



**UNDERGRADUATE STUDENT MANUAL**

**Department of Mechanical Engineering  
and Applied Mechanics**

**University of Pennsylvania**

*September 2005*

MEAM Website: <http://www.me.upenn.edu>

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## WHAT IS MECHANICAL ENGINEERING AND APPLIED MECHANICS?

### **What is Mechanical Engineering and Applied Mechanics?**

Mechanical engineering and applied mechanics is the study of forces, deformations, and motions of solid bodies and fluids, heat generation and transport, and applications to analysis, design, and manufacture of mechanisms, machines, and their components.

### **The Department**

The Department of Mechanical Engineering and Applied Mechanics (MEAM) was the second engineering curriculum established in the University (c. 1872), and its many alumni are noted for their distinguished careers and contributions in engineering, management, science, and education.

The Mechanical Engineering and Applied Mechanics (MEAM) curriculum at Penn offers its students a broad based education that will allow them to adapt to changes in technology in our rapidly changing society. At the same time, the curriculum offers the flexibility to specialize in one or more areas in mechanical engineering (for example, computer-aided-design and manufacturing (CAD/CAM), energy engineering, mechanical design, fluid mechanics, or structure mechanics) or even such cross-disciplinary areas as robotics, biomechanics, micro-electromechanical systems (MEMS), or mechanics of materials. Our students are encouraged to do research during their course of study and provided every opportunity to master critical skills to be successful in their future career.

### **Careers in Mechanical Engineering and Applied Mechanics**

The career opportunities available to our graduates are perhaps the broadest among all fields of engineering. A wide variety of industries, including aerospace, automotive, electronics and computers, chemical, and biomedical recruit mechanical engineers. Positions range from research and development to design and manufacturing to field engineering and marketing. Some recent graduates have taken positions with consulting and financial institutions, while others have gone on to graduate studies in engineering, business, law, and medicine.

## GENERAL INFORMATION

### **Undergraduate Academic Advisor**

All freshmen in MEAM are assigned to a designated faculty member in the Mechanical Engineering department (Prof. Howard Hu hhu@seas and Prof. John Bassani, bassani@seas) who will serve as their academic advisor for their freshman year. Students are expected to consult with their advisor on academic matters during posted office hours or by appointment.

### **Electronic Mail**

All students in the School of Engineering and Applied Science receive an electronic mail account on the SEAS mainframe. These accounts are issued through the Computing and Educational Technology (CETS) Office, Room 169 Levine Hall. With this account students can access their electronic mail and read the bulletin boards. Many professors establish newsgroups on the electronic bulletin board for specific courses. Students should have already obtained their accounts through Campus Express (<http://campusexpress.upenn.edu>) before arriving at Penn.

### **Mailboxes**

Every student in the School of Engineering and Applied Science has a personal mailbox. Undergraduate mailboxes for the Department of Mechanical Engineering are located on the second floor of the Towne Building, room 279. These mailboxes are one of our principal means of communicating with students, and all students should get into the habit of checking his/her mailbox on a regular basis.

## **Student Society**

The undergraduate student body of the Department of Mechanical Engineering has a student chapter of the American Society of Mechanical Engineers (ASME), which functions as a student technical and professional society. Students elect their own officers and conduct a variety of programs of academic, professional and social interest to them. If you are interested in joining the society or obtaining more information about its activities please contact the President, John Prosser, (jprosser@seas) or the ASME Faculty Advisor, Prof. Mark Yim (yim@seas).

There are other clubs and honor societies for Mechanical Engineering students. These include the Solar Car (Project Leader Zachary Kirkhorn, zacharyk@seas and Noël Camacho, noelrc@seas), Society of Automotive Engineers (<http://www.seas.upenn.edu/~sae>), Formula Society of Automotive Engineers (FSAE) (<http://www.seas.upenn.edu/~fsae/>). Student engineering societies traditionally are a strong force in shaping professional attitudes and providing information about the profession, job directions and opportunities, opportunities for meeting practicing engineers, and for socializing with people of similar professional interests.

## **CURRICULUM IN MECHANICAL ENGINEERING AND APPLIED MECHANICS**

Mechanical engineering students are expected to formulate a degree program well grounded in the fundamentals of mechanical engineering while having the breadth that is necessary in today's technology-intensive workplace. The curriculum contains sufficient flexibility so that the student can pursue a number of elective options in depth, either in traditional mechanical engineering subjects or in one or more multidisciplinary engineering programs at Penn. Flexibility in the curriculum, primarily in the junior and senior years, enables the student to pursue an elective program in fields such as aeronautics, robotics, design and manufacturing, mechatronics, business administration, advanced mathematics, control systems, and mechanics of materials.

Please visit our website at: <http://www.me.upenn.edu/>

A student interested in pursuing certain engineering disciplines in depth should consider choosing his or her electives accordingly. We list possible areas of specialization below:

### **AREAS OF SPECIALIZATION IN MECHANICAL ENGINEERING AND APPLIED MECHANICS**

The following is a list of courses that may be taken in the professional electives category. Students are encouraged to take courses and specialize in one or two areas.

**Notes:**

1. MEAM courses that may only be offered every other year.
2. You should consult with the instructor before taking these graduate level courses.
3. Students may consider designing an independent study course, MEAM 99, with a MEAM faculty advisor in any area or across two or more areas.

### **Design and Manufacturing**

MEAM 101	Introduction to Computer Aided Design and Manufacturing
ESE 215	Electrical Circuits and Systems
MSE 220	Engineering Materials
MEAM 410	Design of Mechatronic Systems
MEAM 415	Product Design
MEAM 427/527	Finite Element and Applications
MEAM 454	Mechanics of Materials <sup>2</sup>
ESE 460	Principles of Microfabrication Technology
MEAM 540	Optimal Design of Mechanical Systems <sup>2</sup>
MEAM 550	Modeling and Design of Micro-Electro-Mechanical Systems (MEMS) <sup>2</sup>

### **Energy Engineering**

MEAM 338	Thermodynamics II <sup>2</sup>
MEAM 402	Energy Engineering <sup>2</sup>
MEAM 570	Transport <sup>3</sup>
MEAM 572	Micro/Nanoscale Energy Transport <sup>3</sup>

### **Fluid Mechanics and Aerodynamics**

MEAM 427/527	Finite Element and Applications
MEAM 435	Aerodynamics
MEAM 436	Viscous Fluid Flow <sup>2</sup>
MEAM 530	Continuum Mechanics <sup>3</sup>
MEAM 570	Transport <sup>3</sup>
MEAM 642/3	Fluid Mechanics <sup>2,3</sup>

### **Manufacturing Systems**

MEAM 101	Introduction to Computer Aided Design and Manufacturing
ESE 215	Electrical Circuits and Systems
ESE 301	Engineering Probability
MEAM 410	Design of Mechatronic Systems
MEAM 413	Modeling and Control of Mechanical Systems <sup>2</sup>
MEAM 415	Product Design
MEAM 420/520	Robotics
MEAM 427/527	Finite Element and Applications
ESE 460	Principles of Microfabrication Technology
ESE 522	Process Mgmt in Manufacturing <sup>3</sup>
ESE 524	Operations Technology Management <sup>3</sup>

### **Mechanics of Materials/ Structural Mechanics**

MSE 220	Engineering Materials
ESE 341	Structural Systems I - Statics
ESE 342	Design Principles in Structural Systems
MEAM 427/527	Finite Element and Applications
MEAM 454	Mechanics of Materials <sup>2</sup>
MEAM 519	Introduction to Elasticity <sup>3</sup>

### **Mechatronics**

CSE 120	Introduction to Programming
ESE 215/205	Electrical Circuits and Systems
CSE 240	Introduction to Computer Architecture
MEAM 410	Design of Mechatronic Systems
MEAM 413	Modeling and Control of Mechanical Systems <sup>2</sup>
MEAM 420/520	Robotics
ESE 460	Principles of Microfabrication Technology
ESE 522	Fundamentals of Sensor Technology
MEAM 550	Modeling and Design of Micro-Electro-Mechanical Systems (MEMS) <sup>3</sup>

### **Product Design and Innovation**

MEAM 101	Introduction to Computer Aided Design and Manufacturing
MEAM 410	Design of Mechatronic Systems
MEAM 415	Product Design

### **MINOR IN MECHANICAL ENGINEERING AND APPLIED MECHANICS**

Six MEAM courses are required for a minor in MEAM. Any six MEAM courses may be chosen.

# MEAM CPG (course planning guide)

## Math (5 CU)

- MATH 104 (Calculus I)
- MATH 114 (Calculus II)
- MATH 240 (Calculus III)
- MATH 241 (Calculus IV)
- \_\_\_\_\_

**Recom:** Math 412 (Advanced Linear Algebra)

## Natural Science (5 CU)

- PHYS 150 (Principles of Physics I)
- PHYS 151 (Principles of Physics II)
- CHEM 101 (General Chemistry)
- CHEM 053 (General Chemistry Lab)
- \_\_\_\_\_

**Recom:** Bio 101 (Intro. To Biology)

## Core ME (10 CU)

- MEAM 210 (Statics & Str. of Materials)
- MEAM 211 (Eng Mechanics: Dynamics)
- MEAM 245 (Intro to Flight)
- MEAM 247 (MEAM Lab 1)
- MEAM 203 (Thermodynamics I)
- MEAM 302 (Fluid Mechanics)
- MEAM 310 (Design of Thrml/Fluid Sys)
- MEAM 321 (Vibrations of Mech Sys)
- MEAM 333 (Heat & Mass Transfer)
- MEAM 347 (MEAM Lab II)

## Professional Elec (10 CU)

- MEAM 445 (Design Project I)
- MEAM 446 (Design Project II)
- MEAM \_\_\_\_\_
- MEAM \_\_\_\_\_

- MEAM \_\_\_\_\_
- MEAM \_\_\_\_\_
- Breadth \_\_\_\_\_ 1
- Breadth \_\_\_\_\_ 1
- \_\_\_\_\_ 2
- \_\_\_\_\_ 2

### •NOTES:

1. Breadth: Any Non-MEAM, 200 level or above Eng. (EE 215/205, MSE 220 recommended).
2. From the Math, Nat.Sci. or Eng. categories (substitutions possible under petition).
3. Max. 3 100-level courses.

## General Elec (7 CU)

- SS \_\_\_\_\_
- SS \_\_\_\_\_
- H \_\_\_\_\_
- H \_\_\_\_\_
- SS or H \_\_\_\_\_
- SS, H or TBS \_\_\_\_\_
- SS, H or TBS \_\_\_\_\_

*Depth (from SSH)*

\_\_\_\_\_

*Writing Reqt (from SSH)*

\_\_\_\_\_

## Free Elec (3 CU)

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

## MEAM B.S.E. SAMPLE FOUR-YEAR COURSE PLAN

Many courses have prerequisites, and therefore, the sequence in which courses are taken may be important. The following sample course plan shows one sequence which satisfies the prerequisites for the specified courses. The advanced MEAM courses listed in the Course Requirements section can be taken by any student who has taken the freshman and sophomore courses in the sample program. Each student must, however develop a complete course plan in consultation with his or her academic advisor.

### Freshman Year

#### *FALL*

**MATH 104** Calculus I  
**PHYS 150** Principles of Physics I & Lab  
**CHEM 101/053** Introduction to Chemistry & Lab  
**ESE 115 or CSE 110 or CSE 120/130** Intro to Programming

#### *SPRING*

**MATH 114** Calculus II  
**PHYS 151** Principles of Physics II & Lab  
**MEAM 101** Intro to CAD/CAM  
**Writing requirement**

### Sophomore Year

#### *FALL*

**MATH 240** Calculus III  
**MEAM 210** Statics and Strength of Materials  
**MEAM 245** Introduction to Flight  
**MEAM 247** Mechanical Engineering Laboratory I(A)  
**Two electives**

#### *SPRING*

**MATH 241** Calculus IV  
**MEAM 203** Thermodynamics I  
**MEAM 211** Engineering Mechanics: Dynamics  
**MEAM 247** Mechanical Engineering Laboratory I(B)  
**Two electives**

### Junior Year

#### *FALL*

**MEAM 302** Fluid Mechanics  
**MEAM 321** Vibrations  
**MEAM 347** Mechanical Engineering Laboratory II(A)  
**Three electives**

#### *SPRING*

**MEAM 310** Design of Thermal/Fluid Systems  
**MEAM 333** Heat and Mass Transfer  
**MEAM 347** Mechanical Engineering Laboratory II(B)  
**MEAM 445** Mechanical Engineering Design Projects  
**Two electives**

### Senior Year

#### *FALL*

**MEAM 446** Mechanical Engineering Design Projects  
**Four electives**

#### *SPRING*

**Four electives**

## MEAM ELECTIVE SCHEDULE

### **Fall 2005:**

MEAM 402/502: Energy Engineering  
MEAM 405/505, MSE 405/505: Mech Prop Nano/Macro  
MEAM 410/510: Design of Mechatronic Systems  
MEAM 420/520/CSE 390: Robotics  
MEAM 455/BE 455: Continuum Biomechanics  
MEAM 564/ESE 460: Principles of Microfab Tech  
MEAM 572: Micro/Nanoscale Energy Transport

### **Spring 2006\*:**

MEAM 415/515, OPIM 415: Product Design  
MEAM 435/545: Aerodynamics  
MEAM 454/554: Mechanics of Materials  
MEAM 513, ESE 406/505: Modern Feedback Control Theory  
MEAM 555, CBE 444/555: Nanoscale System Biol

### **Fall 2006\*:**

MEAM 402/502: Energy Engineering  
MEAM 405/505, MSE 405/505: Mech Prop Nano/Macro  
MEAM 410/510: Design of Mechatronic Systems  
MEAM 420/CSE 390: Robotics  
MEAM 455/BE 455: Continuum Biomechanics  
MEAM 564/ESE 460: Principles of Microfab Tech

### **Spring 2007\*:**

MEAM 415/515, OPIM 415: Product Design  
MEAM 435/545: Aerodynamics  
MEAM 427/527: Finite Elements and Applications  
MEAM 513, ESE 406/505: Modern Feedback Control Theory

### **Notes**

**(1) Permission required for all 5xx level courses.**

**\*Tentative**

**\*\* Petition needed for counting as MEAM electives.**

### OTHER RECOMMENDED ELECTIVES

Biology 101	Intro to Biology
BE 466	Biological Systems & Control
BE 450	Hemodynamics
BE 451	Advanced Transport Processes in Living Systems
CBE 251	Principles of Biological Chemistry
CSE 240	Introduction to Computer Architecture
CSE 390	Robotics
ESE 115	Introduction to Programming
ESE 215	Electrical Circuits and Systems
ESE 460	The Principles and Practice of Microfabrication Technology
ESE 301	Engineering Probability
ESE 522	Manufacturing Operations Management
ESE 524	Operations Technology Management
ESE 341	Structural Systems
ESE 342	Design principles in Structural Systems
MSE 220	Engineering Materials
Physics 280/580	Biological Physics

## COURSE DESCRIPTIONS

**099. Undergraduate Research and/or Independent Study. (C)** 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 099 is a course that allows a student to formulate, in consultation with a MEAM professor, a program of independent study. It affords students an opportunity to work closely with a MEAM professor and study a topic of interest that is not taught in a MEAM course. Alternatively, students can use this as a vehicle to pursue an independent research project under the supervision of a MEAM professor. To register for this course, the student with the supervising professor, must jointly submit a detailed proposal to the undergraduate curriculum chairman no later than the end of the first week of the term. The proposal must spell out details of the material that will be covered, a list of tasks/assignments that will be completed by the student, and the criteria for grading. MEAM 099 may be taken by any engineering or non engineering student. However, the proposed program of study must be commensurate with the student's background and his/her level of preparation.

### **L/L 101. Introduction to CAD/CAM. (C)**

This course covers the fundamentals of engineering design and manufacturing, engineering practice, and the application of computer aided tools. The topics include: Graphical representation of machinery and machine drawing, Product definition and Computer Aided Design (CAD) 3-D wire frame and solid modeling using Pro/ENGINEER; System Assembly; Tolerancing; Introduction to Computer Aided Engineering analysis techniques including finite element modeling (FEM); Fundamentals of manufacturing processes and machine tools; Introduction to CNC machines and rapid prototyping using modern manufacturing techniques. The course includes tours of engineering and manufacturing facilities and a design project.

### **L/R 203. Thermodynamics I. (A)**

Thermodynamics is the study of the fundamental concepts underlying the conversion of energy 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, material science, physics and other fields. The topics include: Basic definitions, microscopic and macroscopic points of view; properties of pure substances and equations of state; work and heat; the first and second law of thermodynamics and their applications, reversibility and irreversibility, the thermodynamic temperature scale, entropy, availability, second law analysis, power and refrigeration cycles and their engineering applications.

### **L/R 210. Statics and Strength of Materials. (A)** Prerequisite(s): Physics 150. Corequisite(s): Math 240.

This course is intended for students in mechanical engineering, systems-civil, materials science and other fields. It continues the treatment of the statics of particles and rigid bodies begun in Physics 150 and leads to the treatment of deformable bodies and their response to loads. The concepts of stress, strain, and linearly elastic response are introduced and they are applied to the behavior of rods, beams, and shafts. The course incorporates several laboratory activities and the use of computers to solve problems using MATLAB and other simulation software.

### **L/R 211. Engineering Mechanics: Dynamics. (B)** Prerequisite(s): MEAM 210 and MATH 241 concurrently.

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.

### **L/L 245. Introduction to Flight. (A)** Prerequisite(s): Math 240 concurrently and first year physics.

Basic concepts: pressure, density, velocity, forces. The standard atmosphere. Introduction to low speed aerodynamics. Airfoils, wings, and other aerodynamic shapes. Aircraft propulsion.

### **247. Mechanical Engineering Laboratory I. (E)** Prerequisite(s): Sophomore standing in engineering.

This is a sophomore level laboratory course that students will complete over the fall and spring semesters. The course teaches the principles of designing experiments and measurement systems, and involves experiments in statics, dynamics, and CAD/CAM of mechanical systems.

**L/R 302. (CBE350) Fluid Mechanics. (A)** Prerequisite(s): MATH 241 and PHYS 151.

This course introduces the description of phenomena associated with fluid flow. It provides a background to higher-level courses involving fluid flows and heat transfer. Topics covered will include: physical properties of fluids; fluid statics; the principles of conservation of mass, momentum, and energy; fluid kinematics; control-volume technique; Bernoulli equation; dimensional analysis and dynamic similarity; flow in pipes and channels; momentum theorems; laminar and turbulent flow phenomena; boundary layer theory; lift and drag. Physical understanding of fluid flows and applications to practical problems will be stressed.

**L/R 310. Design of Thermal/Fluid Systems. (B)** Prerequisite(s): MEAM 211, 302, MATH 241.

This course teaches students the basic concepts necessary to design, analyze and optimize thermal and fluid engineering systems. Computational design tools are applied to case studies on selected topics ranging from electronics thermal management to building climate control. The topics covered include introduction to engineering design, thermal/fluid equipment and components, reliability, and optimization. A team design project is included.

**L/R 321. Vibrations of Mechanical Systems. (M)** Prerequisite(s): MATH 241 and MEAM 211, CSE 110 or equivalent recommended.

This course teaches the fundamental concepts underlying the dynamics of mechanisms and vibrations in high-speed machinery and the analysis of vibrations in multi-degree of freedom mechanical systems. Students will learn how to analyze transient and steady motion of single and multi-degree of freedom linear and non-linear systems. The course teaches both analytical solution techniques for linear systems and practical simulation methods for analysis and design, with applications to vehicle dynamics and seismic loading of structures.

**L/R 333. (CBE351)Heat and Mass Transfer. (B)** Prerequisite(s): MATH 241 & 302

This course is a required course for all MEAM undergraduates. It covers the fundamentals of heat 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.

**338. (MEAM561)Thermodynamics II. (B)** Prerequisite(s): MEAM 203 or CBE 231.

This course is a second course in thermodynamics, a follow up to MEAM 203. Thermodynamics deals with the conservation of energy and the limitations in nature on various physical processes. Emphasis in this course is placed on the implications of these principles for various engineering systems, particularly those devices which produce useful power (engines) or cooling and heating (refrigerators, heat pumps). Other applications in engineering and science are also considered. Topics dealt with include: introduction to thermodynamics of mixtures; gas-vapor mixtures and their use in climate control and cooling towers; thermodynamic relations and properties of real gases (i.e., generalized charts); chemical reactions and applications to combustion; introduction to phase and chemical equilibrium and to chemical kinetics; kinetic theory of ideal gases and transport phenomena on microscopic scale; introduction to quantum mechanics and statistical mechanics; and applications of statistical mechanics, i.e. radiation (photon gas) and the Debye solid.

**347. Mechanical Engineering Laboratory II. (E)** Prerequisite(s): Junior standing in engineering.

This is a junior level laboratory course that students will complete over the fall and spring semesters. The course teaches the principles of designing experiments and measurement systems, and involves experiments in thermodynamics, fluid mechanics, heat transfer and design of mechanical systems.

**L/R 402. (MEAM502) Energy Engineering. (M)** Prerequisite(s): MEAM 203, and MEAM 333 can be taken concurrently with MEAM 402), or equivalent.

This course covers various important aspects of energy consumption, use, and resources; basic laws of thermodynamics, energy analysis, power cycles; solar energy, nuclear energy include fission and waste treatment; ocean thermal energy conversion, wind and tidal power; and energy system design and optimization.

**405. (MEAM 505,MSE405/505) Mechanical Properties of Macro/Nanoscale Materials. (C)**

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.

**410. (MEAM510) Design of Mechatronic Systems II. (A)** Prerequisite(s): Junior or senior standing in mechanical engineering and a first course in programming, or permission of the instructor.

In many modern mechanical systems, mechanical elements are tightly coupled with electronics used for control or for sensing and possibly with microprocessors. Mechatronics is the study of computer-controlled electromechanical systems. This course is intended to provide an integrated introduction to the design of such systems. The course is intended for juniors and seniors in computer science and engineering, electrical engineering, mechanical engineering and systems engineering. The central focus of this course will be the completion of a team-based project, to be tested in an in-class competition during the final week of the course. Topics to be covered include: a review of mechanics; instrumentation, sensing and measurement; actuation and actuator dynamics; analog and digital interfacing; micro-processor technology and programming; basic control theory.

**413. Modeling and Control of Physical Systems. (B)** Prerequisite(s): MATH 241, and MEAM 321 or SYS 222, or permission of the instructor.

This course is an introduction to automatic control systems and control theory. It is intended for students in computer science and engineering, electrical engineering, mechanical engineering and systems engineering at the junior or senior level. Topics include: Modeling and simulation of feedback systems; classical control theory in the frequency and time domains; introduction to software packages (MATLAB and SIMULINK); frequency response techniques; controllability and observability in the time domain; stability and performance criteria; state-space representation; control system design; digital systems and the effects of sampling, aliasing, and discretization; applications in robotics, flexible structures, servo motors, and vehicle dynamics.

**415. (OPIM415) Product Design. (M).**

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. The course is open to juniors and seniors in SEAS or Wharton.

**420. (MEAM520, CSE390) Robotics (B)** Prerequisite(s): Math 240, Phys 150.

Today's robots replace, assist, or entertain humans in many tasks. Recent examples of robots are planetary rovers, robot pets, medical surgical assistive devices, and semi-autonomous ground vehicles for search and rescue operations. The goal of this class is to introduce the students to the common kinematic and computational principles of the above examples and to provide them with hands on experience with state of the art mobile robots and manipulators. The three main topics are coordinate system transformations and kinematics, visual sensing for localization, and computational geometry for motion planning. Laboratories involve building and programming Lego Mindstorms as well as using a manipulator and a haptic device.

**427. (MEAM527) Finite Element and Applications** Prerequisites: MATH 241 and PHYS 151

The objective of the course is to equip students with the background needed to carry out finite elements-based simulations of various engineering and mathematics problems with commercial finite elements packages. The first part of the course outlines the theory of finite elements. The second part of the course addresses the solution of the classical equations of mathematical physics and discusses the general properties of these solutions. The third part of the course focuses on case studies of problems borrowed from various branches of engineering and science. The content of this part of the course is adjusted according to the students' interests. A sample of cases dealt with in AY 02-03 includes the modeling of the BIACore biosensor (biological interactions in the presence of flow), the modeling of electrophoresis, the structural analysis of airplanes, and the use of finite elements in regulatory environments (in lieu of physical experiments). The students will use Femlab- a general purpose, finite element package.

**433. (MEAM533) Advanced Heat and Mass Transfer. (M)** Prerequisite(s): MEAM 302 and 333, or equivalent.

This course follows a first general course in heat transfer (MEAM 333). The main goal is a more detailed exposure to the basic mechanisms of heat transport processes in engineering applications, and to cover the design methodology for these processes. More generalized formulations, treatment, and results for conductive, convective, radiative and combined transport will be provided. The course will use computers extensively for numerical solutions of complex problems. Several specific design applications will be considered in detail, for example, heat exchangers, thermal stressing, solar collectors, electronic equipment cooling, cooling towers, environmental discharges, engine cooling and structure icing.

**435. (MEAM545) Aerodynamics. (M)** Prerequisite(s): MEAM 302.

This course deals with fluid flows around moving objects, for example, subsonic and supersonic air flows around flying wings and bodies. Topics covered will include: review of fluid kinematics and conservation laws; vorticity theorems; two-dimensional potential flow; airfoil theory; two- and three-dimensional wing theory; shock waves; supersonic wing theory. Laminar and turbulent boundary layers.

**436. (MEAM536) Viscous Fluid Flow. (M)** Prerequisite(s): MEAM 302.

This is an intermediate course in mechanics of viscous fluid flows. It covers the following topics: fundamental laws of fluid mechanics; The kinematics and dynamics of viscous flows; analysis and discussion of the theory of incompressible viscous flow; vorticity dynamics; solutions of Navier Stokes equations; low Reynolds number flows; laminar boundary layer theory; stability and turbulence.

**445. Mechanical Engineering Design Projects. (B)** Prerequisite(s): Junior standing.

This is a capstone design projects course in mechanical engineering and is required of all mechanical engineering students. Students will be involved in selected group or individual projects emphasizing design, development, and experimentation, under the supervision of a MEAM faculty advisor. Projects are sponsored either by industry or by Penn professors. Alternately, students may propose their own projects. Each project is approved by the instructor and the faculty advisor. The work is spread out over MEAM 445 and MEAM 446. In addition to being involved in the design project, MEAM 445 covers project planning, patent and library searches, professional education, ethics, writing skills, communication, and technical presentations.

**446. Mechanical Engineering Design Projects. (A)**

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

**452. Kinematics and Dynamics of Machinery. (B)** Prerequisite(s): MEAM 211 or equivalent or permission of the instructor.

This course teaches the fundamental principles of kinematics and dynamics with applications to mechanisms, machines, robots, and control systems. It is intended for students in mechanical engineering and other engineering disciplines who are interested in the design and analysis of mechanical and electromechanical systems. The topics covered include: Criteria of constraint and degrees of freedom; Velocity, and acceleration analysis of linkages. Kinematic synthesis and design of linkages. Computer aided analysis and design methods. Application to engine dynamics, rotor balancing, robotics, and biomechanics.

**453. Strength of Machine Components. (M)** Prerequisite(s): MEAM 210 or equivalent.

This course is intended for students in material science, mechanical engineering, and civil engineering who are interested in design and manufacture of mechanical components and assemblies. The topics covered include: Three dimensional stress analysis, and failure criteria; stress and deformation in symmetrically-loaded thin circular plates; bending of symmetrically-loaded cylindrical shells; rotating discs; and fluid-film lubrication.

**454. (MEAM554) Mechanics of Materials. (A)** Prerequisite(s): MEAM 210, MATH 240, 241

This course is an upper level course that discusses the behavior of materials, the selection of materials in mechanical components, and the mechanics of deformable bodies. It is intended for students in material science, mechanical engineering, and civil engineering. The topics covered include: Rods and Trusses. Stress. Principal Stresses. Strain. Compatibility. Elastic Stress-Strain Relations. Strain Energy. Plane Strain. Plane Stress. Bending of Beams. Torsion. Rotating Disks. Castigliano's Theorem. Dummy Loads. Principle of Virtual Work. The Rayleigh-Ritz Methods. Introduction to the Finite Element Method. Non-Linear Material Behavior. Yielding. Failure. Composite material systems.

**L/R 455. (BE 455) Continuum Biomechanics.**

This course deals with continuum mechanics with applications to biological systems. Fundamental engineering conservation laws are introduced and illustrated using biological and non-biological examples. The topics include, 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 hands-on experimental and computational laboratory experiences.

*\*\*Undergraduate students after consulting with the instructors or their advisor may take 500-level courses.*

**513. Modern Feedback Control Theory. (M)** Prerequisites: MATH 241 and MEAM 321 or SYS 222, or equivalent.

Methods of modeling, simulation and control of mechanical systems; distributed and lumped parameter systems; applications in vehicle dynamics, robotics, flexible structures, hydraulic machinery; frequency response, impulse response, transform methods; stability analysis; control system design; control laws; effects of nonlinearities; digital control, effect of sampling, discretization, aliasing.

**519. (MSE 550) Introduction to Elasticity. (A)**

General theory; kinematics, equilibrium and constitutive relations. Problems in linear elasticity including torsion, bending, plane stress and plane strain, axial and spherical symmetry. Energy theorems. Approximate methods.

**L/L 520. (MEAM420, CSE390)Robotics and Automation.** Prerequisite: Graduate standing in engineering or permission of instructor. **Same as 420.**

**522. (EE 522) Fundamentals of Sensor Technology (C)**

Explores the principles of sensor science, develops the relationship between intensive and extensive variables, and presents the linear laws between these variables. Students will review the flux-force relations describing kinetic phenomena against the context of means for transducing temperature, stress, strain, magnetic processes and chemical concentration into electrical signals. The need for multivariate signal processing will be introduced and selected applied topics considered.

**527. (MEAM427) Finite Element and Applications (M)**

**Same as 427.**

**528. Advanced Kinematics. (M)** Prerequisites: Multivariate calculus, introductory abstract algebra, mathematical maturity.

Differential geometry, Lie groups and rigid body kinematics; Lie algebra, screws, quaternions and dual number algebra; geometry of curves and ruled surfaces; trajectory generation and motion planning; applications will be to robotics and spatial mechanisms.

**530. (MEAM 630) Continuum Mechanics. (M)** Prerequisites: One graduate level course in applied mathematics and one in either fluid or solid mechanics.

Upper-level course that solidifies general concepts of the mechanics of solids and fluids. Analysis of deformation and motion. Finite strain tensors. Cauchy and nominal stress tensors. Conjugate stress analysis. Balance laws and field equations. Thermodynamics of continuous media. Objectivity of tensor fields; objective stress rates. Constitutive equations; axioms of constitutive theory; internal constraints; material symmetries. Introduction to non-linear elasticity. Curvilinear coordinates and embedded components of tensors. Topics in finite strain plasticity. Bifurcation of solutions and localization of flow.

**535. Advanced Dynamics. (A)**

Rigid body kinematics; Newtonian formulations of laws of motion; concepts of momentum, energy and inertia properties; generalized coordinates, holonomic and nonholonomic constraints. Generalized forces, principle of virtual work, D'Alembert's principle. Lagrange's equations of motion and Hamilton's equations. Conservation laws and integrals of motion. Friction, impulsive forces and impact. Applications to systems of rigid bodies.

**540. Optimal Design of Mechanical Systems.** Prerequisite(s): Basic Differential Calculus (MATH 240 or equivalent), Linear algebra (MATH 312 or equivalent), MEAM 210, Advanced Strength of Materials (MEAM 453 or equivalent, or consent of the instructor), Familiarity with a computer language; Undergraduates need permission.

Optimal design of mechanical elements and systems: mathematical modeling of mechanical design problems in optimization. Highlights and overview of optimization methods: unconstrained optimization, unidirectional search techniques, gradient, conjugate direction, and Newton methods. Constrained optimization: KKT optimality conditions, penalty formulations, augmented Lagrangians, and others. SLP and SQP and other approximate techniques for solving practical design problems. Optimization of structural elements including shape and topology synthesis. Variational formulation of distributed and discrete parameter structures. Design criteria for stiffness, strength, stability, compliance, and dynamic response. Design sensitivity analysis. The course will emphasize computer programs to implement the algorithms discussed and solve realistic design problems. A term project is required.

**545. (435)Aerodynamics**  
**Same as 435.**

**550. (EE 550) Design and Modeling of Micro-Electro-Mechanical Systems.** Prerequisites: Undergraduates need permission

Introduction to Micro-Electro-Mechanical Systems (MEMS). Modeling and multi-energy domain coupled simulations of MEMS devices and systems using simple analytical models as well as state-of-the-art methods and software. Designing MEMS devices for a Surface Micromachining "foundry" process: from paper designs to real devices. Nonlinear dynamics of electrostatically actuated MEMS devices. Synthesis of compliant micro structures. Review of selected papers from the literature. A term-project that includes design and fabrication (at an external "foundry" facility) of a micro device, and a term-paper on a selected topic are required.

**555. (CBE555, BE555) Membranes, Shells, and Polymers in Biology** Prerequisites: Prior coursework in mechanics, biomechanics, or fluids is highly recommended; check with instructor.

Effective mechanical models of many systems, biological as well as non-biological, often amount to reduced dimensionality, material descriptions. Membranes, for example, are two-dimensional material systems "embedded" typically in three-dimensional spaces. Polymer molecules are, in contrast, one-dimensional materials embedded usually, but not always, in three dimensions. We will examine the geometries and properties of these and other systems at microscopic, mesoscopic, and macroscopic levels wherein different features of the mechanical behavior, including statistical mechanical contributions, must be integrated. Course material will draw heavily from the current literature in addition to portions of several texts.

A lecture and topics course for graduate and senior undergraduate students in Mechanical, Chemical, and Bio-engineering. A portion of this course, including aspects of adhesion, will be supervised by Dr. Dan Hammer, Chemical Engineering.

**561. Thermodynamics I. (A)** Prerequisite: Undergraduate thermodynamics.

Advanced classical equilibrium thermodynamics and exergy analysis, and fundamentals of statistical and nonequilibrium thermodynamics. Applications including power cycles, refrigeration and air-conditioning, combustion, diffusion, transport in membranes, fuel cells, superconductivity, elasticity, phase change and near-critical state phenomena.

**564. (EE 460/564) Principles of Microfabrication Technology. (M)** Prerequisite(s): Any of the following courses: EE 218, MSE 321, MEAM 333, CBE 351, CBEM 321/322, Phys 250 or permission of the instructor.

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 EE 564 will be expected to do extra work (including term paper and additional project).

**572. Micro/Nanoscale Energy Transport. (C)** Prerequisite(s): ENM 510 or permission of instructor.

This course will provide a foundation for studying energy transport at small length scales by crystal vibrations, electrons, photons, and molecules. Concepts from solid state physics and statistical thermodynamics will be introduced, and applications to modern microdevices and thermometry techniques will be discussed. Topics to be covered include natural and fabricated microstructures, transport and scattering of phonons and electrons in solids, photon-phonon and photon-electron interactions, radiative recombinations, elementary kinetic theory, Boltzmann transport equation.

**345. (EAS 545) Engineering Entrepreneurship I. (C)**

Engineers and scientists create and lead great companies, hiring managers when and where needed to help execute their vision. Designed expressly for students having a keen interest in technological innovation, this course investigates the roles of inventors and founders in successful technology ventures. Through case studies and guest speakers, we introduce the knowledge and skills needed to recognize and seize a high-tech entrepreneurial opportunity - be it a product or service - and then successfully launch a startup or spin-off company. The course studies key areas of intellectual property, its protection and strategic value; opportunity analysis and concept testing; shaping technology driven inventions into customer-driven products; constructing defensible competitive strategies; acquiring resources in the form of capital, people and strategic partners; and the founder's leadership role in an emerging high-tech company. Throughout the course, emphasis will be placed on decisions faced by founders, and on the sequential risks and determinants of success in the early growth phase of a technology venture. The course is designed for, but not restricted to, students of engineering and applied science and assumes no prior business education.

**346. (EAS 546) Engineering Entrepreneurship II. (B)** Prerequisite(s): EAS 345, Junior or Senior Standing.

This course is the sequel to EAS 345 and focuses on the planning process for a new technology venture. Like its prerequisite, the course is designed expressly for students of engineering and applied science having a keen interest in technological innovation. Whereas EAS 345 investigates the sequential stages of engineering entrepreneurship from the initial idea through the early growth phase of a startup company, EAS 346 provides hands-on experience in developing a business plan for such a venture. Working in teams, students prepare and present a comprehensive business plan for an actual high-tech opportunity. The course expands on topics from EAS 345 with more in-depth attention to: industry and marketplace analysis; competitive strategies related to high-tech product/service positioning, marketing, development and operations; and preparation of sound financial plans. Effective written and verbal presentation skills are emphasized throughout the course. Ultimately, each team presents its plan to a distinguished panel of recognized entrepreneurs, investors and advisors from the high-tech industry.

**EAS 349. Ideas to Assets.** Not every great idea leads to a great product. The process of "crystallizing" a clever idea into a saleable asset demands a mix of creativity, systems thinking, sound business instincts, and the courage to do things differently. Students in this project-centered course will gain the necessary skills and experience from concentrated work on early-stage inventions drawn from Penn's technology portfolio. Is the invention feasible? Patentable? How should it be designed and produced? What will it cost? Is there a market? Does the payoff justify the investment? These and similar questions will be answered through a multifaceted process

including analysis, experimentation, design, and/or market research. The projects are not "case studies," but rather involve real, current intellectual property of potential value to the University. Inventors and specialists from the Center for Technology Transfer will be available to collaborate with the student teams. Project work will be complemented by lectures and exercises dealing with the patent process, cost and market estimation, project planning, economic analysis, and the systems approach to new product design.

**ENM 220. Discrete Dynamical System**

This course will cover the mathematics behind the dynamics of discrete systems. Topics include: Real function iteration, Converging and Diverging sequences, Periodic and chaotic sequences Fixed-point, periodic-point and critical-point theories, Bifurcations and period-doubling transitions to chaos, Symbolic dynamics, Sarkovskii's theorem, Fractals, Complex function iterations, Julia and Mandelbrot sets.

In the past, mathematics was learned only through theoretical means. In today's computer age, students are now able to enjoy mathematics through experimental means. Using numerous computer projects, the student will discover many properties of discrete dynamical systems. In addition, the student will also get to understand the mathematics behind the beautiful images created by fractals.

**ENM 502. Numerical Methods and Modeling. (A)** Prerequisite(s): Knowledge of programming language, linear algebra and ordinary and partial differential equations. Math 240 & 241

Numerical modeling using effective algorithms with applications to problems in engineering, the natural and social sciences, and mathematics. Elements of approximation; Interpolation, integration, and differentiation; Non-linear equations; Numerical linear algebra; Differential equations; Finite difference and finite element approximations; Optimization; Monte Carlo simulation. Use of numerical software packages without a heavy emphasis on programming .

**ENM 510. Foundations of Engineering Mathematics I. (A)** Prerequisites: MATH 240, MATH 241 or equivalent.

Differential and Integral Vector Calculus, Higher-Dimensional Calculus and Functional Analysis, First and Second Order Ordinary Equations, Series Solutions to Singular Equations, Sturm-Liouville Theory, Non-Linear Ordinary Differential Equations. Matrix Algebra, Linear Algebra and Eigenvectors. Applications to Solving Differential and Difference Equations, and Finite Regular Markov Chains. One or more of the following topics are covered if time permits: Tensor Calculus, Variational Calculus, Real Analysis.

**ENM 511. Foundations of Engineering Mathematics II. (B)** Prerequisite: ENM 510 or equivalent.

Ordinary Differential Equations and Sturm-Liouville Theory. The Boundary-Value Problem and Green's Functions. Partial Differential Equations and The Initial-Value, Boundary-Value Problem. The Methods of Characteristics and the Cauchy Problem, Laplace and Fourier Integral Transform Methods, Fourier Analysis. Differential and Integral Complex Analysis, The Residue Theorem and Applications to Evaluating Real Definite Integrals and Inverting Laplace Transforms. One or more of the following topics are covered if time permits: WKBJ Theory and Perturbation Methods for Ordinary Differential Equations, Singular Perturbation and an Introduction to Bifurcation Theory.

**THE FACULTY AND THEIR RESEARCH**

NAME	LOCATION/ PHONE #/ EMAIL	POSITION	RESEARCH
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P.S. Ayyaswamy	241 Towne 898-8362 <a href="mailto:ayya@seas">ayya@seas</a>	Asa Whitney Professor of Dynamical Engineering Graduate Group Chair	Direct contact heat and mass transfer processes, bioheat transfer, arc-plasma heat transfer, hydrodynamic stability.
John L. Bassani	231 Towne 898-5632 <a href="mailto:bassani@seas">bassani@seas</a>	Richard H. and S.L. Gabel Professor of Mechanical Engineering	Plastic deformation of crystals, atomic/continuum property relationships, interface mechanics, fracture mechanics, material stability at large strains.
Haim H. Bau	237 Towne 898-8363 <a href="mailto:bau@seas">bau@seas</a>	Professor	Bifurcation and instability phenomena in and feedback control of buoyancy-driven flows, transport phenomena in micron and submicron size structures, meso- and microelectromechanical systems, interaction between stress waves transmitted in a solid waveguide and adjacent medium.
George Biros	220 Towne 898-3108 <a href="mailto:biros@seas">biros@seas</a>	Assistant Professor	Computational science and engineering, optimization algorithms, inverse problems, computational fluid mechanics, integral equations, fast multipole methods, parallel and scientific computing.
Ira M. Cohen	299 Towne 898-7076 <a href="mailto:imcohen@seas">imcohen@seas</a>	Professor	Basic problems in fluid mechanics and heat transfer as applied to microelectronic manufacturing.
Dennis E. Discher	208 Towne 898-8342 <a href="mailto:discher@seas">discher@seas</a>	Associate Professor	Mechanics and structural assemblies of biomolecules, mechanochemistry of cells, mechanics and statistical mechanics of networks and complex fluids.
Howard H. Hu	224 Towne 898-8504 <a href="mailto:hhu@seas">hhu@seas</a>	Associate Professor	Modeling of complex flows with multiphase or polymeric fluids, computational fluid dynamics, hydrodynamic stability.

Vijay Kumar	222 Towne 898-3630 <a href="mailto:kumar@cis">kumar@cis</a>	Professor, Department Chair; UPS Foundation Professor; Director of the GRASP Labor	Coordination of multiple robots, dynamics of mechanical systems with frictional contacts, actively coordinated mobility systems, rapid prototyping and fixturing.
Noam Lior	212 Towne 898-4803 <a href="mailto:lior@seas">lior@seas</a>	Professor	Heat transfer and fluid mechanics, thermodynamics and Second-Law analysis, energy conversion, solar energy, combustion, flash evaporation and water desalination, destruction of hazardous wastes by photocatalysis and supercritical oxidation.
Jennifer R. Lukes	222 Towne 898-3254 <a href="mailto:jrlukes@seas">jrlukes@seas</a>	William K. Gemmill Term Assistant Professor	Nanoscale thermal, fluid, and mass transport; molecular dynamics simulation; laser- based materials characterization; field-directed patterning for nanofabrication; flow measurement in confined geometries; micro-and nanoscale engineering.
Pedro Ponte Castañeda	235 Towne 898-5046 <a href="mailto:ponte@seas">ponte@seas</a>	Professor	Nonlinear composite materials, fracture mechanics, microstructure evolution and localization in manufacturing processes, nonlinear variational principles in mechanics.
Prashant Purohit	210 Towne 898-3870	Assistant Professor	Rod theories for DNA and biopolymers, Mechanics of sub-cellular organelles, Mechanics at the bio-nano interface, Martensitic phase transitions in solids.
Karl T. Ulrich	1317 SH-DH 898-6727 <a href="mailto:ulrich@opim.wharton.upenn.edu">ulrich@opim.wharton.upenn.edu</a>	Associate Professor of Operations and Information Mgmt. (Wharton School)	Product design, product development, technology and operation management, computer-aided design, manufacturing.
Vaclav Vitek	218 LRSM 898-7883 <a href="mailto:vitek@seas">vitek@seas</a>	Professor of Material Science and Engineering	Computer modeling of the structure and properties of grain boundaries, metal-metal and metal-ceramic interfaces.

Mark Yim

229T  
898-5269  
[yim@seas](mailto:yim@seas)

Associate Professor  
Gabel Family Term  
Junior Professor of  
Mechanical  
Engineering and  
Undergraduate  
Curriculum Chairman

Modular Self-reconfigurable  
Robotics, Virtual reality  
(haptics), meso-scale devices  
(typically larger than MEMS).

**ADJUNCT FACULTY AND LECTURERS**

<b>NAME</b>	<b>LOCATION/ PHONE #/ EMAIL</b>	<b>POSITION</b>
Michael Carchidi	208 Towne 898-8342 <a href="mailto:carchidi@seas">carchidi@seas</a>	Lecturer
Thomas Cassel	310 Towne 573-9016 <a href="mailto:cassel@seas">cassel@seas</a>	Practice Professor
Robert Jeffcoat	318 Towne 898-5791 <a href="mailto:rj@seas">rj@seas</a>	Adjunct Professor
Daniel Newman	320 Towne 898-4817 <a href="mailto:daniel.i.newman@boeing">daniel.i.newman@boeing</a>	Lecturer

## THE STAFF

NAME	LOCATION/ PHONE #/ EMAIL	POSITION
Maryeileen Banford	297 Towne 898-2826 <a href="mailto:banford@seas">banford@seas</a>	Graduate Assistant
Terry Kientz	191 Towne 898-8363 <a href="mailto:tkientz@seas">tkientz@seas</a>	Electrical Engineer
Towanda Marner	297 Towne 898-4825 <a href="mailto:tmarner@seas">tmarner@seas</a>	Undergraduate Assistant
Bob Miller	166 Towne 898-2865	Tech Instrumentation
Lynda Mules	233 Towne 898-2770 <a href="mailto:lynda@seas">lynda@seas</a>	Office Manager
Peter Szczesniak	168B Towne 573-8150 <a href="mailto:peterszc@seas">peterszc@seas</a>	Instruction Lab Coordinator
Wally Szczesniak	166 Towne 898-2865	Tech Instrumentation