



**UNDERGRADUATE STUDENT MANUAL**

**Department of Mechanical Engineering  
and Applied Mechanics**

**University of Pennsylvania**

**September 2009**

*[www.me.upenn.edu](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.

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

The Mechanical Engineering and Applied Mechanics (MEAM) curriculum at Penn offers its students a broad based education that will allow them to adapt to developments in technology in a 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 are provided every opportunity to master critical skills enabling success in their future careers.

The career opportunities available to our graduates are perhaps the broadest among all fields of engineering. A wide variety of industries recruit mechanical engineers, including aerospace, automotive, electronics and computers, chemical, and biomedical. 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.

## **ADVISING AND DEGREE INFORMATION**

### **Undergraduate Advisor**

All students will have a faculty member as an advisor. This faculty member will approve administrative forms such as courses and petitions. He or she will also serve as a resource for advice on academic, career, or other issues that may arise. Students are assigned advisors as freshmen. Every effort will be made to maintain continuity year to year, although there are circumstances where advisors need to be changed. Students may change to any advisor that will accept them.

### **Mailbox**

Every student in the School of Engineering and Applied Science has a personal mailbox. Undergraduate mailboxes (mail “folders”) for the Department of Mechanical Engineering are located on the second floor of the Towne Building, room 279. Students should get into the habit of checking his/her mailfolder on a regular basis.

### **Submatriculation**

Undergraduate students may begin an engineering graduate program while still completing their undergraduate program. Application is normally made before the end of the student's junior year. The submatriculant may take up to three graduate courses to fulfill both undergraduate and graduate degree requirements while registered as an undergraduate student. To apply for submatriculation, submit an application via Penn's online application system. A minimum GPA of 3.0 is required in order to apply for submatriculation.

### **Minor In Mechanical Engineering and Applied Mechanics**

Six MEAM courses are required for a minor in MEAM (6 CUs). Any six MEAM credit units may be chosen. MEAM minors are not available to students who are majoring in MEAM.

## STUDENT ORGANIZATIONS

Student engineering societies traditionally are a strong force in shaping professional attitudes and providing information about the profession and job directions. It also provides opportunities for meeting practicing engineers and for socializing with people of similar professional interests.

### **ASME Student Chapter**

[www.seas.upenn.edu/~asme/](http://www.seas.upenn.edu/~asme/)

The American Society of Mechanical Engineers (ASME) 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.

**President:** Dale Yates-Berg, dyates@seas

**Faculty Advisor:** Prof. Mark Yim, yim@grasp.cis

### **Formula SAE Car**

[www.seas.upenn.edu/~fsae/](http://www.seas.upenn.edu/~fsae/)

Students design, fabricate, and compete with small formula-style race cars. The vehicles are judged in three different categories: static inspection and engineering design, solo performance trials, and high-performance track endurance.

**Captain:** Ryan-Jinhan Kumbang, ryak@seas

**Faculty Advisor:** Prof. Robert Jeffcoat, rlj@seas

### **Penn Electric Racing**

[www.seas.upenn.edu/~electric/](http://www.seas.upenn.edu/~electric/)

Penn Electric Race Team is a student-run non-profit organization created with the vision of designing, building and racing an alternative energy car. Since the program's inception, it has evolved into a diverse group of students whose purpose has expanded to being much more than a student-centered entity.

**Team Leader:** Zachary Goldberg, zgs@seas

**Faculty Advisor:** Prof. Robert Jeffcoat, rlj@seas

### **Pi Tau Sigma**

[www.pitausigma.net/](http://www.pitausigma.net/)

Pi Tau Sigma is a Mechanical Engineering Honor Society, instituted in order to establish a closer bond of fellowship among its members which will result in mutual benefit to those in the profession of mechanical engineering. Pi Tau Sigma's core values are: Integrity, Service, and Leadership.

**President:** Max Chapados, chapaa@seas

**Faculty Advisor:** Prof. Mark Yim, yim@grasp.cis

### **SAE Student Chapter**

[www.seas.upenn.edu/~sae](http://www.seas.upenn.edu/~sae)

Penn's chapter of the Society of Automotive Engineers is just a small part of the international SAE presence. Over 84,000 engineers, business executives, educators, and students from more than 97 countries form a network of membership who share information and exchange ideas for advancing the engineering of mobility systems.

**President:** Zachary Goldberg, zgs@seas

**Faculty Advisor:** Prof. Robert Jeffcoat, rlj@seas

## **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.

There are several types of courses that make up the 40 credits needed for graduation:

|       |  |
|-------|--|
|       | 5 credit units = Math                    |
|       | 5 credit units = Natural Science         |
|       | 10 credit units = Core MEAM courses      |
|       | 10 credit units = Professional Electives |
|       | 7 credit units = General Electives       |
| +     | 3 credit units = Free Electives          |
| <hr/> |  |
|       | 40 credit units = Total                  |

### **COURSE PLANNING GUIDE**

On the following page, you will find the Course Planning Guide (CPG). The CPG will indicate which of the above courses are required and which are recommended. It will also include websites for further requirement information, such as the writing requirement.

The CPG can also be found:

- MEAM website: [www.me.upenn.edu/undergrad/requirements/2009.html](http://www.me.upenn.edu/undergrad/requirements/2009.html)
- Penn InTouch: <https://sentry.isc.upenn.edu/intouch/>

## MEAM COURSE PLANNING GUIDE

### **Math (5 CU)**

[www.seas.upenn.edu/undergraduate/handbook/courses/math-courses.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/math-courses.php)

- MATH 104 Calculus I
- MATH 114 Calculus II
- MATH 240 Calculus III
- MATH 241 Calculus IV
- \_\_\_\_\_<sup>1</sup>

1. Recom: EAS 205 Applications of Scientific Comp

### **Natural Science (5 CU)**

[www.seas.upenn.edu/undergraduate/handbook/courses/nat-science-courses.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/nat-science-courses.php)

- MEAM 110 Intro to Mechanics
- MEAM 147 Intro to Mechanics Lab
- PHYS 151 Principles of Physics II
- CHEM 101 General Chemistry I
- CHEM 053 General Chemistry Lab I
- \_\_\_\_\_<sup>2</sup>

2. Recom: BIOL 101 Intro. To Biology  
BIOL 121 Intro Bio-Molec Bio Life  
PHYS 280 Biological Physics

### **Core MEAM (10 CU)**

- MEAM 203 Thermodynamics I
- MEAM 210 Statics & Str. of Materials
- MEAM 211 Eng Mechanics: Dynamics
- MEAM 247 MEAM Lab I – Fall
- MEAM 247 MEAM Lab I – Spring
- MEAM 302 Fluid Mechanics
- MEAM 321 Vibrations of Mech Sys
- MEAM 333 Heat & Mass Transfer
- MEAM 347 ME Design Lab
- MEAM 348 ME Design Lab
- MEAM 354 Mechanics of Solids

Note:

**Bold courses** are required MEAM courses.

### **Professional Electives (10 CU)<sup>3</sup>**

- MEAM 445 Design Project I
- MEAM 446 Design Project II
- EAS 105 Intro to Scientific Computing<sup>4</sup>
- MEAM Upper level \_\_\_\_\_<sup>5</sup>
- MEAM Upper level \_\_\_\_\_<sup>5</sup>
- MEAM Upper level \_\_\_\_\_<sup>5</sup>
- Professional Elective \_\_\_\_\_<sup>6</sup>
- Professional Elective \_\_\_\_\_<sup>6</sup>
- Professional Elective \_\_\_\_\_<sup>6,7</sup>
- Professional Elective \_\_\_\_\_<sup>6,7</sup>

3. Max of three 100-level courses.

4. CIS 110 or 120 may be substituted for EAS 105.

5. MEAM 402, 410, 415, 420, 435, 454, 455, 513, 514  
ENM 427, grad level MEAM and others by petition.

6. Math, Natural Science or Engineering categories.

7. Advanced dual degree requirements with approval.

### **General Electives (7 CU)**

[www.seas.upenn.edu/undergraduate/handbook/courses/ssh-breadth.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/ssh-breadth.php)

[www.seas.upenn.edu/undergraduate/handbook/courses/tech-bus-courses.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/tech-bus-courses.php)

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

Two general electives (above) must be taken in the same department). The second of the two is known as:

**Depth** \_\_\_\_\_

One general elective (above) must fulfill the:

**Writing Requirement** \_\_\_\_\_

[www.seas.upenn.edu/undergraduate/handbook/courses/writing-requirement.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/writing-requirement.php)

### **Free Electives (3 CU)**

[www.seas.upenn.edu/undergraduate/handbook/courses/free-elective.php](http://www.seas.upenn.edu/undergraduate/handbook/courses/free-elective.php)

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

## 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. However, each student must develop a complete course plan in consultation with his or her academic advisor.

### Freshman Year

| CUs  |  |                          | CUs    |   |                                |
|------|--|--------------------------|--------|---|--------------------------------|
| FALL |  |                          | SPRING |   |                                |
| 1.5  | <b>MEAM 110/147</b>  | Intro to Mechanics & Lab | 1.5    | <b>PHYS 151</b>                                   | Principles of Physics II & Lab |
| 1    | <b>MATH 104</b>  | Calculus I               | 1      | <b>MATH 114</b>                                   | Calculus II                    |
| 1.5  | <b>CHEM 101/053</b>  | Intro to Chemistry & Lab | 1      | Professional elective (i.e. MEAM 101 or MEAM 150) |                                |
| 1    | Elective (i.e. EAS 105, MEAM 101, Social Science/Humanities, etc.) |                          | 1      | Writing Requirement                               |                                |
|      |  |                          | 1      | Natural Science elective                          |                                |

### Sophomore Year

| CUs  |                                    |                                       | CUs    |                                    |                                       |
|------|------------------------------------|---------------------------------------|--------|------------------------------------|---------------------------------------|
| FALL |                                    |                                       | SPRING |                                    |                                       |
| 1    | EAS 105                            | Intro to Scien. Comp.                 | 1      | <b>MEAM 203</b>                    | Thermodynamics I                      |
| 1    | <b>MEAM 210</b>                    | Statics and Strength of Materials     | 1      | <b>MEAM 211</b>                    | Engineering Mechanics: Dynamics       |
| .5   | <b>MEAM 247</b>                    | Mechanical Engineering Laboratory I-A | .5     | <b>MEAM 247</b>                    | Mechanical Engineering Laboratory I-B |
| 1    | <b>MATH 240</b>                    | Calculus III                          | 1      | <b>MATH 241</b>                    | Calculus IV                           |
| 1    | Professional elective              |                                       | 1      | Social Science/Humanities elective |                                       |
| 1    | Social Science/Humanities elective |                                       |        |                                    |                                       |

### Junior Year

| CUs  |                                    |                                   | CUs  |                         |                                   |
|------|------------------------------------|-----------------------------------|------|-------------------------|-----------------------------------|
| FALL |                                    |                                   | FALL |                         |                                   |
| 1    | <b>MEAM 302</b>                    | Fluid Mechanics                   | 1    | <b>MEAM 333</b>         | Heat and Mass Transfer            |
| 1    | <b>MEAM 321</b>                    | Vibrations                        | 1    | <b>MEAM 354</b>         | Mechanics of Solids               |
| 1    | <b>MEAM 347</b>                    | Mechanical Engineering Design Lab | 1    | <b>MEAM 348</b>         | Mechanical Engineering Design Lab |
| 1    | Social Science/Humanities elective |                                   | 1    | Upper-level MEAM course |                                   |
| 1    | Free elective                      |                                   | 1    | Math elective           |                                   |

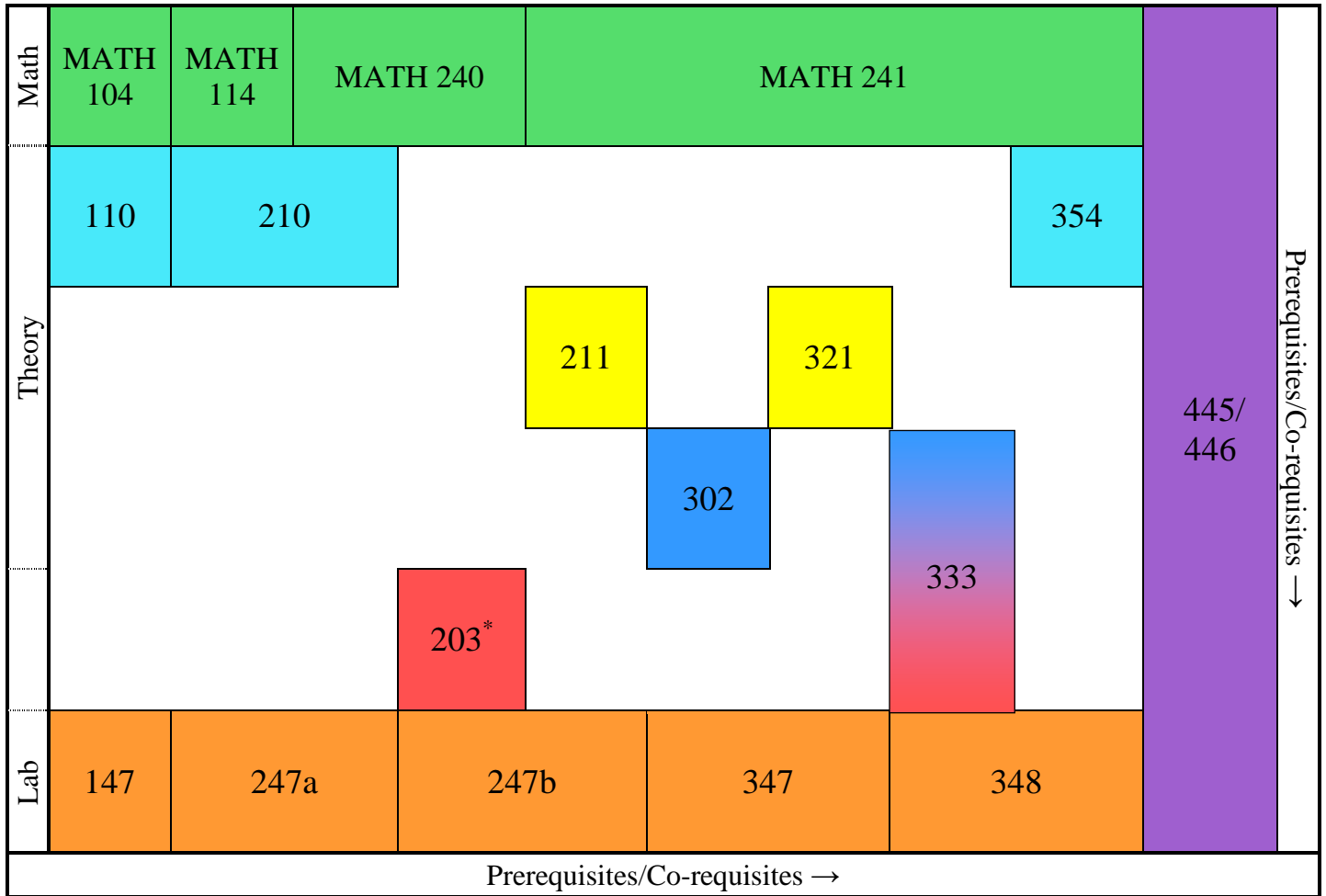
### Senior Year

| CUs  |   |  | CUs    |   |  |
|------|---|--|--------|---|--|
| FALL |   |  | SPRING |   |  |
| 1    | <b>MEAM 445</b>                         | Mechanical Engineering Design Projects | 1      | <b>MEAM 446</b>                         | Mechanical Engineering Design Projects |
| 1    | Upper-level MEAM course                 |  | 1      | Upper-level MEAM course                 |  |
| 1    | Professional elective                   |  | 1      | Professional elective                   |  |
| 1    | Social Science/Humanities /TBS elective |  | 1      | Social Science/Humanities /TBS elective |  |
| 1    | Free elective                           |  | 1      | Free elective                           |  |

|  |
|--|
| Note: <b>Bold courses</b> are required MEAM courses. |
|--|

## MEAM CONCEPT FLOWCHART

This chart shows the connections between the core MEAM courses.



Top to Bottom: Top courses are prerequisites or co-requisites for the courses underneath. Concepts from the courses on top are used in courses underneath.

Left to Right: Courses on the left are prerequisites or co-requisites for courses to their right. Concepts from the courses on the left are used in courses on the right.

\*Note: MEAM 203 has no prerequisites.

## MEAM ELECTIVE SCHEDULE

Permission required for all 5xx level courses.

### **Fall 2009 Electives**

|                       |  |
|-----------------------|--|
| MEAM 101              | Intro to Mechanical Design                 |
| MEAM 150              | Fundamentals of Mechanical Prototyping     |
| MEAM 245              | Intro to Flight                            |
| MEAM 402/502          | Energy Engineering                         |
| MEAM 405/505          | Mech Prop Nano/ Macro                      |
| MEAM 410/510          | Design of Mechatronic Systems              |
| MEAM 415/515, IPD 515 | Product Design                             |
| MEAM 420/520          | Robotics                                   |
| MEAM 511, IPD 511     | Creative Thinking and Design               |
| MEAM 519              | Elasticity and Micromechanics of Materials |
| MEAM 529              | RF MEMS                                    |
| MEAM 530              | Continuum Mechanics                        |
| MEAM 535              | Advanced Dynamics                          |
| MEAM 564              | Principles of Microfab Tech                |
| MEAM 570              | Transport Processes                        |
| EAS 105               | Intro to Scientific Computing              |
| EAS 545               | Engineering Entrepreneurship I             |
| EAS 546               | Engineering Entrepreneurship II            |
| ENM 427, MEAM 527     | Finite Elements and Applications           |
| ENM 510               | Fundamentals of Engineering Math I         |
| IPD 527               | Industrial Design I                        |

### **Tentative Spring 2010 Electives**

|                       |   |
|-----------------------|---|
| MEAM 101              | Intro to Mechanical Design                  |
| MEAM 111              | Visual Thinking                             |
| MEAM 150              | Fundamentals of Mechanical Prototyping      |
| MEAM 215              | Elements of Mechanical Engineering Design   |
| MEAM 415/515, IPD 515 | Product Design                              |
| MEAM 435/545          | Aerodynamics                                |
| MEAM 513              | Modern Feedback Control Theory              |
| MEAM 514, IPD 514     | Design for Manufacturability                |
| MEAM 537              | Nanomechanics and Nanotribology             |
| EAS 402/502           | Renewable Energy and Its Impacts            |
| EAS 449, IPD 549      | Product Development/Entrepreneurial Venture |
| EAS 545               | Engineering Entrepreneurship I              |
| EAS 546               | Engineering Entrepreneurship II             |
| ENM 511               | Foundations of Engineering Math II          |
| ENM 540               | Topics in Computation and Engineering       |
| IPD 501               | Integrated Computer-Aided Design            |

**RECOMMENDED ELECTIVES outside of MEAM**

|                    |  |
|--------------------|--|
| BIOL 101           | Intro to Biology   |
| BIOL 121           | Introduction to Biology - The Molecular Biology of Life    |
| BE 450             | Hemodynamics   |
| CIS 240            | Introduction to Computer Architecture                      |
| ESE 215            | Electrical Circuits and Systems                            |
| ESE 301            | Engineering Probability                                    |
| ESE 460            | The Principles and Practice of Microfabrication Technology |
| ESE 522            | Manufacturing Operations Management                        |
| MSE 220            | Engineering Materials                                      |
| PHYS 280, BCHE 280 | Biological Physics   |

## AREAS OF SPECIALIZATION IN MECHANICAL ENGINEERING AND APPLIED MECHANICS

A student interested in pursuing certain engineering disciplines in depth should consider choosing his or her electives accordingly. Students are encouraged to take courses and specialize in one or two areas. We list possible areas of specialization below which may be taken in the professional electives category:

### Energy Engineering

|              |                                  |
|--------------|----------------------------------|
| MEAM 338     | Thermodynamics II                |
| MEAM 402/502 | Energy Engineering               |
| MEAM 570     | Transport                        |
| MEAM 572     | Micro/Nanoscale Energy Transport |
| EAS 401/501  | Energy and Its Impacts           |
| EAS 402/502  | Renewable Energy and Its Impacts |

### Fluid Mechanics and Aerodynamics

|                       |                                 |
|-----------------------|---------------------------------|
| MEAM 435/545          | Aerodynamics                    |
| MEAM 513, ESE 406/505 | Modern Feedback Control Theory  |
| MEAM 530              | Continuum Mechanics             |
| MEAM 570              | Transport                       |
| ENM 427, MEAM 527     | Finite Element and Applications |

### Manufacturing

|                       |   |
|-----------------------|---|
| MEAM 101              | Introduction to Computer Aided Design and Manufacturing |
| MEAM 150              | Fundamentals of Mechanical Prototyping                  |
| MEAM 410/510          | Design of Mechatronic Systems                           |
| MEAM 415/515, IPD 515 | Product Design  |
| MEAM 420/520          | Robotics  |
| MEAM 454/554          | Mechanics of Materials                                  |
| MEAM 564              | Principles of Microfabrication Technology               |
| ENM 427, MEAM 527     | Finite Element and Applications                         |
| ESE 215               | Electrical Circuits and Systems                         |
| ESE 522               | Process Mgmt in Manufacturing                           |

### Mechatronics

|              |   |
|--------------|---|
| MEAM 410/510 | Design of Mechatronic Systems             |
| MEAM 420/520 | Robotics                                  |
| MEAM 564     | Principles of Microfabrication Technology |
| CIS 120      | Introduction to Programming               |
| CIS 240      | Introduction to Computer Architecture     |
| ESE 215      | Electrical Circuits and Systems           |
| ESE 522      | Process Mgmt in Manufacturing             |

### **Product Design and Innovation**

|                       |   |
|-----------------------|---|
| MEAM 101              | Introduction to Computer Aided Design and Manufacturing |
| MEAM 111              | Visual Thinking   |
| MEAM 215              | Elements of Mechanical Engineering Design               |
| MEAM 410/510          | Design of Mechatronic Systems                           |
| MEAM 415/515, IPD 515 | Product Design  |
| MEAM 511, IPD 511     | Creative Thinking and Design                            |
| MEAM 514, IPD 514     | Design for Manufacturability                            |
| EAS 545               | Engineering Entrepreneurship I                          |
| EAS 546               | Engineering Entrepreneurship II                         |
| ESE 400/540           | Engineering Economics                                   |

### **Structural Mechanics & Mechanics of Materials**

|                   |                                 |
|-------------------|---------------------------------|
| MEAM 454/554      | Mechanics of Materials          |
| MEAM 519, MSE 550 | Introduction to Elasticity      |
| MEAM 530          | Continuum Mechanics             |
| ENM 427, MEAM 527 | Finite Element and Applications |
| MSE 220, BE 220   | Structural Biomaterials         |

#### **Note:**

- Permission required for all 5xx level courses.
- MEAM courses may not be offered every year.
- Students may consider designing an independent study course, MEAM 099, with a MEAM faculty advisor in any area or across two or more areas.

## COURSE DESCRIPTIONS

**099. Undergraduate Research and/or Independent Study.** Open to all students. A maximum of 2 cu. of MEAM 099 may be applied toward the B.A.S. or B.S.E. degree requirements.

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.

**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).

**110. Introduction to Mechanics.** Co-requisite: Math 104.

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.

**111. Visual Thinking.**

Visual Thinking is a drawing, creative thinking, and iterative prototyping course using a series of mechanical design projects to help move engineers, (and artists and others) out of the often analytical, even equation based comfort zones into the broader realm of unpredictable time constrained problem solving. This kind of problem solving sees "solutions" as a broad to infinite range of possibilities instead of as a single final predictable answer. Drawing is utilized both as a critical communication tool, and as tangible speculation in the development of designs. Dozens of creative thinking strategies are implemented towards the accomplishment of 3 challenge projects, 2 of which are team work, and one individual.

**147. Introduction to Mechanics Lab.** Co-requisite: MEAM 110 or credit for AP Physics C, Mechanics.

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.

**150. Fundamentals of Mechanical Prototyping.**

Constructing functional prototypes is an intrinsic part of the mechanical design process. This hands-on course covers the fundamentals of layout, measurement, part generation, milling, turning, and computer-controlled machining. By immersion in the department's manufacturing environment, students will gain an intuitive understanding of the techniques and skills necessary to successfully prototype a wide variety of mechanical systems. Enrollment is limited.

### **203. Thermodynamics I.**

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, materials science, physics and other fields. The topics include: Basic definitions, microscopic and macroscopic points of view; properties of pure substances and reversibility and irreversibility, the thermodynamic temperature scale, entropy, availability, second law analysis, power and refrigeration cycles and their engineering applications.

**210. Statics and Strength of Materials.** Prerequisite(s): Physics 150 or MEAM 110/147. Corequisite(s): Math 240. MEAM 247 is strongly recommended.

This course is intended for students in mechanical engineering, systems-civil, materials science and other fields. It continues the treatment of the statics of rigid bodies begun in Physics 150 and MEAM 110 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, shafts and pressure vessels. Safety factors and the onset of mechanical failure are discussed. The course incorporates the use of computers to solve problems, and includes a written library research assignment and a team design project.

**211. Engineering Mechanics: Dynamics.** 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.

**215. Elements of Mechanical Engineering Design.** Prerequisite(s): MEAM 210, MSE 220, or equivalent; MATH 240. Corequisite: MEAM 101 helpful but not required.

This course introduces the broad field of mechanical design, in which engineering science and inventive thinking are combined to solve real-world problems. Many of the tools, techniques, materials, and devices required for practical applications are covered, with emphasis on how to intelligently select and employ them. Topics include modern design methods (simulation, graphics, ergonomics, etc), manufacturing processes (machining, casting, automation, etc), and physical components (bearings, gears, pumps, motors, etc). Students receive a comprehensive technological grounding which, in conjunction with theoretical and specialized knowledge, will empower them to produce creative and practicable new designs.

**245. Introduction to Flight.** Prerequisite(s): PHYS 150 or MEAM 110/147. Corequisite(s): MATH 240.

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

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

Corequisite(s): MEAM 210 (fall), and 203 and 211 (spring), are strongly recommended.

This is a sophomore level laboratory course that students will complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement systems as well as design. The fall semester follows closely with MEAM 210, doing experiments to explore the principles taught in statics and strength of materials. The spring semester follows closely with MEAM 203 and MEAM 211 with project based design projects in thermodynamics and dynamics.

**302. Fluid Mechanics.** Prerequisite(s): MATH 241 and PHYS 150 or MEAM 110/147.

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.

**310. Design of Thermal/Fluid Systems.** Prerequisite(s): MEAM 203, 302, MATH 241. Corequisite(s): MEAM 333.

The objective of the course is to teach the principles of design, with emphasis on components and systems involving the flow of fluids, heat and mass transfer, air conditioning and refrigeration, energy conversion, power generation, and propulsion. The topics covered include introduction to engineering design, economics, modeling, creativity, thermal/fluid equipment and components, reliability, liability, safety, optimization, and materialization of the design as a market product. At least one team design, construction, and testing project is included.

**321. Vibrations of Mechanical Systems.** Prerequisite(s): MATH 241 and MEAM 211.

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.

**333. Heat and Mass Transfer.** Prerequisite(s): MATH 241 and MEAM 302.

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

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

To introduce students to advanced classical equilibrium thermodynamics based on Callen's postulatory approach, to exergy (Second-Law) analysis, and to fundamentals of statistical and nonequilibrium thermodynamics. Applications to be discussed include advanced power and aerospace propulsion cycles, fuel cells, combustion, diffusion, transport in membranes, materials properties, superconductivity, elasticity, and biological processes.

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

This is a junior level laboratory course. The course teaches the principles of design and measurement systems including basic electromechanical systems. It follows MEAM 302 and MEAM 321 including experiments in fluid mechanics, and vibration in the design of mechanical systems.

**348. Mechanical Engineering Design Laboratory.** Prerequisite(s): Junior standing in engineering.

This course is a junior lab which follows MEAM 333 Heat Transfer and MEAM 354 Mechanics of Materials with design projects based on those topics. In the broader context of design/independent skill development, this course also introduces open ended topics, wider design options, and introduces project planning and management.

**354. Mechanics of Solids.** Prerequisite(s): MEAM 210 or equivalent, BE 200, or permission of instructor.

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.

**402. (MEAM 502) Energy Engineering.** Prerequisite(s): MEAM 203 (Thermodynamics), or equivalent and MEAM 333 or equivalent (Heat Transfer, that could be taken concurrently with MEAM 402).

Quantitative introduction to the broad area of energy engineering, from basic principles to applications. The focus is on the science and engineering, and includes environmental impact and some economics considerations. A review of energy consumption, use, and resources; sustainability, methods of energy and exergy (second law) analysis; power cycles, combined cycles, and co-generation; batteries and fuel cells; nuclear energy and wastes; fusion power; solar energy; power generation in space.

**405. (MEAM 505, MSE 405, MSE 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.

**410. (MEAM 510) Design of Mechatronic Systems II.** Prerequisite(s): Junior or senior standing in mechanical engineering and a first course in programming.

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).

**413. Modeling and Control of Physical Systems.** Prerequisite(s): MATH 241 and MEAM 321 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. (MEAM 515, OPIM 415, IPD 515) 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. The course is open to juniors and seniors in SEAS or Wharton.

**420. (MEAM520, CIS 390) Robotics.** Prerequisite(s): Math 240, PHYS 150 or MEAM 110/147.

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 planetary rovers, robotic pets, medical surgical-assistive devices, and semi-autonomous search-and-rescue vehicles. This introductory-level course presents the fundamental kinematic, dynamic, and computational principles underlying most modern robotic systems. The main topics of the course include: coordinate transformations, manipulator kinematics, mobile-robot kinematics, actuation and sensing, feedback control, vision, motion planning, and learning. The material is reinforced with hands-on lab exercises including basic robot-arm control and the programming of vision-guided mobile robots.

**ENM 427. (MEAM 527) Finite Elements and Applications.** Prerequisite(s): MATH 241 and PHYS 151.

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 hand-on experience with the multi-physics, finite element package FemLab.

**433. (MEAM 533) Advanced Heat and Mass Transfer.** 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. (MEAM 545) Aerodynamics.** Prerequisite(s): MEAM 302.

This course deals with fluid flows around moving objects, for example, subsonic and supersonic airflows 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.

**436. (MEAM 536) Viscous Fluid Flow.** 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.** Prerequisite(s): Senior 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.**

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

**454. (MEAM 554) Mechanics of Materials.** 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.

**455. (BE 455, MEAM 544) 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 hands-on experimental and computational laboratory experiences.

## **GRADUATE COURSE DESCRIPTIONS**

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

### **509. Mechanics of Human Motion.**

This course considers normal human movement (especially grasping, reaching, walking, and running), pathological conditions (e.g., resulting from disease, injury, malformations), and engineering approaches such as prostheses (limb replacements) and orthoses (limb assists) that may ameliorate the conditions and promote normal movements and function. In doing so, we will also learn musculoskeletal anatomy, comparative anatomy, muscle mechanics, and neural control. An objective of the course is to bring together technical analysis and synthesis skills of students with the practical problems of persons disabled by amputation, stroke, spinal cord injury, and other causes. The potential problems of applying engineering techniques to human beings will be emphasized. Engineering design comprises that are necessary are also given emphasis.

### **511. (IPD 511) Creative Thinking and Design.**

This is a creative & iterative problem solving course that uses a series of mechanical design challenge projects to move students into the broad realm of unpredictable often incalculable time-constrained problem solving. It explores a wide variety of problem definition, exploration and solving “tools,” and a variety of surrounding “design thinking” topics, such as ethics and the design of experience. Drawing and prototyping are used in the projects for ideation, iteration, speculation and communication.

**513. (ESE 406, ESE 505) Modern Feedback Control Theory.** Prerequisite(s): ESE 210. Juniors and Seniors encouraged to enroll. Sophomores require permission.

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.

### **514. (IPD 514) Design for Manufacturability.**

Prerequisite(s): 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.

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.

### **519. (MSE 550) 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.

**521. Title: Introduction to Parallel Computing for Scientific Applications.** Prerequisites: Programming.

Familiarity with Linux or Unix will help.

From numerical weather prediction and earthquake simulations, to quantum mechanics, and to genome sequencing and molecular dynamics, high-performance computing (HPC) is a fundamental tool for science. The basic principles on how to design, implement, and evaluate HPC techniques will be covered. Topics include parallel non-numerical and numerical algorithms, computing platforms, and message passing interface. Science applications will sample techniques applied to partial differential equations, many-body problems, and statistical physics. Practical problem-solving and hands-on examples will be a basic part of the course.

### **522. Fundamentals of Sensor Technology.**

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.

**528. Advanced Kinematics.** 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.

**529. (ESE 529) RF MEMS. (M)**

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 MEMS.

**530. Continuum Mechanics.**

Prerequisite(s): Multivariable Calculus, Linear Algebra, Partial Differential Equations.

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.

**535. Advanced Dynamics.**

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.

**537. Nanomechanics and Nanotribology.** Prerequisites: Freshman physics; MEAM 354 or equivalent, or consent of instructor.

Engineering is progressing to ever smaller scales, enabling new technologies, materials, devices, and applications. Mechanics enters a new regime where the role of surfaces, interfaces, defects, material property variations, and quantum effects play more dominant roles. This course will provide an introduction to nano-scale mechanics and tribology at interfaces, and the critical role these topics play in the developing area of nanoscience and nanotechnology. We will discuss how mechanics and tribology at interfaces become integrated with the fields of materials science, chemistry, physics, and biology at this scale. We will cover a variety 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. Literature reviews, critical peer discussion, individual and team problem assignments, a laboratory project, and student presentations will be assigned as part of the course.

**540. Optimal Design of Mechanical Systems.** Prerequisites: MATH 240, 312 or equivalent; MEAM 210, 453 or equivalent, or permission of the instructor; familiarity with a computer language; undergraduates need permission.

Mathematical modeling of mechanical design problems for 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.

**550. Design and Modeling of Micro-Electro-Mechanical Systems.** Prerequisites: MEAM 527 or equivalent is recommended. 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. (CBE 444/555, BE 444/555) Nanoscale Systems Biology.** Prerequisite(s): Background in Biology, Chemistry or Engineering with coursework in thermodynamics or permission of instructor.

From single molecule studies to single cell manipulations, the broad field of cell and molecular biology is becoming increasingly quantitative and increasingly a matter of systems simplification and analysis. The elaboration of various stresses on cellular structures, influences of interaction pathways and convolutions of incessant thermal motions will be discussed via lectures and laboratory demonstration. Topics will range from, but are not limited, to protein folding/forced unfolding to bimolecular associations, cell and membrane mechanics, and cell motility, drawing from very recent examples in the literature. Frequent hands-on exposures to modern methods in the field will be a significant element of the course in the laboratory. Skills in analytical and professional presentations, papers and laboratory work will be developed.

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

To introduce students to advanced classical equilibrium thermodynamics based on Callen's postulatory approach, to exergy (Second-Law) analysis, and to fundamentals of statistical and nonequilibrium thermodynamics.

Applications to be discussed include advanced power and aerospace propulsion cycles, fuel cells, combustion, diffusion, transport in membranes, materials properties, superconductivity, elasticity, and biological processes.

**564. (ESE 460/574) The Principles and Practice of Microfabrication Technology.** Prerequisite(s): Any of the following courses: ESE 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 ESE 574 will be expected to do extra work (including term paper and additional project).

**570. (CBE 640) 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.

**571. Advanced Topics in Transport Phenomena.** Prerequisite(s): Either MEAM 570, MEAM 642, CHE 640 or equivalent, or written permission of the Instructor.

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: Multi-component transport processes; Electrokinetic phenomena; Phase change at interfaces: Solidification, melting, condensation, evaporation, and combustion; Radiation heat transfer: properties of real surfaces, non-participating media, gray medium approximation, participating media transport, equation of radiative transfer, optically thin and thick

limits, Monte-Carlo methods: Microscale energy transport in solids; microstructure, electrons, phonons, interactions of photons with electrons, phonons and surfaces; microscale radiation phenomena.

**572. Micro/Nanoscale Energy Transport.** Prerequisite: Undergraduate thermodynamics and heat transfer (or equivalent), or permission of the instructor. Undergraduates may enroll with permission of the instructor.

As materials and devices shrink to the micro- and nanoscale, they transmit heat, light, and electronic energy much differently than at macroscopic length scales. This course provides a foundation for studying the transport of thermal, optical, and electronic energy from a microscopic perspective. Concepts from solid state physics and statistical mechanics will be introduced to analyze the influence of small characteristic dimensions on the propagation of crystal vibrations, electrons, photons, and molecules. 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, photonphonon and photon-electron interactions, radiative recombinations, elementary kinetic theory, and the Boltzmann transport equation.

**575. Physicochemical Hydrodynamics and Interfacial Phenomena.**

The course will focus on a few topics relevant to micro-fluidics and nano-technology. In particular, we will learn how the solid liquid interface acquires charge and the role that this charge plays in colloid stability, electroosmosis, and electrophoresis. Other topics will include controlled nano-assembly with dielectrophoresis, and stirring at very low Reynolds numbers (Lagrangian Chaos). The focus of the course will be on the physical phenomena from the continuum point of view. The mathematical complexity will be kept to a minimum. Software tools such as Maple and Femlab will be used throughout the course. The course will be reasonably self-contained and necessary background material will be provided consistent with the students' level of preparation.

## **PRIMARY FACULTY IN MECHANICAL ENGINEERING AND APPLIED MECHANICS**

As of 9/1/09

**Paulo E. Arratia**, Assistant Professor

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Micro- and Nanofluidics, Complex Fluids such as polymeric & biological materials, Transport Phenomena with emphasis on fluid & nonlinear dynamics, Rheology, and Soft-Condensed Matter including granular media.

**Portonovo S. Ayyaswamy**, Asa Whitney Professor of Dynamical Engineering

Office: 229B Towne Phone: 215-898-8362 Email: ayya@seas

Phase change heat and mass transfer processes, bioheat/mass transfer, arc-plasma heat transfer, thermal aspects in MEMS.

**John L. Bassani**, Chair and Richard H. and S.L. Gabel Professor of Mechanical Engineering

Office: 231 Towne Phone: 898-5632 Email: bassani@seas

Plastic deformation of crystals, atomic/continuum property relationships, interface mechanics, fracture mechanics, material stability at large strains, mechanics of living cells.

**Haim H. Bau**, Professor

Office: 237 Towne Phone: 215-898-8363 Email: bau@seas

Bifurcation and instability phenomena in and feedback control of flows, transport phenomena in micron and submicron size structures, meso- and microelectromechanical systems.

**Robert Carpick**, Professor

Office: 271 Towne Phone: 215-898-4608 Email: carpick@seas

Experimental nanomechanics and nanotribology (friction, adhesion, lubrication, wear). Development, characterization, and applications of nanostructured materials. Application and development of advanced scanning force microscopy tools.

**Howard H. Hu**, Professor

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Modeling of complex flows with multiphase or polymeric fluids, computational fluid dynamics, hydrodynamic stability.

**Katherine J. Kuchenbecker**, Skirkanich Assistant Professor of Innovation in Mechanical Engineering and Applied Mechanics

Office: 224 Towne Phone: 215-573-2786 Email: kuchenbe@seas

Haptic (touch-based) interaction; design and control of haptic interfaces for virtual environments and teleoperation; identification of dynamic systems; understanding human upper-limb movement; developing medical devices and medical robotic systems.

**Vijay Kumar**, Associate Dean; UPS Foundation Professor  
Office: 470 Levine Phone: 215-898-3630 Email: kumar@grasp

Robotics, dynamics of systems with frictional contacts, actively coordinated mobility systems, mechanism design and control.

**Noam Lior**, Professor  
Office: 212 Towne Phone: 215-898-4803 Email: lior@seas

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, heat treatment.

**Jennifer R. Lukes**, Associate Professor  
Office: 222 Towne Phone: 215-898-3254 Email: jrlukes@seas

Molecular dynamics simulation, molecular mechanical engineering, micro/nanoscale heat transfer.

**Pedro Ponte Castañeda**, Professor and Graduate Group Chair  
Office: 235 Towne Phone: 215-898-5046 Email: ponte@seas

Nonlinear composite materials, fracture mechanics, microstructure evolution and localization in manufacturing processes, nonlinear variational principles in mechanics.

**Prashant Purohit**, Assistant Professor  
Office: 210 Towne Phone: 215-898-3870 Email: purohit@seas

Rod theories for DNA and biopolymers, Mechanics of sub-cellular organelles, Mechanics at the bio-nano interface, Martensitic phase transitions in solids.

**Mark Yim**, Gabel Family Term Junior Professor; Undergraduate Curriculum Chair  
Office: 229A Towne Phone: 215-898-5269 Email: yim@grasp.cis

Modular reconfigurable robots and locomotion, PolyBot; MEMS and batch fabrication techniques; brute force digital time optimal control.

## AFFILIATED FACULTY AND LECTURERS

As of 9/01/09

**Peter Bressler**, Adjunct Associate Professor

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**Jennifer Buck**, Lecturer

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**Michael Carchidi**, Senior Lecturer

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**Thomas A.V. Cassel**, Professor of Practice

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**Jonathan P. Fiene**, Lecturer and Director of Laboratory Programs

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**Robert L. Jeffcoat**, Adjunct Professor

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**Bruce Kothmann**, Lecturer

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**Shawn Sarbacker**, Adjunct Assistant Professor

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**Denise Graham**, Assistant to Dr. Carpick

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**Sue Waddington Pilder**, Office Manager and Assistant to the Chair

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**Peter Rockett**, Instructional/Experimental Machinist

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**Peter Szczesniak**, Instructional Laboratory Coordinator

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