

MECHANICAL ENGINEERING AND APPLIED MECHANICS (MEAM)

MEAM 091 Shop Tr. Manual Milling

Fundamental principles of manual milling of metals, including hands-on training in the machine shop.

One-term course offered either term

Activity: Lecture

0.25 Course Units

MEAM 092 Shop Tr. Manual Turning

Fundamental principles of manual turning of metals using a lathe, including hands-on training in the machine shop.

One-term course offered either term

Activity: Lecture

0.25 Course Units

MEAM 093 Shop Tr. Hybrid Milling

Building upon the basics covered in MEAM 091, this intermediate-level course includes detailed operation sequencing, fixture design, and hands-on conversational CNC programming for the ProtoTrak Hybrid Mill.

Activity: Lecture

0.25 Course Units

MEAM 094 Tr. CNC Milling/solidcam

Building upon proficiency in MEAM 091 and 093, this hands-on course covers the details of full computer-controlled machining using SolidCAM and the Haas MiniMill.

One-term course offered either term

Activity: Lecture

0.25 Course Units

MEAM 095 Shop Tr. CNC Turning

Building upon the basics of MEAM 092, this course explores advanced computer-controlled turning using SolidCAM and the Haas TL-1.

One-term course offered either term

Activity: Lecture

0.25 Course Units

MEAM 099 Independent Study

An opportunity for the student to become closely associated with a professor in (1) a research effort to develop research skills and technique and/or (2) to develop a program of independent in-depth study in a subject area in which the professor and student have a common interest. The challenge of the task undertaken must be consistent with the student's academic level. To register for this course, the student and professor jointly submit a detailed proposal. Subject to the approval of the MEAM Undergraduate Curriculum Chair.

One-term course offered either term

Activity: Independent Study

1 Course Unit

Notes: Open to all students. A maximum of 2 c.u. of MEAM 099 may be applied toward the B.A.S. or B.S.E. degree requirements

MEAM 101 Introduction to Mechanical Design

This hands-on, project-based course covers the fundamentals of the modern mechanical design process, from needfinding and brainstorming to the basics of computerized manufacturing and rapid prototyping. Topics include: product definition (needfinding, observation, sketching, and brainstorming); computer-aided design (part creation, assemblies, and animation using SolidWorks); fundamental engineering design practices (material selection, dimensioning, tolerances, etc.); basic computer simulation and analysis; and rapid prototyping (laser cutter, 3-D fused-deposition modeling, and an introduction to computer-controlled machining).

One-term course offered either term

Activity: Lecture

1 Course Unit

Notes: This course is available to all Engineering majors.

MEAM 110 Introduction to Mechanics

This lecture course and a companion laboratory course (MEAM 147) build upon the concepts of Newtonian (classical) mechanics and their application to engineered systems. This course introduces students to mechanical principles that are the foundation of upper-level engineering courses including MEAM 210 and 211. The three major parts of this course are: I. Vector Mechanics; II. Statics and Structures; and III. Kinematics and Dynamics. Topics include: vector analysis, statics of rigid bodies, introduction to deformable bodies, friction, kinematics of motion, work and energy, and dynamics of particles. Case studies will be introduced, and the role of Newtonian mechanics in emerging applications including bio- and nano- technologies will be discussed.

Course usually offered in fall term

Corequisites: MATH 104 (The Engineering section of this class is strongly recommended) and MEAM 147.

Activity: Lecture

1 Course Unit

MEAM 147 Introduction to Mechanics Lab

This half-credit laboratory class is a companion to the Introduction to Mechanics lecture course (MEAM 110). It investigates the concepts of Newtonian (classical) mechanics through weekly hands-on experiments, emphasizing connections between theoretical principles and practical applications in engineering. In addition to furthering their understanding about the workings of the physical world, students will improve their skills at conducting experiments, obtaining reliable data, presenting numerical results, and extracting meaningful information from such numbers.

Course usually offered in fall term

Corequisite: MEAM 110

Activity: Laboratory

0.5 Course Units

MEAM 201 Machine Design and Manufacturing

Building upon the fundamentals of mechanical design taught in MEAM 101, this hands-on, project-based course provides students with the knowledge and skills necessary to design, analyze, manufacture, and test fully-functional mechanical systems. Topics covered include an introduction to machine elements, analysis of the mechanics of machining, manufacturing technology, precision fabrication (milling, turning, and computer-controlled machining), metrology, tolerances, cutting-tool fundamentals and engineering materials. Enrollment is limited.

Course usually offered in spring term

Prerequisite: MEAM 101; MEAM 210 or equivalent as co/pre-requisite (or permission of the instructor)

Activity: Lecture

1 Course Unit

MEAM 203 Thermodynamics I

Thermodynamics studies the fundamental concepts related to energy conversion in such mechanical systems as internal and external combustion engines (including automobile and aircraft engines), compressors, pumps, refrigerators, and turbines. This course is intended for students in mechanical engineering, chemical engineering, materials science, physics and other fields. The topics include properties of pure substances, first-law analysis of closed systems and control volumes, reversibility and irreversibility, entropy, second-law analysis, exergy, power and refrigeration cycles, and their engineering applications.

Course usually offered in spring term

Prerequisites: MATH 104 and MATH 114

Activity: Lecture

1 Course Unit

MEAM 210 Statics and Strength of Materials

This course is primarily intended for students in mechanical engineering, but may also be of interest to students in materials science and other fields. It continues the treatment of statics of rigid bodies begun in MEAM 110/PHYS 150 and progresses to the treatment of deformable bodies and their response to loads. The concepts of stress, strain, and linearly elastic response are introduced and applied to the behavior of rods, shafts, beams and other mechanical components. The failure and design of mechanical components are discussed.

Course usually offered in fall term

Prerequisite: MEAM 110/MEAM 147 or PHYS 150

Corequisites: MATH 240 and MEAM 247 are strongly recommended

Activity: Lecture

1 Course Unit

MEAM 211 Engineering Mechanics: Dynamics

This course introduces the basic concepts in kinematics and dynamics that are necessary to understand, analyze and design mechanisms and machines. These concepts are also fundamental to the modeling and analysis of human movement, biomechanics, animation of synthetic human models and robotics. The topics covered include: Particle dynamics using energy and momentum methods of analysis; Dynamics of systems of particles; Impact; Systems of variable mass; Kinematics and dynamics of rigid bodies in plane motion; Computer-aided dynamic simulation and animation.

Course usually offered in spring term

Prerequisite: MEAM 210

Corequisites: MATH 241 or ENM 251 and ENGR 105 or equivalent

Activity: Lecture

1 Course Unit

MEAM 220 Introduction to Materials Science and Engineering

The course is an introduction to the most important concepts in materials science and engineering with a goal of building the foundations for all other courses related to materials and how to think about materials in other areas of engineering and the physical sciences. It covers atomic bonding, crystal structure and symmetry, glasses, defects, diffusion, elasticity, plasticity, fracture, phase diagrams, phase transformations, and an introduction into thermal, electrical, magnetic and optical properties and materials processing. Material classes will include metals, ceramics, polymers, semiconductors, and composites.

Course usually offered in fall term

Also Offered As: MSE 220

Prerequisites: Knowledge of basic calculus and chemistry

Activity: Lecture

1 Course Unit

MEAM 247 Mechanical Engineering Laboratory I

This is the first of a two semester sophomore level laboratory sequence that students complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement as well as analysis and application to design. This fall semester course follows closely with MEAM 210, involving experiments to explore the principles of statics and strength of materials.

Course usually offered in fall term

Prerequisite: Sophomore standing in engineering

Corequisite: MEAM 210 strongly recommended

Activity: Laboratory

0.5 Course Units

MEAM 248 Mechanical Engineering Lab I

This is the second of a two-semester sophomore level laboratory sequence that students complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement as well as analysis and application to design. The spring semester course follows closely with MEAM 203 and MEAM 211, expanding upon the principles of experimentation, measurement, analysis, and design of systems through hands-on laboratories and projects in thermodynamics and dynamics.

Course usually offered in spring term

Prerequisite: Sophomore standing in engineering

Corequisites: MEAM 203 and MEAM 211 are strongly recommended

Activity: Lecture

0.5 Course Units

MEAM 302 Fluid Mechanics

Physical properties; fluid statics; Bernoulli equation; fluid kinematics; conservation laws and finite control-volume analysis; conservation laws and differential analysis; inviscid flow; The Navier-Stokes equation and some exact solutions; similitude, dimensional analysis, and modeling; flow in pipes and channels; boundary layer theory; lift and drag.

Course usually offered in fall term

Prerequisites: MATH 241 or ENM 251 and PHYS 150 or MEAM 110/MEAM 147

Activity: Lecture

1 Course Unit

MEAM 321 Vibrations of Mechanical Systems

This course teaches the fundamental concepts underlying the dynamics of vibrations for single-degree of freedom, multi-degree and infinite-degree of freedom mechanical systems. The course will focus on Newton's Force Methods, Virtual-Work Methods, and Lagrange's Variation Methods for analyzing problems in vibrations. Students will learn how to analyze transient, steady state and forced motion of single and multi-degree of freedom linear and non-linear systems. The course teaches analytical solution techniques for linear systems and practical numerical and simulation methods for analysis and design of nonlinear systems.

Course usually offered in spring term

Prerequisites: MATH 241 or ENM 251 and MEAM 211

Activity: Lecture

1 Course Unit

MEAM 333 Heat and Mass Transfer

This course covers fundamentals of heat and mass transfer and applications to practical problems in energy conversion and conservation. Emphasis will be on developing a physical and analytical understanding of conductive, convective, and radiative heat transfer, as well as design of heat exchangers and heat transfer with phase change. Topics covered will include: types of heat transfer processes, their relative importance, and the interactions between them, solutions of steady state and transient state conduction, emission and absorption of radiation by real surfaces and radiative transfer between surfaces, heat transfer by forced and natural convection owing to flow around bodies and through ducts, analytical solutions for some sample cases and applications of correlations for engineering problems. Students will develop an ability to apply governing principles and physical intuition to solve problems.

Course usually offered in spring term

Prerequisites: MEAM 203 and MEAM 302

Activity: Lecture

1 Course Unit

MEAM 347 Mechanical Engineering Design Laboratory

This is the first of a two-semester junior level laboratory sequence that students complete over the fall and spring semesters. The course is project-based, with problems whose solution requires experimental data and quantitative analysis, as well as creative mechanical design. The technical content is connected to MEAM 302 and MEAM 354, including aerodynamics, applied fluid systems and structural analysis. The course also includes electromechanical systems and applications of finite element analysis.

Course usually offered in fall term

Prerequisite: Junior standing in engineering

Activity: Laboratory

1 Course Unit

MEAM 348 Mechanical Engineering Design Laboratory

This is the second of a two-semester junior level laboratory sequence that students complete over the fall and spring semesters. The course is project-based, with open-ended design problems that challenge students to develop original experiments and choose appropriate analyses, with an increasing emphasis on teamwork and project planning. The technical content is connected to MEAM 321 and MEAM 333, including multimodal transient heat transfer and dynamic systems modeling.

Course usually offered in spring term

Prerequisite: Junior standing in engineering

Activity: Laboratory

1 Course Unit

MEAM 354 Mechanics of Solids

This course builds on the fundamentals of solid mechanics taught in MEAM 210 and addresses more advanced problems in strength of materials. The students will be exposed to a wide array of applications from traditional engineering disciplines as well as emerging areas such as biotechnology and nanotechnology. The methods of analysis developed in this course will form the cornerstone of machine design and also more advanced topics in the mechanics of materials.

Course usually offered in fall term

Prerequisites: MEAM 210 or equivalent, BE 200 or permission of instructor.

Activity: Lecture

1 Course Unit

MEAM 405 Mechanical Properties of Macro/Nanoscale Materials

The application of continuum and microstructural concepts to consideration of the mechanics and mechanisms of flow and fracture in metals, polymers and ceramics. The course includes a review of tensors and elasticity with special emphasis on the effects of symmetry on tensor properties. Then deformation, fracture and degradation (fatigue and wear) are treated, including mapping strategies for understanding the ranges of material properties.

Course usually offered in fall term

Also Offered As: MEAM 505, MSE 405, MSE 505

Activity: Lecture

1 Course Unit

MEAM 415 Product Design

This course provides tools and methods for creating new products. The course is intended for students with a strong career interest in new product development, entrepreneurship, and/or technology development. The course follows an overall product design methodology, including the identification of customer needs, generation of product concepts, prototyping, and design-for-manufacturing. Weekly student assignments are focused on the design of a new product and culminate in the creation of a prototype, which is launched at an end-of-semester public Design Fair. The course project is a physical good - but most of the tools and methods apply to services and software products. The course is open to any Penn sophomore, junior, senior or graduate student.

One-term course offered either term

Also Offered As: IPD 515, OIDD 415

Activity: Lecture

1 Course Unit

MEAM 421 Control for Autonomous Robots

This course introduces the hardware, software and control technology used in autonomous ground vehicles, commonly called "self-driving cars." The weekly laboratory sessions focus on development of a small-scale autonomous car, incrementally enhancing the sensors, software, and control algorithms to culminate in a demonstration in a realistic outdoor operating environment. Students will learn basic physics and modeling; controls design and analysis in Matlab and Simulink; software implementation in C and Python; sensor systems and filtering methods for IMUs, GPS, and computer vision systems; and path planning from fixed map data.

One-term course offered either term

Also Offered As: ESE 421

Prerequisite: CIS 110 or CIS 120 or ENGR 105; ESE 210 or ESE 215 or MEAM 211 or permission of the instructor

Activity: Lecture

1.5 Course Unit

MEAM 445 Mechanical Engineering Design Projects

This capstone design project course is required of all mechanical engineering students. Student teams will design and test complex mechanical systems that address a societal or consumer need. Projects are devised by the team, sponsored by industry, or formulated by Penn professors. Each project is approved by the instructor and a faculty advisor. Topics treated in the course include project planning, prototyping, patent and library searches, intellectual property, ethics, and technical writing and presentations. The work is spread over MEAM 445 and MEAM 446.

Course usually offered in fall term

Prerequisite: Junior standing

Activity: Lecture

1 Course Unit

MEAM 446 Mechanical Engineering Design Projects

This is the second course in the two course sequence involving the capstone design project. See MEAM 445 for course description.

Course usually offered in spring term

Activity: Lecture

1 Course Unit

MEAM 455 Continuum Biomechanics

Continuum mechanics with applications to biological systems. Fundamental engineering conservation laws are introduced and illustrated using biological and non-biological examples. Kinematics of deformation, stress, and conservation of mass, momentum, and energy. Constitutive equations for fluids, solids, and intermediate types of media are described and applied to selected biological examples. Class work is complemented by computational laboratory experiences.

Course usually offered in fall term

Also Offered As: BE 455

Activity: Lecture

1 Course Unit

MEAM 502 Energy Engineering in Power Plants and Transportation Systems

Most energy consumed in the U.S. and in the world is produced using thermal-to-mechanical energy conversion. In this course, students will learn the engineering principles that govern how heat is converted to mechanical power in electric power plants, jet aircraft, and internal combustion engines. Topics covered include a review of thermodynamics and basic power cycles, supercritical, combined, and hybrid cycles, cogeneration, jet propulsion, and reciprocating internal combustion engines. A brief introduction to desalination and combustion is also included. The material in this course will provide students a foundation important for industrial and research employment in energy engineering.

Course usually offered in fall term

Prerequisites: Undergraduate engineering thermodynamics (MEAM 203 or equivalent), and heat transfer (MEAM 333 or equivalent)

Activity: Lecture

1 Course Unit

MEAM 503 Direct Energy Conversion: from Macro to Nano

The course focuses on devices that convert thermal, solar, or chemical energy directly to electricity, i.e., without intermediate mechanical machinery such as a turbine or a reciprocating piston engine. A variety of converters with sizes ranging from macro to nano scale will be discussed, with the advantages offered by nanoscale components specifically highlighted. Topics will include thermoelectric energy converters and radioisotope thermoelectric generators (RTGs), thermionic energy converters (TEC), photovoltaic (PV) and thermophotovoltaic (TPV) cells, as well as piezoelectric harvesters. Additional topics may include magnetohydrodynamic (MHD) generators, alkali metal thermal-to-electric converters (AMTEC), and fuel cells.

One-term course offered either term

Prerequisites: Basics of thermodynamics (MEAM 203 or equivalent), Basics of heat transfer (MEAM 333 or equivalent)

Activity: Lecture

1 Course Unit

MEAM 504 Tribology

The course will comprehensively cover both theoretical and practical tribology, the science and technology of interacting surfaces in relative motion. The various modes of lubrication, hydrodynamic, elastohydrodynamic, hydrostatic, mixed, solid and dry, will be studied in detail. The contact between solid surfaces will be covered, leading to an understanding of friction and various modes of wear. At each stage, it will be shown how the tribological principles learned can be applied in practice to improve the efficiency and durability of mechanical equipment and thereby enhance sustainability through energy and materials conservation.

One-term course offered either term

Prerequisites: Senior standing in Mechanical Engineering or Materials Science or by permission of the instructor.

Activity: Lecture

1 Course Unit

MEAM 505 Mechanical Properties of Macro/Nanoscale Materials

The application of continuum and microstructural concepts to consideration of the mechanics and mechanisms of flow and fracture in metals, polymers and ceramics. The course includes a review of tensors and elasticity with special emphasis on the effects of symmetry on tensor properties. Then deformation, fracture and degradation (fatigue and wear) are treated, including mapping strategies for understanding the ranges of material properties.

Course usually offered in fall term

Also Offered As: MEAM 405, MSE 405

Activity: Lecture

1 Course Unit

MEAM 507 Fundamentals of Materials

This course will provide a graduate level introduction to the science and engineering of materials. It is designed specifically to meet the needs of students who will be doing research that involves materials but who do not have an extensive background in the field. The focus is on fundamental aspects of materials science and will emphasize phenomena and how to describe them. The course assumes an undergraduate background in any area of physical/chemical science and undergraduate mathematics appropriate to this. The course will also be accessible to students of applied mathematics.

One-term course offered either term

Also Offered As: MSE 507

Activity: Lecture

1 Course Unit

MEAM 508 Materials and Manufacturing for Mechanical Design

The selection of materials and manufacturing processes are critical in the design of mechanical systems. Material properties and manufacturing processes are often tightly linked, thus this course covers both topics in an integrated manner. The properties and manufacturing processes for a wide range of materials (i.e., metals, ceramics, polymers, composites) are examined from both a fundamental and practical perspective. From a materials standpoint, the course focuses on mechanical properties, including modulus, strength, fracture, fatigue, wear, and creep. Established and emerging manufacturing processes will be discussed. Design-based case studies are used to illustrate the selection of materials and processes.

One-term course offered either term

Activity: Lecture

1 Course Unit

MEAM 510 Design of Mechatronic Systems

In many modern systems, mechanical elements are tightly coupled with electronic components and embedded computers. Mechatronics is the study of how these domains are interconnected, and this hands-on, project-based course provides an integrated introduction to the fundamental components within each of the three domains, including: mechanical elements (prototyping, materials, actuators and sensors, transmissions, and fundamental kinematics), electronics (basic circuits, filters, op amps, discrete logic, and interfacing with mechanical elements), and computing (interfacing with the analog world, microprocessor technology, basic control theory, and programming).

Course usually offered in fall term

Also Offered As: MEAM 410

Prerequisite: Graduate standing in engineering or permission of the instructor

Activity: Lecture

1 Course Unit

MEAM 513 Feedback Control Design and Analysis

Basic methods for analysis and design of feedback control in systems.

Applications to practical systems. Methods presented include time response analysis, frequency response analysis, root locus, Nyquist and Bode plots, and the state-space approach.

Course usually offered in spring term

Also Offered As: ESE 505

Prerequisites: MEAM 321 or ESE 210, Juniors and Seniors encouraged to enroll

Activity: Lecture

1 Course Unit

MEAM 514 Design for Manufacturability

This course is aimed at providing current and future product design/development engineers, manufacturing engineers, and product development managers with an applied understanding of Design for Manufacturability (DFM) concepts and methods. The course content includes materials from multiple disciplines including: engineering design, manufacturing, marketing, finance, project management, and quality systems.

Course usually offered in spring term

Also Offered As: IPD 514

Prerequisites: MEAM 101 or equivalent, MEAM 210 or equivalent, senior or graduate standing in the School of Design, Engineering, or Business with completed product development and/or design engineering core coursework or related experience.

Activity: Lecture

1 Course Unit

MEAM 516 Advanced Mechatronic Reactive Spaces.

This course combines performance art and advanced mechatronics concepts that include the design and implementation of large-scale actuation, advanced sensing, actuation and control. This course pairs design school and engineering students to form interdisciplinary teams that together design and build electro-mechanical reactive spaces and scenic/architectural elements in the context of the performing arts. The two disciplinary groups will be treated separately and receive credit for different courses (ARCH746 will be taught concurrently and in some cases co-located) as they will be learning different things. Engineering students gain design sensibilities and advanced mechatronics in the form of networked embedded processing and protocols for large scale actuation and sensing. Design students learn elementary mechatronics and design reactive architectures and work with engineering students to build them. The class will culminate in a some artistic performance (typically with professional artists) such as a Shakespeare play, robotic ballet, a mechatronic opera.

Course usually offered in spring term

Also Offered As: IPD 516

Prerequisite: MEAM 510 (Mechatronics) or equivalent

Activity: Lecture

1 Course Unit

MEAM 517 Control and Optimization with Applications in Robotics

This course covers a variety of advanced topics in model-based nonlinear control, primarily focused on computational techniques and dynamic robotic applications. Students will learn both the theoretical basics of nonlinear and optimal control along with computational algorithms.

Topics include dynamic programming, trajectory optimization, canonical underactuated systems, control of limit cycles, stability analysis, nonsmooth mechanics, and model predictive control. Applications include walking and running robots, manipulation, and flying machines.

As the course will cover state of the art techniques, we will review relevant research papers. At the end of the semester, students will prepare and present a final project on a related topic of their choosing.

Prerequisites: MATH 312 or equivalent, MEAM 513/ESE 505, ESE 500, MEAM 520 or equivalent, MEAM 211 or equivalent, programming experience highly recommend, or permission of the instructor.

Activity: Lecture

1 Course Unit

MEAM 519 Elasticity and Micromechanics of Materials

This course is targeted to engineering students working in the areas on micro/nanomechanics of materials. The course will start with a quick review of the equations of linear elasticity and proceed to solutions of specific problems such as the Hertz contact problem, Eshelby's problem etc. Failure mechanisms such as fracture and the fundamentals of dislocations/plasticity will also be discussed.

One-term course offered either term

Also Offered As: MSE 550

Activity: Lecture

1 Course Unit

MEAM 520 Introduction to Robotics

The rapidly evolving field of robotics includes systems designed to replace, assist, or even entertain humans in a wide variety of tasks. Recent examples include human-friendly robot arms for manufacturing, interactive robotic pets, medical and surgical assistive robots, and semi-autonomous search-and-rescue vehicles. This course presents the fundamental kinematic, dynamic, and computational principles underlying most modern robotic systems. The main topics of the course include: rotation matrices, homogeneous transformations, manipulator forward kinematics, manipulator inverse kinematics, jacobians, path and trajectory planning, sensing and actuation, feedback control, haptic interfaces, and teleoperation. The material is reinforced with hands-on lab exercises involving a robotic arm and a haptic interface.

Course usually offered in fall term

Prerequisites: MEAM 211 and MATH 240 or equivalent

Activity: Lecture

1 Course Unit

MEAM 527 Finite Element Analysis

The objective of this course is to equip students with the background needed to carry out finite elements-based simulations of various engineering problems. The first part of the course will outline the theory of finite elements. The second part of the course will address the solution of classical equations of mathematical physics such as Laplace, Poisson, Helmholtz, the wave and the Heat equations. The third part of the course will consist of case studies taken from various areas of engineering and the sciences on topics that require or can benefit from finite element modeling. The students will gain hands-on experience with the multi-physics, finite element package FemLab.

Course usually offered in fall term

Also Offered As: ENM 427

Prerequisites: MATH 241 or ENM 251 and PHYS 151

Activity: Lecture

1 Course Unit

MEAM 529 Introduction to MEMS and NEMS

Introduction to RM MEMS technologies; need for RF MEMS components in wireless communications. Review of micromachining techniques and MEMS fabrication approaches. Actuation methods in MEMS, TRF MEMS design and modeling. Examples of RF MEMS components from industry and academia. Case studies: micro-switches, tunable capacitors, inductors, resonators, filters, oscillators and micromachined antennas. Overview of RF NEMS.

Course usually offered in fall term

Activity: Lecture

1 Course Unit

MEAM 530 Continuum Mechanics

This course serves as a basic introduction to the Mechanics of continuous media, and it will prepare the student for more advanced courses in solid and fluid mechanics. The topics to be covered include: Tensor algebra and calculus, Lagrangian and Eulerian kinematics, Cauchy and Piola-Kirchhoff stresses, General principles: conservation of mass, conservation of linear and angular momentum, energy and the first law of thermodynamics, entropy and the second law of thermodynamics; constitutive theory, ideal fluids, Newtonian and non-Newtonian fluids, finite elasticity, linear elasticity, materials with microstructure.

Course usually offered in spring term

Prerequisites: Multivariable Calculus, Linear Algebra, Partial Differential Equations

Activity: Lecture

1 Course Unit

MEAM 535 Advanced Dynamics

Three-Dimensional Geometry: Introduction to Reference Frames, Geometry of Rotations of Reference Frames and of Vectors, Euler Angle, Axis-Angle Representations, Properties of Rotation Matrices. Kinematics: Kinematics of Rigid-Body Motion, Rotations, Angular Velocity and Acceleration, Linear Velocity and Acceleration, Applications to Planar Linkage Analysis. Constraints: Configuration Space, Holonomic and Non-holonomic Constraints, Degrees of Freedom, Tests for Holonomic versus Non-holonomic Constraints, Generalized Coordinates, Generalized Speeds, Partial Speeds, Partial Velocities, Principle of Virtual Work for Holonomic and Non-holonomic systems. Constraint Forces: Virtual Work, D'Alembert Equations, Lagrange's Equations for Non-holonomic systems. Distribution of Mass: Center-of-Mass, Vector and Scalar Moments of Inertia. Vector Spaces: Operators, Dyads, Dyadic, Moment-of-Inertia Tensor, Rigid Bodies. Dynamics: Kinetic Energy and Angular Momentum, Lagrangian/Hamiltonian Mechanics and Conservation Laws, Poisson Brackets and Constants of the Motion, Kane-Lagrange Equations with Non-Holonomic Constraints, Kane-Lagrange Equations, Null Spaces and Computing Constraint Forces. Variational Calculus: The Principle of Least Action, A Study of Small Perturbations and Linear Stability Analysis.

Course usually offered in fall term

Prerequisites: MEAM 211 and some Linear Algebra. Senior or Master's Standing in Engineering or permission of the instructor.

Activity: Lecture

1 Course Unit

MEAM 536 Viscous Fluid Flow and Modern Applications

This is an intermediate course that builds on the basic principles of Fluid Mechanics. The course provides a more in depth and unified framework to understand fluid flow at different time and length scales, in particular viscous flows. Topics include review of basic concepts, conservation laws (momentum, mass, and heat), fluid kinematics, tensor analysis, Stokes' approximations, non-Newtonian fluid mechanics, and turbulence. The course will explore important modern topics such as microfluidics, swimming of micro-organisms, wind turbines, rheology, biofluid mechanics, and boundary layers.

Course not offered every year

Activity: Lecture

1 Course Unit

Notes: This course is intended for juniors, seniors and graduate students from the Schools of Engineering and/or Arts and Sciences that have a general interest in fluid dynamics and its modern applications. Students should have an understanding of basic concepts in fluid mechanics and a good grasp on differential equations.

MEAM 537 Nanotribology

Engineering is progressing to ever smaller scales, enabling new technologies, materials, devices, and applications. This course will provide an introduction to nano-scale tribology and the critical role it plays in the developing areas of nanoscience and nanotechnology. We will discuss how contact, adhesion, friction, lubrication, and wear at interfaces originate, using an integrated approach that combines concepts of mechanics, materials science, chemistry, and physics. We will cover a range of concepts and applications, drawing connections to both established and new approaches. We will discuss the limits of continuum mechanics and present newly developed theories and experiments tailored to describe micro- and nano-scale phenomena. We will emphasize specific applications throughout the course. Reading of scientific literature, critical peer discussion, individual and team problem assignments, and a peer-reviewed literature research project will be assigned as part of the course.

Course usually offered in spring term

Also Offered As: MSE 537

Prerequisites: Freshman physics; MEAM 354 or equivalent, or consent of instructor.

Activity: Lecture

1 Course Unit

MEAM 538 Turbulence

This course is an introductory course on turbulent flows. The course provides physical and mathematical framework for quantitative and qualitative descriptions of fundamental processes involved in turbulent flows. Topics include the Navier-Stokes equations, the statistical description of turbulence, equations for mean and fluctuations, energy cascade, turbulence spectra, Kolmogorov hypotheses, behavior of shear flows, and isotropic turbulence. The course will also explore modern topics such as computational modeling of turbulence.

Taught by: MEAM 302 or equivalent

One-term course offered either term

Prerequisite: MEAM 302 or equivalent

Activity: Lecture

1 Course Unit

Notes: Instructor Permission required for undergraduates

MEAM 543 Performance, Stability and Control of UAVs

This course covers the application of classical aircraft performance and design concepts to fixed-wing and rotary-wing Unmanned Aerial Vehicles (UAVs). A survey of the latest developments in UAV technology will be used to motivate the development of quantitative mission requirements, such as payload, range, endurance, field length, and detectability. The implications of these requirements on vehicle configuration and sizing will be revealed through application of the fundamentals of aerodynamics and propulsion systems. The course will also cover basic flight dynamics and control, including typical inner-loop feedback applications.

One-term course offered either term

Prerequisites: MEAM 210, 211, MATH 240 or equivalents

Activity: Lecture

1 Course Unit

MEAM 545 Aerodynamics

Review of fluid kinematics and conservation laws; vorticity theorems; two-dimensional potential flow; airfoil theory; finite wings; oblique shocks; supersonic wing theory; laminar and turbulent boundary layers. Course usually offered in spring term

Prerequisite: MEAM 302

Activity: Lecture

1 Course Unit

MEAM 550 Design of Microelectromechanical Systems

A course that covers the design and fabrication of micro- and nano-electromechanical systems. Topics in the course include micro- and nano-fabrication techniques, mechanics of flexures, thin film mechanics, sensing and actuation approaches (e.g., electrostatic, piezoelectric, and piezoresistive), as well as materials and reliability issues. The fundamentals of these topics will be augmented with device-based case studies.

Course not offered every year

Prerequisites: MEAM 354 or equivalent is recommended.

Activity: Lecture

1 Course Unit

MEAM 553 Atomic Modeling in Materials Science

This course covers two major aspects of atomic level computer modeling in materials. 1. Methods: Molecular statics, Molecular dynamics, Monte Carlo, Kinetic Monte Carlo as well as methods of analysis of the results such as radial distribution function, thermodynamics deduced from the molecular dynamics, fluctuations, correlations and autocorrelations. 2. Semi-empirical descriptions of atomic interactions: pair potentials, embedded atom method, covalent bonding, ionic bonding. Basics of the density functional theory. Mechanics, condensed matter physics, thermodynamics and statistical mechanics needed in interpretations are briefly explained.

Course usually offered in spring term

Also Offered As: MSE 561

Prerequisites: Ability to write a basic code in a computer language such as fortran, C, C++

Activity: Lecture

1 Course Unit

MEAM 555 Nanoscale Systems Biology

Nano-science and engineering approaches to systems in biology are of growing importance. They extend from novel methods, especially microscopies that invite innovation to mathematical and/or computational modeling which incorporates the physics and chemistry of small scale biology. Proteins and DNA, for example, are highly specialized polymers that interact, catalyze, stretch and bend, move, and/or store information. Membranes are also used extensively by cells to isolate, adhere, deform, and regulate reactions. In this course, students will become familiar with cell & molecular biology and nano-biotechnology through an emphasis on nano-methods, membranes, molecular machines, and 'polymers' - from the quantitative perspectives of thermodynamics, statistical physics, and mechanics. We specifically elaborate ideas of energetics, fluctuations and noise, force, kinetics, diffusion, etc. on the nano- thru micro- scale, drawing from very recent examples in the literature. Laboratory experiments will provide hands-on exposure to microscopies in a biological context (eg. fluorescence down to nano-scale, AFM), physical methods (eg. micromanipulation, tracking virus-scale particles or quantum dots), and numerical problems in applied biophysics, chemistry, and engineering. A key goal of the course is to familiarize students with the concepts and technology (plus their limitations) as being employed in current research problems in nanoscale systems biology, extending to nanobiotechnology.

One-term course offered either term

Also Offered As: BE 555, CBE 555

Prerequisites: Background in Biology, Physics, Chemistry or Engineering with coursework in Thermodynamics or permission of the instructor.

Activity: Lecture

1 Course Unit

MEAM 561 Thermodynamics: Foundations, Energy, Materials

To introduce students to advanced classical equilibrium thermodynamics based on Callen's postulational approach, to exergy (Second-Law) analysis, and to fundamentals of nonequilibrium thermodynamics. Applications to be treated include the thermodynamic foundations of energy processes and systems including advanced power generation and aerospace propulsion cycles, batteries and fuel cells, combustion, diffusion, transport in membranes, materials properties and elasticity, superconductivity, biological processes.

Course not offered every year

Prerequisites: Undergraduate thermodynamics.

Activity: Lecture

1 Course Unit

MEAM 564 The Principles and Practice of Microfabrication Technology

A laboratory course on fabricating microelectronic and micromechanical devices using photolithographic processing and related fabrication technologies. Lectures discuss: clean room procedures, microelectronic and microstructural materials, photolithography, diffusion, oxidation, materials deposition, etching and plasma processes. Basic laboratory processes are covered in the first two thirds of the course with students completing structures appropriate to their major in the final third. Students registering for ESE 574 will be expected to do extra work (including term paper and additional project).

Course usually offered in fall term

Also Offered As: ESE 460, ESE 574

Prerequisites: Any of the following courses: ESE 218, MEAM 333, CBE 351, PHYS 250 or permission of the instructor

Activity: Lecture

1 Course Unit

MEAM 570 Transport Processes I

The course provides a unified introduction to momentum, energy (heat), and mass transport processes. The basic mechanisms and the constitutive laws for the various transport processes will be delineated, and the conservation equations will be derived and applied to internal and external flows featuring a few examples from mechanical, chemical, and biological systems. Reactive flows will also be considered.

Course usually offered in fall term

Activity: Lecture

1 Course Unit

MEAM 571 Advanced Topics in Transport Phenomena

The course deals with advanced topics in transport phenomena and is suitable for graduate students in mechanical, chemical and bioengineering who plan to pursue research in areas related to transport phenomena or work in an industrial setting that deals with transport issues. Topics include: Transport processes with drops, Bubbles and particles; Phase change Phenomena: -condensation, evaporation, and combustion; Radiation heat transfer: non-participating media, participating media, equation of radiative transfer, optically thin and thick limits; Introduction to Hydrodynamic and Thermal Instability; Microscale energy transport; Nano-particle motion in fluids and transport.

Course not offered every year

Prerequisites: Either MEAM 570, MEAM 642, CBE 640 or equivalent, or Written permission of the Instructor.

Activity: Lecture

1 Course Unit

MEAM 575 Micro and Nano Fluidics

The course focuses on topics relevant for micro-fluidics, lab on chip technology, point of care diagnostics, nano-technology, biosensing, and interfacial phenomena. Although we will discuss briefly the fabrication of micro and nano fluidic devices, the course will mostly focus on physical phenomena from the continuum point of view. The mathematical complexity will be kept to a minimum. The course will be reasonably self-contained, and any necessary background material will be provided, consistent with the students' background and level of preparation. Specifically, we will examine fluid and nanoparticle transport under the action of pressure, electric, magnetic, and capillary forces; the structure and role of superhydrophobic surfaces; how the solid/liquid interface acquires electric charge; ion transport in electrolytes (Poisson-Nernst-Planck equations); colloid stability; electroosmosis, electrophoresis, and particle polarization; electrowetting and digital microfluidics; particle and cell sorting; immunoassays; and enzymatic amplification of nucleic acids.

Course not offered every year

Activity: Lecture

1 Course Unit

MEAM 580 Electrochemistry for Energy, Nanofabrication and Sensing

Principles and mathematical models of electrochemical processes in energy conversion and storage, water desalination, nanofabrication, electroplating, and sensing for engineering and science graduate students and advanced undergraduates, lacking prior background in electrochemistry. The course covers equivalent circuits, electrode kinetics, electrokinetic and transport phenomena, and electrostatics. The course will introduce and use the finite element program COMSOLTM. We will discuss, among other things, applications to stationary and flow batteries, supercapacitors, integrated electric circuit fabrication, electrokinetics, and biosensing. In contrast to CBE 545 Electrochemical Energy Conversion that focuses on solid state electrochemistry, this course emphasizes liquid-based electrochemistry.

One-term course offered either term

Prerequisites: Undergraduate course in Fluid Mechanics (MEAM 302), and in Heat and Mass Transfer (MEAM 333)

Activity: Lecture

1 Course Unit

MEAM 597 Master's Thesis Research

One-term course offered either term

Activity: Masters Thesis

1 Course Unit

MEAM 599 Master's Independent Study

One-term course offered either term

Activity: Independent Study

1 Course Unit

MEAM 613 Nonlinear Control Theory

The course studies issues in nonlinear control theory, with a particular emphasis on the use of geometric principles. Topics include: controllability, accessibility, and observability, for nonlinear systems; Forbenius' theorem; feedback and input/output linearization for SISO and MIMO systems; dynamic extension; zero dynamics; output tracking and regulation; model matching disturbance decoupling; examples will be taken from mechanical systems, robotic systems, including those involving nonholonomic constraints, and active control of vibrations.

Course not offered every year

Also Offered As: CBE 617, CIS 613, ESE 617

Prerequisites: A sufficient background to linear algebra (ENM 510 or ENM 511 or equivalent) and a course in linear control theory (MEAM 513 or equivalent), or written permission of the instructor.

Activity: Lecture

1 Course Unit

MEAM 620 Advanced Robotics

This course covers advanced topics in robotics and includes such topics as multi-body dynamics, nonlinear control theory and planning algorithms with application to robots and systems of multiple robots.

Course usually offered in spring term

Prerequisites: Graduate standing in engineering and MEAM 535 or ESE 500 or CIS 580 or MEAM 520.

Activity: Lecture

1 Course Unit

MEAM 630 Advanced Continuum Mechanics

This course is a more advanced version of MEAM 530. The topics to be covered include: tensor algebra and calculus, Lagrangian and Eulerian kinematics; Cauchy and Piola-Kirchhoff stresses. General principles: conservation of mass, conservation of linear and angular momentum, energy and the first law of thermodynamics, entropy and the second law of thermodynamics. Constitutive theory, ideal fluids, Newtonian and non-Newtonian fluids, finite elasticity, linear elasticity, materials with microstructure.

Course not offered every year

Prerequisites: One graduate level course in applied mathematics and one in either fluid or Solid Mechanics.

Activity: Lecture

1 Course Unit

MEAM 632 Plasticity

This course develops the mathematical theory of plastic deformation for both crystalline and disordered materials. Phenomenological models for strain-hardening, creep and size-dependent plastic flow as well as physically-based theories for single crystals are discussed. Applications are drawn from problems in structural mechanics, deformation processing, friction and contact, and fracture. Large strain deformations and problems involving strain localization are considered.

Course not offered every year

Prerequisites: MEAM 519 or permission of instructor.

Activity: Lecture

1 Course Unit

MEAM 633 Mechanics of Adhesion and Fracture

This course focuses on mechanics aspects of adhesion and fracture of solids. The topics are intimately related, as fracture involves decohesion. Topics include forces of interaction between surfaces of solids, perfect versus imperfect adhesion, aspects of contact mechanics, linear analysis of cracks in elastic materials, non-linear analysis of cracks in elastic-plastic materials, J-integral methods, phenomenological theories, crack growth and healing, and stability. Micro-mechanical models of fracture are analyzed using non-linear elasticity and energy methods.

Applications to various material systems and processes, including structural materials, layered materials, friction and wear.

Course not offered every year

Prerequisites: Background equivalent to MEAM 519 and ENM 510

Activity: Lecture

1 Course Unit

MEAM 634 Rods and Shells

This course is intended for 2nd year graduate students and introduces continuum mechanics theory of rods and shells with applications to structures and to biological systems as well as stability and buckling. The course begins with topics from differential geometry of curves and surfaces and the associated tensor analysis on Riemannian spaces. A brief introduction to variational calculus is included since variational methods are a powerful tool for formulating approximate structural mechanics theories and for numerical analysis. The structural mechanics theories of rods, plates and shells are introduced including both linear and nonlinear theories.

Course not offered every year

Prerequisites: First-year graduate-level applied mathematics for engineers (ENM 510 and 511) and a first course in continuum mechanics or elasticity or permission of instructor.

Activity: Lecture

1 Course Unit

MEAM 635 Composite Materials

This course deals with the prediction of the average, or effective properties of composite materials. The emphasis will be on methods for determining effective behavior. The course will be concerned mostly with linear mechanical and physical properties, with particular emphasis on the effective conductivity and elastic moduli of multi-phase composites and polycrystals. However, time-dependent and non-linear properties will also be discussed.

Course not offered every year

Prerequisite: ENM 510

Corequisite: ENM 511

Activity: Lecture

1 Course Unit

MEAM 642 Advanced Fluid Mechanics

Fluid mechanics as a vector field theory; basic conservation laws, constitutive relations, boundary conditions, Bernoulli theorems, vorticity theorems, potential flow. Viscous flow; large Reynolds number limit; boundary layers.

One-term course offered either term

Activity: Lecture

1 Course Unit

MEAM 646 Computational Mechanics

The course is divided into two parts. The course first introduces general numerical techniques for elliptical partial differential equations - finite difference method, finite element method and spectral method. The second part of the course introduces finite volume method. SIMPLER formulation for the Navier-Stokes equations will be fully described in the class. Students will be given chances to modify a program specially written for this course to solve some practical problems in heat transfer and fluid flows.

Course not offered every year

Prerequisites: ENM 510, ENM 511, and one graduate level introductory course in mechanics. FORTRAN or C programming experience is necessary.

Activity: Lecture

1 Course Unit

MEAM 650 Mechanics of Soft and Biomaterials

This course is aimed to expose the students to a variety of topics in mechanic materials via discussion of "classic" problems that have had the widest impact long period of time and have been applied to analyze the mechanical behavior a variety of biological and engineering materials.

One-term course offered either term

Also Offered As: MSE 650

Activity: Lecture

1 Course Unit

MEAM 662 Advanced Molecular Thermodynamics

This course begins with a brief review of classical thermodynamics, including the development of Maxwell relationships and stability analysis. The remainder of the course develops the fundamental framework of statistical mechanics, then reviews various related topics including ideal and interacting gases, Einstein and Debye models of crystals, lattice models of liquids, and the basis of distribution function theory.

Course usually offered in fall term

Also Offered As: BE 662, CBE 618

Activity: Lecture

1 Course Unit

MEAM 663 Entropic Forces in Biomechanics

This course is targeted for engineering/physics students working in the areas of nano/bio technology. The course will start with a quick review of statistical mechanics and proceed to topics such as Langevin dynamics, solution biochemistry (Poisson-Boltzmann and Debye-Huckel theory), entropic elasticity of bio-polymers and networks, reaction rate kinetics, solid state physics and other areas of current technological relevance. Students will be expected to have knowledge of undergraduate mechanics, physics and thermodynamics.

One-term course offered either term

Activity: Lecture

1 Course Unit

MEAM 690 Advanced Topics in Thermal Fluid Science or Energy

This course will be offered when demand permits. The topics will change due to the interest and specialties of the instructor(s). Some topics could include: Computational Fluid Mechanics, Visualization of Computational Results, Free Surface Flows, Fluid Mechanics of the Respiratory System, and transport in Reacting Systems.

Course not offered every year

Activity: Lecture

1 Course Unit

MEAM 691 Special Topics in Mechanics of Materials

This course will be offered when demand permits. The topics will change due to the interests and specialties of the instructor(s). Some topics could include: Compliant Mechanisms, Optimal Control, and Fluid-Structure interaction.

Course not offered every year

Activity: Lecture

1 Course Unit

MEAM 692 Topics in Mechanical Systems

This course will be offered when demand permits. The topics will change due to the interests and specialties of the instructor(s). Some topics could include: Electromagnetics, Control Theory, and Micro-Electro-Mechanical Systems.

Course not offered every year

Activity: Lecture

1 Course Unit

MEAM 699 MEAM Seminar

The seminar course has been established so that students get recognition for their seminar attendance as well as to encourage students to attend. Students registered for this course are required to attend weekly departmental seminars given by distinguished speakers from around the world. There will be no quizzes, tests, or homeworks. The course will be graded S/U. In order to obtain a satisfactory (S) grade, the student will need to attend more than 70% of the departmental seminars. Participation in the seminar course will be documented and recorded on the students transcript. In order to obtain their degree, doctoral students will be required to accumulate six seminar courses and MS candidates (beginning in the Fall 2001) two courses. Under special circumstances, i.e. in case of conflict with a course, the student may waive the seminar requirement for a particular semester by petition to the Graduate Group Chair.

One-term course offered either term

Activity: Seminar

1 Course Unit

MEAM 895 Teaching Practicum

This course provides training in the practical aspects of teaching. The students will work with a faculty member to learn and develop teaching and communication skills. As part of the course, students will participate in a range of activities that may include: giving demonstration lectures, leading recitations, supervising laboratory experiments, developing instructional laboratories, developing instructional material, preparing homework assignments, and preparing examinations. Some of the recitations will be supervised and feedback and comments will be provided to the student by the faculty responsible for the course. At the completion of the 0.5 c.u. of teaching practicum, the student will receive a Satisfactory/Unsatisfactory grade and a written evaluation from the faculty member responsible for the course. The evaluation will be based on comments of the students taking the course and the impressions of the faculty.

One-term course offered either term

Activity: Lecture

0.5 Course Units

MEAM 899 Independent Study

For students who are studying specific advanced subject areas in mechanical engineering and applied mechanics. Before the beginning of the term, the student must submit a proposal outlining and detailing the study area, along with the faculty supervisor's consent, to the graduate group chair for approval. At the conclusion of the independent study, the student should prepare a brief report.

One-term course offered either term

Activity: Independent Study

1 Course Unit

MEAM 990 Masters Thesis

Master's Thesis

Activity: Masters Thesis

1 Course Unit

MEAM 995 Dissertation

Activity: Dissertation

1 Course Unit

MEAM 999 Thesis/Dissertation Research

For students working on an advanced research program leading to the completion of master's thesis or Ph.D. dissertation requirements.

One-term course offered either term

Activity: Independent Study

1 Course Unit

Notes: Both terms.