

# MECHANICAL ENGINEERING

CU Boulder's Mechanical Engineering Graduate Program (<http://www.colorado.edu/mechanical/prospective-students/graduate/>) is one of the top ranked programs in the U.S. News & World Report Best Graduate Schools issue among public universities. Students receive a strong education and conduct groundbreaking tier-one research. We have 50+ faculty members conducting fundamental and applied research in air quality, biomedical, materials, mechanics of materials, micro/nanoscale, robotics and systems design, and thermo fluid sciences.

Boulder is also home to research and development operations for many large companies and four federal research labs: the National Center for Atmospheric Research, the National Institute for Standards and Technology, the National Oceanic and Atmospheric Administration, and the National Renewable Energy Laboratory.

Recent doctoral and master's graduates accepted employment at companies including, but not limited to: ConocoPhillips, Ford, Google, NASA Jet Propulsion Laboratory, Lockheed Martin, Nike, Sandia National Laboratories and Seagate. Many of our graduating PhD students also enter careers in academia.

## Master's Degrees

- Mechanical Engineering - Master of Science (MS) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/mechanical-engineering/mechanical-engineering-master-science-ms/>)
- Mechanical Engineering - Professional Master of Science (MSME) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/mechanical-engineering/mechanical-engineering-professional-master-science-msme/>)

## Doctoral Degree

- Mechanical Engineering - Doctor of Philosophy (PhD) (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/mechanical-engineering/mechanical-engineering-doctor-philosophy-phd/>)

## Certificates

- Advanced Mechanics and Failure Analysis - Graduate Certificate (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/mechanical-engineering/advanced-mechanics-failure-analysis-graduate-certificate/>)
- Mechanical Design and Product Development - Graduate Certificate (<https://catalog.colorado.edu/graduate/colleges-schools/engineering-applied-science/programs-study/mechanical-engineering/mechanical-design-product-development-graduate-certificate/>)

## Faculty

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

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Instructor; MSEE, University of Illinois at Urbana–Champaign

Ahmed, Alaa A. ([https://experts.colorado.edu/display/fisid\\_144736/](https://experts.colorado.edu/display/fisid_144736/))  
Professor; PhD, University of Michigan

Ban, Chunmei ([https://experts.colorado.edu/display/fisid\\_165780/](https://experts.colorado.edu/display/fisid_165780/))  
Associate Professor; PhD, SUNY at Binghamton

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Professor; PhD, Northwestern University

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Professor; PhD, University of California, Davis

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Assistant Professor; PhD, Duke University

Branch, Melvyn C.  
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Bruns, Carson J. ([https://experts.colorado.edu/display/fisid\\_159851/](https://experts.colorado.edu/display/fisid_159851/))  
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Research Professor; PhD, Stanford University

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Assistant Professor; PhD, Stanford University

Zable, Jack L.  
Professor Emeritus

## Courses

### MCEN 5010 (3) Microsystems Integration

A microsystem consists of microelectronic, optoelectronic, microwave, microelectromechanical and energy components interconnected. Thermal, electrical, fabrication and assembly issues for microsystems represented by iPhone series will be studied. The packaging and interconnection technologies used to establish the design and manufacturing infrastructure of microsystems will be reviewed. Other optoelectronic, MEMS and batter components for microsystems will also be studied.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4010

**Requisites:** Restricted to students with 87-180 credits (Senior, Fifth Year Senior) Mechanical (MCEN) majors or College of Engineering graduate students only.

**Grading Basis:** Letter Grade

### MCEN 5012 (3) Renewable Fuels, Fuel Cells and Internal Combustion Engines

With the accelerated availability of carbon-free and renewable fuels, we will explore high-efficiency, low-emissions fuel cell and internal combustion engine energy conversion technologies, preparing students to enter the rapidly changing fields of power and propulsion on the path to net-zero greenhouse gas emissions. Through thermodynamic modeling, systems engineering, and requirements flow-down, students will apply the fundamentals of thermodynamics, fluids and heat transfer, combustion and electrochemistry for fuel cells and IC Engines.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4012

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

### MCEN 5014 (3) Energy Materials Characterization

Introduces theoretical framework for characterization techniques including X-ray diffraction, X-ray photoelectron spectroscopy and imaging methods used in the structural and morphological characterization of energy materials. Helps students determine characterization techniques suitable for their study and understand their data. Uses energy storage case studies to provide the methodologies for determining the nature and composition of materials. Helps students learn new characterization techniques from the literature and seek the characterization resources from DOE funded user facilities.

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) majors with 57+ credits (Junior or Senior).

**Recommended:** Prerequisite MCEN 1024 Chemistry or equivalent, and MCEN 2024 Materials Science or equivalent.

### MCEN 5020 (3) Methods of Engineering Analysis 1

Studies selected topics from linear algebra, multi-variable calculus, differential equations, and Fourier series. Assigns computer exercises. Correlates with analysis topics in other mechanical engineering graduate courses, and emphasizes applications. Prior courses in Calculus I, II, II, differential equations, and linear algebra strongly recommend.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Math

**MCEN 5021 (3) Introduction to Fluid Dynamics**

Focuses on physical properties of gases and liquids, and kinematics of flow fields. Analyzes stress; viscous, heat-conducting Newtonian fluids; and capillary effects and surface-tension-driven flow. Other topics include vorticity and circulation, ideal fluid flow theory in two and three dimensions, Schwartz-Christoffel transformations, free streamline theory, and internal and free-surface waves.

**Requisites:** Requires corequisite course of MCEN 5020. Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5022 (3) Classical Thermodynamics**

First and second laws of thermodynamics. Entropy and availability. Cycle analysis. Thermodynamic properties of pure substances and mixtures. Property relations. Chemical reactions and chemical availability. Energy systems analysis.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Thermal

**MCEN 5023 (3) Solid Mechanics 1**

Introduces stress, strain and motion of a continuous system. Discusses material derivative; fundamental laws of mass, momentum, energy and entropy; constitutive equations and applications to elastic and plastic materials.

**Equivalent - Duplicate Degree Credit Not Granted:** ASEN 5012

**Requisites:** Requires coreq course of MCEN 5020. Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering (MCEN) majors only.

**Additional Information:** Departmental Category: Solids

**MCEN 5024 (3) Materials Chemistry and Structures**

Provides graduate level students with a comprehensive overview of the chemistry and structure of material systems, with a focus on chemical bonding, the resulting material structures and their properties. This course is intended to become one of the four core courses offered in the new Materials Science curriculum. Course topics include: bonding in solids, crystalline and amorphous states, basic group theory, diffraction, metals and alloys, ceramics, and an intro to mat. characterization.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Materials

**MCEN 5027 (1) Graduate Seminar**

Offers weekly presentations by visiting speakers, faculty, and students.

**Repeatable:** Repeatable for up to 6.00 total credit hours.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5030 (3) Introduction to Research**

Provides students with fundamental skills important for success in research. Covers approaches to generating project and program ideas, securing funding, performing a literature search to understand the state of a field, communicating results through presentations and papers, understanding scientific ethics, developing a network of trusted peers, establishing and negotiating collaborations, fostering diversity, ensuring equity and inclusivity, and establishing a professional profile and becoming a leader in your field.

**Requisites:** Restricted to undergraduate or graduate Mechanical Engineering students only.

**MCEN 5032 (3) Sustainable Energy**

Examines sustainability of our current energy systems, including transportation, using environmental and economic indicators. Uses systems analysis that addresses energy supply and demand. Explores the science and technology as well as environmental and economic feasibility of efficiency measures and renewable energy technologies. Additional emphasis is given to the global nature of the challenges and the potential for locally optimal solutions.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4032

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Thermal

**MCEN 5034 (3) Thermodynamics of Materials**

Provides a unified presentation of fundamental concepts applicable to the thermodynamics of engineering materials. Develops quantitative tools for understanding the physical principles that govern phase equilibrium and transformation. Generates binary and ternary phase diagrams and determine the resulting materials structures and corresponding physical and mechanical properties.

**Recommended:** Prerequisites MCEN 2024 and MCEN 3012.

**Additional Information:** Departmental Category: Materials

**MCEN 5040 (3) Methods of Engineering Analysis 2**

Studies selected topics from the theory of complex variables, integral transform methods, partial differential equations, and variational methods. Assigns computer exercises. Correlates with analysis topics in other mechanical engineering graduate courses, and emphasizes applications.

**Requisites:** Requires prerequisite course of MCEN 5020 (minimum grade D-). Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Math

**MCEN 5041 (3) Advanced Fluid Mechanics 1**

Highlights exact solution of Navier-Stokes equations and fundamentals of rotating fluids. Considers Low Reynolds number flow; similarity solutions; viscous boundary layers, jets, and wakes; and unsteady viscous flow.

**Requisites:** Requires corequisite course of MCEN 5020. Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5042 (3) Heat Transfer**

Studies development of equations governing transport of heat by conduction, convection, and radiation, and their solution. Includes analytical and numerical solution of initial and boundary value problems representative of heat conduction in solids. Describes heat transfer in free and forced convection, including laminar and turbulent flow. Also involves radiation properties of solids, liquids, and gases and transport of heat by radiation.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Thermal

**MCEN 5044 (3) Mechanical Behavior of Materials**

This introductory-level graduate course incorporates relevant aspects of materials science, solid mechanics, thermodynamics and mathematics, and applies them to achieve a fundamental understanding of the mechanical behavior of crystalline and non-crystalline engineering materials.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering (MCEN) majors only.

**Additional Information:** Departmental Category: Materials

**MCEN 5045 (3) Design for Manufacturability**

Topics include general design guidelines for manufacturability; aspects of manufacturing processes that affect design decisions; design rules to maximize manufacturability; economic considerations; value engineering and design for assembly. Presents case studies of successful products exhibiting DFMA principles. Prerequisite of MCEN 4026 required for undergraduate students.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering (MCEN) majors only.

**Additional Information:** Departmental Category: Materials

**MCEN 5055 (3) Advanced Product Design**

Introduces engineering design and development of consumer products. Includes learning sketching, brainstorming, idea generation, design thinking, user-centered design, product requirements and specifications, product constraints, human factors, aesthetics, industrial design, intellectual property, concept prototyping, idea selection, tolerancing, cost estimating, design for assembly, and materials selection. Entails a semester-long team re-design of a consumer product.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Design

**MCEN 5057 (3) Environmental Modeling**

Enables students to develop and evaluate pollutant transport, fate, exposure, and risk models for air, water, and multi-media systems, with a special emphasis on air. Emphasizes the fundamental physics and chemistry that govern contaminant fate and transport and the basic mathematical equations and numerical approaches for describing these processes.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4057

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5064 (3) Soft Machines**

Introduces soft machines as a new paradigm of engineering that starts to impact healthcare, consumer electronics, renewable energy and collaborative robotics. Prepares students to participate in research on soft machines by starting with fundamentals of soft materials and by covering soft robotics, stretchable electronics, energy harvesting and functional polymers. Includes guest lectures, a literature review and a hands-on lab project.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4046 and MSEN 5046

**Requisites:** Restricted to students with 87-180 credits (Senior, Fifth Year Senior) Mechanical (MCEN) majors or College of Engineering graduate students only.

**Grading Basis:** Letter Grade

**MCEN 5065 (3) Graduate Design I**

First part of a two-course graduate product design experience in mechanical engineering. Covers problem definition and specifications, determining design requirements, user feedback, alternative design concepts, engineering analysis, concept prototypes and CAD drawings. Students make several oral design reviews, a final design presentation and prepare a written report. Entails a team product design, fabrication and testing cycle of sponsored project. Students who complete this course are encouraged to take MCEN 5075 Graduate Design II.

**Requisites:** Requires prerequisite course of MCEN 5055 (minimum grade C-).

**Additional Information:** Departmental Category: Design

**MCEN 5075 (3) Graduate Design II**

Second part of two-course graduate product design experience in mechanical engineering. Includes refinement of prototype, design optimization, fabrication, testing, and evaluation. Students orally present the final design and prepare a written report and operation manual for the product. Entails a team product design, fabrication, and testing cycle of a sponsored project, leading to a fully-functional product.

**Requisites:** Requires prerequisite course of MCEN 5065 (minimum grade C-).

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Design

**MCEN 5110 (3) Regenerative Biology and Tissue Repair**

Presents the regenerative biology behind tissue systems, along with the regenerative medicine of that tissue with an emphasis on engineering principles, using the assigned reading as a guideline. Follows lectures with class discussions of current papers on the regenerative biology of the same tissue system. In the final 1 & 2 classes assigned to this topic, individual graduate students give 20 min presentations on a relevant regenerative medicine/engineering-focused paper.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4110 and BMEN 4110 and BMEN 5110

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**MCEN 5111 (3) Introduction to Microfluidics**

Microfluidics deals with the behavior of fluids in small scale. It is a highly multidisciplinary field at the intersection of engineering, physics, chemistry, biology, medicine, nanotechnology, and biotechnology. This course covers the fundamentals and fabrication of microfluidic devices and their applications, particularly in lab-on-a-chip. Includes lectures, literature discussion, team presentations, and possibly one lab on microfluidic devices. Enhances your understanding of microfluidic technologies and their broad applications.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5111 and MCEN 4111 and BMEN 4111

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite MCEN 3021 or CHEN 3200 or CVEN 3313.



**MCEN 5112 (3) Introduction to Nanoscale Transport**

Introduces the basic concepts, theoretical methods, and experimental techniques related to nanoscience and nanoengineering that are ubiquitous in microelectronics, renewable energy technology, heat transfer, nano-optics, MEMS/NEMS, and emerging quantum technologies. Discusses microscopic pictures and theories of various energy transport and conversion phenomena and real-world examples and demonstrations.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4112

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors with 57+ credits only.

**MCEN 5113 (3) Mechanics of Cancer**

Cancer is considered to be an organ or an ecosystem, in which a critical component of the tumor microenvironment is mechanical forces. This course will cover the role of mechanics in cancer and cancer-related processes, with a focus on solid mechanics and fluid mechanics. In this course, you will apply engineering principles to come away with an appreciation of how mechanics influences cancer and its etiology as well as the development of future treatments.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5113 and MCEN 4113 and BMEN 4113

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical and Biomedical Engineering undergraduate majors only.

**MCEN 5115 (3) Mechatronics and Robotics I**

Focuses on design and construction of microprocessor-controlled electro-mechanical systems. Lectures review critical circuit topics, introduce microprocessor architecture and programming, discuss sensor and actuator component selection, robotic systems and design strategies for complex, multi-system devices. Lab work reinforces lectures and allows hands-on experience with robotic design. Students must design and build an autonomous robotic device. Project expenses may be incurred (\$50 maximum).

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4115

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Design

**MCEN 5117 (3) Anatomy and Physiology for Engineers**

Explores human physiological function from an engineering, specifically mechanical engineering, viewpoint. Provides an introduction to human anatomy and physiology with a focus on learning fundamental concepts and applying engineering (mass transfer, fluid dynamics, mechanics, modeling) analysis.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 4117 and BMEN 5117 MCEN 4117

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5121 (3) Compressible Flow**

Applies energy, continuity, and momentum principles to compressible flow. Topics include normal and oblique shocks; Prandtl-Meyer expansion; methods of characteristics; and one-, two-, and three-dimensional subsonic, supersonic, and hypersonic flows.

**Requisites:** Requires prerequisite course of MCEN 5021 (minimum grade D-). Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5122 (3) Statistical Thermodynamics**

Axiomatic formulation of macroscopic thermodynamics. Quantum mechanical description of atomic and molecular structure. Statistical mechanics description of thermodynamic properties of gases, liquids and solids. Elementary kinetic theory of gases and evaluation of transport properties. Department enforced requisite: undergraduate thermodynamics.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Thermal

**MCEN 5125 (3) Optimal Design**

Focuses on linear optimization and will introduce non-linear optimization. Formulating engineering applications as optimization problems that can be solved using industry known solvers will be learned. Some of these applications will include minimum cost mechanical design, wind farm power maximization, minimum energy control, production control, and more. Previous programming experience required.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4125

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Design

**MCEN 5127 (3) Biomedical Ultrasound**

Covers the design of ultrasound systems for medical imaging and therapy, including the physics of wave propagation, transducers, pulse-echo imaging, flow and tissue characterization, and microbubble contrast, with an emphasis on current topics in biomedical ultrasound. Includes lectures on theory, practice and special topics; a laboratory on wave propagation; oral presentations on current literature; programming exercises for data processing; and a team design project.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5127 and MCEN 4127 and BMEN 4127

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) and Biomedical Engineering (BMEN) majors with 57+ credits (Junior or Senior).

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5131 (3) Air Pollution Control Engineering**

Introduces air quality regulations, meteorology and modeling. Examines methods for controlling major classes of air pollutants, including particulate matter and oxides of sulfur and nitrogen, as well as control technology for industrial sources and motor vehicles. Requires interdisciplinary design projects.

**Equivalent - Duplicate Degree Credit Not Granted:** EVEN 5151 and MCEN 4131 and EVEN 4131

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering or Environmental Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5133 (3) Intro to Tissue Biomechanics**

Focuses on developing an understanding of the fundamental mechanical principles that govern the response of hard and soft biological tissue to mechanical loading. Specifically, covers mechanical behavior of biological materials/tissues, classical biomechanics problems in various tissues, the relationship between molecular, cellular and physiological processes and tissue biomechanics and critical analysis of related journal articles.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4133

**Additional Information:** Departmental Category: Materials

**MCEN 5135 (3) Wind Energy and Wind Turbine Design**

Focuses on understanding and applying principles related to current wind energy technologies. Students will apply technical coursework from throughout the engineering curriculum (environmental, fluids, statics, dynamics, power, economics, etc.) to the process of designing wind turbines and wind farms. Practical, real world examples will be integrated into the lessons and problems.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4135

**Requisites:** Restricted to Mechanical (MCEN), Civil (CVEN) or Aerospace (ASEN) Engineering graduate students only.

**Additional Information:** Departmental Category: Design

**MCEN 5137 (3) Anatomy and Physiology 2**

Provides in-depth understandings of anatomy and physiology as well as introductions to transport phenomena, flow mechanics and solid mechanics in several organ systems: the cardiovascular, pulmonary, kidney, endocrine and digestive systems. Introduces artificial physiological systems to replace or assist physiological functions and introduce the concepts of physiological barriers that prevent diagnosis or effective therapeutics.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4137

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5138 (3) Feedback Control**

Introduction to fundamental principles and techniques for analysis and synthesis of feedback control systems in the time and frequency domains. Laplace transforms, transfer functions and block diagrams. Stability, dynamic response, and steady-state analysis. Analysis and design of control systems using root locus and frequency response methods. Computer aided design and analysis. Introduction to state space representations and state feedback control.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4138 ECEN 4138 or ECEN 5138

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite MCEN 4043 or comparable knowledge gained through outside coursework.

**MCEN 5141 (3) Indoor Air Pollution**

Describes the impact of indoor air pollutants on human health, including an introduction to key pollutants and their sources. Students will estimate emission factors, calculate generation/ventilation rates, quantify the impact of deposition and chemical reactions and explore relevant control technology. Current issues will also be addressed, including climate change, green building design, economic concerns and relevance to the developing world.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4141

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5147 (3) Mechanobiology**

Studies how mechanical forces modulate the morphological and structural fitness of biological tissues. Current molecular mechanisms by which cells convert mechanical stimulus into chemical activity and the literature supporting them will be discussed. Students will acquire an understanding and expertise from the analysis of primary literature and completion of a synthesis project.

**Requisites:** Restricted to students with 87-180 credits (Senior, Fifth Year Senior) Mechanical (MCEN) majors or College of Engineering graduate students only.

**Grading Basis:** Letter Grade

**MCEN 5151 (3) Flow Visualization**

Explores techniques for the visualization of the physics of fluid flows including seeding with dyes, particles and bubbles, and shadowgraphy and schlieren. Reviews optics and fluid physics, especially atmospheric clouds. Assignments are student-driven, to individuals and mixed teams of graduates, undergraduates, engineering majors and photography/video majors.

**Equivalent - Duplicate Degree Credit Not Granted:** CINE 4200, MCEN 4151, ARTF 5200, ATLS 4151 and ATLS 5151

**Additional Information:** Departmental Category: Fluids

**MCEN 5152 (3) Introduction to Combustion**

Focuses on the mechanisms by which fuel and oxidizers are converted into combustion products. Application to practical combustion devices such as Otto, Diesel, gas turbine and power plant combustion systems. Consideration of combustion-generated air pollution, fire safety and combustion efficiency.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4152

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Thermal

**MCEN 5153 (3) Introduction to Fracture Mechanics**

This course will introduce fundamental concepts, analytical approaches, and experimental methods to characterize the fracture of solid materials. Topics to be discussed include: linear elastic analysis of 2D cracks, energy flows and criteria for elastic fracture, experimental methods for elastic fracture, application of fracture mechanics in adhesion, introduction to elastic plastic fracture, and nonlinear fracture mechanics of soft materials.

**Requisites:** Requires prerequisite course of MCEN 2063 or CVEN 3161 or MCEN 5023 or ASEN 5012 (all minimum grade C).

**MCEN 5154 (3) Biocolloids and Biomembranes**

Covers the thermodynamics and mechanics of biological membranes and biomedical colloids. Considers intermolecular and surface forces, self-assembly and colloidal stability. Addresses structure-property relationships and design principles for biomedical applications. Focuses on monolayers, bilayers, micelles, filomicelles, liposomes, polymersomes, emulsions, microbubbles, polyplexes and polyelectrolyte multilayer capsules.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4154

**Recommended:** Prerequisites APPM 2360 and PHYS 1120.

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Materials

**MCEN 5155 (3) Automated Mechanical Design Synthesis**

Introduces computational approaches to automatically generate complex multimaterial mechanical designs that satisfy predefined high-level specifications, discusses algorithms to solve design as a constrained non-convex multi-objective optimization problem. Topics: expert-driven design process; computational analysis tools based on mechanical simulation (finite element methods, mesh-free methods); topological optimization; compositional design; multi-objective optimization; evolutionary design; design for manufacturing with additives (FDM, SLA, Inkjet). Students design a part to specifications, fabricate using advanced (3D printing, laser cutting, CNC, etc) tools.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4155

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite students should be comfortable with MATLAB, PDEs, linear algebra, free body diagrams, mechanical modeling/design; exposure to finite-element modeling and state-space representations.

**MCEN 5157 (3) Modeling of Human Movement**

Human movement analysis is used in physical rehabilitation, sport training, human-robot interaction, animation, and more. Course provides a systematic overview of human movement on multiple levels of analysis, with an emphasis on the phenomenology amenable to computational modeling. Covers muscle physiology, movement-related brain areas, musculoskeletal mechanics, forward and inverse dynamics, optimal control and Bayesian inference, learning and adaptation. Inspires students to see and appreciate the complexities of movement control in all aspects of daily life.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5157 and MCEN 4157

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) and Biomedical Engineering (BMEN) majors with 57+ credits (Junior or Senior).

**MCEN 5161 (3) Aerosols**

Introduces atmospheric aerosols and properties of their distributions, followed by fundamental descriptions of single particle dynamics, thermodynamics, nucleation, coagulation, mass transfer and populations dynamics. During the second half of the course, the focus will shift to sources and sinks of atmospheric aerosols, their impacts on atmospheric chemistry and radiation, and the impacts of these processes on air quality and climate.

**Requisites:** Restricted to graduate students only.

**Additional Information:** Departmental Category: Fluids

**MCEN 5171 (3) Biofluids on the Micro Scale**

Introduces fundamental physical concepts and basic mechanisms of biological fluids in microscale. Elaborates on the application of fluid mechanics principles to major biological systems, including human organ systems and animal locomotion in microscale. Covers physiologically relevant fluid flow phenomena on the cellular level and the underlying physical mechanisms from an engineering perspective. Related state-of-art technologies such as organ-on-a-chip and micro/nano fabrication will be emphasized. Will enhance your understanding of organ-on-a-chip technologies and their broad applications.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5171 and MCEN 4171 and BMEN 4171

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) and Biomedical Engineering (BMEN) majors with 57+ credits (Junior or Senior).

**MCEN 5173 (3) Finite Element Analysis**

Introduces the theory behind and applications of the finite element method as a general and powerful tool to model a variety of phenomena in mechanical engineering. Applications include structural mechanics, mechanics of elastic continua and heat conduction.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4173

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Solids

**MCEN 5174 (3) Failure of Engineering Materials**

Examines the fundamental concepts regarding the failure of engineering materials. Case studies are used to integrate a basic understanding of material failure mechanisms with analysis techniques and tools. Topics include the elastic properties (isotropic and anisotropic materials) and the origin of elastic behavior, viscoelasticity, plasticity (dislocation mechanisms, yielding criteria, strengthening mechanisms), creep, fracture and fatigue.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4174

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Materials

**MCEN 5183 (3) Mechanics of Composite Materials**

Introduces various kinds of composite materials, composite fabrication techniques, the physical and mechanical behavior of composites, and analytical and experimental methodologies.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4183

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Solids

**MCEN 5193 (3) Design of Coffee**

Serves as an introduction to how engineers use their disciplinary training to approach and solve problems outside of the traditional confines of their discipline, as illustrated by the roasting and brewing of coffee. In addition to focusing on the science, engineering and craftsmanship of making a cup of coffee from bean to cup, we will also study the global sourcing and sustainability aspects of coffee.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4193

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.



**MCEN 5194 (3) Electrochemical Energy Conversion and Storage**

Presents the fundamentals, principles and experimental techniques of electrochemistry, the background of ionic or electronic conduction of metal, semiconductor, inorganic and polymer materials and applications in the areas of batteries, fuel cells, electrochemical double layer capacitors, electrochemical photonics, sensors and semiconductor electrochemistry.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4194

**Recommended:** Prerequisites MCEN 2024 and MCEN 3032.

**Grading Basis:** Letter Grade

**Additional Information:** Departmental Category: Materials

**MCEN 5195 (3) Bioinspired Robotics**

Bioinspired design views the process of how we learn from nature as an innovation strategy translating principles of function, performance, and aesthetics, from biology to human technology. The creative design process is driven by interdisciplinary exchange among engineering, biology, medicine, art, architecture and business. Diverse teams of students will collaborate on, create, and present original bioinspired design projects in the ITLL.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4195

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) majors with 57+ credits (Junior or Senior).

**Recommended:** Prerequisite MCEN 3017 and MCEN 3025 or comparable electronics and design knowledge.

**MCEN 5208 (1-4) Special Topics**

Credit hours and subject matter to be arranged.

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Requisites:** Restricted to undergraduate or graduate Mechanical Engineering students only.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5228 (1-4) Special Topics in Mechanical Engineering**

Subject matter to be selected from topics of current interest.

**Repeatable:** Repeatable for up to 30.00 total credit hours. Allows multiple enrollment in term.

**Requisites:** Restricted to graduate students in the College of Engineering and Applied Science or undergraduate Mechanical Engineering (MCEN) majors with 57+ credits (Junior or Senior).

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5231 (3) Computational Fluid Dynamics**

This course is an in-depth introduction to the basic principles and applications of computational fluid dynamics (CFD). Students learn about fundamental CFD concepts such as discretization, meshing, error and accuracy; and focus on computational solutions of flow and transport problems using the finite element method. Students conduct multiple hands-on simulation-based activities and exercises on canonical and realistic engineering flow/transport problems. Final project for the course culminates in a mini-conference/symposium where students present their work.

**Equivalent - Duplicate Degree Credit Not Granted:** BMEN 5231 and MCEN 4231 and BMEN 4231

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**MCEN 5255 (3) Design for Mfg**

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Design

**MCEN 5258 (1-3) Sp Tpcs-Combustion Seminar**

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Special Topics

**MCEN 5279 (3) Aesthetics in Design**

Focuses on aesthetic aspects of design via hands-on design-build experiences. Students individually create dynamic artifacts of their own choice with the assistance of teammates. Content includes major design movements since 1900, constructive critique practice, hand sketching techniques and other selected industrial design topics. Students publish their design work on an archival public blog which provides a professional portfolio element.

**Equivalent - Duplicate Degree Credit Not Granted:** ATLS 5279 and MCEN 4279 and ATLS 4279

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**MCEN 5291 (1-2) Project Based Learning in Rural Schools**

Focuses on the use of low cost air quality monitoring tools, dubbed Pods, to implement PBL curriculum in high school environmental science classes in rural communities in Colorado. Each student will be paired with a high school class and will serve as curriculum and technology advisors as well as science experts. During the fall semester, students will be trained to effectively work in those roles and will also travel to their schools to be introduced. During the spring semester, students will support high school teachers in implementing an existing PBL air quality curriculum with the Pods. This will include monthly visits to schools in the spring and reporting back to the class. Enrollment during Fall is required for enrollment during Spring. Previously offered as a special topics course.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4291

**Repeatable:** Repeatable for up to 4.00 total credit hours. Allows multiple enrollment in term.

**MCEN 5292 (3) Materials and Devices in Medicine**

The main objective of this multidisciplinary course is to provide students with a broad survey of biomaterials and their use in medical devices for restoring or replacing the functions of injured, diseased, or aged human tissues and organs. The topics to be covered include: evolution in the medical device industry, a broad introduction to the materials used in medicine and their chemical, physical, and biological properties, discovery of medical problems, potential impacts of treatment innovations, existing devices and design considerations for several major physiological systems (cardiovascular, neuromuscular, skeletal, pulmonary, renal, dermal), materials interaction with the human body, basic mechanisms of wound healing, biocompatibility issues, testing methods and techniques in accordance with standards and relevant regulations, biofunctionalities required for specific applications, as well as state-of-the-art approaches for the development of new regenerative materials targeting cellular mechanisms. Rec

**Requisites:** Requires prerequisite course of MCEN 4117 or MCEN 5117 (minimum grade C). Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**MCEN 5293 (3) Mechanics of Soft Matter**

Provides a general overview of fundamental concepts behind the mechanical behavior of soft matter. The term soft matter (which includes polymers, colloids, liquid crystals and surfactants, to name a few) is typically used to describe classes of materials whose structural unit is much larger than atoms, making their response more complex and often richer than that of traditional solids. The objective of this class is to understand how chemical and mechanical forces between these small units yield macroscopic behaviors that one can observe in everyday life. Key engineering applications will also be discussed.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4293

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite knowledge comparable to that gained through MCEN 2063.

**MCEN 5298 (3) Introduction to Polymers**

Polymers represent a major class of engineering materials that are used by mechanical engineers. In this class, we will discuss the most fundamental concepts regarding polymeric materials. Topics include synthesis/manufacturing and chemical properties of polymers, statistical properties of polymer chains, multiphase polymers including polymer solutions and polymer blends, crystallization and glass transition of polymers, and viscoelastic properties of polymers.

**Equivalent - Duplicate Degree Credit Not Granted:** MCEN 4298

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite knowledge comparable to that gained through MCEN 2024.

**MCEN 5299 (3) Household Energy Systems**

Cooking, heating and lighting in the developing world often involves inefficient and incomplete combustion of solid or liquid fuels. The Global Burden of Disease Study in 2010, ranked this combustion as the 4th largest risk factor, causing 4 million premature deaths per year. There is a strong societal need to tackle this problem. Students leaving this course will be able to meet this need as they will have the skills to assess existing and new technology used in the developing world for cooking, heating and lighting. The course will cover (1) food conversion chemistry with the focus on increasing useable calories, (2) combustion and heat transfer as related to cooking, heating and lighting, and (3) combustion emissions and stove use assessment. There will be case studies interlaced throughout the content and the bulk of the workload will be homeworks and projects. Recommended prerequisite: knowledge comparable to that gained through MCEN 3022 or concurrent enrollment in MC

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering or Environmental Engineering undergraduate majors only.

**MCEN 5448 (3) Linear Systems**

Introduces the theory of linear systems, including state space descriptions of dynamic systems, linear spaces, linear mappings, structure of linear operators, stability, controllability, observability, state variable estimation and feedback control methods.

**Equivalent - Duplicate Degree Credit Not Granted:** ECEN 5448

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Recommended:** Prerequisite MCEN 4138 or MCEN 5138 and strong foundational knowledge of linear algebra and differential equations.

**MCEN 5488 (3) Geometric Control Theory**

Introduce geometric approaches to study dynamical control systems over manifolds. Cover fundamental control-theoretical results, such as controllability, observability, feedback stabilizability, symmetries and group actions, that are beyond linear control systems. Establish connections between control theory and mathematics, especially topology, differential geometry, Lie groups and Lie algebras. Final project focuses on engineering applications related to students' own research interests.

**Equivalent - Duplicate Degree Credit Not Granted:** ECEN 5488

**MCEN 5498 (3) Stochastic Control Theory**

Introduce a toolbox for dealing with stochastic control systems. Cover topics such as stochastic calculus, linear and nonlinear filtering, and dynamic programming. Discuss system theoretic issues and derive optimal control laws for a variety of stochastic control problems, including, e.g., the separation principle for Linear-quadratic-Gaussian problems. Final project focuses on engineering applications related to students' own research interests.

**Equivalent - Duplicate Degree Credit Not Granted:** ECEN 5498

**MCEN 5636 (3) Micro-Electro-Mechanical Systems 1**

Addresses issues of micro-electro-mechanical systems (MEMS) modeling, design, and fabrication. Emphasizes the design and fabrication of sensors and actuators due to significance of these devices in optics, medical instruments, navigation components, communications, and robotics. Department consent required.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Manufacturing and Systems

**MCEN 5832 (3) Special Topics**

**Additional Information:** Departmental Category: Special Topics

**MCEN 5848 (1-6) Independent Study**

Available only through approval of graduate advisor. Subjects arranged to fit the needs of the particular student. May be repeated for up to 6 total credits.

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Requisites:** Restricted to College of Engineering graduate students only.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5858 (1-6) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5868 (1-3) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5878 (1-3) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5888 (1-3) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 5930 (1-3) Professional Internship**

This class provides a structure for Mechanical Engineering graduate students to receive academic credit for internships with industry partners that have an academic component to them suitable for graduate-level work. Participation in the program will consist of an internship agreement between a student and an industry partner who will employ the student in a role that supports the academic goals of the internship. Instructor participation will include facilitation of mid-term and final assessments of student performance as well as support for any academic-related issues that may arise during the internship period. May be taken during any term following initial enrollment and participation in ME graduate programs. Department permission required to enroll.

**Repeatable:** Repeatable for up to 6.00 total credit hours.

**Requisites:** Restricted to Mechanical Engineering graduate students only.

**MCEN 6001 (3) Reacting Flows**

Provides an introduction to reacting flows and combustion. Covers chemical kinetics, including global and detailed mechanisms and the variable density flow equations are derived. Relevant non-dimensional parameters and limiting behaviors are discussed. The Rankine-Hugoniot relations are presented and various aspects of diffusion, kinetically dominated and balanced combustion are outlined. Flame structures are discussed, including laminar and turbulent flames, and the Burke-Schumann solution is outlined. The turbulent forms of the motion equations are derived, and the reactive scalar transport equation and mixture fraction variable are presented. The flamelet progress variable approach is outlined, including a comparison of steady and unsteady flamelet models. Specific topics in spray combustion, triple flames, solid-gas reactors and detonations are discussed.

**Equivalent - Duplicate Degree Credit Not Granted:** ASEN 6001

**Requisites:** Requires prerequisite course of MCEN 5021 (minimum grade C-). Restricted to College of Engineering and Applied Science graduate students or BS/MS Concurrent Degree Students only.

**Additional Information:** Departmental Category: Fluids

**MCEN 6184 (3) Structure and Properties of Polymers**

Emphasizes the relationships between molecular structures and macroscopic properties of polymers. Structural aspects include chain conformation, configuration, and the crystalline and amorphous states. Discusses physical, mechanical and dynamic properties with a focus on solution and phase behavior, transitions of bulk polymers, and rubber and viscoelastic behavior.

**Requisites:** Restricted to College of Engineering graduate students only.

**Recommended:** Prerequisite an intro-level polymer course.

**Additional Information:** Departmental Category: Materials

**MCEN 6228 (1-4) Special Topics in Mechanical Engineering**

Subject matter to be selected from topics of current interest.

**Repeatable:** Repeatable for up to 15.00 total credit hours. Allows multiple enrollment in term.

**Requisites:** Restricted to College of Engineering graduate students only.

**Additional Information:** Departmental Category: Special Topics

**MCEN 6848 (1-6) Independent Study**

Available only through approval of graduate advisor. Subjects arranged to fit the needs of the particular student.

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Requisites:** Restricted to graduate students only.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 6858 (1-6) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 6868 (1-6) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 6878 (1-6) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 6888 (1-6) Independent Study**

**Repeatable:** Repeatable for up to 6.00 total credit hours. Allows multiple enrollment in term.

**Additional Information:** Departmental Category: Miscellaneous

**MCEN 6949 (1) Master's Candidate for Degree**

Registration intended for students preparing for a thesis defense, final examination, culminating activity, or completion of degree.

**Additional Information:** Departmental Category: Thesis

**MCEN 6959 (1-6) Master's Thesis**

**Additional Information:** Departmental Category: Thesis

**MCEN 7221 (3) Turbulence**

Hydrodynamic stability theory, equations for turbulent flows, free shear flows and boundary layers, homogeneous and isotropic turbulence, overview of turbulent combustion, reaction kinetics, energy equation, Favre averaging, Pdfs, premixed and nonpremixed flame modeling, and recent developments.

**Requisites:** Restricted to any College of Engineering and Applied Science graduate students or to Mechanical Engineering undergraduate majors only.

**Additional Information:** Departmental Category: Fluids

**MCEN 7228 (3) Special Topics**

**Additional Information:** Departmental Category: Special Topics

**MCEN 8999 (1-10) Doctoral Dissertation**

**Additional Information:** Departmental Category: Thesis