

Mechanical Engineering Program

Aims and Scope of the Graduate Program

The Mechanical Engineering (ME) program focuses on the following broad areas of research: structures and mechanics of solids, fluid dynamics, thermal sciences, combustion, energy, and control and dynamics. Courses in the program provide a solid foundation in each area, covering subjects such as mechanical behavior of engineering materials, continuum mechanics, thermodynamics, experimental and numerical combustion, control design, dynamic analysis, modeling, and simulation.

Master's Degree

The M.S. degree in Mechanical Engineering (ME) requires a minimum of three semesters of residence at KAUST and one summer. In exceptional circumstances, a student may take extra courses to complete the M.S. degree in ME in one calendar year consisting of two semesters and one summer. Such cases require approval of the ME faculty. In some cases and with permission of the advisor, students may extend their M.S. enrollment for a fourth semester.

A minimum of 36 credits is required to earn an M.S. degree in ME. There are two M.S. degree options in ME: (1) M.S. degree with a thesis and (2) M.S. without a thesis. Both options require a minimum of 24 credits of coursework.

To satisfy the requirement of 24 credits of coursework, students must enroll in core courses, mathematics courses, electives and the engineering seminar as follows:

1. Core Curriculum: (12 credits) Four courses must be selected from the following list: ME 200 a,b; ME 211 a,b; ME 212 a,b; ME 221 a,b; ME 222 a,b; ME 232 a,b; ME 234 a,b; ME 241; and ME 242. Descriptions of these courses are provided below.
2. Elective Curriculum: (12 credits) Four courses must be chosen with the approval of the student's advisor. The selected courses must allow the student to meet the program's mathematics requirements.
3. Research/Capstone Experience: (12 credits) This requirement is satisfied differently depending upon the option the student is pursuing. Details are outlined below.

Mathematics requirement: A minimum of 6 credits of graduate-level courses (i.e., courses numbered 200 and higher) in applied mathematics is required. It is recommended that students take Applied Mathematics I and II (AMCS 201 and 202), as these courses provide a strong foundation in applied mathematics, which is essential for a research career in ME.

Engineering Seminar: MS students in ME are required to register for the ME Seminar (ME 290) for 0 credits. This course requires attendance during the weekly ME seminar. In case, the ME seminar is not held in any particular week, then it is the student's responsibility to attend any other technical seminar offered on campus that week. Students will be awarded a pass/fail grade depending upon satisfactory/unsatisfactory attendance.

Thesis Option

A minimum of 6 credits of thesis research (ME 297) is required although it is expected that a

student will enroll in 12 credits of M.S. thesis work. With permission of the M.S. thesis advisor, a student who enrolls in only 6 credits of thesis research may use one of the following options to earn the six remaining credits of degree requirements:

- **Internship:** 6 credits of research-based summer internship (administered as directed research, ME 299)
- **Two Courses:** Any two 3-credit graduate-level courses in any program at KAUST.
- **Non-Technical Broadening Experience Courses:** 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of ME courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the ME program if the student chooses to continue for a Ph.D. degree in ME at KAUST.

Students are permitted to register more than 12 credits of M.S. thesis research as necessary and with the permission of the thesis advisor.

Evaluation of satisfactory completion of M.S. thesis work is performed by a committee comprising the M.S. thesis advisor and two other faculty members. The chair of the committee must be a faculty member within the ME program. The evaluation of M.S. thesis credits is through a pass or a fail grade. The requirement of a public ME seminar based on the student's work is left to the discretion of the M.S. thesis advisor. For additional details on thesis requirements and committee formation, see General Degree Program Guidelines.

The student is responsible for scheduling the thesis defense date with his/her supervisor and committee members. It is advisable that the student submits a written copy of the thesis to the thesis committee members at least two weeks prior the defense date.

Non-Thesis Option

Research requirement: A minimum of 6 credits of directed research credits (ME 299) is required. Summer internship credits may be used to fulfill the research requirement provided that the summer internship is research-based. Summer internships are subject to approval by the student's academic advisor.

Students must complete the remaining credits through one or a combination of the options listed below:

- **Two Courses:** Any two 3-credit graduate-level courses in any program at KAUST.
- **Non-technical Broadening Experience Courses:** 6 credits of courses that broaden a student's M.S. experience.
- **Ph.D.-Level Courses:** 6 credits of ME courses numbered 300 or greater. Any course in the Ph.D. core requirements that is passed with a minimum grade of B– may be used towards meeting the core Ph.D. requirements of the ME program if the student chooses to continue for a Ph.D. degree in ME at KAUST.
- **Internship:** 6 credits of research-based summer internship (administered as directed research, ME 299)

It should be noted that a student may also mix and match courses to satisfy the six-credit

requirement. For example, a student could take one Ph.D.-level course and one graduate-level course in another program. A student may not enroll in two summer internships.

Degree of Doctor of Philosophy

There are three categories of students admitted to the Degree of Doctor of Philosophy Program in ME: (1) B.S.-to-Ph.D. students, (2) M.S.-to-Ph.D. students who have been awarded their Master's degrees from an institution other than KAUST, and (3) M.S.-to-Ph.D. students who have earned an M.S. degree in ME from KAUST. A Student admitted to the Ph.D. program is designated as a "*Ph.D. Student*" and later as a "*Ph.D. Candidate*" after successful completion of candidacy requirements as described below. The overall Ph.D. degree requirements consist of course work, passing the PhD qualifying examination, successful transition to Ph.D. candidacy, PhD dissertation research, submission of the dissertation and finally successful defense of the Ph.D. dissertation.

Coursework Requirements

B.S.-to-Ph.D. students: B.S.-to-Ph.D. students are required to successfully complete the 24 credits of coursework required of all M.S. students in ME at KAUST. As such, they must complete 12 credits of ME core courses, 6 credits of applied mathematics, 6 credits of electives and also register for the ME seminar for three semesters. B.S.-to-Ph.D. students must also meet the minimum requirement of 12 credits of Ph.D. coursework (with a minimum of 6 of these credits in ME courses at the 300-level or above and 3 credits in applied mathematics. The applied mathematics credits are in addition to the applied mathematics requirement for the M.S. degree. The remaining 3 credits are elective credits to be chosen from any graduate-level course at the University). A B.S.-to-Ph.D. student is therefore required to complete 36 credits of coursework. If a B.S.-to-Ph.D. student meets all other requirements for the M.S. degree, he/she will be awarded an M.S. degree en route to earning the Ph.D.

M.S.-to-Ph.D. students who earned their M.S. from an institution other than KAUST: These students must also complete the minimum 12 credits of coursework for the Ph.D. (with a minimum of 6 of these credits in ME courses at the 300-level or above and 3 credits in applied mathematics. The applied mathematics credits are in addition to the applied mathematics requirement for the M.S. degree. The remaining 3 credits are elective credits to be chosen from any graduate-level course at the University). In addition, they are encouraged to review the 12 credits of core courses and 6 credits of applied mathematics courses required of all M.S. students in ME at KAUST, identify deficiencies in their background and take necessary courses to overcome such deficiencies. The academic advisor may be consulted to chart out a coursework plan. Students are cautioned that the Ph.D. qualifying examination in ME at KAUST relies heavily on material covered in the 12 credits of core courses and AMCS 201/202.

M.S.-to-Ph.D. students: Those students who completed their M.S. in ME at KAUST must complete 12 credits of coursework, with a minimum of 6 of credits in ME courses at the 300-level or higher. The 6-credit ME course requirement is waived for those students were previously enrolled in the non-thesis M.S. program and had already enrolled in 6 credits of coursework at the 300-level or above with a minimum grade of B. The student must also complete 3 credits in applied mathematics. These applied mathematics credits are in addition to the applied mathematics requirement for the M.S. degree. The remaining 3 credits are elective credits to be chosen from any graduate-level course at the University.

All Ph.D. students, regardless of their status upon admission, are required to maintain an average grade of B in these 12 credits.

Designation of a Research Advisor

Each student admitted as a Ph.D. student is assigned an academic advisor whose role is to help the student choose appropriate courses and act as the primary mentor until the student identifies a Ph.D. dissertation research advisor. It is the responsibility of the student to do so within two semesters if the student enters the program with a M.S. and within four semesters if the student enters the program with a B.S. In consultation with the adviser, the student must form a Ph.D. dissertation "supervision" committee shortly thereafter. This committee will consist of at least three members of the KAUST professorial faculty, with at least one member from mechanical engineering. The advisor will serve as chair of this committee. This committee will meet as requested by the student. Further, this committee will meet annually to review progress and, under special circumstances, to approve the registration of the student beyond the fifth year of graduate residence at KAUST. The adviser and the thesis supervision committee provide the majority of mentoring to the student. In addition, the degree program coordinator and other members of the faculty will provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Comprehensive Examination

All Ph.D. students admitted to the ME program must pass an oral comprehensive subject examination within two years and two months of their admission to the PhD program (with the exception of B.S.-to-Ph.D. students admitted in the spring semester. These students have an extra semester to pass the oral subject examination). This comprehensive examination will be given twice per year: once after the close of the Fall Semester and before the beginning of the Spring semester and the other during the week before the beginning of the fall semester or the first week of the fall semester. The subject component will include one oral examination in mathematics and one oral examination in any of the following areas: (a) *fluid mechanics*, (b) *solid mechanics*, (c) *control theory*, and (d) *heat transfer and thermodynamics*. Each oral examination will last one hour and will be closed book and closed notes. The student will be given a list of the examination topics in each area in advance. In the event a student fails the qualifying examination, then at most one additional attempt will be allowed at the discretion of the ME faculty.

Research Proposal Examination

In addition to the subject component of the qualifying examination, a research component examination will be given. This should take place within two semesters of the student passing the subject component of the qualifying examination. The research component will consist of a presentation on the thesis topic. Submission of a 10-page thesis proposal at least 14 days prior to the scheduled presentation is required.

Candidacy Status

Upon completion of all coursework requirements, designation of a research advisor, successful completion of comprehensive and qualifying examinations, completion of at least 12 credits of dissertation research (ME 397) and selection of a dissertation committee, the Ph.D. student becomes a Ph.D. candidate

Dissertation

Ph.D. students in ME are required to register for a minimum of 60 dissertation credits (ME 397). Completion of coursework or passing the qualifying examinations are not required before a PhD student may register for dissertation research. Dissertation research is performed under the supervision of a KAUST faculty member.

F. Registration beyond Fifth Year of Graduate Residence.

The annual approval of the Ph.D. dissertation supervision committee and the Dean is necessary for registration beyond the fifth year of graduate residence at KAUST.

G. Dissertation Defense

A dissertation examination will be given after the student has completed at least 60 credits of Ph.D. Dissertation credits (ME 397) and the dissertation has been formally completed. This examination will be a defense of the doctoral dissertation and a test of the candidate's knowledge in the specialized field of research. The format of the examination will be a public seminar presented by the candidate, with an open question period, followed by a private examination by the examining committee. The examining committee shall consist of five members with the following structure: The student's PhD advisor who may not act as the chair of the examining committee; at least two KAUST professorial faculty members from Mechanical Engineering; at least one KAUST professorial faculty member not from Mechanical Engineering; one member external to KAUST and must hold a doctoral degree. The external member would review the written dissertation and his/her attendance of the dissertation defense is not mandatory.

The Ph.D. candidate must submit copies of the dissertation to committee members at least four weeks in advance of the defense date. The examining committee will determine the pass/fail grade. It is the student's responsibility to ensure that the dissertation complies with all formatting rules, and for collecting the final signatures from the examining committee once all changes to the dissertation have been approved.

MECHANICAL ENGINEERING (ME) COURSE DESCRIPTIONS

ME 200 a,b. Fluid Mechanics. 3 credits (3-0-3); first, second terms.

Prerequisites: Undergraduate fluid mechanics, AMCS 201 and AMCS 202 or equivalent (may be taken concurrently). Fundamentals of fluid mechanics. Microscopic and macroscopic properties of liquids and gases; the continuum hypothesis; review of thermodynamics; general equations of motion; kinematics; stresses; constitutive relations; vorticity, circulation; Bernoulli's equation; potential flow; thin-airfoil theory; surface gravity waves; buoyancy-driven flows; rotating flows; viscous creeping flow; viscous boundary layers; introduction to stability and turbulence; quasi one-dimensional compressible flow; shock waves; unsteady compressible flow; acoustics.

ME 211 a,b. Mechanics of Structures and Solids. 3 credits (3-0-3); first, second terms.

Prerequisite: Undergraduate strength of materials and stress analysis, AMCS 201 and AMCS 202 or equivalent (may be taken concurrently). Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Analysis of structural elements with applications in a

variety of fields. Variational theorems and approximate solutions, introduction to finite elements. A variety of special topics will be discussed in the second term such as, but not limited to, elastic stability, wave propagation, and introductory fracture mechanics.

ME 212 a,b. Continuum Mechanics. 3 credits (3-0-3); first, second terms.

Elements of Cartesian tensors. Configurations and motions of a body. Kinematics—study of deformations, rotations and stretches, polar decomposition. Lagrangian and Eulerian strain velocity and spin tensor fields. Irrotational motions, rigid motions. Kinetics—balance laws. Linear and angular momentum, force, traction stress. Cauchy's theorem, properties of Cauchy's stress. Equations of motion, equilibrium equations. Power theorem, nominal (Piola-Kirchoff) stress. Thermodynamics of bodies. Internal energy, heat flux, heat supply. Laws of thermodynamics, notions of entropy, absolute temperature. Entropy inequality (Clausius-Duhem). Examples of special classes of constitutive laws for materials without memory. Objective rates, corotational, convected rates. Principles of materials frame indifference. Examples: the isotropic Navier-Stokes fluid, the isotropic thermoelastic solid. Basics of finite differences, finite elements, and boundary integral methods, and their applications to continuum mechanics problems illustrating a variety of classes of constitutive laws.

ME 214. Experimental Methods. 3 credits (2-1-3).

Prerequisites: AMCS 201 and AMCS 202 or equivalent (may be taken concurrently), ME 200 a,b or ME 211 a,b or equivalent (may be taken concurrently). Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, with data acquisition and processing systems.

ME 221 a,b. Control Theory. 3 credits (2-1-3); first, second terms.

Prerequisites: Undergraduate Calculus of One and Several Variables, Linear Algebra, Differential Equations, Probability and Statistics or equivalents; AMCS 201 and AMCS 202 or equivalent may be taken concurrently. An introduction to analysis and design of feedback control systems, including classical control theory in the time and frequency domain. Modeling of physical, biological, and information systems using linear and nonlinear differential equations. Linear vs. nonlinear models, and local vs. global behavior, Input/output response, modeling and model reduction, Stability and performance of interconnected systems, including use of block diagrams, Bode plots, the Nyquist criterion, and Lyapunov functions. Robustness and uncertainty management in feedback systems through stochastic and deterministic methods. Basic principles of feedback and its use as a tool for altering the dynamics of systems and managing uncertainty methods. Introductory random processes, Kalman filtering, and norms of signals and systems.

ME 222 a,b. Mechatronics and Intelligent Systems. 3 credits (2-1-3); first, second terms.

Principles, modeling, interfacing and signal conditioning of motion sensors and actuators; acquire and analyze data and interact with operators. Basic electronic devices, embedded microprocessor systems and control, power transfer components and mechanism design. hardware-in-the-loop simulation and rapid prototyping of real-time closed-loop computer control of electromechanical systems; modeling, analysis and identification of discrete-time or samples-data dynamic systems; commonly used digital controller design methods; introduction to nonlinear effects and their compensation in mechatronic systems; robotic manipulation and sensing; obstacle avoidance and

motion planning algorithms; mobile robots, use of vision in navigation systems. The lectures will be divided between a review of the appropriate analytical techniques and a survey of the current research literature. Course work will focus on an independent research project chosen by the student.

ME 224. System Identification and Estimation. 3 credits (3-0-3).

Prerequisite: ME 221 a,b (ME 221 b can be taken concurrently). Deterministic state estimation, recursive observers, estimation for uncertain process dynamics; SISO and MIMO least-squares parameter estimation, linear system subspace identification. Random variables and random processes: linear systems forced by random processes, power-spectral density. Bayesian filtering including Kalman filter. Jump-Markov estimation and fault diagnosis. Nonlinear estimation, particle filters, unscented Kalman filter. Introduction to estimation for hybrid systems.

ME 226. Fuzzy Sets in Engineering. 3 credits (3-0-3).

Prerequisites: AMCS 201 and AMCS 202, working knowledge of the C computer programming language. The relatively new mathematics of fuzzy sets has recently been used to represent and manipulate vague and imprecise information in engineering. This course will present the basics of fuzzy sets and fuzzy mathematics and explore applications in the areas of data representation; function representation; filters and triggers; engineering design and optimization, including (fuzzy) set-based concurrent engineering.

ME 231. Introductory Concepts for Dynamical Systems. 3 credits (3-0-3).

Prerequisites: Undergraduate Calculus of One and Several Variables, Linear Algebra, Differential Equations, Probability and Statistics or equivalents. Nonlinear system dynamics. Initial-and boundary-value problems, ordinary and partial differential equations. Hybrid system models; modeling/simulation environments such as Dymola, Modelica, Ptolemy, Simulink and StateFlow. Networked system models. System analysis: elementary discretization methods, initial value, ordinary differential equation theory; linearization; convolution, state-space and frequency domain representations; stability, input/output operator norms, least squares and inverse problems; model reduction.

ME 232 a,b. Advanced Dynamics. 3 credits (3-0-3); first, second terms.

Prerequisite: AMCS 201 and AMCS 202 or equivalents (may be taken concurrently). Basics in topics in dynamics in Euclidean space, including equilibria, stability, Lyapunov functions, periodic solutions, Poincaré Bendixon theory, Poincaré maps. Attractors and structural stability. The Euler-Lagrange equations, mechanical systems, small oscillations, dissipation, energy as a Lyapunov function, conservation laws. Introduction to simple bifurcations and eigenvalue crossing conditions. Discussion of bifurcations in applications, invariant manifolds, the method of averaging, Melnikov's method, and the Smale horseshoe.

ME 234 a,b. Introduction to Kinematics and Robotics. 3 credits (3-0-3); first, second terms.

Prerequisites: AMCS 201 and AMCS 202 or equivalent (may be taken concurrently) Introduction to the study of planar, rotational, and spatial motions with applications to robotics, computers, computer graphics, and mechanics. Topics in kinematic analysis will include screw theory, rotational representations, matrix groups, and Lie algebras. Applications include robot kinematics, mobility in mechanisms, and kinematics of open and closed chain mechanisms. Additional topics in robotics include path planning for robot manipulators, dynamics and control, and assembly. Course

work will include laboratory demonstrations using simple robot manipulators.

ME 241. Thermodynamics. 3 credits (3-0-3).

Prerequisites: Undergraduate thermodynamics, AMCS 201 and AMCS 202 (may be taken concurrently) or equivalent. Fundamentals of classical and statistical thermodynamics. Basic postulates, thermodynamic potentials, chemical and phase equilibrium, phase transitions, and thermodynamic properties of solids, liquids, and gases.

ME 242. Heat and Mass Transfer. 3 credits (3-0-3).

Prerequisites: Undergraduate thermodynamics, AMCS 201 and AMCS 202 (may be taken concurrently). Transport properties, conservation equations, conduction heat transfer, convective heat and mass transport in laminar and turbulent flows, phase change processes, thermal radiation.

ME 242. Statistical Mechanics. 3 credits (3-0-3).

Prerequisites: AMCS 201 or equivalent, ME 241 or equivalent. This is a course on Statistical mechanics that is divided into four parts of assorted topics. It starts from an overview of some basic concepts in thermodynamics and exposes the formal structure of equilibrium statistical mechanics with applications to ideal non-interacting and interacting systems. Then the course dwells on more advanced topics such as the liquid state, critical phenomena, Ising model and the renormalization group. In the third part, Kinetic theory is presented through a thorough discussion of the Boltzmann equation and the derivations of the continuum equations. Transport processes are then discussed and transport coefficients are calculated. The theory of Brownian motion is also described as another approach to describe non-equilibrium processes. In the last section, Monte Carlo methods are applied to calculate various macroscopic properties for some lattice models.

ME 244. Combustion. 3 credits (3-0-3).

Prerequisite: ME 241 or equivalent. Basic principles including chemical equilibrium, Arrhenius law, and Rankine-Hugoniot relations will be first discussed. Multi-component conservation equations with chemical reaction will be introduced. Various characteristics of premixed and diffusion flames will be studied which covers flame structure, flame stability, flame stabilization, flammability limit, quenching distance, and thermal explosion. Combustion phenomena in gas turbines, gasoline engines, diesel engines and power plants will be discussed. A matched asymptotic expansion technique will be introduced and applied in analyzing flame structures.

ME 250. Energy. 3 credits (3-0-3).

Review of first and second laws of thermodynamics. Principles of energy conversion: vapor power cycles, combustion, combined cycle, and fuel cells. Modeling and forecasting. Heating, transportation, and electricity demand. Fossil-fuel supplies: oil, natural gas, coal, oil sands, and oil shale. Alternative energy sources: hydroelectric, nuclear fission and fusion, wind, biomass, geothermal, biofuels, waves, ocean thermal, solar photovoltaic, and solar thermal. Transportation systems: internal combustion engines, gas turbines, and electric vehicles. Energy systems: pipelines, rail and water transport, shipping, carbon capture and sequestration, transmission lines and electricity distribution networks.

ME 252. Sustainable Energy Engineering. 3 credits (3-0-3).

Prerequisites: Undergraduate Thermodynamics, AMCS 201 and AMCS 202 (may be taken concurrently), ME 250. An in-depth examination of engineering systems to convert, store, transport, and use energy, with emphasis on technologies that reduce or eliminate dependence on fossil fuels and/or emission of greenhouse gases. Topics include thermodynamics of energy conversion, energy resources, stationary power generation (vapor power cycles, combined cycles, solar thermal systems, nuclear fission and fusion, solar photovoltaics, fuel cells, wind, geothermal), carbon sequestration, alternative fuels (hydrogen, biofuels), and transportation systems (internal combustion engines, gas turbines, fuel cell and electric vehicles). The course will emphasize using quantitative methods to assess and compare different technologies.

ME 254. Theory and Methods in Product Design. 3 credits (2-1-3).

Prerequisite: graduate standing in mechanical engineering or consent of instructor. Engineering design process and conceptual design of products. This course provides an experience in preliminary project planning of complex and realistic mechanical engineering systems. Design concepts and techniques are introduced, and the student's design ability is developed in a design or feasibility study chosen to emphasize innovation and ingenuity and provide wide coverage of engineering topics. Design optimization and social, economic and political implications are included. Emphasis on hands-on creative components, teamwork and effective communication. Special emphasis on management of innovation processes for sustainable products, from product definition to sustainable manufacturing and financial models. The patent process. Both individual and group oral presentations are made, and participation in conferences is required.

ME 256. Computer-Aided Engineering Design. 3 credits (2-1-3).

Prerequisites: AMCS 201 and AMCS 202, working knowledge of the C computer programming language. Methods and algorithms for design of engineering systems using computer techniques. Topics include the design process; interactive computer graphics; curves and surfaces (including cubic and B-splines); solid modeling (including constructive solid geometry and boundary models); kinematic and dynamic mechanism simulation; single and multivariable optimization; optimal design, and symbolic manipulation. Assessment of CAD as an aid to the design process.

ME 261. Application of Atmospheric Pressure Plasma. 3 credits (3-0-3).

Introduction to plasma sources in atmospheric pressure condition: dielectric barrier discharge, pulsed corona, arc, elongated arc, and microwave plasma. Application fields for mechanical engineers. Energy: fuel reforming and combustion. Environment: after-treatment of hazardous gases. Manufacturing: surface treatment of materials. Plasma devices for bio-medical application.

ME 290. Mechanical Engineering Seminar. 0 Unit.

All candidates for the M.S. degree in mechanical engineering are required to attend one graduate seminar in Mechanical Engineering each week during the Fall and Spring semesters. In case the ME seminar is not held in any particular week, then it is the student's responsibility to attend any other technical seminar on campus that week. Graded pass/fail.

ME 299. DIRECTED RESEARCH

Prerequisites: M.S. status and consent of instructor. Course may be repeated for credit and must be taken on a pass/fail basis.

ME 300. Advanced Fluid Mechanics. 3 credits (3-0-3).

Prerequisites: ME 200 a,b or equivalent; AMCS 201 and AMCS 202 (may be taken concurrently). A more rigorous mathematical introduction to fluid mechanics. Derivation of Navier-Stokes; physical properties of real gases; the equations of motion of viscous and inviscid dynamics; the dynamical significance of vorticity; vortex dynamics; Kelvin circulation theorem and consequences; Biot-Savart Law, exact solutions in vortex dynamics; motion at high Reynolds numbers; hydrodynamic stability; boundary layers; flow past bodies; compressible flow; subsonic, transonic, and supersonic flow; Lax theory of shock waves.

ME 302. Multi-Phase Flows. 3 credits (3-0-3).

Prerequisites: ME 241, AMCS 201 and AMCS 202, ME 200 a,b, ME 211 a,b or equivalents. Selected topics in engineering two-phase flows with emphasis on practical problems in modern hydro-systems. Fundamental fluid mechanics and heat, mass, and energy transport in multiphase flows. Liquid/vapor/gas (LVG) flows, nucleation, bubble dynamics, cavitating and boiling flows, models of LVG flows; instabilities, dynamics, and wave propagation; fluid/structure interactions. Discussion of two-phase flow problems in conventional, nuclear, and geothermal power plants, marine hydrofoils, and other hydraulic systems.

ME 304. Experimental Methods in Fluid Mechanics. 3 credits (2-1-3).

Prerequisites: ME 200 a,b or equivalent; AMCS 201 and AMCS 202 (may be taken concurrently). Basic sampling theory. Spectral decomposition, aliasing, Nyquist criterion and dynamic range. Basic optics, lasers, diffraction limit. Particle tracking and streak photography. Point measurements of velocity, pitot static tube, hot wires, laser-doppler velocimetry. Measurements of velocity fields in planes and volumes, using particle image velocimetry. Micro-PIV. Measurement of scalar fields. Holographic PIV. High-speed video technology. This course has a significant laboratory component.

ME 305 ab. Computational Fluid Dynamics. 3 credits (3-0-3); first, second terms.

Prerequisites: ME 200 a,b or equivalent; AMCS 201 and AMCS 202 or equivalent. Introduction to floating point arithmetic. Introduction to numerical methods for Euler and Navier-Stokes equations with emphasis on error analysis, consistency, accuracy and stability. Modified equation analysis (dispersion vs. dissipation) and Von Neumann stability analysis. Finite difference methods, finite volume and spectral element methods. Explicit vs. implicit time stepping methods. Solution of systems of linear algebraic systems. Higher-order vs. higher resolution methods. Computation of turbulent flows. Compressible flows with high-resolution shock-capturing methods (e.g. PPM, MUSCL, WENO). Theory of Riemann problems and weak solutions for hyperbolic equations.

ME 306. Hydrodynamic Stability. 3 credits (3-0-3).

Prerequisite: ME 200 a,b or equivalent; AMCS 201 and AMCS 202 (may be taken concurrently). Laminar-stability theory as a guide to laminar-turbulent transition. Rayleigh equation, instability criteria, and response to small inviscid disturbances. Discussion of Kelvin-Helmholtz, Rayleigh-

Taylor, Richtmyer-Meshkov, and other instabilities, for example, in geophysical flows. The Orr-Sommerfeld equation, the dual role of viscosity, and boundary-layer stability. Modern concepts such as pseudo-momentum conservation laws and nonlinear stability theorems for 2-D and geophysical flows.

ME 307. Turbulence. 3 credits (3-0-3).

Prerequisites: ME 200 a,b; AMCS 201 and AMCS 202. Introduction to turbulence. Fundamental equations of turbulent flow. Statistical description of turbulence. Experimental methods for turbulence. Reynolds equations. Kolmogorov's theory. Scales of turbulence. Homogeneous turbulence. Free-shear flows. Bounded flows. Boundary layers. Simulating turbulent flows. Reynolds Average Navier-Stokes approach. Introduction to Large Eddy

ME 308. Introduction to Plasma Physics and Magneto-hydrodynamics 3 credits (3-0-3).

Prerequisites: ME 200 ab; AMCS 201 and AMCS 202. Motion of charged particles; Statistical behavior of plasmas. Vlasov and Fokker-Planck equations and derivation of fluid models for plasmas; closure problem and models. Dispersive waves in plasmas. Ideal and non-ideal magneto-hydrodynamics. Exact solutions. Alfvén and shock waves in MHD. MHD instabilities.

ME 310. Mechanics and Materials Aspects of Fracture. 3 credits (3-0-3).

Prerequisites: ME 211 a,b (concurrently) or equivalent and instructor's permission. Analytical and experimental techniques in the study of fracture in metallic and nonmetallic solids. Mechanics of brittle and ductile fracture; connections between the continuum descriptions of fracture and micromechanisms. Discussion of elastic-plastic fracture analysis and fracture criteria. Special topics include fracture by cleavage, void growth, rate sensitivity, crack deflection and toughening mechanisms, as well as fracture of nontraditional materials. Fatigue crack growth and life prediction techniques will also be discussed. In addition, "dynamic" stress wave dominated, failure initiation growth and arrest phenomena will be covered. This will include traditional dynamic fracture considerations as well as discussions of failure by adiabatic shear localization.

ME 312. Dynamic Behavior of Materials. 3 credits(3-0-3) .

Prerequisites: AMCS 201 and AMCS 202 or equivalent; ME 211 ab. Fundamentals of theory of wave propagation; plane waves, wave guides, dispersion relations; dynamic plasticity, adiabatic shear banding; dynamic fracture; shock waves, equation of state.

ME 313 ab. Theory of Structures. 3 credits (3-0-3) ; first, second terms.

Geometry of spatial curves; finite 3-D rotations; finite deformations of curved rods; dynamics of rods; strings and cables; theory of plastic rods; statistical mechanics of chains; applications including frames and cable structures, polymers, open-cell foams, DNA mechanics, cell mechanics; small strain and von Karman theory of plates; applications to thin films, layered structures, functionally graded thin films, delamination, plastic collapse; surface geometry; finite deformations of shells; dynamics of plates and shells; membranes; theory of plastic plates and shells; fracture of plates and shells; elastic and plastic stability; wrinkling and relaxation; applications including solar sails, space structures, closed cell foams, biological membranes; numerical methods for structural analysis; discrete geometry; finite elements for rods, plates and shells; time-integration methods; thermal analysis.

ME 314. Plasticity. 3 credits (3-0-3).

Prerequisite: ME 211 a,b or instructor's permission. Theory of dislocations in crystalline media. Characteristics of dislocations and their influence on the mechanical behavior in various crystal structures. Application of dislocation theory to single and polycrystal plasticity. Theory of the inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic plastic problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory and applications. Additional topics may include soils, creep and rate-sensitive effects in metals, the thermodynamics of plastic deformation, and experimental methods in plasticity.

ME 315. Computational Mechanics Using Particle Methods. 3 credits (3-0-3).

Prerequisites: ME 319 or equivalent. Particle simulations of continuum and discrete systems. Advances in molecular, mesoscopic, and macroscale simulations using particles, identification of common computing paradigms and challenges across disciplines, discretizations and representations using particles, fast summation algorithms, time integrators, constraints, and multiresolution. Exercises will draw on problems simulated using particles from diverse areas such as fluid and solid mechanics, computer graphics, and nanotechnology.

ME 316. Micromechanics. 3 credits (3-0-3).

Prerequisites: AMCS 201 and AMCS 202 or equivalent, ME 211 a,b and ME 212 a,b or instructor's permission. The course gives a broad overview of micromechanics, emphasizing the microstructure of materials, its connection to Mechanical Engineering. Courses molecular structure, and its consequences on macroscopic properties. Topics include phase transformations in crystalline solids, including martensitic, ferroelectric, and diffusional phase transformations, twinning and domain patterns, active materials; effective properties of composites and polycrystals, linear and nonlinear homogenization; defects, including dislocations, surface steps, and domain walls; thin films, asymptotic methods, morphological instabilities, self-organization; selected applications to microactuation, thin-film processing, composite materials, mechanical properties, and materials design. Open to undergraduates with instructor's permission.

ME 317 ab. Mechanics of Composite Materials and Structures. 3 credits (3-0-3); first, second terms.

Prerequisite: ME 211 ab or instructor's permission. AMCS 201 and AMCS 202. Introduction and fabrication technologies. Elastic response of composite materials (especially fiber and particulate reinforced materials) from the fabrication to the in-service structure. Up scaling strategies from the microstructure to the single ply: kinematic and static bounds, asymptotic expansion and periodical homogenization. Up scaling strategies from the single ply to the structural scale: elastic deformation of multidirectional laminates (lamination theory, ABD matrix). Mechanics of degradation in composite materials: fiber-matrix debonding, plasticity, microcracking and induced delamination. Tools for description of non-linear effects: damage mechanics for laminates, applications of fracture mechanics. Aging and fatigue. Basic criteria-based theories will also be reviewed, including first ply failure, splitting and delamination. Basic experimental illustration will include: hand lay up of a simple laminate, characterization using full field measurement of its material properties.

ME 318. Dynamic Fracture and Frictional Faulting. 3 credits (3-0-3).

Prerequisite: ME 211 a,b or ME 212 a,b or instructor's permission. Introduction to elastodynamics and waves in solids. Dynamic fracture theory, energy concepts, cohesive zone models. Friction laws, nucleation of frictional instabilities, dynamic rupture of frictional interfaces. Radiation from moving cracks. Thermal effects during dynamic fracture and faulting. Crack branching and faulting along nonplanar interfaces. Related dynamic phenomena, such as adiabatic shear localization. Applications to engineering phenomena and physics and mechanics of earthquakes.

ME 319 ab. Computational Solid Mechanics. 3 credits (3-0-3); first, second terms.

Prerequisites: AMCS 201 and AMCS 202 or equivalent; ME 211 a,b or equivalent; ME 212 a,b or taken concurrently. Variational principles in linear elasticity. Finite element analysis. Error estimation. Convergence. Singularities. Adaptive strategies. Constrained problems. Mixed methods. Stability and convergence. Variational problems in nonlinear elasticity. Consistent linearization. The Newton--Rahpson method. Bifurcation analysis. Adaptive strategies in nonlinear elasticity. Constrained finite deformation problems. Contact and friction. Time integration. Algorithm analysis. Accuracy, stability, and convergence. Operator splitting and product formulas. Coupled problems. Impact and friction. Space-time methods. Inelastic solids. Constitutive updates. Stability and convergence. Consistent linearization. Applications to finite deformation viscoplasticity, viscoelasticity, and Lagrangian modeling of solids.

ME 320. Geometry of Nonlinear Systems. 3 credits (3-0-3).

Prerequisite: AMCS 202. Basic differential geometry, oriented toward applications in control and dynamical systems. Topics include smooth manifolds and mappings, tangent and normal bundles. Vector fields and flows. Distributions and Frobenius' theorem. Matrix Control and Dynamical Systems. Lie groups and Lie algebras. Exterior differential forms, Stokes' theorem.

ME 324. Advanced Control Systems. 3 credits (3-0-3).

Prerequisites: AMCS 201 and AMCS 202 or equivalent; ME 221 ab or equivalent. Introduction to modern control systems with emphasis on the role of control in overall system analysis and design. Input-output directions in multivariable systems: eigenvalues and singular value decomposition. System norms and introduction to MIMO robustness. Controller design for multivariable plants: linear quadratic regulator, linear quadratic Gaussian optimal control, H-infinity and H-2 control, sampled-data, model predictive control. Convex design methods: Youla parameterization, linear matrix inequalities; adaptive control, neural networks, fuzzy logic systems; introduction to neuro-fuzzy systems and soft computing. Multivariable control design examples drawn from throughout engineering and science in the field of aerospace, automotive, chemical-and energy-efficient buildings.

ME 326. Robust Control. 3 credits (3-0-3).

Prerequisites: AMCS 201 and AMCS 202 or equivalents; ME 221 ab or equivalent. Linear systems, realization theory, time and frequency response, norms and performance, stochastic noise models, robust stability and performance, linear fractional transformations, structured uncertainty, optimal control, model reduction, m analysis and synthesis, real parametric uncertainty, Kharitonov's theorem, uncertainty modeling.

ME 332. Geometric Mechanics. 3 credits (3-0-3).

Prerequisites: ME 232. The geometry and dynamics of Lagrangian and Hamiltonian systems, including symplectic and Poisson manifolds, variational principles, Lie groups, momentum maps, rigid-body dynamics, Euler-Poincaré equations, stability, and an introduction to reduction theory. More advanced topics (taught in a course the following year) will include reduction theory, fluid dynamics, the energy momentum method, geometric phases, bifurcation theory for mechanical systems, and nonholonomic systems.

ME 340. Advanced Combustion Theory. 3 credits (3-0-3).

Prerequisites: ME 244 or equivalent classes. Review of fundamental concept of and phenomenology of combustion. Singularities in nonlinear problems. Matched asymptotic expansion technique. Large activation energy, Danköhler number and rate ratio asymptotics. Ignition/extinction. Laminar burning velocity. Diffusion flame. Aerodynamic effect. Preferential diffusion, differential diffusion, and heat loss effects. Hydrodynamic and acoustic instabilities. Reduced mechanisms.

ME 342. Combustion Kinetics. 3 credits (3-0-3).

Prerequisites: ME 244 or ME 344 or instructor's consent. Non-equilibrium processes in chemically reacting gases. Example applications to combustion, atmospheric chemistry, plasmas, chemical and materials processing, rocket nozzles, and gaseous lasers. Bimolecular reaction theory (collision theory); transition state theory; unimolecular and association reactions; complex reactions; straight chain reactions; explosions and branched chain reactions; photochemistry, photophysics; energy transfer in fuel tracers; vibrational relaxation; experimental techniques.

ME 344. Gas Dynamics. 3 credits (3-0-3).

Prerequisites: ME 241. Concepts and techniques for description of high-temperature and chemically reacting gases from a molecular point of view. Introductory kinetic theory; chemical thermodynamics; statistical mechanics as applied to properties of gases and gas mixtures; transport and thermodynamic properties; law of mass action; equilibrium chemical composition; Maxwellian and Boltzmann distributions of velocity and molecular energy; examples and applications from areas of current interest such as combustion and materials processing.

ME 346. Turbulent Combustion. 3 credits (3-0-3).

Prerequisites: ME 244, ME 307 or equivalents. Governing equations of reactive fluid flow. Review of fundamental concepts in turbulence. Non-premixed turbulent combustion. Conserved scalar modeling approach and turbulent non-premixed combustion models. Premixed turbulent combustion fundamentals and combustion regimes. Canonical models for premixed turbulent combustion. Partially premixed combustion. Scaling laws for lifted turbulent jet flames.

ME 348. Introduction to Spectroscopy and Laser Diagnostics. 3 credits (3-0-3).

Fundamentals of microwave, infrared, Raman, and electronic spectroscopy. Laser-based diagnostic techniques for measurements of species concentration, temperature, pressure, velocity, and other flow field properties. Topics: rotational, vibrational, and electronic transition frequencies; spectral lineshapes and line-broadening mechanisms; nuclear spin effects; electronic spectra of atoms and molecules; absorption; emission; laser induced fluorescence (LIF); Rayleigh and Raman

scattering methods; Mie theory; laser Doppler velocimetry (LDV) and particle image velocimetry (PIV); applications and case studies. Laser Diagnostics for Thermal Engineering.

ME 397. Ph.D. Dissertation Research.

Prerequisites: Ph.D. status and consent of instructor. Course may be repeated for credit. Maximum number of credits is 12 per semester. Must be taken on a pass/fail basis. Individual investigation on topics of relevance to mechanical engineering.

ME 400. Contemporary Topics in Fluid Mechanics. 3 credits (3-0-3).

Prerequisites: ME 200 a,b and consent of the instructor. Lecture and/or seminar course on advanced topics in fluid mechanics. Topics are determined by the instructor and may vary from year to year. The course may be repeated for credit.

ME 410. Contemporary Topics in Solid Mechanics. 3 credits (3-0-3).

Prerequisites: ME 211 a,b, ME 212 a,b and consent of the instructor. Lecture and/or seminar course on advanced topics in solid mechanics. Topics are determined by the instructor and may vary from year to year. The course may be repeated for credit.

ME 420. Contemporary Topics in Control Theory and Practice. 3 credits (3-0-3).

Prerequisites: ME 221 a,b and consent of the instructor. Lecture and/or seminar course on advanced topics in control theory and practice. Topics are determined by the instructor and may vary from year to year. The course may be repeated for credit.

ME 430. Contemporary Topics in Dynamics. 3 credits (3-0-3).

Prerequisites: ME 232 a,b and consent of the instructor. Lecture and/or seminar course on advanced topics in dynamics. Topics are determined by the instructor and may vary from year to year. The course may be repeated for credit. Maximum number of credits is 3 per semester.

ME 440. Contemporary Topics in Thermal Science and Engineering. 3 credits (3-0-3).

Prerequisites: ME 241 and ME 242 or ME 244 and consent of the instructor. Lecture and/or seminar course on advanced topics in thermal science and engineering. Topics are determined by the instructor and may vary from year to year. The course may be repeated for credit.

ME 450. Contemporary Topics in Design Theory and Practice. 3 credits (3-0-3).

Prerequisites: ME 254 and consent of the instructor. Lecture and/or seminar course on advanced topics in design theory and practice. Topics are determined by the instructor and may vary for year to year. The course may be repeated for credit.