Ira A. Fulton School of Engineering

fulton.asu.edu   **Peter E. Crouch, PhD, Dean**

PURPOSE

Faculty in the Ira A. Fulton School of Engineering offer opportunities for graduate study and research that are designed to transform students into innovative leaders with career-ready skills. Degrees offered include the Master of Engineering (through a partnership of Arizona's three state universities); the Master of Science in Engineering; the MS in the fields of computer science, construction, and engineering; the Master of Computer Science; and the PhD in the fields of engineering and computer science.

The primary purpose of a graduate education is to provide the student with advanced training for a professional, teaching, or research career. The graduate programs are designed to bridge the gap between knowledge of engineering sciences and creative engineering practice, while at the same time increasing the student's depth and breadth of knowledge in an area of emphasis. The performance of scholarly research and the acceptance of professional responsibility for the documented results are considered essential requirements for graduate degrees and entrance into professional careers.

Information about the Ira A. Fulton School of Engineering can be accessed via the World Wide Web at fulton.asu.edu. The individual department and research program Web pages may also be accessed through this main address.

ORGANIZATION

The Fulton School of Engineering is organized as follows:

Del E. Webb School of Construction
Department of Chemical and Materials Engineering
Department of Civil and Environmental Engineering
Department of Computer Science and Engineering
Department of Electrical Engineering
Department of Industrial Engineering
Department of Mechanical and Aerospace Engineering
Harrington Department of Bioengineering

Each academic unit, headed by a chair or director, offers various undergraduate and graduate degree programs. Faculty from these academic units participate in the research programs offered through the school research centers as well as individual laboratories and facilities. Drawing on the interests, strengths, and resources of academic units in the Ira A. Fulton School of Engineering and other schools and colleges within the university, interdisciplinary research centers coordinate research, sponsor conferences and continuing education courses, and serve as liaison between the academic and industrial or technical communities.

ADMISSION REQUIREMENTS

Applicants must meet the general admission requirements established by the Division of Graduate Studies. Additional supporting materials may be required by individual academic units. These materials may include test scores from the Graduate Record Examination, letters of recommendation, and statements of educational and professional goals. International applicants whose native language is not English must also submit Test of English as a Foreign Language (TOEFL) scores. See the requirements listed under each major in this catalog for specific TOEFL information.

General information on admission, expenses, and other such topics may be obtained from the Office of the Associate Dean for Academic Affairs via the college's Web site at fulton.asu.edu. Specific questions on a program should be addressed to the academic unit.

Graduate Programs

Through the Division of Graduate Studies, faculty in the school of engineering offer various graduate programs leading to the MS, MS in Engineering, Master of Engineering, Master of Computer Science, and PhD. Several programs are delivered through both campus-based instruction or via the Internet. See the "Ira A. Fulton School of Engineering Graduate Degrees and Majors" table, page 168.

The school is an internationally recognized center for graduate research. Faculty members conduct research on government or industry-sponsored programs in areas such as aerodynamics, arts and media engineering, biomedical engineering, biotechnology, computer design, computer integrated manufacturing, construction management, environmental fluid dynamics, innovative engineering education, microelectronics manufacturing, power systems, semiconductor materials and devices, signal processing, solar energy, solid-state electronic devices, structural dynamics, telecommunications, thermosciences, and transportation infrastructure.

The research activities of the academic units within the school are complemented and supported by the work of more than 20 centers, institutes, and programs for research and development. For a current list of research programs and signature research themes, access the school's Web site at fulton.asu.edu.

The centers, institutes, and programs in operation include the following:

1. The Advanced Pavement Center studies new paving materials;
2. The Airworthiness Assurance Center of Excellence works on projects to increase aircraft safety;

Ira A. Fulton School of Engineering Graduate Degrees and Majors

Major	Degree	Concentration[1]	Administered By
Aerospace Engineering	MS, MSE, PhD	—	Department of Mechanical and Aerospace Engineering
Bioengineering	MS, PhD	—	Harrington Department of Bioengineering
Chemical Engineering	MS, MSE, PhD	—	Department of Chemical and Materials Engineering
Civil and Environmental Engineering	MS, MSE, PhD	—	Department of Civil and Environmental Engineering
Computer Science	MCS	—	Department of Computer Science and Engineering
	MS, PhD	Optional: arts, media, and engineering[1]	Department of Computer Science and Engineering
Construction	MS	Optional: construction science, facilities, or management[1]	Del E. Webb School of Construction
Electrical Engineering	MS, PhD	Optional: arts, media, and engineering[1]	Department of Electrical Engineering
	MSE	—	Department of Electrical Engineering
Engineering	MEng	—	Ira A. Fulton School of Engineering
Engineering Science	MS	—	Ira A. Fulton School of Engineering
	MSE	Executive embedded systems	Ira A. Fulton School of Engineering
	PhD	Materials science and engineering	Department of Chemical and Materials Engineering
Industrial Engineering	MS, MSE, PhD	—	Department of Industrial Engineering
Materials Engineering	MS, MSE	—	Department of Chemical and Materials Engineering
Materials Science	MS[2]	—	Committee on the Science and Engineering of Materials
Mechanical Engineering	MS, MSE, PhD	—	Department of Mechanical and Aerospace Engineering
Science and Engineering of Materials	PhD[2]	High-resolution nanostructure analysis or solid-state device materials design	Committee on the Science and Engineering of Materials

[1] If a major offers concentrations, one must be selected unless noted as *optional*.

[2] This program is administered by the Division of Graduate Studies.

3. The Arizona Partnership for Advancing Technology in Housing (AzPATH) finds ways to improve the quality and reduce the cost of homebuilding;

4. The Arts, Media, and Engineering program (AME), a joint research and education initiative of the Herberger College of Fine Arts and the Fulton School of Engineering, focuses on the integrated, parallel development of digital media technologies and digital media content;

5. The Center for Low Power Electronics is developing the next generation of ultra-low power electronic systems for mobile and portable applications;

6. The Center for Solid State Electronics Research (CSSER), which operates ASU's NanoFab facility, is working on microelectronics research projects in a wide variety of areas, including nanostructure and low power electronics;

7. The Center for Cognitive Ubiquitous Computing (CUbiC) is making computers easier to use, especially for people with disabilities;

8. Connection One: Communications Circuits and Systems Center is developing technology to improve wireless communication;

9. The Consortium for Embedded and Internetworking Technologies (CEINT) develops technologies that incorporate software designs and applications that communicate with one another;

10. Construction Research and Education for Advanced Technology Environments (CREATE) examines how to build cleanrooms and biotechnology facilities more efficiently;

11. The Environmental Fluid Dynamics Program studies the movement of air and water in the environment, particularly as it relates to pollution;

12. The Institute for Manufacturing Enterprise Systems, a joint effort with the W. P. Carey School of Business,

works to solve problems in the business community related to software, supply chain, operations management, and other topics;

13. The NASA Space Grant Program designs and builds space-related craft, such as satellites and lunar rovers;

14. The National Center for Sustainable Water Supply investigates how to recycle reclaimed water;

15. The National Science Foundation (NSF) Water Quality Center works on projects to identify and remove both biological and chemical contaminants in water;

16. The Partnership for Research in Stereo Modeling (PRISM) uses computer modeling techniques to create three-dimensional models of microscopic objects; and

17. The Power Systems Engineering Research Center studies markets, systems, and transmission and distribution in the power industry.

In addition, faculty and researchers in the school contribute to a number of interdisciplinary research programs involving multiple schools and colleges in the university, including the Biodesign Institute at Arizona State University (AzBio); the Institute for Computing and Information Sciences and Engineering (InCISE); and the Center for Research on Education in Science, Mathematics, Engineering, and Technology (CRESMET).

Information about these programs is available elsewhere in this catalog or via the Web at www.asu.edu.

Center for Professional Development. The Center for Professional Development (CPD) provides engineering and technical professionals the skills and knowledge necessary to master new methods, to lead projects and teams, and to advance professionally. By leveraging the internationally renowned faculty of the Ira A. Fulton School of Engineering and affiliated experts, CPD offers online master's degree programs allowing students with complex schedules to complete graduate degrees from a remote location while receiving the same degree and curriculum a student completes on campus. CPD also administers short courses and conferences, professional certification programs, and in-company customized programs. For more information, call 480/965-1740, or access the Web site at www.asuengineeringonline.com.

Master of Engineering. Arizona's three state universities—Arizona State University, Northern Arizona University, and the University of Arizona—are collaborating to offer the Arizona Master of Engineering partnership. This graduate degree program is designed to meet the educational needs of practicing engineers by offering courses via distance delivery. With input from industry professionals, the three universities are offering courses that develop the skills, fundamental knowledge, and understanding that are critical to today's practicing engineers. For more information, access the Web site at triuniv.engr.arizona.edu.

SCHOOL FACILITIES

Numerous well-equipped laboratories, extensive library holdings, and widely available computer services encourage the best in research and graduate training. Laboratories include facilities for environmental fluid dynamics, interactive nonvisualization via scanning probe microscopy, materials and surface characterization, mechanical testing, molecular beam epitaxy, neuromechanical control, rapid manufacturing processes, transmission microscopy, and surface research, to name only a few of the diverse capabilities of the school's physical resources. Supporting the work of researchers, a well-equipped and well-staffed machine and structures fabrication shop makes special-purpose equipment for student and faculty projects. For more information about laboratories, consult the descriptions of individual programs and centers for research in this catalog.

The Ira A. Fulton School of Engineering offers extensive computing facilities to its faculty and graduate students. The school centrally maintains computing resources for general engineering use, including a large Sun SPARCenter 2000 superserver, Hewlett Packard 9000 superserver, and an IBM Netfinity Quad M7000 NT Server. Also available are specialty computers for World Wide Web services, electronic mail, Internet collaboration, and special applications. Distributed throughout the school are several thousands of networked UNIX workstations and PCs accessing UNIX or NT servers available for research and instruction. UNIX workstations are provided by manufacturers such as Sun Microsystems, Hewlett Packard, Silicon Graphics, and Digital Equipment Corporation. All school computing resources are
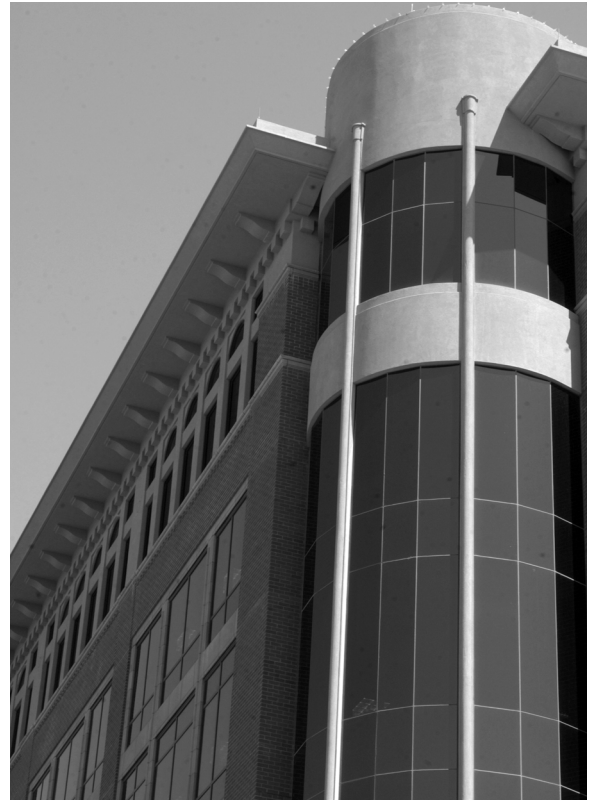
The Brickyard, in downtown Tempe, houses the Ira A. Fulton School of Engineering dean's office and the Department of Computer Science and Engineering.

Tim Trumble photo

interconnected via the Internet standard TCP/IP on 10Mb, 100Mb dedicated ethernet, or through wireless 802.11b access.

ACADEMIC STANDARDS

Maintaining Satisfactory Progress. A student who has been admitted to a graduate program of study in the Ira A. Fulton School of Engineering, on either a regular or provisional basis, must maintain a 3.00 or higher GPA in all work taken for graduate credit as well as an overall 3.00 GPA in all studies at ASU.

A student is placed on academic probation if

1. the student's GPA falls below 3.00 in the approved program of study;

2. the student's overall GPA for all postbaccalaureate courses taken at ASU falls below 3.00; or

3. the student receives a "D" (1.00) or "E" (0.00) in a required deficiency or in a course at the 400 level or above.

A student is recommended for withdrawal from a graduate program if

1. the student is on academic probation because his or her GPA has fallen below 3.00 in the approved program of study or for all postbaccalaureate courses taken at ASU and fails to bring the GPA to 3.00 or above by the time the next nine semester hours are completed;

2. the student receives a "D" (1.00) or lower grade while on academic probation for any reason;

3. the student fails to obtain at least a 3.00 GPA in all courses cited as deficiencies upon admission to a graduate program; or

4. the student fails to meet any other conditions imposed as part of the probation.

A student may appeal any action concerning academic probation and withdrawal by petitioning the graduate affairs committee within the student's academic unit.

COURSES

Graduate courses offered by the Ira A. Fulton School of Engineering that apply to degree requirements are listed under degree majors in this catalog. Basic courses that may be required, or taken as electives are shown below.

ANALYSIS AND SYSTEMS (ASE)
ASE 582 Linear Algebra in Engineering. (3)
fall
Development and solution of systems of linear algebraic equations. Applications from mechanical, structural, and electrical fields of engineering. Prerequisite: MAT 242 (or its equivalent).
ASE 586 Partial Differential Equations in Engineering. (3)
spring
Development and solution of partial differential equations in engineering. Applications in solid mechanics, vibrations, and heat transfer. Prerequisites: MAT 242, 274.
Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

ENGINEERING CORE (ECE)
ECE 500 Research Methods. (1–12)
selected semesters
Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Aerospace Engineering

Master's and Doctoral Programs

fulton.asu.edu/mae
480/965-3291
ECG 346

Robert E. Peck, Chair

Professors: Chattopadhyay, Liu, Mignolet, Peck, Wie

Associate Professors: Lee, Wells

Assistant Professor: Mikellides

The faculty in the Department of Mechanical and Aerospace Engineering offer graduate programs leading to the MS, MSE, and PhD degrees in Aerospace Engineering. A number of areas of study may be pursued, including aerodynamics, design, dynamics and control, propulsion, space systems, and structures. The faculty also offer graduate degree programs in Mechanical Engineering. All of the department's graduate programs stress a sound foundation leading to a specialized area of study.

The application deadline for admission in the fall semester is December 1. Applications received after that date and before July 1 are considered for admission in the spring semester.

Graduate Record Examination. All applicants are required to take the Graduate Record Examination; the subject test in Engineering is highly recommended but not required.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general requirements.

INTEGRATED BSE-MS DEGREE

The Department of Mechanical and Aerospace Engineering offers an integrated, five-year BSE-MS degree. The program is designed for students with strong academic backgrounds who are motivated to pursue independent research. Students have the opportunity to work in a laboratory/research environment and engage in theoretical and/or experimental work with faculty and doctoral student mentors. Undergraduates, majoring in mechanical or aerospace engineering, who have completed a minimum of two semesters of full-time enrollment in MAE and have completed at least 90 semester hours of applicable course work are eligible for the program. Applicants must also have a cumulative

GPA of 3.50 or higher. Students normally submit applications following the completion of their junior year. For more information, contact the department's Graduate Advising Office.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192, for information on the Master of Science in Engineering degree.

MASTER OF ENGINEERING

The faculty also participate in the Arizona Master of Engineering partnership. See "Master of Engineering," page 192.

DOCTOR OF PHILOSOPHY

The PhD degree is conferred upon evidence of excellence in research leading to a scholarly dissertation that is an original contribution to knowledge in the field of aerospace engineering. See "Doctor of Philosophy," page 69, for general requirements.

Program of Study. The program of study must be established no later than the first semester after successfully completing the qualifying examination.

Qualifying Criteria. The purposes of the qualifying criteria are to assess if the student is prepared to continue in the doctoral program and to detect deficiencies in the student's background that can be corrected by appropriate course work and individual study. Within the first year of graduate studies at ASU, a graduate student pursuing a PhD program of study in Aerospace Engineering must complete three 500-level core courses, preferably in the major area of interest, and one 500-level mathematics course, both with an average GPA of 3.25 or higher. Specific qualifying course requirements for each major area are available from the department.

Foreign Language Requirements. None.

Comprehensive Examinations. Written and oral comprehensive examinations are required. The examinations are administered by the program committee.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

Research in Aerospace Engineering is aimed at advancing the design and performance of aircraft, helicopters, and space systems. Specific topics being investigated include aeroacoustics; aeroelasticity; airbreathing and space propulsion; aircraft crashworthiness; flow control; composite structures; flight dynamics, guidance, and controls; fracture mechanics and fatigue; high-speed aerodynamics; hydrodynamic stability; multidisciplinary optimization; satellite design; smart structures; structural dynamics and vibrations;

and unsteady aerodynamics. State-of-the-art laboratory and computational facilities are available to assist in the development of research skills. For more information access the department Web site at fulton.asu.edu/mae.

COURSES

For courses, see "Mechanical and Aerospace Engineering (MAE)," page 201.

Bioengineering

Master's and Doctoral Programs

fulton.asu.edu/~bme/new/
480/965-3028
ECG 334

Eric J. Guilbeau, Chair

CORE FACULTY

Professors: Garcia, Guilbeau, He, Towe
Associate Professors: Abbas, Iasemidis, Joshi, Jung, Massia, Pizziconi, Sweeney
Assistant Professors: Buneo, Caplan, Muthuswamy, Panitch, Steinmetz, Vernon
Research Professors: Brophy, Herman, Khairallah, Reaven, Simper, Yamaguchi
Research Associate Professor: Singh
Research Assistant Professors: Furnish, Helms Tillery, Shimansky
Senior Research Professional: Brandon
Research Scientists: Bowen, Ehteshami, Kennedy, LaBelle, Pauken
Assistant Research Scientist: Carhart
Senior Lecturer: Coursen

AFFILIATED FACULTY

Electrical Engineering
Professor: Kozicki
Associate Professor: Kim

Electronics and Computer Engineering Technology (East campus)
Associate Professor: Macia

Kinesiology
Assistant Professor: Santello

The Bioengineering faculty within the Harrington Department of Bioengineering offer graduate programs leading to the MS and PhD degrees in Bioengineering. Areas of study include biochemical engineering, bioelectrical engineering, biomechanical engineering, biosystems/biotransport engineering, bioinstrumentation, biomaterial engineering, and biocontrol engineering. Research topics include artificial organs, biocontrol systems, biomechanics,

bioinstrumentation, biomaterials, biosystems engineering, biotechnology, cardiovascular engineering, cellular and tissue bioengineering, neural bioengineering, noninvasive imaging, and rehabilitation engineering.

The faculty also participate in the Arizona Master of Engineering partnership. See "Master of Engineering," page 192, for the program description.

Graduate Record Examination. Graduate Record Examination scores are required from all students.

Transition Program. Students applying to the Bioengineering MS or PhD degree programs may have an undergraduate BS degree in a major field other than Bioengineering. The qualifications of transition students are reviewed by the department graduate committee, and a special program of transition course work is designed for successful applicants. In general, transition students should have had, or be prepared to take, calculus through ordinary differential equations, inorganic chemistry, physics, and a number of undergraduate engineering courses in order to be prepared for graduate bioengineering courses. Other course work from the undergraduate program may be required depending upon the research topic selected by the student. Transition students should contact the associate chair to evaluate the undergraduate transcript.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general requirements.

Program of Study. All candidates pursuing an MS degree in Bioengineering are required to complete an approved program of study consisting of the minimum required semester hours, including research and thesis. Special course requirements for the different areas of study are established by the faculty and are available from the Harrington Department of Bioengineering. Part-time students must successfully complete a research seminar course for at least three semesters during the course of study. Candidates whose undergraduate degree was in a field other than bioengineering may be required to complete more than 30 semester hours of credit on the program of study.

Research Seminar Requirements. In addition to the course work and thesis requirements, all full-time master's degree students must successfully complete a research seminar course during each semester of attendance.

Thesis Requirements. A written thesis is required.

Final Examination. A final oral examination in defense of the thesis is required.

Nonthesis Option

The nonthesis option within the MS degree program in Bioengineering is reserved for students who have full-time employment in industry and who intend to enroll in the MS degree program on a part-time basis, or for students who wish to continue their study of bioengineering past the baccalaureate level before seeking admission to a medical school.

Admission Requirements. Students seeking admission to the nonthesis option must request this option when applying for admission to the MS degree program. Students who are admitted to the thesis option are not allowed to subsequently transfer into the nonthesis option. Students admitted to the nonthesis option, however, may subsequently request approval to transfer into the thesis option. Additionally, the student must meet the following criteria to qualify for the nonthesis option: (1) be a full-time employee of a local industry and indicate at the time of application that he or she intends to pursue the MS degree on a part-time basis or (2) declare at the time of application that his or her career goal is to seek admission to a medical school.

Course Requirements. A total of 33 semester hours, including a bioengineering seminar and project, is required for graduation in the nonthesis option. The program of study for the nonthesis option requires the same set of core courses and seminar in bioengineering that is required of students in the thesis option. Instead of research and thesis hours, the student must complete six additional credits of course work selected from the catalog list of BME courses (the total course work requirement, including seminar, is 33 semester hours).

Project. Students admitted to the nonthesis option must also register for three semester hours of BME 593 Applied Project. Students are required to complete an in-depth literature survey and/or research design in some aspect of bioengineering, resulting in a written report.

Defense of the Applied Project. The student is required to successfully defend the Applied Project in bioengineering before his or her graduate supervisory committee.

Financial Aid. Students admitted to the nonthesis option within the bioengineering master's degree program do not qualify for graduate research or teaching assistantships or other financial assistance available to thesis option master's degree students.

Admission to the PhD Program. If the student wishes to subsequently enter the PhD program after completing the requirements for the nonthesis option, the application procedure is the same as if the student was applying with a thesis-track MS degree.

DOCTOR OF PHILOSOPHY

The PhD degree in Bioengineering is conferred upon evidence of excellence in research resulting in a scholarly dissertation that is a contribution to knowledge. See "Doctor of Philosophy," page 69, for general requirements.

Program of Study. Upon admission of the applicant with regular or provisional status, a supervisory committee (program committee) is appointed. This committee is responsible for the guidance and direction of the student's graduate program of study. The program committee is composed of a minimum of three faculty members, including a chair. Generally, the student's graduate advisor serves as chair of the program committee. The program committee advises the student in developing a program of study and assumes

primary responsibility in assessing the student's progress in the program.

Research Seminar Requirements. In addition to the course work and dissertation requirements, all full-time doctoral students must successfully complete a research seminar course during each semester of attendance.

Foreign Language Requirements. None.

Comprehensive Examination. When the PhD student has essentially completed the course work in the approved program of study, the student is given a comprehensive examination covering the field of study.

Admission to Candidacy and Appointment of Dissertation Committee. After the student passes the comprehensive examinations, a dissertation committee composed of at least five faculty members is appointed. The dissertation committee meets to approve the student's dissertation prospectus. Generally, the prospectus should include a pertinent review of the literature, a statement of the proposed study, the hypothesis to be tested, a description of the research design, a discussion of the specific data to be collected, and a description of the means by which the data is to be analyzed. After the dissertation committee has approved the prospectus, the student applies to the Division of Graduate Studies for admission to candidacy.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required. The dissertation is expected to reflect and contribute significantly to knowledge. It must clearly indicate mastery of research methods.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

For current information about research activity, access the Harrington Department of Bioengineering Web site at fulton.asu.edu/~bme/new.

BIOENGINEERING (BME)

BME 411 Biomedical Engineering I. (3)
once a year
Reviews diagnostic and prosthetic methods using engineering methodology. Introduces transport, metabolic, and autoregulatory processes in the human body. Prerequisite with a grade of "C" (2.00) or higher: BME 434.

BME 412 Biomedical Engineering II. (3)
once a year
Reviews electrophysiology and nerve pacing applications. Introduces biomechanics and joint/limb replacement technology, cardiovascular and pulmonary fluid mechanics, and the application of mathematical modeling. Prerequisite: instructor approval.

BME 415 Biomedical Transport Processes. (3)
once a year
Principles of momentum, heat, and mass transport with applications to medical and biological systems and medical device design. Prerequisites: MAT 274; PHY 131.

BME 416 Biomechanics. (3)
fall
Mechanical properties of bone, muscle, and soft tissue. Static and dynamic analysis of human movement tasks such as locomotion. Prerequisite: ECE 210 or 214. Prerequisite with a grade of "C" (2.00) or higher: BME 318.

BME 417 Biomedical Engineering Capstone Design I. (3)
fall
Technical, regulatory, economic, legal, social, and ethical aspects of medical device systems engineering design. Lecture, field trips. Prerequisites: BME 101; ECE 300. Pre- or corequisites with a grade of "C" (2.00) or higher: at least 5 of the 7 following courses: BME 318, 331, 350, 413, 470; ECE 340, 380.

BME 419 Biocontrol Systems. (3)
fall
Applies linear and nonlinear control systems techniques to analysis of neuromusculoskeletal, cardiovascular, thermal, and mass transfer systems of the body. Prerequisites: ECE 201; MAT 274.

BME 434 Applications of Bioengineering Transport Phenomena. (3)
spring
Develops mathematical models of transport phenomena in physiological systems, medical devices, and pharmacokinetic analysis. Prerequisite: ECE 380. Prerequisite with a grade of "C" (2.00) or higher: BME 331.

BME 451 Cell Biotechnology Laboratory. (3)
fall
Mammalian cell culture techniques, including mouse embryonic stem cells, the use of bioreactors, cell fractionation, and digital video imaging. Lecture, lab. Cross-listed as BIO 451. Credit is allowed for only BME 451 or BIO 451. Prerequisites: BIO 353; instructor approval.

BME 470 Microcomputer Applications in Bioengineering. (4)
spring
Uses microcomputers for real-time data collection, analysis, and control of experiments involving actual and simulated physiological systems. Lecture, lab. Fee. Prerequisite: ECE 334. Prerequisite with a grade of "C" (2.00) or higher: BME 235. BME 413 and 423 recommended.

BME 511 Biomedical Engineering I. (3)
once a year
Diagnostic and prosthetic methods using engineering methodology. Transport, metabolic, and autoregulatory processes in the body.

BME 512 Biomedical Engineering II. (3)
once a year
Electrophysiology and nerve pacing applications. Introduces biomechanics and joint/limb replacement, technology, cardiovascular and pulmonary fluid mechanics, and mathematical modeling.

BME 513 Biomedical Instrumentation. (3)
fall
Principles of medical instrumentation. Studies of medical diagnostic instruments and techniques for the measurement of physiologic variables in living systems.

BME 514 Advanced Biomedical Instrumentation. (3)
selected semesters
Principles of applied biophysical measurements using bioelectric and radiological approach. Prerequisites: ECE 334; MAT 274 (or its equivalent).

BME 515 Biomedical Transport Processes. (3)
selected semesters
Principles of momentum, heat, and mass transport with applications to medical and biological systems and medical device design. Prerequisite: instructor approval.

BME 516 Topics in Biomechanics. (3)
fall
Mechanical properties of bone, muscle, and soft tissue. Static and dynamic analysis of human movement tasks, including in-depth project. Prerequisite: instructor approval.

BME 518 Introduction to Biomaterials. (3)
spring
Topics include structure property relationships for synthetic and natural biomaterials, biocompatibility, and uses of materials to replace body parts. Prerequisite: ECE 350 (or its equivalent) or instructor approval.

BME 519 Topics in Biocontrol Systems. (3)
fall
Linear and nonlinear control systems analysis of neuromusculoskeletal, cardiovascular, thermal, and mass transfer systems of the body, including in-depth project. Prerequisites: both ECE 201 and MAT 274 or only instructor approval.

BME 520 Bioelectric Phenomena. (3)
selected semesters
Study of the origin, propagation, and interactions of bioelectricity in living things; volume conductor problem, mathematical analysis of bioelectric interactions, and uses in medical diagnostics.

BME 521 Neuromuscular Control Systems. (3)
spring
Overview of sensorimotor brain structures. Application of nonlinear, adaptive, optimal, and supervisory control theory to eye-head-hand coordination and locomotion.

BME 522 Biosensor Design and Application. (3)
once a year
Theory and principles of biosensor design and application in medicine and biology. Principles of measurements with biosensors. Prerequisite: instructor approval.

BME 523 Physiological Instrumentation Lab. (1)
fall
Laboratory experience with problems, concepts, and techniques of biomedical instrumentation in static and dynamic environments. Lab. Prerequisites: BME 235; ECE 334. Pre- or corequisite: BME 513.

BME 524 Fundamentals of Applied Neural Control. (3)
once a year
Fundamental concepts of electrical stimulation and recording in the nervous system with the goal of functional control restoration. Pre- or corequisite: BME 235 or instructor approval.

BME 525 Surgical Techniques. (2)
spring
Principles of surgical techniques, standard operative procedures, federal regulations, guidelines, and state-of-the-art methods. Lecture, lab.

BME 532 Prosthetic and Rehabilitation Engineering. (3)
once a year
Analysis and critical assessment of design and control strategies for state-of-the-art medical devices used in rehabilitation engineering. Pre- or corequisite: BME 416 or 516 or KIN 610.

BME 533 Transport Processes I. (3)
fall
Unified treatment of momentum, heat, and mass transfer from molecular theory, and continuum points of view. Continuum equations of microscopic and macroscopic systems and multicomponent and multiphase systems. Cross-listed as CHE 533. Credit is allowed for only BME 533 or CHE 533.

BME 534 Transport Processes II. (3)
spring
Continuation of BME 533 or CHE 533, emphasizing mass transfer. Cross-listed as CHE 534. Credit is allowed for only BME 534 or CHE 534. Prerequisite: BME 533 or CHE 533.

BME 543 Thermodynamics of Chemical Systems. (3)
fall
Classical and statistical thermodynamics of nonideal physicochemical systems and processes; prediction of optimum operating conditions. Cross-listed as CHE 543. Credit is allowed for only BME 543 or CHE 543.

BME 544 Chemical Reactor Engineering. (3)
spring
Reaction rates, thermodynamics, and transport principles applied to the design and operation of chemical reactors. Cross-listed as CHE 544. Credit is allowed for only BME 544 or CHE 544. Prerequisite: BME 543 or CHE 543.

BME 551 Movement Biomechanics. (3)
spring
Mechanics applied to the analysis and modeling of physiological movements. Computational modeling of muscles, tendons, joints, and the skeletal system with application to sports and rehabilitation. Prerequisite: BME 416 or 516 or instructor approval.

BME 566 Medical Imaging Instrumentation. (3)
selected semesters
Design and analysis of imaging systems and nuclear devices for medical diagnosis, therapy, and research. Laboratory experiments using diagnostic radiology, fluoroscopy, ultrasound, and CAT scanning. Lecture, lab. Prerequisite: instructor approval.

BME 568 Medical Imaging. (3)
selected semesters
CT, SPECT, PET, and MRI. 3-D *in vivo* measurements. Instrument design, physiological modeling, clinical protocols, reconstruction algorithms, and quantitation issues. Prerequisite: instructor approval.

BME 593 Applied Project. (1–12)
selected semesters

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Chemical Engineering

Master's and Doctoral Programs

fulton.asu.edu/~cme
480/965-3313
ECG 202

Subhash Mahajan, Chair

Professors: Lin, Mahajan, Raupp, Wang

Associate Professors: Beckman, Burrows, Rivera, Sierks

Assistant Professors: Allen, Dillner, Heys, Park

The faculty in the Department of Chemical and Materials Engineering offer graduate programs leading to the MS, MS in Engineering, and the PhD degrees in Chemical Engineering. Areas of research emphasis include biotechnology and biomaterials, chemical therapies for neurodegenerative diseases, adhesion in biological and inorganic systems, electronic materials processing, environmentally-benign manufacturing, process design and operations, water and air purification, surface and reaction engineering, and photocatalysis. Within the Engineering Science major, students may select materials science and engineering as the area of study (see "Engineering Science," page 193, for program description).

The faculty also participate in offering the interdisciplinary program leading to the Doctor of Philosophy degree with a major in Science and Engineering of Materials (see "Science and Engineering of Materials," page 326, for program description). A *Graduate Student Handbook,* detailing information on graduate studies in Chemical Engineering, is available to admitted students. Students should contact the department.

The faculty also participate in the Arizona Master of Engineering partnership. See "Master of Engineering," page 192, for the program description.

Graduate Record Examination. Graduate Record Examination scores are required from all applicants.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general requirements.

Transition Program. Students applying for the program leading to a master's degree with a major in Chemical Engineering, or in the area of study of materials science and engineering under the Engineering Science major, may have an undergraduate BS degree in a major field other than chemical engineering or materials science. The qualifications of transition students are reviewed by the department graduate committee, and a special program is designed for successful applicants. In general, applicants should have had, or should be prepared to take, calculus through differential equations and physics. Transition students are expected to complete the essential courses in their area of study from the undergraduate program to prepare themselves for the graduate courses. Other course work from the undergraduate program may be required depending upon the area of study selected by the student.

Transition students should contact the graduate coordinator for an evaluation of the undergraduate transcript.

Program of Study. All candidates for the MS in Engineering or MS in Chemical Engineering, or in the area of study of materials science and engineering under the Engineering Science major, are required to complete an approved program of study consisting of the minimum required semester hours, including research report (MSE) or thesis (MS). Special course requirements for the different areas of study are established by the faculty and are available from the departmental graduate coordinator. In addition to the course/thesis requirements, all full-time graduate students must successfully complete a seminar course during each semester of attendance; part-time students must enroll in a seminar course at least three times during the course of study. Candidates whose undergraduate degree was in a field other than chemical engineering or materials science may be required to complete more than 30 semester hours.

Thesis Requirements. A thesis or equivalent is required.

Final Examination. A final oral examination is required in defense of the thesis or equivalent.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192, for information on the Master of Science in Engineering degree.

DOCTOR OF PHILOSOPHY

The PhD degree in Chemical Engineering, or in the area of study of materials science and engineering under the Engineering Science major, is conferred upon evidence of excellence in research resulting in a scholarly dissertation that is a contribution to existing knowledge.

See "Doctor of Philosophy," page 69, for general requirements.

Doctoral Program. Upon successful completion of the qualifying examination, a research supervisory committee is formed and the doctoral student is required to submit a research proposal. Following the acceptance of the research proposal, the student is given a comprehensive examination to determine initiative, originality, breadth, and high level of professional commitment to the problem selected for inves-

tigation. Upon successful completion of the comprehensive examination, the student applies for admission to candidacy.

Master's Degree in Passing. Students who are enrolled in the PhD degree program in Chemical Engineering, but who do not hold a previously earned master's degree in chemical engineering, can obtain the MSE degree (the "Master's in Passing") upon completion of course requirements, the PhD qualifying examination, prospectus, and the comprehensive examination.

As this degree is only available to students who are enrolled as regular students in the PhD program in Chemical Engineering, all of the above requirements (including course work) can be applied toward the PhD requirements.

Foreign Language Requirements. Candidates in the program leading to the PhD degree in Chemical Engineering, or in the area of study of materials science and engineering under the Engineering Science major, normally are not required to pass an examination showing reading competency of a foreign language. However, the supervisory committee may establish such a requirement in special cases depending upon the research interests of the candidate. If the foreign language is required, the student must successfully fulfill the requirement before taking the comprehensive examination.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

Atmospheric Aerosols. Chemistry and physics of aerosols, visibility degradation, climatological effects, human health impacts, atmosphere-biosphere interactions, novel aerosol instrumentation, ultrafine particle characterization, sources of atmospheric particles, environmental fate of pollutants.

Biochemical Engineering. Biological colloids, bioadhesion, biofilms, biochips, protein engineering, enzyme kinetics, biomedical engineering, antibody-based therapeutics, neurogenerative diseases, atomic force microscopy, protein-protein interactions, coagulation.

Chemical Process Control. Advanced process identification and control. Control oriented approaches to supply chain management. Application to chemical, petroleum, and semiconductor manufacturing industries.

Chemical Process Engineering. Chemical process design fundamentals, optimization techniques and applications, process modeling, simulation, dynamics and control, and applied statistics.

Electronic Materials. Adsorption, catalysis, solid-state materials processing for control of properties, adhesion, surface cleaning, plasma etching, physical vapor deposition, polymer processing, photolithography, semiconductor materials processing, chemical vapor deposition, surface reactions, electrochemical reactions, optimization of electroplating processing, and surface analysis.

Environmental Analysis. Energy and environmental design considerations, purification of effluent streams, water reclamation and purification, sea water desalination, CMP effluent recovery, analysis of air and water pollution, modeling of pollution systems, and recycling for pollution control.

Materials Science and Engineering. Semiconductor processing and characterization, polymeric and ceramic composites, materials for high critical temperature superconductor applications, ferritic thin films for capacitor and memory applications, high temperature materials for space applications, mechanical behavior of high-strength Al-Li alloys, environmentally influenced mechanical effects, and micro-biologically influenced corrosion reactions.

In addition to the strong core programs, the department emphasizes multidisciplinary research at the leading edge of science, where departmental strengths interface with materials and solid-state research, life sciences, bioengineering, atmospheric sciences, and environmental studies.

Faculty in chemical engineering are also involved in numerous research centers and programs across campus, including the Center for Solid State Science, the Molecular and Cellular Biology master's degree program, and the Atmospheric Sciences certificate program.

For more information, access the department Web site at fulton.asu.edu/~cme.

CHEMICAL ENGINEERING (CHE)

CHE 433 Modern Separations. (3)
spring
Design of modern separation equipment in chemical engineering other than fractionation. Prerequisites: CHE 334, 342.

CHE 458 Semiconductor Material Processing. (3)
selected semesters
Introduces the processing and characterization of electronic materials for semiconductor applications. Prerequisites: CHE 334, 342.

CHE 475 Biochemical Engineering. (3)
selected semesters
Applies chemical engineering methods, mass transfer, thermodynamics, and transport phenomena to industrial biotechnology. Prerequisite: instructor approval.

CHE 476 Bioreaction Engineering. (3)
selected semesters
Principles of analysis and design of reactors for processing with cells and other biologically active materials; applications of reaction engineering in biotechnology. Prerequisite: instructor approval.

CHE 477 Bioseparation Processes. (3)
selected semesters
Principles of separation of biologically active chemicals; the application, scale-up, and design of separation processes in biotechnology. Prerequisite: instructor approval.

CHE 501 Introduction to Transport Phenomena I: Fluids. (3)
spring
Transport phenomena, with emphasis on fluid systems. Credit is allowed for only CHE 501 or 331. Prerequisite: transition student with instructor approval.

CHE 502 Introduction to Transport Phenomena II: Heat and Mass Transfer. (3)
fall
Applies heat and mass transport principles. Design of heat exchangers and continuous contactors. Credit is allowed for only CHE 502 or 334. Prerequisite: transition student with instructor approval.

CHE 504 Introduction to Applied Chemical Thermodynamics. (3)
fall
Applies conservation and accounting principles with nonideal property estimation techniques. Lecture, recitation. Credit is allowed for only CHE 504 or 342. Prerequisite: transition student with instructor approval.

CHE 505 Introduction to Chemical Reactor Design. (3)
spring
Applies kinetics to chemical reactor design. Lecture, recitation. Credit is allowed for only CHE 505 or 442. Prerequisite: transition student with instructor approval.

CHE 527 Advanced Applied Mathematical Analysis in Chemical Engineering. (3)
fall
Formulation and solution of complex mathematical relationships resulting from the description of physical problems in mass, energy, and momentum transfer and chemical kinetics.

CHE 533 Transport Processes I. (3)
spring
Unified treatment of momentum, heat, and mass transfer from molecular theory, and continuum points of view. Continuum equations of microscopic and macroscopic systems and multicomponent and multiphase systems. Cross-listed as BME 533. Credit is allowed for only BME 533 or CHE 533.

CHE 534 Transport Processes II. (3)
fall
Continuation of BME 533 or CHE 533, emphasizing mass transfer. Cross-listed as BME 534. Credit is allowed for only BME 534 or CHE 534. Prerequisite: BME 533 or CHE 533.

CHE 536 Convective Mass Transfer. (3)
selected semesters
Turbulent flow for multicomponent systems, including chemical reactions with applications in separations and air pollution. Prerequisite: CHE 533 or MAE 571.

CHE 543 Thermodynamics of Chemical Systems. (3)
fall
Classical and statistical thermodynamics of nonideal physicochemical systems and processes; prediction of optimum operating conditions. Cross-listed as BME 543. Credit is allowed for only BME 543 or CHE 543.

CHE 544 Chemical Reactor Engineering. (3)
spring
Reaction rates, thermodynamics, and transport principles applied to the design and operation of chemical reactors. Cross-listed as BME 544. Credit is allowed for only BME 544 or CHE 544. Prerequisite: BME 543 or CHE 543.

CHE 561 Advanced Process Control. (3)
spring
Dynamic process representation, linear optimal control, optimal state reconstruction, and parameter and state estimation techniques for continuous and discrete time systems.

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Civil and Environmental Engineering

Master's and Doctoral Programs

fulton.asu.edu/civil

480/965-3589

ECG 252

Sandra L. Houston, Chair

Richard Snell Presidential Chair Professor: Crittenden

Professors: Allenby, Fox, Houston, Johnson, Kavazanjian, Mamlouk, Mays, Rajan, Singhal, Witczak

Associate Professors: Abbaszadegan, Fafitis, Mobasher, Muccino, Westerhoff

Assistant Professors: Allen, Kaloush, Peccia

Research Faculty: Alum, Chen, El-Basyouny, Kabiri-Badr, Zapata

The faculty in the Department of Civil and Environmental Engineering offer graduate programs leading to the MS, the MS in Engineering (MSE), and the PhD degrees in Civil and Environmental Engineering.

The faculty also participate in the Arizona Master of Engineering partnership. See "Master of Engineering," page 192, for program description.

Graduate Record Examination. Submission of Graduate Record Examination (GRE) scores, general test, is required for all degree-seeking applicants.

TOEFL Examination. International applicants, whose native language is not English, are required to have taken the Test of English as a Foreign Language (TOEFL), and achieved a minimum score of 550.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general requirements.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192.

DOCTOR OF PHILOSOPHY

The PhD degree is conferred upon students based on evidence of excellence in research leading to a scholarly dissertation that is a contribution to knowledge in the field of civil engineering. See "Doctor of Philosophy," page 69, for general requirements.

Letters of Recommendation. Submission of three letters of recommendation is required for those applying for admission to the PhD degree program. One letter must be from the chair or advisor of the applicant's previous degree program.

Program of Study. The program of study must be prepared soon after a student has been admitted to the program, a supervisory committee has been formed, and a preliminary examination (if required by the supervisory committee) has been taken.

Foreign Language Requirements. None.

Comprehensive Examinations. Written and oral comprehensive examinations are required. The examinations are administered by the supervisory committee. Students should request permission from the Division of Graduate Studies to take the examinations when they have essentially completed the course work in their approved program of study.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

A broad range of theoretical and experimental research programs have been established in civil and environmental engineering to prepare graduate students for careers in professional practice and research. These programs are constantly evolving with the changes in society and the profession, and many are multidisciplinary in nature.

Experimental and theoretical research conducted by the civil and environmental engineering faculty and students is carried out in the specialized areas of construction engineering, environmental engineering, geotechnical/geoenvironmental engineering, structures/materials engineering, transportation/materials engineering, and water resources engineering. For more information about these activities, access the Web site at fulton.asu.edu/civil.

Areas of Study

Areas of study in the civil and environmental engineering curriculum are described below.

Construction Engineering. This area of study includes the analysis, design, and construction of civil engineering structures; construction materials and practice; quality control; and civil engineering project management.

Environmental Engineering. This area of study includes water and wastewater treatment; water reuse and water resource sustainability; chemical and microbial pollutant identification, monitoring, and transport/fate modeling; and chemical and microbial inactivation and removal.

Geotechnical/Geoenvironmental Engineering. This area of study includes the analysis and design of foundation systems, seepage control, earthdams and water resource structures, earthwork operations, fluid flow-through porous media, response of foundations and embankments to earthquakes, and solutions to environmental problems.

Structures/Materials Engineering. This area of study considers the planning, analysis, and design of steel and concrete bridges, buildings, dams; special offshore and space structures; Portland cement concrete; composite materials; and structural retrofit of existing bridges.

Transportation/Materials Engineering. This area of study includes (1) transportation design and operation, and (2) pavements and materials. Transportation design and operation covers geometric design of highways, traffic operations, and highway capacity and safety. Pavements and materials focuses on pavement analysis and design, pavement maintenance and rehabilitation, pavement evaluation and management, characterization of highway materials, and durability of highway structures.

Water Resources Engineering. This area of study is concerned with surface and groundwater flow, planning and management of water supply, and water distribution system modeling.

CIVIL AND ENVIRONMENTAL ENGINEERING (CEE)

CEE 423 Structural Design. (3)
fall
Analysis and design of reinforced concrete steel, masonry, and timber structures. Fee. Prerequisite: CEE 421. Pre- or corequisite: CEE 420.

CEE 440 Engineering Hydrology. (3)
fall
Descriptive hydrology; hydrologic cycle, models, and systems. Rain-runoff models. Hydrologic design. Concepts, properties, and basic equations of groundwater flow. Prerequisite: CEE 341.

CEE 441 Water Resources Engineering. (3)
spring
Applies the principles of hydraulics and hydrology to the engineering of water resources projects; design and operation of water resources systems; water quality. Prerequisite: CEE 341.

CEE 452 Foundations. (3)
fall
Applies soil mechanics to foundation systems, bearing capacity, lateral earth pressure, and slope stability. Prerequisite: CEE 351.

CEE 466 Sanitary Systems Design. (3)
fall
Capacity; planning and design of water supply; domestic and storm drainage; and solid waste systems. Prerequisite: CEE 361.

CEE 474 Transportation Systems Engineering. (3)
fall
Introduces transportation systems and modeling, traffic characteristic analysis, traffic predictions, highway capacity, signal timing, transportation systems management, and transit. Prerequisites: CEE 372; ECE 384.

CEE 475 Highway Geometric Design. (3)
spring
Design of visible elements of roadway, design controls, at-grade intersections, freeways, and interchanges. Lecture, computer lab. Fee. Credit is allowed for only CEE 475 or 576. Prerequisite: CEE 372.

CEE 486 Integrated Civil Engineering Design. (3)
fall and spring
Requires completion of a civil engineering design in a simulated practicing engineering environment. Limited to undergraduates in their final semester. Lecture, team learning. Prerequisites: CEE 321, 341, 351, 361, 372.

CEE 511 Pavement Analysis and Design. (3)
fall
Design of flexible and rigid pavements for highways and airports. Surface, base, and subgrade courses. Cost analysis and pavement selection. Credit is allowed for only CEE 511 or 412. Prerequisites: CEE 351; ECE 351.

CEE 512 Pavement Performance and Management. (3)
selected semesters
Pavement management systems, including data collection, evaluation, optimization, economic analysis, and computer applications for highway and airport design. Prerequisite: instructor approval.

CEE 514 Bituminous Materials and Mixture. (3)
selected semesters
Types of bituminous materials used in pavement mixtures. Chemical composition, physical properties, desirable aggregate characteristics, optimum asphalt contents, superpave asphalt binder, mixture design. Lecture, lab. Prerequisite: ECE 351.

CEE 515 Properties of Concrete. (3)
selected semesters
Materials science of concrete. Cement chemistry, mechanisms of hydration, interrelationships among micro- and macro-properties of cement-based materials. Mechanical properties, failure theories, fracture mechanics of concrete materials. Cement-based composite materials and the durability aspects. Lecture, lab. Prerequisite: ECE 350 or 351.

CEE 521 Stress Analysis. (3)
fall
Introduces tensors: kinematics, stress analysis, and constitutive assumptions leading to elastic and plastic behavior. Strain energy and energy methods; applications. Cross-listed as MAE 520. Credit is allowed for only CEE 521 or MAE 520.

CEE 522 Experimental Stress Analysis. (3)
selected semesters
Specification and analysis of stress and strain at a point, stress-strain relationships. Mechanical, optical, and electrical strain gages and circuits, digital data acquisition and analysis, closed loop mechanical testing, fracture mechanics, optical methods and photoelasticity, and introduction to nondestructive testing. Lecture, lab.

CEE 524 Advanced Steel Structures. (3)
fall
Strength properties of steel and their effects on structural behavior. Elastic design of steel structures. Plastic analysis and design of beams, frames, and bents. Plastic deflections. Plastic design requirements. Multistory buildings. Prerequisite: CEE 420.

CEE 526 Finite Elements for Engineers. (3)
fall
Direct stiffness, method of weighted residuals, weak formulation, and variational techniques in the solution of engineering problems. Cross-listed as MAE 527. Credit is allowed for only CEE 526 or MAE 527. Prerequisite: CEE 432 or MAE 404 (or their equivalents).

CEE 527 Advanced Concrete Structures. (3)
selected semesters
Ultimate strength design. Combined shear and torsion. Serviceability. Plastic analysis. Special systems. Prerequisite: CEE 421.

CEE 530 Prestressed Concrete. (3)
selected semesters
Materials and methods of prestressing. Analysis and design for flexure, shear, and torsion. Prestress losses due to friction, creep, shrinkage, and anchorage set. Statically indeterminate structures. Design of flat slabs, bridges, and composite beams. Prerequisite: CEE 421.

CEE 532 Developing Software for Engineering Applications. (3)
spring
Fundamentals of engineering software development and object-oriented programming. Programming in C++. Development of matrix toolbox. Introduces finite element method. Computer graphics. Credit is allowed for only CEE 532 or 432. Prerequisite: CEE 321.

CEE 533 Structural Optimization. (3)
selected semesters
Linear and nonlinear programming. Problem formulation. Design sensitivity analysis. FEM-based optimal design of structural and mechanical systems. Cross-listed as MAE 521. Credit is allowed for only CEE 533 or MAE 521. Prerequisites: ASE 582; CEE 526 (or MAE 527).

CEE 536 Structural Dynamics. (3)
selected semesters
Free vibration and forced response of discrete and continuous systems, exact and approximate methods of solution, response spectra, computational techniques, special topics. Lecture, recitation. Cross-listed as MAE 515. Credit is allowed for only CEE 536 or MAE 515.

CEE 537 Topics in Structural Engineering. (1–3)
selected semesters
Advanced topics, including nonlinear structural analysis, experimental stress analysis, advanced finite elements, plasticity and viscoelasticity, composites, and damage mechanics. Prerequisite: instructor approval.

CEE 540 Groundwater Hydrology. (3)
selected semesters
Physical properties of aquifers, well pumping, subsurface flow modeling, unsaturated flow, numerical methods, land subsidence, and groundwater pollution. Prerequisite: CEE 440 or instructor approval.

CEE 541 Surface Water Hydrology. (3)
selected semesters
Hydrologic cycle and mechanisms, including precipitation, evaporation, and transpiration; hydrograph analysis; flood routing; statistical methods in hydrology and hydrologic design. Prerequisite: CEE 440 or instructor approval.

CEE 543 Water Resources Systems. (3)
selected semesters
Theory and application of quantitative planning methodologies for the design and operation of water resources systems. Class projects using a computer, case studies. Prerequisite: instructor approval.

CEE 546 Free Surface Hydraulics. (3)
selected semesters
Derivation of 1-D equations used in open channel flow analysis; computations for uniform and nonuniform flows, unsteady flow, and flood routing. Mathematical and physical models. Prerequisite: CEE 341.

CEE 547 Principles of River Engineering. (3)
selected semesters
Uses of rivers, study of watershed, and channel processes. Sediment sources, yield, and control; hydrologic analysis. Case studies. Prerequisite: CEE 341 or instructor approval.

CEE 548 Sedimentation Engineering. (3)
selected semesters
Introduces the transportation of granular sedimentary materials by moving fluids. Degradation, aggregation, and local scour in alluvial channels. Mathematical and physical models. Prerequisite: CEE 547 or instructor approval.

CEE 550 Soil Behavior. (3)
selected semesters
Physicochemical aspects of soil behavior, stabilization of soils, and engineering properties of soils. Prerequisite: CEE 351.

CEE 551 Advanced Geotechnical Testing. (3)
selected semesters
Odometer, triaxial (static and cyclic) back pressure saturated and unsaturated samples, pore pressure measurements, closed-loop computer-controlled testing, in-situ testing, and sampling. Lecture, lab. Prerequisite: CEE 351.

CEE 553 Advanced Soil Mechanics. (3)
selected semesters
Applies theories of elasticity and plasticity to soils, theories of consolidation, failure theories, and response to static and dynamic loading. Prerequisite: CEE 351.

CEE 554 Shear Strength and Slope Stability. (3)
selected semesters
Shear strength of saturated and unsaturated soils strength-deformation relationships, time-dependent strength parameters, effects of sampling, and advanced slope stability. Prerequisite: CEE 351.

CEE 555 Advanced Foundations. (3)
selected semesters
Deep foundations, braced excavations, anchored bulkheads, reinforced earth, and underpinning. Prerequisite: CEE 351.

CEE 556 Seepage and Earth Dams. (3)
selected semesters
Transient and steady-state fluid flow through soil, confined and unconfined flow, pore water pressures, and application to earth dams. Prerequisite: CEE 351.

CEE 557 Geoenvironmental Engineering. (3)
selected semesters
Environmental site assessment, solid waste management, waste containment system design, soil and groundwater remediation, soil erosion control, brownfields development. Prerequisite: CEE 351 or instructor approval.

CEE 559 Earthquake Engineering. (3)
selected semesters
Characteristics of earthquake motions, selection of design earthquakes, site response analyses, seismic slope stability, and liquefaction. Prerequisite: CEE 351.

CEE 560 Soil and Groundwater Remediation. (3)
selected semesters
Presents techniques for remediation of contaminated soils and groundwaters with basic engineering principles. Prerequisite: instructor approval.

CEE 561 Physical-Chemical Treatment of Water and Waste. (3)
selected semesters
Theory and design of physical and chemical processes for the treatment of water and wastewaters. Prerequisite: CEE 361.

CEE 562 Environmental Biochemistry and Waste Treatment. (3)
selected semesters
Theory and design of biological waste treatment systems. Pollution and environmental assimilation of wastes. Prerequisite: CEE 362.

CEE 563 Environmental Chemistry Laboratory. (3)
selected semesters
Analyzes water, domestic and industrial wastes, laboratory procedures for pollution evaluation, and the control of water and waste treatment processes. Lecture, lab. Prerequisite: CEE 361.

CEE 564 Contaminant Fate and Transport. (3)
selected semesters
Fate and transport processes with emphasis on governing equations and parameters relevant to the migration of chemicals in the environment. Prerequisite: CEE 361.

CEE 565 Modeling and Assessment of Aquatic Systems. (3)
selected semesters
Development of predictive models of water quality; methods to assess environmental impacts; applications to water quality management. Prerequisite: CEE 361 or instructor approval.

CEE 566 Industrial/Hazardous Waste Treatment. (3)
selected semesters
Emphasizes treatment of local industrial/hazardous waste problems, including solvent recovery and metals. Lecture, project. Prerequisites: CEE 561, 563.

CEE 567 Environmental Microbiology. (4)
fall
Overview of the microbiology of natural and human-impacted environment, microbial detection methodologies, waterborne disease outbreaks, risk assessment, and regulations. Credit is allowed for only CEE 567 or 467. Lecture, lab. Prerequisite: CEE 361 or instructor approval.

CEE 568 Unit Processing in Environmental Engineering. (3)
spring
Design and operation of unit processes for water and wastewater treatment. Prerequisite: CEE 361 (or its equivalent) or instructor approval.

CEE 573 Traffic Engineering. (3)
selected semesters
Driver, vehicle, and roadway characteristics, laws and ordinances, traffic control devices, traffic engineering studies, and Transportation System Management measures. Prerequisite: CEE 372.

CEE 574 Highway Capacity. (3)
selected semesters
Highway capacity for all functional classes of highways. Traffic signalization, including traffic studies, warrants, cycle length, timing, phasing, and coordination. Prerequisite: CEE 372.

CEE 576 Highway Geometric Design. (3)
spring
Design of visible elements of roadway, design controls, at-grade intersections, freeways, and interchanges. Lecture, computer lab. Credit is allowed for only CEE 576 or 475. Prerequisite: CEE 372 (or its equivalent) or instructor approval.

CEE 580 Practicum. (1–12)
selected semesters

CEE 583 Highway Materials, Construction, and Quality. (3)
fall
Properties of highway materials, including aggregates, asphalt concrete, and portland cement concrete; construction practice; material delivery, placement, and compaction; quality control. Lecture, field trips. Credit is allowed for only CEE 583 or 483. Prerequisites: a combination of CEE 351 and 372 and ECE 351 (or their equivalents) or instructor approval.

CEE 590 Reading and Conference. (1–12)
selected semesters

CEE 591 Seminar. (1–12)
selected semesters
Topics may include the following:
• Transportation Systems Pro-Seminar

CEE 592 Research. (1–12)
selected semesters
CEE 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Environmental Microbiology
• Intelligent Transportation Systems
• Structural Design
CEE 599 Thesis. (1–12)
selected semesters
CEE 792 Research. (1–15)
selected semesters
CEE 799 Dissertation. (1–15)
selected semesters
Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Computer Science

Master's and Doctoral Programs

www.eas.asu.edu/~csedept/index.php

480/965-3190

BYENG 501

Sethuraman Panchanathan, Chair

Professors: Baral, Colbourn, Collofello, Farin, Kambhampati, Lee, Lewis, Nielson, Panchanathan, Tsai, J. Urban, S. Urban, Vrudhula,Yau

Associate Professors: Bazzi, Candan, Dasgupta, Dietrich, Gupta, Huey, Liu, Miller, O'Grady, Richa, Sen, Xue

Assistant Professors: Cam, Chatha, Davulcu, Kim, Li, Ryu, Sarjoughian, Syrotiuk, Wonka

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The faculty in the Department of Computer Science and Engineering offer graduate programs leading to MS and PhD degrees in Computer Science. The faculty also offer a professional graduate program leading to the Master of Computer Science degree. The department offers a concentration in the area of arts, media, and engineering, and graduate students can exercise this option while pursing their graduate studies.

Areas of study and research areas include algorithms, artificial intelligence, bioinformatics, computer-aided geometric design and computer graphics, computer networks, database systems, distributed computing and operating systems, embedded systems, information assurance, intelligent information integration, multimedia information systems, and software engineering. In addition, the department conducts research closely with the Center for Cognitive Ubiquitous Computing; Center for Research in Arts, Media, and Engineering; and Partnership for Research in Stereo Modeling in various aspects of computer science.

For more information, access the research section of the Web site at www.eas.asu.edu/~csedept/index.php.

DOCTOR OF PHILOSOPHY

The PhD degree in Computer Science is available for students of high ability who show promise for original research.

Admission. An applicant for the PhD program should have the equivalent of a baccalaureate major in computer science, computer engineering, or a closely related area. Most applicants should have earned the master's degree, but applicants with exceptional attainments in their baccalaureate are admitted directly into the PhD program. The primary factors affecting admission include the applicant's GPA, depth of preparation in computer science and engineering, GRE (verbal, quantitative, analytical, and computer science) scores, a statement of purpose and three letters of recommendation. An international student must submit TOEFL scores. The application deadline for admission in the fall semester is December 1, and the deadline for admission in the spring semester is August 1. The deadlines for financial aid are the same as the admission deadline. See "Doctor of Philosophy," page 69, for general requirements.

Residency. In addition to the Division of Graduate Studies's requirement for one year of full-time residency, the Department of Computer Science and Engineering stipulates one additional year of full-time residency for dissertation research.

Degree Requirements

A detailed description of degree requirements is available at the department Web site.

Program of Study. Each student must file a program of study for approval by the supervisory committee, the department, and the Division of Graduate Studies.

Foreign Language Requirements. None. The program committee, however, may establish a requirement depending upon the research interests of the candidate.

Comprehensive Examinations. A student must pass a comprehensive examination, which has a mandatory written component, before being admitted to candidacy. The examination has both oral and written components, testing the student's general knowledge in the dissertation area as well as closely related areas. International students must achieve a passing score on the TSE or SPEAK exam before the comprehensive examination.

Dissertation Requirements. A student must complete a dissertation based on original work to demonstrate creativity in research and scholarly proficiency in the subject area.

Final Examination. The student must pass a final oral examination in defense of the dissertation.

Satisfactory Progress. The student maintaining a cumulative GPA of 3.50 or higher and fulfilling other requirements of the PhD degree is considered to be making satisfactory progress toward the degree.

Course Load. The maximum number of hours allowed per semester is 12. Special permission is required to take more than 12 hours in one semester.

Advising. The advising office of the department provides advising service to all computer science and engineering students. The e-mail address is cse.advising@asu.edu.

Maximum Time Limit. The maximum time limit is five years for students entering the PhD program with a BS degree and four years for students entering the PhD program with an MS degree.

MASTER OF SCIENCE

The MS degree program in Computer Science stresses formal course work to provide breadth of material, and it culminates with a thesis that demonstrates depth in a particular research area.

Admission. See "Admission to the Division of Graduate Studies," page 58, for general requirements. An applicant for the MS program should normally have a baccalaureate degree in computer science, computer engineering, or a closely related area. The applicant's undergraduate GPA and depth of preparation in computer science and engineering are the primary factors affecting admission. Every applicant must submit scores for the Graduate Record Examination (GRE) (verbal, quantitative, and analytical required; the subject test in computer science is optional). An international student must also submit Test of English as a Foreign Language (TOEFL) scores. The application deadline for admission in the fall semester is December 1, and the deadline for admission in the spring semester is August 1. Deadlines for financial aid are the same as the admission deadlines.

Program of Study. Each student defines a potentially unique program of study in conjunction with an advisor, subject to approval of the department and the Division of Graduate Studies. The program of study must contain a minimum of 30 semester hours of approved graduate-level work, including three hours of CSE 592 Research and three hours of CSE 599 Thesis. For the arts, media, and engineering concentration, students substitute one hour of AME 592 and one hour of AME 599. At least 18 semester hours must be CSE 5xx credits at ASU (excluding CSE 598 courses but including CSE 592 and CSE 599). At least 21 semester hours must be for formal course work (including CSE 591 but excluding CSE 590, CSE 592, CSE 593, CSE 599, and similar credits for independent projects). For the arts, media, and engineering concentration, students take nine semester hours through the Arts, Media, and Engineering Program as part of this 21 semester hours.

All MS students must take at least three semester hours in each of the following three areas: foundations, systems, and applications. At least two of the three area courses must be at 500 level (not 598). The classes listed as 400 level must be taken as CSE 598. See area courses section for a partial list of courses in each area. Every MS student is required to take at least nine semester hours of courses in their research area, possibly including courses from the list of area courses, and possibly including three credit hours of independent study. No foreign language credit is required.

Final Examination. The student must pass a final oral examination in defense of the thesis and over the course work taken for the degree and the appropriate undergraduate prerequisites.

MASTER OF COMPUTER SCIENCE

The faculty in the Department of Computer Science and Engineering offer a professional program leading to the Master of Computer Science (MCS) degree. The MCS program provides a professionally oriented, graduate-level education in computer science and engineering. The program reflects the dual nature of computer science as both a scientific and engineering discipline by allowing emphasis on theory as well as practical applications. Students can study topics such as artificial intelligence, computer-aided geometric design, computer architecture, computer graphics, computer science theory, database concepts, digital systems design, distributed systems, language processing, networking, operating systems, and software engineering.

Admission. An applicant for the MCS program should normally have a baccalaureate degree in computer science, computer engineering, or a closely related area. The applicant's undergraduate GPA, GRE (verbal, quantitative, and analytical) score, and depth of preparation in computer science and engineering are the primary factors affecting admission. The GRE subject test in computer science is optional. An international student must also submit the results of the TOEFL. The application deadline for admission in the fall semester is December 1, and August 1 for the spring semester. The deadlines for financial aid are the same as the application deadlines. See "Admission to the Division of Graduate Studies," page 58.

Degree Requirements

A detailed description of the degree requirements is available at the department Web site.

Program of Study. Each student defines a potentially unique program of study subject to approval by the department and the Division of Graduate Studies. The program of study must contain a minimum of 30 semester hours of approved graduate-level work. At least 18 of these hours must be CSE 5xx credits at ASU (excluding CSE 598 courses). At least 27 hours must be for formal course work (including CSE 591 but excluding CSE 593, and similar credits for independent projects). No credits for CSE 590 Reading and Conference, CSE 592 Research, or CSE 599 Thesis, are allowed on a program of study for the MCS degree. MCS students must register for a three unit CSE 593 final project and complete it with a passing grade.

All MCS students must take at least three semester hours in each of the following three areas: foundations, systems, and applications. At least two of the three area courses must be at 500 level (not 598). The classes listed as 400 level must be taken as CSE 598. Please see area courses section for a partial list of courses in each area. The department may prescribe additional courses based on the background of the candidate.

Foreign Language Requirements. None.

Thesis Requirements. None.

Final Examination. MCS students must complete a graded final project (CSE 593) and submit a report on the project.

Satisfactory Progress. The student maintaining a cumulative GPA of 3.00 or higher and fulfilling other requirements of the MS or MCS degree is considered to be making satisfactory progress toward the degree.

Course Load. See "Course Load," page 180 in the PhD section.

Advising. See "Advising," page 181 in the PhD section.

Maximum Time Limit. ASU policy applies.

COMPUTER SCIENCE AND ENGINEERING (CSE)

CSE 408 Multimedia Information Systems. (3)
fall
Design, use, and applications of multimedia systems. Introduces acquisition, compression, storage, retrieval, and presentation of data from different media such as images, text, voice, and alphanumeric. Prerequisite: CSE 310.

CSE 412 Database Management. (3)
fall and spring
Introduces DBMS concepts. Data models and languages. Relational database theory. Database security/integrity and concurrency. Fee. Prerequisite: CSE 310.

CSE 420 Computer Architecture I. (3)
once a year
Computer architecture. Performance versus cost tradeoffs. Instruction set design. Basic processor implementation and pipelining. Prerequisite: CSE 330.

CSE 421 Microprocessor System Design I. (4)
fall and spring
Assembly language programming and logical hardware design of systems using 8-bit microprocessors and microcontrollers. Fundamental concepts of digital system design. Reliability and social, legal implications. Lecture, lab. Fee. Prerequisite: CSE 225 or EEE 225.

CSE 422 Microprocessor System Design II. (4)
fall and spring
Design of microcomputer systems using contemporary logic and microcomputer system components. Requires assembly language programming. Fee. Prerequisite: CSE 421.

CSE 423 Capstone Project. (3)
fall and spring
Development process: specification, design, implementation, evaluation, and testing with economic, social, and safety considerations. Written or oral communication skills enrichment. Fee. Prerequisite: CSE 422.

CSE 428 Computer-Aided Processes. (3)
selected semesters
Hardware and software considerations for computerized manufacturing systems. Specific concentration on automatic inspection, numerical control, robotics, and integrated manufacturing systems. Prerequisite: CSE 330.

CSE 430 Operating Systems. (3)
fall and spring
Operating system structure and services, processor scheduling, concurrent processes, synchronization techniques, memory management, virtual memory, input/output, storage management, and file systems. Fee. Prerequisites: CSE 330, 340.

CSE 432 Operating System Internals. (3)
fall
IPC, exception and interrupt processing, memory and thread management, user-level device drivers, and OS servers in a modern microkernel-based OS. Prerequisite: CSE 430.

CSE 434 Computer Networks. (3)
fall and spring
Cryptography fundamentals; data compression; error handling; flow control; multihop routing; network protocol algorithms; network reliability, timing, security; physical layer basics. Prerequisite: CSE 330.

CSE 438 Systems Programming. (3)
selected semesters
Design and implementation of systems programs, including text editors, file utilities, monitors, assemblers, relocating linking loaders, I/O handlers, and schedulers. Prerequisite: CSE 421 or instructor approval.

CSE 440 Compiler Construction I. (3)
once a year
Introduces programming language implementation. Implementation strategies such as compilation, interpretation, and translation. Major compilation phases such as lexical analysis, semantic analysis, optimization, and code generation. Prerequisites: CSE 340, 355.

CSE 445 Distributed Computing with Java and CORBA. (3)
fall and spring
Frameworks for distributed software components. Foundations of client-server computing and architectures for distributed object systems. Dynamic discovery and invocation. Lecture, projects. Fee. Prerequisite: CSE 360 or instructor approval.

CSE 446 Client-Server User Interfaces. (3)
selected semesters
Client-server model and its use in creating and managing window interfaces. Toolkits and libraries, including X11, Microsoft Foundation Classes, and Java Abstract Window Toolkit. Lecture, projects. Fee. Prerequisite: CSE 310 or instructor approval.

CSE 450 Design and Analysis of Algorithms. (3)
fall and spring
Design and analysis of computer algorithms using analytical and empirical methods; complexity measures, design methodologies, and survey of important algorithms. Prerequisite: CSE 310.

CSE 457 Theory of Formal Languages. (3)
once a year
Theory of grammar, methods of syntactic analysis and specification, types of artificial languages, relationship between formal languages, and automata. Prerequisite: CSE 355.

CSE 459 Logic for Computing Scientists. (3)
selected semesters
Propositional logic, syntax and semantics, proof theory versus model theory, soundness, consistency and completeness, first order logic, logical theories, automated theorem proving, ground resolution, pattern matching unification and resolution, Dijkstras logic, proof obligations, and program proving. Prerequisite: CSE 355.

CSE 460 Software Analysis and Design. (3)
fall and spring
Object-oriented and structured analysis and design; software architecture and design patterns; component-based development; software safety and reliability. Fee. Prerequisite: CSE 360.

CSE 461 Software Engineering Project I. (3)
fall and spring
First of two-course software team-development sequence. Planning, management, design, and implementation using object-oriented technology, CASE tools, CMM-level-5 guidelines. Lecture, lab, oral and written communications. Fee. Prerequisite: CSE 360.

CSE 462 Software Engineering Project II. (3)
fall and spring
Second of two-course software team-development sequence. Software evolution, maintenance, reengineering, reverse engineering, component-based development, and outsourcing. Lecture, lab, oral and written communications. Fee. Prerequisite: CSE 461.

CSE 463 Introduction to Human Computer Interaction. (3)
spring
Design, evaluate, and implement interactive software intended for human use. Prerequisite: CSE 310.

CSE 470 Computer Graphics. (3)
fall and spring
Display devices, data structures, transformations, interactive graphics, 3-D graphics, and hidden line problems. Fee. Prerequisites: CSE 310; MAT 342.

CSE 471 Introduction to Artificial Intelligence. (3)
fall and spring
State space search, heuristic search, games, knowledge representation techniques, expert systems, and automated reasoning. Fee. Prerequisites: CSE 240, 310.

CSE 476 Introduction to Natural Language Processing. (3)
selected semesters
Principles of computational linguistics, formal syntax, and semantics, as applied to the design of software with natural (human) language I/O. Prerequisite: CSE 310 or instructor approval.

CSE 477 Introduction to Computer-Aided Geometric Design. (3)
once a year
Introduces parametric curves and surfaces, Bezier and B-spline interpolation, and approximation techniques. Prerequisites: CSE 210, 470; MAT 342.

CSE 484 Internship. (1–12)
selected semesters

CSE 507 Virtual Reality Systems. (3)
selected semesters
Computer generated 3-D environments, simulation of reality, spatial presence of virtual objects, technologies of immersion, tracking systems. Lecture, lab. Prerequisite: CSE 408 or 470 or 508 or instructor approval.

CSE 508 Digital Image Processing. (3)
once a year
Digital image fundamentals, image transforms, image enhancement and restoration techniques, image encoding, and segmentation methods. Prerequisite: EEE 303 or instructor approval.

CSE 509 Digital Video Processing. (3)
spring
Concepts of digital video compression, video analysis, video indexing, browsing and retrieval, video transmission over networks, video processors, MPEG 1, 2, 4, and 7 standards. Lecture, projects. Pre- or corequisite: CSE 408 or 508.

CSE 510 Database Management System Implementation. (3)
once a year
Implementation of database systems. Data storage, indexing, querying, and retrieval. Query optimization and execution, concurrency control, and transaction management. Prerequisite: CSE 412.

CSE 512 Distributed Database Systems. (3)
once a year
Distributed database design, query processing, and transaction processing. Distributed database architectures and interoperability. Emerging technology. Prerequisite: CSE 412.

CSE 513 Rules in Database Systems. (3)
selected semesters
Declarative and active rules. Logic as a data model. Evaluation and query optimization. Triggers and ECA rules. Current research topics. Prerequisite: CSE 412.

CSE 514 Object-Oriented Database Systems. (3)
selected semesters
Object-oriented data modeling, definition, manipulation. Identity and inheritance. Query languages. Schema evolution. Versioning. Distributed object management. Extended relational systems. Prerequisite: CSE 412.

CSE 515 Multimedia and Web Databases. (3)
spring
Data models for multimedia and Web data; query processing and optimization for inexact retrieval; advanced indexing, clustering, and search techniques. Prerequisites: CSE 408, 412.

CSE 517 Hardware Design Languages. (3)
fall and spring
Introduces hardware design languages. Modeling concepts for specification, simulation, and synthesis. Cross-listed as EEE 517. Credit is allowed for only CSE 517 or EEE 517. Prerequisite: CSE 423 or EEE 425 or instructor approval.

CSE 518 Synthesis with Hardware Design Languages. (3)
selected semesters
Modeling VLSI design in hardware design languages for synthesis. Transformation of language-based designs to physical layout. Application of synthesis tools. Prerequisite: CSE 517.

CSE 520 Computer Architecture II. (3)
fall
Computer architecture description languages, computer arithmetic, memory-hierarchy design, parallel, vector, multiprocessors, and input/output. Prerequisites: CSE 420, 430.

CSE 521 Microprocessor Applications. (4)
selected semesters
Microprocessor technology and its application to the design of practical digital systems. Hardware, assembly language programming, and interfacing of microprocessor-based systems. Lecture, lab. Prerequisite: CSE 421.

CSE 523 Microcomputer Systems Software. (3)
selected semesters
Developing system software for a multiprocessor, multiprogramming, microprocessor-based system using information and techniques presented in CSE 421, 422. Prerequisite: CSE 422.

CSE 526 Parallel Processing. (3)
selected semesters
Real and apparent concurrency. Hardware organization of multiprocessors, multiple computer systems, scientific attached processors, and other parallel systems. Prerequisite: CSE 330 or 423.

CSE 531 Distributed and Multiprocessor Operating Systems. (3)
once a year
Distributed systems architecture, remote file access, message-based systems, object-based systems, client/server paradigms, distributed algorithms, replication and consistency, and multiprocessor operating systems. Prerequisite: CSE 432 or instructor approval.

CSE 532 Advanced Operating System Internals. (3)
selected semesters
Memory, processor, process and communication management, and concurrency control in the Windows NT multiprocessor and distributed operating system kernels and servers. Prerequisites: CSE 432, 531 (or 536).

CSE 534 Advanced Computer Networks. (3)
fall and spring
Advanced network protocols and infrastructure, applications of high-performance networks to distributed systems, high-performance computing and multimedia domains, special features of networks. Prerequisite: CSE 434.

CSE 535 Mobile Computing. (3)
spring
Mobile networking, mobile information access, adaptive applications, energy-aware systems, location-aware computing, mobile security and privacy. Prerequisite: CSE 434.

CSE 536 Advanced Operating Systems. (3)
spring
Protection and file systems. Communication, processes, synchronization, naming, fault tolerance, security, data replication, and coherence in distributed systems. Real-time systems. Prerequisite: CSE 430.

CSE 539 Applied Cryptography. (3)
spring
Use of cryptography for secure protocols over networked systems, including signatures, certificates, timestamps, electrons, digital cash, and other multiparty coordination. Prerequisite: CSE 310 or instructor approval.

CSE 540 Compiler Construction II. (3)
selected semesters
Formal parsing strategies, optimization techniques, code generation, extensibility and transportability considerations, and recent developments. Prerequisite: CSE 440.

CSE 550 Combinatorial Algorithms and Intractability. (3)
once a year
Combinatorial algorithms, nondeterministic algorithms, classes P and NP, NP-hard and NP-complete problems, and intractability. Design techniques for fast combinatorial algorithms. Prerequisite: CSE 450.

CSE 555 Theory of Computation. (3)
once a year
Rigorous treatment of regular languages, context-free languages, Turing machines and decidability, reducibility, and other advanced topics in computability theory. Prerequisite: CSE 355 or instructor approval.

CSE 561 Modeling and Simulation Theory and Application. (3)
fall or spring
Modeling theories, simulation protocols, object-oriented modeling, model design, simulation analysis, network-based systems, discrete-event modeling, continuous modeling, hybrid modeling. Prerequisite: graduate standing.

CSE 562 Software Process Automation. (3)
selected semesters
Representing the software process; creating a measured and structured working environment; using, constructing, and adapting component-based tools. Prerequisite: CSE 360.

CSE 563 Software Requirements and Specification. (3)
selected semesters
Examines the definitional stage of software development; analysis of specification representations, formal methods, and techniques emphasizing important application issues. Prerequisite: CSE 460.

CSE 564 Software Design. (3)
once a year
Examines software design issues and techniques. Includes a survey of design representations and a comparison of design methods. Prerequisite: CSE 460.

CSE 565 Software Verification, Validation, and Testing. (3)
once a year
Test planning, requirements-based and code-based testing techniques, tools, reliability models, and statistical testing. Prerequisite: CSE 460.

CSE 566 Software Project, Process, and Quality Management. (3)
once a year
Project management, risk management, configuration management, quality management, and simulated project management experiences. Prerequisite: CSE 360.

CSE 570 Advanced Computer Graphics I. (3)
once a year
Hidden surface algorithms, lighting models, and shading techniques. User interface design. Animation techniques. Fractals and stochastic models. Raster algorithms. Prerequisite: CSE 470.

CSE 571 Artificial Intelligence. (3)
once a year
Definitions of intelligence, computer problem solving, game playing, pattern recognition, theorem proving, and semantic information processing; evolutionary systems; heuristic programming. Prerequisite: CSE 471.

CSE 572 Data Mining. (3)
spring
Advanced data mining techniques: classification, clustering, association, preprocessing; performance evaluation; information assurance, Web mining, security and privacy issues, and other applications. Cross-listed as CBS 572. Credit is allowed for only CBS 572 or CSE 572. Prerequisite: CSE 412 or 471 or ECE 380 (or their equivalents).

CSE 573 Advanced Computer Graphics II. (3)
selected semesters
Modeling of natural phenomena: terrain, clouds, fire, water, and trees. Particle systems, deformation of solids, antialiasing, and volume visualization. Lecture, lab. Prerequisite: CSE 470.

CSE 574 Planning and Learning Methods in AI. (3)
selected semesters
Reasoning about time and action, plan synthesis and execution, improving planning performance, applications to manufacturing intelligent agents. Prerequisite: CSE 471 (or its equivalent).

CSE 576 Topics in Natural Language Processing. (3)
selected semesters
Comparative parsing strategies, scoping and reference problems, nonfirst-order logical semantic representations, and discourse structure. Prerequisite: CSE 476 or instructor approval.

CSE 577 Advanced Computer-Aided Geometric Design I. (3)
once a year
General interpolation; review of curve interpolation and approximation; spline curves; visual smoothness of curves; parameterization of curves; introduces surface interpolation and approximation. Prerequisites: both CSE 470 and 477 or only instructor approval.

CSE 578 Advanced Computer-Aided Geometric Design II. (3)
selected semesters
Coons patches and Bezier patches; triangular patches; arbitrarily located data methods; geometry processing of surfaces; higher dimensional surfaces. Prerequisites: both CSE 470 and 477 or only instructor approval.

CSE 579 NURBS: Nonuniform Rational B-Splines. (3)
selected semesters
Projective geometry, NURBS-based modeling, basic theory of conics and rational Bezier curves, rational B-splines, surfaces, rational surfaces, stereographic maps, quadrics, IGES data specification. Prerequisites: CSE 470, 477.

CSE 590 Reading and Conference. (1–12)
selected semesters

CSE 591 Seminar. (1–12)
selected semesters
Topics may include the following:
• Multimedia Systems. (3)
  Credit is allowed for only CSE 591 or AME 598.

CSE 592 Research. (1–12)
selected semesters

CSE 593 Applied Project. (1–12)
selected semesters

CSE 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Advanced Hardware Systems Design using VHDL and FPGAs
• Client-Server User Interfaces
• Computational Models for the Arts. (3)
  fall
  Covers computability and intractability; kolmogorov complexity in the context of randomness and determinism.
• Computer Graphics
• Database Management
• Distributed Computing with Java and CORBA
• Introduction to Artificial Intelligence
• Microcomputer System Hardware
• Microprocessor System Design I
• Microprocessor System Design II
• Operating Systems
• Real-Time Embedded Systems
• Signal Processing and Programming for the Arts. (3)
  spring
  Introduces basic concepts behind the functioning of existing, widely used digital arts and media tools.
• Software Analysis and Design
• Software Engineering for Embedded Systems
• Software Engineering Project I
• Software Engineering Project II
• Testing Embedded Systems

CSE 599 Thesis. (1–12)
selected semesters

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Construction

Master's Program

construction.asu.edu

480/965-3615

USE 138

William W. Badger, Director

Professor: Badger

Associate Professors: Ariaratnam, Bashford, Chasey, Ernzen, Kashiwagi, Sawhney, Wiezel

Assistant Professors: Fiori, Knutson, Mitropoulos, Sullivan

RESEARCH ACTIVITY

Applied research is an integral part of the MS degree in Construction. The Del E. Webb School of Construction has several major ongoing research projects. The general fields of study include Alliance for Construction Excellence, Construction Research Education Advanced Technology Environments, Advanced Technology Homes, Performance-Based Studies Research Group, alternative project delivery systems, construction productivity studies, construction information technology, and construction and behavior of deep foundation. For more information, access the Web site at construction.asu.edu.

MASTER OF SCIENCE

The faculty in the Del E. Webb School of Construction offer a graduate program leading to the MS degree in Construction. Concentrations are available in construction science, facilities management, and construction management. The interdisciplinary nature of the program allows a candidate's program of study to reflect both individual interests and career goals.

The primary objective of the program is to allow students with a baccalaureate degree in construction or a related field such as architecture, business, or engineering to broaden and improve their professional capabilities in construction. The program is designed to meet the growing need for professionals with advanced technical, management, and applied research skills in the construction industry.

The *construction science* concentration allows students with an interest in field engineering or supervision of heavy and industrial construction projects to pursue a more technically oriented course of study. The *facilities* (management) concentration supports the needs of the student desiring a career in the maintenance, operation, renovation, or decommissioning of existing facilities. The (construction) *management* concentration allows students seeking upper-level management positions in various sectors of the construction industry to improve their competency in project, program, and company management areas.

Admission Requirements. Applicants are expected to satisfy all requirements for admission to the Division of Graduate Studies. In addition, applicants are expected to be competent in basic construction topics. Admission is based upon an evaluation of the student's academic background and potential for success. Students whose native language is not English must also submit a Test of English as a Foreign Language (TOEFL) score of at least 550.

Graduate Record Examination (GRE). Applicants must submit scores on the verbal, quantitative, and analytical sections of the GRE for admission.

Application Deadline. Completed college and departmental application materials should be received by February 1 for admission in the fall semester.

Degree Requirements. As soon as possible after selecting the student's supervisory committee, the student must file a program of study with the Division of Graduate Studies.

The program of study consists of the following: thesis option—30 semester hours of graduate study culminating in a thesis and an oral defense; or nonthesis option—36 semester hours of graduate study culminating in an oral and written comprehensive examination.

Supervisory Committee. Each student is required to form a supervisory committee. The committee consists of three members. All tenure-track faculty are eligible. Other individuals are eligible in accordance with the guidelines established by the Division of Graduate Studies.

Satisfactory Progress. The Del E. Webb School of Construction adheres to ASU and Ira A. Fulton School of Engineering academic standards for good standing.

Course Load. Students may take up to 12 semester hours in any given semester. During any summer session only seven hours are allowed. Students who are employed as research or teaching assistants must maintain 12 hours of enrolled credit per semester.

Advising. Students are encouraged to meet with an advisor. Call 480/965-3615 for an appointment.

Maximum Time Limit. The Del E. Webb School of Construction adheres to the university policy regarding maximum time allowed to complete a degree program.

ACCELERATED MASTER OF SCIENCE

The Del E. Webb School of Construction faculty have developed an accelerated Master of Science program. This degree program is in keeping with the construction industry's interest in more formal education at the graduate level for working professionals. The primary objective of this program is to allow professionals in the field of construction who are actively involved in the industry to pursue a graduate degree. The program covers topics relevant to the industry. The courses are designed to enhance each student's knowledge of the construction industry and current technology. The courses are presented in 46 weeks meeting two times per week. Applied research is an integral part of the degree program. Students are required to complete a research project.

Admission Requirements. Applicants are expected to satisfy all requirements for admission to the Division of Graduate Studies. In addition, applicants are expected to have a minimum of five year's work experience in a responsible position in construction or related field as determined by an interview with the director. Applicants should also submit a letter of intent, current résumé, and three letters of recommendation. Admission for the program is in the fall only.

DEGREE REQUIREMENTS

Course work. The program consists of 36 semester hours culminating in a comprehensive oral exam. The degree is presented in 46 weeks meeting two evenings per week. Twelve required courses are presented. Students progress through the program as a cohort, beginning and finishing together.

CON 496 Construction Contract Administration 3
CON 500 RM: Research Techniques...3
CON 533 Strategies of Estimating and Bidding............................3
CON 540 Construction Productivity...3
CON 545 Construction Project Management 3
CON 547 Strategic Planning..3
CON 589 Construction Company Financial Control.....................3
CON 598 ST: Advanced Construction Theory 3
CON 598 ST: Construction Business Strategies...........................3
CON 598 ST: Progressive Construction Applications 3
CON 592 R: Directed Independent Research 3
CON 593 Applied Project..3

Supervisory Committee. Each student is required to form a supervisory committee. The committee consists of three members. All tenure-track faculty are eligible. Other individuals are eligible in accordance with the guidelines established by the Division of Graduate Studies.

Thesis or Culminating Experience. A formal research project paper is required. The paper is part of the final comprehensive oral exam.

Satisfactory Progress. The Del E. Webb School of Construction adheres to ASU and Ira A. Fulton School of Engineering academic standards for good standing.

Advising. Students are encouraged to meet with an advisor. Call 480/965-3615 for an appointment.

Maximum Time Limit. The accelerated master's program is a 46-week cohort program. Students are required to complete the entire program in the 46-week time frame.

CONSTRUCTION (CON)

CON 424 Structural Design. (3)
fall
Economic use of concrete, steel, and wood in building and engineered structures. Design of beams, columns, concrete formwork, and connections. Lecture, field trips. Prerequisite: CON 310.

CON 453 Construction Labor Management. (3)
fall and spring
Labor and management history, union, and open shop organization of building and construction workers; applicable laws and government regulations; goals, economic power, jurisdictional disputes, and grievance procedures. Prerequisites: CON 371; ECN 112.

CON 455 Construction Project Management. (3)
fall and spring
Study of methods for coordinating people, equipment, materials, money, and schedule to complete a project on time and within

approved cost. Lecture, class projects, CPC exam. Fee. Prerequisite: CON 371. Pre- or corequisite: CON 495.

CON 468 Mechanical and Electrical Estimating. (3)
fall
Analysis and organization of performing a cost estimate for both mechanical and electrical construction projects. Computer usage. Prerequisites: a combination of CON 273 and 345 and 383 or only instructor approval.

CON 471 Mechanical and Electrical Project Management. (3)
spring
Specialty contracts and agreements, scheduling, material handling, labor unit analysis, and job costing for mechanical and electrical construction. Prerequisite: CON 371.

CON 472 Development Feasibility Reports. (3)
fall and spring
Integrates economic location theory, development cost data, market research data, and financial analysis into a feasibility report. Computer orientation. Prerequisite: REA 380.

CON 477 Residential Construction Business Practices. (3)
fall
Topics addressed include development, marketing, financing, legal issues, and sales.

CON 483 Advanced Building Estimating. (3)
fall and spring
Concepts of pricing and markup, development of historic costs, life cycle costing, change order and conceptual estimating, and emphasizing microcomputer methods. Prerequisite: CON 383.

CON 486 Heavy Construction Estimating. (3)
fall
Methods analysis and cost estimation for construction of highways, bridges, tunnels, dams, and other engineering works. May be repeated for credit. Lecture, field trips. Prerequisites: CON 341, 383.

CON 495 Construction Planning and Scheduling. (3)
fall and spring
Various network methods of project scheduling, such as AOA, AON Pert, bar-charting, line-of-balance, and VPM techniques. Microcomputers used for scheduling, resource allocation, and time/cost analysis. Lecture, lab. Fee. Prerequisites: CON 383; STP 226. Pre- or corequisite: CON 389.

CON 496 Construction Contract Administration. (3)
fall and spring
Surveys administrative procedures of general and subcontractors. Studies documentation, claims, arbitration, litigation, bonding, insurance, and indemnification. Discusses ethical practices. Lecture, field trips. Prerequisites: COM 225 or ECE 300; senior standing.

CON 500 Research Methods. (1–12)
selected semesters
Topics may include the following:
• Research Techniques.

CON 533 Strategies of Estimating and Bidding. (3)
fall
Explores advanced concepts of the estimating process, such as modeling and statistical analysis, to improve bid accuracies. Prerequisite: CON 483 or 486 or instructor approval.

CON 540 Construction Productivity. (3)
fall
Productivity concepts. Data collection. Analysis of productivity data and factors affecting productivity. Means for improving production and study of productivity improvement programs. Pre- or corequisite: CON 495.

CON 543 Construction Equipment Engineering. (3)
spring
Analyzes heavy construction equipment productivity using case studies. Applies engineering fundamentals to the planning, selection, and utilization of equipment. Lecture, case studies.

CON 545 Construction Project Management. (3)
spring
Theory and practice of construction project management. Roles of designer, owner, general contractor, and construction manager. Lecture, field trips. Pre- or corequisite: CON 495.

CON 547 Strategic Planning. (3)
fall
Business planning process of the construction enterprise. Differences between publicly held and closely held businesses and their exposure.

CON 551 Alternative Project Delivery Methods. (3)
fall
Design/construction interaction; conceptual estimation and scheduling; the RFQ/RFP process; legal, insurance, risk allocation issues; procurement and selection.

CON 561 International Construction. (3)
spring
Investigation of the cultural, social, economic, political, and management issues related to construction in foreign countries and remote regions.

CON 565 Performance-Based Systems. (3)
fall
Identifying the multicriteria methodology in the procurement of facilities contractual work. Prerequisite: instructor approval.

CON 567 Advanced Procurement Systems. (3)
spring
Development of multicriteria decision procurement model for selecting the performing contractor. Prerequisite: instructor approval.

CON 570 Cleanroom Construction I. (3)
fall
Design issues for cleanroom facilities; the construction's viewpoint, including planning, structures, mechanical, and tool installation. Lecture, site visits. Prerequisite: instructor approval.

CON 571 Cleanroom Construction II. (3)
spring
Construction issues for cleanroom facilities, including scheduling, cost estimating, project management, mechanical, safety certification, and tool hook-up. Lecture, site visits. Prerequisite: CON 570 or instructor approval.

CON 575 Information Technology in Construction. (3)
spring
Use of information technology in the construction enterprise for improved communications, process modeling, and decision making. Prerequisite: instructor approval.

CON 589 Construction Company Financial Control. (3)
fall
Financial accounting and cost control at the company level in construction companies. Accounting systems. Construction project profit calculations. Financial analysis. Lecture, case studies.

CON 592 Research. (1–12)
selected semesters
Topics may include the following:
• Directed Independent Research.

CON 593 Applied Project. (1–12)
selected semesters

CON 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Advanced Construction Theory.
• Construction Business Strategies.
• Progressive Construction Applications.

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Electrical Engineering

Master's and Doctoral Programs

fulton.asu.edu/ee

480/965-3424

ENGRC 552

Joseph C. Palais, Director of Graduate Studies

Regents' Professors: Balanis, Ferry, Heydt

Professors: Chakrabarti, Crouch, Goodnick, Gorur, Hui, Karady, Kiaei, Kozicki, Lai, Palais, Pan, Phillips, Rodriguez, Roedel, Schroder, Shen, Si, Spanias, Tao, Thornton, Tsakalis, Vittal, Y. Zhang

Associate Professors: Aberle, Allee, Bakkaloglu, Clark, Cochran, Diaz, Duman, El-Sharawy, Grondin, Holbert, Karam, Kim, Morrell, Papandreou-Suppappola, Skromme, Tylavsky

Assistant Professors: Abbaspour-Tamijami, Ayyanar, Barnaby, Cao, Joo, Qian, Reisslein, Tepedelenlioglu, Vasileska, J. Zhang

The Department of Electrical Engineering offers opportunities for study beyond the bachelor's degree in several areas, including control systems, electromagnetics, antennas, and microwave circuits, electronic and mixed-signal integrated circuit design, power engineering, signal processing and communications systems, solid-state electronics, and arts, media, and engineering. Students may pursue degrees of Master of Science (MS), Master of Science in Engineering (MSE), Master of Engineering (MEng), and Doctor of Philosophy (PhD).

RESEARCH ACTIVITY

Opportunities at the master's or doctoral level are offered to students whose goals are research, development, design, manufacturing, systems, engineering management, teaching, or other professional activities in electrical engineering or related disciplines.

Research participation in the Department of Electrical Engineering is available in a broad spectrum of subjects encompassing traditional as well as new specialities. Significant research activity exists in control systems, electromagnetics, antennas, and microwave circuits, electronic and mixed-signal circuit design, power engineering, signal processing and communication, solid-state electronics, and arts, media, and engineering. Engineering education, low-power electronics, power systems, solid-state electronics, and telecommunications have been selected for support as part of a program establishing excellence centers at ASU.

For a current list of the subjects available for research in the department, access the department's Web site at fulton.asu.edu/~eee.

The faculty also participate in offering the interdisciplinary program leading to the PhD degree in the Science and Engineering of Materials; see "Science and Engineering of Materials," page 326. The faculty also participate in the Master of Engineering program; see "Engineering," page 192.

Admission. See "Admission to the Division of Graduate Studies," page 58. A student whose undergraduate degree is not based on an ABET-accredited program must submit scores on the Graduate Record Exam and must have earned the equivalent of a 3.50 GPA in the final two years of study. For all graduate programs in electrical engineering, the deadline for spring admission is August 31, and the deadline for fall admission is January 31. For more information on programs, faculty, financial aid, and for admission forms, access the department's Web site at fulton.asu.edu/~eee.

DOCTOR OF PHILOSOPHY

The PhD degree in Electrical Engineering is awarded based upon evidence of excellence in research leading to a scholarly dissertation that is a contribution to knowledge.

See "Doctor of Philosophy," page 69, for general requirements.

Program of Study. The official program of study must be filed no later than the semester before all degree requirements are met.

Foreign Language Requirements. None.

Qualifying Examination. Every student must pass a qualifying examination consisting of a short research paper and an oral presentation of the research. The examination must take place before the end of the second semester in attendance at ASU.

Comprehensive Examinations. Written and oral comprehensive examinations are required before the student is admitted to candidacy. The examinations are administered by the supervisory committee.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general information.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192, for information on the MSE degree.

A final written comprehensive exam is required for option two in this program. Most master's degree students are admitted to the MSE program, option two. Those who are offered financial support or who are outstanding students showing research potential are admitted to the MS program. A tentative program of study must be filed during the first semester enrolled for classes.

ARTS, MEDIA, AND ENGINEERING PROGRAM

The Electrical Engineering faculty offer the MS and PhD degrees with a concentration in arts, media, and engineering in collaboration with the Departments of Computer Science and Engineering, Dance, and Theatre and the Schools of Art and Music. For more information, see "Arts, Media, and Engineering," page 214.

ONLINE PROGRAMS

A wide selection of graduate-level electrical engineering courses are offered online. By taking classes over the Internet, students can complete all requirements for an MSE degree from off campus. Students in the MS and PhD programs can also utilize the online classes in their programs of study. The Ira A. Fulton School of Engineering Center for Professional Development provides support for the online classes. For more information about these programs, see "Center for Professional Development," pages 169 and 193.

ELECTRICAL ENGINEERING (EEE)

EEE 405 Filter Design. (3)
fall
Principles of active and passive analog filter design, frequency domain approximations, sensitivity and synthesis of filters. Prerequisite: EEE 303.

EEE 407 Digital Signal Processing. (4)
fall and spring
Time and frequency domain analysis, difference equations, z-transform, FIR and IIR digital filter design, discrete Fourier transform, FFT, and random sequences. Lecture, lab. Fee. Prerequisites: EEE 303; MAT 342 (or 343).

EEE 425 Digital Systems and Circuits. (4)
fall and spring
Digital logic gate analysis and design. Propagation delay times, fan out, power dissipation, noise margins. Design of MOS and bipolar logic families, including NMOS, CMOS, standard and advanced TTL, ECL, and BiCMOS. Inverter, combinational and sequential logic circuit design, MOS memories, VLSI circuits. Computer simulations using PSPICE. Lecture, lab. Fee. Prerequisite: ECE 334.

EEE 433 Analog Integrated Circuits. (4)
fall and spring
Analysis, design, and applications of modern analog circuits using integrated bipolar and field-effect transistor technologies. Lecture, lab. Fee. Prerequisite: ECE 334.

EEE 434 Quantum Mechanics for Engineers. (3)
fall
Angular momentum, wave packets, Schroedinger wave equation, probability, problems in one dimension, principles of wave mechanics, scattering, tunneling, central forces, angular momentum, hydrogen atom, perturbation theory, variational techniques. Prerequisites: ECE 352; EEE 340.

EEE 435 Microelectronics. (3)
spring
Introduces basic CMOS processing and fabrication tools. Covers the fundamentals of thermal oxidation, CVD, implantation, diffusion, and process integration. Internet lecture, Internet or on-campus lab. Fee. Pre- or corequisite: EEE 436.

EEE 436 Fundamentals of Solid-State Devices. (3)
fall and spring
Semiconductor fundamentals, pn junctions, metal-semiconductor contacts, metal-oxide-semiconductor capacitors and field-effect transistors, bipolar junction transistors. Prerequisite: ECE 352.

EEE 437 Optoelectronics. (3)
selected semesters
Basic operating principles of various types of optoelectronic devices that play important roles in commercial and communication electronics; light-emitting diodes, injection lasers, and photodetectors. Prerequisite: EEE 436.

EEE 439 Semiconductor Facilities and Cleanroom Practices. (3)
fall
Microcontamination, controlled environments, cleanroom layout and systems, modeling, codes and legislation, ultrapure water, production materials, personnel and operations, hazard management, advanced concepts. Prerequisite: EEE 435 or instructor approval.

EEE 440 Electromagnetic Engineering II. (4)
spring
Second half of an introductory course in electromagnetic theory and its application in electrical engineering. Analytical and numerical solution of boundary value problems. Advanced transmission lines; waveguides; antennas; radiation and scattering. Lecture, lab. Fee. Prerequisite: EEE 340.

EEE 443 Antennas for Wireless Communications. (3)
spring
Fundamental parameters; radiation integrals; wireless systems; wire, loop, and microstrip antennas; antenna arrays; smart antennas; ground effects; multipath. Prerequisite: EEE 340.

EEE 445 Microwaves. (4)
fall
Waveguides; circuit theory for waveguiding systems; microwave devices, systems, and energy sources; striplines and microstrips; impedance matching transformers; measurements. Lecture, lab. Fee. Prerequisite: EEE 340.

EEE 448 Fiber Optics. (4)
fall
Principles of fiber-optic communications. Lecture, lab. Fee. Prerequisites: EEE 303, 340.

EEE 455 Communication Systems. (4)
fall and spring
Signal analysis techniques applied to the operation of electrical communication systems. Introduction to and overview of modern digital and analog communications. Lecture, lab. Fee. Prerequisite: EEE 350.

EEE 459 Communication Networks. (3)
spring
Fundamentals of communication networks. Study of Seven-Layer OSI model. Focus on functionality and performance of protocols used in communication networks. Prerequisite: EEE 350.

EEE 460 Nuclear Concepts for the 21st Century. (3)
spring
Radiation interactions, damage, dose, and instrumentation. Cosmic rays, satellite effects; soft errors; transmutation doping. Fission reactors, nuclear power. TMI, Chernobyl. Radioactive waste. Prerequisite: PHY 241 or 361.

EEE 463 Electrical Power Plant. (3)
fall
Nuclear, fossil, and solar energy sources. Analysis and design of steam supply systems, electrical generating systems, and auxiliary systems. Power plant efficiency and operation. Prerequisites: ECE 201, 340 (or PHY 241).

EEE 470 Electric Power Devices. (3)
fall
Analyzes devices used for short circuit protection, including circuit breakers, relays, and current and voltage transducers. Protection against switching and lightning over voltages. Insulation coordination. Prerequisite: EEE 360.

EEE 471 Power System Analysis. (3)
spring
Review of transmission line parameter calculation. Zero sequence impedance, symmetrical components for fault analysis, short circuit calculation, review of power flow analysis, power system stability, and power system control concepts. Prerequisite: EEE 360.

EEE 473 Electrical Machinery. (3)
fall
Operating principles, constructional details, and design aspects of conventional DC and AC machines, transformers and machines used in computer disc drives, printers, wrist watches, and automobiles. Prerequisite: EEE 360.

EEE 480 Feedback Systems. (4)
fall and spring
Analysis and design of linear feedback systems. Frequency response and root locus techniques, series compensation, and state variable feedback. Lecture, lab. Fee. Prerequisite: EEE 303.

EEE 482 Introduction to State Space Methods. (3)
fall
Discrete and continuous systems in state space form controllability, stability, and pole placement. Observability and observers. Pre- or corequisite: EEE 480.

EEE 505 Time-Frequency Signal Processing. (3)
fall
Joint time-frequency analysis of time-varying signals and systems; linear and quadratic time-frequency representations; applications in current areas of signal processing. Prerequisite: EEE 407.

EEE 506 Digital Spectral Analysis. (3)
spring
Principles and applications of digital spectral analysis, least squares, random sequences, parametric, and nonparametric methods for spectral estimation. Prerequisites: EEE 407, 554.

EEE 507 Multidimensional Signal Processing. (3)
fall
Processing and representation of multidimensional signals. Design of systems for processing multidimensional data. Introduces image and array processing issues. Prerequisite: EEE 407 or instructor approval.

EEE 508 Digital Image Processing and Compression. (3)
spring
Fundamentals of digital image perception, representation, processing, and compression. Emphasizes image coding techniques. Signals include still pictures and motion video. Prerequisites: EEE 350 and 407 (or their equivalents).

EEE 511 Artificial Neural Computation Systems. (3)
selected semesters
Networks for computation, learning function representations from data, learning algorithms and analysis, function approximation and information representation by networks, applications in control systems and signal analysis. Prerequisite: instructor approval.

EEE 517 Hardware Design Languages. (3)
fall and spring
Introduces hardware design languages. Modeling concepts for specification, simulation, and synthesis. Cross-listed as CSE 517. Credit is allowed for only CSE 517 or EEE 517. Prerequisite: CSE 423 or EEE 425 or instructor approval.

EEE 523 Advanced Analog Integrated Circuits. (3)
fall and spring
Analysis and design of analog integrated circuits: analog circuit blocks, reference circuits, operational-amplifier circuits, feedback, and nonlinear circuits. Prerequisite: EEE 433 (or its equivalent).

EEE 524 Communication Transceiver Circuits Design. (4)
spring
Communication transceivers and radio frequency system design; fundamentals of transceivers circuits; RF, IF, mixers, filters, frequency synthesizers, receivers, CAD tools, and lab work on IC design stations. Lecture, lab. Prerequisites: EEE 433 and 455 (or their equivalents). Pre- or corequisites: EEE 445 and 523 (or their equivalents).

EEE 525 VLSI Design. (3)
fall and spring
Analysis and design of Very Large Scale Integrated (VLSI) circuits. Physics of small devices, fabrication, regular structures, and system timing. Prerequisite: EEE 425 (or its equivalent).

EEE 526 VLSI Architectures. (3)
fall
Special-purpose architectures for signal processing. Design of array processor systems at the system level and processor level. High-level synthesis. Prerequisites: both CSE 330 and EEE 407 or only instructor approval.

EEE 527 Analog to Digital Converters. (3)
spring
Detailed introduction to the design of Nyquist rate, CMOS analog to digital converters. Prerequisite: EEE 523.

EEE 528 Phase-Locked Loop Systems and Circuits. (3)
selected semesters
Fundamentals, concepts of system analysis and design, and principles that apply to phase-locked loops (PPLs) used in frequency synthesis. Prerequisite: EEE 433. Pre- or corequisite: EEE 523.

EEE 529 Mixed-Signal Circuit Design. (3)
selected semesters
Analysis and design of mixed-signal integrated circuits with emphasis in CMOS technology. Prerequisites: EEE 523, 525.

EEE 530 Advanced Silicon Processing. (3)
spring
Thin films, CVD, oxidation, diffusion, ion-implantation for VLSI, metallization, silicides, advanced lithography, dry etching, rapid thermal processing. Pre- or corequisite: EEE 435.

EEE 531 Semiconductor Device Theory I. (3)
fall
Transport and recombination theory, pn and Schottky barrier diodes, bipolar and junction field-effect transistors, and MOS capacitors and transistors. Prerequisite: EEE 436 (or its equivalent).

EEE 532 Semiconductor Device Theory II. (3)
spring
Advanced MOSFETs, charge-coupled devices, solar cells, photodetectors, light-emitting diodes, microwave devices, and modulation-doped structures. Prerequisite: EEE 531.

EEE 533 Semiconductor Process/Device Simulation. (3)
fall
Process simulation concepts, oxidation, ion implantation, diffusion, device simulation concepts, pn junctions, MOS devices, bipolar transistors. Prerequisite: EEE 436 (or its equivalent).

EEE 534 Semiconductor Transport. (3)
spring
Carrier transport in semiconductors. Hall effect, high electric field, Boltzmann equation, correlation functions, and carrier-carrier interactions. Prerequisites: EEE 434, 436 (or 531).

EEE 535 Electron Transport in Nanostructures. (3)
spring
Nanostructure physics and applications. 2-D electron systems, quantum wires and dots, ballistic transport, quantum interference, and single-electron tunneling. Prerequisites: EEE 434, 436.

EEE 536 Semiconductor Characterization. (3)
spring
Measurement techniques for semiconductor materials and devices. Electrical, optical, physical, and chemical characterization methods. Prerequisite: EEE 436 (or its equivalent).

EEE 537 Semiconductor Optoelectronics. (3)
fall
Electronic states in semiconductors, quantum theory of radiation, absorption processes, radiative processes, nonradiative processes, photoluminescence, and photonic devices. Prerequisites: EEE 434, 436 (or 531).

EEE 538 Introduction to Microelectromechanical Systems. (3)
fall
Microelectromechanical systems and devices emphasizing analytical and numerical modeling of actuation and sensing mechanisms with an overview of fabrication technology. Prerequisites: ECE 214, 334; EEE 436 (or their equivalents).

EEE 539 Introduction to Solid-State Electronics. (3)
fall
Crystal lattices, reciprocal lattices, quantum statistics, lattice dynamics, equilibrium, and nonequilibrium processes in semiconductors. Prerequisite: EEE 434.

EEE 540 Fast Computational Electromagnetics. (3)
selected semesters
Method of moments, finite difference time-domain, finite element methods implemented using fast algorithms (wavelets, FMM, Nystrom) to gain high efficiency. Prerequisite: EEE 440.

EEE 541 Electromagnetic Fields and Guided Waves. (3)
selected semesters
Polarization and magnetization; dielectric, conducting, anisotropic, and semiconducting media; duality, uniqueness, and image theory; plane wave functions, waveguides, resonators, and surface guided waves. Prerequisite: EEE 440 (or its equivalent).

EEE 543 Antenna Analysis and Design. (3)
fall
Impedances, broadband antennas, frequency independent antennas, miniaturization, aperture antennas, horns, reflectors, lens antennas, and continuous sources design techniques. Prerequisite: EEE 443 (or its equivalent).

EEE 544 High-Resolution Radar. (3)
selected semesters
Fundamentals; wideband coherent design, waveforms, and processing; stepped frequency; synthetic aperture radar (SAR); inverse synthetic aperture radar (ISAR); imaging. Prerequisites: EEE 303 and 340 (or their equivalents).

EEE 545 Microwave Circuit Design. (3)
spring
Analysis and design of microwave attenuators, in-phase and quadrature-phase power dividers, magic tee's, directional couplers, phase shifters, DC blocks, and equalizers. Prerequisite: EEE 445 or instructor approval.

EEE 546 Advanced Fiber Optics. (3)
selected semesters
Theory of propagation in fibers, couplers and connectors, distribution networks, modulation, noise and detection, system design, and fiber sensors. Prerequisite: EEE 448 or instructor approval.

EEE 547 Microwave Solid-State Circuit Design I. (3)
selected semesters
Applies semiconductor characteristics to practical design of microwave mixers, detectors, limiters, switches, attenuators, multipliers, phase shifters, and amplifiers. Prerequisite: EEE 545 or instructor approval.

EEE 548 Coherent Optics. (3)
selected semesters
Diffraction, lenses, optical processing, holography, electro-optics, and lasers. Prerequisite: EEE 440 (or its equivalent).

EEE 549 Lasers. (3)
selected semesters
Theory and design of gas, solid, and semiconductor lasers. Prerequisite: EEE 448 or instructor approval.

EEE 550 Transform Theory and Applications. (3)
selected semesters
Introduces abstract integration, function spaces, and complex analysis in the context of integral transform theory. Applications to signal analysis, communication theory, and system theory. Prerequisite: EEE 303.

EEE 551 Information Theory. (3)
selected semesters
Entropy and mutual information, source and channel coding theorems, applications for communication and signal processing. Prerequisite: EEE 554.

EEE 552 Digital Communications. (3)
spring
Complex signal theory, digital modulation, optimal coherent and incoherent receivers, channel codes, coded modulation, Viterbi algorithm. Prerequisite: EEE 554.

EEE 553 Coding and Cryptography. (3)
selected semesters
Introduces algebra, block and convolutional codes, decoding algorithms, turbo codes, coded modulation, private and public key cryptography. Prerequisite: EEE 554.

EEE 554 Random Signal Theory. (3)
fall and spring
Applies statistical techniques to the representation and analysis of electrical signals and to communications systems analysis. Prerequisite: EEE 350 or instructor approval.

EEE 555 Modeling and Performance Analysis. (3)
selected semesters
Modeling and performance analysis of stochastic systems and processes such as network traffic queuing systems and communication channels. Prerequisite: EEE 554.

EEE 556 Detection and Estimation Theory. (3)
selected semesters
Combines the classical techniques of statistical inference and the random process characterization of communication, radar, and other modern data processing systems. Prerequisites: EEE 455, 554.

EEE 557 Broadband Networks. (3)
fall
Physics of wireless and optical communications. Broadband multiplexing and switching methods. Blocking and queuing analysis. Network optimization, routing, and economics. Prerequisite: EEE 350.

EEE 558 Wireless Communications. (3)
fall
Cellular systems, path loss, multipath fading channels, modulation and signaling for wireless, diversity, equalization coding, spread spectrum, TDMA/FDMA/CDMA. Prerequisite: EEE 552.

EEE 571 Power System Transients. (3)
selected semesters
Simple switching transients. Transient analysis by deduction. Damping of transients. Capacitor and reactor switching. Transient recovery voltage. Travelling waves on transmission lines. Lightning. Protection of equipment against transient overvoltages. Introduces computer analysis of transients. Prerequisite: EEE 471.

EEE 572 Advanced Power Electronics. (3)
spring
Analyzes device operation, including thyristors, gate-turn-off thyristors, and transistors. Design of rectifier and inverter circuits. Applications such as variable speed drives, HVDC, motor control, and uninterruptable power supplies. Prerequisite: EEE 470.

EEE 573 Electric Power Quality. (3)
spring
Sinusoidal waveshape maintenance; study of momentary events, power system harmonics, instrumentation, filters, power conditioners, and other power quality enhancement methods. Prerequisite: EEE 360 (or its equivalent).

EEE 574 Computer Solution of Power Systems. (3)
fall
Algorithms for digital computation for power flow, fault, and stability analysis. Sparse matrix and vector programming methods, numerical integration techniques, stochastic methods, solution of the least squares problem. Prerequisite: EEE 471.

EEE 577 Power Engineering Operations and Planning. (3)
fall
Economic dispatch, unit commitment, dynamic programming, power system planning and operation, control, generation modeling, AGC, and power production. Prerequisite: EEE 471 or graduate standing.

EEE 579 Power Transmission and Distribution. (3)
spring
High-voltage transmission line electric design; conductors, corona, RI and TV noise, insulators, clearances. DC characteristic, feeders voltage drop, and capacitors. Prerequisite: EEE 470.

EEE 581 Filtering of Stochastic Processes. (3)
selected semesters
Modeling, estimation, and filtering of stochastic processes, with emphasis on the Kalman filter and its applications in signal processing and control. Prerequisites: EEE 482, 550, 554.

EEE 582 Linear System Theory. (3)
selected semesters
Controllability, observability, and realization theory for multivariable continuous time systems. Stabilization and asymptotic state estimation. Disturbance decoupling, noninteracting control. Prerequisite: EEE 482.

EEE 584 Internship. (3)
selected semesters
Work performed in an industrial setting that provides practical experience and adds value to classroom and research learning processes.

EEE 585 Digital Control Systems. (3)
selected semesters
Analysis and design of digital and sampled data control systems, including sampling theory, z-transforms, the state transition method, stability, design, and synthesis. Prerequisites: EEE 482, 550.

EEE 586 Nonlinear Control Systems. (3)
selected semesters
Stability theory, including phase-plane, describing function, Liapunov's method, and frequency domain criteria for continuous and discrete, nonlinear, and time-varying systems. Prerequisite: EEE 482.

EEE 587 Optimal Control. (3)
selected semesters
Optimal control of systems. Calculus of variations, dynamic programming, linear quadratic regulator, numerical methods, and Pontryagin's principle. Cross-listed as MAE 507. Credit is allowed for only EEE 587 or MAE 507. Prerequisite: EEE 482 or MAE 506.

EEE 588 Design of Multivariable Control Systems. (3)
selected semesters
Practical tools for designing robust MIMO controllers. State feedback and estimation, model-based compensators, MIMO design methodologies, CAD, real-world applications. Prerequisite: EEE 480 (or its equivalent).

EEE 591 Seminar. (1–12)
selected semesters
Topics may include the following:
• Analog Integrated Circuits
• Communication Systems
• Digital Signal Processing
• Digital Systems and Circuits
• Electromagnetic Engineering II
• Feedback Systems
• Fiber Optics
• Microelectronics
• Microwaves
• Real-Time DSP
   Credit is allowed for only EEE 591 or 498.

EEE 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Image Understanding. (3)
   Credit is allowed for only EEE 598 or AME 598.

EEE 606 Adaptive Signal Processing. (3)
fall
Principles/applications of adaptive signal processing, adaptive linear combiner, Wiener least-squares solution, gradient search, performance surfaces, LMS/RLS algorithms, block time/frequency domain LMS. Prerequisites: EEE 506, 554.

EEE 607 Speech Coding for Multimedia Communications. (3)
spring
Speech and audio coding algorithms for applications in wireless communications and multimedia computing. Prerequisite: EEE 407. Pre- or corequisite: EEE 506.

EEE 631 Heterojunctions and Superlattices. (3)
selected semesters
Principles of heterojunctions and quantum well structures, band line-ups, optical, and electrical properties. Introduces heterojunction devices. Prerequisites: EEE 436, 531.

EEE 641 Advanced Electromagnetic Field Theory. (3)
selected semesters
Cylindrical wave functions, waveguides, and resonators; spherical wave functions and resonators; scattering from planar, cylindrical, and spherical surfaces; Green's functions. Prerequisite: EEE 541 (or its equivalent).

EEE 643 Advanced Topics in Electromagnetic Radiation. (3)
spring
High-frequency asymptotic techniques, geometrical and physical theories of diffraction (GTD and PTD), moment method (MM), radar cross section (RCS) prediction, Fourier transforms in radiation, and synthesis methods. Prerequisite: EEE 543.

EEE 647 Microwave Solid-State Circuit Design II. (3)
fall
Practical design of microwave free-running and voltage-controlled oscillators using Gunn and Impatt diodes and transistors; analysis of noise characteristics of the oscillator. Prerequisites: EEE 545, 547.

EEE 684 Internship. (1–2)
fall, spring, summer
Work performed in an industrial setting that provides practical experience and adds value to classroom and research learning processes.

EEE 686 Adaptive Control. (3)
selected semesters
Main topics covered: adaptive identification, convergence, parametric models, performance and robustness properties of adaptive controllers, persistence of excitation, and stability. Prerequisites: both EEE 582 and 586 or only instructor approval.

EEE 731 Advanced MOS Devices. (3)
spring
Threshold voltage, subthreshold current, scaling, small geometry effects, hot electrons, and alternative structures. Prerequisite: EEE 531.

EEE 784 Internship. (3)
selected semesters
Work performed in an industrial setting that provides practical experience and adds value to the classroom and research learning processes.

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Engineering

Master's Programs

MASTER OF ENGINEERING

Arizona's three state universities—Arizona State University, Northern Arizona University, and the University of Arizona—are partnering in offering: the Master of Engineering (MEng).

The MEng partnership is intended to meet the educational needs of practicing engineers. With input from industry professionals, the three universities are developing programs that address the enhancement and development of skills, knowledge, and understanding that are critical to today's practicing engineer. Courses are offered through a variety of distance-delivery methods and in flexible formats. Students enrolled in the program are able to take advantage of course offerings at any of the three universities. These offerings reflect the diversity of strengths across the state. Students enrolled in Web-delivered courses incur a special course fee. For more information, see the MEng Web site at www.triuniv.engr.arizona.edu.

The MEng program offers students the opportunity to identify an engineering emphasis in traditional academic areas of study (electrical engineering, mechanical engineering, for example), nontraditional areas of study (transportation, quality and reliability, for example) or student-initiated areas of study (interdisciplinary).

Admission. See "Admission to the Division of Graduate Studies," page 58.

Applicants who have graduated from accredited U.S. institutions and who have a suitable background for the desired field of study must have a minimum grade point average of 3.00 (on a 4.00 scale) for the last 60 units of the undergraduate transcript (or for the last 12 units of the post-baccalaureate transcript). The Graduate Record Exam (GRE) may be required for a particular area of study or concentration. Graduates of non-U.S. institutions must satisfy admission requirements in addition to those specified above.

Individuals not meeting the requirements for regular admission may be recommended for provisional admission or deferred admission status at the discretion of the MEng Admission Committee. Upon completion of recommended course work, provisional and/or deferred admission status students may be elevated to regular status.

Individuals wanting to take courses offered in the MEng program, while not seeking a degree, are encouraged to obtain nondegree admission status through the Division of Graduate Studies.

Program of Study. Division of Graduate Studies requirements of the home institution must be followed. All programs of study require the completion of at least 30 semester hours of graduate credit. Each program of study requires three semester hours of course work in each of the following subject areas: engineering management/business and applied engineering mathematics.

All students are expected to take at least 10 semester hours from their home institution. Before the first month of the semester in which the 10th semester hour is taken, the MEng student should prepare a program of study. Once the program of study has been approved by the student's advisory committee, it should be forwarded for approval by the academic director of the home institution.

At the discretion of an academic unit or academic working group, a practice-oriented project may constitute part of the program of study not to exceed six semester hours. Students must maintain a minimum GPA of 3.00 in courses taken as part of their program of study and maintain a 3.00 or higher for all graduate courses (500-level or above).

Foreign Language Requirements. None.

Thesis Requirements. None.

Capstone Event. An appropriate capstone event is defined and managed by the student's advisory committee. A capstone event could include, but is not limited to, the following: a written and/or oral defense of an applied project; a final examination that captures the essence of the master's degree focus and represents a major portion of the student's course work; or an overview presentation incorporating knowledge gained from the program with integration and reflection of learning as applied to the job. The student's advisory committee has the authority to determine the format of the capstone event.

Time Limit. The time limit for completing the MEng degree is six years from the time of admission.

MASTER OF SCIENCE IN ENGINEERING

The faculty in the Ira A. Fulton School of Engineering offer professional programs leading to the Master of Science in Engineering (MSE) degree with majors in Aerospace Engineering, Chemical Engineering, Civil Engineering, Electrical Engineering, Engineering Science, Industrial Engineering, Materials Engineering, and Mechanical Engineering. The programs are designed to bridge the gap between knowledge of engineering sciences and creative engineering practice while at the same time increasing the depth and breadth of knowledge in selected areas of emphasis. The pattern of course work applicable to the degree is potentially unique for each student, although it must conform to the general guidelines for subject matter content for the degree as authorized in this catalog.

Two options are available within the MSE degree program. Option one requires a thesis and is designed primarily for full-time students. Option two is designed for full-time students not intending to write a thesis and for students who hold full-time jobs and must attend university classes on a part-time basis. A thesis or equivalent is not required of students who elect this option.

Admission. Applicants are expected to satisfy all requirements for admission to the Division of Graduate Studies. Entry into this program normally requires a bachelor's degree with a major in engineering or in a closely related bachelor's degree program.

Deficiencies for admission to the graduate degree programs are specified at the time of admission. The verbal, quantitative, and analytical components of the Graduate Record Examination (GRE) are recommended but not required unless specified by the respective academic unit in which the major is offered. TOEFL scores must be submitted by international applicants before admission is considered. Applicants with TOEFL scores of 550 or higher may be regularly admitted without requiring further language study. Applicants with scores below 550 may be regularly admitted but must complete study in ASU's American English and Culture Program (AECP) before enrolling in course work in the academic program.

Program of Study. In general, all candidates for the MSE degree program are required to complete 30 semester hours. Additional courses may be assigned by the supervisory committee depending on the background of the candidate.

Option 1. A minimum of six semester hours of research and thesis credit must be included in the 30 hours.

Option 2. A minimum of 30 semester hours and a comprehensive examination are required.

Foreign Language Requirements. None.

Thesis Requirements. Only students who elect option one are required to write a thesis.

Final Examination. A final oral examination in defense of the thesis is required for students who choose option one. A final comprehensive examination is required for students in option two. Examination format and times should be obtained from the academic unit.

CENTER FOR PROFESSIONAL DEVELOPMENT

As a unit of the Ira A. Fulton School of Engineering, the Center for Professional Development (CPD) provides engineers and technical professionals the skills and knowledge necessary to master new methods, to lead projects and teams, and to advance professionally. Programs are offered in traditional classroom environments and through distance learning. By leveraging the nationally renowned faculty of the school and affiliate experts, CPD administers short courses and conferences, professional certification programs, off-campus graduate degree programs, and in-company customized programs.

The school offers a growing list of MSE programs to engineering professionals globally. We understand that adult students have professional, family, and community responsibilities in addition to their educational goals. We strive to provide convenient and high-quality programs while ensuring high academic standards.

Distance Learning Programs for Engineering Professionals

The distance learning programs are offered to professionals seeking flexible "anytime, anyplace" off-campus education programs. A broad portfolio of programs offers engineering and technical professionals new strategies, tools and methods, and technology to remain competitive in the New Economy. In general, professionals pursuing the MSE distance learning programs have two or more years of professional experience and are sponsored by their employer through tuition benefit programs. Traditional program areas include electrical engineering, materials science engineering, chemical engineering, industrial engineering and non-traditional specialty areas such as semiconductor processing and manufacturing. Executive-focused programs are offered through the MSE in Engineering Sciences with a concentration in executive embedded systems engineering.

For more information, access the school's Web site at cpd.asu.edu.

ONLINE GRADUATE PROFESSIONAL PROGRAMS

Through the Center for Professional Development (CPD), the Ira A. Fulton School of Engineering provides engineers and technical professionals the skills and knowledge necessary to master new methods, lead projects and teams, and to advance professionally. Programs are offered in both traditional classroom environments and through distance learning. By leveraging the nationally renowned faculty of the Fulton School and affiliate experts, CPD administers short courses and conferences, professional certification programs, off-campus graduate degree programs, and in-company customized programs.

For information on programs, access the center's Web site at cpd.asu.edu.

Engineering Science

Master's and Doctoral Programs

fulton.asu.edu
480/965-3313

Subhash Mahajan, Chair

Regents' Professor: Mayer

Professors: Adams, Alford, Dey, Krause, Mahajan, Newman, Picraux, Sieradzki, Van Schilfgaarde

Associate Professor: Chawla

The faculty of the Ira A. Fulton School of Engineering offer graduate programs leading to the MS, the MSE, and the PhD degrees in Engineering Science. Faculty offer programs of a special and interdisciplinary nature.

Executive focused programs are offered through the MSE in Engineering Sciences with a concentration in executive embedded systems engineering. For more information, access the school's Web site at cpd.asu.edu.

Graduate Record Examination. Graduate Record Examination (GRE) scores are required from all applicants.

MATERIALS SCIENCE AND ENGINEERING

Faculty members who advise students in this area of study are located within the Department of Chemical and Materials Engineering. Courses offered carry the MSE prefix; see "Materials Science and Engineering," page 199.

For more information call 480/965-3313, send e-mail to cmerec@asu.edu, or visit ECG 202.

Each student admitted as a regular degree candidate is required to complete an approved program of study. Students who have an undergraduate degree in an area other than materials science, or a similarly named program, may qualify for admission to a transition program and may be required to take one or more undergraduate courses in preparation for enrollment in graduate courses in materials science and engineering. The program of study of transition students is determined by the student's supervisory committee after review of the student's academic record.

Research activities in materials science and engineering include growth, processing and characterization of electronic materials; electroceramics; deformation behavior of materials at different length scales; computational materials science; and nanoscience and nanotechnology. Some of the research projects that are currently being pursued are growth of group III nitrides by organometallic vapor phase epitaxy and molecular beam epitaxy and their fabrication into high frequency, high power, and high temperature devices; fabrication of spintronic devices for very high frequency applications; synthesis of high k dielectric films by organometallic vapor phase epitaxy and correlation of properties with microstructures; process-induced defects in implantation and annealing of GaN; creep and thermal fatigue behaviors of lead-free solder balls used in electronic packaging; modeling of the evolution of thin film microstructures; and synthesis and characterization of quantum dots.

For students who study under faculty in the area of Materials Science and Engineering, see the appropriate courses listed in "Materials Engineering," page 198.

ONLINE MSE IN ENGINEERING SCIENCE

Executive Embedded Systems Concentration

The MSE degree in Engineering Science concentration in executive embedded systems provides an interdisciplinary engineering curriculum and strategically aligns a core business curriculum to prepare engineers for management and leadership positions within technical organizations.

The program develops engineers on the "fast track" for leadership advancement. To further prepare these engineering leaders, 12 semester hours of business courses are offered in this program. The program delivery format for the engineering courses is an accelerated trimester (10 week sessions). The W.P. Carey School of Business curriculum is delivered with five week course sessions. The curriculum will be delivered via the Internet to allow professionals flexible access to the cohort-based curriculum.

The online program is tailored to the needs of the working professional. The program is administered as a cohort based, two-year program of study, consisting of 42 semester hours (12 courses and a six semester hour value-added capstone project). Courses are delivered "anytime, anyplace" through the myASU portal.

There will be 12 required courses defined in the following program of study. The following is a sample.

Trimester 1
ACC 591 S: Financial and Managerial Accounting 3
CSE 598 ST: Real-Time Embedded Systems 3

Trimester 2
CSE 598 ST: Software Engineering for Embedded Systems 3
FIN 591 S: Managerial Finance................................... 3

Trimester 3
CSE 566 Software Project, Process, and Quality Management ... 3
CSE 598 ST: Distributed Computing with Java and CORBA 3

Trimester 4
ACC 591 S: Strategic Cost Management and e-Business 3
CSE 534 Advanced Computer Networks 3

Trimester 5
CSE 598 ST: Advanced Hardware Systems Design using
VHDL and FPGAs 3
CSE 598 ST: Testing Embedded Systems 3

Trimester 6
CSE 531 Distributed and Multiprocessor Operating Systems...... 3
MGT 591 S: Organizational Management 3

Profile of Student. The program targets engineering professionals working full-time in an industry with at least a BS degree in electrical or computer engineering. In general, students are mid-level engineering managers in industry and aspire to engineering leadership and/or executive management positions. No GRE testing is required for admission. Cohorts are formed at the beginning of each semester. For additional information on the program, access the Web site at cpd.asu.edu.

Industrial Engineering

Master's and Doctoral Programs

fulton.asu.edu/ie

480/965-3185

GWC 502

Gary L. Hogg, Chair

Professors: Cochran, Fowler, Henderson, Hogg, Hubele, Montgomery, Runger, Shunk, Wolfe, Ye

Associate Professors: Anderson-Rowland, Mackulak, Moor, Roberts, Villalobos

Assistant Professors: Gel, Keha, Kulahci, Wu

Senior Lecturers: Pfund, Thompson

OVERVIEW

The faculty in the Department of Industrial Engineering offer three graduate degree programs leading to the Master of Science, the Master of Science in Engineering, and the PhD degrees in Industrial Engineering. The three primary areas of study in the department are information systems engineering/management systems engineering, operation research and production systems, and quality and reliability in engineering. Additional programs in manufacturing and semiconductor manufacturing are also offered.

The overall educational objective of graduate study in industrial engineering is to improve each student's ability to understand, analyze, and resolve problems within complex organizations. Industrial engineers must develop qualitative and quantitative abilities to assist management in such diverse organizations as banks, government, hospitals, military, and manufacturing operations.

The faculty in the Department of Industrial Engineering are internationally recognized for their state-of-the-art research projects funded through both the government and industry. They are active in advising, in teaching innovation, and in continuous improvement of our curriculum. For up-to-date information about research activity, access the department's Web site at fulton.asu.edu/ie.

ADMISSION STANDARDS AND PROCEDURES

All students applying for one of the master's or doctoral degree programs must submit Graduate Record Examination scores, a statement of purpose, and three letters of recommendation to the Division of Graduate Studies. Applicants may have a baccalaureate degree in a major field other than industrial engineering, although engineering, mathematics, or science is preferred. A minimum GPA of 3.20 is required for admission to the master's degree program and of 3.50 is required for admission to the doctoral degree program.

PRIMARY AREAS OF STUDY

Quality and Reliability in Engineering. This focus area includes all aspects of design of experiments, statistical process control, data mining, and all modern tools leading to a clear understanding of quality and reliability systems.

Operation Research and Production Systems. This area of study focuses on applied operations research with emphasis on optimization tools, descriptive modeling, and simulation.

Information Systems Engineering/Management Systems Engineering. This area of study includes all aspects of enterprise modeling; information modeling; security systems applications, integration, and management and applying the systems approach to large-scale engineering systems.

DOCTOR OF PHILOSOPHY

The PhD degree is offered for students who have completed a bachelor's or master's degree in engineering, or a closely related field, with distinction. The degree requirement is 89 semester hours after the baccalaureate and is conferred upon evidence of excellence in research that culminates in a dissertation representing a significant contribution to the field of industrial engineering. See "Doctor of Philosophy," page 69, for general requirements.

Curriculum requirements are as follows:

1. A total of 89 semester hours.
2. A four-course core (IEE 505, 545 or 566, or 567, 572 or 578, and 574 or 575).
3. A minimum of 60 semester hours of course work beyond the bachelor's degree. The 60 hours includes courses taken in a master's program.
4. Twelve credit hours each of research (IEE 792) and dissertation (IEE 799).
5. A one-hour teaching internship course (IEE 784).
6. A two-hour research methods course (IEE 700).
7. Two one-hour graduate seminar courses (IEE 594).
8. A written and an oral comprehensive exam is required after completion of the 60 semester hours of course work in the program of study. Upon successful completion of the comprehensive examination, the student is admitted to candidacy.
9. Submission of an approved dissertation followed by its successful defense.

Foreign Language. None.

MASTER OF SCIENCE AND MASTER OF SCIENCE IN ENGINEERING

The Master of Science is a research degree with 31 semester hours requiring a thesis and an oral defense. The Master of Science in Engineering degree is a nonresearch degree with 31 semester hours requiring additional course work and a written comprehensive examination.

Curriculum requirements are as follows:

1. A four-course core (IEE 505, 545 or 566 or 567, 572 or 578, and 574 or 575).

2. Four courses from one of the three primary areas of study (QRE, ORPS and ISE/MSE).

3. Two elective courses, 500-level or above. Elective courses in other departments are encouraged but must be approved by the student's committee.

4. One semester hour of graduate seminar (IEE 594).

5. Successful completion of a written comprehensive exam with material from three of the four required core courses.

6. Students completing three hours each of research and MS thesis can reduce area course requirements by one course and eliminate one elective course, or they may alternatively eliminate two elective courses. A minimum GPA of 3.20 is required in the first 18 hours defined by the program of study to pursue the MS thesis option. The thesis oral defense constitutes a final examination.

Foreign Language. None.

Other Areas of Study. Two specialty areas of study, SEMI and MAN are defined on the department's Web site at fulton.asu.edu/ie.

INDUSTRIAL ENGINEERING (IEE)

IEE 463 Computer-Aided Manufacturing and Control. (3)
spring
Computer control in manufacturing, CIM, NC, logic controllers, group technology, process planning, and robotics. Cross-listed as MAE 453. Credit is allowed for only IEE 463 or MAE 453. Credit is allowed for only IEE 463 or 543. Fee. Prerequisite: IEE 360 or MAE 351.

IEE 505 Information Systems Engineering. (3)
fall and spring
Studies information systems application engineering. Topics include information technology, data modeling, data organization, process mapping, application and database engineering, and user interface development. Fee. Prerequisites: CSE 200; graduate standing.

IEE 511 Analysis of Decision Processes. (3)
spring
Methods of making decisions in complex environments and statistical decision theory; effects of risk, uncertainty, and strategy on engineering and managerial decisions. Prerequisites: ECE 380; graduate standing.

IEE 530 Enterprise Modeling. (3)
spring
Focuses on social, economic, and technical models of the enterprise with emphasis on the management of technological resources. Includes organization, econometric, financial, and large-scale mathematical models. Prerequisite: graduate standing.

IEE 532 Management of Technology. (3)
fall
Topics include designing a technical strategy; technological forecasting; interfacing marketing engineering and manufacturing; designing and managing innovation systems; creativity; application of basic management principles to technology management. Prerequisite: IEE 431 or 541.

IEE 533 Scheduling and Network Analysis Models. (3)
spring
Applies scheduling and sequencing algorithms, deterministic and stochastic network analysis, and flow algorithms. Prerequisites: ECE 380; IEE 376.

IEE 541 Engineering Administration. (3)
fall
Introduces quantitative and qualitative approaches to management functions, engineering administration, organizational analysis, decision making, and communication. Credit is allowed for only IEE 541 or 431. Prerequisite: graduate standing.

IEE 543 Computer-Aided Manufacturing and Control. (3)
spring
Computer control in manufacturing, CIM, NC, logic controllers, group technology, process planning and robotics. Credit is allowed for only IEE 543 or 463. Prerequisite: graduate standing.

IEE 545 Simulating Stochastic Systems. (3)
fall and spring
Analyzes stochastic systems using basic queuing networks and discrete event simulation. Basic network modeling, shared resources, routing, assembly logic. Credit is allowed for only IEE 545 or 475. Prerequisites: CSE 200; IEE 376. Pre- or corequisite: IEE 385.

IEE 547 Human Factors Engineering. (3)
fall and spring
Study of people at work; designing for human performance effectiveness and productivity. Considerations of human physiological and psychological factors. Credit is allowed for only IEE 547 or 437. Prerequisite: graduate standing.

IEE 552 Strategic Technological Planning. (3)
spring
Studies concepts of strategy, strategy formulation process, and strategic planning methodologies with emphasis on engineering design and manufacturing strategy, complemented with case studies. Presents and uses an analytical executive planning decision support system throughout course. Prerequisite: graduate standing. Pre- or corequisites: IEE 545, 561, 572, 574.

IEE 553 Information Systems Assurances. (3)
fall
Develops and applies engineering approaches to assuring the security of enterprise information systems, including principles of dependable information systems, technologies for information systems, intrusion detection, system response, and recovery. Lecture, lab. Prerequisite: IEE 505 or instructor approval.

IEE 560 Object-Oriented Information Systems. (3)
spring
Applies object-oriented technology and concepts to enterprise information systems. Topics include requirement analysis, object-oriented design and programming, rapid application development, object data management, and development of object-oriented distributed applications. Fee. Prerequisite: IEE 505.

IEE 561 Production Systems. (3)
spring
Understanding how factories operate, how performance is measured, and how operational changes impact performance metrics. Operational philosophies, increasing production efficiency through quantitative methods. Prerequisites: IEE 376, 385.

IEE 562 Computer-Aided Manufacturing (CAM) Tools. (3)
spring
Current topics in automation, distributed control, control code generation, control logic validation, CAM integration, CAD/CAM data structures, planning for control systems. Topics vary by semester. Prerequisite: IEE 463 or 543.

IEE 563 Distributed Information Systems. (3)
fall and spring
Introduces concepts and technologies that form the core of distributed enterprise information systems. Topics include client-server architectures, distributed objects and paradigms, Internet, World Wide Web, distributed information sharing, network programming, and e-commerce and enterprise applications. Fee. Prerequisite: IEE 505.

IEE 564 Planning for Computer-Integrated Manufacturing. (3)
fall
Theory and use of IDEF methodology in planning for flexible manufacturing, robotics, and real-time control. Simulation concepts applied to computer-integrated manufacturing planning. Prerequisite: graduate standing.

IEE 565 Computer-Integrated Manufacturing Research. (3)
spring
Determination and evaluation of research areas in computer-integrated manufacturing, including real-time software, manufacturing information systems, flexible and integrated manufacturing systems, robotics, and computer graphics. Prerequisite: IEE 564.

IEE 566 Simulation in Manufacturing. (3)
spring in even years
Uses simulation in computer-integrated manufacturing with an emphasis on modeling material handling systems. Programming, declarative,

and intelligence-based simulation environments. Prerequisite: IEE 475 or 545.

IEE 567 Simulation System Analysis. (3)
fall
Simulation modeling of processes involving discrete and continuous system components. Topics include random number generators, output analysis, variance reduction, and statistical issues related to simulation. Prerequisite: IEE 475 or 545.

IEE 570 Advanced Quality Control. (3)
spring
Process monitoring with control charts (Shewhart, cusum, EWMA), feedback adjustment and engineering process control, process capability, autocorrelation, selected topics from current literature. Prerequisite: IEE 385.

IEE 571 Quality Management. (3)
fall
Total quality concepts, quality strategies, quality and competitive position, quality costs, vendor relations, the quality manual, and quality in the services. Prerequisite: graduate standing.

IEE 572 Design of Engineering Experiments. (3)
fall and spring
Analysis of variance and experimental design. Topics include strategy of experimentation, factorials, blocking and confounding, fractional factorials, response surfaces, nested and split-plot designs. Prerequisite: ECE 380.

IEE 573 Reliability Engineering. (3)
spring
Nature of reliability, time to failure densities, series/parallel/standby systems, complex system reliability, Bayesian reliability, and sequential reliability tests. Prerequisite: ECE 380.

IEE 574 Applied Deterministic Operations Research Models. (3)
fall and spring
Develops advanced techniques in operations research for the solution of complex industrial systems problems. Goal programming, integer programming, heuristic methods, dynamic and nonlinear programming. Prerequisite: IEE 376 or 385.

IEE 575 Applied Stochastic Operations Research Models. (3)
spring
Formulate and solve industrial systems problems with stochastic components using analytical techniques. Convolution, continuous-time Markov chains, queues with batching, priorities, balking, open/closed queuing networks. Prerequisites: IEE 376, 385.

IEE 576 Modeling and Analysis of Semiconductor Manufacturing Operations. (3)
fall
Applies operations research and statistical methods to solve problems that involve semiconductor manufacturing operations. Prerequisites: IEE 376, 385.

IEE 577 Advanced Information System Operations. (3)
fall
Industrial engineering knowledge and skills for information system operations, including aspects (security, quality of service, user interface, information modeling), problems, and solutions. Prerequisite: IEE 505.

IEE 578 Regression Analysis. (3)
fall
Regression model building oriented toward engineers and physical scientists. Topics include linear regression, diagnostics, biased and robust fitting, nonlinear regression. Prerequisite: IEE 385.

IEE 579 Time Series Analysis and Forecasting. (3)
fall in odd years
Forecasting time series by regression-based, exponential smoothing, and ARIMA model techniques; uses digital computer programs to augment the theory. Prerequisite: IEE 385.

IEE 582 Response Surfaces and Process Optimization. (3)
spring
Classical response surface analysis and designs, including steepest ascent, canonical analysis, and multiple responses. Other topics include process robustness studies, robust design, and mixture experiments. Prerequisite: IEE 572.

IEE 584 Internship. (3)
spring
Work performed in an industrial setting that provides practical experience and adds value to the classroom and research learning process. Practice.

IEE 593 Applied Project. (1–12)
selected semesters

IEE 594 Conference and Workshop. (1)
fall and spring
Orientation to the developing work in the field with an emphasis on what the IE faculty are doing.

IEE 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Advanced Topics in Deterministic Operations Research. (3)
• Advanced Topics in Scheduling. (3)
• Data Mining: Analysis of Massive Data Sets. (3)
• Design and Manufacturing. (3)
• Embedded Systems. (3)
• Engineering Approaches to Information Systems Security. (3)
• Enterprise Internet/Intranet. (3)
• Enterprise Modeling/Integration. (3)
• Entrepreneurship for Engineers. (3)
• Introduction to Rapid Prototyping and Mechatronics. (3)
• Manufacturing and Logistics Systems. (3)
• Multicriteria Decision Making. (3)
• Performance-Based Decision Support Systems. (3)
• Six-Sigma Methodology. (3)
• Strategic Technical Management. (3)
• Strategic Issues in Manufacturing. (3)
• Supply Chain Modeling and Analysis. (3)

IEE 599 Thesis. (1–12)
selected semesters

IEE 672 Advanced Topics in Experimental Design. (3)
spring in even years
Multilevel and mixed-level factorials and fractions, design optimality, incomplete blocks, unbalanced designs, random effects and variance components, analysis of covariance. Prerequisite: IEE 572.

IEE 677 Regression and Generalized Linear Models. (3)
spring in odd years
Theory of linear models, including least squares, maximum likelihood, likelihood-based inference. Generalized linear models, including Poisson and logistic regression, generalized estimating equations. Prerequisite: IEE 578.

IEE 679 Time Series Analysis and Control. (3)
fall in even years
Identification, estimation, diagnostic checking techniques for ARIMA models, transfer functions, multiple time series models for feedback and feedforward control schemes. Prerequisite: IEE 579.

IEE 700 Research Methods. (1–12)
selected semesters

IEE 784 Internship. (1–12)
selected semesters

IEE 792 Research. (1–12)
selected semesters

IEE 799 Dissertation. (1–15)
selected semesters

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Materials Engineering

Master's and Doctoral Programs

www.eas.asu.edu/~cme

480/965-3313

ECG 202

Subhash Mahajan, Chair

Regents' Professor: Mayer

Professors: Adams, Alford, Dey, Krause, Mahajan, Newman, Picraux, Sieradzki

Associate Professors: Chawla, Van Schilfgaarde

The faculty in the Department of Chemical and Materials Engineering offer graduate programs leading to the Master of Science (MS) degree, the Master of Science in Engineering (MSE) degree, and the PhD degree in Engineering Science with a concentration in materials science and engineering (see "Engineering Science," page 193, for program description). Areas of study include electronic and advanced materials processing, mechanical behavior of materials, composites, thin films, ceramics, characterization and simulation of materials, and biomaterials.

A *Graduate Student Handbook,* detailing information on studies in the master's and doctoral programs, is available to admitted students. For information on graduate studies in Materials Engineering, access the Web site at www.eas.asu.edu/~cme, or call the Department of Chemical and Materials Engineering at 480/965-3313.

The faculty also participate in offering the interdisciplinary program leading to the PhD degree with a major in Science and Engineering of Materials (see "Science and Engineering of Materials," page 326, for program description).

Graduate Record Examination. Graduate Record Examination scores are required from all applicants.

MASTER OF SCIENCE

For more information, including general requirements, see "Master's Degrees," page 67.

Transition Program. Students applying for the program leading to a master's degree with a major in Materials Engineering may have an undergraduate BS degree in a major field other than Materials Engineering or Materials Science. The qualifications of transition students are reviewed by the department graduate committee and a special program is then designed for successful applicants. In general applicants should have had, or should be prepared to take, calculus through differential equations, chemistry, and physics. Transition students are expected to complete the essential courses in their area of study from the undergraduate program in order to be prepared for the graduate courses. Other course work from the undergraduate program may be

required depending upon the area of study selected by the student. Transition students should contact the graduate coordinator for an evaluation of their undergraduate transcript.

Program of Study. All candidates for the MSE or MS degree in Materials Engineering are required to complete an approved program of study consisting of the minimum required semester hours, including research report (MSE) or thesis (MS). Special course requirements for the different areas of study are established by the faculty and are available from the departmental graduate coordinator. In addition to the course/thesis requirements, all full-time graduate students must successfully complete a seminar course during each semester of attendance. Part-time students must enroll in a seminar course at least three times during the course of study. Candidates whose undergraduate degree was in a field other than Materials Engineering or Materials Science may be required to complete more than 30 semester hours.

Thesis Requirements. A thesis or equivalent is required for the MS degree.

Final Examination. A final oral examination or equivalent is required in defense of the thesis.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192, for program description.

DOCTOR OF PHILOSOPHY

The PhD degree with a concentration in materials science and engineering under the Engineering Science major, is conferred upon evidence of excellence in research resulting in a scholarly dissertation that is a contribution to existing knowledge. See "Doctor of Philosophy," page 69, for general requirements.

Doctoral Program. Upon successful completion of the qualifying examination, a research supervisory committee is formed and the doctoral student is required to submit a research proposal. Following acceptance of the research proposal, the student is given a comprehensive examination to determine initiative, originality, breadth, and level of professional commitment to the problem selected for investigation. Upon successful completion of the comprehensive examination, the student applies for admission to candidacy.

Foreign Language Requirements. Candidates in the program leading to the PhD degree in the area of study in materials science and engineering, under the Engineering Science major, normally are not required to pass an examination showing reading competency of a foreign language. However, the supervisory committee may establish such a requirement in special cases depending upon the research interests of the candidate. If a foreign language is required, the student must successfully fulfill the requirement before taking the comprehensive examination.

Dissertation Requirement. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

The research thrusts in Materials Engineering are:

1. growth, processing, and characterization of electronic materials;

2. electroceramics;

3. deformation behavior of materials at different length scales;

4. computational materials science; and

5. nanoscience and nanotechnology.

Some of the research projects that are currently being pursued are:

1. growth of group III nitrides by organometallic vapor phase epitaxy and molecular beam epitaxy and their fabrication into high frequency, high power, and high temperature devices;

2. fabrication of spintronic devices for very high frequency applications;

3. synthesis of high k dielectric films by organometallic vapor phase epitaxy and correlation of properties with microstructures;

4. process-induced defects in implantation and annealing of GaN;

5. creep and thermal fatigue behaviors of lead-free solder balls used in electronic packaging;

6. modeling of the evolution of thin film microstructures; and

7. synthesis and characterization of quantum dots.

For more information, access the Web site at www.eas.asu.edu/~cme.

MATERIALS SCIENCE AND ENGINEERING (MSE)

MSE 510 X-Ray and Electron Diffraction. (3)
spring
Fundamentals of x-ray diffraction, transmission electron microscopy, and scanning electron microscopy. Techniques for studying surfaces, internal microstructures, and fluorescence. Lecture, demonstrations. Prerequisite: transition student with instructor approval.

MSE 511 Corrosion and Corrosion Control. (3)
spring in odd years
Introduces corrosion mechanisms and methods of preventing corrosion. Topics include: electrochemistry, polarization, corrosion rates, oxidation, coatings, and cathodic protection. Prerequisite: transition student with instructor approval.

MSE 512 Analysis of Material Failures. (3)
spring in even years
Identifies types of failures. Analytical techniques. Fractography, SEM, nondestructive inspection, and metallography. Mechanical and electronic components. Prerequisite: transition student with instructor approval.

MSE 513 Polymers and Composites. (3)
fall
Relationship between chemistry, structure, and properties of engineering polymers. Design, properties, and behavior of fiber composite systems.

MSE 514 Physical Metallurgy. (3)
spring
Crystal structure and defects. Phase diagrams, metallography, solidification and casting, and deformation and annealing. Prerequisite: transition student with instructor approval.

MSE 515 Thermodynamics of Materials. (3)
spring
Principles of statistical mechanics, statistical thermodynamics of single crystals, solutions, phase equilibrium, free energy of reactions, free electron theory, and thermodynamics of defects. Prerequisite: transition student with instructor approval.

MSE 516 Mechanical Properties of Solids. (3)
fall
Effects of environmental and microstructural variables of mechanical properties, including plastic deformation, fatigue, creep, brittle fracture, and internal friction. Prerequisite: transition student with instructor approval.

MSE 517 Introduction to Ceramics. (3)
fall
Principles of structure, property relations in ceramic materials. Processing techniques. Applications in mechanical, electronic, and superconducting systems. Prerequisite: transition student with instructor approval.

MSE 520 Theory of Crystalline Solids. (3)
selected semesters
Anisotropic properties of crystals; tensor treatment of elastic, magnetic, electric and thermal properties, and crystallography of Martensitic transformations.

MSE 521 Defects in Crystalline Solids. (3)
spring
Introduces the geometry, interaction, and equilibrium between dislocations and point defects. Discusses relations between defects and properties. Prerequisite: ECE 350 or instructor approval.

MSE 530 Materials Thermodynamics and Kinetics. (3)
spring
Thermodynamics of alloy systems, diffusion in solids, kinetics of precipitation, and phase transformations in solids. Prerequisites: ECE 340, 350.

MSE 540 Fracture, Fatigue, and Creep. (3)
spring in odd years
Relationship between microstructure and fracture; fatigue and creep properties of materials. Environmental effects and recent developments. Current theories and experimental results. Prerequisite: MSE 440 (or its equivalent).

MSE 550 Advanced Materials Characterization. (3)
fall
Analytical instrumentation for characterization of materials; SEM, SIMS, Auger, analytical TEM, and other advanced research techniques.

MSE 552 Electron Microscopy I. (3)
fall
Kinematical and dynamical electron diffraction and microscopy. Defect structure and composition using STEM imaging, x-ray and electron-energy-loss spectroscopy. Cross-listed as PHY 552/SEM 552. Credit is allowed for only MSE 552 or PHY 552 or SEM 552. Prerequisite: instructor approval.

MSE 553 Electron Microscopy Laboratory I. (3)
fall
Lab support for MSE 552. Cross-listed as PHY 553/SEM 553. Credit is allowed for only MSE 553 or PHY 553 or SEM 553. Pre- or corequisite: MSE 552 or PHY 552 or SEM 552.

MSE 554 Electron Microscopy II. (3)
spring
Determination of structure and composition of materials using high-resolution imaging, convergent-beam diffraction, and electron holography. Novel developments and applications. Cross-listed as PHY 554/SEM 554. Credit is allowed for only MSE 554 or PHY 554 or SEM 554. Prerequisite: instructor approval.

MSE 555 Electron Microscopy Laboratory II. (3)
spring
Lab support for MSE 554. Cross-listed as PHY 555/SEM 555. Credit is allowed for only MSE 555 or PHY 555 or SEM 555. Pre- or corequisite: MSE 554 or PHY 554 or SEM 554.

MSE 560 Strengthening Mechanisms. (3)
selected semesters
Deformation of crystalline materials. Properties of dislocations. Theories of strain hardening, solid solution, precipitation, and transformation strengthening. Prerequisite: ECE 350 (or its equivalent).

MSE 561 Phase Transformation in Solids. (3)
spring in even years
Heterogeneous and homogeneous precipitation reactions, shear displacive reactions, and order-disorder transformation.

MSE 562 Ion Implantation. (3)
selected semesters
Includes defect production and annealing. Generalized treatment, including ion implantation, neutron irradiation damage, and the interaction of other incident beams. Prerequisite: MSE 450.

MSE 570 Polymer Structure and Properties. (3)
spring in even years
Relationships between structure and properties of synthetic polymers, including glass transition, molecular relaxations, crystalline state viscoelasticity, morphological characterization, and processing.

MSE 571 Ceramics. (3)
selected semesters
Includes ceramic processing, casting, molding, firing, sintering, crystal defects, and mechanical, electronic, and physical properties. Prerequisites: MSE 521, 561.

MSE 573 Magnetic Materials. (3)
selected semesters
Emphasizes ferromagnetic and ferrimagnetic phenomena. Domains, magnetic anisotrophy, and magnetostriction. Study of commercial magnetic materials. Prerequisite: MSE 520 (or its equivalent).

MSE 598 Special Topics. (1–4)
selected semesters
Topics may include the following:
• Composite Materials. (3)
• Computer Simulation in Materials Science. (3)
• Contemporary Issues in Semiconductor Processing and Manufacturing. (3)
• Electronic Thin Films. (3)
• Growth and Processing of Semiconductors. (3)
• Growth and Processing of Semiconductors Laboratory. (1)
• Nanomaterials: Synthesis and Evaluation. (3)
• Vacuum Systems Science and Engineering. (3)

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Mechanical Engineering

Master's and Doctoral Programs

fulton.asu.edu/mae
480/965-3291
ECG 346

Robert E. Peck, Chair

Professors: Boyer, Davidson, Fernando, Peck, Roy, Shah, Sieradzki, Squires, Tseng, Van Schilfgaarde, Yao

Associate Professors: Chen, McNeill, Peralta, Phelan

Assistant Professors: Calhoun, Friesen, Sugar

The faculty in the Department of Mechanical and Aerospace Engineering offer graduate programs leading to the degrees of MS, MSE, and PhD in Mechanical Engineering. A number of areas of study may be pursued, including mechanical design, manufacturing, thermal sciences, engineering mechanics, and system dynamics and controls.

The faculty also offer graduate degree programs in Aerospace Engineering.

All of the graduate programs stress a sound foundation in fundamentals leading to a specialized area of study.

Graduate studies in one of the specialized fields of mechanical engineering prepare students for a professional career in industry, government, or academic institutions.

Graduate Record Examination. All applicants are required to take the Graduate Record Examination; the subject test in engineering is highly recommended but not required.

MASTER OF SCIENCE

See "Master's Degrees," page 67, for general requirements.

INTEGRATED BSE-MS DEGREE

The Department of Mechanical and Aerospace Engineering offers an integrated, five-year BSE-MS degree. The program is designed for students with strong academic backgrounds who are motivated to pursue independent research. Students have the opportunity to work in a laboratory/research environment and engage in theoretical and/or experimental work with faculty and doctoral student mentors. Undergraduates, majoring in Mechanical or Aerospace Engineering, who have completed a minimum of two semesters of full-time enrollment in MAE and have completed at least 90 semester hours of applicable course work are eligible for the program. Applicants must also have a cumulative GPA of 3.50 or higher. Students normally submit applications following the completion of their junior year. For more information, contact the department's Graduate Advising Office.

MASTER OF SCIENCE IN ENGINEERING

See "Master of Science in Engineering," page 192, for information on the Master of Science in Engineering degree.

MASTER OF ENGINEERING

The faculty also participate in the Arizona Master of Engineering partnership. See "Master of Engineering," page 192.

DOCTOR OF PHILOSOPHY

The PhD degree is conferred upon evidence of excellence in research leading to a scholarly dissertation that is an original contribution to knowledge in the field of mechanical engineering. See "Doctor of Philosophy," page 69, for general requirements.

Program of Study. The program of study must be established no later than the first semester after successfully completing the qualifying examination.

Qualifying Criteria. The purposes of the qualifying criteria are to assess if the student is qualified to continue in the doctoral program and to detect deficiencies in the student's background that can be corrected by appropriate course work and individual study. Within the first year of graduate

studies at ASU, a graduate student pursuing a PhD program of study in Mechanical Engineering must complete three 500-level core courses, preferably in the major area of interest, and one 500-level mathematics course, both with an average GPA of 3.25 or higher. Specific qualifying course requirements for each major area are available from the department.

Foreign Language Requirements. None.

Comprehensive Examinations. Written and oral comprehensive examinations are required. The examinations are administered by the program committee.

Dissertation Requirements. A dissertation based on original work demonstrating creativity in research and scholarly proficiency in the subject area is required.

Final Examination. A final oral examination in defense of the dissertation is required.

RESEARCH ACTIVITY

The department offers a broad range of theoretical and experimental research in mechanical and thermal-fluid systems. In particular, research in mechanical design includes CAD/CAM/CAE, design automation, engineering informatics, geometric modeling, and knowledge-based design. Research in manufacturing includes rapid prototyping and MEMS. Research undertaken in thermal sciences includes combustion and emission control, computational fluid dynamics, cryogenics, electronic cooling, energy conversion and management, environmental and geophysical fluid dynamics, heat transfer in complex flows, hydrodynamic stability, micro-/nanoscale transport processes, non-Newtonian fluid mechanics, noise control, pollution monitoring and transport, superconductivity, turbulence modeling, and two-phase flow modeling and experiments. Research undertaken in engineering mechanics includes corrosion, crystallography, damage and fracture mechanics, failure analysis and reliability, multidisciplinary optimization, nanomechanics of materials, precision materials processing, rotor-bearing system design, smart structures, and thin film growth. Research undertaken in system dynamics and controls includes intelligent control, mechatronics, and robotics.

Multidisciplinary research areas include micro-nano systems; modeling and process simulation; energy and environment; and intelligent and adaptive systems. Modern laboratory and computational facilities are available to assist in the development of research skills. For more information, access the department's Web site at fulton.asu.edu/mae.

MECHANICAL AND AEROSPACE ENGINEERING (MAE)

MAE 404 Finite Elements in Engineering. (3)
once a year
Introduces ideas and methodology of finite element analysis. Applications to solid mechanics, heat transfer, fluid mechanics, and vibrations. Prerequisites: ECE 313; MAT 242 (or 342).

MAE 406 CAD/CAM Applications in MAE. (4)
once a year
Solution of engineering problems with the aid of state-of-the-art software tools in solid modeling, engineering analysis, and manufacturing; selection of modeling parameters; reliability tests on software. 3 hours lecture, 3 hours lab. Fee. Prerequisites: ECE 384; MAE 422, 441 (or 444).

MAE 415 Vibration Analysis. (4)
fall
Free and forced response of single and multiple degree of freedom systems, continuous systems; applications in mechanical and aerospace systems numerical methods. Lecture, lab. Fee. Prerequisites: ECE 212; MAE 319, 422 (or 425); MAT 242 (or 342).

MAE 417 Control System Design. (3)
once a year
Tools and methods of control system design and compensation, including simulation, response optimization, frequency domain techniques, state variable feedback, and sensitivity analysis. Introduces nonlinear and discrete time systems. Prerequisite: MAE 317.

MAE 433 Air Conditioning and Refrigeration. (3)
once a year
Air conditioning processes; environmental control; heating and cooling loads; psychrometry; refrigeration cycles. Prerequisite: MAE 388 or MET 432 or instructor approval.

MAE 434 Internal Combustion Engines. (3)
once a year
Performance characteristics, combustion, carburetion and fuel-injection, and the cooling and control of internal combustion engines. Computer modeling. Lab. Fee. Prerequisite: MAE 388.

MAE 435 Turbomachinery. (3)
once a year
Design and performance of turbomachines, including steam, gas and hydraulic turbines, centrifugal pumps, compressors, fans, and blowers. Pre- or corequisite: MAE 361 or 371.

MAE 436 Combustion. (3)
once a year
Thermochemical and reaction rate processes; combustion of gaseous and condensed-phase fuels. Applications to propulsion and heating systems. Pollutant formation. Prerequisite: MAE 388.

MAE 442 Mechanical Systems Design. (4)
spring
Applies design principles and techniques to the synthesis, modeling, and optimization of mechanical, electromechanical, and hydraulic systems. Lecture, lab. Fee. Prerequisites: MAE 317, 441 (or 444).

MAE 446 Thermal Systems Design. (3)
once a year
Applies engineering principles and techniques to the modeling and analysis of thermal systems and components. Presents and demonstrates optimization techniques and their use. Prerequisite: ECE 300; MAE 388.

MAE 447 Robotics and Its Influence on Design. (3)
once a year
Robot applications, configurations, singular positions, and work space; modes of control; vision; programming exercises; design of parts for assembly. Prerequisite: MAE 317.

MAE 453 Computer-Aided Manufacturing and Control. (3)
spring
Computer control in manufacturing, CIM, NC, logic controllers, group technology, process planning, and robotics. Cross-listed as IEE 463. Credit is allowed for only IEE 463 or MAE 453. Credit is allowed for only IEE 463 or 543. Fee. Prerequisite: IEE 360 or MAE 351.

MAE 455 Polymers and Composites. (3)
fall
Relationship between chemistry, structure, and properties of engineering polymers. Design, properties, and behavior of fiber composite systems. Cross-listed as MSE 470. Credit is allowed for only MAE 455 or MSE 470. Prerequisites: ECE 313, 350.

MAE 460 Gas Dynamics. (3)
spring
Compressible flow at subsonic and supersonic speeds; duct flow; normal and oblique shocks, perturbation theory, and wind tunnel design. Prerequisites: ECE 384; MAE 361 (or 371).

MAE 462 Space Vehicle Dynamics and Control. (3)
fall
Attitude dynamics and control, launch vehicles, orbital mechanics, orbital transfer/rendezvous, space mission design, space structures, spacecraft control systems design. Prerequisite: MAE 317.

MAE 463 Propulsion. (3)
fall
Fundamentals of gas-turbine engines and design of components. Principles and design of rocket propulsion and alternative devices. Lecture, design projects. Prerequisites: ECE 384; MAE 382 (or 460).

MAE 465 Rocket Propulsion. (3)
once a year
Rocket flight performance; nozzle design; combustion of liquid and solid propellants; component design; advanced propulsion systems; interplanetary missions; testing. Prerequisite: MAE 382 or 460.

MAE 466 Rotary Wing Aerodynamics and Performance. (3)
once a year
Introduces helicopter and propeller analysis techniques. Momentum, blade-element, and vortex methods. Hover and forward flight. Ground effect, autorotation, and compressibility effects. Prerequisites: both ECE 384 and MAE 361 or only instructor approval.

MAE 469 Projects in Astronautics or Aeronautics. (3)
fall and spring
Various multidisciplinary team projects available each semester. Projects include design of high-speed rotocraft autonomous vehicles, liquid-fueled rockets, microaerial vehicles, satellites. Fee. Prerequisite: instructor approval.

MAE 471 Computational Fluid Dynamics. (3)
once a year
Numerical solutions for selected problems in fluid mechanics. Fee. Prerequisites: ECE 384; MAE 361 (or 371).

MAE 504 Experimental Methods for Thermal and Fluid Processes. (3)
spring
Theory and application of optical diagnostics and microsensors for characterizing thermofluid processes. Measurements include laser spectroscopy, velocimetry, particle sizing, and surface properties.

MAE 505 Perturbation Methods. (3)
selected semesters
Nonlinear oscillations, strained coordinates, renormalization, multiple scales, boundary layers, matched asymptotic expansions, turning point problems, and WKBJ method. Cross-listed as MAT 505. Credit is allowed for only MAE 505 or MAT 505.

MAE 506 Advanced System Modeling, Dynamics, and Control. (3)
spring
Lumped-parameter modeling of physical systems with examples. State variable representations and dynamic response. Introduces modern control. Prerequisite: ASE 582 or MAT 442.

MAE 507 Optimal Control. (3)
fall
Optimal control of systems. Calculus of variations, dynamic programming, linear quadratic regulator, numerical methods, and Pontryagin's principle. Cross-listed as EEE 587. Credit is allowed for only EEE 587 or MAE 507. Prerequisite: EEE 482 or MAE 506.

MAE 510 Dynamics and Vibrations. (3)
fall
Lagrange's and Hamilton's equations, rigid body dynamics, gyroscopic motion, and small oscillation theory.

MAE 511 Acoustics. (3)
fall
Principles underlying the generation, transmission, and reception of acoustic waves. Applications to noise control, architectural acoustics, random vibrations, and acoustic fatigue.

MAE 512 Random Vibrations. (3)
spring
Reviews probability theory, random processes, stationarity, power spectrum, white noise process, random response of single and multiple DOF systems, and Markov processes simulation. Prerequisite: CEE 536 or MAE 515.

MAE 515 Structural Dynamics. (3)
selected semesters
Free vibration and forced response of discrete and continuous systems, exact and approximate methods of solution, response spectra, computational techniques, special topics. Lecture, recitation. Cross-listed as CEE 536. Credit is allowed for only CEE 536 or MAE 515.

MAE 520 Stress Analysis. (3)
fall
Introduces tensors: kinematics, stress analysis, and constitutive assumptions leading to elastic and plastic behavior. Strain energy and energy methods; applications. Cross-listed as CEE 521. Credit is allowed for only CEE 521 or MAE 520.

MAE 521 Structural Optimization. (3)
selected semesters
Linear and nonlinear programming. Problem formulation. Design sensitivity analysis. FEM-based optimal design of structural and mechanical systems. Cross-listed as CEE 533. Credit is allowed for only CEE 533 or MAE 521. Prerequisites: ASE 582; CEE 526 (or MAE 527).

MAE 523 Fracture Mechanics. (3)
fall
Linear elastic fracture mechanics. Nonlinear problems. Fatigue fracture. Experimental methods in fracture. Prerequisite: CEE 521 or MAE 520.

MAE 524 Theory of Elasticity. (3)
spring
Elastic behavior in two and three dimensions. Airy stress functions and displacement potentials. Elements of fracture. Prerequisite: MAE 520.

MAE 525 Mechanics of Smart Materials and Structures. (3)
once a year
Modeling and analysis of smart materials and adaptive structures. Application areas include vibration and shape control and damage detection. Pre- or corequisite: MAE 510 (or its equivalent) or instructor approval.

MAE 527 Finite Elements for Engineers. (3)
fall
Direct stiffness, method of weighted residuals, weak formulation, and variational techniques in the solution of engineering problems. Cross-listed as CEE 526. Credit is allowed for only CEE 526 or MAE 527. Prerequisite: CEE 432 or MAE 404 (or their equivalents).

MAE 536 Combustion. (3)
selected semesters
Thermodynamics; chemical kinetics of combustion. Explosion and ignition theories. Reactive gas dynamics. Structure, propagation, and stability of flames. Experimental methods. Prerequisite: MAE 436 or instructor approval.

MAE 540 Advanced Product Design Methodology. (3)
fall
Survey of research in engineering design process, artifact and design, knowledge, formal and informal logic, heuristic and numerical searches, theory of structure and complexity. Prerequisite: graduate standing.

MAE 541 CAD Tools for Engineers. (3)
fall
Elements of computer techniques required to develop CAD software. Data structures, including lists, trees, and graphs. Computer graphics, including 2- and 3-D algorithms and user interface techniques.

MAE 544 Mechanical Design and Failure Prevention. (3)
fall
Modes of mechanical failure; applies principles of elasticity and plasticity in multiaxial state of stress to design synthesis; failure theories; fatigue; creep; impact.

MAE 546 CAD/CAM Applications in MAE. (4)
once a year
Solution of engineering problems with the aid of state-of-the-art software tools in solid modeling, engineering analysis, and manufacturing; selection of modeling parameters; reliability tests on software. Open only to students without previous credit for MAE 406. 3 hours lecture, 3 hours lab. Prerequisites: ECE 384; MAE 422, 441 (or 444).

MAE 547 Mechanical Design and Control of Robots. (3)
selected semesters
Homogeneous transformations, 3-D kinematics, geometry of motion, forward and inverse kinematics, workspace and motion trajectories, dynamics, control, and static forces.

MAE 557 Mechanics of Composite Materials. (3)
spring
Analysis, design, and applications of laminated and chopped fiber reinforced composites. Micro- and macromechanical analysis of elastic constants, failure, and environmental degradation. Design project.

MAE 560 Propulsion Systems. (3)
selected semesters
Design of air-breathing gas turbine engines for aircraft propulsion; mission analysis; cycle analysis; engine sizing; component design.

MAE 561 Computational Fluid Dynamics. (3)
spring
Finite-difference and finite-volume techniques for solving the subsonic, transonic, and supersonic flow equations. Method of characteristics. Numerical grid-generation techniques. Prerequisite: MAE 571 or instructor approval.

MAE 563 Unsteady Aerodynamics. (3)
spring
Unsteady incompressible and compressible flow. Wings and bodies in oscillatory and transient motions. Kernel function approach and panel methods. Aeroelastic applications. Prerequisite: MAE 460 or 461.

MAE 564 Advanced Aerodynamics. (3)
fall
Perturbation method. Linearized subsonic and supersonic flows. Thin wing/slender body theories. Lifting surface theory. Panel method computation. Prerequisite: MAE 460 or 461.

MAE 566 Rotary-Wing Aerodynamics. (3)
fall
Introduces helicopter and propeller analysis techniques. Momentum, blade-element, and vortex methods. Hover and forward flight. Ground effect, autorotation, and compressibility effects. Prerequisite: MAE 361.

MAE 571 Fluid Mechanics. (3)
fall
Basic kinematic, dynamic, and thermodynamic equations of the fluid continuum and their application to basic fluid models.

MAE 572 Inviscid Fluid Flow. (3)
spring
Mechanics of fluids for flows in which the effects of viscosity may be ignored. Potential flow theory, waves, and inviscid compressible flows. Prerequisite: MAE 571.

MAE 573 Viscous Fluid Flow. (3)
fall
Mechanics of fluids for flows in which the effects of viscosity are significant. Exact and approximate solutions of the Navier-Stokes system, laminar flow at low and high Reynolds number. Prerequisite: MAE 571.

MAE 575 Turbulent Shear Flows. (3)
fall
Homogeneous, isotropic, and wall turbulence. Experimental results. Introduces turbulent-flow calculations. Prerequisite: MAE 571.

MAE 577 Turbulent Flow Modeling. (3)
spring
Reynolds equations and their closure. Modeling of simple and complex turbulent flows, calculations of internal and external flows, and application to engineering problems. Prerequisite: MAE 571.

MAE 578 Environmental Fluid Dynamics. (3)
fall
Studies fluid motions in Earth's hydrosphere and atmosphere on local and regional scales. Prerequisite: MAE 571.

MAE 581 Thermodynamics. (3)
fall
Basic concepts and laws of classical equilibrium thermodynamics; applications to engineering systems. Introduces statistical thermodynamics.

MAE 582 Statistical Thermodynamics. (3)
once a year
Kinetic and quantum theory. Statistical mechanics; ensemble theory. Structure and thermodynamics of noninteracting and interacting parti-

cles. Boltzmann integro-differential equation. Prerequisite: graduate standing.

MAE 585 Conduction Heat Transfer. (3)
fall
Basic equations and concepts of conduction heat transfer. Mathematical formulation and solution (analytical and numerical) of steady and unsteady, 1- and multidimensional heat conduction and phase change problems. Prerequisites: ECE 384; MAE 388.

MAE 586 Convection Heat Transfer. (3)
spring
Basic concepts and governing equations. Analyzes laminar and turbulent heat transfer for internal and external flows. Natural and mixed convection. Prerequisite: MAE 388.

MAE 587 Radiation Heat Transfer. (3)
fall
Advanced concepts and solution methodologies for radiation heat transfer, including exchange of thermal radiation between surfaces, radiation in absorbing, emitting, and scattering media and radiation combined with conduction and convection. Prerequisite: MAE 388.

MAE 589 Heat Transfer. (3)
fall
Basic concepts; physical and mathematical models for heat transfer. Applications to conductive, convective, radiative, and combined mode heat transfer. Prerequisite: MAE 388.

MAE 594 Graduate Research Conference. (1)
fall and spring
Topics in contemporary research. Required every semester of all departmental graduate students registered for 9 or more semester hours. Not for degree credit.

MAE 598 Special Topics. (1–4)
fall and spring
Open to qualified students. Topics may include the following:
• Advanced Spacecraft Control. (1–3)
• Aeroelasticity. (1–3)
• Aerospace Vehicle Guidance and Control. (1–3)
• Boundary Layer Stability. (1–3)
• Hydrodynamic Stability. (1–3)
• Plasticity. (1–3)
• Polymers and Composites. (1–3)

Omnibus Courses. For an explanation of courses offered but not specifically listed in this catalog, see "Omnibus Courses," page 56.

Statistics

Interdisciplinary Master's and Certificate Programs

The committee, which sets program requirements and supervises programs of study, is composed of faculty from several departments in the Ira A. Fulton School of Engineering, the College of Liberal Arts and Sciences, and the W. P. Carey School of Business.

For more information, see "Statistics," page 83.