MECHL, MTRLS AND ARSPC ENGRG (MMAE)

MMAE 500
Data Driven Modeling
This graduate level course focuses on state of the art techniques in data driven modeling. The course introduces relevant aspects of probability theory, optimization, and the basics of machine learning and deep learning. The course surveys a variety of modeling and learning methodologies and algorithms, such as modern neural network architectures, modal decompositions, identification of linear and nonlinear dynamics, and other advanced topics in data driven modeling. The emphasis will be squarely on the application of modern data driven modeling tools to advanced engineering problems related to solid and fluid mechanics, dynamics, and controls.
Prerequisite(s): MMAE 501* and MMAE 350 with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 501
Engineering Analysis I
Vectors and matrices, systems of linear equations, linear transformations, eigenvalues and eigenvectors, systems of ordinary differential equations, decomposition of matrices, and functions of matrices. Eigenfunction expansions of differential equations, self-adjoint differential operators, Sturm-Liouville equations. Complex variables, analytic functions and Cauchy-Riemann equations, harmonic functions, conformal mapping, and boundary-value problems. Calculus of variations, Euler's equation, constrained functionals, Rayleigh-Ritz method, Hamilton's principle, optimization and control. Prerequisite: An undergraduate course in differential equations.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 502
Engineering Analysis II
Generalized functions and Green's functions. Complex integration: series expansions of complex functions, singularities, Cauchy's residue theorem, and evaluation of real definite integrals. Integral transforms: Fourier and Laplace transforms, applications to partial differential equations and integral equations.
Prerequisite(s): MMAE 501 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 503
Advanced Engineering Analysis
Selected topics in advanced engineering analysis, such as ordinary differential equations in the complex domain, partial differential equations, integral equations, and/or nonlinear dynamics and bifurcation theory, chosen according to student and instructor interest.
Prerequisite(s): MMAE 502 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 504
Random Data Measurement and Analysis
The objective of this course is to explore the application of time- and frequency-domain methods to data. The course builds upon the fundamental principles introduced in statistics and numerical & experimental methods and is intended primarily for graduate students interested in data analyses. The course emphasizes the understanding, application, and interpretation of various methods. Statistical functions (e.g., probability density functions, moments, etc.), time/space- domain (e.g., auto- and cross-correlation) functions, and frequency-domain (e.g., auto- and cross- spectra) methods are derived and applied to practical engineering problems. The application of the methods presented in the course will be illustrated via homework problems that utilize MATLAB. Exams will also be used to reinforce important aspects of the methods. Finally, a project will apply a specific analysis to engineering data applicable to the student's research topic.
Prerequisite(s): MMAE 501*, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 508
Perturbation Methods
Asymptotic series, regular and singular perturbations, matched asymptotic expansions, and WKB theory. Methods of strained coordinates and multiple scales. Application of asymptotic methods in science and engineering.
Prerequisite(s): MMAE 501 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 509
Introduction to Continuum Mechanics
A unified treatment of topics common to solid and fluid mechanics. Cartesian tensors. Deformation, strain, rotation and compatibility equations. Motion, velocity gradient, vorticity. Momentum, moment of momentum, energy, and stress tensors. Equations of motion, frame indifference. Constitutive relations for elastic, viscoelastic, and fluids and plastic solids.
Prerequisite(s): MMAE 501 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 510
Fundamentals of Fluid Mechanics
Kinematics of fluid motion. Constitutive equations of isotropic viscous compressible fluids. Derivation of Navier-Stokes equations. Lessons from special exact solutions, self-similarity. Admissibility of idealizations and their applications; inviscid, adiabatic, irrotational, incompressible, boundary-layer, quasi one-dimensional, linearized and creeping flows. Vorticity theorems. Unsteady Bernoulli equation. Basic flow solutions. Basic features of turbulent flows.
Prerequisite(s): MMAE 501* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 4 **Lab:** 0 **Credits:** 4

MMAE 511
Dynamics of Compressible Fluids
Low-speed compressible flow past bodies. Linearized, subsonic, and supersonic flow past slender bodies. Similarity laws. Transonic flow. Hypersonic flow, mathematical theory of characteristics. Applications including shock and nonlinear wave interaction in unsteady one-dimensional flow and two-dimensional, planar and axisymmetric supersonic flow.
Prerequisite(s): MMAE 510 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 512
Dynamics of Viscous Fluids
Navier-Stokes equations and some simple exact solutions. Oseen-Stokes flows. Boundary-layer equations and their physical interpretations. Flows along walls, and in channels. Jets and wakes. Separation and transition to turbulence. Boundary layers in unsteady flows. Thermal and compressible boundary layers. Mathematical techniques of similarity transformation, regular and singular perturbation, and finite differences.
Prerequisite(s): MMAE 510 with min. grade of C
Lecture: 4 **Lab:** 0 **Credits:** 4

MMAE 513
Turbulent Flows
Stationary random functions. Correlation tensors. Wave number space. Mechanics of turbulence. Energy spectrum. Dissipation and energy cascade. Turbulence measurements. Isotropic turbulence. Turbulent transport processes. Mixing and free turbulence. Wall-constrained turbulence. Compressibility effects. Sound and pseudo-sound generated by turbulence. Familiarity with basic concepts of probability and statistics and with Cartesian tensors is assumed.
Prerequisite(s): MMAE 510 with min. grade of C
Lecture: 4 **Lab:** 0 **Credits:** 4

MMAE 514
Stability of Viscous Flows
Concept of hydrodynamic stability. Governing equations. Analytical and numerical treatment of eigenvalue problems and variational methods. Inviscid stability of parallel flows and spiral flows. Thermal instability and its consequences. Stability of channel flows, layered fluid flows, jets and flows around cylinders. Other effects and its consequences; moving frames, compressibility, stratification, hydromagnetics. Nonlinear theory and energy methods. Transition to turbulence.
Prerequisite(s): MMAE 510 with min. grade of C and MMAE 502 with min. grade of C
Lecture: 4 **Lab:** 0 **Credits:** 4

MMAE 517
Computational Fluid Dynamics
Classification of partial differential equations. Finite-difference methods. Numerical solution techniques including direct, iterative, and multigrid methods for general elliptic and parabolic differential equations. Numerical algorithms for solution of the Navier-Stokes equations in the primitive-variables and vorticity-stream function formulations. Grids and grid generation. Numerical modeling of turbulent flows. Additional Prerequisite: An undergraduate course in numerical methods.
Prerequisite(s): MMAE 510 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 518
Spectral Methods in Computational Fluid Dynamics
Application of advanced numerical methods and techniques to the solution of important classes of problems in fluid mechanics. Emphasis is in methods derived from weighted-residuals approaches, like Galerkin and Galerkin-Tau methods, spectral and pseudospectral methods, and dynamical systems modeling via projections on arbitrary orthogonal function bases. Finite element and spectral element methods will be introduced briefly in the context of Galerkin methods. A subsection of the course will be devoted to numerical turbulence modeling, and to the problem of grid generation for complex geometries.
Prerequisite(s): MMAE 510 with min. grade of C and MMAE 501 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 520
Advanced Thermodynamics
Macroscopic thermodynamics: first and second laws applied to equilibrium in multicomponent systems with chemical reaction and phase change, availability analysis, evaluations of thermodynamic properties of solids, liquids, and gases for single and multicomponent systems. Applications to contemporary engineering systems. Prerequisite: An undergraduate course in applied thermodynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 522
Nuclear, Fossil-Fuel, and Sustainable Energy Systems
Principles, technology, and hardware used for conversion of nuclear, fossil-fuel, and sustainable energy into electric power will be discussed. Thermodynamic analysis -- Rankine cycle. Design and key components of fossil-fuel power plants. Nuclear fuel, reactions, materials. Pressurized water reactors (PWR). Boiling water reactors (BWR). Canadian heavy water (CANDU) power plants. Heat transfer from the nuclear fuel elements. Introduction to two phase flow: flow regimes; models. Critical heat flux. Environmental effects of coal and nuclear power. Design of solar collectors. Direct conversion of solar energy into electricity. Wind power. Geothermal energy. Energy conservation and sustainable buildings. Enrichment of nuclear fuel. Nuclear weapons and effects of the explosions.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 523
Fundamentals of Power Generation
Thermodynamic, combustion, and heat transfer analyses relating to steam-turbine and gas-turbine power generation. Environmental impacts of combustion power cycles. Consideration of alternative and sustainable power generation processes such as wind and tidal, geothermal, hydroelectric, solar, fuel cells, nuclear power, and microbial. Prerequisite: An undergraduate course in applied thermodynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 524
Fundamentals of Combustion
Combustion stoichiometry. Chemical equilibrium. Adiabatic flame temperature. Reaction kinetics. Transport processes. Gas flames classification. Premixed flames. Laminar and turbulent regimes. Flame propagation. Deflagrations and detonations. Diffusion flames. Spray combustion. The fractal geometry of flames. Ignition theory. Pollutant formation. Engine combustion. Solid phase combustion. Combustion diagnostics. Prerequisite: An undergraduate course in thermodynamics and heat transfer or instructor consent.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 525
Fundamentals of Heat Transfer
Modes and fundamental laws of heat transfer. The heat equations and their initial and boundary conditions. Conduction problems solved by separation of variables. Numerical methods in conduction. Forced and natural convection in channels and over exterior surfaces. Similarity and dimensionless parameters. Heat and mass analogy. Effects of turbulence. Boiling and condensation. Radiation processes and properties. Blackbody and gray surfaces radiation. Shape factors. Radiation shields. Prerequisite: An undergraduate course in heat transfer.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 526
Conduction and Diffusion
Heat conduction and Fourier's law. Diffusion and Fick's 1st law. Random walk. Thermal conductivity and diffusion coefficients in solids, liquids and gases. Stokes-Einstein equation. Non-continuum effects and nano-scale transport. Resistances in heat conduction & electrical analogy. Multi-dimensional conduction and diffusion problems. Transient heat conduction and diffusion equation. Fick's 2nd law. Analytical and numerical solution approaches for conduction and diffusion equations (Fourier series, Bessels functions, etc). Sources and sinks in conduction and diffusion including reactions.
Prerequisite(s): MMAE 525 with min. grade of C and MMAE 502 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 527
Heat Transfer: Convection and Radiation
Convective heat transfer analyses of external and internal flows. Forced and free convection. Dimensional analysis. Phase change. Heat and mass analogy. Reynolds analogy. Turbulence effects. Heat exchangers, regenerators. Basic laws of Radiation Heat Transfer. Thermal radiation and quantum mechanics pyrometry. Infrared measuring techniques.
Prerequisite(s): MMAE 525 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 529
Theory of Plasticity
Phenomenological nature of metals, yield criteria for 3-D states of stress, geometric representation of the yield surface. Levy-Mises and Prandtl-Reuss equations, associated and non-associated flow rules, Drucker's stability postulate and its consequences, consistency condition for nonhardening materials, strain hardening postulates. Elastic plastic boundary value problems. Computational techniques for treatment of small and finite plastic deformations.
Prerequisite(s): MMAE 530 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 530
Advanced Mechanics of Solids
Mathematical foundations: tensor algebra, notation and properties, eigenvalues and eigenvectors. Kinematics: deformation gradient, finite and small strain tensors. Force and equilibrium: concepts of traction/stress, Cauchy relation, equilibrium equations, properties of stress tensor, principal stresses. Constitutive laws: generalized Hooke's law, anisotropy and thermoelasticity. Boundary value problems in linear elasticity: plane stress, plane strain, axisymmetric problems, Airy stress function. Energy methods for elastic solids. Torsion. Elastic and inelastic stability of columns.
Prerequisite(s): MMAE 501* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 531
Theory of Elasticity
Notion of stress and strain, field equations of linearized elasticity. Plane problems in rectangular and polar coordinates. Problems without a characteristic length. Plane problems in linear elastic fracture mechanics. Complex variable techniques, energy theorems, approximate numerical techniques.
Prerequisite(s): MMAE 530 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 532
Advanced Finite Element Methods
Continuation of MMAE 451/CAE 442. Covers the theory and practice of advanced finite element procedures. Topics include implicit and explicit time integration, stability of integration algorithms, unsteady heat conduction, treatment of plates and shells, small-strain plasticity, and treatment of geometric nonlinearity. Practical engineering problems in solid mechanics and heat transfer are solved using MATLAB and commercial finite element software. Special emphasis is placed on proper time step and convergence tolerance selection, mesh design, and results interpretation.
Prerequisite(s): CAE 442 with min. grade of C or MMAE 451 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 533
Fatigue and Fracture Mechanisms
Analysis of the general state of stress and strain in solids; dynamic fracture tests (FAD, CAT). Linear elastic fracture mechanics (LEFM), Griffith-Irwin analysis, ASTM, KIC, KIPCI, KIA, KID. Plane stress, plane strain; yielding fracture mechanics (COD, JIC). Fatigue crack initiation. Goodman diagrams and fatigue crack propagation. Notch sensitivity and stress concentrations. Low-cycle fatigue, corrosion and thermal fatigue. Prerequisite: An undergraduate course in mechanics of solids.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 534
Product Design and Innovation
This course covers all aspects of planning new products or services that are commercially viable and add to a company's suite of offerings. It includes such topics as user research, market analysis, need/problem identification, creative thinking, ideation, concepting, competitive benchmarking, human factors, prototyping, evaluation, and testing. The course includes creative, analytical, and technical skills in a balanced approach using such teaching methods as case studies, individual exercises, and group projects.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 535
Vibrations
Analysis of vibrations in solids and structures beginning with a single degree of freedom (SDOF) system. For the SDOF system, consideration of free vibrations in undamped and damped conditions, introduction to the concept of resonance frequency, and analysis of forced harmonic response. Vibrations of multi degree of freedom (MDOF) systems are considered through matrix methods. Topics include the concept of resonant frequencies of MDOF systems, vibration modeshapes, and modal damping. Forced vibrations of MDOF systems are considered through modal analysis. Further topics include the connections of vibration analysis to Laplace and Fourier transforms, the transition from vibration analysis in MDOF system to the analysis of wave propagation in continuous systems (solids), and the applications of vibration and wave analyses to Structural Health Monitoring (SHM) and Non Destructive Evaluation (NDE).
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 536
Experimental Solid Mechanics
Review of applied elasticity. Stress, strain and stress-strain relations. Basic equations and boundary value problems in plane elasticity. Methods of strain measurement and related instrumentation. Electrical resistance strain gauges, strain gauge circuits and recording instruments. Analysis of strain gauge data. Brittle coatings. Photoelasticity; photoelastic coatings; moire methods; interferometric methods. Applications of these methods in the laboratory. Prerequisite: An undergraduate course in mechanics of solids.
Lecture: 3 **Lab:** 2 **Credits:** 4

MMAE 537
Innovation in Science and Technology I
This is the first of a two-part course designed to provide engineering and science students with an opportunity to apply their knowledge and expertise to solving a real-world technical problem. Each students will work on an individualized project to solve a problem or develop a device from concept to design and prototyping. Students will learn the basic necessary skills to analyze a topic, break the problem down to its essential components, and develop a basic understanding of the relevant engineering and physics principles involved. Project topics will include mechanical, material, thermal, fluid, solar, optical and electronic systems. This course is designed for graduate and undergraduate students would like to enrich their academic education by conducting applied study and research without a formal thesis or research program. Students typically register for part I and II of this course in two semesters to complete their work. Undergraduate and graduate levels with interest in R&D. Contact faculty for permit to register.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 538
Engineering Innovation in Science and Technology II
This is the second part of a two-semester course designed to provide science and engineering students with the opportunity to investigate and develop solutions to some challenging real-world problems. Problems are selected by each student, based on her or his background and interest, from a set of topics provided by the faculty. Experimental, theoretical, numerical techniques or a combination thereof are used to advance a solution or to develop a new or improved design, methodology, device, or system. This course is designed for students who have taken MMAE 537 to continue their practical experience by a more in-depth study of their selected topic. The two-part course is designed to simulate an interdisciplinary 'work environment' giving students the necessary support and training to deepen their understanding of underlying engineering and physical principles to help them innovate.
Prerequisite(s): MMAE 537
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 539
Robotic Motion Planning
Configuration space. Path planning techniques including potential field functions, roadmaps, cell decomposition, and sampling-based algorithms. Kalman filtering. Probabilistic localization techniques using Bayesian methods. Trajectory planning. Homework and project will require extensive programming in Matlab or similar environment.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 540
Robotics
Kinematics and inverse kinematics of manipulators. Newton-Euler dynamic formulation. Independent joint control. Trajectory and path planning using potential fields and probabilistic roadmaps. Adaptive control. Force control.
Prerequisite(s): MMAE 501* with min. grade of C and MMAE 443 with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 541
Advanced Dynamics
Kinematics of rigid bodies. Rotating reference frames and coordinate transformations; Inertia dyadic. Newton-Euler equations of motion. Gyroscopic motion. Conservative forces and potential functions. Generalized coordinates and generalized forces. Lagrange's equations. Holonomic and nonholonomic constraints. Lagrange multipliers. Kane's equations. Elements of orbital and spacecraft dynamics. Additional Prerequisite: An undergraduate course in dynamics.
Prerequisite(s): MMAE 501* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 543
Modern Control Systems
Review of classical control. Discrete-time systems. Linear difference equations. Z-transform. Design of digital controllers using transform methods. State-space representations of continuous and discrete-time systems. State feedback. Controllability and observability. Pole placement. Optimal control. Linear-Quadratic Regulator (LQR). Probability and stochastic processes. Optimal estimation. Kalman Filter. Additional Prerequisite: An undergraduate course in classical control.
Prerequisite(s): MMAE 501* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 544
Design Optimization
Optimization theory and practice with examples. Finite-dimensional unconstrained and constrained optimization, Kuhn-Tucker theory, linear and quadratic programming, penalty methods, direct methods, approximation techniques, duality. Formulation and computer solution of design optimization problems in structures, manufacturing and thermofluid systems. Prerequisite: An undergraduate course in numerical methods.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 545
Advanced CAD/CAM
Interactive computer graphics in mechanical engineering design and manufacturing. Mathematics of three-dimensional object and curved surface representations. Surface versus solid modeling methods. Numerical control of machine tools and factory automation. Applications using commercial CAD/CAM in design projects. MMAE 445 (with min. grade of C)/equivalent or instructor consent as prerequisite of MMAE545.
Prerequisite(s): MMAE 445 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 546
Advanced Manufacturing Engineering
Introduction to advanced manufacturing processes such as powder metallurgy, joining and assembly, grinding, water jet cutting, laser-based manufacturing, etc. Effects of variables on the quality of manufactured products. Process and parameter selection. Important physical mechanisms in manufacturing process. Prerequisite: An undergraduate course in manufacturing processes or instructor consent. Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 547
Computer-Integrated Manufacturing Technologies
The use of computer systems in planning and controlling the manufacturing process including product design, production planning, production control, production processes, quality control, production equipment and plant facilities. Prerequisite: Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 549
Optimal Control
The course focuses on unconstrained and constrained optimal control problems for linear and non-linear deterministic systems. It uses basic optimization and principles of optimal control. The course covers introduction to convex optimization and nonlinear systems, dynamic programming, variational calculus, approaches based on Pontryagin's minimum principle, and model predictive control.
Prerequisite(s): MMAE 543 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 550
Optimal State Estimation
Probability and random variables. Stochastic dynamic systems. Kalman filters, information forms, and smoothers. Covariance analysis. Bayesian, adaptive, and nonlinear estimation. Detection theory. Applications to guidance, navigation, and control systems.
Prerequisite(s): MMAE 501* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 552
Intro to the Space Environment
Overview of the space environment, particularly Earth's ionosphere, magnetosphere, and interplanetary space. Effects of solar activity on geospace variability. Basic plasma characteristics. Single particle motions. Waves in magnetized plasmas. Charged particle trapping in planetary magnetic fields and its importance in near-earth-space phenomena. Macroscopic equations for a conducting fluid. Ground and space-based remote sensing and in situ measurement techniques. Space weather effects on human-made systems. Students must have already taken undergraduate courses in electromagnetics and in fluid mechanics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 554
Electrical, Magnetic and Optical Properties of Materials
Electronic structure of solids. Conductors, semiconductors, dielectrics, superconductors. Ferroelectric and piezoelectric materials. Magnetic properties, magnetocrystalline, anisotropy, magnetic materials and devices. Optical properties and their applications.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 555
Introduction to Navigation Systems
Fundamental concepts of positioning and dead reckoning. Principles of modern satellite-based navigation systems, including GPS, GLONASS, and Galileo. Differential GPS (DGPS) and augmentation systems. Carrier phase positioning and cycle ambiguity resolution algorithms. Autonomous integrity monitoring. Introduction to optimal estimation, Kalman filters, and covariance analysis. Inertial sensors and integrated navigation systems.
Prerequisite(s): MMAE 501* with min. grade of C and MMAE 443 with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 556
Nano Manufacturing
This course covers the general methods used for micro- and nano-fabrication and assembly including photolithography techniques, physical and chemical deposition methods, masking, etching, and bulk micromachining as well as self-assembly techniques. It also covers nanotubes, nanowires, nanoparticles, and the devices that use them including both electronic and mechanical-electronic systems as well as nano-structural materials and composites. Focus is on commercially available current processes as well as emerging technologies and evolving research areas. Sensing and instrumentation as well as nano-positioning and actuation are covered briefly.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 557
Computer-Integrated Manufacturing Systems
Advanced topics in computer-integrated manufacturing including control systems, group technology, cellular manufacturing, flexible manufacturing systems, automated inspection, lean production, Just-In-Time production, and agile manufacturing systems. Prerequisite: Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 560
Statistical Quality and Process Control
Basic theory, methods and techniques of on-line, feedback quality control systems for variable and attribute characteristics. Methods for improving the parameters of the production, diagnosis, and adjustment processes so that quality loss is minimized. Same as CHE 560. Prerequisite: Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 561
Solidification and Crystal Growth
Properties of melts and solids. Thermodynamic and heat transfer concepts. Single and poly-phase alloys. Macro and micro segregation. Plane-front solidification. Solute boundary layers. Constitutional supercooling. Convection in freezing melts. Effective segregation coefficients. Zone freezing and purification. Single crystal growth technology. Czochralski, Kyropulous, Bridgman, and Floating Zone methods. Control of melt convection and crystal composition. Equipment. Process control and modeling. Laboratory demonstration. Prerequisite: A background in crystal structure and thermodynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 562
Design of Modern Alloys
Phase rule, multicomponent equilibrium diagrams, determination of phase equilibria, parameters of alloy development, prediction of structure and properties. Prerequisite: A background in phase diagrams and thermodynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 563
Advanced Mechanical Metallurgy
Analysis of the general state of stress and strain in solids. Analysis of elasticity and fracture, with a major emphasis on the relationship between properties and structure. Isotropic and anisotropic yield criteria. Testing and forming techniques related to creep and superplasticity. Deformation mechanism maps. Fracture mechanics topics related to testing and prediction of service performance. Static loading to onset of rapid fracture, environmentally assisted cracking fatigue, and corrosion fatigue. Prerequisite: A background in mechanical properties.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 564
Dislocations and Strengthening Mechanisms
Basic characteristics of dislocations in crystalline materials. Dislocations and slip phenomena. Application of dislocation theory to strengthening mechanisms. Strain hardening. Solid solution and particle strengthening. Dislocations and grain boundaries. Grain size strengthening. Creep. Fatigue. Prerequisite: Background in materials analysis.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 565
Materials Laboratory
Advanced synthesis projects studying microstructure and properties of a series of binary and ternary alloys. Gain hands-on knowledge of materials processing and advanced materials characterization through an integrated series of experiments to develop understanding of the processing-microstructure-properties relationship. Students arc melt a series of alloys, examine the cast microstructures as a function of composition using optical and electron microscopy, DTA, EDS, and XRD. The alloys are treated in different thermal and mechanical processes. The microstructural and mechanical properties modification and changes during these processes are characterized. Groups of students will be assigned different alloy systems, and each group will present their results orally to the class and the final presentation to the whole materials science and engineering group.
Credit: Variable

MMAE 566
Problems in High-Temperature Materials
Temperature-dependent mechanical properties. Creep mechanisms. Basic concepts in designing in high-temperature materials. Metallurgy of basic alloy systems. Surface stability. High-temperature oxidation. Hot corrosion. Coatings and protection. Elements of process metallurgy.Prerequisite: Background in mechanical properties, crystal defects, and thermodynamics.
Prerequisite(s): MMAE 564 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 567
Fracture Mechanisms
Basic mechanisms of fracture and embrittlement of metals. Crack initiation and propagation by cleavage, microvoid coalescence, and fatigue mechanisms. Hydrogen embrittlement, stress corrosion cracking and liquid metal embrittlement. Temper brittleness and related topics.Prerequisite: Background in crystal structure, defects, and mechanical properties.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 568
Diffusion
Theory, techniques and interpretation of diffusion studies in metals. Prerequisite: Background in crystal structures, defects, and thermodynamics.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 569
Advanced Physical Metallurgy
Thermodynamics and kinetics of phase transformations, theory of nucleation and growth, metastability, phase diagrams.Prerequisite: Background in phase diagrams and thermodynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 570
Computational Methods in Materials Science and Engineering
Advanced theories and computational methods used to understand and predict material properties. This course will introduce energy models from classical and first-principles approaches, density functional theory, molecular dynamics, thermodynamic modeling, Monte Carlo simulations, and data mining in materials science. The course will also include case studies of computational materials research (e.g. alloy design, energy storage, nanoscale properties). The course consists of both lectures and computer labs. Background in thermodynamics is required.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 572
Crystallography and Crystal Defect
Geometrical crystallography - formal definitions of lattices, systems, point groups, etc. Mathematical methods of crystallographic analysis. Diffraction techniques: X-ray, electron and neutron diffraction. Crystal defects and their influence on crystal growth and crystal properties.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 576
Materials and Process Selection
Context of selection; decision analysis; demand, materials and processing profiles; design criteria; selection schemes; value and performance oriented selection; case studies.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 578
Fiber Composites
Basic concepts and definitions. Current and potential applications of composite materials. Fibers, Matrices, and overview of manufacturing processes for composites. Review of elasticity of anisotropic solids and transformation of stiffness/compliance matrices. Micromechanics: methods for determining mechanical properties of heterogeneous materials. Macromechanics: ply analysis, off-axis stiffness, description of laminates, laminated plate theories, special types of laminates. Applications of concepts to the design of simple composite structural components. Failure theories, hydrothermal effects.Prerequisite: Background in polymer synthesis and properties.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 579
Advanced Materials Processing
Processing science and fundamentals in making advanced materials, particularly nanomaterials and composites. Applications of the processing science to various processing technologies including severe plastic deformation, melt infiltration, sintering, co-precipitation, sol-gel process, aerosol synthesis, plasma spraying, vapor-liquid-solid growth, chemical vapor deposition, physical vapor deposition, atomic layer deposition, and lithography.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 585
Engineering Optics and Laser-Based Manufacturing
Fundamentals of geometrical and physical optics as related to problems in engineering design and research; fundamentals of laser-material interactions and laser-based manufacturing processes. This is a lecture-dominated class with around three experiments organized to improve students' understanding of the lectures. The topics covered include: geometrical optics (law of reflection and refraction, matrix method, etc.); physical optics (wave equations, interference, polarization, Fresnel equations, etc.); optical properties of materials and Drude theory; laser fundamentals; laser-matter interactions and laser-induced thermal and mechanical effects, laser applications in manufacturing (such as laser hardening, machining, sintering, shock peening, and welding). Knowledge of Heat & Mass Transfer required.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 586
Advanced Failure Analysis
Comprehensive coverage of both the "how" and "why" of metal and ceramic failures. Intellectual tools and understanding needed to analyze failures. Analytical methods including stress analysis, fracture mechanics, fatigue analysis, creep mechanisms, corrosion science, and nondestructive testing. Numerous case studies illustrating the application of basic principles of materials science and failure analysis to a wide variety of real-world situations.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 587
Introduction to Digital Manufacturing
This course is about the digital revolution taking place in the world of manufacturing and how students, workers, managers, and business owners can benefit from the sweeping technological changes taking place. It is about the change from paper-based processes to digital-based processes all through the design/manufacturing/deliver enterprise and across the global supply chain. It touches on digital design, digital manufacturing engineering, digital production, digital quality assurance, and digital contracting from large companies to small. There is also a significant focus on cyber security and the new types of threats that manufacturers face in the new digital world. Other topics covered include intelligent machines, connectivity, the digital thread, big data, and the Industrial Internet of Things (IIoT).
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 588
Additive Manufacturing
This course examines the fundamentals of a variety of additive manufacturing processes as well as design for additive manufacturing, materials available, and properties and limitations of materials and designs. It also examines the economics of additive manufacturing as compared to traditional subtractive manufacturing and other traditional techniques. Additive techniques discussed include 3D printing, selective laser sintering, stereo lithography, multi-jet modeling, laminated object manufacturing, and others. Advantages and limitations of all current additive technologies are examined as well as criteria for process selection. Processes for metals, polymers, and ceramics are covered. Other topics include software tools and connections between design and production, direct tooling, and direct manufacturing. Current research trends are discussed.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 589
Applications in Reliability Engineering I
This first part of a two-course sequence focuses on the primary building blocks that enable an engineer to effectively communicate and contribute as a part of a reliability engineering effort. Students develop an understanding of the long term and intermediate goals of a reliability program and acquire the necessary knowledge and tools to meet these goals. The concepts of both probabilistic and deterministic design are presented, along with the necessary supporting understanding that enables engineers to make design trade-offs that achieve a positive impact on the design process. Strengthening their ability to contribute in a cross functional environment, students gain insight that helps them understand the reliability engineering implications associated with a given design objective, and the customer's expectations associated with the individual product or product platforms that integrate the design. These expectations are transformed into metrics against which the design can be measured. A group project focuses on selecting a system, developing a flexible reliability model, and applying assessment techniques that suggest options for improving the design of the system. Prerequisite: Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 590
Applications in Reliability Engineering II
This is the second part of a two-course sequence emphasizing the importance of positively impacting reliability during the design phase and the implications of not making reliability an integrated engineering function. Much of the subject matter is designed to allow the students to understand the risks associated with a design and provide the insight to reduce these risks to an acceptable level. The student gains an understanding of the methods available to measure reliability metrics and develops an appreciation for the impact manufacturing can have on product performance if careful attention is not paid to the influencing factors early in the development process. The discipline of software reliability is introduced, as well as the influence that maintainability has on performance reliability. The sequence culminates in an exhaustive review of the lesson plans in a way that empowers practicing or future engineers to implement their acquired knowledge in a variety of functional environments, organizations and industries. The group project for this class is a continuation of the previous course, with an emphasis on applying the tools and techniques introduced during this second of two courses. Prerequisite: Undergraduate engineering degree or concurrent enrollment in undergraduate engineering program or consent of instructor.
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 591
Research and Thesis M.S.
Credit: Variable

MMAE 593
MMAE Seminar
Reports on current research. Full-time graduate students in the department are expected to register and attend.
Lecture: 1 **Lab:** 0 **Credits:** 0

MMAE 594
Project for Master of Engineering Students
Design projects for the master of mechanical and aerospace engineering, master of materials engineering, and master of manufacturing engineering degrees.
Credit: Variable

MMAE 596
Semiconductors for Energy Generation
The course focus on advanced topics of two energy generation applications of semiconductors: photovoltaics and thermoelectrics. The goal is to understand the fundamental physics behind material behaviors. Topics include: Basic of semiconductors. Excitation and recombination process. Electron and phonon transport. Scattering mechanisms. Thermodynamics and statistical mechanics of electron and phonon systems. Boltzmann transport equations. Measurement techniques, Review of emerging materials. requires: MS201 minimum C. recommended preparation: MMAE 362 Physics of Solids, or PHYS 437 Solid State Physics.
Prerequisite(s): MS 201 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MMAE 597
Special Topics
Advanced topic in the fields of mechanics, mechanical and aerospace, metallurgical and materials, and manufacturing engineering in which there is special student and staff interest. (Variable credit)
Credit: Variable

MMAE 600
Continuance of Residence
Lecture: 0 **Lab:** 1 **Credits:** 1

MMAE 691
Research and Thesis Ph.D.
Credit: Variable

MMAE 704
Introduction to Finite Element Analysis
This course provides a comprehensive overview of the theory and practice of the finite element method by combining lectures with selected laboratory experiences . Lectures cover the fundamentals of linear finite element analysis, with special emphasis on problems in solid mechanics and heat transfer. Topics include the direct stiffness method, the Galerkin method, isoperimetric finite elements, equation solvers, bandwidth of linear algebraic equations and other computational issues. Lab sessions provide experience in solving practical engineering problems using commercial finite element software. Special emphasis is given to mesh design and results interpretation using commercially available pre- and post-processing software.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 705
Computer Aided Design with Pro Engineer
This course provides an introduction to Computer-Aided Design and an associated finite element analysis technique. A series of exercises and instruction in Pro/ENGINEER will be completed. The operation of Mecanica (the associated FEM package) will also be introduced. Previous experience with CAD and FEA will definitely speed learning, but is not essential.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 707
High-Temperature Structural Materials
Creep mechanisms and resistance. The use of deformation mechanisms maps in alloy design. Physical and mechanical metallurgy of high-temperature, structural materials currently in use. Surface stability: High-temperature oxidation, hot corrosion, protective coatings. Alternative materials of the 21st century. Elements of process metallurgy.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 709
Overview of Reliability Engineering
This course covers the role of reliability in robust product design. It dwells upon typical failure mode investigation and develops strategies to design them out of the product. Topics addressed include reliability concepts, systems reliability, modeling techniques, and system availability predications. Case studies are presented to illustrate the cost-benefits due to pro-active reliability input to systems design, manufacturing and testing.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 710
Dynamic and Nonlinear Finite Element Analysis
Provides a comprehensive understanding of the theory and practice of advanced finite element procedures. The course combines lectures on dynamic and nonlinear finite element analysis with selected computer labs. The lectures cover implicit and explicit time integration techniques, stability of integration algorithms, treatment of material and geometric nonlinearity, and solution techniques for nonlinear finite element equations. The computer labs train student to solve practical engineering problems in solid mechanics and heat transfer using ABQUS and Hypermesh. Special emphasis is placed on proper time step and convergence tolerance selection, mesh design, and results interpretation. A full set of course notes will be provided to class participants as well as a CD-ROM containing course notes, written exercises, computer labs, and all worked out examples.
Prerequisite(s): MMAE 704 with min. grade of C
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 713
Engineering Economic Analysis
Introduction to the concepts of Engineering Economic Analysis, also known as micro-economics. Topics include equivalence, the time value of money, selecting between alternative, rate of return analysis, compound interest, inflation, depreciation, and estimating economic life of an asset.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 715
Project Management
This course will cover the basic theory and practice of project management from a practical viewpoint. Topics will include project management concepts, recourses, duration vs. effort, project planning and initiation, progress tracking methods, CPM and PERT, reporting methods, replanning, team project concepts, and managing multiple projects. Microsoft Project software will be used extensively.
Lecture: 2 **Lab:** 0 **Credits:** 2

MMAE 724
Introduction to Acoustics
This short course provides a brief introduction to the fundamentals of acoustics and the application to product noise prediction and reduction. The first part focuses on fundamentals of acoustics and noise generation. The second part of the course focuses on applied noise control.
Lecture: 2 **Lab:** 0 **Credits:** 2