UNIVERSITY of PENNSYLVANIA

MEAM Master of Science in Engineering Program

GUIDELINES FOR GRADUATE STUDY

September 2013

Mechanical Engineering and Applied Mechanics
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1. INTRODUCTION

Advances in technology have increased the need for mechanical engineers with more complete knowledge and diverse skills than a typical undergraduate program can provide. As a result, graduates with a Master of Science in Engineering (MSE) degree can look forward to greater job opportunities, more rewarding positions, and higher levels of responsibility than engineers with just a Bachelor's degree. Mechanical engineering, which is one of the broadest engineering disciplines, provides an excellent background for individuals interested in occupations ranging from product research and design to technological management. The Department of Mechanical Engineering and Applied Mechanics (MEAM) at the University of Pennsylvania has designed a flexible MSE Program to prepare students for professional careers and leadership roles in industry while also providing them with the opportunity to strengthen their fundamental knowledge and obtain an exposure to research. In recognition of the interdisciplinary nature of the modern workplace, students who enroll in our MSE program are encouraged to take courses in other departments in the School of Engineering and Applied Science, School of Arts and Sciences and the Wharton School of Business.

The information presented here is not exhaustive; students should also obtain information from the Penn Engineering website: www.seas.upenn.edu/graduate/handbook/index.php

More information, updated from time to time, on the MSE program is also available on the department website, www.me.upenn.edu/current-students/masters/pdf/mse-handbook-11.pdf. Reading all of the rules and procedures is essential in order to be familiar with various degree requirements and the plentiful opportunities that are available. These guidelines together with the above publications will answer most of your questions. Advice and answers to special questions may be obtained from your advisor or the Graduate Group Chair[1], as well as the Graduate Program Coordinator[2], who will assist you in any reasonable manner possible.

Students who matriculated before September 2013 are subject to the policies that were in effect as of their matriculation date.

2. ADMINISTRATIVE STRUCTURE

The Graduate Group in Mechanical Engineering and Applied Mechanics administers the graduate program in MEAM. The Graduate Group is comprised of the primary faculty members of MEAM as well as faculty from other departments and schools throughout the University. This unique composition gives students the opportunity to work in emerging and interdisciplinary areas that are relevant to mechanical engineering. The current members of the MEAM graduate group and their research areas are listed in Appendix D. Additional information can be obtained from the department website.

All graduate programs in SEAS are administratively under the auspices of the Associate Dean for Graduate Education,[3] whose activities with respect to graduate studies in MEAM are in conjunction with the recommendations of the MEAM Graduate Group Chair.

3. ADVISOR

The first person with whom a new student has contact is an assigned academic advisor. A program of study is developed with the academic advisor. Later on, if necessary, the student may request a change of advisor, which will be considered and approved by the Graduate Group Chair as appropriate. The academic advisor is responsible for monitoring the student's academic plan and, if applicable, thesis work.

4. DEGREE REQUIREMENTS

To earn an MSE degree in Mechanical Engineering and Applied Mechanics (MEAM), a student must complete 12

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graduate level courses. Of the 12 courses, two must be MEAM seminar courses, at least five must be MEAM courses, two must be mathematics, and the remaining three are electives. There is one required course for each concentration area (see Appendix A). In addition to the one required course for each concentration area, two additional courses must be selected from the preapproved core requirement list for the student's chosen concentration (Appendix A). The remaining two MEAM courses can be any MEAM graduate courses selected by the student in consultation with their advisor. A concentration area should be chosen and declared before the beginning of the second semester of study. One mathematics course must be ENM 510. The second mathematics course can be chosen from the approved list in Appendix A. The elective courses should also be chosen from the preapproved elective list for the student's chosen concentration (Appendix A). Advisor approval is required if a student wishes to take a graduate course not listed. Elective courses are typically in MEAM or other SEAS departments. Courses taken outside of SEAS should be relevant to the student's career goals or to the subdiscipline of interest to the student. Up to two courses may be transferred from other institutions upon the approval of the Graduate Group Chair. Students may take up to two independent study courses (MEAM 599). Independent study courses (MEAM 599) must follow the guidelines detailed in section 6 of this manual and may not be counted as part of the required five MEAM courses. Students electing to write a thesis cannot take an independent study course for degree credit.

The MSE concentration areas are:

- Mechatronic and Robotic Systems
- Micro/Nano Systems
- Heat Transfer , Fluid Mechanics, and Energy
- Mechanics of Materials
- Biomechanics
- Design and Manufacturing

Opportunities are also available for students to customize their concentration with the guidance and approval of their academic advisor. The student and his/her academic advisor should agree upon a program of courses before the student embarks on his/her graduate study.

Appendix A lists the MEAM core, electives and mathematics courses for each concentration area.

Summary of MSE degree Course requirements

Math Requirement	2 ENM* Courses
MEAM Core Requirement	5 MEAM Courses • 1 concentration-specific required core course • 2 additional courses in concentration area • 2 any MEAM (except MEAM 599)
Electives Requirement	3 Courses
Seminar Requirement (Full time students only)	2 Courses
Total	12 Courses

* ENM - Engineering Mathematics

5. GENERAL INFORMATION

Registration:
All students enrolled in a degree program are required to be continuously registered. Three courses per semester (including independent studies) is considered to be a normal full-time load for all students. Seminar (MEAM 699) courses do not count toward the full time load. Students in the MSE program may take up to five courses in a semester if they are in excellent academic standing (with a G.P.A. of 3.5 or better), with approval from the academic advisor and Graduate Group Chair. Part-time students usually take one or, at most, two courses per semester. The student must obtain his/her advisor's approval for any course selection.

Example:

- Students who successfully complete 3 courses per semester will graduate in 2 years (4 semesters)
- Students who successfully complete 4 courses per semester will graduate in 1.5 years (3 semesters)
- Students who successfully complete 5 courses per semester (approval required) will graduate in 1 year (2 semesters)

Leaves of Absence:
Continuous registration as a graduate student is required unless a formal leave of absence is granted by the Dean of Engineering.

Obsoleteness:
The maximum time allowed for the completion of all MSE requirements is seven years. Course units that are older than seven years may not be counted toward the degree requirements.

Changes in Course Program:
Students may add or drop courses without penalty during a semester if it is done by the deadline listed in the current graduate bulletin. The student must inform the advisor of the decision beforehand and receive his/her approval.

Grades, Credits, and Academic Standing:
The grading system is as follows: A (4.0), Excellent; B (3.0), Good; C (2.0), Fair; D (1.0), Poor; F (0.0), Failure. A course in which an F was obtained must be taken again; however, the F will remain on the student's transcript. Courses for which a passing grade was obtained cannot be retaken for credit.

An incomplete (I) or a no report (NR) are temporary notations and students are allowed a period of one semester to clear. Failure to clear an "incomplete" or "no report" within the allotted time will result in an automatic grade of F. *No students will be permitted to graduate if there are any Incomplete, Unsatisfactory, or No Report notations on their records.*
MSE students in Engineering are expected to maintain at least a B- average (2.7) in their work. A student whose record falls below a B- average will be put on academic probation and may be required to withdraw; graduation requires a B- average minimum (exclusive of thesis and dissertation grades).

Academic Integrity:
Each MEAM student is expected to abide by Penn's Code of Academic Integrity (http://www.upenn.edu/provost/PennBook/academic_integrity_code_of). Students should not knowingly use any dishonest method to gain an unfair advantage over other students in academic pursuits, especially through, but not limited to:

- Giving or receiving any unauthorized aid on an assignment or exam, including working in groups on any assignment that has been designated as individual by the professor;
- Misrepresenting the originality of one's work (plagiarism), particularly through direct copying of work and also through failing to note the contributions of others, except as permitted by the instructor;
- Submitting substantially the same work for credit in more than one class, except with prior approval of the instructor.

If there is any doubt as to what is permissible, it is the student's responsibility to ask the instructor. Students caught cheating will be subject to disciplinary action, which may include referral to the Office of Student Conduct. For more information, please see the Student Guide on Academic Integrity: http://www.upenn.edu/academicintegrity/

6. INDEPENDENT STUDY

Independent study courses (MEAM 599) are important vehicles to accommodate special interests of the students that are not served through the regular courses. They create opportunities for mini-projects and a mentoring relationship between students and faculty. Independent study also can serve as a means for students and faculty to lay a potential foundation for dissertation work prior to making a long-term commitment. The student should identify the topic and scope of the independent study in the semester prior to the one in which s/he intends to take on the independent

study, and should identify a faculty advisor whose interests and expertise match the independent study topic.

Since independent studies are less structured than regular courses and typically do not come with strict deadlines, occasionally students tend to fall behind in their work. There is also the possibility of miscommunication between the student and the faculty on the objectives, extent, scope, and the grading method for the independent study.

The purpose of this policy is to set the rules for an independent study with the objectives of maintaining academic rigor and minimizing any potential for a miscommunication.

- An independent study course should require an effort comparable to that of a regular course, about 9 hours a week or a total of 126 hours per semester.
- The student should meet the faculty member administering the independent study (the advisor) on a regular basis, at least once a week. It is the student's responsibility to schedule these weekly meetings. Past experience indicates that failure to maintain regular contact with the student's advisor can lead to a less than satisfactory performance in the independent study course. The key to a successful independent study is a steady effort throughout the semester. The student should not expect to be able to cram a semester's work into a few days of intensive work at the end of the semester.
- Prior to the beginning of the semester in which the student contemplates taking the independent study, the student and his/her advisor should develop an independent study proposal. The first paragraph of the proposal should describe the objectives, scope, and content of the independent study. The second paragraph should state how the independent study will be evaluated and how the student will be graded. The document should be signed by both the student and his/her advisor, and it should be submitted to the Graduate Coordinator, who will convey it to the Graduate Group Chair for approval before the beginning of the semester.
- At the conclusion of the independent study, the student should prepare a brief report specifying what material was covered during the independent study, which objectives were met, and which were not. In the event that objectives were not met, a clear explanation should be provided as to why such objectives were not met. This document should also be signed by the student and his/her advisor, and it will be included in the student's file.
- It is the student's responsibility to make sure that these guidelines are followed. Failure to follow these guidelines may result in the student’s not receiving credit for the independent study.

7. POLICY ON TRANSFER OF CREDIT UNITS EARNED IN OTHER INSTITUTIONS

MSE students may obtain credit for up to two courses taken at another institution. These courses are referred to as transfer courses. Transfer courses must be graduate level courses in which at least a B grade has been earned. Transfer credit will only be considered for courses taken prior to matriculation in the graduate program in the Department of Mechanical Engineering and Applied Mechanics. To obtain credit for courses taken at other institutions, the following procedure must be followed:

- For each transfer course, obtain the course description and the title of the textbook used in the course.
- Identify a professor who teaches a similar course at Penn. If a similar course is not offered at Penn, identify a professor whose areas of expertise are in the general area of the course to be transferred. The professor should certify that the course is of similar level to a graduate course offered at Penn or, if a similar course is not offered at Penn, that the course qualifies for Penn students to take if it were offered here.
- Submit a petition on a standard form (Appendix C) to the Graduate Coordinator who will convey it to the Graduate Group Chair. Attach to the petition a copy of the transcript, the professor's certification, and documents and information noted in Appendix C.

8. MSE THESIS

The majority of MSE students complete an entirely coursework-based degree. There is also an option to complete a thesis-based MSE degree. This option is open only to top MSE students and is subject to availability of advisors with suitable research projects. Students pursuing this option typically take two years to complete the MSE. Students who elect to write a thesis cannot count independent study course units as a part of their 10 course units requirement, but thesis research credits (MEAM 597) may be substituted for up to three courses.

MEAM 597 is the course assigned to thesis/dissertation research. MEAM 597 can be counted towards the core concentration requirement. One, two or three units of this course of independent research may be undertaken simultaneously. The grading of MEAM 597 is done by the student's thesis advisor. Only grades of "S"

(satisfactory), "U" (unsatisfactory) or "I" (incomplete) can be earned in this course.

A full time MSE student who chooses to write a thesis must choose an advisor and a suitable thesis topic by the beginning of his/her second semester of graduate study. The advisor must be a member of the Mechanical Engineering and Applied Mechanics Graduate Group (see Appendix D). The Chair of the Graduate Group, in response to recommendations by the student and the student's advisor, will then appoint, at the latest by the middle of the student's second semester, a Thesis Committee consisting of at least two faculty members, one of whom shall serve as the Thesis Committee Chair. The Chair of the committee must be a member of the MEAM Graduate Group (Appendix D). The thesis advisor may not serve as the Thesis Committee Chair.

Examples of a typical objective of an MSE thesis are:

- To advance the state-of-the-art in research.
- To solve new problems with existing tools.
- Development of a new instrument or measurement technique, or a computer program for analysis or advanced design.

The graduate student must submit a written thesis proposal and present it to the Thesis Committee by the end of the second semester of study, at the latest. The proposal should typically contain a statement of the objective of the work, a pertinent state-of-the-art review, the scope of the study, and an outline of the proposed final document. The Thesis Committee will evaluate the proposal and make recommendations on how it can be improved. The Chair of the Thesis Committee will then inform the Graduate Group Chair, in writing, about the Committee's evaluation of the proposal. The student must obtain the Thesis Committee's approval of the thesis proposal by the end of the student's second semester.

The thesis must be prepared and submitted following the general SEAS and University of Pennsylvania instructions. Instructions for preparation of the thesis can be found at: http://www.upenn.edu/VPGE/masters.html. When the thesis has been approved by the student's thesis advisor, a copy of the thesis must be given to each member of the Thesis Committee, who will then review it. The student must allow sufficient time for the review (at least two weeks). If the Committee feels that the thesis is suitable for presentation, the student may then schedule a thesis defense. The defense is a public presentation of the work; after this presentation, the Thesis Committee will give final approval or disapproval. The announcement of the presentation to the public must be submitted to the Graduate Coordinator for posting at least two weeks prior to the presentation.

All of the requirements of the thesis must be satisfied and approved before the thesis submission date specified by the Office of the Associate Dean for Graduate Education. When final approval of the thesis is obtained, an original and a photocopy of the thesis must be submitted to the Associate Dean for Academic Affairs, 111 Towne Building prior to commencement, by the date specified. Both copies must be unbound and they must have original signatures. Additionally, a hardbound copy of the thesis (prepared according to instructions in Appendix B) must also be submitted to both the Graduate Group Chair of Mechanical Engineering and Applied Mechanics and to the thesis advisor. Failure to follow the above schedule and requirements will result in a delay in awarding the degree.

9. TRANSITION TO THE Ph.D. PROGRAM

Those MSE students who are interested in pursuing a Ph.D. after the completion of their MSE degree program should petition the Graduate Group Chair with the request to take the exam.

Students who aspire to continue for the Ph.D. degree must maintain a GPA of 3.0 or above, and take and pass a qualifier exam, which serves as an important component of determining their ability to independently conduct research of high quality.

Complete details are available in the Ph.D. Guidelines.

10. ATTENDANCE AT DEPARTMENTAL SEMINARS AND THESIS PRESENTATIONS

The attendance of all full-time graduate students at departmental seminars is mandatory. There are many good reasons why students should attend departmental seminars even when the seminars are not directly linked to their areas of research. For example:

- The seminar provides an opportunity to learn about the state-of-the-art in MEAM.
- The seminar provides an opportunity for the student to get acquainted with people from other institutions and companies and get an inside view of the culture at other institutions. On more than one occasion, during job interviews, interviewers have been known to mention a visit to Penn and delivering a seminar. The student would like to be in a position to comment on that particular seminar and state how enjoyable it was.
- The departmental seminars are an excellent opportunity to get together as a department. It is hoped that a full attendance at these seminars will help create departmental spirit and cohesiveness.

Seminar Course

The seminar course (MEAM 699) has been established so that students are recognized for their seminar attendance as well as to encourage students to attend. There are no quizzes, tests, or homeworks. The course is graded S/U and does NOT count towards full time enrollment status. Full time students should take three courses in addition to the MEAM seminar. In order to obtain a satisfactory (S) grade, the student must attend more than 70% of the departmental seminars. For example, in a term in which 12 seminars are given, the student will need to attend at least 9 seminars to obtain a satisfactory grade. Participation in the seminar course will be documented and recorded in the student's transcript. In order to obtain their degree, MSE students will be required to accumulate 2 seminar courses (typically taken in the first two semesters of study). Under special circumstances, e.g., in a case of a conflict with a course offering, the student may waive the seminar requirement for the particular semester by petitioning to the Graduate Group Chair. Part-time students are exempted from the seminar attendance requirement although they are encouraged to attend the seminars.

11. SUBMATRICULATION

Outstanding undergraduate students at the university may submatriculate in the MSE degree program and take graduate-level courses as electives during their junior and senior years. After fulfilling the requirements of both programs, the student will receive a BSE and a MSE degree. Undergraduates at the University of Pennsylvania may double-count up to three graduate-level courses taken while enrolled as a submatriculant towards both the undergraduate and the graduate degree. The MSE degree may be completed in one to two extra semesters of study. In order to complete both degrees in only four and one-half years, students can consider:

- Taking independent study courses in the summer of the fourth year (up to 2 course units of study),
- Taking five courses in the final term,
- Taking extra graduate-level courses (cannot be counted towards the B.S.E. degree) during the undergraduate program.

Students enrolled as a submatriculant can only count graduate courses taken at Penn towards the master's degree. No transfer credit, study abroad, or study away courses will be accepted.

Submatriculation applications (http://www.seas.upenn.edu/undergraduate/advising/documents/ApplicationforSub-matricualtion.pdf) must be submitted by the end of the junior year.

12. DUAL DEGREE PROGRAMS

Dual Degree in Two Engineering Disciplines

Students may enroll in a dual degree program and receive an MSE degree in Mechanical Engineering and any of the other disciplines in the Engineering School such as Electrical and Systems Engineering, Bioengineering, Computer Science, Chemical and Biomolecular Engineering, and Materials Science and Engineering. The dual degree program requires the completion of at least 16 courses and satisfaction of the MSE requirements of each department in which the student wishes to major. This program typically requires four semesters to complete. To enroll in this program, the student must complete an application form, listing the course plan for both programs and obtain the approval from the Graduate Group Chair of each department. Applications for this program are available in the Academic Programs Office in 111 Towne Building.

MBA/MSE Dual Degree Programs

The Mechanical Engineering Department and the Wharton School of Business Administration are committed to the education of excellent managers and engineers who will contribute significantly to the challenges faced by industry. This program leads to two degrees: Master of Business Administration (MBA) and Master of Science in Engineering (MSE). Typically, the program requires 5 semesters of study. To participate in the MBA/MSE Dual

Degree Program, the student must apply to, be accepted by, and meet all the requirements of both schools: the Graduate School of Business and the School of Engineering and Science. This requires separate applications to both schools.

13. SUMMER STUDIES

There are several possibilities for scholarly activities by graduate students at the University during the summer which include:

- Independent study and research (MEAM 599 or 597) with an instructor willing to act as a supervisor during the summer.
- Course work outside SEAS, as well as a limited number of regular courses occasionally offered by some SEAS departments. The advisor, in consultation with the Graduate Group Chair, must approve summer school courses.

Questions on summer session registration should be referred to the Graduate Coordinator.

14. RECORDS

The official graduate student records are kept in 111 Towne Building; transcripts can be viewed on Penn InTouch at https://sentry.isc.upenn.edu/intouch. Graduate students are encouraged to periodically check the accuracy of their records and to bring any discrepancies to the attention of the Graduate Group Chair.

15. GRADUATE ENVIRONMENT

The size of the Department of Mechanical Engineering and Applied Mechanics fosters a close interaction between the graduate students and the entire faculty. Every effort is made to create an environment of scholarship, creativity and learning, which is the very essence of graduate study. This enhances the quality of student-faculty communications and enriches the academic environment to benefit both learning and discovery. The Department strongly supports the Mechanical Engineering Graduate Association (MEGA). MEGA is a student-run association that represents the entire graduate student community in MEAM, and organizes both social and technical events. A chosen representative of MEGA will be invited, if appropriate, to attend Graduate Group meetings to serve as a communication channel for information between the Graduate Group and students.

APPENDIX A

List of approved mathematics courses (all concentrations)

MATHEMATICS REQUIREMENTS

All MSE students are required to take at least two mathematics courses. Students are required to take ENM 510 and the second course must be selected from the following list. Prior approval from the Graduate Group Chair is required if a student would like to take a course other than the ones listed below to satisfy the math requirement.

ENM[4] 502	Numerical Methods and Modeling
ENM 503	Introduction to Probability and Statistics
ENM 510*	**Foundations of Engineering Mathematics I**
ENM 511	Foundations of Engineering Mathematics II
ENM 540	Topics in Computational Science & Engineering
ENM 600	Advanced Engineering Mathematics
ENM 601	Special Topics in Engineering Mathematics
MEAM 527	Finite Element Analysis

[4] ENM - Engineering Mathematics

* Required

List of approved courses for students concentrating in

MECHATRONIC AND ROBOTIC SYSTEMS

Ongoing effort in mechanical systems focuses on modeling and controlling dynamical systems, especially as applied to mechatronic and robotic systems. The graduate courses provide students with a firm theoretical foundation and the interdisciplinary experimental skills that are necessary for dealing with modern-day complex systems. Much of our work involves collaborations with Computer and Information Science and Electrical and Systems Engineering, as well as the Wharton School of Business Administration.

Required Course

MEAM 510	**Design of Mechatronic Systems (Offered in the fall semester only.)**

Preapproved Core Requirement Courses

MEAM 513	Control of Systems
MEAM 516	Advanced Mechatronic Reactive Spaces
MEAM 520	Introduction to Robotics
MEAM 528	Advanced Kinematics (rarely taught)
MEAM 535	Advanced Dynamics
MEAM 550	Design of Microelectromechanical Systems
MEAM 613	Nonlinear Control Theory
MEAM 620	Advanced Robotics
MEAM 625	Haptic Interfaces (rarely taught)

Preapproved Electives Requirement Courses

Any graduate level MEAM course

EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech.
ESE 500	Linear Systems Theory
ESE 504	Introduction to Optimization Theory
ESE 519	Real-Time Embedded Systems
ESE 531	Digital Signal Processing
ESE 540	Engineering Economics
ESE 601	Hybrid Systems
ESE 650	Learning in Robotics
CIS 510	Curves & Surface: Theory & Appl.
CIS 520	Machine Learning
CIS 521	Fundamentals of AI
CIS 540	Principles of Embedded Computation
CIS 543	Physically Based Animation
CIS 580	Machine Perception Development
CIS 581	Computer Vision and Computational Photography
CIT 590	Programming Languages and Techniques
IPD 501	Integrated Computer-Aided Design, Manufacturing and Analysis

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

List of approved courses for students concentrating in

MICRO/NANO SYSTEMS

Micro/Nano systems is a broad field encompassing the design, development, and fabrication of devices and systems that derive unique functionality due to the small size of key components within them. Examples of such systems include microelectromechanical systems (MEMS), nanoelectronic devices, and microfluidics. Mechanical Engineering plays a central role in all of these systems, such as the mechanical design of MEMS-based sensors and the understanding of heat transfer in nanoelectronics. The graduate courses in this area of concentration provide students with a solid theoretical foundation, knowledge of micro/nano-fabrication techniques, and skills to design micro/nano systems.

Required Course

MEAM 537	Nanomechanics and Nanotribology at Interfaces (Spring Course)

Or

MEAM 550	Design of Mictroelectromechanical Systems (Spring Course)

Preapproved Core Requirement Courses

MEAM 505	Mechanical Properties of Macro/Nanoscale Materials
MEAM 537	Nanomechanics and Nanotribology at Interfaces
MEAM 550	Design of Mictroelectromechanical Systems
MEAM 555	Nanoscale Systems Biology
MEAM 564	The Principles and Practice of Microfabrication Technology
MEAM 572	Micro/Nanoscale Energy Transport (rarely offered)
MEAM 575	Micro and Nano Fluidics

Preapproved Electives Requirement Courses

Any graduate level MEAM course

EAS 504	Fundamental Concepts in Nanotechnology
EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech.
ESE 521	The Physics of Solid State Energy Devices
ESE 525	Nanoscale Science and Engineering
MSE 520	Structure of Materials
MSE 565	Fabrication and Characterization of Nanostructured Devices

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

List of approved courses for students concentrating in

HEAT TRANSFER, FLUID MECHANICS, AND ENERGY SCIENCE AND ENGINEERING

Aerospace engineering, materials fabrication and manufacturing, cooling of microelectronic equipment, energy conversion and power generation, and thermal control and treatment of living organisms are critically important in today's economy. Our program in heat transfer, fluid mechanics, and energy is designed to provide the basic tools for dealing with these and other problems of current and future technological interest. The program maintains close collaboration with the departments of Chemical Engineering, Bioengineering, Electrical and Systems Engineering, and Materials Science.

Required Course

MEAM 536	Viscous Fluid Flow (Spring course)
Or	
MEAM 570	Introduction to Transport (Offered Fall 2014)

Preapproved Core Requirement Courses

MEAM 502	Energy Engineering
MEAM 503	Direct Energy Conversion: From Macro to Nano
MEAM 504	Tribology
MEAM 527	Finite Element Analysis
MEAM 536	Viscous Fluid Flow
MEAM 530	Continuum Mechanics
MEAM 545	Aerodynamics
MEAM 561	Thermodynamics: Foundations, Energy, Materials
MEAM 570	Introduction to Transport
MEAM 571	Advanced Transport
MEAM 572	Micro/Nano Energy Transport (rarely offered)
MEAM 575	Micro and Nano Fluidics
MEAM 642	Fluid Mechanics I
MEAM 644	BioTransport: Fluid Mechanics, Heat and Mass Transfer (rarely offered)
MEAM 646	Computational Mechanics
MEAM 647	Foundations of Complex Fluids (rarely offered)
MEAM 662	Advanced Molecular Thermodynamics

Preapproved Electives Requirement Courses

Any graduate level MEAM course

CBE 520	Modeling, Simulations, and Optimization of Chemical Processes
CBE 545	Elec. Energy Conv. & Storage
CBE 546	Fundamentals of Industrial Catalytic Processes
CBE 617	Control of Nonlinear Systems
CBE 618	Advanced Molecular Thermodynamics
CBE 640	Transport Processes I
CBE 641	Transport Processes
CPLN 554	Environmental Management and Evaluation
CPLN 719	Environmental and Energy Planning Challenges for Cities
EAS 501	Energy and Its Impacts
EAS 502	Renewable Energy And Its Impacts: Technology, Ecology, Economics, Sustainability.
EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech. Development
MSE 545	Materials for Energy Storage and Generation
MSE 555	Environmental Degradation of Materials

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

List of approved courses for students concentrating in

MECHANICS OF MATERIALS

The development of new technologies often depends critically on the availability of materials systems capable of withstanding extreme thermomechanical loading conditions. Current examples are provided by the development of advanced engines in the aerospace industry and the design of microchips that are resistant to thermal cycling in the microelectronics industry. In addition, new technologies, such as biomedical technologies, often require the development and understanding of completely new classes of materials systems. The Penn MEAM MSE in Mechanics of Materials is designed to provide the fundamental tools needed to tackle these and other problems of current and future technological interest. These include basic courses in continuum mechanics, elasticity, and plasticity, as well as more advanced ones in fracture, composite materials, biomechanics, and atomistic modeling of materials. The program maintains close collaborations with the Material Science Department and with the bio-medical community.

Required Course

MEAM 519	Introduction to Elasticity

Preapproved Core Requirement Courses

MEAM 504	Tribology
MEAM 505	Mechanical Properties of Macro/Nanoscale Materials
MEAM 530	Continuum Mechanics
MEAM 537	Nanomechanics and Nanotribology at Interfaces
MEAM 554	Mechanics of Materials
MEAM 555	Nanoscale Systems Biology
MEAM 631	Advanced Elasticity
MEAM 632	Plasticity
MEAM 633	Fracture Mechanics
MEAM 634	Rods & Shells
MEAM 635	Composite Materials
MEAM 663	Entropic Forces in Biomechanics

Preapproved Electives Requirement Courses

Any graduate level MEAM course

BE 645	Biological Elasticity
EAS 504	Fundamental Concepts of Nanotechnology
EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech. Development
MSE 660	Atomistic Modeling in Materials Science

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

List of approved courses for students concentrating in

BIOMECHANICS

Research in Biomechanics spans from the molecular level through to tissue-level investigations, with major efforts in cell mechanics and biophysics, biomolecular simulation, gravity effects on cells and tissues, tendon and ligament injury, repair, regeneration, and intervertebral disc function/degeneration, and targeted drug delivery.

Required Course

To be determined in consultation with an academic advisor.

Preapproved Core Requirement Courses

MEAM 527	Finite Element Analysis
MEAM 554	Mechanics of Materials
MEAM 555	Nanoscale Systems Biology
MEAM 570	Introduction to Transport Phenomena
MEAM 644	BioTransport: Fluid Mechanics, Heat and Mass Transfer.
MEAM 663	Entropic Forces in Biomechanics
MEAM 635	Composite Materials
MEAM 642	Fluid Mechanics I

Preapproved Electives Requirement Courses

Any graduate level MEAM course

BE 512	BIO III - Biomaterials
BE 513	Cell Biology
BE 553	Principles, Methods, and Applications of Tissue Engineering
EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech. Development

Graduate course in the BioSciences (requires advisor approval)

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

List of approved courses for students concentrating in

DESIGN AND MANUFACTURING

Global business trends have created a demand for companies to rapidly develop new products at lower costs. In response to these demands companies have been exploring new methods to decrease costs, increase productivity, and create innovative products. In keeping with the needs of local industry the graduate courses below prepare students for careers in Product Design and Manufacturing. Students in the program will study topics such as mechatronics, CAD, computer graphics, industrial design, product design, materials engineering, manufacturing processes, assembly, tolerances, design analysis, plant/process modeling and design, robotics, electrical systems, mechanical systems, controls, intellectual property, and management skills. Graduates of the program will be prepared to be leaders in global manufacturing environment. Much of our work involves collaborations with, among others, the Departments of Computer and Information Science, Electrical and Systems Engineering as well as the School of Design and the Wharton School of Business Administration.

Required Course

MEAM 514	Design for Manufacturability

Preapproved Core Requirement Courses

MEAM 504	Tribology
MEAM 510	Mechatronics
MEAM 516	Advanced Mechatronics
MEAM 527	Numerical and Finite Element Methods
MEAM 537	Nanomechanics and Nanotribology at Interfaces
MEAM 550	Design of Micro-Electro-Mechanical Systems
MEAM 625	Haptic Interfaces (rarely taught)
MEAM 564	The Principles and Practice of Microfabrication Technology

Preapproved Electives Requirement Courses

Any Graduate Level MEAM course

ARCH 726	Furniture Design
CIS 510	Curves & Surface: Theory & Applications
CIS 560	Computer Graphics
EAS 545/546/547/548	Eng. Entrepreneurship I/ Eng. Entrepreneurship II/High Tech. Ventures/High Tech. Development
IPD 501	Integrated Computer Aided Design
IPD 511	Creative Thinking and Design
IPD 515	Product Design
IPD 527	Industrial Design I
OPIM 654	Product Design and Development
OPIM 655	Integrated Marketing and Operations

Advisor approval is required if a student wishes to take an elective graduate course not on the above list.

APPENDIX B

Hard Cover Instructions
for MSE Theses

Guidelines:

In addition to the unbound copies that must be given to the Office of the Associate Dean for Graduate Education and Research, one hardbound copy of each MSE thesis must be submitted to the Graduate Group Chair and one hardbound copy must be submitted to the student's advisor.

There is a charge of $25.00 per copy. Please check with the Graduate Program Coordinator for more information about hard binding your thesis or dissertation.

MSE dissertations are to be bound in a black cover with gold letters.

The lettering on the front should look like the following example:

Alfred E. Neuman

Design Optimization and Control of a Multi-robot System to Study the Size-Dependent Effects in the Mechanics of Muscle Cells Flowing Through Heated Micro Conduits

MSE Theses
Mechanical Engineering and Applied Mechanics
University of Pennsylvania
2013

APPENDIX C

GRADUATE TRANSFER OF CREDIT PETITION

FROM:_____ _____
Name of Student PENN ID #:

DEPT/MAJOR: _____

DATE: _____

Include with this petition, course numbers and descriptions from the appropriate bulletin listing and a final transcript. A maximum of **two** courses may be transferred to the Master's program or a maximum of **nine** to the Ph.D. program if approved. Courses counted towards an undergraduate degree will not be considered for graduate credit unless in an approved submatriculation program.

TRANSFER OF CREDIT TO: ☐ Master's program ☐ Ph.D. program

FROM WHICH UNIVERSITY: _____

Please list courses to be transferred and SEAS equivalent if applicable:

	COURSE	SEAS EQUIVALENT	# CUS
1)	_____	_____	_____
2)	_____	_____	_____
3)	_____	_____	_____
4)	_____	_____	_____
5)	_____	_____	_____
6)	_____	_____	_____
7)	_____	_____	_____
8)	_____	_____	_____
9)	_____	_____	_____

_____
Adviser's Approval Date

_____
Graduate Group Chair Date

☐ Approved ☐ Disapproved

_____
Deputy Dean for Education Date

APPENDIX D

MEAM Graduate Group Members

Paulo E. Arratia (parratia@seas.upenn.edu), Associate Professor. Micro- and nano-fluidics, complex fluids, hydrodynamic instabilities, swimming & locomotion, rheology, and soft-condensed matter.

P. S. Ayyaswamy (ayya@seas.upenn.edu), Asa Whitney Professor of Dynamical Engineering. Phase change heat and mass transfer processes, bioheat/mass transfer: gas embolism, targeted drug delivery, and arc-plasma heat transfer.

Igor Bargatin (bargatin@seas.upenn.edu), Class of 1965 Term Assistant Professor. Micro/nanoelectromechanical systems (MEMS/NEMS). Micro-and nano-scale energy transducers, such as thermionic energy converters and thermal light sources. Composite materials with ultra-low work functions.

John L. Bassani (bassani@seas.upenn.edu), 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, adhesion, mechanics of living cells.

Haim H. Bau (bau@seas.upenn.edu), Professor. Micro and nano fluidics, nanotechnology, real time electron microscope imaging of processes in liquids, lab on chip technology, diagnostic devices for point of care, electrokinetics, electrochemical energy storage, and fluid and particle motion under the actions of electric and magnetic fields.

Robert W. Carpick (carpick@seas.upenn.edu), Professor and Chair. Experimental nanomechanics, nanotribology (contact, friction, adhesion, lubrication, wear), surface science and engineering, and thin films. Development, characterization, and applications of materials and devices at the nanoscale including micro/nanoelectromechanical systems (MEMS/NEMS). Development and application of advanced scanning probe microscopy tools.

Stuart Churchill (churchil@seas.upenn.edu), Carl V. S. Patterson Professor Emeritus of Chemical and Biomolecular Engineering. Combustion, rate processes and correlation, the prediction of turbulent flow and convection.

Dennis E. Discher (discher@seas.upenn.edu), Professor of Chemical and Biomolecular Engineering. Stem cell mechanics, single molecule mechanics, statistical mechanics of networks and complex fluids.

David M. Eckmann (David.Eckmann@uphs.upenn.edu), Horatio C. Wood Professor of Anesthesiology & Critical Care. Experimental and computational biofluid dynamics, interfacial fluid mechanics, molecular mechanics of cellular activation and biological adhesion to vascular tissue, biomimetic materials and targeted drug delivery.

Dawn M. Elliott (delliott@udel.edu), Professor and Director, Biomedical Engineering, College of Engineering, University of Delaware. Orthopaedic biomechanics of the intervertebral disc; anisotropic, nonlinear, and viscoelastic biomechanics; models of disc degeneration; structure-function of the disc.

Daniel S. Gianola (gianola@seas.upenn.edu), Skirkanich Assistant Professor, Materials Science and Engineering. Nano- and micromechanics of materials, atomic-scale deformation mechanisms, *in situ* testing using electron microscopy, strain engineering of transport phenomena for efficient energy conversion, materials under extreme environments.

Howard H. Hu (hhu@seas.upenn.edu), Professor. Numerical simulations of complex flows with multiphase and polymeric fluids, particulate flows, flows in microfluidic devices, electrokinetic phenomena, hydrodynamic interfacial instability.

Daniel E. Koditschek (kod@seas.upenn.edu), Alfred Fitler Moore Professor and Chair of Electrical and Systems Engineering. Robotics, computational neuromechanics, dynamical systems theory applied to design of intelligent machines and their control.

Katherine J. Kuchenbecker (kuchenbe@seas.upenn.edu), Associate Professor and Undergraduate Curriculum Chair. Haptics for teleoperation, virtual environments, and robotic manipulation, with application to medical simulation, robotic minimally invasive surgery, stroke rehabilitation, personal computing, and personal robotics.

Vijay Kumar (kumar@seas.upenn.edu), UPS Foundation Professor. Robotics, multi-vehicle control, dynamical systems, systems biology.

Noam Lior (lior@seas.upenn.edu), Professor. Heat transfer, fluid mechanics, thermodynamics and exergy analysis, with applications to energy conversion, advanced power generation and hybrid systems, global warming alleviation, solar energy, sustainable energy and water desalination development,sustainability science, combustion, water desalination, materials processing.

X. Sherry Liu (xiaoweil@mail.med.upenn.edu), Assistant Professor of Orthopaedic Surgery and Bioengineering. Bone biomechanics, imaging and image analysis of biological tissues, metabolic bone diseases and treatments.

Jennifer R. Lukes (jrlukes@seas.upenn.edu), Associate Professor. Nanoscale thermal, fluid, and mass transport; molecular dynamics simulation; laser-based materials characterization; micro- and nanoscale engineering.

Robert L. Mauck (lemauck@mail.med.upenn.edu), Associate Professor of Orthopaedic Surgery and Bioengineering. Biomechanics of tissue engineered musculoskeletal tissues, Bioreactor development for mechanical stimulation, Mechanobiology of cells and tissues, Fabrication and modeling of hydrogels and nanofibrous scaffolds.

Charles J. McMahon, Jr. (cmcmahon@lrsm.upenn.edu), Professor Emeritus, Materials Science and Engineering. Mechanisms of intergranular embrittlement and fracture in high-strength structural materials, especially as related to environmental effects. Current interests are dynamic embrittlement in nickel and copper-based alloys and in steels.

George J. Pappas (pappasg@grasp.upenn.edu), Joseph Moore Professor of Electrical and Systems Engineering and Department Chair. Hybrid systems, hierarchical control systems, embedded systems, nonlinear systems, geometric control theory, robotics, unmanned aerial vehicles.

Pedro Ponte Castañeda (ponte@seas.upenn.edu), Professor. Nonlinear composite and polycrystalline materials, smart materials, microstructure evolution and localization in manufacturing processes, mechanics of polymers, fracture mechanics, nonlinear variational principles in mechanics.

Prashant Purohit (purohit@seas.upenn.edu), Associate Professor and Graduate Group Chair. Rod theories for DNA and biopolymers, mechanics of sub-cellular organelles, mechanics at the bio-nano interface, martensitic phase transitions in solids.

Celia Reina (celiareinaromo@gmail.com), William K. Gemmill Term Assistant Professor (beginning January 2014). Multiscale modeling, finite plasticity, phase transformations, ductile failure.

Vivek Shenoy (vshenoy@seas.upenn.edu), Professor of Materials Science and Engineering.

Talid R. Sinno (talid@seas.upenn.edu), Associate Professor of Chemical and Biomolecular Engineering. Computational materials science, multiscale modeling and simulation, nucleation and aggregation phenomena in electronic materials and complex fluids.

Louis J. Soslowsky (soslowsk@upenn.edu), Fairhill Professor of Orthopaedic Surgery and Professor of Bioengineering and Director of Penn Center for Musculoskeletal Disorders. Orthopaedic biomechanics and functional tissue engineering; structure-function studies of tendons and ligaments; models of tendon injury, repair, and healing; shoulder joint mechanics.

David J. Srolovitz (srol@seas.upenn.edu), Joseph Bordogna Professor of Engineering and Applied Science. Computational and theoretical materials science; defects, growth, evolution and deformation of materials.

Camillo J. Taylor (cjtaylor@central.cis.upenn.edu), Associate Professor of Computer and Information Science. Reconstructing and rerendering 3D scenes from 2D images and vision guided robotic systems.

Kevin T. Turner, (kturner@seas.upenn.edu), Associate Professor, Gabel Family Term Associate Professor. Micro/nanoscale materials and manufacturing, experimental and computational fracture and contact mechanics, small-scale adhesion mechanics, micro/nanoelectromechanical systems, mechanics of biological interfaces and cells.

Karl T. Ulrich (ulrich@wharton.upenn.edu), CIBC Professor of Operations and Information Management (Wharton School). Product design, product development, innovation, technology development, personal transportation, environmental issues.

Vaclav Vitek (vitek@lrsm.upenn.edu), Professor of Materials Science and Engineering. Computer modeling of the structure and properties of grain boundaries, metal-metal and metal-ceramic interfaces, dislocations and other lattice defects.

Beth A. Winkelstein (winkelst@seas.upenn.edu), Professor of Bioengineering and Neurosurgery. Spine biomechanics; modeling & experimental methods in subfailure mechanics; joint mechanics; mechanical modulation of pain and cellular dysfunction; models of ligament & nerve injury.

Mark Yim (yim@grasp.cis.upenn.edu), Professor and Director of Integrated Product Design. Modular self-reconfigurable robotics, biologically inspired mechanisms, flying devices, self-assembling structures.