MECHANICAL ENGINEERING

Mechanical Engineering
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The mission of the Department of Mechanical Engineering (MME) at the undergraduate level is to offer programs that support and complement the University mission; to provide a general undergraduate education in mechanical engineering that prepares students for employment or graduate study; to include interdisciplinary engineering work; to encourage the professional development of the faculty; and to foster the professional awareness of the students. The BS in Mechanical Engineering degree is accredited by the Engineering Accreditation Commission (EAC) of Accreditation Board of Engineering and Technology (ABET (https://www.abet.org/), 415 N. Charles St., Baltimore, MD 21201, 410-347-7700, eac@abet.org).

Program Educational Objectives

The program educational objectives of the BS in Mechanical Engineering program are to produce graduates who, within a few years of graduation:

1. Apply their engineering and problem-solving skills towards engineering practice, engineering graduate school, or other fields such as medicine, science, business, or law.
2. Value and demonstrate character by acting responsibly, ethically, and professionally.
3. Work synergistically in diverse and global environments to positively impact society.
4. Embrace life-long learning to support professional development and personal wellness.

Student Outcomes

Student outcomes describe what students are expected to know and be able to do by the time of graduation. These relate to the knowledge, skills, and behaviors that students acquire as they progress through the program.

The students outcomes for the BS in Mechanical Engineering program 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

Program Components

The Departments of Mechanical Engineering (MME) and Electrical and Computer Engineering (ECE) work closely together to deliver an exceptional educational experience for our students and to advance the state of the art through research and industry collaborations.

All of our engineering programs have several components:

1. The University of Denver's Common Curriculum, which includes first-year seminar, writing courses, analytical inquiry and scientific inquiry courses, and advanced seminar
2. Basic sciences and mathematics, including chemistry, physics, and mathematics
3. An engineering common curriculum, with fundamental material from computer, electrical, and mechanical engineering
4. An engineering discipline (computer engineering, electrical engineering, mechanical engineering)
5. Multiple integrated design experiences, which are interdisciplinary and involve teams working on impactful real-world problems

6. Depth and/or breadth in the discipline through engineering, math, and science electives personalized to the student's individual interests.

Engineering Design

The feature of engineering programs that most differentiates them from programs in basic or applied science and mathematics is engineering design, which is both an art and a science. Our programs feature a 4-year thread of coursework required of all students, regardless of curriculum, which emphasizes design, project work, team-work, and the application of scientific and technical knowledge and design skills already acquired to the solution of interdisciplinary engineering problems. As the student progresses in the curriculum, more and more reliance is placed on previous work, and more realistic constraints and considerations are required for success. The sequence culminates in a three-quarter capstone design project carried out in the final year. Additional design work is contained in specialized courses, including junior year Integration.

Course of Study

Engineering curricula are highly structured; acquisition of certain knowledge and skills must precede acquisition of more advanced ones. The course plan provides a detailed road map of the curriculum.

We offer an **Engineering Common Curriculum** for the first 5 quarters. As in, the curricula for all engineering programs (computer, electrical and mechanical) are the same for the first 5 quarters. A student can delay choosing an engineering major until the beginning of the spring quarter of their second year. By learning about the various engineering disciplines, students are better able to select the program that is right for them.

The curricula in the last two years includes advanced work in the engineering discipline, integrated engineering design experiences, depth and/or breadth through engineering, math, and science electives, and completion of the University Common Curriculum.

The MME department also offers several 4+1 dual BS-MS degree programs. Students can earn MS degrees in Bioengineering or Mechanical Engineering. For details and timing of the application process, visit the Ritchie's School's 4+1 programs (https://ritchieschool.du.edu/academics-education/41-programs-dual-degrees/) website. Students interested in these programs should discuss them with an advisor as early as possible in their undergraduate careers.

Undergraduate Research Experiences

Students wishing to participate in undergraduate research projects may be eligible for participation in Partners in Scholarship (PinS) or the Ritchie School's Grand Challenge Scholar Program (GCSP (https://ritchieschool.du.edu/academics-education/grand-challenges-scholar-program/)). PinS is a University-wide program in which a student can receive support to collaborate on a project with a faculty member. More information on PINS, including funding opportunities and the Undergraduate Showcase, is available at the Undergraduate Research Center (http://www.du.edu/urc/) website.

The Ritchie School's GCSP provides opportunities for student to work closely with faculty mentor on projects related to the National Academy of Engineering's 14 Grand Challenges. Students can apply for project, stipend or travel support for their projects.

Study Abroad

The University of Denver and the MME department strongly encourage students to participate in study abroad programs, particularly through the Cherrington Global Scholars Program. More information can be found at the Office of International Education (http://www.du.edu/intl/abroad/) website.

Many engineering students participate in study abroad experiences. The engineering curricula have been structured so that students may take advantage of this opportunity in the autumn quarter of the senior year, rather than in the autumn quarter of the junior year, as is more usual in other DU programs. If you are interested, it is important to plan ahead with your advisor to make sure the selected courses at your study abroad site integrate into your course plan.

Cooperative Education Program

Recognizing the value of experiential learning, we have created a paid co-op program which is optional and competitive for all Ritchie School students, though ideally suited for current sophomores and juniors. Through this collaborative program between academia and industry, students work full time at participating companies earning valuable work experience. Typically, students will not take classes for one full academic year, resuming their studies upon their return exactly in sequence but one year removed. In some cases, DU courses can be taken while on co-op. Dr. Matt Gordon is the department contact for students interested in the co-op program.

Fundamentals of Engineering (FE) Examination and Enrollment as an Engineer-Intern (EI)

The FE Exam is the first of a two-step process in order to become registered as a Professional Engineer (PE). The FE exam is a national 6-hour examination administered by NCEES (National Council of Examiners for Engineering and Surveying) in conjunction with the Colorado State Board for Professional Engineers and Land Surveyors.

The MME department encourages, but does not require, mechanical engineering students to complete the FE exam. To register, a student must have completed at least 135 credits to apply to take the FE exam. The NCEES charges a fee to take the exam. For more information, please contact the MME department chair.

After passing the FE exam, the student must send a final transcript recording the receipt of an engineering degree to the Colorado State Board for Professional Engineers and Land Surveyors. Typically, after passing the FE exam, the requirements for registration as a PE are 4 years of engineering experience under the supervision of a PE with increasing engineering responsibility and passing the PE examination.

Criteria for Entering Any of the Engineering Programs

In the first year, students should plan to take the following:

MATH 1951	Calculus I	4
MATH 1952	Calculus II	4
MATH 1953	Calculus III	4
PHYS 1211	University Physics I	5
PHYS 1212	University Physics II	5

Students lacking the mathematics preparation to begin calculus in the first quarter may take MATH 1070 College Algebra and Trigonometry followed by the usual calculus sequence; these students should meet with an advisor from the engineering department before enrolling for courses. Failure to complete the courses listed above in the first year may lead to an additional year of study.

Minors in Engineering for Non-Engineering Students

Students desiring to minor in any of the engineering disciplines must take 20 hours of discipline specific engineering courses in addition to the equivalent of MATH 1951 Calculus I, MATH 1952 Calculus II, and MATH 1953 Calculus III. It is recommended that they have PHYS 1211 University Physics I, PHYS 1212 University Physics II, and PHYS 1213 University Physics III in their curriculum. Degree programs that "naturally flow" into an engineering minor are: chemistry, computer science, biology, mathematics and physics.

Mechanical Engineering

Bachelor of Science in Mechanical Engineering (BSME)

(192 credits required for the degree (http://bulletin.du.edu/undergraduate/undergraduateprograms/traditionalbachelorsprogram/bachelorofscienceinmechanicalengineering/))

Requirements

192 credits are required for the degree, including degree including, at least 48 credits of mathematics and basic science and at least 85 credits of engineering topics.

Code	Title	Credits
ENCE 2101	Digital Design	3
ENEE 2012	Circuits I and Laboratory	4
ENGR 1511	Engineering Connections	1
ENGR 1572	Applied MATLAB Programming	3
ENGR 1611	Introduction to Engineering Design	4
ENGR 1622	Introduction to Mechatronic Systems I	4
ENGR 1632	Introduction to Mechatronic Systems II	4
ENGR 2610	Engineering Integration I	3
ENGR 2620	Engineering Integration II	3
ENGR 2910	Engineering Economics and Ethics	3
ENGR 2950	Engineering Assessment I	0
ENGR 2951	Engineering Assessment II	0
ENGR 3313	Engineering Design Project I	2
ENGR 3323	Engineering Design Project II	3
ENGR 3333	Engineering Design Project III	3
ENME 2410	Materials Science	4
ENME 2510	Statics	4
ENME 2520	Dynamics I with Lab	4
ENME 2530	Dynamics II	3
ENME 2540	System Dynamics	3
ENME 2541	Mechanics of Materials	3
ENME 2651	Fluid Dynamics I	3
ENME 2661	Fluid Dynamics II/Heat Transfer I	3
ENME 2671	Heat Transfer II with Lab	4

ENME 2710	Engineering Thermodynamics I	3
ENME 2720	Engineering Thermodynamics II	3
ENME 2810	Mechanical Engineering Lab I	3
ENME 3511	Machine Design	3
ENME 3810	Mechanical Engineering Capstone Laboratory	3
Engineering Electives		12

Additional Requirements

Chemistry

Code	Title	Credits
CHEM 1010	General Chemistry I	3
CHEM 1240	General Chemistry I Laboratory	1

Computer Science

Code	Title	Credits
COMP 1351	Introduction to Programming I	3

Mathematics

Code	Title	Credits
MATH 1951	Calculus I	4
MATH 1952	Calculus II	4
MATH 1953	Calculus III	4
MATH 2070	Introduction to Differential Equations	4
MATH 2080	Calculus of Several Variables	4

Physics

Code	Title	Credits
PHYS 1211	University Physics I	5
PHYS 1212	University Physics II	5
PHYS 1214	University Physics III for Engineers	4

Additional Math/Science

Math-Sci Electives (10 credit hours) - Take 2-4 math or science courses from the approved list. Note that without prior advisor approval only one approved math or science course may be taken instead of a UCC course in the first two years. See Degree Program Plan for Approved courses.

Technical Requirement

Technical Elective (3 or 4 credit hours) – Take 1 additional approved technical elective course from engineering, math, science or computer science

Notes

Engineering Electives (12 credit hours) - Take 3 - 3000 or higher engineering courses (ENGR, ENME, ENEE, ENCE, ENBI, ENMT, or MTSC), which are not required for the major.

The intro sequence, including ENGR 1511, 1611, 1622, and 1632 may be modified for transfer students, students who start in engineering after their first quarter, students who are enrolled in concurrent degree or secondary major programs, or students completing the requirements for a pre-health program. These modifications must be approved by the student's faculty advisor and the department chair.

Minor

Biomedical Engineering

Biomedical engineering applies engineering principles to biological and medical problems, with the goal of improving human health. The minor includes cross-disciplinary course work in engineering and life sciences, as well as application-based courses that are focused on analyzing, modeling, designing, and realizing bio/biomedical engineering devices, systems, components, or processes.

Prerequisites: Students interested in the program should have the equivalent of MATH 1951, 1952, and 1953. As well as a year of physics, such as PHYS 1211, 1212, 1213 or PHYS 1111, 1112, 1113 before taking the engineering courses.

Code	Title	Credits
Engineering Majors		
Required Courses		
BIOL 1010	Physiological Systems	4

BIOL 1020	Physiological Systems Lab	1
ENBI 3010	Introduction to Biomedical Engineering	4
Science Electives - Minimum of 8 Credits		8
BIOL 3241	Anatomy and Physiology of the Skeletal, Nervous and Muscular systems	
BIOL 3242	Human Anatomy and Physiology - Systems of homeostasis	
BIOL 3254	Advanced Cardiovascular and Pulmonary Physiology	
BIOL 3640	Introductory Neurobiology	
BIOL 3615	Blood Vessel Development and Disease	
BIOL 3647	Neuroscience of Movement	
CHEM 1020	General Chemistry II	
CHEM 1250	General Chemistry II Laboratory	
CHEM 2131	Chemistry of the Elements	
CHEM 2141	Chemistry of the Elements Lab	
PHYS 2300	Physics of the Body	
PHYS 2340	Medical Imaging Physics	
Bioengineering Electives - Minimum of 4 Credits		4
ENBI 3500	Biofluids	
or ENBI 4500	Biofluids	
ENBI 3510	Biomechanics	
ENBI 3800	Topics in Bioengineering	
ENBI 4200	Medical Device Development	
ENBI 4510	Biomechanics	
ENBI 4520	Introduction to Cardiovascular Engineering	
ENBI 4530	Biomechanics of Human Movement	
ENGR 3450	Biosensing Technology	
ENGR 3455	Fluorescence and Its Applications in Biomedical Sensors	
Total Credits		**21**

Code	Title	Credits
Non-Engineering Majors		
Required Courses		
BIOL 1010	Physiological Systems	4
BIOL 1020	Physiological Systems Lab	1
ENBI 3010	Introduction to Biomedical Engineering	4
For students with a major that requires BIOL 1010 and 1020, this can be replaced with additional engineering electives		8
Engineering Electives - minimum of 8 credits		
COMP 1351	Introduction to Programming I	
ENCE 2101	Digital Design	
ENEE 2012	Circuits I and Laboratory	
ENEE 2022	Circuits II	
ENEE 2211	Electronics	
ENEE 3111	Signals & Systems	
ENGR 1572	Applied MATLAB Programming	
ENGR 3100	Instrumentation and Data Acquisition	
ENME 2410	Materials Science	
ENME 2421	Materials Science II	
ENME 2510	Statics	
ENME 2520	Dynamics I with Lab	
ENME 2530	Dynamics II	
ENME 2541	Mechanics of Materials	
ENME 2651	Fluid Dynamics I	
ENME 2661	Fluid Dynamics II/Heat Transfer I	

ENME 2671	Heat Transfer II with Lab	
ENME 2710	Engineering Thermodynamics I	
ENME 2720	Engineering Thermodynamics II	
Bioengineering Elective - Minimum of 4 Credits		4
ENBI 3500	Biofluids	
ENBI 3510	Biomechanics	
ENBI 3800	Topics in Bioengineering	
ENBI 4200	Medical Device Development	
ENBI 4500	Biofluids	
ENBI 4510	Biomechanics	
ENBI 4520	Introduction to Cardiovascular Engineering	
ENBI 4530	Biomechanics of Human Movement	
ENGR 3450	Biosensing Technology	
ENGR 3455	Fluorescence and Its Applications in Biomedical Sensors	
Total Credits		**21**

Minor Requirements for Mechanical Engineering

20 credits, including:

Code	Title	Credits
Select three of the following four courses:		9
ENME 2510	Statics with Lab	
ENME 2410	Materials Science I	
ENME 2651	Fluid Dynamics I	
ENME 2710	Engineering Thermodynamics I	
Electives		**11**
ENME courses at the 2000-level or above		

Mechanical Engineering

First Year					
Fall	**Credits**	**Winter**	**Credits**	**Spring**	**Credits**
FSEM 1111	4	ENGR 1622	4	ENGR 1632	4
CHEM 1010	3	MATH 1952	4	PHYS 1212	5
CHEM 1240	1	PHYS 1211	5	MATH 1953	4
ENGR 1511	1	WRIT 1122	4	WRIT 1133	4
ENGR 1611	4				
MATH 1951	4				
	17		**17**		**17**
Second Year					
Fall	**Credits**	**Winter**	**Credits**	**Spring**	**Credits**
COMP 1351	3	ENEE 2012	4	ENGR 2950	0
ENCE 2101	3	ENGR 1572	3	ENME 2520	4
ENME 2510	4	ENME 2541	3	ENME 2710	3
PHYS 1214	4	MATH 2070	4	MATH 2080	4
Math/Sci Elective or Common Curriculum	4	Math/Sci Elective or Common Curriculum	4	Math/Sci Elective or Common Curriculum	4
	18		**18**		**15**
Third Year					
Fall	**Credits**	**Winter**	**Credits**	**Spring**	**Credits**
ENME 2410	4	ENGR 2610	3	ENGR 2620	3
ENME 2530	3	ENME 2661	3	ENGR 2910	3
ENME 2651	3	ENME 3511	3	ENME 2671	4
ENME 2720	3	Eng / Math-Sci / Tech Elective or Common Curriculum	4	ENME 2540	3
Eng / Math-Sci / Tech Elective or Common Curriculum	4	Eng / Math-Sci / Tech Elective or Common Curriculum	4	Eng / Math-Sci / Tech Elective or Common Curriculum	4
	17		**17**		**17**

Fourth Year					
Fall	Credits	Winter	Credits	Spring	Credits
ENGR 3313	2	ENGR 3323	3	ENGR 3333	3
ASEM	4	ENME 2810	3	ENME 3810	3
Eng / Math-Sci / Tech Elective or Common Curriculum	4	Eng / Math-Sci / Tech Elective or Common Curriculum	4	ENGR 2951	0
Eng / Math-Sci / Tech Elective or Common Curriculum	4	Open Elective	2	Eng / Math-Sci / Tech Elective or Common Curriculum	3-4
				Open Elective	4-3
	14		12		13

Total Credits: 192

Notes

Common Curriculum

These may be taken in any order. They must have 2 courses with attributes of analytical inquiry: society and 2 courses attributes of scientific inquiry: society (16 credits).

ASEM 2XXX - Advanced Seminar Required writing-intensive advanced seminar.   Junior or senior standing is required (4 credits)

Open Elective May be any course at the 1000 level or above (3 or 4 credits as needed to reach 192 total QH).

Eng Electives (12 credit hours) - Take 3 - 3000 or higher engineering courses (ENGR, ENME, ENEE, ENCE, ENBI, ENMT, or MTSC), which are not required for the major.

Math-Sci Electives (10 credit hours) - Take 2-4 math or science courses from the approved list. Note that without prior advisor approval only one approved math or science course may be taken instead of a UCC course in the first two years.

Tech Elective (3 or 4 credit hours) – Take 1 additional approved technical elective course from engineering, math, science or computer science.

Approved Math/Sci Courses (subject to participating department course offerings):

Biology

BIOL 1010 (http://bulletin.du.edu/search/?P=BIOL%201010) Physiological Systems w/BIOL 1020 (http://bulletin.du.edu/search/?P=BIOL%201020) Physiological Systems Lab; BIOL 1011 (http://bulletin.du.edu/search/?P=BIOL%201011) Evolution, Heredity and Biodiversity w/BIOL 1021 (http://bulletin.du.edu/search/?P=BIOL%201021) Evolution, Heredity and Biodiversity Lab; BIOL 2450 (http://bulletin.du.edu/search/?P=BIOL%202450) Human Anatomy; BIOL 2090 (http://bulletin.du.edu/search/?P=BIOL%202090) Biostatistics; BIOL 2120 (http://bulletin.du.edu/search/?P=BIOL%202120) Cell Structure and Function w/BIOL 2121 (http://bulletin.du.edu/search/?P=BIOL%202121) Cell Structure & Function Lab; BIOL 3250 (http://bulletin.du.edu/search/?P=BIOL%203250) Human Physiology

Chemistry

CHEM 1020 (http://bulletin.du.edu/search/?P=CHEM%201020) General Chemistry II w/ CHEM 1250 (http://bulletin.du.edu/search/?P=CHEM%201250) General Chemistry II Laboratory; CHEM 2131 (http://bulletin.du.edu/search/?P=CHEM%202131) Chemistry of the Elements w/ CHEM 2141 (http://bulletin.du.edu/search/?P=CHEM%202141) Chemistry of the Elements Lab; CHEM 2240 (http://bulletin.du.edu/search/?P=CHEM%202240) Introduction to Environmental Chemistry; CHEM 2270 (http://bulletin.du.edu/search/?P=CHEM%202270) Quantitative Chemical Analysis

Math

MATH 2060 (http://bulletin.du.edu/search/?P=MATH%202060) Elements of Linear Algebra; MATH 3080 (http://bulletin.du.edu/search/?P=MATH%203080) Introduction to Probability; MATH 3090 (http://bulletin.du.edu/search/?P=MATH%203090) Mathematical Probability; MATH 3851 (http://bulletin.du.edu/search/?P=MATH%203851) Functions Complex Variable

Physics

PHYS 2251 (http://bulletin.du.edu/search/?P=PHYS%202251) Modern Physics I; PHYS 2252 (http://bulletin.du.edu/search/?P=PHYS%202252) Modern Physics II w/ PHYS 2260 (http://bulletin.du.edu/search/?P=PHYS%202260) Modern Physics Lab; PHYS 2259 (http://bulletin.du.edu/search/?P=PHYS%202259) Uncertainty and Error Analysis; PHYS 2300 (http://bulletin.du.edu/search/?P=PHYS%202300) Physics of the Body; PHYS 2340 (http://bulletin.du.edu/search/?P=PHYS%202340) Medical Imaging Physics; PHYS 3510 (http://bulletin.du.edu/search/?P=PHYS%203510) Analytical Mechanics I; PHYS 3711 (http://bulletin.du.edu/search/?P=PHYS%203711) Optics I

Math/Sci courses not listed above must be approved by the student's advisor.

Requirements for Distinction in the Major in Mechanical Engineering

- Minimum 3.3 cumulative GPA
- Complete an undergraduate research project, including research paper and presentation

ENBI 3010 Intro to Biomedical Eng (4 Credits)
An introduction to biomedical engineering, this course will serve as a survey of the field of study. During the course students will learn to identify a breadth of biomedical engineering problems and also learn about the technical challenges and opportunities that biomedical engineering brings to the life and medical sciences. Topics may include biomechanics, tissue engineering, medical imaging, bioinsturmentation, and medical device design.

ENBI 3500 Biofluids (4 Credits)
The application of fluid dynamics theory and design to problems within the biomedical community. Specific topics covered include the mechanics of inhaled therapeutic aerosols, basic theory of circulation and blood flow, foundations in biotechnology and bioprocessing, and controlled drug delivery. Cross listed with ENBI 4500. Prerequisites: ENME 2661.

ENBI 3510 Biomechanics (4 Credits)
An introduction to the mechanical behavior of biological tissues and systems. Specific topics covered include analysis of the human musculoskeletal system as sensors, levers, and actuators; joint articulations and their mechanical equivalents; kinematic and kinetic analysis of human motion; introduction to modeling human body segments and active muscle loading for analysis of dynamic activities; mechanical properties of hard and soft tissues; mechanical and biological consideration for repair and replacement of soft and hard tissue and joints; orthopedic implants. Cross listed with ENBI 4510. Prerequisites: ENME 2410, ENME 2520, and ENME 2541.

ENBI 3800 Topics in Bioengineering (1-4 Credits)
Special topics in bioengineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENBI 4200 Medical Device Development (4 Credits)
Working in a fast-paced competitive biomedical R&D firm is a dramatic change of pace from most college classes. This course will create a realistic industry environment where students take on the role of development engineers to design and manufacture real-world medical devices. This course is intended to provide a working knowledge of the design and development process specifically for medical device applications.

ENBI 4500 Biofluids (4 Credits)
The application of fluid dynamics theory and design to problems within the biomedical community. Specific topics covered include the mechanics of inhaled therapeutic aerosols, basic theory of circulation and blood flow, foundations in biotechnology and bioprocessing, and controlled drug delivery. Cross listed with ENBI 3500.

ENBI 4510 Biomechanics (4 Credits)
An introduction to the mechanical behavior of biological tissues and systems. Specific topics covered include: Analysis of the human musculoskeletal system as sensors, levers, and actuators; Joint articulations and their mechanical equivalents; Kinematic and kinetic analysis of human motion; Introduction to modeling human body segments and active muscle loading for analysis of dynamic activities; Mechanical properties of hard and soft tissues; Mechanical and biological consideration for repair and replacement of soft and hard tissue and joints; Orthopedic implants. Cross listed with ENBI 3510.

ENBI 4520 Introduction to Cardiovascular Engineering (4 Credits)
An introduction to cardiovascular mechanics with a focus on the quantitative understanding of the mechanical phenomena that governs the cardiovascular system. Specific topics covered include: basic principles of circulation including macro and micro circulation, soft tissue mechanics, applications to cardiovascular diseases, modelling techniques, clinical and experimental methods, and design of cardiovascular devices. Recommended prerequisites: ENME 2541 and ENME 2661.

ENBI 4530 Biomechanics of Human Movement (4 Credits)
An introduction to engineering-based analysis of human movement. Topics include: musculoskeletal anatomy, nueromuscular physiology, muscle mechanics, electromyography, sensorimotor integration, anthropometry, kinematics and kinetics. Recommended pre-requisite material: knowledge of MATLAB, ENGR 1572.

ENBI 4600 Biomedical Engineering: Technology, Research, and Design (4 Credits)
Introduction to Biomedical Engineering is an interdisciplinary course that combines engineering principles with biological and medical sciences to advance healthcare in areas such as diagnosis, monitoring, and therapy. The course provides a foundational understanding of biomedical engineering and prepares students for further study or careers in the field.

ENBI 4610 Experimental Design in Biomedical Sciences (4 Credits)
This course offers an in-depth exploration of experimental design principles within the biomedical sciences, emphasizing statistical analysis, measurement techniques, and ethical considerations. It aims to provide students with practical skills necessary for designing, conducting, and analyzing biomedical research.

ENBI 4620 Bioelectronics (4 Credits)
This course introduces the principles and applications of bioelectronics, focusing on the interface between biological systems and electronic devices. It covers the fundamentals of electronic circuits, signal processing, and sensor technology, and their applications in areas like biometric monitoring, neuroprosthetics, and biosensing.

ENBI 4630 Biomaterials (4 Credits)
This course provides an introduction to the field of biomaterials science, focusing on the fundamental principles, properties, and applications of materials used in biomedical engineering and healthcare. Topics covered include the classification of biomaterials, biocompatibility, interactions with biological systems, surface modifications, fabrication techniques, characterization techniques and current applications in tissue engineering, regenerative medicine, drug delivery, and medical devices.

ENBI 4800 Adv Topics (Bioengineering) (1-5 Credits)
Various topics in Bioengineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENBI 4991 Independent Study (1-5 Credits)

ENBI 4995 Independent Research (1-18 Credits)

ENGR 1511 Engineering Connections (1 Credit)
This course is designed to help engineering students bridge the gap from high school to a college environment in a very challenging major. Topics and activities may include academic success strategies; interviewing engineering alumni; the ethics of the profession; visits to industry sites; seminars by industry and academic experts; establishing the relationships between math, science, and engineering courses with design projects; critical and creative thinking activities; tours of the research labs of the engineering professors; disseminating information on the dual degree programs, the MBA programs, the honor code, and engineering program structures; and readings from and discussions about articles from professional publications. Membership in an engineering professional society is encouraged.

ENGR 1572 Applied MATLAB Programming (3 Credits)
The MATLAB programming environment is used to introduce engineering applications programming. It includes high performance numerical computation and visualization. Programming topics include an overview of an interactive programming environment, generation of m-files, variables and data types, arithmetic operators, mathematical functions, symbolic mathematics, graphic generation, use of programs in application specific toolboxes, embedding and calling C programs in m-files, file input/output, and commenting. Programming is oriented toward engineering problem solving. Prerequisites: COMP 1571 or COMP 1671 or COMP 1351, and MATH 1952.

ENGR 1611 Introduction to Engineering Design (4 Credits)
Introduction to concepts and practice in computer, electrical and mechanical engineering including engineering ethics. Engineering problem-solving as it applies to engineering analysis, synthesis and design. Students practice structured teamwork and program management skills in the context of projects. Emphasis on computer tools with immediate application to engineering practice.

ENGR 1622 Introduction to Mechatronic Systems I (4 Credits)
Introduction to elementary concepts and practices in mechatronic systems engineering, in particular electrical engineering concepts including current and voltage and basic electrical circuit analysis, interfacing electrical circuits with mechanical systems, and assembly and testing of mechatronics subsystems. Students are required to complete simple projects including mechanical and electrical components during which they practice teamwork while gaining skills in electrical and mechatronic systems troubleshooting. Introduction to Multiscan circuit analysis software and Mathcad are among other topics covered in this course.

ENGR 1632 Introduction to Mechatronic Systems II (4 Credits)
Study of fundamentals of computer-based systems and electromechanical systems controlled by microprocessors or microcontrollers. Introduction to digital logic and electronics. Introduction to LabView and use of LabView to build and evaluate circuits and simple electromechanical systems. Use of logic circuits to build analog to digital converters. Program microcontrollers. Study of autonomous vehicles as mechatronic systems and the ability to control them (small cars, robots, helicopters, quadrotors, etc.). Course requirements include a report with detailed analysis of the vehicle control system, flow charts, and program documentation.

ENGR 1700 Machine Shop Practice (1 Credit)
Introduction to concepts and practice in basic machine tool work (i.e. mill, lathe, welding etc.). The course provides the necessary information for majors and non-majors to gain access to the DU Engineering Machine Shop. Class size is limited to 5 students per quarter. Enrollment priority will be given to engineering majors.

ENGR 1911 Introduction to CAD (2 Credits)
This course is intended for transfer students who have had an introduction to engineering, but who need to learn certain techniques and software typically dealt with in ENGR 1611 including engineering ethics. Instructor Permission Required.

ENGR 1921 Introduction in Engineering II (1 Credit)
This course is intended mainly for transfer students who have had an introduction to engineering with topics similar to those in ENGR 1622, Introduction to Mechatronic Systems I, but who need to learn certain techniques and software (Mathcad and Multisim) typically dealt with in ENGR 1622. Prerequisite: Permission of the instructor.

ENGR 1931 Introduction to Engineering III (1 Credit)
This course is intended mainly for transfer students who have had an introduction to engineering with topics similar to those in ENGR 1632, Introduction to Mechatronic Systems II, but who need to learn certain techniques and software (LabView) typically dealt with in ENGR 1632. Prerequisite: Permission of the instructor.

ENGR 2610 Engineering Integration I (3 Credits)
Interdisciplinary course combining topics from computer, electrical and mechanical engineering including engineering ethics, with emphasis on laboratory experience and the design, analysis and testing of interdisciplinary systems. Manufacture of mechanical systems and/or circuit boards. Team project work on interdisciplinary "design-and-build" projects. Prerequisites: Junior standing in the appropriate engineering discipline and ENME 3511 for MME majors or ENCE 3210 and ENEE 2211 for ECE majors (the latter three can be taken concurrently).

ENGR 2620 Engineering Integration II (3 Credits)
Interdisciplinary course combining topics from computer, electrical and mechanical engineering including engineering ethics, with emphasis on laboratory experience and the design, analysis and testing of interdisciplinary systems. Manufacture of mechanical systems and/or circuit boards. Team project work on interdisciplinary "design-and-build" projects. Prerequisite: ENGR 2610.

ENGR 2905 Engineering Cooperative Education (0-12 Credits)
For students on full-time cooperative educational employment. This course may be taken up to four times. Any and all credits will not count toward your degree and you will receive a grade of NC (no credit) for all enrollments. You will choose between a residential and non-residential section.

ENGR 2910 Engineering Economics and Ethics (3 Credits)
This course focuses on the practical applications of economics to engineering focusing on the requirements for both the FE and PE exams. It explains concepts in accounting and finance and applies them to both engineering and personal situations. Topics that are discussed include: economic decision making, interest, inflation, depreciation, income taxes, and rate of return. In addition, the engineer's role in society, including global, economic, environmental, societal, and ethical issues will be discussed.

ENGR 2950 Engineering Assessment I (0 Credits)
Examination covering basic mathematics, science and sophomore-level engineering topics. Co-Requisite: MATH 2080; Prerequisite: ENME 2541 AND ENCE 2101 AND ENEE 2012 AND ENGR 1572.

ENGR 2951 Engineering Assessment II (0 Credits)
Students perform a lifelong learning experience and assessment-related tasks, e.g. a survey and exit interview. The course also includes career and professional development, as well as information on the Fundamentals of Engineering (FE) exam. Engineering students are encouraged, but not required to complete the FE exam. This course should be taken in the last year of attendance. Prerequisites: ENGR 3323.

ENGR 3100 Instrumentation and Data Acquisition (4 Credits)
This course examines different instrumentation techniques and describes how different measurement instruments work. Measurement devices include length, speed, acceleration, force, torque, pressure, sound, flow, temperature, and advanced systems. This course also examines the acquisition, processing, transmission and manipulation of data. Cross listed with ENGR 4100. Prerequisites: PHYS 1213 or PHYS 1214.

ENGR 3200 Introduction to Nanotechnology (4 Credits)
In this highly interdisciplinary series of lectures spanning across engineering, physics, chemistry and Biology, an introduction to the subject of nanotechnology is provided. The most important recent accomplishments so far in the application of nanotechnology in several disciplines are discussed. Then a brief overview of the most important instrumentation systems used by nanotechnologists is provided. The nature of nanoparticles, nanoparticle composites, carbon nanostructures, including carbon nanotubes and their composites is subsequently discussed. The course also deals with nanopolymers, nanobiological systems, and nanoelectronic materials and devices. The issues of modeling of nanomaterials and nanostructures are also covered in this class. Multiscale modeling based on finite element simulations, Monte Carlo methods, molecular dynamics and quantum mechanics calculations is briefly addressed. Most importantly, students should obtain appreciation of developments in nanotechnology outside their present area of expertise. Cross listed with ENGR 4200. Prerequisite: ENME 2410.

ENGR 3313 Engineering Design Project I (2 Credits)
Planning, development and execution of an engineering design project. The project may be interdisciplinary, involving aspects of computer, electrical and mechanical engineering. Projects have economic, ethical, social and other constraints, as appropriate. Design activities include 1) preparation and presentation of proposals in response to requests-for-proposals from "customers," including problem description, quantitative and qualitative criteria for success, alternate designs and project plans; 2) generation and analysis of alternate designs, and choice of best design; 3) formulation of test procedures to demonstrate that the design chosen meets the criteria for success, and testing of the completed project where feasible; 4) reporting on the design and testing. Prerequisite: ENGR 2620 and ((ENME 3511 and ENME 2671) or (ENCE 3231)) and senior standing in engineering.

ENGR 3323 Engineering Design Project II (3 Credits)
Planning, development and execution of an engineering design project. The project may be interdisciplinary, involving aspects of computer, electrical and mechanical engineering. Projects have economic, ethical, social and other constraints, as appropriate. Design activities include 1) preparation and presentation of proposals in response to requests-for-proposals from "customers," including problem description, quantitative and qualitative criteria for success, alternate designs and project plans; 2) generation and analysis of alternate designs, and choice of best design; 3) formulation of test procedures to demonstrate that the design chosen meets the criteria for success, and testing of the completed project where feasible; 4) reporting on the design and testing. Prerequisite ENGR 3313.

ENGR 3333 Engineering Design Project III (3 Credits)
Planning, development and execution of an engineering design project. The project may be interdisciplinary, involving aspects of computer, electrical and mechanical engineering. Projects have economic, ethical, social and other constraints, as appropriate. Design activities include: 1) preparation and presentation of proposals in response to requests-for-proposals from "customers," including problem description, quantitative and qualitative criteria for success, alternate designs and project plans; 2) generation and analysis of alternate designs, and choice of best design; 3) formulation of test procedures to demonstrate that the design chosen meets the criteria for success, and testing of the completed project where feasible; 4) reporting on the design and testing. Prerequisite ENGR 3323.

ENGR 3340 Product Development and Market Feasibility (4 Credits)
In this course, students gain knowledge of designing products for market success by developing a product and optimizing its design for specific mass manufacturing technologies. Students gain experience through the design development process including market feasibility research, human-centered design, brainstorming and ideating new concepts, refinement through design iteration, and constructing alpha and beta prototypes that are designed with mass manufacturing considerations. Projects are based upon real world new product development principles. Students learn and practice the fundamentals of design thinking, design process, and entrepreneurship.

ENGR 3450 Biosensing Technology (4 Credits)
Biosensors are defined as analytical devices incorporating a biological material, a biologically derived material or a biomimic associated with or integrated within a physicochemical transducer or transducing microsystem, which may be optical, electrochemical, thermometric, piezoelectric, magnetic or micromechanical. This course provides instruction in the basic science and engineering concepts required to understand the design and application of biosensors. This module serves as an introduction to some of the biosensors and measurement techniques.

ENGR 3455 Fluorescence and Its Applications in Biomedical Sensors (4 Credits)
The course introduces the principles of fluorescence and its applications in the real world. It covers various topics including fluorophores (dye, fluorescent proteins, quantum dots, etc.), nanomaterials and nanostructures, design of biomedical sensors, point-of-care systems, and wearable devices. Cross listed with ENGR 4455.

ENGR 3510 Renewable and Efficient Power and Energy Systems (4 Credits)
This course introduces the current and future sustainable electrical power systems. Fundamentals of renewable energy sources and storage systems are discussed. Interfaces of the new sources to the utility grid are covered. Prerequisite: ENEE 2012.

ENGR 3520 Introduction to Power Electronics (4 Credits)
This covers fundamentals of power electronics. We discuss various switching converters topologies. Basic knowledge of Efficiency and small-signal modeling for the DC-DC switching converters is covered. Furthermore, magnetic and filter design are introduced. Prerequisites: ENEE 2211 and ENGR 3722.

ENGR 3530 Introduction to Power and Energy Conversion Systems (3 Credits)
Basic concepts of AC systems, single-phase and three-phase networks, electric power generation, transformers, transmission lines, and electric machinery. Cross listed with ENGR 4530. Prerequisite: ENEE 2022.

ENGR 3535 Electric Power Engineering Laboratory (1 Credit)
In this laboratory, the magnetic circuits, single phase transformers, power quality and harmonics synchronous machines, Induction machines and DC machines are studied and tested in a real physical setup. Prerequisite: ENGR 3530.

ENGR 3540 Electric Power Systems (4 Credits)
This course covers methods of calculation of a comprehensive idea on the various aspects of power system problems and algorithms for solving these problems. Prerequisite: ENGR 3530.

ENGR 3545 Electric Power Economy (3 Credits)
This course covers economy aspects of electric power industry and the implications for power and energy engineering in the market environment. Cross listed with ENGR 4545. Prerequisite: ENGR 3530.

ENGR 3590 Power System Protection (3 Credits)
This course covers methods of calculation of fault currents under different types of faults; circuit breakers, current transformers, potential transformers; basic principles of various types of relays; applications of relays in the protection of generator, transformer, line, and bus, etc. Prerequisite: ENEE 2022, ENGR 3530 or equivalent. 3.0 hours. Cross listed with ENGR 4590.

ENGR 3611 Engineering Mathematics (3 Credits)
Applied mathematics for engineers. Generalized Fourier analysis, complex variables, vector calculus, introduction to partial differential equations, and linear algebra. Prerequisites: MATH 2070, MATH 2080.

ENGR 3621 Advanced Engineering Mathematics (4 Credits)
Applied mathematics for engineers. Topics include vector spaces, normed vector spaces, inner product spaces, linear transformations, finite-dimensional linear transformations, linear operators, finite-dimensional linear operators, linear differential systems, linear difference systems, orthogonal transformations, amplitude estimation, fundamentals of real and functional analysis, and introduction to partial differential equations, and applications to engineering systems.

ENGR 3630 Finite Element Methods (4 Credits)
Introduction to the use of finite element methods in one or two dimensions with applications to solid and fluid mechanics, heat transfer and electromagnetic fields; projects in one or more of the above areas. Prerequisites: ENME 2541 AND ENGR 1572.

ENGR 3650 Probability and Statistics for Engineers (4 Credits)
This course covers quantitative analysis of uncertainty and decision analysis in engineering. It covers the fundamentals of sample space, probability, random variables (discrete and continuous), joint and marginal distributions, random sampling and point estimation of parameters. It also covers statistical intervals, hypotheses testing and simple linear regression. The course includes applications appropriate to the discipline. Prerequisite: MATH 1953.

ENGR 3721 Controls (3,4 Credits)
Modeling, analysis and design of linear feedback control systems using Laplace transform methods. Techniques and methods used in linear mathematical models of mechanical, electrical, thermal and fluid systems are covered. Feedback control system models, design methods and performance criteria in both time and frequency domains. A linear feedback control system design project is required. Prerequisites: ENEE 2022, ENGR 3611 or permission of instructor.

ENGR 3722 Control Systems Laboratory (1 Credit)
This laboratory course serves as supplement to ENGR 3721. It aims at providing "hands on" experience to students. It includes experiments on inverted pendulum, gyroscopes, motor control, feedback controller design, time-domain and frequency domain. Corequisite: ENGR 3721.

ENGR 3723 Digital Control (4 Credits)
The course focuses on modeling, analysis, and design of digital control systems. Topics include: z-Transform and difference equations; sampling and aliasing; Zero-Order Hold (ZOH); A/D and D/A conversions; pulse transfer function representation; time and frequency domain representations; input/output analysis; analysis of sample data systems; stability; design of discrete-time controllers; introduction to state-space representation. Cross listed with ENGR 4723. Prerequisites: ENGR 3721 and ENGR 3722.

ENGR 3730 Robotics (3 Credits)
Introduction to the analysis, design, modeling and application of robotic manipulators. Review of the mathematical preliminaries required to support robot theory. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning, and kinetics. Cross listed with ENGR 4730. Prerequisites: ENME 2520 and MATH 2060 or MATH 2200 or permission of instructor.

ENGR 3731 Robotics Lab (1 Credit)
Laboratory that complements the analysis, design, modeling and application of robotic manipulators. Implementation of the mathematical structures required to support robot operation. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning and kinetics. Applications include programming and task planning of a manufacturing robot manipulator. Corequisite: ENGR 3730 or permission of instructor.

ENGR 3735 Linear Systems (4 Credits)
This course focuses on linear system theory in time domain. It emphasizes linear and matrix algebra, numerical matrix algebra and computational issues in solving systems of linear algebraic equations, singular value decomposition, eigenvalue-eigenvector and least-squares problems, linear spaces and linear operator theory. It studies modeling and linearization of multi-input/multi-output dynamic physical systems, state-variable and transfer function matrices, analytical and numerical solutions of systems of differential and difference equations, structural properties of linear dynamic physical systems, including controllability, observability and stability. It covers canonical realizations, linear state-variable feedback controller and asymptotic observer design, and the Kalman filter. Cross listed with ENGR 4735. Prerequisites: ENGR 3611, ENGR 3721, and ENGR 3722, or permission of the instructor.

ENGR 3800 Topics (ENGR) (1-4 Credits)
Special topics in engineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENGR 3900 Engineering Internship (0-4 Credits)
Students in engineering may receive elective credit for engineering work performed for engineering employers with the approval of the chair or associate chair of the department. At the end of the term, a student report on the work is required, and a recommendation will be required from the employer before a grade is assigned. Junior, senior, or graduate status in engineering is normally required. May not be used to satisfy technical requirements. May be taken more than one for a maximum of 6 quarter hours. Prerequisite: permission of instructor.

ENGR 3991 Independent Study (1-5 Credits)
Topics in engineering investigated under faculty supervision. May be taken more than once. Students must obtain and complete an Independent Study form from the Office of the Registrar. Prerequisite: permission of instructor.

ENGR 3995 Independent Research (1-10 Credits)

ENGR 4100 Instrumentation and Data Acquisition (4 Credits)
This course examines different instrumentation techniques and describes how different measurement instruments work. Measurement devices include length, speed, acceleration, force, torque, pressure, sound, flow, temperature, and advanced systems. This course also examines the acquisition, processing, transmission and manipulation of data. Final project or paper. Cross listed with ENGR 3100. Prerequisites: PHYS 1213 OR PHYS 1214.

ENGR 4200 Introduction to Nanotechnology (4 Credits)
The most important recent accomplishments so far in the application of nanotechnology in several disciplines are discussed. Then a brief overview of the most important instrumentation systems used by nanotechnologists is provided. The nature of nanoparticles, nanoparticle composites, carbon nanostructures, including carbon nanotubes and their composites is subsequently discussed. The course also deals with nanopolymers, nanobiological systems, and nanoelectronic materials and devices. The issues of modeling of nanomaterials and nanostructures is also covered. Multiscale modeling based on finite element simulations, Monte Carlo methods, molecular dynamics and quantum mechanics calculations are briefly addressed. Most importantly, students should obtain appreciation of developments in nanotechnology outside their present area of expertise. Cross listed with ENGR 3200.

ENGR 4300 Advanced Numerical Methods (4 Credits)
Fundamental and advanced numerical methods to approximate mathematical problems for engineering applications using modern software such as Matlab. Topics include numerical differentiation and integration, solution to linear and non-linear equations, ordinary and partial differential equations, and initial, boundary, and eigen value problems. Recommended prerequisite: MATH 2070.

ENGR 4350 Reliability (4 Credits)
An overview of reliability-based design. Topics include: fundamentals of statistics, probability distributions, determining distribution parameters, design for six sigma, Monte Carlo simulation, first and second order reliability methods (FORM, SORM). Most Probable Point (MPP) reliability methods, sensitivity factors, probabilistic design.

ENGR 4455 Fluorescence and Its Applications in Biomedical Sensors (4 Credits)
The course introduces the principles of fluorescence and its applications in the real world. It covers various topics including fluorophores (dye, fluorescent proteins, quantum dots, etc.), nanomaterials and nanostructures, design of biomedical sensors, point-of-care systems, and wearable devices. Cross listed with ENGR 3455.

ENGR 4501 Graduate Capstone Design I (3 Credits)
This is a project-centered course. This is the first third of a practical class that plans the engineering design project prior to addressing the design in earnest. This requires teamwork to develop the plan that details the schedule, cost, and who is responsible for which portions of the design effort. In this segment, the engineering teams establish the starting point for the design. This class puts theory into practice with the “shredding” of the RFP, defining a strategy for the team, balancing what has to be done with existing constraints, understanding the “true” problem of the customer, capturing the associated risks, and capturing margins required for the start of any design activity.

ENGR 4502 Graduate Capstone Design II (3 Credits)
This is a project-centered course. This is the second third of a practical class that implements the engineering design process (left side of the vee). This requires teamwork to develop the detailed design, which is a continuation of the accepted proposal. In this segment, the engineering teams add the details to a conceptual design. This class puts theory into practice with requirements development, balancing requirements against the constraints, completing a functional decomposition, developing a CONOPs document, developing a physical architecture, developing a functional architecture, and defining the interfaces through an ICD.

ENGR 4503 Graduate Capstone Design III (3 Credits)
This is a project-centered course. This is the third of a practical class that implements the engineering design process (right side of the vee). This requires teamwork to build, checkout, and test the final product. In this segment, the engineering teams build or procure hardware as a step towards the integration of the system. This class puts theory into practice by building components, developing software modules, integrating software with hardware, checkout of the system, and performing tests to verify construction, validate models, and collect data for acceptance by the team prior to demonstrating the operations of the product to the customer. Test data is collected through instrumentation of the final product with a buy-out and certification by the team. Testing may include performance testing and environmental testing as envisioned in the context diagram.

ENGR 4504 Graduate Capstone Design IV (3 Credits)
This is a project-centered course. This is the fourth of a practical class that implements the entire engineering “vee” design process. This requires teamwork to build, checkout, and test the final design product, e.g. hypothetical missile. In this segment, the engineering teams fine-tune the design process which may address advanced topics such as fault management and resilience. This class puts theory into practice by building components, developing software modules, integrating software with hardware, checkout of the system, and performing tests to verify construction, validate models, and collect data for acceptance by the team prior to demonstrating the operations of the product to the customer. It may also include addressing the beginning of the program through early management and pre-phase A activities. Test data is collected through instrumentation of the final product with a buy-in and certification by the team. Testing may include performance testing, functional testing, and environmental testing as envisioned in the system process.

ENGR 4530 Intro to Power and Energy (4 Credits)
Basic concepts of AC systems, single-phase and three-phase networks, electromechanical energy conversion, electric power generation, transformers, transmission lines, AC machinery, DC motors, and contemporary topics in power and energy conversion. Cross listed with ENGR 3530.

ENGR 4545 Electric Power Economy (4 Credits)
This course covers economy aspects of electric power industry and the implications for power and energy engineering in the market environment. Cross listed with ENGR 3545.

ENGR 4560 Power Generation Operation and Control (4 Credits)
This course covers economic dispatch of thermal units and methods of solution; transmission system effects; generate with limited energy supply; production cost models; control of generation; interchange of power and energy; power system security; state estimation in power systems; optimal power flow. Prerequisite: ENGR 3530 or ENGR 4530 or permission of instructor.

ENGR 4590 Power System Protection (4 Credits)
This course covers methods of calculation of fault currents under different types of fault; circuit breakers, current transformers, potential transformers; basic principles of various types of relays; applications of relays in the protection of generator, transformer, line, and bus, etc. Prerequisite: ENGR 3530 or ENGR 4530.

ENGR 4620 Optimization (4 Credits)
The development and application of various optimization techniques will be explored with engineering examples. Topics include: analytical and numerical methods, linear and non-linear programming techniques for unconstrained and constrained problems, and advanced optimization techniques, e.g. global optimization. Optimization methods will be developed and evaluated in code and used in a real-world application project.

ENGR 4622 Advanced Optimization (4 Credits)
Optimization is an indispensable tool for many fields of science and engineering and is one of the pillars of data science and machine learning. This course introduces optimization methods that are suitable for large-scale problems arising in data science, machine learning, and other engineering applications. We will discuss the development, computation, and convergence aspects for algorithms including gradient methods, accelerated methods, quasi-Newton methods, stochastic optimization, variance reduction, online optimization, as well as distributed optimization. We will also exploit the efficacy of these methods in concrete data science problems, including learning low-dimensional models, deep learning, and (possible) reinforcement learning. This course together with ENGR 4620 Optimization will provide in-depth introductions to optimization.

ENGR 4680 Fault Diagnosis & Prognostics for System Design (4 Credits)
Reliability engineering is a sub-discipline of systems engineering that emphasizes dependability in the lifecycle management of a product. Reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability is closely related to availability, which is typically described as the ability of a component or system to function at a specified moment or interval of time. Normally, quality focuses on the prevention of defects during the warranty phase whereas reliability looks at preventing failures during the useful lifetime of the product or system from commissioning to decommissioning. Diagnosis is used, with variations in the use of logic, analytics, and experience, to determine "cause and effect". In systems engineering, it is typically used to determine the causes of symptoms, mitigations, and solutions. Prognostics is an engineering discipline focused on predicting the time at which a system or a component will no longer perform its intended function. This lack of performance is most often a failure beyond which the system can no longer be used to meet desired performance. The predicted time then becomes the remaining useful life (RUL), which is an important concept in decision making for contingency mitigation. Success in this course requires knowledge of probability theory and statistics, and familiarity with MATLAB/Simulink.

ENGR 4723 Digital Control (4 Credits)
The course focuses on modeling, analysis, and design of digital control systems. Topics include: z-Transform and difference equations; sampling and aliasing; Zero-Order Hold (ZOH); A/D and D/A conversions; pulse transfer function representation; time and frequency domain representations; input/output analysis; analysis of sample data systems; stability; design of discrete-time controllers; introduction to state-space representation. Cross listed with ENGR 3723. Prerequisites: ENGR 3721 and ENGR 3722.

ENGR 4730 Introduction to Robotics (4 Credits)
Introduction to the analysis, design, modeling and application of robotic manipulators. Review of the mathematical preliminaries required to support robot theory. Topics include forward kinematics, inverse kinematics, motion kinematics, trajectory control and planning, and kinetics. Applications include programming and task planning of a manufacturing robot manipulator. Cross listed with ENGR 3730. Prerequisites: ENGR 3611 or ENEE 3111 or instructor approval.

ENGR 4735 Linear Systems (4 Credits)
This course focuses on linear system theory in time domain. It emphasizes linear and matrix algebra, numerical matrix algebra and computational issues in solving systems of linear algebraic equations, singular value decomposition, eigenvalue-eigenvector and least-squares problems, linear spaces and linear operator theory. It studies modeling and linearization of multi-input/multi-output dynamic physical systems, state-variable and transfer function matrices, analytical and numerical solutions of systems of differential and difference equations, structural properties of linear dynamic physical systems, including controllability, observability and stability. It covers canonical realizations, linear state-variable feedback controller and asymptotic observer design, and the Kalman filter. Cross listed with ENGR 3735. Prerequisites: ENGR 3611, ENGR 3721, ENGR 3722, or permission of the instructor.

ENGR 4740 Adaptive Control Systems (4 Credits)
Theoretical and application aspects of robust adaptive control design for uncertain dynamical systems. Topics include: parameter estimation, stability, model reference adaptive systems, self-tuning regulators, gain scheduling, design for robustness against unmodeled dynamics and disturbance signals. Examples will be given from aerospace engineering (changes in the dynamics of aircraft), process control, and robotics. Modern alternatives to traditional adaptive control will be discussed (switching multi-model/multi-controller adaptive schemes). Prerequisite: ENGR 3721 or permission of instructor. Familiarity with MATLAB/Simulink.

ENGR 4745 Adv Non-Linear Control System (4 Credits)
Nonlinear system analysis methods: Existence of solutions of ODEs, uniqueness, continuity, compactness, fixed point, linearization, metric spaces, Contraction Mapping Theorem, Gronwall-Bellman lemma. Phase plane analysis; Limit Cycles. Lyapunov stability of autonomous and non-autonomous systems. Circle criterion, absolute stability, Popov criterion. Passivity and Lyapunov stability. Input-to-State stability. Small Gain Theorem. Describing functions. Nonlinear control system synthesis methods: Passivity-based control. Stability via Feedback Linearization. Lie derivatives.

ENGR 4750 Networked Control Systems (4 Credits)
Fundamental tools and recent advances in networked control. Topics include the control of multi-agent networks found in multi-vehicle coordination, control of sensor networks, unmanned vehicles, and energy systems. Network models, distributed control and estimation, distributed control under limited communications and sensing, formation control, coverage control in mobile sensor networks. Prerequisites: linear algebra, linear control systems, differential equations, familiarity with MATLAB, or permission of instructor.

ENGR 4755 Optimal Control (4 Credits)
Introduction to optimal control theory (control laws that maximize a specified measure of a dynamical system's performance). Topics include: optimality conditions and constraints; calculus of variations; review of mathematical programming (Language multipliers, convexity, Kuhn-Tucker theorem); Pontryagin's maximum principle (constraints, Hamilitonians, bang-bang control); dynamic programming and Linear Quadratic Regulation (Riccati, Hamilton-Jacobi equation). Prerequisites: ENGR 3721 (Controls) and ENGR 3735/4735 (Linear Systems) or equivalent courses.

ENGR 4760 Multivariable Control (4 Credits)
Multivariable aspects of control (systems with multiple actuators and sensors); performance analysis of feedback control systems; sensitivity; robustness and stability margins; disturbance attenuation; design tradeoffs; singular value; characteristic locus. Modern H-infinity control theory and 'mu' synthesis-based robust control design techniques. Enforced Prerequisites and Restrictions ENGR 3721 (Controls) and ENGR 4735 (Linear Systems at a graduate level) or equivalents.

ENGR 4765 Robot Control (4 Credits)
The course focuses on different techniques, methods, and theories for control of robots. The topics covered include: introduction to nonlinear control theory, review of independent joint control, nonlinear and multivariable robot control, feedback linearization control of robots, control of underactuated robots, control of nonholonomic and mobile robots. force and impedance control, and vision-based control. Pre-requisite or co-requisite: ENGR 3730 or ENGR 4730, or equivalent is recommended.

ENGR 4790 Systems Engineering Requirements (4 Credits)
The course covers fundamentals of design and requirements analysis of complex systems to meet overall mission requirements. It spans the whole requirements engineering phase that includes requirements analysis, decomposition, derivation, allocation, verification and validation planning. Students acquire expertise in creating UML and SYML case diagrams and in defining and implementing verification and validation plans. Requirement management methods and tools, associated vernacular, and requirements configuration control are also covered. Prerequisites: ENMT 4100, or permission by the Instructor.

ENGR 4810 Advanced Topics (ENGR) (1-5 Credits)

ENGR 4910 Conceptual Design (4 Credits)
Conceptual design is the part of the design process where—by identifying the essential problems through abstraction, establishing function structures, searching for appropriate working principles and combining these into a working structure— the basic solution path is laid down through the elaboration of a solution principle. Conceptual design specifies the principle solution. Concept design rarely starts at the same point; you might have an existing design that needs iterating or the requirement to create a conceptualized form. Problem solving consists of using generic or ad hoc methods in an orderly manner to find solutions to problems. George Polya (mathematician) presented two important decision-making principles, understanding the problem and devising a plan. To understand what is new, students are asked to look at intellectual property, a category of property that includes intangible creations of the human intellect. There are many types of intellectual property such as patents, and some countries recognize more than others. Designers assess the many different directions a design could take at this stage will allow you to identify what you like and don't like from each one. The preferred concept will then be further developed using engineering drawings, schematics and possibly 3D models which will show how the design will look and operate.

ENGR 4920 Aerospace Missions (4 Credits)
The Design "Problem" in Advanced Aerospace Systems describes the problems in the conceptual design of various types of aircraft, spacecraft, and complex vehicles. It covers the following topics: design of orbital spacecraft, design for Moon missions (such as landers), design for Mars missions (including rovers), design of an unmanned drone for surveillance (high-altitudes), CubeSats (having large constellations), and rockets and missiles (including hypersonic). Problem statements are concise descriptions of design problems. Design teams use them to define the current and ideal states, to freely find user-centered solutions. This class stands as a reference of interest to engineers and scientists working in aerospace engineering and related topics.

ENGR 4940 Mission Operation Controls (4 Credits)
Space operations is based at a centralized control center, a facility used for command & control (C2), and related communication equipment (antennas, etc.). The human operators conduct the day-to-day operations for controlling the spacecraft. They control the spacecraft and its payloads, and carries out all activities related to mission planning and scheduling. For example, normal orbital operations are interrupted every six months to conduct orbital maneuvers. Launch operations begin with spacecraft integration and checked-out for launch. Once safely placed in orbit, command and control goes back and forth between the ground control station and the spacecraft or satellite. A key aspect of spacecraft operations is the transferring of data from the onboard instruments collected by its payload to the ground, eventually disseminating the data to concerned users and analysts through a ground data network. This requires an on-orbit communication architecture.

ENGR 4991 Independent Study (1-5 Credits)

ENGR 4995 Independent Research (1-16 Credits)

ENGR 5991 Independent Study (0-10 Credits)

ENGR 5995 Independent Research (1-16 Credits)

ENME 2410 Materials Science I (4 Credits)
Atomic structure, bonding and crystal structures in solids. Diffusion and crystal defects. Thermodynamics and phase equilibria in one-, two- and three-component systems, binary phase diagrams. Kinetics and phase transformations. Specific microstructure and mechanical properties of metals, glasses, ceramics, polymers and composites. Electrical conduction: energy levels and bands, charge carriers and insulators. Semiconductors of intrinsic and extrinsic types. Laboratory projects/demonstrations. Prerequisites: PHYS 1212 and CHEM 1010 and MATH 1952.

ENME 2421 Materials Science II (3 Credits)
Atomic structure, bonding and crystal structures in solids. Diffusion and crystal defects. Thermodynamics and phase equalibria in one-, two- and three-component systems, binary phase diagrams. Kinetics and phase transformations. Specific microstructure and mechanical properties of metals, glasses, ceramics, polymers and composites. Electrical conduction: energy levels and bands, charge carriers and insulators. Semiconductors of intrinsic and extrinsic types. Laboratory projects/demonstrations. Prerequisites: ENME 2410.

ENME 2510 Statics (4 Credits)
Study of static force systems. Topics include resolution and composition of forces and moments, equilibrium of two-dimensional and three-dimensional force systems, shear and moments in beams, friction, and moments of inertia. Includes a laboratory component where students will engage in hands-on projects that apply loading equilibrium, design of structures, and stress/strain. Prerequisites: MATH 1951 AND PHYS 1211.

ENME 2520 Dynamics I with Lab (4 Credits)
Particles Kinematics, Reference Frames, Coordinate Systems, Newton's Laws, Energy and Momentum, Multiparticle Systems, Collisions, Variable Mass Systems. These topics are addressed through analytical analysis, numerical simulation using Matlab, and experimental data collection. Cross listed with PHYS 2520. Corequisite: MATH 2080; Prerequisite: ENME 2510 AND MATH 2070.

ENME 2530 Dynamics II (3 Credits)
Rotating reference frames, rigid body kinematics, rigid body kinetics, Euler's Laws, inertia, energy and momentum, and three-dimensional motion. Cross listed with PHYS 2530. Prerequisites: ENME 2520.

ENME 2540 System Dynamics (3 Credits)
This course covers modeling, analysis, and control of single and multiple degree-of freedom dynamical systems, including mechanical, electrical, thermal, fluid systems and their combinations (mixed systems). Basic concepts in system theory, such as state variables and stability concepts, will be introduced as well as bond graph notation and approach. Prerequisites: ENME 2530, ENME 2661, ENGR 1572, and ENEE 2012.

ENME 2541 Mechanics of Materials (3 Credits)
Normal and shear stress and strain; elasticity, mechanical properties of materials, principal stresses; torsion, beams, deflection of beams under loads, methods of superposition, failure theory, columns. Prerequisite: ENME 2510.

ENME 2651 Fluid Dynamics I (3 Credits)
Course series provides students with the basic skill levels required to solve fluid-mechanics and heat transfer problems. Topics include hydrostatics, dimensional analysis, incompressible and compressible flows, conduction, convection and radiation. Students explore a variety of solution techniques such as control volume, differential analysis, boundary layer analysis, finite differencing and resistance network analogies. Prerequisite: ENME 2510 and MATH 2070.

ENME 2661 Fluid Dynamics II/Heat Transfer I (3 Credits)
Course series provides students with the basic skills levels required to solve fluid-mechanics and heat transfer problems. Topics include hydrostatics, dimensional analysis, incompressible and compressible flows, conduction, convection and radiation. Students explore a variety of solution techniques such as control volume, differential analysis, boundary layer analysis, finite differencing and resistance network analogies. Prerequisite: ENME 2651.

ENME 2671 Heat Transfer II with Lab (4 Credits)
Course series provides students with the basic skill levels required to solve fluid-mechanics and heat transfer problems. Topics include hydrostatics, dimensional analysis, incompressible and compressible flows, conduction, convection and radiation. Students explore a variety of solution techniques such as control volume, differential analysis, boundary layer analysis, finite differencing and resistance network analogies. Prerequisite: ENME 2661.

ENME 2710 Engineering Thermodynamics I (3 Credits)
Properties of a pure substance. Use of tables of properties. First and second laws of thermodynamics for closed and open systems. Work, heat, power and entropy. Engine, power plant and refrigeration cycles. Gas mixtures, thermodynamic relations and chemical reactions. Prerequisite: PHYS 1212.

ENME 2720 Engineering Thermodynamics II (3 Credits)
Properties of a pure substance. Use of tables of properties. First and second laws of thermodynamics for closed and open systems. Work, heat, power and entropy. Engine, power plant and refrigeration cycles. Gas mixtures, thermodynamic relations and chemical reactions. Prerequisite: ENME 2710.

ENME 2810 Mechanical Engineering Lab I (3 Credits)
Engineering experiments illustrating selected topics in heat transfer, fluid mechanics, solid mechanics, thermodynamics, measurement and control. Use of microcomputers in experimentation and control. This course encourages the development of laboratory experimentation skills, design skills and technical writing skills. Prerequisites: ENME 2540 AND ENME 2671.

ENME 3320 Computer Aided Design and Analysis (4 Credits)
Introduction to the use of computer aided design and analysis with applications to solid and fluid mechanics, heat transfer and vibrations; projects in one or more of the above areas. Emphasis on how to use the software to analyze engineering systems. Prerequisites ENME 2541 and ENME 2651.

ENME 3400 Fatigue (4 Credits)
A detailed overview of fatigue. Topics include: stress life and strain life approaches, fracture mechanics, constant amplitude and spectrum loading, life prediction, fatigue at notches, microstructural effects, environmentally assisted fatigue, retardation and acceleration, multi-axial fatigue, design against fatigue, and reliability. Cross listed with ENME 4400.

ENME 3511 Machine Design (3 Credits)
Application of statics, dynamics, mechanics of materials and manufacturing processes to the design of machine elements and systems. Properties of materials and design criteria. Synthesis and analysis of a machine design project. Prerequisites: ENME 2520 and ENME 2541.

ENME 3545 Mechanisms (4 Credits)
Synthesis, analysis and use of mechanisms. Mechanisms studied include cams, gears and planar linkages, with an emphasis on planar linkages. Prerequisites: ENME 2530 and ENGR 1572.

ENME 3651 Computational Fluid Dynamics (4 Credits)
This course introduces principles and applications of computational methods in fluid flow and topics chosen from heat transfer, mass transfer or two phase flow. The conservation equations, their discretations and solutions, are presented. Convergence and validity of solutions along with computational efficiency are explored. Students learn to apply these techniques using the latest software packages. Prerequisites: ENME 2671.

ENME 3661 Mechanical Energy Systems Engineering (4 Credits)
This course covers energy systems engineering analysis from a mechanical and materials engineering perspective. This course covers energy production from traditional energy systems that use fossil fuel combustion such as internal combustion engines, coal-fired plants, and natural gas turbines, to nuclear energy and renewable energy methods such as wind, solar, hydraulic, and geothermal. Lastly, the course will survey emerging technologies for future (21st century) energy systems. Students should have taken at a minimum Thermodynamics, Dynamics, and Fluid Dynamics courses. Prerequisites: ENME 2720, ENME 2510, ENME 2651.

ENME 3720 Aerospace Engineering: Atmospheric Flight Dynamics (4 Credits)
This course provides and introduction to aerospace engineering analysis and design. In the atmospheric domain, the basics of aerodynamics are covered, followed by flight mechanics. The approach is from a practical perspective in which analysis and design are intertwined. Prerequisites: ENME 2651 and ENME 2720 and ENME 2530.

ENME 3730 Aerospace Engineering: Space Flight Dynamics (4 Credits)
This course is focused on the aerospace discipline of space environment and orbital mechanics. The topics in this discipline are discussed in detail and provide aid in designing spacecraft/space missions. Some of the topics covered in this course include space environment, satellite orbits, spacecraft configurations, transfer orbits, and elementary space propulsion. Prerequisites: ENME 2651 and ENME 2720 and ENME 2530.

ENME 3810 Mechanical Engineering Capstone Laboratory (3 Credits)
This course is the capstone mechanical engineering laboratory course requiring independent experimental design by student teams. Using experimental equipment available in heat transfer, fluid mechanics, solid mechanics, thermodynamics, and measurement and control, the student team is required to design experiments to solve given problems which will be unique to each team. This course encourages students to develop experimental design and research techniques while continuing to improve skills in fundamental lab notebook keeping, uncertainty analysis in measurements, data acquisition, data analysis, report writing, oral presentations, and laboratory safety and procedures. Prerequisite: ENME 2810.

ENME 3820 Topics Mechanical Engineering (0-5 Credits)
Mechanical engineering topics as announced. May be taken more than once. Prerequisite: vary with offering.

ENME 3991 Independent Study (1-5 Credits)
Topics in mechanical engineering investigated under faculty supervision. May be taken more than once. Students must obtain and complete an Independent Study form from the Office of the Registrar. Prerequisite: permission of instructor.

ENME 3995 Independent Research (1-10 Credits)

ENME 4020 Adv Finite Element Analysis (4 Credits)

ENME 4310 Computational Methods for Mechanics and Materials (4 Credits)
An introductory course for the general-purpose computational methods in advanced multiscale materials and mechanics. Students learn the fundamentals on the numerical methods used in mechanical and materials engineering. Cross listed with ENME 3310.

ENME 4360 Elasticity (4 Credits)
Students will be able to apply the fundamental principles of elasticity to solve two- and three-dimensional mechanical engineering problems involved in modern applications of elastic structures, composite materials, tribology and contact mechanics. Dependence on previous knowledge of solid mechanics, continuum mechanics or mathematics is minimized. The emphasis is placed on the engineering applicaitons of elasticity. Suggeted prerequisite: ENME 2541.

ENME 4400 Fatigue (4 Credits)
A detailed overview of fatigue. Topics include: stress life and strain life approaches, fracture mechanics, constant amplitude and spectrum loading, life prediction, fatigue at notches, microstructural effects, environmentally assisted fatigue, retardation and acceleration, multi-axial fatigue, design against fatigue and reliability. Cross listed with ENME 3400.

ENME 4520 Intermediate Dynamics (4 Credits)
Development and analysis of dynamic systems through classical approaches. Topics will include: Vector algebraic/differential geometry for 3D translational and rotational kinematic analyses with motion constraints. Formulation of equations of motion for 3D multibody systems using: Newton/ Euler equations; Angular momentum principle; and D'Alembert principle (aka road-maps). Some exposure to Euler-Lagrange and Kane's Methods calculations. Symbolic and numerical computational solutions to linear/nonlinear algebraic and differential equations governing the configuration, forces, and motion of systems with multiple degrees of freedom. Recommended prerequisites: MATH 2070.

ENME 4530 Advanced Dynamics (4 Credits)
Formulation of equations of motion for constrained 3D multibody systems with: D'Alembert principle (MG road-maps); power, work, and energy; Lagrange's equations; and Kane's method. Euler parameters/quaternions, specified motion, constraint force/torque calculations, feed- forward control, inequality constraints and/or intermittent contact. Tensors and mass property calculations. Symbolic and numerical computer skills for geometry/ kinematic analysis, mass/inertia calculations, forces and motion, and simulation of multi-body dynamic systems. Training for advanced research and professional work. Recommended pre-requisite: ENME 4520.

ENME 4541 Advanced Mechanics of Materials (4 Credits)
This is a second-level course in mechanics of materials with an emphasis on techniques that are useful for mechanical design. Topics may include energy methods, non-symmetrical and nonlinear bending, shear and torsion of closed and open sections, beams in elastic foundations, membrane stress in axisymmetic shells, asisymmetric bending of cylindrical shells, thick-walled cylinders and disks, curved beams, and elastic stability. Recommended prerequisite: ENME 2541.

ENME 4630 Viscous Flow (4 Credits)
Course covers the fundamentals of fluid mechanics from an advanced point of view with emphasis on the mathematical treatment of viscous-flow phenomena. Topics cover the Navier-Stokes equations and its exact and similarity solutions, laminar boundary layer theory, free-shear flows, and the phenomena of instability and transition to turbulence. Recommended prerequisite: ENME 2661.

ENME 4670 Advanced Computational Fluid Dynamics (4 Credits)
Building on the principles and applications of computational methods in fluid flow and topics chosen from heat transfer, mass transfer and two phase flow. Specifically, Monte Carlo and volume of fluid techniques are discussed at length. Additionally, students learn how to set up automated design optimization using the latest software packages. Time permitting, students also are introduced to fluid-solid interaction modeling. Prerequisite: ENME 3651.

ENME 4671 Convective Heat Transfer (4 Credits)
The objective of this course is to examine the physical phenomena associated with heat transfer in the presence of fluid flow. We will develop a mathematical description of the processes (fluid flow and heat transfer) for laminar and turbulent flows for both internal and external situations. Exposure to the fundamentals of fluid mechanics and heat transfer is expected before taking this course.

ENME 4800 Advanced Topics (ME) (0-5 Credits)
Determined by interest and demand. May be taken more than once for credit.

ENME 4900 Grad Professional Development (1 Credit)
This course is required for all MME MS graduate students and all MME PhD graduate students who enter with a BS or enter with an MS but fail their first qualifying exam. One of our objectives is for all graduating students to have good written and verbal communication skills. This course is set up to meet those objectives. During this course, students write a mini-proposal and/or literature review. Students follow guidelines for a funding agency (e.g. NSF or NIH) for the mini-proposal. If students have a research advisor, students can coordinate with their advisor. If students do not have a research advisor, students may pick a topic that most interests them. Both a written proposal and an oral presentation are required of all students. Graduate standing is required.

ENME 4950 Graduate Assessment (0 Credits)
This graduate assessment course is required for all MME graduate students to be taken in their last quarter. All required assessment materials are uploaded to DU Assessment to meet the course requirements. Students will receive emails through the DU Assessment system notifying you of what is required to be uploaded.

ENME 4991 Independent Study (1-10 Credits)

ENME 4995 Independent Research (1-16 Credits)

ENME 5991 Independent Study (1-10 Credits)

ENME 5995 Independent Research (1-16 Credits)

ENMT 3800 Topics (Mechatronics) (1-4 Credits)
Various topics in mechatronics system engineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENMT 3991 Independent study (1-5 Credits)
Topics in mechatronics engineering investigated under faculty supervision. May be taken more than once. Students must obtain and complete an Independent Study form from the Office of the Registrar. Prerequisite: permission of instructor.

ENMT 4000 Space Systems Design I (4 Credits)
The application of advanced theory and concepts as they relate to the development of spacecraft and missile subsystems, and how those subsystems are related under the umbrella of systems engineering. The course emphasizes practical aspects of space systems design and integration, and is team-taught by faculty and functional experts in the various fields. Lecture topics include aerospace materials, mechanics, thermal control, embedded systems, distributed sensor networks and aerospace probability and statistics.

ENMT 4010 Space Systems Design II (4 Credits)
The continuation of Space Systems Design I. Lecture topics include payload communications, guidance and control, spacecraft electric power, propulsion systems, radiation and avionics and sensor subsystems. Prerequisite: Space Systems Design I.

ENMT 4100 Systems Engineering (4 Credits)
Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design and manage complex systems over their life cycles. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge. Systems follow systems theory by having the design interface with its environment. System design typically follow the “V-diagram”, a serial process with structured verification occurring at each level of abstraction (system-subsystem-component hierarchy levels). The V-diagram traces the basic design process, starting with a problem, developing requirements, definitized with a concept of operations, and accomplishing a functional analysis and decomposition. Systems engineering takes a holistic approach to design, taking an idea to a concept and detail design. This includes a functional architecture and physical architecture, with particular attention paid to interfaces. Having built or procured components and developing software, the system is assembled and integrated. Verification and Validation is accomplished at each level of decomposition, starting at the lowest level and moving up to a system level that can be validated with the customer or shareholders. There are a series of milestones that are used to monitor the progress of the design. Instructor permission required.

ENMT 4225 System Models, Simulation & Tools (4 Credits)
A physical model is a smaller or larger physical copy of an object. Physical models allow visualization, from examining the model, of information about the thing the model represents. A model can be a physical object such as a spacecraft or spacecraft subsystem. Modeling and simulation are a key enabler for systems engineering activities as the system representation in a computer readable (and possibly executable) model enables engineers to reproduce the system (or Systems of System) behavior. Modeling is a tool for diagramming and understanding complex processes; Model-Based Systems Engineering (MBSE) is a powerful engine for design growth. It's endlessly adaptable to human needs and technological trends, unlocking incredible potential for analysis, and helping solve tomorrow's grand engineering challenges such as in aerospace. Physics-based models can be combine for use with equations of mathematical physics, coupled with real-time sensor measurements, and their numerical solution in an effort to understand complex design and operations.

ENMT 4270 Fundamentals of System Electrical, Mechanical and Software Design (4 Credits)
Design of individual electrical and mechanical components comprising a system. Comprehensive integrated approach making the transition from design of individual electrical/mechanical components into a complete electrical-mechanical system design. Topics include systems engineering of complex electronics (FPGAs, ASICs, Hybrids), electromagnetic compatibility, electromagnetic interference, electrical compatibility analysis, system power modeling and energy efficiency, electrical systems integration and test methodologies, mechanical system modeling, system thermal/stress analysis methods and tools, mass management, mechanical systems integration and test methodologies. Prerequisites: ENMT 4000, ENMT 4010, or permission by the Instructor. Course Requirements: Assignments and projects.

ENMT 4275 Applied System Electrical, Mechanical, and Software Design (4 Credits)
This is a practice-centered course. Assess case studies of design, implementation and testing, validation and verification of complete complex (e.g. spacecraft) systems to meet mission requirements with performance guarantees. Prerequisites: It is recommended that the elective course ENMT 4270 is taken first, or permission by the Instructor.

ENMT 4280 Design for Feasibility and Resilience (4 Credits)
A feasible design is an activity based on selected testing and engineering analysis, which presents enough information to determine whether or not the project should be advanced to the final design and production fabrication stage. In the fields of engineering, resilience is the ability to absorb or avoid damage without suffering complete failure and is an objective of the design. Resilience is described as the ability to return to the steady-state condition following a perturbation of the control behavior. When thinking about resilience, system engineering typically refer to this as an alternative (or as a complement) to the conventional view of safety. But resilience (or more accurately, the ability to perform in a resilient manner) is not about avoiding failures and breakdowns, i.e., it is not just the opposite of a lack of safety. This has led to early discussions about resilience versus robustness, resilience versus brittleness, etc. The focus of resilience engineering is thus resilient performance, rather resilience as a property (or quality) or resilience in a 'X versus Y' dichotomy. Students enrolling in this course should have knowledge of probability and statistics, familiarity with MATLAB/Simulink, or permission of the instructor.

ENMT 4285 Complex System Architectures, Models, and Tools (4 Credits)
The course focuses on mission requirements and how an overall mission should function by examining different architecture configurations and tools for modeling purposes. Example architecture models include: executable, networked, distributed, real-time, information assurance, framework, and reference. Students learn about development and allocation of functional and non-functional requirements and how to analyze architecture issues. Emphasis is on development of Service Oriented Architecture (SOA) solutions and ability to modeling and analysis using Systems Modeling Language (SysML). Prerequisites: ENMT 4100, or permission by the instructor. Course Requirements: Assignments and projects.

ENMT 4730 Advanced Ground Robotics (4 Credits)
Introduction to path planning and sensing and estimation for robotic manipulations and mobile robots. Review of the mathematical preliminaries required to support robot theory. Topics include advanced sensors, mobile robot mechanisms, advanced manipulator mechanisms, path planning in 2-D and 3-D, and simultaneous localization and mapping. Applications include task and motion planning for idealized and real robots.

ENMT 4800 Adv Topics (Mechatronics) (1-5 Credits)
Various topics in Mechatronics System Engineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENMT 4801 Adv Topics (Mechatronics) (1-5 Credits)
Various topics in Mechatronics System Engineering as announced. May be taken more than once. Prerequisite: varies with offering.

ENMT 4991 Independent Study (1-5 Credits)

ENMT 4995 Independent Research (1-18 Credits)

MTSC 3020 Composite Materials I (4 Credits)
An introduction to composite materials. Properties of fibers and matrices, fiber architecture, elastic properties of laminae and laminates, interface in composites. Cross listed with MTSC 4020. Prerequisites: ENME 2410 and ENME 2541.

MTSC 3800 Topics in Materials Science (1-5 Credits)
Various topics in materials science as announced. May be taken more than once. Prerequisite: varies with each topic.

MTSC 4020 Composite Materials I (4 Credits)
An introduction to composite materials. Properties of fibers and matrices, fiber architecture, elastic properties of laminae and laminates, interface in composites. Cross listed with MTSC 3020.

MTSC 4800 Advanced Topics (MTSC) (1-5 Credits)
Selected topics (depending on student and faculty interest): fracture mechanics, fatigue, nonlinear constitutive models, dynamic behavior of materials, corrosion resistant design, thermodynamics of solids II.

MTSC 4991 Independent Study (1-10 Credits)

MTSC 4995 Independent Research (1-16 Credits)

MTSC 5995 Independent Research (1-16 Credits)