DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The Department of Mechanical and Aerospace Engineering of the Case School of Engineering offers programs leading to bachelors, masters, and doctoral degrees. It administers the programs leading to the degrees of Bachelor of Science in Engineering with a major in Aerospace Engineering and Bachelor of Science in Engineering with a major in Mechanical Engineering. Both curricula are based on four-year programs of preparation for productive engineering careers or further academic training.

Mission

The mission of the Mechanical and Aerospace Engineering Department is to educate and prepare students at both the undergraduate and graduate levels for leadership roles in the fields of Mechanical Engineering and Aerospace Engineering and to conduct research for the benefit of society.

The undergraduate program emphasizes fundamental engineering science, analysis and experiments to insure that graduates will be strong contributors in their work environment, be prepared for advanced study at top graduate schools and be proficient lifelong learners. The graduate programs emphasize advanced methods of analysis, mathematical modeling, computational and experimental techniques applied to a variety of mechanical and aerospace engineering specialties including, applied mechanics, dynamic systems, robotics, biomechanics, fluid mechanics, heat transfer, propulsion and combustion. Leadership skills are developed by infusing the program with current engineering practice, design, and professionalism (including engineering ethics and the role of engineering in society) led by concerned educators and researchers.

The academic and research activities of the department center on the roles of mechanics, thermodynamics, heat and mass transfer, robotics, mechatronics, data analytics, sustainability in manufacturing, and engineering design in a wide variety of applications such as aeronautics, astronautics, biomechanics and orthopedic engineering, biomimetics and biologically-inspired robotics, energy, environment, machinery dynamics, mechanics of advanced materials, nanotechnology and tribology. Many of these activities involve strong collaborations with the Departments of Biology, Electrical Engineering and Computer Science, Materials Science and Engineering, and Orthopaedics of the School of Medicine.

The significant constituencies of the Mechanical and Aerospace Engineering Department are the faculty, the students, the alumni and the external advisory boards. The educational program objectives are established and reviewed continuously, based on the feedback from the various constituencies as well as archival information about the program graduates. The faculty engages in continuing discussions of the academic programs in the regularly scheduled faculty meetings throughout the academic year. Periodic surveys of alumni provide data regarding the preparedness and success of the graduates as well as guidance in program development. Archival data include the placement information for graduating seniors, which provides direct information regarding the success of the graduates in finding employment or being admitted to graduate programs.

Mastery of Fundamentals

- A strong background in the fundamentals of chemistry, physics and mathematics
- Methods of mechanical engineering analysis, both numerical and mathematical, applied to mechanics, dynamic systems and control, thermodynamics, fluid mechanics and heat transfer
- Methods of modern experimental engineering analysis and data acquisition

Creativity

- Ability to identify, model, and solve mechanical and aerospace engineering design problems
- Ability to design experiments to resolve mechanical and aerospace engineering issues
- Ability to perform an individual senior project that demonstrates original research and/or design content

Societal Awareness

- Issues of environmental impact, efficient use of energy and resources, benefits of recycling
- An awareness of the multidisciplinary nature of mechanical and aerospace engineering
- Impact of economic, product liability and other legal issues on mechanical and aerospace engineering manufacturing and design

Leadership Skills

- An ability to work in teams
- Ethical considerations in engineering decisions
- Proficiency in oral and written communication
- Professionalism
- Students are encouraged to develop as professionals through participation in the student chapters of the American Society of Mechanical Engineers (ASME) and the American Institute of Aeronautics and Astronautics (AIAA).
- Students are encouraged to augment their classroom experiences with the cooperative education program and the strong graduate research program of the department.
- Students are encouraged to take the Fundamentals of Engineering Examination as the first step in the process of becoming a registered professional engineer.
- The bachelor's candidate must complete an independent design project with an oral and written final report.
- The master's candidate must demonstrate independent research resulting in a thesis or project suitable for publication and/or presentation in peer reviewed journals and/or conferences.
- The doctoral candidate must complete a rigorous independent thesis containing original research results appropriate for publication in archival journals and presentation at leading technical conferences.

Aerospace Engineering

Aerospace engineering has grown dramatically with the rapid development of the computer in experiments, design and numerical analysis. The wealth of scientific information developed as a result of aerospace activity forms the foundation for the aerospace engineering major.

Scientific knowledge is being developed each day for programs to develop reusable launch vehicles (RLV), the International Space Station (ISS), High Speed Transport (HST), Human Exploration and Development of Space (HEDS) and micro-electro-mechanical sensors and control systems for advanced flight. New methods of analysis and design for structural, fluid, and thermodynamic applications are required to meet these challenges.

The aerospace engineering major has been developed to address the needs of those students seeking career opportunities in the highly specialized and advancing aerospace industries.

Mechanical Engineering

Civilization, as we know it today, depends on the intelligent and humane use of our energy resources and machines. The mechanical engineer's function is to apply science and technology to the design, analysis, development, manufacture, and use of machines that convert and transmit energy, and to apply energy to the completion of useful operations. The top ten choices of the millennium committee of the National Academy of Engineering, asked to select the 20 top engineering accomplishments of the 20th century, was abundant with mechanical engineering accomplishments, electrification (large scale power generation and distribution), automobiles, air travel (development of aircraft and propulsion), mechanized agriculture, and refrigeration and air conditioning.

Research

Aerospace Technology and Space Exploration

Flow in turbomachinery, molecular dynamics simulation of rarefied gas flow, two phase flow, supersonic combustion and propulsion, thermoacoustic refrigeration, in-situ resource utilization from space. Gravitational effects on transport phenomena, fluids and thermal processes in advance life support systems for long duration space travel, interfacial processes, g-jitter effects on microgravity flows, two phase flow in zero and reduced gravity.

Combustion and Fire Engineering

Hydrogen ignition and safety, catalytic combustion, flame spread, fire research and protection, combustion in micro- and partial gravity.

Data Analytics

Multi-domain signal decomposition and analysis, wavelet transform and other transformation methods, data fusion, stochastic modeling and statistical methods for defect detection, root cause diagnosis, and remaining service life prognosis, multi-scale analysis.

Dynamics of Rotating Machinery

Forced and instability vibration of rotor/bearing/seal systems, nonlinear rotor dynamics, torsional rotor vibration, rotor dynamic characteristics of bearings and seals (computational and experimental approach), control of rotor system dynamics, rub-impact studies on bearings and compressor/turbine blading systems. Advanced rotating machinery monitoring and diagnostics.

Engineering Design

Optimization and computer-aided design, feasibility studies of kinematic mechanisms, kinematics of rolling element-bearing geometries, mechanical control systems, experimental stress analysis, failure analysis, development of biologically inspired methodologies.

Heat Transfer

Analysis of heat transfer in complex systems such as biological organisms, multi-functional materials and building enclosures.

Sustainable and Additive Manufacturing

Modeling, characterization and manufacturing of next-generation lithium ion batteries for electric vehicles and perovskite solar cells for low-cost solar power generation, multiphysics electrochemistry modeling, atomic layer deposition, scalable nano-manufacturing, life cycle assessment of lithium ion batteries on environmental sustainability, agile manufacturing work cells based on coordinated, multiple robots, additive manufacturing, in-process sensing and control.

Materials

Development of novel experimental techniques to investigate material response at elevated temperatures and high rates of deformation. Constitutive modeling of damage evolution, shear localization and failure of advanced engineering materials. Fabrication of mechanical properties of composite materials; creep, rupture, and fatigue properties of engineering materials at elevated temperatures.

Multiphase Flow

Application of non-intrusive laser based diagnostic techniques and ultrasound techniques including pulsed ultrasound Doppler velocimetry to study solid-liquid, solid-gas, liquid-gas and solid-liquid-gas, multiphase flows encountered in slurry transport and bio-fluid mechanics.

Nanotechnology

Research related to various nanotechnology applications with particular emphasis on energy conversion, generation and storage in nanostructured materials including the synthesis of polymer-based nanocomposites. Current research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, and biomimetic research on protein-based shark gel.

Musculoskeletal Mechanics and Materials

Design, modeling, and failure analysis of orthopaedic prostheses and material selection; mechanical properties of, and transport processes in, bone and soft tissue; tribology of native and tissue engineered cartilage; nondestructive mechanical evaluation of tissue engineered cartilage.

Robotics

Biologically inspired and biologically based design and control of legged robots. Dynamics, control and simulation of animals and robots. Distributed intelligence, swarm robotics, social robots, wearable telesensors, and tangible game interface.

Sensing and Metrology

Signal transduction mechanisms, design, modeling, functional characterization, and performance evaluation of mechanical, thermal, optical, and magnetic-field sensors, multi-physics sensing, and precision instrumentation.

Tribology and Seals

Time-resolved friction on nano- and microsecond time scale with applications to high speed machining and mechanics of armor penetration. Study of gas lubricated foil bearing systems with application to oil-free turbomachinery. Evaluation of advanced seal concepts and configurations for high temperature applications in gas turbine engines.

Turbomachinery

Vibration characteristics of seals and bearings and measurement of chaotic motion. Rub impact studies of blade tip/casing interactions, particle-blade/casing interactions in centrifugal pumps.

Faculty

Robert X. Gao, PhD
(Technical University of Berlin, Germany)
Cady Staley Professor of Engineering and Department Chair
Signal transduction, mechatronic systems, acoustics, wavelet transform, stochastic modeling, sensors and sensor networks

Ozan Akkus, PhD
(Case Western Reserve University)
Leonard Case Jr. Professor of Engineering
Nano biomechanics, biomedical devices, biomaterials, fracture mechanics

Richard J. Bachmann, PhD
(Case Western Reserve University)
Assistant Professor
Biologically inspired robotics

Paul Barnhart, PhD, PE
(Case Western Reserve University)
Professor
Aerospace engineering, aerospace design

Sunniva Collins, PhD, FASM
(Case Western Reserve University)
Associate Professor, Director of Undergraduate Studies and Online Programs
Design for manufacturing, steel metallurgy, heat treatment, surface engineering, fatigue analysis, fatigue of metals, welding, material analytical methods

Malcolm N. Cooke, PhD
(Case Western Reserve University)
Associate Professor
Advanced manufacturing systems, computer integrated manufacturing

Kathryn Daltorio, PhD
(Case Western Reserve University)
Assistant Professor
Biologically-inspired robotics, control, learning, kinetics, and kimematics for robots design

Umut A. Gurkan, PhD
(Purdue University)
Associate Professor
Micro-and nano-scale technologies, biomanufacturing, cell mechanics, and microfluidics

Yasuhiro Kamotani, PhD
(Case Western Reserve University)
Professor
Experimental fluid dynamics, heat transfer, microgravity fluid mechanics

Chirag Kharangate, PhD
(Purdue University)
Assistant Professor
Thermal management, two-phase flows, computational fluid dynamics, microgravity

Kiju Lee, PhD
(John Hopkins University)
Nord Distinguished Assistant Professor
Robotics, distributed system design and control, modular robotics, multi-body dynamical systems

Bo Li, PhD
(California Institute of Technology)
Assistant Professor
Solid and computational mechanics, meshfree methods, failure processes in solids, biomechanics, thermal-fluid structure interaction and high performance computing

Ya-Ting T. Liao, PhD
(Case Western Reserve University)
Assistant Professor
Fire dynamics, computational fluid dynamics, thermal fluids

Brian Maxwell, PhD
(University of Ottawa, Canada)
Assistant Professor
Detonations, Turbulent combustion, Compressible and reactive flows

Vikas Prakash, PhD
(Brown University)
Professor
Experimental and computational solid mechanics, dynamic deformation and failure, time resolved high-speed friction, nanomechanics, energy storage

Roger D. Quinn, PhD
(Virginia Polytechnic Institute & State University)
Arthur P. Armington Professor of Engineering
Biologically inspired robotics, agile manufacturing systems, structural dynamics, vibration and control

Clare M. Rimnac, PhD
(Lehigh University)
Wilbert J. Austin Professor of Engineering
Biomechanics; fatigue and fracture mechanics

Fumiaki Takahashi, PhD
(Keio University)
Professor
Combustion, fire science and engineering

Yingchun (Chris) Yuan, PhD
(University of California at Berkeley)
Professor
Sustainable manufacturing, lithium ion battery, modeling and characterization for energy storage

Research Faculty

Alexis Abramson, PhD
(University of California at Berkeley)
Research Professor
Macro/micro/nanoscale heat transfer and energy transport

R. Balasubramaniam, PhD
(Case Western Reserve University)
Research Associate Professor, National Center for Space Exploration Research
Microgravity fluid mechanics

Uday Hegde, PhD
(Georgia Institute of Technology)
Research Associate Professor, National Center for Space Exploration Research
Combustion, turbulence and acoustics

Mohammad Kassemi, PhD
(University of Akron)
Research Professor, National Center for Space Exploration Research
Computational fluid mechanics

Vedha Nayagam, PhD
(University of Kentucky)
Research Associate Professor, National Center for Space Exploration Research
Low gravity combustion and fluid physics

Associated Faculty

James Drake, BSE
(Case Western Reserve University)
Adjunct Instructor
Manufacturing processes

Kenneth Loparo, PhD
(Case Western Reserve University)
Professor of Electrical Engineering and Computer Science
Control; robotics; stability of dynamical systems; vibrations

David Matthiesen, PhD
(Massachusetts Institute of Technology)
Associate Professor of Materials Science Engineering
Microgravity crystal growth

Wyatt S. Newman, PhD
(Massachusetts Institute of Technology)
Professor of Electrical Engineering and Computer Science
Mechatronics; high-speed robot design; force and vision-bases machine control; artificial reflexes for autonomous machines; rapid prototyping; agile manufacturing

Mario Garcia Sanz, PhD
(University of Navarra)
Professor of Electrical Engineering and Computer Science
Systems and control, spacecraft controls, automated manufacturing

Ravi Vaidyanathan, PhD
(Case Western Reserve University)
Adjunct Assistant Professor; Imperial College
Robotics and control

Xiong Yu, PhD, PE
(Purdue University)
Associate Professor
Geotechnical engineering, non-destructive testing, intelligent infrastructures

Emeritus Faculty

Maurice L. Adams, PhD
(University of Pittsburgh)
Professor Emeritus
Dynamics of rotating machinery, nonlinear dynamics, vibration, tribology, turbomachinery

Dwight T. Davy, PhD, PE
(University of Iowa)
Professor Emeritus
Musculo-skeletal biomechanics; applied mechanics

Isaac Greber, PhD
(Massachusetts Institute of Technology)
Professor Emeritus
Fluid dynamics; molecular dynamics and kinetic theory; biological fluid mechanics; acoustics

Jaikrishnan R. Kadambi, PhD
(University of Pittsburgh)
Professor Emeritus
Experimental fluid mechanics, laser diagnostics, bio-fluid mechanics, turbomachinery

Thomas P. Kicher, PhD
(Case Institute of Technology)
Arthur P. Armington Professor Emeritus of Engineering
Elastic stability; plates and shells; composite materials; dynamics; design; failure analysis

Joseph M. Mansour, PhD
(Rensselaer Polytechnic Institute)
Professor Emeritus
Biomechanics and applied mechanics

Eli Reshotko, PhD
(California Institute of Technology)
Kent H. Smith Emeritus Professor of Engineering
Fluid Dynamics; heat transfer, propulsion; power generation

James S. Tien, PhD
(Princeton University)
Professor Emeritus
Combustion, propulsion, and fire research

Undergraduate Programs

Bachelor of Science in Engineering

Program Educational Objectives: Aerospace Engineering

- Graduates will enter and successfully engage in careers in Aerospace Engineering and other professions appropriate to their background, interests, and skills.

- Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.
- Graduates will develop as leaders in their chosen professions.

Program Educational Objectives: Mechanical Engineering

- Graduates will enter and successfully engage in careers in Mechanical Engineering and other professions appropriate to their background, interests, and skills.
- Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.
- Graduates will develop as leaders in their chosen professions.

Student Outcomes

- An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering science and mathematics
- 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
- An ability to communicate effectively with a range of audiences
- 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
- 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
- An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- An ability to acquire and apply new knowledge as needed, using appropriate learning strategies
- The Bachelor of Science in Engineering degree program with a major in Aerospace Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

The Bachelor of Science in Engineering degree program with a major in Mechanical Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Bachelor of Science in Engineering

Major in Aerospace Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

Major Courses		
EMAE 160	Mechanical Manufacturing	3
EMAE 181	Dynamics	3
EMAE 250	Computers in Mechanical Engineering	3
EMAE 251	Thermodynamics	3
EMAE 252	Fluid Mechanics	3
EMAE 285	Mechanical Engineering Measurements Laboratory	4
EECS 304	Control Engineering I with Laboratory	3
ECIV 310	Strength of Materials	3
EMAE 350	Mechanical Engineering Analysis	3
EMAE 353	Heat Transfer	3
EMAE 355	Design of Fluid and Thermal Elements	3
EMAE 359	Aero/Gas Dynamics	3
EMAE 376	Aerostructures	3
EMAE 383	Flight Mechanics	3
EMAE 384	Orbital Dynamics	3
EMAE 356	Aerospace Design	3
EMAE 382	Propulsion	3
EMAE 398	Senior Project	3
One Technical Elective		3
For the Engineering Core natural science and math requirement		
PHYS 221	Introduction to Modern Physics	3
Total Units		61

Technical Electives by Program

- All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, EECS all, EECS cross-listed, EMAC all, EMSE all, EMSE cross-listed
- All 300- and 400-level courses in ECHE
- All 300-level MATH and STAT courses with the concurrence of the advisor

Bachelor of Science in Engineering
Suggested Program of Study: Major in Aerospace Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)[**,d]	4	
Calculus for Science and Engineering I (MATH 121)[**,d]	4	
General Physics I - Mechanics (PHYS 121)[**,d]	4	
First Seminar (FSCC 100)[*]	4	
PHED (two half semester classes)*		
Calculus for Science and Engineering II (MATH 122)[**,d]		4
General Physics II - Electricity and Magnetism (PHYS 122)[**,d]		4
Chemistry of Materials (ENGR 145)[**,d]		4
Elementary Computer Programming (ENGR 131)[**,d]		3
SAGES University Seminar[*,d]		3
Year Total:	16	18

Second Year	Units	
	Fall	Spring
Mechanical Manufacturing (EMAE 160)[d]	3	
Statics and Strength of Materials (ENGR 200)[**,d]	3	
Calculus for Science and Engineering III (MATH 223)[**,d]	3	
Computers in Mechanical Engineering (EMAE 250)[d]	3	
SAGES University Seminar[*,d]	3	
Introduction to Circuits and Instrumentation (ENGR 210)[**,d]		4
Introduction to Modern Physics (PHYS 221)[**,d]		3
Elementary Differential Equations (MATH 224)[**,d]		3
Dynamics (EMAE 181)[d]		3
Thermodynamics (EMAE 251)		3
Year Total:	15	16

Third Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Mechanical Engineering Measurements Laboratory (EMAE 285)[d]	4	
Fluid Mechanics (EMAE 252)	3	
Strength of Materials (ECIV 310)[d]	3	
Mechanical Engineering Analysis (EMAE 350)	3	
Breadth elective[**,d]		3
Aero/Gas Dynamics (EMAE 359)		3
Aerostructures (EMAE 376)		3
Control Engineering I with Laboratory (EECS 304)		3
Heat Transfer (EMAE 353)		3
Year Total:	16	15

Fourth Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Design of Fluid and Thermal Elements (EMAE 355)[d]	3	
Flight Mechanics (EMAE 383)	3	
Orbital Dynamics (EMAE 384)	3	
Open Elective[d]	3	
Breadth elective[**,d]		3
Aerospace Design (EMAE 356)		3
Propulsion (EMAE 382)		3
Senior Project (EMAE 398)[d]		3
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)[**,d]		3
Technical Elective[d]		3
Year Total:	15	18

Total Units in Sequence:	129

Hours required for graduation: 129

*	University general education requirement
**	Engineering general education requirements
d	May be taken fall or spring semester.

Bachelor of Science in Engineering

Major in Mechanical Engineering

In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatestudies/csedegree) and university general education requirements (http://bulletin.case.edu/undergraduatestudies/degreeprograms), the major requires the following courses:

Major Courses		
EMAE 160	Mechanical Manufacturing	3
EMAE 181	Dynamics	3
EMAE 250	Computers in Mechanical Engineering	3
EMAE 251	Thermodynamics	3
EMAE 252	Fluid Mechanics	3
EMAE 260	Design and Manufacturing I	3
EMAE 285	Mechanical Engineering Measurements Laboratory	4
EECS 304	Control Engineering I with Laboratory	3
ECIV 310	Strength of Materials	3
EMAE 350	Mechanical Engineering Analysis	3
EMAE 353	Heat Transfer	3
EMAE 355	Design of Fluid and Thermal Elements	3
EMAE 360	Design and Manufacturing II	3
EMAE 370	Design of Mechanical Elements	3
EMAE 398	Senior Project	3
Four Technical Electives		12
Total Units		58

Technical Electives by Program

- All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, EECS all, EECS cross-listed, EMAC all, EMSE all, EMSE cross-listed
- All 300- and 400-level courses in ECHE
- All 300-level MATH and STAT courses with the concurrence of the advisor

Science Electives for Mechanical Engineering Majors

The Student Information System is currently set up to accept PHYS 221 Introduction to Modern Physics or STAT 312 Basic Statistics for Engineering and Science as a science elective. Other courses for individual students can be selected with the approval of the student's advisor and the chair using an Academic Advisement Requirement Form (https://case.edu/ugstudies/media/caseedu/undergraduate-studies/forms--applications/advisement-report-correction.pdf).

Bachelor of Science in Engineering

Suggested Program of Study: Major in Mechanical Engineering

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu).

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)[**,d]	4	
Calculus for Science and Engineering I (MATH 121)[**,d]	4	
General Physics I - Mechanics (PHYS 121)[**,d]	4	
First Seminar (FSCC 100)[*]	4	
PHED (two half semester classes)[*]		
Calculus for Science and Engineering II (MATH 122)[**,d]		4
General Physics II - Electricity and Magnetism (PHYS 122)[**,d]		4
Elementary Computer Programming (ENGR 131)[**,d]		3
Chemistry of Materials (ENGR 145)[**,d]		4
SAGES University Seminar[*]		3
Year Total:	16	18

Second Year	Units	
	Fall	Spring
Mechanical Manufacturing (EMAE 160)[d]	3	
Statics and Strength of Materials (ENGR 200)[**,d]	3	
Calculus for Science and Engineering III (MATH 223)[**,d]	3	
Computers in Mechanical Engineering (EMAE 250)[d]	3	
SAGES University Seminar[*,d]	3	
Introduction to Circuits and Instrumentation (ENGR 210)[**,d]		4
Elementary Differential Equations (MATH 224)[**,d]		3
Dynamics (EMAE 181)[d]		3
Thermodynamics (EMAE 251)		3
Science Elective[**,d]		3
Year Total:	15	16

Third Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Mechanical Engineering Measurements Laboratory (EMAE 285)[d]	4	
Fluid Mechanics (EMAE 252)	3	
Strength of Materials (ECIV 310)[d]	3	
Mechanical Engineering Analysis (EMAE 350)	3	
Breadth elective[**,d]		3
Technical Elective[d]		3
Design and Manufacturing I (EMAE 260)[d]		3
Control Engineering I with Laboratory (EECS 304)		3
Design of Mechanical Elements (EMAE 370)		3
Heat Transfer (EMAE 353)		3
Year Total:	16	18

Fourth Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Design of Fluid and Thermal Elements (EMAE 355)[d]	3	
Design and Manufacturing II (EMAE 360)	3	
Open Elective[d]	3	
Technical Elective[d]	3	
Breadth elective[**,d]		3
Technical Elective[d]		3
Technical Elective[d]		3
Senior Project (EMAE 398)[d]		3
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)[**]		3
Year Total:	15	15

Total Units in Sequence:		129

Hours required for graduation: 129

*	University general education requirement
**	Engineering general education requirement
d	May be taken fall or spring semester.

Double Major Mechanical and Aerospace Engineering

The department also offers a double major in Mechanical and Aerospace Engineering. Students completing this plan of study meet the requirements for both the Aerospace Engineering program and the Mechanical Engineering program. The course selection details are provided in the course listing section.

Suggested Program of Study: Double Major in Mechanical and Aerospace Engineering

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)[**,d]	4	
Calculus for Science and Engineering I (MATH 121)[**,d]	4	
General Physics I - Mechanics (PHYS 121)[**,d]	4	
First Seminar (FSCC 100)[*]	4	
PHED (two half semester classes)[*]		
Calculus for Science and Engineering II (MATH 122)[**,d]		4
General Physics II - Electricity and Magnetism (PHYS 122)[**,d]		4
Elementary Computer Programming (ENGR 131)[**,d]		3
Chemistry of Materials (ENGR 145)[**,d]		4
SAGES University Seminar[*,d]		3
Year Total:	16	18

Second Year	Units	
	Fall	Spring
Mechanical Manufacturing (EMAE 160)[d]	3	
Statics and Strength of Materials (ENGR 200)[**,d]	3	
Calculus for Science and Engineering III (MATH 223)[**,d]	3	
Computers in Mechanical Engineering (EMAE 250)[d]	3	
SAGES University Seminar[*,d]	3	
Introduction to Circuits and Instrumentation (ENGR 210)[**,d]		4
Introduction to Modern Physics (PHYS 221)[**,d]		3
Elementary Differential Equations (MATH 224)[**,d]		3
Dynamics (EMAE 181)		3
Thermodynamics (EMAE 251)		3
Year Total:	15	16

Third Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Mechanical Engineering Measurements Laboratory (EMAE 285)[d]	4	
Fluid Mechanics (EMAE 252)	3	
Strength of Materials (ECIV 310)[d]	3	
Mechanical Engineering Analysis (EMAE 350)	3	
Design and Manufacturing I (EMAE 260)[d]		3
Heat Transfer (EMAE 353)		3
Aero/Gas Dynamics (EMAE 359)		3
Design of Mechanical Elements (EMAE 370)		3
Aerostructures (EMAE 376)		3
Control Engineering I with Laboratory (EECS 304)		3
Year Total:	16	18

Fourth Year	Units	
	Fall	Spring
Breadth elective[**,d]	3	
Flight Mechanics (EMAE 383)	3	
Orbital Dynamics (EMAE 384)	3	
Design of Fluid and Thermal Elements (EMAE 355)[d]	3	
Design and Manufacturing II (EMAE 360)	3	
Aerospace Design (EMAE 356)		3
Propulsion (EMAE 382)		3
Senior Project (EMAE 398)[**,d]		3
Professional Communication for Engineers (ENGR 398) & Professional Communication for Engineers (ENGL 398)[**]		3
Breadth elective[**,d]		3
Breadth elective[*,d]		3
Year Total:	15	18

Total Units in Sequence:		132

Hours required for graduation: 132

*	University general education requirement
**	Engineering general education requirement
d	May be taken fall or spring semester.

Cooperative Education (http://engineering.case.edu/coop)

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at engineering.case.edu/coop. Alternatively or additionally, students may obtain employment as summer interns.

BS/MS Program

The combined bachelors/masters program allows a student to double count 9 credit hours of graduate course work towards the Bachelor of Science in Engineering degree in any one of the department's two degree programs. By completing the remaining graduate credit hours and a thesis, a student may earn a Master of Science degree in mechanical or aerospace engineering. This typically takes 5 years or slightly longer. Application to this program is initiated in the spring of the junior year with the department's graduate student programs office. A minimum grade point of 3.2 is required for consideration for this accelerated program. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/#accerlerationtowardgraduatedegreestext).

BS/MS Academic Program Details

The current regulations for the MS degree by the School of Graduate Studies (http://www.case.edu/provost/gradstudies) require a minimum of 18 credit hours of coursework at the 400-level (or higher). Please note that any 400-level course taken prior to admission to the BS/MS Program cannot typically be counted as part of the MS degree. However, EMAE 398 Senior Project may be included in the double counted credit hours toward the MS Thesis, if appropriate.

Follow the links below to learn more about the components of the BS/MS Program.

- BS/MS Application Process (https://engineering.case.edu/emae/bs-ms/application-process)
- BS/MS Thesis Project (https://engineering.case.edu/emae/bs-ms/thesis)
- BS/MS Financial Aid (https://engineering.case.edu/emae/bs-ms/financial-aid)
- BS/MS Graduation (https://engineering.case.edu/emae/bs-ms/graduation)

If you have additional questions, please contact either:

- Professor Kiju Lee kiju.lee@case.edu

- Student Affairs Coordinator Carla Wilson cxw75@case.edu

Master of Engineering and Management Program

Another option is the 5 year TiME Program taught in conjunction with the Weatherhead School of Management in which a student completes a BS in Aerospace or Mechanical Engineering and earns a Master of Engineering and Management.

Minor in Mechanical Design and Manufacturing

A minor in Mechanical Design and Manufacturing is offered to students in other departments with an interest in design and manufacturing. The minor consists of an approved set of five EMAE courses.

Required Courses:		
EMAE 160	Mechanical Manufacturing	3
EMAE 260	Design and Manufacturing I	3
EMAE 370	Design of Mechanical Elements	3
		9
Two of the following:		6
EMAE 290	Computer-Aided Manufacturing	3
EMAE 372	Structural Materials by Design	4
EMAE 390	Advanced Manufacturing Technology	3
EMAE 397	Independent Laboratory Research (can be used as an elective in this minor sequence under the following conditions)	1 - 3
1). Student writes a one-page proposal clearly explaining how the project involves mechanical design and/or manufacturing at an advanced undergraduate level.		
2). The proposal is approved by both the student's major advisor, and the EMAE advisor for the mechanical design and manufacturing minor.		
Total Units		15

Graduate Programs

Master of Science in Aerospace Engineering or Mechanical Engineering

Research- or Project-Focused Track

For a thesis-focused MS, each candidate must complete a minimum of 30 hours of graduate-level credits, including at least 21 hours of graduate-level courses and 9 credit hours of MS thesis research.

For the project-focused MS option, students must complete 30 credit hours distributed in either of three ways: 24, 27 or 30 credit hours (8, 9 or 10 courses) of approved graduate course work and 6, or 3 credit hours of project replacing the MS thesis.

For a course-focused MS option, requirements consist of the completion of 30 hours of approved coursework at the 400 level or higher, satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student's curricular program, and additional requirements as specified by the program. Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

List of Required Graduate Courses

Depending on the area of interest, students should select courses from this list with the approval of their advisor. Courses with double asterisks are required for the specific track.

I. Biomechanics

EMAE 414	Nanobiomechanics in Biology	3
EMAE 415	Introduction to Musculo-skeletal Biomechanics **	3
EMAE 456	Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS) **	3
EMAE 466	Mechanics of Biological Fluids	3
EMAE 480	Fatigue of Materials	3

II. Dynamics, Control and Manufacturing

EECS 475	Applied Control **	3
EMAE 481	Advanced Dynamics I **	3
EMAE 487	Vibration Problems in Engineering **	3
EMAE 488	Advanced Robotics	3
EMAE 540	Advanced Dynamics II	3
EMAE 560	Sustainable Manufacturing **	3

III. Fluids and Thermal Sciences

EMAE 453	Advanced Fluid Dynamics I **	3
EMAE 454	Advanced Fluid Dynamics II	3
EMAE 455	Advanced Thermodynamics **	3
EMAE 457	Combustion	3
EMAE 459	Advanced Heat Transfer **	3
EMAE 471	Computational Fluid Dynamics	3

IV. Solid Mechanics

ECIV 411	Elasticity, Theory and Applications **	3
ECIV 420	Finite Element Analysis **	3
EMAE 401	Mechanics of Continuous Media **	3
EMAE 689	Special Topics	1 - 18

V. Online and other Courses

EMAE 450	Advanced Mechanical Engineering Analysis	3
EMAE 460	Theory and Design of Fluid Power Machinery	3
EMAE 461	Chemistry of Fire Safe Polymers and Composites	3
EMAE 494	Energy Systems	3

** *Required courses for the given track*

In addition, a BS/MS program and a 5-year BS/MEM (Master of Engineering Management) are also offered for our undergraduate students as indicated in the preceding section.

A Master of Science in Mechanical Engineering is also available exclusively online. Visit http://online-engineering.case.edu/mechanical/ for more details.

Master of Engineering

The Department of Mechanical and Aerospace Engineering participates in the practice-oriented Master of Engineering Program offered by the Case School of Engineering. In this program, students complete a core program consisting of five courses and select a four-course sequence in an area of interest.

The Master of Engineering degree is also available exclusively online. Visit http://online-engineering.case.edu/masters for more details.

Master of Science in Mechanical Engineering with Specialization

Fire Science and Engineering

The Case School of Engineering at Case Western Reserve University offers an MS graduate program in Fire Science and Engineering. Students will choose either a Master of Science in Mechanical Engineering or a Master of Science in Macromolecular Science and Engineering, both with a concentration in fire science. Case Western Reserve offers a unique intersection of expertise in macromolecular and combustion science and mechanical and chemical engineering, making us singularly suited to cover all aspects of fire protection, safety, and flammability.

Through a 30-credit-hour curriculum, students explore and learn how to apply the fundamental principles of fire behavior and dynamics, protection and suppression systems, polymeric materials structure, properties and selection and more. The program is designed to be completed in 12 months, but can be spread out over multiple years.

The Fire Science and Engineering program at Case Western Reserve covers all aspects of combustion and fire suppression. After graduating from this degree program, students will be ready to apply their thorough understanding of:

- The chemistry of fire and materials
- Flammability logistics
- Fire dynamics and fire behavior
- Fire risk assessment
- Fire protection engineering
- Combustion
- Fire and safety-related codes
- Human behavior and life safety analysis
- Structural fire protection
- Passive fire protection systems
- Polymer engineering

Elective tracks:

- Mechanical Engineering track to focus on mechanical engineering and combustion related to fire protection and suppression
- Macromolecular Science and Engineering track to focus on polymer chemistry and materials, and the chemistry of flammability and fire suppression

Degree Options

The Fire Science and Engineering master's degree program comprises 30 credit hours, which may be all coursework or include an MS thesis (9 credit hours) or a project (3 to 6 credit hours). Students can choose to receive a Master of Science in Mechanical Engineering with a concentration in Fire Science and Engineering, or a Master of Science in Macromolecular Science and Engineering with a concentration in Fire Science and Engineering.

Six core fire protection engineering courses are required. Other courses can be chosen from the elective track for mechanical engineering or macromolecular science and engineering. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers. The macromolecular science and engineering track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression.

The degree can be finished in one year or in multiple years. Students have the option of completing a thesis or research project at their employers' laboratories with Case Western Reserve faculty members as co-advisors.

This fire protection engineering degree is offered over three semesters: 12 credits in the fall semester; 12 credits in the spring semester; and 6 credits in the summer. See the university's academic calendar (https://case.edu/registrar/dates-deadlines/academic-calendar).

Core Course Requirements

EMAC 404	Polymer Foundation Course IV: Engineering	3
EMAE 457	Combustion	3
EMAC 461	Chemistry of Fire Safe Polymers and Composites	3
or EMAE 461	Chemistry of Fire Safe Polymers and Composites	
EMAC 463	Fire Dynamics	3
or EMAE 463	Fire Dynamics	
EMAC 464	Fire Protection Engineering	3
or EMAE 464	Fire Protection Engineering	

Elective Tracks

Elective Track I: Mechanical Engineering

Choose 3 or more courses from the following:

EMAE 453	Advanced Fluid Dynamics I	3
EMAE 459	Advanced Heat Transfer	3
EMAE 558	Conduction and Radiation	3
ECIV 424	Structural Dynamics	3

Elective Track II: Macromolecular Science and Engineering

Choose 3 or more courses from the following:

EMAC 401	Polymer Foundation Course I: Organic Chemistry	3
EMAC 402	Polymer Foundation Course II: Physical Chemistry	3
EMAC 403	Polymer Foundation Course III: Physics	3
EMAC 405	Polymer Characterization Laboratory	3

Minimum requirements for the MS degree with the Fire Science and Engineering concentration are:

Thesis-Focused Track

1. Completion of at least 18 hours of graduate coursework at or above the 400 level. The coursework should consist of the following:

- Two of the three core courses from the Fluids and Thermal Sciences area in Mechanical and Aerospace Engineering.
- Four of the six core courses from the Fire Science and Engineering concentration.

2. Completion of nine hours of thesis work culminating in a thesis examination given by at least three professors, plus approval by the chair of the department offering the degree.

3. Completion of another three credit hours of MS thesis, or taking a three-credit-hour graduate class, or taking the 1 credit seminar course for 3 semesters.

Project-Focused Track

Completion of at least 30 hours of graduate coursework at or above the 400 level. The coursework should consist of the following:

- Two of the three core courses from the Fluids and Thermal Sciences area in Mechanical and Aerospace Engineering.
- Six of the six core courses from the Fire Science and Engineering concentration. Among these courses, up to two can be replaced by Special Problem coursework (i.e. project).
- The Special Problem topic needs to be in Fire Science and Engineering field and be approved by the chair of the department offering the degree. The Special Problem course may be carried out at the student's place of employment with nominal supervision by a faculty advisor or in the school's laboratories under direct supervision.
- One additional course at or above the 400 level. Students should consult their advisor regarding selection of this course.
- Completion of another three credit hours of MS thesis, or taking a three-credit-hour graduate class, or taking the 1 credit seminar course for 3 semesters.

For additional information, please contact:

Gary Wnek, Chair of the Department of Macromolecular Science and Engineering

Ya-Ting Liao, Assistant Professor in the Department of Mechanical and Aerospace Engineering

Learn more about the faculty who teach these courses. (http://engineering.case.edu/fire/faculty)

How to Apply

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to know whether they wish to apply for the MS in Mechanical Engineering or the MS in Macromolecular Science and Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements here (http://www.case.edu/gradstudies/prospective-students/admissions-information).

When you are ready to apply, electronic applications can be submitted here (https://app.applyyourself.com/AYApplicantLogin/fl_ApplicantConnectLogin.asp?id=case-gr).

Doctor of Philosophy Program

Students wishing to pursue the doctoral degree in mechanical and aerospace engineering must successfully pass the doctoral qualifying examination consisting of both written and oral components. Qualifying exams are offered on applied mechanics, dynamics and design or fluid and thermal engineering sciences. Students can choose to take it in the fall or spring semesters. The minimum course requirements for the PhD degree are as follows:

Depth Courses

All programs of study must include 6 graduate level mechanical courses in mechanical engineering or aerospace engineering. Usually, these courses follow a logical development of a branch of mechanics, dynamics, and design or fluid and thermal engineering science determined in conjunction with the student's dissertation advisor to meet the objectives of the dissertation research topic.

Breadth and Basic Science Courses

A minimum of six graduate courses are required to fulfill the breadth and basic science courses. The basic science requirement is satisfied by taking two courses in the area of science and mathematics. Four additional courses are needed to provide the breadth outside the student's area of research.

Dissertation Research

All doctoral programs must include a minimum of 18 credit hours of thesis research, EMAE 701 Dissertation Ph.D.

List of Required Ph.D. Courses

Courses in bold are required for the specific track.

I. Biomechanics

EMAE 414	Nanobiomechanics in Biology	3
EMAE 415	Introduction to Musculo-skeletal Biomechanics	3
EMAE 456	Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS)	3
EMAE 466	Mechanics of Biological Fluids	3
EMAE 480	Fatigue of Materials	3

II. Dynamics, Control and Manufacturing

EECS 475	Applied Control	3
EMAE 481	Advanced Dynamics I	3
EMAE 487	Vibration Problems in Engineering	3
EMAE 488	Advanced Robotics	3
EMAE 540	Advanced Dynamics II	3
EMAE 560	Sustainable Manufacturing	3

III. Fluids and Thermal Sciences

EMAE 453	Advanced Fluid Dynamics I	3
EMAE 454	Advanced Fluid Dynamics II	3
EMAE 455	Advanced Thermodynamics	3
EMAE 457	Combustion	3

EMAE 459	Advanced Heat Transfer	3
EMAE 471	Computational Fluid Dynamics	3

IV. Solid Mechanics

ECIV 411	Elasticity, Theory and Applications	3
ECIV 420	Finite Element Analysis	3
EMAE 401	Mechanics of Continuous Media	3
EMAE 501	Constitutive Modeling of Solids	3
EMAE 689	Special Topics	1 - 18

V. Online and other Courses

EMAE 450	Advanced Mechanical Engineering Analysis	3
EMAE 460	Theory and Design of Fluid Power Machinery	3
EMAE 461	Chemistry of Fire Safe Polymers and Composites	3
EMAE 494	Energy Systems	3

Residence and Teaching Requirements

All doctoral programs must meet the residency requirements of the School of Graduate Studies and the teaching requirements of the Case School of Engineering.

Facilities

The education and research philosophy of the Department of Mechanical and Aerospace Engineering for both the undergraduate and graduate programs is based on a balanced operation of analytical, experimental, and computational activities. All three of these tools are used in a fundamental approach to the professional activities of research, development, and design. Among the major assets of the department are the experimental facilities maintained and available for the faculty, students, and staff.

The introductory undergraduate courses are taught through the Robert M. Ward '41 Laboratory, the Bingham Student Workshop, the Reinberger Product and Process Development Laboratory, and the Reinberger Design Studio. The Ward Laboratory is modular in concept and available to the student at regularly scheduled class periods to conduct a variety of prepared experimental assignments. The lab is equipped with a variety of instruments ranging from classic analog devices to modern digital computer devices for the collection of data and the control of processes. Advanced facilities are available for more specialized experimental tasks in the various laboratories dedicated to each specific discipline. Most of these laboratories also house the research activities of the department, so students are exposed to the latest technology in their prospective professional practice. Finally, every undergraduate and graduate degree program involves a requirement, i.e., Project, Thesis or Dissertation, in which the student is exposed to a variety of facilities of the department.

The following is a listing of the major laboratory facilities used for the advanced courses and research of the department.

Biorobotics Laboratory Facilities

The Biorobotics Laboratory (http//biorobots.cwru.edu/) consists of approximately 1080 square feet of laboratory and 460 square feet of office space. The lab includes two CNC machines for fabrication of smaller robot components. The lab's relationship with CAISR (Center for Automation and Intelligent Systems Research) provides access to a fully equipped machine shop where larger components are fabricated.

The laboratory hardware features several biologically inspired hexapod robots including two cockroach-like robots, Robot III and Robot IV. Both are based on the Blaberus cockroach and have 24 actuated revolute joints. They are 17 times larger than the insect (30 inches long). Robot IV is actuated with pneumatic artificial muscles. A compressed air facility has been installed to operate the robots. In addition, the lab contains structural dynamic testing equipment (sensors, DAQ boards, shakers) and an automated treadmill (5 feet by 6 feet) for developing walking robots. The Biorobotics Laboratory contains 20 PCs and a dedicated LAN connected to the campus. Algor Finite Element Analysis software, Mechanical Desktop, and Pro/Engineer are installed for mechanical design and structural analysis. Also, the lab has developed dynamic simulation software for analyzing walking animals and designing walking robots.

Distributed Intelligence and Robotics Laboratory

The Distributed Intelligence and Robotics Laboratory (DIRL) is a new laboratory in the Department of Mechanical and Aerospace Engineering that facilitates research activities on robotics and mechatronics.
The primary research focuses on distributed intelligence, multi-agent systems, biologically-inspired robotics and medical applications. The laboratory is currently being constructed to house self-sufficient facilities and equipment for designing, testing, and preliminary manufacturing. The DIRL also conduct theoretical research related to design methodology and control algorithms based on information theory, complexity analysis, and group theory.

Mechanics of Materials Experimental Facility

The major instructional, as well as research facility for experimental methods in mechanics of materials, is the Daniel K. Wright Jr. Laboratory. Presently, the facility houses a single-stage gas-gun along with tension/compression split Hopkinson bar and torsional Kolsky bar apparatus for carrying out fundamental studies in dynamic deformation and failure of advanced material systems. Hewlett Packard and Tektronix high speed, wide bandwidth digitizing oscilloscopes along with strain-gage conditioners and amplifiers are available for data recording and processing. The facility houses state-of-the-art laser interferometry equipment for making spatial and temporal measurements of deformation. High-speed Hg-Cd-Te detector arrays are available for making time-resolved multi-point non-contact temperature measurements.

A Schenck Pegasus digital servo-controlled hydraulic testing system with a 20Kip Universal testing load frame equipped with hydraulic grips and instrumentation is available for quasi-static mechanical testing under load or displacement control. A newly developed moiré microscope is available for studying large-scale inelastic deformation processes on micron size scales. CCD camera along with the appropriate hardware/software for image acquisition, processing and analyzing of full field experimental data from optical interferometers such as moiré microscope, photo-elasticity, and other laser based spatial interferometers are available.

Multiphase Flow and Laser Diagnostics Laboratory

A laser diagnostics laboratory is directed toward investigation of complex two-phase flow fields involved in energy-related areas, bio-fluid mechanics of cardiovascular systems, slurry flow in pumps and thermoacoustic power and refrigeration systems. The laboratory is equipped with state-of-the-art Particle Image Velocimetry (PIV) equipment, Pulsed Ultrasound Doppler Velocimeter, Ultrasound concentration measurement instrumentation and modern data acquisition and analysis equipment including PCs. The laboratory houses a clear centrifugal slurry flow pump loop and heart pump loop. Current research projects include investigation of flow through microchip devices, CSF flow in ventricles, investigation of solid-slurry flow in centrifugal pumps using ultrasound technique and PIV, thermo-acoustic refrigeration for space application.

Rotating Machinery Dynamics and Tribology Laboratory

This laboratory focuses on rotating machinery monitoring and diagnostic methods relating chaos content of dynamic non-linearity and model-based observers' statistical measures to wear and impending failure modes. A double-spool-shaft rotor dynamics test rig provides independent control over spin speed and frequency of an adjustable magnitude circular rotor vibration orbit for bearing and seal rotor-dynamic characterizations.

Simultaneous radial and axial time-varying loads on any type of bearing can be applied on a second test rig. Real-time control of rotor-mass unbalance at two locations on the rotor while it is spinning up to 10,000 rpm, simultaneous with rotor rubbing and shaft crack propagation, can be tested on a third rig. Self-excited instability rotor vibrations can be investigated on a fourth test rig.

Musculoskeletal Mechanics and Materials Laboratories

These laboratories are a collaborative effort between the Mechanical and Aerospace Engineering Department of the Case School of Engineering and the Department of Orthopaedics of the School of Medicine that has been ongoing for more than 40 years. Research activities have ranged from basic studies of mechanics of skeletal tissues and skeletal structures, experimental investigation of prosthetic joints and implants, measurement of musculoskeletal motion and forces, and theoretical modeling of mechanics of musculoskeletal systems. Many studies are collaborative, combining the forces of engineering, biology, biochemistry, and surgery. The Biomechanics Test labs include Instron mechanical test machines with simultaneous axial and torsional loading capabilities, a non-contacting video extensometer for evaluation of biological materials and engineering polymers used in joint replacements, acoustic emission hardware, and software, and specialized test apparatus for analysis of joint kinematics. The Bio-imaging Laboratory includes microscopes and three-dimensional imaging equipment for evaluating tissue microstructure and workstations for three-dimensional visualization, measurement, and finite element modeling. An Orthopaedic Implant Retrieval Analysis lab has resources for characterization and analysis of hard tissues and engineering polymers, as well as resources to maintain a growing collection of retrieved total hip and total knee replacements that are available for the study of implant design. The Soft Tissue Biomechanics lab includes several standard and special test machines. Instrumentation and histology facilities support the activities within the Musculoskeletal Mechanics and Materials Laboratories

nanoEngineering Laboratory

The nanoEngineering Laboratory focuses on research related to various nanotechnology applications with particular emphasis on energy conversion, generation, and storage in nanostructured and bio-inspired materials. Synthesis of polymer-based nanocomposites, nanofluids, and individual nanostructures is accomplished with tools available in the laboratory. Furthermore, the laboratory houses various pieces of equipment for thermal and electrical characterization of these materials. Research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, characterization of nanomaterials for thermal management (of electronics and buildings) as well as thermal insulation applications, and biomimetic research on a protein-based shark gel.

Other Experimental Facilities

The department facilities also include several specialized laboratories.

Engineering Services Fabrication Center offers complete support to assist projects from design inception to completion of fabrication. Knowledgeable staff is available to assist Faculty, Staff, Students, Researchers, and personnel associated with Case Western Reserve University.

The Bingham Student Workshop is a 2380 sq.ft. facility complete with machining, welding, metal fabrication, and woodworking equipment. This facility is available for the Case undergrads in Mechanical Engineering. Before gaining access to the shop all ME students are required to take the EMAE 160, Mechanical Manufacturing course. This course gives the student a foundation in basic machining, welding, sheet metal fabrication, and safety. Manual drafting, design, and computer-aided drafting is also included in the course. After completion, the student can use the shop for other Mechanical Engineering courses requiring prototypes. The BSW, is also, used for senior projects and student organizations, such as the SAE Baja and Formula and the Design-Build and Fly.

The Harry A. Metcalf Laboratory in Glennan Hall Room 458, which was made possible through the generous gift of Sylvia Lissa to honor her late husband and Mechanical Engineering graduate, Class of 1903, has recently been renovated and updated. The restructuring of the computational lab and adjacent experimental lab takes advantage of the Case School of Engineering's Virtual Desktop Infrastructure built on Citrix XenDesktop via gigabit networking. This high-speed networking provides access to software packages including SolidWorks, PTC Creo, MasterCam, Abaqus, MatLab, Microsoft Office, Mathematica, LabView, and many others. The lab is set up to allow the students to use their laptops or ones provided in the lab by the Department for course and project work. As a result of using the Virtual Desktop Infrastructure, engineering students will also be able to access the engineering software listed above from anywhere on any device. Students' home drives are automatically mapped as well when using the virtual applications so that they have access to their files at all times on any device.

The Reinberger Design Studio includes a total of 33 Wyse terminals for Undergraduate Student design use. The Studio is tied directly to the campus network allowing information to be shared with the HAMCL and other network resources. The Studio is used for the instruction of the SolidWorks 2005 CAD software, MasterCam 9.0 CAM software, Solidworks CAD/CAM/FEA software, and Algor 16.1 FEA software. The RDS also offers a 3D Systems SLA 250 and a Dimension machine for generating SLA models from CAD models.

The Reinberger Product and Process Development Laboratory is 1600 square feet of laboratory and office space dedicated to computer-aided engineering activities. The computer numerical control (CNC) laboratory includes both two industrial sized machine tools with additional space for lecture and group project activities. The CNC machine tools located in the laboratory are; a HAAS VF3 4 axis-machining center, a HAAS 2 axis lathe. A Mitutoyo coordinate measuring machine (CMM) located in its own laboratory space completes the facilities. The CMM enables students to inspect their manufactured components to a very degree of precision. The laboratory is used to support both undergraduate and graduate manufacturing courses (EMAE 390, EMAE 490).

High Performance Computing- For high performance computing the department uses the CWRU high performance computing cluster (HPCC). The HPCC consists of 112 compute nodes with Intel Pentium 4 Xeon EM64T processors. All nodes are interconnected with Gigabit Ethernet for MPI message passing and all nodes are interconnected by a separate Ethernet for the purpose of out-of-band cluster management. The MAE Department also has direct access to all the Ohio Supercomputing Center and all NSF supercomputing centers, primarily to the Pittsburgh Supercomputing Center. Computing-intensive research projects can obtain an account on those supercomputers through their advisers. Research projects carried on in cooperation with the NASA Glenn Research Center can have access to NASA computing facilities. Sophisticated, extensive, and updated general and graphics software are available for applications in research and classroom assignments.

Courses

EMAE 160. Mechanical Manufacturing. 3 Units.
The course is taught in two sections-Graphics and Manufacturing. Manufacturing To introduce manufacturing processes and materials and their relationships to mechanical design engineering. Course includes hands-on machining and metal fabrication lab. Also, each lab creates a 'virtual' field trip of a manufacturing facility to be shared with the class. Graphics Development of mechanical engineering drawings in orthographic, sectional, and pictorial views using manual drafting and computer-aided drafting (CAD software), dimensioning, tolerancing geometric dimensioning and tolerancing and assembly drawings will also be covered. All students are paired up to give a Manufacturing Design Presentation demonstrating the course material. The course has two (75) minute lectures and one (110) minute Machining Lab per week.

EMAE 181. Dynamics. 3 Units.
Elements of classical dynamics: particle kinematics and dynamics, including concepts of force, mass, acceleration, work, energy, impulse, momentum. Kinetics of systems of particles and of rigid bodies, including concepts of mass center, momentum, mass moment of inertia, dynamic equilibrium. Elementary vibrations. Recommended preparation: MATH 122 and PHYS 121 and ENGR 200.

EMAE 250. Computers in Mechanical Engineering. 3 Units.
Numerical methods including analysis and control of error and its propagation, solutions of systems of linear algebraic equations, solutions of nonlinear algebraic equations, curve fitting, interpolation, and numerical integration and differentiation. Recommended preparation: ENGR 131 and MATH 122.

EMAE 251. Thermodynamics. 3 Units.
Thermodynamic concepts and definitions, properties of pure substances, work and heat, first and second laws, entropy, power and refrigeration cycles, thermodynamic relations, mixtures and solutions, chemical reactions, phase and chemical equilibrium. Prereq: CHEM 111, PHYS 121 and MATH 122.

EMAE 252. Fluid Mechanics. 3 Units.
Fluid properties, hydrostatics, fluid dynamics and kinematics, control volume analysis, differential analysis, dimensional analysis and similitude, viscous internal flows, external flows and boundary layers, lift and drag. Prereq: EMAE 251 and MATH 223.

EMAE 260. Design and Manufacturing I. 3 Units.
This is the second course of a 4-course sequence focusing on "Engineering Design and Manufacturing." This course develops students' competence and self-confidence as design engineers by exposing the students to design as a creative process and its relationship with modern manufacturing practices. The outcomes of the course focus on the student's ability to apply their knowledge of mathematics, science, and engineering to design a system, component, or process that meets desired needs within realistic, multi-dimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Additionally, students will be given the opportunity to identify, formulate, and solve engineering problems, while applying professional and ethical practices. Professional communication skills are emphasized and expected during all stages of the design process. The course has five main areas of emphasis: design as a creative process, decision-based design methodologies, project management, engineering economics, and design for manufacture (CAD/CAM/CAE) using industrial software tools. The course exposes the student to the integration of engineering design, manufacturing, and management disciplines and includes activities to consider and understand the complex processes associated with controlling and managing product data through all stages of the product life-cycle (PLM). Topics include: engineering ethics, design as a creative process, design methodologies, project management, engineering economics, product life-cycle management (PLM), CAD/CAE/CAM, and the role of digital manufacturing within the design process. Design/Rapid Prototyping Studio activities are an integral part of the course, and enable the students to be part of a design and build team working on various project-based tasks. Prereq: EMAE 160.

EMAE 272. Actuators and Drive Trains. 3 Units.
Graphical, analytical, and computer techniques for analyzing displacements, velocities, and accelerations in mechanisms. Analysis and synthesis of linkages, cams, and gears. Analysis of actuators, including motors, linear actuators, solenoids, hydraulics, pneumatics,and piezoelectrics. Laboratory projects include analysis, design, construction, and evaluation of students' devices that include both actuators and transmission mechanisms. Prereq: EMAE 181 and EMAE 250.

EMAE 285. Mechanical Engineering Measurements Laboratory. 4 Units.
Techniques and devices used for experimental work in mechanical and aerospace engineering. Lecture topics include elementary statistics, linear regression, propagation of uncertainty, digital data acquisition, characteristics of common measurement systems, background for measurement laboratories, and elements of report writing. Hands-on laboratory experiences may include measurements in solid mechanics, dynamics, and fluid and thermal sciences, which are summarized in group reports. At least one report will focus on design of a measurement. Recommended preparation: EMAE 181, ENGR 225 and ECIV 310.

EMAE 290. Computer-Aided Manufacturing. 3 Units.
An advanced design and manufacturing engineering course covering a wide range of topics associated with the 'design for manufacturability' concept. Students will be introduced to a number of advanced solid modeling assignments (CAD), rapid prototyping (RP), and computer-aided manufacturing (CAM). In addition students will be introduced to computer numerical control (CNC) manual part-programming for CNC milling and turning machine tools. All students will be given a design project requiring all detail and assembly drawings for a fully engineered design. The course has two (50) minute lectures and one (110) minute CAD/CAM Lab per week. Prereq: EMAE 160.

EMAE 350. Mechanical Engineering Analysis. 3 Units.
Methods of problem formulation and application of frequently used mathematical methods in mechanical engineering. Modeling of discrete and continuous systems, solutions of single and multi-degree of freedom problems, boundary value problems, transform techniques, approximation techniques. Recommended preparation: MATH 224.

EMAE 352. Thermodynamics in Energy Processes. 3 Units.
Thermodynamic properties of liquids, vapors and real gases, thermodynamic relations, non-reactive mixtures, psychometrics, combustion, thermodynamic cycles, compressible flow. Prereq: ENGR 225.

EMAE 353. Heat Transfer. 3 Units.
Steady-state and transient conduction, principles of convection, empirical relations for forced convection, natural convection, boiling and condensation, radiation heat transfer, heat exchangers, mass transfer. Prereq: EMAE 251 and EMAE 252.

EMAE 355. Design of Fluid and Thermal Elements. 3 Units.
Synthesis of fluid mechanics, thermodynamics, and heat transfer. Practical design problems originating from industrial experience. Recommended preparation: ENGR 225 and EMAE 325.

EMAE 356. Aerospace Design. 3 Units.
Interactive and interdisciplinary activities in areas of fluid mechanics, heat transfer, solid mechanics, thermodynamics, and systems analysis approach in design of aerospace vehicles. Projects involve developing (or improving) design of aerospace vehicles of current interest (e.g., hypersonic aircraft) starting from mission requirements to researching developments in relevant areas and using them to obtain conceptual design. Senior standing required.

EMAE 359. Aero/Gas Dynamics. 3 Units.
Review of conservation equations. Potential flow. Subsonic airfoil. Finite wing. Isentropic one-dimensional flow. Normal and oblique shock waves. Prandtl-Meyer expansion wave. Supersonic airfoil theory. Recommended preparation: ENGR 225 and EMAE 325.

EMAE 360. Design and Manufacturing II. 3 Units.
This is the third course of a 4-course sequence focusing on "Engineering Design and Manufacturing," and is the senior capstone design course focused on a semester-long design/build/evaluate project. The course draws on a student's past and present academic and industrial experiences and exposes them to the design and manufacture of a product or device that solves an open-ended "real world" problem with multidimensional constraints. The course is structured and time-tabled within the Case School of Engineering (CSE) to give the EMAE 360 students the opportunity to team with students from other CSE departments (e.g., BME and EECS) to form multidisciplinary design teams to work on the solution to a common problem. The outcomes of the course continue to focus on the student's ability to function on multidisciplinary teams while applying their knowledge of mathematics, science and engineering to design a system, component, or process that meets desired needs within realistic, multidimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Professional communication skills are emphasized and expected during all stages of the design process and will include formal and informal oral presentations, periodic peer-focused design reviews, and a development through its various evolutionary stages to completion. Counts as SAGES Senior Capstone. Prereq: EMAE 160 and EMAE 260.

EMAE 363. Mechanical Engineering Modern Analysis Methods. 3 Units.
This is a required mechanical engineering course to develop an in-depth fundamental understanding of current analysis software tools, as well as to develop an ability to perform practical analyses using current software tools to analyze assigned industrial case studies for the following topical areas: (1) mechanism synthesis, (2) finite element analyses for stress and deflection, (3) machinery vibration, and (4) computational fluid dynamics. It is comprised of three lectures and one software application laboratory period per week. Prereq: ENGR 225, EMAE 181, EMAE 250, and ECIV 310.

EMAE 370. Design of Mechanical Elements. 3 Units.
Application of mechanics and mechanics of solids in machine design situations. Design of production machinery and consumer products considering fatigue and mechanical behavior. Selection and sizing of basic mechanical components: fasteners, springs, bearings, gears, fluid power elements. Recommended preparation: ECIV 310 and EMAE 271.

EMAE 371. Computational Fluid Dynamics. 3 Units.
Finite difference, finite element, and spectral techniques for numerical solutions of partial differential equations. Explicit and implicit methods for elliptic, parabolic, hyperbolic, and mixed equations. Unsteady incompressible flow equations in primitive and vorticity/stream function formulations. Steady and unsteady transport (passive scalar) equations. Offered as EMAE 371 and EMAE 471.

EMAE 372. Structural Materials by Design. 4 Units.
Materials selection and design of mechanical and structural elements with respect to static failure, elastic stability, residual stresses, stress concentrations, impact, fatigue, creep, and environmental conditions. Mechanical behavior of engineering materials (metals, polymers, ceramics, composites). Influence of ultrastructural and microstructural aspects of materials on mechanical properties. Mechanical test methods covered. Models of deformation behavior of isotropic and anisotropic materials. Methods to analyze static and fatigue fracture properties. Rational approaches to materials selection for new and existing designs of structures. Failure analysis methods and examples, and the professional ethical responsibility of the engineer. Four mandatory laboratories, with reports. Offered as EMAE 372 and EMSE 372. Prereq or Coreq: ENGR 200.

EMAE 376. Aerostructures. 3 Units.
Mechanics of thin-walled aerospace structures. Load analysis. Shear flow due to shear and twisting loads in open and closed cross-sections. Thin-walled pressure vessels. Virtual work and energy principles. Introduction to structural vibrations and finite element methods. Recommended preparation: ECIV 310.

EMAE 377. Biorobotics Team Research. 3 Units.
Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multi-disciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 467, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 379. Mechanics and Control of Compliant Robotics. 3 Units.
Robots are fundamentally mechanical devices designed to function autonomously or semi-autonomously. In autonomous systems including animals and robots, one of the most important mechanical properties is stiffness. Selective compliance allows robots to grasp a wide range of objects and traverse rougher terrain. A new field of Soft Robotics aims to create robots that are robust, cheap, and safe in close proximity to humans. However, as engineers challenge themselves to make increasingly soft robots, new challenges in design and control need to be addressed. This course will provide an introduction to state of the art in robotics as cyber-physical systems from a fundamental mechanics perspective. Topics include: grasping, wearable assistive locomotion, legged locomotion, locomotion in fluids, and locomotion over soft terrain. Offered as EMAE 379 and EMAE 479. Prereq: (ENGR 131 or EECS 132) and EMAE 181 and EECS 304.

EMAE 382. Propulsion. 3 Units.
Energy sources of propulsion. Performance criteria. Review of one-dimensional gas dynamics. Introduction of thermochemistry and combustion. Rocket flight performance and rocket staging. Chemical, liquid, and hybrid rockets. Airbreathing engine cycle analysis. Recommended preparation: ENGR 225.

EMAE 383. Flight Mechanics. 3 Units.
Aircraft performance: take-off and landing, unaccelerated flight, range and endurance, flight trajectories. Aerodynamics and propulsion. Aircraft static stability and control, simple maneuvers. Aircraft flight dynamics and control, flight simulation. Prereq: EMAE 181, EMAE 325, EMAE 359, EECS 304.

EMAE 384. Orbital Dynamics. 3 Units.
Spacecraft orbital mechanics: the solar system, elements of celestial mechanics, orbit transfer under impulsive thrust, continuous thrust, orbit transfer, decay of orbits due to drag, elements of lift-off and re-entry. Rigid body dynamics, altitude dynamics and control, simulations.

EMAE 387. Vibration Problems in Engineering. 4 Units.
Free and forced vibration problems in single and multi-degree of freedom damped and undamped linear systems. Vibration isolation and absorbers. Modal analysis and approximate solutions. Introduction to vibration of continuous media. Noise problems. Laboratory projects to illustrate theoretical concepts and applications. Recommended preparation: MATH 224 and EMAE 181.

EMAE 390. Advanced Manufacturing Technology. 3 Units.
This course will focus on advanced manufacturing technologies and processes, with an emphasis on the fundamental understanding of the material behaviors and process in the manufacturing operations. Topics will include: materials in manufacturing, glass manufacturing, polymer composite manufacturing, metal casting, metal machining, metal forming, grinding, welding, heat treatment, and quality control. The course will be lecture-based, with lab-based class project in the machine shop and think[box] studios. Prereq: EMAE 290.

EMAE 396. Special Topics in Mechanical and Aerospace Engineering. 1 - 18 Units.
(Credit as arranged.)

EMAE 397. Independent Laboratory Research. 1 - 3 Units.
Independent research in a laboratory.

EMAE 398. Senior Project. 3 Units.
Individual or team design or experimental project under faculty supervisor. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Recommended preparation: Senior standing, EMAE 360, and consent of instructor. Counts as SAGES Senior Capstone.

EMAE 399. Advanced Independent Laboratory Research/Design. 1 - 3 Units.
Students perform advanced independent research or an extended design project under the direct mentorship of the instructor. Typically performed as an extension to EMAE 397 or EMAE 398. Prereq: EMAE 397.

EMAE 400T. Graduate Teaching I. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experiences will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 401. Mechanics of Continuous Media. 3 Units.
Vector and tensor calculus. Stress and traction, finite strain and deformation tensors. Kinematics of continuous media, general conservation and balance laws. Material symmetry groups and observer transformation. Constitutive relations with applications to solid and fluid mechanics problems.

EMAE 410. Two-Phase Flow and Heat Transfer. 3 Units.
Basic two-phase flow equations, homogeneous model, drift-flux model, flow regimes, pressure drop in two-phase flow. Nucleation and bubble dynamics, pool boiling, subcooled boiling, forced convection boiling, critical heat flux in pool boiling, critical heat flux in forced convection boiling, minimum heat flux, film boiling, post dryout heat transfer. Flow instabilities, choking in two-phase flow, film and dropwise condensation. Applications to heat exchangers. Special boiling and two-phase flow problems.

EMAE 414. Nanobiomechanics in Biology. 3 Units.
This course will elucidate the forces at play at the level of proteins including those associated with mass, stiffness, viscosity, thermal and chemical factors. Basic polymer mechanics within the context of biological molecules will be covered and structures of key proteins associated with mechanical functions, such as actin, myosin and the cell membrane will be explained. Generation of force by polymerization of filamentous proteins as well as motor proteins will be included. Interaction forces between proteins, DNA/RNA mechanics will also be elucidated. Besides lectures, there will be term long project assignments (outreach-based or detailed literature survey on a subject associated with nanomechanics of cells/proteins). Recommended Preparation: Mechanics of Materials, Thermodynamics, Statics, Introductory Level Differential Equations, Introductory Level Fluid Mechanics.

EMAE 415. Introduction to Musculo-skeletal Biomechanics. 3 Units.
Structural behavior of the musculo-skeletal system. Function of joints, joint loading, and lubrication. Stress-strain properties of bone and connective tissue. Analysis of fracture and repair mechanisms. Viscoplastic modeling of skeletal membranes. Recommended preparation: EMAE 181 and ECIV 310.

EMAE 424. Introduction to Nanotechnology. 3 Units.
An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as EECS 424 and EMAE 424.

EMAE 450. Advanced Mechanical Engineering Analysis. 3 Units.
This course is intended to equip students with tools for solving mathematical problems commonly encountered in mechanical, fluid and thermal systems. Specific goals are to: i) Enable the student to properly categorize the problem in a variety of ways ii) Enable the student to identify appropriate approaches to solving the problem ii) Provide the student experience in applying some common methods for obtaining numerical solutions iii) Provide the student with understanding of trade-offs and expectations for the methods used. The course covers topics related to analytical and computational approaches to problems categorized in a variety of ways including: 1. Linear versus nonlinear problems 2) finite degrees of freedom v. infinite degrees of freedom, 3) equilibrium v. propagation v. eigenvalue problems, 4) direct formulations v. indirect formulations 5) analytical v. numerical solutions. The course will be built around specific examples from solid mechanics, dynamics, vibrations, heat transfer and fluid mechanics. The significance of the various categorizations will be developed as an ongoing part of the approach to solving the problems. Prereq: EMAE 350 or Requisites Not Met permission.

EMAE 453. Advanced Fluid Dynamics I. 3 Units.
Derivation and discussion of the general equations for conservation of mass, momentum, and energy using tensors. Several exact solutions of the incompressible Newtonian viscous equations. Kinematics and dynamics of inviscid, incompressible flow including free streamline theory developed using vector, complex variable, and numerical techniques.

EMAE 454. Advanced Fluid Dynamics II. 3 Units.
Continuation of EMAE 453. Low Reynolds number approximations. Matching techniques: inner and outer expressions. High Reynolds number approximations: boundary layer theory. Elements of gas dynamics: quasi one-dimensional flow, shock waves, supersonic expansion, potential equation, linearized theory, and similarity rules. Recommended preparation: EMAE 453.

EMAE 455. Advanced Thermodynamics. 3 Units.
Basic ideas of thermodynamics and dominant methods of their development: operational, postulational, and statistical. Entropy and information theory. Irreversible thermodynamics. Applications.

EMAE 456. Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS). 3 Units.
Microscale technologies have enabled advanced capabilities for researchers in unexplored territories of cells in biology and medicine. Biological (or Biomedical) Micro-Electro-Mechanical Systems (MEMS) and Biomanufacturing involve the fundamentals of mechanics, electronics and advanced microfabrication technologies with specific emphasis on biological applications. MEMS is an interdisciplinary research area which brings together multiple disciplines including, mechanical engineering, biomedical engineering, chemical engineering, materials science, electrical engineering, clinical sciences, medicine, and biology. MEMS based technologies have found real world applications in tissue engineering, implantable microdevices, proteomics, genomics, molecular biology, and point-of-care platforms. This course aims to: (1) introduce the need for miniaturized systems in biology and medicine and the fundamental design and microfabrication concepts, (2) introduce the basics of microscale manipulation of cells, biological agents, and biomanufacturing, employing the fundamentals of microscale behaviors of fluids and mechanical systems, (3) expose the students to applications of MEMS and on-chip technologies in biology and medicine.

EMAE 457. Combustion. 3 Units.
Chemical kinetics and thermodynamics; governing conservation equations for chemically reacting flows; laminar premixed and diffusion flames; turbulent flames; ignition; extinction and flame stabilization; detonation; liquid droplet and solid particle combustion; flame spread, combustion-generated air pollution; applications of combustion processes to engines, rockets, and fire research.

EMAE 459. Advanced Heat Transfer. 3 Units.
Analysis of engineering heat transfer from first principles including conduction, convection, radiation, and combined heat and mass transfer. Examples of significance and role of analytic solutions, approximate methods (including integral methods) and numerical methods in the solution of heat transfer problems. Recommended preparation: EMAE 453.

EMAE 460. Theory and Design of Fluid Power Machinery. 3 Units.
Fluid mechanic and thermodynamic aspects of the design of fluid power machinery such as axial and radial flow turbomachinery, positive displacement devices and their component characterizations. Recommended preparation: Consent of instructor.

EMAE 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.
Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAC 461 and EMAE 461.

EMAE 463. Fire Dynamics. 3 Units.
This course introduces compartment fires and burning behavior of materials. Topics include: buoyant driven flow, fire plume, ceiling jet, vent flow, flashover and smoke movement as well as steady burning of liquids and solids; ignition, extinction and flame spread over solids. Recommended Preparation: Elementary knowledge in thermo-fluids is required. Offered as EMAE 463 and EMAC 463. Prereq: EMAE 325 or Requisites Not Met permission.

EMAE 464. Fire Protection Engineering. 3 Units.
This course introduces essentials of fire protection in industry and houses. Topics include: hazard identification (release of flammable gases and their dispersion), fire and explosion hazards, prevention and risk mitigation, fire detection systems, mechanisms of fire extinguishment, evaluation of fire extinguishing agents and systems. Offered as EMAC 464 and EMAE 464.

EMAE 466. Mechanics of Biological Fluids. 3 Units.
This is a senior/graduate level course which aims to provide a solid grasp of the role of mechanics in biological fluids and in the human circulatory system that will help in the research and design of new medical instruments, equipment, and procedures. The course will cover properties of Newtonian and non-Newtonian fluids, hydrostatic and dynamic forces, principles of continuity, conservation of mass, energy and momentum and their applications in biological fluids, laminar and turbulent flows and boundary layer, introduction to Navier Stokes, dimensional analysis and similarity, blood flow in the cardiovascular system, gas exchange in the pulmonary system, blood flow in microcirculation and vessels. Important concepts will be covered by case studies.

EMAE 471. Computational Fluid Dynamics. 3 Units.
Finite difference, finite element, and spectral techniques for numerical solutions of partial differential equations. Explicit and implicit methods for elliptic, parabolic, hyperbolic, and mixed equations. Unsteady incompressible flow equations in primitive and vorticity/stream function formulations. Steady and unsteady transport (passive scalar) equations. Offered as EMAE 371 and EMAE 471.

EMAE 477. Biorobotics Team Research. 3 Units.
Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multi-disciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 467, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 479. Mechanics and Control of Compliant Robotics. 3 Units.
Robots are fundamentally mechanical devices designed to function autonomously or semi-autonomously. In autonomous systems including animals and robots, one of the most important mechanical properties is stiffness. Selective compliance allows robots to grasp a wide range of objects and traverse rougher terrain. A new field of Soft Robotics aims to create robots that are robust, cheap, and safe in close proximity to humans. However, as engineers challenge themselves to make increasingly soft robots, new challenges in design and control need to be addressed. This course will provide an introduction to state of the art in robotics as cyber-physical systems from a fundamental mechanics perspective. Topics include: grasping, wearable assistive locomotion, legged locomotion, locomotion in fluids, and locomotion over soft terrain. Offered as EMAE 379 and EMAE 479.

EMAE 480. Fatigue of Materials. 3 Units.
Fundamental and applied aspects of metals, polymers and ceramics. Behavior of materials in stress and strain cycling, methods of computing cyclic stress and strain, cumulative fatigue damage under complex loading. Application of linear elastic fracture mechanics to fatigue crack propagation. Mechanisms of fatigue crack initiation and propagation. Case histories and practical approaches to mitigate fatigue and prolong life.

EMAE 481. Advanced Dynamics I. 3 Units.
Particle and rigid-body kinematics and dynamics. Inertia tensor, coordinate transformations and rotating reference frames. Application to rotors and gyroscopes. Theory of orbital motion with application to earth satellites. Impact dynamics. Lagrange equations with applications to multi-degree of freedom systems. Theory of small vibrations. Recommended preparation: EMAE 181.

EMAE 487. Vibration Problems in Engineering. 3 Units.
Free and forced-vibration problems in single and multi-degree of freedom damped and undamped linear systems. Vibration isolation and absorbers. Modal analysis and approximate solutions. Introduction to vibration of continuous media. Noise problems. Laboratory projects to illustrate theoretical concepts and applications. Recommended preparation: EMAE 181 and MATH 224.

EMAE 488. Advanced Robotics. 3 Units.
This course will focus on up-to-date knowledge and theories related to robotics and multi-agent systems. Related mathematics and theories including group theory (Lie groups), rigid-body motions (SO(3) and SE(3)), kinematics, dynamics, and control will be studied. In addition, the class will also discuss structural, computational and task complexity in robotic systems based on combinatorial analysis, information theory, and graph theory. Lecture and discussion topics: Kinematics; Introduction to Group Theory and Lie Groups; Rigid-body Motions (SO(3), SE(3)); Multi-body Dynamical Systems: Order-N computational methods; Complexity Analysis for Robotic Systems; Structural complexity, information-theoretic complexity, and task complexity; Special Discussion Topics; Special discussion topics may vary each year. Students enrolled in this class will be required to conduct a final project. Two or three students will work as a team. The topics for student teams may include: computer simulation of multi-body dynamical systems, art robot design, and complexity analysis for coupled complex systems. The detailed information will be provided in the first week of the class. The final presentations and demonstrations will be held during the last week of class and will be open to the public audience. Students are also required to submit a final report following a IEEE conference paper template.

EMAE 489. Robotics I. 3 Units.
Orientation and configuration coordinate transformations, forward and inverse kinematics and Newton-Euler and Lagrange-Euler dynamic analysis. Planning of manipulator trajectories. Force, position, and hybrid control of robot manipulators. Analytical techniques applied to select industrial robots. Recommended preparation: EMAE 181. Offered as EECS 489 and EMAE 489.

EMAE 494. Energy Systems. 3 Units.
The overarching goal of this course is to introduce energy systems to graduate students, allowing the class to explore energy resource options and technologies. We will evaluate (from a scientific, mathematical and societal perspective) the trade-offs and uncertainties of various energy systems and explores a framework for assessing solutions. Topics will include resource estimation, environmental effects and economic evaluations of fossil fuels, nuclear power, hydropower, solar energy and more. Prereq: Junior or Senior Undergraduate Engineering major or Graduate Engineering major.

EMAE 500T. Graduate Teaching II. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching, recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstration) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 501. Constitutive Modeling of Solids. 3 Units.
Fundamentals of constitutive modeling of deformable solids. Hyper-elastic, viscoelastic, plastic, and viscoplastic material responses and how microstructural mechanisms influence the macroscopic mechanical behavior in different materials. The course also aims at equipping students with necessary background to develop constitutive models that can be used in commercial/research finite element software for the analysis of complex structures and components. Prereq: EMAE 401.

EMAE 540. Advanced Dynamics II. 3 Units.
Using variational approach, comprehensive development of principle of virtual work, Hamilton's principle and Lagrange equations for holonomic and non-holonomic systems. Hamilton's equations of motion, canonical transformations, Hamilton-Jacobi theory and special theory of relativity in classical mechanics. Modern dynamic system formulations.

EMAE 552. Viscous Flow Theory. 3 Units.
Compressible boundary layer theory. Blowing and suction effects. Three-dimensional flows; unsteady flows. Introduction to real gas effects. Recommended preparation: EMAE 454.

EMAE 554. Turbulent Fluid Motion. 3 Units.
Mathematics and physics of turbulence. Statistical (isotropic, homogeneous turbulence) theories; success and limitations. Experimental and observational (films) evidence. Macrostructures and microturbulence. Other theoretical approaches. Recommended preparation: EMAE 454.

EMAE 557. Convection Heat Transfer. 3 Units.
Energy equation of viscous fluids. Dimensional analysis. Forced convection; heat transfer from non-isothermal and unsteady boundaries, free convection and combined free and forced convection; stability of free convection flow; thermal instabilities. Real gas effects, combined heat and mass transfer; ablation, condensation, boiling. Recommended preparation: EMAE 453 and EMAE 454.

EMAE 558. Conduction and Radiation. 3 Units.
Fundamental law, initial and boundary conditions, basic equations for isotropic and anisotropic media, related physical problems, steady and transient temperature distributions in solid structures. Analytical, graphical, numerical, and experimental methods for constant and variable material properties. Recommended preparation: Consent of instructor.

EMAE 560. Sustainable Manufacturing. 3 Units.
This course provides an in-depth presentation of a number of important topics related to sustainable manufacturing processes and systems. The topics cover contents ranging from conventional manufacturing to emerging nano-manufacturing techniques. Some of the important goals of this course are: a. Students learn to understand the fundamental methods and techniques of sustainable manufacturing. b. Students learn the cutting-edge theory and practices in sustainable manufacturing on improving the sustainability performance or developing sustainable processes from real industrial practices. c. Students learn state-of-the-art knowledge on environmental impact assessment methods of industrial pollutants. d. Students apply the learned knowledge and skills in class discussions and project implementation. Prereq: EMAE 390.

EMAE 600T. Graduate Teaching III. 0 Unit.
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 601. Independent Study. 1 - 18 Units.

EMAE 649. Project M.S.. 1 - 6 Units.

EMAE 650. Grad Student Seminar. 1 Unit.
This seminar course is to broaden the knowledge and enhance the academic background of the graduate students in Mechanical and Aerospace Engineering through attending seminars on the cutting-edge research topics presented by both internal and externally-invited speakers.

EMAE 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.)

EMAE 689. Special Topics. 1 - 18 Units.

EMAE 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EMAE Plan B MS Program.

EMAE 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.