Department of Mechanical Engineering

Chairperson:	Ghaddar, Nesreen K.
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Associate Professors:	Hamade, Ramsey; Kuran, Albert; Shihadeh, Alan
Assistant Professors:	Abdallah, Samer; Asmar, Daniel; Lakkis, Issam; Oweis, Ghanem
Lecturers:	Abu Ghali, Kamel; Kasamani, Jihad; Metni, Najib; Najm, Wajih
Instructor:	Seif, Cherbel
Assistant Instructors:	Ammouri, Ali; Kfoury, Elie

Graduate Programs

Master of Engineering (ME), specialization: Mechanical Engineering

General Information

The Department of Mechanical Engineering offers a graduate program leading to the degree of master of engineering, with a major in mechanical engineering. Students may choose to concentrate in any of the following areas:

- Thermal and Fluid Sciences
- Design, Materials, and Manufacturing
- Mechatronics

The student is encouraged to select a concentration area of personal interest. The master's degree requires a minimum of 21 credit hours of course work and a thesis worth 9 credits. Research is a time consuming process, and between 20 and 24 months are usually required to complete the master's degree. The student and the graduate adviser, in coordination with the thesis committee, develop a plan of study tailored to the student's specific interest and background. It is advisable that this plan be developed no later than the first month of the second semester of graduate work. The required 21 course credit hours and thesis are distributed as follows:

- A mandatory three-credit course in applied mathematics. The math course or math oriented course offered by other departments must be approved by the graduate student's adviser; acceptable courses include, but are not limited to the following:

MECH 630	Finite Element Methods in Mechanical Engineering
MECH 663	Computational Fluid Dynamics
MECH 764	Advanced Topics in Computational Fluid Dynamics
ENMG 604	Deterministic Optimization Models
MATH 307	Topics in Analysis
MATH 351	Topics in Applied Mathematics

- At least two advanced fundamental mechanical engineering three-credit courses from two different concentrations, which are not in the same concentration as the student's major, and as approved by the student's graduate thesis adviser. The following is a list of recommended courses by concentration:

  - **Thermal and Fluid Sciences:** MECH 701, MECH 760, MECH 761, MECH 762

  - **Design, Materials, and Manufacturing:** MECH 624, MECH 720, MECH 721

  - **Mechatronics:** MECH 740, MECH 643, MECH 645

- Four technical courses (12 credit hours). Of these 12 credit hours, a minimum of nine must be completed in the major area of mechanical engineering concentration to achieve greater depth in that area. It is advisable to make the selection in connection with thesis topic. A maximum of three credit hours may be completed in other engineering graduate programs subject to approval by the graduate student's adviser. A student may not register more than once in MECH 796, Special Projects in Mechanical Engineering. The following is a list of recommended mechanical engineering technical courses by concentration.

  - **Thermal and Fluid Sciences:** MECH 602, MECH 603, MECH 604, MECH 606, MECH 607, MECH 609, MECH 663, MECH 665, MECH 701, MECH 760, MECH 761, MECH 762, MECH 764

  - **Design, Materials, and Manufacturing:** MECH 622, MECH 624, MECH 625, MECH 626, MECH 627, MECH 628, MECH 630, MECH 631, MECH 633, MECH 634, MECH 720, MECH 721, MECH 722, MECH 729, MECH 736, MECH 740

  - **Mechatronics:** MECH 628, MECH 633, MECH 634, MECH 641, MECH 642, MECH 643, MECH 644, MECH 645, MECH 648, MECH 740.

- Seminar Course: MECH 797 (zero credit). Students must register for the course once per year.
- Thesis: MECH 799 (equivalent to nine credit hours) based on independent research.

Requirements

A student applying for admission to a graduate program is only eligible if s/he has a bachelor of engineering degree with a mechanical engineering major or the equivalent. A student must also satisfy the requirements of the University and the Faculty of Engineering and Architecture for admission to graduate study, as specified in the relevant sections of the university catalogue (see pp. 37, 41, 42, 213).

Doctor of Philosophy (PhD), specialization: Mechanical Engineering

The Faculty of Engineering and Architecture offers a graduate program of study leading to the PhD degree with specializations in mechanical engineering.

General Information

The graduate curriculum offers students opportunities to develop levels of expertise and knowledge consistent with a career of technical leadership. The doctoral program emphasizes the acquisition of advanced knowledge and the fostering of individual experience of significant intellectual exploration.

The educational objectives of the PhD program are to develop

- the expertise in a core area of mechanical engineering;
- the ability to identify pertinent research problems, formulate and execute a research plan, and generate and analyze original research results;
- the ability to communicate those results through oral presentations and written publications;
- and the practice of independent learning and advancing knowledge.

Admission Requirements

Candidates for the doctoral degree program are expected to have an outstanding academic record demonstrated by a minimum undergraduate cumulative grade average of 80.0 according to AUB standards (3.0 GPA in a 4.0 grade system) and have completed a master's degree in mechanical engineering or a related discipline with a cumulative grade average of 85.0 according to AUB standards (3.33 GPA in a 4.0 grade system).

The application to the doctoral program follows the deadlines set by the Admissions Office. All applicants are required to take the General Exam section of the Graduate Record Examination (GRE) and submit their scores. Students other than AUB graduates and graduates of recognized colleges or universities in North America, Great Britain, Australia, and New Zealand are required to take the Test of English as a Foreign Language (TOEFL) and receive a minimum score of 600 if taken manually, or 250 if taken via computer. Admission to the PhD Program is upon the recommendations of the department and the FEA Graduate Studies Committee, and requires the approval of the AUB Board of Graduate Studies.

PhD Program Description

The PhD program in Mechanical Engineering requires a minimum of 18 credit hours of course work beyond the master's degree. The student must pass a two part PhD Qualification Examination. In addition, the student must submit an original dissertation based on independent research that makes a significant contribution to his/her area of research. The dissertation is the principal component of the doctoral program, and the part that will serve as the major indicator of a candidate's abilities. A minimum of 30 credits registered as dissertation work is required.

Advisers

After admission into the department, a general adviser will be assigned to the PhD student to guide her/him with the initial selection of courses and to introduce the student to the various research areas in the department. The student must select a dissertation adviser by the end of the first semester after admission to the program. The student must seek the faculty members that are in the student's area of interest, and discuss with them possible research topics for the PhD dissertation. Once an adviser is identified, the student will develop a Proposed Program of Study that lists the courses the student intends to take and the proposed dates for the written and oral Doctoral Qualifying Examinations. The Proposed Program of Study must then be submitted to the ME Graduate Committee for approval.

Course Requirements

The PhD program requires a minimum of 18 credit hours of course work beyond the master's degree. The program is composed of 6 credit hours of core courses of advanced study in mechanical engineering and mathematics, 6 credit hours of technical graduate level courses of advanced study in the student's area of research (major course area requirements), and 6 credit hours of courses in a minor specialization area of study selected by the student in a field different from the major field of study. The minor specialization, 6 credit hours of courses, must be taken outside of the Mechanical Engineering Department. The minor requirement could be satisfied through courses previously taken in the master degree program. This however, will not reduce the required minimum of 18 credit hours of course work needed beyond the master's degree.

Core Course Requirements

At least 6 credit hours of core courses of advanced study in mechanical engineering are needed to satisfy this requirement. The core requirement is as follows:

- A mandatory advanced course in mathematics (3 credits) from outside the ME department. The adviser must approve the selected math course and all other courses taken by the candidate. The math core requirement is satisfied if the student has completed at least 6 credits of advanced math beyond the bachelor's degree.
- At least one advanced fundamental mechanical engineering course (3 credits) from any of the basic areas; thermal-fluid sciences; mechatronics; and design, materials and manufacturing. The course should not be in the student's major research area and must be approved by the graduate thesis adviser.

Major Course Area Requirements

Doctoral candidates are expected to pursue course work that directly supports their research and addresses recommendations made during the qualification period by their advisor and their dissertation committee. The following major course areas are offered:

- Thermal and Fluid Sciences
- Mechatronics
- Design, Materials and Manufacturing

The major course area is a program of advanced study which gives the candidate both depth and breadth in a field of engineering or science. The student is expected to complete at least 6 credit hours of technical graduate level courses (600 level and above) in the student's major area of research as approved by his/her dissertation adviser. The FEA Graduate Studies Committee may approve other major course areas than those listed above. The major course area requirements represent the principal component of the candidate's course work.

Minor Subject Requirements

The minor is a program of advanced study that will help the student to develop knowledge and some competence in an area related to the major field of study. Two graduate courses (not less than 6 credits) must be taken in a coherent field that is different than the major field of study. These subjects cannot be taken in the ME department but may be taken in other engineering or basic science departments. Some of this requirement could be satisfied through courses taken during the master's degree program. This however will not reduce the required minimum of 18 credit hours of course work needed beyond the master's degree. All courses taken in the minor area must be graduate courses and must be taken while the student is registered in a graduate program at the AUB. The minor program must be approved *in advance* by the student's dissertation committee, and by the FEA Graduate Studies Committee. The approval of the department offering the minor should also be sought.

PhD Qualification Examination

The qualification examination for admission to PhD candidacy has two parts. Part 1: the written qualification examination must be completed before the end of the second semester of enrollment in the doctoral program. Part 2: the oral qualification examination must be completed within one year following the completion of Part 1.

The purpose of the qualifying examination is to determine whether the applicant possesses the attributes of a doctoral candidate: mastery of the core mechanical engineering disciplines, ingenuity and skill in solving unfamiliar problems.

The oral and written qualifying examinations will be held at end of the fall and the spring semester every year.

The mechanical engineering faculty will review each student's performance in the qualifying examination and decide whether he or she passes or fails. Students who fail sections of Part 1 may be permitted to take that section of the examination again, in which case they must do so the next time it is offered. In no case will a student be allowed to repeat any section of this examination more than once.

Part 1: Written Qualification Examination

Students must demonstrate that they have mastered the concepts of advanced calculus, solution of differential equations, and computational methods.

The student must take four sections of the written qualification examination in four sub-disciplines which are normally selected from the list of topics below:

- Applied Mechanics
- Materials and Manufacturing Processes
- System Dynamics and Control
- Design
- Fluid Mechanics
- Thermodynamics
- Heat and Mass Transfer

Part 2: Oral Qualification Examination

Students must give a presentation on their proposed dissertation research area to a committee comprised of the dissertation adviser(s), the dissertation committee members, and other interested faculty. The proposed oral examination will include questioning by the committee to assess whether the candidate has sufficient background to perform research in their chosen area. The oral examination may include a component in the student's major core area of studies. The criterion for passing requires that the research topic is of PhD standard, original, clear in its contribution to existing knowledge, and that the proposed methodology is appropriate. A student who fails the oral qualification examination should repeat it within four months after addressing the comments of the dissertation committee compiled by the dissertation committee chair in the examination report.

Dissertation Requirements

Following successful completion of the first part of the qualifying examination, all PhD candidates must submit a dissertation proposal summarizing their dissertation problem and the planned approach. The purpose of the proposal is to inform the department and faculty, in a concise statement, of the candidate's research program and those involved in it. It should explain what the student intends to do and how he/she intends to go about it. The dissertation proposal must provide sufficient literature citation to indicate an awareness of previous work, and enough detail to show how the work is expected to advance knowledge in the field.

Doctoral Dissertation Committee

The doctoral dissertation committee includes the primary adviser(s), other mechanical engineering faculty, and expert(s) of professorial rank from outside the department, Faculty, or other institutions of higher learning in Lebanon or abroad. The committee must have at least five members. The doctoral committee is usually chaired by the dissertation adviser, unless he/she is not a member of the ME faculty, in which case a member of the ME faculty will chair the committee. At least one of the committee members must be from outside the ME department. The candidate may also invite qualified individuals from outside AUB faculty to serve as additional members of his/her committee. Although research collaboration is encouraged, research work previously accomplished at AUB or elsewhere, not under the supervision of a member of the FEA/AUB faculty, cannot be accepted in full or partial fulfillment of the thesis requirement. Note that the doctoral dissertation committee also serves as the examining committee for the oral qualifying examination.

External Examiner

An external examiner of high standing from abroad will be nominated by the chair of the department in consultation with the dissertation adviser, to review the dissertation before the defense. Comments by the external examiner will be shared with the student and the student will be given an opportunity to revise the dissertation and incorporate revisions in the work in a timely manner. The external examiner may choose to attend the dissertation defense and participate in the deliberations.

All PhD candidates must defend their dissertation in an oral examination, open to the community, in which the candidate is examined by their committee.

Course Plan for PhD Students

All courses that are offered for the master's program will also be offered as graduate courses for those in the PhD program.

Core Course Requirement

- At least one math course offered outside the ME department and approved by the graduate student adviser.
- The following is a list of recommended core courses by major areas:
  - Thermal and Fluid Sciences: MECH 606, MECH 607, MECH 701 MECH 760, MECH 761, MECH 762.
  - Mechatronics: MECH 641, MECH 642, MECH 729, MECH 740
  - Design, Materials and Manufacturing: MECH 622, MECH 720, MECH 721

Major Area Course Requirement

Thermal and Fluid Sciences: MECH 602, MECH 603, MECH 604, MECH 606, MECH 607, MECH 663, MECH 665, MECH 701, MECH 702, MECH 703, MECH 751, MECH 760, MECH 761, MECH 762, MECH 764, MECH 765, MECH 766, MECH 767, MECH 768, MECH 769, MECH 898.

Mechatronics: MECH 624, MECH 626, MECH 627, MECH 628, MECH 631, MECH 641, MECH 642, MECH 643, MECH 644, MECH 729, MECH 740, MECH 745, MECH 746, MECH 747, MECH 898.

Design, Materials and Manufacturing: MECH 622, MECH 624, MECH 625, MECH 626, MECH 627, MECH 628, MECH 630, MECH 631, MECH 633, MECH 634, MECH 641, MECH 642, MECH 720, MECH 721, MECH 729, MECH 736, MECH 740, MECH 769, MECH 898.

Seminar Course

Seminar Course: MECH 797 (no credit). The student must register for this course once a year.

PhD Dissertation

MECH 899 PhD Dissertation: A minimum of 30 credits is required. A student may register for a maximum of twelve credits in any given semester. Dissertation credit may be repeated as many times as necessary.

Residence Requirements

The student must register for at least four semesters beyond the completion of the master's degree. Requirements for the degree of doctor of philosophy must be completed within a period of five years after starting graduate work beyond the master's degree. An extension will require the approval of the Board of Graduate Studies.

Graduation Requirements

A student can graduate at the end of any academic semester provided the student has satisfied the following requirements:

- Passed all the required courses with a minimum grade of 80 in each graduate course
- Attained a minimum cumulative course average of 85 excluding courses taken prior to admission to the program
- Passed the Doctoral Qualifying Examinations: Part 1 and Part 2 as set by the department
- Successfully defended a doctoral dissertation of original scholarly work
- Met the residence requirements and all pertinent AUB regulations

Course Descriptions

MECH 602 Energy Conservation and Utilization 3 cr.
A course that deals with methods for reduction of losses and gains from a building envelope; energy conservation in cooling, heating, air-handling, and plumbing systems; energy management program. *Prerequisites: MECH 310, MECH 412. Alternate years.*

MECH 603 Solar Energy 3 cr.
A course discussing the fundamentals of solar radiation, collectors and concentrators, energy storage, estimation and conversion formulas for solar radiation. *Prerequisite: MECH 412. Alternate years.*

MECH 604 Refrigeration 3 cr.
A course on fundamental concepts and principles: cold storage, functions and specifications of refrigeration equipment, applications. *Prerequisite: MECH 412. Alternate years.*

MECH 606 Aerosol Dynamics 3 cr.
This course covers the physical and chemical principles that underlie the behavior of aerosols--collections of solid or liquid particles suspended in gases, such as clouds, smoke, and dust--and the instruments used to measure them. Topics include: aerosol particle characterization; transport properties and phenomena in quiescent, laminar, and turbulent flows; gas- and particle-particle interactions; and applications to human respiratory tract deposition and atmospheric pollution. *Prerequisites: MECH 314, MECH 414, MECH 412, or consent of instructor. Alternate years.*

MECH 607 Micro Flows Fundamentals and Applications 3 cr.
A course on theory and applications of micro flows. The continuum hypothesis and the various flow regimes. Shear and pressure driven micro flows. Electrokinetically driven liquid micro flows. Compressibility effects of the micro flow of gases. Particulate flows in bio-applications. Modeling techniques. Hybrid continuum-molecular methods. Reduced order modeling of micro flows in multi-physics micro flow applications. Case studies in BioMEMS. *Prerequisites: MECH 310, MECH 314, and MECH 412, or equivalent. Alternate years.*

MECH 609 Experimental Methods in Fluid Dynamics 3 cr.
This is a graduate level course aimed at introducing students to experimental methods used to measure fluid flow quantities such as pressures, forces, and velocities. The course starts with an introduction to what and why we measure, and uncertainty analysis and measurement error estimation. Some basic techniques for data reduction and data post-processing are introduced. The available fluid measurement methods are surveyed briefly, with selected applications. Emphasis is on advance optical diagnostic techniques; namely particle image velocimetry (PIV), and laser induced fluorescence (LIF). The theoretical foundations of these techniques are established, and the discussion extended to practical considerations including software and hardware components. A few laboratory sessions are incorporated into the course to supplement the lectures, and make use of the instruments available in the ME department, including the open circuit wind tunnel and the PIV system. In addition to the lectures and lab sessions, emphasis is also on the available literature. Prior knowledge of the basic principles of fluid mechanics and fluid systems is required. MATLAB is needed for course work. *Prerequisite: MECH 314.*

MECH 622 Advanced Manufacturing Processes 3 cr.
A course that deals with the underlying principles of material fabrication. Metal machining: mechanics of cutting, materials, technology (tooling, CNC machining). Phase change processes. Deformation processes. Non-traditional processes. *Prerequisite: MECH 421. Alternate years.*

MECH 624 Mechanics of Composite Materials 3 cr.
A course on anisotropic elasticity and laminate theory, analysis of various members of composite materials, energy methods, failure theories, and micromechanics. Materials and fabrication processes are introduced. *Prerequisites: MECH 320 or CIVE 310 and MECH 340 or equivalents. Alternate years.*

MECH 625 Fatigue of Materials 3 cr.
A course that deals with high cycle fatigue; low cycle fatigue; S-N curves; notched members; fatigue crack growth; cycling loading; Manson-Coffin curves; damage estimation; creep and damping. *Prerequisite: MECH 320 or CIVE 310. Alternate years.*

MECH 626 Metals and their Properties 3 cr.
A course that investigates ferrous and non-ferrous alloys; industrial equilibrium diagrams; heat treatment of metals; surface properties of metals; plastic deformation of metals; elements of fracture mechanics; process-structure-properties relations. *Prerequisite: MECH 340. Alternate years.*

MECH 627 Polymers and their Properties 3 cr.
A course on chemistry and nomenclature, polymerization and synthesis, characterization techniques, physical properties of polymers, viscoelasticity and mechanical properties and applications. *Prerequisite: MECH 440. Alternate years.*

MECH 628 Design of Mechanisms 3 cr.
A course involving graphical and analytical synthesis of single- and multi-loop linkage mechanisms for motion, path, and function generation through 2-3-4- and 5-precision positions; optimum synthesis of linkage mechanisms; synthesis of cam-follower mechanisms; synthesis of gear trains. *Prerequisite: MECH 332. Alternate years.*

MECH 630 Finite Element Methods in Mechanical Engineering 3 cr.
A course on the classification of machine components; displacement-based formulation; line elements and their applications in design of mechanical systems; isoparametric formulation; plane stress, plane strain, axi-symmetric, and solid elements and their applications; modeling considerations and error analysis; introduction to ALGOR general formulation and Galerkin approach; and the analysis of field problems. *Prerequisites: MECH 431 and MECH 420. Alternate years.*

MECH 631 Micro Electro Mechanical Systems (MEMS) 3 cr.
A course that deals with materials for micro-sensors and micro-actuators, materials for micro-structures, microfabrication techniques and processes for micromachining, computer-aided design and development of MEMS, commercial MEMS structures and systems, packaging for MEMS, future trends, and includes a team project. *Prerequisite: MECH 430. Alternate years.*

MECH 633 Biomechanics 3 cr.
A course on study of the biomechanical principles underlying the kinetics and kinematics of normal and abnormal human motion. Emphasis is placed on the interaction between biomechanical and physiologic factors (bone, joint, connective tissue, and muscle physiology and structure) in skeleto-motor function and the application of such in testing and practice in rehabilitation. The course is designed for engineering students with no previous anatomy/physiology. *Prerequisites: CIVE 210, MECH 320 or CIVE 310, or consent of instructor. Annually.*

MECH 634 Biomaterial and Medical Devices 3 cr.
A course that examines the structure-property relationships for biomaterials and the medical applications of biomaterials and devices. The first part of the course focuses on the main classes of biomaterials, metal, ceramic, polymeric, and composite implant materials, as well as their interactions with the human body (biocompatibility). The second part of the course examines the various applications of biomaterials and devices in different tissue and organ systems such as orthopedic, cardiovascular, dermatology, and dental applications. Experts from the medical community will be invited to discuss the various applications. *Prerequisite: MECH 340 or consent of instructor. Annually.*

MECH 641 Robotics 3 cr.
A course discussing concepts and subsystems; robot architecture; mechanics of robots: kinematics and kinetics; sensors and intelligence; actuators; trajectory planning of end effector motion; motion and force control of manipulators; robot languages. *Prerequisites: MECH 431, MECH 432, and MECH 433. Annually.*

MECH 642 Computer Vision 3 cr.
An introductory course on the problems and solutions of modern computer vision. Topics covered include image acquisition, sampling and quantization; image segmentation; geometric framework for vision: single view and two-views; camera calibration; stereopsis; motion and optical flow; recognition; pose estimation in perspective images. *Prerequisites: MATH 202 and EECE 230. Alternate years.*

MECH 643 Mechatronics and Intelligent Machines Engineering II 3 cr.
A course on sensors, sensor noise and sensor fusion; actuators; system models and automated computer simulation; information, perception, and cognition; planning and control; architectures, design, and development; a team project is included. *Prerequisites: MECH 340 and MECH 530. Alternate years.*

MECH 644 Modal Analysis 3 cr.
A course reviewing MDOF system vibrations, frequency response functions, damping, mobility measurement, curve fitting and modal parameter extraction, derivation of mathematical models, laboratory experiments, and projects are included. *Prerequisite: MECH 531. Alternate years.*

MECH 645 Noise and Vibration Control 3 cr.
A course on fundamental concepts in noise and vibration, passive and active damping strategies, damping materials, control methods, and applications. *Prerequisites: MECH 230, MATH 212, and MECH 531. Alternate years.*

MECH 648 Nonlinear Systems: Analysis, Stability, and Control 3 cr.
This course presents a comprehensive exposition of the theory of nonlinear dynamical systems and its control with particular emphasis on techniques applicable to mechanical systems. The course will be punctuated by a rich set of mechanical system examples, ranging from violin string vibration to jet engines, from heart beats to vehicle control, and from population growth to nonlinear flight control. *Prerequisite: MECH 433 Control Systems or equivalent. Alternate years.*

MECH 663 Computational Fluid Dynamics 3 cr.
A course that deals with discretization process in fluid dynamics; numerical approaches and applications; iterative and direct matrix methods; numerical implementation of turbulence models. *Prerequisites: MECH 314 and MECH 412. Alternate years.*

MECH 665 Unsteady Gas Flow 3 cr.
A course examining equations of unsteady continuous adiabatic multidimensional flows, unsteady continuous one-dimensional flow of a perfect gas with and without discontinuity, applications, and pressure exchangers. *Prerequisite: MECH 414. Alternate years.*

MECH 701 Principles of Combustion 3 cr.
A course on gas-phase reaction mechanisms and thermo-chemical kinetics; theory of ignition, flame propagation, and detonation; characteristics of premixed, diffusion, laminar, and turbulent flames; combustion aerodynamics; liquid and solid fuels in practical systems; pollutant formation and reduction mechanisms. *Prerequisites: CHEM 202, MECH 414, MECH 412, or equivalents. Alternate years.*

MECH 702 Pollutant Formation and Control in Combustion 3 cr.
Fundamentals of gas and condensed phase pollutant formation, measurement, and control pertaining to practical combustion systems. Topics include heat and mass transfer in reacting systems, chemical reaction kinetics, particle coagulation kinetics, and flame structure and propagation. These fundamental subjects are applied in the study of pollutant formation and control in practical systems including internal combustion engines, jet engines, and industrial boilers. Removal of gaseous and particulate pollutants from effluent streams by use of adsorption, absorption, catalytic processes, inertial separation, and electrostatic precipitators. *Prerequisites: MECH 311, MECH 411, MECH 412, CHEM 202 or consent of instructor. May be repeated for credit when topics vary. Alternate years.*

MECH 703 Combustion Modeling 3 cr.
Topics include chemical thermodynamics and chemical kinetics, conservation laws for reacting flow problems, diffusion controlled vs. chemistry controlled combustion, Laminar non-premixed and premixed flames and jets multi-phase combustion, detonations waves, turbulent combustion, and combustion stability. *Prerequisites: CHEM 202, MECH 311, MECH 412 or equivalents. Alternate years.*

MECH 707 Statistical Mechanics and Thermodynamics 3 cr.
This course examines the basic principles of statistical mechanics and their relation to the laws of thermodynamics and the concepts of temperature, work, heat, and entropy; the microcanonical, canonical, and grand canonical distributions; the applications to lattice vibrations, ideal gas, photon gas, quantum statistical mechanics; the Fermi and Bose systems, and interacting and non-interacting systems. *Prerequisites: MECH 310.*

MECH 720 Advanced Machine Design 3 cr.
A course that involves the analysis of stress and strain, torsion, design of axi-symmetrically loaded members, beams on elastic foundations, elastic stability, surface contact and wear, impact, and finite element applications to nonlinear problems. *Prerequisite: MECH 520. Alternate years.*

MECH 721 Elasticity and Plasticity 3 cr.
A course on tensor analysis, the general state of stresses, properties and deformation of solid materials, elasticity, plasticity, matrix methods, and applications. *Prerequisite: MECH 320 or CIVE 310. Alternate years.*

MECH 729 Spatial Mechanisms 3 cr.
A course that covers position, velocity, and acceleration analysis of spherical and spatial mechanisms; isometry; geometry of rotation axes; finite position synthesis, the 4R spherical linkage; lines and screws; the RSSR, RSSP, 4C, and 5TS spatial linkages; platform manipulators. *Prerequisite: MECH 628. Alternate years.*

MECH 736 Modeling Solidification Processes 3 cr.
The course seeks to impart a coherent view of solidification processes and how they are modeled. Topics for the first part of the course include: homogeneous and heterogeneous nucleation, with plane front, cellular and dendritic pattern, columnar and equiaxed grain growth. Phenomena affecting the quality of castings such as micro-segregation, constituent under-cooling, macro-segregation and porosity formation are also covered. In the second part solidification models are developed and applied in the context of casting operations. The course covers: heat flow in solidification processes; thermodynamics of solidification: nucleation and growth; binary phase diagrams, phase diagram computation; microstructure evolution, constitutional under-cooling; columnar and equiaxed solidification enthalpy method; mushy zone modeling; phase-field method; volume-averaging of conservation equations; multi-scale models; and modeling solidification defects. *Prerequisites: MECH 340, MECH 420, or consent of instructor. Alternate years.*

MECH 740 Advanced Dynamics 3 cr.
A course that examines three-dimensional kinetics and kinematics, theory of rotating axis, Hamilton's equations, Lagrange's equation, and Euler's equations. *Prerequisite: MECH 230 or equivalent. Alternate years.*

MECH 746 Space Mechanisms 3 cr.
Topics covered are mobility, spatial displacements, formulation of the kinematic equation, analysis and synthesis of spherical mechanisms, analysis and synthesis of spatial mechanisms, optimum synthesis of spherical and spatial kinematic chains, and analysis of platform manipulators. *Prerequisite: MECH 628.*

MECH 747 Nonlinear Finite Element Analysis 3 cr.
A course that covers governing equations and geometric and material nonlinearities; formulation of nonlinear problems; solution algorithms; vector and matrix methods; direct and iterative equations solvers; FE methods for nonlinear mechanics; element technology; numerical implementation of constitutive models; pitfalls of nonlinear analysis. *Prerequisite: MECH 630. Alternate years.*

MECH 751 Simulation of Multiphase Flows 3 cr.
Multiphase flows are important to many engineering and environmental applications. This course is intended to give an overview of the fundamentals involved in dispersed multiphase flows, and develop a working knowledge which would allow the student to numerically predict these flows. The course examines the conservation equations for multiphase systems; discretization using the finite-volume method; pressure-based algorithms for multi-fluid flow at all speeds: mass conservation based algorithms and geometric conservation based algorithms (SIMPLE, SIMPLEC, PISO, etc.); the partial elimination and SINCE algorithms; weighted pressure correction; mutual influence of volume fractions; implicit volume fraction equations; bounding the volume fractions; numerical implementation; and applications. *Prerequisite: MECH 663. Alternate years.*

MECH 760 Advanced Fluid Mechanics 3 cr.
A course that examines fundamental concepts and principles, basic relations for continuous fluids, vorticity dynamics, Kelvin and Helmholtz theorems, Navier-Stokes equations, turbulent and oscillating flows. *Prerequisite: MECH 314 or equivalent. Alternate years.*

MECH 761 Convection Heat Transfer 3 cr.
A course that covers fundamental modes of heat transfer; similarity between heat, momentum, and mass transfer in forced and buoyancy-driven flows; simultaneous heat, momentum, and mass transfer with phase change. *Prerequisites: MECH 314 and MECH 412. Alternate years.*

MECH 762 Advanced Thermodynamics 3 cr.
A course on advanced thermodynamic concepts; gas mixtures and multi-phase systems; chemical reactions; thermodynamic property relations; chemical and phase equilibrium; applications. *Prerequisite: MECH 414. Alternate years.*

MECH 763 Radiative Heat Transfer 3 cr.
Principles of thermal radiation and their application to engineering heat and photon transfer problems. Quantum and classical models of radiative properties of materials, electromagnetic wave theory for thermal radiation, radiative transfer in absorbing, emitting, and scattering media, and coherent laser radiation. Applications cover infrared instrumentation, global warming, furnaces, and high temperature processing. *Prerequisite: MECH 412. Alternate years.*

MECH 764 Advanced Topics in Computational Fluid Dynamics 3 cr.
A course on numerical solution of compressible unsteady flows, advanced turbulence modeling, the segregated approach, the multigrid technique, and an introduction to multi-phase flows. *Prerequisite: MECH 663. Alternate years.*

MECH 765 Advanced Finite Volume Techniques 3cr.
Linear multigrid; non-linear multigrid; mesh agglomeration: structured and unstructured grids; mesh generation: structured and unstructured grids; free surface simulation; and solidification simulation. *Prerequisite: MECH 411. Alternate years.*

MECH 766 Turbulent Flow and Transport 3cr.
Methods of analysis of turbulent fluid flow. In-depth discussion of algebraic, one-equation, and two-equation turbulence models. The power and limitations of turbulence models. Numerical implementation. *Prerequisite: MECH 660 Advanced Fluid Mechanics. Alternate years.*

MECH 767 Heat Conduction 3 cr.
Solutions of steady and transient heat conduction problems with various boundary conditions; approximate analytical methods; application of numerical techniques; moving boundaries, problems in freezing and melting; anisotropic and composite materials. *Prerequisite: MECH 412. Alternate years.*

MECH 768 Transport through Porous Media 3 cr.
The course is designed for graduate students interested in the flow of multi-phase, multi-component fluids through porous media. The course emphasizes physics of the momentum, heat and mass transport formulation and computations in multi-dimensional systems, including theoretical models of fluid flow, capillary effects, application of fractal and percolation concepts, characterization of porous materials, multiphase flow and heat transfer, turbulent flow and heat transfer, improved measurement techniques, and enhanced design correlations. *Prerequisite: MECH 412. Alternate years.*

MECH 769 Advanced Scientific Computing 3 cr.
In this course students will learn how to solve and visualize large-scale continuum type problems using high-performance cluster-type computing systems. Sections of the course will concentrate on discretization methods multigrid methods in a parallel computing context. Different parallel computing paradigms are introduced with emphasis on domain decomposition methods, and the practical aspects of their implementations using MPI. *Prerequisite: Prior knowledge of C programming and familiarity with the UNIX operating system. Alternate years.*

MECH 796 Special Projects in Mechanical Engineering 3 cr.

MECH 797 Seminar 0 cr.
A seminar that consists of weekly presentations on current research or applied projects in mechanical engineering presented by faculty, students, and invited scholars. This is a pass fail course based on attendance.

MECH 798 Special Topics in Mechanical Engineering 3 cr.

MECH 799 Thesis

MECH 898 Advanced Topics in Mechanical Engineering 3 cr.

MECH 899 PhD Dissertation