MECHANICAL ENGINEERING

The part-time Mechanical Engineering program is designed for working engineers who want to enhance their effectiveness in a complex and rapidly evolving technological and organizational environment. The program broadens and strengthens students' understanding of traditional fundamentals but also introduces them to contemporary applications and technologies.

Program Committee

Jaafar A. El-Awady, Program Chair
Professor of Mechanical Engineering
Whiting School of Engineering
Johns Hopkins University

Christopher Stiles, Program Vice Chair
Senior Professional Staff
Applied Physics Laboratory
Johns Hopkins University

Michael P. Boyle, Program Manager
Principal Professional Staff
Applied Physics Laboratory
Johns Hopkins University

Thomas Urban
Principal Professional Staff
Whiting School of Engineering
Johns Hopkins University

Programs

- Mechanical Engineering, Master of Science (https://e-catalogue.jhu.edu/engineering/engineering-professionals/mechanical-engineering/mechanical-engineering-master-science/)
- Mechanical Engineering, Post-Master's Certificate (https://e-catalogue.jhu.edu/engineering/engineering-professionals/mechanical-engineering/mechanical-engineering-post-masters-certificate/)

Courses

EN.535.603. Applied Optimal Control. 3 Credits.
The course focuses on the optimal control of dynamical systems subject to constraints and uncertainty by studying analytical and computational methods leading to practical algorithms. Topics include calculus of variations, nonlinear local optimization, global stochastic search, dynamic programming, linear quadratic (gaussian) control, numerical trajectory optimization, model-predictive control. Advanced topics include approximate dynamic programming and optimal control on manifolds. The methods and algorithms will be illustrated through implementation of various simulated examples. Recommended Course Background: Linear Algebra and Differential Equations; experience with control systems; programming in MATLAB and/or Python.

EN.535.606. Advanced Strength Of Materials. 3 Credits.
This course reviews stress and strain in three dimensions, elastic and inelastic material behavior, and energy methods. It also covers use of the strength of materials approach to solving advanced problems of torsion and bending of beams. Prerequisite(s): Fundamental understanding of stress and strain and axial, torsion, and bending effects in linear elastic solids.

EN.535.607. Mechanics of Solids and Structures: Theory and Applications I. 3 Credits.
This course provides an introduction to the mathematical and theoretical foundations of the mechanics of solids and structures. We will begin with the mathematical preliminaries used in continuum mechanics: vector and tensor calculus, then introduce 3D kinematics and strain measures, descriptions of stress in a 3D body, equilibrium, and constitutive rules. These concepts will be applied to develop the constitutive equations for solids, methods for solving boundary values problems that occur in engineering structures, energy methods and foundations of large deformation.

EN.535.608. Hypersonic Technologies and Systems. 3 Credits.
"Hypersonics" is a general term used to describe flight at speeds greater than Mach 5 (or five times the sound speed). The technologies associated with hypersonic flight have been investigated for many decades and applications of hypersonic systems currently include ballistic missiles, re-entry vehicles, launch vehicles, and interceptor missiles. There is currently a resurgence in interest in new hypersonic applications for weapon applications, reusable aircraft, and reusable space launchers. With a view towards the history of hypersonics and developing worldwide trends, this course provides a survey of hypersonic technologies, systems and applications while addressing the underlying fundamental physics, analysis approaches, and design methodologies.

EN.535.610. Computational Methods of Analysis. 3 Credits.
This course will provide an introduction to computational methods of analysis, with the aim of preparing the student to take a real-world problem and break it down to its component parts, perform computational analysis, and report findings in a comprehensive and informative manner. This course introduces the student to several application areas, and the corresponding computational tools, assumptions, and limitations. Throughout the course, the student will solve problems computationally in a hands-on manner, with a particular emphasis on tradeoffs between complexity, cost, and utility.

EN.535.612. Intermediate Dynamics. 3 Credits.
This course develops student's ability to accurately model the dynamics of single and multi-body engineering systems undergoing motion in 3D space. The course begins with formulating the differential geometry and kinematics of curvilinear coordinates to permit kinematic descriptions of relative motion and rotation of rigid bodies and mechanisms subject to common engineering constraints such as substructure interconnections, dry friction, and rolling. Momentum and inertia properties of rigid body dynamics follow. Students are then introduced to analytical dynamics, where Lagrange's equations and Kane's method are derived and studied to facilitate efficient formulation of the equations of motion governing the dynamics of systems subject to conservative and non-conservative forces and engineering constraints. The course also concludes with gyroscopic dynamics with applications to inertial guidance and spacecraft attitude dynamics. Prerequisite(s): Mathematics through calculus and linear algebra.

EN.535.613. Structural Dynamics and Stability. 3 Credits.
This course introduces the propagation of elastic waves, and the loss of stability in engineering structures and systems. In the first part of the course, fundamental physical principles of elasticity and wave mechanics are reviewed and developed to provide students with the capability to model and analyze wave propagation, reflection, and refraction in isotropic and anisotropic engineering structures such as rods, beams, and plates. In the second part of the course, mechanical stability models are studied and applied in terms of dynamic behavior where the combined effects of vibration, gyroscopic motion, impact/shock, and buckling lead to new structural configurations or unstable motions that must often be avoided in design. Applications span nondestructive evaluation, composites, cables, aircraft/space structures, rotordynamics, aeroelasticity, civil engineering structures, and others. Prerequisite(s): Undergraduate or graduate course in vibrations.

EN.535.614. Fundamentals of Acoustics. 3 Credits.
This course introduces the physical principles of acoustics and their application. Fundamental topics include the generation, transmission, and reception of acoustic waves. Applications covered are selected from acoustic arrays, underwater acoustics, architectural acoustics, and biomedical acoustics. Prerequisite(s): Some familiarity with linear algebra, complex variables, and differential equations.

EN.535.618. Fabricatology - Advanced Materials Processing. 3 Credits.
The “Fabricatology” is a course that students can learn how to make desired shapes, structures, and surfaces across various length scales. It will introduce rich scientific and engineering knowledge related to fabrication at multiple length scales and the generated materials and mechanical systems can be utilized for studying diverse topics including energy harvesting, metamaterials, wetting, and information storage. From this course, students can learn principles and technologies to control shapes at various length scales and processes to control internal structures or surface properties for desired properties/functions. They will be also introduced to exciting recent developments in the field such as 3D printing so that they can have a comprehensive knowledge about the subject.

EN.535.620. Fluid Dynamics I. 3 Credits.
This first graduate course in fluid dynamics starts from derivation of the flow equations and examines a number of limiting behaviors. When viscous effects are ignored all together, we obtain the familiar limit of potential flow. Boundary layer theory is introduced to examine the effect of viscosity near surfaces. And in the limit where viscosity is dominant, we obtain what is known as “creeping flow” where inertia can be ignored all together. Our approach will rely on developing the theory and considering classical examples in order to advance our understanding of fluid motion in each of these areas.

EN.535.621. Intermediate Fluid Dynamics. 3 Credits.
This course prepares the student to solve practical engineering flow problems and concentrates on the kinematics and dynamics of viscous fluid flows. Topics include the control volume and differential formulations of the conservation laws, including the Navier-Stokes equations. Students examine vorticity and circulation, dynamic similarity, and laminar and turbulent flows. The student is exposed to analytical techniques and experimental methods, and the course includes an introduction to computational methods in fluid dynamics. It also includes a programming project to develop a numerical solution to a practical fluid flow problem. Prerequisite(s): An undergraduate fluid mechanics course.

EN.535.622. Robot Motion Planning. 3 Credits.
This course investigates the motion planning problem in robotics. Topics include motion of rigid objects by the configurations space and retraction approaches, shortest path motion, motion of linked robot arms, compliant motion, coordinated motion of several objects, robust motion with error detection and recovery, and motion in an unknown environment

EN.535.623. Intermediate Vibrations. 3 Credits.
Course topics include transient and forced vibration of 1- and N-degree-of-freedom systems and an introduction to vibration of continuous systems. Hamilton’s Principle and Lagrange’s equations are used throughout the course to derive the equation(s) of motion. MATLAB is introduced and used to solve the equations of motion and plot the response of the system. This course also addresses common topics in applied vibrations such as the environmental testing, the shock response spectrum, random vibration, vibration isolation, and the design of tuned-mass damper systems. Prerequisite(s): An undergraduate vibrations course.

EN.535.625. Turbulence. 3 Credits.
Fundamental equations of fluid mechanics, Reynolds averaging, and the closure problem. Scaling and self-preservation in boundary-free and wall-bounded shear flows. Isotropic turbulence and spectral theories. Vorticity dynamics, intermittency, and cascade models. Turbulence modeling: one- and two-equation models, Reynolds stress modeling, and large-eddy simulations.

EN.535.626. Mechanics of Flight. 3 Credits.
This course provides a comprehensive overview of aerodynamics, covering the principles and applications from subsonic to hypersonic flight. Students will explore key topics such as airfoil and wing theory, shock waves, high-temperature gas dynamics, and the design considerations for various flight regimes. The course combines theoretical foundations with practical insights, preparing students to analyze and optimize aerodynamic performance in modern aerospace engineering.

EN.535.627. Computer-Aided Design. 3 Credits.
This course introduces the student to the intricacies of Computer-Aided Design (CAD) utilizing Creo Parametric. Throughout the course, students will acquire a comprehensive skill set encompassing sketching, solid part modeling, assembly modeling, drawing creation, advanced modeling techniques, sheet metal design, geometric dimensioning and tolerancing (GD&T), as well as mechanisms and finite element analysis (FEA). The curriculum commences with an introduction to Creo Parametric, offering insights into its interface, sketching tools, and parametric design principles. Subsequently, students engage in a detailed exploration of solid part modeling, mastering 3D modeling techniques. Assembly modeling follows, emphasizing constraints, relationship management, and collaborative design principles for large assemblies. Participants also gain proficiency in creating 2D engineering drawings, utilizing annotation tools, and adhering to dimensioning and tolerancing standards. The course progresses to advanced modeling, incorporating features like surfacing and other advanced modeling techniques for real-world engineering applications. Sheet metal design principles are introduced, covering unfolding, bending techniques, and design considerations unique to sheet metal components. Students learn symbols, standards, and the application of GD&T principles in CAD models. The exploration of CAD extends to mechanisms, incorporating kinematic analysis, modeling, simulation, and dynamic analysis. Finally, Finite Element Analysis (FEA) is introduced, covering basics, mesh generation, boundary conditions, and result interpretation. By the end of the course, students will be equipped with advanced skills in computer-aided design, positioning them for success in roles demanding proficiency in engineering design and analysis, especially using Creo Parametric but these skills extend to every CAD program.

EN.535.628. Computer-Integrated Design and Manufacturing. 3 Credits.
This course emphasizes the computer automation of design and manufacturing systems. A survey of the automation techniques used for integration in modern design and manufacturing facilities is presented. Discussions are presented related to the system integration of computer-aided design (CAD), computeraided engineering (CAE), computer-aided manufacturing (CAM), robotics, material resource planning, tool management, information management, process control, and quality control. The current capabilities, applications, limitations, trends, and economic considerations are stressed.

EN.535.630. Kinematics & Dynamics of Robots. 3 Credits.
This course introduces the basic concepts and tools used to analyze the kinematics and dynamics of robot manipulators. Topics include kinematic representations and transformations, positional and differential kinematics, singularity and workspace analysis, inverse and forward dynamics techniques, and trajectory planning and control. Prerequisite(s): The course project and assignments will require some programming experience or familiarity with tools such as MATLAB.

EN.535.632. Applied Finite Elements. 3 Credits.
This Applied Finite Elements course provides a wide-ranging exploration of the practical applications of finite element analysis (FEA) using both Creo Simulate and Ansys. Creo Simulate's integration with the Creo Parametric, a computer-aided design (CAD) tool, affords a number of advantages, most notably a remarkable efficiency in performing analyses and the possibility for Simulate to seamlessly manipulate the CAD model in performing design optimizations. Within Simulate, students will learn to perform linear structural static analyses of parts and assemblies. Students will also learn to represent preloaded bolts, create both solid and thin shell meshes, and improve the reliability of FEA results through convergence studies. Within Ansys, and industry standard FEA program, students will revisit the most common types of analyses, making some comparisons back to the results from Creo Simulate. Next, students will then learn to partition CAD geometry into mesh-able volumes then construct high quality hexahedral meshes. Finally, students perform a broad array of other simulation types that include transient structural, nonlinear materials, explicit dynamics, and computational fluid dynamics. Opportunities exist throughout the course to individually apply the techniques covered in ways applicable to students' personal interests, career, or career ambitions.

EN.535.633. Intermediate Heat Transfer. 3 Credits.
This course covers the following topics: transient heat conduction, forced and free convection in external and internal flows, and radiation processes and properties. Prerequisite(s): An undergraduate heat transfer course.

EN.535.634. Applied Heat Transfer. 3 Credits.
This course focuses on the inevitable tradeoffs associated with any thermodynamic or heat transfer system, which result in a clear distinction between workable and optimal systems. The point is illustrated by means of a number of concrete problems arising in power and refrigeration systems, electronics cooling, distillations columns, heat exchange, and co-generation systems. Prerequisite(s): An undergraduate heat transfer course.

EN.535.635. Introduction to Mechatronics. 3 Credits.
Mechatronics is the integration of mechanisms, electronics, and control. This interdisciplinary course is primarily lab and project based, but also includes lectures to provide background in key underlying principles. The course's main objective is to provide experience designing and prototyping a mechatronic or robotic system to accomplish a specific task or challenge. Topics include mechanism design, motor and sensor integration and theory, programming of microprocessors, mechanics prototyping, and the design process. Students will work in teams to complete a hardware-based final project. Prerequisite(s): Mathematics through calculus and linear algebra.

EN.535.638. Mechanical Packaging for Electronics Systems. 3 Credits.
This course will provide students with a fundamental understanding of the principles and techniques used to design and analyze the mechanical packaging of electronics systems. Lectures will include discussions on practical approaches to the design of enclosures, including manufacturability and assembly as well as analytical approaches to thermal and structural concerns. Upon completion of this course, students will have a clear understanding of the engineering considerations and tradeoffs used in developing rugged mechanical designs for electronics systems to be used in many environments.

EN.535.641. Mathematical Methods For Engineers. 3 Credits.
This course covers a broad spectrum of mathematical techniques needed to solve advanced problems in engineering. Topics include linear algebra, the Laplace transform, ordinary differential equations, special functions, partial differential equations, and complex variables. Application of these topics to the solutions of physics and engineering problems is stressed. Prerequisite(s): Vector analysis and ordinary differential equations.

EN.535.642. Control Systems for Mechanical Engineering Applications. 3 Credits.
This class provides a comprehensive introduction to the theory and application of classical control techniques for the design and analysis of continuous-time control systems for mechanical engineering applications. Topics include development of dynamic models for mechanical, electrical, fluid-flow and process-control systems, introduction to Laplace transforms, stability analysis, time and frequency domain analysis techniques, and classical design methods. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.

EN.535.643. Plasticity. 3 Credits.
The theory of the inelastic behavior of metallic materials. Experimental background and fundamental postulates for the plastic stress-strain relations. Mechanisms of plastic flow; single-crystal and polycrystalline plasticity. Boundary value problems. Variational principles, uniqueness and the upper and lower bound theorems of limit analysis. Slip line theory. Dynamic plasticity and wave phenomena. Finite strain plasticity and instability.

EN.535.645. Digital Control and Systems Applications. 3 Credits.
This class will provide a comprehensive treatment of the analysis and design of discrete-time control systems. The course will build upon the student's knowledge of classical control theory and extend that knowledge to the discretetime domain. This course is highly relevant to aspiring control systems and robotics engineers since most control system designs are implemented in micro-processors(hence the discrete-time domain) vice analog circuitry. Additionally, the course will go into advanced control system designs in the state-space domain and will include discussions of modern control design techniques including linear-quadratic optimal control design, pole-placement design, and state-space observer design. The class will use a series of applications that build in complexity throughout the semester to emphasize and reinforce the material.
Prerequisite(s): EN.535.642 Control Systems for Mechanical Engineering Applications.

EN.535.652. Thermal Systems Design and Analysis. 3 Credits.
Thermodynamics, fluid mechanics, and heat transfer principles are applied using a systems perspective to enable students to analyze and understand how interactions between components of piping, power, refrigeration, and thermal management systems affect the performance of the entire system. Following an overview of the fundamental principles involved in thermal and systems analyses, the course will cover mathematical methods needed to analyze the systems and will then explore optimization approaches that can be used to improve designs and operations of the thermal systems to minimize, for example, energy consumption or operating costs. Students are expected to perform basic computer programming in a language chosen by the student (e.g., Matlab, Python, etc). Example Matlab code to complement the course content will be provided by the instructor. Prerequisite(s): Undergraduate courses in thermodynamics and heat transfer.

EN.535.659. Manufacturing Systems Analysis. 3 Credits.
This course is a review of the fundamentals of modern manufacturing processes, computer-aided design/ manufacturing tools, flexible manufacturing systems, and robots. The course addresses relationships between process machinery, process conditions, and material properties. Examples of how components are manufactured within hightech industries are presented.

EN.535.660. Precision Mechanical Design. 3 Credits.
This course will provide the student with a fundamental understanding of the principles and techniques used to design precision machines, instruments, and mechanisms. Lectures will include discussions on the implementation and design of mechanisms, bearings, actuators, sensors, structures, and precision mounts used in precision design. Upon completion of this course, students will have a clear understanding of positional repeatability and accuracy, deterministic design, exact constraint design, error modeling, and sources of machine and instrumentation errors.

EN.535.661. Biofluid Mechanics. 3 Credits.
Introduction to fundamental fluid mechanics of physiological systems including the blood flow in the cardiovascular system and the air flow in the laryngeal and respiratory systems. Basic physiology of those systems will be introduced. Fundamental principles and mathematical/physical models for the air and blood flows in the physiological systems and their practical applications will be discussed. Simple computer models with MATLAB will be used in the course.

EN.535.662. Energy and Environment. 3 Credits.
The course focuses on the impacts of energy consumption and generation on the environment. Second law thermodynamic analysis will be used to help understand the quality of different energy sources and to assess whether they are being used to their fullest abilities. Given the attention given to climate change, greenhouse gas emissions from the energy sector will be evaluated. Life Cycle Assessment will be introduced to help understand broader environmental impacts from the acquisition of raw materials to the disposal of devices and equipment. The course will examine the key places where energy is used in the economy (buildings, industry, transportation) then transition to key sources of energy and issues in generation of energy (utilities, nuclear energy, alternative energy, energy storage, water-energy nexus).

EN.535.663. Biosolid Mechanics. 3 Credits.
This class will introduce fundamental concepts of statics and solid mechanics and apply them to study the mechanical behavior bones, blood vessels, and connective tissues such as tendon and skin. Topics to be covered include the structure and mechanical properties of tissues, such as bone, tendon, cartilage and cell cytoskeleton; concepts of small and large deformation; stress; constitutive relationships that relate the two, including elasticity, anisotropy, and viscoelasticity; and experimental methods for measuring mechanical properties.

EN.535.664. Fundamental Principles for Bio-microfluidic Systems. 3 Credits.
Through lectures and team-projects, this course illustrates the fundamental design principles and applications of microfluidic system for biological and biomedical applications. Topics to be covered include issues associated with being in micrometers in science and engineering, fluid mechanics in micro systems, surface tension, wetting phenomena, electrokinetic phenomena in microscale. The course is not intended to provide students with extensive training in particular design and fabrication processes of such systems. However, students will learn to apply particular microfluidic object manipulation principle to design an innovative, conceptual microfluidic system. Undergraduate level of Fluid Mechanics and Thermodynamics and completion of a term project are required.

EN.535.667. Biomechanics of Human Movement. 3 Credits.
This course explores the methods and underlying principles for the modeling and analysis of human motion. The course begins with the fundamentals of human motion from walking through running. Next, the biology and stimuli needed to produce motion through the coordinated action of musculoskeletal system will be covered. Typical methods used to quantify the kinematics and kinetics of motion will be taught along with optimization techniques needed for analysis. Finally, the simulation of muscle driven locomotion will be taught for walking and running, as well as some discussion of the role of assistive devices.

EN.535.670. Advanced Aerodynamics. 3 Credits.
This course provides the basic aerodynamic concepts and tools for aerospace vehicle design and analysis, focusing on physical-based approaches with some introduction to numerical-based methods, where experimental wind tunnel or flight test data are considered as the benchmark results. The physical-based part will emphasize inviscid-incompressible flow followed by inviscid-compressible flow and introducing some basic elements of viscous flow plus a brief introduction to computational fluid dynamics (CFD), as the numerical-based methods.

EN.535.671. Aerospace Materials, Structures and Design. 3 Credits.

EN.535.672. Advanced Manufacturing Systems. 3 Credits.
This course examines the effect that new technology, engineering, and business strategies have on transforming US industry into a world-class, competitive force. Emphasis is placed on the state of the art of factory automation and computer-integrated manufacturing. Topics include advanced manufacturing processes, rapid prototyping, intelligent manufacturing controls, and information technology in manufacturing. Technical principles related to advanced manufacturing are presented. Examples of actual production systems illustrate how industry is adopting the latest technology to meet customer requirements for quality, low cost, and flexibility.

EN.535.673. Mechanized Assembly: Hardware and Algorithms. 3 Credits.
Generally speaking, manufacturing engineering consists of two large subtopics: fabrication and assembly. This course covers topics in the design and analysis of mechanized assembly systems such as those used in parts feeding and pick-andplace machines. Specific topics will include: Describing Planar and Spatial Rotations, Planar Linkages (4-Bar, Crank-sliders), Classical Theory of Gears, Differential Geometry Methods, Singularities of Mechanisms and Robots, Spatial Linkage Synthesis and Screw Theory, Transmissions and Spatial Gearing, Automated Parts Transfer (Fences and Bowl Feeders), Assembly Planning, Tolerancing, Parts Entropy, Deployable Mechanism Design.

EN.535.684. Modern Polymeric Materials. 3 Credits.
Through lectures and in class demonstrations, this course covers a broad range of topics in the polymeric materials science and engineering field. We will address the structure and property relationships in thermoplastics, thermoset, amorphous, semicrystalline, oriented and biological polymeric materials; synthesis and processing (including rheology) of polymers; flow and fracture of polymeric materials under different conditions. Modern polymer characterization techniques will be introduced. Frontiers in the recent findings in biopolymers, polymer based 3D printing, polymers for tissue engineering will also be discussed. The course is not intended to provide students with extensive training in particular polymer area, but rather a general overview of the key topics in modern polymeric materials.

EN.535.691. Haptic Interface Design. 3 Credits.
This course provides an introduction to haptic interface design and analysis for human-robot interaction involving virtual environments, augmented reality, and teleoperation. Topics include human touch perception, haptic-focused mechatronic design, system modeling and analysis (kinematic and dynamic), human-in-the-loop feedback control, and haptic feedback evaluation. Recommended: coursework or knowledge of Dynamics and knowledge of feedback control, mechatronics, and Matlab.

EN.535.693. Fabrication of Biomaterials, Engineering Tissues, and Food. 3 Credits.
Students will learn how to manufacture biocompatible or cell-encapsulated materials for various purposes, including applications in regenerative medicine, individualized drug screening and animal-free meat production.

EN.535.706. Mechanics of Solids and Structures: Theory and Applications II. 3 Credits.
This course provides an overview of the area of the mechanics of solids and materials, with the intent of providing the foundation for graduate students interested in research that involves these disciplines. The course is based on the principles of continuum mechanics, and covers the fundamental concepts of elasticity, plasticity, and fracture as applied to materials. One objective is to get graduate students to the point that they can understand significant fractions of research seminars and papers in this area. This mathematically rigorous course emphasizes the setup and solution of boundary value problems in mechanics, and attempts to integrate the primary behaviors with deformation and failure mechanisms in materials. This course does not require Mechanics of Solids and Structures: Theory and Applications I as a prerequisite. It is recommended that students taking this course have taken a prior course in Mechanics of Materials, preferably at the upper-level undergraduate level.

EN.535.720. Mechanics of Composite Materials and Structures. 3 Credits.
Topics in this course include anisotropic elasticity, laminate analysis, strength of laminates, failure theories, bending, buckling, and vibration of composite plates. The second part of the course is devoted to the applications of the structural analysis of composite structures by means of finite-elements computer codes.

EN.535.721. Advanced Composite Materials & Manufacturing Processes. 3 Credits.
This course offers an in-depth exploration of advanced composite materials and manufacturing processes used to build lightweight, high-performance composite and adhesive bonded structures ideal for applications in aerospace, automotive, energy, infrastructure, marine vessels, and more. The course explores advanced composites, typically described as continuous fiber-reinforced polymer matrix laminates with exceptional strength, stiffness, and low weight. Additional topics include fundamentals of polymer matrix composites (PMCs), properties of high-performance reinforcements and matrices, manufacturing processes used to produce solid laminates and sandwich panels, laminate design considerations, and physical and mechanical testing. Through lectures, readings, assignments, and a final design and manufacturing project, students will gain broad experience in composite material selection, manufacturing processes, and design of these exceptional lightweight structures for demanding engineering applications.

EN.535.724. Dynamics of Robots and Spacecraft. 3 Credits.
This course provides an introduction to Lagrangian mechanics with application to robot and spacecraft dynamics and control. Topics include rigid body kinematics, efficient formulation of equations of motion by using Lagrange's equations, solutions of equations of motion, Hamilton's principle, and introduction to stability and control theory.

EN.535.731. Engineering Materials: Properties and Selection. 3 Credits.
Become familiar with different classes of engineering materials and their tradeoffs associated with design criteria such as strength, toughness, corrosion resistance, and fabricability, as well as some common test methods for evaluating material properties. This course will concentrate on metal alloys but will also consider polymers and ceramics. Topics specific to metals will include effects of work hardening and heat treatment, corrosion, and elevated temperature properties. Topics specific to polymers will include viscoelasticity, stress relaxation and creep, and phase transitions. Topics specific to ceramics will include flaw-dominated strength, fracture energy, and statistical determination of strength. The course also includes an introduction to the Ashby method of material selection and optimization.

EN.535.732. Fatigue and Fracture of Materials. 3 Credits.
This course will introduce the theory and application of fracture mechanics. The perspectives of multiple disciplines including mechanics, materials, manufacturing, statistics, and nondestructive evaluation will be integrated to develop a holistic view of design and sustainment of fatigue-limited structures. The course will provide a solid foundation of classic approaches to solving fatigue and fracture problems while simultaneously discussing the underlying physical mechanisms that drive material behavior. These methods will be applied during the latter part of the course in a group project where you work with a team on a simulated failure investigation. You will use your knowledge of fracture mechanics and emerging software tools to develop a safety risk assessment for a simulated aviation mishap. Prerequisites: Undergraduate or introductory courses in materials and mechanics and the ability to write code in MATLAB or another language is highly recommended.

EN.535.733. Inclusions, Fibers, and Fractures: Micromechanics of Heterogenous Materials and Composites. 3 Credits.

EN.535.734. Ultra-high Temperature Materials. 3 Credits.
This is a treatise course on high temperature materials. The primary objective of this course is to provide an introduction to processing, characterization, and properties of various types of materials suitable for extreme environment applications including alloys, ceramics, composites, and carbons. The course will discuss both established high temperature materials and recent advances in high temperature materials development. Other topics to be covered include thermodynamics and kinetics in materials chemistry and structure-property relations.

EN.535.735. Computational Fluid Dynamics. 3 Credits.
This is a three-branch course covering theory, implementation, and application of computational fluid dynamics (CFD). The theory side covers the basics of CFD, finite volume discretization schemes, time integration, solution of systems of equations, boundary conditions, error analysis, turbulence models, and meshing. On the implementation side students will implement a number of small-scale CFD solvers and pre-processing tools in order to get a working knowledge of the simulation process. The application side covers the use of fully featured, readily available CFD solver to study an array of gradually complex flow phenomena.

EN.535.737. Multiscale Modeling and Simulation of Mechanical Systems. 3 Credits.
This course offers an in-depth exploration of the principles, methodologies, and applications of multiscale modeling for mechanical systems. This course is designed to bridge the gap between theoretical concepts and practical implementation, the course provides students with a solid foundation in the techniques that span multiple length and time scales, essential for designing and analyzing complex engineering systems. Through a balanced mix of lectures, discussions, case studies, and hands-on applications, students will gain proficiency in both microscopic and macroscopic modeling techniques, including the finite element method, molecular dynamics, ab-initio approaches, and data-driven methodologies. By the end of the course, students will be equipped with the necessary skills to address and solve real-world engineering challenges, making them adept at applying advanced modeling techniques in both academic and industrial settings.

EN.535.741. Optimal Control and Reinforcement Learning. 3 Credits.
This course will explore advanced topics in nonlinear systems and optimal control theory, culminating with a foundational understanding of the mathematical principals behind Reinforcement learning techniques popularized in the current literature of artificial intelligence, machine learning, and the design of intelligent agents like Alpha Go and Alpha Star. Students will first learn how to simulate and analyze deterministic and stochastic nonlinear systems using well-known simulation techniques like Simulink and standalone C++ Monte-Carlo methods. Students will then be introduced to the foundations of optimization and optimal control theory for both continuous- and discrete- time systems. Closed-form solutions and numerical techniques like co-location methods will be explored so that students have a firm grasp of how to formulate and solve deterministic optimal control problems of varying complexity. Discrete-time systems and dynamic programming methods will be used to introduce the students to the challenges of stochastic optimal control and the curse-of-dimensionality. Supervised learning and maximum likelihood estimation techniques will be used to introduce students to the basic principles of machine learning, neural-networks, and back-propagation training methods. The class will conclude with an introduction of the concept of approximation methods for stochastic optimal control, like neural dynamic programming, and concluding with a rigorous introduction to the field of reinforcement learning and Deep-Q learning techniques used to develop intelligent agents like DeepMind's Alpha Go.
Prerequisite(s): EN.535.641 Mathematical Methods for Engineers.

EN.535.742. Applied Machine Learning for Mechanical Engineers. 3 Credits.
This course covers machine learning fundamentals (e.g., optimization, perceptron, and universal approximation), some popular and advanced machine learning techniques (e.g., Supervised, Unsupervised, Probabilistic, Convolutional, and Generative Networks), and supercomputing techniques (with a focus on MARCC) to address mechanical engineering-related machine learning problems. The course requires Python 3+ programming skills; a free 3-hour Python 3+ tutorial will be provided to those who need to learn Python.

EN.535.743. Intermediate Applied Artificial Intelligence in Mechanical Engineering. 3 Credits.
This course offers an applied understanding of artificial intelligence (AI) and machine learning (ML). It covers topics such as machine learning models, Python essentials, and cloud-based platforms, and specialized subjects such as object detection, generative models, AI security, and natural language processing (NLP). Through a blend of theoretical instruction and hands-on exercises, students will master the algorithms, methodologies, and tools required to solve complex engineering challenges using AI. Students will develop ML models using TensorFlow and limited PyTorch, object detection techniques such as SSD (Single Shot Detector) and YOLO (You Only Look Once), generative models such as generative adversarial networks (GANs), and various NLP implementations. They will also learn how to secure AI systems against adversarial attacks and complete exercises on application programming interfaces (APIs), cloud computing, and web development frameworks such as Flask. Emphasis will be placed on real-world applications and state-of-the-art technologies to equip students with the skills required to implement AI solutions effectively and securely in various engineering contexts.

EN.535.748. Stress Waves, Impacts and Shockwaves. 3 Credits.
Elastic waves in unbounded media. Elastic waveguides. Waves in elastic-plastic and nonlinear elastic materials. Analysis of impact on materials and structures. Impact on various scales, from planetary to microscopic. Shock waves. Impact signatures in materials (time permitting).

EN.535.750. Biomechanics of the cell: From nano- and micro-mechanics to cell organization and function. 3 Credits.
Mechanical aspects of the cell are introduced. Discussion of the role of proteins, membranes and cytoskeleton in cellular function and how to describe them using simple mathematical models.

EN.535.752. Advanced Flight Dynamics and Control of Aerospace Vehicles. 3 Credits.
This course is an introduction to the mathematical derivation, behavioral insight into and control of the dynamics of aerospace vehicles. The course will cover current vehicles of interest ranging from small unmanned aircraft, to hypersonic aircraft and spacecraft in earth orbit. Starting from first principles in vector math and conservation of linear and angular momentum in inertial and non-inertial (rotating) coordinate systems we will develop the fundamental equations of motion that describe the flight of these vehicles. Because understanding is best achieved through hands on experience students will develop and implement the necessary vector math, transformations, earth environment models and rigid body dynamics in MATLAB; the models you develop will directly parallel and follow the progression of the course ultimately realizing a full nonlinear 6-degree-of-freedom simulation of an aircraft that we will use to investigate and understand the nature of their dynamic motion and to discover and implement control systems to change and improve their natural dynamic response.

EN.535.761. Hypersonic Aerothermodynamics. 3 Credits.
The course objective is to demonstrate the design process of a hypersonic vehicle's thermal protection system (TPS). The first half of the course analyzes the inviscid flow-field surrounding blunt and slender bodies traveling at high speeds. Topics include compressible gas dynamics, high-temperature physics, and reacting flows. The second half of the course then uses the flow field predictions to calculate the aerothermal loads and material response of the TPS. Topics include compressible boundary layers, material ablation, and thermal conduction into the TPS. The students will solve a combination of theoretical and numerical problems using MATLAB or Python, culminating in a final design project.

EN.535.762. Guidance, Navigation and Controls for Hypersonic Vehicles. 3 Credits.
Guidance, Navigation and Controls for Hypersonic Vehicles Hypersonic flight remains a challenging task in the aerospace research and industry. This course covers the topic of Guidance, Navigation and Controls (GNC) with an emphasis on GNC of hypersonic vehicles. It will review the concepts of aerospace systems kinematics and dynamics. Students will be introduced to optimal control theory with some classical applications like Zermelo's Navigation Problem, Minimum-Time to Climb Problem, etc. Students will also learn about nonlinear control theory with applications in spacecraft attitude stabilization and tracking. Finally, students will be introduced to estimation techniques and their use in GNC. The most up-to-date challenges in hypersonic GNC will be presented. The course will take an applied route. Students will be required to read and discuss research articles and work on projects.

EN.535.763. Aerospace Propulsion. 3 Credits.
This course provides a technical perspective on the predominant aerospace propulsion systems in use today, as well as the systems and technologies currently under development for advanced future applications. The goal is to equip professional engineers with a broad technical understanding of both state-of-the-art and emerging propulsion systems, as well as the foundational tools necessary for analyzing and assessing these systems for targeted applications. The course covers fundamental concepts and techniques for propulsion system analysis and design, including thermodynamics, compressible gas dynamics, and combustion chemistry. It then delves into space (rocket) vehicle analysis and propulsion system design, followed by aircraft propulsion, encompassing aircraft performance analysis, piston engines, gas turbine engines, and ramjet engines. The final portion of the course focuses on emerging technologies such as electric propulsion, eVTOL, hypersonic (scramjet), and detonation-cycle (pulse detonation and rotating detonation wave) engines. Recommended for students with basic familiarity in fluid mechanics, thermodynamics, and numerical solvers (e.g., MATLAB or Python) from undergraduate coursework, this course is otherwise self-contained and has no formal prerequisites.

EN.535.766. Numerical Methods. 3 Credits.
Most problems encountered in engineering and physics applications involve the solution of partial differential equations (PDEs). The analytical solution of PDEs is not generally available and one viable way to find the particular solution is by using numerical methods. Numerical methods enable us to find a numerical solution of the PDE by converting the PDE into a set of algebraic equations. To obtain a reliable and accurate numerical solution of the PDE, however, one should apply an appropriate numerical method with proper parameters depending on the types and properties of the PDE. While a number of tools to find the numerical solutions are available these days, the knowledge on the numerical methods will greatly help you to choose the right tool and set the correct parameters. In this course, a comprehensive introduction to the numerical methods for solving PDEs encountered in engineering and physics will be given. Mathematical analyses to identify the types and properties of the PDEs and the way to choose the proper numerical method to solve the given PDE will be introduced. Assessments of the stability and accuracy of each numerical method will also be discussed. For hands-on experience on applying the numerical methods, MATLAB or Python programming will be used for homework assignments and the final project. The knowledge you obtain throughout this course will make you more confident in applying numerical methods to deal with complex mathematical problems you may encounter in your career.

EN.535.771. Naval Architecture Design. 3 Credits.
Explore the essential principles of Naval Architecture and Marine Engineering in this course, designed to bridge theory and practice. Through a combination of lectures, hands-on assignments, and a comprehensive practicum project, students will delve into key topics such as vessel geometry, structural and hydrostatic analyses, dynamic stability, and propulsion systems. Emphasizing practical application, the course integrates systems architecture principles, including trade studies and adherence to design requirements. This course is for engineers interested in maritime projects or advancing their studies in Naval Architecture. Proficiency in CAD/FEA design tools and MATLAB is recommended.

EN.535.773. Acoustical Oceanography. 3 Credits.
Acoustical Oceanography will cover how active and passive use of sound can be used to study physical parameters and processes, as well as biological species and behaviors, in the ocean environment. The first half of the course will focus on the underlying physics of sound propagation, generation, reception, and scattering in the ocean environment. This foundation will then be leveraged and expanded upon to explore applications of acoustical oceanography for physical, geological, and biological insight through both direct and inverse methods. Throughout the course current research topics will be presented including acoustic tomography, geologic bottom inversion, and marine mammal characterization.

EN.535.782. Haptic Applications. 3 Credits.
An introduction to the required theoretical and practical background in the design and development of haptic applications. Haptic technology enables users to touch and/or manipulate virtual or remote objects in simulated environments or tele-operation systems. This course aims to cover the basics of haptics through lectures, assignments, and readings on current topics in haptics. Prerequisite(s): Recommended course background: graduate and senior undergraduate students who are enthusiastic to learn about haptics and basic familiarity with MATLAB.

EN.535.800. Independent Study. 3 Credits.
An individually tailored, supervised project on a subject related to mechanical engineering. The content and expectations are formalized in negotiations between the student and the faculty sponsor. This course may only be taken in the second half of a student's master degree program. All independent studies must be supervised by a current ME instructor (exceptions must be approved by the Mechanical Engineering Program Chair) and must rely on material from prior ME courses. The independent study project proposal form (see https://ep.jhu.edu/current-students/student-forms/) must be approved prior to registration.

EN.535.820. Master's Graduate Research. 3 Credits.
This course provides masters students in mechanical engineering the opportunity to conduct original research for a thesis under the guidance of a faculty advisor. Students will identify a research topic, review relevant literature, develop research questions and/or hypotheses, design a study methodology, collect and analyze data, and interpret findings. The culmination of the course is a scholarly project report suitable for publication that demonstrates the student's mastery of mechanical engineering research methods and their ability to advance knowledge in the field. The research must be conducted at the level of at least a master's degree, as determined by the student's research advisor, which can be an academic advisor, a current full-time faculty member at the Department of Mechanical Engineering at Johns Hopkins University, a research staff member at the Johns Hopkins University Applied Physics Laboratory, or an active instructor affiliated with one of the Engineering for Professionals programs. Prior written approval of the advisor and the program chair must be received before enrolling in this course. The thesis approval form (see https://ep.jhu.edu/current-students/student-forms/) must be approved prior to registration.

EN.535.821. Master's Graduate Thesis. 3 Credits.
This course provides guidance and support for mechanical engineering masters students writing their final thesis. Students will review relevant literature, refine their research questions/hypotheses, analyze data, draw conclusions based on their research, and work with feedback from peers and faculty advisors to improve their writing. The primary focus of the course is the production of the master's thesis, including ensuring necessary components like an introduction, literature review, methodology, results, and discussion sections are present. Students will develop scholarly writing and editing skills so that their thesis is publication-ready by the end of the course, demonstrating their ability to conduct and clearly convey independent research in mechanical engineering. Students interested in this course must have prior approval from their advisor and the Program Chair to follow the Thesis track. Upon approval by the committee, the final electronic thesis is submitted to the library. Note: If the final electronic thesis has not been submitted to the MSE library (https://www.library.jhu.edu/library-services/electronic-theses-dissertations/) by the end of the second semester, the research advisor may assign an "I" [incomplete] grade until all conditions are met.