Department of Mechanical Engineering Courses

About Course Numbers:
Each Carnegie Mellon course number begins with a two-digit prefix that designates the department offering the course (i.e., 76-xxx courses are offered by the Department of English). Although each department maintains its own course numbering practices, typically, the first digit after the prefix indicates the class level: xx-1xx courses are freshmen-level, xx-2xx courses are sophomore level, etc. Depending on the department, xx-6xx courses may be either undergraduate senior-level or graduate-level, and xx-7xx courses and higher are graduate-level. Consult the Schedule of Classes (https://ten-apps.as.cmu.edu/open/SG/SGServ/et/) each semester for course offerings and for any necessary pre-requisites or co-requisites.

24-050 Study Abroad
Fall
No course description provided.

24-101 Fundamentals of Mechanical Engineering
Fall and Spring: 12 units
The purpose of this course is to introduce the student to the field of mechanical engineering through an exposition of its disciplines, including structural analysis, mechanism design, fluid flows, and thermal systems. By using principles and methods of analysis developed in lectures, students will complete two major projects. These projects will begin with conceptualization, proceed with the analysis of candidate designs, and culminate in the construction and testing of a prototype. The creative process will be encouraged throughout. The course is intended primarily for CIT freshmen. 3 hrs. lec., 2 hrs. rec./lab.
Course Website: http://www.cmru.edu/me/undergraduate/index.html (http://www.cmru.edu/me/undergraduate/)

24-104 Special Topics: Maker Series: Intro to Modern Making
Fall and Spring: 3 units
This course teaches the safe operation of fabrication tools, including 3D printer, laser cutter, hand tools and power tools through structured activities. Included as preparation for modern making, a significant portion of the course is dedicated to learning the use of SolidWorks 3D CAD software. The acquisition of these skills culminates in the development and fabrication of a prototype solution to a real-world problem.
Course Website: http://www.cmru.edu/me (http://www.cmru.edu/me/)

24-105 Special Topics: Maker Series: Intro to Laser Cutting & Engraving
Fall and Spring: 1 unit
This course teaches the safe operation of the laser cutter- engraver machine through structured hand-on activities. A significant portion of this course is dedicated to learning the safe operation of machinery, color mapping, and material selection for prototyping. Homework assignments are important for reinforcement of skills learned, and are flexible for students to complete guided or self-directed projects. 1-unit (2-weeks)

24-200 Special Topics: Maker Series: Intro to Manual Machining
Fall and Spring: 1 unit
This course teaches the safe operation of a manual machine shop. It includes the operation of lathes, drills, and other tools and equipment. A significant portion of this course is dedicated to learning the safe operation of machinery, color mapping, and material selection for prototyping. Homework assignments are important for reinforcement of skills learned, and are flexible for students to complete guided or self-directed projects. 1-unit (2-weeks)

24-202 Introduction to Computer Aided Design
Fall and Spring: 1 unit
Introduction to computer aided design using SolidWorks 3D CAD software. Includes the creation and analysis of components and assemblies, generation of drawings, and exporting for manufacturing. Two hours of guided computer lab work each week. Prerequisite: Undergraduate Mechanical Engineering standing.
Prerequisites: 24-104 or 24-101
Course Website: http://www.cmru.edu/me/undergraduate/index.html (http://www.cmru.edu/me/undergraduate/)

24-203 Special Topics: Maker Series: Intro to Manual & CNC Machining
Fall and Spring: 3 units
This course teaches safe operation of a CNC machine through structured hands-on activities. A significant portion of the course is dedicated to learning the safe operation of machinery, color mapping, and material selection for prototyping. Homework assignments are important for reinforcement of skills learned, and are flexible for students to complete guided or self-directed projects.

24-204 Special Topics: Maker Series: Intro to Welding
Fall and Spring: 2 units
This course teaches the safe operation of MIG welding equipment through structured hands-on activities. A significant portion of the course is dedicated to learning the safe operation of machinery, color mapping, and material selection for prototyping. Homework assignments are important for reinforcement of skills learned, and are flexible for students to complete guided or self-directed projects.

24-206 Special Topics: Maker Series: Intro to Wood Working
Fall and Spring: 3 units
This course teaches the safe operation of a CNC machine through structured hands-on activities. A significant portion of the course is dedicated to learning the safe operation of machinery, color mapping, and material selection for prototyping. Homework assignments are important for reinforcement of skills learned, and are flexible for students to complete guided or self-directed projects. 1-unit (2-weeks)
Prerequisite: 24-206

24-210 Special Topics: Maker Series: Inventive Projects
Fall and Spring
This course explores many types of mechanisms for movement and their optimal applications. A significant portion of class will be dedicated to hands-on labs, during which students will be introduced to the basic methods of movement. Prerequisites: 24-101 or 24-104
Course Website: https://www.meche.engineering.cmu.edu/
24-213 Special Topics: Citizen Science: Sensors, Makers and the Environment  
Spring: 9 units  
This course will introduce students to technical aspects of citizen science, using air pollution as a case study. Students will learn about important air pollutants and the environmental regulations that govern these pollutants in the U.S. Students will be introduced to data quality requirements for applications ranging from regulatory pollutant monitoring to education/outreach. Students will also learn about operating principles for both laboratory- and consumer-grade pollutant monitoring equipment. The class will culminate in a project where student teams will design, construct, and test a low-cost air pollutant monitoring system. The groups will then deploy these sensor packages to collect and present their data. The project will use the TechSpark maker space. It is primarily aimed at non-engineering majors.

24-221 Thermodynamics  
Fall: 10 units  
Temperature and thermometry; equations of state for fluids and solids; work, heat, and the first law; internal energy, enthalpy, and specific heats; energy equations for a range of phenomena; the second law; irreversibility, absolute temperature, and entropy; combined first and second laws; availability; power and refrigeration cycles. Applications to a wide range of processes and devices. 3 hrs. lec., 1 hr recitation.  
Prerequisites: (33-151 or 33-141 or 33-106 or 33-121) and 21-122 Min. grade C and 24-101.  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-231 Fluid Mechanics  
Spring: 10 units  
Prerequisites: (33-151 or 33-106 or 33-141) and 21-122 Min. grade C  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-261 Statics  
Fall: 10 units  
This course is the first in a two-semester sequence on the solid mechanics of engineering structures and machines. The course begins with a review of the statics of rigid bodies, which includes the identification of statically indeterminate problems. Two- and three-dimensional statics problems are treated. Thereafter, the course studies stresses and deflections in deformable components. In turn, the topics covered are: simple tension, compression, and shear; thin-walled pressure vessels; torsion; and bending of beams. For each topic, statically indeterminate problems are analyzed and elementary considerations of strength are introduced. 3 hrs. lec., 1 hr rec./lab.  
Prerequisites: (33-106 or 33-121 or 33-151 or 33-141)  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-262 Stress Analysis  
Spring: 10 units  
This course is the second in a two-semester sequence on the solid mechanics of engineering structures and machines. The basic topics of uniaxial tension/compression, torsion, and flexural deformation from 24-261 are reviewed. Combined loadings and stresses are then treated, which lead to a consideration of failure criteria. Two-dimensional elasticity and the finite element method are introduced. Stress concentrations are quantified analytically, numerically, and with the use of engineering handbooks. Cyclic failure criteria are introduced, and both static and cyclic failure criteria are applied to results from numerical analysis. 3 hrs. lec., 1 hr rec./lab.  
Prerequisites: (33-106 or 33-141 or 33-151) and 24-261  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-280 Special Topics: C++ Programming for Engineers  
Fall and Spring: 9 units  
Using the C++ programming language as a platform, this course serves as an intermediate-level programming course with a strong emphasis on software requirements for engineering applications. Students will refine and enhance their coding skills while applying their mathematical, analytical and design backgrounds. Topics covered include data structures, algorithm design, numerical computation, modular programming, data modeling, interactive graphics, object-orientation, and user interfaces, all in an engineering-specific domain.  
Prerequisites: 15-110 or 15-112  
Course Website: http://www.cmu.edu/me (http://www.cmu.edu/me/)

24-281 Introduction to Scientific Computing  
Fall and Spring: 2 units  
This course provides an introduction to scientific computing with Matlab for engineers. The course introduces the basics of Matlab syntax and programming, data analysis, visualization, curve fitting and interpolation, symbolic computation, differential equations, and debugging. The use of Matlab in solving mechanical engineering applications will be demonstrated.  
Course Website: https://www.meche.engineering.cmu.edu/

24-282 Special Topics: Linear Algebra and Vector Calculus for Engineers  
Fall and Spring: 11 units  
This course will introduce the fundamentals of vector calculus and linear algebra. The topics include vector and matrix operations, determinants, linear systems, matrix eigenvalue problems, vector differential calculus including gradient, divergence, curl, and vector integral calculus including integral theorems. Lecture and assignments will emphasize the applications of these topics to engineering problems. The content covered in 24-281 Introduction to Scientific Computing will be a part of this course. Student evaluation will include weekly homework assignments (requiring both written answers as well as Matlab scripts), two midterms and a final exam.  
Prerequisite: 21-122

24-291 Environmental Systems on a Changing Planet  
Fall: 9 units  
This course introduces the interconnected Earth systems that regulate our climate and ecosystems, providing the resources required to sustain all life, including human societies. Environmental systems are the fascinating connections between the oceans, atmosphere, continents, ecosystems, and people that provide our planet with resources that all life depends on. Human activities disrupt these natural systems, posing critical threats to the sustainable functioning of environmental systems. The course will explore how solar and biochemical energy moves through the Earth’s interconnected systems, recycling nutrients; how complex environmental systems function to produce critical resources such as food and water; and how human activities interfere with environmental systems. Case studies include the interplay between climate change feedbacks, wildfires, and forest ecosystems; the hazards that everyday chemical toxins pose to ecosystems and human health and reproduction; and growing threats to ecosystem health and biodiversity. We will also develop the environmental, scientific, and information literacy required to understand current environmental issues that are frequently debated in the public sphere. This course draws on principles learned in high school science and satisfies the science requirement for the interdisciplinary Minor in Environmental and Sustainability Studies.

24-292 Renewable Energy Engineering  
Intermittent: 9 units  
Introduction to engineering principles of various renewable energy systems, including the following topics: background on climate change and carbon sequestration, engineering analysis of renewable energy systems such as solar photovoltaic, (solar thermal), wind power, hydropower, wave energy, bio mass energy, geothermal energy, and hydrogen based fuel cells. In addition, transitional energy systems such as nuclear power and advanced combined cycles will be introduced. Both engineering performance and present state of development will be discussed. Students will review and present their progress on various subjects, which will be selected based on personal interest.  
Prerequisites: 33-141 or 33-106  
Course Website: http://www.andrew.cmu.edu/user/satbirs/24292/
24-300 Fundamentals of CNC Machining  
Fall and Spring: 2 units  
This course expands upon basic machining principles gained in 24-200 to translate into automated machining. Topics covered include advanced fixturing, CAM programming using Mastercam X7 to produce toolpaths for automated machining and set up and operation of 3 axis vertical CNC machining centers. This course will focus on the programming of these machine tools using geometry from CAD data. Students learn in this course how to do part orientation, plan operation ordering, tool selection, speeds and feeds, cut verification, and to assign all of the above to a specific geometry in the CAD model. Both 2D/UD and 3D machining will be practiced.  
24-200 Machine Shop Practice is a pre-requisite for this course.  
Prerequisite: 24-200

24-302 Mechanical Engineering Seminar I  
Fall and Spring: 2 units  
The purpose of this course is to help students develop good presentation skills and to provide a forum for presentations and discussions of professional ethics. Students will make at least two presentations, one of which is related to professional ethics. Student grades will be based on their presentation skills and their participation in class discussions.  
1 hr. rec.  
Prerequisites: Junior standing or permission of instructor  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-311 Numerical Methods  
Spring: 12 units  
Use of numerical methods for solving engineering problems with the aid of a digital computer. The course will contain numerical methods such as roots of equations, linear algebraic equations, optimization, curve fitting, integration, and differential equation solving. MATLAB will be used as the programming language. Programming cluster laboratory times will be available twice a week. Problems will be drawn from all fields of interest to mechanical engineers.  
3 hrs. lecture plus lab  
Prerequisite: 21-260  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-321 Thermal-Fluids Experimentation  
Spring: 12 units  
24-321 Thermal-Fluids Experimentation Spring: 12 units This is a capstone course for the thermal-fluids core-course sequence. This course covers techniques of measurement, uncertainty analysis, and realization of systems, which demonstrate fundamental principles in thermodynamics, fluid mechanics, and heat transfer. The principles of designing thermal experiments are also integrated into this course.  
Prerequisites: 24-231 and 24-232 and 24-221  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-322 Heat Transfer  
Fall: 10 units  
Measurement techniques. 3 hrs. lec., 1 hr. recitation.  
Prerequisites: 21-260 Min. grade C and 24-231 and 24-221  
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-334 Introduction to Biomechanics  
Fall: 9 units  
This course covers the application of solid and fluid mechanics to living tissues. This includes the mechanical properties and behavior of individual cells, the heart, blood vessels, the lungs, bone, muscle and connective tissues as well as methods for the analysis of human motion.  
Prerequisite: 24-231  
Course Website: http://www.cmu.edu/me/
24-370 Engineering Design I: Methods and Skills
Fall: 12 units
In this course, students will learn methods and skills for the engineering design process, consisting of four stages: concept design, detail design, analysis, and manufacturing. The course covers the engineering design process in a holistic fashion by discussing theories and practices of the four stages and inter-relating them. Hands-on assignments, including computational and physical projects, are given to enhance the learning outcome. After taking this course, students will be able to: express ideas in sketches; interpret and create engineering drawings; select and apply machine elements; model detailed shapes with CAD tools; analyze product performance with CAE tools; choose materials and manufacturing schemes, and create and test prototypes. Recommended: 24-200 (machine shop practice).
Prerequisites: 24-200 and 24-262 and 24-202 Min. grade C
Course Website: http://www.cmu.edu/me/undergraduate/index.html (/http://www.cmu.edu/me/undergraduate/)

24-371 Special Topics: Design of Machine Elements
Spring: 9 units
In this class, the students will gain an understanding of the best practices in the design of machine elements, such as shafts, gears, power draw, fasteners, brakes/couplings, flywheels, bearings, etc. The course material consists of the study of stress and deflection under common loading conditions, effect of material properties, static and fatigue failure models, cost considerations, and manufacturability in the context of the machine components. Student learning will be achieved through interactive lectures on underlying technical approaches in conjunction with a group project where students will be required to design and fabricate an ensemble of machine elements. Students will also learn about the strong connections between theory, analytical methods, available computational tools, and field design. Assessment of the learning objectives will happen via homework, class exams, and demonstration of the group project. This course builds upon the skills and methods taught in Design-I (24-370) and will help students prepare to enter the modern workplace where mechanical design takes place.
Prerequisite: 24-370

24-391 Mechanical Engineering Project
Fall and Spring
Practice in the organization, planning, and execution of appropriate engineering projects. These investigations may be assigned on an individual or a team basis and in most cases will involve experimental work. 9 hrs. lab.
Course Website: https://www.meche.engineering.cmu.edu/education/undergraduate-education/index.html (/https://www.meche.engineering.cmu.edu/education/undergraduate-education/)

24-392 Mechanical Engineering Project
All Semesters
Practice in the organization, planning, and execution of appropriate engineering projects. These investigations may be assigned on an individual or a team basis and in most cases will involve experimental work.
Course Website: https://www.meche.engineering.cmu.edu/education/undergraduate-education/index.html (/https://www.meche.engineering.cmu.edu/education/undergraduate-education/)

24-421 Internal Combustion Engines
Fall: 12 units
This course discusses working principles of internal combustion engines found in many practical applications. Focus is given to understanding the design of air handling system, in-cylinder fuel/air mixing, geometric design of the combustion chamber, engine performance and calibration, and mechanism of pollutant formation and reduction. Introductory discussion of advanced automotive engine concepts, alternative fuels, gas turbine engines, rocket engines, and hybrid electric vehicles is also provided. The course relies on a number of lab experiments, analysis of actual experimental data, and a combination of analytical and numerical homework assignments. 3 hrs. lecture 2 hrs. lab
Prerequisites: 24-221 and 24-231
Course Website: http://www.andrew.cmu.edu/user/satbirs/24421/

24-424 Energy and the Environment
Fall: 9 units
Fuel cycles for conventional and non-conventional energy resources; relationships between environmental impacts and the conversion or utilization of energy; measures of system and process efficiency; detailed study and analysis of coal-based energy systems including conventional and advanced power generation, synthe tic fuels production, and industrial processes; technological options for multi-media (air, water, land) pollution control; mathematical modeling of energy-environmental interactions and tradeoffs and their dependency on technical and policy parameters; methodologies for energy and environmental forecasting; applications to issues of current interest. Junior or Senior standing in CIV or permission of instructor. 3 hrs lecture
Course Website: http://www.cmu.edu/me/undergraduate/index.html (/http://www.cmu.edu/me/undergraduate/)

24-425 Combustion and Air Pollution Control
Intermittent: 9 units
Formation and control of gaseous and particulate air pollutants in combustion systems. Basic principles of combustion, including thermochemical equilibrium, flame temperature, chemical kinetics, hydrocarbon chemistry, and flame structure. Formation of gaseous and particulate pollutants in combustion systems. Combustion modifications and post-combustion technologies for pollutant control. Relationship between technology and regional, national, and global air pollution control strategies. The internal combustion engine and coal-fired utility boiler are used as examples. 3 hours lecture Cross listed as 24-740 and 19440/19-740
Course Website: http://www.cmu.edu/me/undergraduate/index.html (/http://www.cmu.edu/me/undergraduate/)

24-428 Computational Analysis of Transport Phenomena
Spring: 9 units
In this course, students will develop basic understanding and skill sets to perform simulations of transport phenomena (mass, momentum, and energy transport) for engineering applications using a CAE tool, learn to analyze and compare simulation results with theory or available data, and develop ability to relate numerical predictions to behavior of governing equations and the underlying physical system. First 8 weeks of the course will include lectures and simulation-based homework assignments. During last 7 weeks, teams of students will work on self-proposed projects related to computational analysis of transport phenomena. In the project, students will learn to approach loosely defined problems through design of adequate computational mesh, choice of appropriate numerical scheme and boundary conditions, selection of suitable physical models, efficient utilization of available computational resources etc. Each team will communicate results of their project through multiple oral presentations and a final written report. Detailed syllabus of the course is provided on the URL given below.
Prerequisites: 24-221 and 24-231 and 24-322
Course Website: http://www.andrew.cmu.edu/user/satbirs/24618/

24-441 Engineering Design II: Conceptualization and Realization
Fall and Spring: 12 units
Conceptualization and Realization Fall and Spring 12 units. This course guides students through the design process in the applied design of a practical mechanical system. Lectures describe the typical design process and its associated activities, emphasizing methods for innovation and tools for design analysis. Professional and ethical responsibilities of designers, interactions with clients and other professionals, regulatory aspects, and public responsibility are discussed. The design project is typically completed in teams and is based on a level of engineering knowledge expected of seniors. Proof of practicality is required in the form of descriptive documentation. Frequently, a working model will also be required. Oral progress reports and a final written and oral report are required. 3 hrs. rec., 3 hrs lab Senior standing and Machine Shop Practice 24-200 required.
Prerequisites: 24-262 and 24-370
Course Website: http://www.cmu.edu/me/undergraduate/index.html (/http://www.cmu.edu/me/undergraduate/)
24-451 Feedback Control Systems
Fall: 12 units
Fundamentals of feedback control with emphasis on classical techniques and an introduction to discrete-time (computer controlled) systems. Topics include the following: frequency domain modeling and state space modeling of dynamical systems; feedback control system concepts and components; control system performance specifications such as stability, transient response, and steady state error; analytical and graphical methods for analysis and design - root locus, Bode plot, Nyquist criterion; design and implementation of proportional, proportional-derivative, proportional-integral-derivative, lead, lag, and lead-lag controllers. Extensive use of computer-aided analysis and design software. 4 hrs lec.
Prerequisites: (15-110 or 15-112) and 24-352.
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-452 Mechanical Systems Experimentation
Fall and Spring: 9 units
Experimentation in dynamic systems and controls. The course will cover translational and rotational systems. Topics will include mechanical elements, natural frequencies, mode shapes, free and forced response, frequency response and Bode plots, time constants, transient response specifications, feedback controls such as PID control, and stability for single-degree-of-freedom and multi-degree-of-freedom systems. The course will introduce and use state-of-the-art experimentation hardware and software.
Course Website: http://www.cmu.edu/me/undergraduate/index.html (http://www.cmu.edu/me/undergraduate/)

24-453 Special Topics: Introduction to Programmable Logic Controllers
Fall and Spring: 3 units
Programmable Logic Controllers (PLCs) are prevalent in many industrial process control and manufacturing applications. Knowledge of and experience with PLCs is a marketable skill, opening up many career opportunities in a wide range of industries. This course provides an introduction to the applications of PLCs and techniques used for their programming and implementation. The course will be primarily lab-based, aimed at introducing the capabilities, limitations, and applications of PLCs through hands-on experience. Topics include ladder logic, PLC programming, PLC memory structures, program execution, troubleshooting methods, and typical industrial practices.
Prerequisite: 24-352

24-480 Special Topics: Artificial Intelligence and Machine Learning for Engineering
Spring: 9 units
This course introduces algorithms that are at the center of modern day artificial intelligence (AI) and machine learning (ML) techniques. The course takes an engineering-focused approach to AI/ML by investigating the wide array of sources of data available in the world, how these sources generate data, and algorithms and methods that are used to transform this data into knowledge/insights.
Prerequisites: (15-112 or 15-110) and (19-250 or 36-217 or 36-225 or 36-220)

24-491 Department Research Honors
Fall and Spring
This course is designed to give students increased exposure to "open-ended" problems and research type projects. It involves doing a project on a research or design topic and writing a thesis describing that project. The project would be conducted under the supervision of a mechanical engineering faculty member (the advisor), and must be approved by the advisor before inception. This course can be taken at any time after the junior year and before graduation which includes the summer after the junior year. Completion of 18 units of this course with a grade of B or better is a partial fulfillment of the requirements for Departmental Research Honors.
Course Website: https://www.meche.engineering.cmu.edu/education/undergraduate-education/index.html (https://www.meche.engineering.cmu.edu/education/undergraduate-education/)

24-492 Department Research Honors
Fall and Spring
This course is designed to give students increased exposure to "open-ended" problems and research type projects. It involves doing a project on a research or design topic and writing a thesis describing that project. The project would be conducted under the supervision of a mechanical engineering faculty member (the advisor), and must be approved by the advisor before inception. This course can be taken at any time after the junior year and before graduation which includes the summer after the junior year. Completion of 18 units of this course with a grade of B or better is a partial fulfillment of the requirements for Departmental Research Honors.
Course Website: https://www.meche.engineering.cmu.edu/education/undergraduate-education/index.html (https://www.meche.engineering.cmu.edu/education/undergraduate-education/)

24-614 Microelectromechanical Systems
Intermittent: 12 units
This course introduces fabrication and design fundamentals for Microelectromechanical Systems (MEMS): on-chip sensor and actuator systems having micron-scale dimensions. Basic principles covered included microfabrication, mechanics of silicon and thin-film materials, electrostatic force, capacitive motion detection, fluidic damping, piezoelectricity, piezoresistivity, and thermal micromechanics. Applications covered include pressure sensors, micromirror displays, accelerometers, and gas microsensors. Grades are based on exams and homework assignments.
Prerequisites: 24-351 or 18-321

24-623 Molecular Simulation of Materials
Spring: 12 units
The purpose of this course is to expose engineering students to the theory and implementation of numerical techniques for modeling atomic-level behavior. The main focus is on molecular dynamics and Monte Carlo simulations. Students will write their own simulation computer codes, and learn how to perform calculations in different thermodynamic ensembles. Consideration will be given to heat transfer, mass transfer, fluid mechanics, mechanics, and materials science applications. The course assumes some knowledge of thermodynamics and computer programming. 4 hrs lec.
Prerequisites: 24-221 and 24-311

24-626 Air Quality Engineering
Intermittent: 12 units
The course provides a quantitative introduction to the processes that control atmospheric pollutants and the use of mass balance models to predict pollutant concentrations. We survey major processes including emission rates, atmospheric dispersion, chemistry, and deposition. The course includes discussion of basic atmospheric science and meteorology to support understanding air pollution behavior. Concepts in this area include vertical structure of the atmosphere, atmospheric general circulation, atmospheric stability, and boundary layer turbulence. The course also discusses briefly the negative impacts of air pollution on society and the regulatory framework for controlling pollution in the United States. The principles taught are applicable to a wide variety of air pollutants but special focus is given to tropospheric ozone and particulate matter. The course is intended for graduate students as well as advanced undergraduates. It assumes a knowledge of mass balances, fluid mechanics, chemistry, and statistics typical of an undergraduate engineer but is open to students from other scientific disciplines. 12 units
Prerequisites: 09-105 and 24-231 and 36-220
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)
24-628 Energy Transport and Conversion at the Nanoscale  
Spring: 12 units  
Energy transport and conversion processes occur at the nanoscale due to interactions between molecules, electrons, phonons, and photons. Understanding these processes is critical to the design of heat transfer equipment, thermoelectric materials, electronics, light emitting diodes, and photovoltaics. The objective of this course is to describe the science that underlies these processes and to introduce the contemporary experimental and theoretical tools used to understand them. The course includes a laboratory that gives the students experience with modern transport measurement instrumentation and data analysis. Integrated literature reviews and a final project require students to apply learned fundamentals to understanding state-of-the-art research and technology. 4 hrs. lecture  
Prerequisites: 24-322 and 24-221 or equivalents  
Course Website: http://www.cmu.edu/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-629 Direct Solar and Thermal Energy Conversion  
Intermittent: 12 units  
This course introduces graduates and senior undergraduates to the principles and technologies for directly converting heat and solar light into electricity using solid-state devices. The first part of the course reviews the fundamentals of quantum mechanics, solid state physics and semiconductor device physics for understanding solid-state energy conversion. The second part discusses the underlying principles of thermoelectric energy conversion, thermionic energy conversion, and photovoltaics. Various solar thermal technologies will be reviewed, followed by an introduction to the principles of solar thermophotovoltaics and solar thermoelectrics. Spectral control techniques which are critical for solar thermal systems will also be discussed. By applying the basic energy conversion theory and principles covered in lectures, students will finish a set of 4 homework assignments. This course also requires one project in which students will work individually to review one present solar or thermal energy conversion technology 12 units  
Course Website: http://www.cmu.edu/me/

24-631 Thermal Design  
Spring: 12 units  
This course guides students through the design process of a practical thermal system. The course plan assumes a mastery of the fundamentals of thermodynamics, fluid mechanics and heat transfer at the undergraduate level. Lectures aim at design aspects and analysis techniques commonly used in the development of thermal systems. Lecture topics include heat sinks, heat pipes, compact heat exchangers, sensors and instrumentation, thermoelectric devices, and special topics closely related to the theme of the design activity for the semester. Design activity is conducted in teams and includes several cycles of oral presentations, class discussions, and a final written report. System design and analysis of performance are heavily based on computer-added design tools and simulation means. Student performance in this course is evaluated based on individual homework assignments on the various topics presented in class and on a team design project.  
Prerequisite: 24-322

24-632 Special Topics: Additive Manufacturing Processing and Product Development  
Fall: 12 units  
Introduction to additive manufacturing (AM) processing fundamentals and applications using SolidWorks 3-D CAD software and a variety of polymer and metal AM machines. Includes a brief history of AM processing, a review of and technical fundamentals of current AM processes, a study of the current AM market, and future directions of the technology. Lab Sessions will support an open-ended product development project. Lectures on metals AM will address current research impacting industry. Students will also perform a literature review of papers on the state of the art. Basic Solidworks knowledge required.  
Prerequisite: 24-322  
Course Website: http://www.cmu.edu/me/

24-633 Additive Manufacturing Laboratory  
Spring: 12 units  
Hands-on laboratory projects will teach students about all aspects of metals additive manufacturing (AM). Students will learn how to use SOLIDWORKS for part design, create and transfer design files to the AM machines, run the machines to build parts, perform post-processing operations, and characterize AM parts. Students will work in teams and complete three separate lab projects, each utilizing a different material system, part design, AM process/machine, post-processing steps and characterization methods.  
Prerequisites: 24-632 or 24-262 or equivalents  
Course Website: http://www.cmu.edu/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-635 Structural Analysis  
Fall: 9 units  
Classical and matrix-based methods of structural analysis; energy principles in structural mechanics. Basic concepts of force and displacement methods for analyzing redundant structural systems. Matrix methods utilizing the flexibility (force) and stiffness (displacement) concepts.  
Prerequisite: 24-262

24-636 Energy Modalities in Biology and Medicine  
Spring: 12 units  
This course covers a wide range of energy-based applications in biology and medicine, such as cancer treatments by cryosurgery (freezing), thermal ablation (heating), photodynamic therapy (light-activated drugs), and irreversible electroperoration (a non-thermal electrical application). This course also covers thermal regulation in humans and other mammals, as well as cryopreservation (low-temperature preservation) of tissues and organs for the benefit of organ banking and transplant medicine. The course combines lectures and individual assignments relating to the underlying principles of engineering, with teamwork on open-ended projects relating to concurrent challenges at the convergence of engineering and medical sciences. The course plan assumes a mastery of the fundamentals of heat transfer at the undergraduate level.  
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-640 Climate Change Mitigation  
Intermittent: 12 units  
Have you ever thought about how we could address the climate change problem? In this course we will study the technological and policy options for responding to the threat of climate change. We will review climate-change science, understand the current systems for energy supply and use, and have a deep dive onto technological solution for low-carbon energy supply and use, as well as the policy frameworks that can help us reduce greenhouse gas emissions. 2hrs 40min of lectures per week.  
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-643 Energy Storage Materials and Systems  
Intermittent: 12 units  
Contemporary energy needs require large scale electrochemical energy conversion and storage systems. Batteries are playing a prominent role in portable electronics and electric vehicles. This course introduces principles and mathematical models of electrochemical energy conversion and storage. Students will study thermodynamics, reaction kinetics pertaining to electrochemical reactions, phase transformations relating to batteries. This course includes applications to batteries, fuel cells, supercapacitors  
Course Website: http://www.andrew.cmu.edu/user/venkatv/24643/

24-650 Applied Finite Element Analysis  
Intermittent: 12 units  
This is an introductory course on the finite element method with emphasis on application of the method to a wide variety of problems. The theory of finite element analysis is presented and students learn various applications of the method through assignments utilizing standard finite element software packages commonly used in industry. Various types of analyses are considered, which may include, for example, static, pseudo-static, dynamic, modal, buckling, contact, heat transfer, thermal stress and thermal shock. Students also learn to use a variety of element types in the models created, such as truss, beam, spring, solid, plate, and shell elements.  
Prerequisites: 24-262 and 24-322  
Course Website: https://www.meche.engineering.cmu.edu/education/graduate-programs/index.html (https://www.meche.engineering.cmu.edu/education/graduate-programs/)
24-653 Special Topics: Materials and Their Processing for Mechanical Engineers
Spring: 12 units
The study of the major classes of materials (e.g., metals, alloys, ceramics, polymers, composites) and their structure-processing-property relationships is integral to many engineering disciplines. This course will introduce the fundamental concepts behind how the processing of materials influences their atomic/molecular structures and resulting properties. The course will adopt a game-based learning approach in which students will utilize the virtual Minecraft environment to study crystal structures, imperfections (defects), diffusion, and phase equilibria. These concepts are then applied to characterize and interpret the (mechanical, electrical, magnetic, and optical) properties of various material systems as part of a final collaborative group project.

24-655 Cellular Biomechanics
Intermittent: 9 units
This course discusses how mechanical quantities and processes such as force, motion, and deformation influence cell behavior and function, with a focus on the connection between mechanics and biochemistry. Specific topics include: (1) the role of stresses in the cytoskeleton dynamics as related to cell growth, spreading, motility, and adhesion; (2) the generation of force and motion by motor molecules; (3) stretch-activated ion channels; (4) protein and DNA deformation; and (5) mechanosignaling. If time permits, we will also cover protein trafficking and secretion and the effects of mechanical forces on gene expression. Emphasis is placed on the biomechanics issues at the cellular and molecular levels; their clinical and engineering implications are elucidated. 3 hrs. lec. Prerequisite: Instructor permission.
Course Website: http://www.cmu.edu/me/graduate/index.html

24-658 Image-Based Computational Modeling and Analysis
Spring: 12 units
Image-based computational modeling and analysis play an important role in mathematical modeling and computer simulation of many physical and biological phenomena. This course integrates mechanical engineering, biomedical engineering, material sciences, computer science, and mathematics together. Topics to be studied include scanning techniques, image processing, geometric modeling, mesh generation, computational mechanics, as well as broad applications in biomecine, material sciences and engineering. The techniques introduced are applied to examples of multi-scale modeling and simulations in various research fields.
Course Website: http://www.cmu.edu/me/graduate/index.html

24-663 Special Topics: Biomechanics of Human Movement
Spring: 12 units
This course provides an overview of the mechanical principles underlying human movement biomechanics and the experimental and modeling techniques used to study it. Specific topics will include locomotion, motion capture systems, force plates, muscle mechanics, musculoskeletal modeling, three-dimensional kineamtics, inverse dynamics, forward dynamic simulations, and imaging-based biomechanics. Homework and final class projects will emphasize applications of movement biomechanics in orthopedics, rehabilitation, and sports. ***Students are expected to have knowledge of ordinary differential equations and rigid body dynamics at the level of 24-351.***

24-664 Introduction to Biomechanics
Fall: 12 units
The purpose of this course is to achieve a broad overview of the application of mechanics to the human body. This includes solid, fluid, and viscoelastic mechanics applied to single cells, the cardiovascular system, lungs, muscles, bones, and human movement. The physiology of each system will be reviewed as background prior to discussing mechanics applications within that system. There are no firm prerequisites, but statics, fluid mechanics, and biology are helpful.
Course Website: http://www.cmu.edu/me/

24-665 Special Topics: Wearable Health Technologies
Spring: 12 units
This course will provide an overview of emerging wearable health technologies and give students hands-on experience in solving ongoing technical challenges. The wearable sensing field is experiencing explosive growth, with exciting applications in medicine. New lightweight devices will make it easier to monitor health conditions in real time, automatically import data into health informatics systems, and provide haptic feedback with humans in the loop. We will review several aspects of these technologies, including hardware, software, user experience, communication networks, applications, and big data analytics. Students will be paired with a company for a semester-long project that tackles timely computational challenges. Project placement, in any language, is a prerequisite.

24-666 Special Topics: Introduction to Geometric Dimensioning and Tolerancing
Spring: 3 units
Geometric Dimensioning and Tolerancing (GD and T) encompasses a language and system of rules used to precisely and unambiguously communicate the intended geometry and allowable variation of manufactured objects. This tolerance informs the design, process selection, tooling, and inspection of a part. This course will introduce students to this system of communication and its applications. Topics will include interpreting GD and T on engineering drawings, implementing it in Solidworks, and performing tolerance analyses. Prerequisite: 24-370

24-667 Special Topics: Introduction to Geometric Dimensioning and Tolerancing
Spring: 3 units
Geometric Dimensioning and Tolerancing (GD and T) encompasses a language and system of rules used to precisely and unambiguously communicate the intended geometry and allowable variation of manufactured objects. This tolerance informs the design, process selection, tooling, and inspection of a part. This course will introduce students to this system of communication and its applications. Topics will include interpreting GD and T on engineering drawings, implementing it in Solidworks, and performing tolerance analyses.

24-671 Electromechanical Systems Design
Fall and Spring: 12 units
This course guides students through the design process as applied to mechatronic systems, which feature electrical, mechanical, and computational components. Lectures describe the typical design process and its associated activities, emphasizing methods for analyzing and prototyping mechatronic systems. Professional and ethical responsibilities of designers, interactions with clients and other professionals, regulatory aspects, and public responsibility are discussed. The design project is team-based and is based on a level of engineering knowledge expected of seniors. Proof of practicality is required in the form of descriptive documentation and a working prototype system at the end of the course. Oral progress reports and a final written and oral report are required. Prerequisites: (16-311 or 24-354) and 24-370 and 24-352
Course Website: http://www.cmu.edu/me/

24-672 Special Topics in DIY Design and Fabrication
Fall: 12 units
The traditional principles of mass production are being challenged by concepts of highly customized and personalized goods. A growing number of do-it-yourself (DIY) inventors, designers, makers, and entrepreneurs is accelerating this trend. This class offers students hands-on experience in DIY product design and fabrication processes. Over the course of the semester, students work individually or in small groups to design customized and personalized products of their own and build them using various DIY fabrication methods, including 3D laser scanning, 3D printing, laser cutting, molding, vacuum forming, etc. In addition to design and fabrication skills, the course teaches students skills for communicating their ideas effectively through industrial design sketches and presenting their products with aesthetically refined graphics.
Course Website: https://www.andrew.cmu.edu/course/24-672/
24-677 Special Topics: Linear Control Systems
Fall: 12 units
This course provides a practical introduction to the analysis and design of model-based control for linear systems. Topics include modeling and linearization of multi-input multi-output dynamic systems using the state-variable description, fundamentals of linear algebra (linear space, linear transformation, linear dynamics), analytical and numerical solutions of systems of linear time-invariant differential and difference equations, structural properties of linear dynamic physical systems (controllability, observability and stability), canonical realizations, and design of state feedback/feedforward, optimal, and stochastic controllers and observers (pole placement, LQR, MPC, Kalman filter approaches). Students will learn how to design linear controllers and implement them to solve real-world problems in control and robotics.

Course Website: https://www.meche.engineering.cmu.edu/education/graduate-programs/index.html (https://www.meche.engineering.cmu.edu/education/graduate-programs/)

24-680 Quantitative Entrepreneurship: Analysis for New Technology Commercialization
Intermittent: 12 units
This course provides engineers with a multidisciplinary mathematical foundation for integrated modeling of engineering design and enterprise planning decisions in an uncertain, competitive market. Topics include economics in product design, manufacturing and operations modeling and accounting, consumer choice modeling, survey design, conjoint analysis, decision-tree analysis, optimization, model integration and interpretation, and professional communication skills. Students will apply theory and methods to a team project for a new product or emerging technology, developing a business plan to defend technical and economic competitiveness. This course assumes fluency with basic calculus, linear algebra, and probability theory.
Prerequisite: 21-259

24-681 Computer-Aided Design
Intermittent: 12 units
This course is the first section of the two-semester sequence on computational engineering. Students will learn how computational and information technologies are rapidly changing the way engineering design is practiced in industry. The course covers the theories and applications of the measurement, representation, modeling, and simulation of three-dimensional geometric data used in the engineering designed process. Students taking this course are assumed to have knowledge of the first course in computer programming. 4 hrs lecture, 2 hrs computer cluster
Course Website: http://www.andrew.cmu.edu/course/24-681/

24-683 Design for Manufacture and the Environment
Fall: 12 units
Design for Manufacturing and the Environment examines influences of manufacturing and other traditionally downstream issues on the overall design process. Manufacturing is one facet that will be examined. Other downstream influences that will be studied include: assembly, robustness and quality, platform design, maintenance and safety, economics and costing, lean manufacturing and globalization. In addition, a core part of the course will focus on environment-based design issues. The class will study basic fundamentals in each of these areas and how they affect design decisions, Prerequisites: Senior standing in mechanical engineering, or permission of instructor
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-684 Special Topics: Nanoscale Manufacturing Using Structural DNA Nanotechnology
Fall: 12 units
This course provides an introduction to modern nanoscale manufacturing using structural DNAnanotechnology. This DNA-based approach to manufacturing has much in common with other fabrication methods in micro- and nano-engineering: computer aided design tools are necessary for device design and resulting structures can only be seen using advanced microscopy. However, instead of machine and materials down to micro- and nanostructures, DNA origami is fabricated using a “bottom up” approach for self-assembling individual oligonucleotides into 2D and 3D nanostructures. Resulting structures can be designed to have novel mechanical and electrical properties and have applications as biocatalysts, nanoscale medicine, biological computing, and energy systems. The course will include lectures, hands-on physical modeling, homework problems, 3D modeling of DNA origami using caDNAno and CANDO software, and student team projects and presentations.

Course Website: https://www.meche.engineering.cmu.edu/

24-685 Engineering Optimization without Project
Fall: 9 units
This course introduces students to 1) the process of formally representing an engineering design or decision-making problem as a mathematical problem and 2) the theory and numerical methods needed to understand and solve the mathematical problem. Theoretical topics focus on constrained nonlinear programming, including necessary and sufficient conditions for local and global optimality and numerical methods for solving nonlinear optimization problems. Additional topics such as linear programming, mixed integer programming, global optimization, and stochastic methods are briefly introduced. Model construction and interpretation are explored with metamodeling and model reformulation techniques, study of model boundedness, constraint activity, and sensitivity analysis. Matlab is used in homework assignments for visualization and algorithm development, and students apply theory and methods to a topic of interest in a course project. Fluency with multivariable calculus, linear algebra, and computer programming is expected. Students who are unfamiliar with Matlab are expected to learn independently using available tutorials and examples provided. This course is identical to 24-785 Engineering Optimization, except students in 24-685 will not complete the project, but will be responsible for any homework assignments and exams. 19785 and 24785: 12-units including the team-based engineering optimization project 19685 and 24685: 9-units excluding the project Prerequisites: 21-259 and 21-341
Course Website: http://www.cmu.edu/me/

24-686 Advanced Mechanical Design
Intermittent: 12 units
This course will build expert foundational knowledge in mechanical design. Students will perform a series of multi-week modules in which they design, fabricate, and test high-performance mechanical components or assemblies individually or in small teams. Interactive lectures and topic readings on underlying technical approaches will occur simultaneously, thereby drawing a strong connection between theory, analytical methods, computational tools, and experience-based intuition. Modules will address optimal structures for tensile, bending, buckling, and torsion conditions, fatigue life, mechanism design, fluid power system design, and optimization of dynamical system properties. This course builds on the skills and methods taught in 24-370, Engineering Design I, and students are recommended to first take 24-370 and its prerequisites or similar courses at their undergraduate institution. Priority will be given to students who have already passed 24-200 Machine Shop Practice.
Prerequisite: 24-370
Course Website: http://www.cmu.edu/me (http://www.cmu.edu/me/)

24-693 Special Topics: Leadership and Communication
Fall and Spring: 12 units
The objective of this course is to prepare students to be better leaders and communicators in their future careers, in industry, academia, and elsewhere. Topics include: psychological analysis of leaders and followers, negotiation and conflict resolution, interviewing, organizational decision making, and harnessing and deploying skills in challenging situations. To address these topics, the course employs new teaching techniques involving hands on activities, for example mock interviews and role playing around challenging situations. Learning outcomes include: improved ability to adapt, communicate, and lead in difficult situations in real time, understand team interactions and group dynamics to become a successful leader and follower, best practices in negotiating and resolving conflict in team situations and business interactions, and understand fundamentals of the interview process to achieve best outcomes.

24-695 Telling Your Story: Methods and Skills for Communicating Compelling Research
Fall: 6 units
This course will examine approaches to communicating research to a technical audience in a way that is engaging and effective. The course will examine established methods in story telling, and discuss skills necessary to develop and master. The course will cover both written and oral communication. This course is open only to MechE students in at least their third year of their PhD, and students must have completed research ready for dissemination to use as a basis for their course projects. Students will develop written documents and give presentations throughout the class.
24-704 Probability and Estimation Methods for Engineering Systems
Fall: 12 units
Course covers rules of probability, random variables, probability distribution functions, and random processes. Topics for estimating the parameters of probability models and related statistical inference. Application to the analysis and design of engineered systems under conditions of variability and uncertainty. 12 units Prerequisites(s): 26-211, or 36-220 or equivalent. Cross listed CEE 12-704
Prerequisite: 36-220
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-711 Fluid Dynamics
Fall: 12 units
This course focuses on development and application of control volume forms of mass, momentum and energy conservation laws, differential forms of these laws in Eulerian and Lagrangian coordinates, and Navier-Stokes equations. Students also explore applications to problems in incompressible and compressible laminar flows, boundary layers, hydrodynamic lubrication, transient and periodic flows, thermal boundary layers, convective heat transfer, and aerodynamic heating. 4 hrs. lec. Prerequisites: 24-701 or permission of the instructor. Prerequisite: 24-701
Course Website: https://www.meche.engineering.cmu.edu/

24-718 Computational Fluid Dynamics
Fall: 12 units
This course focuses on numerical techniques for solving partial differential equations including the full incompressible Navier-Stokes equations. Several spatial-temporal discretization methods will be taught, namely the finite difference method, finite volume method and briefly, the finite element method. Explicit and implicit approaches, in addition to methods to solve linear equations are employed to study fluid flows. A review of various finite difference methods which will be used to analyze elliptic, hyperbolic, and parabolic partial differential equations and the concepts of stability, consistency and convergence are presented at the beginning of the course to familiarize the students with general numerical methods. Detailed syllabus of the course is provided on the URL given below. 4 hr. lec. Prerequisites: 24-311 and 24-231
Course Website: http://www.andrew.cmu.edu/user/saratbis/24718/

24-721 Advanced Thermodynamics
Intermittent: 12 units
The course covers advanced macroscopic thermodynamics and introduces statistical thermodynamics. Review of first and second laws. Axio-matic formulation of macroscopic equilibrium thermodynamics and property relationships. Criteria for thermodynamic equilibrium with application to multiphase and multi-component systems. Thermodynamic stability of multiphase systems. Elementary kinetic theory of gases and evaluation of transport properties. Statistical-mechanical evaluation of thermodynamic properties of gases, liquids, and solids. Students are expected to have an undergraduate level of understanding of Thermodynamics (comparable to 24-221). 4 hrs. lec. Prerequisite: 24-221
Course Website: http://www.andrew.cmu.edu/user/venkat/24721/

24-722 Energy System Modeling
Fall: 12 units
This course focuses on the thermodynamic modeling of energy systems with emphasis on energy/availability analysis techniques. These techniques are developed and applied to both established and emerging energy technologies, such as internal combustion engines, gas- and coal-fired power plants, solar and wind energy systems, thermochemical hydrogen production cycles, and fuel cells. The course will also consider the integration of components such as reformers and electrolyzers. Modern computational tools are used throughout the course. The course culminates with a group project that requires developing sophisticated, quantitative models of an integrated energy system. Students are expected to have completed an undergraduate course in thermodynamics comparable to 24-221. Prerequisites: 24-221 or 27-215 or 06-221
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-727 Special Topics: Aerosol Measurement Technology
Intermittent: 12 units
This course explores modern methods and instrumentation used to characterize key physical and chemical properties of aerosol particles, and the fundamental principles underlying the technology. Topics include particle sampling and collection (aerodynamic size, impaction, electrostatic precipitation), aerosol charging and neutralization, particle size measurements (electrical mobility, optically, and aerodynamically based), particle detection (optical and electrical), aerosol optical properties, and the characterization of particle chemical composition (online mass spectrometry, in particular). Methods for analyzing both individual and ensembles of aerosol particles are discussed and compared. Recent advances reported in the literature are explored through student-led presentations. Students write a term paper describing and justifying their choice of techniques to solve a realistic aerosol measurement need. While the focus is on atmospheric aerosol particles, industrial applications such as particle synthesis and characterization are also discussed.
Course Website: http://www.cmu.edu/me/

24-730 Advanced Heat Transfer
Spring: 12 units
This course is open to students from all areas of engineering, although an undergraduate background in heat transfer is assumed. This class is an appropriate preparation for the doctoral qualifying exam. Topics to be covered include: mathematical formulation of heat transfer problems, heat conduction, thermal radiation, hydraulic boundary layers, and laminar and turbulent convection. Problems and examples will include theory and applications drawn from a spectrum of engineering design problems. Prerequisite: Undergraduate Heat Transfer 24-322 or equivalent. Prerequisite: 24-322
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-740 Combustion and Air Pollution Control
Spring: 12 units
24-740 Combustion and Air Pollution Control This course examines the generation and control of air pollution from combustion systems. The course’s first part provides a brief treatment of combustion fundamentals, including thermochemical equilibrium, flame temperature, chemical kinetics, hydrocarbon chemistry, mass transfer, and flame structure. This foundation forms the basis for exploring the formation of gaseous (oxides of nitrogen, carbon monoxide, hydrocarbons, and sulfur dioxide) and particulate pollutants in combustion systems. The course then describes combustion modifications for pollutant control and theories for pollutant removal from effluent streams. The internal combustion engine and utility boilers serve as prototypical combustion systems for discussion. The course also addresses the relationship between technology and the formulation of rational regional, national, and global air pollution control strategies. Cross listed 19-740, 19-440, 24-425
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-751 Introduction to Solid Mechanics I
Fall: 12 units
This is the first course in a two-part professionally oriented course sequence covering a variety of important problems in solid mechanics. Topics covered typically include torsion of non-circular cross sections, the field equations of elasticity and boundary conditions, and a number of classical plane stress/ plane strain solutions in rectangular and polar coordinates. Emphasis is placed on not only elasticity theory and how classical elasticity solutions are derived, but also on their use in constructing and interpreting the results from finite element simulations of applied engineering problems. Where applicable, comparisons are also made between solutions derived via the full theory of elasticity and simplified solutions developed in strength of materials courses. 4 hrs. lec.
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)
24-753 Special Topics: Robotic Materials: Designs, Principles & Mechanics
Fall and Spring: 12 units
This is an interdisciplinary course focused on principles, theoretical models, and material architectures relevant to applications of condensed soft matter to problems in engineering. Special attention will be given to the design of soft, elastically-deformable machines and electronics that are primarily composed of elastomers, gels, fluids, gas, and other non-rigid matter. Specific topics will include the mechanics of hyperelastic solids, statistical mechanics of polymers and polymer composites, energy-based modeling techniques derived from the Laws of Thermodynamics, and their applications in modeling soft multifunctional material systems. Additionally, we will explore emerging paradigms in soft robotics, wearable computing, and human machine interaction, including material architectures for artificial muscles, stretchable electronics, and sensorized robotic skin. This course will include extensive reading with problem set assignments, a take-home exam, and final report. Students need familiarity with undergraduate-level solid mechanics, vector mechanics, thermodynamics, and ODEs.
Prerequisite: 24-751

24-755 Finite Elements in Mechanics I
Fall: 12 units
The basic theory and applications of the finite element method in mechanics are presented. Development of the FEM as a Galerkin method for numerical solution of boundary value problems. Applications to second-order steady problems, including heat conduction, elasticity, convective transport, viscous flow and others. Introduction to advanced topics, including fourth-order equations, time dependence and nonlinear problems. 12 Units.
Prerequisite(s): Graduate standing or consent of instructor.
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-760 Special Topics: Robot Dynamics and Analysis
Fall: 12 units
This course covers the dynamics of robotic systems with a focus on the mathematical structure of the dynamics and numerical analysis. Topics will start by reintroducing basic kinematics and dynamics in a more formal mathematical framework before moving on to contact conditions, friction, termodynamics, hybrid dynamical systems, and contact invariant optimization. After the course students will be able to write simulation and optimization methods for analyzing robotic systems. Students should have taken a prior course in dynamics, and be comfortable with linear algebra, multivariable calculus, and programming in Matlab.
Prerequisites: 16-711 or 24-351
Course Website: http://www.andrew.cmu.edu/user/amj1/classes/robotdynamics.html

24-771 Linear Systems
Fall: 12 units
Topics include review of classical feedback control; solution of differential and difference equations; Laplace and Z-transforms, matrix algebra, and convolution; state variable modeling of linear continuous and discrete processes; linearization of nonlinear processes; state variable differential and difference equations; computer-aided analysis techniques for control system design; state variable control principles of controllability, observability, stability, and performance specifications; trade-offs between state variable and transfer function control engineering design techniques; and design problems chosen from chemical, electrical, and mechanical processes. 4 hrs. lec. Prerequisite: An undergraduate course in classical control engineering. Consent of the instructor.
Prerequisite: 24-451
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-774 Special Topics: Advanced Control Systems Integration
Fall: 12 units
This course focuses on the practical implementation of feedback / feedforward controllers. The entire controller design process is presented, including system modeling and identification, compensator design, simulation, and hardware prototyping. This is a project-based course in which students complete the controller design process on a nonlinear, MIMO hardware system. The goal is train students on the system integration skills necessary for success in industry or experimental laboratory work.
Prerequisites: 24-773 or 24-776 or 10-776
Course Website: http://www.cmu.edu/me/

24-776 Non Linear Control
Intermittent: 12 units
Nonlinear Control (12 Units) This course provides an introduction to the analysis and design of nonlinear systems and nonlinear control systems; stability analysis using Lyapunov stability methods; and design of stabilizing controllers using a variety of methods selected from linearization, vibrational control, sliding modes, feedback linearization and geometric control. 4 hrs. lec.
Prerequisite: 24-771

24-780 Engineering Computation
Fall: 12 units
This course covers the practical programming and computational skills necessary for engineers. These include: (1) programming in C++, (2) visualization using OpenGL, (3) basic data structures, and (4) basic algorithms. The course covers computational techniques required for solving common engineering problems and background algorithms and data structures used in modern Computer-Aided Design, Computer-Aided Manufacturing, and Computer-Aided Engineering tools. The course also offers intensive hands-on computational assignments for practice of common applications.
Prerequisite: Consent of instructor
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-781 Engineering Computation Project I
Fall: 24-781 This project course is the first section of the two-semester sequence of Computational Engineering Projects. The course provides the students with hands-on problem-solving experience by using commercial computational tools and/or developing their own custom software. Each student, individually or along with other students, will work on a project under the guidance of Carnegie Mellon faculty members and/or senior engineers from industry. Students may select a project topic from those presented by advising faculty members and/or industry engineers. Alternatively, a student may propose and work on his/her own project topic if he/she can identify a sponsoring faculty member or industry engineer.
Prerequisite: Consent of instructor
Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-782 Computational Engineering Project II
Spring
This project course is the second section of the two-semester sequence of Computational Engineering Projects. The course provides the students with hands-on problem-solving experience by using commercial computational tools and/or developing custom software. Each student, individually or along with other students, will work on a project under the guidance of Carnegie Mellon faculty members and/or senior engineers from industry. Students may select a project topic from those presented by advising faculty members and/or industry engineers. Pending instructor permission, a student may alternatively work on his/her own project under the guidance of a sponsoring faculty member or an industry engineer. MCDSM students only. 12/24 hrs lab Prerequisite: 24-781
Prerequisite: 24-781
Course Website: http://www.cmu.edu/me/

24-784 Special Topics: Trustworthy AI Autonomy
Intermittent: 12 units
Innovations driven by recent progress in artificial intelligence such as deep learning and reinforcement learning, have shown human-competitive performance. However, as research expands to real-world cyber-physical autonomy, the question of safety is becoming a crux for the transition from theories to practice. This course will first review fundamental knowledge for trustworthy AI autonomy, including adversarial attack/defend, generative models, hierarchical Bayesian models, safe reinforcement learning, rare-event/few-shot learning, and robust evaluation. Then from the research perspective, students will explore the novelty and potential extension of various state-of-the-art trustworthy AI research and their implementation through a series of readings. Students will develop the ability to conduct research in teams. Knowledge and research skills learned in this course can be applied to self-driving, healthcare devices, assistant robots, and intelligent manufacturing. This course is devised for research-focused students who have backgrounds and interests in statistical machine learning, robotics and control, and human-machine interaction. Other interested students should contact the instructor to determine if it is a good fit for them.
24-785 Engineering Optimization
Intermittent: 12 units
Engineering Optimization Intermittent: 12 units This course introduces students to 1) the process of formally representing an engineering design or decision-making problem as a mathematical problem and 2) the theory and numerical methods needed to understand and solve the mathematical problem. Theoretical topics focus on constrained nonlinear programming, including necessary and sufficient conditions for local and global optimality and numerical methods for solving nonlinear optimization problems. Additional topics such as linear programming, mixed integer programming, global optimization, and stochastic methods are briefly introduced. Model construction and interpretation are explored with metamodeling and model reformulation techniques, study of model boundedness, constraint activity, and sensitivity analysis. Matlab is used in homework assignments for visualization and algorithm development, and students apply theory and methods to a topic of interest in a course project. Fluency with multivariable calculus, linear algebra, and computer programming is expected. Students who are unfamiliar with Matlab are expected to learn independently using available tutorials and examples provided. 4 hrs.lecture Prerequisites: None 19785 and 24785: 12-units including the team-based engineering optimization project 19685 and 24685: 9-units excluding the project Prerequisites: 21-341 and 21-259

24-787 Machine Learning and Artificial Intelligence for Engineers
Fall: 12 units
This course introduces fundamental machine learning and artificial intelligence techniques useful for engineers working on data-intensive problems. Topics include: Probability and Bayesian learning, generative and discriminative classification methods, supervised and unsupervised learning, neural networks, support vector machines, clustering, dimensionality reduction, regression, optimization, evolutionary computation, and search. The lectures emphasize the theoretical foundations and the mathematical modeling of the introduced techniques, while bi-weekly homework assignments focus on the implementation and testing of the learned techniques in software. The assignments require knowledge of Python including text and image input/output, vector and matrix operations, simple loops, and data visualization. Students must have undergraduate level experience with linear algebra and vector calculus. Prerequisites: 21-341 and 15-112

Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-788 Machine Learning and Artificial Intelligence for Engineers - Project
Spring: 12 units
This course provides an open-ended computational project experience in artificial intelligence and machine learning. This course will enable student teams to design, develop and test data-driven computational algorithms. Course objectives are: - Gain experience in data sciences and data-driven methods for engineering - Learn advanced programming and computational system design - Learn project planning and management, project evaluation, teamwork, technical communication. The projects will target problems involving experimental, simulated or crowd-sourced data. Each project will aim to build an artificial intelligence or machine learning system that accomplishes one or more of the following: identify patterns in data, establish a mathematical model for the input/output relationships, classify data into distinct categories, use existing data to synthesize new solutions to a synthesis problem. Team activities include: three presentations, two written reports, a final technology demo, and one final report in the form of an archival publication. Prerequisites: 10-601 Min. grade C or 10-701 Min. grade C or 24-787 Min. grade C or 15-781 Min. grade C

Course Website: http://www.cmu.edu/me/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-789 Graduate Seminar I
All Semesters
Graduate seminar speakers include faculty, students, and invited guests from industry and academia. Through seminars, students widen their perspectives and become more aware of other topics in mechanical engineering

Course Website: http://www.cmu.edu/me/graduate/index.html (http://www.cmu.edu/me/graduate/)

24-892 Locomotion Seminar
Intermittent
The CMU Bipedal Locomotion Seminar is a weekly meeting amongst students and professors who study bipedal locomotion using a variety of approaches. Each week, one graduate student participant gives a presentation on a topic of their choosing related to their research. We encourage discussion and interaction, especially from fellow students. Each meeting is intended to work like a small, informal conference discussion or workshop, providing students with new perspectives on their projects, practice presenting and answering questions, and a forum for meeting colleagues. We encourage participation from all interested students and faculty, including members of Carnegie Mellon, The University of Pittsburgh, and Disney Research Pittsburgh. Please join the waitlist and contact one of the instructors for admission.

Course Website: http://www.andrew.cmu.edu/user/amj1/locomotion_seminar.html