

# Mechanical Engineering and Mechanics

## OUR MISSION

The mission of the Department of Mechanical Engineering and Mechanics is to provide quality education and training to undergraduate and graduate students, to develop new knowledge and engineering methodology through research, and to provide service to industry and society at large.

The undergraduate program provides students with the basic education they will need to function in an engineering environment, pursue graduate studies, continue their professional development, and establish an awareness of the culture and society in which we live. Because of technological innovations and the long term demands of global competition, the department seeks to prepare our students to adapt to the rapid advances and changes in technology, and to serve as agents and leaders in effecting these changes, while being cognizant of the needs and concerns of the society at large.

The graduate program bridges between the generalized undergraduate studies and the more focused research and remarkable accomplishments of our faculty. New graduate students participate in research by working closely with their faculty advisors; however, they are quickly encouraged to work and think independently, assuming greater responsibility for critical research functions. This learning process prepares the students for future research and development positions in industry or academia, where they can contribute toward the improvement and advancement of the community and society at large.

## OUR FACULTY

A complete listing of the faculty can be found on our website (<https://engineering.lehigh.edu/meche/faculty/>).

## B.S. IN MECHANICAL ENGINEERING

Mechanical engineering is one of the broadest of the engineering professions, dealing generally with systems for energy conversion, material transport and the control of motions and forces.

Mechanical engineers may choose from among many different activities in their careers, according to their interests and the changing needs of society. Some concentrate on the conversion of thermal, nuclear, solar, chemical and electrical energy, or on the problems of air, water, and noise pollution. Some concentrate on the design of mechanical systems used in transportation, manufacturing or health care industries or by individual consumers. Some will be working, a decade from now, in fields that do not yet exist. Most will be engaged with concepts involving all four dimensions of space and time.

## STUDENT ENROLLMENT AND GRADUATION DATA

The Mechanical Engineering undergraduate program is accredited by the Engineering Accreditation Commission of ABET (<http://www.abet.org>) and is the largest undergraduate program within Lehigh's P.C. Rossin College of Engineering and Applied Science. Our enrollment and graduation figures can be found in this table (<https://engineering.lehigh.edu/academics/accreditation/#meche>).

## PROGRAM OBJECTIVES

In harmony with the mission stated previously, the department has adopted three Program Educational Objectives (PEOs) for the undergraduate program in Mechanical Engineering.

Program graduates are expected, three to five years from graduation, to:

1. Successfully practice mechanical engineering and/or pursue advanced education, possibly towards other professions such as law, medicine, business, etc.
2. Participate at varying degrees in research and development, and other creative efforts in science, engineering, technology and/or technological entrepreneurship.
3. Engage in activities that demonstrate a commitment to professionalism and personal development and demonstrate leadership qualities.

By "successfully practice mechanical engineering" we mean:

- Advancement in careers in Mechanical, other Engineering, or careers such as health care, consulting, entrepreneurship, finance, management etc. assuming the utilization of basic engineering and science/mathematics principles and/or methodology taught in an ME program.
- Assuming increased levels of responsibility is a clear indicator of success.
- Effective communication with peers and working/leading diverse multi-disciplinary teams.
- Recognizing the global, societal and ethical contexts of their work.

In order to achieve these objectives the ME program ensures that its graduates are capable of the Student Outcomes (1-7) proposed by the accreditation organization ABET and adopted verbatim by the Lehigh University ME program. These outcomes are:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Achievement of the aforementioned educational objectives is served first through a sound education in mathematics, physics, and engineering sciences; second, by exposure to the engineering process (creation, innovation, analysis, and judgment) through design courses, projects, laboratories, and a choice of technical electives that permits a degree of specialization; and third, by the development of cultural awareness through courses in humanities and social sciences. Students may also take elective courses that transcend traditional disciplinary lines, while still satisfying the requirements for mechanical engineering.

The curriculum leading toward the bachelor of science in mechanical engineering combines a broad base in mathematics, physical sciences, and the engineering sciences (mechanics of solids, materials, dynamics and fluid, thermal and electrical sciences), including laboratory. Special emphasis is placed on the practice of modern Integrated Product Development, combining state-of-the-art computer aided design and manufacturing methods in a business oriented framework. Several specific application fields are chosen toward the end of the program in the form of four or more courses elected from a wide variety of 300-level offerings. Courses in mechanical engineering and engineering mechanics are equally available.

The course requirements for a B.S. degree in mechanical engineering are listed below. In addition to required mathematics, physics, chemistry and basic engineering courses, the program includes a minimum of seven courses in humanities and social sciences (see humanities/social sciences), two free electives and five approved electives. The total graduation requirement is 129 credits.

**UNDERGRADUATE CURRICULUM IN MECHANICAL ENGINEERING**

First Year			
First Semester	Credits	Second Semester	Credits
ENGL 001 (Composition & Literature)	3	ENGL 002 (Composition & Literature II)	3
MATH 021 (Calculus I)	4	MATH 022 (Calculus II)	4
ENGR 005 (Introduction to Engineering Practice)	2	ECO 1 or HSS elective <sup>2</sup>	4
Select one of the following:	5-6	Select one of the following	5-6
ENGR 010 & CHM 030 <sup>1</sup>		ENGR 010 & CHM 030 <sup>1</sup>	
PHY 011 & PHY 012 (Introductory Physics I and Lab) <sup>1</sup>		PHY 011 & PHY 012 (Introductory Physics I and Lab) <sup>1</sup>	
<b>14-15</b>		<b>16-17</b>	
Second Year			
First Semester	Credits	Second Semester	Credits
ME 010 (Graphics for Engineering Design)	3	ME 104 (Thermodynamics I)	3
MECH 003 (Fundamentals of Engineering Mechanics)	3	MECH 012 (Strength of Materials)	3
ME 017 (Numerical Methods in ME)	2	MATH 205 (Linear Methods)	3
MAT 033 (Engineering Materials and Processes)	3	PHY 021 & PHY 022 (Introductory Physics II and Lab)	5
MATH 023 (Calculus III)	4	HSS Elective	3-4
<b>15</b>		<b>17-18</b>	
Third Year			
First Semester	Credits	Second Semester	Credits
ME 021 (Mechanical Engineering Laboratory I)	1	ME 121 (Mechanical Engineering Lab II)	1
ME 231 (Fluid Mechanics)	3	ME 240 (Manufacturing)	3
MECH 102 (Dynamics)	3	ME 252 (Mechanical Elements)	3
HSS Electives	6-8	ME 211	3
Select one of the following:	3	ECE 083 (Introduction to Electrical Engineering)	3
ME 215 (Engineering Reliability)		ECE 162 (Electrical Laboratory)	1
MATH 231 (Probability & Statistics)		Select one of the following:	3
MATH 208 (Complex Variables)		ME 242 (Mechanical Engineering Systems)	
MATH 230 (Numerical Methods)		ME 245 (Engineering Vibrations)	
<b>16-18</b>		<b>17</b>	
Fourth Year			
First Semester	Credits	Second Semester	Credits
ME 111 (Professional Development (fall only))	1	Engineering Required/ Technical-Elective courses	12-14
Engineering Required/ Technical-Elective courses	6-8	HSS & Free Electives <sup>3</sup>	4
ME 212	2		

HSS and Free Electives <sup>3</sup>	4-6
<b>13-17</b>	
<b>16-18</b>	

**Total Credits: 124-135****Total Credits Required for Graduation 129**

1

Required natural science courses, one taken fall semester and the other taken in spring

2

For ME program the preferred course in this semester is ECO 001 Principles of Economics 4 credits.

3

Total credits for HSS and free electives must be at least 19 of which at least 13 must be HSS electives (for detailed description of HSS electives see the pages of RCEAS).

Required HSS courses 10 credits: ECO 001 Principles of Economics 4 credits

ENGL 001 Critical

Reading and Composition 3 credits

ENGL 002 Research and

Argument 3 credits

Senior year Required/Technical-Elective courses total 20 credits according to the following schedule:

ME 321	Introduction to Heat Transfer ( For 3 credits; available Fall or Spring)	3
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ME 207	Mechanical Engineering Laboratory III (For 2 credits; available Fall or Spring)	2
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Engineering Elective A: Select one of the following for 3 credits		3
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MECH 302	Advanced Dynamics (Spring Semester)
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MECH 305	Advanced Mechanics of Materials (Fall Semester)
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ME 304	Thermodynamics II (Fall Semester)
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ME 322	Gas Dynamics (Spring Semester)
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ME 331	Advanced Fluid Mechanics (Fall Semester)
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ME 343	Control Systems (Fall Semester)
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Engineering Elective B: Select one of the following for 3 credits:		3
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Any ME or MECH three-hundred-level course, excluding ME 300 and ME 310

Engineering Electives C: Select three courses for 9 credits		9
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Any ME or MECH three-hundred-level course or an engineering/science/mathematics course, as approved by the department. ME 300 and ME 310 can count once each towards Engineering Electives C.

**Total Credits 20**

4

Total Credits Required: 129

**For the flow chart of the program please follow the link:** Flow Chart ([http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/mechanicalengineeringandmechanics/BSME\\_Flowchart\\_2022-23.pdf](http://catalog.lehigh.edu/coursesprogramsandcurricula/engineeringandappliedscience/mechanicalengineeringandmechanics/BSME_Flowchart_2022-23.pdf))

\*Co-op students must take ME 021 sophomore year, second semester (18-19 credit hours). Co-op students will take a MATH elective (3), ME 231 (3), MECH 102(3), and a HSS elective (3-4) during the summer after the sophomore year (12-13 credit hrs.). See Co-op program for details

**Co-Op Program**

To participate in the Co-op program students must rank in the top third of the engineering class after three semesters of study and attend a summer program between the sophomore and junior years. Students

must see their advisor or contact the Co-op Faculty Liaison for further details.

### B.S. IN ENGINEERING MECHANICS

The curriculum in engineering mechanics is designed to prepare students for careers in engineering research and development, and it is especially appropriate for students wishing to specialize in the analysis of engineering systems. In many industries and governmental laboratories there is a demand for men and women with broad training in the fundamentals of engineering in which engineering mechanics and applied mathematics play an important role.

The first two years of the curriculum is the same as that in mechanical engineering. One of the advantages of the curriculum is the flexibility it offers through 18 credits of technical and six credits of personal electives in the junior and senior years. Beyond the sophomore year there are required courses in dynamics, solid mechanics, fluid mechanics, heat transfer, principles of electrical engineering, mathematics, vibrations, and senior laboratories or projects. It is recommended that the electives be chosen either to concentrate in areas such as applied mathematics and computational mechanics, solid mechanics, engineering materials, and fluid mechanics or to obtain further depth in all areas. The academic advisor for the engineering mechanics program will provide guidance in formulating the student's goals and choosing electives.

In addition to the required and elective courses in mathematics, sciences and engineering, the B.S. degree program in engineering mechanics includes a minimum of seven courses in humanities and social sciences (see humanities/social sciences). The total graduation requirement is 127 credits.

### UNDERGRADUATE CURRICULUM IN ENGINEERING MECHANICS

First Year			
First Semester	Credits	Second Semester	Credits
ENGL 001 (Composition & Literature)	3	ENGL 002 (Composition & Literature II)	3
MATH 021 (Calculus I)	4	MATH 022 (Calculus II)	4
ENGR 005 (Introduction to Engineering Practice)	2	ECO 1 or HSS elective <sup>2</sup>	3-4
Select one of the following:	5-6	Select one of the following	5-6
ENGR 010 & CHM 030 <sup>1</sup>	6	ENGR 010 & CHM 030 <sup>1</sup>	6
PHY 011 & PHY 012 (Introductory Physics I and Lab) <sup>1</sup>	5	PHY 011 & PHY 012 (Introductory Physics I and Lab) <sup>1</sup>	5
<b>14-15</b>		<b>15-17</b>	
Second Year			
First Semester	Credits	Second Semester	Credits
ME 010 (Graphics for Engineering Design)	3	ME 104 (Thermodynamics I)	3
MECH 003 (Fundamentals of Engineering Mechanics)	3	MECH 012 (Strength of Materials)	3
ME 017 (Numerical Methods in ME)	2	PHY 021 & PHY 022 (Introductory Physics II and Lab)	5
MAT 033 (Engineering Materials and Processes)	3	MATH 205 (Linear Methods)	3
MATH 023 (Calculus III)	4	Elective	3-4
Elective	2-3		
<b>17-18</b>		<b>17-18</b>	
Third Year			
First Semester	Credits	Second Semester	Credits
ME 021 (Mechanical Engineering Laboratory I)	1	ME 121 (Mechanical Engineering Lab II)	1
ME 231 (Fluid Mechanics)	3	ME 240 (Manufacturing)	3

MECH 102 (Dynamics)	3	MATH 208 (Complex Variables)	3
MATH 230 (Numerical Methods)	3	ECE 083 (Introduction to Electrical Engineering)	3
Electives	6-8	ECE 162 (Electrical Laboratory)	1
		Electives	3-4
		Select one of the following:	3
		ME 242 (Mechanical Engineering Systems)	
		ME 245 (Engineering Vibrations)	
<b>13-15</b>		<b>17-18</b>	
Fourth Year			
First Semester	Credits	Second Semester	Credits
ME 111 (Professional Development [fall only])	1	Engineering Required/ Technical-Elective courses	9-11
Engineering Required/ Technical-Elective courses	9-11	HSS and Free Electives <sup>3</sup>	4
HSS and Free Electives <sup>3</sup>	4	undefined	
<b>14-16</b>		<b>13-15</b>	

**Total Credits: 120-132**

### TOTAL CREDITS REQUIRED FOR GRADUATION 127

1

Required natural science courses, one taken fall semester and the other taken in spring

2

For ME/MECH programs the preferred course in this semester is ECO 001 Principles of Economics) 4 credits.

3

Total credits for HSS and free electives must be at least 19 of which at least 13 must be HSS electives (for detailed description of HSS electives see the pages of RCEAS).

Required HSS courses 10 credits: ECO 001 Principles of Economics 4 credits

ENGL 001 Critical

Reading and Composition 3 credits

ENGL 002 Research and

Argument 3 credits

Senior year Required/Technical-Elective courses total 23 credits according to the following schedule:

ME 321	Introduction to Heat Transfer ( For 3 credits; available Fall or Spring)	3
ME 207	Mechanical Engineering Laboratory III (For 2 credits; available Fall or Spring)	2
Engineering Elective A:	Select two of the following for 6 credits	6
MECH 302	Advanced Dynamics (Spring Semester)	
MECH 305	Advanced Mechanics of Materials (Fall Semester)	
ME 304	Thermodynamics II (Fall Semester)	
ME 322	Gas Dynamics (Spring Semester)	
ME 331	Advanced Fluid Mechanics (Fall Semester)	
ME 343	Control Systems (Fall Semester)	
Engineering Elective B:	Select 4 courses for 12 credits	12

From any ME or MECH three-hundred-level course, excluding ME 300 and ME 310

**Total Credits** **23**

4

Total Credits Required: 127

*\*Co-op students must take ME 021 sophomore year, second semester (18-19 credit hours). Co-op students will take ME 231 (3), MECH 102(3), and two HSS electives (6-8) during the summer after the sophomore year (12-14 credit hours). See Co-op program for details.*

Typical recommended options:

#### Applied Mathematics and Computational Mechanics

MECH 305	Advanced Mechanics of Materials	3
MECH 312	Finite Element Analysis	3
MATH 309	Probability with Applications and Simulations	3
MATH 322	Methods of Applied Analysis I	3
MATH 323	Methods of Applied Analysis II	3

#### Solid Mechanics

MECH 305	Advanced Mechanics of Materials	3
MECH 307	Mechanics of Continua	3
MECH 312	Finite Element Analysis	3
MECH 313	Fracture Mechanics	3
MATH 322	Methods of Applied Analysis I	3

#### Engineering Materials

MECH 305	Advanced Mechanics of Materials	3
MECH 313	Fracture Mechanics	3
MAT 218	Mechanical Behavior of Macro/ Nanoscale Materials	3
PHY 031	Introduction to Modern Physics	3
PHY 363	Physics of Solids	3

#### Fluid Mechanics

ME 331	Advanced Fluid Mechanics	3
ME 322	Gas Dynamics	3
MECH 326	Aerodynamics	3
MATH 322	Methods of Applied Analysis I	3

#### MINOR IN AEROSPACE ENGINEERING

The minor in aerospace engineering provides a foundation for students who intend to pursue a career in the aerospace industry. This minor will also provide sufficient technical background in aerospace studies for undergraduates who plan to enter graduate programs in this field. The minor requires a minimum of 15 credits from the following course selection:

##### Required Courses

ME 255	Introduction to Aerospace Engineering	3
MECH 326	Aerodynamics	3
MECH 328	Fundamentals of Aircraft Design	3

##### Elective Courses

Select two of the following: 6

ME 309	Composite Materials	
ME 322	Gas Dynamics	
ME 331	Advanced Fluid Mechanics	
ME 333	Propulsion Systems	
ME 343	Control Systems	
ME 348	Computer-Aided Design	
ME 354	Automatic Control of Aerospace Vehicles	
MECH 305	Advanced Mechanics of Materials	
MECH 312	Finite Element Analysis	

**Total Credits** **15**

#### MINOR IN ENERGY ENGINEERING

The minor in energy engineering touches upon the technologies associated with the transformation and use of energy in various forms. Since every sector of engineering and the economy require energies of one form or another, the courses included in this minor program will permit student exposure to fossil, nuclear and renewable energy technologies. The mechanical engineering curriculum provides the fundamental knowledge in thermodynamics, fluid mechanics and other related areas leading up to the courses for the energy engineering minor. The courses offer a wide variety of topics including fundamental, analytical and design aspects of energy conservation as well as various forms of energy used in power generation, transportation and industry.

The minor in energy engineering requires a minimum of 15 credits, which must be taken from MEM offerings. The minor in energy is primarily intended for ME Majors but students with other majors, particularly Chemical engineering will be able to take some or all the related courses. Four courses are required with some degree of choice and an additional course must be selected from a broader set.

##### Required course

ME 304	Thermodynamics II	3
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##### Elective Energy Courses

Select at least three of the following: 9

ME 360	Nuclear Reactor Engineering	
ME 362	Nuclear Fusion and Radiation Protection	
ME 364	Renewable Energy	
ME 366	Power Generation Technologies	

##### Additional Electives

Select one of the following: 3

CHE 373	Fundamentals of Air Pollution	
CHE/ME 376	Energy: Issues & Technology	
CHE 386	Process Control	
ME 322	Gas Dynamics	
ME 331	Advanced Fluid Mechanics	
ME 343	Control Systems	
Other Energy related 300 level courses with the approval of the ME Dept. Chair.		

**Total Credits** **15**

#### MINOR IN MECHANICS OF MATERIALS

The minor in mechanics of materials provides a view of mechanical strength and behavior of materials based on understanding a few basic concepts and using simplified material models. Courses selected for the minor emphasize concepts such as superposition of loadings; relation between external loads and internal stresses; factor of safety; safe design based on allowable stress or allowable loads; allowable deformation; and reliability of structures. Courses offer a wide variety of topics including analytical and numerical methods for solving mechanics problems; manufacturing and polymer processing.

The mechanics of materials minor requires a minimum of 15 credits, which must be taken from MEM offerings. Two courses are required; and three additional electives must be selected. The minor is not available for students having a major in the Department of Mechanical Engineering and Mechanics.

##### Required courses

MECH 003	Fundamentals of Engineering Mechanics	3
MECH 012	Strength of Materials	3

##### Electives

Select three of the following: 9

ME 010	Graphics for Engineering Design	
ME 215	Engineering Reliability	
ME 240	Manufacturing	
ME 252	Mechanical Elements	
ME 385	Polymer Product Manufacturing	

MECH 102	Dynamics
MECH 305	Advanced Mechanics of Materials
MECH 312	Finite Element Analysis
MECH 313	Fracture Mechanics

**Total Credits** **15**

### GRADUATE PROGRAMS

The Department offers programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Mechanical Engineering.

The mission of the Department of Mechanical Engineering and Mechanics is to provide quality education and training to undergraduate and graduate students, to develop new knowledge and engineering methodology through research, and to provide service to industry and society at large.

Consistent with the above mission statement, the education components of the graduate programs strive to:

- Educate graduate students to a level of Mechanical Engineering higher to that of the high quality undergraduate program. This level is mainly defined by the content and scope of the core courses offered.
- Enable students to engage in advanced study and research with scholars on a variety of topics relating to Mechanical Engineering.
- Familiarize students with issues relating to support, funding and presentation of research results and products.

In addition to the foregoing objectives, the presence of graduate programs and students has additional, beneficial effects on the goals of the Department and the University, such as:

- Interaction of undergraduate students with a diverse body of highly motivated learners.
- Increase in the efficiency of actual basic and applied research.
- Continuous incentive for improvement in the methods and material taught to graduate and undergraduate students.

Subject to approval, courses from other engineering curricula, such as electrical engineering, industrial engineering, materials science and engineering, chemical engineering, civil and environmental engineering, and computer science and engineering, together with courses in mathematics and engineering mathematics, may be included in the degree program.

### MASTERS DEGREE PROGRAM

The Department of Mechanical Engineering and Mechanics offers a Master of Science degree which requires 30 credit hours of graduate work (audit courses may not be used towards the degree) and must satisfy the following University course distribution requirements, as outlined in the RCEAS Graduate Student Handbook. The minimum program for all Masters degrees includes:

- Not less than 24 credits of 300- and 400-level coursework of which at least 18 hours is at the 400-level. Thesis credits count as part of the 400-level requirement.
- Not less than 18 credit hours in Mechanical Engineering and Mechanics.
- Not less than 15 credit hours of 400-level coursework in Mechanical Engineering and Mechanics.
- No course below the 300-level in Mechanical Engineering and Mechanics can be used towards the degree; however, two courses (6 credits) outside of the department, but in the engineering field, at level 200 and above, may apply, with approval from a student's advisor and the Departmental Graduate Committee.

### Master of Science in Mechanical Engineering

The Master of Science degree in Mechanical Engineering requires a total of 30 credits with a minimum of 18 credits in Mechanical Engineering and Mechanics. The courses taken for the MS degree must satisfy both the core course requirements and the University course distribution requirements. Three core courses must be taken, corresponding to a total of 9 credits. In addition, the student selects three other MEM courses (9 credits) at the 300 and 400 level. The

remaining 12 credits are free electives approved by the Graduate Program Coordinator or the Student's Advisor such that all courses for the MS degree satisfy the distribution requirements of the University Masters Level Degree. Under circumstances where the student arrives at Lehigh with an excellent academic record of graduate study at another (peer) institution, and subject to an approval process within the Department, alternative courses may be substituted for selected core courses.

Group I: Required Core Course in Engineering Mathematics:		3
ME 452	Mathematical Methods In Engineering I	
Group II: Required Core Course in Mechanical Engineering (2 courses):		6
ME 402	Advanced Manufacturing Science	
ME 413	Numerical Methods in Mechanical Engineering	
ME 423	Heat and Mass Transfer	
ME 430	Advanced Fluid Mechanics	
ME 433	Linear Systems and Control	
ME 453	Mathematical Methods in Engineering II	
MECH 406 or MECH 408	Fundamentals of Solid Mechanics <sup>1</sup> Introduction to Elasticity	
MECH 425	Analytical Methods in Dynamics and Vibrations	
Group III: Three other MEM courses at the 300 and 400 level. (Only one course may be at the 300 level).		9
Group IV: up to 4 free electives (12 credits) approved by the Graduate Program Coordinator or the Student's Advisor		12

1

Only one of the courses, MECH 406 or MECH 408, may be used to satisfy the core course requirement. Students are able to take both courses during their graduate degree program. However, only the grade from the first course completed is considered in the core course GPA calculation.

### Doctor of Philosophy in Mechanical Engineering

The Ph.D. program in Mechanical Engineering and Mechanics requires innovative research in collaboration with one or more faculty members, along with the completion of 72 credit hours beyond the bachelor's degree (if graduate study is carried out entirely at Lehigh University), or 48 beyond the master's degree (obtained at another university). The first stage of Ph.D. candidacy in Mechanical Engineering and Mechanics is attained by achieving a minimum GPA of 3.35 in five core courses (see core course requirements in the table below). Ph.D. students must also take ME 453, which can either be taken as part of the five core course requirement or taken as an additional course. Under circumstances where the student arrives at Lehigh with an excellent academic record of graduate study at another (peer) institution, and subject to an approval process within the Department, alternative courses may be substituted for selected core courses. The second stage of candidacy involves completion of a General Examination, which is based on an assessment of a research topic, formulation of a research proposal, and completion of an associated oral examination. Formal University candidacy for the Ph.D. is granted upon submittal of a proposal for the dissertation research and recommendation of the doctoral committee followed by approval of the Rossin College of Engineering and Applied Science. Coursework for the Ph.D. is determined in consultation with the student's advisor and approved by the doctoral committee. To complete the Ph.D. degree, the student must present and defend a dissertation before the doctoral committee.

Group I: Required Core Courses in Engineering Mathematics (two courses):

ME 452	Mathematical Methods In Engineering I
ME 413	Numerical Methods in Mechanical Engineering

or ME 453	Mathematical Methods in Engineering II
Group II: Required Core Courses in Mechanical Engineering (minimum of 2 courses, up to 3 courses):	
ME 423	Heat and Mass Transfer
ME 430	Advanced Fluid Mechanics
ME 433	Linear Systems and Control
MECH 406 or MECH 408	Fundamentals of Solid Mechanics <sup>1</sup> Introduction to Elasticity
MECH 425	Analytical Methods in Dynamics and Vibrations
Group III: Optional Core Course	
ME 402	Advanced Manufacturing Science

1

Only one of the courses, MECH 406 or MECH 408, may be used to satisfy the core course requirement. Students are able to take both courses during their graduate degree program. However, only the grade from the first course completed is considered in the core course GPA calculation.

#### Course requirements for the PhD Degree

Students pursuing the PhD must complete a total of eight courses. Five of these courses are indicated in the aforementioned core courses for the PhD degree. These core courses are defined according to the following groups. Group I : two (2) core mathematics courses (ME 452 and either ME 413 or ME 453). Group II : at least two MEM core courses selected from MECH 406, ME 423, MECH 425, ME 430, ME 433 and any core courses that may be added in the future. Group III : ME 402; if ME 402 is not chosen, then three core courses must be selected from Group II.

In addition to the required core courses, it is necessary to complete two (2) graduate courses in the student's (MEM) emphasis area (depth requirement) and one (1) graduate course outside the (MEM) emphasis area but related to the student's research (breadth requirement). A Group I math core course cannot be used to satisfy the breadth requirement. For students working in an interdisciplinary area, the advisor in coordination with the PhD committee possess the freedom to choose the most appropriate courses for the depth and breadth requirements. PhD students must also take ME 453, which can either be taken as part of the five core course requirement or as an additional course.

A minimum GPA of 3.35/4.0 (based on the first five graduate core courses taken) must be attained. This minimum GPA requirement represents the first stage of candidacy for the PhD degree at the Department level. If the minimum requirement is not met, the student may petition to: (a) take one replacement course from the same Group I, II or III of core courses; or (b) take one replacement course in the form of a (non-core) advanced course, but only after the petition is approved and the course instructor is made aware of the student's petition for grade replacement. All petitions require approval of the PhD advisor, then approval of the Graduate Committee.

A student pursuing the PhD after completion of an MS/MSc degree from another institution may petition to have two courses taken at that institution be approved as equivalent to MEM core courses, with no more than one course equivalent to a Lehigh Group I core course (math course) and one course equivalent to a Group II core course (course in a fundamental subject area). In addition, the student may petition to substitute courses taken elsewhere for the two (2) non-core advanced courses in their subject area (depth requirement) and the one (1) non-core course outside their emphasis area (breadth requirement). All of the foregoing replacement courses must be approved by the instructor of the corresponding Lehigh course. The student must submit a petition with the following: (a) a syllabus in English or a sufficiently detailed print-out of the course catalog from the MS institution; (b) a letter of support or a signed petition from the PhD advisor; and (c) any additional documentation beyond the syllabus as requested by the instructor. If permission is granted for the foregoing replacement courses, three (3) core courses will remain for completion at Lehigh.

#### General Examination for the PhD Degree

The General Examination is completed during the fourth semester of graduate study when all required core courses have been taken and the minimum GPA of 3.35/4.0 has been attained. Immediately following successful completion of the core courses, the student forms the Doctoral Committee, which includes the dissertation advisor as the Committee Chair. The minimum number of committee members is four. Of these, three, including the Committee Chair, are to be voting Lehigh faculty members. With the written approval of the Dean of the College, one of the three aforementioned faculty members, each of whom must have a doctoral degree, may be drawn from categories that include departmentally approved adjunct, professors of practice, university lecturers, and courtesy faculty appointees. This latter member may not serve as the Committee Chair. The fourth required member must be from outside the student's Department (or outside the student's program if there is only one Department in the college). Committees may include additional members who possess the requisite expertise and experience. Committee members must be approved by the University's Graduate and Research Committee; such approval may be delegated to the department or program sponsoring the degree. The Doctoral Committee is responsible for both administration of the General Exam and oversight of the student's program of study. Students taking the General Examination should register for three credits of ME 440. During the first half of the fourth semester, the advisor assigns a topic to the student after discussion with the student and approval of the Doctoral Committee. The student then does a literature search and defines several major unresolved issues in a report that should not exceed seven (7) pages of text. During the second half of the semester, the student formulates a research proposal that aims to clarify the underlying principles of the originally defined topic, while addressing the major unresolved issues. The format will conform to the guidelines for a proposal of a major funding agency (NSF, NIH, DOE, DOD) and will not exceed ten (10) pages of text. The student submits the proposal to the PhD committee and schedules the oral exam by the last day of class. The Committee decides on a grade to be assigned for completion of the three credit independent study course. The General Examination must be passed at least seven months before the degree is to be conferred.

#### Proposal for the PhD Degree

In order to formally become a PhD candidate at the University level, the student must prepare a proposal for the dissertation research; this proposal includes a course plan for all courses to be taken during the PhD program. The proposal is presented to, and approved by, the PhD Committee. The student then submits the proposal, signed by the Committee members, to the RCEAS Associate Dean for Research and Operations.

#### Additional Requirements for the PhD Degree

Two or more manuscripts must be submitted for (peer-reviewed) journal publication prior to the dissertation defense. At least one of these manuscripts must have gone through a first (external) review process. A student may petition, with detailed justification, to account for unusual preparation efforts, for example: submittal of a single manuscript to an extraordinarily competitive journal; an unreasonably long review time for a submitted manuscript; and alternate products consistent with the indicators of scholarship in the student's area of research.

The minimum number of department seminars must have been attended by the student during the course of the PhD program.

#### **RESEARCH FACILITIES**

The department has a wide range of computational, computer graphics and experimental systems. The department's CAD Lab has over 50 computers that include high-end engineering workstations. The university supports networks of hundreds of PCs as well as links to the Internet with thousands of online services.

Experimental facilities include 11 pulsed and continuous laser units for laser diagnostics in the areas of fluid and solid mechanics, four image processing systems, and a number of unique facilities for observing and controlling flow past surfaces and through machines, including two wind tunnels and three large-scale water channels.

There are well-equipped laboratories for multidisciplinary studies of phenomena in the area of solid mechanics, including electron microscopy facilities. Other facilities include mechanical, electrodynamic and servocontrolled hydraulic testing machines, photoelastic equipment, and Moire strain measuring instruments.

Extensively equipped, interdepartmental robotics, controls, and manufacturing laboratories are also available.

## RECENT RESEARCH ACTIVITIES

### Continuum and Solid Mechanics

Formulation of field equations and constitutive equations in nonlinear elasticity theories; mechanics of viscoelastic solids and fluids, plasticity theory; generalized continuum mechanics; thermo-mechanical and electromechanical interactions; analyses and modeling of manufacturing processes; free vibration and dynamic response of elastic shells, elastic-plastic deformation of shells upon cyclic thermal loading, and applications of shell analysis to nuclear power plant components; optical stress analysis; biomechanics of gait; wave propagation; finite amplitude wave propagation; composite materials and fabrication; tribology, surface friction and wear.

### Fracture Mechanics

Stress analysis of materials containing defects, including viscoelastic, nonhomogeneous, and anisotropic materials; analytical and experimental studies and modeling of crack growth under static, periodic, and random loadings and environmental effects; optimizations of fracture control; crack propagation theories for nonlinear material; influence of cracks on the strength of structural members and of interfaces; hydraulic fracture; applications to reliability and durability of composites, structural and microelectronic components, and to processes for resource recovery.

### Thermofluids

Structure of turbulent boundary layers, wakes and jets; vortex solid boundary interactions; boundary layers in compressible flow, including hypersonic regimes; vortex breakdown in internal machinery and in flow past wings; drag reduction in turbulent flows; flow induced noise and vibration; flutter of blades in axial-flow turbomachinery and of tails and fins on aircraft; aero- and hydroelastic phenomena and noise generation of fliers and swimmers in nature; flow-structure interactions in rotating and oscillating systems for power generation; unsteady aerodynamic flows past three dimensional wings and bodies; flow structure and heat transfer at end-wall junctions in rotating machinery and on surfaces of aircraft flows in micro-hydro-electromechanical and nano-scale systems; convective heat transfer in systems of electronic components; flows through complex components of power generation systems; transport of coal particles; flow and heat transfer in fluidized beds; cycle analysis applied to coal gasifiers; control optimization of heat pumps; laser-Doppler and particle image velocimetry; liquid crystal sensors for heat transfer; Raman spectral techniques applied to two-phase flow; laser diagnostics and image processing of complex flow and heat transfer systems.

### Theoretical Fluid Mechanics

Vortex boundary layer interaction, modeling of turbulent boundary layers; geophysical flows such as frontal systems and mountain flows; statistical mechanics of plasmas, liquids and shock waves; finite amplitude waves in stratified gases and liquids; shock wave propagation; non-Newtonian flows in flexible tubes with application to hemorheology; magneto-fluid mechanics; wing theory; thermally driven flows; noise generation due to flow past trailing edges of fliers in nature.

### Design

Geometric modeling; tolerance analysis and synthesis; assembly modeling; geometric dimensioning and tolerancing; 3D digitizing; data and information structures; design for manufacturing; design methodology, tools and practices; expert systems in design; industry projects with Integrated Product Development (IPD) focus.

### Manufacturing

Free-form surface machining; coordinate measuring machine applications to geometric dimensions and tolerances; Taguchi's method; injection molding; sheet metal fabrication; FEA/FEM applications to plastic deformation of metals; rapid prototyping; intelligent manufacturing incorporating process modeling, sensor

subsystems for in situ product quality monitoring, and knowledge-based control for real-time process adaptation; blow molding; composites processing; thermoforming; resin transfer molding; spin coating; electronic packaging.

### Systems Dynamics and Controls

Modeling, simulation and control of dynamic systems including: control of unstable processes, programmed logic control experience, compensator design and construction, issues in digital implementation, state-of-the-industrial art experimental equipment, energy methods and bond graph modeling, methods of model identification from experimental data; application to various mechanisms, vehicles, chemical processes, aircraft systems, chemical processes, hydraulic systems, thermodynamic systems, microelectromechanical actuators; application to mechatronics for the integration of mechanical systems, computer control and programming for the design of smart consumer products and intelligent manufacturing machinery.

### Stochastic Processes

Modeling of random behavior in mechanical systems; static and time-dependent stochastic fracture mechanics, with particular applications to assessments of reliability and service life prediction.

### Engineering Mathematics

General research areas within the division include: Analytical and numerical methods for the solution of ordinary and partial differential equations; industrial applications. Asymptotic methods. Finite element techniques. Wavelets. Nonlinear studies; stability and bifurcation. Navier-Stokes equations; boundary layer theory; turbulence modelling. Non-Newtonian fluids; viscometric flows; materials processing. Geophysical flows. Wave propagation; solutions. Combustion phenomena. Continuum mechanics; large deformation analyses; buckling; fracture mechanics. Thermoelasticity. Applied probability and stochastic processes; stochastic differential equations. Statistical mechanics.

### Mechanical Engineering Courses

#### ME 010 Graphics for Engineering Design 0,3 Credits

Graphical description of mechanical engineering design for visualization and communication by freehand sketching, production drawings, and 3D solid geometric representations. Introduction to creation, storage, and manipulation of such graphical descriptions through an integrated design project using state-of-the art, commercially available computer-aided engineering software. Lectures and laboratory. (ES 1), (ED 2).

#### ME 017 Numerical Methods in Mechanical Engineering 2 Credits

Numerical methods applied to mechanical engineering problems. Techniques for interpolation, curve fitting, plotting of numerical data, etc. Numerical techniques for solving algebraic and differential equations. Computational platforms to be used include MATLAB.

**Prerequisites:** ENGR 010

#### ME 021 Mechanical Engineering Laboratory I 0,1 Credits

Experimental methods in mechanical engineering and mechanics. Analysis of experimental error and error propagation. Introduction to elementary instrumentation. Introduction to digital data acquisition.

**Prerequisites:** MECH 012

**Can be taken Concurrently:** MECH 012

#### ME 050 Supplemental Topics in Mechanical Engineering 1-2 Credits

Completion of material for Mechanical Engineering courses transferred from other institutions. Student will be scheduled for that part of Mechanical Engineering that is required for completion of missing material. Subject matter and credit hours to be determined by department chair for each student.

#### ME 104 Thermodynamics I 0,3 Credits

Basic concepts and principles of thermodynamics with emphasis on simple compressible substances. First and second law development, energy equations, reversibility, entropy and efficiency. Properties of pure substances and thermodynamic cycles.

**Prerequisites:** (MATH 033 or MATH 023) and (PHY 011)

**Can be taken Concurrently:** MATH 033, MATH 023, PHY 011

**ME 111 Professional Development 1 Credit**

Examination of ethical and professional choices facing mechanical engineers. Written and oral communications. Must have senior standing in Mechanical Engineering and Mechanics.

**ME 121 Mechanical Engineering Laboratory II 0,1 Credits**

A continuation of ME 21 including use of transducers, advanced instrumentation, and data acquisition. Emphasis on experimental exercises that illustrate, and/or introduce material from thermodynamics, and fluid mechanics. Includes proposal writing and interpretation of results.

**Prerequisites:** ME 021 and ME 104 and ME 231

**Can be taken Concurrently:** ME 231

**ME 141 General Aviation Technology and Operations 2 Credits**

A Federal Aviation Administration (FAA) certified course for students interested in understanding the engineering and operational aspects of the general aviation industry, including aerodynamics, aircraft systems and performance, weather, navigation, flight procedures, regulations, maneuvers, and the physiology of flight. Successful completion of the course will fulfill the FAA requirement for the ground school component of a private pilot certification.

**ME 142 Instrument Ground Training 2 Credits**

A Federal Aviation Administration (FAA) certified course for students interested in pursuing an instrument rating from the FAA. Successful completion of the course will fulfill the FAA requirement for the ground school component of an instrument rating.

**Prerequisites:** ME 141

**ME 205 Application of Differential Equations in Mechanical Engineering 3 Credits**

Solution and application of differential equations in engineering, including linear methods underpinning solution methodologies. Applications of differential equations include: Newton's law of cooling; linear and nonlinear dynamical systems; mechanical vibrations; beam theory; column buckling; heat/diffusion, wave, and Laplace's equations. This course counts as a fifth mathematics course or an Engineering C elective for MEM students.

**Prerequisites:** MATH 022 and ME 017

**Can be taken Concurrently:** ME 017

**ME 207 Mechanical Engineering Laboratory III 2 Credits**

Formulation of laboratory experiments through open-ended planning, including decision criteria for laboratory techniques and approaches. Execution of experiments based on individual plans, followed by assessment of experimental results.

**Prerequisites:** ME 121

**ME 211 (BIOC 211, BIOE 211, ENGR 211, MAT 211) Capstone Design Project I 3 Credits**

Students work on teams, integrating knowledge and skills acquired in their prior course work, to design practical solutions to real-world problems, typically in collaboration with industry, entrepreneurs, faculty, or campus departments. Teams perform in-depth engineering design while considering engineering standards and the project business case. Constraints, including technical, financial, environmental, societal, supply chain, regulatory, and others are considered throughout. Teams produce written reports, oral presentations, and prototypes appropriate for the project.

**Prerequisites:** ME 010 and ME 231 and ME 240 and MECH 102

**Can be taken Concurrently:** ME 240, MECH 102

**ME 212 (BIOC 212, BIOE 212, ENGR 212, MAT 212) Capstone Design Project II 2 Credits**

Students continue developing their solutions from ME 211 through prototype fabrication and testing, iteration, and failure mode analysis. New information about the project, as well as new knowledge, standards, and constraints, may be identified, considered and integrated into the solution. Teams are expected to produce a final project-specific prototype, an implementation plan appropriate to the project, as well as related business case financial models. Additional deliverables include written reports and presentations.

**Prerequisites:** ME 211

**ME 215 Engineering Reliability 3 Credits**

Applications of reliability methods to engineering problems. Modeling and analysis of engineered components and systems subjected to environmental and loading conditions. Modeling content encompasses mechanistically based probability and experientially based statistical approaches. Concepts needed for design with uncertainty are developed. Principles are illustrated through case studies and projects. Engineering applications software will be extensively utilized for the projects.

**Prerequisites:** (MATH 023 or MATH 033) and MECH 012

**Can be taken Concurrently:** MECH 012

**ME 231 Fluid Mechanics 3 Credits**

Kinematics of fluid flow and similarity concepts. Equations of incompressible fluid flow with inviscid and viscous applications. Turbulence. One-dimensional compressible flow, shock waves. Boundary layers, separation, wakes and drag.

**Prerequisites:** (MATH 205 or ME 205) and ME 104

**ME 240 Manufacturing 0,3 Credits**

Analytical and technological base for several manufacturing processes and common engineering materials. Processes include metal cutting, metal deformation, injection molding, thermoforming, and composites. Process planning, computer-aided manufacturing, manufacturing system engineering, and quality measurements. Design project. Weekly laboratory.

**Prerequisites:** ME 010 and MECH 012

**ME 242 Mechanical Engineering Systems 3 Credits**

The modeling and analysis of mechanical, fluid, electrical and hybrid systems, with emphasis on lumped models and dynamic behavior, including vibrations. Source-load synthesis. Analysis in temporal and frequency domains. Computer simulation of nonlinear models, and computer implementation of the superposition property of linear models.

**Prerequisites:** MECH 102 and MATH 205

**ME 245 Engineering Vibrations 3 Credits**

Physical modeling of vibrating systems. Free and forced single and multiple degree of freedom systems. Computer simulations. Engineering applications.

**Prerequisites:** MECH 102 and MATH 205 and ME 017

**ME 252 Mechanical Elements 3 Credits**

Methods for the analysis and design of machine elements such as springs, gears, clutches, brakes, and bearings. Motion analysis of cams and selected mechanisms. Projects requiring the design of simple mechanisms of mechanical sub-assemblies.

**Prerequisites:** MECH 012 and ME 010 and MECH 102

**ME 255 Introduction to Aerospace Engineering 3 Credits**

An introductory course in the core engineering principles used in the aerospace industry: aerodynamics, controls, propulsion, and structures. The course is designed for any engineering student who may intend to work in the aerospace industry and develops a basic understanding of the technologies used in the design and operation of today's aircraft, rockets, and spacecraft.

**Prerequisites:** ME 104

**ME 299 Special Topics In Mechanical Engineering 1-4 Credits**

**Repeat Status:** Course may be repeated.

**ME 300 Apprentice Teaching 1-3 Credits**

**Repeat Status:** Course may be repeated.

**ME 304 Thermodynamics II 3 Credits**

Availability and Second Law Analysis. Design of gas and vapor power cycles, and refrigeration systems. Generalized property relations for gases and gas-vapor. Combustion and chemical equilibrium. Design of engineering systems and processes incorporating thermodynamic concepts and analysis.

**Prerequisites:** ME 104

**ME 309 (MAT 309) Composite Materials 3 Credits**

Principles and technology of composite materials. Processing, properties, and structural applications of composites, with emphasis on fiber-reinforced polymers.

**Prerequisites:** MECH 003 and MAT 033



**ME 310 (TE 310) Directed Study 1-3 Credits**

Project work on any aspect of engineering, performed either individually or as a member of a team made up of students, possibly from other disciplines. Project progress is reported in the form of several planning and project reports. Direction of the projects may be provided by faculty from several departments and could include interaction with outside consultants and local communities and industries. Consent of department required.

**Repeat Status:** Course may be repeated.

**ME 312 Analysis and Synthesis Of Mechanisms 3 Credits**

Types of motion. Degrees of freedom of motion. Position, velocity and acceleration analysis of linkage mechanisms. Systematic approach to the design of linkage mechanisms. Motion generation, path synthesis and function synthesis. Structural synthesis of planar and spatial mechanisms. Static force analysis of mechanisms using virtual work.

**Prerequisites:** MATH 205 and MECH 102

**ME 314 (MAT 314) Metal Forming Processes 3 Credits**

Mechanical metallurgy and mechanics of metal forming processes. Yield criteria. Workability. Friction and lubrication. Engineering analysis of forging, extrusion, wire and tube drawing, rolling, sheet forming and other processes. Recent developments in metal forming.

**ME 315 (BIOE 315) Bioengineering Statistics 3 Credits**

Probability and statistics applied to bioengineering problems focusing on modeling and data analysis. Types of data, types of distributions, parametric and nonparametric analyses, goodness-of-fit, regression, power analysis, and multivariate analysis, life models, simulation, cluster analysis, and Bayesian statistics. Projects and case studies.

**Prerequisites:** MATH 231

**ME 316 (BIOE 316) Introduction to Force Spectroscopy 3 Credits**

Fundamentals of major force spectroscopy methods, including atomic force microscopy, optical tweezers, and magnetic tweezers. Principles of force measurement, force calibration, and signal and noise. Applications to the mechanical properties of biomaterials, such as polymer elasticity, protein folding, nanoindentation, and structural transitions in macromolecules. Closed to students who have taken BIOE 416.

**Prerequisites:** MECH 003

**ME 321 Introduction to Heat Transfer 3 Credits**

Analytical and numerical solutions to steady and transient one-and two-dimensional conduction problems. Forced and natural convection in internal and external flows. Thermal radiation. Thermal design of engineering processes and systems.

**Prerequisites:** ME 104 and ME 231

**ME 322 Gas Dynamics 3 Credits**

Flow equations for compressible fluids; thermodynamic properties of gases. Normal shock waves. Steady one-dimensional flows with heat addition and friction. Oblique shock waves. Expansion waves. Nozzle flows. Shock tubes; performance calculations and design. Supersonic wind tunnels; diffuser design. Real gas effects.

**Prerequisites:** ME 231 and ME 104

**ME 323 Reciprocating and Centrifugal Engines 0,3 Credits**

Thermal analysis and design of internal combustion engines (conventional and unconventional), gas turbine engines, air breathing jet engines, and rockets. Components such as jet nozzles, compressors, turbines, and combustion chambers are chosen to exemplify the theory and development of different types of components. Both ideal fluid and real fluid approaches are considered.

**Prerequisites:** ME 104

**ME 325 Ethical Issues for Mechanical Engineers 3 Credits**

Introduction to Engineering Ethics familiarizes students with the methods used for developing ethical approaches in engineering practice. Through reading, writing and discussion this course takes a 'case-study' approach. Cases are historical and contemporary and may include: Challenger, Chernobyl, Bhopal, Ford Pinto, Essure as well as more general areas as: Genetic Technology, Energy, AI, Medical Technology and the newly emerging study of Design Ethics. Each student will research and prepare a major presentation. Senior standing and/or instructor permission required.

**Prerequisites:** ME 111

**ME 331 Advanced Fluid Mechanics 3 Credits**

Kinematics of fluid flow. Conservation equations for inviscid and viscous flows; integral forms of equations. Two-dimensional potential flow theory of incompressible fluids with applications. Boundary layers. Introduction to free shear layer and boundary layer stability and structure of turbulence. Transition from laminar to turbulent boundary layers. Separation of flow. Steady and unsteady stall. Secondary flows. Hydrodynamic lubrication. Measurement techniques.

**Prerequisites:** ME 231

**ME 333 Propulsion Systems 3 Credits**

Review of jet and rocket engine technologies. Jet and rocket engine thermodynamic and aerodynamic principles. Performance of turbojet, turbofan, and turboprop jet engines. Rocket engines include liquid, cryogenic, solid, and electric propulsion.

**Prerequisites:** ME 104 and MECH 326

**Can be taken Concurrently:** MECH 326

**ME 340 Advanced Mechanical Design 3 Credits**

Probabilistic design of mechanical components and systems. Reliability functions, hazard models and product life prediction. Theoretical stress-strength-time models. Static and dynamic reliability models. Optimum design of mechanical systems for reliability objectives or constraints.

**ME 341 Mechanical Systems 3 Credits**

Advanced topics in mechanical systems design. Kinematics and dynamics of planar machinery. Shock and vibration control in machine elements. Balancing of rotating and reciprocating machines. Design projects using commercial computer-aided-engineering software for the design and evaluation of typical machine systems.

**Prerequisites:** ME 252

**ME 342 Dynamics of Engineering Systems 3 Credits**

Dynamic analysis of mechanical, electromechanical, fluid and hybrid engineering systems with emphasis on the modeling process. Lumped and distributed-parameter models. Use of computer tools for modeling, design and simulation. Design projects.

**Prerequisites:** ME 242

**ME 343 Control Systems 3 Credits**

A comprehensive course in classical and modern linear control systems. Includes root locus, frequency response, state space, and digital control techniques with extensive use of computational methods. A design project provides experience with practical design issues and tradeoffs.

**Prerequisites:** ME 242 or ECE 125 or ME 245

**ME 348 Computer-Aided Design 3 Credits**

Impact of computer-aided engineering tools on mechanical design and analysis. Part geometry modeling and assembly modeling using solid representations. Analysis for mass properties, interference, kinematics, displacements, stresses and system dynamics by using state-of-the-art commercially available computer-aided-engineering software. Integrated design projects.

**Prerequisites:** ME 010 and MECH 012 and MECH 102 and MATH 205

**ME 350 Special Topics 1-5 Credits**

A study of some field of mechanical engineering not covered elsewhere. Consent of department chair required.

**Repeat Status:** Course may be repeated.

**ME 354 Automatic Control of Aerospace Vehicles 3 Credits**

The forces and moments acting on rigid aircraft are developed from basic aerodynamics and used to determine the equations of motion and the resulting dynamic models. Analysis from these dynamic models supports the design of flight control, guidance, and autopilot systems. Modern control methods for missiles and spacecraft are also included. Undergraduate course assumes rigid airplane structures, while the graduate course develops the effects of flexible structures.

**Prerequisites:** MECH 326 and ME 343

**ME 355 Spacecraft Systems Engineering 3 Credits**

Systems engineering approach to design, integration, testing, and operations of spacecraft for various missions. Technologies currently used in modern spacecraft bus and payload systems, astrodynamics, launch systems, life-cycle costs, and operational issues. Team works to design a spacecraft that meets a specific set of mission requirements.

**Prerequisites:** ME 255

**ME 356 Astrodynamics 3 Credits**

Kepler's Laws are discussed and proven from basic mechanics, then used to determine the equations of motion for a satellite. Subsequent topics include various kinds of orbits in use today, orbit determination, orbital maneuvers, and rendezvous. Interplanetary trajectories, satellite attitude dynamics, rocket vehicles, and orbital perturbations are also discussed.

**Prerequisites:** MECH 102

**ME 360 Nuclear Reactor Engineering 3 Credits**

A consideration of the engineering problems related to nuclear reactor design and operation. Topics include fundamental properties of atomic and nuclear radiation, reactor fuels and materials, reactor design and operation, thermal aspects, safety and shielding, instrumentation and control. Course includes several design projects stressing the major topics in the course. Must have senior standing in engineering or physical science.

**ME 362 Nuclear Fusion and Radiation Protection 3 Credits**

Structure of the nucleus. Quantum theory. Nuclear energy release: Fission vs. Fusion. Plasma for fusion. Power balances in fusion plasmas. Magnetic and inertial confinement fusion concepts. Magnetic equilibrium configurations and limitations. The Tokamak. Emerging and alternative concepts. Fusion reactor economics. Radiation sources and Radioactive decay. Interactions of radiation with matter, detectors and protection from radiation. Energy deposition and dose calculations. Applications in dosimetry, imaging and spectroscopy. Must have senior standing in engineering or physical science.

**ME 364 Renewable Energy 3 Credits**

Fundamentals and design aspects of Renewable Energy (RE) technologies; biofuels, hydropower, solar photovoltaic, solar thermal, wind, geothermal energies. Details and difficulties in implementing RE. Senior standing in Engineering. Credit not given for both ME 364 and ME 464.

**Prerequisites:** ME 104 and ME 231

**ME 366 Power Generation Technologies 3 Credits**

The energy matrix is changing due to economic, environmental, and political pressure, requiring a transition to become more efficient, carbon-neutral, resilient, and competitive. This course looks at the design and performance of conventional (coal and natural gas) power generation systems, including thermal cycles, power plant efficiency, technologies for environmental compliance, carbon capture and sequestration, plant flexibilization and energy storage, and advanced plant data analytics. Must have junior standing in engineering or physical science.

**ME 368 Fundamentals of Energy Efficiency Practicum 3 Credits**

Studies of the plant operation and energy usage. Students work with the Lehigh Industrial Assessment Center to do technical and economic feasibility studies of optimizing energy consumption. Industrial experience. Fundamentals of best practices to save energy, reduce waste, and increase productivity. Consent of instructor required.

**Prerequisites:** ME 104 and ME 231

**ME 373 Mechatronics 3 Credits**

Synergistic integration of mechanical engineering with electronics and intelligent computer control in designing and manufacturing machines, products and processes; semiconductor electronics, analog signal processing, with op amps, digital circuits, Boolean algebra, logic network designs, Karnaugh map, flip-flops and applications, data acquisition, A/D and D/A, interfacing to personal computers, sensors and actuators, microcontroller programming and interfacing.

**ME 374 Mechatronics Laboratory 3 Credits**

Experiments and applications utilizing combinations of mechanical, electrical, and microprocessor components. Theory and application of electronic and electromechanical equipment, operation and control of mechatronic systems. Projects integrating mechanical, electronic and microcontrollers.

**ME 376 (CHE 376) Energy: Issues & Technology 3 Credits**

Energy usage and supply, fossil fuel technologies, renewable energy alternatives and environmental impacts. The scope will be broad to give some perspective of the problems, but in-depth technical analysis of many aspects will also be developed.

**Prerequisites:** CHE 210 or ME 104 or CHM 342 or MAT 205

**ME 385 Polymer Product Manufacturing 3 Credits**

Polymer processes such as injection molding through a combination of theory development, practical analysis, and utilization of commercial software. Polymer chemistry and structure, material rheological behavior, processing kinetics, molecular orientation development, process simulation software development, manufacturing defects, manufacturing window establishment, manufacturing process design, manufacturing process optimization. Must have senior level standing in engineering or science. Credit not given for both ME 385 and ME 485.

**ME 387 (CHE 387, ECE 387) Digital Control 3 Credits**

Sampled-data systems; z-transforms; pulse transfer functions; stability in the z-plane; root locus and frequency response design methods; minimal prototype design; digital control hardware; discrete state variables; state transition matrix; Liapunov stability state feedback control (two lectures and one laboratory per week).

**Prerequisites:** CHE 386 or ECE 212 or ME 343

**ME 388 Honors Project for Eckardt Scholar 1-4 Credits**

Opportunity for Eckardt Scholars to pursue an extended project for senior honors. Transcript will identify department in which project was completed.

**Repeat Status:** Course may be repeated.

**ME 389 (CHE 389, ECE 389) Control Systems Laboratory 2 Credits**

Experiments on a variety of mechanical, electrical and chemical dynamic control systems. Exposure to state-of-the-art control instrumentation: sensors, transmitters, control valves, analog and digital controllers. Emphasis on design of feedback controllers and comparison of theoretical computer simulation predictions with actual experimental data. Lab teams will be interdisciplinary.

**Prerequisites:** CHE 386 or ECE 212 or ME 343

**ME 401 (MSE 401) Integrated Product Development 3 Credits**

An integrated and interdisciplinary approach to engineering design, concurrent engineering, design for manufacturing, industrial design and the business of new product development. Topics include design methods, philosophy and practice, the role of modeling and simulation, decision making, risk, cost, material and manufacturing process selection, platform and modular design, mass customization, quality, planning and scheduling, business issues, teamwork, group dynamics, creativity and innovation. The course uses case studies and team projects. ME 402.

**ME 402 (MAT 402) Advanced Manufacturing Science 3 Credits**

The course focuses on the fundamental science-base underlying manufacturing processes, and applying that science base to develop knowledge and tools suitable for industrial utilization. Selected manufacturing processes representing the general classes of material removal, material deformation, material phase change, material flow, and material joining are addressed. Students create computer-based process simulation tools independently as well as utilize leading commercial process simulation packages. Laboratory experiences are included throughout the course.

**ME 411 Boundary-Layer Theory 3 Credits**

The course is intended as a first graduate course in viscous flow. An introduction to boundary-layer theory, thermodynamics and heat transfer at the undergraduate level are assumed to have been completed. Topics include the fundamental equation of continuum fluid mechanics, the concept of asymptotic methods and low and high Reynolds number flows, laminar boundary layers, generalized similarity methods, two- and three-dimensional flows, steady and unsteady flows and an introduction to hydrodynamic stability. The material is covered in the context of providing a logical basis as an introduction to a further course in turbulent flows.

**ME 413 Numerical Methods in Mechanical Engineering 3 Credits**

Zeros of functions, difference tables, interpolation, integration, differentiation. Divided differences, numerical solution of ordinary differential equations of the boundary and initial value type. Eigen problems. Curve fitting, matrix manipulation and solution of linear algebraic equations. Partial differential equations of the hyperbolic, elliptic and parabolic type. Application to problems in mechanical engineering.

**ME 415 Flow-Induced Vibrations 3 Credits**

Excitation of streamlined- and bluff-bodies by self-excited, vortex, turbulence, and gust-excitation mechanisms. Analogous excitation of fluid (compressible and free-surface) systems having rigid boundaries. Extensive case studies.

**ME 420 Advanced Thermodynamics 3 Credits**

Critical review of thermodynamics systems. Criteria for equilibrium. Applications to electromagnetic systems. Statistical thermodynamics. Irreversible thermodynamics. Thermoelectric phenomena.

**ME 421 Topics in Thermodynamics 3 Credits**

Emphasis on theoretical and experimental treatment of combustion processes including dissociation, flame temperature calculations, diffusion flames, stability and propagation; related problems in compressible flow involving one-dimensional, oblique shock waves and detonation waves. Methods of measurement and instrumentation.

**ME 423 Heat and Mass Transfer 3 Credits**

This course is a first graduate course in the basic concepts of heat and mass transfer, providing a broad coverage of key areas in diffusion, conduction, convection, heat and mass transfer, and radiation. Topics covered include: the conservation equations, steady and transient diffusion and conduction, periodic diffusion, melting and solidification problems, numerical methods, turbulent convection, transpiration and film cooling, free convection, heat transfer with phase change, heat exchanges, radiation, mixed mode heat and mass transfer.

**ME 424 Unsteady and Turbulent Flow 3 Credits**

Stability of laminar flow; transition to turbulence. Navier-Stokes equations with turbulence. Bounded turbulent shear flows; free shear flows; statistical description of turbulence.

**ME 426 Radiative and Conductive Heat Transfer 3 Credits**

Principles of radiative transfer; thermal-radiative properties of diffuse and specular surfaces; radiative exchange between bodies; radiative transport through absorbing, emitting and scattering media. Advanced topics in steady-state and transient conduction; analytical and numerical solutions; problems of combined conductive and radiative heat transfer.

**ME 428 Boundary Layers and Convective Heat Transfer 3 Credits**

Navier-Stokes and energy equations, laminar boundary layer theory, analysis of friction drag, transfer and separation. Transition from laminar to turbulent flow. Turbulent boundary layer theory. Prandtl mixing length, turbulent friction drag, and heat transfer. Integral methods. Flow in ducts, wakes and jets. Natural convection heat transfer.

**ME 430 Advanced Fluid Mechanics 3 Credits**

This course is a first graduate course in incompressible fluid mechanics, providing a broad coverage of key areas of viscous and inviscid fluid mechanics. Topics covered include: Flow kinematics, differential equations of motion, viscous and inviscid solutions, vorticity dynamics and circulation, vorticity equation, circulation theorems, potential flow behavior, irrotational and rotational flows, simple boundary layer flows and solutions, and real fluid flows and consequences.

**ME 431 Advanced Gas Dynamics 3 Credits**

Method of characteristics. Unsteady continuous flow. Unsteady flows with discontinuities. Shock tubes. Detonation waves. Two-dimensional and axisymmetric supersonic flows. Momentum and energy equation of compressible viscous fluids.

**ME 433 (CHE 433, ECE 433) Linear Systems and Control 3 Credits**

This course covers the following topics in linear systems and control theory: review of fundamental concepts in linear algebra, state-space representation of linear systems, linearization, time-variance and linearity properties of systems, impulse response, transfer functions and their state-space representations, solution to LTI and LTV state equations, Jordan form, Lyapunov stability, input-output stability, controllability, stabilizability, observability, detectability, Canonical forms, minimal realizations, introduction to optimal control theory, Linear Quadratic Regulator (LQR), Algebraic Riccati Equation (ARE), frequency domain properties of LQR controllers.

**ME 434 (CHE 434, ECE 434) Multivariable Process Control 3 Credits**

A state-of-the-art review of multivariable methods of interest to process control applications. Design techniques examined include loop interaction analysis, frequency domain methods (Inverse Nyquist Array, Characteristic Loci and Singular Value Decomposition) feed forward control, internal model control and dynamic matrix control. Special attention is placed on the interaction of process design and process control. Most of the above methods are used to compare the relative performance of intensive and extensive variable control structures.

**Prerequisites:** CHE 433 or ME 433 or ECE 433

**ME 436 (CHE 436, ECE 436) Systems Identification 3 Credits**

The determination of model parameters from time-history and frequency response data by graphical, deterministic and stochastic methods. Examples and exercises taken from process industries, communications and aerospace testing. Regression, quasilinearization and invariant-embedding techniques for nonlinear system parameter identification included.

**ME 437 (CHE 437, ECE 437) Stochastic Control 3 Credits**

Linear and nonlinear models for stochastic systems. Controllability and observability. Minimum variance state estimation. Linear quadratic Gaussian control problem. Computational considerations. Nonlinear control problem in stochastic systems.

**Prerequisites:** CHE 433 or ME 433 or ECE 433

**ME 440 General Examination 3 Credits**

A critical assessment and definition of major unresolved issues for an assigned research topic during the first half of the semester, followed by formulation of a research proposal in accord with the format of a federal funding agency during the second half of the semester. In addition to the written proposal, the student gives a presentation to the Doctoral Committee, followed by extensive discussion. Grade assigned by the committee; minimum grade of B+ required. Instructor (doctoral student adviser) approval required.

**ME 444 Experimental Stress Analysis in Design 3 Credits**

Fundamental concepts of strain measurements and application of strain gages and strain gage circuits. Two- and three-dimensional photoelasticity, stress separation techniques, birefringent coatings, moiré methods, caustics. Use of image analysis in data acquisition and interpretation. Selected laboratory experiments.

**ME 446 Mechanical Reliability 3 Credits**

Design of mechanical engineering systems to reliability specifications. Probabilistic failure models for mechanical components. Methods for the analysis and improvement of system reliability. Effect of component tolerance and parameter variation on system failure. Reliability testing.

**ME 450 Special Topics 3 Credits**

An intensive study of some field of mechanical engineering not covered in more general courses.

**Repeat Status:** Course may be repeated.

**ME 452 (BIOE 452, CHE 452, ENGR 452) Mathematical Methods in Engineering I 3 Credits**

Analytical techniques relevant to the engineering sciences are described. Vector spaces; eigenvalues; eigenvectors. Linear ordinary differential equations; diagonalizable and non-diagonalizable systems. Inhomogeneous linear systems; variation of parameters. Non-linear systems; stability; phase plane. Series solutions of linear ordinary differential equations; special functions. Laplace and Fourier transforms; application to partial differential equations and integral equations. Sturm-Liouville theory. Finite Fourier transforms; planar, cylindrical, and spherical geometries.

**ME 453 Mathematical Methods in Engineering II 3 Credits**

Theory of complex functions; Cauchy-Riemann relations. Integration in the complex plane, Cauchy's integral formula. Laurent series; singular points; contour integrals; Fourier and Laplace transforms. Evaluation of real integrals; Cauchy principal values. Laplace's equation; conformal mappings; Poisson formulae. Singular integral equations. Classification of partial differential equations. Hyperbolic systems of partial differential equations; uniqueness, shock formation. Nonlinear parabolic equations; Burger's equation.

**ME 454 Automatic Control of Aerospace Vehicles 3 Credits**

The forces and moments acting on aircraft are developed from basic aerodynamics and used to determine the equations of motion and the resulting dynamic models. Analysis from these dynamic models supports the design of flight control, guidance, and autopilot systems. Modern control methods for missiles and spacecraft are also included. Effects of flexible structures are developed. Cannot receive credit if previously completed ME 354.

**Prerequisites:** MECH 326 and MECH 343

**ME 456 Astrodynamics 3 Credits**

Kepler's Laws are proven from basic mechanics, then used to determine the equations of motion for a satellite. Subsequent topics include various kinds of orbits in use today, orbit determination, orbital maneuvers, and rendezvous. Interplanetary trajectories, satellite attitude dynamics, rocket vehicles, and orbital perturbations are also discussed. ME 456 is the graduate level version of ME 356; requires additional assignments and/or projects appropriate for graduate level study. Credit will not be given for both ME 356 and ME 456.

**ME 458 Modeling of Dynamic Systems 3 Credits**

Modeling of complex linear and nonlinear energetic dynamic engineering systems. Emphasis on subdivision into multiport elements and representation by the bondgraph language using direct, energetic, and experimental methods. Field lumping. Analytical and graphical reductions. Simulation and other numerical methods. Examples including mechanisms, electromechanical transducers, electric and fluid circuits, and thermal systems.

**ME 460 Engineering Project 1-6 Credits**

Project work on some aspect of mechanical engineering in an area of student and faculty interest. Selection and direction of the project could involve interaction with local communities or industries. Consent of department required.

**Repeat Status:** Course may be repeated.

**ME 461 Integrated Product Development (IPD) Projects-1 2 Credits**

Technical and economic feasibility study of new products. Selection and content of the project is determined by the faculty project advisor in consultation with the student, progress and final reports, oral and posters presentations. Consent of the program director and faculty project adviser required.

**Prerequisites:** TE 401 or ME 401

**ME 462 IPD: Manufacturing 3 Credits**

Industry sponsored Integrated Product Development Project (IPD) projects. The student works with an industry sponsor to create detailed design specifications, fabricate and test a prototype new product and plan for production. Selection and content of the project is determined by the faculty project advisor in consultation with the industry sponsor. Deliverables include progress and final reports, oral presentations, posters and a prototype. Consent of the department chair and faculty project advisor required.

**ME 464 Renewable Energy 3 Credits**

Fundamentals and design aspects of Renewable Energy (RE) technologies; bio-fuels, hydropower, solar photovoltaic, solar thermal, wind, geothermal energies. Details and difficulties in implementing RE. ME 464 is graduate level version of ME 364 and will require additional assignments and/or projects appropriate for graduate level study. Closed to students who have taken ME 364.

**ME 466 Fundamentals of Acoustics 3 Credits**

Vibration-induced acoustic radiation, wave equation in planar, cylindrical and spherical coordinates. Sound in tubes, pipes, wave guides, acoustic enclosures. Impedance and source-media-receiver transmission concepts. Noise and its measurements.

**ME 468 Advanced Energy Efficiency Practicum 3 Credits**

Critical assessments of energy management systems. Establishment of framework for industrial facilities to manage energy systems. Fundamentals of best practices for energy efficiencies associated with industrial energy savings. Progress and final reports required. Engineering graduate students only. Consent of instructor required.

**ME 475 Directed Studies 1-3 Credits**

Special problems related to a topic in mechanical engineering and mechanics.

**ME 485 Polymer Product Manufacturing 3 Credits**

An exploration of the science underlying polymer processes such as injection molding through a combination of theory development, practical analysis, and utilization of commercial software. Polymer chemistry and structure, material rheological behavior, processing kinetics, molecular orientation development, process simulation software development, manufacturing defects, manufacturing window establishment, manufacturing process design, manufacturing process optimization. This course is a version of ME 385 for graduate students, with research projects and advanced assignments. Closed to students who have taken ME 385. Must have graduate level standing in engineering or science.

**ME 490 Thesis 1-6 Credits**

**Repeat Status:** Course may be repeated.

**ME 499 Dissertation 1-15 Credits**

**Repeat Status:** Course may be repeated.

**Mechanics Courses****MECH 002 Elementary Engineering Mechanics 3 Credits**

Static equilibrium of particles and rigid bodies. Elementary analysis of simple truss and frame structures, internal forces, stress, and strain. Credit will not be given for both MECH 002 and MECH 003.

**Prerequisites:** (MATH 022 or MATH 052 or MATH 032) and (PHY 010 or PHY 011)

**Can be taken Concurrently:** MATH 022, MATH 052, MATH 032

**MECH 003 Fundamentals of Engineering Mechanics 0,3 Credits**

Static equilibrium of particles and rigid bodies. Analysis of simple truss and frame structures, internal forces, stress, strain, and Hooke's Law, torsion of circular shafts; pure bending of beams. Is intended as a prerequisite for MECH 012. Credit not given for both MECH 002 and MECH 003.

**Prerequisites:** (MATH 022 or MATH 032) and PHY 011

**Can be taken Concurrently:** MATH 022, MATH 032

**MECH 012 Strength of Materials 0,3 Credits**

Stress due to normal, bending, and shear loads in beams; stress transformations via Mohr's circle; principal stress analysis; plastic yield criteria; design of thin-walled pressure vessels; deflection of beams and static indeterminacy; finite element analysis of simple structures; stresses in thick-walled cylinders; stress concentration effects.

**Prerequisites:** MECH 003 and (MATH 023 or MATH 033)

**Can be taken Concurrently:** MATH 023, MATH 033

**MECH 050 Supplemental Topics in Mechanics 1-2 Credits**

Completion of material for MECH courses transferred from other institutions. Student will be scheduled for that part of MECH course that is required for completion of missing material. Subject matter and credit hours to be determined by department chair for each student.

**MECH 102 Dynamics 3 Credits**

Particle dynamics, work-energy, impulse-momentum, impact, systems of particles; kinematics of rigid bodies, kinetics of rigid bodies in plane motion, energy, momentum, eccentric impact.

**Prerequisites:** (MECH 002 or MECH 003) and (MATH 023 or MATH 033)

**Can be taken Concurrently:** MATH 023, MATH 033

**MECH 103 Principles of Mechanics 4 Credits**

Composition and resolution of forces; equivalent force systems; equilibrium of particles and rigid bodies; friction. Kinematics and kinetics of particles and rigid bodies; relative motion; work and energy; impulse and momentum.

**Prerequisites:** (MATH 023 or MATH 033) and (PHY 010 or PHY 011)

**MECH 300 Apprentice Teaching 3 Credits****MECH 302 Advanced Dynamics 3 Credits**

Fundamental dynamic theorems and their application to the study of the motion of particles and rigid bodies, with particular emphasis on three-dimensional motion. Use of generalized coordinates; Lagrange's equations and their applications.

**Prerequisites:** MATH 205 and (MECH 102 or MECH 103)

**MECH 305 Advanced Mechanics of Materials 3 Credits**

Strength, stiffness, and stability of mechanical components and structures. Fundamental principles of stress analysis: three-dimensional stress and strain transformations, two-dimensional elasticity, contact stresses, stress concentrations, energy and variational methods. Stresses and deformations for rotating shafts, thermal stresses in thick-walled cylinders, curved beams, torsion of prismatic bars, and bending of plates. Projects relate analysis to engineering design.

**Prerequisites:** MECH 012 and MATH 205

**MECH 307 Mechanics of Continua 3 Credits**

Fundamental principles of the mechanics of deformable bodies. Study of stress, velocity and acceleration fields. Compatibility equations, conservation laws. Applications to two-dimensional problems in finite elasticity, plasticity, and viscous flows.

**Prerequisites:** MECH 305

**MECH 312 Finite Element Analysis 3 Credits**

Basic concepts of analyzing general media (solids, fluids, heat transfer, etc.) with complicated boundaries. Emphasis on mechanical elements and structures. Element stiffness matrices by minimum potential energy. Isoparametric elements. Commercial software packages (ABAQUS, NISA) are used. In addition, students develop and use their own finite element codes. Applications to design.

**Prerequisites:** MECH 012

**MECH 313 Fracture Mechanics 3 Credits**

Fracture mechanics as a foundation for design against or facilitation of fracture. Fracture behavior of solids; fracture criteria; stress analysis of cracks; subcritical crack growth, including chemical and thermal effects; fracture design and control, and life prediction methodologies.

**Prerequisites:** MECH 012 and MATH 205

**MECH 326 Aerodynamics 3 Credits**

Application of fluid dynamics to flows past lifting surfaces. Normal force calculations in inviscid flows. Use of conformal mappings in two dimensional airfoil theory. Kutta condition at a trailing edge; physical basis. Viscous boundary layers. Thin airfoil theory. Section design; pressure profiles and separation. Lifting line theory. Compressible subsonic flows; Prandtl-Glauert Rule. Airfoil performance at supersonic speeds.

**Prerequisites:** ME 231

**MECH 328 Fundamentals of Aircraft Design 3 Credits**

Review of dynamic pressure, lift, drag. International Standard Atmosphere. Basics of wing sections. Parasitic and induced drag, best glide ratio and minimum sink of gliders. Basics of planforms, propulsion (piston/propeller and jet). Performance estimates (max speed, climb, endurance, range, stall), stability and trim, aerodynamic moments. Phugoid. Wing spar analysis. Electric aircraft.

**Prerequisites:** MECH 012

**MECH 350 Special Topics 3 Credits**

A study of some field of engineering mechanics not covered elsewhere. Consent of department required.

**MECH 404 Mechanics & Behavior of Structural Members 3 Credits**

Behavior of structural members under a variety of loading conditions in the elastic and inelastic range. Introduction to the theory of elasticity and plasticity. Basics of linear elastic fracture mechanics and fatigue. Analysis of structural member behavior in axial, bending, shear, and torsion. Stability analysis of beam-columns. Beams on elastic foundations. Energy concepts and their use in structural analysis.

**MECH 406 Fundamentals of Solid Mechanics 3 Credits**

An introductory graduate course in the mechanics of solids. Topics to be addressed include: curvi-linear tensor analysis, analysis of strain and nonlinear kinematics, stress, work conjugate stress-strain measures, conservation laws and energy theorems, variational calculus, isotropic and anisotropic linear elasticity, boundary value problems, beam and plate theories.

**MECH 408 Introduction to Elasticity 3 Credits**

This course is a first graduate course in solid mechanics. It addresses: kinematics and statics of deformable elastic solids; compatibility, equilibrium and constitutive equations; problems in plane elasticity and torsion; energy principles, approximate methods and applications.

**MECH 410 Theory of Elasticity II 3 Credits**

Advanced topics in the theory of elasticity. The subject matter may vary from year to year and may include, theory of potential functions, linear thermoelasticity, dynamics of deformable media, integral transforms and complex-variable methods in classical elasticity. Problems of boundary layer type in elasticity; current developments on the microstructure theory of elasticity.

**MECH 411 Continuum Mechanics 3 Credits**

An introduction to the continuum theories of the mechanics of solids and fluids. This includes a discussion of the mechanical and thermodynamical bases of the subject, as well as the use of invariance principles in formulating constitutive equations. Applications of the theories to specific problems are given.

**MECH 413 Fracture Mechanics 3 Credits**

Elementary and advanced fracture mechanics concepts; analytical modeling; fracture toughness concept; fracture toughness testing; calculation of stress intensity factors; elastic-plastic analysis; prediction of crack trajectory; fatigue crack growth and environmental effects; computational methods in fracture mechanics; nonlinear fracture mechanics; fracture of composite structures; application of fracture mechanics to design.

**MECH 415 Stability of Elastic Structures 3 Credits**

Basic concepts of instability of a structure; bifurcation, energy increment, snap-through, dynamic instability. Analytical and numerical methods of finding buckling loads of columns. Postbuckling deformations of cantilever columns. Dynamic buckling with nonconservative forces. Effects of initial imperfections. Inelastic buckling. Instability problems of thin plates and shells.

**MECH 418 Finite Element Methods 3 Credits**

Finite element approximations to the solution of differential equations of engineering interest. Linear and nonlinear examples from heat transfer, solid mechanics, and fluid mechanics are used to illustrate applications of the method. The course emphasizes the development of computer programs to carry out the required calculations. Must have knowledge of a high-level programming language.

**MECH 419 (CHE 419) Asymptotic Methods in the Engineering Sciences 3 Credits**

Introductory level course with emphasis on practical applications. Material covered includes: Asymptotic expansions. Regular and singular perturbations; algebraic problems. Asymptotic matching. Boundary value problems; distinguished limits. Multiple scale expansions. W.K.B. Theory. Non-linear wave equations.

**MECH 424 Unsteady Fluid Flows 3 Credits**

Gas dynamics, finite amplitude disturbances in perfect and real gases; channel flows; three-dimensional acoustics; theories of the sonic boom. Motions in fluids with a free surface; basic hydrodynamics, small amplitude waves on deep water; ship waves; dispersive waves; shallow water gravity waves and atmospheric waves. Hemodynamics; pulsatile blood flow at high and low Reynolds number. Models of the interaction of flow with artery walls.

**MECH 425 Analytical Methods in Dynamics and Vibrations 3 Credits**

This course will mainly cover the following topics: coordinate systems, conservations laws, inertial frames, systems of particles, DAE sets, variable-mass systems, transport equation, review of some of the basic concepts from variational calculus, D'Alembert's principle, Hamilton's principle, Lagrange multipliers, generalized momenta, 3D rigid-body motion, Inertia matrices, Euler angles, inertial and elastic coupling, discrete eigenvalue problem, linearization of nonlinear systems, chaotic systems, Hamilton's principle for continuous systems, Torsion, Sturm-Liouville equations, Rayleigh's quotient, finite-element eigen-problems, interpolating functions, combined-effect vibrations, and some other related topics.

**MECH 432 Inelastic Behavior Of Materials 3 Credits**

Time-independent and dependent inelastic material behavior. Time-independent plasticity. Yield criteria in multi-dimensions, J2 incremental plasticity in multi-dimensions with associated flow rule. Numerical integration of plasticity equations by radial return and other methods. Deformation theory of plasticity. Time dependent behavior including linear viscoelasticity and nonlinear creep behavior. Nonlinear material behavior at elevated temperatures.

**MECH 445 Nondeterministic Models in Engineering 3 Credits**

Application of probability and stochastic processes to engineering problems for a variety of applications. Modeling and analysis of common nondeterministic processes. Topics are selected from the following: linear and nonlinear models for random systems; random functions; simulation; random loads and vibrations; Kalman filtering, identification, estimation, and prediction; stochastic fracture and fatigue; probabilistic design of engineering systems; and spatial point processes. Must have advanced calculus and some exposure to probability and statistics.

**MECH 450 Special Problems 3 Credits**

An intensive study of some field of applied mechanics not covered in more general courses.

**Repeat Status:** Course may be repeated.

**MECH 454 Mechanics and Design of Composites 3 Credits**

Mechanics of anisotropic materials. Manufacturing and measurements of mechanical properties. Stress analysis for design of composite structures. Hydrothermal effects and residual stresses. Laminate design, micromechanics of lamina. Bolted and bonded joints. Impact and damage in composites. Lectures and laboratory.