MAE - Mechanical and Aerospace Engineering

MAE 111 Mechanical and Aerospace Engineering Information Literacy and Research (2 Credit Hours)
This course will introduce students to the needs, access, evaluation, use, impact and ethical/legal aspects of information, and to the application of information literacy and research in the fields of mechanical and aerospace engineering.
Prerequisites: ENGN 110

MAE 195 Topics (1-3 Credit Hours)
Permission of the chair required.

MAE 201 Materials Science (3 Credit Hours)
Principles of materials science with emphasis on the relationship between structure and properties and their control through composition and processing. Metals, polymers, ceramics, and composite materials are considered.
Prerequisites: MATH 211 with a grade of C or better

MAE 203 Mechanical Engineering Laboratory I - Materials Science (1 Credit Hour)
This laboratory involves experiments demonstrating lecture material covered in the MAE 201 course.
Pre- or corequisite: MAE 201 and CS 150 or ENGN 150

MAE 204 Engineering Mechanics I - Statics (3 Credit Hours)
Introduction to mechanical engineering problems and their solutions through the study of statics of particles and rigid bodies. Emphasis will be placed on the relationship of the static loads with the mechanical properties of the materials being considered. Introduction to the concepts of stress and strain and internal forces as applied to static bodies.
Prerequisites: MATH 211 with a grade of C or better
Pre- or corequisite: PHYS 231N

MAE 205 Dynamics (3 Credit Hours)
Introduction to engineering problems and their solutions through a study of the dynamics of particles and rigid bodies. General force systems are studied including friction.
Prerequisites: A grade of C or better in MAE 204 or CEE 204
Pre- or corequisite: MATH 212

MAE 220 Engineering Mechanics II - Solid Mechanics (3 Credit Hours)
Introduction to concepts of stress, strain and their relation to each other. Stress and strain in axially loaded members and circular rods and tubes subjected to torsion. Normal and shear stress in beams under bending loads. Additional topics include bending deflection, transformation of stress and strain, Mohr's circles, statically indeterminate problems, combined stress and thin walled pressure vessels.
Prerequisites: A grade of C or better in MAE 204 or CEE 204

MAE 225 Mechanical Engineering Laboratory II - Solid Mechanics (1 Credit Hour)
Experimental study of the mechanical behavior of materials under axial, bending and torsional loads. Measurements of elastic properties and strengths. Statistical treatment of data. Use of strain gauges. Experiments with composite materials and piezo-electric transducers. Use of data acquisition system. Experiments parallel lectures in MAE 220.
Prerequisites: ENGN 150 or CS 150
Pre- or corequisite: MAE 220

MAE 230 Engineering Graphics and Computer Solid Modeling (2 Credit Hours)
Graphical communication for engineers by means of 3D parametric modeling and its applications in industry. Fundamentals of sketching, basics of surface design, assembly modeling, and dynamic modeling of mechanisms using industry standard parametric modeling software. Emphasis on developing the skills needed for engineering design, including use of engineering standards.

MAE 303 Mechanics of Fluids (3 Credit Hours)
Fundamental concepts, fluid statics, basic equations in integral form, open-channel flow, Bernoulli's equation, dimensional analysis and similitude, incompressible viscous flow, pipe friction, boundary layers, introduction to differential analysis.
Prerequisites: MATH 307, MATH 312, and a grade of C or better in MAE 205

MAE 305 Mechanical Engineering Laboratory III - Thermo/Fluids (1 Credit Hour)
An introduction to thermo-fluid experimentation and measurement; basic flow phenomena demonstrated; measurement techniques for flow temperature, pressure and properties; report writing and data reduction methods, including statistical treatment of data; formal oral reports.
Prerequisites: Junior standing
Pre- or corequisite: MAE 303 and MAE 311

MAE 311 Thermodynamics I (3 Credit Hours)
Essential definitions of thermodynamics, first law, physical properties, ideal and real gases, second law, reversibility, irreversibility and consequences of thermodynamic cycles.
Prerequisites: MATH 312, and a grade of C or better in CHEM 121N

MAE 312 Thermodynamics II (3 Credit Hours)
Concepts and principles dealing with thermodynamic cycles, relations and generalized charts, mixtures of fluids, chemical reactions, chemical and phase equilibrium, thermodynamic aspects of fluid flow; introduction to compressible flow, isentropic and normal shock wave relations.
Prerequisites: MATH 307, and a grade of C or better in MAE 303, and a grade of C or better in MAE 311

MAE 315 Heat and Mass Transfer (3 Credit Hours)
Fundamental laws of heat transfer by conduction, convection, and radiation; boundary-layer concepts; simultaneous heat, mass, and momentum transfer.
Prerequisites: A grade of C or better in MAE 303, and a grade of C or better in MAE 311

MAE 332 Mechanical Engineering Design I (3 Credit Hours)
Introduction to machine design including review of stress and deflection analysis. Statistical considerations in design, strength of mechanical elements with emphasis on theories of failure and fatigue design.
Prerequisites: MAE 201, a grade of C or better in MAE 205, a grade of C or better in MAE 220, and MET 120 or MET 230
Pre- or corequisite: MAE 225

MAE 336 Electromechanical Systems (3 Credit Hours)
Introduction to analog and digital circuits; sensors, actuators and signals; laboratory instrumentation (oscilloscope, function generator, etc.); data acquisition; and embedded microcontroller systems. Students will perform electronics experiments as homework assignments.
Prerequisites: CS 150 or ENGN 150 and PHYS 232N

MAE 340 Computational Methods in Mechanical Engineering (3 Credit Hours)
A survey of modern computing techniques for mechanical engineers. Numerical algorithms are presented to solve practical problems in mechanical engineering as found in solid mechanics, fluid mechanics, dynamics, and heat transfer. Emphasis is on providing computational experience in applied numerical methods using computers. Topics include roots of equations, simultaneous equations, differentiation, integration, regression analysis, interpolation and differential equations. Analysis, understanding, and quantification of computational errors are included in all topics and applications.
Prerequisites: ENGN 150 or CS 150, MATH 307 and MATH 312

MAE 367 Cooperative Education (1-3 Credit Hours)
Available for pass/fail grading only. Student participation for credit based on the academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and Career Development Services prior to the semester in which the work experience is to take place.
Prerequisites: Approval by department and Career Development Services in accordance with the policy for granting credit for Cooperative Education programs

MAE 368 Internship (1-3 Credit Hours)
Available for pass/fail grading only. Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students to gain short duration career-related experience.
Prerequisites: Approval by department and Career Development Services

MAE 369 Practicum (1-3 Credit Hours)
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career-related experience.
Prerequisites: Approval by department and Career Development Services

MAE 403/503 Flight Mechanics (3 Credit Hours)
Aircraft concepts including performance prediction and optimization, flight and maneuver envelopes, and steady flight performance. Additional topics: longitudinal static stability and trim; aircraft dynamics; development, separation and solution of aircraft equations of motion; natural modes; dynamic stability; sensors and actuators; and design of stability augmentation and autopilot systems.
Prerequisites: MAE 303 with a grade of C or better and MAE 340
Pre- or corequisite: MAE 436

MAE 404/504 Vibrations (3 Credit Hours)
Free and forced vibrations of undamped and damped, single-degree of freedom, multi-degree of freedom, and continuous systems. Exact and approximate methods to find natural frequencies.
Prerequisites: A grade of C or better in MAE 205, a grade of C or better in MAE 220; MAE 340 and MATH 312

MAE 406/506 Flight Vehicle Aerodynamics (3 Credit Hours)
Inviscid flow concepts including: Euler equations, stream function, velocity potential, singularities, vorticity and circulation laws. Viscous flow topics including boundary layers, separation, and turbulent flow. In addition, external flows, lift and drag, thin airfoil theory, finite wing theory and airfoil design will be discussed.
Prerequisites: A grade of C or better in MAE 303; MAE 340

MAE 411/511 Mechanical Engineering Power Systems Theory and Design (3 Credit Hours)
Thermodynamic properties of gases and vapors relating to power generating devices, work-energy relations, combustion, and heat exchangers. Performance analyses and design concepts of gas turbines, internal combustion engines, steam power plants and heat exchanger equipment from theoretical and applied viewpoints.
Prerequisites: MAE 312 and MAE 315

MAE 412/512 Environmental Control (3 Credit Hours)
Engineering principles as applied to the analysis and design of systems for automatically controlling man or machine environments. Course encompasses fundamentals of heating, ventilating, air conditioning, refrigeration, cryogenics, and design of building energy systems.
Prerequisites: MAE 312 and MAE 315

MAE 413/513 Energy Conversion (3 Credit Hours)
Introduction of relevant kinetic theory, solid state, and thermodynamic principles; operation and analysis of thermoelectric, photovoltaic, thermionic, magnetohydrodynamic devices, fuel cell, isotopic, and solar power generators. Course seeks to define engineering limits of converter efficiency and other performance criteria.
Prerequisites: MAE 312

MAE 414/514 Introduction to Gas Dynamics (3 Credit Hours)
One-dimensional compressible flow considering isentropic flow, normal shocks, flow in constant area ducts with friction, flow in ducts with heating and cooling, oblique shocks, Prandtl-Meyer expansions, shock-expansion theory, flow around diamond shaped airfoils, and wind tunnel mechanics.
Prerequisites: A grade of C or better in MAE 303 and a grade of C or better in MAE 311

MAE 417/517 Propulsion Systems (3 Credit Hours)
Basic principles of design, operation and performance of propulsion systems - including turbojet, turboprop, turbofan, and ramjet engines. Introduction to chemical rockets, ion and plasma thrusters.
Prerequisites: MAE 312 or MAE 414

MAE 420/520 Aerospace Structures (3 Credit Hours)
Analysis of aircraft and space vehicle structural components. Effects of bending, torsion and shear on typical aerospace structural components, statically indeterminate beams, shear center and shear flow. Introduction to typical aerospace structures. Introduction to composite structures.
Prerequisites: MAE 332 with a grade of C or better

MAE 422/522 Modern Engineering Materials (3 Credit Hours)
Limitations of conventional materials; inter-relationship among materials, design and processing, material selection criteria and procedures; strengthening mechanisms in metals; superelasticity; shape memory effect, amorphous metals; structure-property relationship in polymers; polymers crystallinity; thermoplastic and thermosets; high-temperature restraint polymers; ceramics; toughening mechanisms in ceramics.
Prerequisites: MAE 201, MAE 203, and a grade of C or better in MAE 220; MAE 332

MAE 431/531 Mechanisms Analysis and Design (3 Credit Hours)
Basic relations necessary for analysis of plane motion mechanisms, numerical and analytical solutions for some of the basic mechanisms, methods of calculating rolling and sliding velocities and accelerations of contacting bodies, cams, and gears.
Prerequisites: A grade of C or better in MAE 205, a grade of C or better in MAE 332, and MATH 312 or MATH 285

MAE 433 Mechanical Engineering Design II (3 Credit Hours)
Statistical considerations in design, strength of mechanical elements with emphasis on theories of failure and fatigue design in mechanical elements such as screws, fasteners, connections, welded joints, and flexible mechanical elements. Kinematic analysis, force analysis, and design of spur, helical, worm, and bevel gears. Antifriction bearings, lubrication and journal bearings, shaft design, mechanical spring design, design of clutches, brakes and couplings.
Prerequisites: A grade of C or better in MAE 332 and senior standing

MAE 434W Project Design and Management I (3 Credit Hours)
This course prepares students to complete their design projects in MAE 435. Lecture topics include engineering economics; project planning; costing and risk analysis; and product realization techniques. Course involves written and oral presentations for students to improve communication and teamwork skills. This is a writing intensive course.
Prerequisites: A grade of C or better in MAE 332, ENGL 211C or ENGL 221C or ENGL 231C
Pre- or corequisite: MAE 433

MAE 435 Project Design and Management II (3 Credit Hours)
Conceptual design ideas are expanded into detailed design ideas. Product realization is applied to complete hardware. Course covers Gantt charts, preliminary design, evaluation and trading matrices, detailed design and analysis, oral and technical reporting including cost analysis. Ethics and patent issues are also included.
Prerequisites: MAE 433 and MAE 434W

MAE 436 Dynamic Systems and Control (3 Credit Hours)
Analysis and synthesis of feedback systems; functional description of dynamic systems; basic controllers; sensitivity, stability and error analysis; transient and steady-state response using computational techniques, root locus and frequency response methods; state-space analysis of control systems.
Prerequisites: A grade of C or better in MAE 205; MAE 336, MATH 307 and MATH 312

MAE 438/538 Applied Analog and Digital Control (3 Credit Hours)
Computer-aided analysis and design of practical control systems. Introduction to state-space, digital signal processing and digital control. Laboratory sessions on aliasing, analog, system identification, and real-time control.
Prerequisites: a grade of C or better in MAE 436

MAE 440/540 Introduction to Finite Element Analysis (3 Credit Hours)
Basic concepts of finite-element method, method of weighted residuals, interpolation functions, numerical implementation of finite-element method, applications to engineering problems such as beam deflection, heat conduction, and plane elastic problems.
Prerequisites: MAE 340

MAE 441 Computer-Aided Design of Mechanical Systems (3 Credit Hours)
Case studies are used to introduce students to CAD software; design processes involving modeling, analysis and design, and verification. Typical case studies are beam and plate designs, turbine blade design, and pipe networks. Advanced topics include: thermal stress analysis and plates and shells.
Prerequisites: ENGN 150 or CS 150, and a grade of C or better in MAE 220; MATH 312
Pre- or corequisite: MAE 332

MAE 450/550 Principles of Naval Architecture (3 Credit Hours)
Basic principles of naval architecture related to ship geometry, stability, strength, resistance, propulsion, vibration and motions in waves and controllability.
Prerequisites: MATH 212 with a grade of C or better

MAE 460/560 Introduction to Space Systems Engineering (3 Credit Hours)
Introduction to spacecraft systems starting from mission design and space environment considerations and proceeding through propulsion, altitude control, spacecraft structural design, thermal control, power and communications for spacecraft.
Prerequisites: MATH 307 and PHYS 232N

MAE 495/595 Topics in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Special topics of interest with emphasis placed on recent developments in mechanical and aerospace engineering or engineering mechanics. (offered fall, spring, summer)
Prerequisites: Senior standing; Permission of the chair is required

MAE 496 Topics in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Special topics of interest with emphasis placed on recent developments in mechanical engineering or engineering mechanics. (offered fall, spring, summer)
Prerequisites: senior standing; permission of the chair is required

MAE 497/597 Independent Study in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Individual analytical, computational, and/or experimental study in an area selected by student. Supervised and approved by the advisor.
Prerequisites: Senior standing; Permission of the chair is required

MAE 503 Flight Mechanics (3 Credit Hours)
Aircraft concepts including performance prediction and optimization, flight and maneuver envelopes, and steady flight performance. Additional topics: longitudinal static stability and trim; aircraft dynamics; development, separation and solution of aircraft equations of motion; natural modes; dynamic stability; sensors and actuators; and design of stability augmentation and autopilot systems.
Prerequisites: MAE 303 with a grade of C or better and MAE 340
Pre- or corequisite: MAE 436

MAE 504 Vibrations (3 Credit Hours)
Free and forced vibrations of undamped and damped, single-degree of freedom, multi-degree of freedom, and continuous systems. Exact and approximate methods to find natural frequencies.
Prerequisites: A grade of C or better in MAE 205, a grade of C or better in MAE 220; MAE 340 and MATH 312

MAE 506 Flight Vehicle Aerodynamics (3 Credit Hours)
Inviscid flow concepts including: Euler equations, stream function, velocity potential, singularities, vorticity and circulation laws. Viscous flow topics including boundary layers separation, and turbulent flow. In addition, external flows, lift and drag, thin airfoil theory, finite wing theory and airfoil design will be discussed.
Prerequisites: A grade of C or better in MAE 303; MAE 340

MAE 511 Mechanical Engineering Power Systems Theory and Design (3 Credit Hours)
Thermodynamic properties of gases and vapors relating to power generating devices, work-energy relations, combustion, and heat exchangers. Performance analyses and design concepts of gas turbines, internal combustion engines, steam power plants and heat exchanger equipment from theoretical and applied viewpoints.
Prerequisites: MAE 312 and MAE 315

MAE 512 Environmental Control (3 Credit Hours)
Engineering principles as applied to the analysis and design of systems for automatically controlling man or machine environments. Course encompasses fundamentals of heating, ventilating, air conditioning, refrigeration, cryogenics, and design of building energy systems.
Prerequisites: MAE 312 and MAE 315

MAE 513 Energy Conversion (3 Credit Hours)
Introduction of relevant kinetic theory, solid state, and thermodynamic principles; operation and analysis of thermoelectric, photovoltaic, thermionic, magnetohydrodynamic devices, fuel cell, isotopic, and solar power generators. Course seeks to define engineering limits of converter efficiency and other performance criteria.
Prerequisites: MAE 312

MAE 514 Introduction to Gas Dynamics (3 Credit Hours)
One-dimensional compressible flow considering isentropic flow, normal shocks, flow in constant area ducts with friction, flow in ducts with heating and cooling, oblique shocks, Prandtl-Meyer expansions, shock-expansion theory, flow around diamond shaped airfoils, and wind tunnel mechanics.
Prerequisites: A grade of C or better in MAE 303 and a grade of C or better in MAE 311

MAE 517 Propulsion Systems (3 Credit Hours)
Basic principles of design, operation and performance of propulsion systems - including turbojet, turboprop, turbofan, and ramjet engines. Introduction to chemical rockets, ion and plasma thrusters.
Prerequisites: MAE 312 or MAE 414

MAE 520 Aerospace Structures (3 Credit Hours)
Analysis of aircraft and space vehicle structural components. Effects of bending, torsion and shear on typical aerospace structural components, statically indeterminate beams, shear center and shear flow. Introduction to typical aerospace structures. Introduction to composite structures.
Prerequisites: MAE 332 with a grade of C or better

MAE 522 Modern Engineering Materials (3 Credit Hours)
Limitations of conventional materials; inter-relationship among materials, design and processing, material selection criteria and procedures; strengthening mechanisms in metals; superelasticity; shape memory effect, amorphous metals; structure-property relationship in polymers; polymers crystallinity; thermoplastic and thermosets; high-temperature restraint polymers; ceramics; toughening mechanisms in ceramics.
Prerequisites: MAE 201, MAE 203, and a grade of C or better in MAE 220; MAE 332

MAE 531 Mechanisms Analysis and Design (3 Credit Hours)
Basic relations necessary for analysis of plane motion mechanisms, numerical and analytical solutions for some of the basic mechanisms, methods of calculating rolling and sliding velocities and accelerations of contacting bodies, cams, and gears.
Prerequisites: A grade of C or better in MAE 205, a grade of C or better in MAE 332, and MATH 312 or MATH 285

MAE 538 Applied Analog and Digital Control (3 Credit Hours)
Computer-aided analysis and design of practical control systems. Introduction to state-space, digital signal processing and digital control. Laboratory sessions on aliasing, analog, system identification, and real-time control.
Prerequisites: a grade of C or better in MAE 436

MAE 540 Introduction to Finite Element Analysis (3 Credit Hours)
Basic concepts of finite-element method, method of weighted residuals, interpolation functions, numerical implementation of finite-element method, applications to engineering problems such as beam deflection, heat conduction, and plane elastic problems.
Prerequisites: MAE 340

MAE 550 Principles of Naval Architecture (3 Credit Hours)
Basic principles of naval architecture related to ship geometry, stability, strength, resistance, propulsion, vibration and motions in waves and controllability.
Prerequisites: MATH 212 with a grade of C or better

MAE 560 Introduction to Space Systems Engineering (3 Credit Hours)
Introduction to spacecraft systems starting from mission design and space environment considerations and proceeding through propulsion, altitude control, spacecraft structural design, thermal control, power and communications for spacecraft.
Prerequisites: MATH 307 and PHYS 232N

MAE 595 Topics in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Special topics of interest with emphasis placed on recent developments in mechanical and aerospace engineering or engineering mechanics. (offered fall, spring, summer)
Prerequisites: Senior standing; Permission of the chair is required

MAE 597 Independent Study in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Individual analytical, computational, and/or experimental study in an area selected by student. Supervised and approved by the advisor.
Prerequisites: Senior standing; permission of the chair is required

MAE 601 Engineering Mathematics (3 Credit Hours)
Applications of linear algebra, ordinary and partial differential equations, and complex variables to engineering problems.

MAE 602 Fluid Dynamics and Aerodynamics (3 Credit Hours)
Conservation laws for viscous and inviscid flows. Boundary conditions; analytical and numerical solution of viscous flow problems; boundary-layer theory; 2 and 3-dimensional potential flows; applications to airfoils, wings, and internal flows; introduction to turbulence.
Prerequisites: MAE 601 or MATH 691

MAE 603 Advanced Mechanics of Solids (3 Credit Hours)
Stress, strain, equilibrium for deformable solids; material behavior of elasticity, hyperelasticity, plasticity and viscoelasticity; failure criteria, fracture; thermal effect; energy methods and their applications to bars and beams for static, stability and dynamic problems.

MAE 604 Analytical Dynamics (3 Credit Hours)
Advanced kinematics with moving reference frames. Euler equations of motion. Gyroscopic theory. Principle of virtual work, D'Alembert's principle, Hamilton's principle, Lagrange's equations of motion and rigid body dynamics.

MAE 605 Advanced Classical Thermodynamics (3 Credit Hours)
Rigorous development of the macroscopic theory of thermodynamics; structural basis for equations of state and general properties of matter; phase and chemical equilibria.
Prerequisites: MAE 601 or MATH 691

MAE 607 Continuum Mechanics (3 Credit Hours)
Indicial notations and tensor calculus; strain and stress tensors, rate of deformation tensor, Eulerian and Lagrangian descriptions, conservation principles, constitutive formulations for elastic solids and viscous fluids, formulation of fluid mechanics and solid mechanics problems. Simple applications.
Pre- or corequisite: MATH 691 or MAE 601

MAE 608 Applied Mathematics for Engineers (3 Credit Hours)
Linear algebra. Vectors and matrices. Partial differential equations. Curve fittings. Applied probabilities. Statistics of distributions. Testing of hypotheses and decisions. Quality control.

MAE 620 Heat Transfer I (3 Credit Hours)
Aspects of conduction, convection and radiation heat transfer, including governing equations, boundary layer flows, analytical and numerical solutions to one-, two-, and three-dimensional problems.
Prerequisites: MAE 602

MAE 640 Modern Control Theory (3 Credit Hours)
Formulation of state space equations governing dynamics and stability of linear systems. Controllability; observability. State feedback control design. Optimal control methods. State observers and estimators.

MAE 667 Cooperative Education in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Student participation for credit based on academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and the Cooperative Education program prior to the semester in which the work experience is to take place.
Prerequisites: Approval by Department and Career Development Services

MAE 668 Internship in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career-related experience.
Prerequisites: Approval by Department and Career Development Services

MAE 669 Practicum in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students an opportunity to gain short duration career-related experience. Student is usually already employed--this is an additional project within the organization.
Prerequisites: Approval by Department and Career Development Services

MAE 672 Design of Experiments (3 Credit Hours)
This course will focus on formal experiment design. Topics to be discussed will include review of statistics, ANOVA, multiple comparisons, residuals, modal adequacy checking, randomized complete block designs, factorial designs, 2^k factorial and fractional factorial designs, random and mixed effects in factorials, and optimization. The course will also provide an introduction to response surface methods. Laboratory exercises will use designed experiments as applied to aerospace testing, including wind tunnel testing and instrument calibration.

MAE 682 Concurrent Engineering (3 Credit Hours)
Study of principles of concurrent engineering with emphasis on the design/ manufacture interface for single products; Rapid prototyping projects; Designof injection-molded and stamped parts for cost.

MAE 685 Projects Design and Manufacturing (3 Credit Hours)
Project(s) course to allow graduate students to complete a practical engineering assignment in design and manufacturing areas.
Prerequisites: Permission of the instructor

MAE 690 Mechanical and Aerospace Engineering Seminar (1 Credit Hour)
Regular tutorials on recent topics of interest in mechanical and aerospace engineering and engineering mechanics.

MAE 695 Topics in Mechanical and Aerospace Engineering (3 Credit Hours)
Special topics of interest with emphasis placed on recent developments in mechanical and aerospace engineeringor engineering mechanics.

MAE 696 Experimental Research Project (3 Credit Hours)
An independent laboratory experience in the area of either aerodynamics, structural dynamics or applied automatic control. Results will be reported in a format and quality similar to a technical conference paper.

MAE 697 Independent Study in Mechanical and Aerospace Engineering (3 Credit Hours)
Individual analytical, computational and/or experimental study in an area selected by the student. Supervised and approved by the advisor.

MAE 698 Master's Project in Mechanical and Aerospace Engineering (1-3 Credit Hours)
Individual project, investigation under the direction of the student's major professor.

MAE 699 Thesis Research in Mechanical and Aerospace Engineering (1-6 Credit Hours)
Thesis research in mechanical and aerospace engineering or engineering mechanics leading to the Master of Science degree.
Prerequisites: instructor approval required

MAE 710 Supersonic Flow (3 Credit Hours)
This course will examine governing equations for supersonic flow, including full potential equations, small disturbance theory, hodographs, and method of characteristics. It will also serve as an introduction to three-dimensional flows, compressible boundary layer flows, internal flows in nozzles and diffusers, airfoil flows, slender bodies of revolution flows, conical flows, and wing flows.
Prerequisites: MAE 514 and MAE 602

MAE 711 Hypersonic Aerodynamics (3 Credit Hours)
General consideration of hypersonic flow and similarity principles, hypersonic flow past slender bodies with sharp and blunt leading edges. Hypersonic blunt-body flow. Real gas, viscous and low density effects, and consideration of nonequilibrium phenomena in hypersonic flows.
Prerequisites: MAE 710

MAE 712 Experimental Aerodynamics (3 Credit Hours)
This course will examine techniques for static and dynamic measurement of pressure, temperature, and velocity. Experiment control and statistical treatment of data will be discussed, as will probe methods, including multi-hole pressure probes and hot-wire anemometers, and non-intrusive methods, including laser Doppler velocimetry and other optical methods. Surface and stream flow visualization and surface measurements will also be covered.
Prerequisites: MAE 602 and MAE 710

MAE 713 Turbulent Flow (3 Credit Hours)
Isotropic and homogeneous turbulence. Mixing length theories, Equilibrium turbulence models, Two-equation models (k-epsilon). Large eddy simulation. Reynold's stress transport models. Numerical simulations. Compressible and non-equilibrium turbulence effects.
Prerequisites: MAE 602 and MAE 715 or MAE 815

MAE 715 Boundary Layer Theory (3 Credit Hours)
Boundary layer equations; method of matched asymptotic expansions; body oriented coordinates, finite-difference solutions; separations, wake and jet flows; thermal and compressible boundary layers, transformations and finite-difference solutions, unsteady boundary layers. Introduction to hydrodynamic stability and turbulence.
Prerequisites: MAE 602

MAE 716 Computational Fluid Dynamics I (3 Credit Hours)
This course will cover the following topics: classification of single partial differential equations; finite difference methods; stability analysis, including convergence, consistency, and efficiency; basics of finite volume methods; model equations of hyperbolic, parabolic and elliptic type; and explicit and implicit schemes, central and upwind schemes, and weak solutions of quasi-linear hyperbolic equations.
Prerequisites: MAE 601 or MATH 691

MAE 718 Aerospace Test Facilities (3 Credit Hours)
A comprehensive examination of aerodynamic test facilities for use in subsonic, transonic, supersonic and hypersonic flow regimes. Aspects of wind tunnel design and operation will be discussed, as will flow quality and wall and support interferences. Advanced concepts including cryogenic wind tunnels, adaptive wall test sections and magnetic suspension will be examined, in addition to dynamic testing. There will be a review of flight test methods, including extraction of aerodynamic parameters from flight test data, a review of engine test facilities, and a review of ground test facilities for space structures and other space systems.
Prerequisites: Permission of the instructor

MAE 720 Heat Transfer II (3 Credit Hours)
Aspects of conduction, convection and radiation heat transfer, including governing equations, boundary layer flows, analytical and numerical solutions to one-, two- and three-dimensional problems.
Prerequisites: MAE 620

MAE 723 Nuclear Engineering (3 Credit Hours)
This course will consider nuclear power plant systems, and will introduce power reactor control kinetic behavior including safety coefficients, accumulative poisons, and temperature control parameters. It will also examine primary and secondary plant as a transient system.

MAE 730 Finite Element Analysis (3 Credit Hours)
This course provides an understanding of the finite element method (FEM) as derived from an integral formulation perspective. It demonstrates the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. It also provides insight into the theoretical formulation and numerical implementation of finite element methods.

MAE 731 Mechanics of Composite Structures (3 Credit Hours)
Stress-strain relations for a lamina; failure theories. Micro-mechanical behavior of a lamina. Constitutive relations of a laminate. Bending, buckling and vibration of laminated plates. Approximate and finite element methods of solution.

MAE 734 Theory of Vibrations (3 Credit Hours)
This course will introduce applied modal analysis, modes of vibration of discrete systems, modal coordinates, transfer functions in frequency domain, modes of vibration of continuous systems, and approximate systems response. It will also examine Finite Elements methods and nonlinear vibrations. Applications will be extended to rods, beams, plates and shells.
Prerequisites: MAE 504 and MAE 601 or MATH 691

MAE 740 Autonomous and Robotic Systems Analysis and Control (3 Credit Hours)
Kinematics, dynamics and control of complex non-linear electro-mechanical systems, particularly robotic manipulators.

MAE 741 Optimal Control Theory (3 Credit Hours)
Parameter optimization, optimization problem for dynamic systems with terminal and path constraints; optimal feedback control with and without the presence of uncertainty; nonlinear optimal control system.
Prerequisites: MAE 640

MAE 742 Multibody Dynamics: Theories and Applications (3 Credit Hours)
Basic theories are presented for formulation of equations of kinematics and dynamics of systems made of interconnected bodies. Topics include constrained motion, principle of virtual work and constrained dynamics. Examples cover robotic motion and biomechanics applications such as human locomotion.
Prerequisites: Permission of instructor

MAE 743 Kinematic Synthesis of Mechanisms (3 Credit Hours)
Classification of mechanisms; type and number synthesis, application of graph theory, expert systems for synthesis; introduction to dimensional synthesis via path and function generation; finite displacement theory including concept of poles, circlepoint, and centerpoint curves; structural error minimization using Chebychev's approximation; optimization approaches, current applications to robot manipulators, robot hands, space structures, and combustion engines.
Prerequisites: Permission of instructor

MAE 744 Atmospheric Flight Dynamics and Control (3 Credit Hours)
Principles governing the dynamics and control of vehicles in atmospheric flight. Equations of motion development and solution including inertial/gravitational/aerodynamic/propulvsive loads, linear longitudinal and lateral-directional motions, and nonlinear trim and simulation. Flight control system design and analysis incorporating flying quality requirements, linear conventional/contemporary and frequency/time domain techniques for control and guidance functions, validation with nonlinear simulation, gain scheduling.
Prerequisites: MAE 403 or MAE 503 and MAE 604

MAE 745 Space Flight Dynamics and Control (3 Credit Hours)
Principles governing the dynamics and control of vehicles in space flight. Equations of motion development and solution including inertial/gravitational/aerodynamic/propulsive loads, decoupled translational and attitude motions. Ortibal mechanics including elements, initial-value propagation, adjustments/transfers, Lambert boundary-value problem, perturbations, and nonlinear simulation. Attitude dynamics including torque free, gravity moment, axisymmetric/unsymmetric vehicles, and dual spinners. Flight control system design and analysis including impulsive velocities, finite burns, Lambert targeting, linear designusing momentum wheels, and nonlinear phase-plane design using thrusters.
Prerequisites: MAE 604 and MAE 640

MAE 746 Advanced Control Methodologies (3 Credit Hours)
Review of multivariable dynamic math models including state space, transfer function, and matrix fractions. Multivariable design criteria including stability, performance,and robustness. Theory and application of multivariable control design techniques including LQR/LQG/LTR, H-infinity, Eigenspace Assignment and other advanced methods.
Prerequisites: MAE 640

MAE 747 Aerospace Vehicle Performance (3 Credit Hours)
This course will study the flight performance of aerospace vehicles, including a review of aerodynamic and propulsion characteristics. Range, flight and maneuver envelopes for vehicles in atmospheric flight will also be examined. It will introduce various methods of design for trajectory optimization, including launch vehicles. An open-ended, design-oriented project will be required.
Prerequisites: MAE 602 and MAE 514 or MAE 710

MAE 748 Flight Control Actuators and Sensors (3 Credit Hours)
This course will provide an overview of the governing principles and operations of actuator and sensor hardware used in aircraft and spacecraft flight control systems. Hydraulic, electro-hydraulic and electric actuators will be examined, as well as control jets and momentum wheels, accelerometers, and rate gyros. Other topics include air-data systems, inertial navigation systems and satellite navigation systems. The course will also examine dynamic model development, analysis and simulation, nonlinear hardware characteristics, and the influence on closed-loop vehicle behavior.
Prerequisites: MAE 503, MAE 538, and MAE 604

MAE 750 Nanoscale Mechanical and Structural Properties of Materials (3 Credit Hours)
Elastic and plastic properties of nanoscale materials, strain gradient dislocation plasticity, nanoindentation and nanoindentation creep, thin film mechanical and structural properties, kinetic-based investigations of hardening mechanisms in nanolayer composites.

MAE 751 Fatigue and Fracture (3 Credit Hours)
Divided into areas of fatigue and fracture; stress-controlled and strain-controlled fatigue; effect of mean stresses, notches, etc.; multiaxial stresses; variable amplitude loading; ductile and brittle fracture; linear elastic fracture mechanics; crack-tip plasticity; fracture testing; applications to fatigue life estimation. Requires permission of the instructor.

MAE 752 Mechanical Behavior of Materials (3 Credit Hours)
This course will examine the macroscopic behavior of materials with respect to elasticity, plasticity, and viscoelasticity. Other topics include yield criteria, fracture, the influence of high and low temperatures, and corrosion and radiation.
Prerequisites: Permission of instructor

MAE 753 Composite Materials (3 Credit Hours)
This course will examine reinforcements, matrices, particulate-composites, short-fiber and continuous-fiber reinforced composites. Directionally solidified composites will also be studied, including the prediction of elastic failure properties. Other topics to be covered include design considerations and experimental work.
Prerequisites: Permission of the instructor

MAE 772 Response Surface Methodology (3 Credit Hours)
An applied course in response surface methodology with aerospace applications. Empirical model building, method of least squares, second order models, model adequacy checking, canonical analysis. Method of steepest ascent, multiple response optimization. Rotatable, cuboidal and small run designs. Design optimality and efficiency metrics, robust design, restrictions on randomization. Laboratory exercises include RSM applied to wind tunnel testing and optimization.
Prerequisites: MAE 672

MAE 780 Engineering Optimization (3 Credit Hours)
Formulation and solution algorithms for Linear Programming (LP) problems. Unconstrained and constrained nonlinear programming (NLP) problems. Optimum solution for practical engineering systems.

MAE 781 Advanced Design (3 Credit Hours)
Concepts, principles and procedures related to analysis of stresses and strains in machine components. Consideration of function of parts along with factors such as forces, life required, maximum cost, weight and space restrictions, number of parts to be produced, material selection, kinematics,environmental restrictions. Finite element analysis to illustrate different aspects of stress analysis. Requires permission of the instructor.

MAE 783 Robots and Manufacturing Automation (3 Credit Hours)
This course will introduce the engineering of industrial robots used for manufacturing automation. Topics to be covered include spatial descriptions and transformations of manipulators, manipulator kinematics and inverse kinematics; manipulator velocities; static forces; and dynamics and trajectory generation. Other topics to be covered include design and on-line computer control of the manipulator.

MAE 785 Advanced Manufacturing Technology (3 Credit Hours)
Treatment of the next generation of manufacturing technology. Topics include additive manufacturing; rapid prototypying; electronic manufacturing; micro and nanofabrication; process simulation; product life cycle management; and sustainable design and manufacturing.
Prerequisites: MAE 682 or consent of instructor

MAE 788 Computational Intelligence for Engineering Design Optimization Problems (3 Credit Hours)
The concepts and algorithms of computational intelligence and their application to engineering design are discussed, including artificial neural networks, evolutionary optimization, and swarm intelligence. Both single and multi-objective optimization problems with continuous and/or discrete variables are also discussed.

MAE 789 Engineering Design with Uncertainties (3 Credit Hours)
An introduction to managing uncertainties and risk in strength design of mechanical components, including the study of the theoretical background, computational implementation, and applications of reliability-based methods for engineering analysis and design.
Prerequisites: MAE 608

MAE 794 Cellular Biomechanics (3 Credit Hours)
A broad introduction to the field of cellular biomechanics. Topics include overview of cell architecture, cytoskeleton, adhesion and molecular motors, biomolecular/biopolymer dynamics and mechanics, techniques to measure cell mechanical properties, techniques to mechanically stimulate cells, models of cell mechanical behavior, mechanobiology and mechanotransduction. Will include discussion of classic and current research articles. Course content will aim to cater to students with diverse backgrounds – students with biological science background will be exposed to physical science concepts and analysis; students with engineering/physical science background will be exposed to biological phenomena and concepts.
Prerequisites: MATH 212

MAE 795 Topics in Mechanical and Aerospace Engineering (3 Credit Hours)
Selected topics in mechanical and aerospace engineering or engineering mechanics.

MAE 797 Independent Study in Mechanical and Aerospace Engineering (3 Credit Hours)
Individual analytical, computational and/or experimental study in an area selected by the student. Supervised and approved by the advisor.

MAE 810 Supersonic Flow (3 Credit Hours)
This course will examine governing equations for supersonic flow, including full potential equations, small disturbance theory, hodographs, and method of characteristics. It will also serve as an introduction to three-dimensional flows, compressible boundary layer flows, internal flows in nozzles and diffusers, airfoil flows, slender bodies of revolution flows, conical flows, and wing flows.
Prerequisites: MAE 514 and MAE 602

MAE 811 Hypersonic Aerodynamics (3 Credit Hours)
General consideration of hypersonic flow and similarity principles, hypersonic flow past slender bodies with sharp and blunt leading edges. Hypersonic blunt-body flow. Real gas, viscous and low density effects, and consideration of nonequilibrium phenomena in hypersonic flows.
Prerequisites: MAE 710

MAE 812 Experimental Aerodynamics (3 Credit Hours)
This course will examine techniques for static and dynamic measurement of pressure, temperature, and velocity. Experiment control and statistical treatment of data will be discussed, as will probe methods, including multi-hole pressure probes and hot-wire anemometers, and non-intrusive methods, including laser Doppler velocimetry and other optical methods. Surface and stream flow visualization and surface measurements will also be covered.
Prerequisites: MAE 602 and MAE 710

MAE 813 Turbulent Flow (3 Credit Hours)
Isotropic and homogeneous turbulence. Mixing length theories, Equilibrium turbulence models, Two-equation models (k-epsilon). Large eddy simulation. Reynold's stress transport models. Numerical simulations. Compressible and non-equilibrium turbulence effects.
Prerequisites: MAE 602 and MAE 715 or MAE 815

MAE 815 Boundary Layer Theory (3 Credit Hours)
Boundary layer equations; method of matched asymptotic expansions; body oriented coordinates, finite-difference solutions; separations, wake and jet flows; thermal and compressible boundary layers, transformations and finite-difference solutions, unsteady boundary layers. Introduction to hydrodynamic stability and turbulence.
Prerequisites: MAE 602

MAE 816 Computational Fluid Dynamics I (3 Credit Hours)
This course will cover the following topics: classification of single partial differential equations; finite difference methods; stability analysis, including convergence, consistency, and efficiency; basics of finite volume methods; model equations of hyperbolic, parabolic and elliptic type; and explicit and implicit schemes, central and upwind schemes, and weak solutions of quasi-linear hyperbolic equations.
Prerequisites: MAE 601 or MATH 691

MAE 818 Aerospace Test Facilities (3 Credit Hours)
A comprehensive examination of aerodynamic test facilities for use in subsonic, transonic, supersonic and hypersonic flow regimes. Aspects of wind tunnel design and operation will be discussed, as will flow quality and wall and support interferences. Advanced concepts, including cryogenic wind tunnels, adaptive wall test sections and magnetic suspension will be examined, in addition to dynamic testing. There will be a review of flight test methods, including extraction of aerodynamic parameters from flight test data, a review of engine test facilities, and a review of ground test facilities for space structures and other space systems.
Prerequisites: Permission of the instructor

MAE 820 Heat Transfer II (3 Credit Hours)
Aspects of conduction, convection and radiation heat transfer, including governing equations, boundary layer flows, analytical and numerical solutions to one-, two- and three-dimensional problems.
Prerequisites: MAE 620

MAE 823 Nuclear Engineering (3 Credit Hours)
This course will consider nuclear power plant systems, and will introduce power reactor control kinetic behavior including safety coefficients, accumulative poisons, and temperature control parameters. It will also examine primary and secondary plant as a transient system.

MAE 830 Finite Element Analysis (3 Credit Hours)
This course provides an understanding of the finite element method (FEM) as derived from an integral formulation perspective. It demonstrates the solutions of (1-D and 2-D) continuum mechanics problems such as solid mechanics, fluid mechanics and heat transfer. It also provides insight into the theoretical formulation and numerical implementation of finite element methods.

MAE 831 Mechanics of Composite Structures (3 Credit Hours)
Stress-strain relations for a lamina; failure theories. Micro-mechanical behavior of a lamina. Constitutive relations of a laminate. Bending, buckling and vibration of laminated plates. Approximate and finite element methods of solution.

MAE 834 Theory of Vibrations (3 Credit Hours)
This course will introduce applied modal analysis, modes of vibration of discrete systems, modal coordinates, transfer functions in frequency domain, modes of vibration of continuous systems, and approximate systems response. It will also examine Finite Elements methods and nonlinear vibrations. Applications will be extended to rods, beams, plates and shells.
Prerequisites: MAE 504 and MAE 601 or MATH 691

MAE 840 Autonomous and Robotic Systems Analysis and Control (3 Credit Hours)
Kinematics, dynamics and control of complex non-linear electro-mechanical systems, particularly robotic manipulators.

MAE 841 Optimal Control Theory (3 Credit Hours)
Parameter optimization, optimization problem for dynamic systems with terminal and path constraints; optimal feedback control with and without the presence of uncertainty; nonlinear optimal control system.
Prerequisites: MAE 640

MAE 842 Multibody Dynamics: Theories and Applications (3 Credit Hours)
Basic theories are presented for formulation of equations of kinematics and dynamics of systems made of interconnected bodies. Topics include constrained motion, principle of virtual work and constrained dynamics. Examples cover robotic motion and biomechanics applications such as human locomotion.
Prerequisites: Permission of instructor

MAE 843 Kinematic Synthesis of Mechanisms (3 Credit Hours)
Classification of mechanisms; type and number synthesis, application of graph theory, expert systems for synthesis; introduction to dimensional synthesis via path and function generation; finite displacement theory including concept of poles, circlepoint, and centerpoint curves; structural error minimization using Chebychev's approximation; optimization approaches, current applications to robot manipulators, robot hands, space structures, and combustion engines.
Prerequisites: Permission of instructor

MAE 844 Atmospheric Flight Dynamics and Control (3 Credit Hours)
Principles governing the dynamics and control of vehicles in atmospheric flight. Equations of motion development and solution including inertial/gravitational/aerodynamic/propulvsive loads, linear longitudinal and lateral-directional motions, and nonlinear trim and simulation. Flight control system design and analysis incorporating flying quality requirements, linear conventional/contemporary and frequency/time domain techniques for control and guidance functions, validation with nonlinear simulation, gain scheduling.
Prerequisites: MAE 403 or MAE 503 and MAE 604

MAE 845 Space Flight Dynamics and Control (3 Credit Hours)
Principles governing the dynamics and control of vehicles in space flight. Equations of motion development and solution including inertial/gravitational/aerodynamic/propulsive loads, decoupled translational and attitude motions. Ortibal mechanics including elements, initial-value propagation, adjustments/transfers, Lambert boundary-value problem, perturbations, and nonlinear simulation. Attitude dynamics including torque free, gravity moment, axisymmetric/unsymmetric vehicles, and dual spinners. Flight control system design and analysis including impulsive velocities, finite burns, Lambert targeting, linear designusing momentum wheels, and nonlinear phase-plane design using thrusters.
Prerequisites: MAE 604 and MAE 640

MAE 846 Advanced Control Methodologies (3 Credit Hours)
Review of multivariable dynamic math models including state space, transfer function, and matrix fractions. Multivariable design criteria including stability, performance,and robustness. Theory and application of multivariable control design techniques including LQR/LQG/LTR, H-infinity, Eigenspace Assignment and other advanced methods.
Prerequisites: MAE 640

MAE 847 Aerospace Vehicle Performance (3 Credit Hours)
This course will study the flight performance of aerospace vehicles, including a review of aerodynamic and propulsion characteristics. Range, flight and maneuver envelopes for vehicles in atmospheric flight will be examined. It will introduce various methods of design for trajectory optimization, including launch vehicles. An open-ended, design-oriented project will also be required.
Prerequisites: MAE 602 and MAE 514 or MAE 610

MAE 848 Flight Control Actuators and Sensors (3 Credit Hours)
This course will provide an overview of the governing principles and operations of actuator and sensor hardware used in aircraft and spacecraft flight control systems. Hydraulic, electro-hydraulic and electric actuators will be examined, as well as control jets and momentum wheels, accelerometers, and rate gyros. Other topics include air-data systems, inertial navigation systems and satellite navigation systems. The course will also examine dynamic model development, analysis and simulation, nonlinear hardware characteristics, and the influence on closed-loop vehicle behavior.
Prerequisites: MAE 503, MAE 538, and MAE 604

MAE 850 Nanoscale Mechanical and Structural Properties of Materials (3 Credit Hours)
Elastic and plastic properties of nanoscale materials, strain gradient dislocation plasticity, nanoindentation and nanoindentation creep, thin film mechanical and structural properties, kinetic-based investigations of hardening mechanisms in nanolayer composites.

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Prerequisites: MAE 672

MAE 880 Engineering Optimization (3 Credit Hours)
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MAE 881 Advanced Design (3 Credit Hours)
Concepts, principles and procedures related to analysis of stresses and strains in machine components. Consideration of function of parts along with factors such as forces, life required, maximum cost, weight and space restrictions, number of parts to be produced, material selection, kinematics,environmental restrictions. Finite element analysis to illustrate different aspects of stress analysis. Requires permission of the instructor.

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MAE 885 Advanced Manufacturing Technology (3 Credit Hours)
Treatment of the next generation of manufacturing technology. Topics include additive manufacturing; rapid prototyping; electronic manufacturing; micro and nanofabrication; process simulation; product life cycle management; and sustainable design and manufacturing.
Prerequisites: MAE 682 or consent of instructor

MAE 888 Computational Intelligence for Engineering Design Optimization Problems (3 Credit Hours)
The concepts and algorithms of computational intelligence and their application to engineering design are discussed, including artificial neural networks, evolutionary optimization, and swarm intelligence. Both single and multi-objective optimization problems with continuous and/or discrete variables are also discussed.

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An introduction to managing uncertainties and risk in strength design of mechanical components, including the study of theoretical background, computational implementation, and applications of reliability-based methods for engineering analysis and design.
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Prerequisites: MATH 212

MAE 895 Topics in Mechanical and Aerospace Engineering (3 Credit Hours)
Selected topics in mechanical and aerospace engineering or engineering mechanics.

MAE 897 Independent Study in Mechanical and Aerospace Engineering (3 Credit Hours)
Individual analytical, computational and/or experimental study in an area selected by the student. Supervised and approved by the advisor.

MAE 899 PhD Dissertation Research in Mechanical and Aerospace Engineering (1-9 Credit Hours)
Based on the Ph.D candidate's dissertation research in mechanical and aerospace engineering topics under the direction of the candidate's advisor.
Prerequisites: Instructor approval required

MAE 998 Master's Graduate Credit (1 Credit Hour)
This course is a pass/fail course for master's students in their final semester. It may be taken to fulfill the registration requirement necessary for graduation. All master's students are required to be registered for at least one graduate credit hour in the semester of their graduation.

MAE 999 Doctoral Graduate Credit (1 Credit Hour)
This course is a pass/fail course doctoral students may take to maintain active status after successfully passing the candidacy examination. All doctoral students are required to be registered for at least one graduate credit hour every semester until their graduation.