Stevens Institute of Technology 2006-2007 Catalog

The Charles V. Schaefer, Jr. School of Engineering

Department of Mechanical Engineering

CONSTANTIN CHASSAPIS, DIRECTOR

FACULTY*

Professors

Constantin Chassapis, Ph.D. (1988), City University of New York
Richard B. Cole, P.E., Ph.D. (1971), Stevens Institute of Technology
Souran P. Manoochehri, Ph.D. (1986), University of Wisconsin, Madison
Marehalli G. Prasad, Ph.D. (1980), Purdue University
Siva Thangam, Ph.D. (1980), Rutgers University

Associate Professors

Sven K. Esche, Ph.D. (1997), Ohio State University
Hamid A. Hadim, Ph.D. (1985), University of Kansas
Kishore Pochiraju, Ph.D. (1993), Drexel University
Zhenqi Zhu, Ph.D. (1995), University of Connecticut

Assistant Professors

Jae-Hun Chung, Ph.D. (1996), University of California, Davis
Frank Fisher, Ph.D. (2002), Northwestern University
Yong Shi, Ph.D. (2004), Massachusetts Institute of Technology

Industry Professors

Richard Berkof, P.E., Ph.D. (1969), City University of New York
David Dietz, P.E., Ph.D. (1984), Stevens Institute of Technology
Jan Nazalewicz, P.E., M.E. (1965), Warsaw Polytechnic
John Nastasi, Master of Design, (2003), Harvard University

Contributing Faculty

Erol Cesmebasi, Ph.D. (1981), University of Michigan

Travel Directions

Campus Map

* The list indicates the highest earned degree, year awarded, and institution where earned.

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UNDERGRADUATE PROGRAMS

The range and scope of mechanical engineering has undergone radical changes over the past decade, while retaining and expanding traditional areas of endeavor. Some of the changes have been due to the improvements in auxiliary fields, such as materials, or to the introduction of new fields, such as microelectromechanical systems (MEMS), information technology, nanotechnology, and bioengineering.

Traditionally, the design and production of machines have been major concerns of the mechanical engineer, working to the basic criteria of price, efficiency, and delivery date. Safety and environmental considerations have added new dimensions to the mechanical engineer's problem. This is most apparent in the design of new automobiles, where improved mileage and cleaner engines have been coupled with a reduction in weight and size, and greater emphasis on highway safety.

In all areas, increasing emphasis has been placed on synthesis, looking to the performance of complete systems as opposed to that of single components. Career opportunities are traditionally found in such diverse areas as power generation, design of machinery, manufacturing, research and development, guidance systems, product design and development, robotics, propulsion engineering, system analysis and design, and many others. Our graduates wishing to further their education have been successful in gaining admission to the schools of their choice.

Reflecting the wide diversity of subject matter to be found in the present-day practice of mechanical engineering, the department offers a multitude of opportunities for study and research. Major areas of interest include energy conversion, design and manufacturing, HVAC, solid mechanics, automatic controls, dynamics, fluid mechanics, machine design, heat transfer, turbomachinery, combustion, robotics, and noise control. If you have particular interests or highly-specific objectives, we can generally satisfy your individual goals by elective courses and appropriate project work. Furthermore, it ought to be noted that the available pool of electives allows the student to specialize in one of the following concentration areas: Aerospace Engineering, Automation and Robotics, Automotive Engineering, Biomedical Engineering, Mechatronics, Pharmaceutical Manufacturing, Power Plant Engineerin,g and Product Design and Manufacture.

Mission and Objectives

The mission of the Mechanical Engineering Department is to produce graduates with a broad-based foundation in fundamental engineering principles and liberal arts, together with the depth of disciplinary knowledge needed to succeed in a career in mechanical engineering or a related field including a wide variety of advanced technological and management careers.

To achieve its mission, the Department of Mechanical Engineering, with input from its constituents, has established the following Program Educational Objectives:

- Graduates identify and solve problems in mechanical engineering and related fields using their broad-based knowledge of fundamental engineering concepts and state-of-the art tools and techniques.
- Graduates develop mechanical and thermal devices and systems to meet the needs of society.
- Graduates excel in working within and leading multi-disciplinary teams.
- Graduates conduct themselves in a socially responsible manner and engage in technological change.

Course Sequence

The course sequence for mechanical engineering is as follows:

Freshman Year					
Term I					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CH 115	General Chemistry I	3	0	6	3
CH 117	General Chemistry Lab I	0	3	0	1
MA 115	Calculus I	3	0	6	3
E 101	Eng. Experiences I #	1	0	0	0
E 121	Engineering Design I	0	3	2	2
E 120	Engineering Graphics	0	2	2	1
E 115	Intro. to Programming	1	1.5	3	2
HUM	Humanities	3	0	6	3
	# credit applied in E 102				
TOTAL		**11**	**9.5**	**25**	**15**

Term II

		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
Science	Science Elective I (1)	3	0	6	3
E 102	Eng. Experiences II #	1	0	0	1
MA 116	Calculus II	3	0	6	3
PEP 111	Physics I	3	0	6	3
E 122	Engineering Design II	0	3	3	2
HUM	Humanities	3	0	6	3
	# credit for E 101 & 102				
TOTAL		**13**	**3**	**27**	**15**

Sophomore Year					
Term III					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 221	Differential Equations	4	0	8	4
PEP 112	Physics II	3	0	6	3
E 126	Mechanics of Solids	4	0	8	4
E 245	Circuits & Systems	2	3	7	3
E 231	Engineering Design III	0	3	2	2
HUM	Humanities	3	0	6	3
TOTAL		**16**	**6**	**37**	**19**

Term IV					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 227	Multivariable Calculus	3	0	6	3
	OR approved alternative**				
E 232	Engineering Design IV	2	3	7	3
E 234	Thermodynamics**	3	0	6	3
Science	Science Elective II (1)	2	3	7	3
ME 225	Dynamics	3	0	6	3

Hu	Humanities	3	0	6	3
TOTAL		**16**	**6**	**38**	**18**

Junior Year					
Term V					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
ME 342	Fluid Mechanics	3	3	6	4
E 344	Materials Processing	3	0	6	3
E 321	Engineering Design V	0	3	2	2
E 243	Prob. & Statistics	3	0	6	3
ME 361	Design of Machine Comp.	3	0	6	3
HUM	Humanities	3	0	6	3
TOTAL		**15**	**6**	**32**	**18**

Term VI					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
ME 345	Modeling & Simulation	2	3	5	3
E 355	Engineering Economics	3	3	6	4
ME 322	Engineering Design VI	1	3	4	2
ME 335	Thermal Engineering	3	1	6	3
ME 358	Machine Dyn. & Mechan.	3	1	6	3
G.E.	General Elective (2)	3	0	6	3
TOTAL		**15**	**11**	**33**	**18**

Senior Year					
Term VII					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
ME 354	Heat Transfer	3	0	6	3
ME 483	Control Systems	3	1	6	3

G.E.	General Elective (2)	3	0	6	3
ME 423	Engineering Design VII	1	6	4	3
T.G.	Technogenesis Core**	3	0	6	3
T.E.	Technical Elective ‡	3	0	6	3
TOTAL		**16**	**7**	**34**	**18**

Term VIII

		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
ME 491	Manuf. Processes & Systems	3	0	6	3
T.E.	Technical Elective ‡	3	0	6	3
G.E.	General Elective (2)	3	0	6	3
ME 424	Engineering Design VIII	1	6	4	3
ME 470	ME Systems Laboratory	0	3	2	2
Hu	Humanities	3	0	6	3
TOTAL		**13**	**9**	**30**	**17**

** Core option – specific course determined by engineering program
(1) Basic Science electives – note: engineering programs may have specific requirements
- one elective must have a laboratory component
- two electives from the same science field cannot be selected
(2) General Education Electives – chosen by the student
- can be used towards a minor or ME concentration area
- can be applied for research or approved international studies
‡ T.E.: Mechanical Engineering Elective (to be selected from available ME 4xx and ME 5xx course offerings), can be used towards ME concentration area.

GRADUATION REQUIREMENTS

The following are requirements for graduation of all engineering students and **are not included for academic credit**. They will appear on the student record as pass/fail.

Physical Education

All engineering students must complete a minimum of three semester credits of Physical Education (P.E.). A large number of activities are offered in lifetime, team and wellness areas. Students must complete at least one course in their first semester at Stevens; the other two can be completed at any time, although it is recommended that this be done within the first half of the student's program of study. Students can enroll in more than the minimum required P.E. for graduation and are encouraged to do so.

Participation in varsity sports can be used to satisfy the full P.E. requirement.

Participation in supervised, competitive club sports can be used to satisfy up to two credits of the P.E. requirement with approval from the P.E. Coordinator.

English Language Proficiency

All students must satisfy an English Language proficiency requirement.

PLEASE NOTE: *A comprehensive Communications Program will be implemented for the Class of 2009. This may influence how the English Language Proficiency requirement is met. Details will be added when available.*

Areas of Concentration

Mechanical engineering students can select their elective courses among two technical electives and three general electives in various ways. Some of them may wish to cluster those electives in ways that would help them gain expertise in an area of specialization within mechanical engineering. The following groupings are possible specialty (concentration) areas that students can select from within the mechanical engineering program:

Aerospace Engineering
ME 545 Introduction to Aerospace Engineering and two courses from the following:

ME 423 and ME 424 Senior Design Project
ME 453 Advanced Fluid Mechanics
ME 520 Analysis & Design of Composites
ME 546 Introduction to Turbomachinery

Automotive Engineering
ME 423 and ME 424 Senior Design Project
ME 515 Automotive Engineering
ME 529 Modern and Advanced Combustion Engines

Biomedical Engineering
ME 525 Biomechanics
ME 526 Medical Device Design and Manufacture in a Regulated Environment and one course from the following:
ME 527 Human Movement and Control
BME 306 Bio-Engineering
BME 342 Transport in Biological Systems
BME 482 Engineering Physiology

Mechatronics
ME 522 Mechatronics I
ME 523 Mechatronics II
ME Introduction to Micro-Elecromechanical Systems

Pharmaceutical Manufacturing
ME 530 Introduction to Pharmaceutical Manufacturing
ME 535 Good Manufacturing Practice in Pharmaceutical Facilities Design
ME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing

Power Plant Engineering
ME 510 Power Plant Engineering and two

courses from the following:
ME 529 Modern and Advanced Combustion Engines
ME 532 Air Pollution Principles & Control
ME 546 Introduction to Turbomachinery
ME 595 Heat Exchanger Design

Product Design and Manufacturing
ME 554 Introduction to Computer-Aided Design
ME 564 Principles of Optimum Design and Manufacture
ME 566 Design for Manufacturability

Robotics and Automation
ME 522 Mechatronics I
ME 551 Microprocessor Applications in Mechanical Engineeting
ME 598 Introduction to Robotics

Minors

Students from other engineering programs may pursue a minor in Mechatronics by taking the required courses indicated below. Enrollment in a minor program means that you must also meet Stevens' requirements for minor programs. Only courses completed with a grade of "C" or better are accepted towards the minor.

Requirements for a Minor in Mechatronics
ME 225 Dynamics
ME 358 Machine Dynamics and Mechanics
ME 483 Control Systems
ME 509 Mechatronics I
ME 551 Microprocessor Applications in ME **or** ME 523 Mechatronics II **or**
ME 573 Introduction to Micro-Electromechanical Systems (MEMS)

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GRADUATE PROGRAMS

The Department of Mechanical Engineering provides three programs of graduate study leading to the degree of Master of Engineering: Mechanical, the professional Mechanical Engineer degree and the Doctor of Philosophy degree with a concentration in mechanical engineering. A major objective of the graduate program is to encourage research work at all levels so that individuals can progressively undertake more challenging problems with a wider research scope as they gain confidence and competence.

The Department of Mechanical Engineering has active research interests in the following areas: composites and structured materials, computational fluid dynamics and heat transfer, computer-aided design and manufacturing, integrated product and process design, control theory, design of thermal systems, industrial heat transfer, kinematics, knowledge-based engineering systems, machine design, metal forming, noise control and vibration, precision engineering, robotics and automation, system dynamics nano/micro modeling, and micro/nanofabrication.

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Master's Program

The Master of Engineering - Mechanical degree program is intended to extend and broaden the undergraduate preparation. It can be considered as a terminal degree or as preparation for the Ph.D. program. A bachelor's degree with a concentration in mechanical engineering is needed for acceptance to the master's program. Applicants with undergraduate degrees in other engineering disciplines may be required to take appropriate undergraduate courses before being formally admitted into the program.

The Master of Engineering - Mechanical degree requires 30 credits, approved by the student's academic advisor. Fifteen of the credits (or five courses) form the core and comprise the student's major field.

Core Courses

ME 641 Engineering Analysis I
ME 635 Simulation and Modeling
ME 636 Project Management and Organizational Design
and *two* more courses from any *one* of the following four tracks:

Manufacturing Systems

ME 644 Computer-Integrated Design and Manufacturing
ME 645 Design of Production Systems
ME 652 Advanced Manufacturing
ME 665 Advanced Product Development

Product Design

ME 615 Thermal System Design
ME 644 Computer-Integrated Design and Manufacturing
ME 659 Advanced Structural Design
ME 665 Advanced Product Development

Thermal Engineering

ME 601 Engineering Thermodynamics
ME 604 Advanced Heat Transfer
ME 615 Thermal Systems Design
ME 674 Fluid Dynamics

Pharmaceutical Manufacturing

ME 535 Good Manufacturing Practices in Pharmaceutical Facilities Design
ME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing

ME 628 Pharmaceutical Finishing and Packaging Systems
ME 645 Production Systems

The remaining five courses (15 credits) constitute the student's elective field and will consist of:

- at least one course of 600-level or higher given in the Mechanical Engineering Department;
- a maximum of four courses of 500-level given in the Mechanical Engineering Department;
- a maximum of one course given in other departments.

A student may substitute a project (ME 800 Special Problems in Mechanical Engineering, 3 credits) or a thesis (ME 900 Thesis in Mechanical Engineering, 5 credits) for the appropriate number of credits. The available pool of electives allows the student to specialize in one of the following areas: Advanced Manufacturing, Air Pollution Technology, Computational Fluid Mechanics and Heat Transfer, Design and Production Management, Power Generation, Robotics and Control, Structural Analysis and Design, and Vibration and Noise Control.

In order to graduate with a Master of Engineering - Mechanical degree, a student must obtain a minimum of "B" average in the major field, as well as an overall average of "B" in all the courses needed to meet the 30-credit requirement for the degree. Please see the Office of Graduate Admissions section on Student Status.

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Doctoral Program

Admission to the doctoral program will be made through the Department Director and will be based on an assessment of your academic background, competence, and aptitude for advanced study and research. An appropriate Master of Engineering degree or its equivalent is required. If deemed acceptable, you will be assigned an advisor with whom you will select a thesis topic and complete a study plan within the first year in the program.

Courses are selected to develop skills in a particular area of interest. While this coursework is necessary to develop the tools and skills of your profession, the most important aspect of the doctoral program is your original research topic.

The subject of the doctoral dissertation (ME 960) is open to a wide range of particular choices. The selection of a topic by the doctoral aspirant provides for a sub-specialization within the broad range of mechanical engineering disciplines. The courses selected for your study plan should complement your dissertation subject.

Upon submission of an approved study plan by the student, a doctoral committee is appointed for each student by the Department Director, with the thesis advisor as the chairperson. All doctoral students are required to present a research proposal (includes a written report and an oral presentation) to the doctoral committee for its approval. The candidate must present the proposal within 18 months of enrollment into the program. The committee, at its discretion, may decide on additional oral/written examinations before qualifying a student for the doctoral program and accepting the proposed dissertation plan. In the cases where the committee rejects a proposal, the candidate may submit a request for a second and final chance for presenting a revised dissertation proposal during the following academic semester.

Upon satisfactory completion of the thesis proposal and all coursework, you will be considered a doctoral candidate and continue the research which will form the basis of your dissertation. The dissertation must be based upon original investigation in the field of mechanical engineering, approved by the departmental supervisory committee and must be a contribution worthy of publication in the current professional literature. Before receiving the doctoral degree, you must also satisfy the requirements for residence and publication of the dissertation.

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Nanotechnology Concentration

The Mechanical Engineering doctoral program is an integral part of the institute-wide Nanotechnology Graduate Program. A Ph.D. degree option in Mechanical Engineering with concentration on Nanotechnology is available to students who satisfy the conditions and requirements of the Nanotechnology area which are outlined in a separate section of the catalog.

Mechanical Engineer Program

Thirty credits beyond a master’s degree are required for the Mechanical Engineer degree (with no more than three courses at the 500 level). A design project, ME 950 (12 credits), is a part of the 30 credits. The degree candidate must also demonstrate professional competence by having at least two years of responsible engineering experience. This industrial experience is to be completed before entering the program or in the process of being satisfied upon entering the program.

Each candidate will be assigned an advisor. The candidates and their advisors will submit a study plan for approval to the departmental committee on the engineer degree. The plan must include descriptions of the required professional experience and the design project. There will be an oral presentation of the design project after the departmental committee has approved a written report.

It is assumed that you will already have the Master of Engineering degree in your concentration from Stevens, or its equivalent; otherwise, additional courses will be required.

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INTERDISCIPLINARY PROGRAMS

Product-Architecture and Engineering Program

The Master of Engineering in Product-Architecture and Engineering degree program is intended to integrate the study of Product Design, Computational Architecture, and Engineering with production methodologies and emerging materials. All students in the program must complete 10 courses (30 credits) comprised of five core courses and up to five elective courses. Three of the five electives must be taken from the recommended list (see below) of relevant graduate courses offered by the mechanical engineering department. The remaining two courses (6 credits) constitute the student's elective field and will consist of at least one course of 600-level or higher offered within the Product-Architecture and Engineering program. Students may elect to complete a Thesis (PAE 900: Thesis in Product-Architecture and Engineering) in lieu of completing of the two open electives.

A Bachelor of Science degree in Engineering, a B.I.D. (B.F.A, B.A., or B.S.) in Industrial Design, or a B.Arch. (Bachelor in Architecture) is needed for acceptance to the program. Applicants with undergraduate degrees in other engineering or design disciplines may be required to take appropriate undergraduate courses before being formally admitted into the program.

Core Courses

PAE 610 The Creative Form and the Digital Environment
PAE 620 The Creative Form and the Production Environment
PAE 630 Introduction to Interactive Digital Media
PAE 640 Performative Environments
PAE 800 Product Architecture and Engineering Design Project

To complete the degree requirements students can choose from the following list of courses:

ME 502 Introduction to Engineering Analysis
ME 520 Analysis and Design of Composites
ME 564 Principles of Optimum Design and Manufacture
ME 566 Design for Manufacturability
ME 635 Simulation and Modeling

In order to graduate with a Master of Engineering in Product-Architecture and Engineering, a student must obtain a minimum of "B" average in the major field, as well as an overall average of "B" in all the courses needed to meet the 30-credit requirement for the degree. Please see the Office of Graduate Admissions section on Student Status.

Integrated Product Development

The Integrated Product Development degree is an integrated Master's of Engineering degree program. The core courses emphasize the design, manufacture, implementation, and life-cycle issues of engineering systems. The remaining courses provide a disciplinary focus. The program embraces and balances qualitative, as well as quantitative, aspects and utilizes state-of-the-art tools and methodologies. It aims to educate students in problem-solving methodologies, modeling, analysis, simulation, and technical management. The program trains engineers in relevant software applications and in productive deployment and integration in the workplace.

All students in this program must complete ten courses (30 credits) comprised of four core courses and up to six elective courses selected from one of the four engineering tracks listed below. The student, with the approval of the program director, may design customized tracks. Up to six elective credits may be taken in lieu of the course credits toward a project relevant to the selected track.

Core Courses - Integrated Product Development

IPD 601 Integrated Product Development I
IPD 602 Integrated Product Development II
IPD 611 Simulation and Modeling
IPD 612 Project Management and Organizational Design
(Full course descriptions can be found in the Interdisciplinary Programs section.)

Students then choose from one of the following four engineering tracks:

Armament Engineering Track
Electrical and Computer Engineering Track
Manufacturing Technologies Track
Systems Reliability and Design Track

The complete description of the IPD program can be found in the Interdisciplinary Programs section.

Armament Engineering Track

This technology track provides an interdisciplinary graduate education in Armament Engineering. The program emphasizes system engineering of military weapons from concept through development and field use. Technical disciplines in the design and manufacture of explosives, modeling and simulation of the interior and exterior ballistics, rocket and missile design, guidance and control, modern research instrumentation, and testing procedures are emphasized.

ME 504 Interior Ballistics and Design for Projection
ME 505 Theory and Performance of Propellants and Explosives I
ME 506 Theory and Performance of Propellants and Explosives II
ME 507 Exterior Ballistics
ME 508 Terminal Ballistics
Plus one free elective

Manufacturing Technologies Track

This track integrates product design, materials processing and manufacturing expertise with modern computer software technology. The program is specifically concerned with product design for manufacturing, manufacturing systems analysis and development, robotics and control and the integration of the various phases and activities associated with turning a concept into a deliverable product. Different manufacturing processes are introduced, and the design and control of these processes are discussed. Of particular interest are the development and implementation of models to predict the effects of design and manufacturing choices on system performance, producibility and economics.

ME 560 Total Quality Control
ME 564 Principles of Optimal Design and Manufacture
ME 598 Introduction to Robotics
ME 621 Introduction to Modern Control Engineering
ME 645 Design of Production Systems
ME 644 Computer-Integrated Design and Manufacturing **or**
ME 520 Analysis and Design of Composites

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Graduate Certificate Programs

The Mechanical Engineering department offers several graduate certificate programs to students meeting the regular admission requirements for the master’s program. Each graduate certificate program is self-contained and highly focused, carrying 12 or more graduate credits. All of the courses may be used toward the Master of Engineering degree, as well as for the graduate certificate. Current programs include:

Advanced Manufacturing

ME 645 Design of Production Systems
ME 566 Design for Manufacturability
ME 621 Introduction to Modern Control Engineering
ME 652 Advanced Manufacturing

Air Pollution Technology

ME 532 Air Pollution Principles and Control
ME 590 Environmental Law for Practicing Engineers
ME 612 Selected Topics in Air Pollution Technology

Computational Fluid Mechanics and Heat Transfer

ME 594 Computer Methods in Mechanical Engineering
ME 604 Advanced Heat Transfer **or**
ME 609 Convective Heat Transfer
ME 674 Fluid Dynamics
ME 675 Computational Fluid Dynamics and Heat Transfer

Design and Production Management

ME 566 Design for Manufacturability
ME 636 Project Management and Organizational Design
ME 644 Computer-Integrated Design and Manufacturing
ME 645 Design of Production Systems

Ordnance Engineering

ME 505 Theory and Performance of Propellants and Explosives I
ME 507 Exterior Ballistics

and any two of the following three courses:

ME 504 Interior Ballistics and Design for Projection
ME 506 Theory of Performance of Propellants and Explosives II
ME 508 Terminal Ballistics

Power Generation

ME 510 Power Plant Engineering
ME 595 Heat Exchanger Design

and two of the following:

ME 529 Modern and Advanced Combustion Engines
ME 546 Introduction to Turbomachinery
ME 625 Gas Turbines

Product Architecture and Engineering

PAE 610 The Creative Form and the Digital Environment
PAE 620 The Creative Form and the Production Environment
PAE 630 Introduction to Interactive Digital Media
PAE 640 Performative Environments

Robotics and Control

ME 598 Introduction to Robotics
ME 621 Introduction to Modern Control Engineering
ME 622 Optimal Control and Estimation of Dynamical Systems **or**
ME 623 Design of Control Systems
ME 654 Advanced Robotics

Structural Analysis and Design

ME 658 Advanced Mechanics of Solids
ME 659 Advanced Structural Design
ME 663 Finite-Element Methods
ME 664 Special Topics in Applied Finite-Element Methods **or**
ME 668 Engineering Fracture Mechanics

Vibration and Noise Control

ME 584 Vibration and Acoustics in Product Design
ME 611 Engineering Acoustics
ME 631 Mechanical Vibrations I
ME 651 Analytic Dynamics

Interdisciplinary Graduate Certificate in Pharmaceutical Manufacturing Practices

The Graduate Certificate in Pharmaceutical Manufacturing Practices is an interdisciplinary School of Engineering certificate developed by the Department of Mechanical Engineering and the Department of Chemical, Biomedical, and Materials Engineering. This certificate is intended to provide professionals with skills required to work in the pharmaceutical industry. The focus is on engineering aspects of manufacturing and the design of facilities for pharmaceutical manufacturing, within the framework of the regulatory requirements in the pharmaceutical industry.

The certificate is designed for technologists in primary manufacturers, including pharmaceutical, biotechnology, medical device, diagnostic, and cosmetic companies, as well as in related companies and organizations, including architect/engineer/construction firms, equipment manufacturers and suppliers, government agencies, and universities.

PME 530 Introduction to Pharmaceutical Manufacturing
PME 535 Good Manufacturing Practice in Pharmaceutical Facilities Design
PME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing

and one of the following electives:

PME 531 Process Safety Management
PME 538 Chemical Technology Processes in Pharmaceutical Manufacturing

PME 539 Bioprocess Technology in Pharmaceutical Manufacturing
PME 541 Validation of Computerized Systems
PME 628 Pharmaceutical Finishing and Packaging Systems
PME 649 Design of Water, Steam, and CIP Utility Systems for Pharmaceutical Manufacturing

(Full course descriptions can be found in the Interdisciplinary Programs section.)

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DESIGN & MANUFACTURING INSTITUTE

The Design & Manufacturing Institute (DMI) is a unique research and development organization for advancing the state-of-the-art through design and manufacturing integration. DMI is pioneering an automated approach to integrated product and process development with a multidisciplinary staff involved in developing software applications to support and automate engineering tasks for commercial, military, and research projects.

Housed in the Carnegie Laboratory - an 18,000-square-foot facility - DMI provides a broad array of services related to product design, engineering analysis, materials characterization, and the rapid manufacturing and prototyping of molds and parts to industry (commercial and military). The facility includes a design center, full-scale production services, and a quality-assurance laboratory. State-of-the-art software packages are used to perform a variety of design and production services, such as computer modeling and structural analysis.

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LABORATORIES

Advanced Manufacturing Laboratory

This laboratory contains industrial-scale NC machines with CAD/CAM software and is part of the Design & Manufacturing Institute. The equipment is designed to form an integrated manufacturing system.

Alfred W. Fielding Computer-Aided Design Laboratory

This laboratory contains a number of high-speed workstations and peripherals serviced via local area networks. The installed software includes the general purpose CAD/CAM package *Pro-Engineer* and *Solid Works*, as well as finite element codes [*ABAQUS*, *ALGOR*, *ANSYS,* and *Pro-Mechanica*.] Also installed are several special-purpose design, analysis, and educational packages.

Engineered Structural Materials Laboratory

This laboratory focuses on the design, modeling, and analysis and characterization of modern micro/nano structurally engineered materials. The laboratory has filament winding, resin transfer molding, and robotic lamination equipment for prototyping tailored composite materials. The laboratory is capable of characterizing physical and mechanical properties, long-term durability, and failure behavior of composite structures.

Fluid Mechanics Laboratory

This laboratory includes a low-noise subsonic wind tunnel with several custom-fabricated test sections, a pump performance test-rig, a blower and internal-flow test-rig, a hydraulic bench, and experimental set-ups for flow metering, force of a jet, and dimensional-analysis/similitude. The laboratory is fully networked and includes space to support undergraduate and graduate design and research projects in aerodynamics and hydraulics with modern flow instrumentation and computer-aided data acquisition systems.

Kenneth A. Roe Senior Design Laboratory

This facility provides work space and support (instrumentation, tools, etc.) for the design, construction, and testing of capstone-design projects in mechanical engineering. The laboratory serves as a base for all the senior design teams. It has workbenches for at least ten design teams to build and assemble prototypes.

Mechanical Systems Laboratory

This laboratory houses 10 experimental set-ups in mechanisms, machine systems, and robotics, including apparatus for experiments on vibrations of machine systems (natural response, step response, frequency response, resonance, etc.), gear mechanisms (train value, rigid vs. flexible machine, etc.), and balancing of rotors, as well as the experiments with various displacement sensors to measure beam deflection and calculate beam stiffness; to measure backlash existeing in mechanical joints and motion systems; and to measure motion errors in mechanical systems of various components. Several educational robot manipulators and Lego-based mobile platforms are included.

Metal Forming Laboratory (MFL)

This Laboratory focuses on advancing the state-of-the-art in computer modeling of thermo-mechanical processing of metals. The results of the computer simulations are verified using experimental techniques. The manufacturing processes investigated include forging, rolling, extrusion, and stamping. Recent projects have explored the microstructure changes in metals during the hot forging of aerospace components, whereby the resulting grain size is predicted as a function of the processing parameters using heuristic models and numerical approaches on multiple lengths scales.

Noise and Vibration Control Laboratory

Research activities in the areas of engineering acoustics, vibrations, and noise control are conducted in this laboratory. The laboratory has an anechoic chamber of internal dimensions 4.52m x 5.44m x 2.45m high. In addition, the laboratory houses sophisticated instrumentation, such as multi-channel signal analyzer and sound and vibration transducers, transducers with adapters for mounting to a robot end effector, and a number of grippers designed and constructed by students.

Precision Engineering Laboratory

Precision Engineering Laboratory sensors and actuators, as well as precision coordinate measuring machines, provide powerful tools for research, development, and education. Current experimental studies include the development of an innovative diamond wheel sharpening process at high-speed; a six degree-of-freedom robotic measuring system; precision industrial robot design and performance evaluation techniques; service robots; and ultra-precision fine-position systems for industrial robots.

Product-Architecture Digital Media Laboratory

This lab focuses on advanced digital design environments, including geometric modeling, interactivity, scripting languages and virtual reality. The lab is fitted out with a full Computer-Aided Three-Dimensional Interactive Application (CATIA) suite. Interactive digital media is explored using scripting capabilities in Maya, Action Scripting, and Rhino and include a full set of ceiling-mounted cameras, blob tracking devices, and projection systems for full scale performative environment studies. Three dimensional scanning technologies are explored using a wide array of devices, including a Cyrax-Lidar type scanner, and a Roland DGA LPX–250. Touch Probe Scanning and reverse engineering is also possible using the MicroScribe-G2LX. Nonlinear digital video editing is achieved on 2 dual G-5 Macintosh systems hosting a full Final Cut Pro software suite and DVD authoring tools. The lab is equipped with a 25-seat virtual reality theater, with rear projection stereoscopic projection systems, haptic gloves, head mounted display, and a full VR Eon Reality scripting suite.

Robotics and Control Laboratory (RCL)

The Robotics and Control Laboratory (RCL) provides experimental research support in advanced intelligent control of robotic systems with emphasis on nonlinear systems adaptive control, intelligent control, neural networks, and optimization-based design and control. Projects include investigations on man-machine systems, telerobotics, haptics, robotic deburring, and robust and adaptive motion, force, and vision-based control. The major facilities consist of one PA-10 robot, a Phantom haptic device with GHOST development software, two PUMA 500s, and several robotic arms. The PA-10 is equipped with a JR3 wrist and an ATI base force sensor and a Sony eye-in-hand camera system.

Thermodynamics Laboratory

This laboratory includes a CFR engine set-up equipped with a custom-made power controller and a fully computerized data-acquisition system, a two-stage, 10-hp, air compressor with inter-cooling, instrumented with a computer-assisted data acquisition system, a hot water furnace experimental setup, and an educational version of a vapor-compression refrigeration/heat pump cycle. Modern emissions testing equipment and computer-aided data acquisition systems are available for use.

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UNDERGRADUATE COURSES

ME 225 Dynamics
(3-0-3)
Particle kinematics and kinetics, systems of particles, work-energy, impulse and momentum, rigid-body kinematics, relative motion, Coriolis acceleration, rigid-body kinetics, direct and oblique impact, eccentric impact. Prerequisites: MA 116, E 126, PEP 102.

ME 322 Engineering Design VI
(1-3-2)
This course is intended to teach modern systematic design techniques used in the practice of mechanical engineering. Methodology for the development of design objective(s), literature surveys, base case designs, and design alternatives are given. Economic analyses with an emphasis on capital investment and operating costs are introduced. Integrated product and process design concepts are emphasized with case studies. Students are encouraged to select their senior capstone design project near the end of the course, form teams, and commence preliminary work. A number of design projects are required of all students. Corequisite: ME 345.

ME 335 Thermal Engineering
(2-3-3)
Applications of First and Second Laws to thermal systems, including gas-turbine and internal- and external-combustion engines. Vapor cycles, including supercritical binary and combined cycles. Regeneration and recuperation, gas compression, refrigeration, and gas liquefaction psychometry. Introduction to energy conversion systems. Laboratory work in air compressors, internal combustion engines, furnaces, heat pumps, and gas turbines. Prerequisite: E 234.

ME 342 Fluid Mechanics
(3-3-4)
Properties of a fluid; basic flow analysis techniques; fluid kinematics; hydrostatics; rigid body motion of a fluid; control volume analysis; conservation of mass, and linear and angular momentum; Bernoulli and energy equations; dimensional analysis; viscous flow in pipes; flow metering devices; external flows; estimation of lift and drag; turbomachinery; and open channel flow. Prerequisites: E 126, PEP 102, ME 225, and MA 221.

ME 345 Modeling and Simulation

(2-3-3)
Modeling and simulation methodologies, including model-block building, logical and data modeling, validation, simulation and trade-off analysis, decision-making and optimization. Product and assembly modeling; visual simulation; process modeling; production modeling; process plans and resource modeling, entity flow modeling including conveyors, transporters, and guided vehicles; and input and output statistical analysis. Several CAD/CAE simulation software suites are used. Prerequisites: E 234, ME 225, and MA 227.

ME 354 Heat Transfer
(3-0-3)
Basic modes of heat transfer, steady heat conduction, extended surface heat transfer, transient heat conduction, computational methods, forced and free convection, boiling and condensation, thermal radiation, and heat exchangers. Design projects. Prerequisites: MA 227, E 234, and ME 342.

ME 358 Machine Dynamics and Mechanisms
(2-3-3)
The principles of dynamics as applied to the analysis of the accelerations and dynamic forces in machines, such as linkages, cam systems, gears, trains, belts, chains, and couplings. The effect these dynamic forces have on the dynamic balance and operation of the machines and the attending stresses in the individual components of the machines. Some synthesis techniques. Students also work in teams on a semester-long project associated with the design of a mechanical system from recognizing the need through a detailed conceptual design. Prerequisites: MA 227, E 246, ME 225.

ME 361 Design of Machine Components
(2-3-3)
Application of the principles of strength of materials to the analysis and design of machine parts. Stress and deflection analysis. Curved bars, multi-support shafts, torsion, cylinders under pressure, thermal stresses, creep and relaxation, rotating disks, fasteners, springs, bearings, gears, brakes, and other machine elements are considered. Failure of structural materials under cyclic stress. Prerequisites: E 126, MA 221, and ME 358.

ME 421 Energy Conversion Systems
(3-0-3)
Technology and economics of energy sources; storage and utilization; overview of fundamental concepts of mechanical, thermal, chemical, nuclear, and electrical energy conversion (practical and visionary) and thermochemical conversion, including combustion in power plants; propulsion systems; thermomechanical conversion in nozzles and turbomachinery; "direct" energy conversion in fuel cells; and nuclear energy conversion. Prerequisites: ME 335, ME 342. Corequisite: ME 354.

ME 423-424 Engineering Design VII-VIII
(0-8-3) (0-8-3)
Senior design courses. Complete design sequence with a required capstone project spanning two semesters. While the focus is on the capstone disciplinary design experience, it includes the two-credit core module on E 421 Engineering Economic Design during the first semester.

ME 453 Advanced Fluid Mechanics
(3-0-3)
Differential equations of fluid flow, Navier-Stokes equations, introduction to fluid turbulence, inviscid incompressible flow, introduction to airfoil theory, compressible fluid flow, and applications nozzles, ducts, and airfoils. Prerequisites: MA 227, ME 342.

ME 463-464 Research in Mechanical Engineering I-II
(0-8-3) (0-8-3)
Individual investigation of a substantive character undertaken at an undergraduate level under the guidance of a faculty advisor leading to a thesis with a public defense. The thesis committee consists of the faculty advisor and one or more readers. Prior approval from the department is required. Hours to be arranged with the faculty advisor.

ME 470 Mechanical Engineering Systems Laboratory (0-3-2)
Experiments in selected mechanical engineering systems areas, including principles and applications of experimentation, data-acquisition, design of experiments, and written and oral reporting on experimental hardware and results. Prerequisites: ME 354, ME 483, ME 358, ME 361, ME 335, and ME 342. Corequisite: ME 491.

ME 471 Mechanics of Materials
(3-0-3)
Multidimensional stress, strain, and transformation equations; yield conditions and theories of failure; constitutive laws including linear elasticity, viscoelasticity, and temperature influences; equations of elasticity; simple applications to uniaxial stress and symmetric bending; unsymmetrical bending and shear center of beams; torsions; combined stresses with applications to beams, thin-walled cylinders, and pressure tanks; shrink fits; bending beyond the elastic limit; and instability and energy methods. Prerequisite: ME 361.

ME 473 Design of Mechanical Systems
(3-0-3)
Static and dynamic force analysis of mechanisms, dynamics of reciprocating and rotating machinery, balancing of machinery, friction and wear, vibration and noise control in machines, manipulators and robots, and computer-aided design. Prerequisites: MA 227, ME 358.

ME 483 Control Systems
(3-0-3)
Analysis and synthesis of feedback control systems to achieve specified stability and performance criteria, stability via root-locus techniques, Nyquist's criterion, Bode and Nichol's plots, effect of various control laws and pole-zero compensation on performance, applications to servomechanisms, hydraulic and pneumatic control systems, and analysis of nonlinear systems. Prerequisite: MA 227, E 246, and ME 225.

ME 491 Manufacturing Processes and Systems
(3-0-3)
Analysis of both bulk-forming (forging, extrusion, rolling, etc.) and sheet-forming processes, metal cutting, and other related manufacturing processes; physics and stochastic nature of manufacturing processes and their effects on quality, rate, cost, and flexibility; role of computer-aided manufacturing in manufacturing system automation; and methodologies used to plan and control a manufacturing system, forecasting, production scheduling, facility layout, inventory control, and project planning. Prerequisites: ME 345, ME 361.

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GRADUATE COURSES

All Graduate courses are 3 credits except where noted.

Mechanical Engineering

ME 501 Basic Engineering Mechanics*
This course is intended to provide an introduction to engineering mechanics. Topics include static and dynamics, strength of materials, and systems modeling. The course will emphasize basic relationships in these areas necessary to the understanding of design and manufacturing principles as covered in ME 503.

ME 502 Introduction to Engineering Analysis*
Basic concepts and introduction to engineering analysis techniques in mechanical and manufacturing engineering. Topics include: applications of ordinary and partial differential equations, linear algebra, and numerical analysis to mechanical and manufacturing engineering systems. Prerequisite: ME 501 or equivalent.

ME 503 Principles of Mechanical Engineering*
This course is intended to provide non-mechanical engineering students with an understanding of the principles of mechanical design. It is given from the viewpoint that design is the central activity of the engineering profession, and it is more concerned with the introduction of mechanical engineering principles pertinent to the design of products. This course presents design as an interdisciplinary activity that draws on such diverse subjects as materials selection, modeling and analysis, and manufacturing processes.

ME 504 Interior Ballistics and Design for Projection
This course introduces the students to the fundamental principles of interior ballistics. Terminology and the Lagrange approximation are discussed. The governing equations of propellant burning are introduced. Projectile design practices are discussed in detail. Sabot and cartridge case design, as well as gun tube design, are covered. Term project focuses on use of interior ballistic equations tailored to a specific job application. Prerequisites: none (at Dover, NJ).

ME 505-506 Theory and Performance of Propellants and Explosives III-IV
These two courses will deal with the theory, performance, and life-cycle applications of propellants, explosives, pyrotechnics, and advanced warhead and propulsion systems. Topics include: 1) physical and chemical principles which govern the characteristics, performance, and design for use of energetics and advanced warhead and propulsion systems; 2) current theory to explain stability, sensitivity, combustion, detonation, initiation, power, shaped charge effect, and flash and smoke formations; 3) calculation procedures to estimate performance of energetics and warhead and propulsion systems, and 4) modern instrumentation and test procedures for material and system evaluation. First and second semesters (at Dover, NJ).

ME 507 Exterior Ballistics
Basic principles of exterior ballistics are introduced. Flight terminology, vacuum trajectories, and flat fire point mass trajectories are discussed. Siacci Method, Coriolis effect, yaw of repose, wind effects, 6-DOF trajectories, and modified point mass trajectories are covered. Prerequisite: none (At Dover, NJ)

ME 508 Terminal Ballistics
Simplified equations for determination of flight stability and roll resonance are developed. Terminal ballistics are described and nomenclature introduced. Shock and stress wave effects in materials are discussed. Penetration and perforation of solids and the governing equations are described. Penetration of armor by shaped charge jets are discussed. Term project focuses on investigation of terminal ballistic effects tailored to a specific job application. Prerequisite: ME 507 (at Dover, NJ).

ME 509 Special Topics in Mechanical Engineering*
Courses on special topics of current interest in mechanical engineering, including, but not limited to, nuclear power engineering and computer-aided building energy analysis. Prerequisite: approval of the Department Head.

ME 510 Power Plant Engineering
Analysis of thermodynamics, hydraulic, environmental, and economic considerations that affect the design and

performance of modern power plants; overview of power generation system and its components, including boilers, turbines, circulating water systems, and condensate-feedwater systems; fuels and combustion; auxiliary pumping and cleanup systems; gas turbine and combined cycles; and introduction to nuclear power plants and alternate energy systems based on geothermal, solar, wind, and ocean energy.

ME 515 Automotive Engineering*
Analysis of the automotive vehicle as an entire integrated system under highway and off-road conditions. Significant subject areas include power-train design, control, and stability; suspension design, tire-road interface, soil-vehicle interface, four-wheeled, tracked, and unconventional vehicles; and emphasis is on design theory.

ME 520 Analysis and Design of Composites
Composite material characterization; composite mechanics of plates, panels, beams, columns, and rods integrated with design procedures; analysis and design of composite structures, joining methods, and procedures; and introduction to manufacturing processes of filament winding, braiding, injection, compression and resin transfer molding, machining and drilling, and industrial applications.

ME 521 Nondestructive Evaluation*
This course will introduce principles and applications of Nondestructive Evaluation (NDE) techniques that are important in designing, manufacturing, and maintenance. Most commonly used methods, such as ultrasonics, magnetics, radiography, penetrants, and eddy currents, will be discussed. Physical concepts behind each of these methods, as well as, practical examples of their applications, will be emphasized. Cross-listed with CE 530.

ME 522 Mechatronics I
This course introduces principles of mechatronics to integrate mechanical, electronic/electrical, and control/computer/software components for motion control systems. Electromechanical components and integration concepts include: machine construction and control concepts, control modes (open/closed loop, servo, and process control) and motion profiles, motion drivers and actuators (AC drives, motors, gearing, servo and stepper motors), PLC control and programming (ladder and Boolean and combinatorial logic interfaces), microprocessor/computer based (logic, operating systems, SCADA, and HMI), field devices, signal conditioning, and communication (I/O hardware and management, vision systems, protocols, and programming languages), and introduction to system integration.

ME 525 Biomechanics**
(3-0-3)
This course introduces the fundamental principles of

mechanics applied to the study of biological systems and relates the design of implants and prosthetics to the biomechanics of the musculoskeletal system. Specific types of tissue covered include bone, ligament, skeletal and cardiac muscle, and articular cartilage. An introduction to the basic concepts of continuum mechanics is provided, including finite-deformation kinematics, stress, constitutive equations, and the governing conservation laws of mass, momentum, and energy applied to deformable continua. Rigid-body kinematics is introduced in the context of applications in biomechanics.

ME 526 Medical Device Design and Manufacture in a Regulated Environment **
(3-0-3)
This course focuses on the design and manufacture of medical devices in a regulated environment. Current commercially available therapeutic devices are used as illustrations. For each device, the relevant physiology and common pathology is presented from an engineering point of view. This information is translated into user and functional requirements for the design of the therapeutic device. Based on these requirements, we explore how mechanical engineers contribute to the design and manufacture of these devices within a regulated environment.

ME 527 Human Movement and Control**
(3-0-3)
This course blends robotics theory, control theory neural networks theory, and neuroscience to understand in some depth the primate motor system. The goal is to understand how the brain uses vision and other sensory feedback to plan and control movements of the limb.

ME 529 Modern and Advanced Combustion Engines*
The internal combustion engine examined in terms of the four fundamental disciplines that determine its characteristics: 1) fluid mechanics, 2) chemistry of combustion and of exhaust emission, 3) first and second laws of thermodynamics, and 4) mechanics of reciprocating and rotary motion; high output Otto and diesel engines for terrestrial, maritime, and aerospace environments; normal and abnormal combustion; stratified charge and advanced low-emission engines; hybrid and multifuel engines; Sterling and other space engines; and free-piston and rotary-piston concepts and configurations.

ME 530 Introduction to Pharmaceutical Manufacturing
Pharmaceutical manufacturing is vital to the success of the technical operations of a pharmaceutical company. This course is approached from the need to balance company economic considerations with the regulatory compliance requirements of safety, effectiveness, identity, strength, quality, and purity of the products manufactured for distribution and sale by the company.

Overview of chemical and biotech process technology and equipment, dosage forms and finishing systems, facility engineering, health, safety and environment concepts, and regulatory issues. Cross-listed with PME 530.

ME 532 Air Pollution Principles and Control
An introduction to the principles and control of air pollution, including: regulations, measurement, and instrumentation of air pollution; air pollution chemistry; atmospheric dispersion modeling; inertial separators; electrostatic precipitators; scrubbers; filters; absorption and adsorption; and thermal treatment, catalytic reduction, mobile sources, and indoor air quality. Cross-listed with EN 506.

ME 535 Good Manufacturing Practice in Pharmaceutical Facilities Design
Current Good Manufacturing Practice compliance issues in design of pharmaceutical and biopharmaceutical facilities. Issues related to process flow, material flow and people flow, and A&E mechanical, industrial, HVAC, automation, electrical, and computer. Bio-safety levels. Developing effective written procedures, so that proper documentation can be provided, and then documenting through validation that processes with a high degree of assurance do what they are intended to do. Levels I, II, and III policies. Clinical phases I, II, III and their effect on plant design. Defending products against contamination. Building quality into products. Cross-listed with PME 535.

ME 538 Chemical Technology Processes in API Manufacturing
Bulk active pharmaceutical ingredient manufacturing and unit operations. Process scale-up. Transport processes, including mass, heat, and momentum transfer. Process synthesis, analysis, and design. Traditional separation processes, including distillation, evaporation, extraction, crystallization, and absorption. New separation processes, including pressure swing adsorption, molecular sieves, ion exchange, reverse osmosis, microfiltration, nanofiltration, ultrafiltration, diafiltration, gas permeation, pervaporation, supercritical fluid extraction, and high performance liquid chromatography (HPLC). Batch and continuous reactors for homogeneous, heterogeneous, catalytic, and non-catalytic reactions. Cross-listed with PME 538.

ME 539 Bioprocess Technology in Pharmaceutical Manufacturing
This course provides a broad overview of topics related to the design and operations of modern biopharmaceutical facilities. It covers process, utilities, and facility design issues, and encompasses all major manufacturing areas, such as fermentation, harvest, primary and final purification, media and buffer preparation, equipment cleaning and sterilization, and critical process utilities. Unit operations include cell culture, centrifugation, conventional and tangential flow

filtration, chromatography, solution preparation, and bulk filling. Application of current Good Manufacturing Practices and Bioprocessing Equipment Standards (BPE-2002) will be discussed. Cross-listed with ChE 539 and PME 539.

ME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing
Validation of a pharmaceutical manufacturing process is an essential requirement with respect to compliance with Good Manufacturing Practices (GMP) contained within the Code of Federal Regulations (21 CFR). Course covers validation concepts for plant, process, cleaning, sterilization, filtration, analytical methods and computer systems; and GAMP (Good Automated Manufacturing Practice), IEEE SQAP, and new electronic requirements - 21 CFR Part 11. Master validation plan, IQ, OQ, and PQ protocols and relationships to GMP. National (FDA) and international (EU) regulatory affairs for cGMP (current Good Manufacturing Practice) and cGLP (current Good Laboratory Practice) requirements in development, manufacturing, and marketing. Handling the FDA inspection. Cross-listed with PME 540.

ME 541 Validation of Computerized Systems
Computers and computerized systems are ubiquitous in pharmaceutical manufacturing. Validation of these systems is essential to assure public safety and compliance with appropriate regulatory issues regarding validation: GMP, GCP, 21CFR Part 11, etc. This course covers validation concepts for various classes of computerized systems and applications used in the pharmaceutical industry; importance of requirements engineering in validation; test protocols and design; and organizational maturity considerations. Prerequisite: PME 540. Cross-listed with PME 541.

ME 543 Air Conditioning
Thermodynamic analysis of refrigeration cycles, properties of refrigerants, and coolants; psychrometry; factors affecting human comfort; environmental control requirements in industrial processes; estimation of infiltration and ventilation; heat transmission coefficients; insulation; heating and cooling load on buildings; numerical methods for building energy analysis; selection of air distribution systems, ducting, and fans; and selection of water and steam distribution systems, piping, and pumps.

ME 545 Introduction to Aerospace Engineering (3-0-3)**
This course lays the foundations in aerospace engineering. Topics include the history of aviation, basic aerodynamics, airfoils, wings and other aerodynamic shapes, aircraft performance, stability and control, aircraft structures (structural analysis and materials), propulsion, flight test, rockets, space flight, and orbits.

ME 546 Introduction to Turbomachinery
Aerodynamic and thermodynamic fundamentals

applicable to turbomachinery; design configurations and types of turbomachinery; turbine, compressor, and ancillary equipment kinematics, thermodynamics and performance; and selection and operational problems of turbomachinery.

ME 551 Microprocessor Applications in Mechanical Engineering
Introduction to basic concepts and current state-of-the-art hardware; architectures and elementary programming; instruction sets; fundamental software concepts; interfacing microprocessors to external devices; microprocessors in control systems; and hands-on laboratory applications of microprocessors in mechanical engineering systems.

ME 554 Introduction to Computer-Aided Design (CAD)
An introduction to using a computer system to aid in engineering design, fundamental components of hardware and software, databases and database management, numerical control, and computer-aided manufacturing (CAM). Integration of manufacturing system from conceptual design through quality control to final shipping is discussed. Applications include solids modeling, CAD drawing, and solution using finite element method.

ME 560 Total Quality Control
Covers the general area of management of operations, both manufacturing and nonmanufacturing. The focus of the course is on productivity and total quality management. Topics include quality control and quality management, systems of inventory control, work and materials scheduling, and process management. Cross-listed with MGT 760.

ME 564 Principles of Optimum Design and Manufacture
Application of mathematical optimization techniques, including linear and nonlinear methods, to the design and manufacture of devices and systems of interest to mechanical engineers; optimization techniques include: constrained and unconstrained optimization in several variables, problems for structured multi-stage decision, and linear programming; formulation of design and manufacturing problems using computer-based methods; and optimum design of parts and assemblies to minimize the cost of manufacture.

ME 566 Design for Manufacturability
Processes involved in the design and development of parts and assemblies for manufacturability and functionality; characteristics and capabilities of significant manufacturing processes; principles of design for manufacturability; product planning; conceptual design; embodiment design; dimensional tolerances; optimum design of products to minimize cost of manufacture; materials specifications for ease of manufacturability and good functional results; design for

ease of assembly; integrated product development; and concurrent engineering practice.

ME 573 Introduction to Microelectromechanical Systems
Introduction to microsystem design, modeling, and fabrication. Course topics include material properties of Microelectromechanical systems (MEMS), microfabrication technologies, structural behavior, sensing, and actuation principles and methods. Emphasis on microsystems design, modeling, and simulation, including lumped element modeling and finite element analysis. The emerging nano-materials, processes, and devices will also be discussed. Student teams design microsystems (sensors, actuators, and sensing/control systems) of a variety of types, (optical MEMS, bioMEMS, inertial sensors, etc.) to meet a set of performance specifications using a realistic microfabrication process. Prerequisites: ME 345, ME 361, and MT 596, or permission of instructor.

ME 584 Vibration and Acoustics in Product Design*
Basics of concurrent design as they apply to quiet product design; vibration and acoustic characteristics in design of products and systems; source-path-receiver model for vibration and acoustics; vibration of one and two degree(s)-of-freedom models; features of continuous systems, design for low vibration, and vibration control; acoustic plane and spherical waves; acoustical source models; acoustic performance descriptions; design of quiet products and systems; application of computational methods; and case studies.

ME 590 Environmental Law for Practicing Engineers*
Review of laws regarding air, water, and noise pollution. Role of engineer representing a company or public before government agencies. Permit system, implementation plans, and other legal sanction. Site studies and environmental-impact statements.

ME 594 Computer Methods in Mechanical Engineering*
Problems in mechanical engineering illustrating the application of computer methods to solve roots of algebraic and transcendental equations, systems of algebraic equations, curve fitting, numerical integration and differentiation, and ordinary and partial differential equations.

ME 595 Heat Exchanger Design
Basic principles of heat exchanger design; types of heat exchangers; heat exchanger effectiveness; uncertainty analysis of design and operating parameters; fouling factors; heat transfer augmentation in heat exchangers; two-phase flow, boiling, and condensation in heat exchangers; the second law of thermodynamics for optimization of heat exchanger design; tube vibrations; codes and standards; and an individually supervised heat exchanger design project.

ME 596 Thermal Analysis and Design in Electronic Packaging
Introduction to electronic packaging, thermal characteristics and operating environment of electronic components, and reliability; fundamental concepts and basic modes of heat transfer; contact and interface thermal resistance; convective cooling of components and systems; modeling of chips, packages, and printed circuit boards; finned array and heat sink analysis; cold plate and heat exchanger design and analysis; computer-aided design; heat pipes; and liquid and immersion cooling.

ME 597 Integrated Design and Packaging of Electronic Systems
This is a multidisciplinary course in the analysis and design of electronic systems. Topics include: introduction to conduction, convection, and radiation heat transfer as applied to electronic systems; design of heat sinks for small to large frames; structural analysis, including shock and vibration modeling; introduction to electromagnetic shielding; and integrated product design for manufacturing, reliability, and quality control.

ME 598 Introduction to Robotics
Elements of a robotic/flexible automation system; overview of applications; manipulator anatomy; drive systems; end effectors; sensors; computer control: functions, levels of intelligence, motion control, and programming and interfacing to sensors and actuators; applications: identification, hardware selection, work-cell design, economics, and case studies; design of parts and assemblies; and advanced topics.

ME 601 Engineering Thermodynamics
Fundamental laws of the thermodynamics of mechanical, thermal, and chemical equilibrium systems; thermodynamic properties of materials including multiphase, multicomponent systems with gaseous chemical reactions; and analysis of thermodynamic systems (open and closed) based primarily on the first and second laws.

ME 604 Advanced Heat Transfer
Fundamental modes of heat transfer; conduction, thermal resistance, extended surface with variable cross-section area, and application of analytical, numerical, and analog methods to the steady and unsteady state; convection, fluid flow and elementary boundary layer theory, dimensional analysis, forced convection for internal and external flows, natural convection, laminar and turbulent flow correlation formulas, and condensation and boiling; and radiation, physical foundations, radiative properties of surfaces, enclosure radiation, view factors, electrical analogy, and gas radiation.

ME 605 Conduction Heat Transfer*
Lumped, integral, and differential formulation of general

laws, statement of particular laws, initial and boundary conditions; steady one-dimensional conduction, and principles of superposition; extended surfaces, power series solutions and Bessel functions, and approximate solutions; steady two- and three-dimensional conduction, unsteady problems, separation of variables, and orthogonal functions; steady periodic problems and complex temperature; finite difference formulation and numerical solutions; and introduction to finite element formulation of conduction problems.

ME 609 Convective Heat Transfer*
Place of convective heat transfer among engineering sciences, concepts related to thermodynamics, mechanics, and deformable moving media. General principles: conservation of mass, balance of linear momentum, conservation of total energy, and increase of entropy; and formulation of parallel flows, buoyancy driven flows, thermal boundary layers, fully developed heat transfer in pipes and channels, and heat transfer correlations for turbulent flows.

ME 610 Advanced Topics in Mechanical Engineering*
Courses on advanced topics of current interest in mechanical engineering, including, but not limited to, any of the following: steam turbines, random vibrations, stability of nonlinear mechanical systems, stress waves in solids, lubrication theory, radiative heat transfer, mechanism design, and buckling of metal structures. Prerequisite: approval of the Department Director.

ME 611 Engineering Acoustics*
Fundamentals of wave motion, acoustical plane waves, spherical waves, transmission of sound through media, radiation of sound, acoustical source mechanisms, absorption of sound, principles of underwater acoustics, and ultrasonics.

ME 612 Selected Topics in Air Pollution Technology*
This course will concentrate on a group of current topics in air pollution technology. For example: public health aspects of air pollution, incineration, fugitive emissions, modeling and prediction of near-field dispersion, air quality measurement, aerosols, odor control, and current industrial applications and practice. The course will extend coverage of air pollution topics into additional areas not covered in conventional courses and provide flexibility for new, timely subjects.

ME 615 Thermal Systems Design
Introduction to fluid mechanics and heat transfer; design of piping systems; selection of pumps; analysis and design of heat exchangers; modeling and simulation of thermal systems; system optimization and design; and case studies.

ME 617 Flame Structure and Combustion Processes*

The structures of flames in a variety of practical combustion devices (e.g., coal and oil burners, reciprocating engines, etc.) are described theoretically and compared to experimental results. Based on this understanding, the basic "tradeoff" between efficiency and pollutant emissions is established.

ME 621 Introduction to Modern Control Engineering
Introduction to state space concepts; state space description of physical systems, such as electrical, mechanical, electromechanical, thermal, hydraulic, pneumatic, aerospace, etc. systems. Eigenvalues, eigenvectors, and other topics in linear algebra, modal decomposition, and other coordination transformations. Relationship between classical transfer function methods and modern state methods. Analysis of linear continuous and discrete time linear systems, solution by state transition matrix, control ability, observability, and stability properties; and synthesis of linear feedback control systems via pole assignment and stabilizability and performance index minimization. Brief introduction to optimal control, estimation, and identification. (Alternate years.)

ME 622 Optimal Control and Estimation of Dynamical Systems*
Introduction to vector stochastic processes; response of linear differential systems to white noise, state estimation of linear stochastic systems by Kalman Filtering, combined optimal control, and estimation of continuous time Linear Quadratic Gaussian (LQG) regulators; optimization techniques for dynamic systems using nonlinear programming methods and variational calculus; optimal control of linear and nonlinear systems by Pontryagin's maximum principle and Hamilton-Jacobi-Bellman theory of dynamic programming; computational methods in optimal control and estimation; and applications to aerospace, mechanical electrical, and other physical systems. Spring semester. Prerequisite: ME 621 or equivalent.

ME 623 Design of Control Systems*
This course focuses on the application of advanced process control techniques in pharmaceutical and petrochemical industries. Among the topics considered are bioreactor and polymerization reactor modeling, biosensors, state and parameter estimation techniques, optimization of reactor productivity for batch, fed-batch and continuous operations, and expert systems approaches to monitoring and control. An overview of a complete automation project of a pharmaceutical plant, from design to start-up, will be discussed, including process control issues and coordination of interdisciplinary requirements and regulations. Guest speakers from local industry will present current technological trends. A background in differential equations, biochemical engineering, and basic process control is required. Cross-listed with ChE 661.

ME 625 Gas Turbines*
Gas turbine cycles, theoretical and practical; cycles with intercooling, recuperation, and reheat; the closed cycle turbine; cycles on the H-S charts; heat exchangers; intercoolers; compressor and turbine types; turbine cooling; aircraft gas turbines; turboprops and turbojets; afterburners and wet compression for jets; industrial gas turbines; nuclear fuel applications; and regulation of gas turbines.

ME 628 Pharmaceutical Finishing and Packaging Systems
Finishing and packaging systems in the pharmaceutical and health-related industries for various product and dosage forms. Unit operations, such as blending, granulating, compressing, branding, and coating for tablets, as well as blending and filling for capsules. Packaging equipment for tablet and capsule counting, capping, security sealing and banding, labeling, cartoning, and blister packing. Design tools for selection, specification, line layout, and computer simulation. Project-based design of typical packaging line for either solid dose or liquid products. Project will require analysis of material flow, space constraints, operator needs, and equipment selection, resulting in CAD design layout and computer simulation. Also, development of complete documentation, including equipment specifications, capital expenditure request, purchase order, test plan, and validation documents. Cross-listed with PME 628.

ME 631 Mechanical Vibrations I
Vibration of linear system with one degree of freedom; multidegree of freedom systems; vibration control; Lagrange's equation; theory of small vibrations; matrix methods; normal coordinates; and approximate methods of Holzer and Rayleigh-Stodola.

ME 632 Mechanical Vibrations II*
Vibration of continuous systems; theory and applications using finite element method; nonlinear systems; transient response, shock, and impact phenomena; and random vibrations.

ME 635 Simulation and Modeling
This course emphasizes the development of modeling and simulation concepts and analysis skills necessary to design, program, implement, and use computers to solve complex systems/products analysis problems. The key emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems/products. Overview of modeling techniques and methods used in decision analysis, including multi-attribute utility models, decision trees, and optimization methods are discussed. Cross-listed with IPD 611 and SYS 611.

ME 636 Project Management and Organizational Design

This project-based course exposes students to tools and methodologies useful for forming and managing an effective engineering design team in a business environment. Topics covered will include: personality profiles for creating teams with balanced diversity; computational tools for project coordination and management; real-time electronic documentation as a critical design process variable; and methods for refining project requirements to ensure that the team addresses the right problem with the right solution. Cross-listed with IPD 612.

ME 639 Modeling and Simulation of Pharmaceutical Manufacturing Systems
This course will review identification of pharmaceutical processes and systems, model formulation, algorithm development, and solution techniques of relevance to pharmaceutical manufacturing. Development of concepts and analysis skills necessary for modeling and simulation of pharmaceutical manufacturing processes and systems are emphasized. Overview of modeling techniques, process model development, product and assembly models, optimization techniques, and methods used in decision analysis, including multi-attribute utility models, decision trees, and discrete event simulation is presented. Prerequisite: undergraduate degree in engineering or its equivalent. Cross-listed with CHE 639 and PME 639.

ME 641 Engineering Analysis I
Introduction to the application of engineering analysis techniques and mathematical principles of mechanical engineering. In addition to analytical and computational techniques, case studies and project-based examples will be given.

ME 642 Engineering Analysis II
Topics included are applications of complex variables, linear algebra, ordinary and partial differential equations, numerical analysis, and other mathematical methods applied to mechanical engineering. Prerequisite: Degree in Mechanical Engineering or its equivalent.

ME 644 Computer-Integrated Design and Manufacturing
Fundamentals of Computer-Integrated Design and Manufacturing addresses design and manufacturing as a global closed-loop system comprising four major functions: marketing, part design, process specifications, and production. The emphasis of this course is on the computer integration of the islands of automation created by isolated computerized systems within these major functions in an enterprise.

ME 645 Design of Production Systems
Introduction to the design and control of production systems using mathematical, computational and other modern techniques. Topics that will be investigated include forecasting, inventory systems, aggregate

production planning, material requirements planning, project planning, job sequencing, operations scheduling, and reliability, in addition to capacity, flexibility, and economic analysis of flexible manufacturing systems.

ME 648 Mechanics of Continuous Media*
A basically physical approach to the study of continuum mechanics; Cartesian tensor notation and the concepts of stress, deformation and flow in continuous media; conservation equations and constitutive relations developed and used to establish mathematical models for the deformation of elastic, plastic, and viscoelastic solids; and the flow of Newtonian and non-Newtonian fluids.

ME 649 Design of Water, Steam, and CIP Utility Systems for Pharmaceutical Manufacturing
Water and steam systems: water used as excipient, cleaning agent or product dilutent, and water quality selection criteria; generation, storage, and distribution systems; bio-burden control; USP PWS (purified water systems) and USP WFI (water for injection) systems; engineering considerations, including specification, design, installation, validation, operation, testing, and maintenance; common unit operations, including deionization, reverse osmosis, distillation, ultrafiltration, and ozonation systems; process considerations, including pretreatment, storage and distribution, materials of construction, microbial control pyrogen control, and system maintenance; FDA requirements; clean-in-place systems; and steam generation and distribution systems. Cross-listed with PME 649.

ME 651 Analytic Dynamics
Fundamentals of Newtonian mechanics; principle of virtual work; D'Alembert's Principle; Hamilton's Principle; Lagrange's equations; Hamilton's equations; motion relative to moving reference frames; rigid-body dynamics; Hamilton-Jacobi equation; and applications.

ME 652 Advanced Manufacturing
This course is intended to give the student an in-depth appreciation of contemporary and emerging manufacturing methods in use in a wide variety of durable and consumable goods industries. The initial emphasis will be on the mechanics of material removal/material flows and processing. Next, contemporary net-shape composite manufacturing processing techniques, equipment, and testing methods will be presented and demonstrated whenever possible. The course will conclude with hands-on manufacturing projects accomplished in teams, focusing on the study of the field of manufacturing processes from a mechanical engineering design standpoint. Topics will include optimum mechanical design for cost, weight, stress, energy, and tolerances.

ME 653 Design and Fabrication of Micro and Nano Electromechanical Systems
This course follows the introductory course and covers

advanced topics in the design, modeling, and fabrication of micro and nano electromechanical systems. The materials will be broad and multidisciplinary including: review of micro and nano electromechanical systems, dimensional analysis and scaling, thermal, transport, fluids, microelectronics, feedback control, noise, and electromagnetism at the micro and nanoscales; the modeling of a variety of new MEMS/NEMS devices; and alternative approaches to the continuum mechanics theory. The goal will be achieved through a combination of lectures, case studies, individual homework assignments, and design projects carried out in teams.

ME 654 Advanced Robotics*
Robot path control, dynamics of robot systems, and mechanical drive systems; microcomputers, computational architectures, and digital control of manipulators; sensors, force and compliance control, vision systems, tactile sensing, range finding, and navigation; and intelligence and task planning. Prerequisite: ME 598 or equivalent.

ME 658 Advanced Mechanics of Solids*
Torsion, bending, and shear of beams with solid or thin-walled sections; curved beams; shrink fits, pressure vessels, and spinning discs; experimental techniques and strain rosettes; buckling of bars, beams, rings, and boiler tubes; thermal stress problems; introduction to theory of elasticity.

ME 659 Advanced Structural Design
This course deals with methodologies for designing modern structures and other performance-driven products. The course entails aspects of computer-aided engineering (CAE), integration of CAE and design, methodologies for failure and stability analysis, designing with anisotropic materials, such as composites, modeling process-material-performance relationships, and the use of such models in design, multidisciplinary design optimization, and integrated product design automation.

ME 661 Advanced Stress Analysis*
Stress analysis of axisymmetric bodies; beams on elastic foundations; introduction to plate theory and fracture mechanics; plasticity; and creep and fatigue of engineering materials. Prerequisite: ME 658 or its equivalent.

ME 663 Finite-Element Methods
Development of the fundamental equations of finite-element theory, and using the matrix displacement approach. Detailed case studies of one-dimensional (truss and beam), two-dimensional (plane stress/strain and axisymmetric solid), and plate-bending elements are explained. Applications include interactive model building and solutions.

ME 664 Special Topics in Applied Finite-Element Methods*

This course covers the development and application of finite-element theory to fluid structure interaction, large deformations of incompressible material, electromechanical coupling problems, and nonlinear heat transfer with phase change. Prerequisite: ME 663 or equivalent.

ME 665 Advanced Product Development
This course addresses methodologies and tools to define product development phases and also provides experience working in teams to design high-quality competitive products. Primary goals are to improve ability to reason about design, material and process alternatives, and apply modeling techniques appropriate for different development phases, as well as development of competitive product design and plans for its manufacture along with facilities layout simulation, testing, and service. Topics covered are: user requirements gathering, quality function deployment (QFD), design for assembly, design for materials and manufacturing processes, optimizing the design for cost and producibility, manufacturing process specifications and planning, process control and optimization, SPC and six sigma process, tolerance analysis, flexible manufacturing, product testing and rapid prototyping.

ME 668 Engineering Fracture Mechanics*
Fracture energy, linear elastic fracture mechanics, stress intensity factor, crack opening displacement (COD), fracture mechanics in design, elastic plastic fracture mechanics, numerical methods in fracture mechanics, introduction to fatigue, fatigue crack initiation, and fatigue crack propagation. Prerequisite: ME 658 or equivalent.

ME 673 Aeroelasticity*
Review of two-dimensional thin air-foil theory, thin air foils in unsteady motion, and transient harmonic time dependence; fundamentals of vibration of continuous and lumped systems; aeroelastic vibrations, single degree of freedom flutter, stall flutter, and coupled bending-torsion flutter; and multiple degrees of freedom, cascades, and turbomachines.

ME 674 Fluid Dynamics
Stress in a continuum; kinematics of fluid motion; rate of strain and vorticity; relation between stress and rate of strain; the Navier-Stokes equations; inviscid flow; stream function, velocity potential, and circulation; Kelvin and Helmholtz theorems; two-dimensional incompressible flows; the Kuta-Joukowski theorem; and introduction to compressible flows, boundary layers, and drag-on bodies. Prerequisite: ME 641 or equivalent.

ME 675 Computational Fluid Dynamics and Heat Transfer*
Computational techniques for solving problems in fluid flow and heat transfer and review of governing equations for fluid flow, special topics in numerical analysis, algorithms for incompressible flow, and

treatment of complicated geometrical constraints. 2.5 credits. Prerequisites: ME 594 and ME 674 or the equivalent.

ME 679 Mechanics of Compressible Fluids*
Pressure wave propagation; one-dimensional flow; isentropic flow, adiabatic flow, diabatic flow, and real and ideal flow in nozzles and diffusers; normal shock and Rankine-Hugoniot relation; flow in constant area ducts with friction; flow in ducts with heating and cooling; Fanno, Rayleigh, and Busemann lines; generalized one-dimensional continuous flow; unsteady one-dimensional flow; and method of characteristics.

ME 684 Multiphase Flows*
Fundamental principles of two-phase gas-liquid flow and associated heat transfer as applied to power, chemical, petrochemical, and process industries; topics include: flow patterns, homogeneous and separated flow models, two-phase pressure drops, drift-flux model, critical flow, flooding, nucleation theory, pool and flow boiling, critical heat flux, post-critical heat flux, heat transfer, condensation, and thermal-hydraulic instabilities. Prerequisites: ME 601 and ME 674.

ME 700 Seminar in Mechanical Engineering*
Presentations and discussions by advanced graduate students on selected topics. No credit, pass/fail.

ME 800 Special Problems in Mechanical Engineering*
Three credits for the degree of Master of Engineering (Mechanical).

ME 801 Special Problems in Mechanical Engineering*
Three credits for the degree of Doctor of Philosophy.

ME 802 Special Problems in Mechanical Engineering*
Three credits for the degree of Mechanical Engineer.

ME 900 Thesis in Mechanical Engineering*
For the degree of Master of Engineering (Mechanical). Six credits with advisor approval.

ME 950 Mechanical Engineering Design Project*
Design project for the degree of Mechanical Engineer. Twelve credits with advisor approval.

ME 960 Research in Mechanical Engineering*
Original work, which may serve as the basis for the dissertation, required for the degree of Doctor of Philosophy. Hours and credits to be arranged.

*By request.

**Pending Approval.

Nanotechnology

NANO 600 Nanoscale Science and Technology

This course deals with the fundamentals and applications of nanoscience and nanotechnology. Size-dependent phenomena, ways and means of designing and synthesizing nanostructures, and cutting-edging applications will be presented in an integrated and interdisciplinary manner.

Integrated Product Development

IPD 601 Integrated Product Development I
The first IPD course addresses methodologies and tools to define product development phases and also provides experience working in teams to design high-quality competitive products. Primary goals are to improve ability to reason about design, material. and process alternatives and apply modeling techniques appropriate for different development phases. Topics covered are: user requirements gathering, quality function deployment (QFD), design for assembly, design for materials and manufacturing processes, and optimizing the design for cost and producibility.

IPD 602 Integrated Product Development II
The second IPD course builds on the product definition and development processes. It focuses on the implementation of competitive product design and plans for its manufacture. along with facilities layout simulation, testing. and service. Project deliverables are comprehensive product, process, and testing specifications. Topics include: manufacturing process specifications and planning, process control and optimization, SPC and six sigma process, tolerance analysis, flexible manufacturing, product testing, and rapid prototyping. Prerequisite: IPD 601.

IPD 611 Simulation and Modeling
This course emphasizes the development of modeling and simulation concepts and analysis skills necessary to design, program, implement. and use computers to solve complex systems/products analysis problems. The key emphasis is on problem formulation, model building, data analysis, solution techniques, and evaluation of alternative designs/processes in complex systems/products. Overview of modeling techniques and methods used in decision analysis, including multi-attribute utility models, decision trees, and optimization methods are discussed. Cross-listed with ME 635 and SYS 611.

IPD 612 Project Management and Organizational Design
This project-based course exposes students to tools and methodologies useful for forming and managing an effective engineering design team in a business environment. Topics covered will include: personality profiles for creating teams with balanced diversity; computational tools for project coordination and management; real-time electronic documentation as a critical design process variable; and methods for refining project requirements to ensure that the team addresses

the right problem with the right solution. Cross-listed with ME 636 and SYS 612.

Product-Architecture and Engineering

PAE 610 The Creative Form and the Digital Environment

This course introduces advanced three-dimensional geometric modeling and associated computer-aided design, and visualization applications in architecture, product design and computer graphics production. This course provides a theoretical foundation, an introduction to a selection of current hardware and software tools, and extensive opportunities to develop advanced design skills through hands-on design lab sessions. Background in computational skills is an advantage, but not required. Successful completion enables students to acquire the skills necessary to undertake independent CAD/CAM projects in subsequent PA 620, and to undertake more advanced subjects in this area.

PAE 620 The Creative Form and the Production Environment

This course continues the exploration of advanced digital design applications initially raised in PAE 610. The course will focus on the general relationships between design-oriented geometric models and the digitally-enabled production methodologies deployed to develop them into physical reality. Particular emphasis will be placed on the opportunities and limitations associated with different manufacturing processes and strategies. This seminar course will investigate the fabrication of digital structures through the use of rapid prototyping (RP) and computer-aided manufacturing (CAM) technologies, which offer the production of building components directly from 3-D digital models. This course focuses on the development of repetitive non-standardized building systems (mass-customization) through digitally controlled variation and serial differentiation.

PAE 630 Introduction to Interactive Digital Media

This course provides students with the conceptual framework for employing interactive digital media in the design process and delivering the practical skills for making immediate and effective use of the emerging digital repertoire for design representation. A series of assignments of increasing sophistication constitute the course's homework.

PAE 640 Performative Environments

Performative Environments explores the potentials of interactive digital media as an integral part of architectural spaces. The seminar examines a series of case studies and looks critically into body-centric interactivity, intelligent environments, and narrative spaces. Performative Environments integrates interactivity, physical computing, design, and the production environments to develop dynamic media and physical installations. For the final project, students work in groups to develop dynamic media and install interactive surfaces in public spaces addressing different functional needs.

PAE 800 Product-Architecture and Engineering Design Project
Design Project for the degree of Master of Engineering (Product-Architecture and Engineering).

PAE 900 Thesis in Product-Architecture and Engineering*
For the degree of Master of Engineering (Product-Architecture and Engineering). Three credits with advisor approval.

*By request.

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Pharmaceutical Manufacturing Practices

PME 530 Introduction to Pharmaceutical Manufacturing
Pharmaceutical manufacturing is vital to the success of the technical operations of a pharmaceutical company. This course is approached from the need to balance company economic considerations with the regulatory compliance requirements of safety, effectiveness, identity, strength, quality, and purity of the products manufactured for distribution and sale by the company. Overview of chemical and biotech process technology and equipment, dosage forms and finishing systems, facility engineering, health, safety and environment concepts, and regulatory issues.

PME 531 Process Safety Management
This course reviews the 12 elements of the Process Safety Management (PSM) model created by the Center for Chemical Process Safety of the American Institute of Chemical Engineers. PSM systems were developed as an expectation/demand of the public, customers, in-plant personnel, stockholders, and regulatory agencies because reliance on chemical process technologies were not enough to control, reduce, and prevent hazardous materials incidents. PSM systems are comprehensive sets of policies, procedures, and practices designed to ensure that barriers to major incidents are in place, in use, and effective. The objectives of this course are to: define PSM and why it is important, describe each of the 12 elements and their applicability, identify process safety responsibilities, give real examples and practical applications to help better understand each element, share experiences and lessons learned of all participants, and assess the quality and identify enhancements to a student's site PSM program.

PME 535 Good Manufacturing Practice in Pharmaceutical Facilities Design
Current Good Manufacturing Practice compliance issues in design of pharmaceutical and biopharmaceutical

facilities. Issues related to process flow, material flow and people flow, and A&E mechanical, industrial, HVAC, automation, electrical, and computer. Bio-safety levels. Developing effective written procedures so that proper documentation can be provided, and then documenting through validation that processes with a high degree of assurance do what they are intended to do. Levels I, II, and III policies. Clinical phases I, II, III, and their effect on plant design. Defending products against contamination. Building quality into products.

PME 538 Chemical Technology Processes in API Manufacturing
Bulk active pharmaceutical ingredient manufacturing and unit operations. Process scale-up. Transport processes, including mass, heat, and momentum transfer. Process synthesis, analysis, and design. Traditional separation processes, including distillation, evaporation, extraction, crystallization, and absorption. New separation processes, including pressure swing adsorption, molecular sieves, ion exchange, reverse osmosis, microfiltration, nanofiltration, ultrafiltration, diafiltration, gas permeation, pervaporation, supercritical fluid extraction, and high performance liquid chromatography (HPLC). Batch and continuous reactors for homogeneous, heterogeneous, catalytic, and non-catalytic reactions.

PME 539 Bioprocess Technology in API Manufacturing
This course provides a broad overview of topics related to the design and operations of modern biopharmaceutical facilities. It covers process, utilities, and facility design issues, and encompasses all major manufacturing areas, such as fermentation, harvest, primary and final purification, media and buffer preparation, equipment cleaning and sterilization, and critical process utilities. Unit operations include cell culture, centrifugation, conventional, and tangential flow filtration, chromatography, solution preparation, and bulk filling. Application of current Good Manufacturing Practices and Bioprocessing Equipment Standards (BPE-2002) will be discussed. Cross-listed with CHE 539 and ME 539.

PME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing
Validation of a pharmaceutical manufacturing process is an essential requirement with respect to compliance with Good Manufacturing Practices (GMP) contained within the Code of Federal Regulations (21 CFR). This course covers validation concepts for plant, process, cleaning, sterilization, filtration, analytical methods, and computer systems, and GAMP (Good Automated Manufacturing Practice), IEEE SQAP, and new electronic requirements - 21 CFR Part 11. Master validation plan, and IQ, OQ, and PQ protocols and relationships to GMP. National (FDA) and international (EU) regulatory affairs for cGMP (current Good Manufacturing Practice) and

cGLP (current Good Laboratory Practice) requirements in development, manufacturing, and marketing. Handling the FDA inspection.

PME 541 Validation of Computerized Systems
Computers and computerized systems are ubiquitous in pharmaceutical manufacturing. Validation of these systems is essential to assure public safety and compliance with appropriate regulatory issues regarding validation: GMP, GCP, 21 CFR Part 11, etc. This course covers validation concepts for various classes of computerized systems and applications used in the pharmaceutical industry; importance of requirements engineering in validation; test protocols and design; and organizational maturity considerations. Prerequisite: PME 540. Cross-listed with ME 541.

PME 560 Quality in Pharmaceutical Manufacturing
This course provides a detailed exploration of quality programs with specific application to the particular requirements of the pharmaceutical industry. Students will develop an understanding of the quality philosophy which drives the industry from discovery through manufacturing, and of the systems and tools that are employed to implement and maintain a sustainable and successful quality system. Application of quality strategies in research and development, commercial production, computer systems, post-marketing, and other areas will be included. Where appropriate, case studies will be used to illustrate the challenges and issues associated with quality system deployment.

PME 628 Pharmaceutical Finishing and Packaging Systems
Finishing and packaging systems in the pharmaceutical and health-related industries for various product and dosage forms. Unit operations, such as blending, granulating, compressing, branding, and coating for tablets, as well as blending and filling for capsules. Packaging equipment for tablet and capsule counting, capping, security sealing and banding, labeling, cartoning, and blister packing. Design tools for selection, specification, line layout, and computer simulation. Project-based design of typical packaging line for either solid dose or liquid products. Project will require analysis of material flow, space constraints, operator needs, and equipment selection, resulting in CAD design layout and computer simulation. Also, development of complete documentation, including equipment specifications, capital expenditure request, purchase order, test plan, and validation documents.

PME 649 Design of Water, Steam, and CIP Utility Systems for Pharmaceutical Manufacturing
Water & steam systems: (water used as excipient, cleaning agent, or product diluent) water quality selection criteria; generation, storage, and distribution systems; bio-burden control; USP PWS (purified water systems) and USP WFI (water for injection) systems;

engineering considerations, including specification, design, installation, validation, operation, testing, and maintenance; common unit operations, including deionization, reverse osmosis, distillation, ultrafiltration, and ozonation systems; process considerations, including pretreatment, storage and distribution, materials of construction, microbial control, pyrogen control, and system maintenance; FDA requirements; clean-in-place systems; and steam generation and distribution systems.

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