Mechanical Engineering

Program Description

The Mechanical Engineering Department offers a design-oriented undergraduate program that emphasizes fundamental engineering principles. Students receive a strong foundation in mechanical engineering disciplines, and a working knowledge of modern engineering tools. Many courses are augmented through hands-on and project-based experiences. Successful graduates are well-prepared for a mechanical engineering career in a world of rapid technological change.

The program leading to the degree of Bachelor of Science in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org (http://www.abet.org/).

Bachelor of Science in Mechanical Engineering

The Mechanical Engineering program intentionally embeds several professional and technical skills, e.g., working on teams, engineering design, technical communication and programming, throughout the Mechanical Engineering curriculum. During the freshman and sophomore years, students complete a set of core courses that include mathematics, basic sciences, and fundamental engineering disciplines. This includes early open-ended design experiences in Introduction to Design (EDNS151), Introduction to Mechanical Engineering: Programming and Hardware Interface (MEGN200), and Introduction to Mechanical Engineering: Design and Fabrication (MEGN201). Additionally, courses in Humanities & Social Science (H&SS) allow students to explore the linkages between the environment, human society, and engineered systems.

In the middle years, Mechanical Engineering offers a four course project-based design sequence to learn engineering tools, including MATLAB, SolidWorks, and LabVIEW, to solve engineering problems in a hands-on environment. This experience teaches design methodology and stresses the creative aspects of the mechanical engineering profession. This course sequence helps prepare students for open-ended, industry-based project in the senior design experience.

In the junior and senior years, students complete an advanced mechanical engineering core that includes fluid mechanics, thermodynamics, heat transfer, numerical methods, control systems, machine design, computer-aided engineering, and manufacturing processes. This engineering core is complemented by courses in economics and electives in Humanities & Social Science (H&SS). Students must also take three advanced technical electives and three additional free electives to explore specific fields of interest. In the senior year, all students must complete a capstone design course focused on a multidisciplinary engineering project.

Students in mechanical engineering spend considerable time with design and testing equipment available in the CECS Garage, a large machine shop, and automation spaces for prototyping and testing equipment. Students are also encouraged to get involved in research with our faculty in the Department of Mechanical Engineering. These research areas include: biomechanics; solid mechanics and materials; thermal-fluid systems; and robotics. Our students also find internship opportunities to gain practical experience and explore the many industries under the mechanical engineering umbrella.

There are plenty of opportunities outside of the curriculum for students to explore their passions. We have an active Mines Maker Space, Robotics Club, and Abilities Research & Design Group, a group of students enabling those with disabilities to try new activities or advance their performance in a given sport. These are just a few of the clubs and societies where students engage with the community or compete in design challenges nation-wide.

Program Educational Objectives (Bachelor of Science in Mechanical Engineering)

The Mechanical Engineering program contributes to the educational objectives described in the Mines' Graduate Profile and the ABET Accreditation Criteria. Accordingly, the Mechanical Engineering Program at Mines has established the following program educational objectives for the B.S. in Mechanical Engineering degree:

Within three to five years of completing their degree, graduates will be:

- Applying their Mechanical Engineering education as active contributors in the workforce or graduate school;
- Effective at communicating technical information in a diverse and globally integrated society;
- Demonstrating their commitment to continued professional development through training, coursework, and/or professional society involvement;
- Exemplifying ethical and social responsibility in their professional activities.

Bachelor of Science in Mechanical Engineering Degree Requirements:

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Total Semester Hrs: 134.5

* Mechanical Engineering students are required to take three Mechanical Engineering elective courses. At least one of these courses must be from the Advanced Engineering Sciences list. The remaining must be from either the Advanced Engineering Sciences list or the Mechanical Engineering Electives list.

**Advanced Engineering Sciences:**

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**Mechanical Engineering Electives:**

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### Mechanical Engineering - (2020-2021 Catalog)

#### Major GPA

During the 2016-2017 Academic Year, the Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree's GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree's GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

- CEEN241
- EENG281
- EENG307
- EGGN205
- EGGN250
- EGGN350
- EGGN450
- EGGN491
- EGGN492
- EDNS491
- EDNS491
- MEGN100 through MEGN999 inclusive

#### Combined Mechanical Engineering Baccalaureate and Masters Degrees

Mechanical Engineering offers a five year combined program in which students have the opportunity to obtain specific engineering skills supplemented with graduate coursework in mechanical engineering. Upon completion of the program, students receive two degrees, the Bachelor of Science in Mechanical Engineering and the Master of Science in Mechanical Engineering.

Admission into a graduate degree program as a Combined Undergraduate/Graduate degree student may occur as early as the first semester Junior year and must be granted no later than the end of registration the last semester Senior year. Students must meet minimum GPA admission requirements for the graduate degree.

Students are required to take an additional thirty credit hours for the M.S. degree. Up to nine of the 30 credit hours beyond the undergraduate degree requirements can be 400-level courses. The remainder of the courses will be at the graduate level (500-level and above). The
Mechanical Engineering Graduate Bulletin provides detail into the graduate program and includes specific instructions regarding required and elective courses. Students may switch from the combined program, which includes a non-thesis Master of Science degree to a M.S. degree with a thesis option; however, if students change degree programs they must satisfy all degree requirements for the M.S. with thesis degree.

General CSM Minor/ASI requirements can be found here (catalog.mines.edu/undergraduate/undergraduateinformation/minorasi/).

**Mechanical Engineering Areas of Special Interest (ASI) and Minor Programs**

**General Requirements**

The Mechanical Engineering Department offers minor and ASI programs. Students who elect an ASI or minor, must fulfill all prerequisite requirements for each course in a chosen sequence. Students in the sciences or mathematics must be prepared to meet prerequisite requirements in fundamental engineering and engineering science courses. Students in engineering disciplines are better positioned to meet the prerequisite requirements for courses in the minor and ASI Mechanical Engineering program. (See Minor/ASI section of the Bulletin for all requirements for a minor/ASI at CSM.)

For an Area of Special Interest in Mechanical Engineering, the student must complete a minimum of 12 hours from the following:

- **MEGN212** INTRODUCTION TO SOLID MECHANICS 3.0
- **MEGN315** DYNAMICS 3.0
- **MEGN351** FLUID MECHANICS 3.0
- **MEGN361** THERMODYNAMICS I 3.0

For a Minor in Mechanical Engineering, the student must complete a minimum of 18 hours from the following:

1. **Required Courses (choose three, 9 credit hours)**
   - **MEGN212** INTRODUCTION TO SOLID MECHANICS 3.0
   - **MEGN315** DYNAMICS 3.0
   - **MEGN351** FLUID MECHANICS 3.0
   - **MEGN361** THERMODYNAMICS I 3.0

2. **Tracks (choose one track):**
   - **Robotics, Automation & Design Track (10 credit hours)**
     - **MEGN324** INTRODUCTION TO FINITE ELEMENT ANALYSIS 3.0
     - **MEGN481** MACHINE DESIGN 3.0
     - **MEGN381** MANUFACTURING PROCESSES 3.0
     - or **MEGN441** INTRODUCTION TO ROBOTICS
     - or **MEGN416** ENGINEERING VIBRATION
     - or **MEGN485** MANUFACTURING OPTIMIZATION WITH NETWORK MODELS
   - **Solid Materials Track (9 credit hours)**
     - **MEGN324** INTRODUCTION TO FINITE ELEMENT ANALYSIS 3.0
     - **MEGN412** ADVANCED MECHANICS OF MATERIALS 3.0
     - **MEGN416** ENGINEERING VIBRATION 3.0
   - **Thermal-Fluids Track (9 credit hours)**
     - **MEGN451** FLUID MECHANICS II - AERODYNAMICS 3.0
     - **MEGN461** THERMODYNAMICS II 3.0
     - **MEGN471** HEAT TRANSFER 3.0

**Biomechanical Engineering Minor**

**General Requirements**

To obtain a Biomechanical Engineering Minor, students must take at least 18.0 credits from the courses listed below. Fundamentals of Biology I (CBEN110), Fundamentals of Biology II (CBEN120), and Introduction to Biomechanical Engineering (MEGN330) are required (11.0 credits). Three more courses may be chosen from the proposed list of electives. The list of electives will be modified as new related courses become available.

**Required Courses (11.0 credits)**

- **CBEN110** FUNDAMENTALS OF BIOLOGY I 4.0
- **CBEN120** FUNDAMENTALS OF BIOLOGY II 4.0
- **MEGN330** INTRODUCTION TO BIOMECHANICAL ENGINEERING 3.0

**Biomechanical Engineering Elective Courses**

- **MEGN430** MUSCULOSKELETAL BIOMECHANICS 3.0
- **MEGN435** MODELING AND SIMULATION OF HUMAN MOVEMENT 3.0
  - or **MEGN535** MODELING AND SIMULATION OF HUMAN MOVEMENT
- **MEGN436** COMPUTATIONAL BIOMECHANICS 3.0
  - or **MEGN536** COMPUTATIONAL BIOMECHANICS
- **MEGN531** PROSTHETIC AND IMPLANT ENGINEERING 3.0
- **MEGN532** EXPERIMENTAL METHODS IN BIOMECHANICS 3.0
- **MEGN537** PROBABILISTIC BIOMECHANICS 3.0
- **MEGN553** INTRODUCTION TO COMPUTATIONAL TECHNIQUES FOR FLUID DYNAMICS AND TRANSPORT PHENOMENA 3.0
  - or **MEGN x98, x99** SPECIAL TOPICS 3.0
- **MTGN472** BIOMATERIALS I 3.0
  - or **MTGN572** BIOMATERIALS
- **MTGN570** BIOCOMPATIBILITY OF MATERIALS 3.0
- **CBEN311** INTRODUCTION TO NEUROSCIENCE 3.0
- **CBEN306** ANATOMY AND PHYSIOLOGY: BONE, MUSCLE, AND BRAIN 3.0
- **CBEN309** ANATOMY AND PHYSIOLOGY: BONE, MUSCLE, AND BRAIN LABORATORY 3.0
- **CBEN320** CELL BIOLOGY AND PHYSIOLOGY 3.0
- **CBEN454** APPLIED BIOINFORMATICS 3.0
  - or **CBEN554** APPLIED BIOINFORMATICS
- **MATH331** MATHEMATICAL BIOLOGY 3.0
- **PHGN433** BIOPHYSICS 3.0

* As the content of these courses varies, the course must be noted as relevant to the biomechanical engineering minor.
Minor and ASI in Advanced Manufacturing

The interdisciplinary Advanced Manufacturing program will prepare undergraduates to meet the challenges of careers in advanced manufacturing. Undergraduate students have the following degree options:

- Area of Special Interest (12 credit hours)
  - Requirements: AMFG401 and 9 credit hours of electives (see Table 1)
- Minor (18 credit hours)
  - Requirements: AMFG401 and one other core course to be determined and 12 credit hours of electives (see Table 1)

Table 1: Undergraduate elective courses, listed by specialty area
(AMFG531, AMFG 511 and FEGN 526 require approval by appropriate program directors)

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ASI in Aerospace Engineering

For an Area of Special Interest in Aerospace Engineering, the student must complete a minimum of 12 credit hours from the following:

- MEGN451 | FLUID MECHANICS II - AERODYNAMICS | 3.0 |
- MEGN471 | HEAT TRANSFER | 3.0 |
- MEGN414 | MECHANICS OF COMPOSITE MATERIALS | 3.0 |
- MEGN4XX | AEROSPACE STRUCTURES | 3.0 |

Courses

MEGN200. INTRODUCTION TO MECHANICAL ENGINEERING: PROGRAMMING AND HARDWARE INTERFACE. 3.0 Semester Hrs.
Equivalent with LAIS200.
This course introduces programming skills using Matlab as a means to collect and analyze data and utilizes Arduinos as a platform for prototyping circuits and designs. This course reinforces the engineering design process through problem definition and identifying constraints and criteria, encouraging multiple solutions, and introducing analysis in design through prototyping. Prerequisite: EDNS151 or EDNS155 or HNRS105 or HNRS115, CSC1101, CSC1102.

MEGN201. INTRODUCTION TO MECHANICAL ENGINEERING: DESIGN & FABRICATION. 3.0 Semester Hrs.
(I, II, S) This course reinforces basic drawing skills from Cornerstone Design, introduces SolidWorks tools to advance modeling skills, introduces machine shop skills (including safety and use of mill, lathe and CNC) and introduces GD&T practices important in fabrication and manufacturing, and prob-stats relevant to manufacturing. 3 hours lecture; 3 semester hours. Prerequisite: EDNS151 or EDNS155.

MEGN212. INTRODUCTION TO SOLID MECHANICS. 3.0 Semester Hrs.
This course introduces students to the principles of Solid Mechanics. Upon completion, students will be able to apply Solid Mechanics theories to analyze and design machine elements and structures using isotropic materials. The skills and knowledge learned in this course form the required foundation for Intro to Finite Element Analysis, Advanced Mechanics of Material, Machine Design and other advanced topics in engineering curricula. Practically, it enables students to solve real-world mechanical behavior problems that involve structural materials. This course places an early focus on ensuring students have mastered the creation of free body diagrams given a mechanical system, then moves on to introduce and reinforce learning of stress and strain transformations, and failure theories. In practicing this knowledge, students will be able to analyze and design machine elements and structures of homogenous and heterogeneous geometries under axial, torsional, bending, transverse shear, internal pressure loads, and non-uniform loads. Students will be able to quantitatively communicate the outcomes. May not also receive credit for CEEN311. Prerequisite: CEEN241 (C- or better).

MEGN298. SPECIAL TOPICS. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MEGN299. INDEPENDENT STUDY. 1-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: “Independent Study” form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

MEGN300. INSTRUMENTATION & AUTOMATION. 3.0 Semester Hrs.
(I, II) This course will explore instrumentation and automation of electro-mechanical systems. Students will utilize LabView and electro-mechanical instrumentation to solve advanced engineering problems. Class activities and projects will highlight the utility of LabView for real-time instrumentation and control. 2 hours lecture; 1 hour other; 3 semester hours. Prerequisite: MEGN200, MEGN201.

MEGN301. MECHANICAL INTEGRATION & DESIGN. 2.0 Semester Hrs.
(I, II) Students will utilize the engineering design process and knowledge in systems level design to produce a mechanical product/process. Students will reverse engineer a product/process to emphasize the steps in the design process. Students will select a longer course project, which is intended to reinforce engineering skills from other courses. The project topics would parallel one of the four research disciplines in ME, and students would be able to choose a topic pathway that emphasizes opportunities for mechanical engineering graduates. Prerequisites: MEGN200, MEGN201, and MEGN300. 1 hour lecture, 1 hour other; 2 semester hours.

MEGN315. DYNAMICS. 3.0 Semester Hrs.
This course will cover particle kinematics (including 2-D motion in x-y coordinates, normal-tangential coordinates, & polar coordinates), rigid body kinematics (Including relative velocities and accelerations), rigid body kinetics (including the equation of motion, work and energy, linear impulse-momentum, & angular momentum), and introduction to vibrations. Prerequisite: CEEN241 (C- or better) and MATH225 (C- or better). Co-requisite: MATH307 (only required for Mechanical Engineering Majors).
MEGN324. INTRODUCTION TO FINITE ELEMENT ANALYSIS. 3.0 Semester Hrs.
This course aims to teach basic proficiency with Finite Element Analysis (FEA), which is the most widely used computer aided engineering tool in industry, academia, and government. Fundamentals of FEA theory are introduced, but the majority of the course is spent learning practical skills with commercial FEA software. Students will work interactively with the instructor and with their peers to complete hands-on FEA examples based primarily on problems in structural mechanics. Applications of FEA for heat conduction, natural frequency analysis, and design optimization are covered briefly. The course will conclude with a mini project on which students use FEA skills for engineering analysis and design. The importance of verification and validation (V&V) for critical evaluation of FEA predictions is emphasized, and students will make frequent use of statics and solid mechanics principles to corroborate their FEA results. Prerequisite: MEGN212 (C- or better) or CEEN311 (C- or better).

MEGN330. INTRODUCTION TO BIOMECHANICAL ENGINEERING. 3.0 Semester Hrs.
(I) The application of mechanical engineering principles and techniques to the human body presents many unique challenges. The discipline of Biomedical Engineering (more specifically, Biomechanical Engineering) has evolved over the past 50 years to address these challenges. Biomechanical Engineering includes such areas as biomechanics, biomaterials, bioinstrumentation, medical imaging, and rehabilitation. This course is intended to provide an introduction to, and overview of, Biomechanical Engineering and to prepare the student for more advanced Biomechanical coursework. At the end of the semester, students should have a working knowledge of the special considerations necessary to apply various mechanical engineering principles to the human body. 3 hours lecture; 3 semester hours. Prerequisite: CEEN311 and PHGN200. Co-requisite: MEGN315.

MEGN340. COOPERATIVE EDUCATION. 3.0 Semester Hrs.
(I,I.II,S) Supervised, full-time engineering related employment for a continuous six-month period in which specific educational objectives are achieved. Students must meet with the Department Head prior to enrolling to clarify the educational objectives for their individual Co-op program. Prerequisites: Second semester sophomore status and a cumulative grade-point average of at least 2.00. 3 semester hours credit will be granted once toward degree requirements. Credit earned in MEGN340, Cooperative Education, may be used as free elective credit hours if, in the judgment of the Department Head, the required term paper adequately documents the fact that the work experience entailed high-quality application of engineering principles and practice. Applying the credits as free electives requires the student to submit a Declaration of Intent to Request Approval to Apply Co-op Credit toward Graduation Requirements form obtained from the Career Center to the Department Head.

MEGN351. FLUID MECHANICS. 3.0 Semester Hrs.
This course will cover principles of fluid properties, fluid statics, control-volume analysis, Bernoulli equation, differential analysis and Navier-Stokes equations, dimensional analysis, internal flow, external flow, open-channel flow, and turbomachinery. May not also receive credit for CEEN310 or PEGN251. Prerequisite: CEEN241 (C- or better) or MGN317 (C- or better).

MEGN361. THERMODYNAMICS I. 3.0 Semester Hrs.
This course is a comprehensive treatment of thermodynamics from a mechanical engineering point of view. Topics include: Thermodynamic properties of substances inclusive of phase diagrams, equations of state, internal energy, enthalpy, entropy, and ideal gases; Principles of conservation of mass and energy for steady-state and transient analyses; First and Second Law of thermodynamics, heat engines, and thermodynamic efficiencies; Application of fundamental principles with an emphasis on refrigeration and power cycles. May not also receive credit for CBEN210. Prerequisite: MATH213 (C- or better).

MEGN381. MANUFACTURING PROCESSES. 3.0 Semester Hrs.
Equivalent with MEGN380. Manufacturing Processes is a survey course, that introduces a wide variety of traditional and advanced manufacturing processes with emphasis on process selection and hands-on experiences. Students are expected to have basic knowledge in material science, basic machining and GD&T before entering the class. Throughout the course students analyze the relationships between material properties, process variables and product functionality. Students design and evaluate processes for identifying value while eliminating waste using learned skill-sets including lean methodologies, six-sigma and statistical process control. Quality, cost, standards and ethics related to manufacturing are discussed throughout the semester. Prerequisite: MEGN201 and MTGN202.

MEGN391. AUTOMOTIVE DESIGN: SAE COLLEGIATE DESIGN SERIES (FORMULA SAE). 1.0 Semester Hr.
This course introduces students to automotive design and fabrication. Students will design, fabricate, test, and analyze a formula style race car for the Formula SAE Collegiate Design Series international competition. Provide engineering students an opportunity to develop engineering skills beyond the classroom in a team oriented, competitive, and hands-on environment. Students will learn about a broad range of automobile design topics to include vehicle dynamics, propulsion, chassis design, electrical systems and aerodynamic devices. Both theoretical and hands-on skills will be exercised. Additionally, students will learn basic mechanical drawing, analysis and fabrication skills. Special emphasis will be placed on workplace safety, teamwork and peer leadership. Finally, students will gain experience in program management to include budgeting, resource management, scheduling and solving real world open-ended problems. Prerequisite: MEGN200.

MEGN398. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MEGN399. INDEPENDENT STUDY. 1-6 Semester Hr.
(I, II) Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite:“Independent Study” form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.
MEGN408. INTRODUCTION TO SPACE EXPLORATION. 1.0 Semester Hrs.
(I) Overview of extraterrestrial applications of science and engineering by covering all facets of human and robotic space exploration, including its history, current status, and future opportunities in the aerospace and planetary science fields. Subtopics include: the space environment, space transportation systems, destinations (Low-Earth orbit, Moon, Mars, asteroids, other planets), current research, missions, and projects, the international and commercial perspectives, and discussion of potential career opportunities. This seminar-style class is taught by CSM faculty, engineers and scientists from space agencies and research organizations, aerospace industry experts, and visionaries and entrepreneurs of the private space commerce sector. 1 lecture hour; 1 semester hour.

MEGN412. ADVANCED MECHANICS OF MATERIALS. 3.0 Semester Hrs.
This Advanced Mechanics of Materials course builds upon the learning outcomes of the pre-requisite Mechanics of Materials (Solid Mechanics) course to teach students the fundamentals of elastic deformations. Introduction to Theory of Elasticity and to Fracture Mechanics is realized through theory development, application examples, and numerical solutions. Knowledge from this course will enable students to work on variety of engineering applications in Mechanical, Materials, Aerospace, Civil and related engineering fields. Major covered topics include: vector and tensor calculus, stress and strain, stress functions, elastic constitutive equations, yield theories, numerical implementation techniques, and an introduction to applications including fracture mechanics. Prerequisite: MEGN212 (C- or better) or CEEN311 (C- or better).

MEGN414. MECHANICS OF COMPOSITE MATERIALS. 3.0 Semester Hrs.
Introductory course on the mechanics of fiber-reinforced composite materials. The focus of the course is on the determination of stress and strain in a fiber-reinforced composite material with an emphasis on analysis, design, failure by strength-based criteria, and fracture of composites. Anisotropic materials are discussed from a general perspective then the theory is specialized to the analysis of fiber-reinforced materials. Both thermal and hygroscopic sources of strain are introduced. Classical laminated plate theory is next developed, and design of laminated composite structures is introduced. The analysis of helically reinforced composite tubes concludes the course. Prerequisite: MEGN212 (C- or better).

MEGN416. ENGINEERING VIBRATION. 3.0 Semester Hrs.
This course introduces linear theory of mechanical vibrations as applied to single- and multi-degree-of-freedom systems. Specifically, students learn to analyze and measure free and forced vibrations of spring-mass-damper systems in response to different types of loading including harmonic, impulse, and general transient loading. Force balance and energy methods are introduced as means to create models of vibrating mechanical components. Ultimately, students learn to apply these theories to design vibration isolators and dampers for machines subject to translational and rotational vibrations, including machines with rotating unbalances and two or more vibrating masses. Prerequisite: MEGN315 (C- or better).

MEGN430. MUSCULOSKELETAL BIOMECHANICS. 3.0 Semester Hrs.
(II) This course is intended to provide mechanical engineering students with a second course in musculoskeletal biomechanics. At the end of the semester, students should have in-depth knowledge and understanding necessary to apply mechanical engineering principles such as statics, dynamics, and mechanics of materials to the human body. The course will focus on the biomechanics of injury since understanding injury will require developing an understanding of normal biomechanics. 3 hours lecture; 3 semester hours. Prerequisite: MEGN330 (C- or better).

MEGN435. MODELING AND SIMULATION OF HUMAN MOVEMENT. 3.0 Semester Hrs.
Introduction to modeling and simulation in biomechanics. The course includes a synthesis of musculoskeletal properties, interactions with the environment, and computational optimization to construct detailed computer models and simulations of human movement. Prerequisite: MEGN315, MEGN330.

MEGN436. COMPUTATIONAL BIOMECHANICS. 3.0 Semester Hrs.
Computational Biomechanics provides an introduction to the application of computer simulation to solve fundamental problems in biomechanics and bioengineering. Musculoskeletal biomechanics, joint kinematics, medical image reconstruction, hard and soft tissue modeling, and medical device design are considered in the context of a semester-long project to develop and evaluate an artificial knee implant. Leading commercial software tools are introduced with hands-on exercises. An emphasis is placed on understanding the limitations of the computer model as a predictive tool and the need for rigorous verification and validation of all modeling tasks. Clinical application of biomechanical modeling tools is highlighted and impact on patient quality of life is discussed. Prerequisite: MEGN324, MEGN330.

MEGN441. INTRODUCTION TO ROBOTICS. 3.0 Semester Hrs.
(I) Overview and introduction to the science and engineering of intelligent mobile robotics and robotic manipulators. Covers guidance and force sensing, perception of the environment around a mobile vehicle, reasoning about the environment to identify obstacles and guidance path features and adaptively controlling and monitoring the vehicle health. A lesser emphasis is placed on robot manipulator kinematics, dynamics, and force and tactile sensing. Surveys manipulator and intelligent mobile robotics research and development. Introduces principles and concepts of guidance, position, and force sensing; vision data processing; basic path and trajectory planning algorithms; and force and position control. EENG307 is recommended to be completed before this course. Prerequisites: CSCI261 and EENG281 or EENG282 or PHGN215. 2 hours lecture; 3 hours lab; 3 semester hours.

MEGN451. FLUID MECHANICS II - AERODYNAMICS. 3.0 Semester Hrs.
Review of elementary fluid mechanics and engineering; Two-dimensional external flows, boundary layers, and flow separation; Gas dynamics and compressible flow: Isentropic flow, normal and oblique shocks, rocket propulsion, Prandtl-Meyer expansion fans; Application of computational fluid dynamics. Prerequisite: MEGN351 (C- or better).

MEGN461. THERMODYNAMICS II. 3.0 Semester Hrs.
This course extends the subject matter of Thermodynamics I (MEGN361) to include the study of exergy, ideal gas mixture properties, psychrometrics and humid air processes, chemical reactions, and the 1st, 2nd and 3rd Laws of Thermodynamics as applied to reacting systems. Chemical equilibrium of multi-component systems, and simultaneous chemical reactions of real combustion and reaction processes are studied. Concepts of the above are explored through the analysis of advanced thermodynamic systems. 3 hours lecture; 3 semester hours. Prerequisite: MEGN351 (C- or better), MEGN361 (C- or better).
MEGN466. INTRODUCTION TO INTERNAL COMBUSTION ENGINES. 3.0 Semester Hrs.
Introduction to Internal Combustion Engines (ICEs); with a specific focus on Compression Ignition (CI) and Spark Ignition (SI) reciprocating engines. This is an applied thermo science course designed to introduce students to the fundamentals of both 4-stroke and 2-stroke reciprocating engines ranging in size from model airplane engines to large cargo ship engines. Course is designed as a one-semester course for students without prior experience with ICE engines, however, the course will also include advanced engine technologies designed to deliver more horsepower, utilize less fuel, and meet stringent emission regulations. Discussion of advancements in alternative fueled engines will be covered as well. This course also includes an engine laboratory designed to provide hands-on experience and provide further insight into the material covered in the lectures. Prerequisite: MEGN351, MEGN361. Co-requisite: MEGN471.

MEGN467. PRINCIPLES OF BUILDING SCIENCE. 3.0 Semester Hrs.
This course covers the fundamentals of building heating, ventilation, and air conditioning (HVAC) systems and the use of numerical heat and moisture transfer models to analyze or design different building envelope and HVAC systems. Prerequisite: MEGN351, MEGN361. Co-requisite: MEGN471.

MEGN469. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN469, MTGN469.
(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials - science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. Prerequisites: MEGN361 or CBEN357 or MTGN351. 3 hours lecture; 3 semester hours.

MEGN471. HEAT TRANSFER. 3.0 Semester Hrs.
(I, II) Engineering approach to conduction, convection, and radiation, including steadystate conduction, nonsteady-state conduction, internal heat generation conduction in one, two, and three dimensions, and combined conduction and convection. Free and forced convection including laminar and turbulent flow, internal and external flow. Radiation of black and grey surfaces, shape factors and electrical equivalence. Prerequisite: MEGN351 (C- or better), MEGN361 (C- or better), and MATH307. 3 hours lecture; 3 semester hours.

MEGN481. MACHINE DESIGN. 3.0 Semester Hrs.
(I, II) In this course, students develop their knowledge of machine components and materials for the purpose of effective and efficient mechanical design. Emphasis is placed on developing analytical methods and tools that aid the decision making process. The course focuses on determination of stress, strain, and deflection for static, static multiaxial, impact, dynamic, and dynamic multiaxial loading. Students will learn about fatigue failure in mechanical design and calculate how long mechanical components are expected to last. Specific machine components covered include shafts, springs, gears, fasteners, and bearings. 3 hours lecture; 3 semester hours. Prerequisite: MEGN315 (C- or better) or PHGN350 (C- or better), and MEGN324 (C- or better).

MEGN485. MANUFACTURING OPTIMIZATION WITH NETWORK MODELS. 3.0 Semester Hrs.
Equivalent with EBN9456.
(I) We examine network flow models that arise in manufacturing, energy, mining, transportation and logistics: minimum cost flow models in transportation, shortest path problems in assigning inspection effort on a manufacturing line, and maximum flow models to allocate machine-hours to jobs. We also discuss an algorithm or two applicable to each problem class. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Prerequisites: MATH111. 3 hours lecture; 3 semester hours.

MEGN486. LINEAR OPTIMIZATION. 3.0 Semester Hrs.
(I) This course addresses the formulation of linear programming models, linear programs in two dimensions, standard form, the Simplex method, duality theory, complementary slackness conditions, sensitivity analysis, and multi-objective programming. Applications of linear programming models include, but are not limited to, the areas of manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. Prerequisite: MATH332 or EBN9509. 3 hours lecture; 3 semester hours.

MEGN487. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.
Equivalent with MEGN587.
(I) This course addresses both unconstrained and constrained nonlinear model formulation and corresponding algorithms (e.g., Gradient Search and Newton's Method, and Lagrange Multiplier Methods and Reduced Gradient Algorithms, respectively). Applications of state-of-the-art hardware and software will emphasize solving real-world engineering problems in areas such as manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with an algorithm such as MINOS) these optimization problems is introduced. Offered every other year. Prerequisite: MATH111. 3 hours lecture; 3 semester hours.

MEGN488. INTEGER OPTIMIZATION. 3.0 Semester Hrs.
Equivalent with MEGN588.
(I) This course addresses the formulation of integer programming models, the branch-and-bound algorithm, total unimodularity and the ease with which these models are solved, and then suggest methods to increase tractability, including cuts, strong formulations, and decomposition techniques, e.g., Lagrangian relaxation, Benders decomposition. Applications include manufacturing, energy, mining, transportation and logistics, and the military. Computer use for modeling (in a language such as AMPL) and solving (with software such as CPLEX) these optimization problems is introduced. Offered every other year. Prerequisite: MATH111. 3 hours lecture; 3 semester hours.

MEGN489. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once. Prerequisite: none. Variable credit; 1 to 6 credit hours. Repeatable for credit under different titles.

MEGN499. INDEPENDENT STUDY. 1-6 Semester Hr.
Individual research or special problem projects supervised by a faculty member, when a student and instructor agree on a subject matter, content, and credit hours. Note that MEGN499 does not count as an MEGN Technical Elective, though the course does count as a Free Elective. Prerequisite: Independent Study form must be completed and submitted to the Registrar.
**Professor and Department Head**  
John R. Berger

**George R. Brown Distinguished Professor**  
Robert J. Kee

**Professors**  
Cristian V. Ciobanu  
Greg Jackson  
Alexandra Newman  
Brian G. Thomas

**Associate professors**  
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Mohsen Asle Zaeem  
Joel M. Bach  
Gregory Bogin  
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Mark Deinert  
Anthony Petrella  
Jason Porter, Assistant Department Head for Graduate Studies  
Anne Silverman  
Aaron Stebner  
Neal Sullivan  
Ruichong “Ray” Zhang  
Xiaoli Zhang

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Paulo Tabares-Velasco  
Nils Tilton  
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**Teaching Associate Professors**  
Oyvind Nilsen  
Derrick Rodriguez

**Teaching Assistant Professors**  
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Kelly Rickey  
Greg Vanderbeek  
Jeffrey Wheeler  
James Wong

**Emeriti Professors**  
Robert King  
Michael B. McGrath  
Graham G.W. Mustoe  
Terry Parker

**Emerita Professor**  
Joan P. Gosink

**Emeriti Associate Professor**  
David Munoz  
John Steele

**Research Professor**  
George Gilmer

**Research Associate Professors**  
Sandrine Ricote  
Huayang Zhu

**Post-Doctoral Fellow**  
Ankit Gupta  
Rajesh Jah  
Yasuhiro Suzuki

**Affiliate Professor of Mechanical Engineering**  
Michael Mooney

**Research Assistant Professors**  
Behnam Aminahmedi  
Seongmook Cho  
Christopher B. Dreyer  
Garrison Hommer  
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George Sowers