls, or dynamical systems theory, and a basic understanding of probability theory; or permission of instructor.
Cowan 3 hours spring/even years

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: 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 scaling. 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). Application to downscaling in atmospheric data. Co-listed with 560.701.
Igusa, Meneveau 3 hours fall

530.710 Optical Measurement Techniques
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 nonliner optics, birefringence; optical fibers, data transmission, and networking.
Katz 3 hours

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.
Staff 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.
Ramesh 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

530.757 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.
Ramesh 2 hours

530.762 Advanced Mathematical Methods of Engineering
A problem-oriented, unified view of the classical methods of applied mathematics based on the theory of Hilbert spaces: Fourier and Fourier-Bessel series, spherical harmonics, Green's functions, theory of distributions.
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

530.766 Numerical Methods
Elementary introduction to numerical methods for the solution of fundamental problems in engineering. Computer assignments requiring programming.
Knio, Mittal 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.
Knio 3 hours spring

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 nonlinear oscillations and wave propogation, homogenization, singular perturbations, nonlinear 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

530.800 Independent Study
Staff 1-3 hours

530.801-802 Graduate Research
Staff 1-3 hours

530.803-804 Mechanical Engineering Graduate Seminar
Staff 1 hour

530.807-808 Graduate Seminar in Fluid Mechanics
Meneveau 1 hour

530.809-810 Mechanics and Materials Graduate Seminar
Hemker 1 hour

Cross-listed

270.621 Transmission Electron Microscopy: Practice and Applications
fall/even years

270.622 Transmission Electron Microscopy: Theory and Understanding
spring/odd years

500.405 Energy Engineering: Fundamentals and Future

500.602 Seminars in Environmental and Applied Fluid Mechanics

500.745 Seminar in Computational Sensing and Robotics

500.809 Mechanics of Materials and Structures Graduate Seminar

520.353 Control Systems

520/580.672 Biosensing and BioMEMS

560.201 Statics and Mechanics of Materials

560.202 Dynamics

560.701 Uncertainty Analysis and Downscaling

560.730 Finite Element Methods

580.448 Biomechanics of the Cell and Organisms

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
	530.620	Robot Actuators and Sensors (graduate)
	530.624	Dynamics of Robots and Spacecraft (graduate)
	530.646	Introduction to Robotics
	530.676	Locomotion in Mechanical and Biological Systems
Computer Science	600.435	Artificial Intelligence
	600.446	Computer-Integrated Surgery I and II
	600.452	Computer-Integrated Surgery Seminar
	600.461	Computer Vision
	600.646	Advanced Computer-Integrated Surgery II
Electrical/Computer Engineering	520.214	Signals and Systems
	520.353	Control Systems
	520.454	Control Systems Design