Mechanical Engineering

PROGRAM DESCRIPTION

The graduate program in Mechanical Engineering at Mines combines a strong foundation in engineering fundamentals with applied skills to solve real-world engineering problems. The Department offers the following degrees:

- Master of Science (Non-thesis: on-campus or online modalities available)
- Master of Science (Thesis)
- Doctor of Philosophy

The Department's course offerings and cutting-edge research are aligned with four core Mechanical Engineering focus areas: i) Biomechanics, ii) Robotics and Automation, iii) Solid Mechanics, Materials, and Manufacturing, and iv) Thermal, Fluids and Energy Systems. In many cases, student course work and thesis research encompass more than one research area and elements from other disciplines.

Biomechanics applies engineering principles to living things, with a primary focus on the musculoskeletal system of the human body. Research in this area addresses rehabilitation engineering, patient-specific biomechanical modeling, assessment of human interaction with equipment, assistive devices, and implants, mobility and performance analysis, and bioinstrumentation. Research projects use advanced computational modeling and experimentation with human subjects.

Robotics and Automation research areas apply innovative technologies to problems in robotics, robot-human interaction, manufacturing, and health care. Our research ranges from artificial intelligence to autonomous and remotely operated robot technologies, including applications in additive manufacturing, underground mine safety, medical and healthcare, space, and advanced control. We use both high-performance computational and physical prototyping methods to advance research in these areas.

Solid Mechanics, Materials, and Manufacturing research areas develop novel computational and experimental solutions for problems in the mechanical behavior of advanced materials and manufacturing. Research in the division spans multiple length scales, from the atomic up to the structural, unraveling the complex relationships between material microstructure, mechanical properties and performance. Our work includes development of state-of-the-art characterization and experimental techniques, advanced mechanical behavior models, and novel manufacturing process development.

Thermal, Fluid and Energy Systems research areas address a wide array of cutting-edge topics that rely on thermodynamics, heat transfer, fluid mechanics, and chemical phenomena. Research uses advanced experimental diagnostics and numerical simulation tools to solve problems in a wide range of fields, including energy storage and conversion, sustainable transportation and fuels, water purification and processing, and aerodynamics. Projects range in scope from characterization and modeling of molecular-scale processes to design and analysis of commercial-scale systems.

Program Details

The Mechanical Engineering Department offers the degrees Master of Science and Doctor of Philosophy in Mechanical Engineering. The master's program is designed to prepare candidates for careers in industry or government or for further study at the PhD level; both thesis and non-thesis options are available. The PhD degree program is sufficiently flexible to prepare candidates for careers in industry, government, or academia. The following information provides details on these degrees.

Mines's Combined Undergraduate / Graduate Degree Program

Students enrolled in Mines's combined undergraduate/graduate program may double count up to six credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. See Graduate section of the Catalog under *Combined Undergraduate/ Graduate Degree Programs for specific details on* what types of courses are allowed and under what conditions. These courses must have been passed with "B-" or better, must not be substitutes for required coursework, and must meet all other University, Department, and Program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

Program Restrictions

Transfer Courses: Graduate-level courses taken at other universities and passed with a grade equivalent of "B" or better will be considered for transfer credit into the Mechanical Engineering Department. Approval from the Advisor and/or Thesis Committee and ME Department Head will be required as appropriate.

Internships: The Mechanical Engineering Graduate Program does not accept Internships (such as SYGN: 598I) for Graduate Credit.

Master of Science Degree Requirements

The MS degree in Mechanical Engineering requires 30 credits. Requirements for the MS thesis option are 24 credits of coursework and 6 credits of thesis research. The MS non-thesis option requires 30 credits of coursework.

Advisor and Thesis Committee: Students must have an Advisor from the Mechanical Engineering Department Faculty to direct and monitor their academic plan, research, and independent studies. The MS graduate Thesis Committee must have at least three members, two of whom must be permanent faculty in the Mechanical Engineering Department.

MS Non-Thesis Degree

MEGN502	ADVANCED ENGINEERING ANALYSIS	3.0
ME CORE	Two courses from the Mechanical Engineering Core List	6.0
ME ELECTIVES	Any 500-level or above MEGN, AMFG, or FEGN courses	12.0
TECHNICAL ELECTIVES	Any 500-level or above courses	9.0
Total Semester Hrs		**30.0**

Time Limit: As stipulated by the Mines Graduate School, a candidate for a Masters degree must complete all requirements for the degree within five years of the date of admission into the degree program.

An online modality is also available for Masters Non-Thesis.

MS Thesis Degree

MEGN502	ADVANCED ENGINEERING ANALYSIS	3.0
MEGN503	GRADUATE SEMINAR Enrollment required every Fall and Spring semester	0.0
ME CORE	Courses from the Mechanical Engineering Core List	6.0
ME ELECTIVES	Any 500-level or above MEGN, AMFG, or FEGN courses.	9.0
TECHNICAL ELECTIVES	Any 500-level or above courses (Approved by Advisor/Thesis Committee)	6.0
MEGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT	6.0
Total Semester Hrs		**30.0**

Thesis Defense: At the conclusion of the MS Thesis Option, the student will be required to make a formal presentation and defense of their thesis research to their Advisor and Thesis Committee.

Doctor of Philosophy Degree Requirements

The PhD degree in Mechanical Engineering requires 72 credits of coursework + research credits. A minimum of 30 credits of course work and 30 credits of research credits must be completed. A minimum of 12 of the 30 credits of required coursework must be taken at Colorado School of Mines.

MEGN502	ADVANCED ENGINEERING ANALYSIS	3.0
MEGN503	GRADUATE SEMINAR Enrollment required every Fall and Spring semester	0.0
ME CORE	Courses from the Mechanical Engineering Core List	6.0
TECHNICAL ELECTIVES	Technical Electives. Any 500-level or above courses approved by Advisor/Thesis Committee.	21.0
MEGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT	30.0
TOTAL CREDITS	Remaining 12 credits can come from Research and/or Technical Electives	72.0

MILESTONE	TIMELINE
Select a permanent advisor	Second semester
Complete the PhD qualifying examination	By the end of third semester
Complete all core curriculum course requirements	Fourth semester
Submit Degree Audit and Admission to Candidacy forms	By fifth semester
Establish a dissertation committee and present research proposal	By fifth semester
Present a preliminary defense	12 months before dissertation defense
Present a dissertation defense	

Advisor and Thesis Committee: Students must have an Advisor from the Mechanical Engineering Department Faculty to direct and monitor their academic plan, research, and independent studies. The PhD graduate Thesis Committee must have at least four members; at least two members must be permanent faculty in the Mechanical Engineering Department, and at least one member must be from outside the department. This outside member must chair the committee. Students who choose to have a minor program must select a representative from the minor areas of study to serve on the Thesis Committee.

Qualifying Exam: Students enrolled in the Mechanical Engineering PhD program will be required to pass a Qualifying Exam. PhD students with a minimum graduate grade point average of 3.0 are eligible to take the qualifying exam. Students must have completed at least four 500-level courses before taking the qualifier.

The Qualifying Exam assesses some attributes expected of a successful PhD student, including:

- ability to review, synthesize and apply fundamental concepts;
- creative and technical ability of the student to solve open-ended and challenging problems;
- technical communication skills.

Exam results of Pass, Conditional Pass or Fail will be provided to the student in a timely manner by the Qualifying Exam Chair. A Conditional Pass will require the student to take a remedial plan. Students have two attempts to pass the exam. If the student fails the exam on their first attempt, they must retake the exam in the following semester. One-semester extensions may be granted by the Qualifying Exam Chair.

Research Proposal: After passing the Qualifying Examination, the PhD student will prepare a written Research Proposal for the Dissertation and present it formally to the Dissertation Committee, which is selected by the student and the student's advisor and approved by the Department Head. This Research Proposal gives the Committee an early chance to discuss the work and to help the student more clearly define the work and identify the salient aspects. The research proposal must be completed before admission to candidacy.

Degree Audit and Admission to Candidacy: PhD students must complete the Degree Audit form by the posted deadlines and the Admission to Candidacy form by the first day of classes of the semester in which they want to be considered PhD candidates.

Additionally, full-time PhD students must complete the following requirements within the first two calendar years after enrolling into the PhD program:

- have a Thesis Committee appointment form on file in the Graduate Office;
- complete all prerequisite and core curriculum course requirements;
- pass the qualifier; and
- be admitted into full candidacy for the degree.

Preliminary Defense: Prior to the final Dissertation Defense, the PhD student will make an oral presentation to the student’s Committee to summarize research accomplishments and remaining goals and work plan. This meeting serves as a final check to assess if the student's progress is on schedule for graduation. The student must give no more than a 45-minute presentation that summarizes the work already accomplished, including their relevant publication(s) and a proposed plan of the work needed to culminate in a formal defense and graduation. The Committee will provide feedback and, as necessary, revisions to the proposed work plan such that its completion should lead to a successful Dissertation Defense and publication record in a realistic time frame. The time period between the Research Proposal and the Preliminary Defense can span a few years, but the Preliminary Defense should take place 12 months and no less than 6 months prior to the date of Dissertation Defense.

Required Number of Publications and Presentations: The required and recommended journal publications for PhD students prior to graduation are listed below. Students wanting to defend before meeting these requirements must submit a one-page petition with a reasonable explanation to the ME Graduate Curriculum Committee.

Journal publications **-** *Required:* Minimum of one first-author paper accepted or published (DOI is required) in a peer-reviewed journal (recognized as high quality in the research field), before Dissertation Defense. *Recommended:* Three or more first-author papers accepted or published in peer-reviewed journals.

Presentations **-** *Required:* Minimum of one research presentation (poster or podium) at an external technical conference before the Dissertation Defense. *Recommended:* Two or more conference presentations (poster or podium), before the Dissertation Defense in which the student is the first author on these presentations.

Thesis Defense: At the conclusion of the student's PhD program, the student will make a formal presentation and defense of her/his thesis research. A student must pass this defense to earn a PhD degree. The Dissertation document should be submitted to the Dissertation Committee at least 10 days prior to the Defense. The Committee will perform a post-presentation review of the Dissertation, technical contributions, and publications with the student. The Committee may request revisions to the Dissertation and additional work that requires subsequent review by the advisor and or the Committee.

Time Limit: As stipulated by the Mines Graduate School, a candidate for a doctoral degree must complete all requirements for the degree within nine years of the date of admission into the degree program.

MECHANICAL ENGINEERING CORE COURSES (ME CORE)		
MEGN505	ADVANCED DYNAMICS	3.0
MEGN514	CONTINUUM MECHANICS	3.0
MEGN551	ADVANCED FLUID MECHANICS	3.0
MEGN571	ADVANCED HEAT TRANSFER	3.0

Courses

MEGN501. ADVANCED ENGINEERING MEASUREMENTS. 3.0 Semester Hrs.

Equivalent with EGGN501,
Introduction to the fundamentals of measurements within the context of engineering systems. Topics that are covered include: errors and error analysis, modeling of measurement systems, basic electronics, noise and noise reduction, and data acquisition systems. Prerequisite: EENG281 or equivalent, and MATH201 or equivalent, Graduate student status.
Course Learning Outcomes

- Understand operational principles of many sensors.
- Be able to read and understand spec. sheets.
- Apply uncertainty analysis to experimental design and estimate order of magnitude of expected erros.
- Apply techniques for improving sensor system performance.
- Identify components needed for a sensor system and how each component affects the overall system performance.
- Understand how different measurement principles can be used to measure the same engineering values and apply physics understanding to find the most appropriate sensing options.
- Learn some experiment rules of thumb and basic troubleshooting skills.

MEGN502. ADVANCED ENGINEERING ANALYSIS. 3.0 Semester Hrs.

Introduce advanced mathematical and numerical methods used to solve engineering problems. Analytic methods include series solutions, special functions, Sturm-Liouville theory, separation of variables, and integral transforms. Numerical methods for initial and boundary value problems include boundary, domain, and mixed methods, finite difference approaches for elliptic, parabolic, and hyperbolic equations, Crank-Nicolson methods, and strategies for nonlinear problems. The approaches are applied to solve typical engineering problems. The student must have a solid understanding of linear algebra, calculus, ordinary differential equations, and Fourier theory.
Course Learning Outcomes

- Analytically solve higher-order constant coefficient Ordinary Differential Equations (ODEs).
- Solve systems of constant coefficient ODEs analytically and numerically.
- Categorize, solve and visualize solutions of variable coefficient ODEs with series solution methods.
- Develop a deep understanding of Sturm-Liouville problems by solving Bessel, Legendre and Equidimensional equations, and exploring the key characteristics of eigenfunctions.
- Solve Partial Differential Equations (PDEs) analytically using separation of variables and integral transforms, including Fourier and Laplace transforms.
- Numerically solve Initial Value Problems (IVPs) using Euler, and Runge-Kutta methods.
- Apply explicit and implicit Finite-Difference Methods (FDM) to solve combined IVPs and Boundary Value Problems (BVPs).
- Attain working knowledge of weighted residuals, and use the Finite-Element Methods (FEM) to solve PDEs relevant to mechanical engineering disciplines.
- Develop programming skills and algorithmic thinking necessary to model and solve advanced engineering mathematical problems.
- Troubleshoot written codes, validate numerical codes against analytical benchmarks, and analyze the results.

MEGN503. GRADUATE SEMINAR. 0.0 Semester Hrs.

This is a seminar forum for graduate students to present their research projects, critique others' presentations, understand the breadth of engineering projects both within their specialty area and across the Division, hear from leaders of industry about contemporary engineering as well as socio-economical and marketing issues facing today's competitive global environment. In order to improve communication skills, each student is required to present a seminar in this course before his/her graduation from the Mechanical Engineering graduate program. 1 hour per week; 0 semester hours. Course is repeatable, but no coursework credit is awarded. Prerequisites: Graduate standing.

MEGN505. ADVANCED DYNAMICS. 3.0 Semester Hrs.
This course will teach advanced methods for describing and analyzing equations of motion for mechanical systems. This class is intended for students who have a solid grasp of dynamics and differential equations. Course topics include: Lagrangian mechanics, Hamiltonian mechanics, constraints in mechanical systems, 3-D rigid body motion, stability and bifurcations of nonlinear systems, and dynamical systems theory. With these tools, students will have the capacity to model and analyze the dynamics of complex mechanical systems. The knowledge and skills from this class will help prepare students for potential careers in biomechanics, robotics, aerospace, and more.
Course Learning Outcomes

- 1. Analyze the kinematics of mechanical systems in both inertial and rotating reference frames using the vector differentiation formula.
- 2. Apply Lagrange’s equations and Hamilton’s equations to derive the equations of motion for mechanical systems.
- 3. Analyze mechanical systems with both holonomic and nonholonomic constraints using Lagrange’s equations.
- 4. Evaluate the stability of equilibrium points in nonlinear ordinary differential equation models of dynamics.
- 5. Analyze bifurcations in ordinary differential equation models as parameters of the system are changed.
- 6. Analyze the dynamics of systems of rigid bodies in 3-dimensions.
- 7. Create models of the equations of motion of real-world mechanical systems using Newtonian, Lagrangian, or Hamiltonian mechanics.
- 8. Analyze the motion of mechanical systems and the impacts of parameters using numerical methods for ordinary differential equations.

MEGN510. THEORY OF ELASTICITY. 3.0 Semester Hrs.
This is a graduate course that builds upon your knowledge of Continuum Mechanics to develop an understanding of the Theory of Elasticity. Working individually and in small groups, we will review tensor analysis, develop the governing field equations, specify boundary conditions, and apply solution methods to solve linear elastic deformation problems. In addition, we will explore solutions for plane strain, plane stress, and non-circular torsional examples. Students will prepare for future studies of non-linear elasticity, inelasticity, and fracture mechanics.
Course Learning Outcomes

- Apply the conventions of indicial notation, orthonormal basis transformation rules of tensors, dyadic representation of tensors, and eigenvalue problems of second-order tensors.
- Apply tensor algebra and calculus definitions in Cartesian, Cylindrical, and Spherical coordinates.
- Recognize the physical significance and geometric interpretation of the strain-displacement relations and compatibility equations. Calculate principal strains and the corresponding principal directions of strain, maximum longitudinal, and maximum shear strain.
- Calculate the strain state at a point by applying strain transformation equations to experimental data collected from strain gauges and rosettes.
- Calculate normal and shear tractions on planes of interest, projected shear traction, principal stresses and principal directions of stress.
- Formulate the field equations for linear isotropic elasticity and derive alternative forms for field equations.
- Apply the semi-inverse method and an Airy stress function to solve two-dimensional elasticity problems in plane strain and plane stress. Using numerical analysis software, plot the solutions and interpret the results and their significance.
- Apply the Prandtl stress function to solve torsional elasticity problems. Using numerical analysis software, plot the solutions and interpret the results and their significance.
- Apply conditions for material symmetry to develop the stiffness and compliance tensors for monoclinic, orthotropic, transversely isotropic, cubic, and isotropic materials.

MEGN511. FATIGUE AND FRACTURE. 3.0 Semester Hrs.
Equivalent with MTGN545,
Equivalent with MTGN545. This is a graduate level course in which students will learn basic fracture mechanics as applied to engineering materials. This course will cover crack growth and fracture mechanisms; cohesive strength concept; displacement, strain and stress fields in LEFM; stress intensity factors, stress concentrations, and strain energy release rate within LEFM; fracture toughness tests; plastic zone concepts; and fatigue life prediction.
Course Learning Outcomes

- Obtain and analyze case studies of fracture incidents to determine what caused the incident (comment on crack growth mechanism(s) and fracture mechanism) and make recommendations for how to prevent such an incident from happening again.
- Solve for and analyze the stress, strain and displacement fields for a general fracture mechanics problem in the linear elastic fracture (LEFM) regime
- Identify and formulate stress functions, stress intensity factors (SIFs) and strain energy release rates for general problems within the LEFM regime. Students will also be able to predict stress states and evaluate failure criteria using SIFs.
- Evaluate a fracture toughness test to judge if the test is valid using the most common ASTM testing standards (if they exist).
- Perform plastic zone correction analysis using simplified models.
- Apply simplified fatigue analysis to a specimen to estimate allowable stresses, evaluate possible fatigue damage and judge life expectancy prediction.
- Implement a simplified numerical model using software often used in industry, perform a delamination onset and growth experiment and analyze a composite specimen using two different crack advancing models.

MEGN514. CONTINUUM MECHANICS. 3.0 Semester Hrs.
This is a graduate course covering fundamentals of continuum mechanics and constitutive modeling. The goal of the course is to provide graduate students interested in fluid and solid mechanics with the foundation necessary to review and write papers in the field. Students will also gain experience interpreting, formulating, deriving, and implementing three-dimensional constitutive laws. The course explores six subjects: 1. Mathematical Preliminaries of Continuum Mechanics (Vectors, Tensors, Indicial Notation, Tensor Properties and Operations, Coordinate Transformations) 2. Stress (Traction, Invariants, Principal Values) 3. Motion and Deformation (Deformation Rates, Geometric Measures, Strain Tensors, Linearized Displacement Gradients) 4. Balance Laws (Conservation of Mass, Momentum, Energy) 5. Ideal Constitutive Relations (Frictionless & Linearly Viscous Fluids, Elasticity) 6. Constitutive Modeling (Formulation, Derivation, Implementation, Programming).

Course Learning Outcomes

- Students will learn vector calculus and index notation by solving problems sets and writing their own Matlab toolboxes of vector calculus operators.
- Students will learn general formulations of stress, strain, motion and balance laws by solving problem sets.
- Students will be introduced to constitutive modeling for both fluids and solids by solving problem sets and coding a model of their choice for the final project.

MEGN515. COMPUTATIONAL MECHANICS. 3.0 Semester Hrs.
A graduate course in computational mechanics with an emphasis on a studying the major numerical techniques used to solve problems that arise in mechanics and some related topical areas. Variational methods are applied throughout as a general approach in the development of many of these computational techniques. A wide range of problems are addressed in one- and two- dimensions which include linear and nonlinear elastic and elastoplastic steady state mechanics problems. Computational algorithms for time dependent problems such as transient dynamics and viscoplasticity are also addressed. In the latter part of the course an introduction to computational methods employing boundary integral equations, and particle methods for solving the mechanical behavior of multi-body systems are also given. Note all the software used in this course is written in MATLAB which has become a widely acceptable engineering programming tool. Prerequisite: MEGN502.
Course Learning Outcomes

- Understand and apply the variational approach to governing equations in the development of finite element algorithms.
- Develop, implement and apply computational algorithms to solve linear and nonlinear steady problems.
- Develop, implement and apply computational algorithms to solve transient problems.
- Perform extensive computer coding in MATLAB to develop and modify existing computational mechanics algorithms.

MEGN517. NONLINEAR MATERIAL BEHAVIOR. 3.0 Semester Hrs.
This course provides students with a foundational knowledge in the mechanics of solid materials displaying nonlinear deformation behavior. The course introduces general measures of deformation, such as deformation tensors, velocity gradients, stretch rate and spin tensors, as well as measures of stress, including Cauchy, Green, nominal and material stress. These concepts create a foundation on which are built in-depth descriptions of hypoelastic, hyperelastic, and viscoelastic materials, as well as plastic and viscoplastic material behaviors. For each material behavior addressed, students will put relevant mechanics theory into practice by solving problems from contemporary applications (e.g., additive manufacturing, biomechanics, battery mechanics, aerospace). A working knowledge of continuum mechanics or elasticity theory would be helpful but is not required.
Course Learning Outcomes

- Explain and apply different measures of deformation, including displacement, different strain tensors, and corresponding compatibility equations.
- Explain, compare, and apply different stress tensors as well as different constitutive relationships between stress and strain tensors; analyze boundary conditions.
- Recall and apply different functional forms of the strain energy density, explain the differences between hypo and hyper-elastic stress-strain relations, and analyze the relevance of these materials in practical applications.
- Analyze the properties and deformation behaviors of polymers; calibrate or design the properties of polymers using scaling relationships.
- Explain and apply flow and hardening laws that govern the behavior of metals loaded beyond yield, and analyze incremental stress-strain relations and stability through the perspective of maximum plastic flow and Drucker’s postulate,
- Analyze creep behavior and viscoplastic materials in the small and high strain rate regimes.

MEGN523. APPLIED COMPUTATIONAL FLUID DYNAMICS. 3.0 Semester Hrs.
The Applied Computational Fluid Dynamic course introduces the student to modeling and analysis of fluid mechanics problems via the finite difference and finite volume method. Fundamentals of CFD theory, solution, procedures, techniques, and analysis are discussed. Students will use ANSYS/Fluent CFD software to solve various fluid mechanics problems. Prerequisites: MEGN351.
Course Learning Outcomes

- The student will demonstrate the ability to use modern CFD software tools to create flow geometries, generate an adequate mesh to obtain an accurate solution, select appropriate solvers to obtain a flow solution, and visualize the resulting flow field.
- The student will replicate results from simple CFD models using fundamental numerical solutions through the governing fluid mechanics equations.
- The students will analyze a flow field to determine various quantities of interest, such as flow rates, heat fluxes, pressures, friction losses.
- The student will demonstrate the ability to recognize the type of fluid flow that is occurring in a particular physical system and to use the appropriate models/equations to investigate the flow.
- The student will design a complex (real) fluid-flow system, then using CFD solve for the flow, finally investigate the fluid-flow behavior, accuracy and explain the results.
- The student will demonstrate the ability to communicate the results, application and impact of typical CFD solutions to fluid-flow problems.

MEGN527. VEHICLE DYNAMICS AND POWERTRAIN SYSTEMS. 3.0 Semester Hrs.
This course offers an introduction to automotive engineering with a focus on vehicle design, suspension, powertrain and aerodynamics. The course is designed to introduce students to both theoretical and practical concepts of vehicle design with applications in increasing fuel efficiency and vehicle performance. The study of automotive engineering is of increasing importance as new technologies emerge and advances continue to be made to existing designs to create the ultimate driving experience; while having minimal impact on the environment by reducing tailpipe gas emissions, noise pollution, and waste material during manufacturing of new vehicles. Prerequisites: MEGN391.
Course Learning Outcomes

- Students will use fundamental lateral and longitudinal dynamic equations to design the proper suspension setup for various road and racing scenarios
- Students will be able to identify key components of a vehicle’s suspension and powertrain system and describe their respective function to the performance of the vehicle

- Students will perform relevant calculations and numerical modeling related to vehicle design and handling characteristics (e.g. roll, over/under-steer)
- Students will be able to analyze the overall design of a vehicle's exterior to calculate the impact of drag and lift forces on vehicle performance as it relates to fuel efficiency and top speed.
- Students will solve basic engine performance calculations related to power and torque and determine which final drive ratio is adequate for certain racing applications

MEGN532. EXPERIMENTAL METHODS IN BIOMECHANICS. 3.0 Semester Hrs.
Introduction to experimental methods in biomechanical research. Topics include experimental design, hypothesis testing, motion capture, kinematic models, ground reaction force data collection, electromyography, inverse dynamics calculations, ethical conduct of human subjects research, and clinical and engineering applications. There is a strong emphasis on hands-on data collection and technical presentation of results. The course will culminate in individual projects combining multiple experimental measurement techniques. 3 hours lecture; 3.0 semester hours. Prerequisite: Graduate Student Standing.
Course Learning Outcomes

- Collect motion tracking, force and electromyographic data to answer biomechanical research questions.
- Process experimental data using appropriate filtering and normalization techniques.
- Analyze experimental data in biomechanics including kinematics, ground reaction forces, and electromyography.
- Interpret biomechanical data to apply results to physiological phenomena.

MEGN535. MODELING AND SIMULATION OF HUMAN MOVEMENT. 3.0 Semester Hrs.
Introduction to musculoskeletal modeling and simulation in movement biomechanics. The class includes a synthesis of musculoskeletal properties and interactions with the environment to construct detailed computer models and simulations. Topics include kinematic model definition, modeling nonlinear muscle properties, inverse dynamics, forward dynamics, movement optimization, and muscle recruitment solutions. The class culminates in final projects incorporating musculoskeletal models, simulation development and computational analysis. This class requires a background in programming, dynamics, and an introduction to biomechanics. This is a graduate version of the undergraduate course MEGN 435; students may not take both MEGN 435 and MEGN 535. Prerequisite: MEGN315 and MEGN330.
Course Learning Outcomes

- Develop and implement musculoskeletal models using contemporary computational tools.
- Identify the assumptions, challenges, and opportunities in biomechanical modeling.
- Critically evaluate scholarly articles in biomechanical modeling and simulation literature.

MEGN536. 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 biomechanical investigations and analyses, culminating in a final design project which requires utilization of the tools and skills learned during the course to design and analyze an assistive device. Leading commercial software tools are introduced with hands-on exercises. An emphasis is placed on understanding the advantages and limitations of the computational tools 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: MEGN330, MEGN324.
Course Learning Outcomes

- Execute constrained optimization analyses in MATLAB to solve inverse kinematics, inverse dynamics, and muscle recruitment problems to calculate, predict, and analyze biomechanical quantities (e.g., joint kinematics and kinetics, muscle forces, and joint contact loads) during human motion.
- Apply musculoskeletal modeling software for verification, validation, and uncertainty quantification of biomechanics computations.
- Apply the v-diagram for medical device design control and explain the implementation of the engineering tasks embodied by this design paradigm.
- Apply computational biomechanics skills to design a medical device; analyze and justify the strengths and weaknesses of the design.

MEGN540. MECHATRONICS. 3.0 Semester Hrs.
A course focusing on implementation aspects of mechatronic and control systems. Significant lab component involving embedded C programming on a mechatronics teaching platform, called a haptic paddle, a single degree-of-freedom force-feedback joystick.
Course Learning Outcomes

- Become proficient in mechanical system modeling, system identification and simulations.
- Develop an understanding of how control theory is applied and implemented in practice.
- Learn fundamentals of and how to use semiconductor devices in mechatronic systems.
- Learn the basics of sensor and actuator theory, design, and application.
- Gain experience in embedded C programming for mechatronic systems.
- Gain experience in research article reading and technical presentations.

MEGN544. ROBOT MECHANICS: KINEMATICS, DYNAMICS, AND CONTROL. 3.0 Semester Hrs.
Mathematical representation of robot structures. Mechanical analysis including kinematics, dynamics, and design of robot manipulators. Representations for trajectories and path planning for robots. Fundamentals of robot control including, linear, nonlinear and force control methods. Introduction to off-line programming techniques and simulation. Robotics students should register for ROBO554. Prerequisite: EENG307 and MEGN441.
Course Learning Outcomes

- Understand fundamental concepts of robotics, including kinematics, dynamics and control theory for spatial motion.
- Analyze forward kinematics using Euler angles, angle-axis, and quaternion representation, compute inverse kinematics, and address kinematic singularities through constraint optimization.

- Design trajectory planning algorithms using splines and B-splines for smooth motion generation.
- Model robotic system dynamics using the Newton-Euler equations and compute inverse dynamics with recursive methods.
- Understand fundamental joint space control methodologies.
- Implement kinematics, dynamics, and control methodologies for robotic manipulators in simulation.

MEGN545. ADVANCED ROBOT CONTROL. 3.0 Semester Hrs.
The goal of this course is to give the students an introduction to a fundamental working knowledge of the main techniques of intelligent learning-based control and their applications in robotics and autonomous systems. Specific topics include neural network based control, model predictive control, reinforcement learning based control, fuzzy logic control, and human-in-the-loop control.
Course Learning Outcomes

- Obtain a basic understanding of a variety of intelligent control techniques and know how these techniques are applied to robotics engineering.
- Design robot control systems using neural network.
- Design robot control systems using reinforcement learning.
- Read and assess technical papers in intelligent robot control.
- Conduct class projects related to advanced robot control.

MEGN551. ADVANCED FLUID MECHANICS. 3.0 Semester Hrs.
This is a first-year graduate course that covers the fundamentals of incompressible fluid mechanics with a focus on differential analysis and building a foundation in the required concepts for subsequent study of computational fluid dynamics, turbulence, and compressible flow. We also explore the underlying mathematics of fluid mechanics and demonstrate how advanced mathematical tools can elucidate the real-world physics governing fluid flows. The course is divided into four parts covering (i) the governing equations of fluid mechanics, (ii) Stokes flows, (iii) ideal flows, and (iv) boundary layer flows.
Course Learning Outcomes

- Derive the conservation of mass and momentum equations in differential form.
- Physically describe the competing roles of pressure, viscosity, advection, and inertia and recognize how they are manifested in the governing equations and different flow regimes.
- Analyze fluid flows kinematically using flow lines and vorticity.
- Use order-of-magnitude analyses to simplify and solve partial differential equations.
- Identify and solve simple Stokes flows.
- Model two-dimensional potential flows.
- Derive the boundary layer equations and use them to model jets, wakes, and flat plates.

MEGN552. FLUID, THERMAL, AND MASS TRANSPORT. 3.0 Semester Hrs.
This course establishes the theoretical underpinnings of fluid mechanics, including fluid kinematics, stress-strain relationships, and derivation of the fluid-mechanical conservation equations. These include the mass-continuity and Navier-Stokes equations as well as the multi-component energy and species-conservation equations. Fluid-mechanical boundary-layer theory is developed and applied to situations arising in chemically reacting flow applications including combustion, chemical processing, and thin-film materials processing. 3 hours lecture; 3 semester hours. Prerequisite: MEGN451 or CBEN430.
Course Learning Outcomes

- Develop a fundamental and practical understanding of multi-component fluid flow.
- Derive and solve appropriate conservation equations.
- Learn computational methods to analyze multi-component and reacting flows
- Develop a sound engineering judgment for recognizing salient fluids characteristics.
- Identify and use dimensional or similarity reductions and generalizations.

MEGN553. COMPUTATIONAL FLUID DYNAMICS. 3.0 Semester Hrs.
Introduction to Computational Fluid Dynamics (CFD) for graduate students with no prior knowledge of this topic. Basic techniques for the numerical analysis of fluid flows. Acquisition of hands-on experience in the development of numerical algorithms and codes for the numerical modeling and simulation of flows and transport phenomena of practical and fundamental interest. Capabilities and limitations of CFD. Prerequisite: MEGN451.
Course Learning Outcomes

- Learn in-depth theoretical and mathematical development about the finite difference and finite volume methods for the numerical solution of the mass, momentum, energy, and species transport problems.
- Learn how to develop computer codes for solving the hyperbolic, parabolic, elliptic partial differential equations.
- Develop numerical codes for the solution of the 2D compressible Navier-Stokes equations.
- Learn how to validate and verify computer codes.
- Analyze and interpret the computed solutions of the governing conservation equations and to represent the computed numerical solution graphically using visualization techniques.
- Experience with the Ansys Fluent CFD code.

MEGN554. ORBITAL MECHANICS. 3.0 Semester Hrs.
Orbital Mechanics introduces students to the dynamics that govern motion of bodies in space and the utilization of these dynamics in spacecraft orbit and trajectory design. This course develops the mathematical foundation of propagating, describing, and manipulating the motion of a spacecraft in orbit. Throughout the semester students will script their own universe simulators to examine the various forces and geometries in orbit. Prerequisites: MEGN315.
Course Learning Outcomes

- 1. Calculate the position of a body (satellite) under Keplerian dynamics as a function of time.
- 2. Interpret the state and orbit type of a body (satellite) in an elliptical orbit using classic orbital elements.
- 3. Implement a state propagator for a body (satellite) in an elliptical orbit in Keplerian dynamics and under common perturbation models.
- 4. Calculate the impulsive delta-V maneuvers required to manipulate a body's (satellite) orbit state in common transfers
- 5. Have a basic understanding of the considerations taken when designing satellite orbits

MEGN560. DESIGN AND SIMULATION OF THERMAL SYSTEMS. 3.0 Semester Hrs.
In this course the principles of design, modeling, analysis, and optimization of processes, devices, and systems are introduced and applied to conventional and advanced energy conversion systems. It is intended to integrate conservation principles of thermodynamics (MEGN261) with the mechanism relations of fluid mechanics (MEGN351) and heat transfer (MEGN471). The course begins with general system design approaches and requirements and proceeds with mathematical modeling, simulation, analysis, and optimization methods. The design and simulation of energy systems is inherently computational and involves modeling of thermal equipment, system simulation using performance characteristics, thermodynamic properties, mechanistic relations, and optimization (typically with economic-based objective functions). Fundamental principles for steady-state and dynamic modeling are covered. Methods for system simulation which involves predicting performance with a given design (fixed geometry) are studied. Analysis methods that include Pinch Technology, Exergy Analysis, and Thermo-economics are examined and are considered complementary to achieving optimal designs. Optimization encompasses objective function formulation, systems analytical methods, and programming techniques. System optimization of the design and operating parameters of a configuration using various objective functions are explored through case studies and problem sets. Economics and optimization for analyses and design of advanced energy systems, such as Rankine and Brayton cycle power plants, combined.
Course Learning Outcomes

- Understand and distinguish between the various principles of design,modeling, analysis, and simulation as it applies to energy conversion systems.
- Be adept at integrating conservation principles of thermodynamics with mechanistic relations of fluid mechanics and heat transfer to predict the performance of energy conversion processes, devices, and systems.
- Understand the basic elements of techno-economic analysis and optimization-based design of thermal systems.
- Develop proficiency in the use of computational modeling, simulation, and optimization techniques to solve more realistic, complex problems in thermal systems.

MEGN561. ADVANCED ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.
First year graduate course in engineering thermodynamics that emphasizes a greater depth of study of undergraduate subject matter and an advancement to more complex analyses and topics. The course begins with fundamental concepts, 1st and 2nd Law analyses of processes, devices, and systems and advances to equations of state, property relations, ideal and non-ideal gas mixtures, chemically reacting systems, and phase equilibrium. Historical and modern contexts on the development and advancements of thermodynamic concepts are given. Fundamental concepts are explored through the analysis of advanced thermodynamic phenomena and use of computational tools to solve more realistic problems. Prerequisite: MEGN261, MEGN351, MEGN471.
Course Learning Outcomes

- Understand the fundamental theory of the 1st and 2nd Laws of Thermodynamics.
- Recognize critical assumptions, property relations, and approaches for different physical situations.
- Understand how thermodynamic problems are solved and solve them using available computational tools and techniques.
- Use engineering thermodynamics in their research work or applications.

MEGN565. ELECTRIC VEHICLE POWERTRAIN SYSTEMS. 3.0 Semester Hrs.
In the fast-evolving world of sustainable transportation, it is essential for engineers in the automotive industry to understand energy conversion, storage, utilization, and optimization of vehicle powertrains. Electric Vehicle Powertrain Systems (EVPS) is designed to provide students with a comprehensive understanding of the essential powertrain components in battery-electric vehicles (BEVs) including motors, controllers, and battery packs. Through a combination of theoretical modeling and hands-on projects, students will gain knowledge and skills in powertrain system design to achieve vehicle objectives, encompassing energy analysis, power requirements, and efficiency considerations. The course will also explore the state-of-the-art in safety measures, management strategies, control systems, charging/balancing techniques, and State of Charge (SOC)/State of Health (SOH) estimation for EV battery packs. Prerequisites: MEGN 300 or EENG282.
Course Learning Outcomes

- Articulate the functions and interrelationships of the core powertrain components in electric vehicles, including the motor, controller, and battery pack
- Design a vehicle powertrain architecture and select powertrain components that meet the overarching goals of an electric vehicle, incorporating top-level requirements such as energy use, power output, and efficiency optimization
- Implement the Road Load Equation on dynamic course profiles to determine vehicle, battery, motor, and controller power and system energy requirements
- Explain the operating principles and fundamental characteristics of Li-ion batteries using underlying electrochemical processes and implement them in an equivalent circuit battery model
- Apply experimental methods used to characterize the performance of Li-ion cells in automotive applications, while elucidating the principles and significance of these techniques in assessing battery behavior and performance.
- Critically assess and compare the state of the art in safety protocols, management strategies, control systems, and charging/balancing techniques for battery packs in electric vehicle powertrain systems.
- Devise a functional design for a battery pack tailored to the specific requirements and constraints of a full-size electric vehicle, integrating considerations such as energy storage capacity, thermal management, safety measures, and space utilization
- Describe the basic operating principles of EV motors and controllers
- Explain the fundamentals and applications of Field Oriented Control in an EV powertrain
- Calculate vehicle performance characteristics based on operating limits of the full BEV architecture, including the batteries, motor, and controller

MEGN566. COMBUSTION. 3.0 Semester Hrs.
(I) An introduction to combustion. Course subjects include: the development of the Chapman-Jouget solutions for deflagration and detonation, a brief review of the fundamentals of kinetics and thermochemistry, development of solutions for diffusion flames and

premixed flames, discussion of flame structure, pollutant formation, and combustion in practical systems. Prerequisite: MEGN451 or CBEN430. 3 hours lecture; 3 semester hours.

MEGN567. PRINCIPLES OF BUILDING SCIENCE. 3.0 Semester Hrs.
First or second year graduate course that covers the fundamentals of building energy systems, moist air processes, heating, ventilation, and air conditioning (HVAC) systems and the use of numerical models for heat and mass transfer to analyze advanced building technologies such as phase change materials, green roofs or cross laminated timber. This is a graduate version of the undergraduate course MEGN 467; students may not take both MEGN 467 and MEGN 567. Prerequisites: MEGN261, MEGN351, MEGN471.
Course Learning Outcomes

- Understand and apply fundamental principles to HVAC design.
- Describe components in HVAC systems.
- Understand how building HVAC loads are calculated and calculate building HVAC loads.
- Analyze advance building technologies using building energy simulations tools.
- Write technical report based on energy modeling results.

MEGN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN569,CHEN569,MLGN569,MTGN569,
Equivalent with CBEN569, CHEN569, MLGN569, MTGN569. 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. This is a graduate version of the undergraduate course MEGN469; students may not take both MEGN469 and MEGN569.
Course Learning Outcomes

- Contrast the advantages and disadvantages of fuel cells to other energy conversion technologies.
- Describe the basic mechanisms of fuel cell reactions, electron transfer, and ionic transport at the molecular scale.
- Calculate the ideal fuel cell voltage and efficiency as a function of gas concentrations, pressure, and temperature. Derive equations for activation, IR, and concentration losses in fuel cell systems.
- Identify the most significant kinetic constraints that limit current fuel cell performance and suggest research directions to improve performance. Describe and compare the major strategies for fuel cell stacking.
- Describe and compare the major strategies for fuel cell stacking.
- Describe and discuss the ancillary equipment necessary for a complete fuel-cell system, including fuel reforming and thermal management.
- Examine approaches to system modeling to identify system limitations and integration needs.
- Use numerical simulations to explore the interrelation between fuel cell system design, operating conditions, and performance/efficiency.

MEGN570. ELECTROCHEMICAL SYSTEMS ENGINEERING. 3.0 Semester Hrs.
In this course, students will gain fundamental, quantitative insight into the operation of electrochemical devices for engineering analysis across a range of length scales and applications. The course will use the development of numerical models as a lens through which to view electrochemical devices. However, the course will also deal extensively with "real world" systems and issues, including experimental characterization, system optimization and design, and the cyclical interplay between models and physical systems. The course begins by establishing the equations that govern device performance at the most fundamental level, describing chemical and electrochemical reactions, heat transfer, transport of charged and neutral species, and material properties in operating devices. Subsequently, these equations will be used to discuss and analyze engineering issues facing three basic types of electrochemical devices: fuel cells, batteries, and sensors. At each juncture will evaluate our equations to determine when simpler models may be more suitable. Throughout the semester, concepts will be applied in homework assignments, including an over-arching, semester-long project to build detailed numerical models for an application of each student's choosing.
Course Learning Outcomes

- Apply conservation of mass, species and energy to model electrochemical processes and predict performance.
- Use numerical simulations to design and optimize electrochemical systems.
- Given multiple alternatives, students will choose an appropriate level of detail for charge transfer and mass transport models.
- Interpret model simulation results to identify limiting physical processes in a given electrochemical device.

MEGN571. ADVANCED HEAT TRANSFER. 3.0 Semester Hrs.
This course provides students with the foundational knowledge and skills to use analytical and numerical approaches to solve interesting problems for design and performance analysis of materials, devices, and systems that involve heat transfer. The topics include steady-state and transient conduction, boundary layer convection heat transfer, and gray body radiative surface exchange. The knowledge of these topics and the mathematical and numerical skills are combined in various multi-mode heat transfer problems related to an array of industries such as sustainable energy conversion, aerospace, and/or manufacturing and materials processing, electronics packaging, and building design and analysis. A final course project gives students the opportunity to utilize the skills gained in this course in a team design project.
Course Learning Outcomes

- Apply energy balances to control volumes/surfaces to derive and solve differential equations for steady and transient temperatures and heat fluxes within an object and at boundary interfaces.
- Develop reduced order models of internal and external flows using appropriate heat transfer correlations with or without turbulence, phase change, or buoyancy to predict profiles of temperature and heat fluxes.
- Calculate surface radiative properties, evaluate view factors, and solve numerically radiation exchange between surfaces.
- Identify and implement reduced-order models of heat exchangers and other thermal systems to estimate performance and complete design studies.
- Implement computational models of multi-modal heat transfer within thermal devices, including solution of coupled differential equations and non-linear systems of equations.

MEGN579. OPTIMIZATION MODELS IN MANUFACTURING. 3.0 Semester Hrs.

This course addresses the mathematical formulation and solution of optimization models relevant in manufacturing operations. The types of optimization models examined include: (i) network models; (ii) linear programs; (iii) integer programs; and (iv) nonlinear programs. Application areas include scheduling, blending, design, equipment replacement, logistics and transportation, among other topics. Students learn not only how to mathematically formulate the models, but also how to solve them with a state-of-the-art modeling language (AMPL) and appropriate solver (e.g. CPLEX or Minos). Algorithms for each problem class will be briefly discussed. This is a graduate version of the undergraduate course MEGN 479; students may not take both MEGN 479 and MEGN 579.
Course Learning Outcomes

- Understand the concept of optimization.
- Understand how optimization can be applied in a manufacturing setting.
- Differentiate between network models, linear programs, integer programs, and nonlinear programs.
- Be able to algebraically represent each type of optimization model.
- Implement optimization formulations in an algebraic modeling language and solve to obtain and analyze solutions.

MEGN585. NETWORK MODELS. 3.0 Semester Hrs.

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. Offered every other year. This is a graduate version of the undergraduate course MEGN 485; students may not take both MEGN485 and MEGN 585.
Course Learning Outcomes

- Understand how to differentiate spanning tree, shortest path, maximum flow and minimum cost flow models.
- Understand how to graphically depict and mathematically model spanning tree, shortest path, maximum flow and minimum cost flow models.
- Understand algorithms that solve model spanning tree, shortest path, maximum flow and minimum cost flow models.
- Understand the difference between network and non-network optimization models

MEGN586. LINEAR OPTIMIZATION. 3.0 Semester Hrs.

We address 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. This is a graduate version of the undergraduate course MEGN 486; students may not take both MEGN 486 and MEGN 586.
Course Learning Outcomes

- Understand how to formulate linear optimization models.
- Understand how to solve linear optimization models, both by hand and with the computer through an algebraic modeling language and a state-of-the-art solver.
- Understand the special structure underlying linear optimization models and how this affects their ability to be solved.
- Understand sensitivity and post-optimality analysis.

MEGN587. NONLINEAR OPTIMIZATION. 3.0 Semester Hrs.

Equivalent with MEGN487,
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.
Course Learning Outcomes

- Understand how to formulate nonlinear optimization models.
- Understand how to solve nonlinear optimization models, both by hand and with the computer through an algebraic modeling language and a state-of-the-art solver.
- Understand the special structure underlying nonlinear optimization models and how this affects their ability to be solved.

MEGN588. INTEGER OPTIMIZATION. 3.0 Semester Hrs.

Equivalent with MEGN488,
(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. 3 hours lecture; 3 semester hours. Prerequisite: MATH111.
Course Learning Outcomes

- Understand how to formulate linear-integer optimization models.
- Understand how to solve linear-integer optimization models, both by hand and with the computer through an algebraic modeling language and a state-of-the-art solver.
- Understand the special structure underlying linear-integer optimization models and how this affects their ability to be solved.
- Understand decomposition techniques to aid in solution.

MEGN592. RISK AND RELIABILITY ENGINEERING ANALYSIS AND DESIGN. 3.0 Semester Hrs.

The importance of understanding, assessing, communicating, and making decisions based in part upon risk, reliability, robustness, and uncertainty is rapidly increasing in a variety of industries (e.g.: petroleum, electric power production, etc.) and has been a focus of some industries for many decades (e.g.: nuclear power, aerospace, automotive, etc). This graduate class will provide the student with a technical understanding of and ability to use common risk assessment tools such as Reliability Block Diagrams (RBD), Failure Modes and Effects Analysis (FMEA), and

Probabilistic Risk Assessment (PRA); and new tools being developed in universities including Function Failure Design Methods (FFDM), Function Failure Identification and Propagation (FFIP), and Uncoupled Failure Flow State Reasoning (UFFSR) among others. Students will also be provided with a high-level overview of what risk really means and how to contextualize risk information. Methods of communicating and making decisions based in part upon risk.

Course Learning Outcomes

- Understand and be able to use probability statistics.
- Understand and be able to use Bayesian statistical methods.
- Demonstrate ability to use PRA software.
- Demonstrate ability to model a complex engineered system using several (RBD, FMEA, PRA, FFDM, etc) risk and reliability methods.

MEGN598. SPECIAL TOPICS IN MECHANICAL ENGINEERING. 0-6 Semester Hr.

Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MEGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.

Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MEGN651. ADVANCED COMPUTATIONAL FLUID DYNAMICS. 3.0 Semester Hrs.

This course covers the fundamentals of computational fluid dynamics (CFD) for unsteady incompressible fluids flows, including examples of heat and mass transport. The course focuses on finite volume-methods, efficient projection methods for simulating unsteady flows, and recent advances in immersed boundary methods for complicated geometries. The course is entirely based on weekly homework, through which students learn how to build and benchmark their own CFD codes. By the end of the course, students should have the required fundamentals to either build their own research codes or use commercial and open source CFD codes intelligently. Prerequisites: MEGN502 and MEGN551 are recommended.

Course Learning Outcomes

- Develop an in-house CFD code that simulates unsteady incompressible fluid flows with heat and mass transport.
- Verify the spatial and temporal accuracy of CFD codes.
- Explain how the competing roles of advection and diffusion impact CFD.
- Explain how the role of pressure in incompressible flows impacts CFD.
- Model flow over a complex surface using an immersed boundary method.

MEGN686. ADVANCED LINEAR OPTIMIZATION. 3.0 Semester Hrs.

As an advanced course in optimization, we expand upon topics in linear programming: advanced formulation, the dual simplex method, the interior point method, algorithmic tuning for linear programs (including numerical stability considerations), column generation, and Dantzig-Wolfe decomposition. Time permitting, dynamic programming is introduced. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Prerequisite: MEGN586.

Course Learning Outcomes

- Understand how to formulate complicated linear optimization models.
- Dual Simplex Method and Interior Point Method.
- Algorithmic Tuning.
- Column Generation and Dantzig-Wolfe Decomposition.

MEGN688. ADVANCED INTEGER OPTIMIZATION. 3.0 Semester Hrs.

As an advanced course in optimization, we expand upon topics in integer programming: advanced formulation, strong integer programming formulations (e.g., symmetry elimination, variable elimination, persistence), in-depth mixed integer programming cuts, rounding heuristics, constraint programming, and decompositions. Applications of state-of-the-art hardware and software emphasize solving real-world problems in areas such as manufacturing, mining, energy, transportation and logistics, and the military. Computers are used for model formulation and solution. Prerequisite: MEGN588.

Course Learning Outcomes

- Know how to formulate advanced integer optimization models 2. Be familiar with advanced algorithms to solve these models 3. Be able to use software, including scripting, to model and solve these models 4. Understand the theory behind and mathematical tenants of advanced integer optimization models.
- Be familiar with advanced algorithms to solve these models.
- Use software, including scripting, to model and solve these models.
- Understand the theory behind and mathematical tenants of advanced integer optimization models.

MEGN698. SPECIAL TOPICS. 0-6 Semester Hr.

(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

MEGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.

(I, II, S) Individual research or special problem projects supervised by a faculty member, also, 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: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

MEGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.

Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.

Professor and Department Head

Anthony J. Petrella, Department Head

Professors

Alexandra Newman, Director of Operations Research with Engineering Program

Carl Frick, Professor and Dean of Graduate Studies

Cristian Ciobanu

Gregory Jackson

John Berger, Dean of Energy and Materials

Mohsen Asle Zaeem

Neal Sullivan

Robert Braun, University Distinguished Professor of Mechanical Engineering and Director of Mines/NREL Advanced Energy Systems Program

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Associate Professors

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Elijah Kuska

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Sandrine Ricote

Huayang Zhu

Research Assistant Professors

Omid Babaie-Rizvandi

Carolina Herradon Hernandez

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